東京大学
THE UNIVERSITY OF TOKYO

sgi

Glare Generation Based on Wave Optics

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Contents

- Introduction
- Previous Work
- Fraunhofer Diffraction
- Simulation of Glare and its Implementation
- Integration to Real-time Image Generation
- Conclusion and Future Work

First ...

- Introduction
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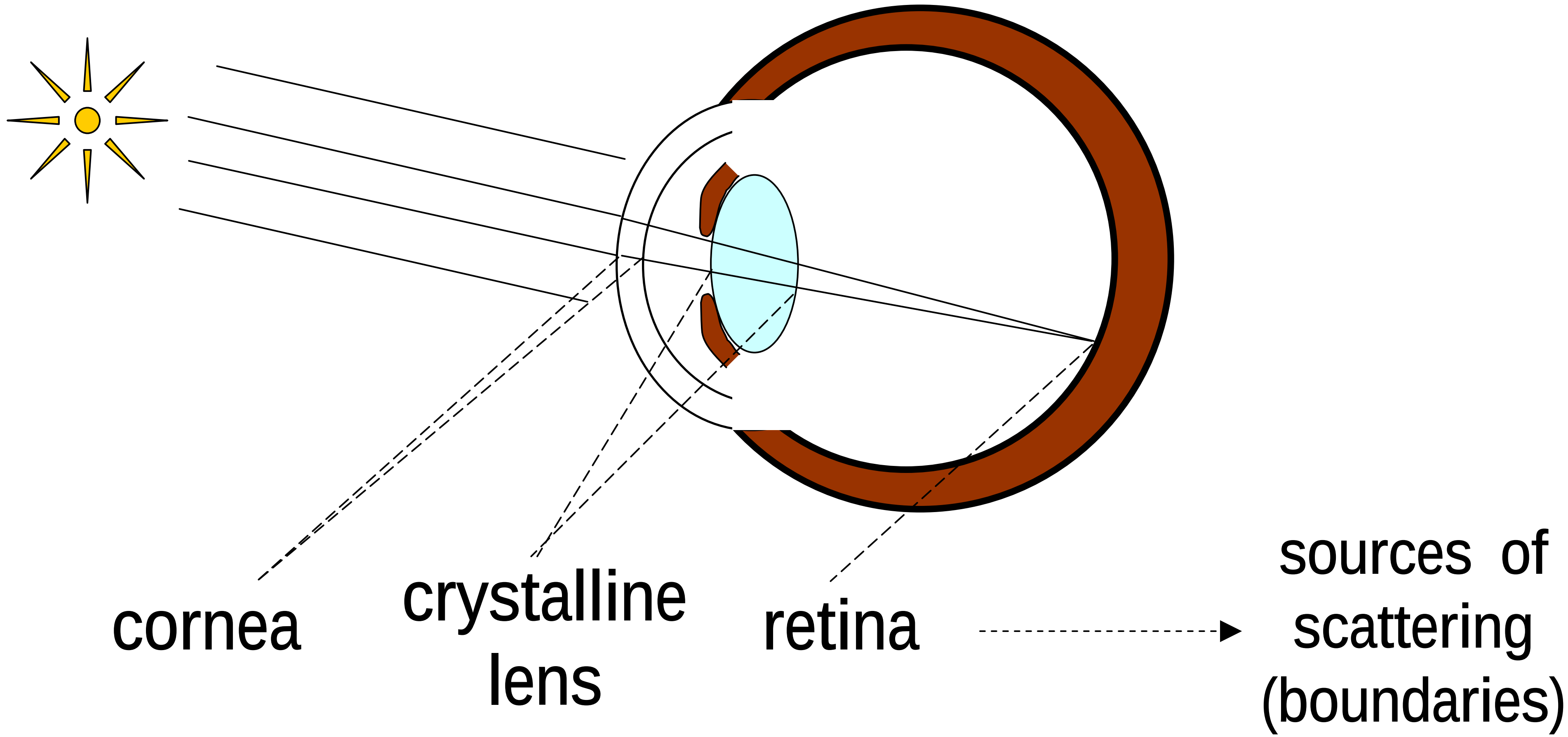
What is glare?

- Diffraction or scattering of light ray in human eye caused by very bright light sources
- Blurred shape or streaks around the light source
- Undesired in real life
- Used as a visual effect in computer graphics

Presented by Masaki Kawase
www.daionet.gr.jp/~masa

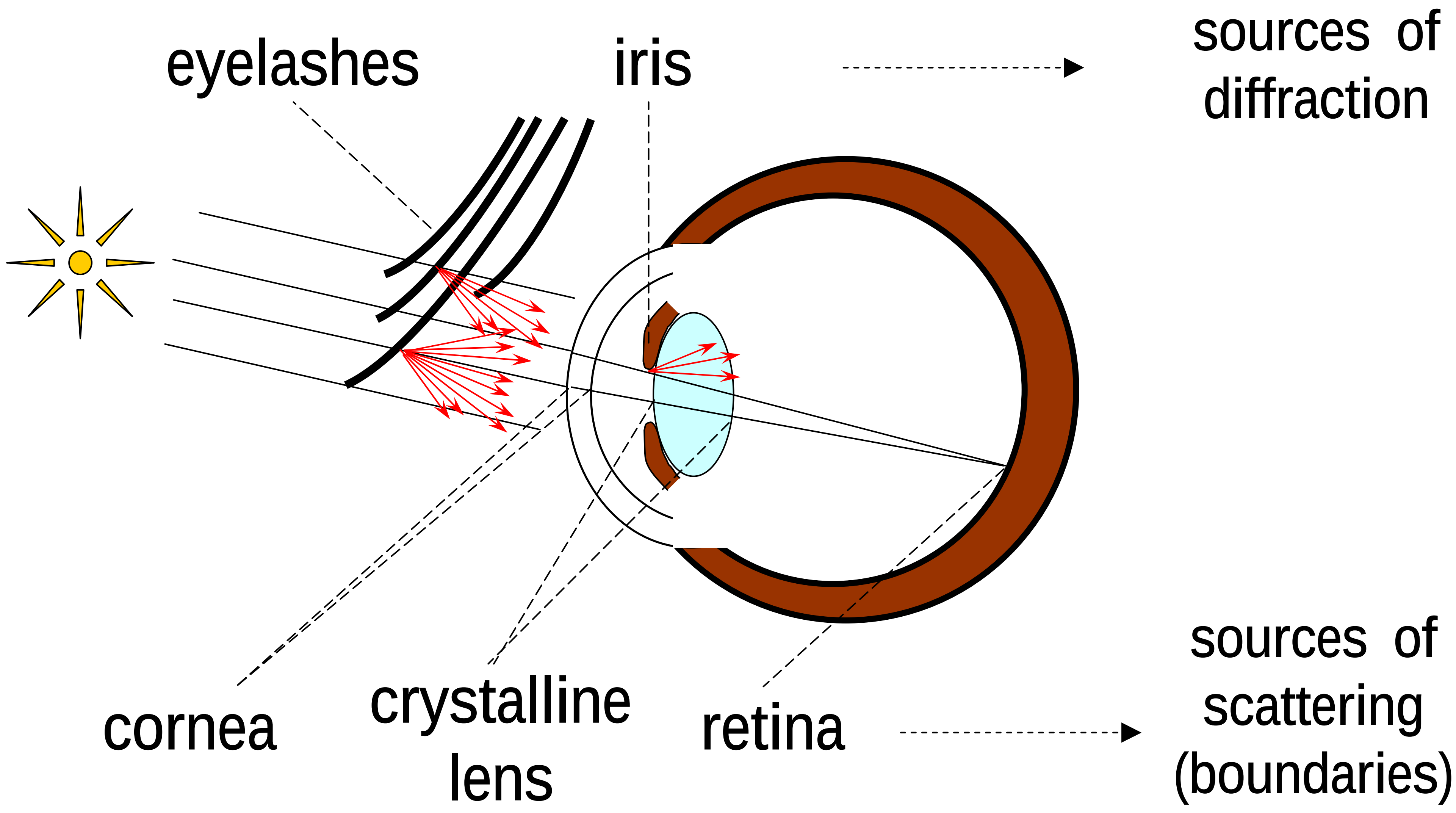
Where does glare occur?

- Scattering



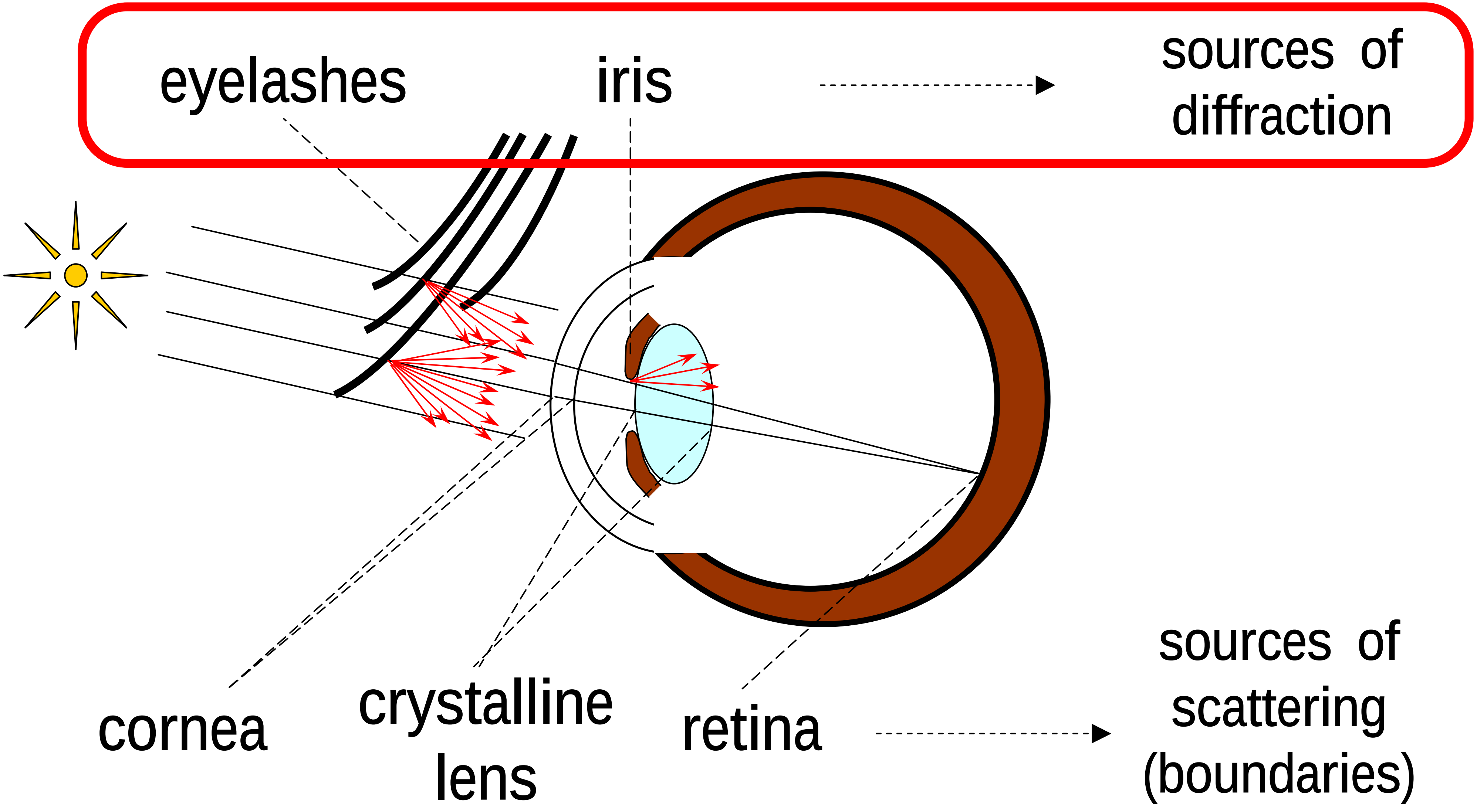
Where does glare occur?

