

# Computer graphics III – Into

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- Computer Graphics Group • Charles University, Prague • [cgg.mff.cuni.cz](http://cgg.mff.cuni.cz) •

# RENDERING



 corona





01 EKTORP three-seat sofa  
**\$749**

## A room with a view

Put a rocking chair in front of your favourite window and experience how relaxing it is to get away from it all by just coming home. Life is in full swing outside, but you feel totally calm.

**IKEA**®

Seat cushions filled with high resilience foam ride comfortable support for your body when you rise. Cover: 53% linen, 47% viscose/reyon, W120xL80cm, moacm, Risane natural.

02 New FABRIKÖR glass-door cabinet \$399 The shelves in the cabinet are adjustable - makes it easy to adjust the height to suit what you want to store. May be completed with DODDER LED lighting strip. Powder coated steel and tempered glass. Designer: Nike Karlsson. W57xD47, H150cm. Light green 702.422.94

03 VÄRMDÖ rocking-chair \$169 Wooden furniture that is suitable for both indoor and outdoor use. Solid pine. Designer: Nike Karlsson. W65xD74, H106cm. Black 002.059.58

04 BJÖRNLOKA rug, flatwoven \$199 The durable, soil-resistant wool surface makes this rug perfect in your living room or under your dining table. The rug is machine-woven. User surface: 100% pure new wool. W170xL240cm. Beige/black 402.290.05

05 HEMNES coffee table \$229 Stained, clear lacquered solid pine. Designer: Carina Bengt. L90xW90, H46cm. Grey-brown 402.579.51



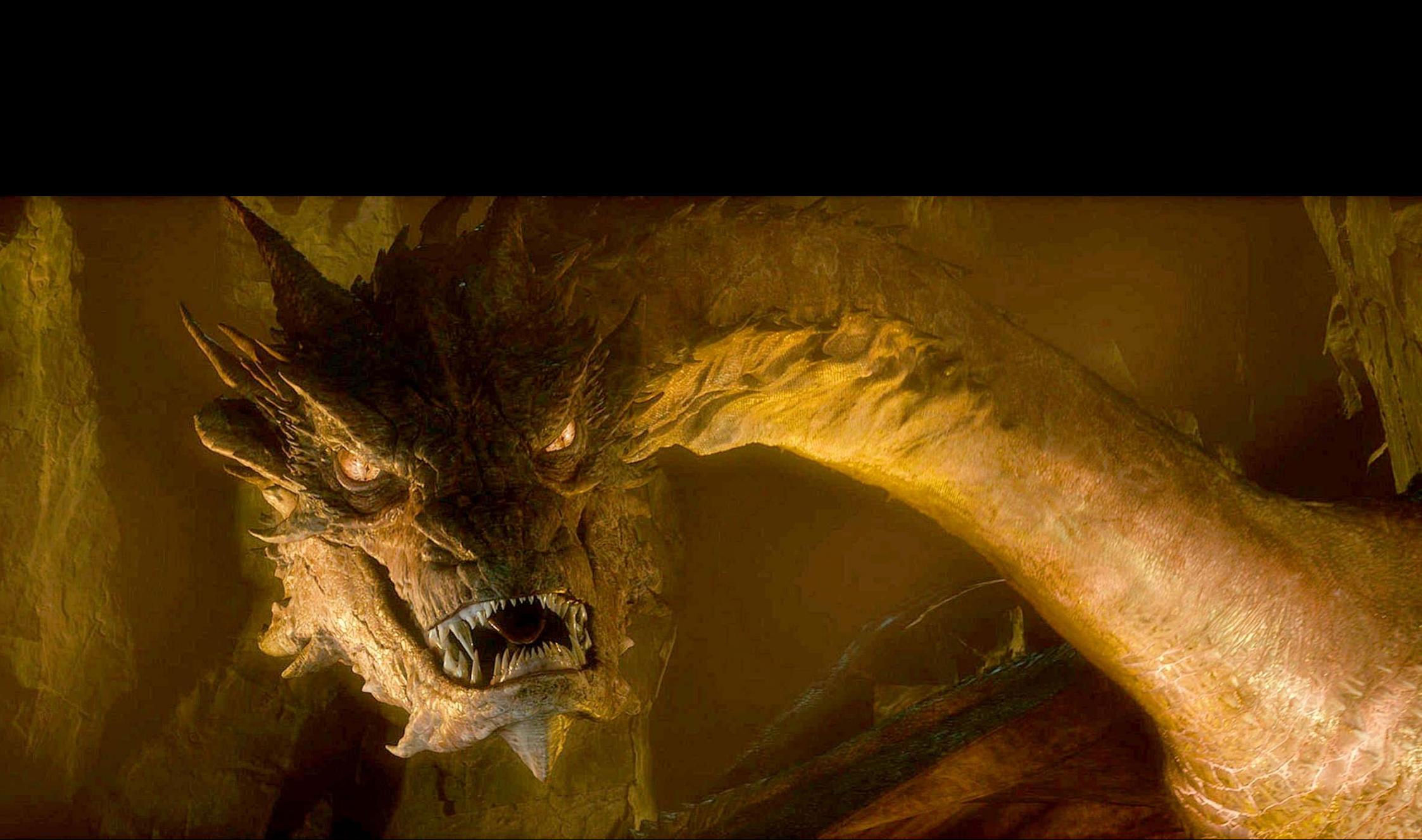
Show products (3) ^



Chair "Bertil", 2006



ŠKODA Catalogue



By Weta Digital  
© 20<sup>th</sup> Century Fox



By Weta Digital  
© 20<sup>th</sup> Century Fox



© 2000, IL&M



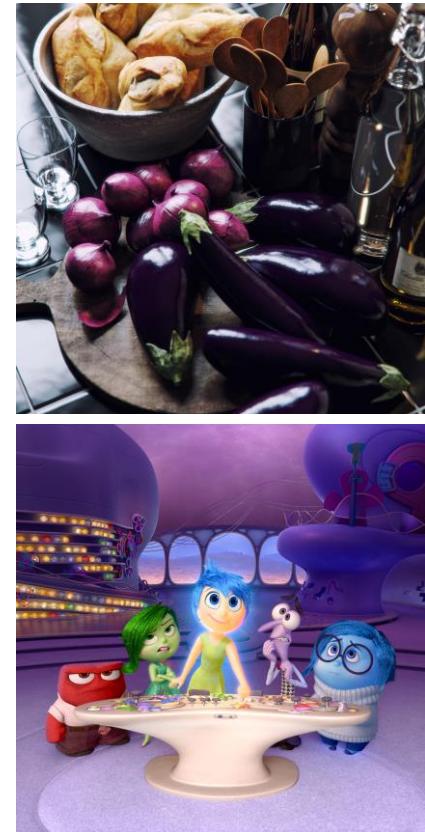






# Realistic 3D graphics

- **3D scene modeling**
  - 3DS Max, Blender, Rhino / CaptureReality
- **Object appearance**
  - Light reflectance models, textures, wear&tear
- **Animation**
  - Manual (character rigging, animation curves, ....)
  - Physics based (rigid body, water simulation, explosions, ...)
  - Captured (mocap)
- **Lighting & rendering**
  - primary light sources + global illumination (GI) -> light transport simulation
- **Video compositing and compression**
- **Image display (HDR imaging)**

