Photon Mapping

Thanks to Henrik Wann Jensen, UCSD

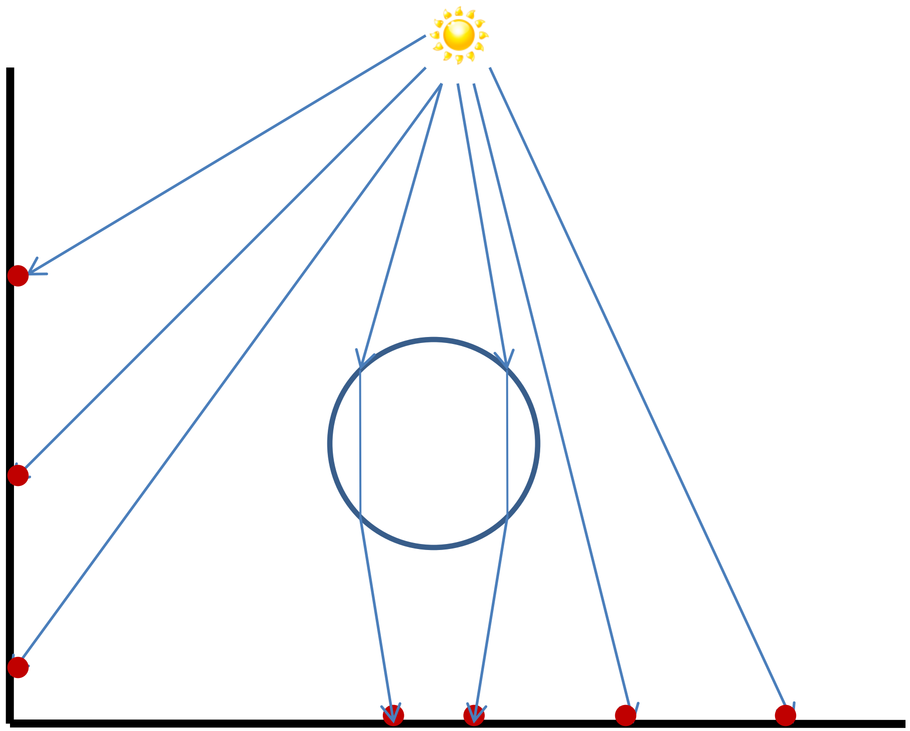
Photon mapping

A two-pass method

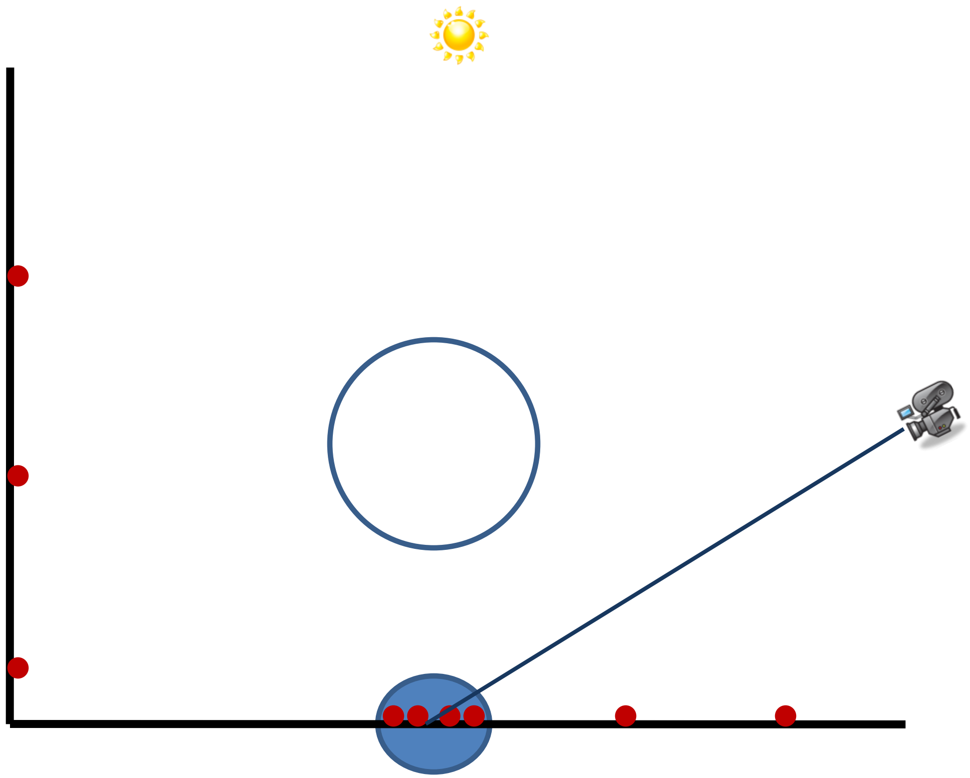
Pass 1: Build the photon map (photon tracing)

Pass 2: Render the image using the photon map

Building the photon map: Photon tracing



Rendering using the photon map



What is a photon?

- Flux (power) - not radiance!
- Collection of physical photons
  - A fraction of the light source power
  - Several wavelengths combined into one entity

Photon emission

Given Φ Watt lightbulb.
Emit N photons.
Each photon has the power $\frac{\Phi}{N}$ Watt.

- Photon power depends on the number of emitted photons. Not on the number of photons in the photon map.

