Distribution Ray Tracing: Continuation

Computer Graphics, CSCD18

Fall 2008

Instructor: Leonid Sigal

Back to Distribution Ray Tracing

- Based on one of the approximate integration approaches we need to compute
  - Let's try uniform sampling

$$\mathbf{L}(\overline{\mathbf{p}},\vec{\mathbf{d}}_{\mathbf{e}}) = \int_{\phi\in[0,2\pi]}\int_{\theta\in[0,2\pi]} \rho\left(\vec{\mathbf{d}}_{\mathbf{e}},\vec{\mathbf{d}}_{\mathbf{i}}(\phi,\theta)\right)\mathbf{L}\left(\overline{\mathbf{p}},-\vec{\mathbf{d}}_{\mathbf{i}}(\phi,\theta)\right)\left(\vec{\mathbf{n}}\cdot\vec{\mathbf{d}}_{\mathbf{i}}(\phi,\theta)\right)\sin\theta\,\mathbf{d}\theta\,\mathbf{d}\phi$$

$$\approx \sum_{\mathbf{m}=1}^{\mathbf{M}}\sum_{\mathbf{n}=1}^{\mathbf{N}} \rho\left(\vec{\mathbf{d}}_{\mathbf{e}},\vec{\mathbf{d}}_{\mathbf{i}}(\phi_{\mathbf{m}},\theta_{\mathbf{n}})\right)\mathbf{L}\left(\overline{\mathbf{p}},-\vec{\mathbf{d}}_{\mathbf{i}}(\phi_{\mathbf{m}},\theta_{\mathbf{n}})\right)\left(\vec{\mathbf{n}}\cdot\vec{\mathbf{d}}_{\mathbf{i}}(\phi_{\mathbf{m}},\theta_{\mathbf{n}})\right)\sin\theta\,\Delta\theta\,\Delta\phi$$

where

$$\theta_{\mathbf{n}} = \left(\mathbf{n}-\frac{1}{2}\right)\Delta\theta \qquad \Delta\theta = \frac{\pi/2}{\mathbf{M}}$$

$$\phi_{\mathbf{m}} = \left(\mathbf{m}-\frac{1}{2}\right)\Delta\phi \qquad \Delta\phi = \frac{2\pi}{\mathbf{N}}$$

midpoint of the interval (sample point)

Interval width

Importance Sampling in Distribution Ray Tracing

- **Problem:** Uniform sampling is too expensive (e.g. **100** samples/hemisphere with depth of ray recursion of **4** => **100^4=10^8** samples per pixel … with **10^5** pixels =>**10^{15} samples**)

- **Solution:** Sample more densely (using **importance sampling**) where we know that effects will be most significant (e.g. visible surfaces, light sources, etc.)
  - Direction toward point or extended light source are significant
  - Specular and off-axis specular are significant
  - Texture/lightness gradients are significant
  - Sample less with greater depth of recursion

Importance Sampling (review)

- **Idea:** Approximates any integral by samples drawn independently and identically from some desired importance distribution $\mathbf{Q(x)}$

$$\frac{1}{\mathbf{N}}\sum \mathbf{f}(\mathbf{x}_\mathbf{i}) \approx \int \mathbf{Q}(\mathbf{x})\mathbf{f}(\mathbf{x})\,\mathbf{dx}, \quad \mathbf{x}_\mathbf{i} \sim \mathbf{Q}(\mathbf{x})$$

- This is not quite what we want, but if we (scale) or divide by $\mathbf{Q(x_i)}$

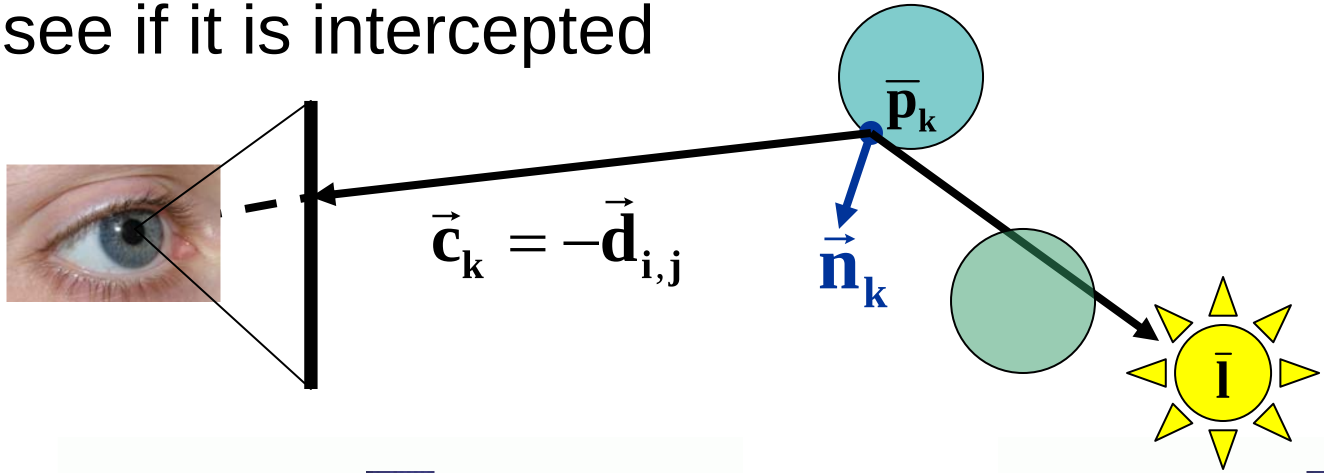
$$\frac{1}{\mathbf{N}}\sum \mathbf{w}_\mathbf{i}\mathbf{f}(\mathbf{x}_\mathbf{i}) \approx \int \mathbf{f}(\mathbf{x})\,\mathbf{dx} \quad \text{, for } \mathbf{w}_\mathbf{i} = \frac{1}{\mathbf{Q}(\mathbf{x}_\mathbf{i})}$$