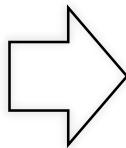


# Rendering = (forward) light simulation

3D scene



Image



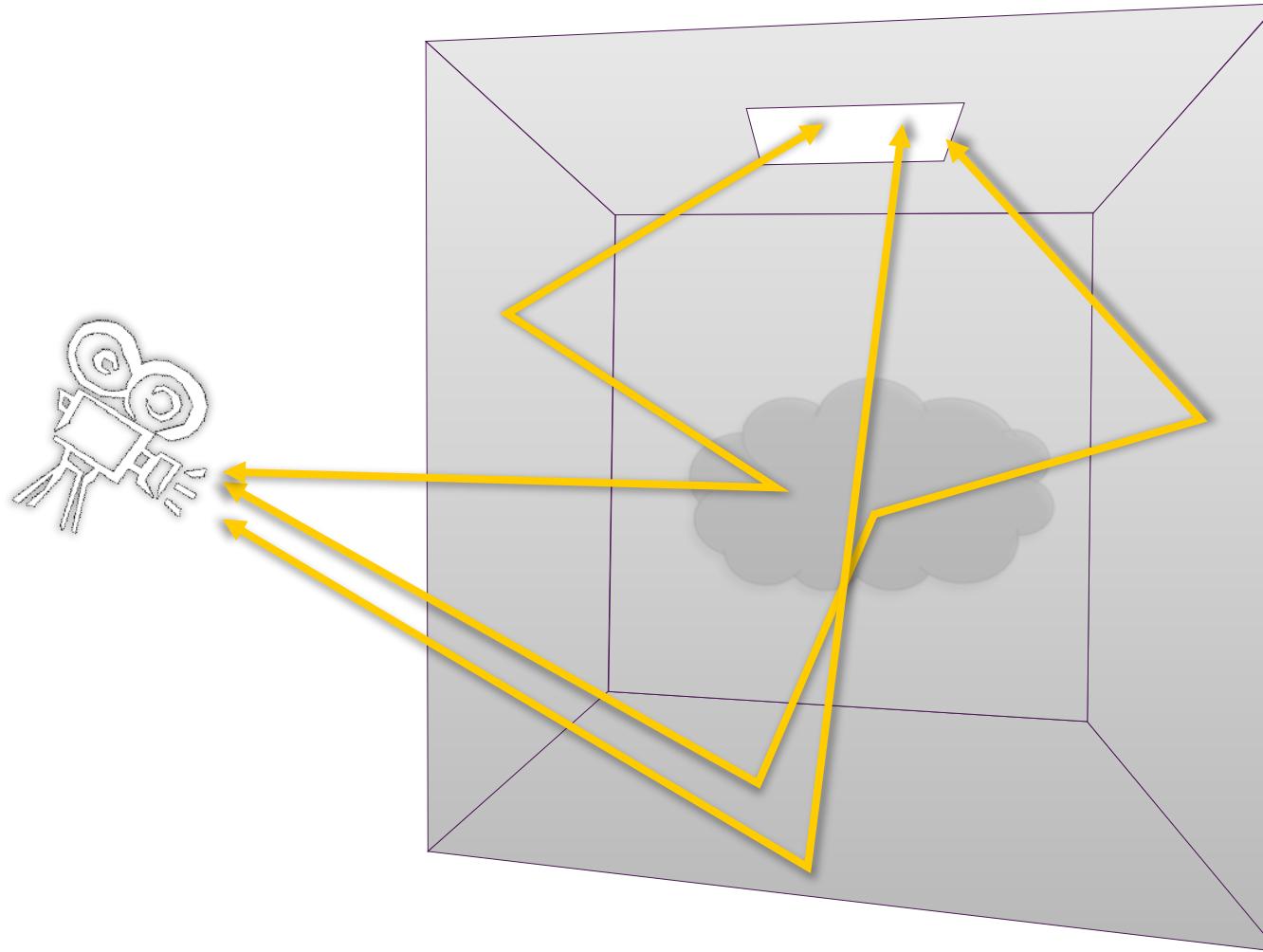


arnold



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# Light simulation

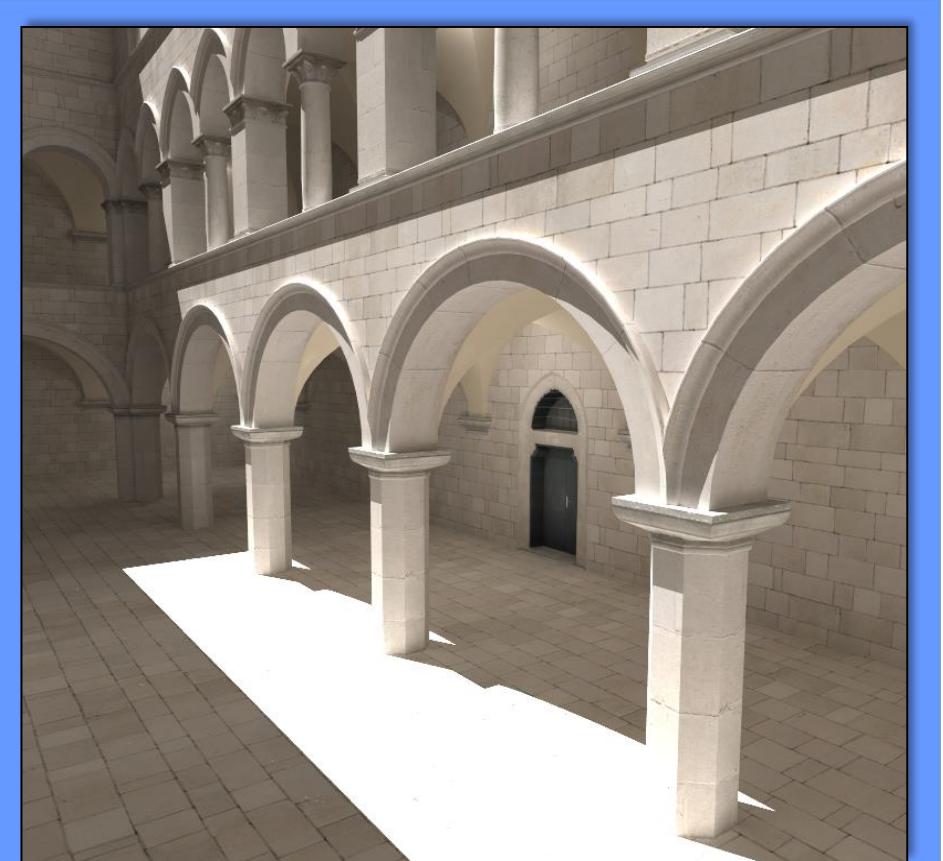


$$L_o = L_e + \int_{\Omega} L_i \cdot f_r \cdot \cos{\theta} \cdot d\omega$$

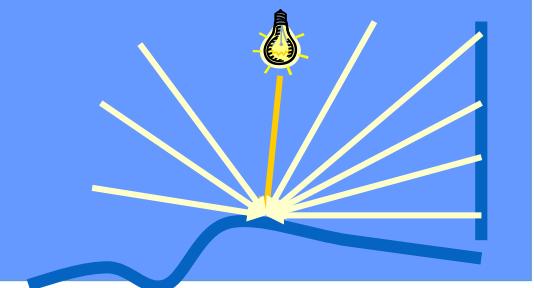
# Global illumination – GI



Direct illumination



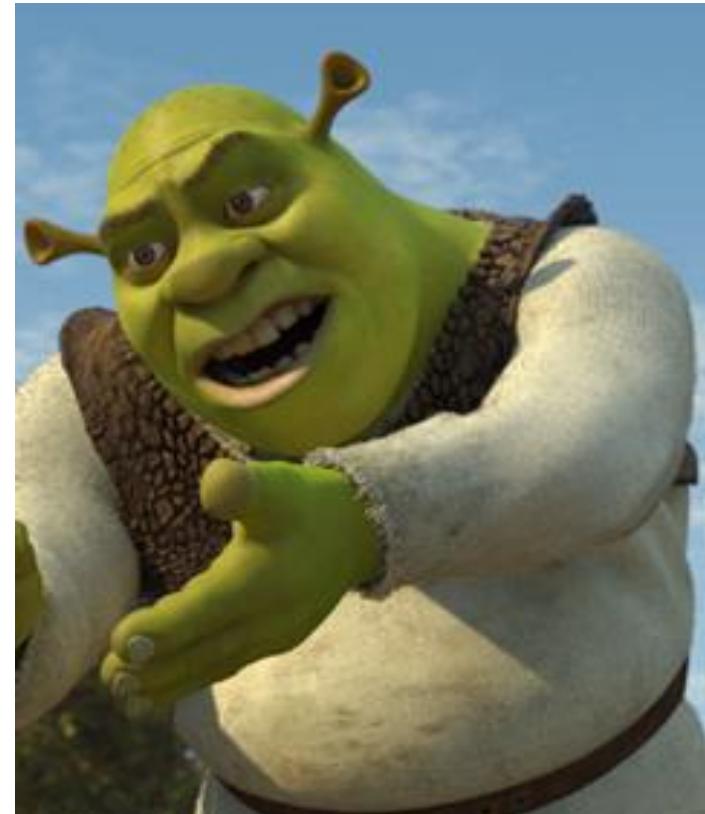
**Global** =  
direct +  
indirect



# Global illumination – GI

- **Direct illumination**

- Light reflects only once on its way from the source to the camera



