Computer Graphics

CSC 418/2504

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Slides 2-39 courtesy of Aaron Hertzmann

CSC418: Advanced Rendering Lecture

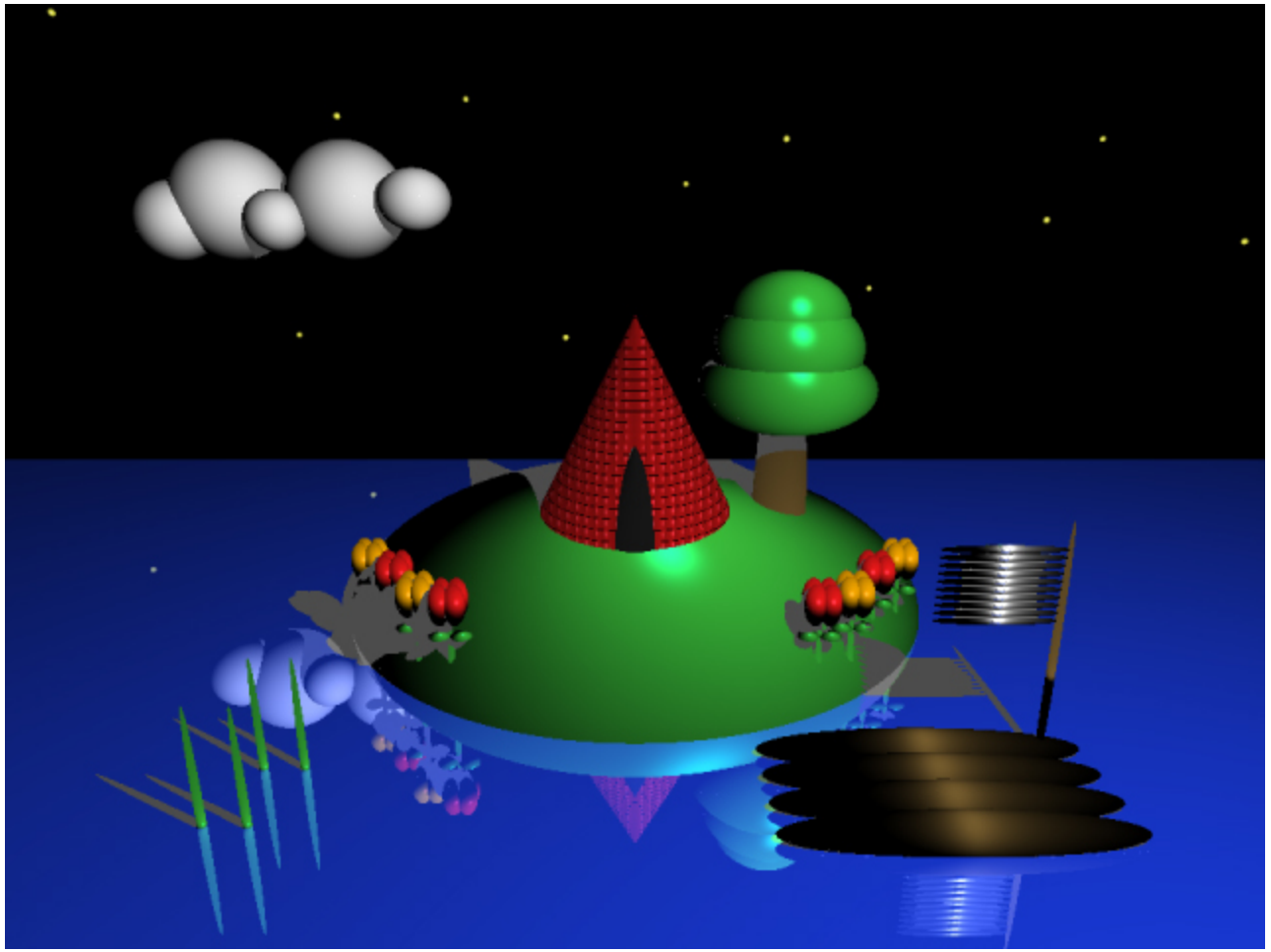
Distribution Ray Tracing & Advanced Camera Effects:

- extended light sources and soft shadows
- spatial super-sampling for anti-aliasing
- temporal super-sampling for motion blur
- sampling over lens for limited depth of field
- optical distortions

Photon Mapping

- Caustics
- Participating media
- Sub-surface scattering

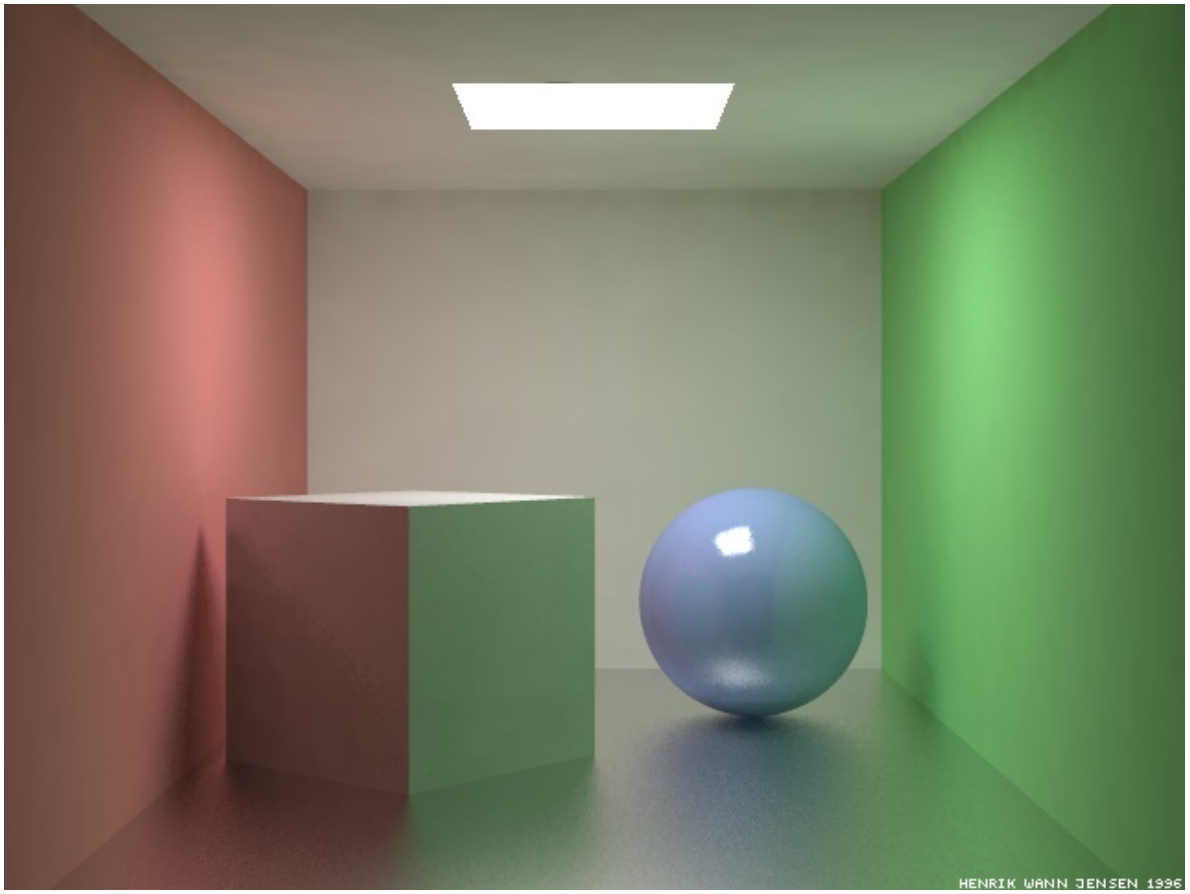
Global Illumination with Basic Ray-Tracing



Amy Lo

Advanced Global Illumination

H. W. Jensen

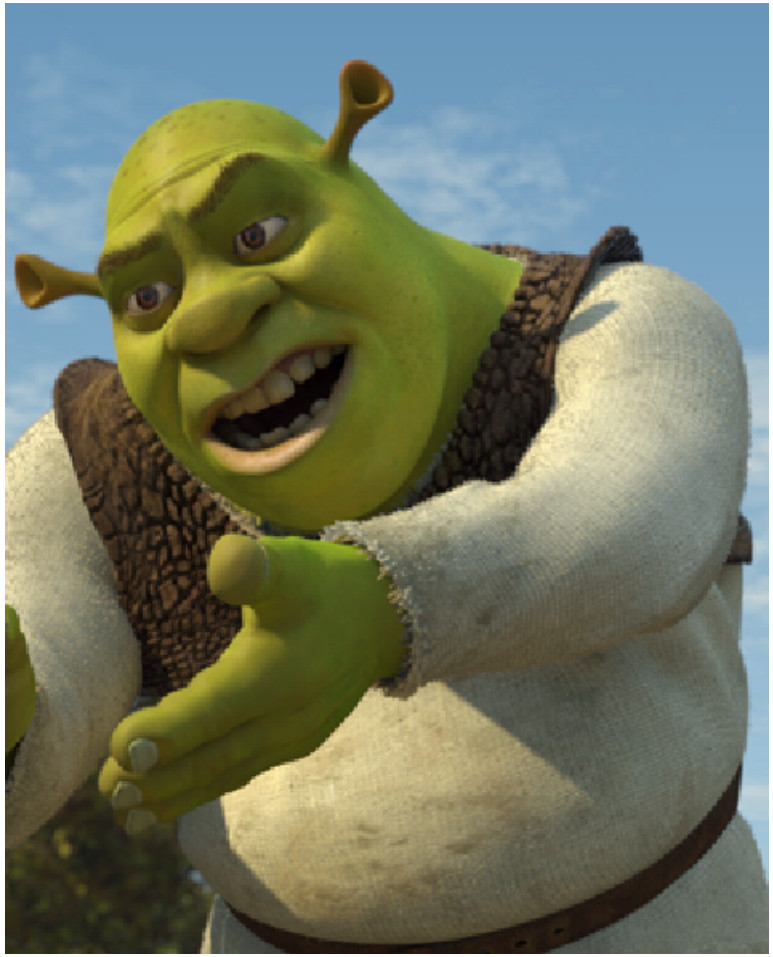


- Secondary reflection (colour bleeding)
- Imperfect specularities
- Extended light sources
- Softer lighting