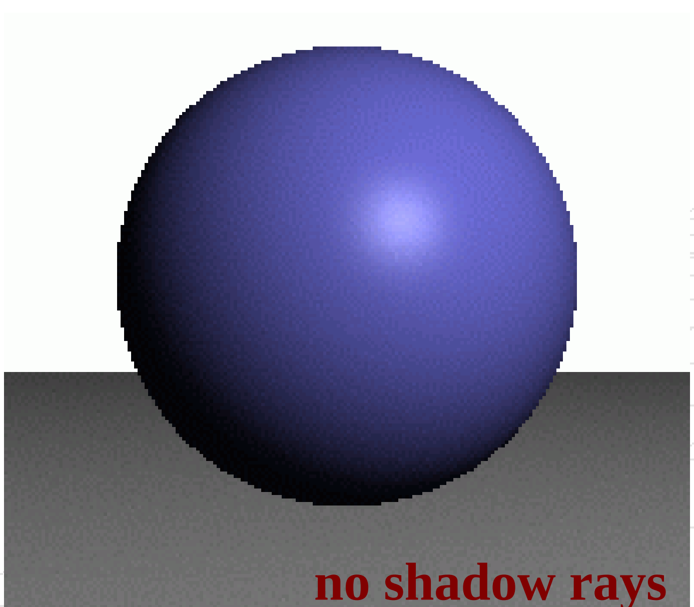
Benefits of Distribution Ray Tracing

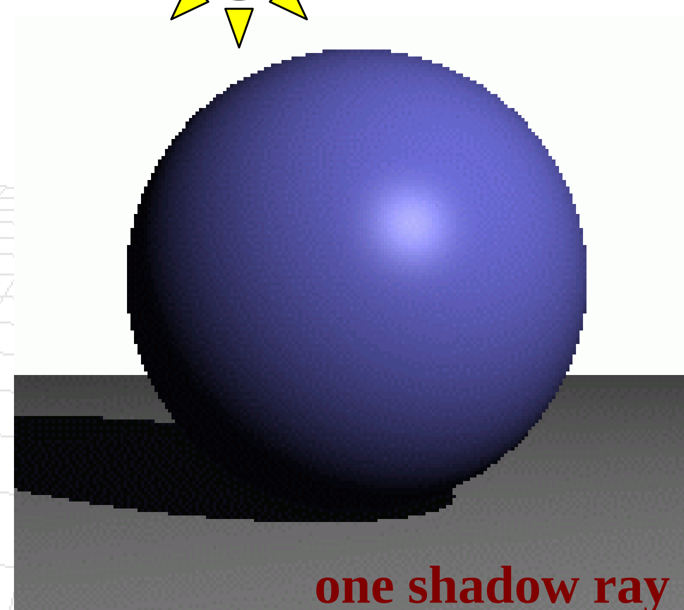
- Better global diffuse lighting
  - Color bleeding
  - Bouncing highlights
- Extended light sources
- Anti-aliasing
- Motion blur
- Depth of field
- Subsurface scattering

Shadows in Ray Tracing

- Recall, we shoot a ray towards a light source and see if it is intercepted



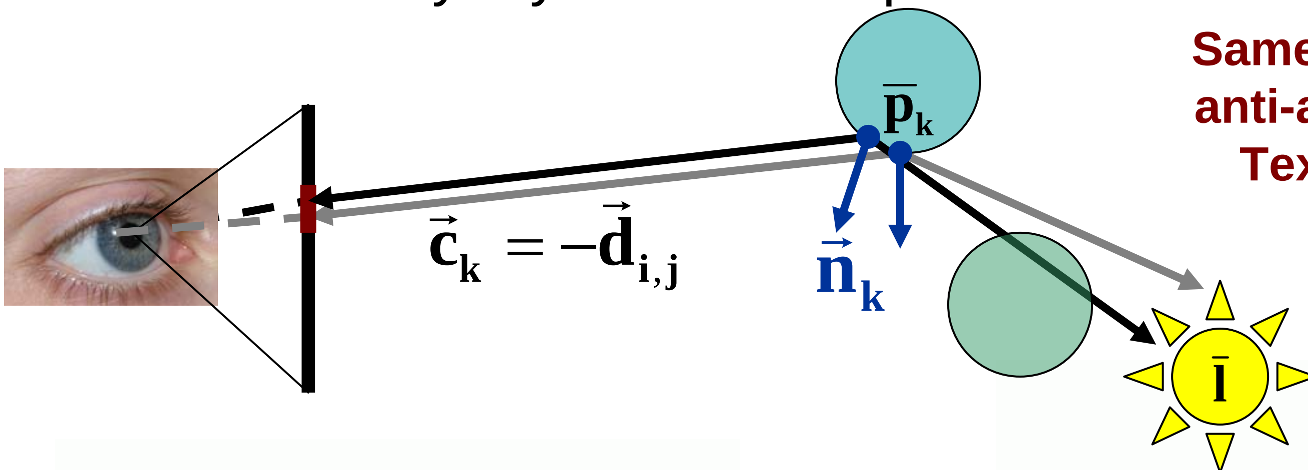




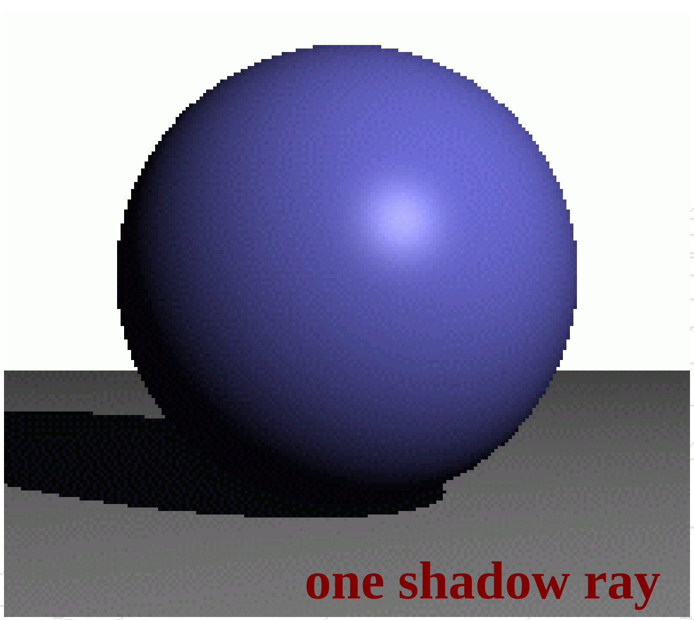
Images from the slides by Durand and Cutler

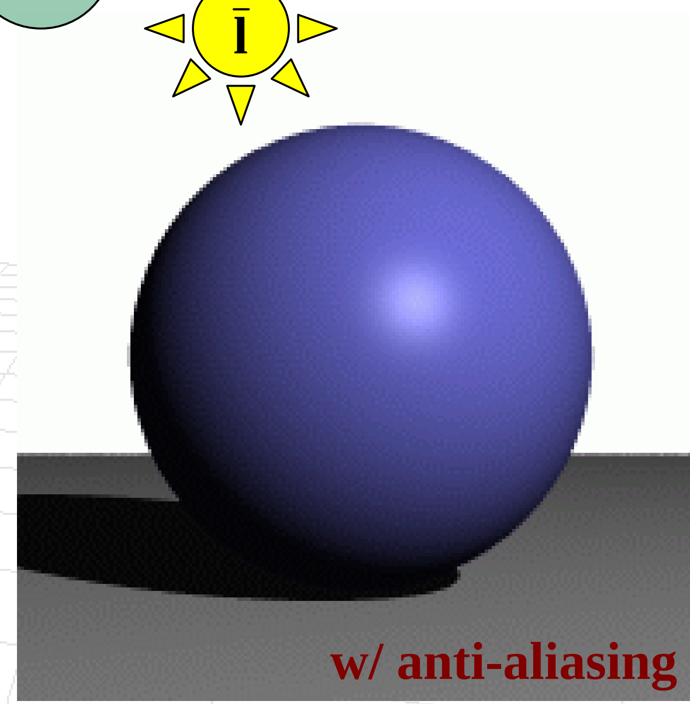
Anti-aliasing in Distribution Ray Tracer

- Lets shoot multiple rays from the same point and attenuate the color based on how many rays are intercepted



Same works for anti-aliasing of Textures !!!