- **Global illumination**

- Global = Direct + Indirect
- Light transport between surfaces in the scene

# Global illumination – Color bleeding



Image courtesy Michael Bunnell

# Global illumination – Caustics

- Focusing of light as it's reflected or refracted, leading to local increase of intensity



Photograph

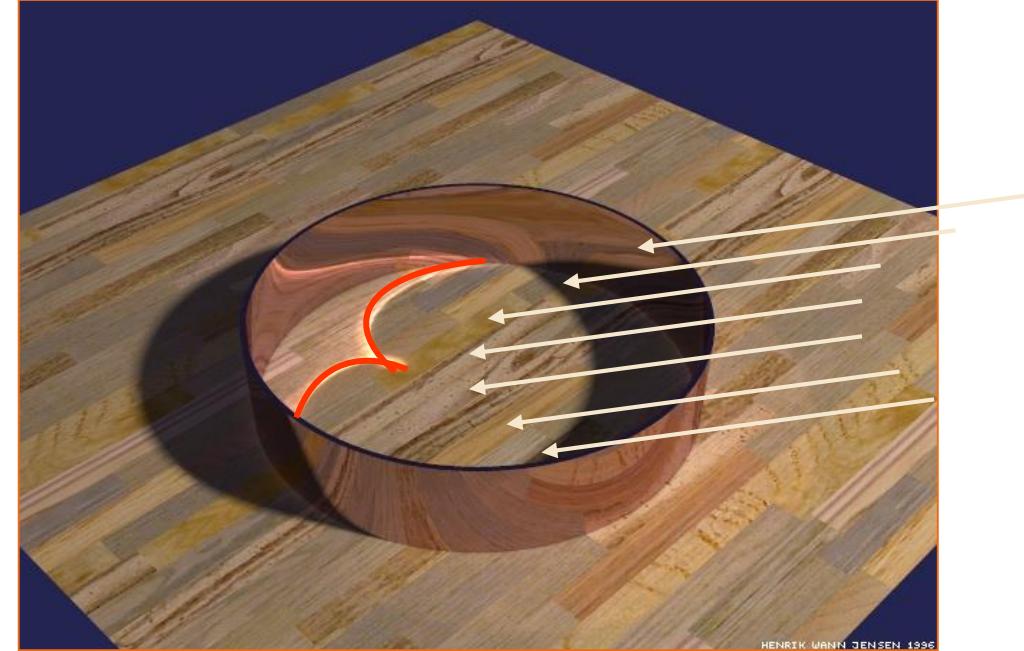
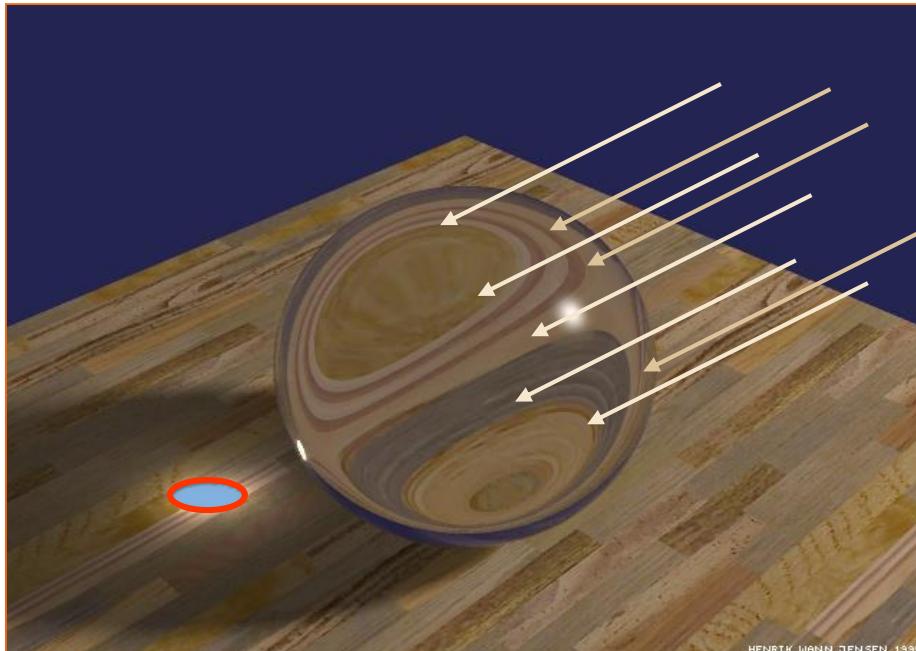


Simulation using photon maps

HENRIK WANN JENSEN 1995

# Caustics

- In physics or in computer vision, a caustic refers to a singularity of light intensity (infinite density of light energy)



