Papers To Be Presented

- **Physically-Based Real-Time Lens Flare Rendering – *SIGGRAPH 2011***
  - Interactive rendering – few frames per second
- **Practical Real-Time Lens-Flare Rendering - *Eurographics 2013***
  - Real-time rendering – hundreds frames per second

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Physically-Based Real-Time Lens Flare Rendering

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Hans-Peter Seidel, Sungkil Lee

Presented by Keunhong Lee

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Background (1)

What is the lens flare?

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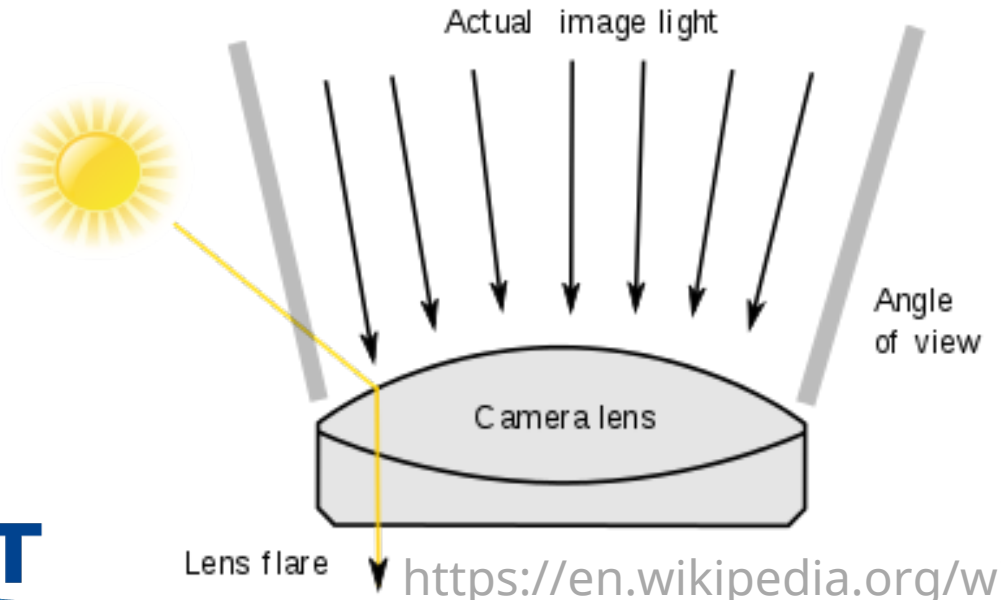
Lens Flare

- Lens flare is the light scattered in lens systems through generally **unwanted image formation mechanisms**, such as **internal reflection and scattering** from material inhomogeneities in the lens.



https://en.wikipedia.org/wiki/Lens_flare

Lens Hood

https://commons.wikimedia.org/wiki/File:Five_lens_hoods.JPG

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Deliberate Use of Lens Flares

- Lens flare **does not** seem like what we see with our **eyes** - it seems like what **“real photograph”** is.

Taking “warm” photograph with lens flares.

http://nikonblog.co.kr/953

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Examples

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Examples

http://cayty.tistory.com/1360

http://m.blog.naver.com/marsem/110159181635

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Examples (synthesized)

http://cayty.tistory.com/1360

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Examples (synthesized)

http://m.blog.naver.com/marsem/110159181635

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Examples

http://nikonblog.co.kr/953

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Examples

http://nikonblog.co.kr/953

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Flare and Ghost

Flare and Ghost

http://nikonblog.co.kr/953
http://www.spiritofexploration.com/images/sun2.png

Background (2)

What makes the lens flare?

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Shape of the Ghost

- **Shape of the aperture** determines the shape of the ghost.

APERTURE LABORATORIES

https://en.wikipedia.org/wiki/File:Lens_Flare_at_Borobudur_Stairs_Kala_Arches.JPG
https://en.wikipedia.org/wiki/Aperture#/media/File:Aperture_in_Canon_50mm_f1.8_II_lens.jpg

https://www.youtube.com/watch?v=AenC4B59rSA

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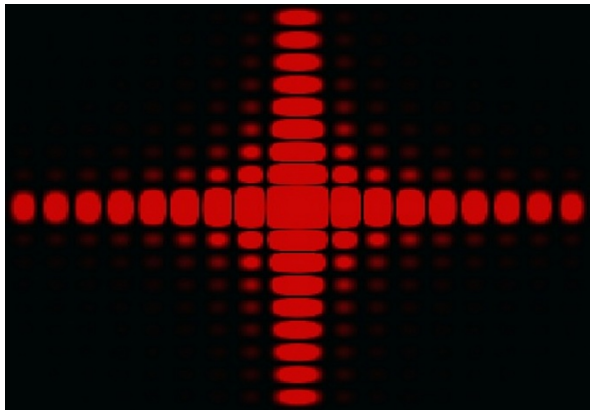
Shape of the Flare (“Star”)

- Fraunhofer diffraction
- Caused by the wave nature
- Calculate over RGB channels
- **Shape of the aperture**
  + dust and scratches



https://en.wikipedia.org/wiki/Fraunhofer_diffraction#/media/File:Rectangular_diffraction.jpg

