Apparent Contrast and Brightness Enhancement

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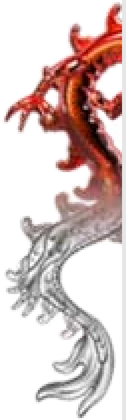
MPI Informatik

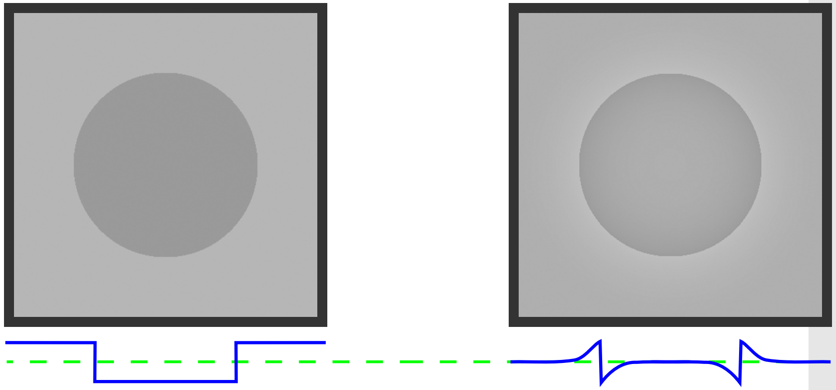
Motivation

- Image display
  - Limited dynamic range of existing display technology
  - Cannot match to physical contrast and brightness of real world scenes
  - Physical match not really required for good reproduction of image appearance
- Modern tone mapping operators good at optimizing the physical contrast and luminance use
- Human preference
  - Enhanced contrast and brightness improve image appearance
- Can we still boost the contrast and brightness impression?

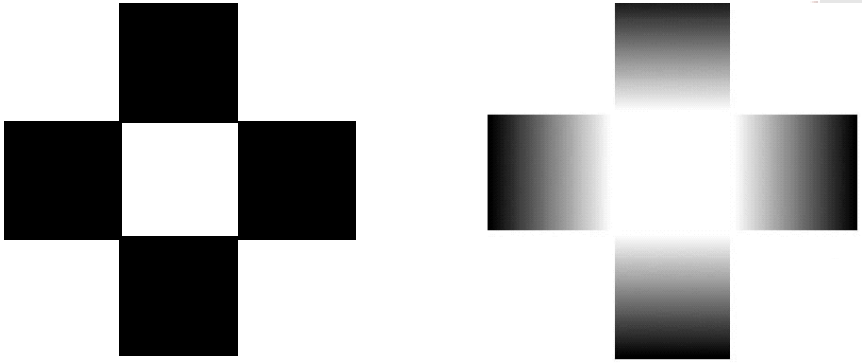


Human perception

- Spatial vision
  - Image appearance can be strongly affected by skillful introduction of intensity gradients between neighboring pixels
- Cornsweet illusion
  - Apparent contrast boost



- Glare illusion
  - Apparent brightness boost



Contrast Enhancement: Motivation

HDR image (reference)

restore missing contrast

tone mapping result

- Usual contrast enhancement techniques
  - either enhance everything
  - or require manual intervention
  - change image appearance
- Tone mapping often gives numerically optimal solution
  - no dynamic range left for enhancement

Krawczyk et al. EG2007

Overview

Reference HDR Image

Measure Lost Contrast at Several Feature Scales

Tone Mapped Image

Enhance Lost Contrast in Tone Mapped Image

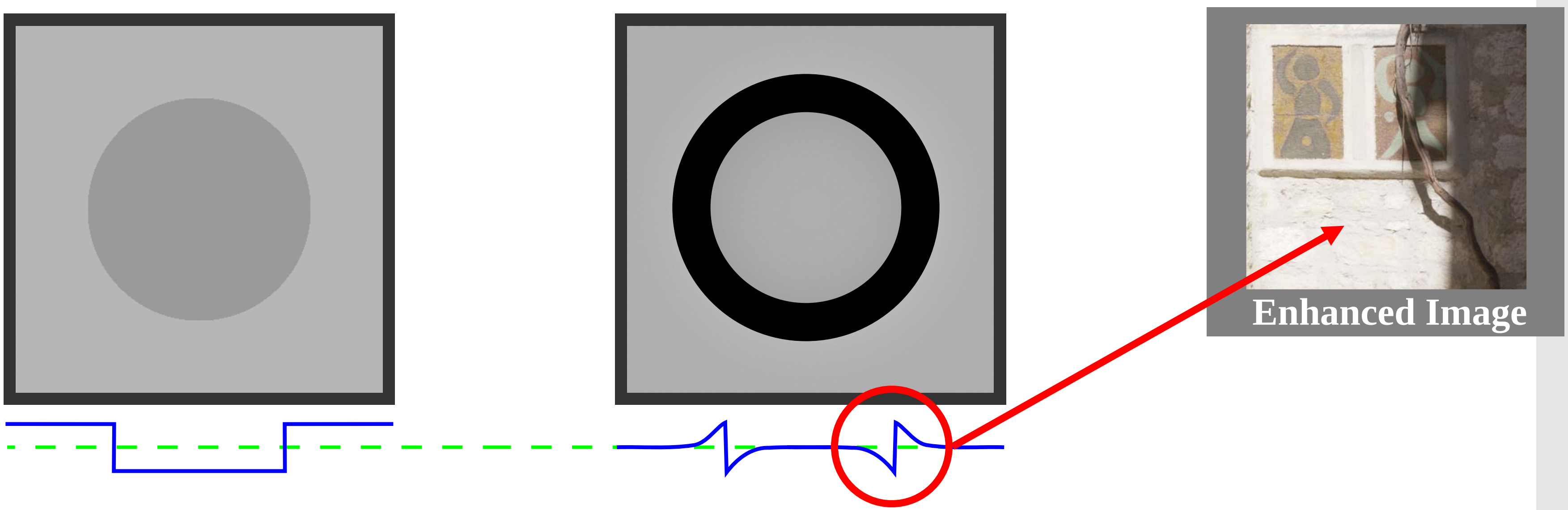
Enhanced TM Image

communicate lost image contents

maintain image appearance

Krawczyk et al. EG2007

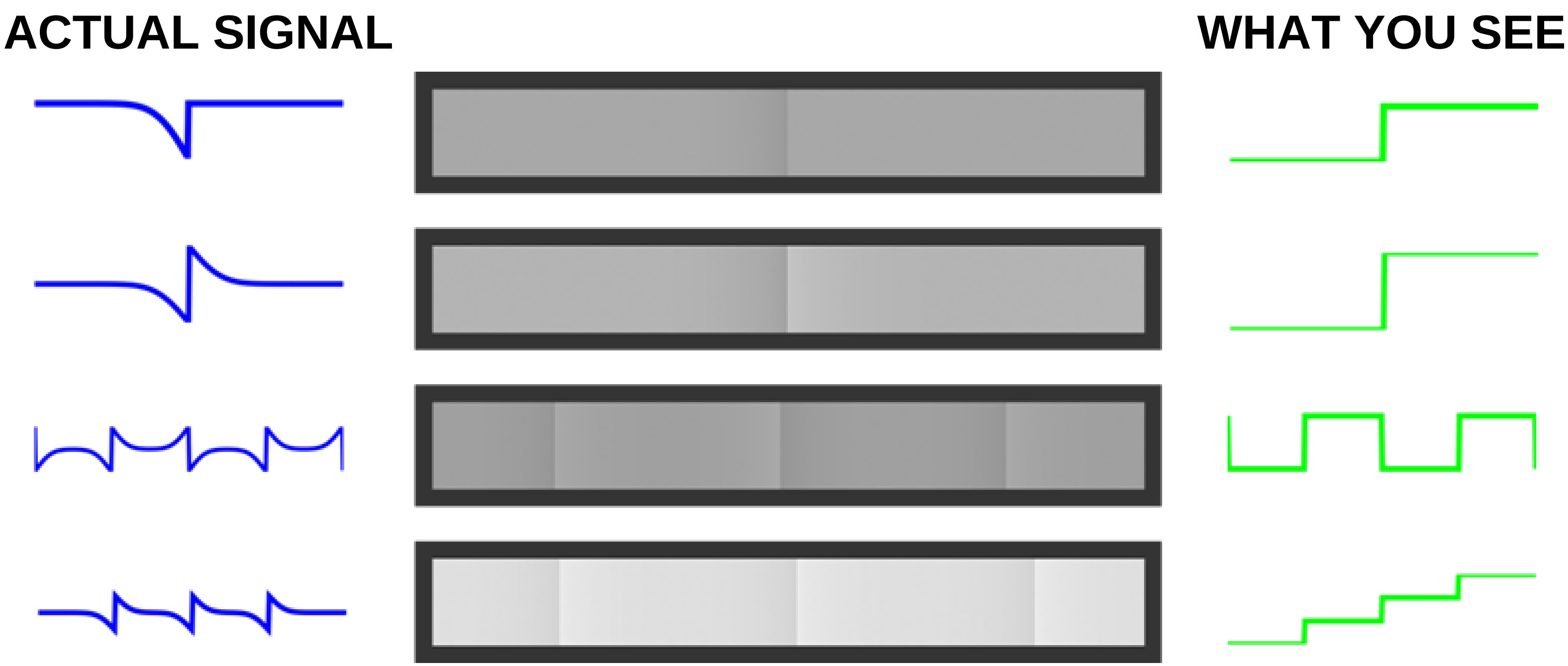
Cornsweet Illusion



- Create apparent contrast based on Cornsweet illusion
- **Countershading**
  - gradual darkening / brightening towards a contrasting edge
  - contrast appears with 'economic' use of dynamic range

Krawczyk et al. EG2007

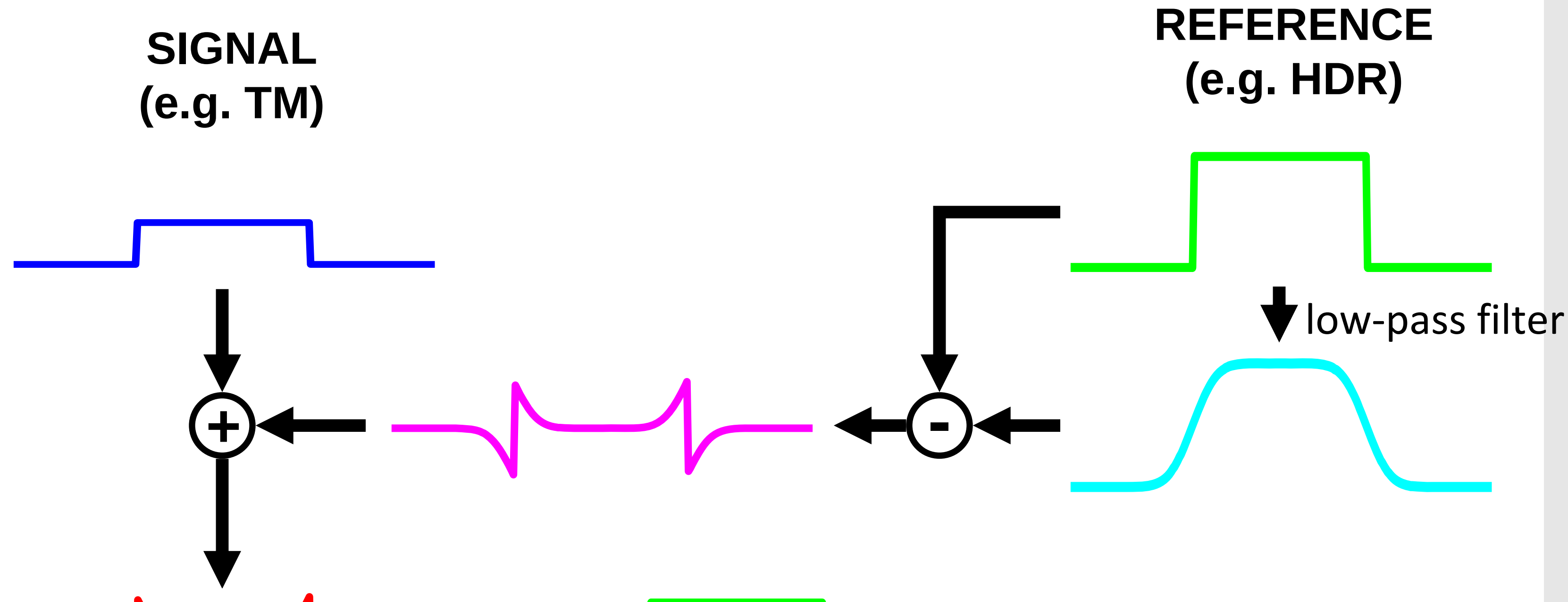
Details of Contrast Illusion

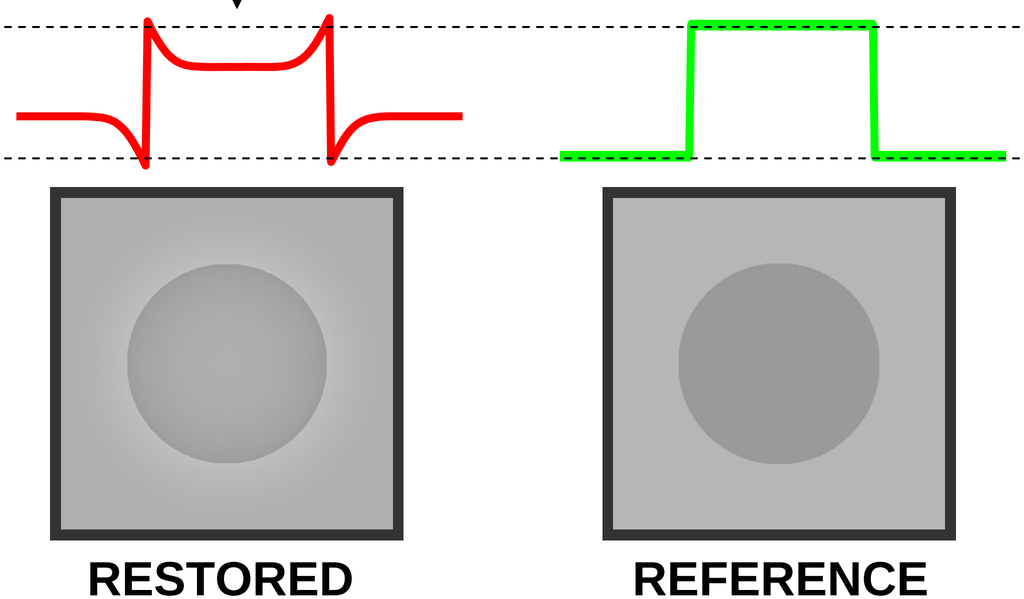


1. Contrast between areas caused by luminance profiles
2. Properties:
   - shape of the profile matches the shape of the enhanced feature
   - amplitude of the profile defines the perceived contrast
   - noise (texture) does not cancel the illusion
   - profiles should not be discernible

Krawczyk et al. EG2007

Construction of Simple Profile (1/2)

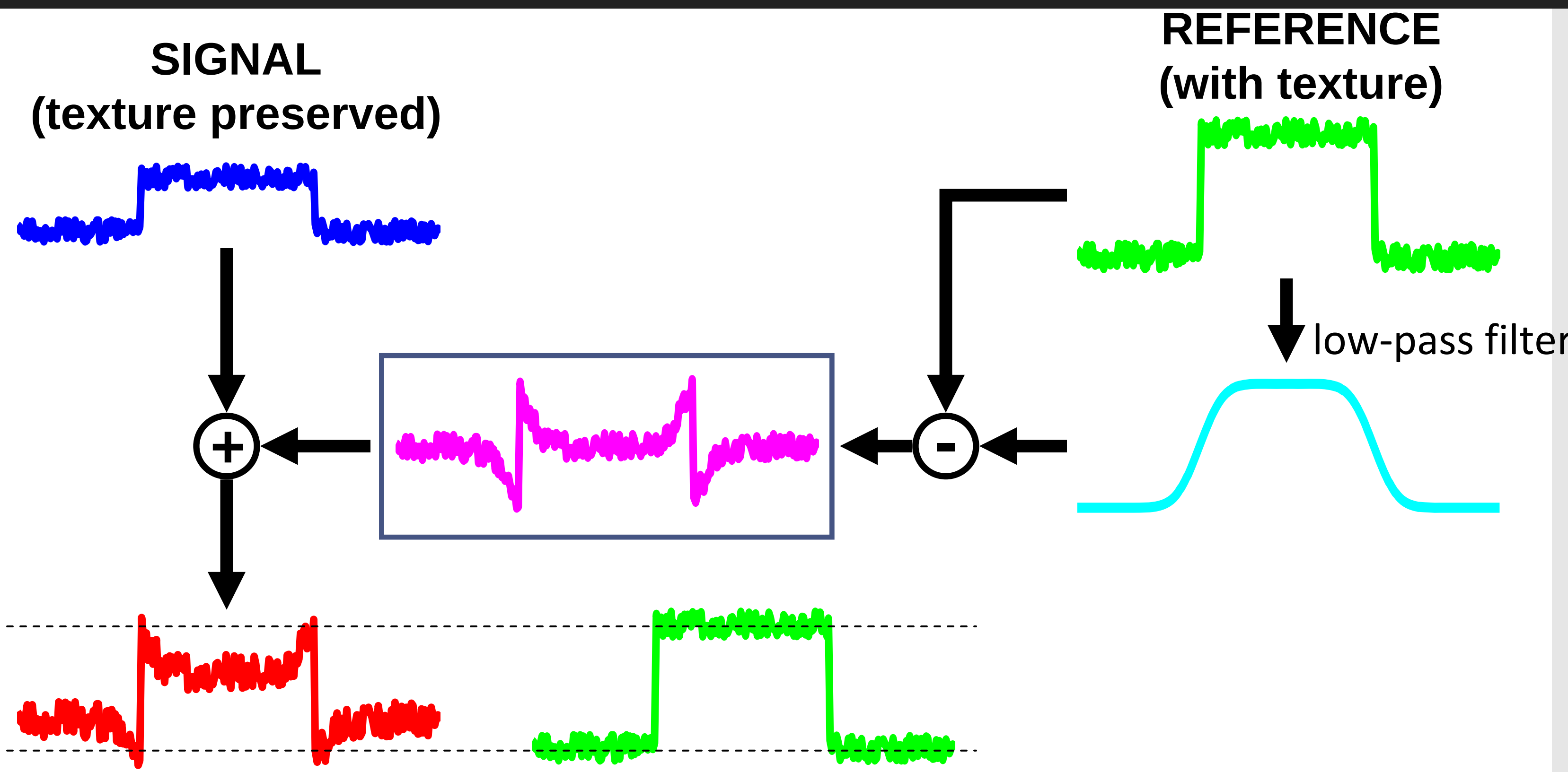




- Profile from low-pass filtered reference
- Size and amplitude adjusted manually
- This is **unsharp masking**

Krawczyk et al. EG2007

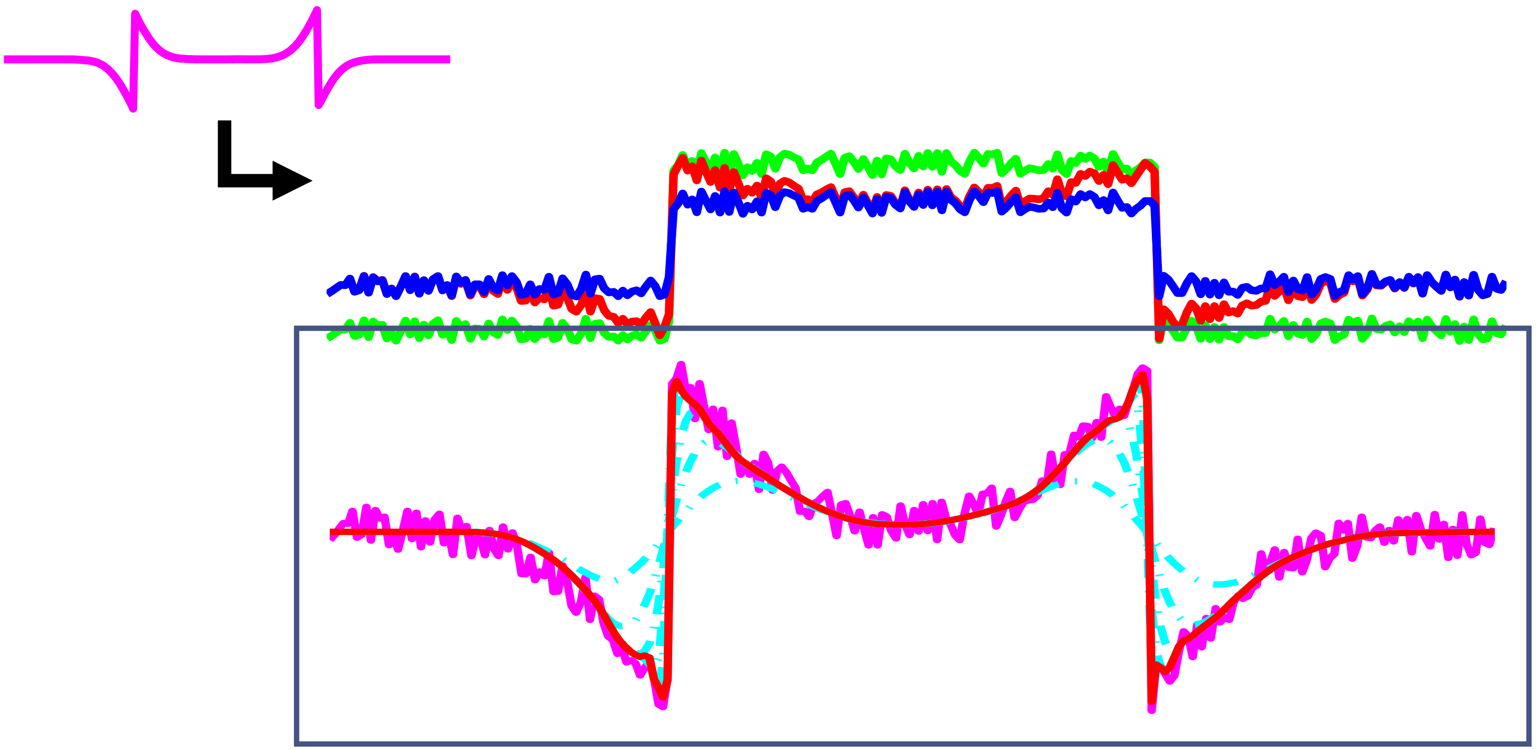
Construction of Simple Profile (2/2)



Well preserved signal is exaggerated by **unsharp masking**

Krawczyk et al. EG2007

Correct Profile for Textured Area



- Profile constructed directly from the reference image contains high frequency features which exaggerate texture
- **Sub-band components allow to select features**
  - **high frequency component present only at high contrast edge**

Krawczyk et al. EG2007

Multi-resolution Contrast Metric

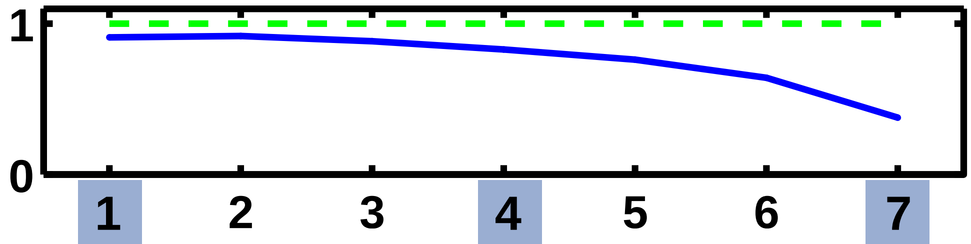
Reference HDR Image

Measure Lost Contrast at Several Feature Scales

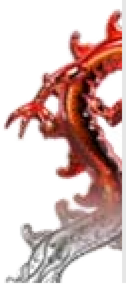
Tone Mapped Image

$$C_l = \frac{|Y - Y_{mean}|}{Y_{mean}}$$

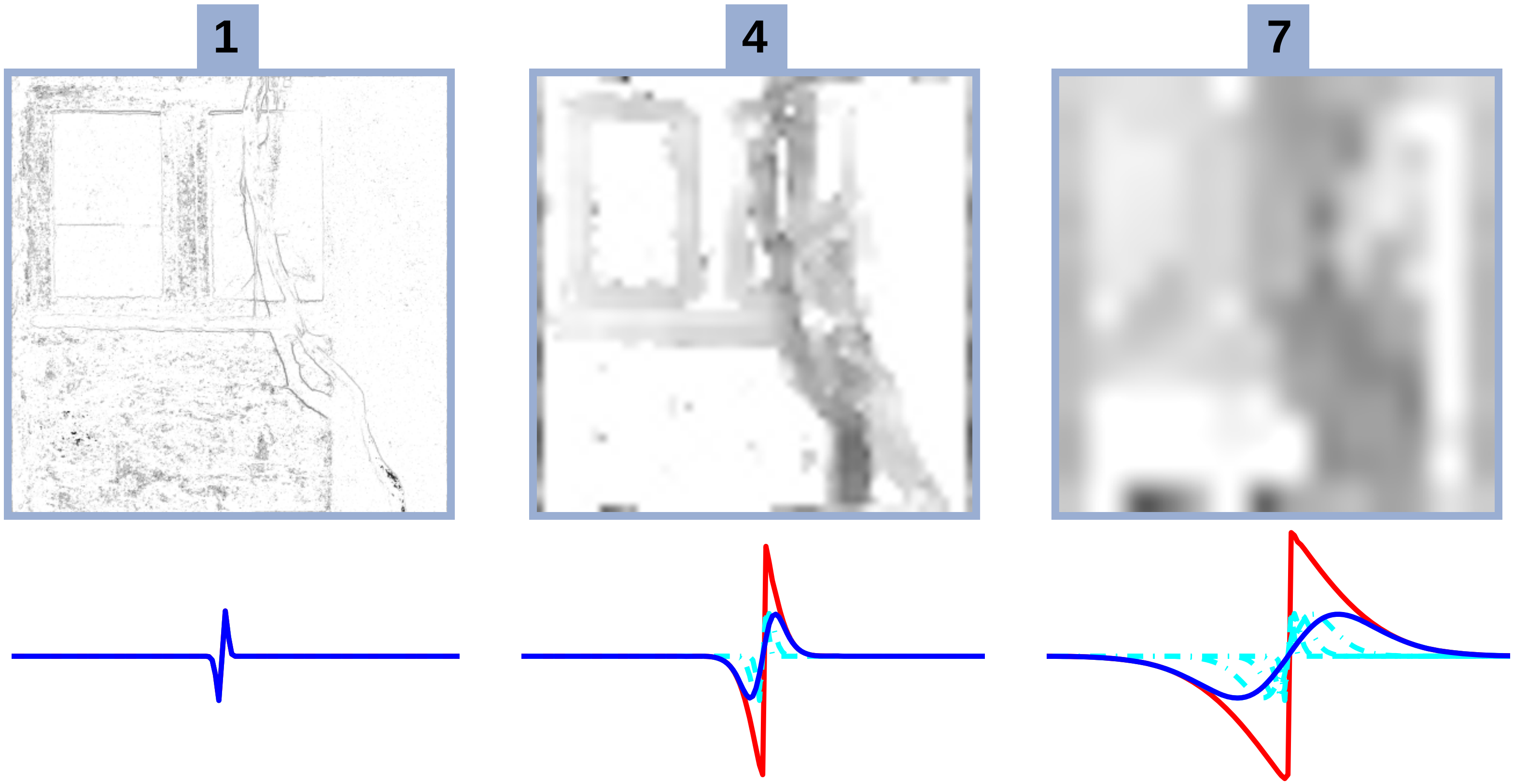
$$R_l = \frac{C_l^{inp}}{C_l^{ref}}$$



Contrast ratios at several scales

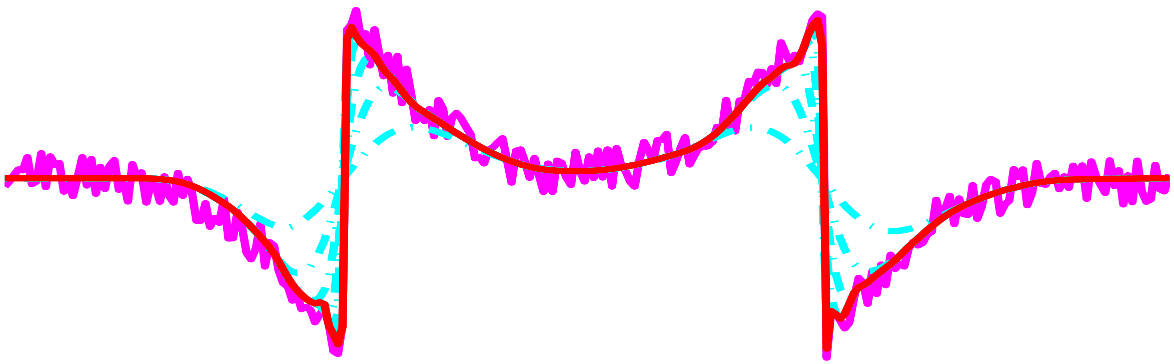


Link: Contrast Metric & Profiles



1. Contrast ratio at each scale defines the sub-band amplitude (blue)
2. Contrast for larger scales appears also on smaller scales
   - the full profile is always reconstructed (red)
3. Scale of contrast measure defines the profile size