Diffuse point light

Generate random direction
Emit photon in that direction

```
// Find random direction
do {
  x = 2.0*random()-1.0;
  y = 2.0*random()-1.0;
  z = 2.0*random()-1.0;
} while ( (x*x + y*y + z*z) > 1.0 );
```

Example: Diffuse square light

- Generate random position p on square
- Generate diffuse direction d
- Emit photon from p in direction d

// Generate diffuse direction

u = random();

v = 2*π*random();

d = vector($cos(v)\sqrt{u}$, $sin(v)\sqrt{u}$, $\sqrt{1-u}$);

Projection maps

Surface interactions

The photon is

- Stored (at diffuse surfaces) and
- Absorbed (A) or
- Reflected (R) or
- Transmitted (T)

$$A + R + T = 1.0$$

Storing the photon

```
struct photon {
  float x,y,z;       // position
  char p[4];         // power packed as 4 bytes
  char phi,theta;    // incident direction
  short flag;        // flag used for kd-tree
}
```

Memory overhead: 20 bytes/photon.

Photon scattering

The simple way:

Given incoming photon with power Φ_p

Reflect photon with the power $R * \Phi_p$

Transmit photon with the power $T * \Phi_p$

- Risk: Too many low-powered photons - wastefull!
- When do we stop (systematic bias)?
- Photons with similar power is a good thing.

Russian Roulette

- Statistical technique
- Known from Monte Carlo particle physics
- Introduced to graphics by Arvo and Kirk in 1990

Terminate un-important photons and still get the correct result.

Russian Roulette Example

Surface reflectance: $R = 0.5$
Incoming photon: $\Phi_p = 2$ W

```
r = random();
if ( r < 0.5 )
  reflect photon with power 2 W
else
  photon is absorbed
```

Reflect 100 photons with power 2 Watt instead of 200 photons with power 1 Watt.

Russian Roulette Example 2

Surface reflectance: R = 0.2
Surface transmittance: T = 0.3
Incoming photon: Φ_p = 2 W

```
r = random();
if ( r < 0.2 )
  reflect photon with power 2 W
else if ( r < 0.5 )
  transmit photon with power 2 W
else
  photon is absorbed
```

Sampling a BRDF

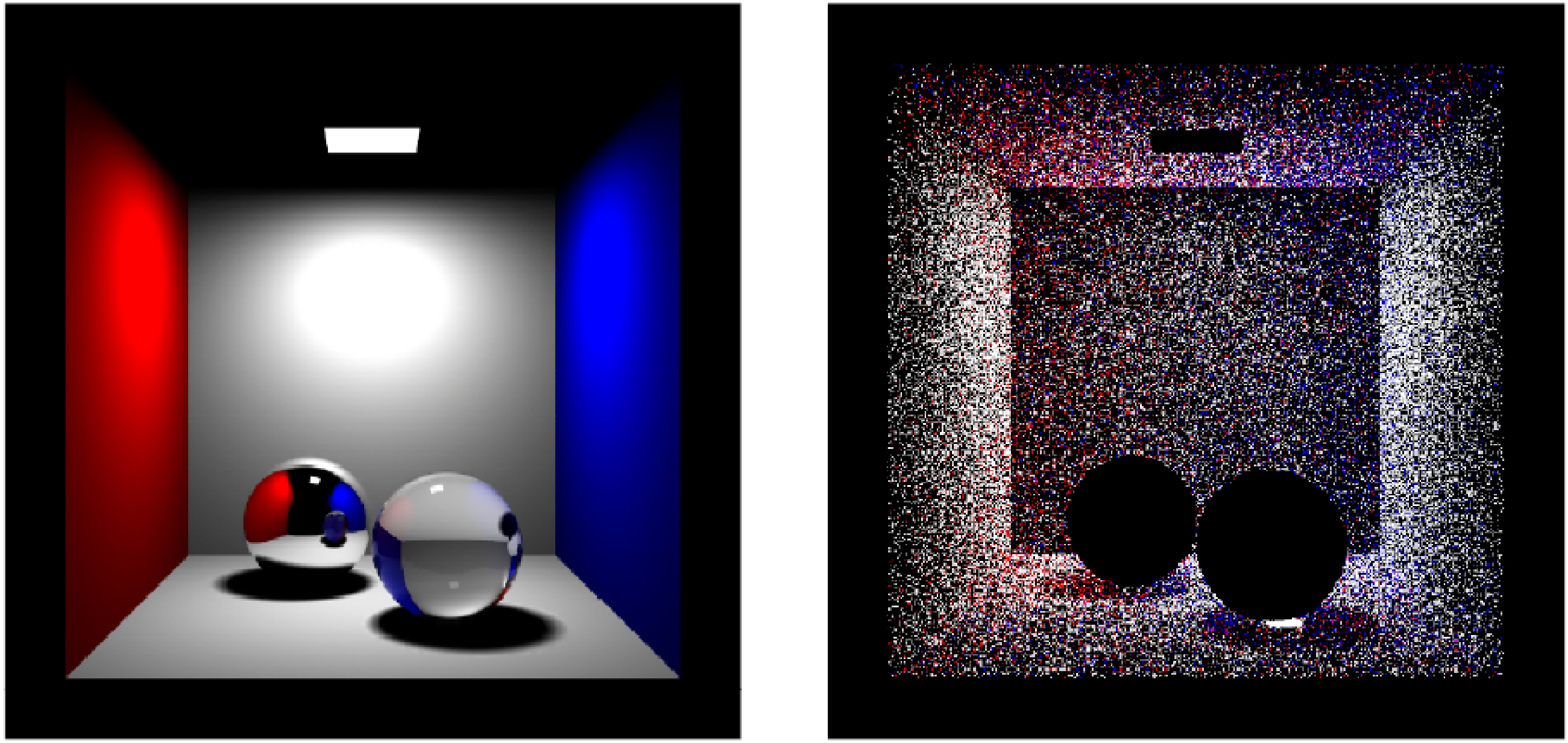
$$f_r(x, \vec{\omega}_i, \vec{\omega}_o) = w_1 \cdot f_{r,d} + w_2 \cdot f_{r,s}$$

```
r = random()·(w1 + w2);
if ( r < w1 )
  reflect diffuse photon
else
  reflect specular
```

Photon tracing

Overview:

```
While (we want more photons) {
  Emit a photon
  while (photon hits a surface) {
   Store photon
   Use Russian Roulette to scatter photon
  }
}
Build balanced kd-tree
```



(a) (b)

Figure 4.4: "Cornell box" with glass and chrome spheres: (a) ray traced image (direct illumination and specular reflection and transmission), (b) the photons in the corresponding photon map.