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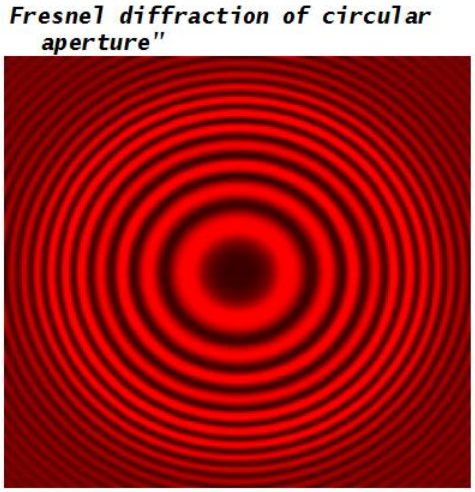
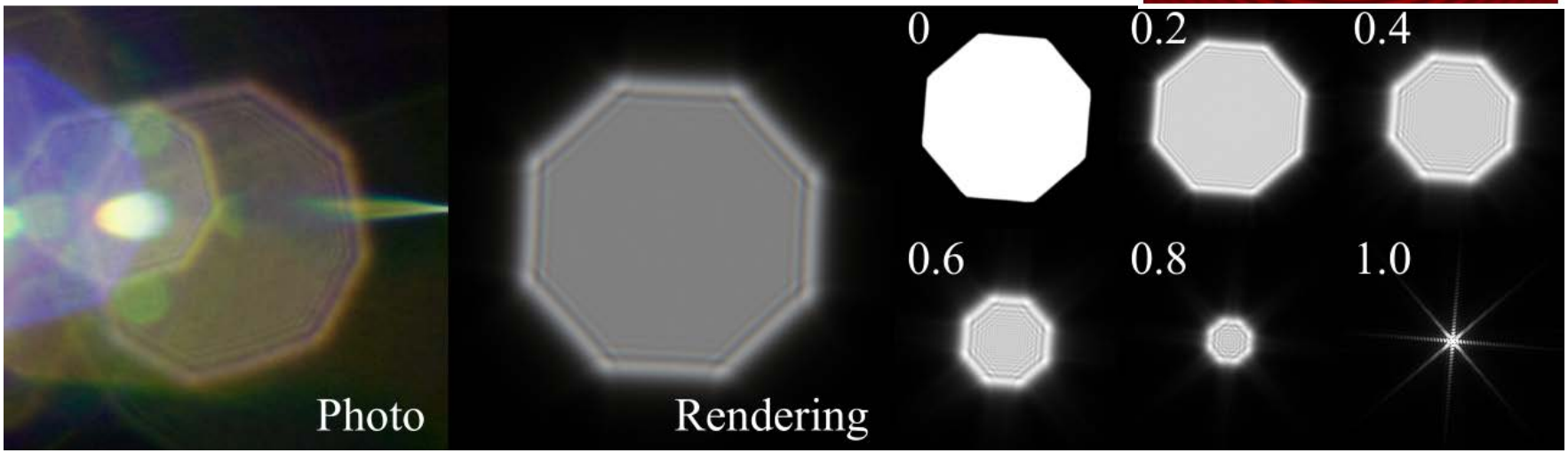
“Rings”

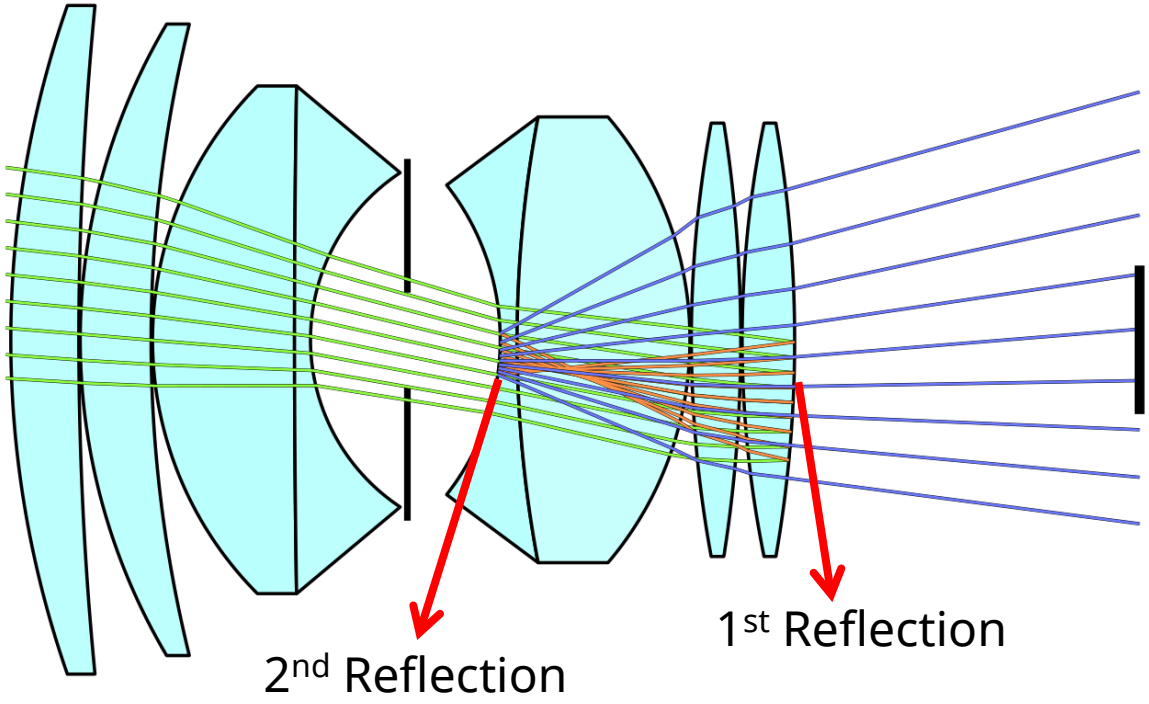
- Fresnel Diffraction
- When Fresnel number ~ 1
- ** if Fresnel number << 1 then occurs Fraunhofer diffraction