- Scattering and Diffraction



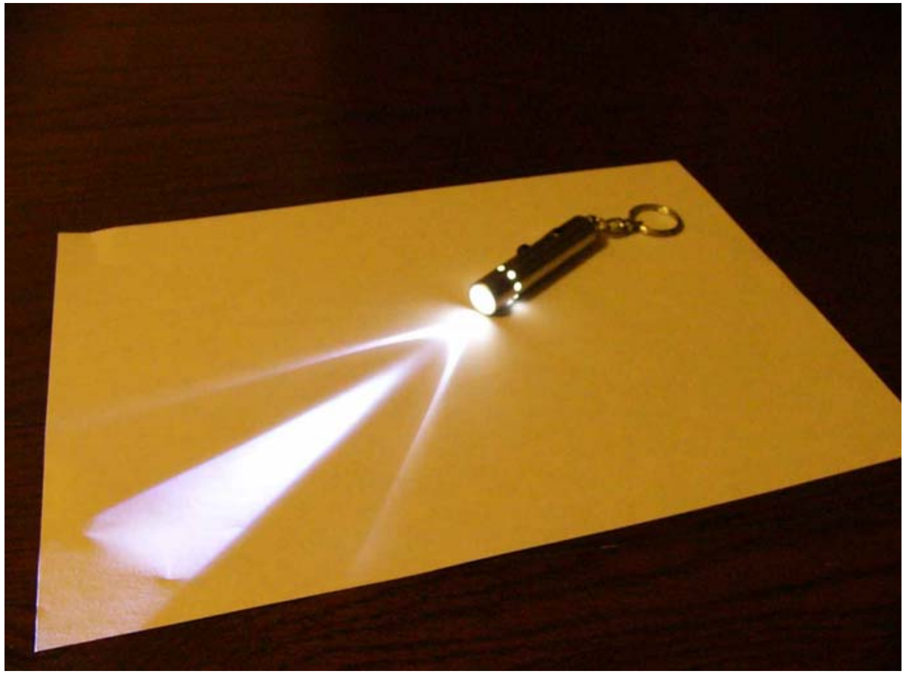
Where does glare occur?

- Scattering and Diffraction



An experiment of glare

- Are eyelashes prevailing sources of glare?



A pen-light used for the experiment

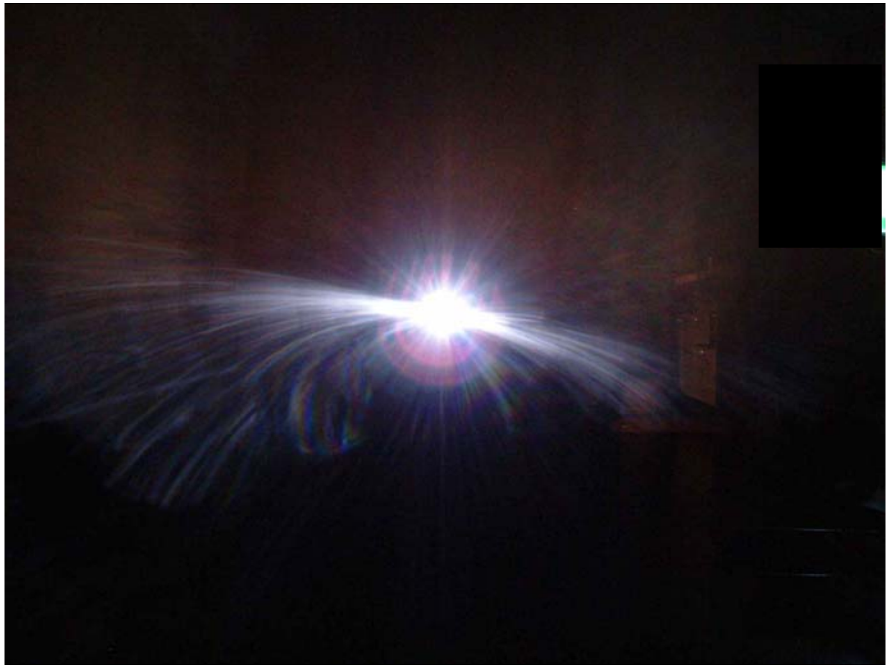
A direct snapshot of the pen-light

An experiment of glare

- Are eyelashes prevailing sources of glare?

- Yes, they are!

A set of false eyelashes attached to the camera



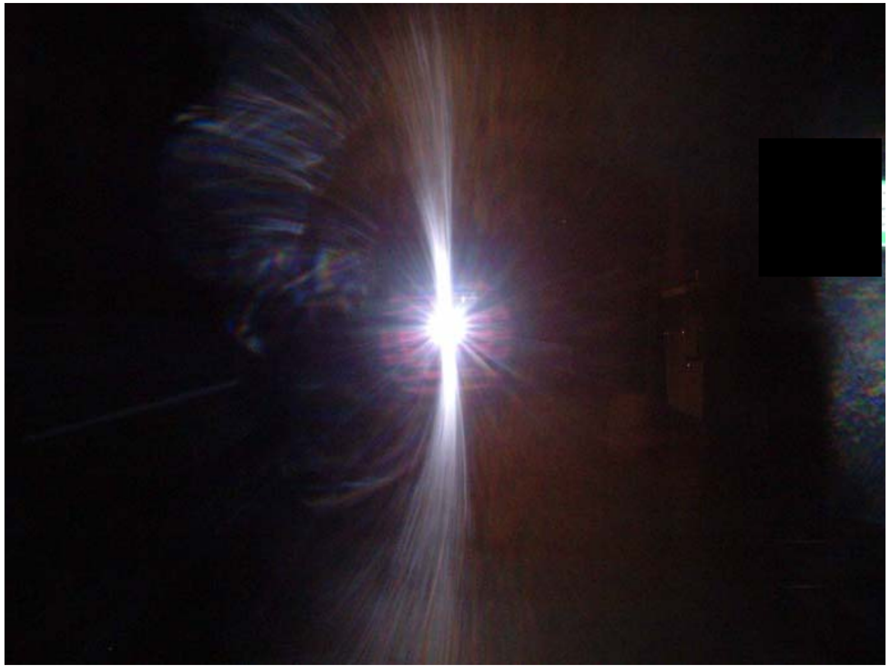
A direct snapshot of the pen-light

An experiment of glare

- Are eyelashes prevailing sources of glare?

  - Yes, they are.

The same false eyelashes rotated 90 degree



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An experiment of glare

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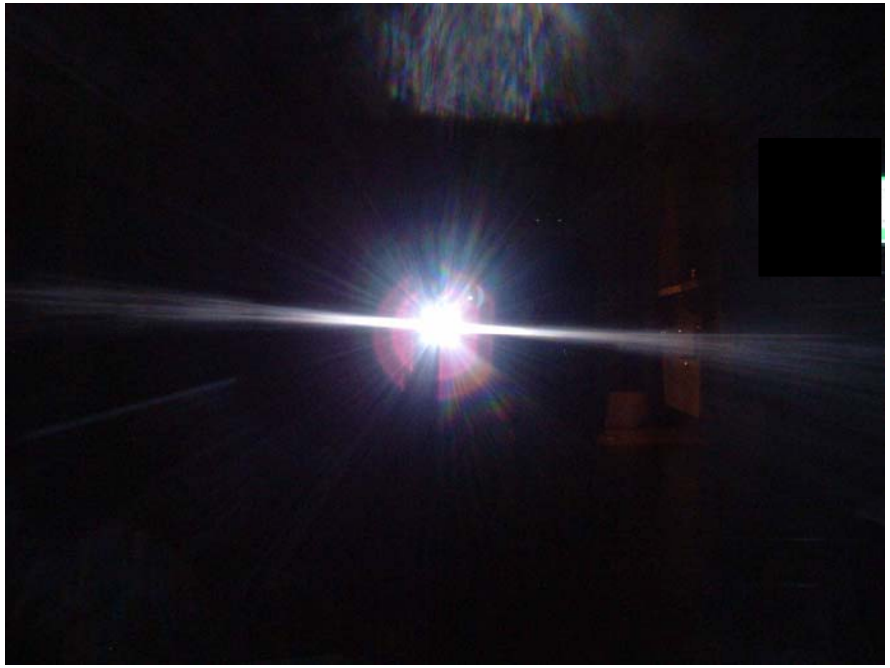
Another set of false eyelashes attached to the camera



A direct snapshot of the pen-light

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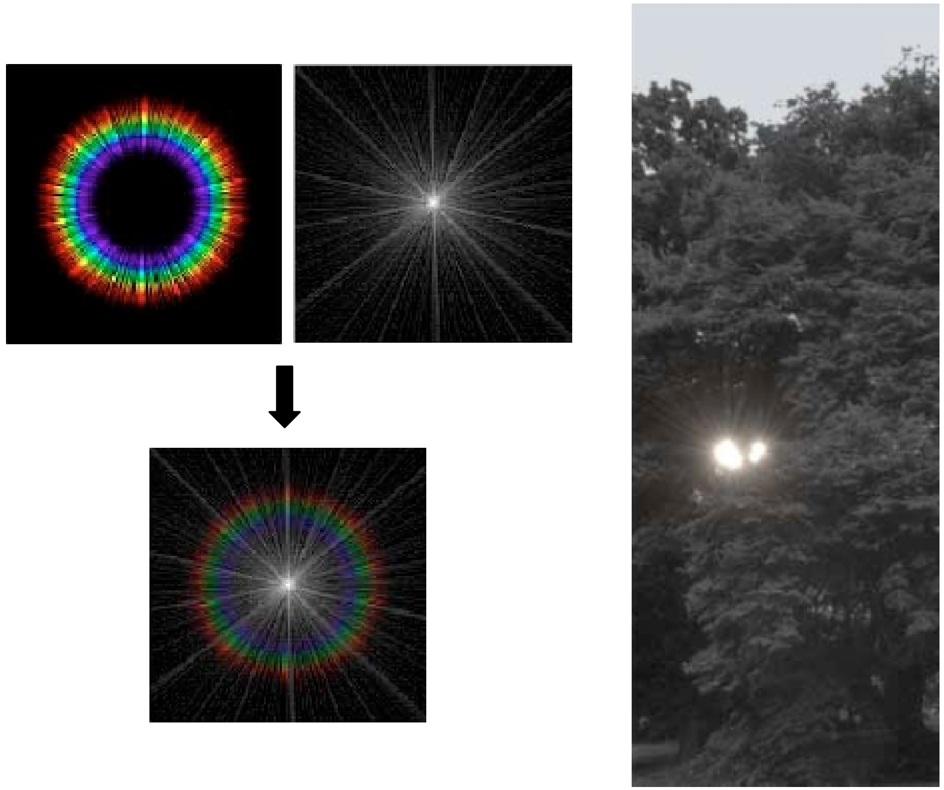
Previous Work

- Shinya89
  - Simulated a cross filter of a camera
  - Crossing streaks of light ray is placed on a ray traced image
- Nakamae90
  - Glare design based on statistical distribution of eyelash direction, angles of streaks are generated using random numbers

Nakamae, Kaneda, Okamoto and Nishita, Siggraph '90

Previous Work

- Rokita93
  - Glare effect using billboards placed at light sources
- Spencer95
  - Thorough analysis of the human eye structure
  - Glare filter composition
  - Spectrum effect



Spencer, Shirley, Zimmerman and Greenberg, Siggraph '95

Previous Work

- Debevec97
  - Glare effect on HDR images
- Mitchell02
  - Glare filter using RADEON pixel shader
- Kawase02
  - Glare filter using NVIDIA pixel shader (XBOX)

Paul E. Debevec, Siggraph '97

J. L. Mitchell, Siggraph 2002 Course Note

Masaki Kawase, A scene from "DOUBLE-S.T.E.A.L" ("Wreckless")

Previous Work

- Comparison

	glare shape	real-time (HW accelerated)	reflection
Nakamae90	manual design	no	no
Spencer95	manual composition	no	no
Mitchell02	manual design	yes	yes
Our method	physically based generation	yes	yes