Direct vs. indirect illumination

Tabellion and Lamorlette

Direct Illumination only



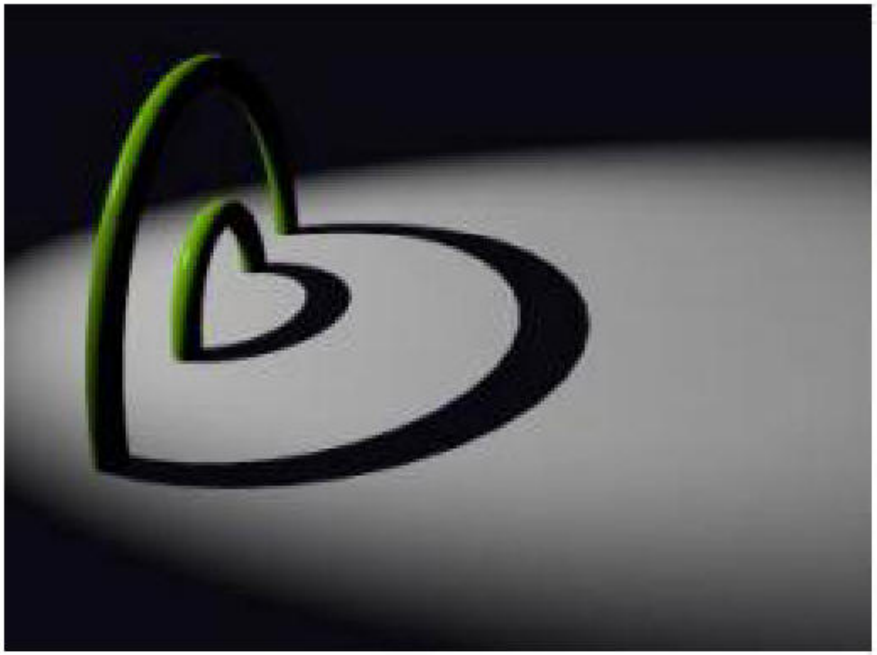
Direct and indirect illumination

Effects of Global Illumination

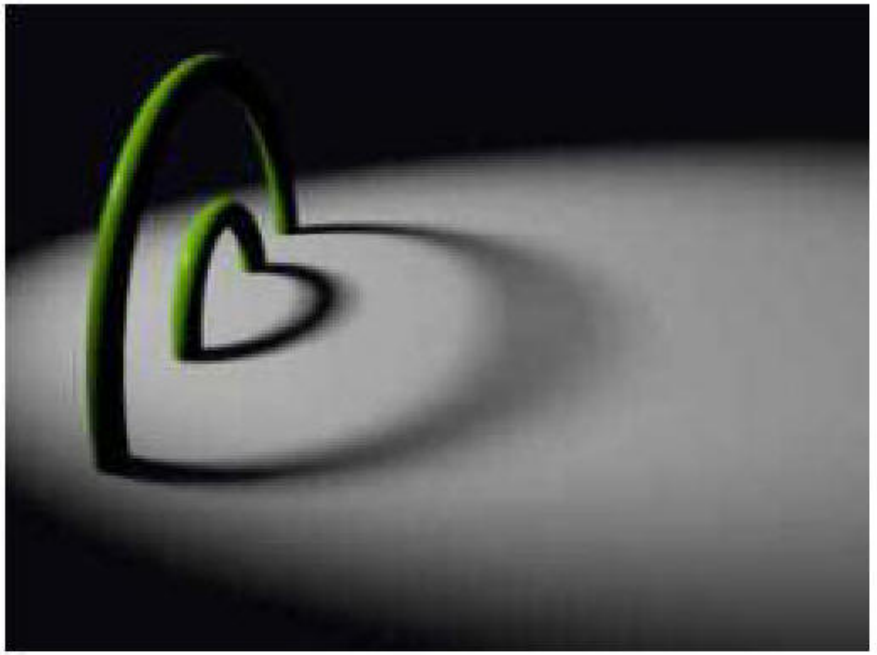
Veach & Guibas

- Secondary reflection (metal teapot), refraction (glass teapot), and *caustics* (where glass teapot focuses light on the table)
- Hidden light sources (e.g., behind door)
- Softer lighting

Extended Light Sources, Shadows & Penumbra

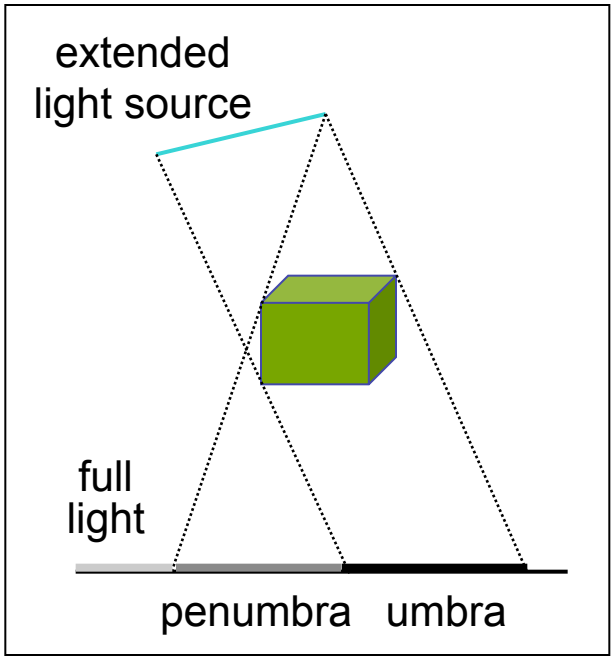


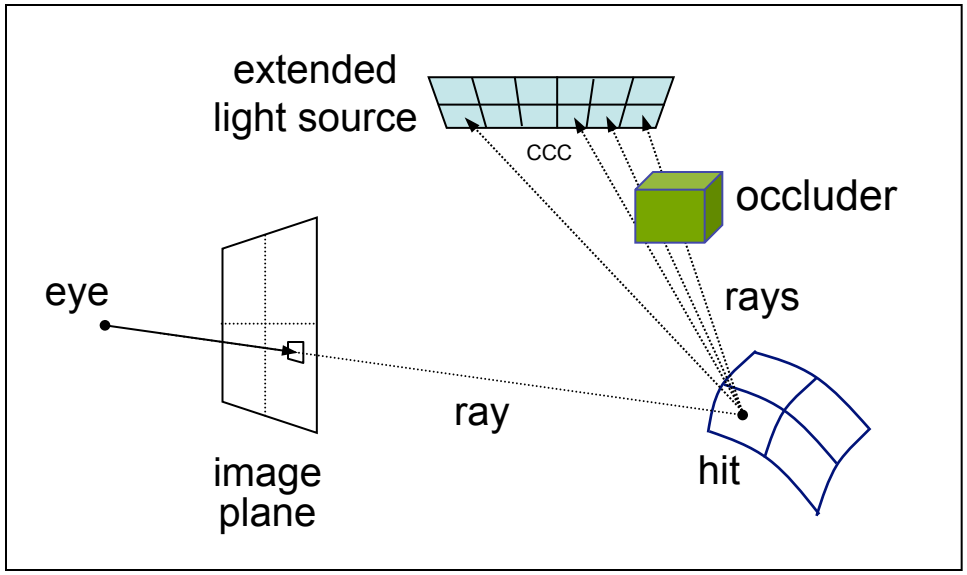
Point light sources produce hard shadows.

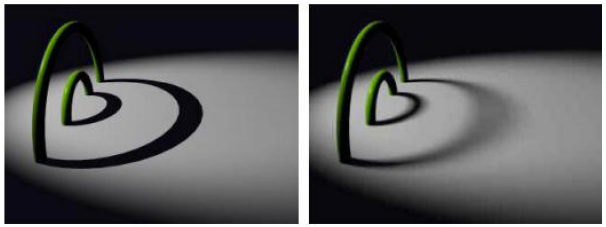


Extended sources produce softer shadows.