Photon mapping

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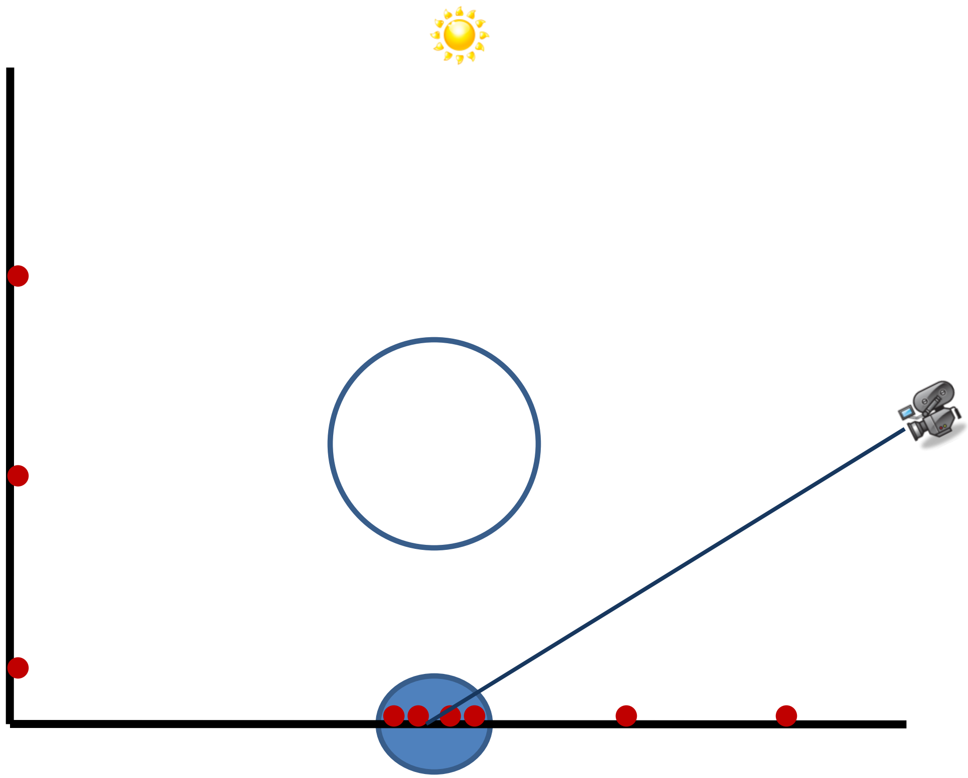
Pass 2: Render the image using the photon map

Rendering using the photon map



Rendering

We want a Radiance value, L, per pixel.

The photon map stores flux/power.

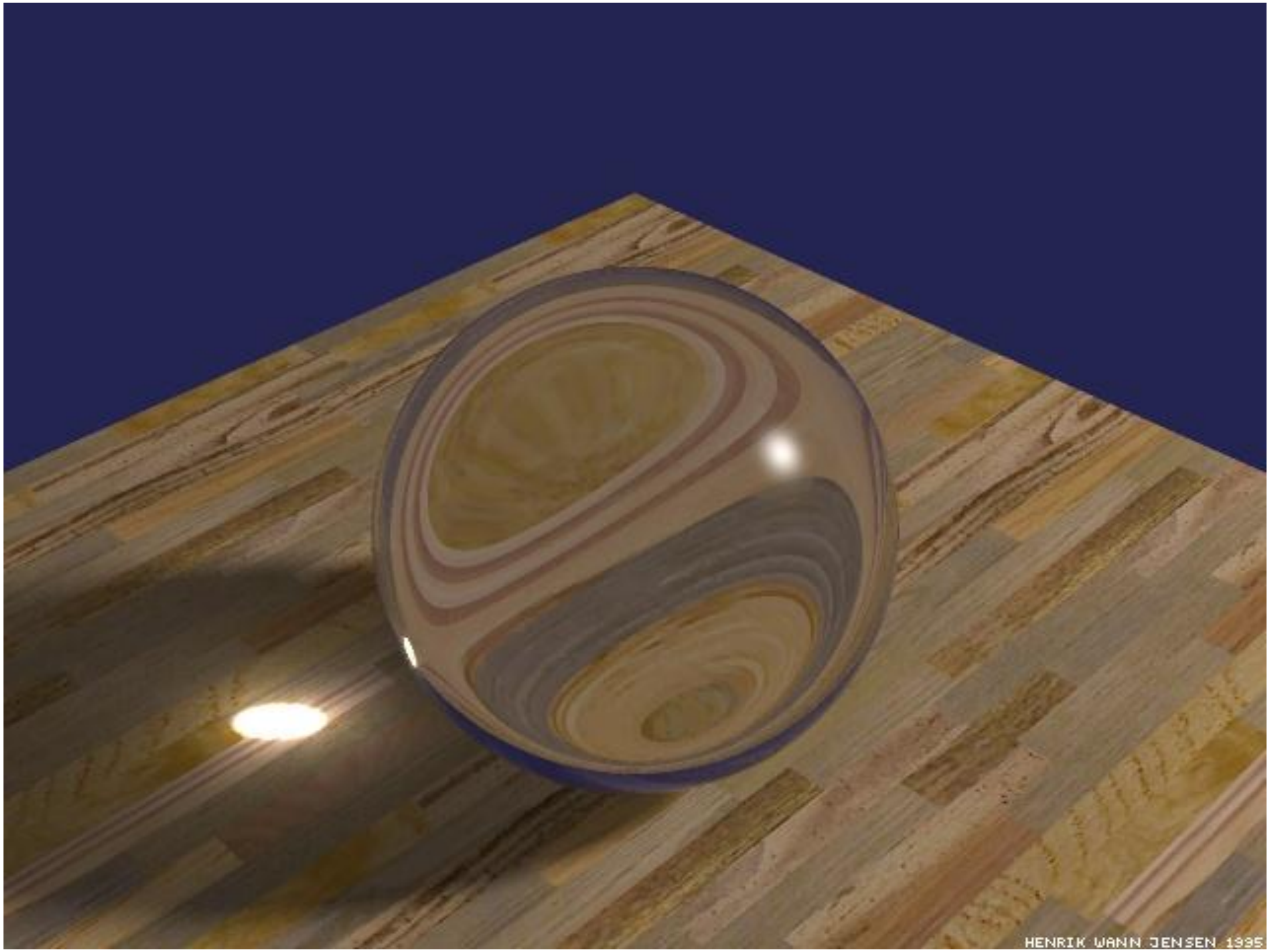
Radiance is the differential flux per differential solid angle per differential cross-sectional area:

$$L(x, \vec{\omega}) = \frac{d\Phi^2(x, \vec{\omega})}{d\omega \, \cos\theta \, dA}$$

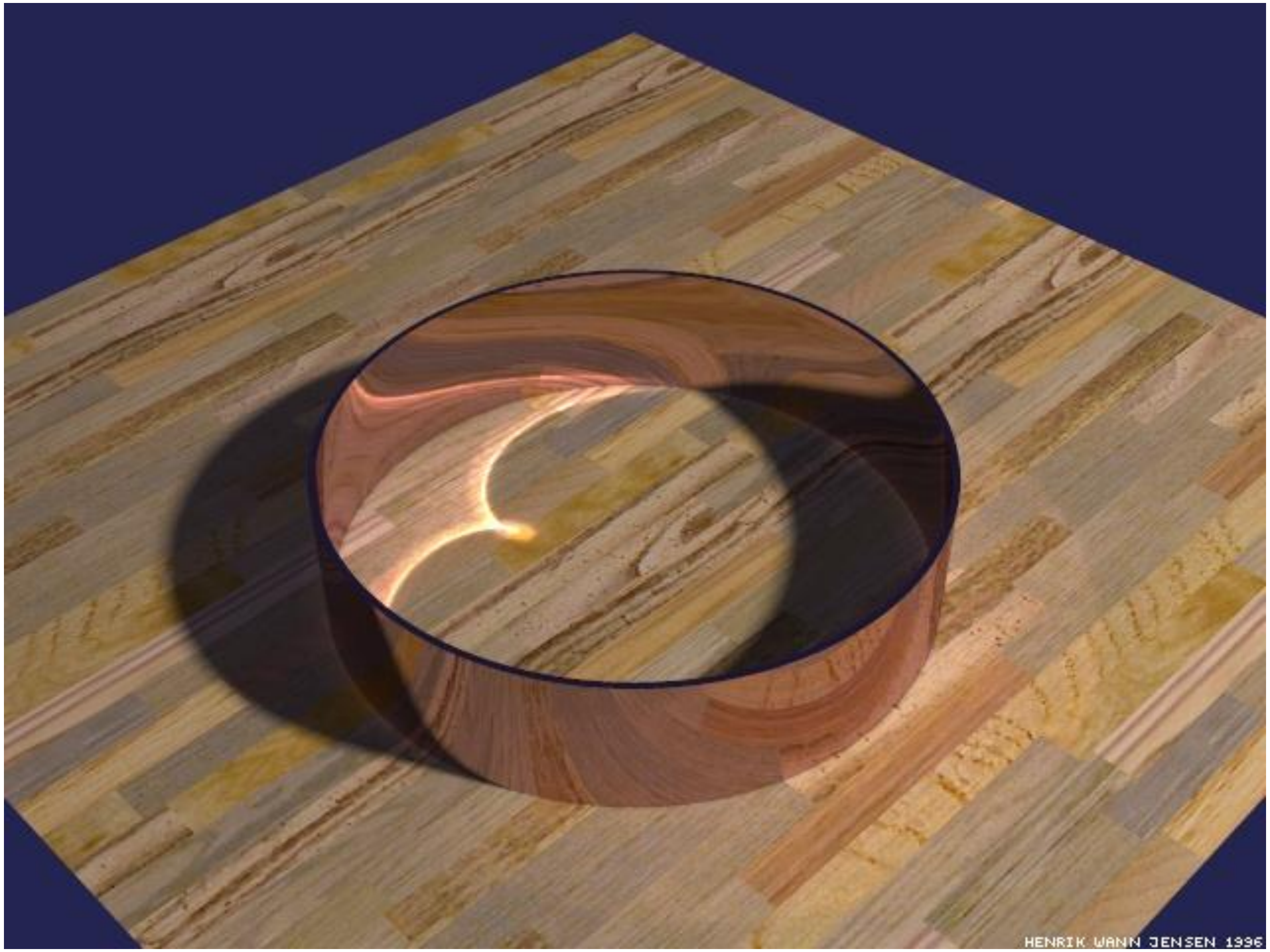
Radiance estimate

$$
\begin{aligned}
L(x,\vec{\omega}) &= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) L'(x,\vec{\omega}') \cos\theta' \, d\omega' \\
&= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) \frac{d\Phi'^2(x,\vec{\omega}')}{d\omega' \cos\theta' \, dA} \cos\theta' d\omega' \\
&= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) \frac{d\Phi'^2(x,\vec{\omega}')}{dA} \\
&\approx \sum_{p=1}^{n} f_r(x,\vec{\omega}'_p,\vec{\omega}) \frac{\Delta\Phi_p(x,\vec{\omega}'_p)}{\Delta A}
\end{aligned}
$$