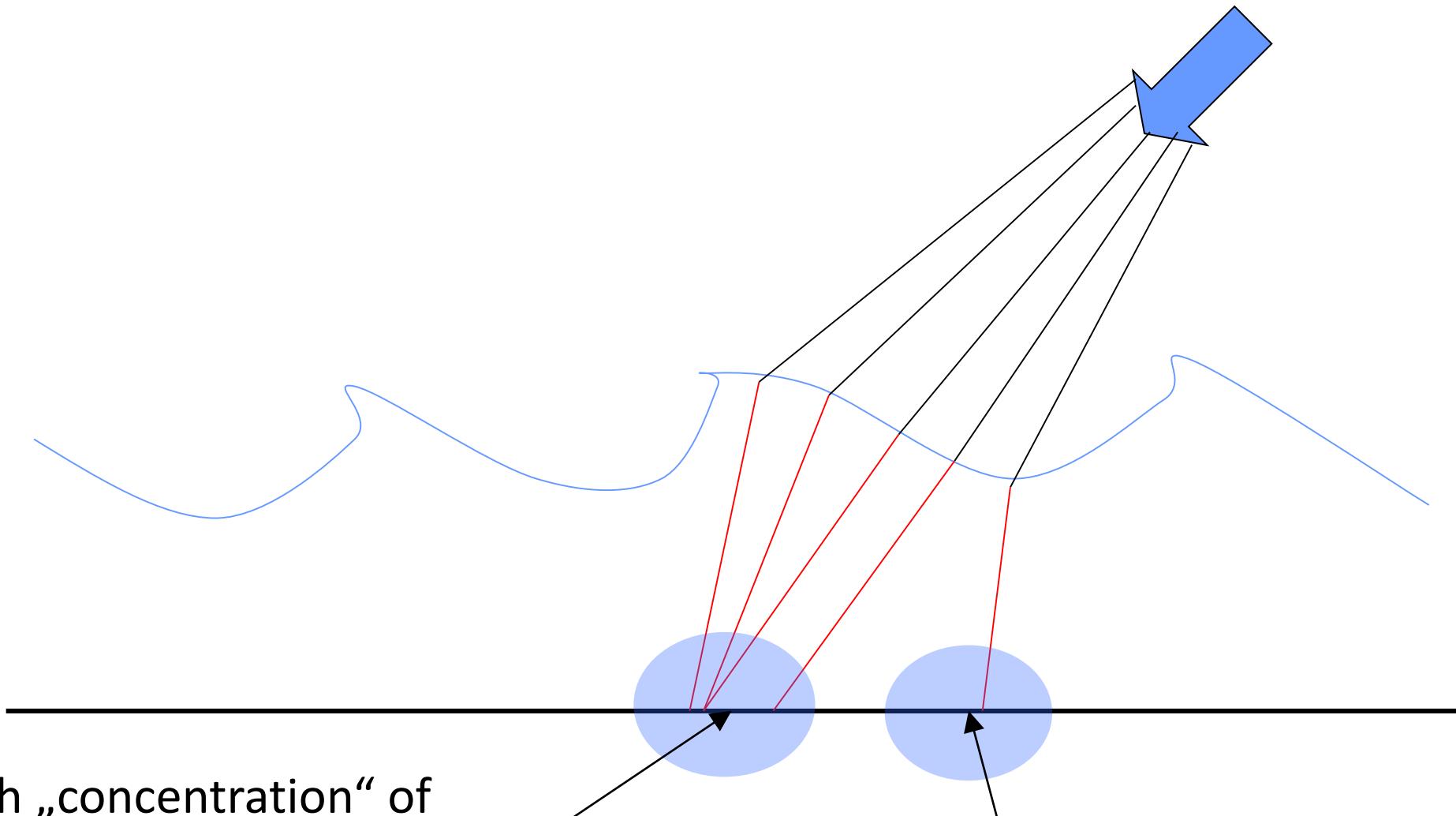
# Global illumination – Caustics



- Reflections + refractions on water surface
- Caustics at the bottom



# Caustics under water surface



High „concentration“ of  
photons – high light intensity

Low intensity

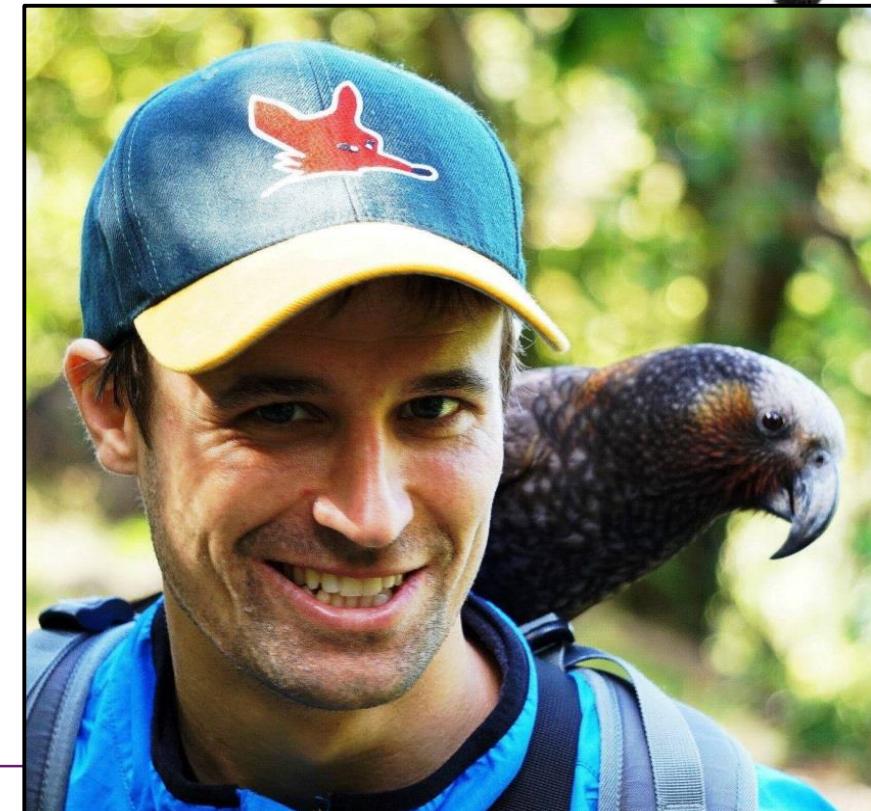
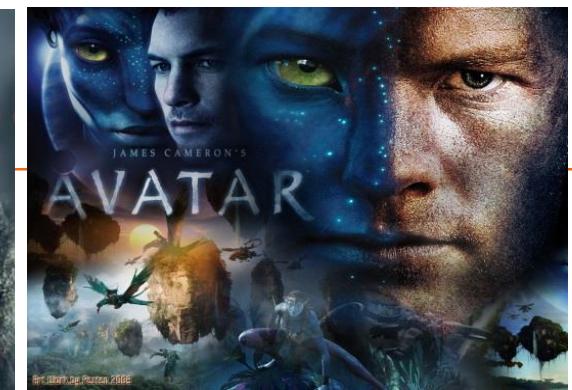
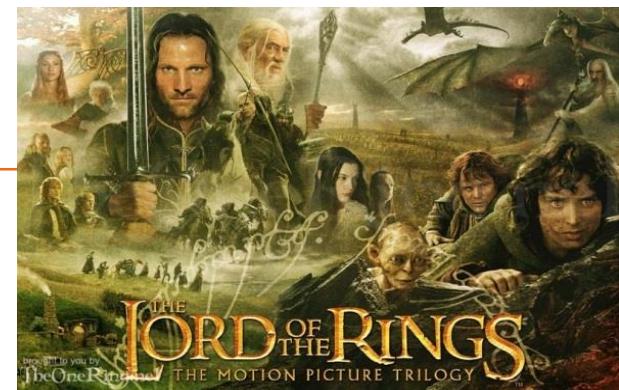
# We collaborate with...





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# Other interesting (local) companies...