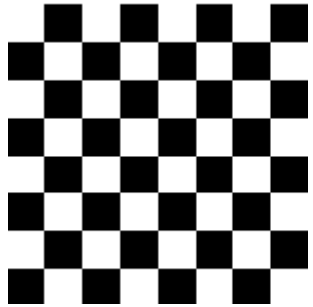
Extended Light Sources, Shadows & Penumbra

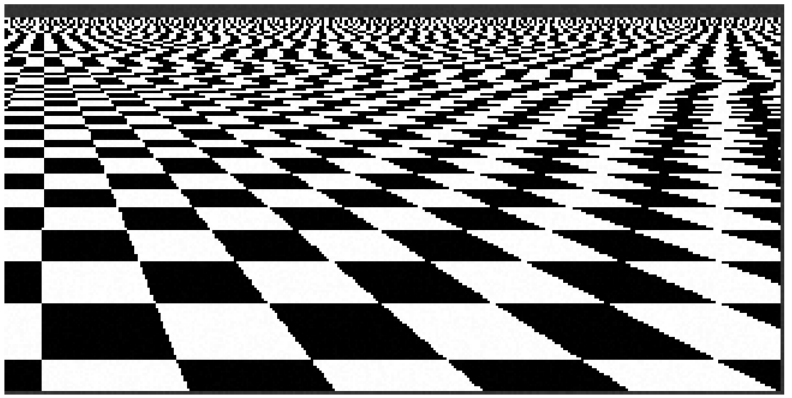




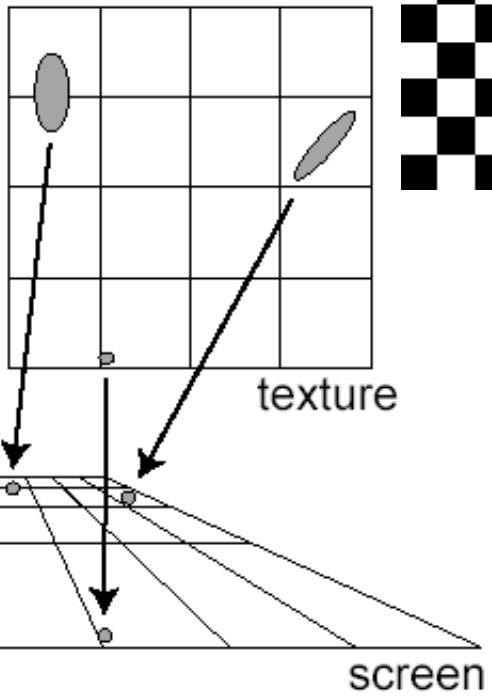


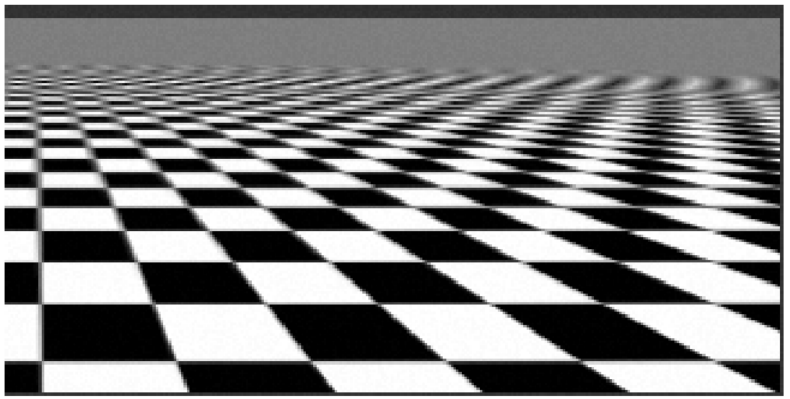
Spatial Aliasing



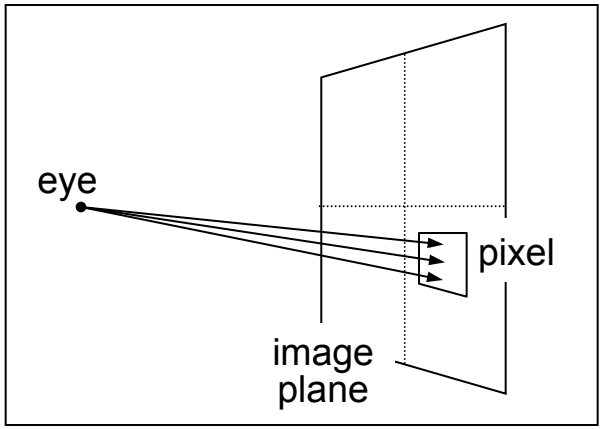


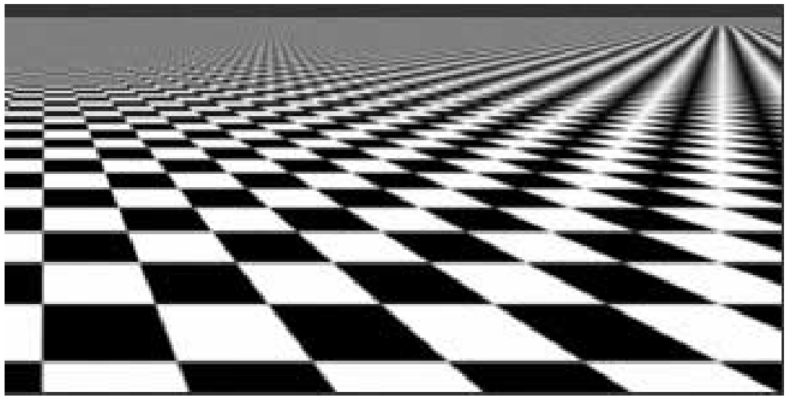
Single sample per pixel





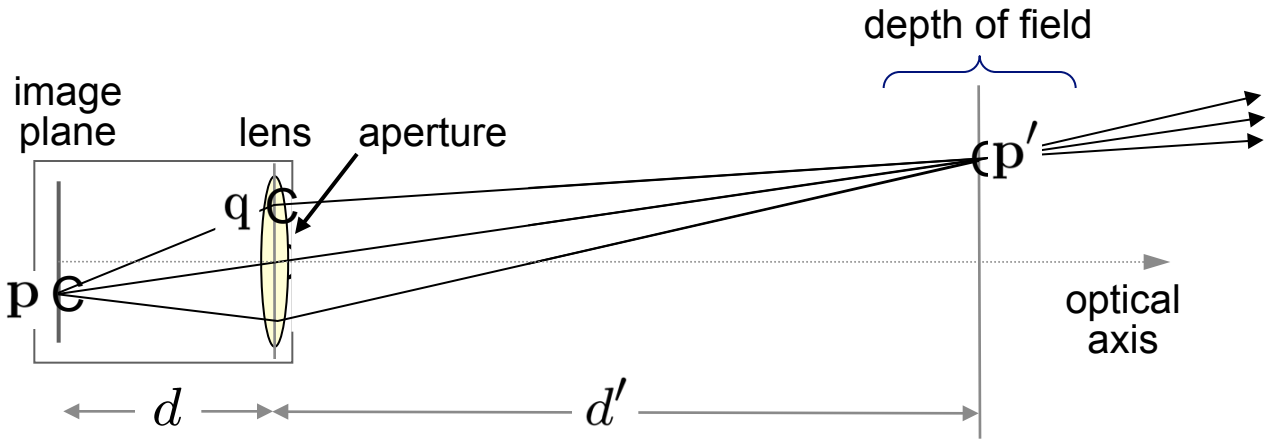
Mipmapping (in OpenGL)





Higher-quality anti-aliasing

Depth of Field



Thin lens model:

$$\frac{1}{d} + \frac{1}{d'} = \frac{1}{f}$$

Ray paths (in camera centered coordinates):

From a point on the image plane, $\mathbf{p}_{ij} = (x_i, y_j, d)$, to points on focal plane, $\mathbf{q} = (a, b, 0)$, and then through the point of perfect focus

$$\mathbf{p}'_{ij} = \frac{d'}{d}(x_i, y_j, -d)$$

So, for pixel (i, j), spawn rays from focal plane towards $\mathbf{p}'_{ij}$:

$$\mathbf{r}_{ij,ab}(\lambda) = (a, b, 0) + \lambda\,(\mathbf{p}'_{ij} - (a, b, 0))$$