Radiance estimate



30000 photons / 50 photons in radiance estimate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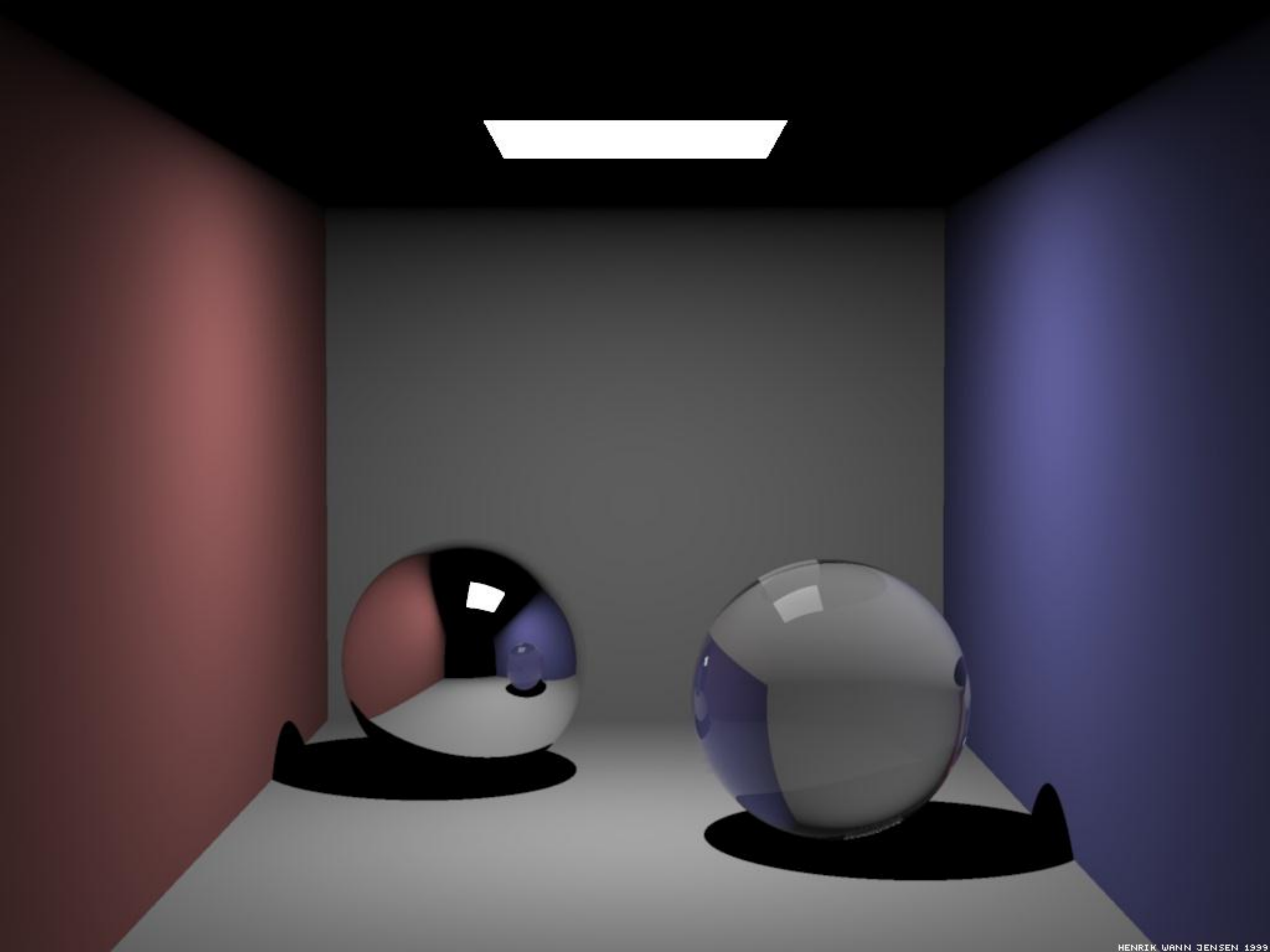