Our method

- Automatic generation of glare with the input of the sources of diffraction

- Glare computation based on diffraction theory in wave optics – more physically based

- Easy to get wide variety of glare by changing the input images

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- **Fraunhofer diffraction**
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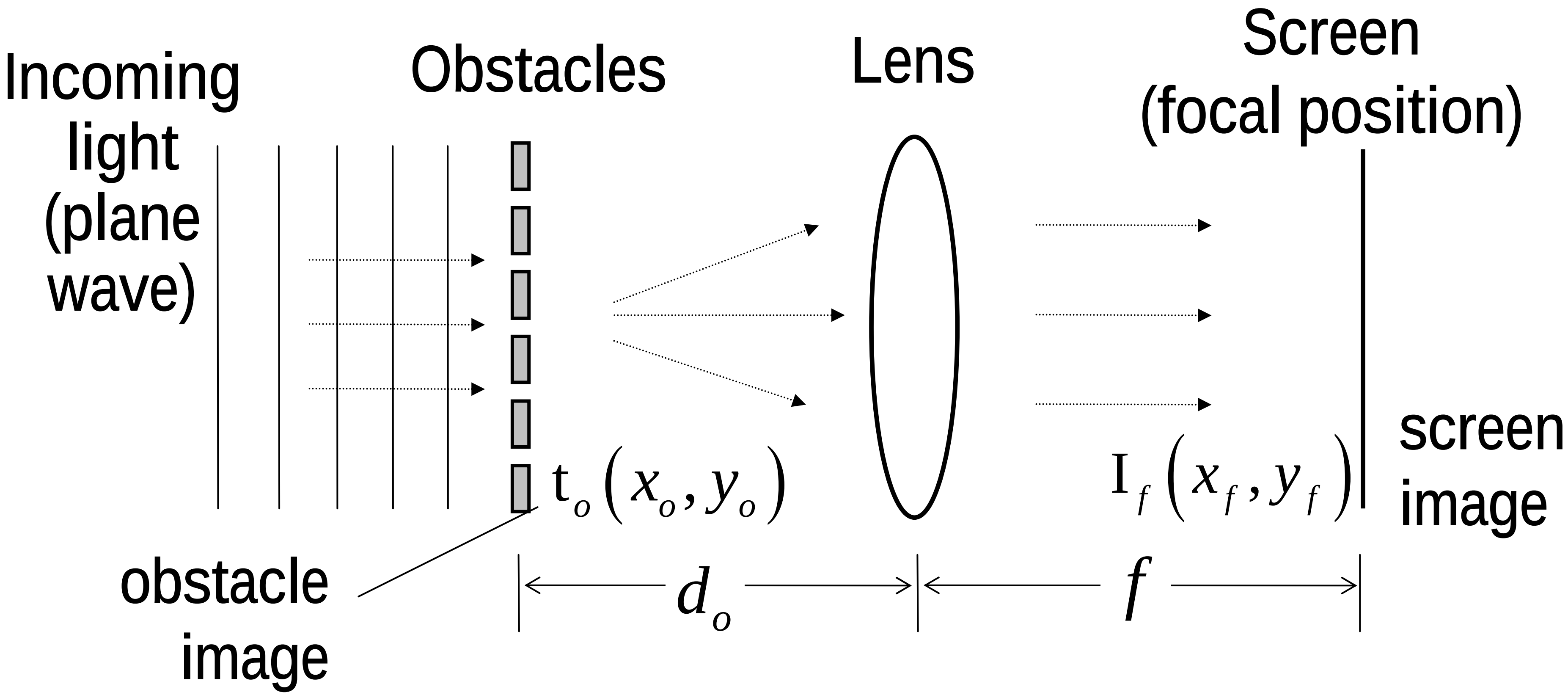
What is Fraunhofer diffraction?

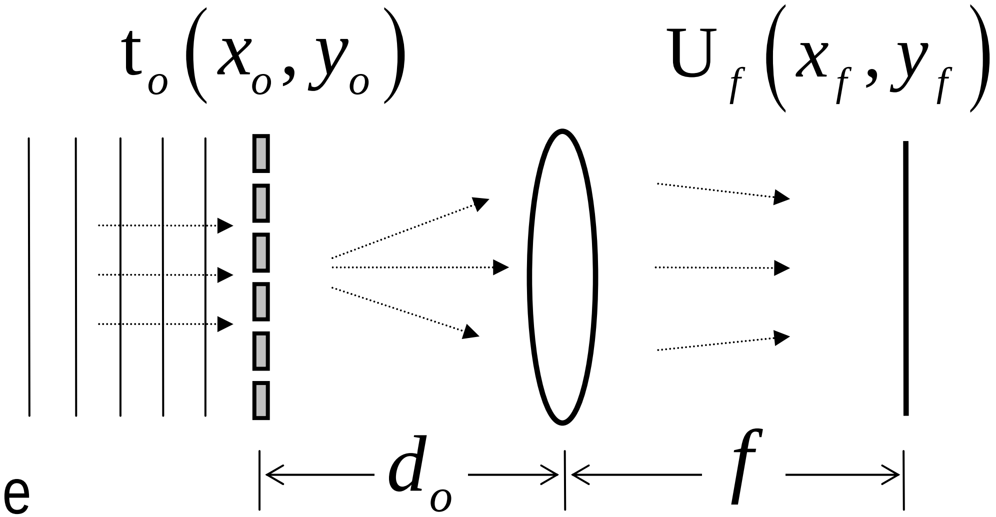
- A fundamental theory in wave optics
- An approximation of diffraction light distribution through lens onto a screen at the focal position



Equation of complex amplitude distribution

Fraunhofer diffraction

- Derived from Huygens' principle and the wave equation



complex amplitude distribution

light source amplitude

$$U_f(x_f, y_f) = \frac{A}{j\lambda f} \exp\left[j\frac{\pi}{\lambda}\left(1 - \frac{d_o}{f}\right)\left(x_f^2 + y_f^2\right)\right]$$

$$\times \iint_{-\infty}^{\infty} t_o(x_o, y_o) \exp\left[-j\frac{2\pi}{\lambda f}\left(x_o x_f + y_o y_f\right)\right] dx_o dy_o$$

unit imaginary number

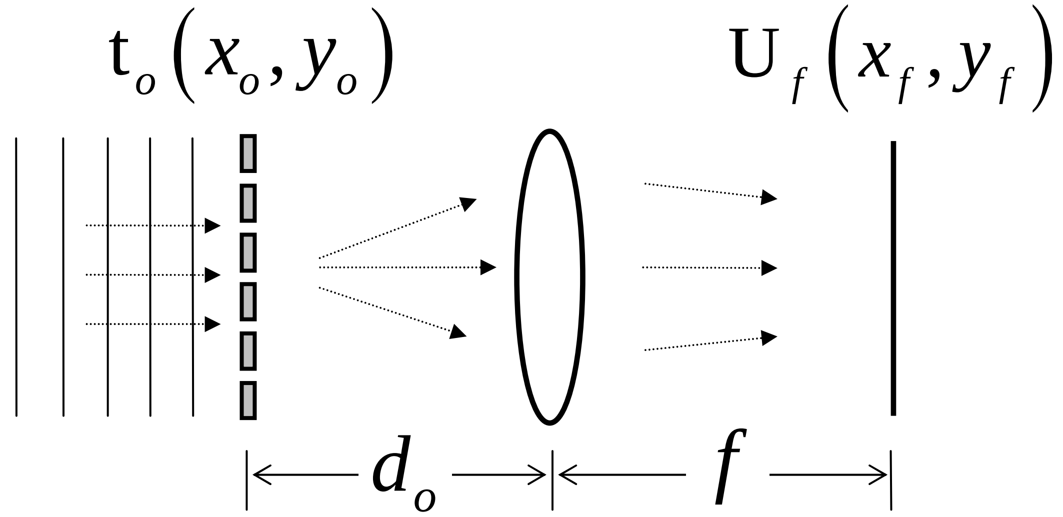
light wave length

[Goodman1968] ***Introduction to Fourier Optics***

Factors of the amplitude distribution

Fraunhofer diffraction

- Represented using Fourier transform



$$U_f(x_f, y_f) = \frac{A}{j\lambda f} \exp\left[j\frac{\pi}{\lambda}\left(1 - \frac{d_o}{f}\right)\left(x_f^2 + y_f^2\right)\right]$$

phase component

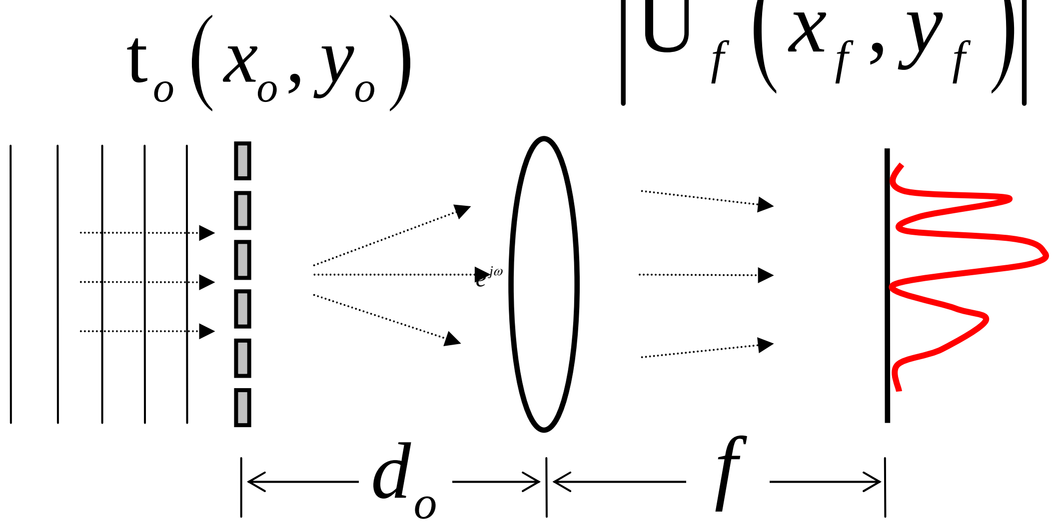
$$\times \iint_{-\infty}^{\infty} t_o(x_o, y_o) \exp\left[-j\frac{2\pi}{\lambda f}\left(x_o x_f + y_o y_f\right)\right] dx_o dy_o$$

Fourier transform

Luminance intensity distribution

Fraunhofer diffraction

- Square of absolute value of the amplitude



$$I_f(x_f, y_f) = \left| U_f(x_f, y_f) \right|^2$$

$$= \frac{A^2}{\lambda^2 f^2} \left| \iint_{-\infty}^{\infty} t_o(x_o, y_o) \exp\left[-j \frac{2\pi}{\lambda f} (x_o x_f + y_o y_f) \right] dx_o dy_o \right|^2$$

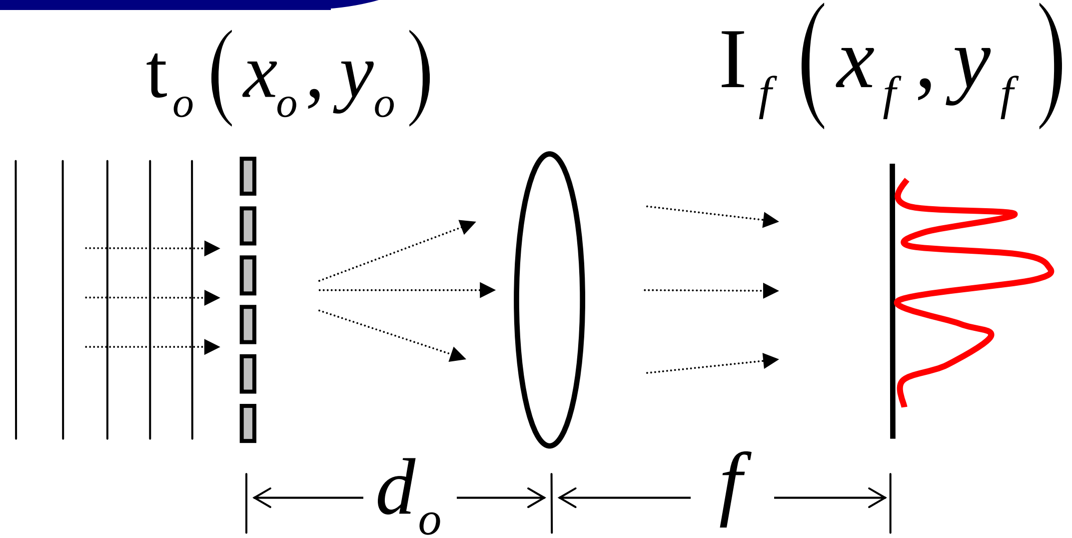
The $e^{j\omega}$ factor (phase component) diminishes to 1.