Number of Ghosts

- Any combination of even-number reflection is possible



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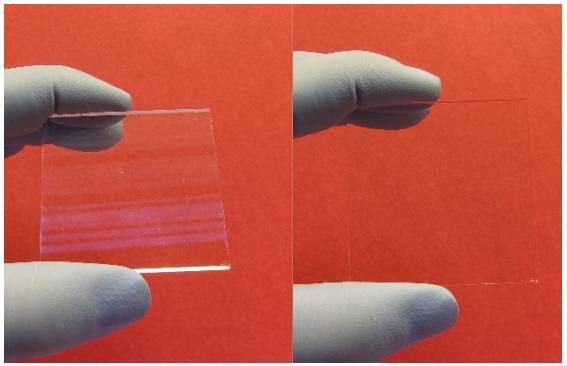
Color of the Ghost

- Why the ghost has color, not just a white one?
- **Anti-reflective coating** makes the color



https://en.wikipedia.org/wiki/File:Lens_Flare_at_Borobudur_Stairs_Kala_Arches.JPG
https://en.wikipedia.org/wiki/Anti-reflective_coating#/media/File:Antireflection_coating_split_pic.jpg

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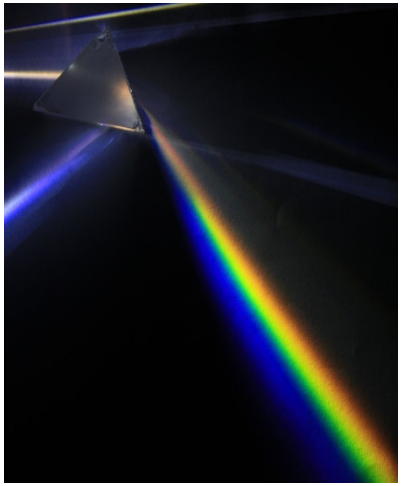
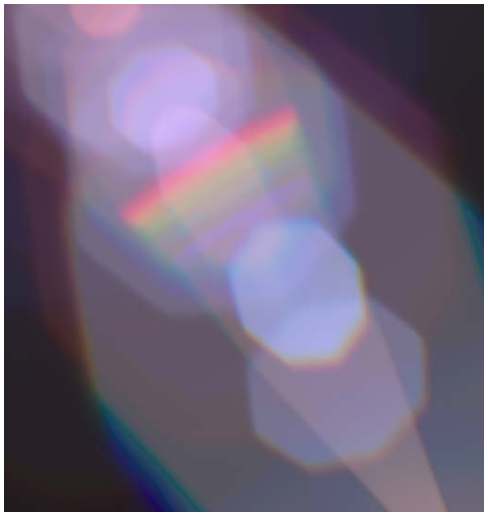
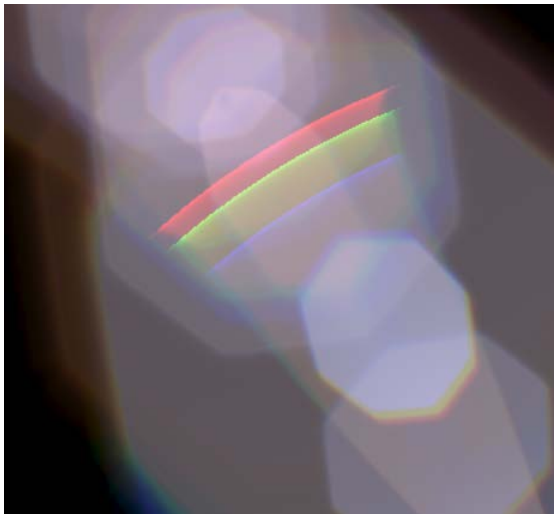
Rainbows

- Caused by **chromatic aberration**
- In this case, RGB channels are NOT sufficient







https://en.wikipedia.org/wiki/Prism#/media/File:Light_dispersion_of_a_mercury-vapor_lamp_with_a_flint_glass_prism_IPNr%C2%B00125.jpg

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Acceleration & Approximations

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Refraction Model

- Sellmeier's empirical approximation (1871)
- B1~B3 and C1~C3 can be obtained from the material database.

$$n^2(\lambda) = 1 + \frac{B_1\lambda^2}{\lambda^2 - C_1} + \frac{B_2\lambda^2}{\lambda^2 - C_2} + \frac{B_3\lambda^2}{\lambda^2 - C_3}$$