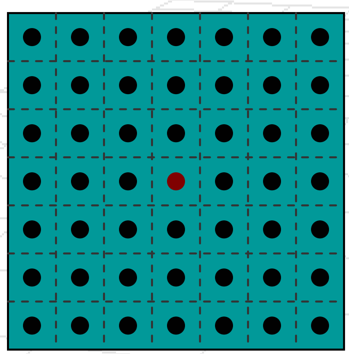
Images from the slides by Durand and Cutler

Anti-aliasing by Deterministic Integration

- **Idea:** Use multiple rays for every pixel

- **Algorithm**
  - Subdivide pixel ***(i,j)*** into squares
  - Cast ray through square centers
  - Average the obtained light

- Susceptible to structured noise, repeating textures

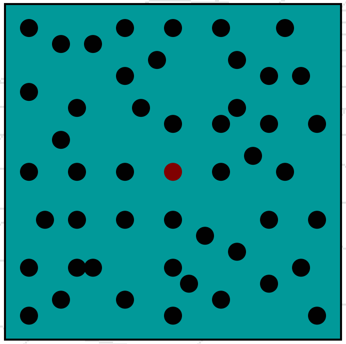


Anti-aliasing by Monte Carlo Integration

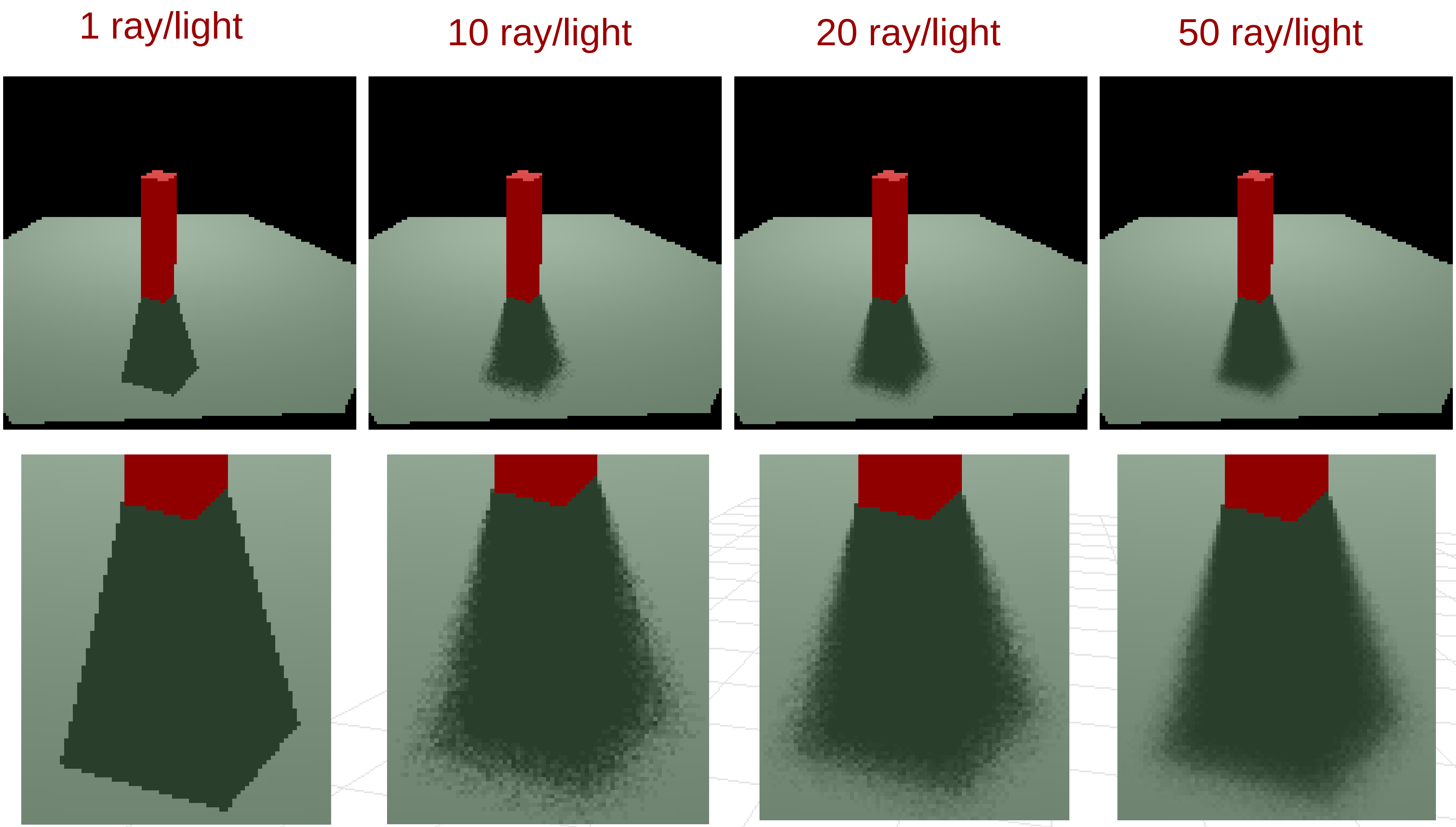
- **Idea:** Use multiple rays for every pixel

- **Algorithm**
  - Randomly sample point inside the pixel ***(i,j)***
  - Cast ray through square centers
  - Average the obtained light

- **Does not** suffer from structured noise, repeating textures



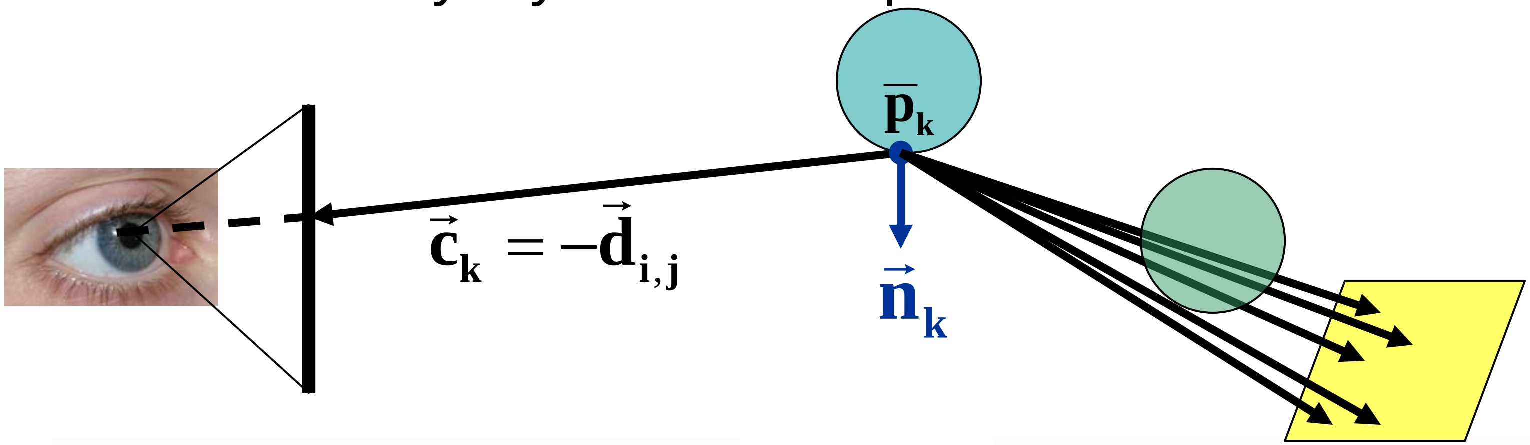
How many rays do you need?