# Realistic image synthesis: Ingredients

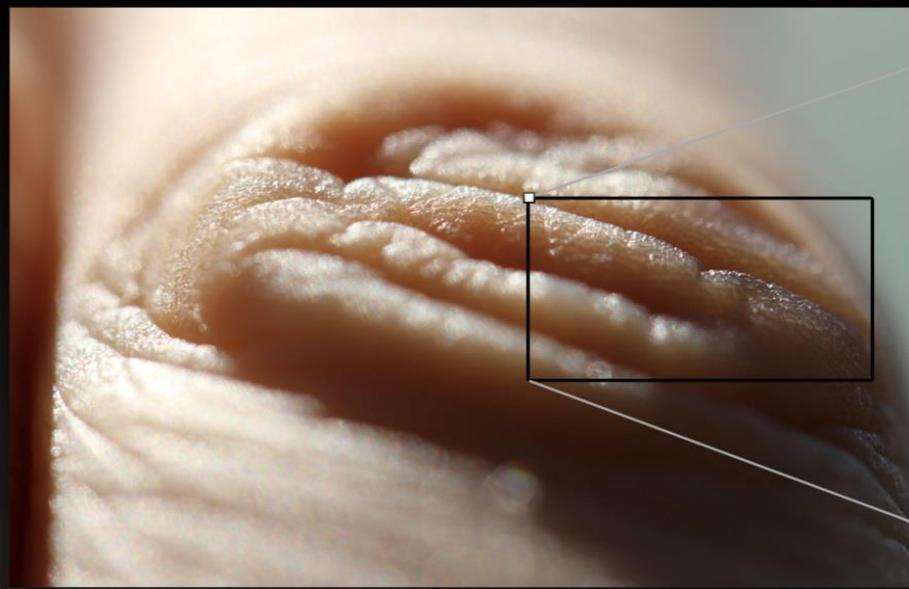
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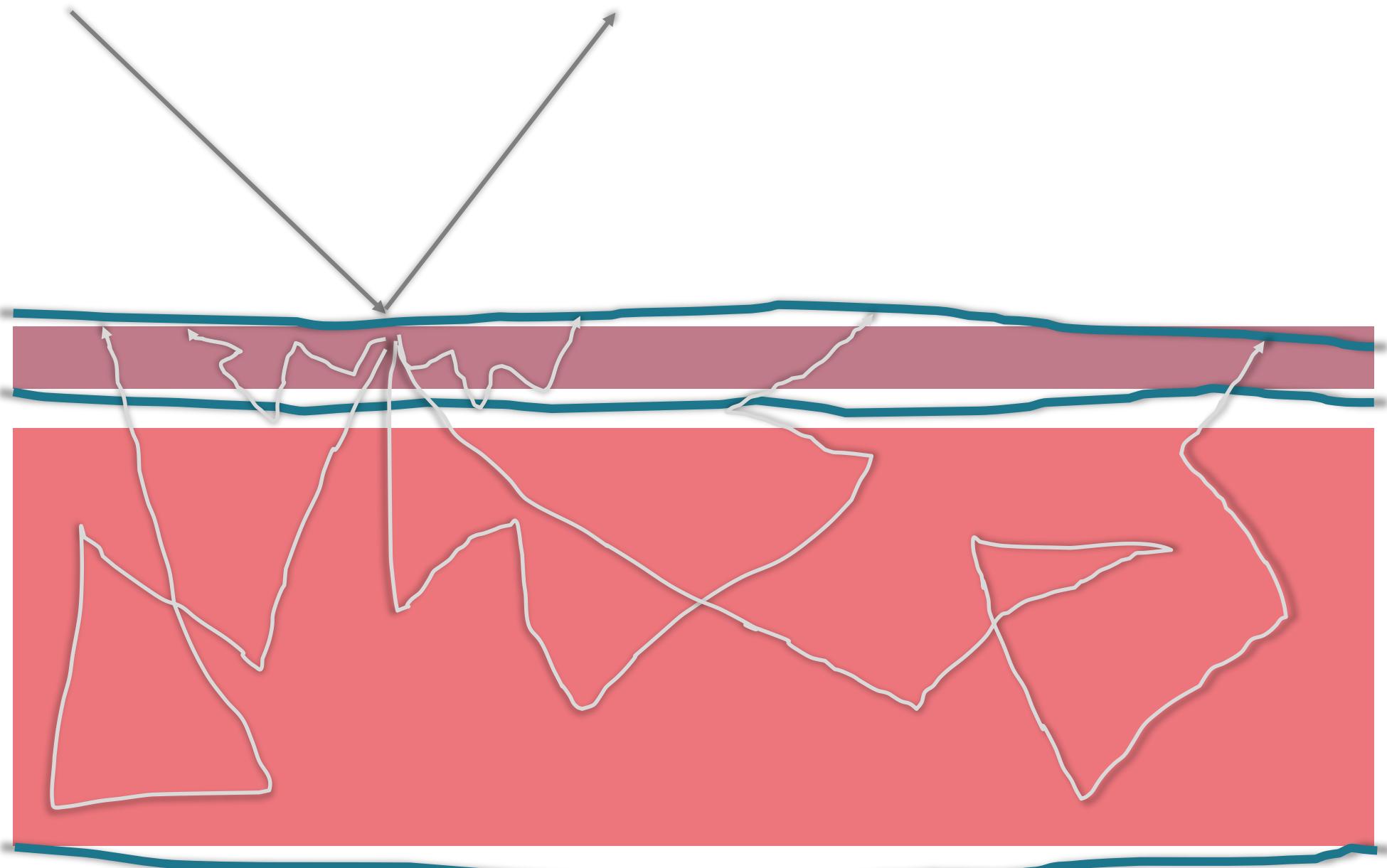
- Describe the “amount of light” in space – **radiometry**
- Describe light interaction with surfaces – **BRDF**
- Describe equilibrium light distribution – **rendering equation (RE)**
- **Image rendering** = numerical solution of the RE
  - Find the equilibrium light distribution in a 3D scene
  - Methods
    - Finite elements (radiosity) – obsolete
    - **Monte Carlo** (stochastic ray tracing) – prevalent