Formula: Countershading Profile



$$P = \sum_{l=1}^{N} (1 - \uparrow R_l) \times (\log Y^{ref}_{\sigma(l-1)} - \log Y^{ref}_{\sigma(l)})$$

amplitude of profile — sub-band component of profile

1. Contrast ratio R_l on scale l drives the amplitude of sub-band component of profile at size l
2. Sum of N sub-band components gives the countershading profiles P that match the contrasts in the reference image

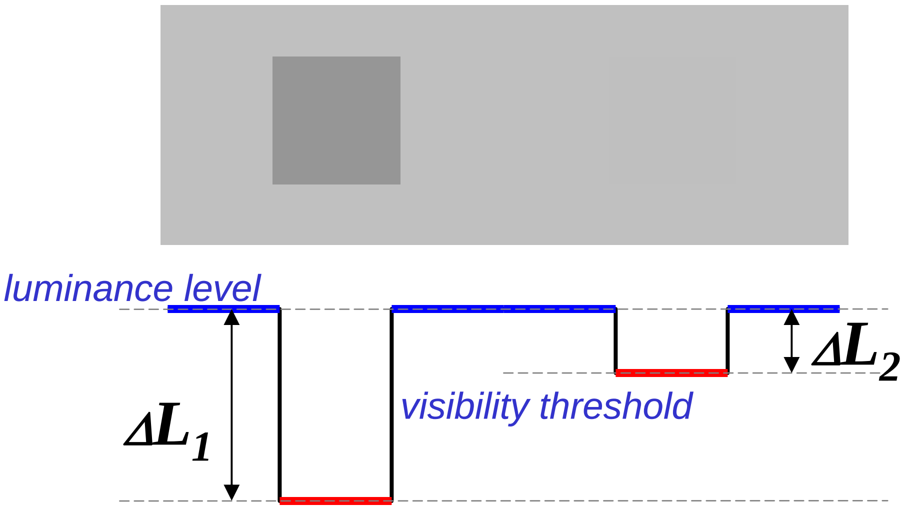
Adaptive Countershading

final contrast restoration

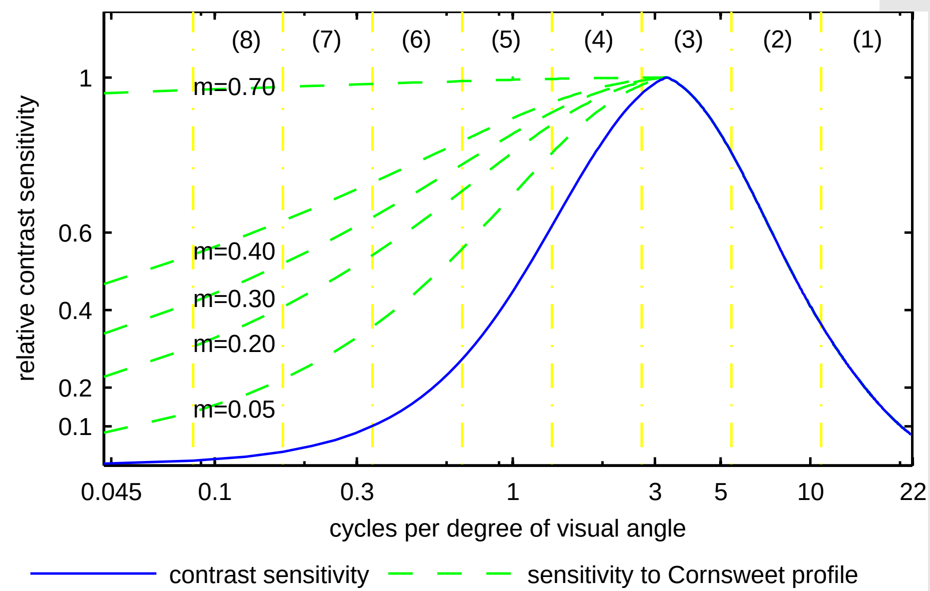
progress of restoration

- **Objectionable visibility of countershading profiles**

Visual Detection Model

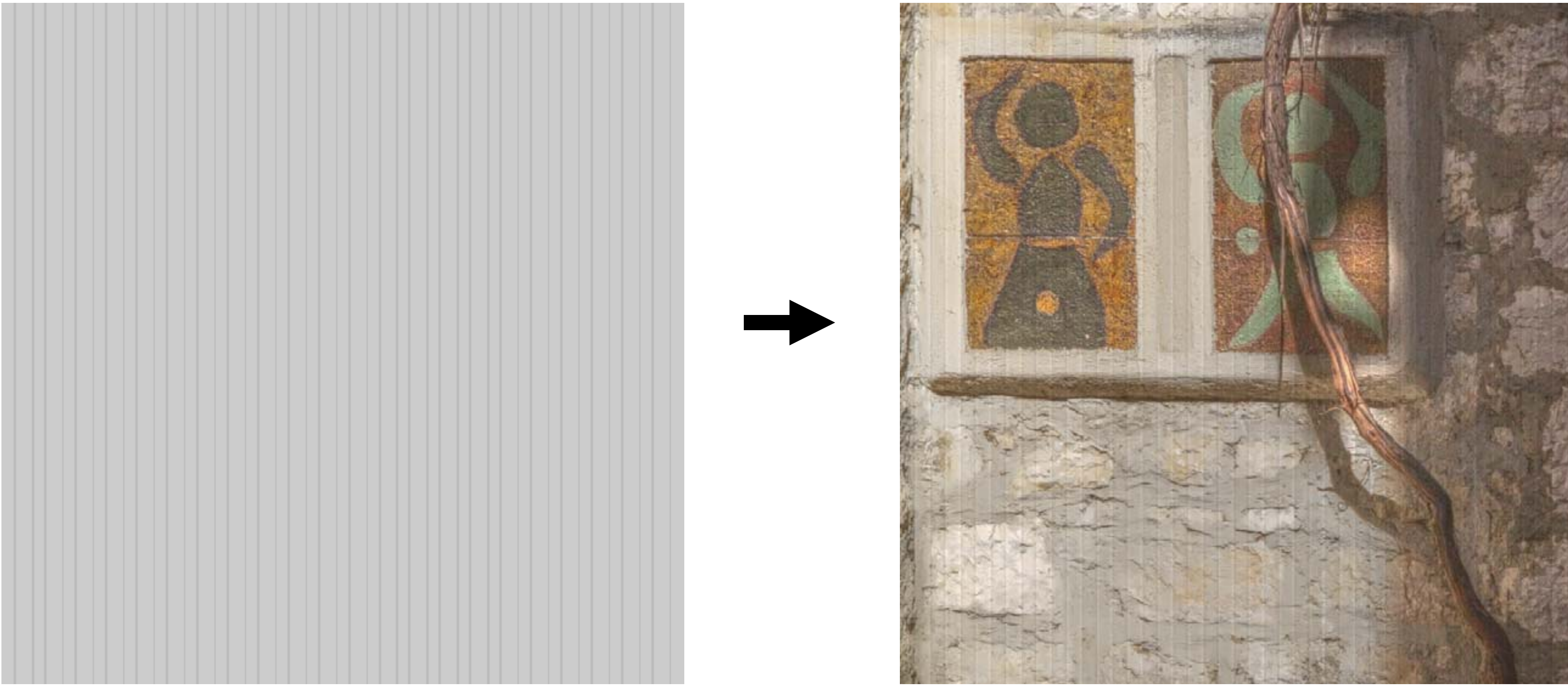


[Dooley and Greenfield, 1977]



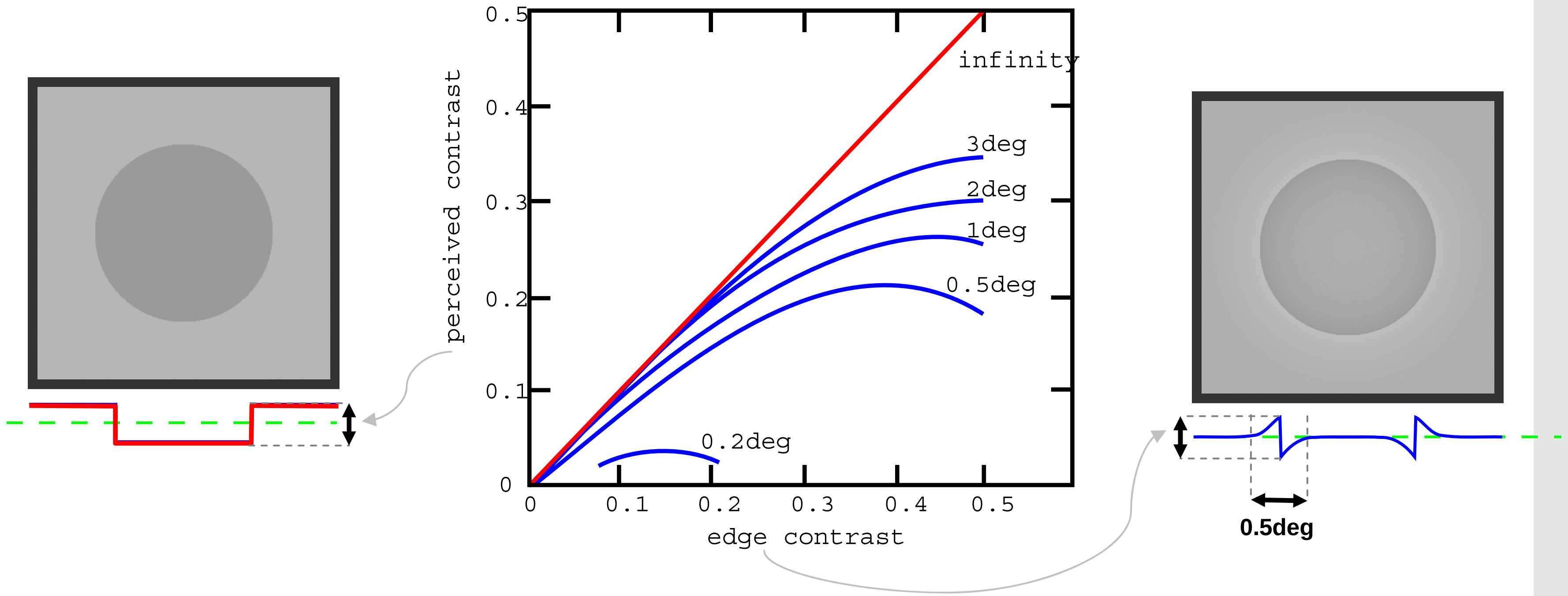
- Luminance masking
  - absolute luminance level L defines minimum perceivable luminance difference ΔL
  - defined by t.v.i. functions
- Spatial contrast sensitivity
  - reduced sensitivity to low frequencies
  - defined by CSF functions
  - improved by supra-threshold measurements of Cornsweet profile

Hiding Countershading Profiles



- Contrast masking
  - existing contrast masks new signals of similar orientation and frequency
  - defined by a power function of contrast present in an area
- <u>Essential improvement</u>
  - previous models allow for rather small amplitudes of profiles

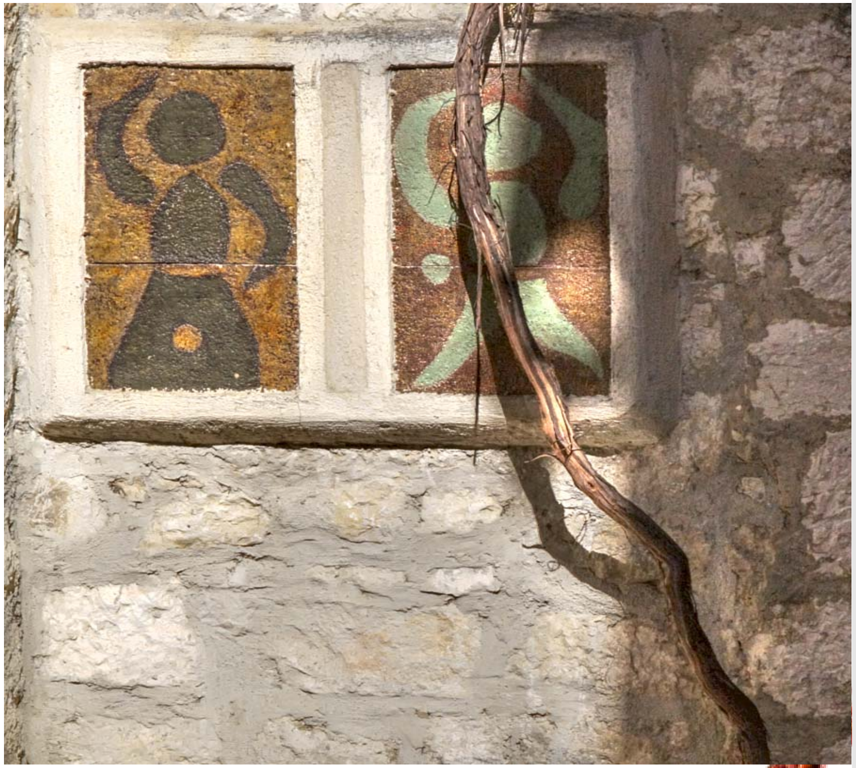
Limits of Countershading Profiles



- Measurements plot for the Cornsweet effect
  - contrast at the profile edge (x) and the matching contrast at the step edge (y)
- Masking allows for stronger enhancement
- Maximum correction depends on profile size
  - natural images unlikely require correction of a large contrast with a small profile

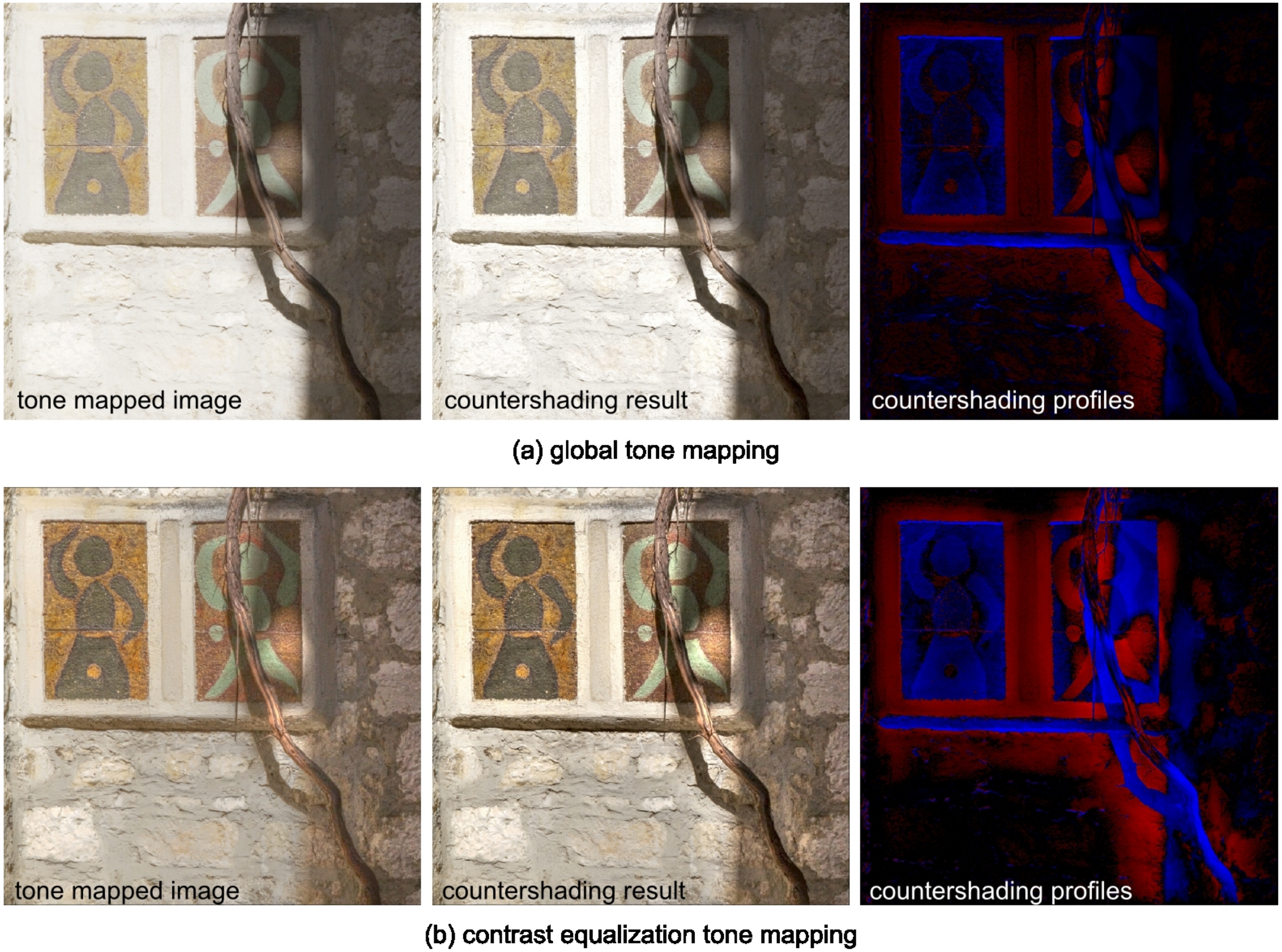
Adaptive Countershading

without visual model



with visual model

Restoration of TM Images (1/3)

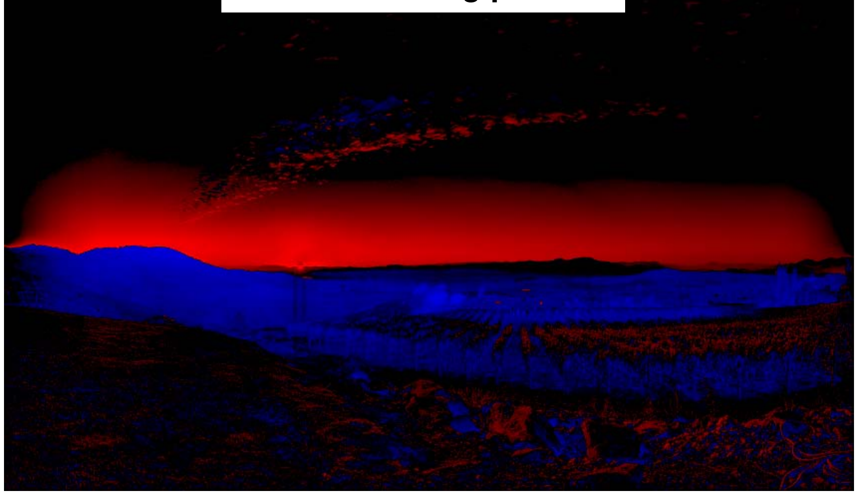


Restoration of TM Images (2/3)

reference HDR image (clipped)

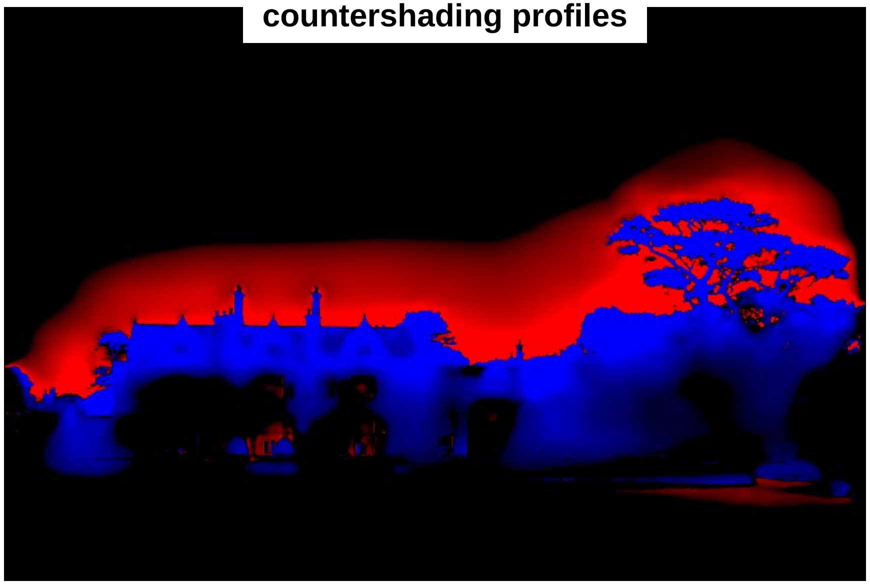
countershading of tone mapping

countershading profiles



tone mapping

Restoration of TM Images (3/3)



C-shading vs. Unsharp Mask

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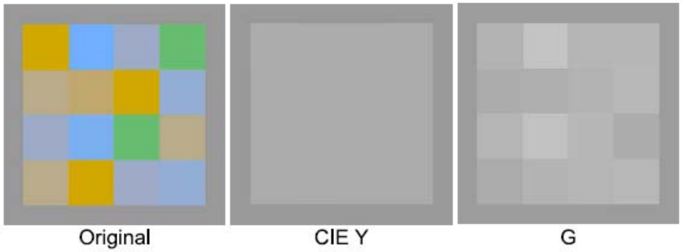
adaptive countershading

unsharp masking

tone mapping

Countershading Variants

- Traditional countershading
  - performed in the achromatic channel to enhance perceived luminance contrast
- Cross-modal approach
  - Use depth signal to derive countershading profile
  - Countershading over chromatic channels enhances the overall image contrast
- Color2Grey:
  - dimensionality reduction 3->1: may lead to information loss
  - countershading in the achromatic channel used to reproduce lost chromatic contrast



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Purpose: Contrast Restoration

Reference Depth Map

Measure Missing Contrast at Several Feature Scales

Enhance Missing Contrast in The Input Image

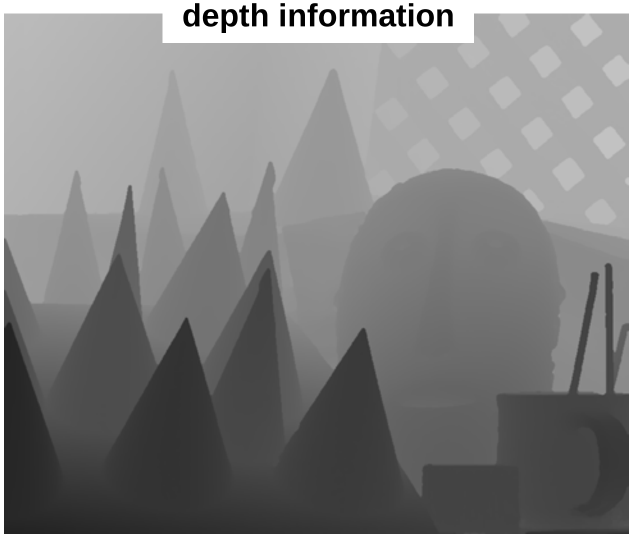
Input Image

Enhanced Image

Luft et al. SIG2008

Depth Map as Contrast Reference

depth information



original image

adaptive countershading

depth darkening [Luft2006]

Luft et al. SIG2008

Colourfulness Countershading

- "Strasbourg": Gradient method tone mapping, strong global contrast loss so strong restoration effect.
- Colourfulness contrast at border between sky and buildings
  - promotes FG/BG separation
  - creates impression of greater dynamic range
  - increases impression of depth

Smith et al. EG2006

Countershading Results (original)

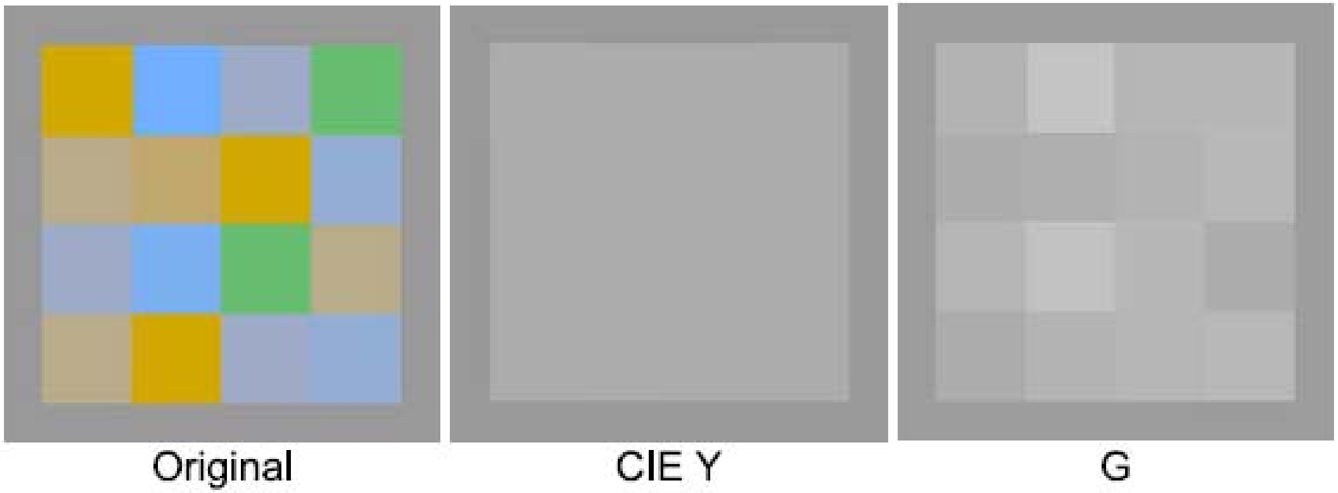
Smith et al. EG2006

Countershading Results (chroma enhancement)