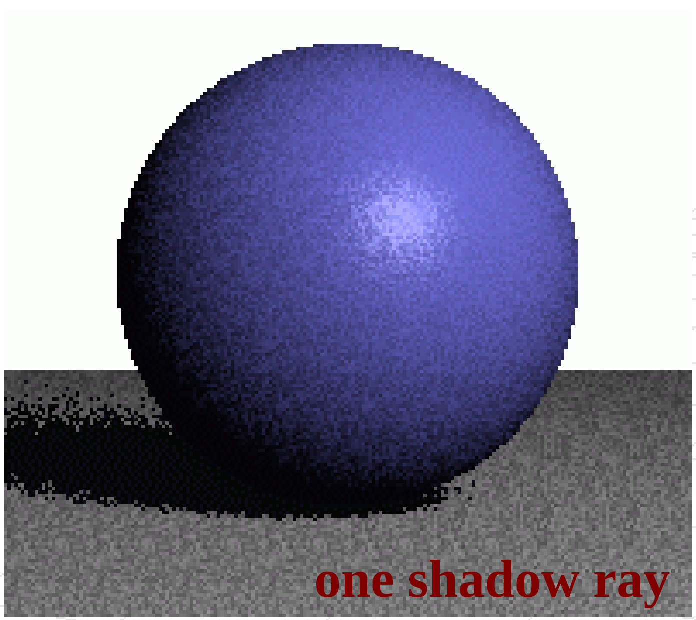


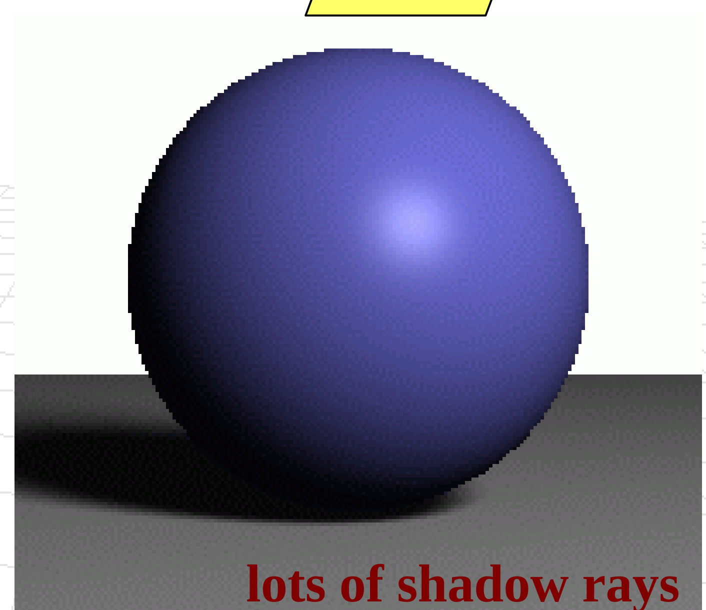
Images taken from http://web.cs.wpi.edu/~matt/courses/cs563/talks/dist_ray/dist.html

Soft Shadows with Distribution Ray Tracing

- Lets shoot multiple rays from the same point and attenuate the color based on how many rays are intercepted