$$\omega = \frac{\pi}{\lambda} \left(1 - \frac{d_o}{f} \right) \left(x_f^2 + y_f^2 \right)$$

Luminance intensity distribution

Fraunhofer diffraction

- Square of absolute value of the amplitude



output image

input image

$$I_f(x_f, y_f) = \frac{A^2}{\lambda^2 f^2} \left| \int\int_{-\infty}^{\infty} t_o(x_o, y_o) \exp\left[-j \frac{2\pi}{\lambda f} (x_o x_f + y_o y_f) \right] dx_o dy_o \right|^2$$

2D Fourier transform

Easy to implement using FFT

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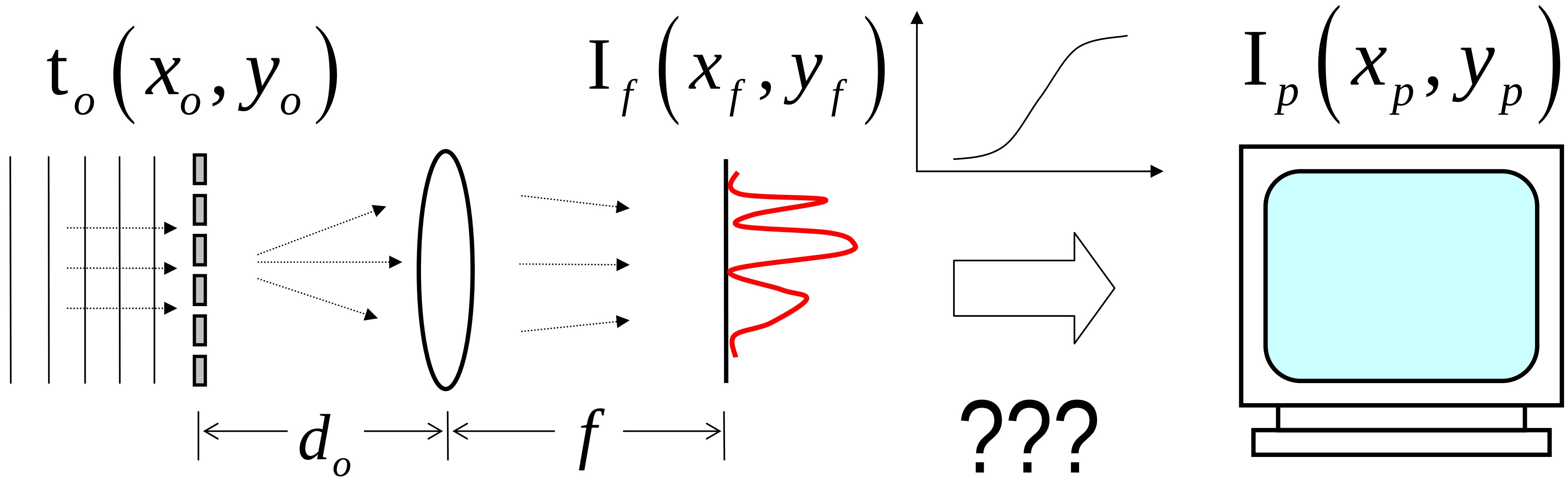
Diffraction intensity and the pixel value

- The luminance intensity distribution $\mathrm{I}_f\left(x_f, y_f\right)$ is an HDR（High Dynamic Range） image
  - –How to map the value to 8bit frame buffer value?



Tone mapping function

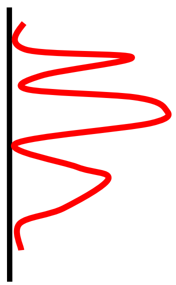
- [Tumblin1999, ACM TOG] using sigmoid function

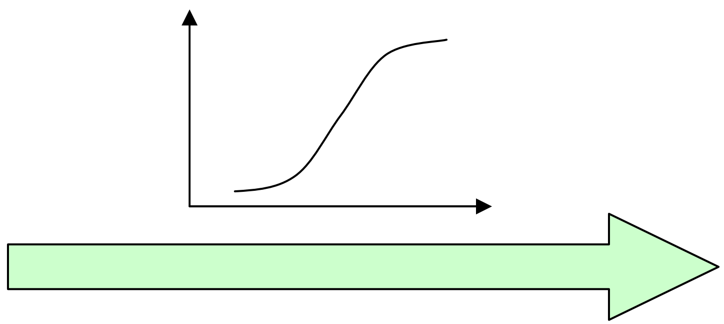
$$\mathrm{I}_p\left(x_p, y_p\right) = \mathrm{sig}\left\{\mathrm{I}_f\left(x_p, y_p\right)\right\},$$

where $\mathrm{sig}(x) = \dfrac{x^g + \dfrac{1}{k}}{x^g + k} D.$

- g : defines slope at $x = 1$
- k^2 : defines maximum contrast
- D : defines maximum luminance