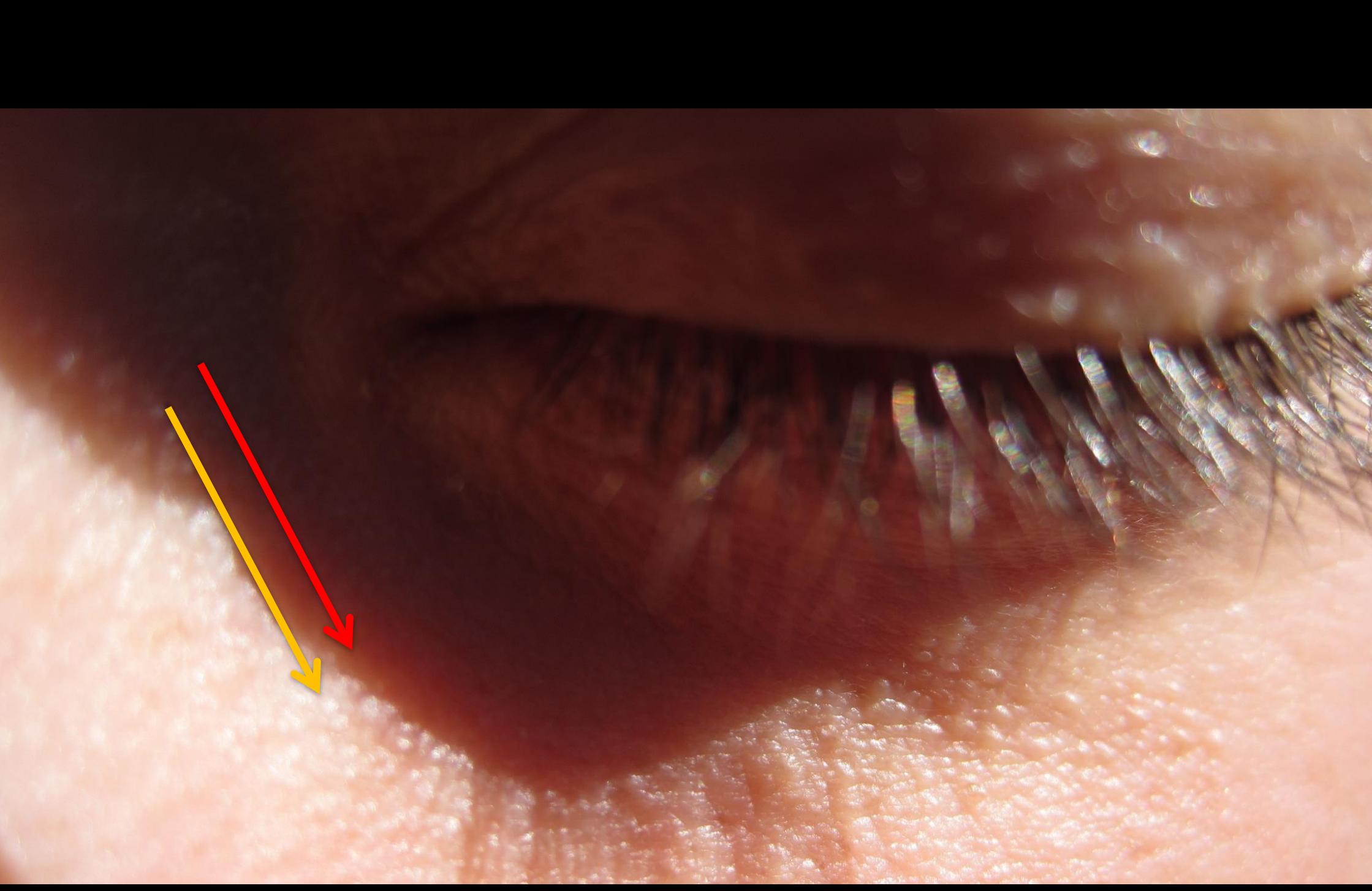
**Example of our rendering research:**

## **Smart(er) subsurface scattering**

Křivánek and d'Eon. **A Zero-Variance-Based Sampling Scheme for Monte Carlo Subsurface Scattering**, ACM SIGGRAPH Talks 2014.

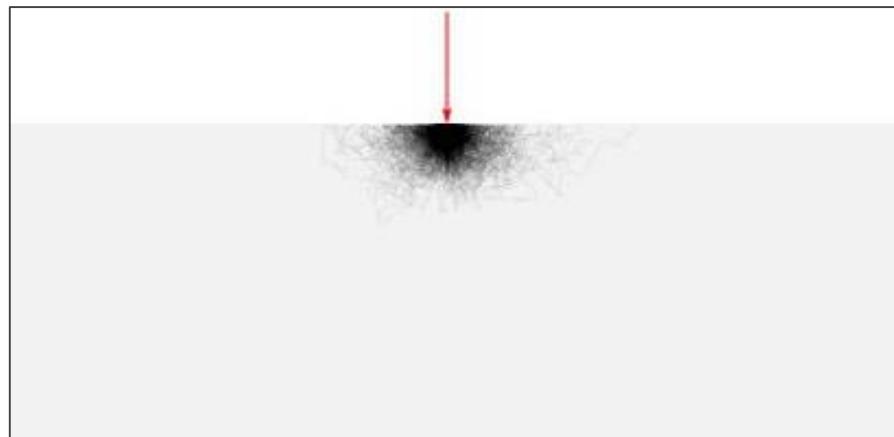
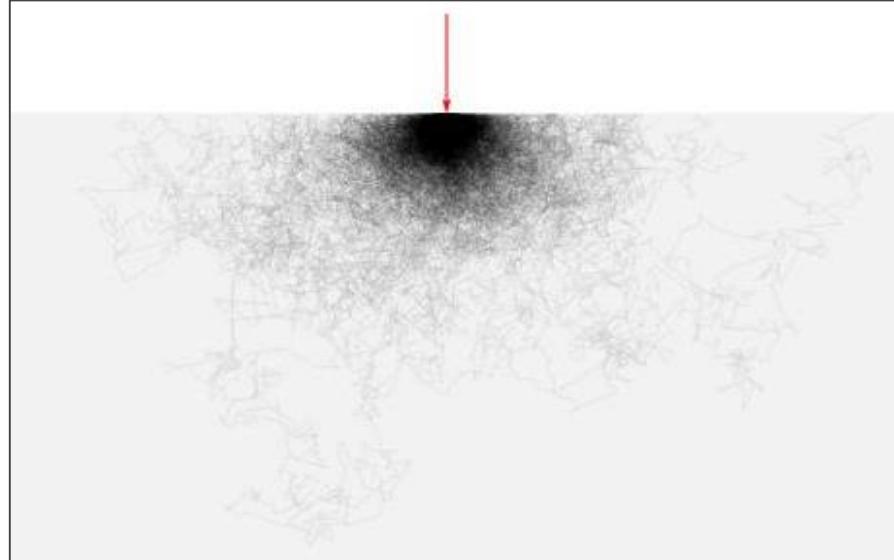






# Light simulation under the surface

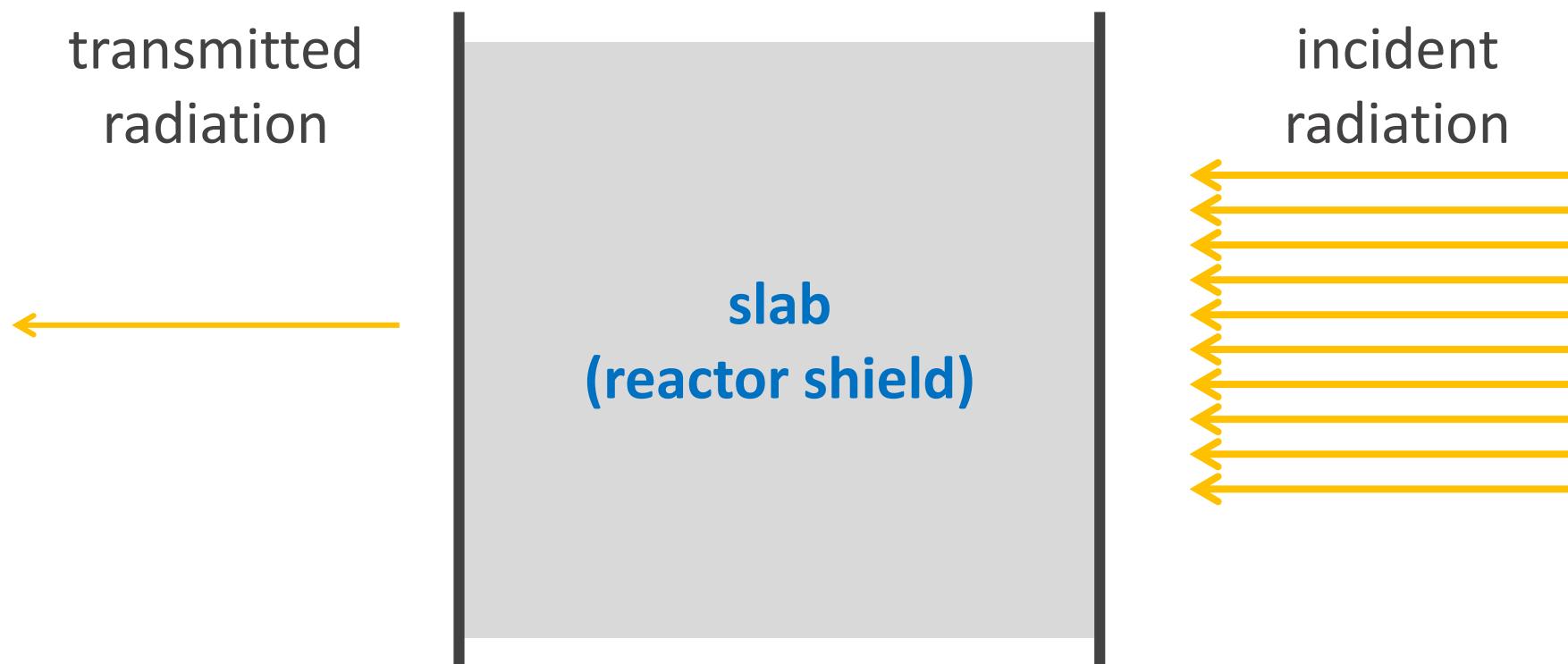
- Classical random walk
  - Oblivious to the boundary
- Goal
  - Guide paths toward the boundary