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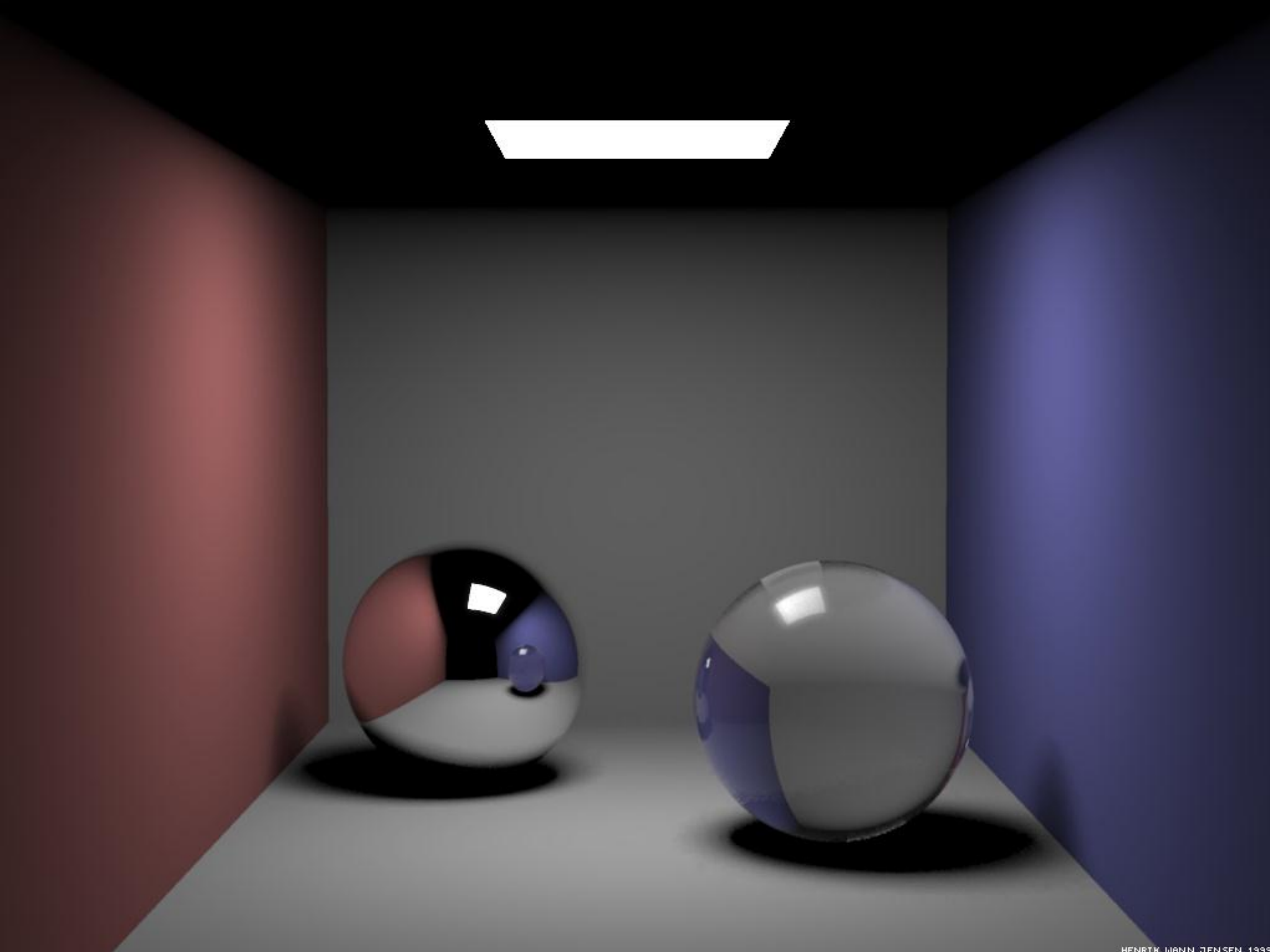
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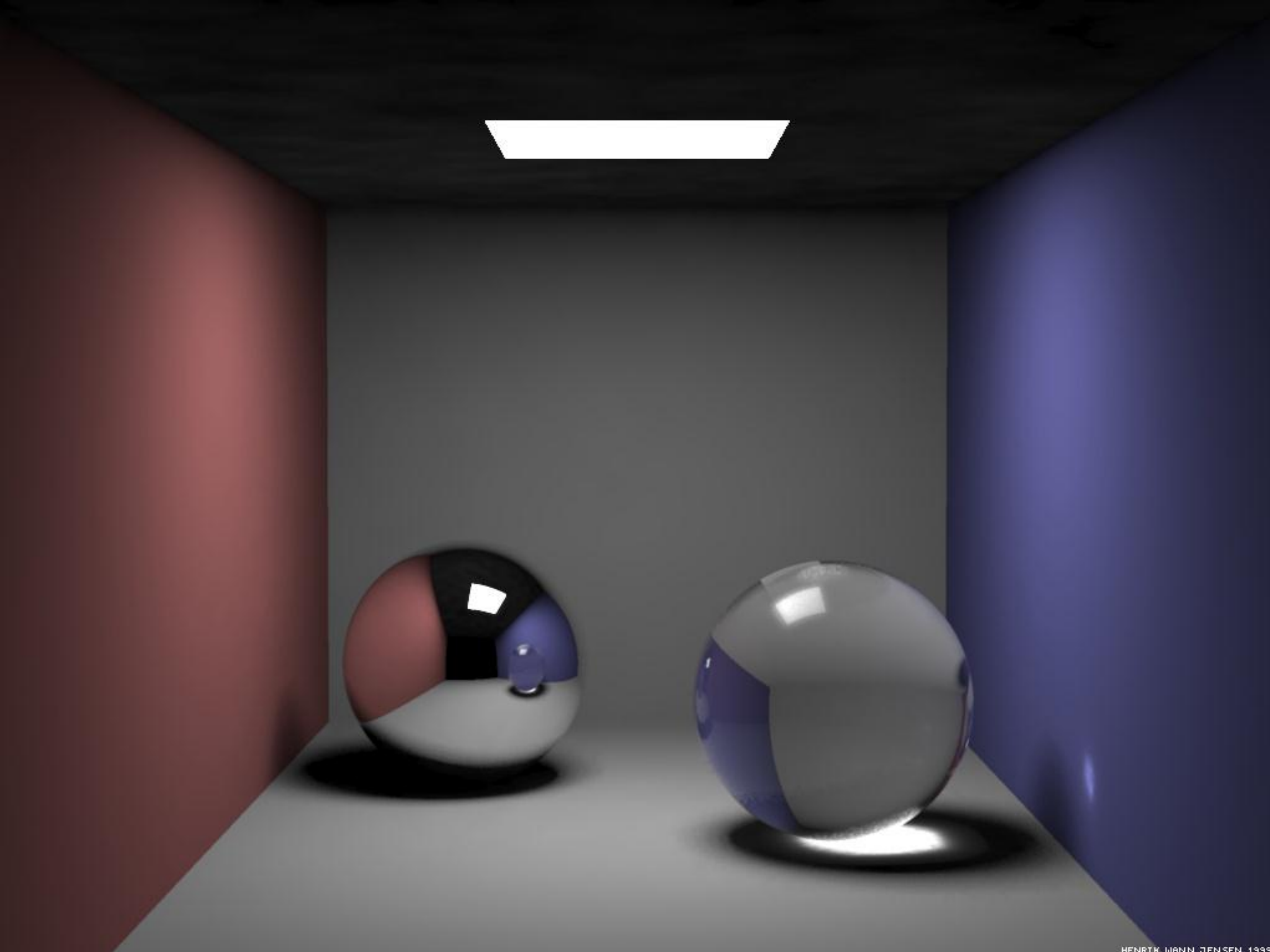