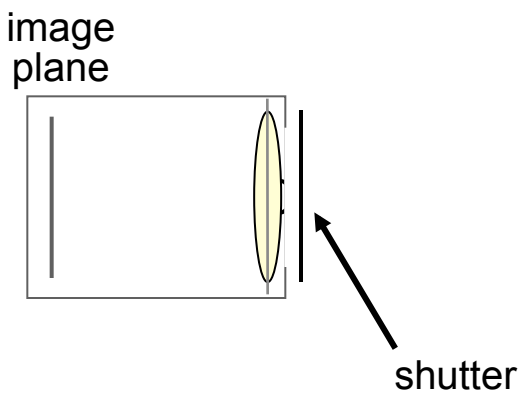
Depth of Field

P. Haeberli

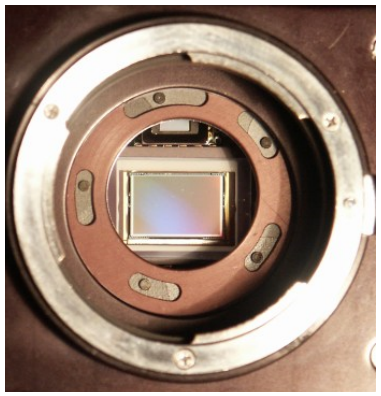
Depth of Field

Depth of Field

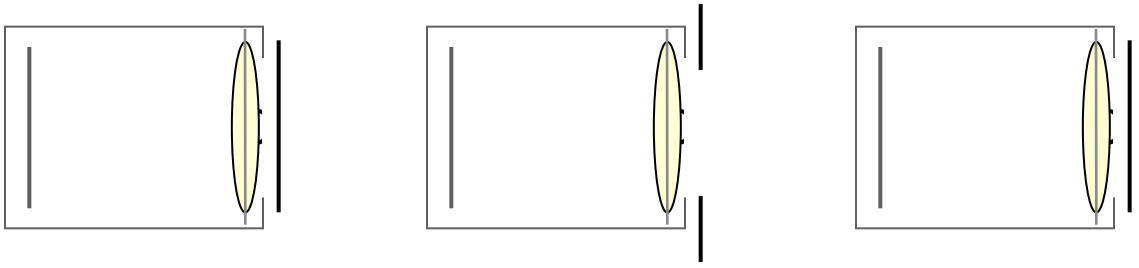
Camera shutter



Closed



Open



$$Q = \int_{t\alpha\beta} I(\vec{d}(\alpha,\beta),t)\, d\alpha\, d\beta\, dt$$

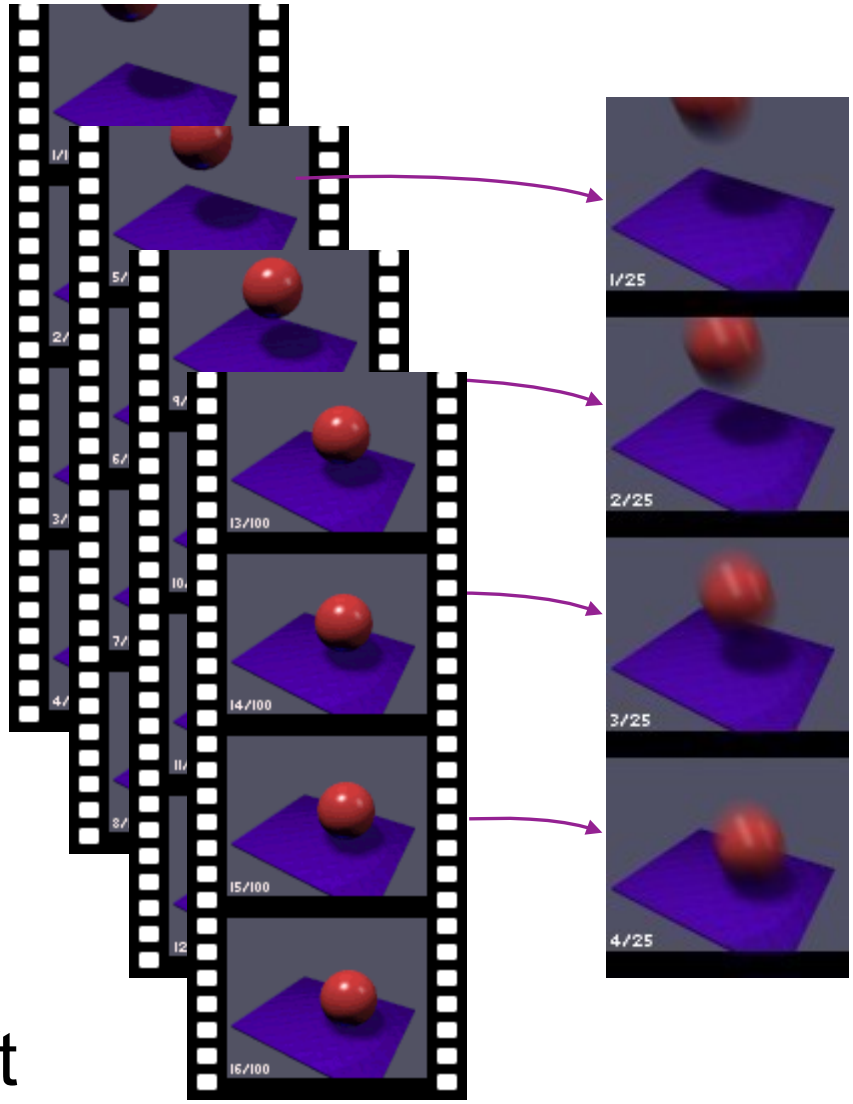
Temporal Integration / Motion Blur

Distribution ray casting within a temporal aperture

Cook, Porter & Carpenter

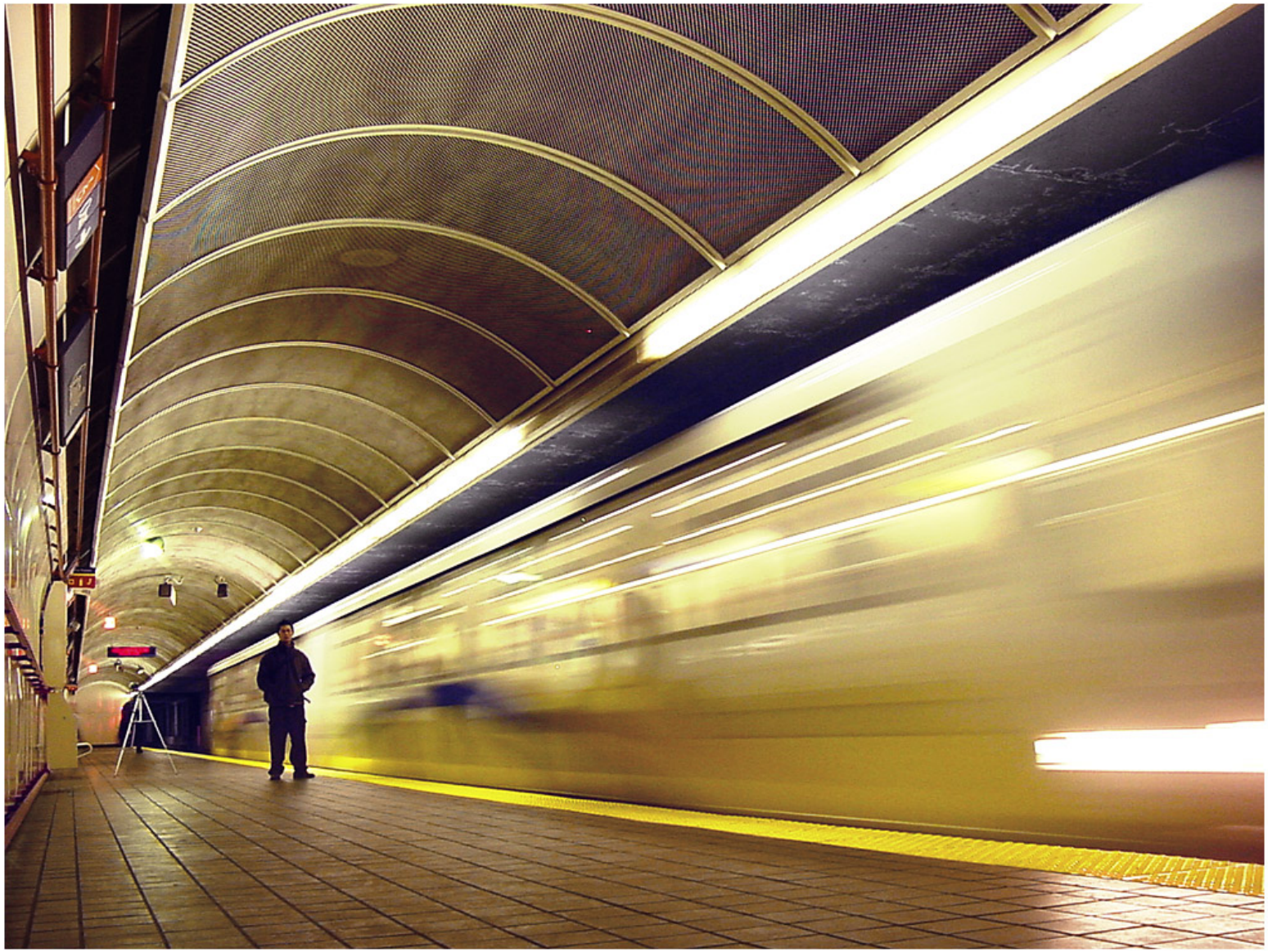
Temporal Integration / Motion Blur

Super-sampling within temporal aperture ⇨ cast multiple rays "while shutter is open", and then integrate the image irradiance.



$$I = \int_{t\alpha\beta} I(d(\alpha,\beta),t)\, d\alpha\, d\beta\, dt$$

Long exposure photography



Long exposure photography

30 seconds

1/10 second

Long exposure photography

20 minute exposure

Camera shake

Photographic considerations

Basic camera settings:

- Shutter speed (exposure time), measured in seconds
- Aperture size, measured in f-stops
- Focal length (zoom)
- Film/CCD sensitivity (ISO)