Smith et al. EG2006

Color2Grey Application

- Isoluminant color pattern transformed to grey G using Helmholz-Kohlraush effect, which takes into account the contribution of chromatic component into brightness



Smith et al. EG2008

Color2Grey Application

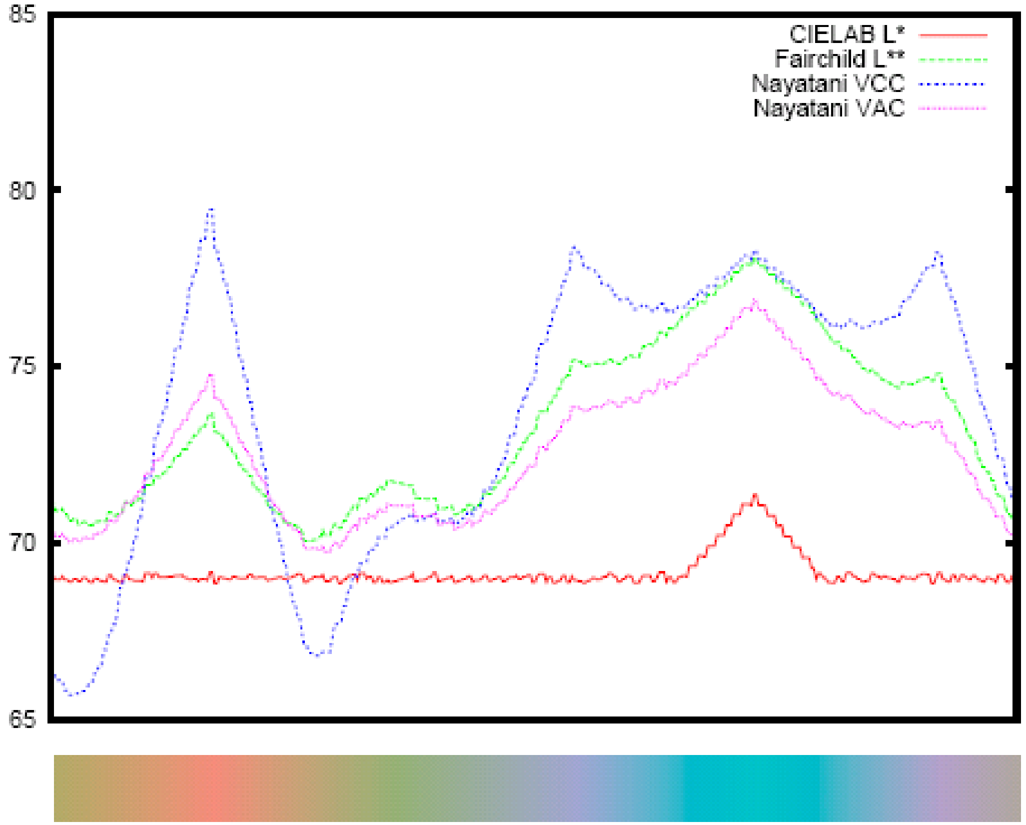


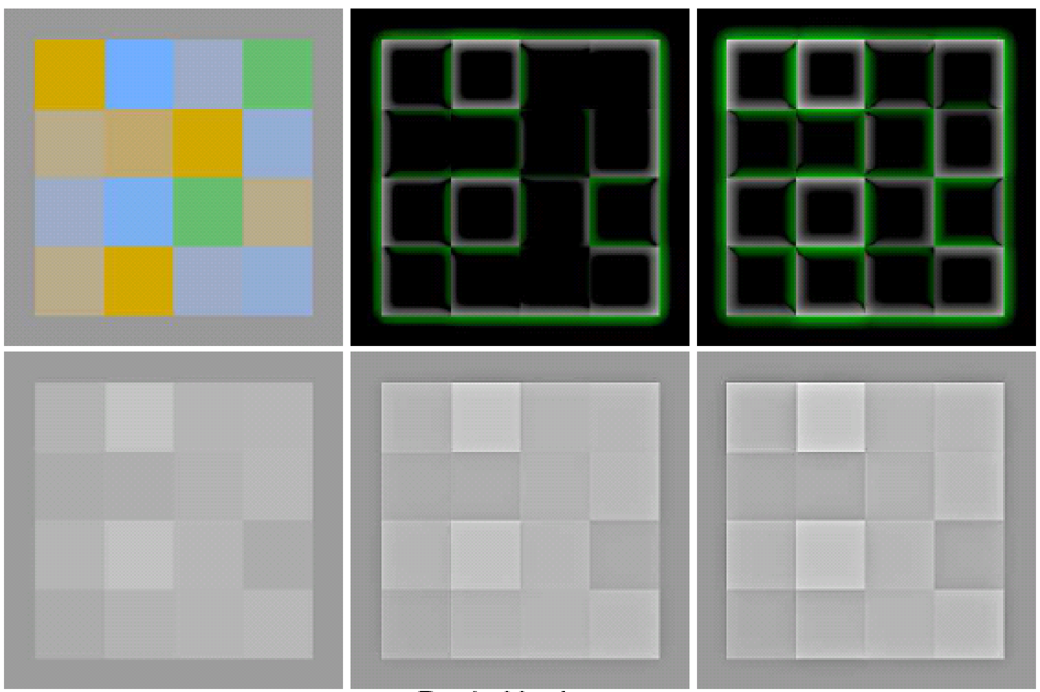
Figure 1: *Lightness values from various H-K effect predictors applied to a spectrum of isoluminant colours, compared to CIE* L^*.

Smith et al. EG2008

Color2Grey Application

- G'_{L*} : The effect of adding multi-resolution countershading correction $h_i(G_{L*})$ (*upper-left*) to the greyscale image G_{L*} (*lower-left*)

$$G'_{L^*} = G_{L^*} + \sum_{i=0}^{n-1} k_i \lambda_i h_i(G_{L^*})$$



Original I and G | Basic Unsharp | G'

The correction is driven by contrast in chroma channels of the original image I (*upper-left*)

$$\lambda_i = \left(\frac{\Delta E(h_i(I))}{|h_i(G_{L^*})|} \right)^p$$

Smith et al. EG2008

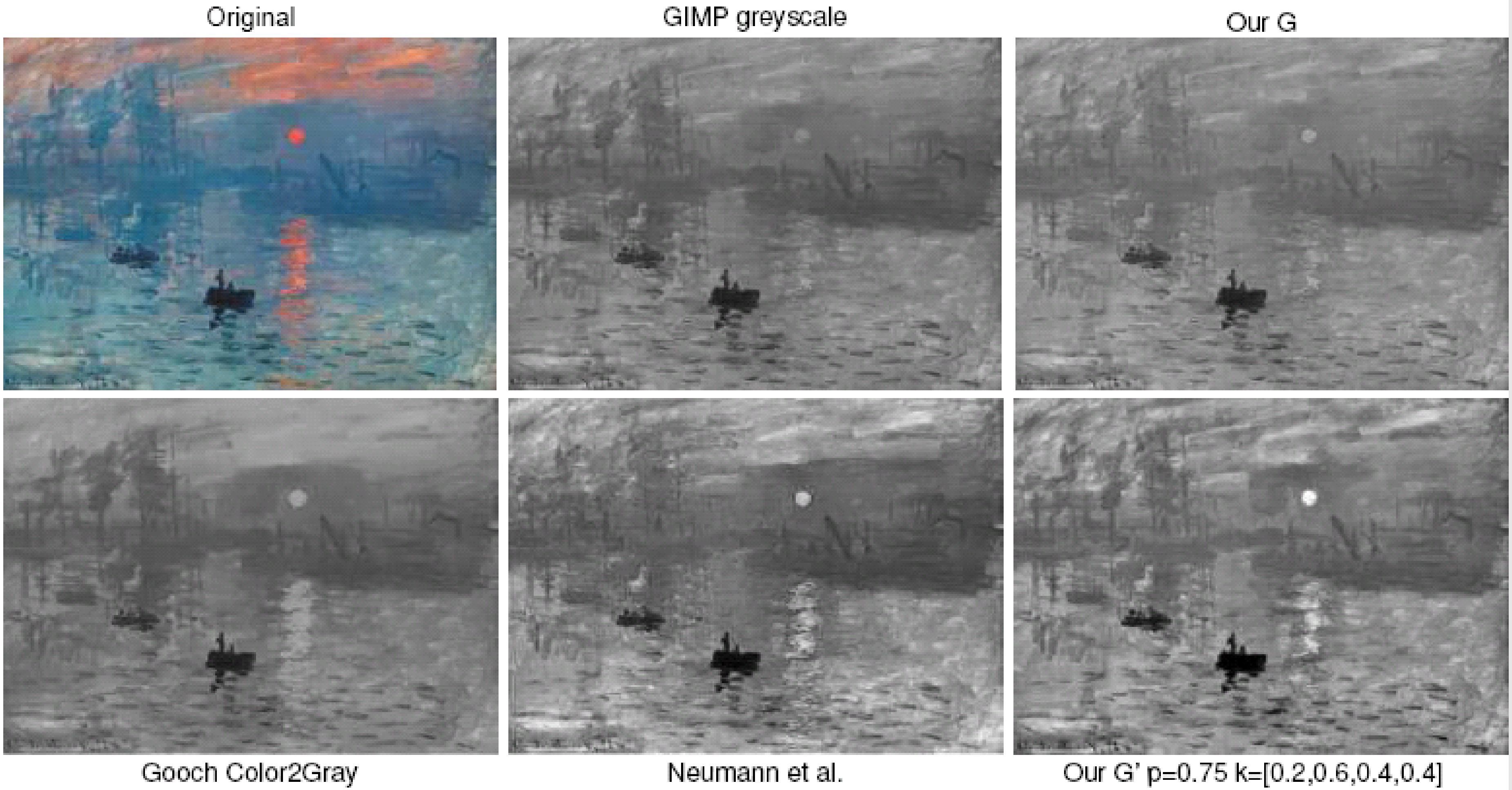
Color2Grey Application

Original Video Frame　　Gimp greyscale

Frame from our G　　Frame from our G' p=0.8,k={0.2,0.8,0,0}

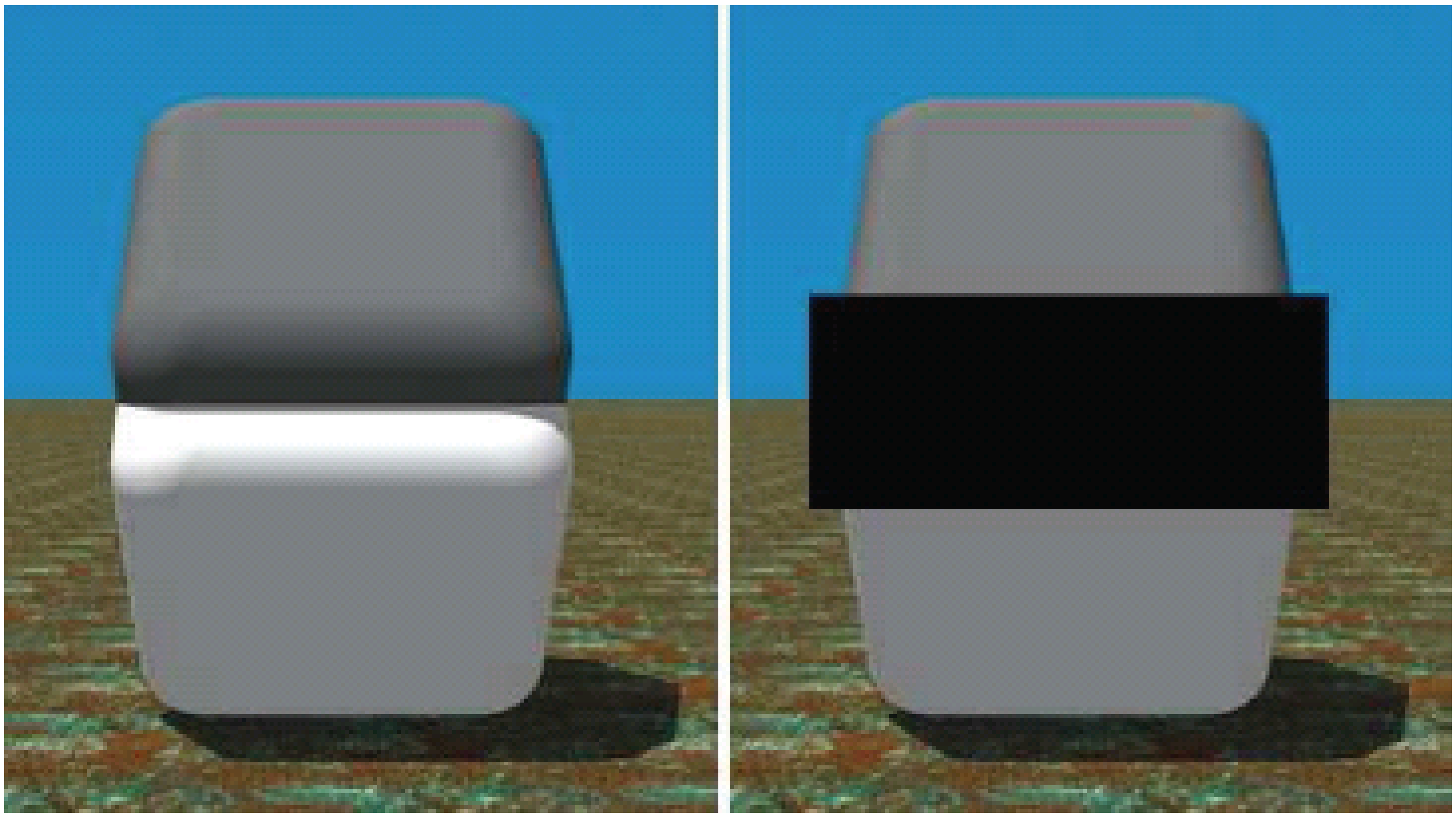
Smith et al. EG2008

Color2Grey Application



Smith et al. EG2008

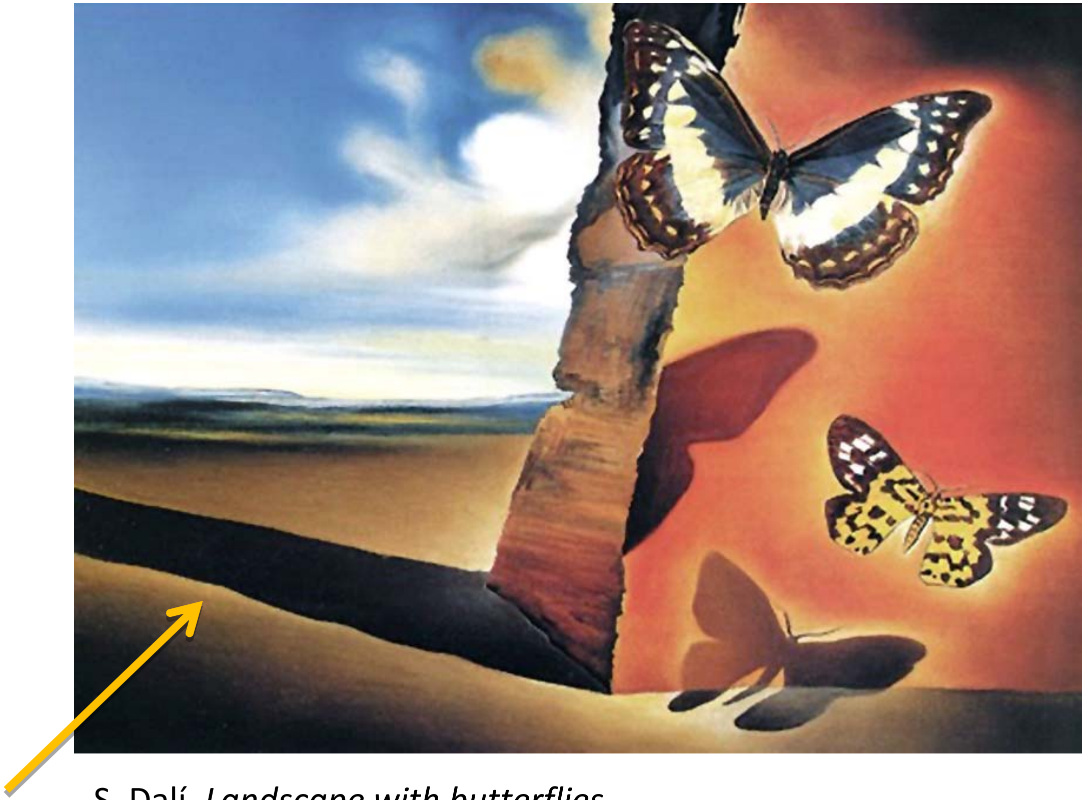
Countershading in 3D?



3D Cornsweet Illusion

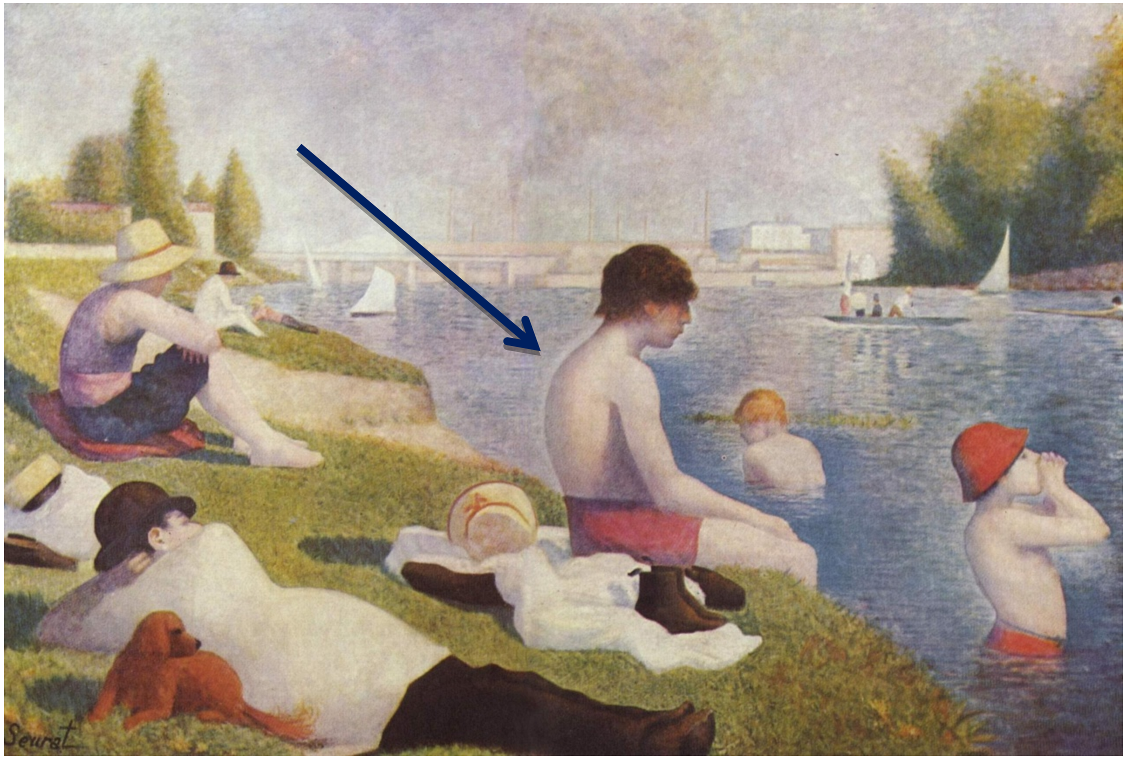
Purves-Lotto illusion: much stronger effect in 3D