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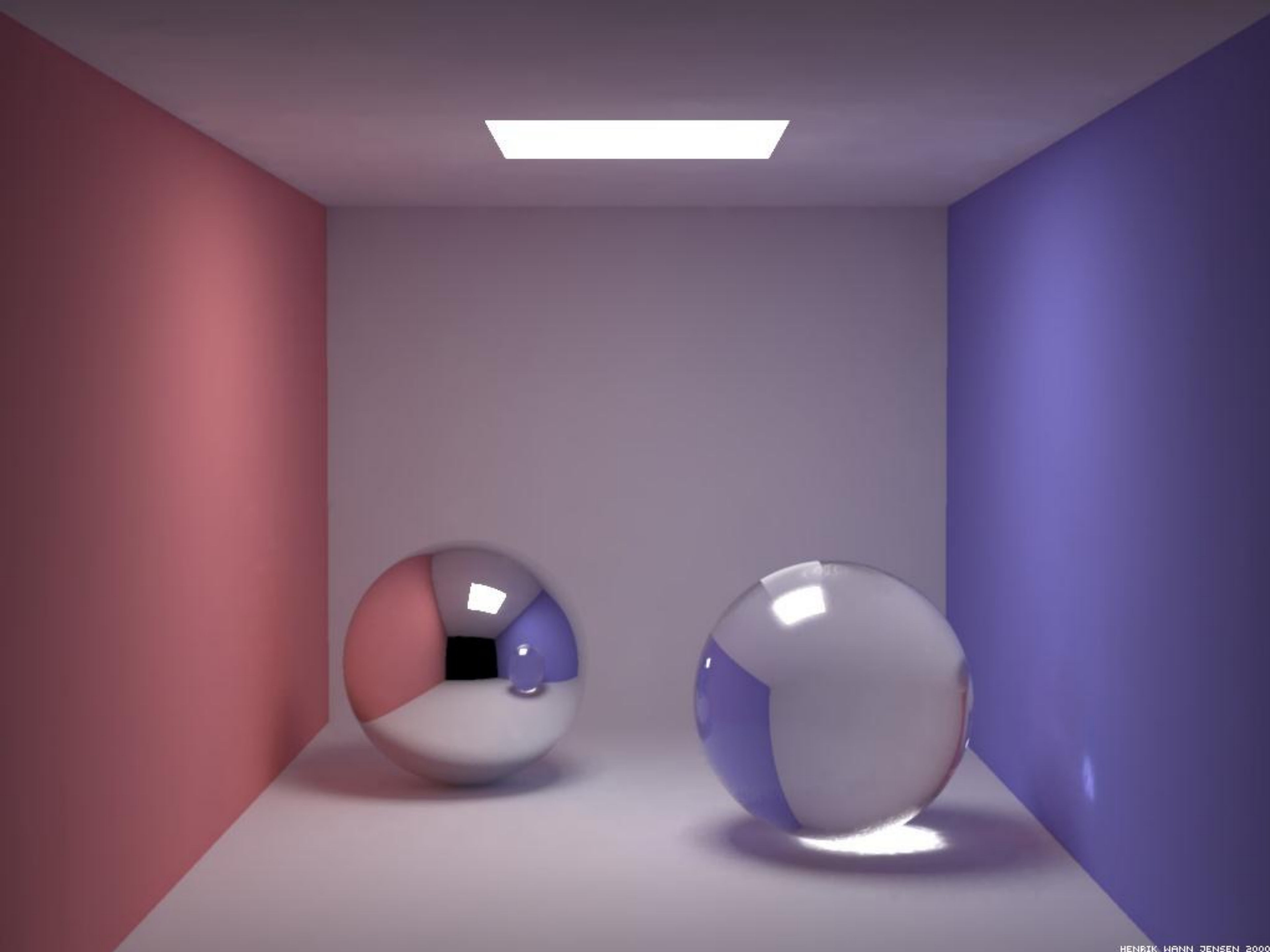
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Adding water --- more caustics