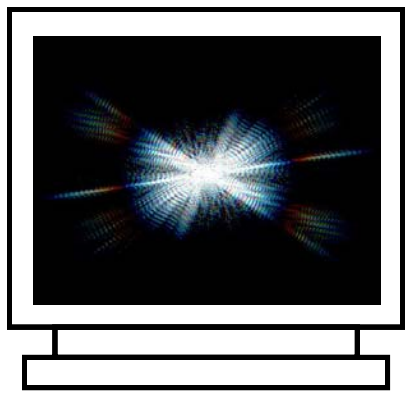
$\mathrm{I}_f\left(x_f, y_f\right)$





parameter adjustment

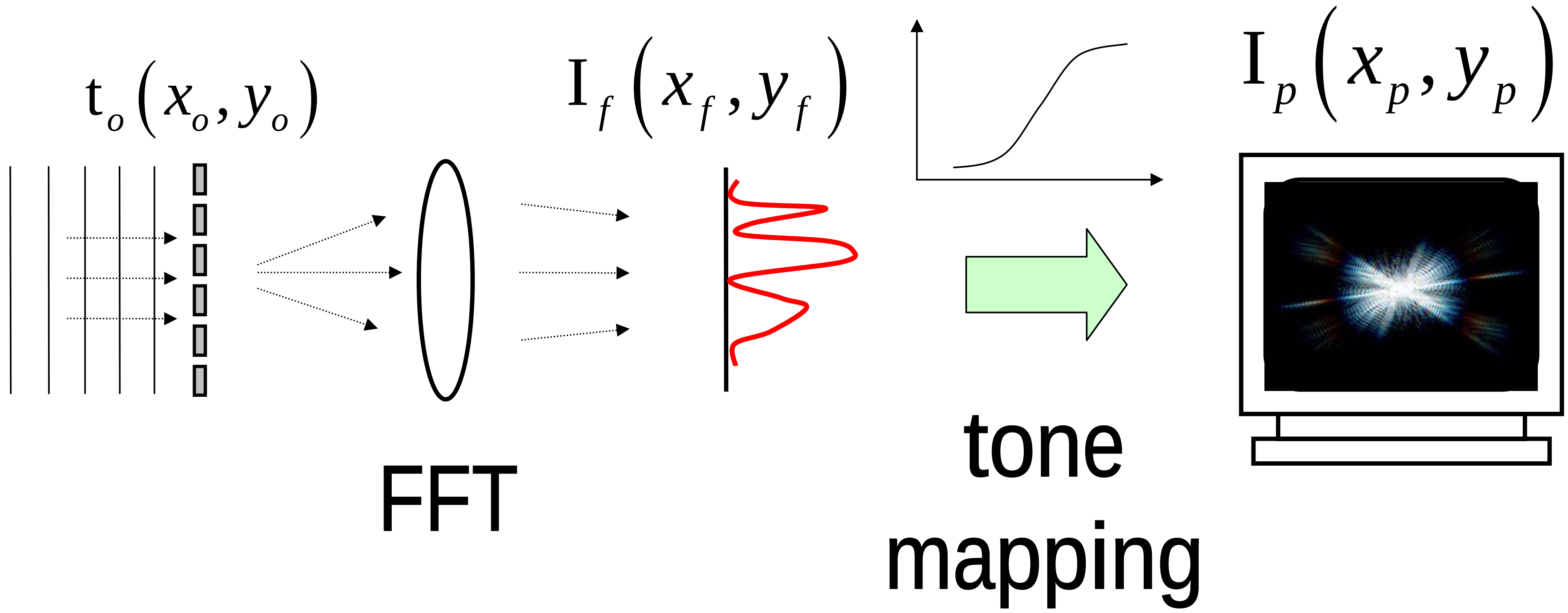
$\mathrm{I}_p\left(x_p, y_p\right)$



Tone mapping summary

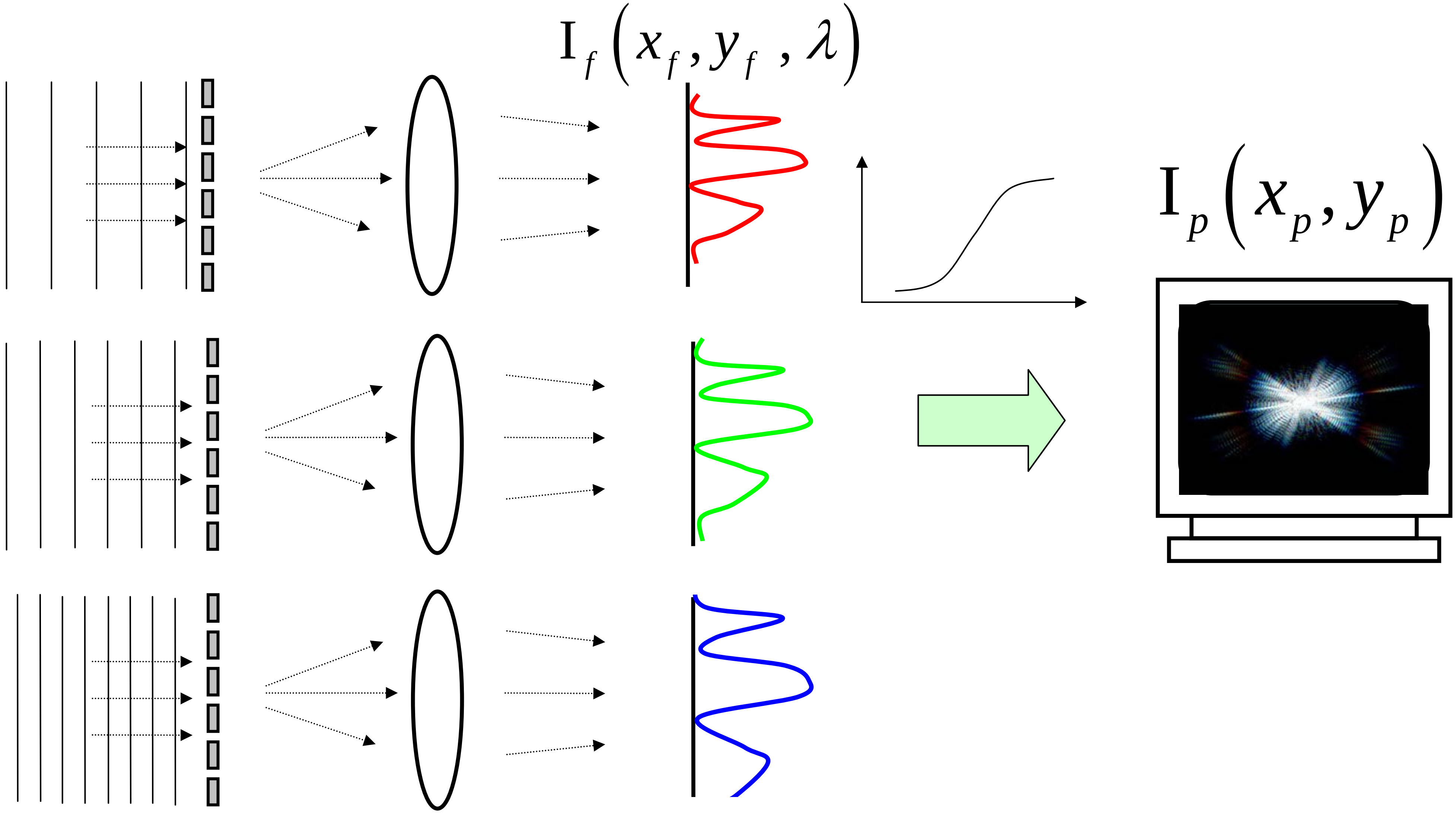
- glare image =

  toneMapping{ FFT(obstacle image) }



Spectrum effect

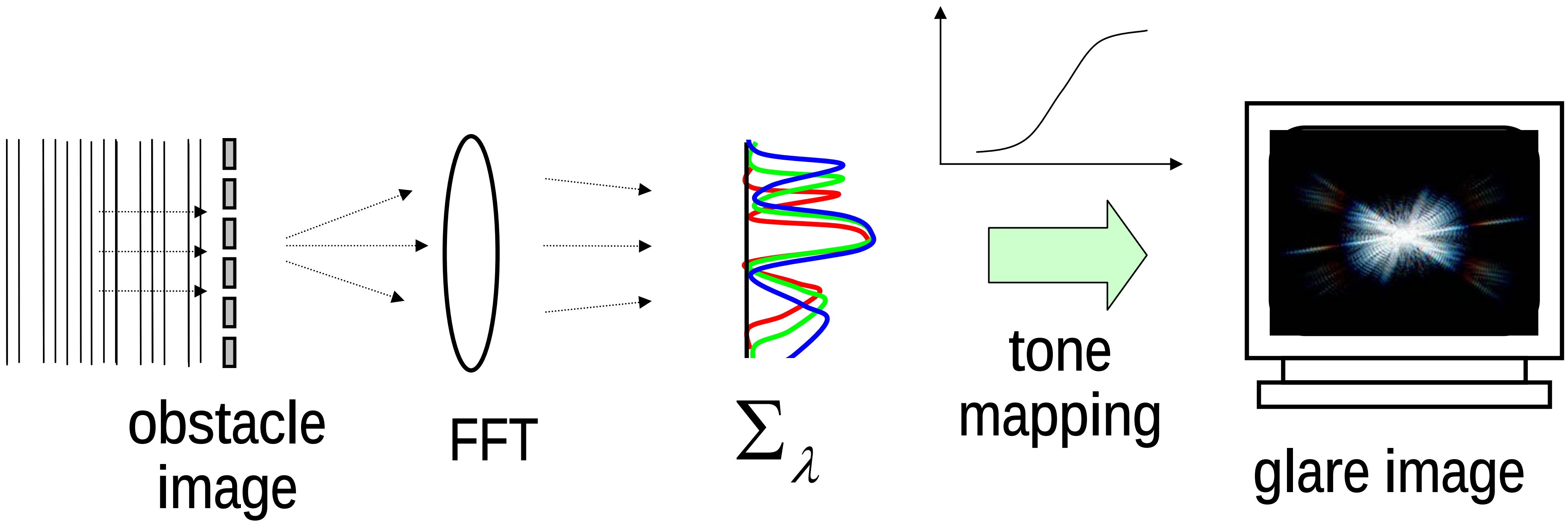
- Composition of the results for multiple wave lengths



Spectrum effect

- glare image =
  toneMapping

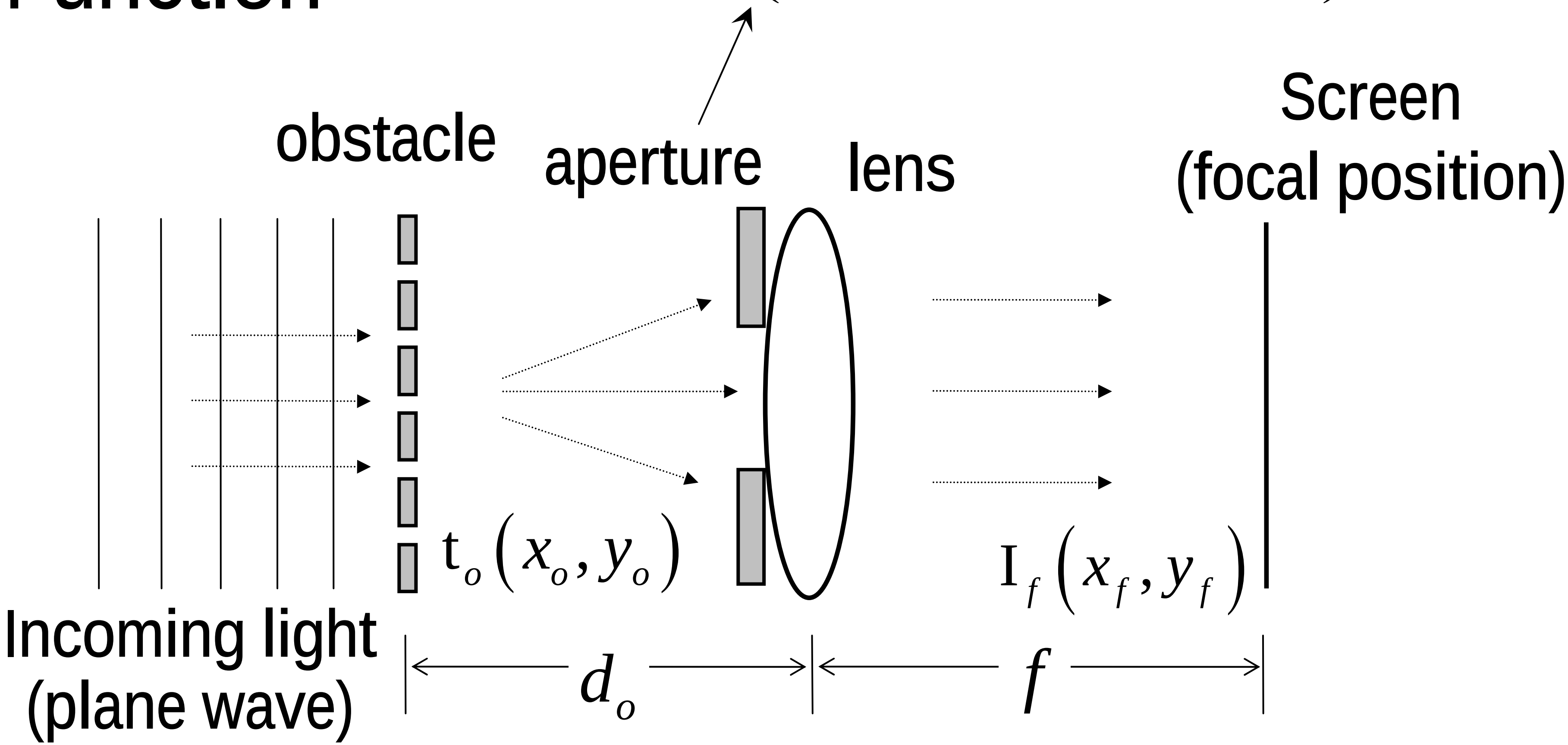
$$\left\{ \sum_{\lambda} \mathrm{FFT}(\lambda, \text{obstacle image}) \right\}$$



Aperture effect

- Employing a Pupil Function

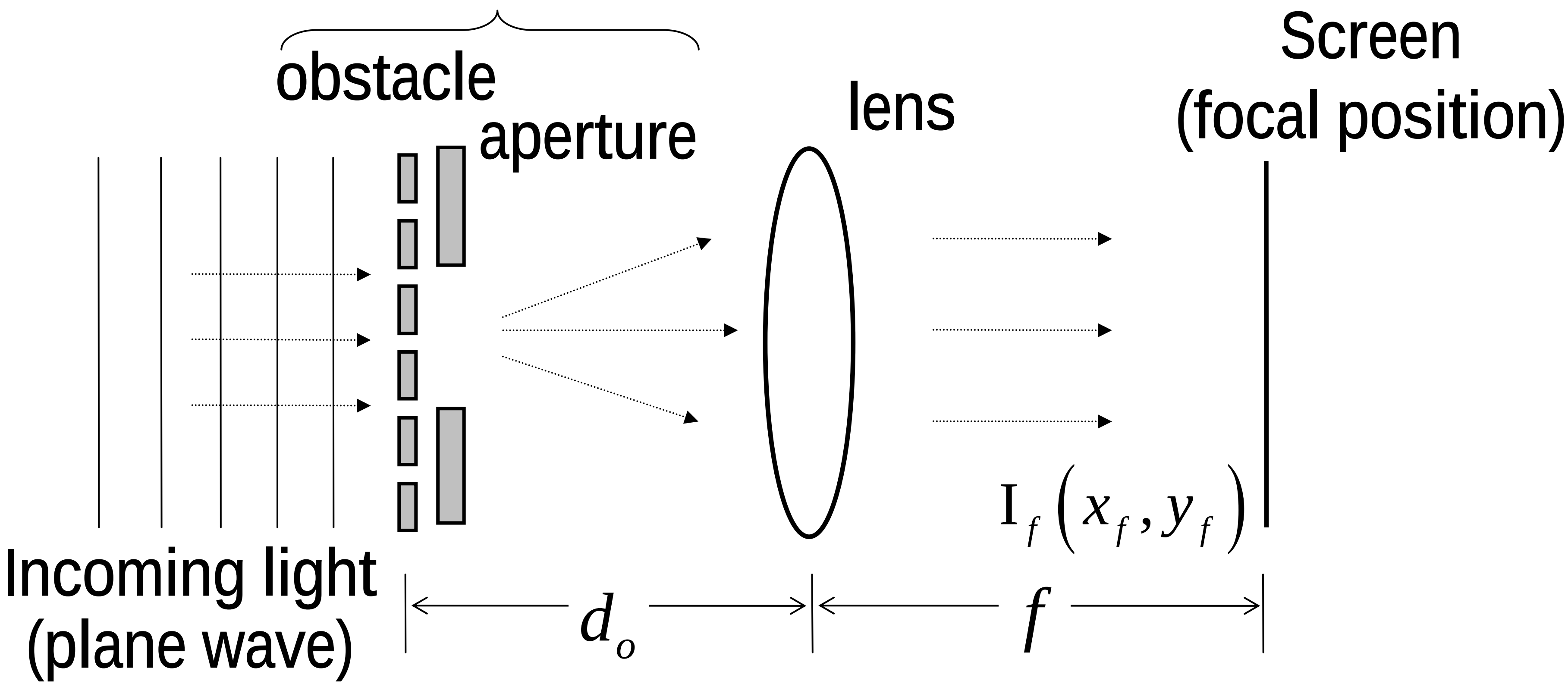
$$P\left(x_o + \frac{d_o}{f}x_f, y_o + \frac{d_o}{f}y_f\right)$$