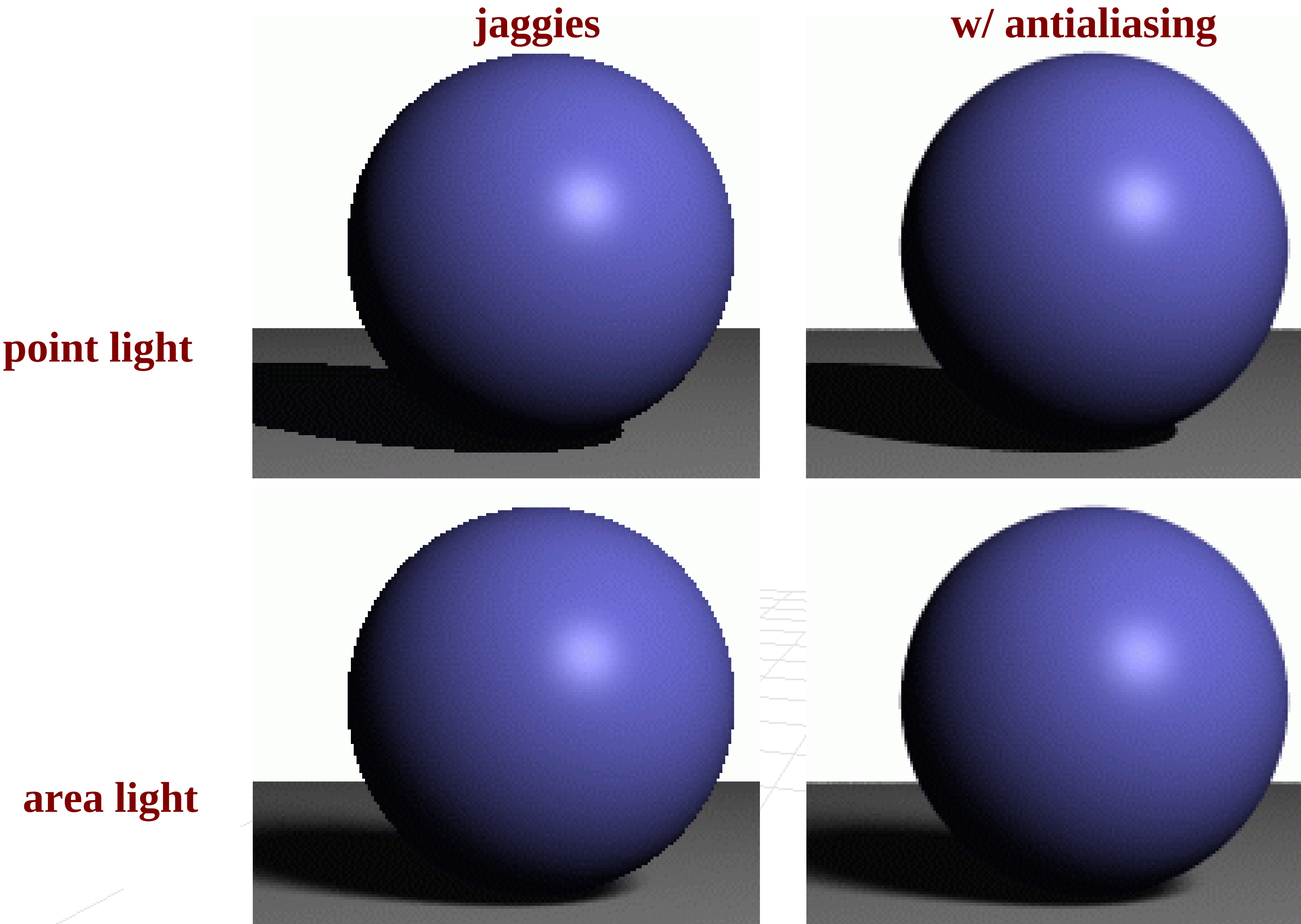






Images from the slides by Durand and Cutler

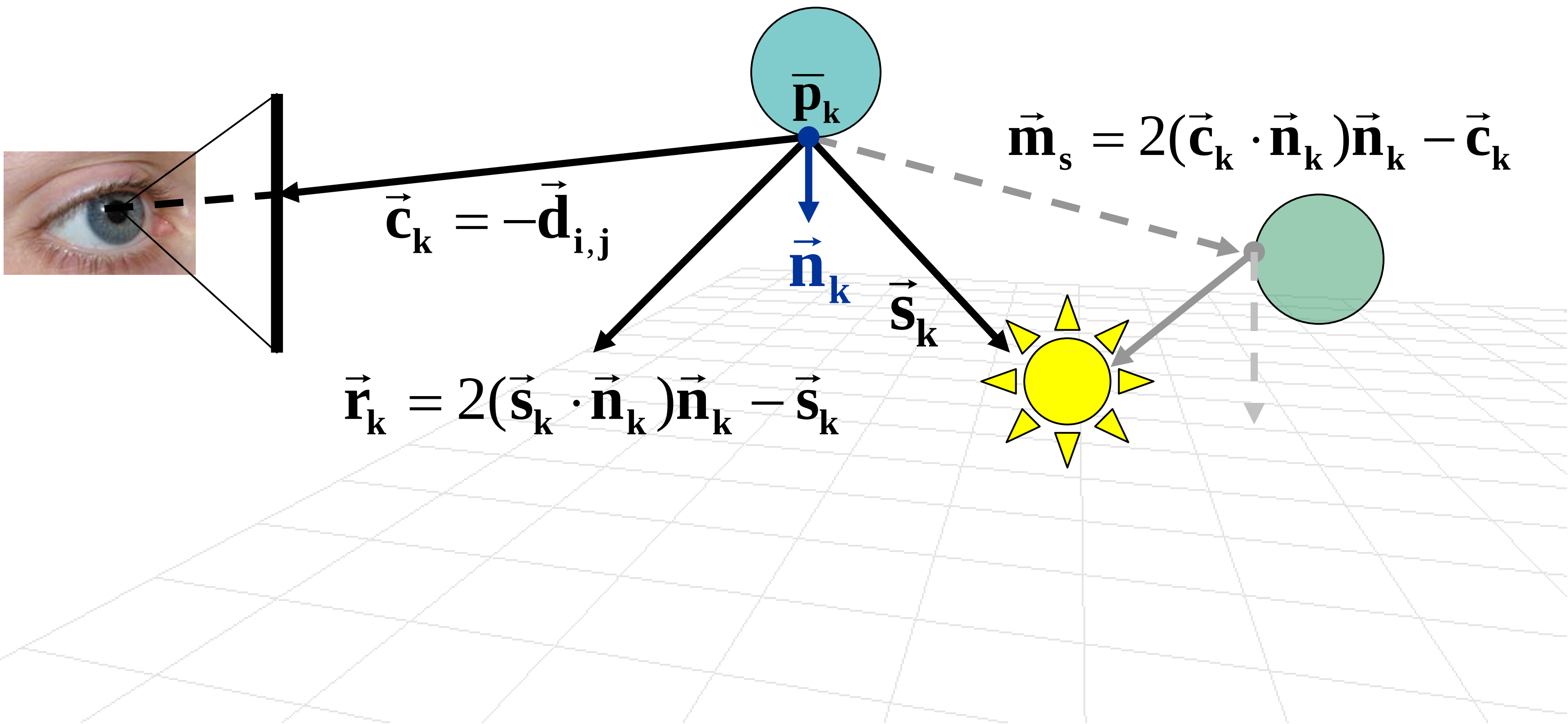
Antialiasing – Supersampling



Images from the slides by Durand and Cutler

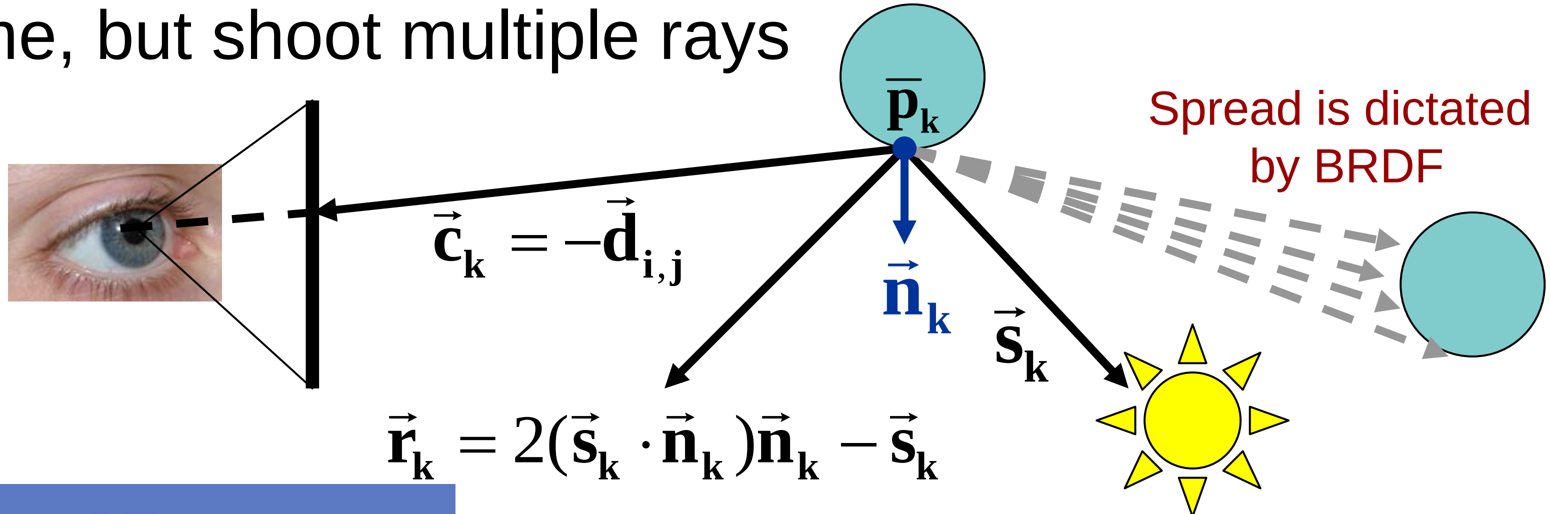
Specular Reflections

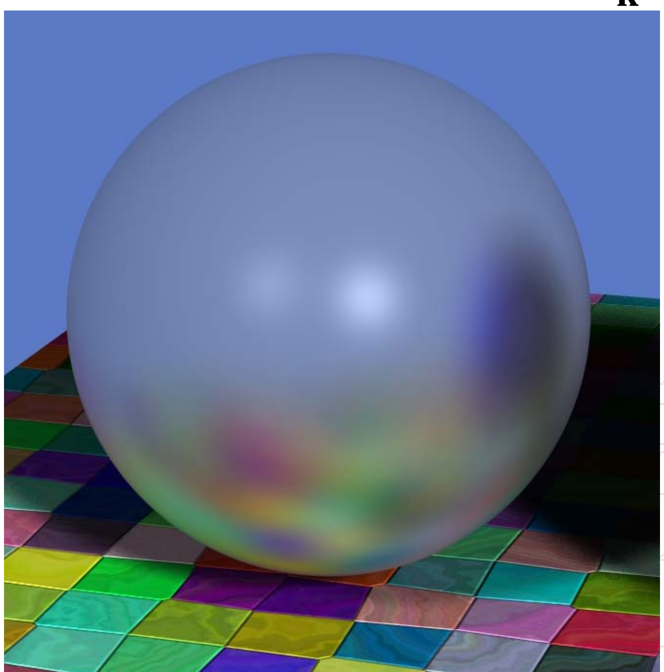
- Recall, we had to shoot a ray in a perfect specular reflection direction (with respect to the camera) and get the radiance at the resulting hit point