Image noise

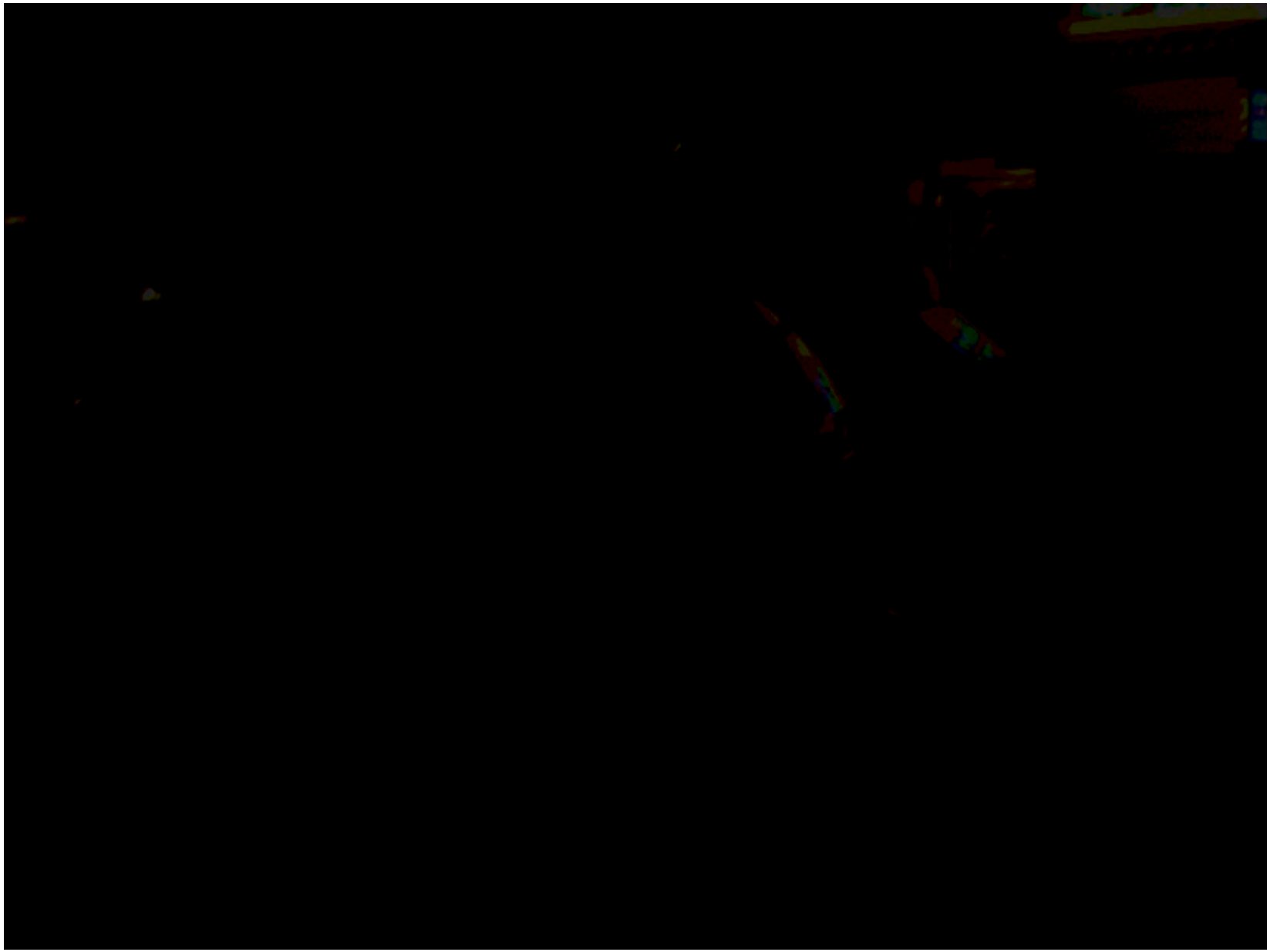


Image noise

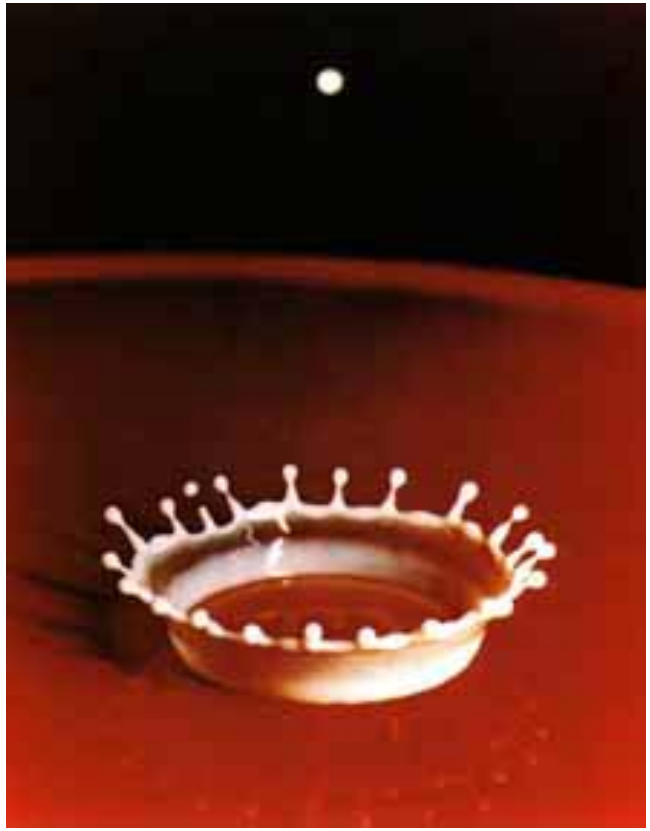
Photography considerations

- Image = Light + sensor noise
- Less light means a noisier image

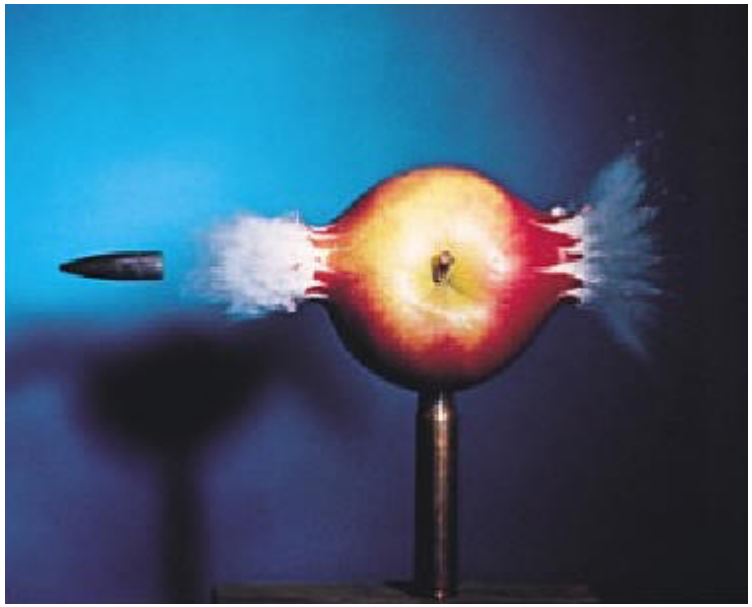
- Longer exposure time (faster shutter): more light, more motion blur
- More sensor sensitivity (higher ISO): more signal, more noise
- Bigger aperture (f-stop): more light, smaller depth-of-field

- Photographers carefully balance shutter, ISO, and f-stop

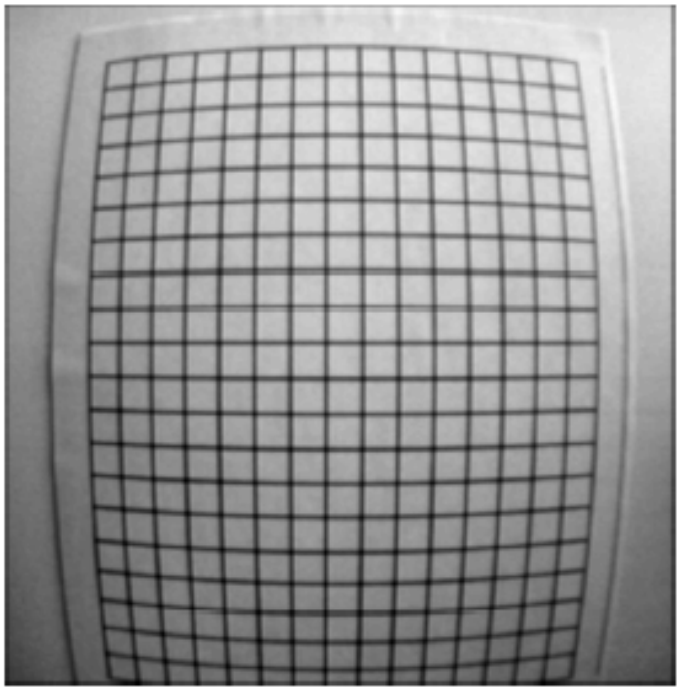
How were these images created?