Aperture effect

- An approximation

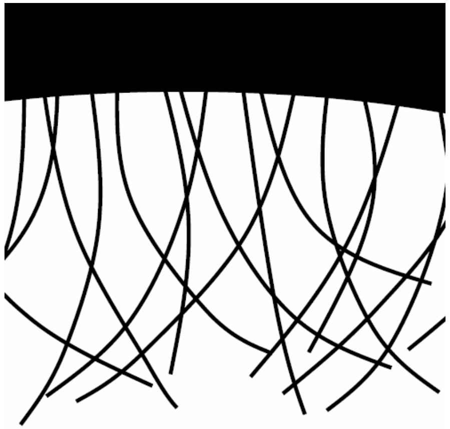
$$t_o(x_o, y_o)P(x_o, y_o)$$



Implementation results

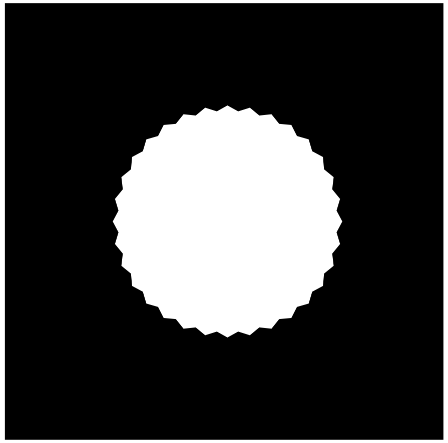
- Image generation using FFT, spectrum and tone mapping

$t_o(x_o, y_o)$

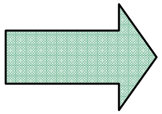


eyelashes and the upper eyelid

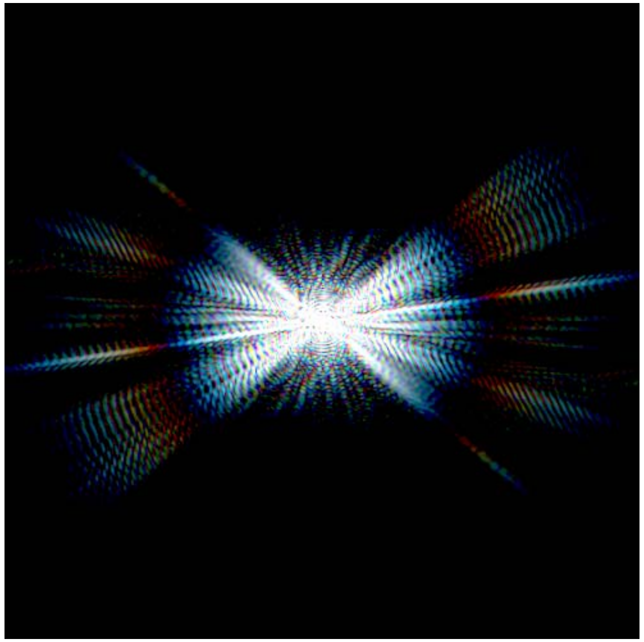
$P(x_o, y_o)$



iris shape



$I_p(x_p, y_p)$

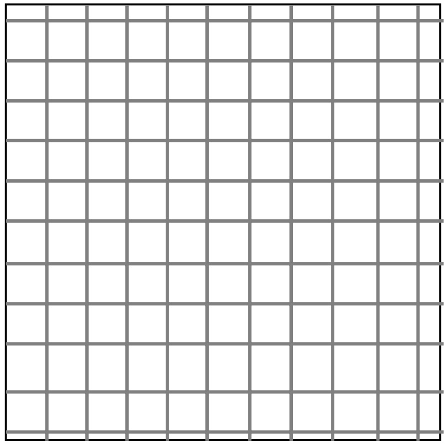


Output glare image

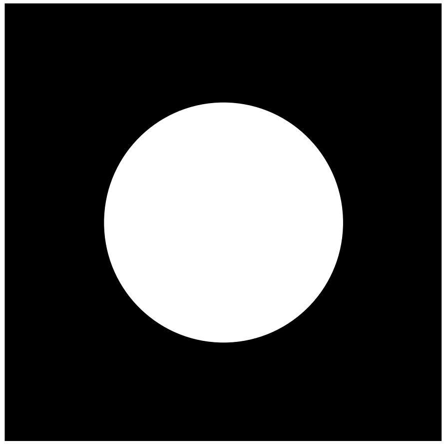
Implementation results

- Image generation using FFT, spectrum and tone mapping

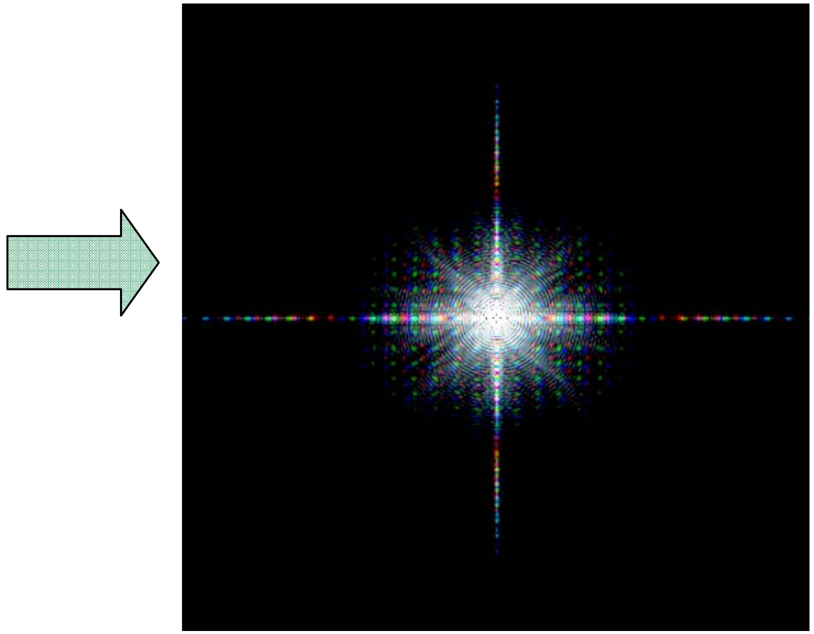
$t_o(x_o, y_o)$ $P(x_o, y_o)$ $I_p(x_p, y_p)$



A cross filter of a camera



A diaphragm on the lens

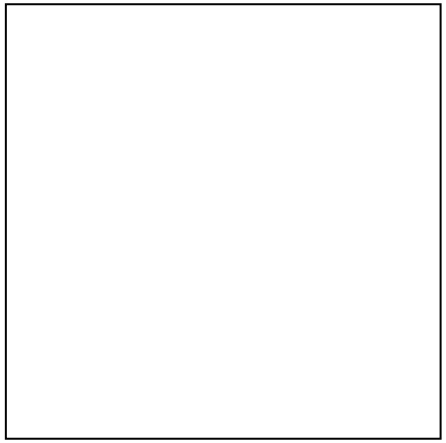


Output glare image

Implementation results

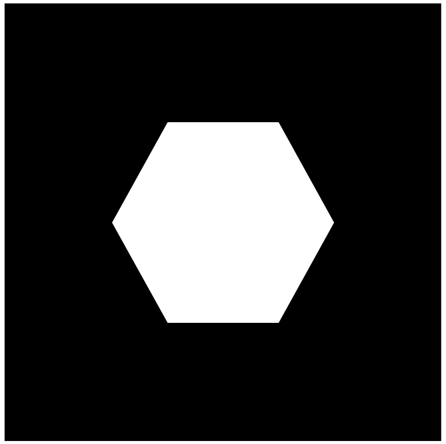
- Image generation using FFT, spectrum and tone mapping

$t_o\left(x_o, y_o\right)$



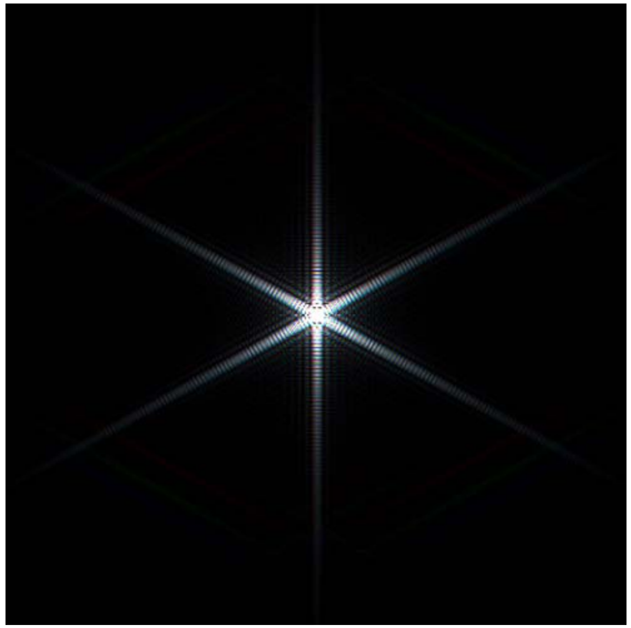
No filter

$P\left(x_o, y_o\right)$



Trigonal diaphragms

$I_p\left(x_p, y_p\right)$



Output glare image

Implementation results

- Overlaying glare images onto an HDR (High Dynamic Range) image

Regular range

High intensity range

Result

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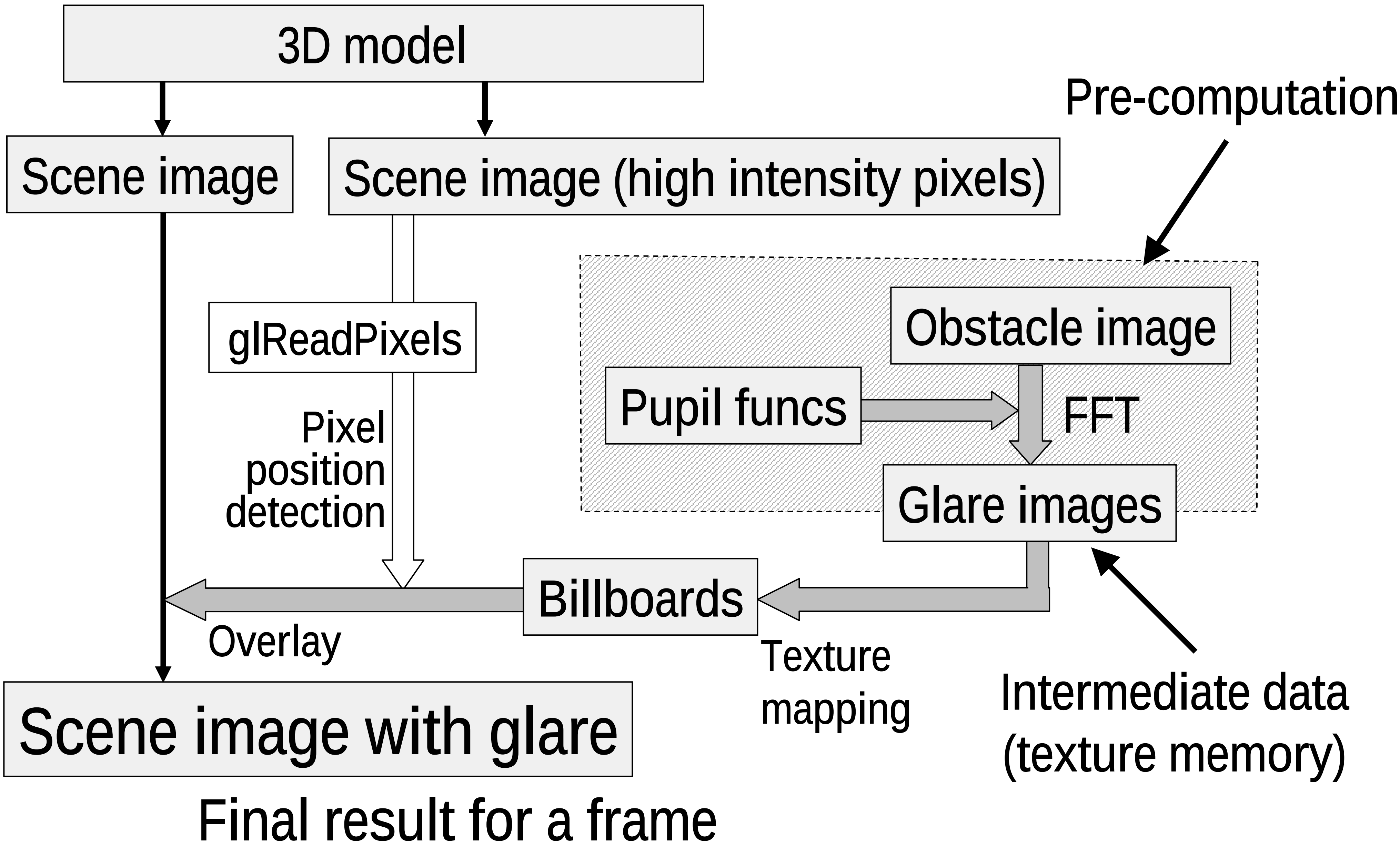
Integration to real-time rendering