Specular Reflections with DRT

- Same, but shoot multiple rays





Justin Legakis

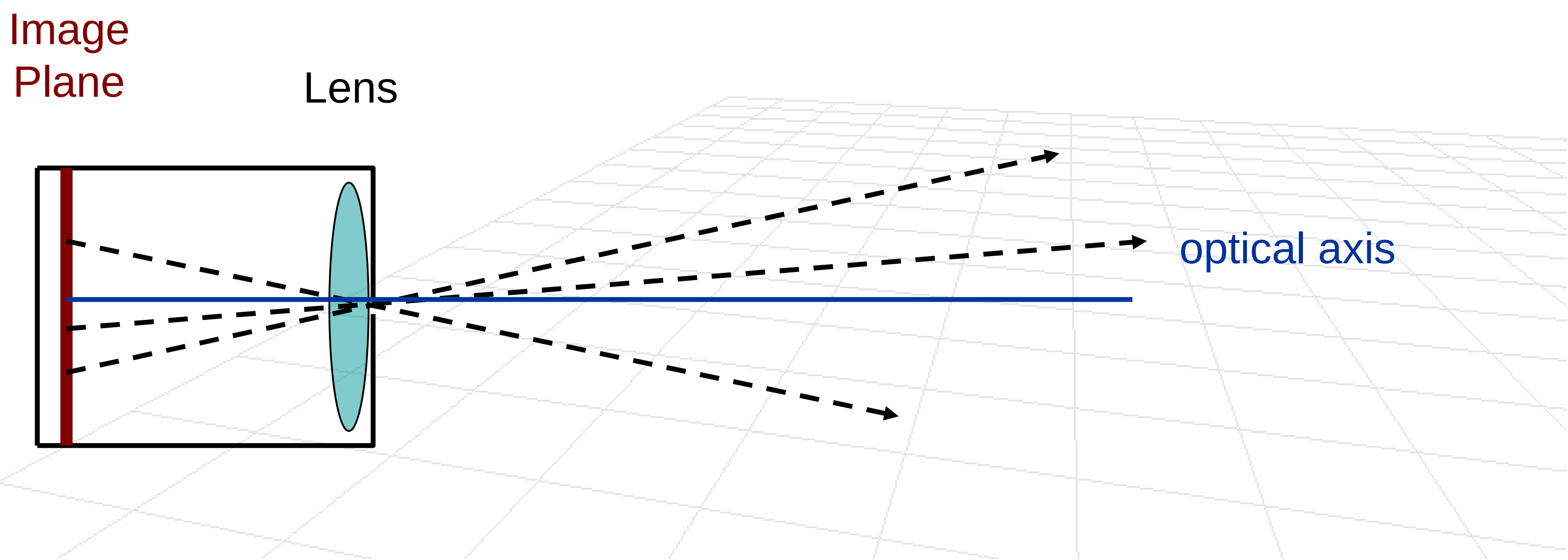
Perfect Reflections (Metal)

Perfect Reflections (glossy polished surface)

[Jensen]

Depth of Field

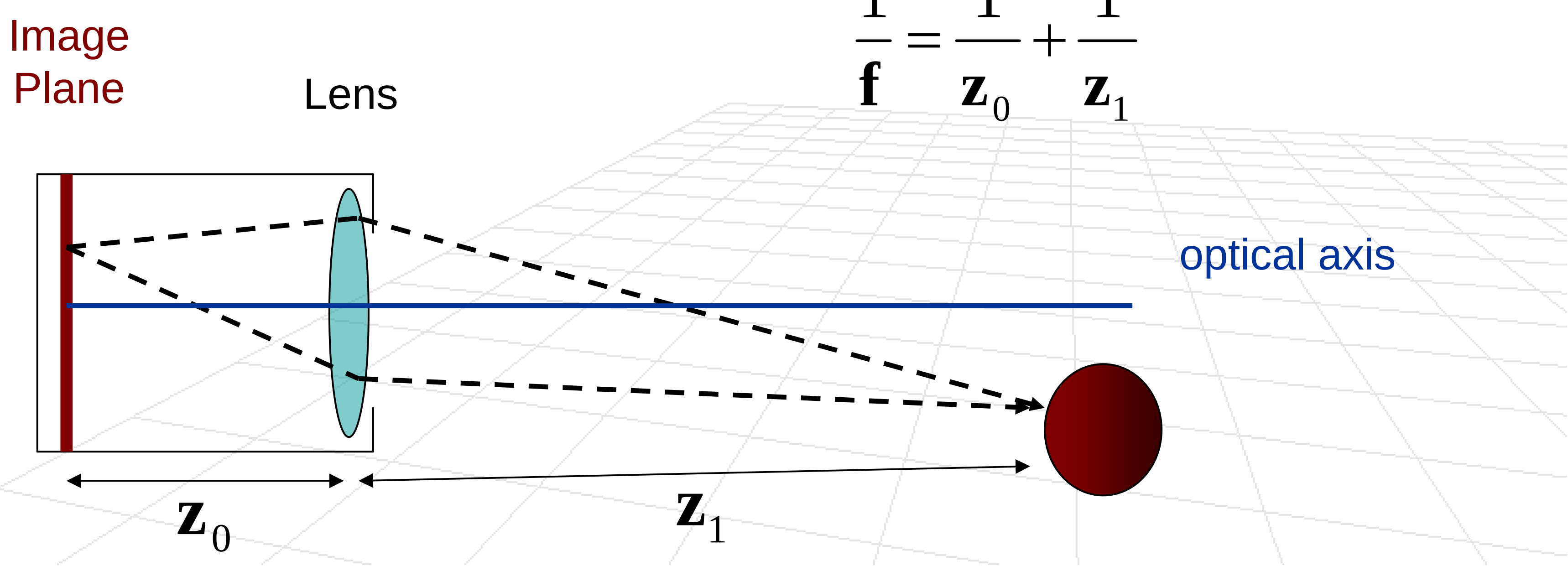
- So far with our Ray Tracers we only considered **pinhole camera model** (no lens)
  - or alternatively, lens, but tiny aperture