Scene-aligned Countershading



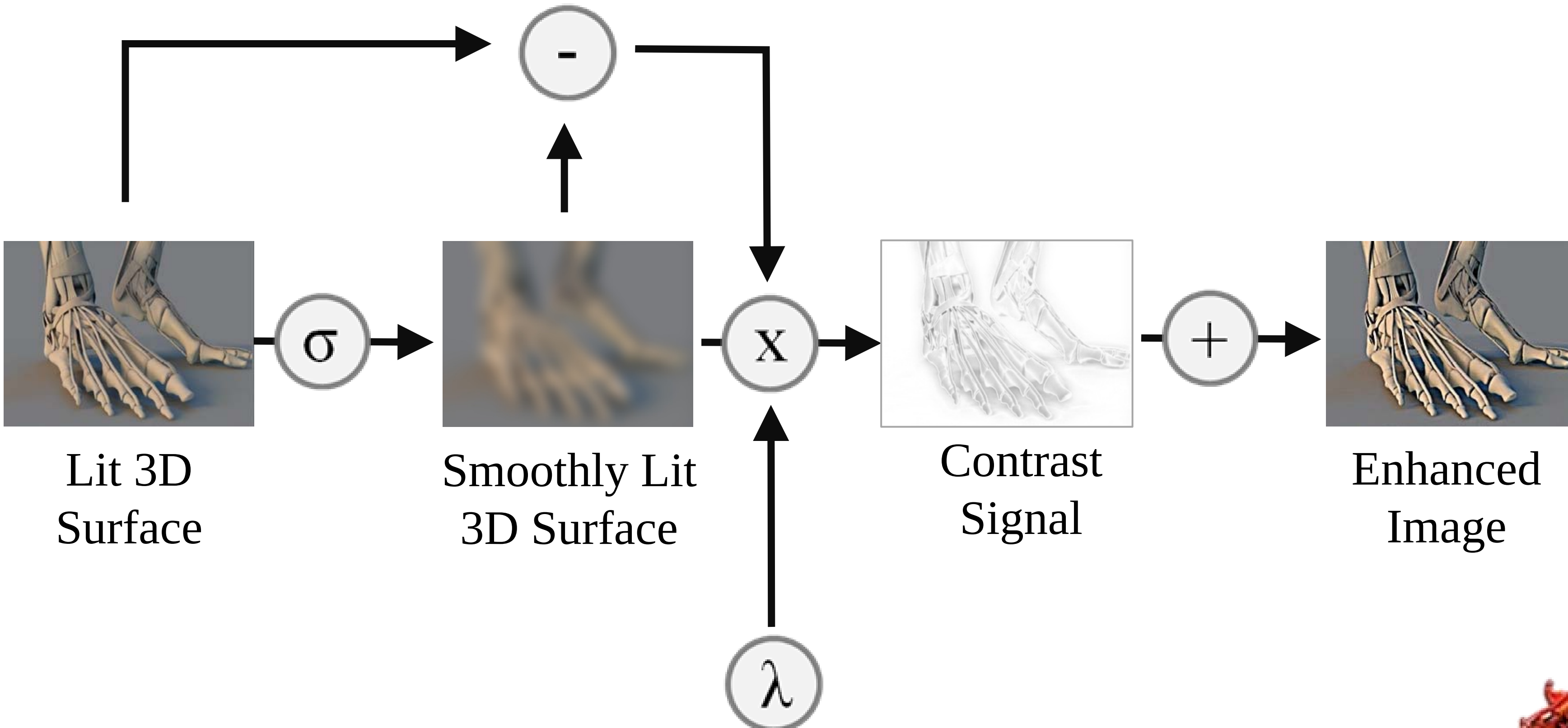
S. Dalí, *Landscape with butterflies*

Scene-aligned Countershading



G. Seurat, *Bathers at Asnieres*

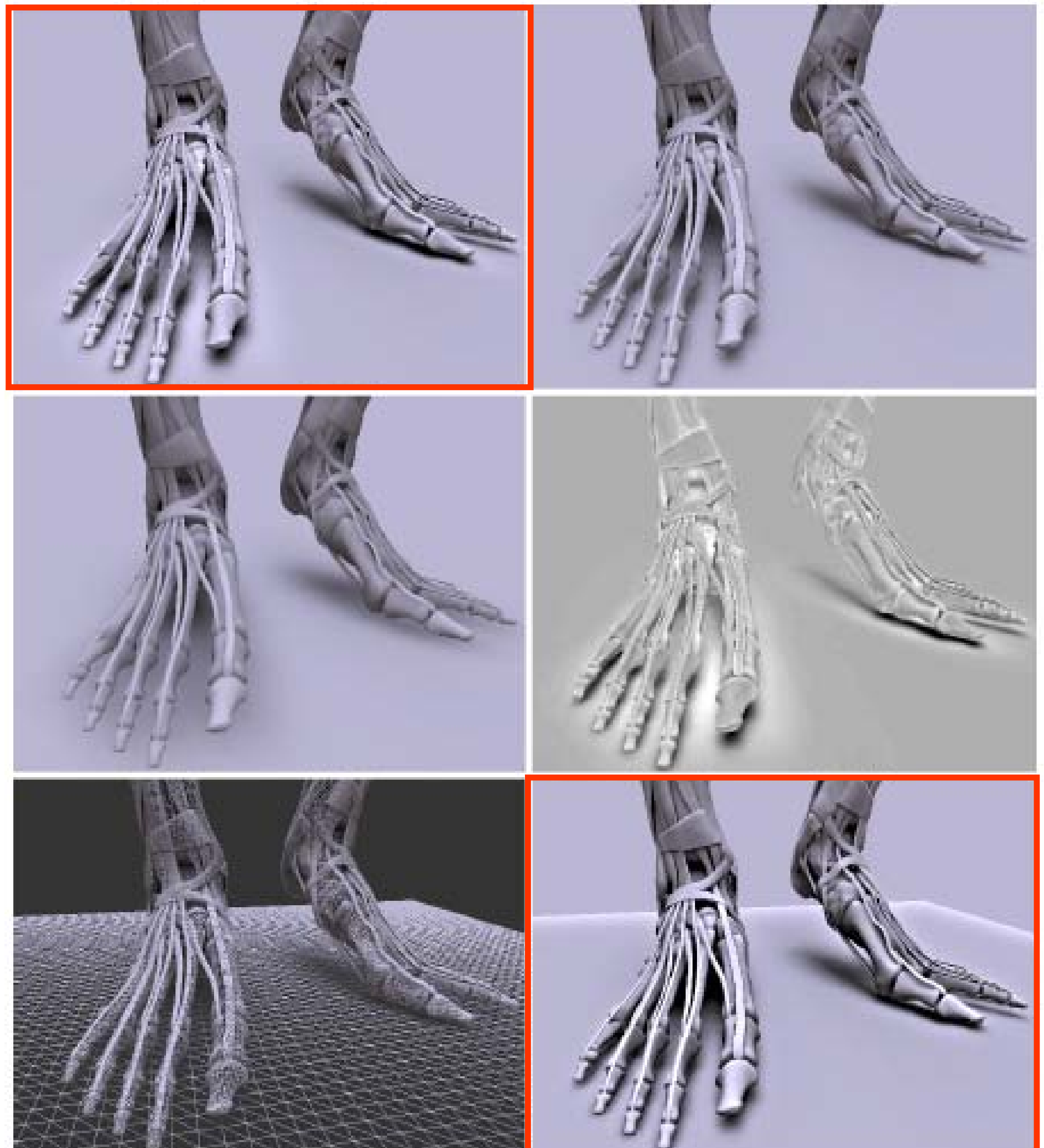
3D Unsharp Masking



$$U(S) = S + \lambda(S - S_\sigma)$$

Ritschel et al. SIG2008

3D Unsharp Masking



3D unsharp masking

Original image

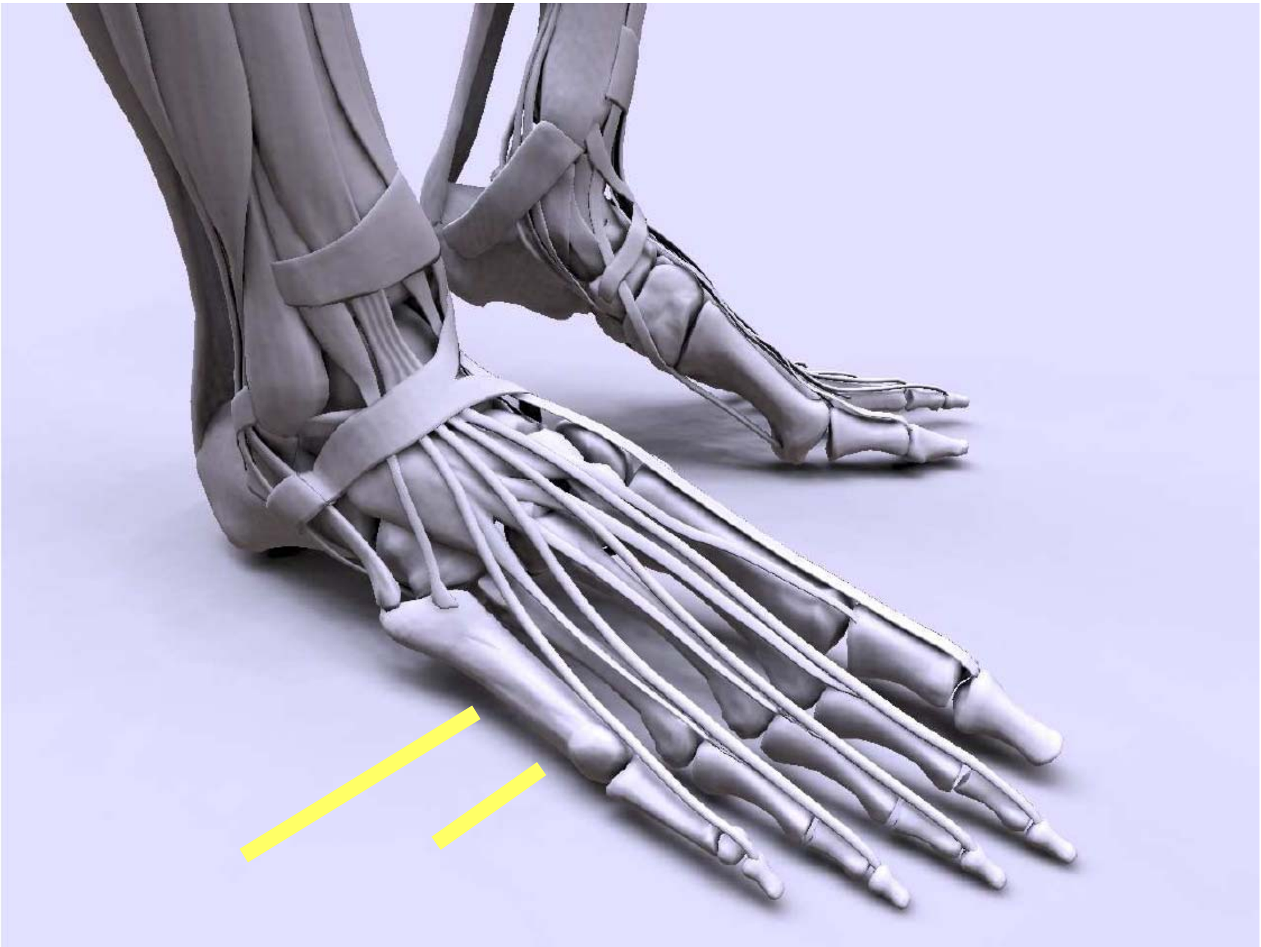
3D blurred signal

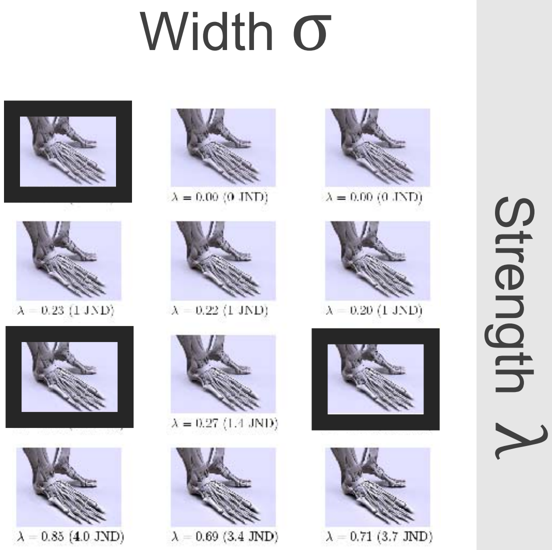
Enhancement signal

Mesh

2D unsharp masking

Adjustable Effect



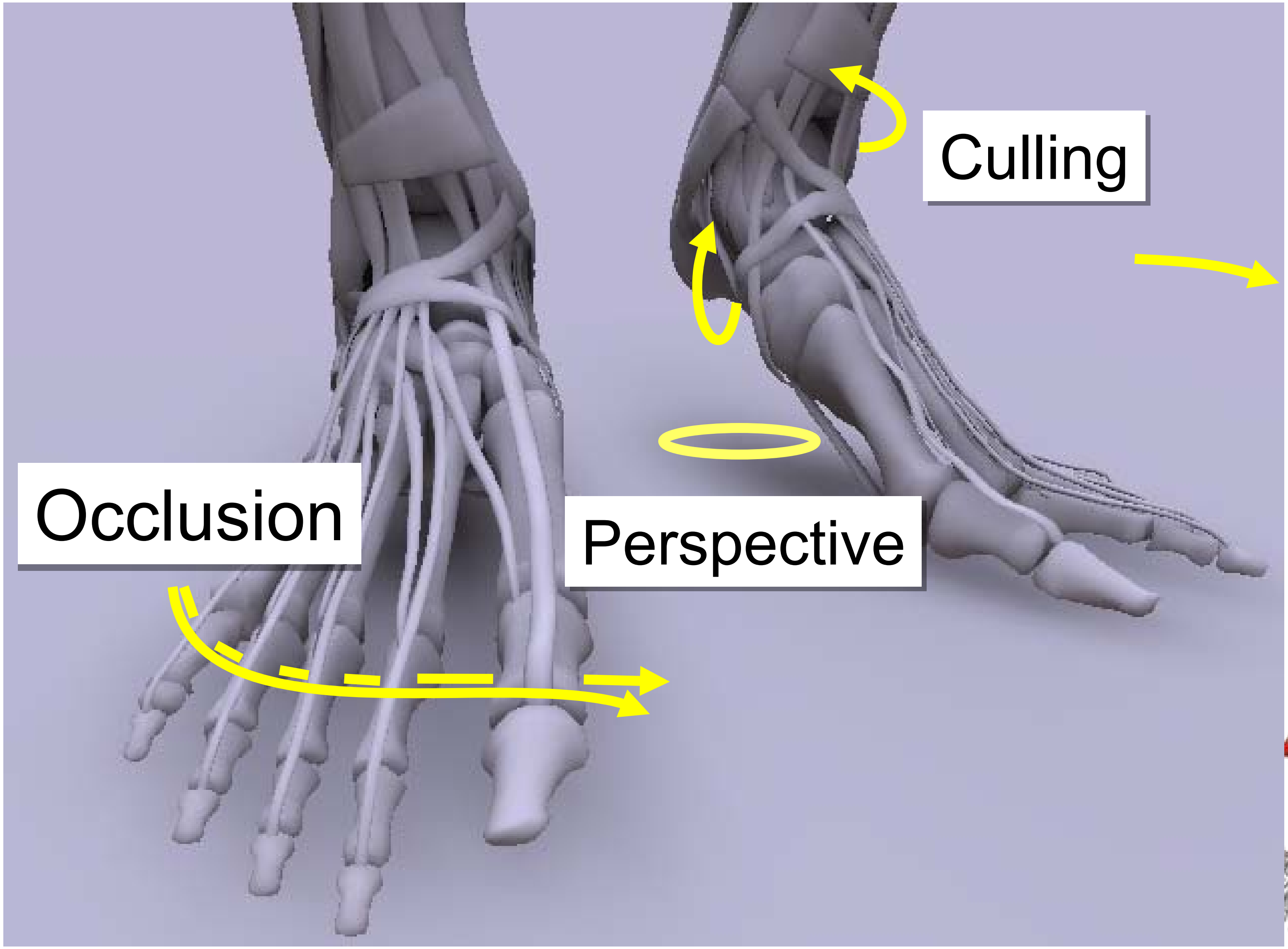


$$U(S) = S + \lambda(S - S_\sigma)$$

2D vs. 3D Unsharp Masking Comparison

	2D	3D
Signal	Image	Lit Surface
Smoothing	(Gaussian) Image Blur	Laplacian Surface Blur
Representation	Pixels	Lit vertices and pixels
Smoothness σ	Image distance	Geodesic world distance
Strength λ	Factor	Factor

3D Unsharp Masking: Scene Coherence



Ritschel et al. SIG2008

Complex Mesh

3D unsharp masked rendering

Original rendering

Ritschel et al. SIG2008

Enhanced Text Contrast in the Shadow

3D unsharp masking

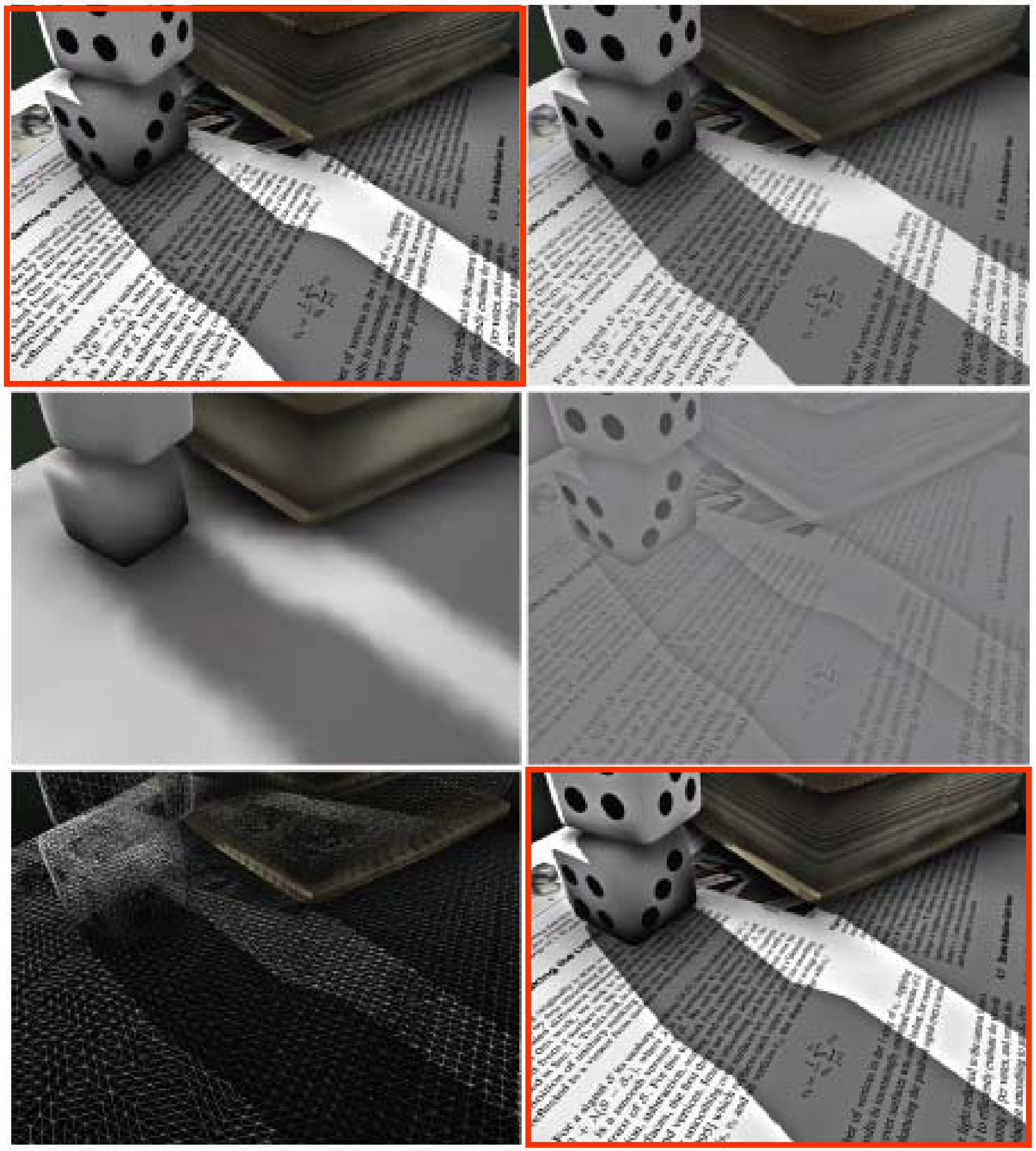
Original image

3D blurred signal

Enhancement signal

Mesh

2D unsharp masking

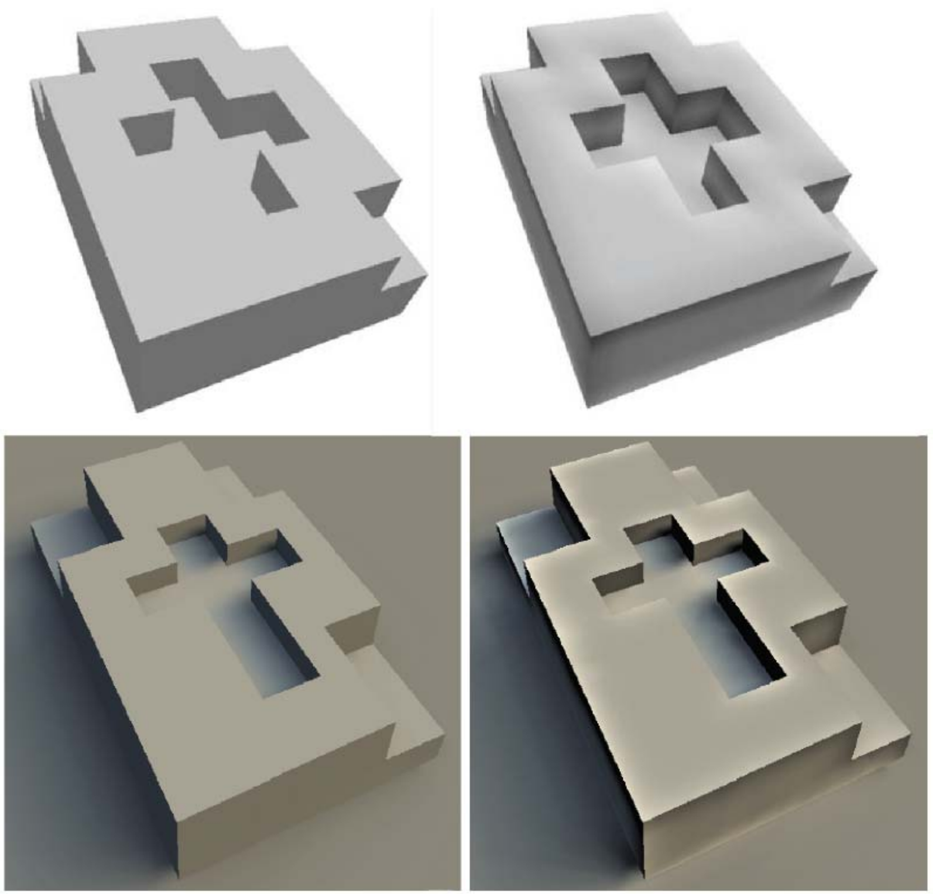


Results – Legibility

Normal Enhancement

- Only **geometric** term
  - Shadows ?
  - Hightlights ?
  - Reflectance ?
- Vertex resolution
- 3D unsharp masking: Pixel resolution

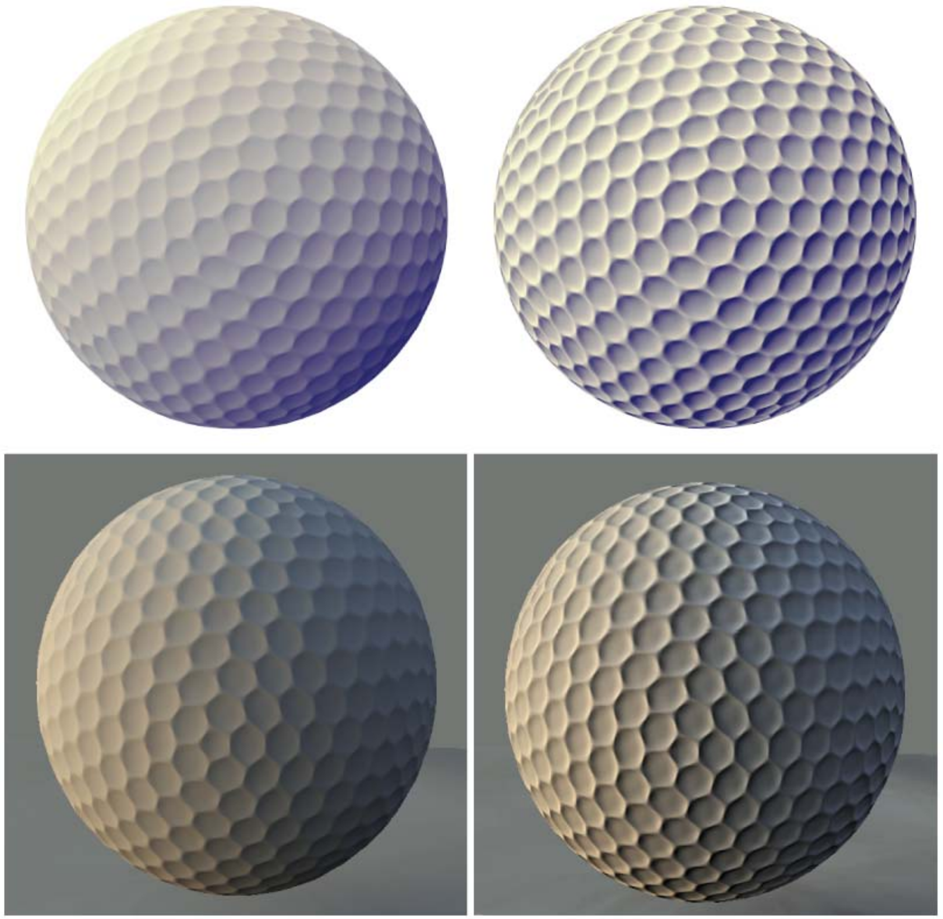
Cignoni et al. ´05, C & G Vol. 29



Exaggerated Shading

- Object enhancement
  - Illuminate each vertex at grazing angle
  - Improves geometry understanding
  - Highlights?
  - Shadows?
- Scene enhancement
  - Change everything
- Both have applications

Rusinkiewicz et al., SIGGRAPH‘06



Specular Shading

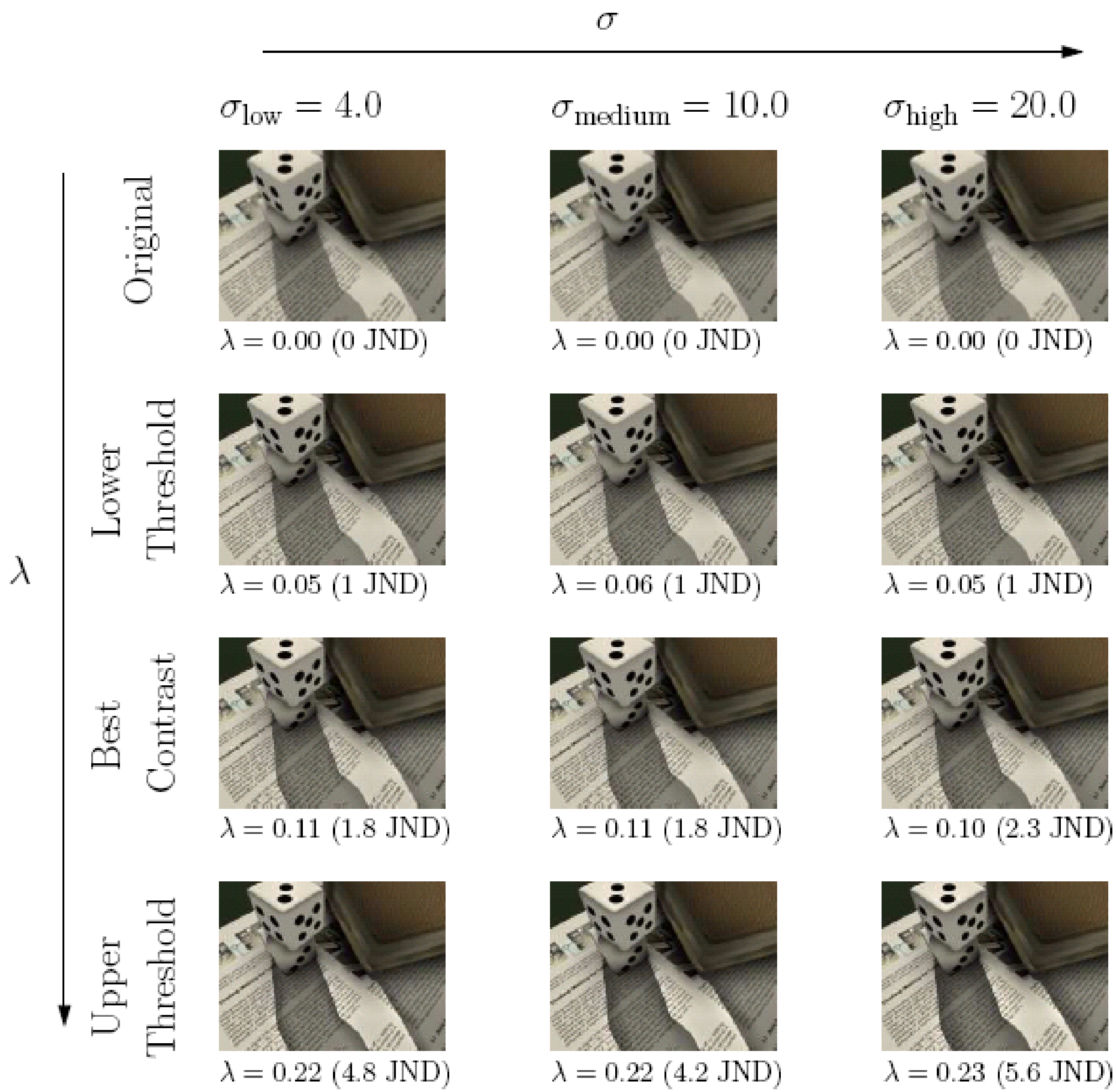
Study

- Goals
  - Find suitable settings
  - See limitations
  - Rank preference
- Method of adjustments
  - Strength λ: adjustable
  - Fixed width σ: low, medium, high
  - 4 scenes,15 participants
  - Task: Find such λ that:

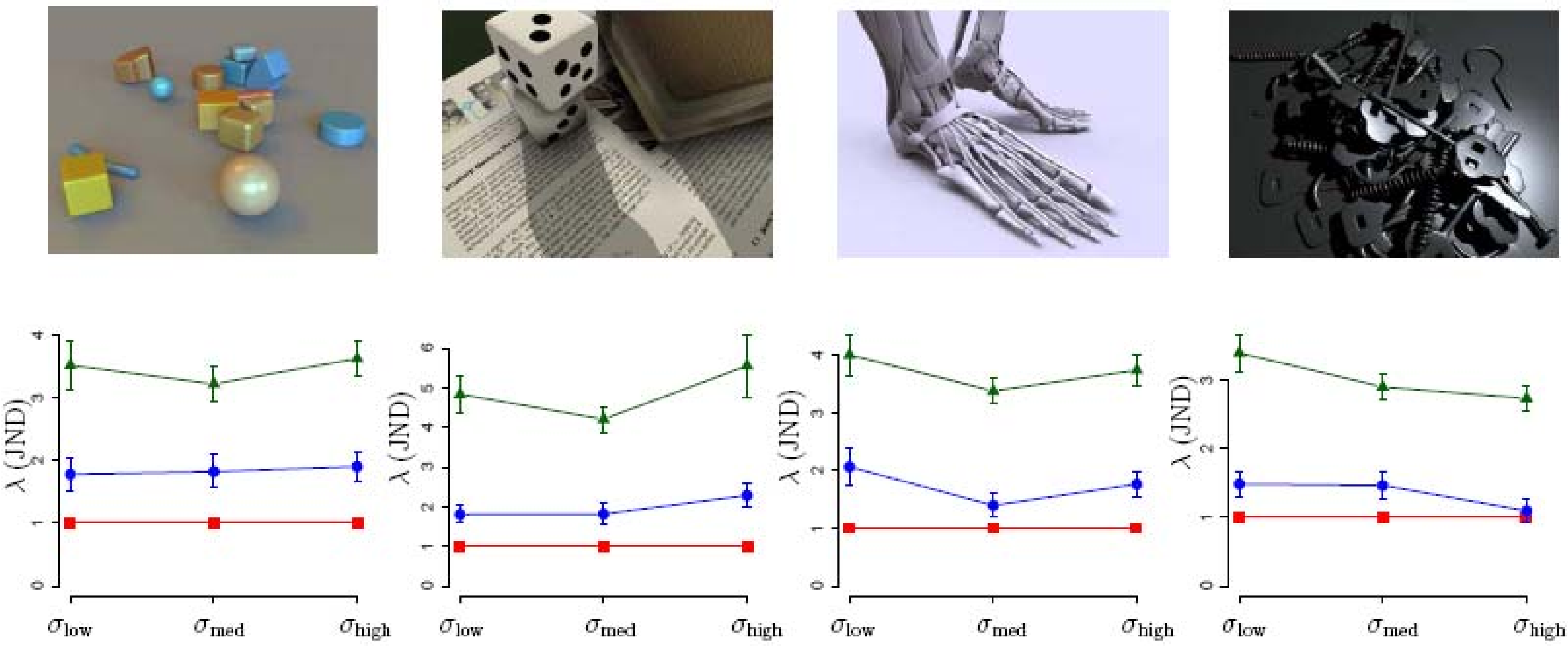
    1. Added enhancement is ***just noticeable***
    2. Added enhancement becomes ***objectionable***
    3. Image appearance is ***preferred***