- Interactive operation of 3D models makes glare move along the reflective surfaces

A snapshot from a real-time interactive demo

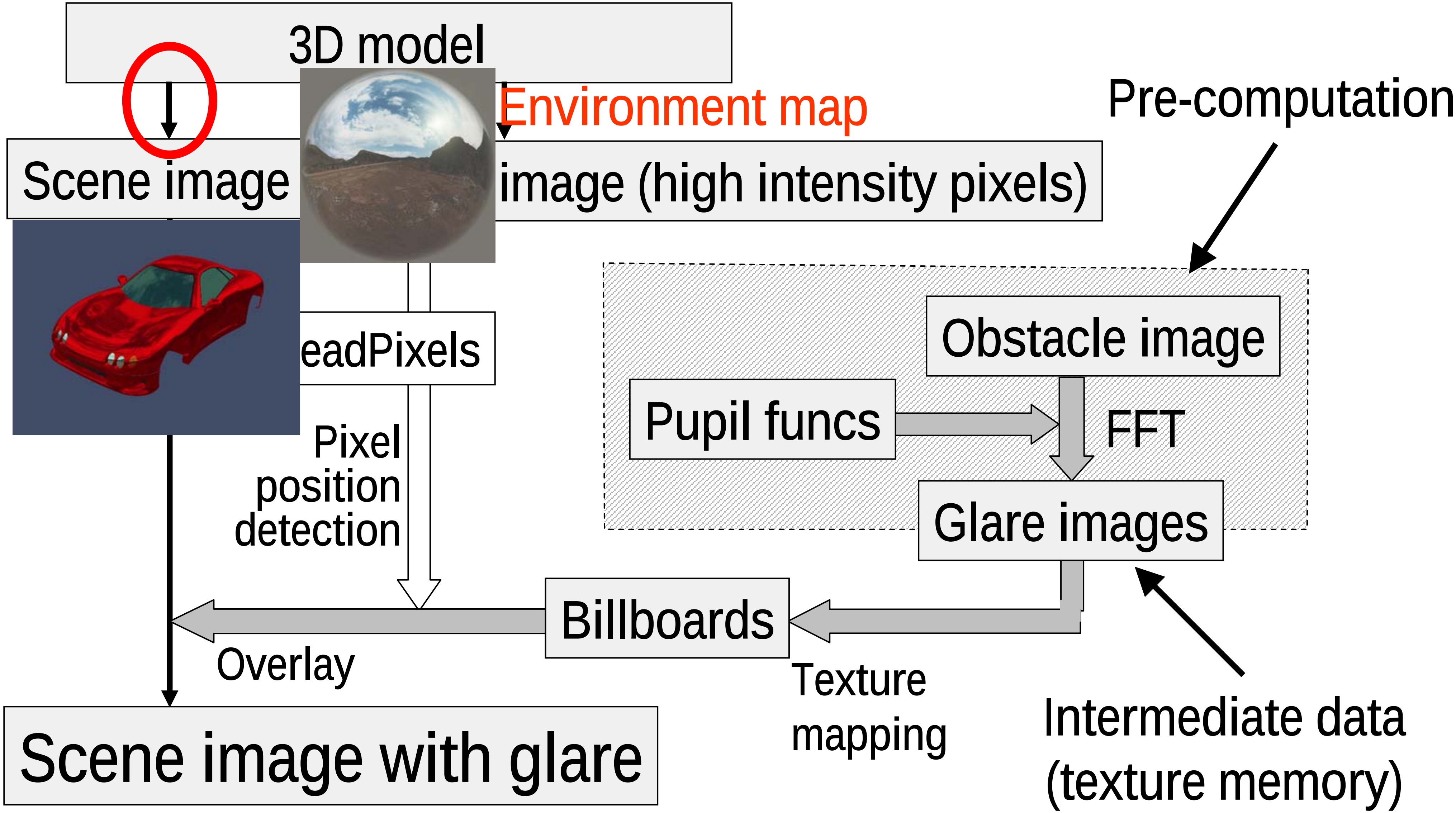
Multi-pass rendering flow

Integration



Multi-pass rendering flow

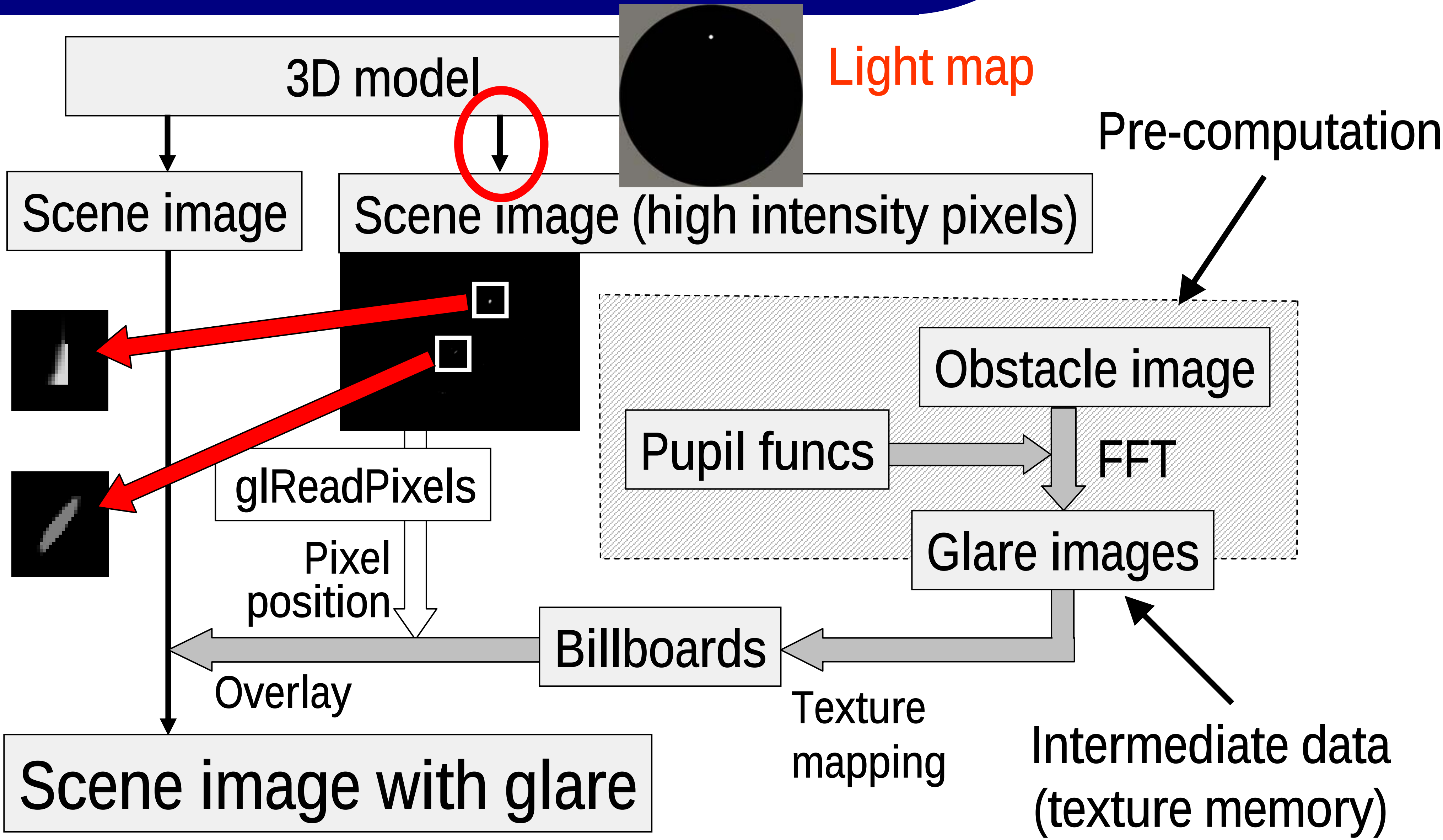
Integration



Final result for a frame

Multi-pass rendering flow

Integration



Final result for a frame

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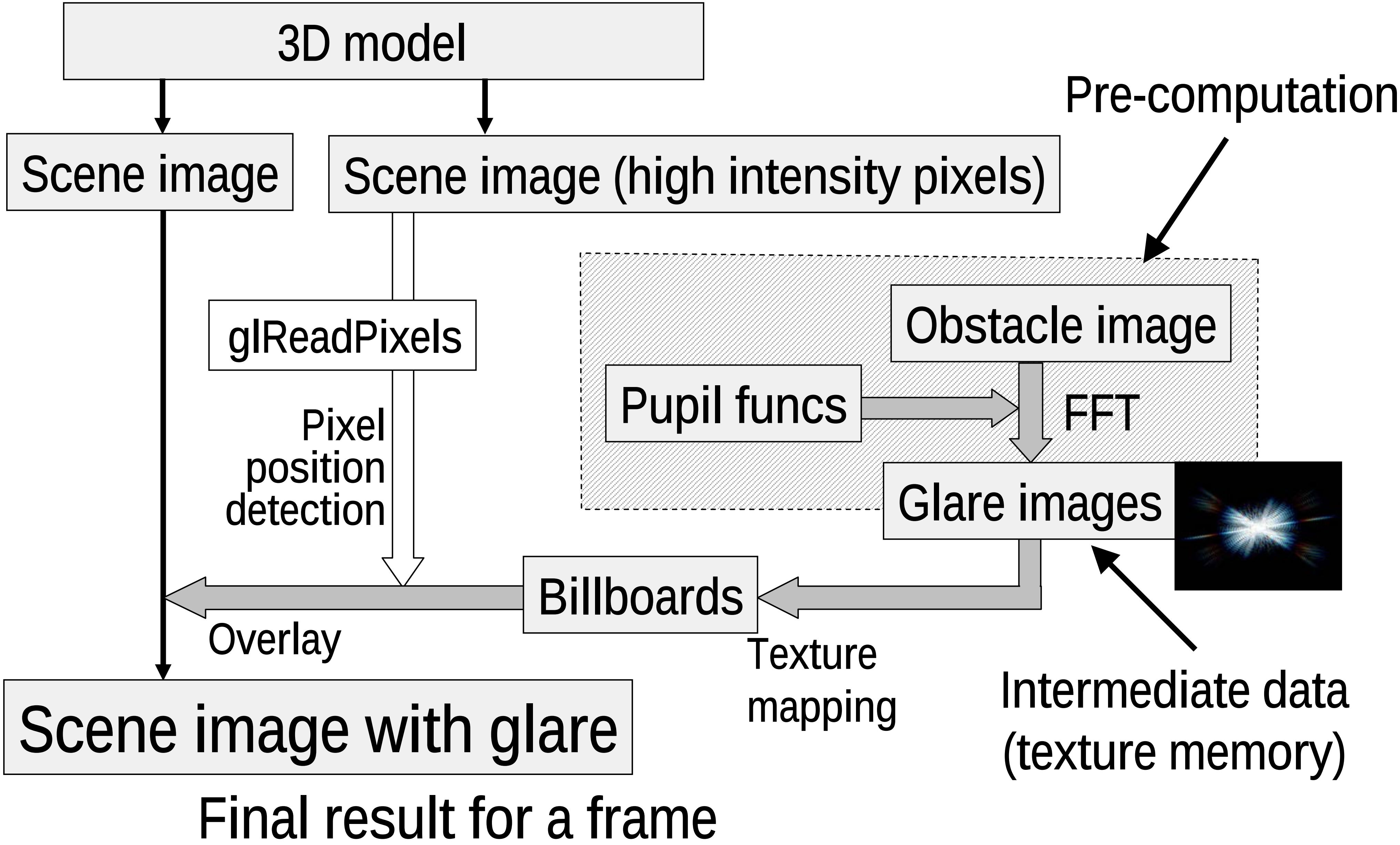
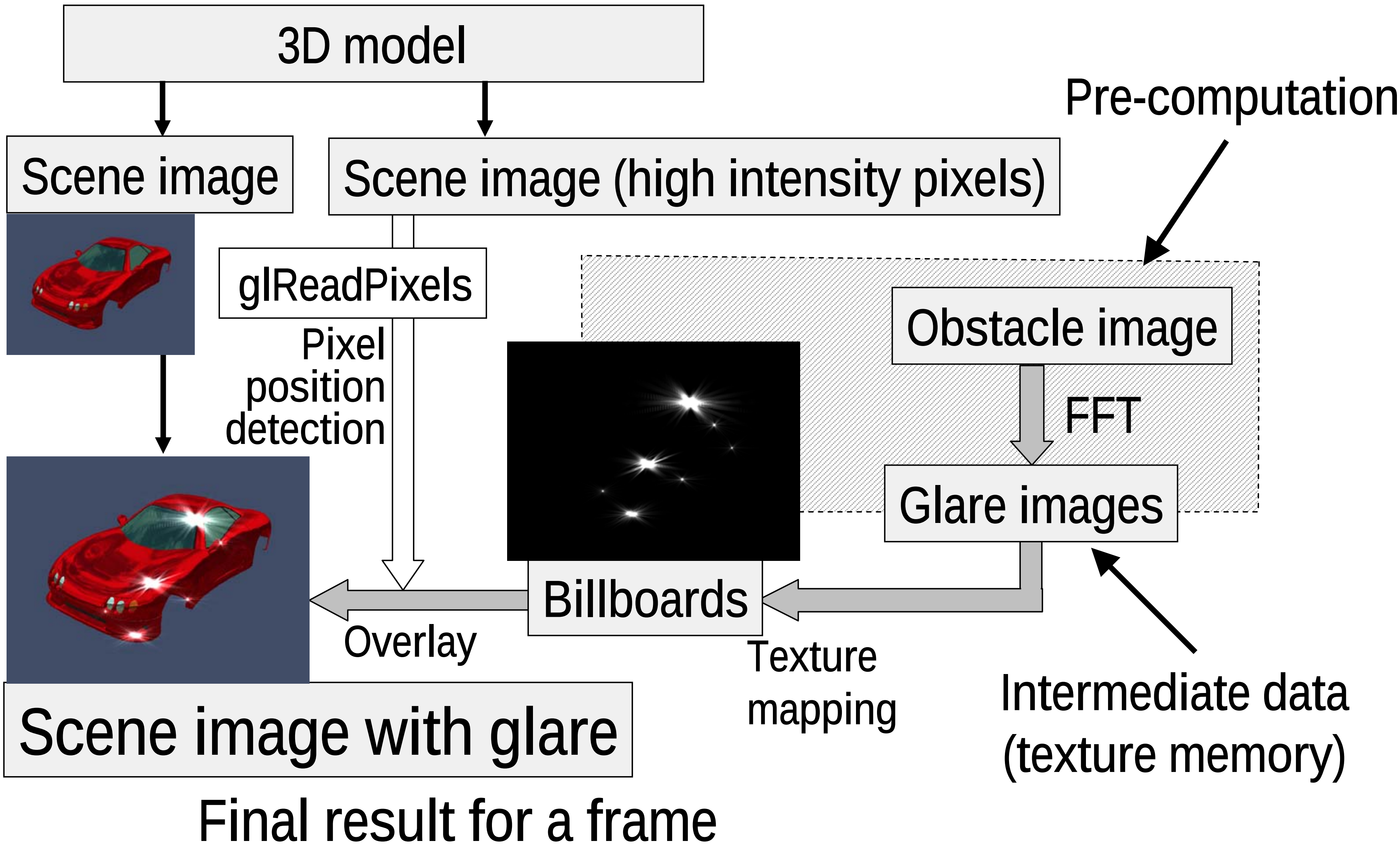


Multi-pass rendering flow

Integration



Dynamic glare

- Moving glare changes shape

An example position of the high intensity pixels detected on the fly

Selected input obstacle image and pupil window function

$$t_o(x_o, y_o) * P(x_o, y_o)$$

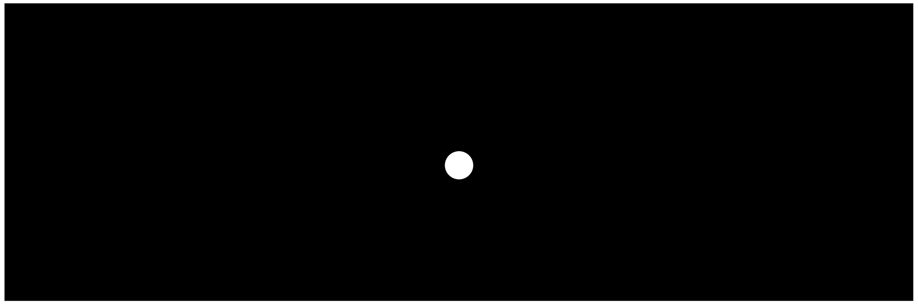
Output glare image

$$I_p(x_f, y_f)$$

Dynamic glare

- Moving glare changes shape

An example position of the high intensity pixels detected on the fly



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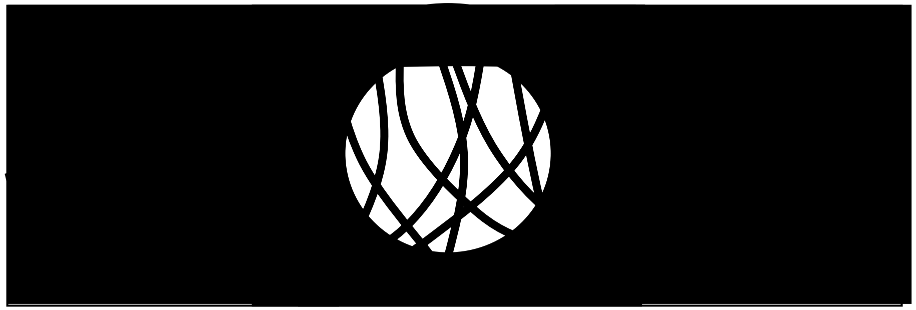