Depth of Field

- So far with our Ray Tracers we only considered pinhole camera model (no lens)
  - or alternatively, lens, but tiny aperture
- What happens if we put a lens into our "camera"
  - or increase the aperture
- Remember the thin lens equation?

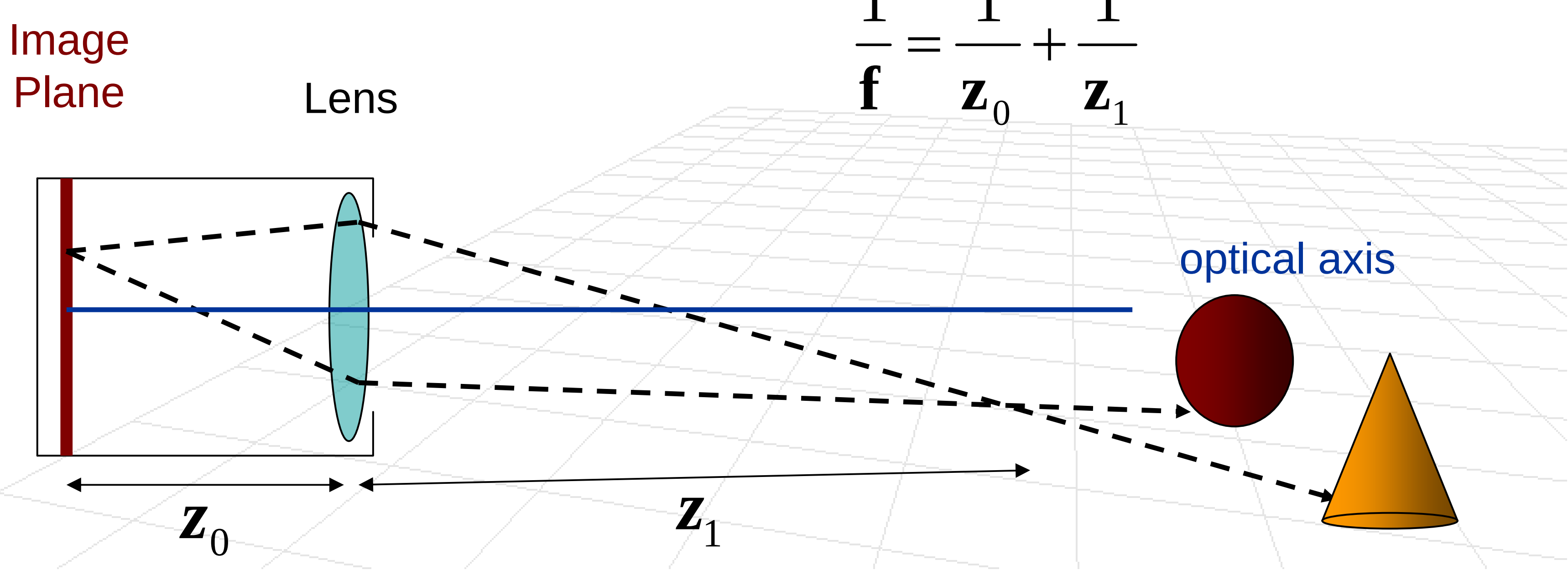
$$\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{z}_0} + \frac{1}{\mathbf{z}_1}$$



Depth of Field

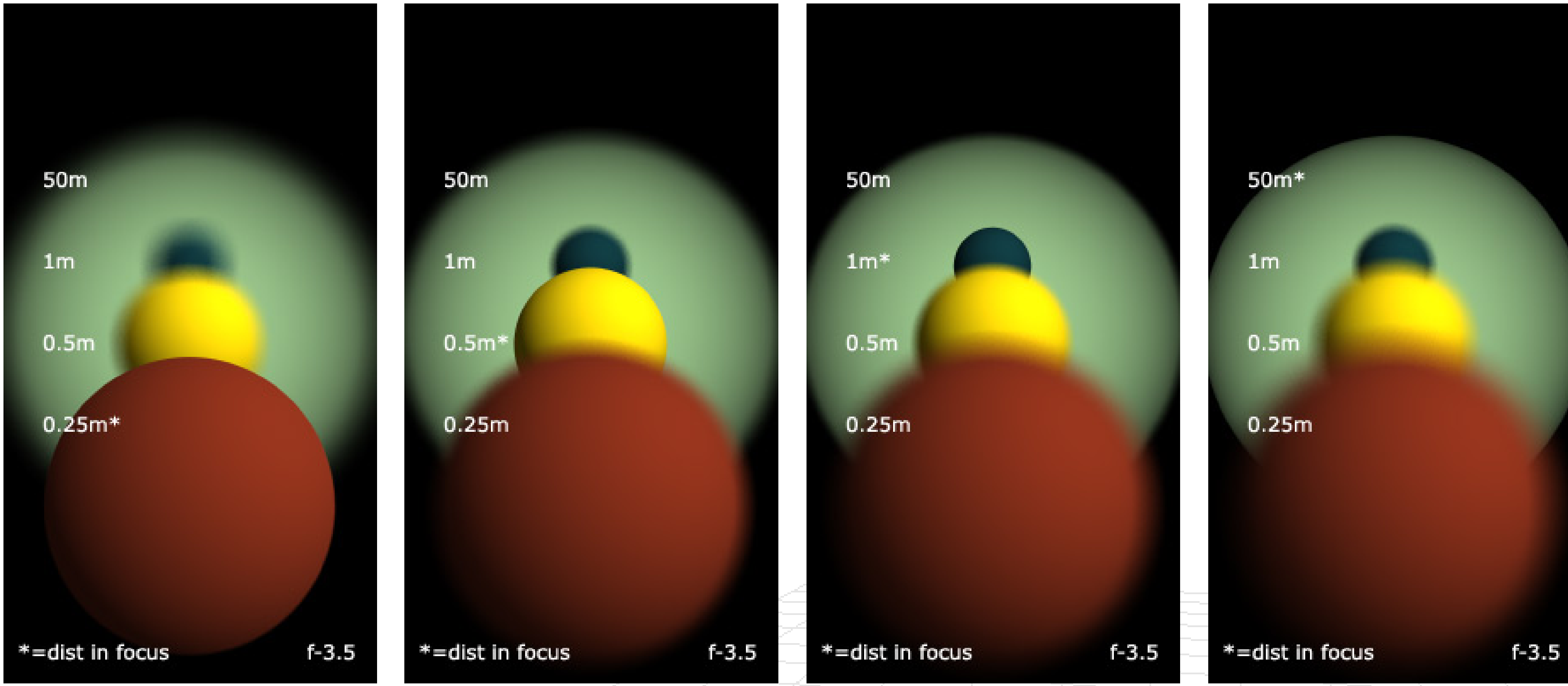
- So far with our Ray Tracers we only considered pinhole camera model (no lens)
  - or alternatively, lens, but tiny aperture
- What happens if we put a lens into our "camera"
  - or increase the aperture
- Remember the thin lens equation?