Ihrke et al. SPIE2009

Results


σ
λ
$\sigma_{\text{low}} = 4.0$
$\sigma_{\text{medium}} = 10.0$
$\sigma_{\text{high}} = 20.0$
Original
Lower Threshold
Best Contrast
Upper Threshold
$\lambda = 0.00$ (0 JND)
$\lambda = 0.00$ (0 JND)
$\lambda = 0.00$ (0 JND)
$\lambda = 0.05$ (1 JND)
$\lambda = 0.06$ (1 JND)
$\lambda = 0.05$ (1 JND)
$\lambda = 0.11$ (1.8 JND)
$\lambda = 0.11$ (1.8 JND)
$\lambda = 0.10$ (2.3 JND)
$\lambda = 0.22$ (4.8 JND)
$\lambda = 0.22$ (4.2 JND)
$\lambda = 0.23$ (5.6 JND)

Results

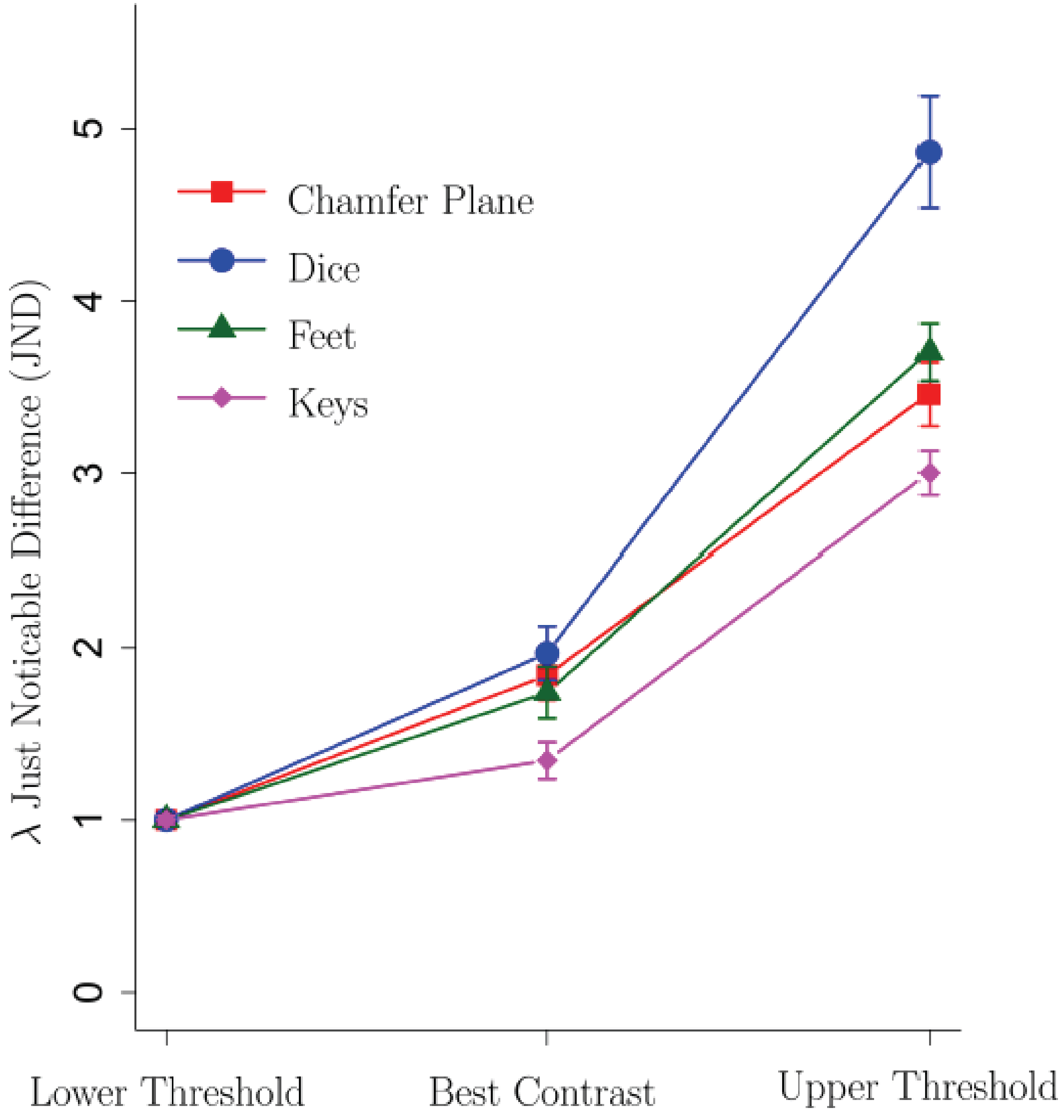


just visible — best contrast — objectionable

Ihrke et al. SPIE2009

Results

- 2 JND
  - preferred
- 4 JND
  - objectionable



Ihrke et al. SPIE2009

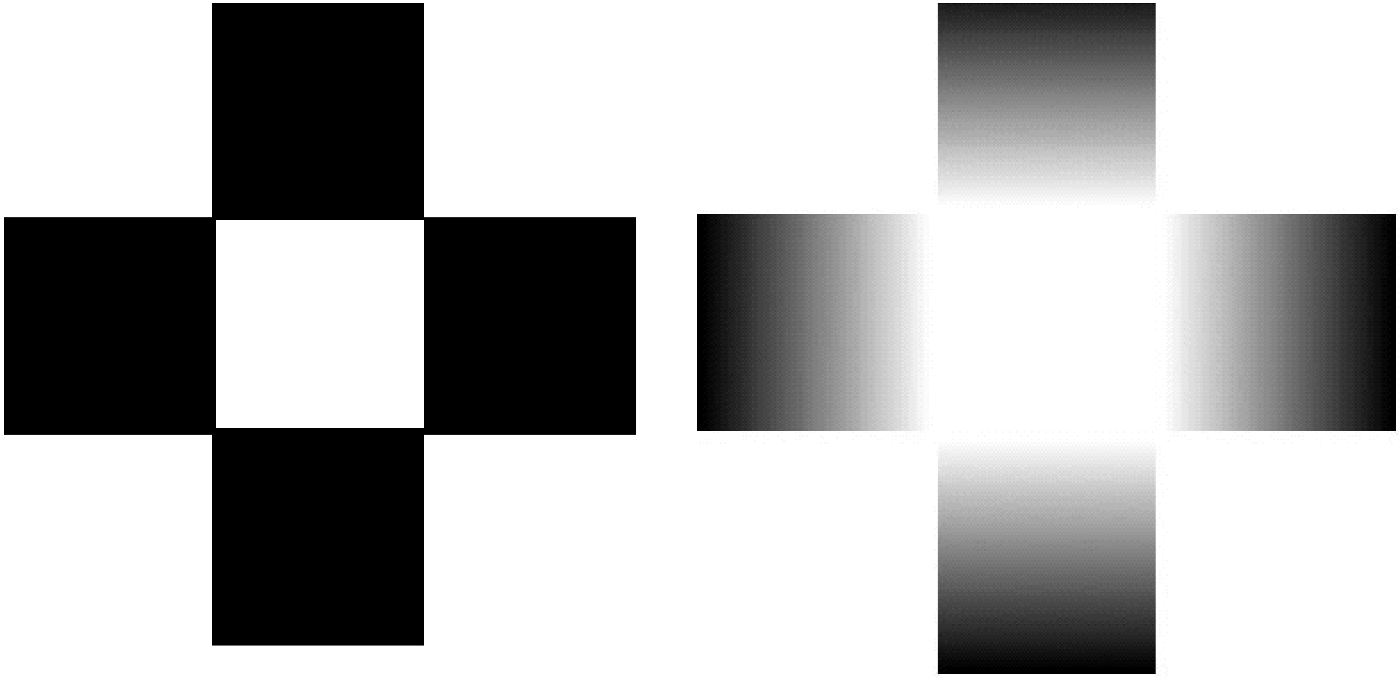
Summary

Better communicate image contents with a minimal change to image appearance

- Application of Cornsweet illusion to image enhancement
  - Generalization of unsharp masking
  - Automatic enhancement given the reference data:
    - HDR image
    - depth information
    - shading in 3D scene
  - Scene consistent 3D unsharp masking leads to even stronger effects

Glare Illusion

- Glowing effect [Zavagno and Caputo 2001]



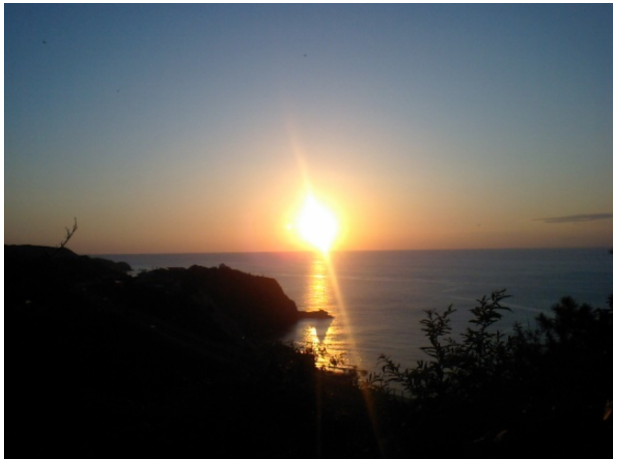
Glare Illusion

“Alan Wake” © Remedy Entertainment

Glare Illusion in Different Media

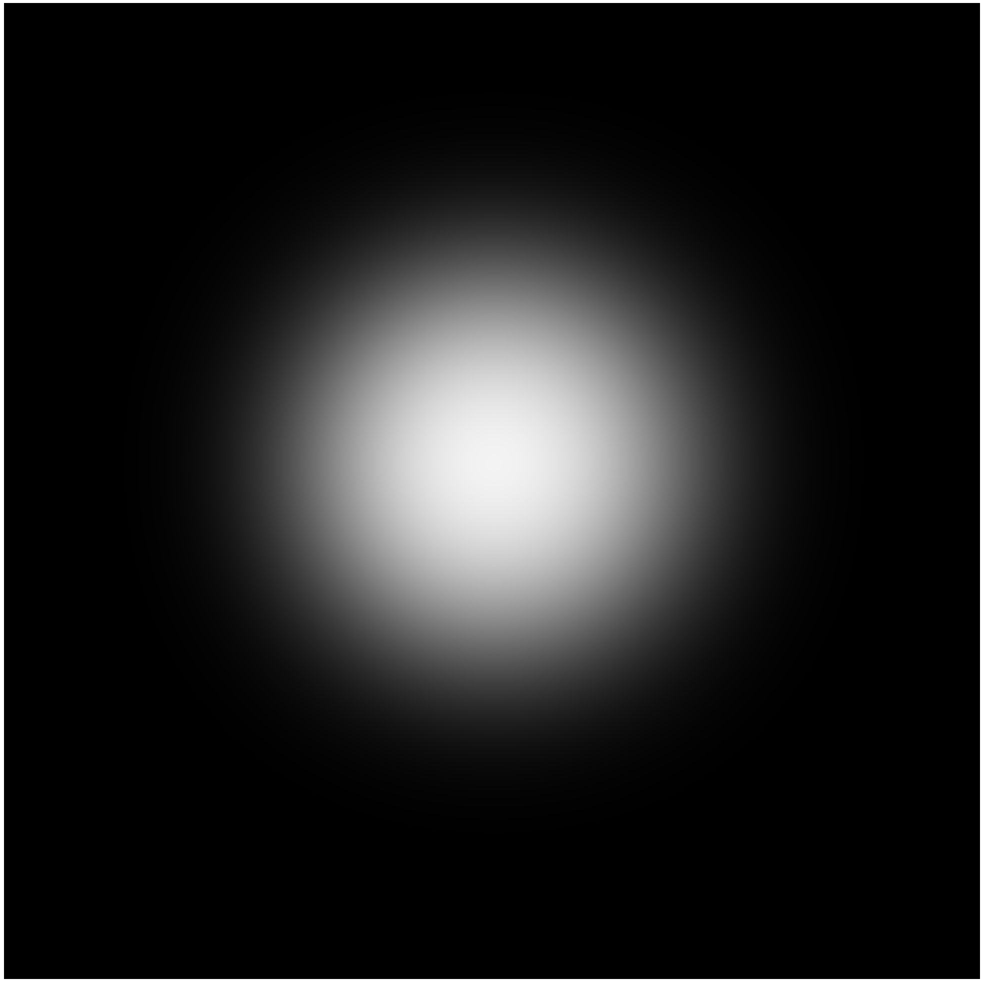
Arts

Computer Games



Photography

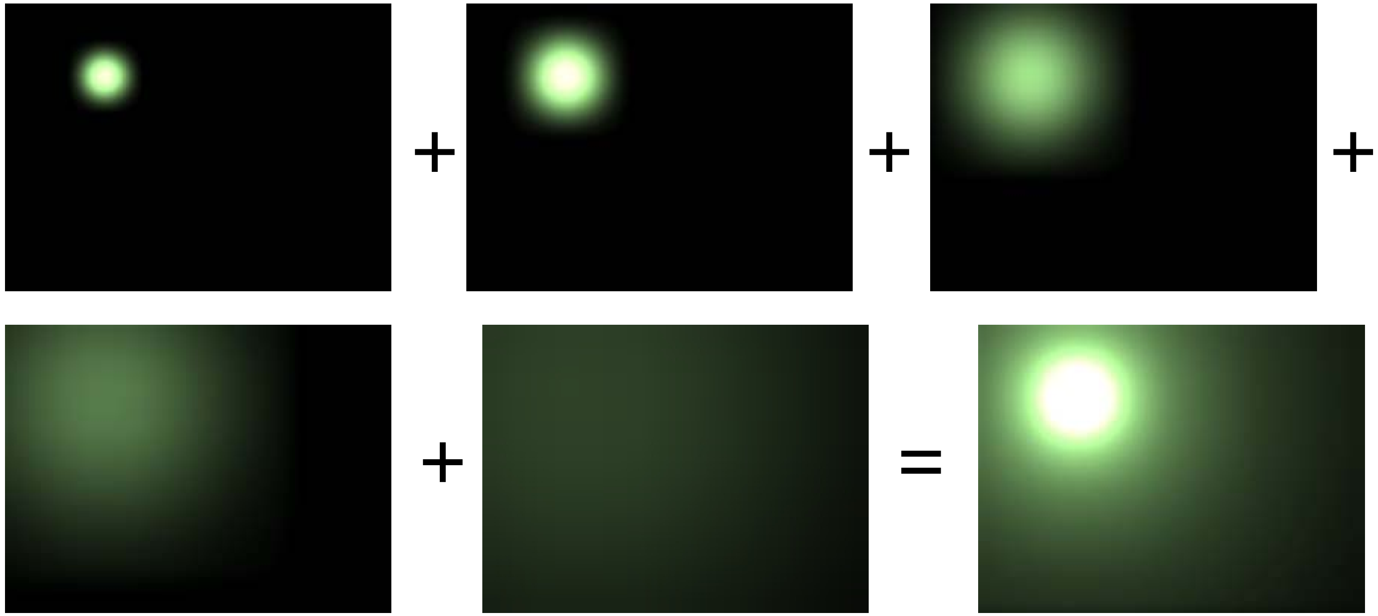
In Games



- Simple approximation: convolution with Gaussian
- Already does a good job in conveying brightness
  Yoshida *et al*. (2008)

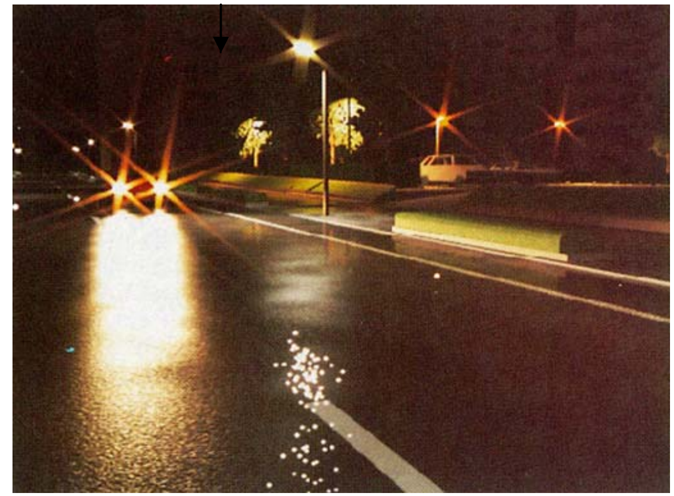
In Games

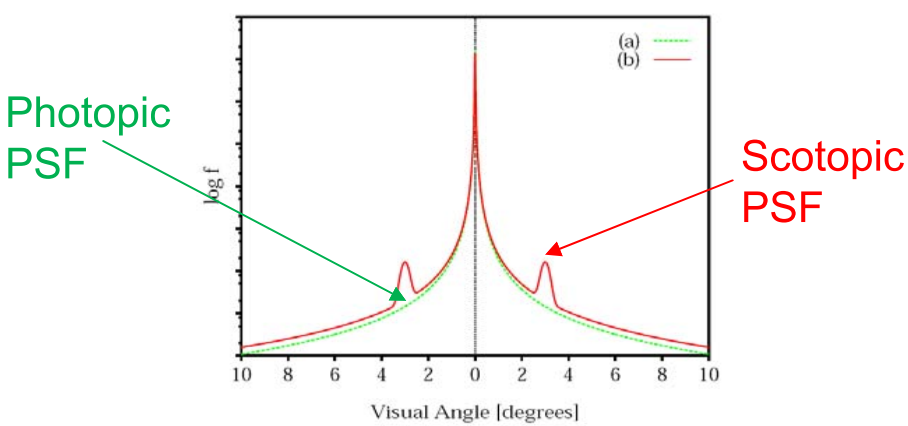
- Kawase, Practical Implementation of High Dynamic Range Rendering, Game Developer's Conference 2004



Glare in Realistic Rendering

- Optics-based models for rendering glare illusion
  - [Nakamae et al. 1990]
  - [Rokita 1993]
  - [Ward Larson et al. 1997]
  - [Kakimoto et al. 2004, 2005]
  - [Van den Berg et al. 2005]
  - [Spencer et al. 1995]





Psychophysical Experiment

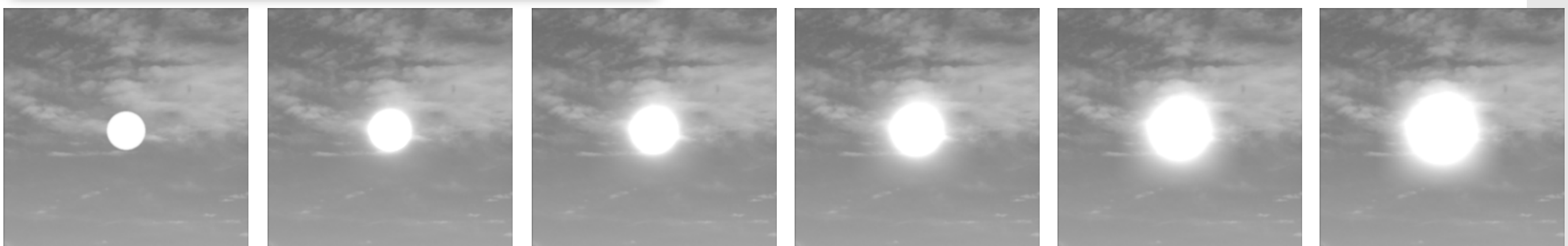
- Goal
  - Measuring the brightness boosts caused by glare illusion
- 2 methods, 6 patterns for each
  - Gaussian: blurring kernel
    - Cheap approximation
  - Spencer et al.: human eye's PSF (disability glare)
    - Optical correctness
- 10 subjects
  - 20 minutes per person
- Barco Coronis Color 3MP Diagnostic Luminance Display (max. 430 cd/m^2)
- Dimly illuminated room (60 lux)

Yoshida et al. APGV2008

Stimuli

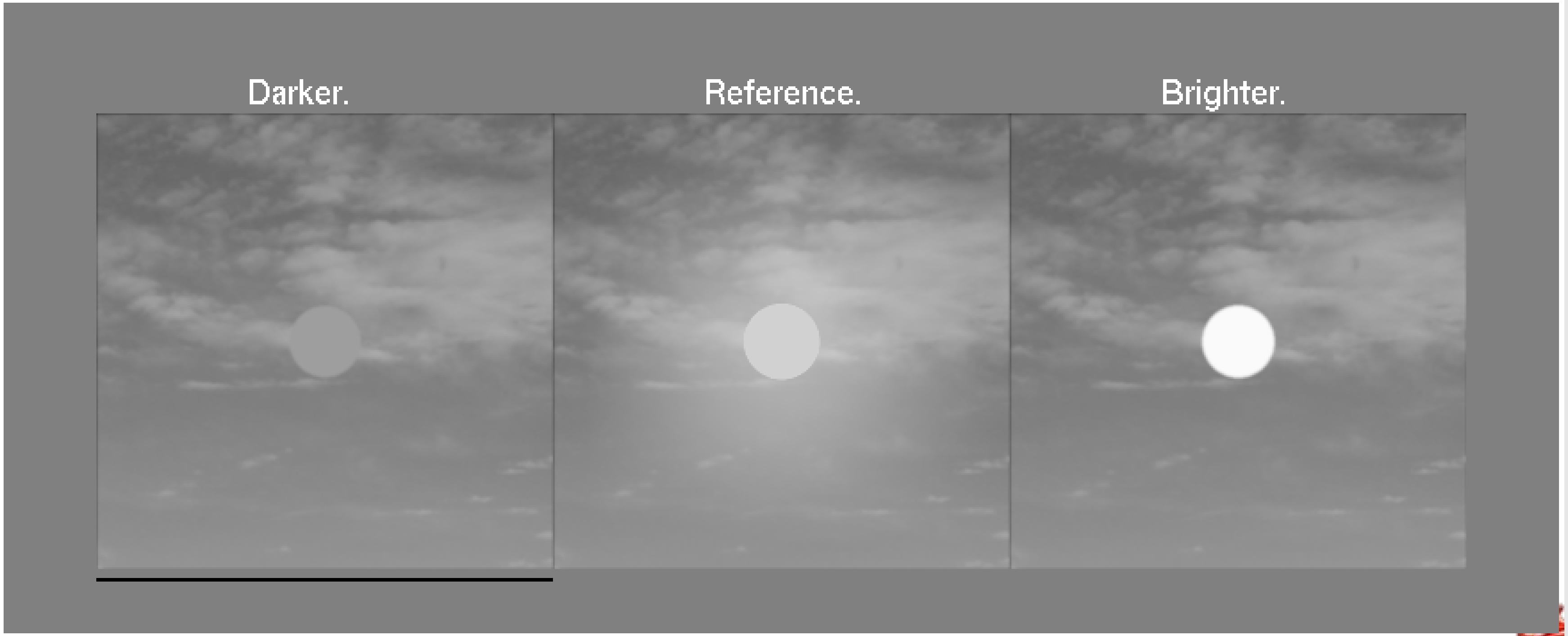
Method I (Gaussian)

Method II (Spencer et al.)



Yoshida et al. APGV2008

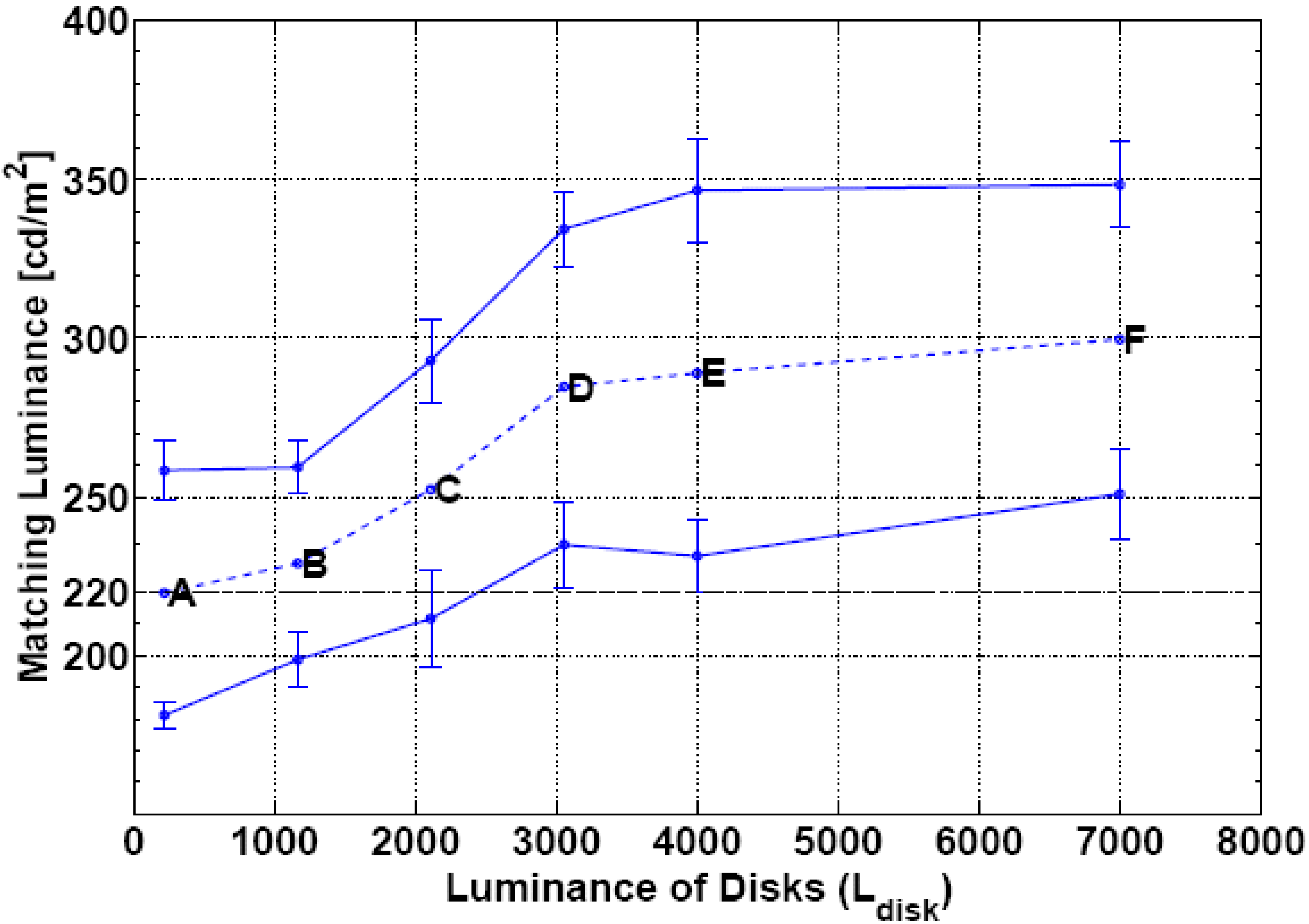
Perceptual Experiment



Task: Adjust the target disk luminance as close as possible to that of the reference, but slightly yet visibly darker/brighter.