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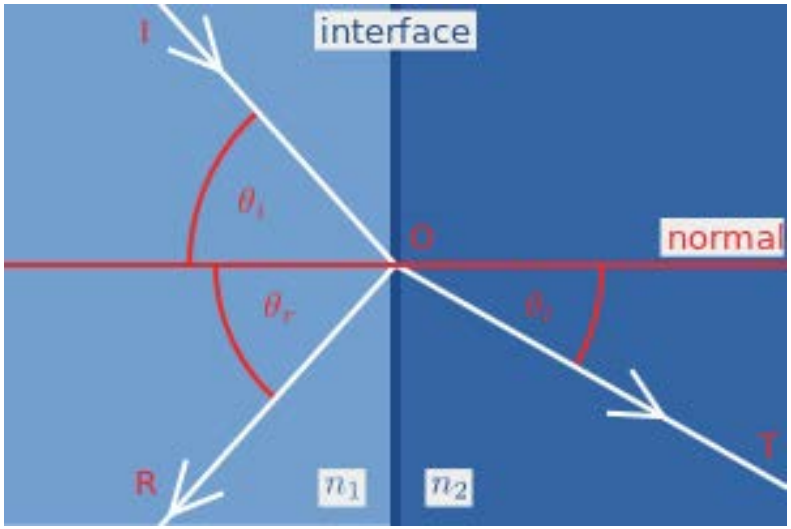
Reflection Ratio

- Fresnel equation
- Determines how much light is reflected.



$$R = \frac{1}{2}\left(\frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2}\right)^2 + \frac{1}{2}\left(\frac{n_1 \cos\theta_2 - n_2 \cos\theta_1}{n_1 \cos\theta_2 + n_2 \cos\theta_1}\right)^2$$

$$T = 1 - R.$$

https://en.wikipedia.org/wiki/Fresnel_equations#/media/File:Fresnel1.svg

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Absorbance

- Energy loss during the transmission
  - [Hack] Ignore

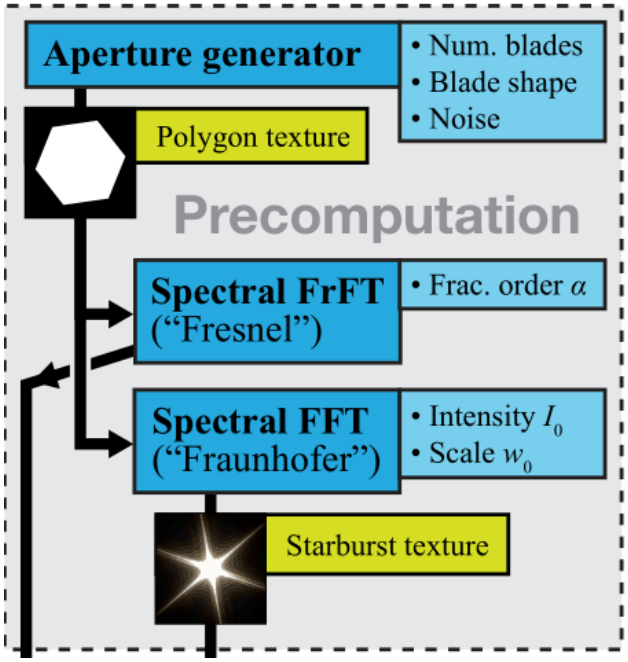
Rings and Stars

- Once the aperture model is determined, also the shape of rings and stars
  - Save the pre-calculated shape as **textures**

- For Fresnel diffractions,

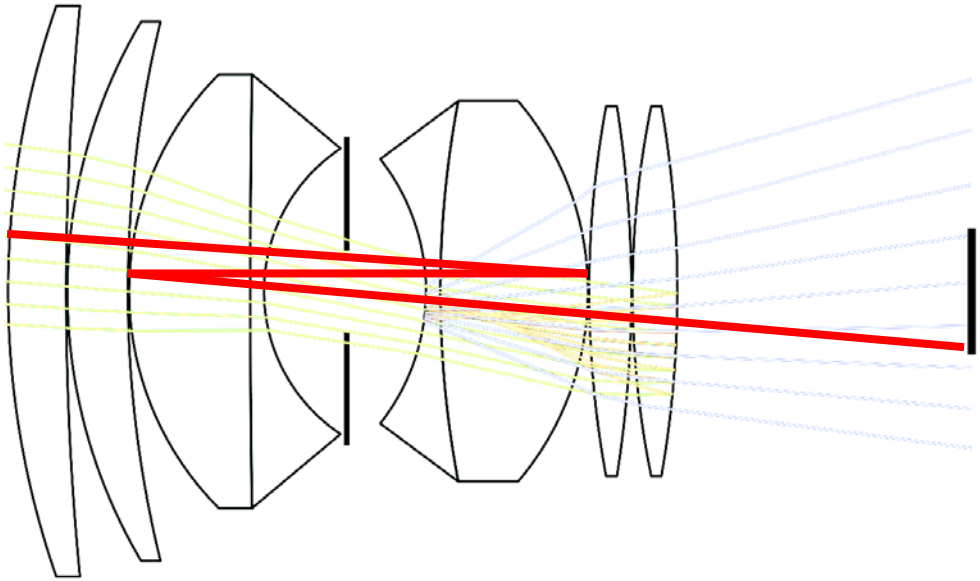
$$\alpha = 0.15 \cdot (\lambda/400\,\mathrm{nm}) \cdot (\#/18)$$

  works well for most cases;