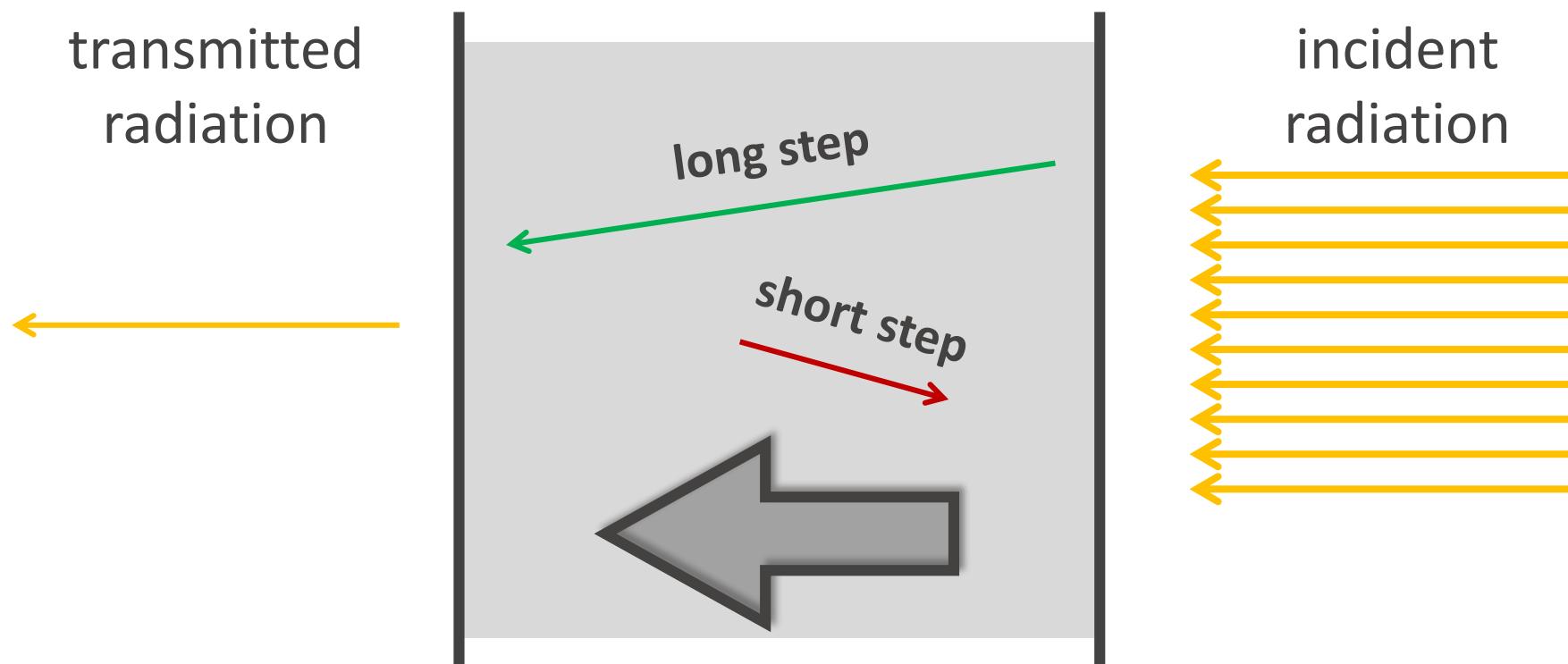
# Previous work in neutron transport

- Reactor shield design
  - One in a billion particles makes it through



# Previous work in neutron transport

- Path stretching [Clark '66, Ponti '71, Spanier '71]



# Zero-variance random walk theory

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- Zero variance random walk theory  
[Kahn '54, Kalos and Whitlock '08, Hoogenboom '08, Booth '11]
- [Dwivedi '81]
  - Synergistic path stretching and angular sampling
  - Solid theory, no heuristics

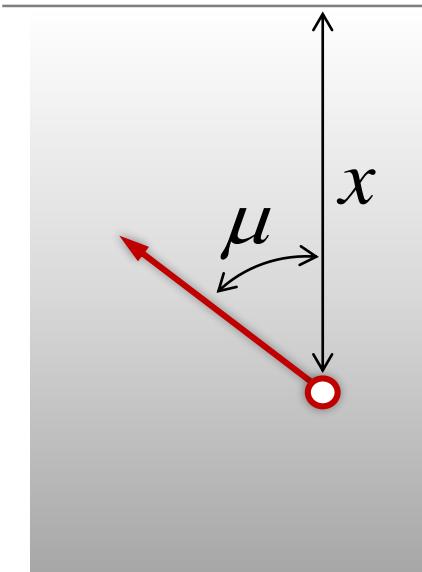
# Analytical radiance solution

- Case's singular eigenfunctions  
[Case 1960, McCormick and Kuscer 1973]



Singular eigenfunctions

*Kenneth W. Case*

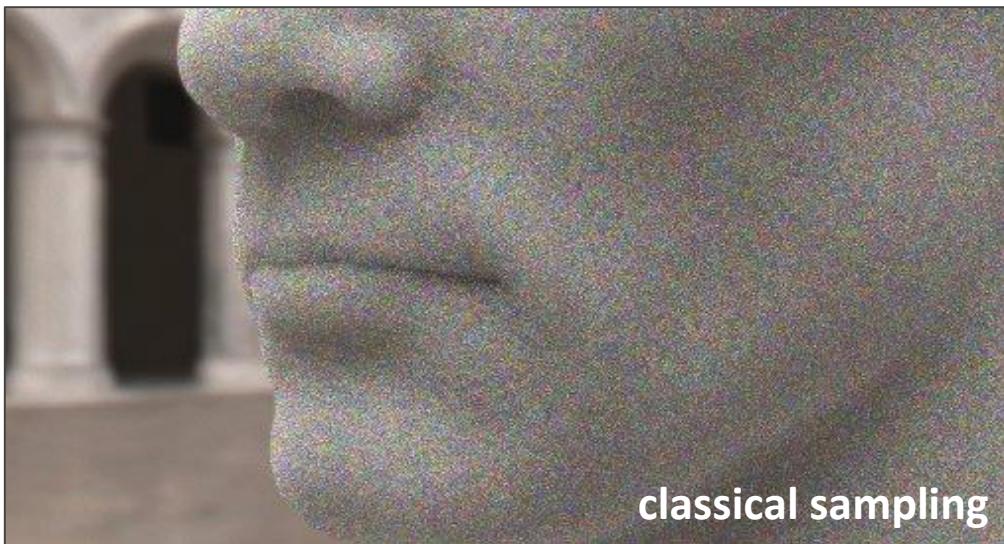


$$(x, \mu) = \int_{-1}^1 \phi(v, \mu) e^{-x/v} dv + \phi_0(v_0, \mu) e^{-x/v_0}$$