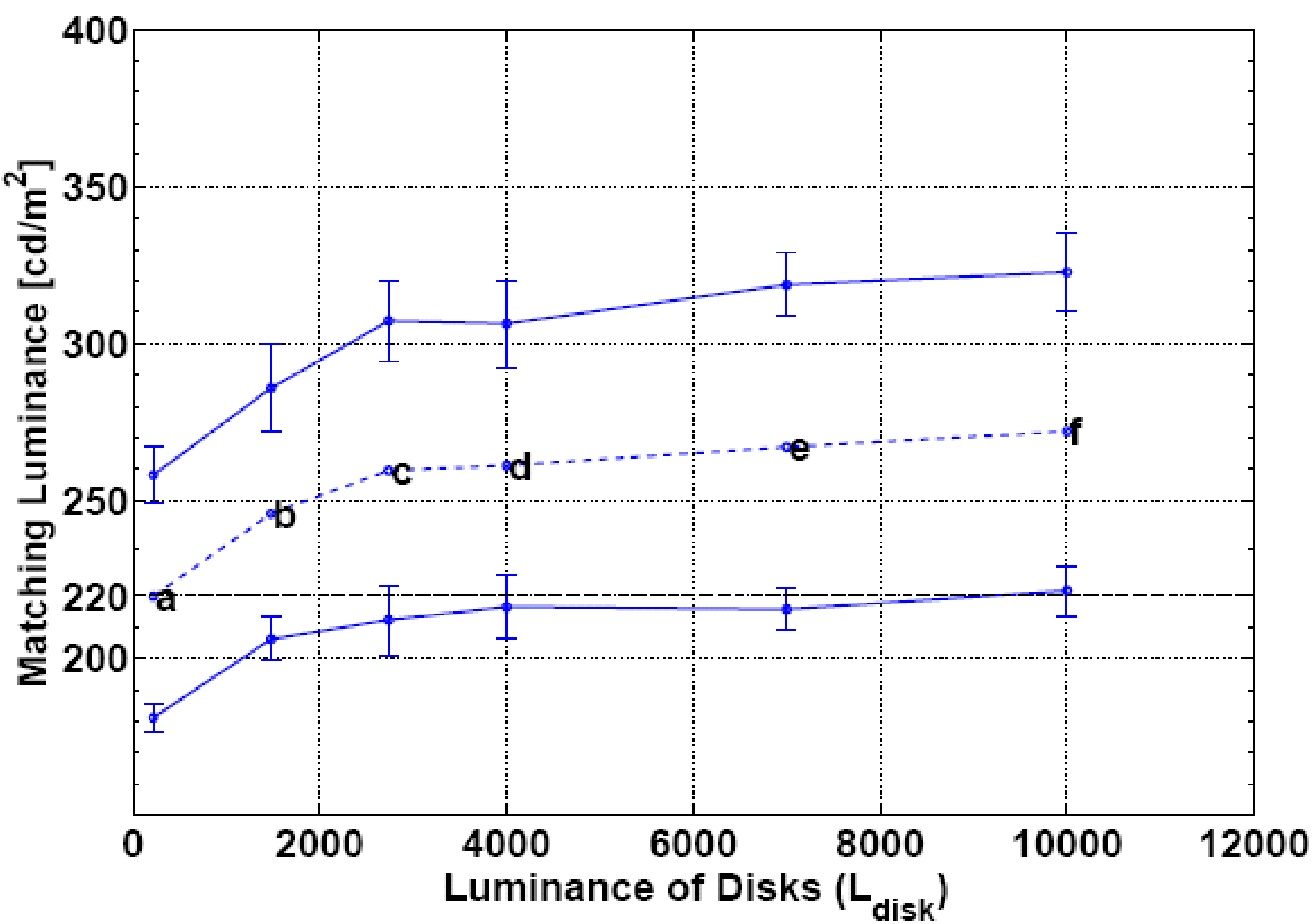
Yoshida et al. APGV2008

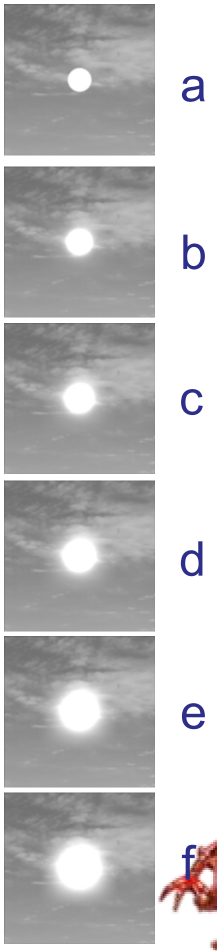
Method I (Gaussian)



Yoshida et al. APGV2008

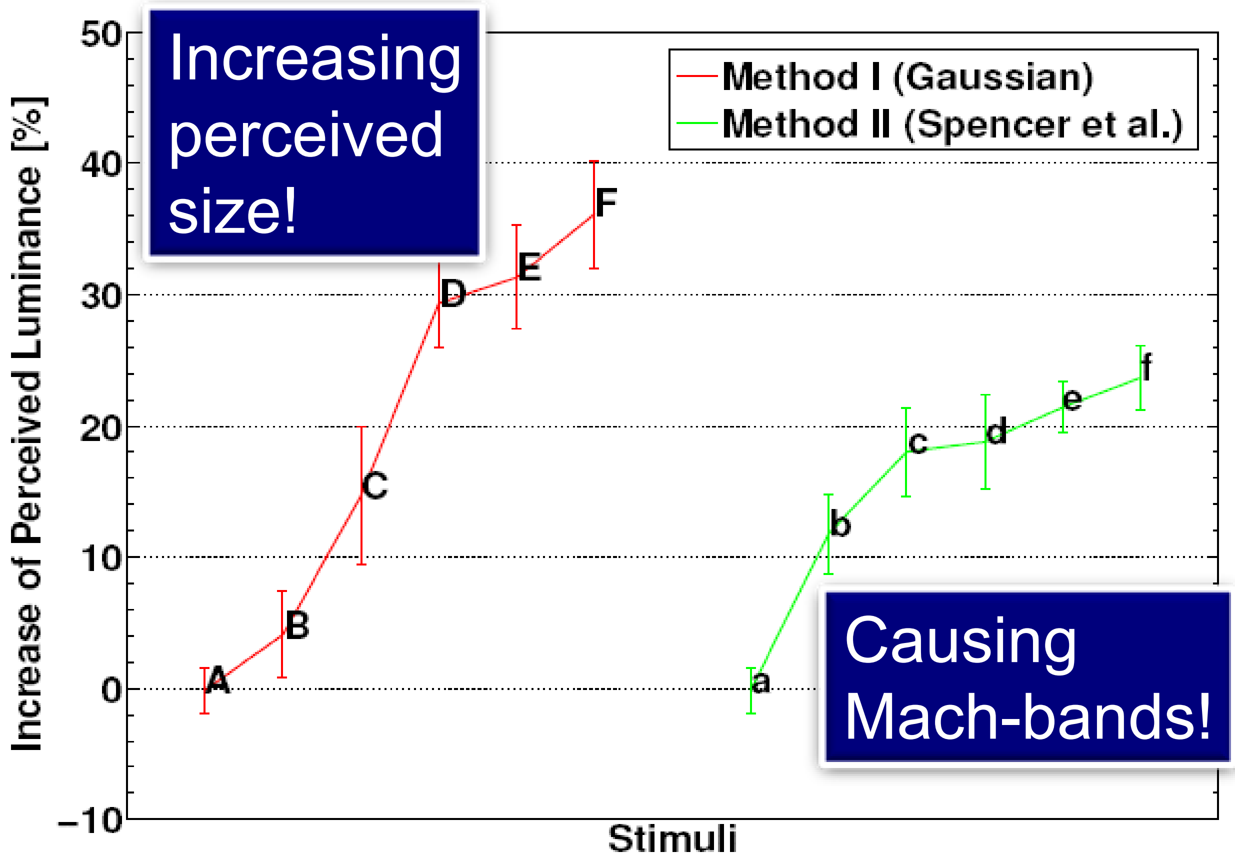
Method II (Spencer et al.)

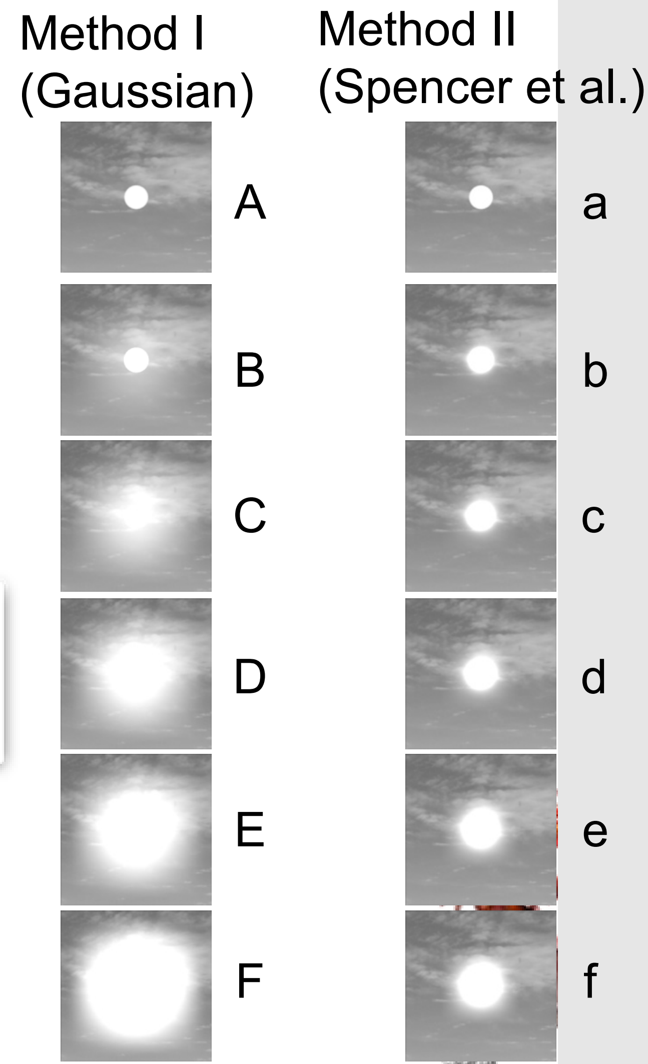




Yoshida et al. APGV2008

Trade-offs





- Measuring brightness boost of the glare illusion
  - Increasing the perceived luminance by 20 – 35 %
  - Gaussian blurring is equally effective
- Trade-offs for both Gaussian and human eye's PSF

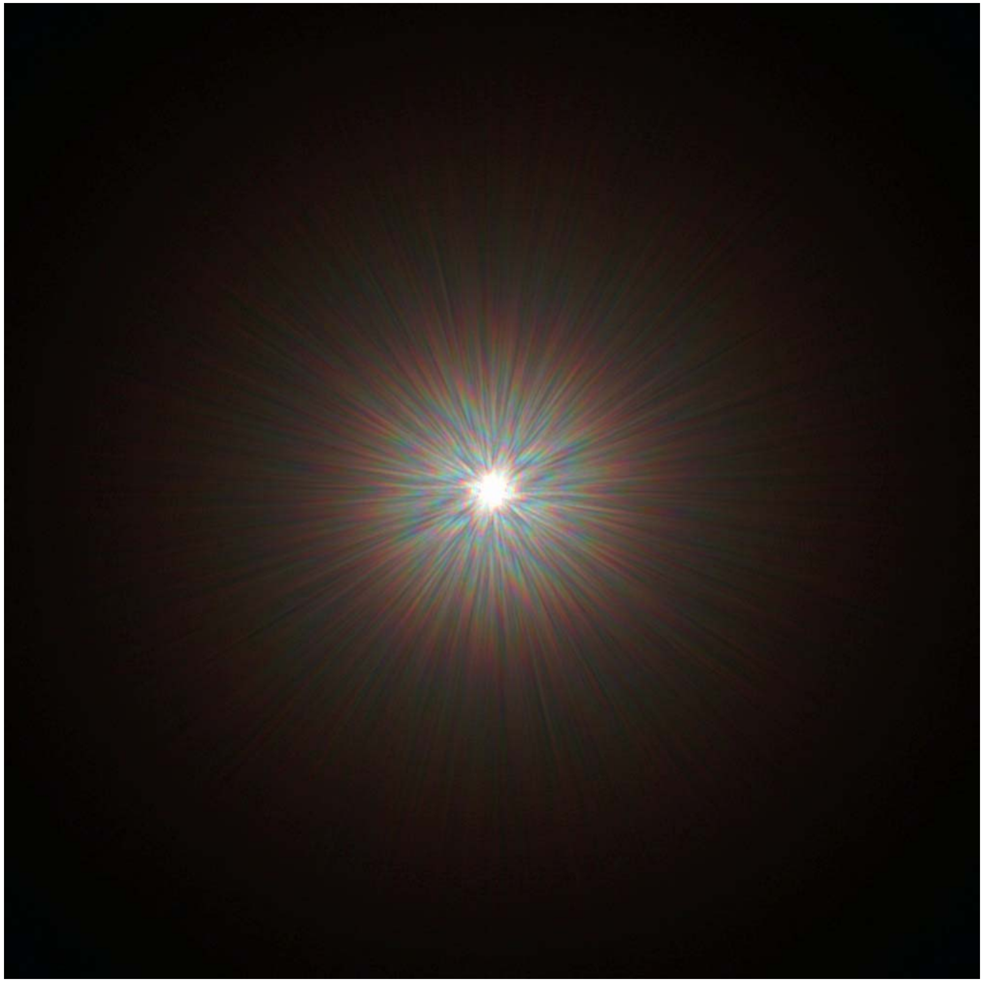
Yoshida et al. APGV2008

Dynamic Glare

- **Realism**
  Colorful haloes around bright lights by camera or eyes
- **Temporal glare**
  Changes over time (in eyes)
- **Motivation**
  Model of dynamic human eye to simulate temporal glare
- **Study**
  Can temporal glare boost even further boost brightness?

Ritschel et al. EG2008

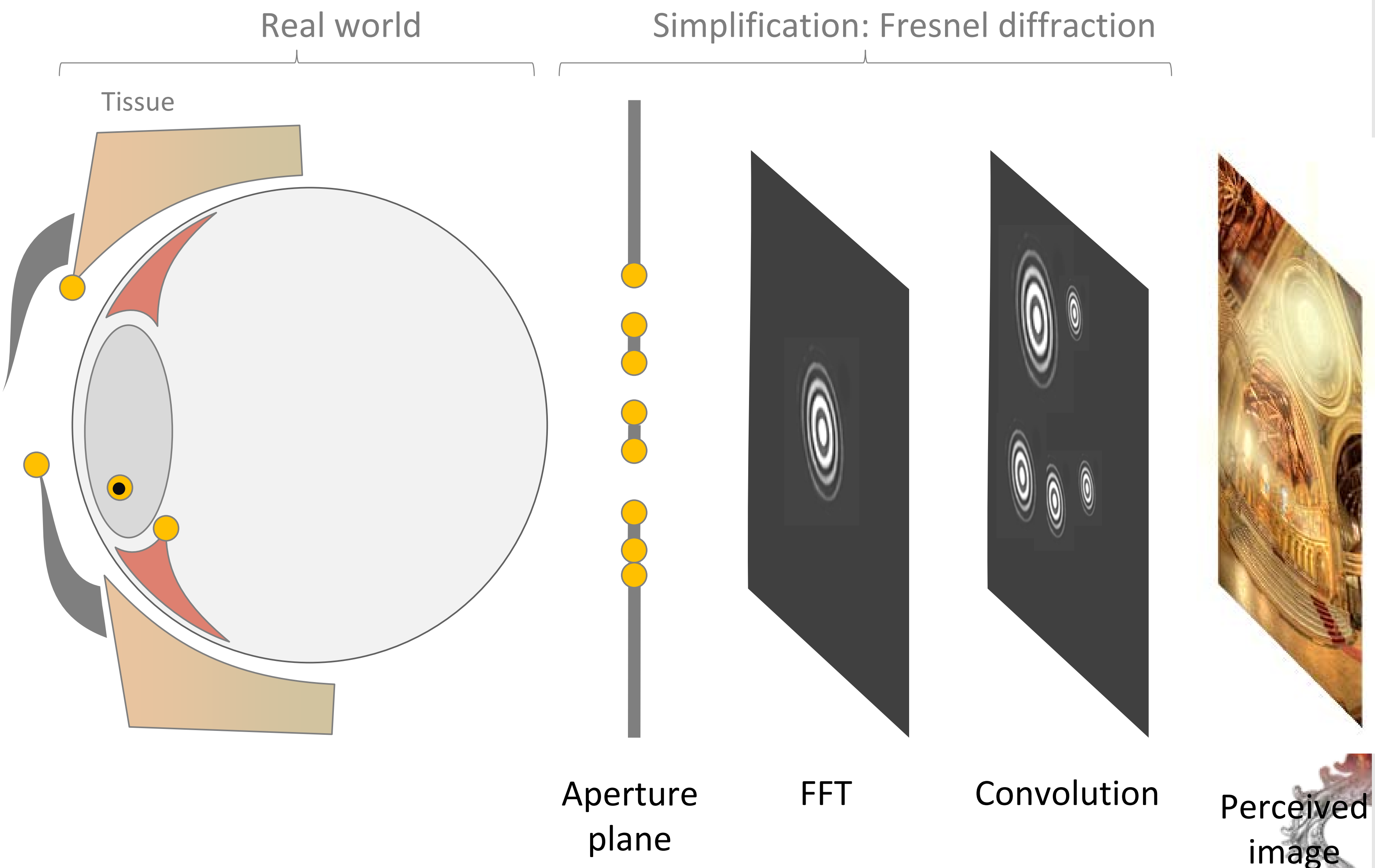
Point spread function (*PSF*)



- **P**oint
  Spread
  Function
- Key to glare modeling
- Describes, how
  a **pixel** maps to
  a **pattern** under
  an **aperture**

Ritschel et al. EG2008

Our Simplified Model



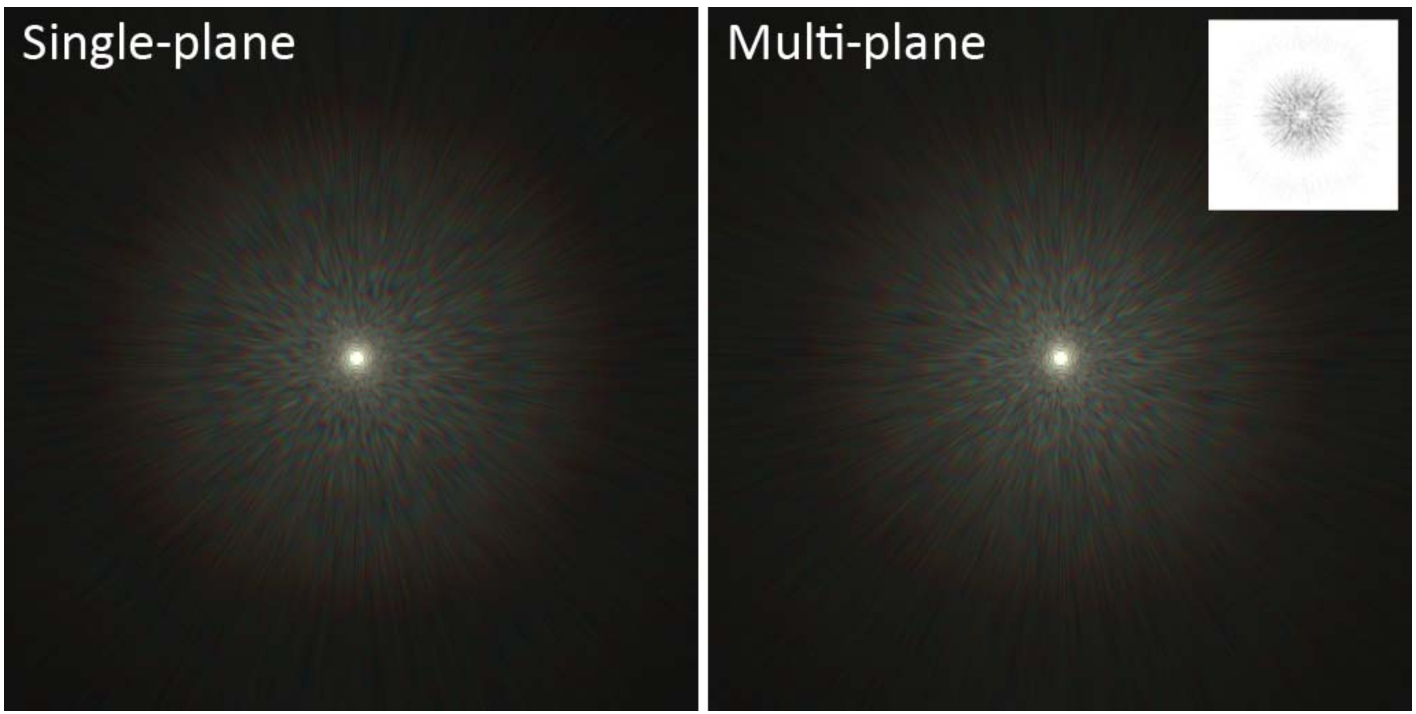
Ritschel et al. EG2008

Diffraction: Single vs. Multi Aperture Planes

$$L_i(x_i, y_i) = K \left| \mathcal{F}\left\{ P(x_p, y_p) E(x_p, y_p) \right\}_{p=\frac{x_i}{\lambda d}, q=\frac{y_i}{\lambda d}} \right|^2$$

$$K = 1/(\lambda d)^2$$

$$E(x_p, y_p) = e^{i \frac{\pi}{\lambda d}(x_p^2 + y_p^2)}$$



Ritschel et al. EG2008

Diffraction: Fraunhofer vs. Fresnel

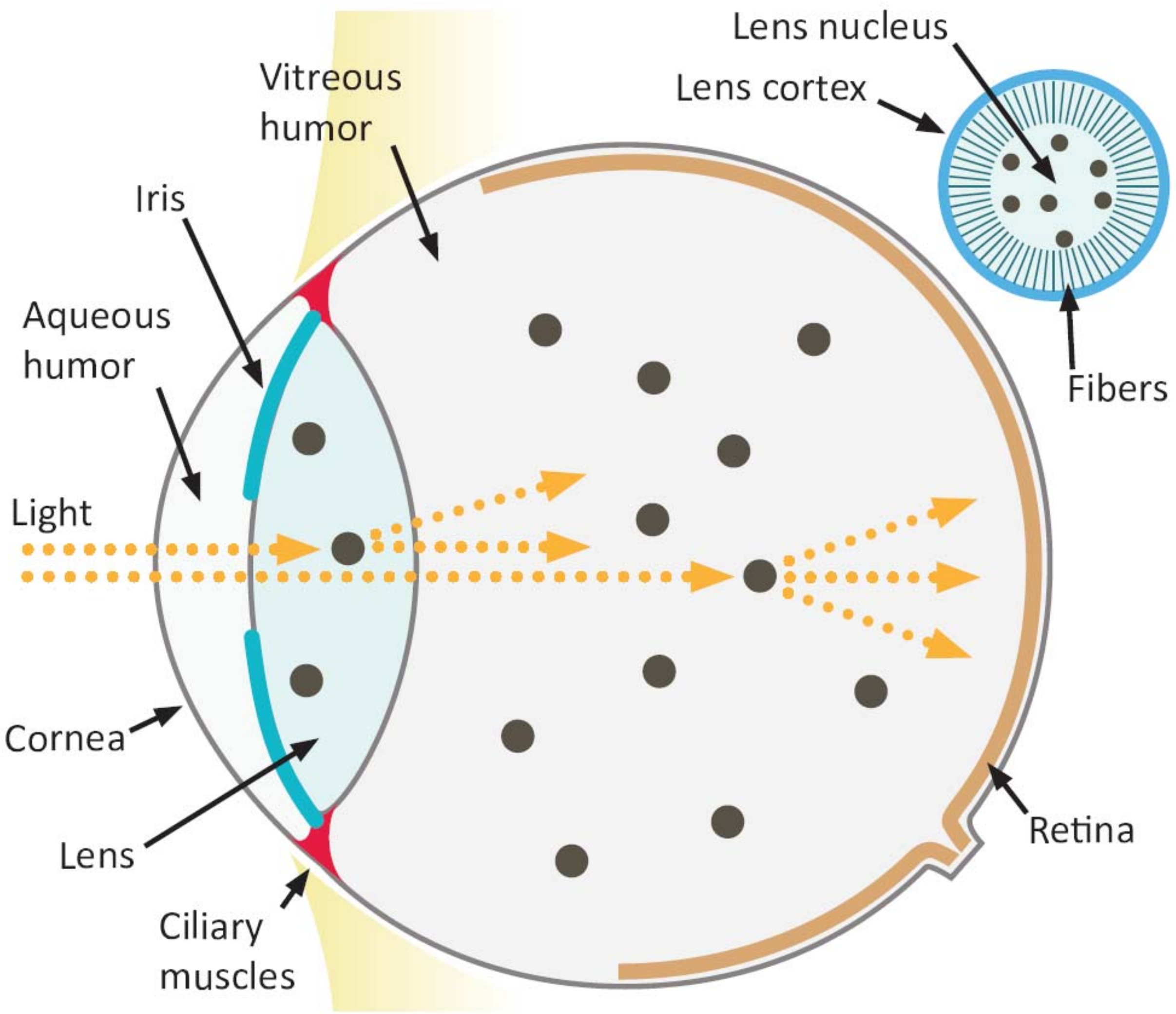
$$L_{\mathrm{i}}(x_{\mathrm{i}},y_{\mathrm{i}}) = K\left|\mathcal{F}\{P(x_{\mathrm{p}},y_{\mathrm{p}})E(x_{\mathrm{p}},y_{\mathrm{p}})\}_{p=\frac{x_i}{\lambda d},q=\frac{y_i}{\lambda d}}\right|^2$$

$$K = 1/(\lambda d)^2$$

$$E(x_{\mathrm{p}},y_{\mathrm{p}}) = e^{i\frac{\pi}{\lambda d}(x_{\mathrm{p}}^2+y_{\mathrm{p}}^2)}$$