Number of Ghosts

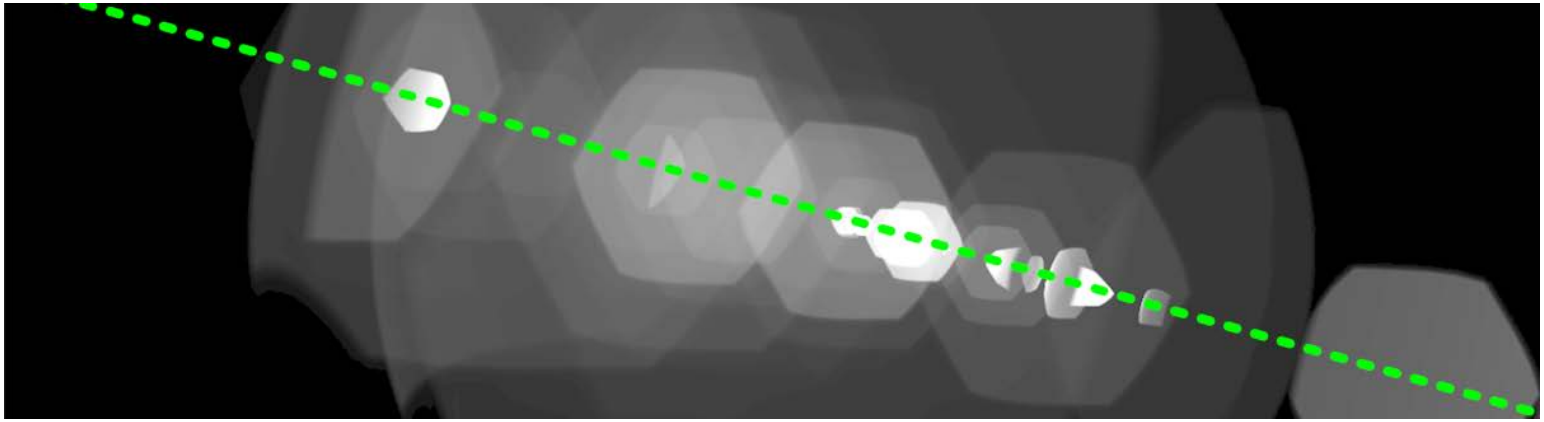
- **Inter-aperture reflection** requires at least 3 aperture traversals – Ignore this case



$$N = (f(f-1) + b(b-1))/2$$

Axial Symmetry

- In the middle of the aperture,
  we can **reuse** the ray-tracing result through the **axis**.



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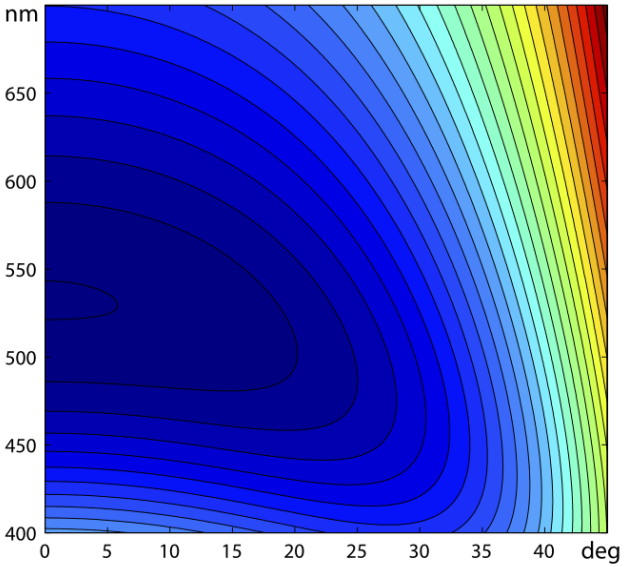
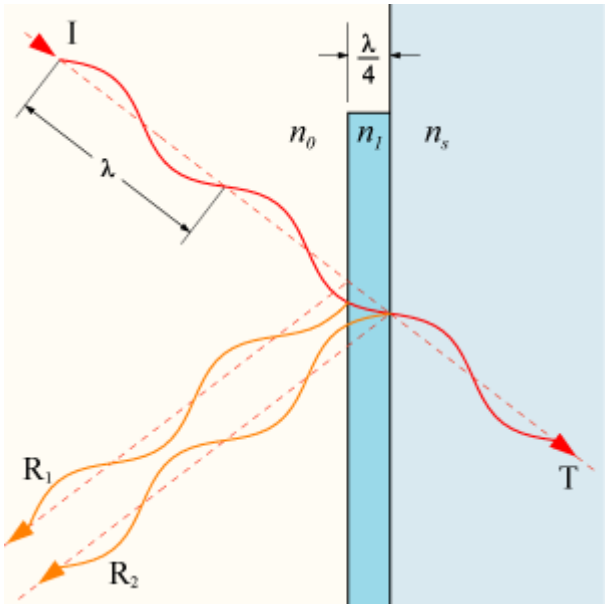
Anti-Reflective Coating

- Actual composition is trade secrete :)
- But, a *quarter-wave* coating is sufficient





https://en.wikipedia.org/wiki/Optical_coating#/media/File:Optical-coating-2.png

Culling Ghosts

- Removing 20% weakest delivers 20% speedup without visible artifacts.
- Even 40% removal is still acceptable.