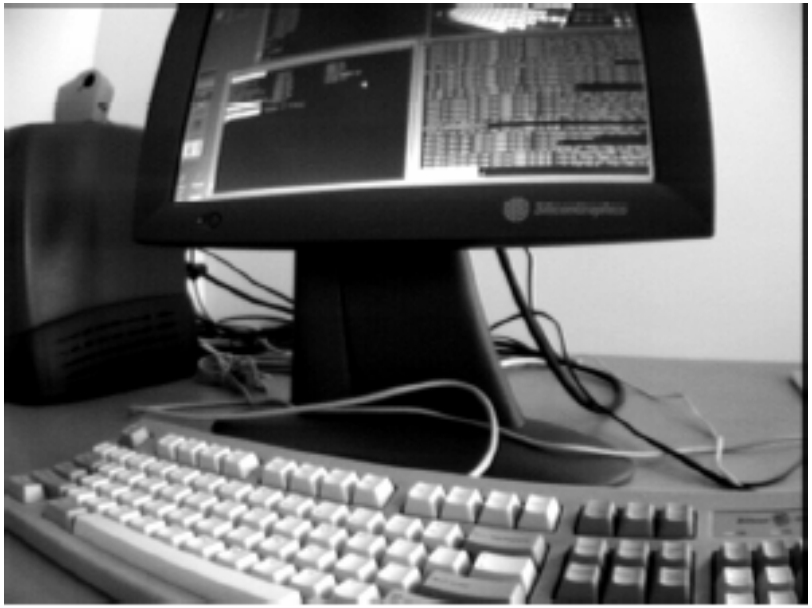


Doc Edgerton, 1936

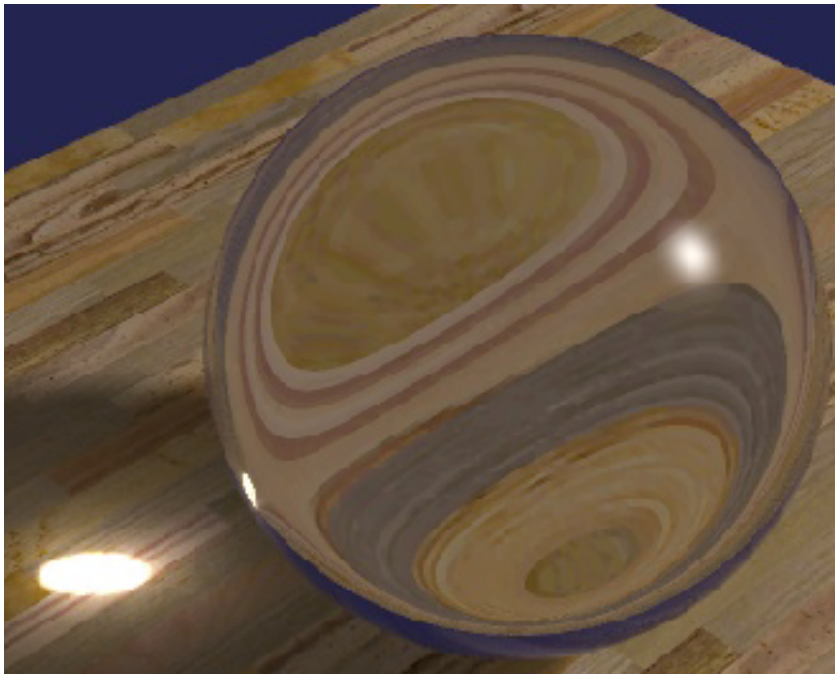


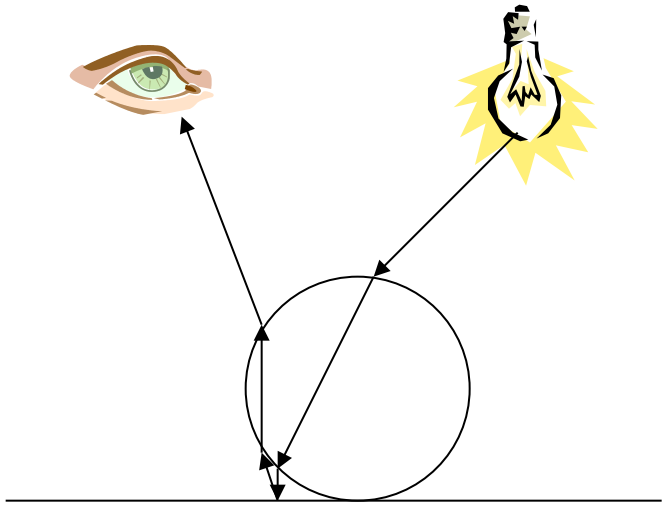
Optical Distortion





Refraction with Caustics

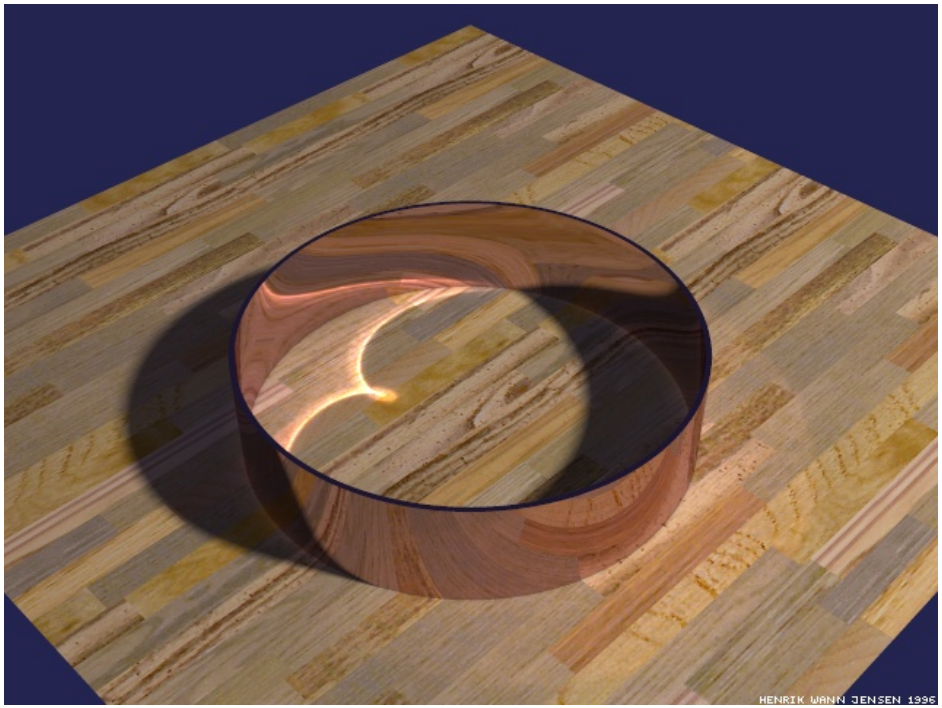




H. W. Jensen, J. C. Hart

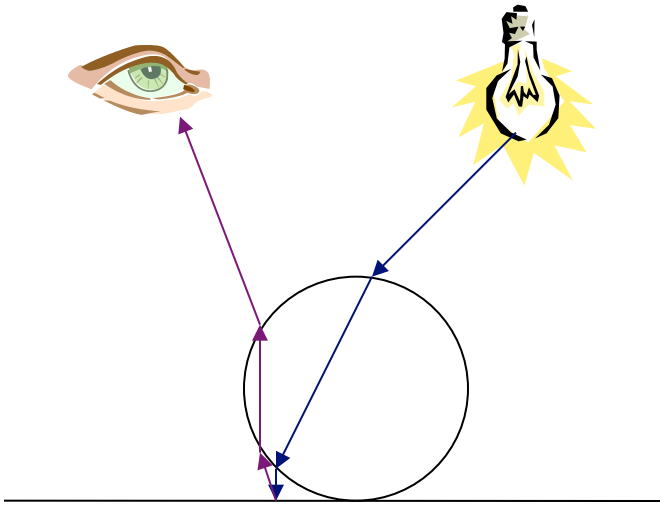
Caustics

Reflection with Caustics



H. W. Jensen

Photon Mapping

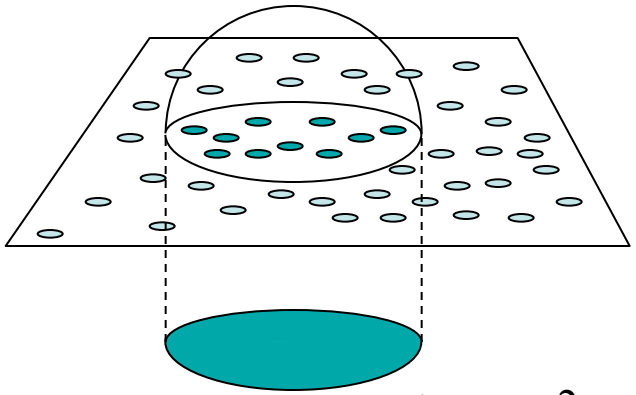


Two passes:

1. Emit photons (discrete amounts of light) from light sources and "gather" them on each surface
2. Render the scene, treating photons as light sources (with filtering)

Applications:

Indirect illumination with scattering



$$\Delta A = \pi r^2$$

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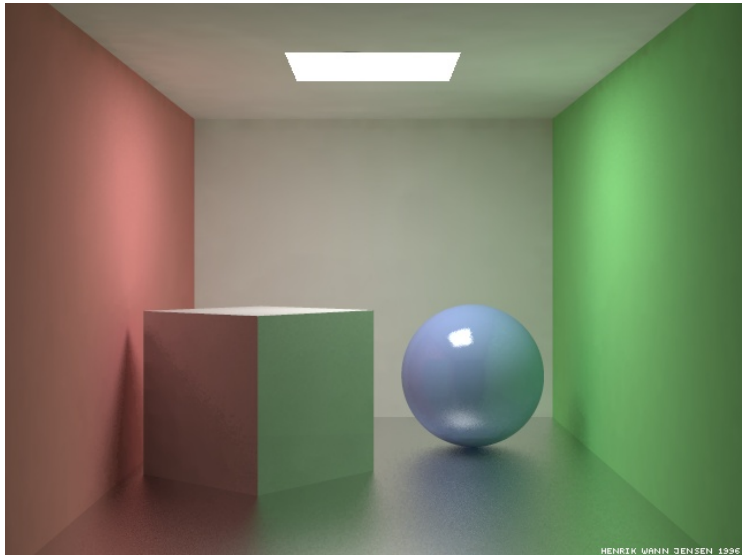
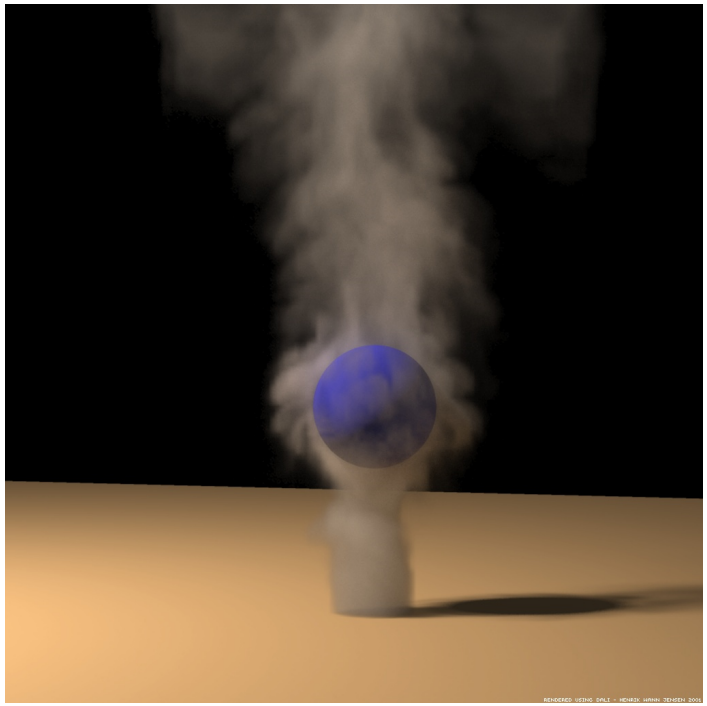
Other photon mapping effects

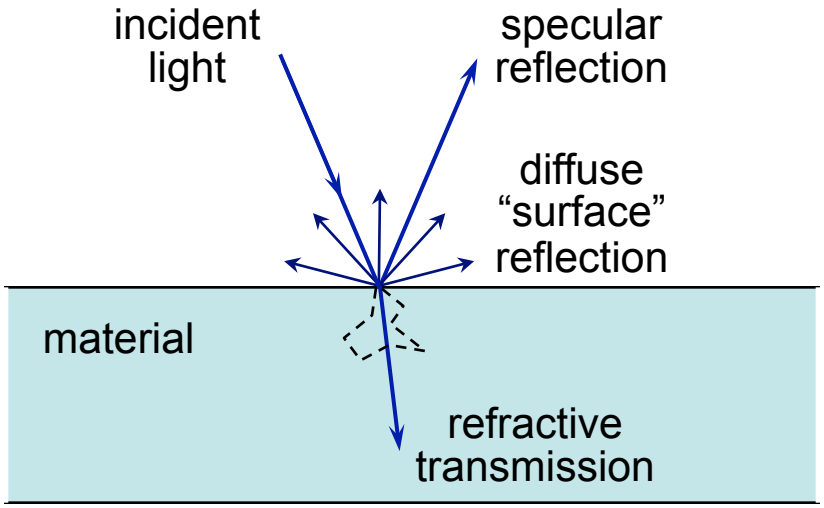


Indirect illumination
(50 minutes with PM; 6 hours with *Radiance*)



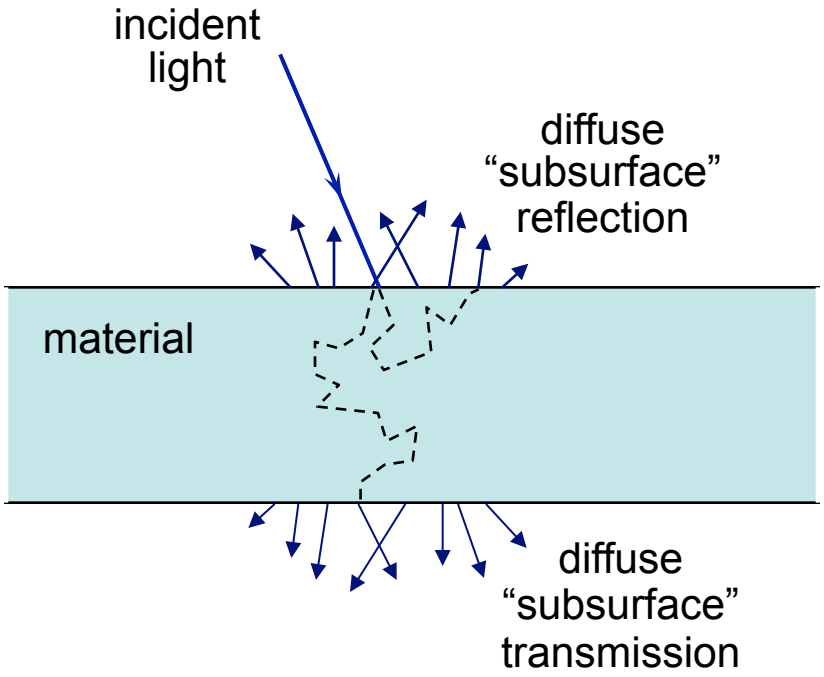
Participating media (e.g., fog, smoke)

Subsurface Scattering



Conventional ray tracing with local Phong reflectance and “perfect” specular reflection and refractive transmission.

Subsurface Scattering



Most materials other than metals scatter light below the surface, with subsequent emission occurring over a spatial neighbourhood (e.g. biological tissues, marble, porcelain, liquids …)