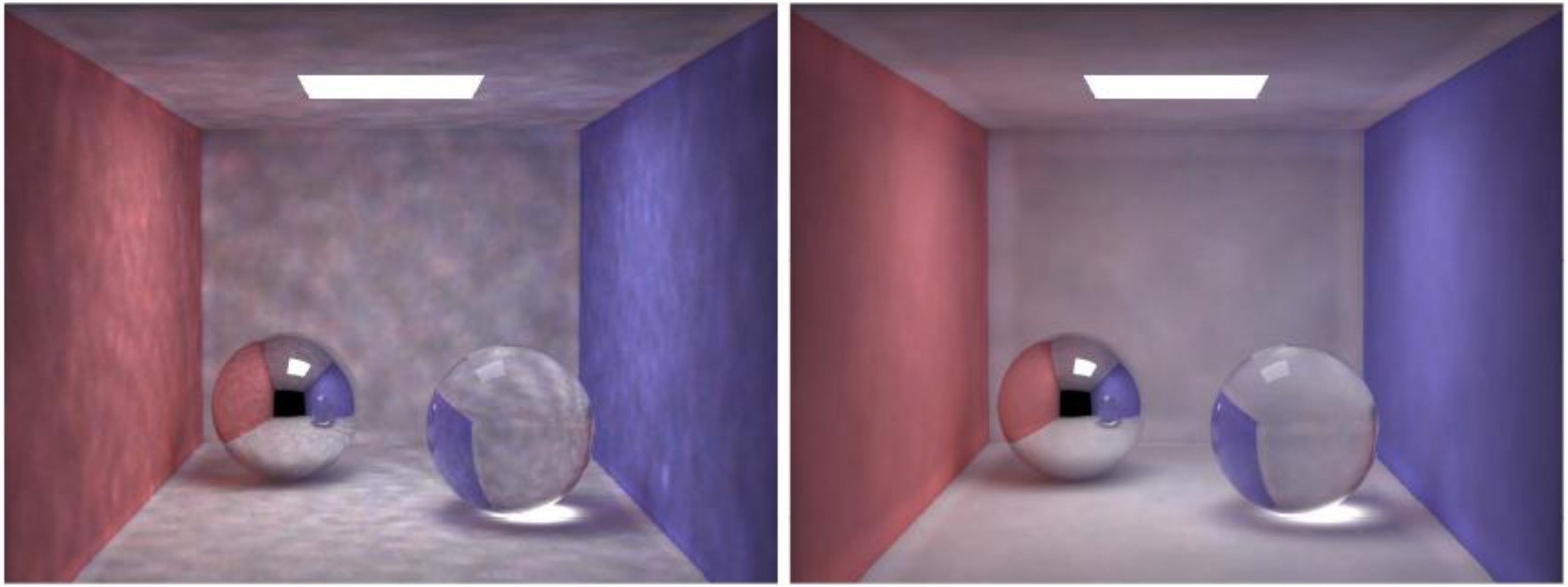
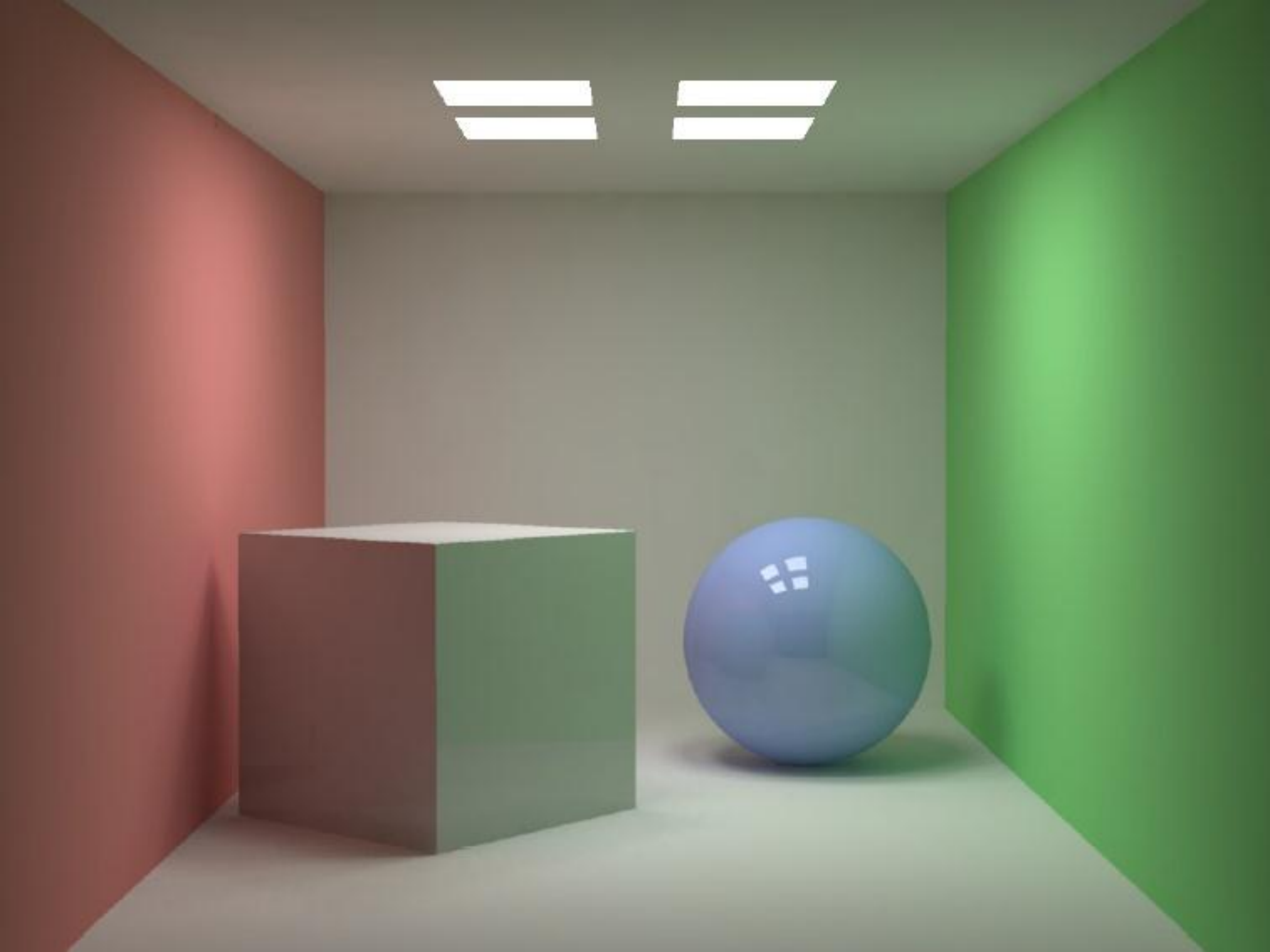


Figure 4.20: Global photon map radiance estimates visualized directly using 100 photons (left) and 500 photons (right) in the radiance estimate.

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Practice Problems

Does photon mapping capture paths of light rays that are not typically captured in ray tracing or radiosity? If your answer is no, explain why not. If your answer is yes, give an example of one such path.

Practice Problems

In photon mapping, we collect two separate maps: (1) a global map, and (2) a caustic map. Explain the caustic paths and explain why this map is separated from the global map.

How are shadows captured in photon mapping?

Give some pros and cons of photon mapping compared to ray tracing and radiosity.