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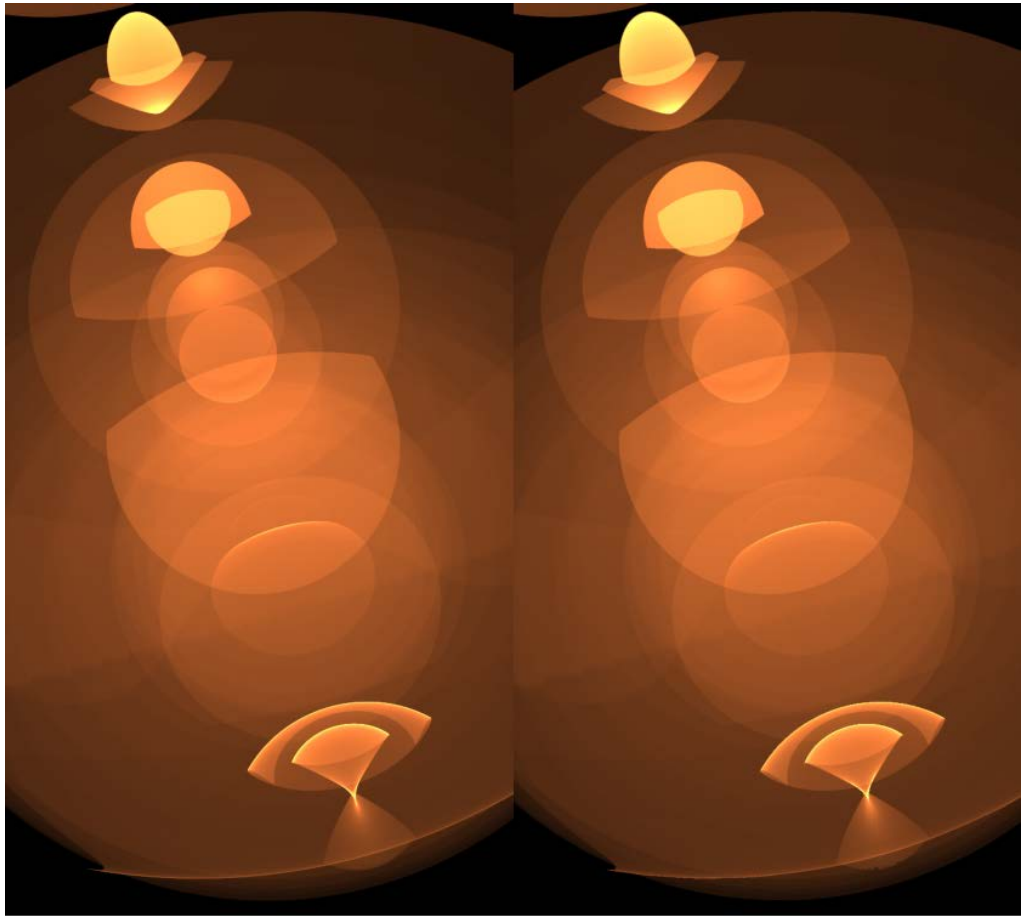
Comparing with Ray-Tracing

8192^2 samples per ghost

159s per frame



128^2 samples per ghost

29.8ms per frame

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Practical Real-Time Lens-Flare Rendering

Sungkil Lee, Elmar Eisemann

Presented by Keunhong Lee

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Linearization of Equations (1)

- For small θ,
  $\sin\theta \approx \theta$, $\tan\theta \approx \theta$, and $\cos\theta \approx 1$

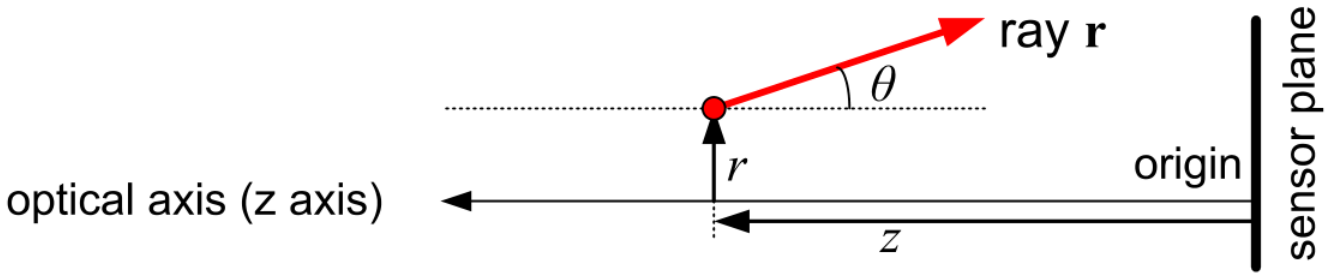

Figure 2: *2D-vector notation of a ray* $\mathbf{r} = [r\ \theta]^{\mathsf{T}}$.