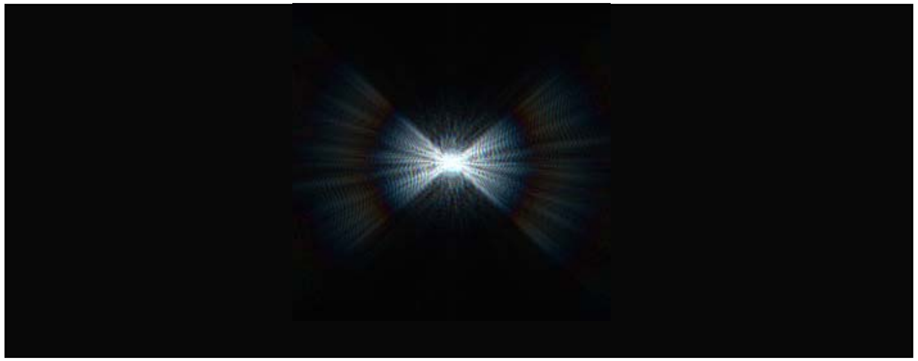


Output glare image

$$I_p(x_f, y_f)$$



Dynamic glare

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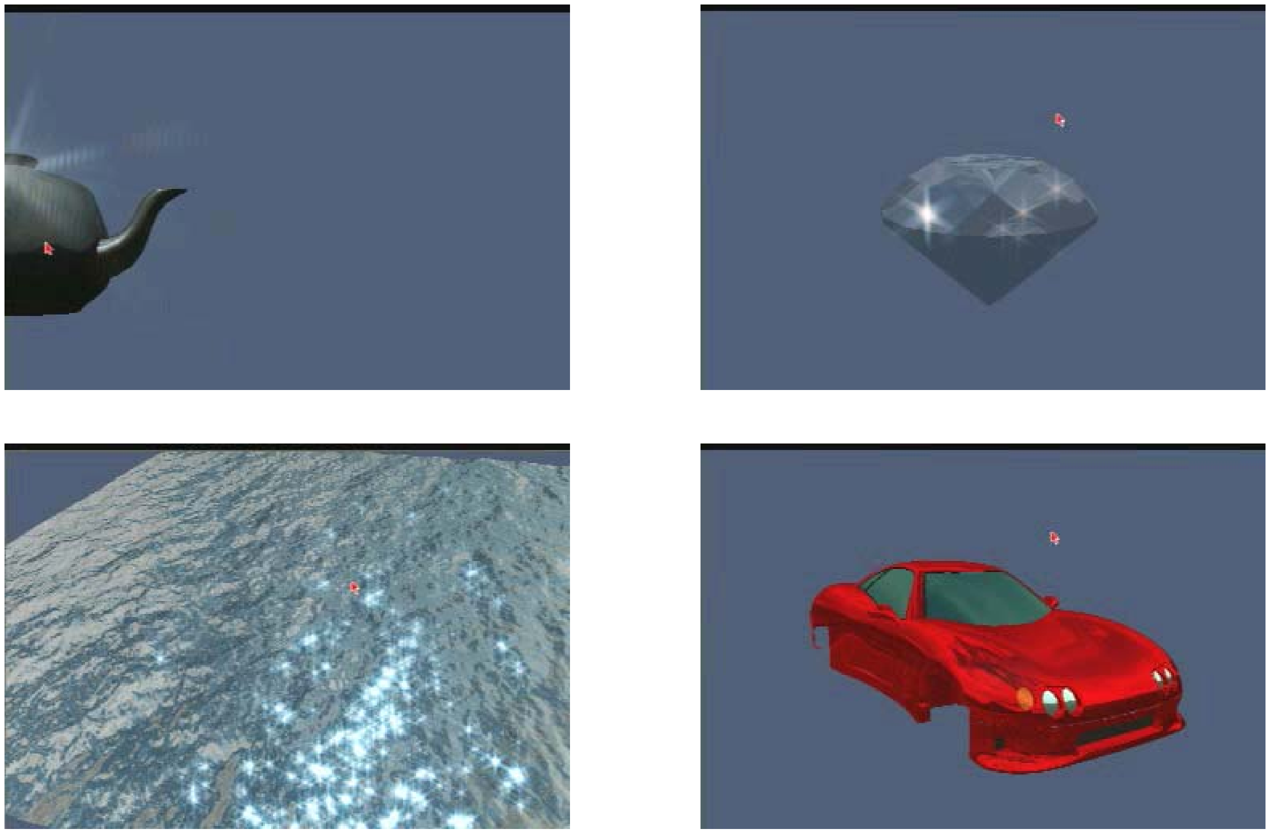
$$t_o(x_o, y_o) * P(x_o, y_o)$$

Output glare image

$$I_p(x_f, y_f)$$

Integration to real-time rendering

- Demonstrations (recorded real-time)
  - SGI Onyx3400 InfiniteReality4
  - 1GB texture memory



Finally ...

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Conclusion

- Established a glare simulation model based on Fraunhofer diffraction
- Implemented using FFT and a Tone mapping technique
  - Enabled users to design glare using obstacle and pupil image as inputs
- Integrated the result into real-time rendering loop

Future Work

- More accurate simulation model
  - Smoother spectrum effect (more sampling of λ)
  - 3D position of obstacles and aperture
- Optimization of performance
  - Especially when number of high intensity pixels is big
- Beyond a mere special effect
  - Application to ophthalmology or engineering

    Postoperative simulation

    Automobile headlamp evaluation

Q&A