Subsurface Scattering

H. W. Jensen

Subsurface Scattering

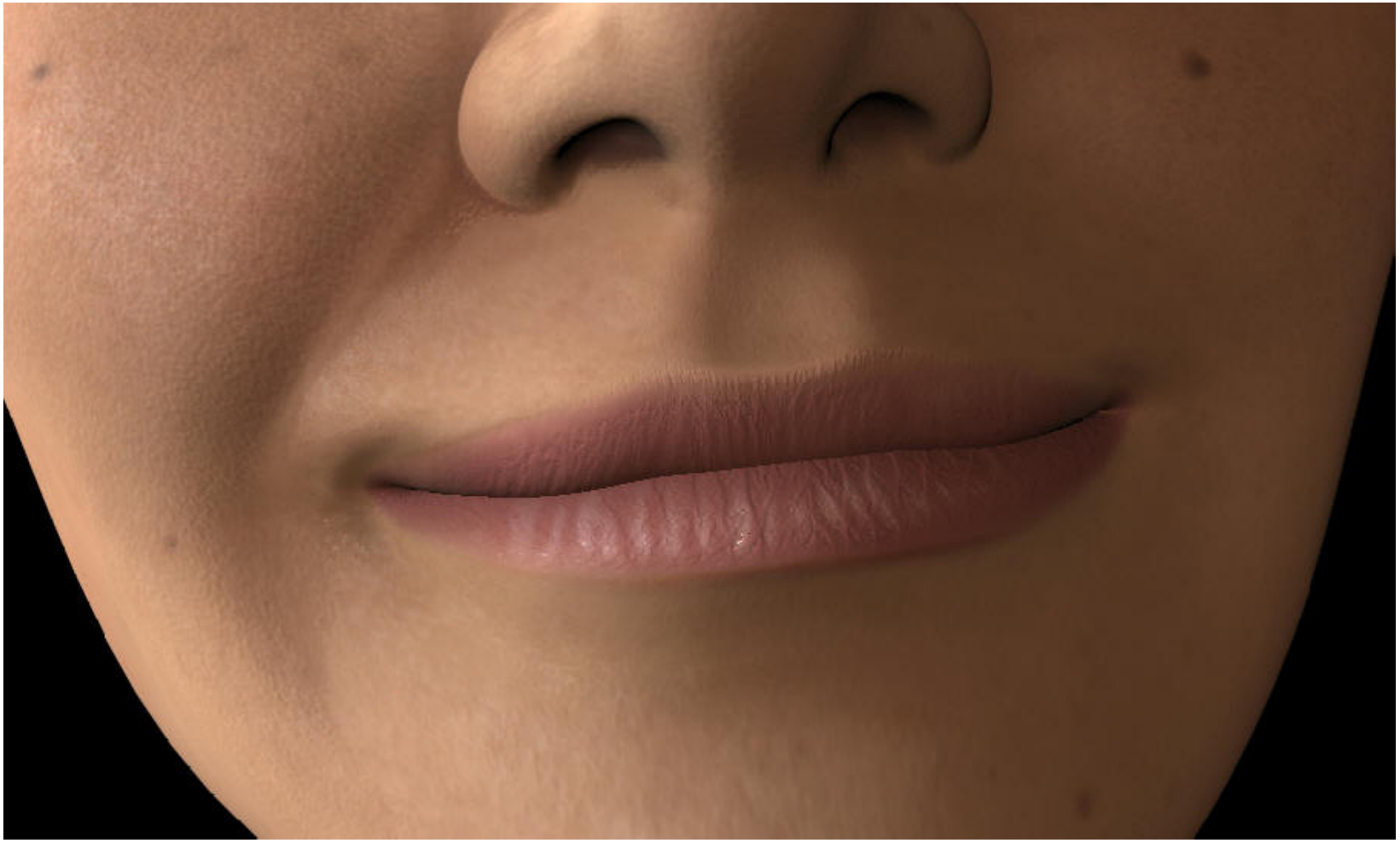
H. W. Jensen

Subsurface Scattering

Rendering with BRDF

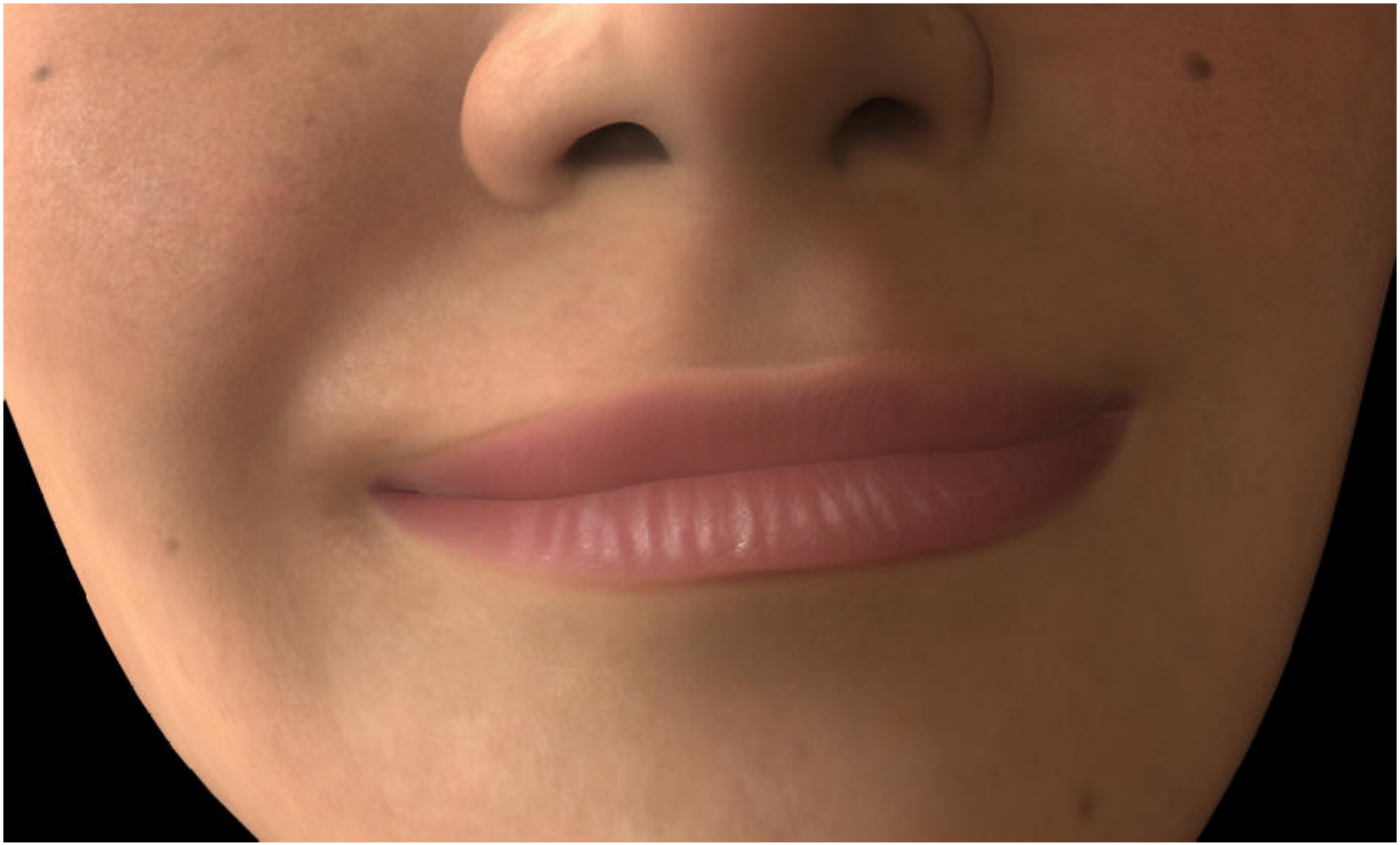
Rendering with BSSRDF

Subsurface Scattering



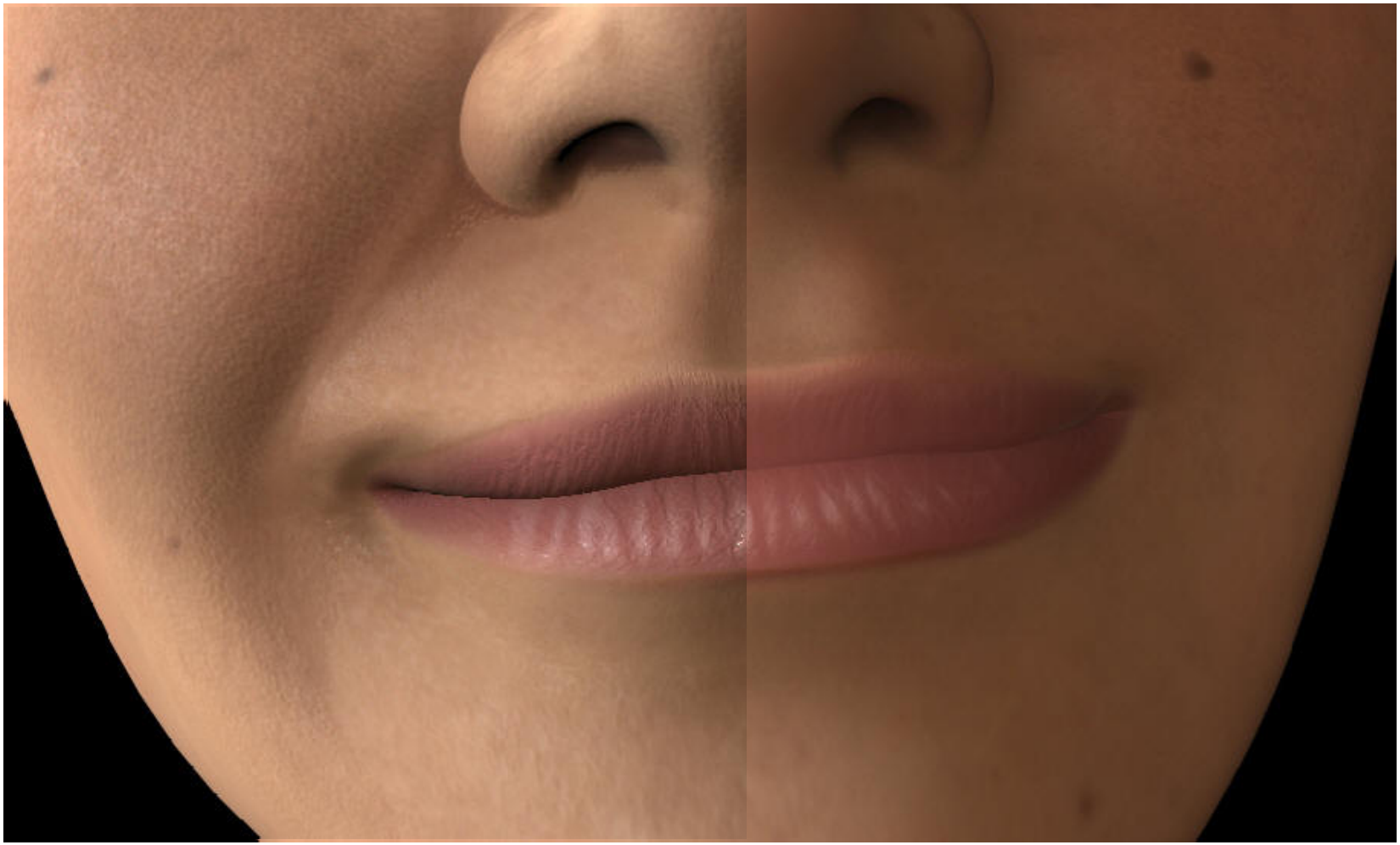
Jensen & Buhler

Subsurface Scattering



Jensen & Buhler

Subsurface Scattering



Jensen & Buhler

Summary

- **Global illumination:** direct + indirect illumination
- **Distribution ray tracing:** integrate multiple rays over an interval (soft shadows, depth of field, motion blur, ...)
- **Photon mapping:** emit and trace particles from light, gather on surfaces, filter and treat as light sources (caustics, subsurface scattering, participating media)
- **Path tracing:** "brute force ray tracing", sends rays from the eye and traces them back until light reached or max depth. (all of the above + indirect lighting, caustics, ...)