Linearization of Equations (2)

Optical component	Ray transfer matrix
Translation ($\mathbf{T}_i$)	$\begin{bmatrix} 1 & d_i \\ 0 & 1 \end{bmatrix}$
Refraction at spherical dielectric interface ($\mathbf{R}_i$)	$\begin{bmatrix} 1 & 0 \\ \frac{n_1 - n_2}{n_2 R_i} & \frac{n_1}{n_2} \end{bmatrix}$
Reflection from a spherical mirror ($\mathbf{L}_i$)	$\begin{bmatrix} 1 & 0 \\ \frac{2}{R_i} & 1 \end{bmatrix}$

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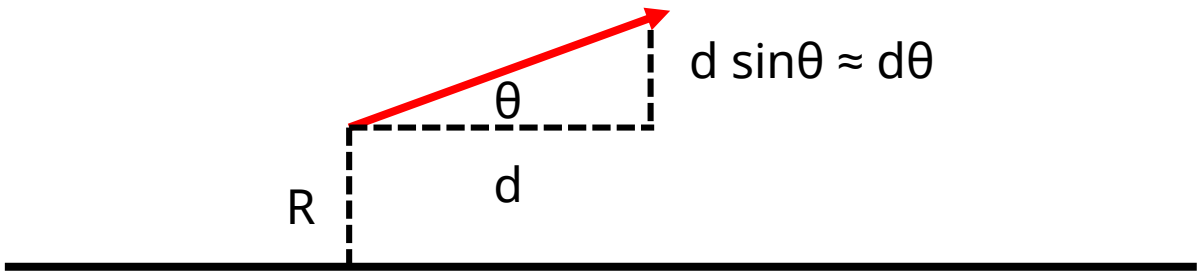
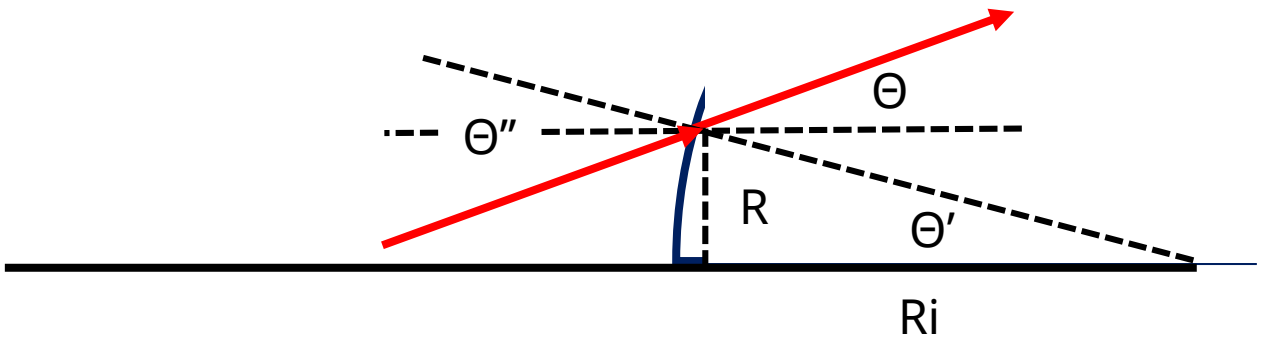
Displacement Matrix

$$\begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix} \begin{pmatrix} R \\ \theta \end{pmatrix} = \begin{pmatrix} R + \theta d \\ \theta \end{pmatrix}$$



Refraction Matrix

$$\begin{pmatrix} 1 & 0 \\ \frac{n1-n2}{n2Ri} & \frac{n1}{n2} \end{pmatrix} \begin{pmatrix} R \\ \theta \end{pmatrix}$$