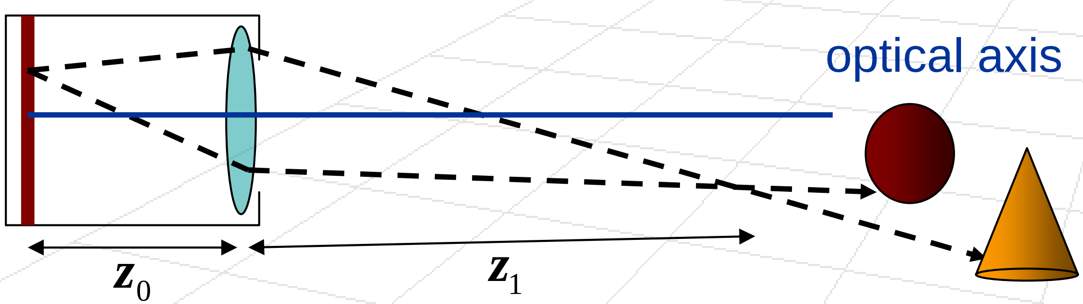
$$\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{z}_0} + \frac{1}{\mathbf{z}_1}$$



Changing the focal-length in DRT

increasing focal length →

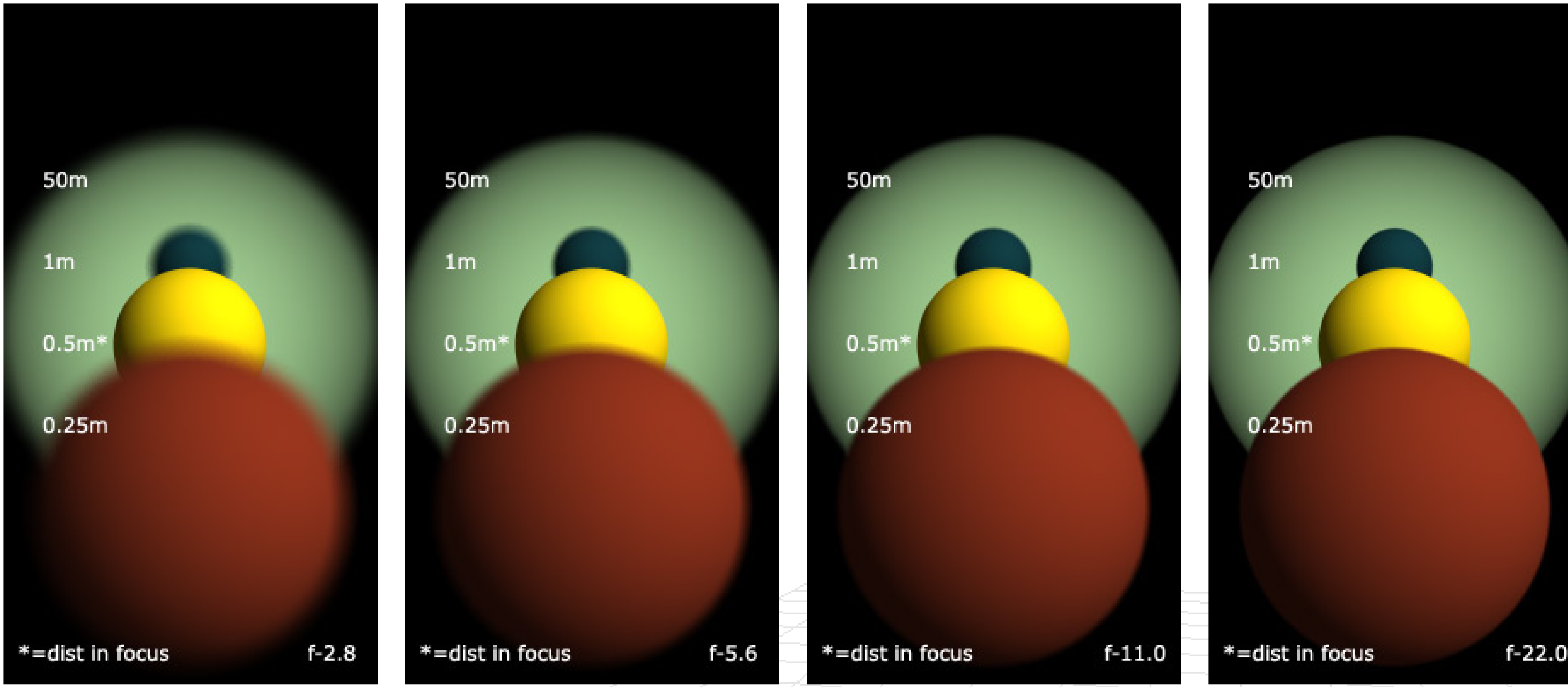


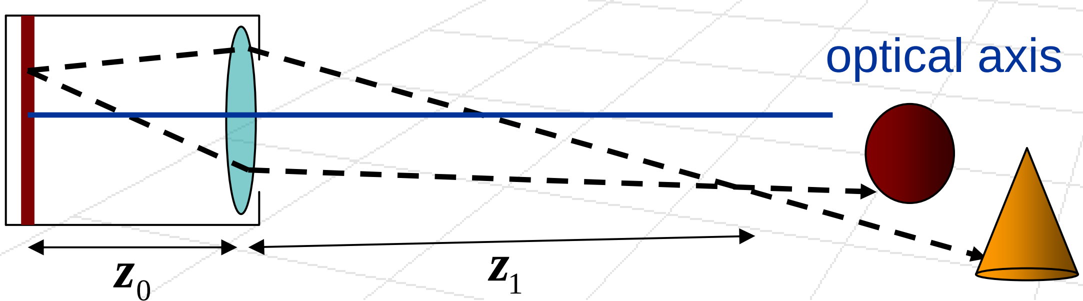


220x400 pixels
144 samples per pixel
~4.5 minutes to render

Changing the aperture in DRT

decreasing aperture →





220x400 pixels
144 samples per pixel
~4.5 minutes to render

Depth of Field

P. Haeberli

Depth of Field

Depth of Field

Depth of Field

Depth of Field