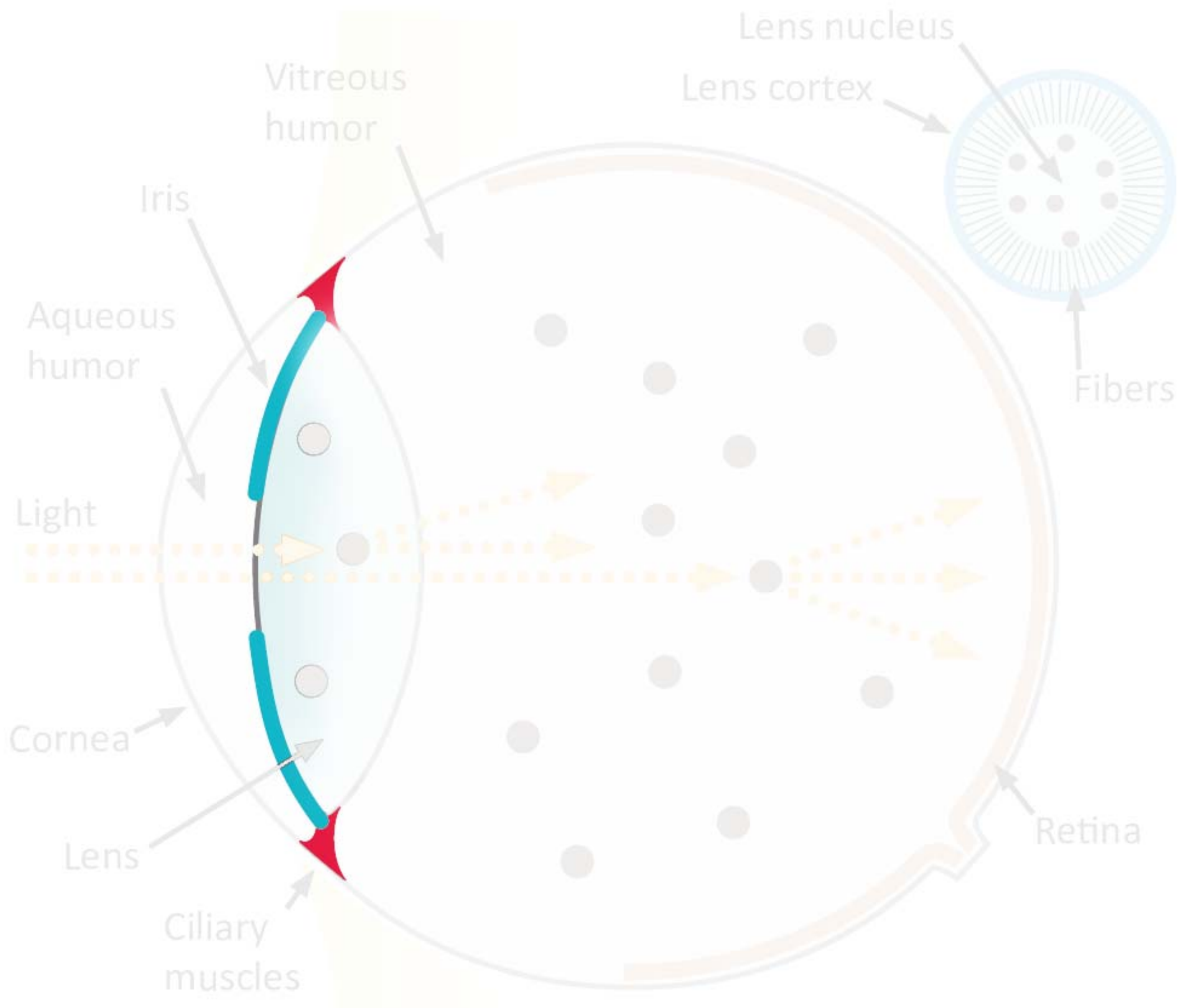
Ritschel et al. EG2008

Temporal Glare Pipeline



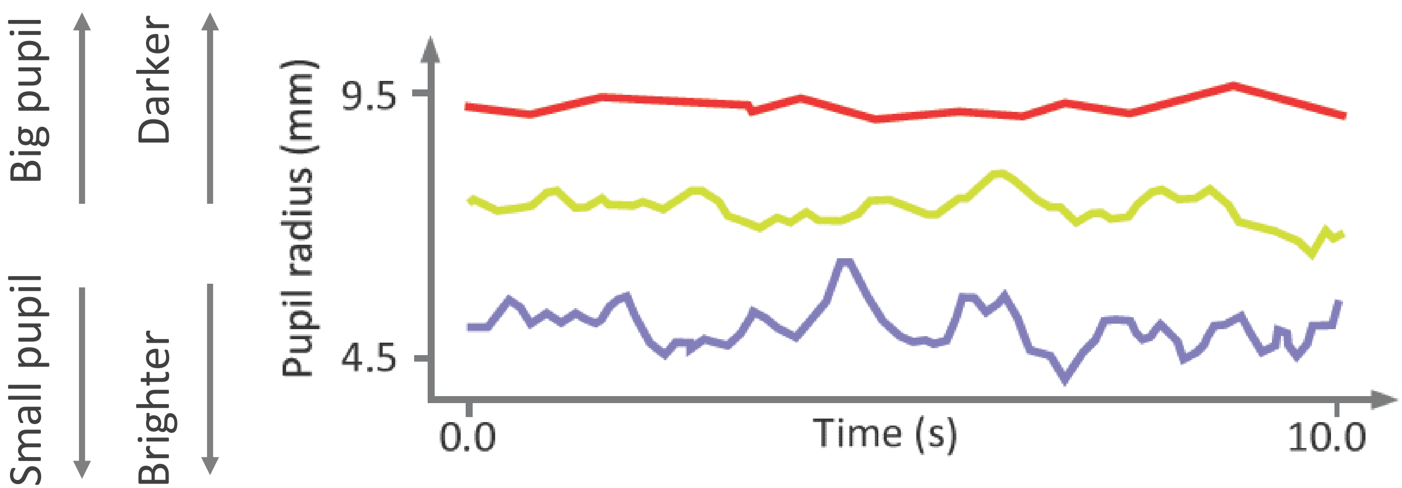
Ritschel et al. EG2008

Aperture: Pupil

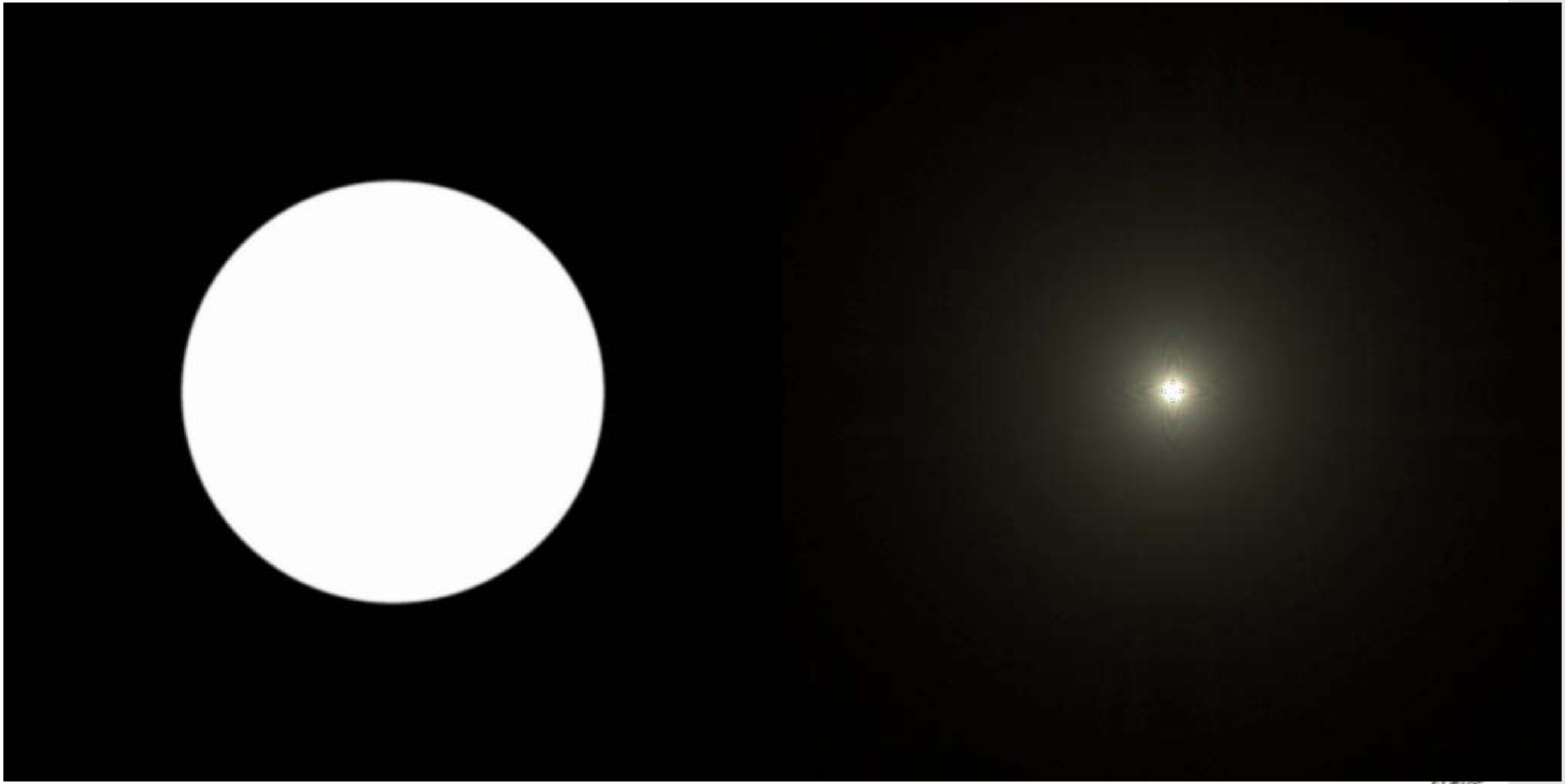


Aperture: Pupil

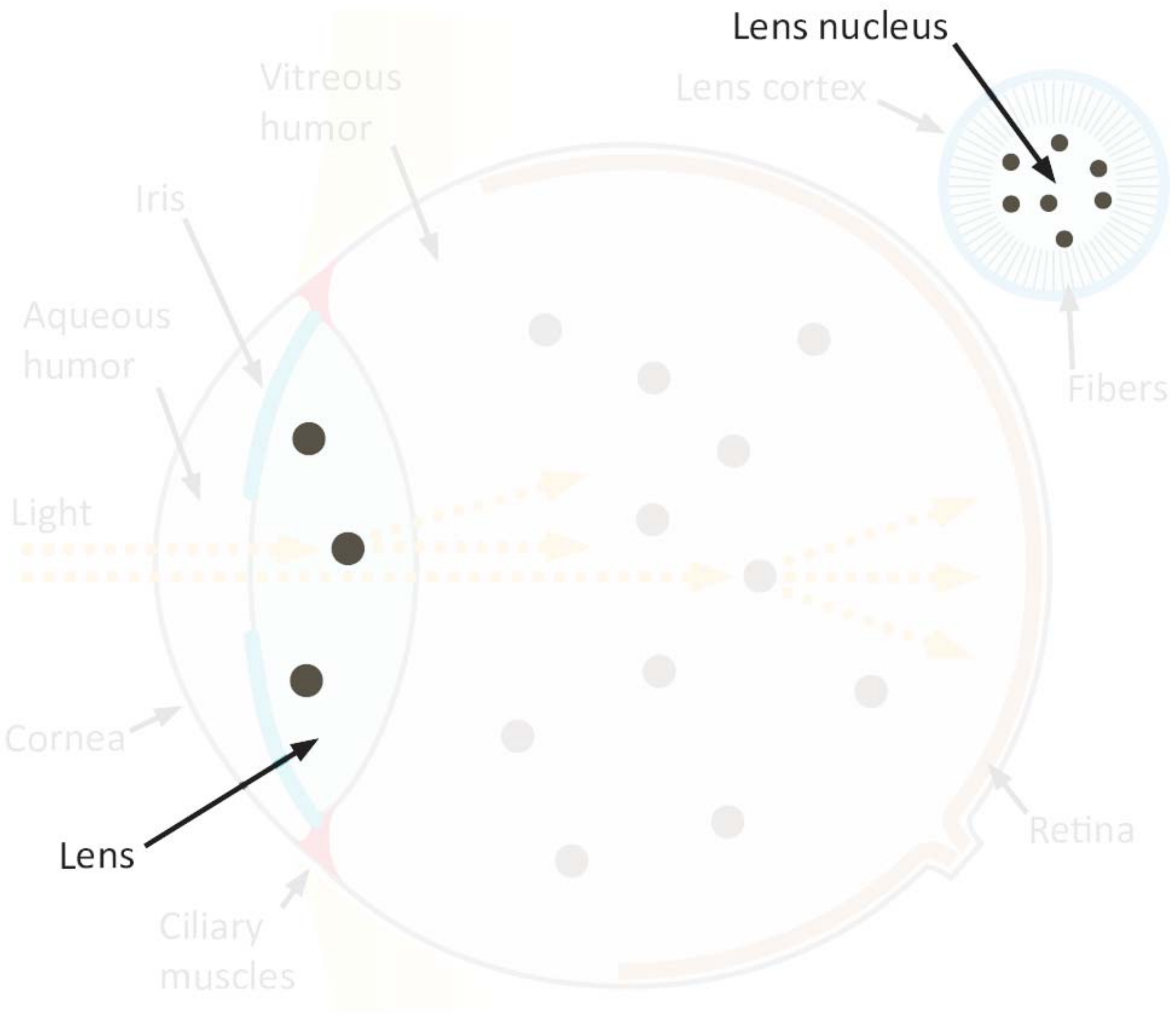
- **Adaptation**
- Can convert HDR image into pupil size
- Pupillary hippus:
  Strong contrast between glare source and background
- Stronger for smaller pupils, i.e. bright conditions