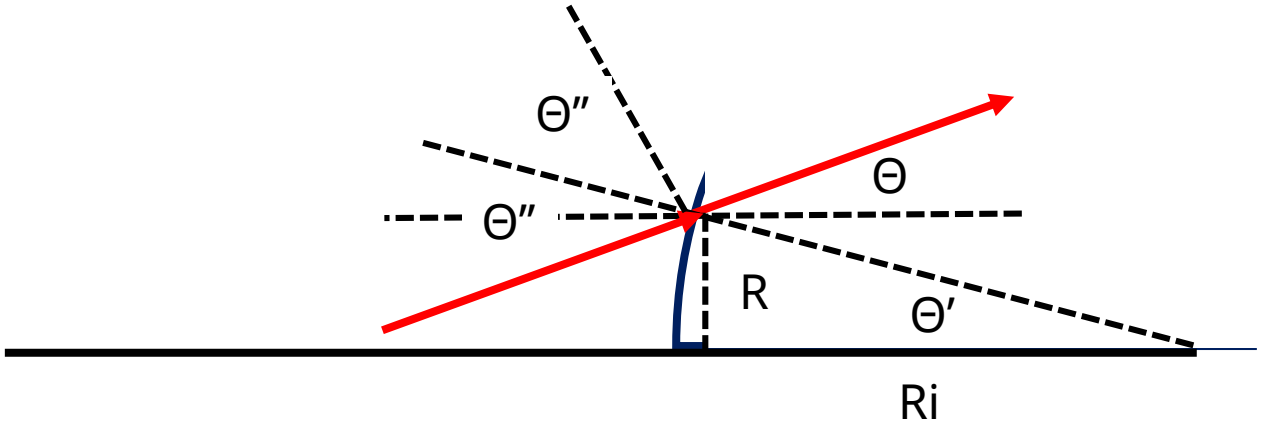


$$\Theta' \approx \frac{R}{Ri}$$

$$\Theta'' = \Theta + \Theta'$$

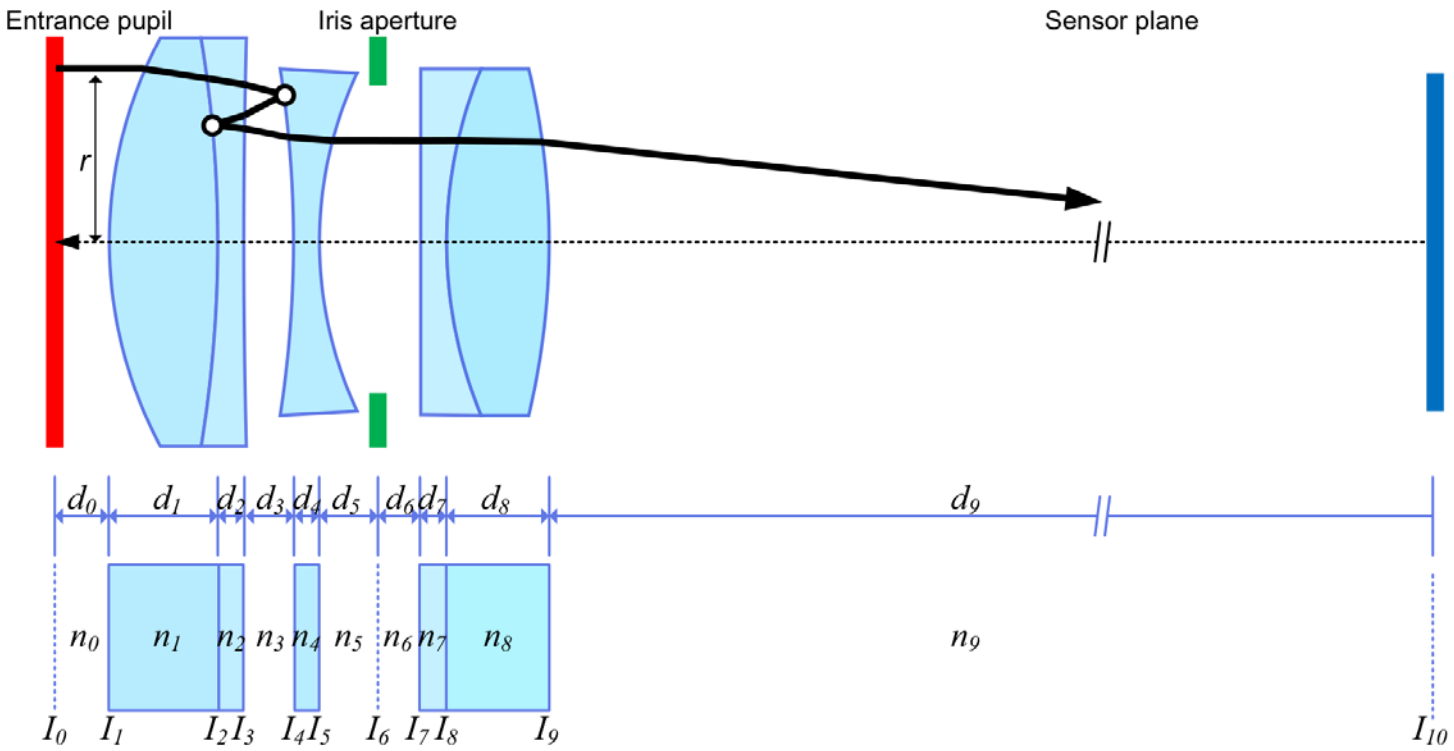
Reflection Matrix

$$\begin{pmatrix} 1 & 0 \\ \frac{2}{Ri} & 1 \end{pmatrix} \begin{pmatrix} R \\ \theta \end{pmatrix}$$



$$\Theta' \approx \frac{R}{Ri}$$

Formulation of Internal-Reflection



$$\mathbf{M}_f = \underbrace{\mathbf{D}_9\mathbf{D}_8\mathbf{D}_7\mathbf{T}_6}_{\mathbf{M}_s}\underbrace{\mathbf{D}_5\mathbf{D}_4\mathbf{D}_3\mathbf{T}_2\mathbf{L}_2^{-1}\mathbf{T}_2\mathbf{R}_3^{-1}\mathbf{T}_3\mathbf{L}_4\mathbf{D}_3\mathbf{D}_2\mathbf{D}_1\mathbf{T}_0}_{\mathbf{M}_a}$$

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Performance

297 fps vs 4.1 fps

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Questions?

Thank you for listening!

Figures without reference came from the papers

http://fallout.wikia.com/wiki/File:36_Ambassador_of_Peace.png

Quizes

1. What determines the number of ghosts?

2. What determines the shape of ghosts?

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