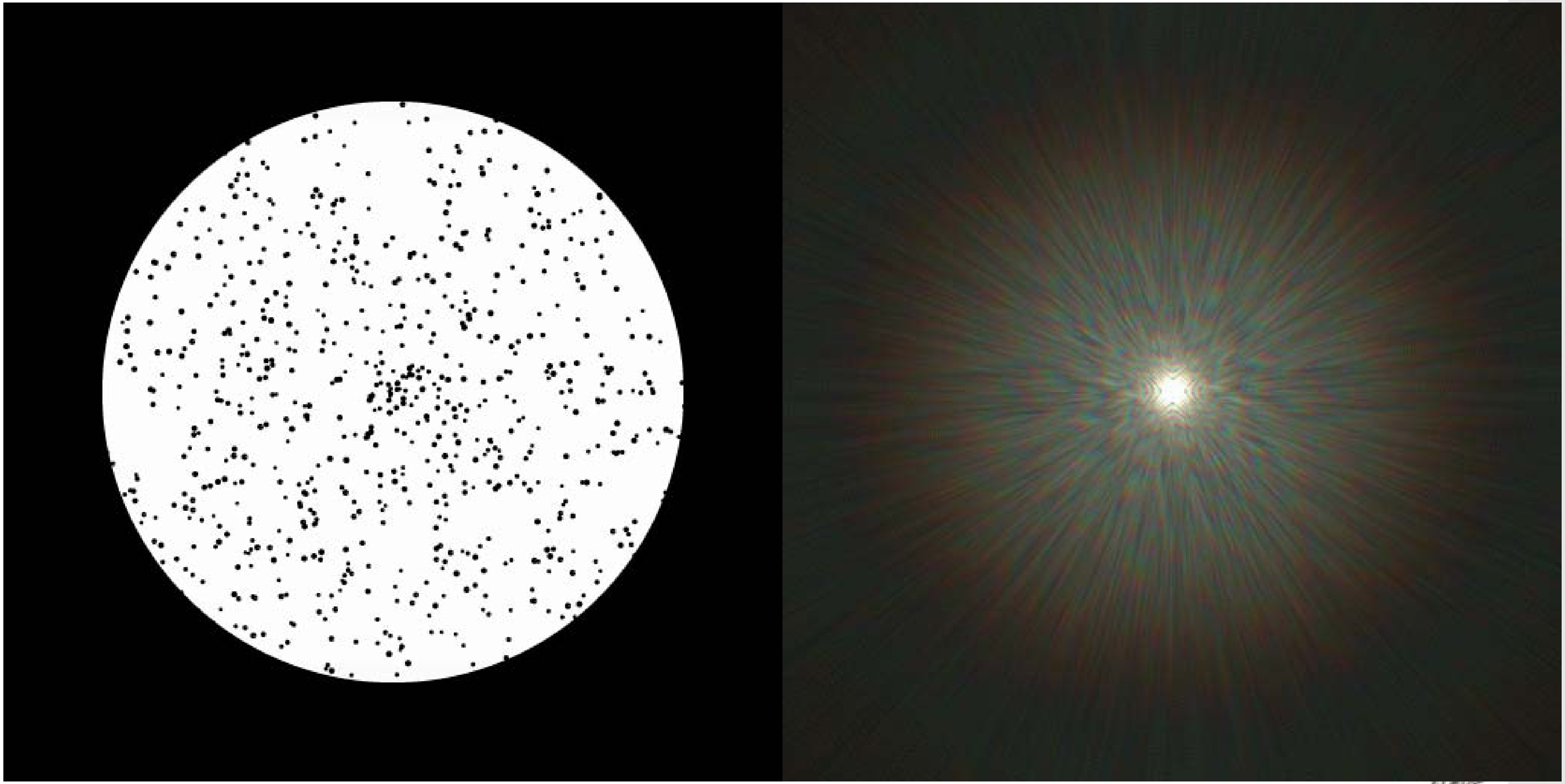
Aperture: Pupil



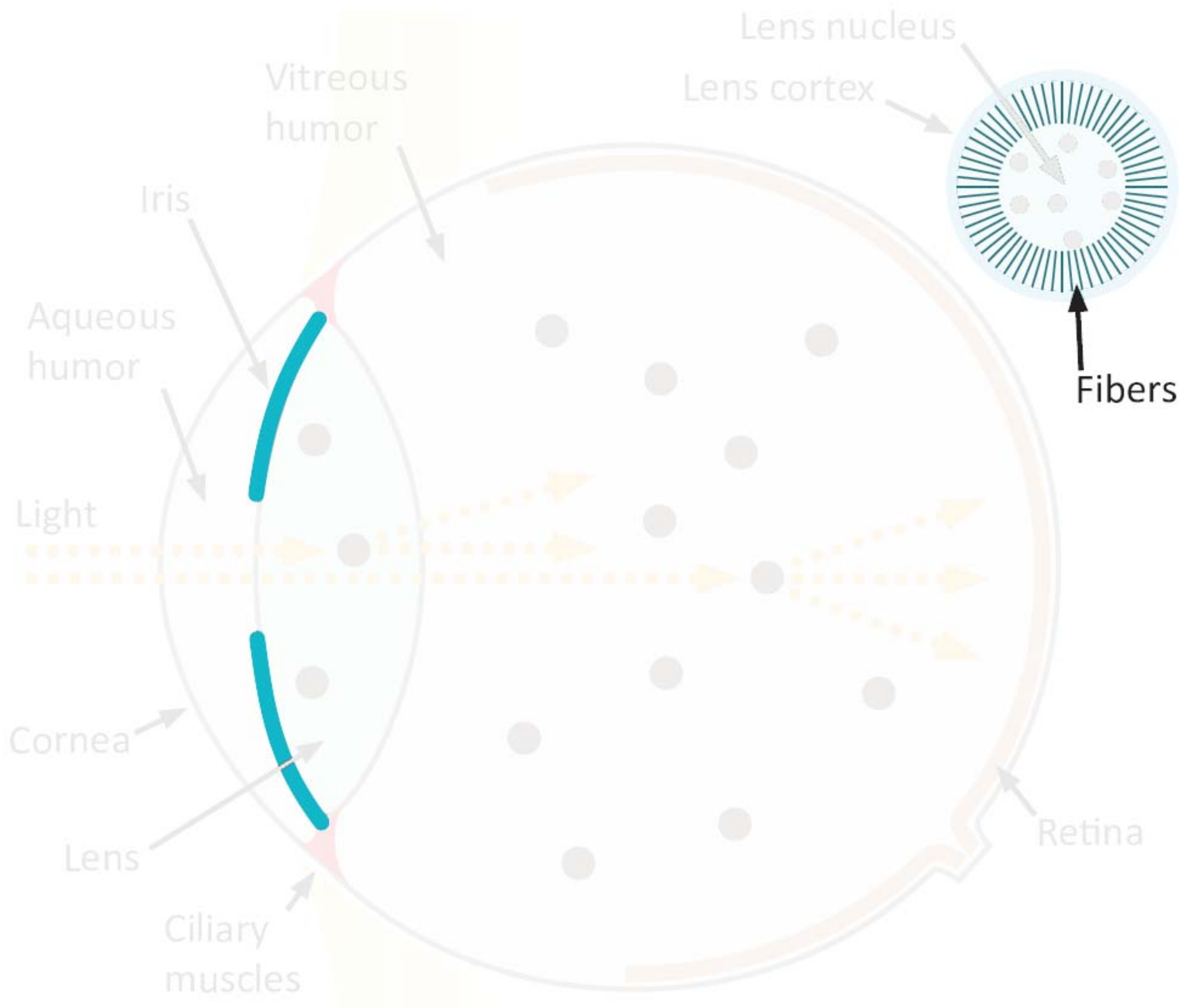
Aperture: Lens



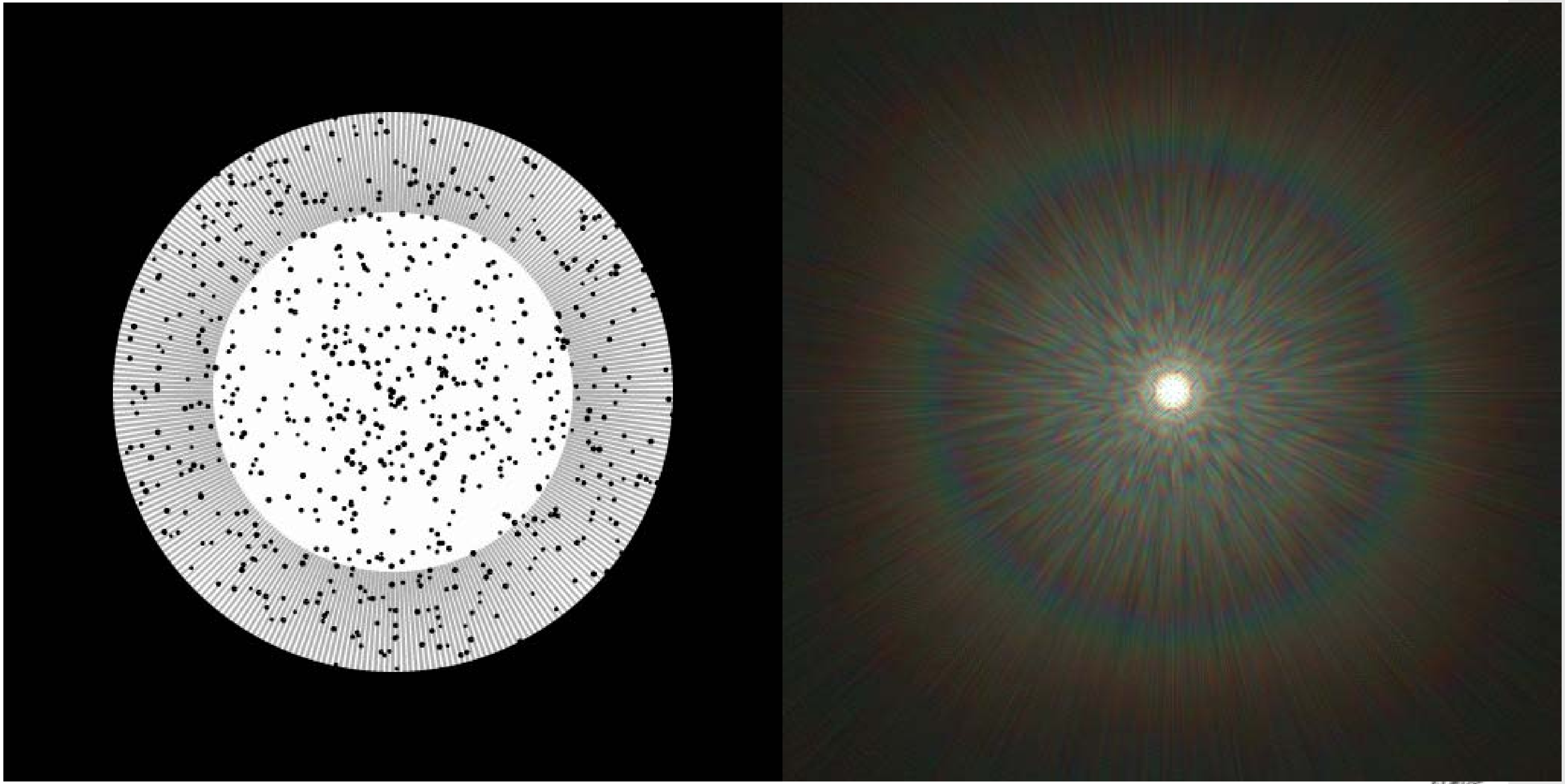
Aperture: Lens



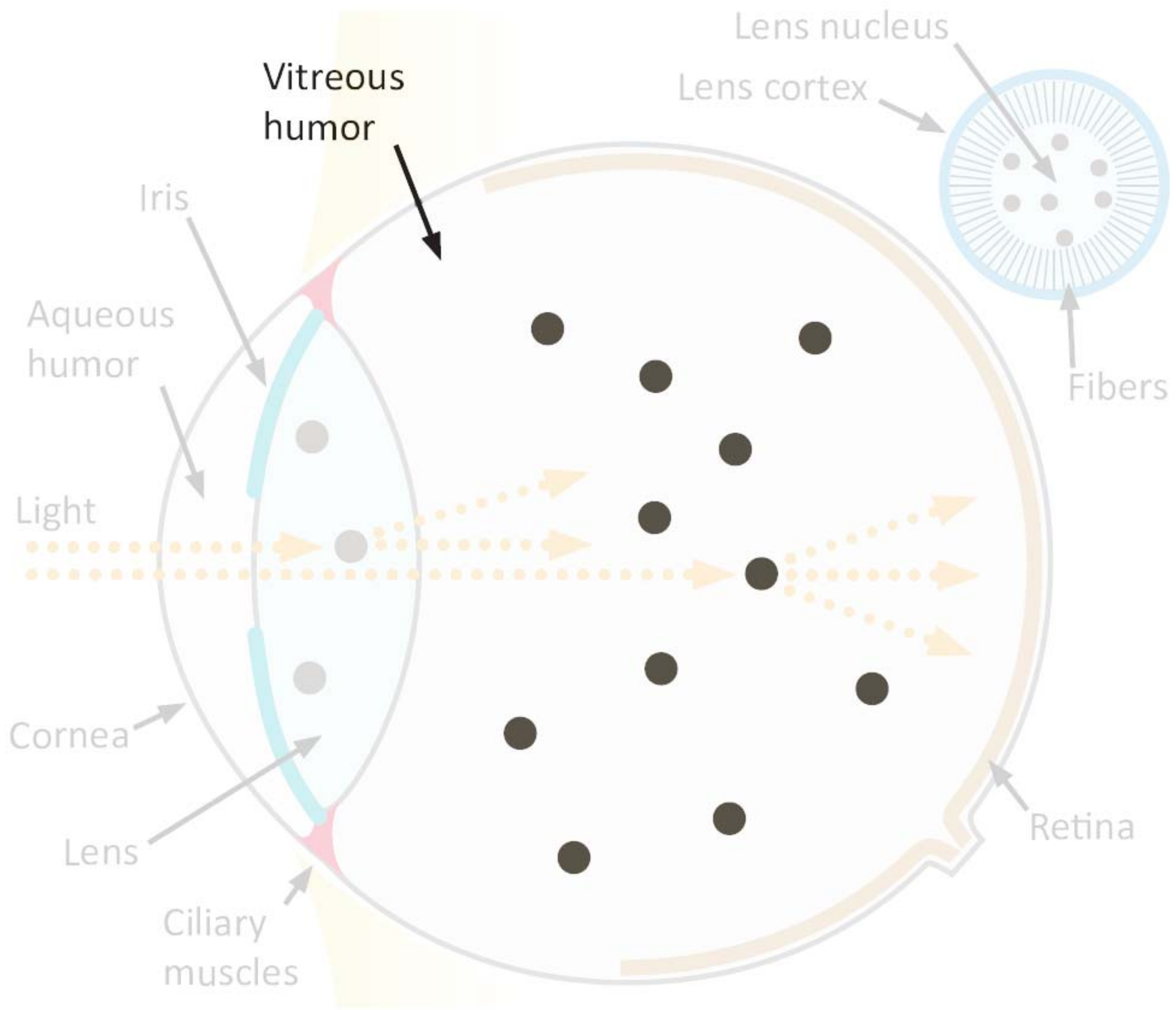
Aperture: Gratings / Lens fibers



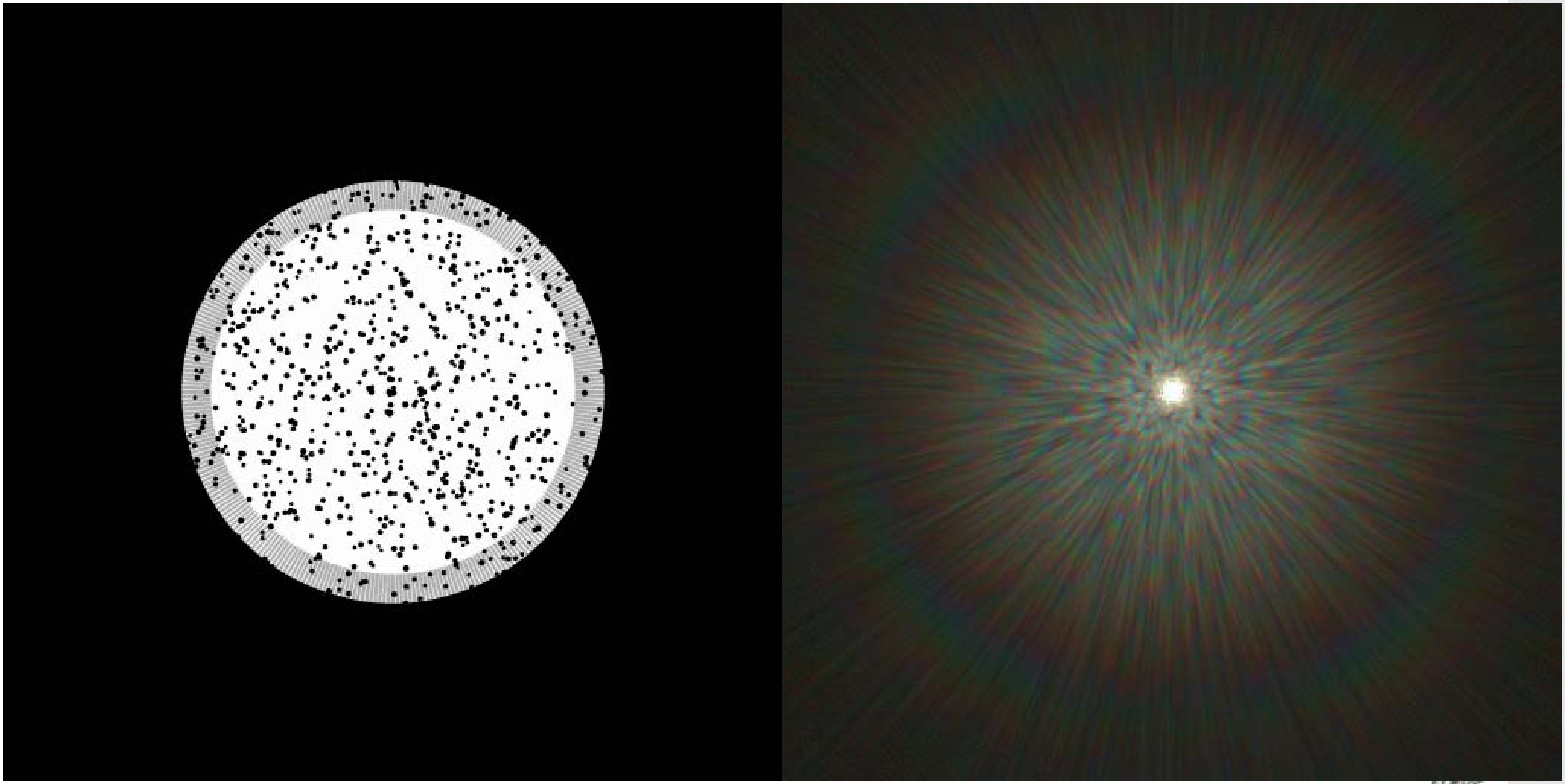
Aperture: Gratings / Lens fibers



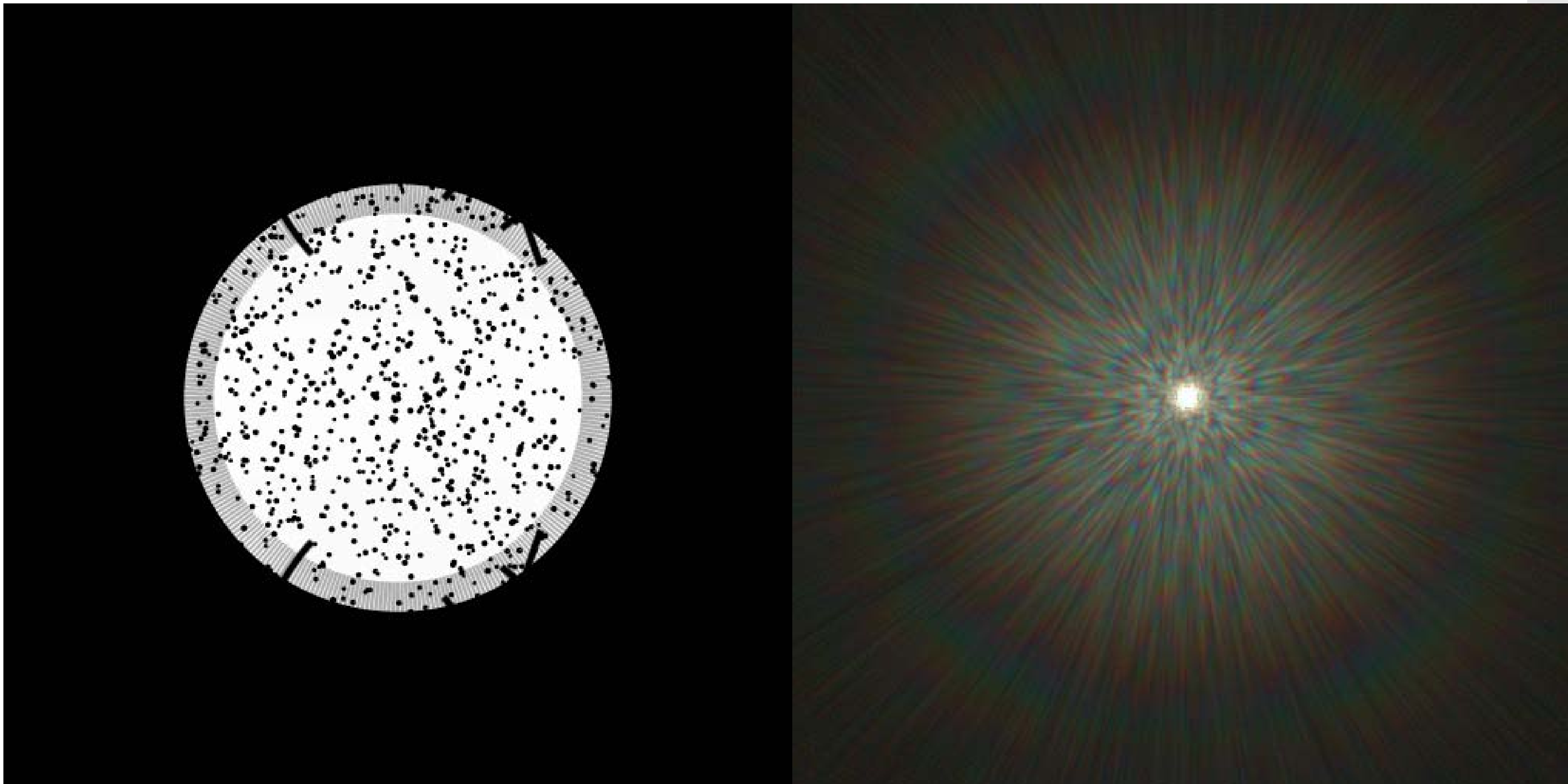
Aperture: Vitreous Humor



Aperture: Vitreous Humor

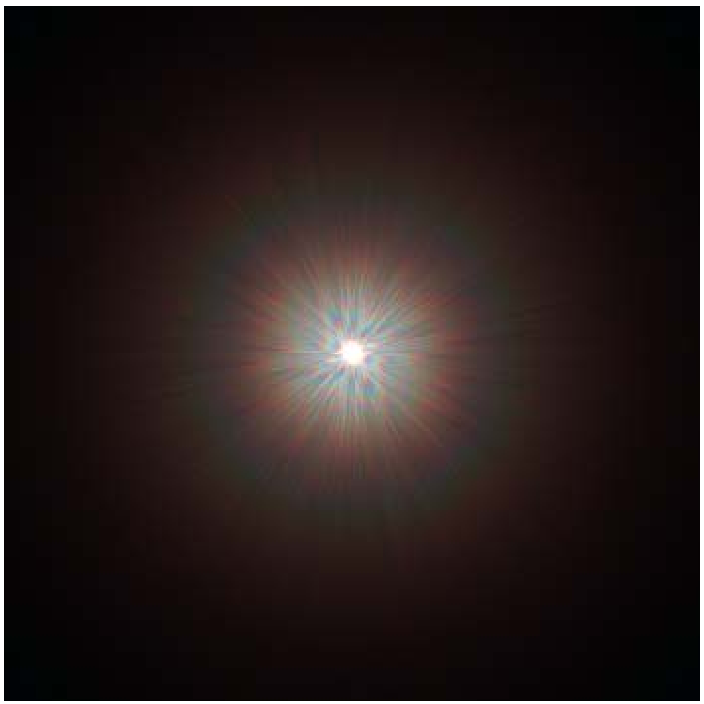


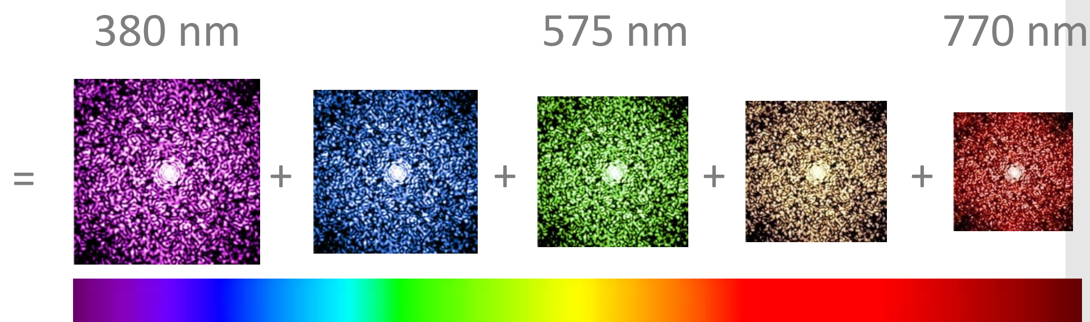
Aperture: Eyelashes (*optional*)



Chromatic Blur

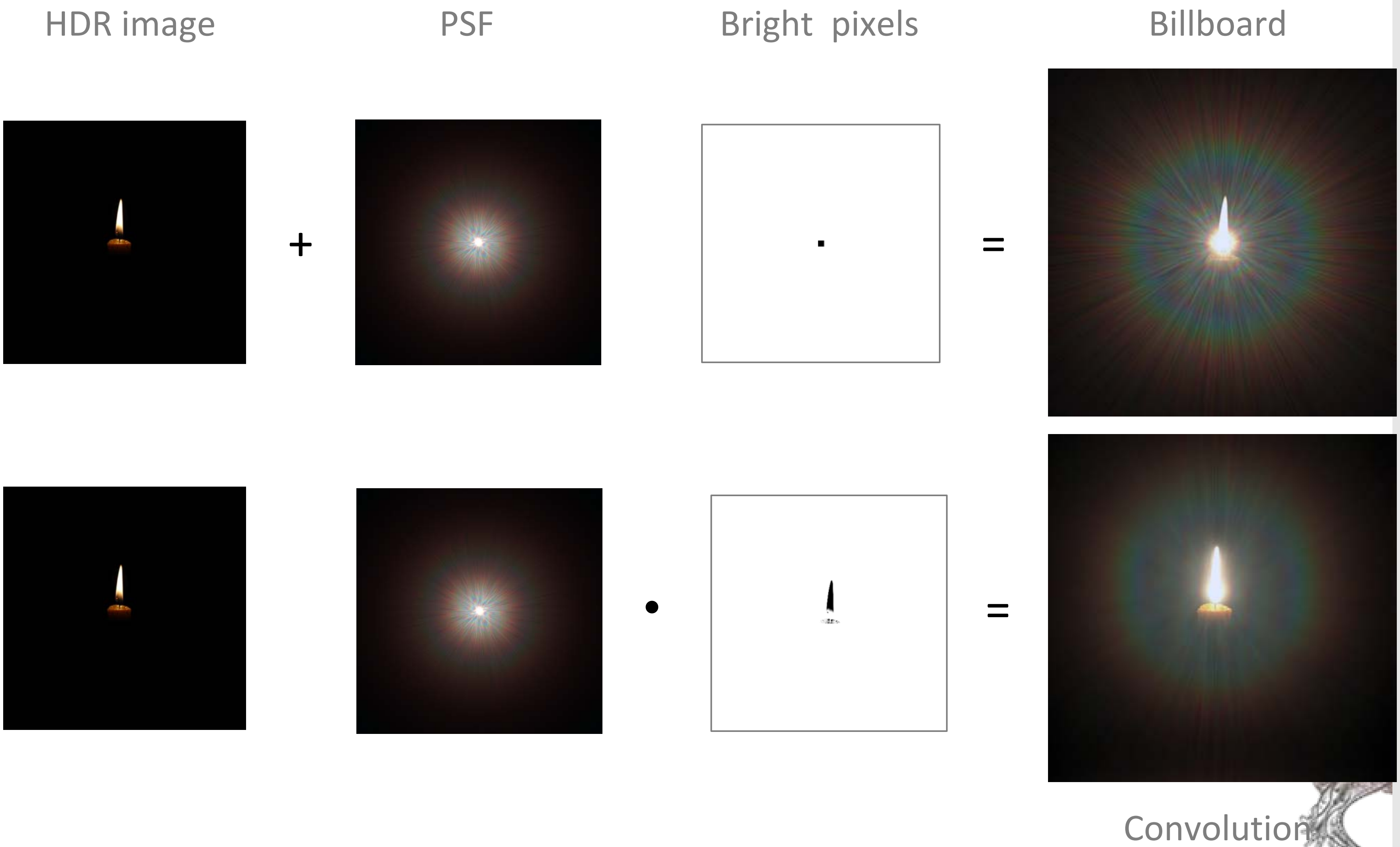
- Compute one wavelength - Get others for free!
- They are scaled copy of base wavelength, i.e. 575 nm (approximation)





$$\begin{aligned} F_s(\mathbf{x}) &= \sum_{i=0}^{n-1} s(\lambda_i) F_{575\,\mathrm{nm}}(\mathbf{x}_i) \\ \lambda_i &= 380\,\mathrm{nm} + i\,\frac{770\,\mathrm{nm} - 380\,\mathrm{nm}}{n} \\ \mathbf{x}_i &= \mathbf{x}\,\frac{575\,\mathrm{nm}}{\lambda_i} \,. \end{aligned}$$

Convolution

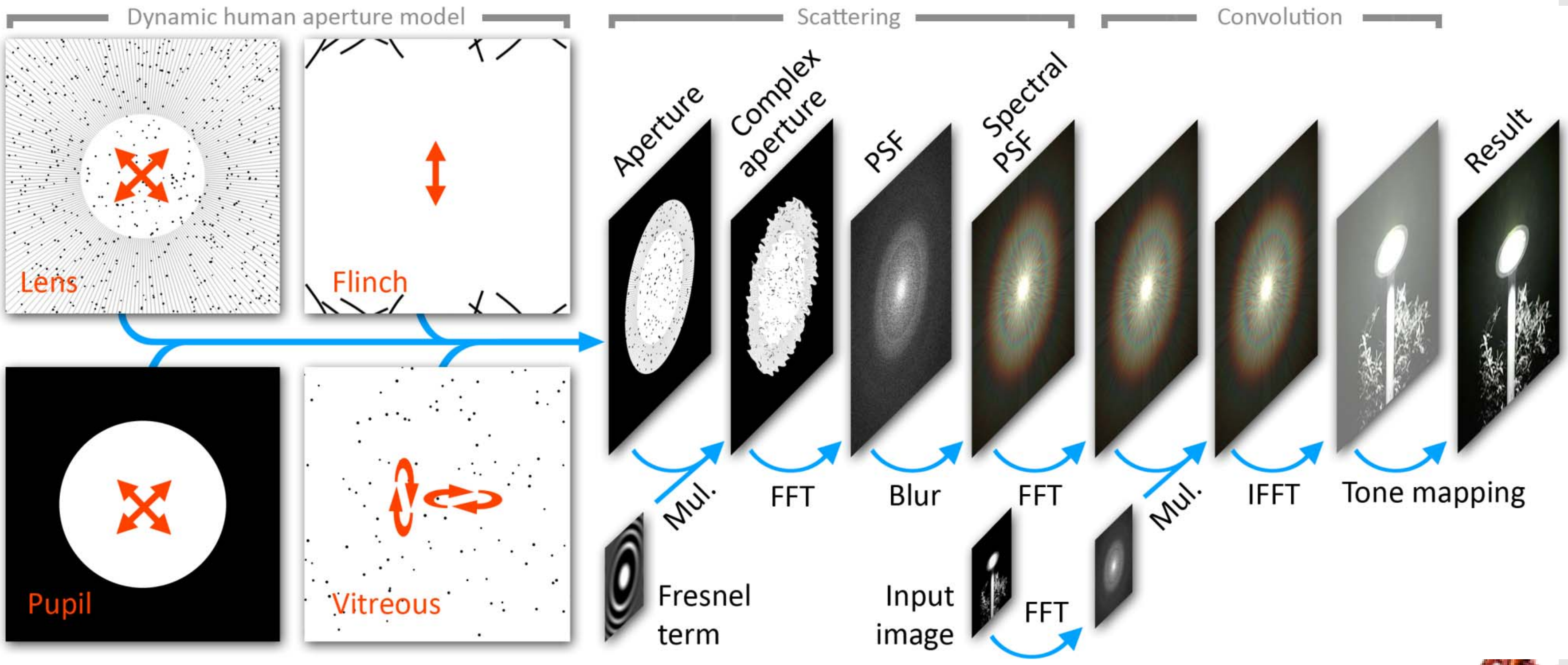


Convolution

Convolution

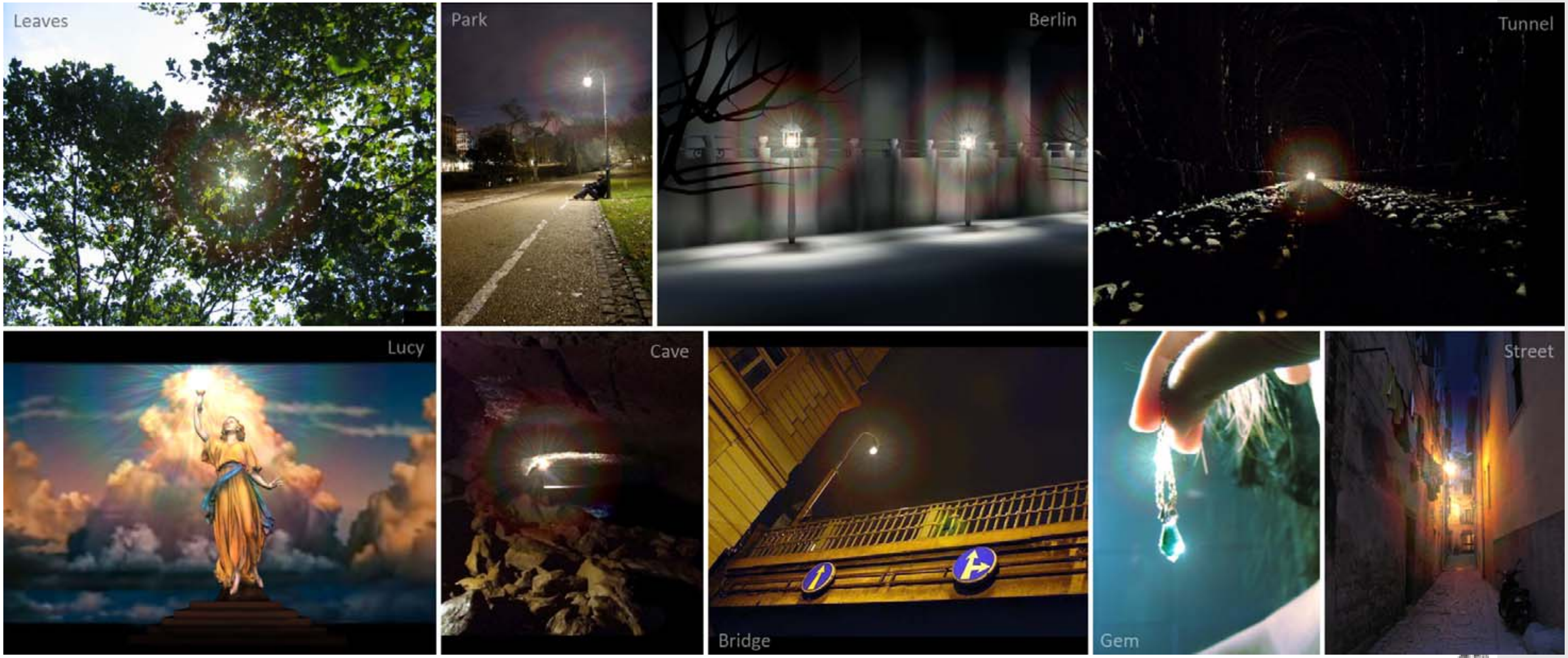
Billboard

Temporal Glare Pipeline



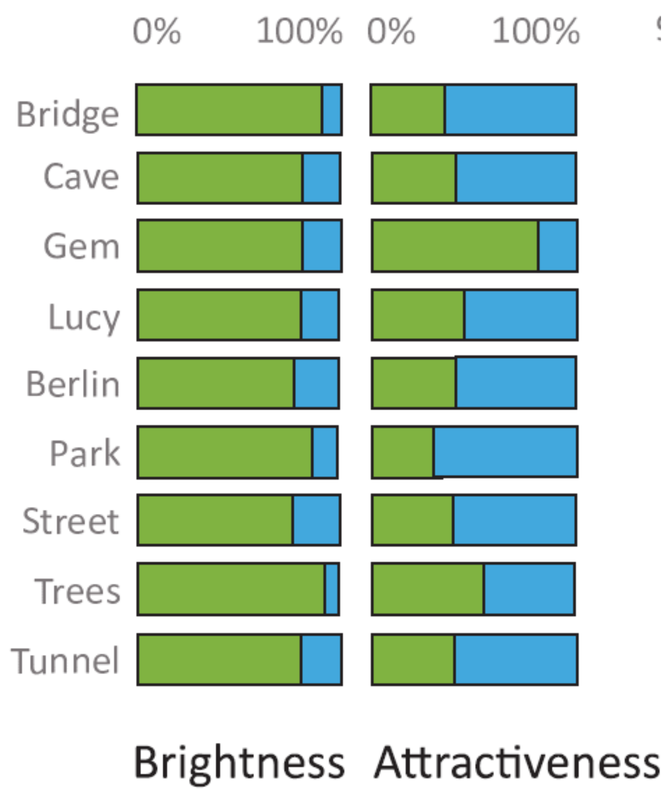
Results: Study

1. Two-alternative-forced-choice (bright, attractive, real)
   10 subjects
2. Method of adjustment
   4 subjects



Results: Study

1. Two-alternative-forced-choice (bright, attractive)
   10 subjects
2. Method of adjustment: dynamic glare ~5% brighter
   4 subjects



Summary/Limitations

- Glare illusion might boost apparent brightness up to 30%
- Comprehensible model of light scattering in the eye taking into account dynamic eye elements
- Real-time rendering
- Model might miss important parts
- Model might contain unimportant parts
  - No differential study
- Other temporal low-level eye physics like
  - Floaters
  - Local adaptation ("After images")

http://www.mpi-inf.mpg.de/resources/hdr/TemporalGlare/

Acknowledgements

- I would like to thank Grzegorz Krawczyk, Tobias Ritschel, Kaleigh Smith, Akiko Yoshida, and Matthias Ihrke for help in preparing slides.