transient terms      asymptotic terms

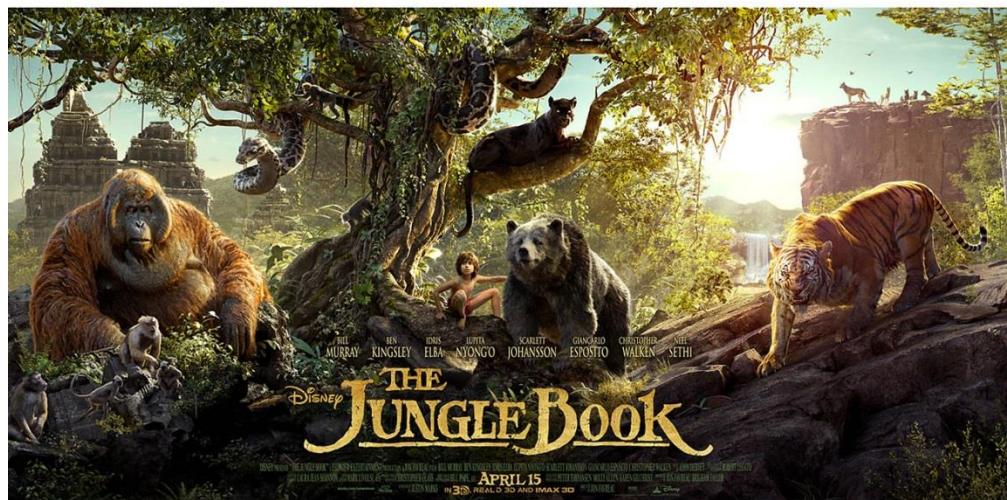
# Use in rendering

equal-time comparison, 100 samples per pixel





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# 3D PRINTING & APPEARANCE FABRICATION

# 3D printing



prosthetics



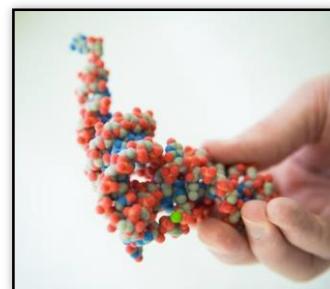
auto & aero



prototyping



utility items

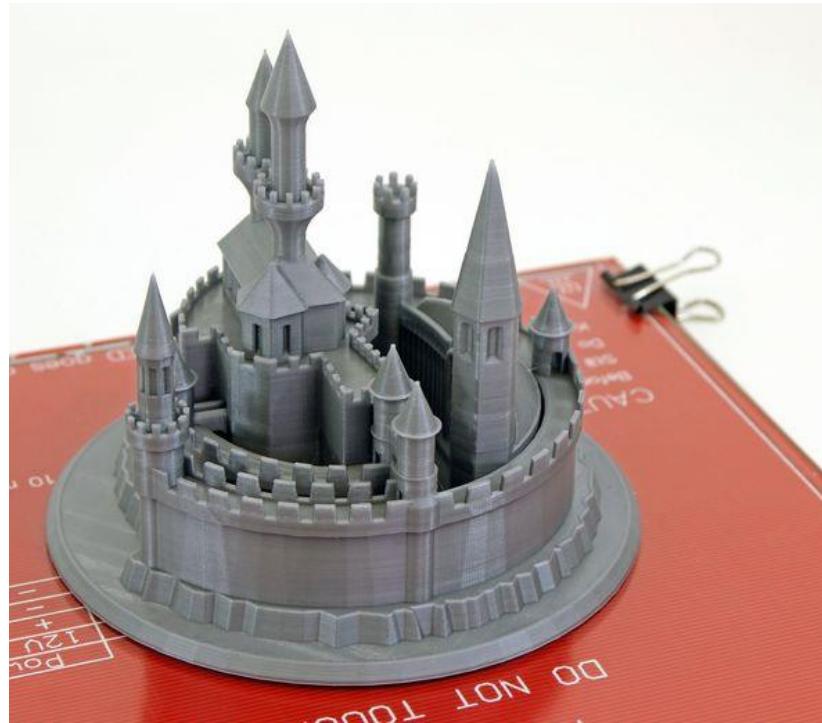


learning



fashion & art

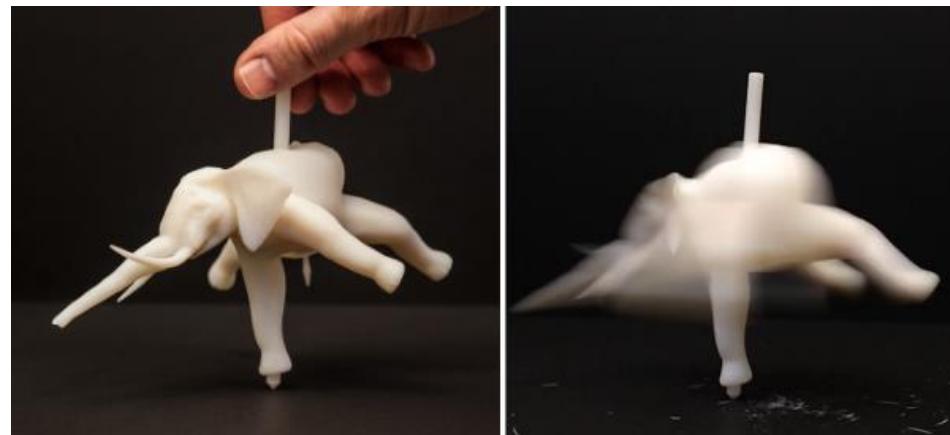
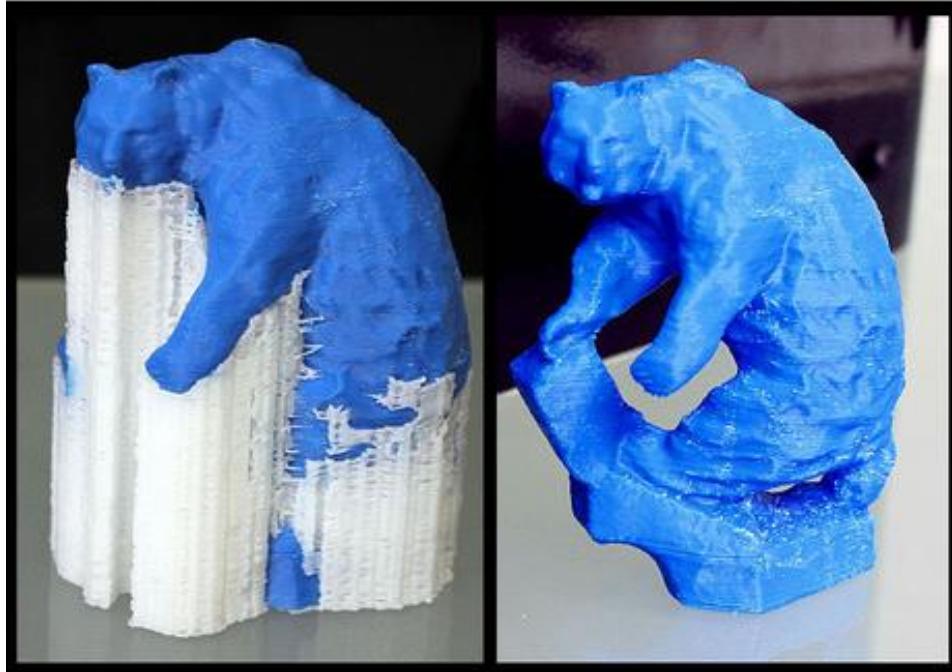
# 3D printing – FDM



© 2016, Prusa Research

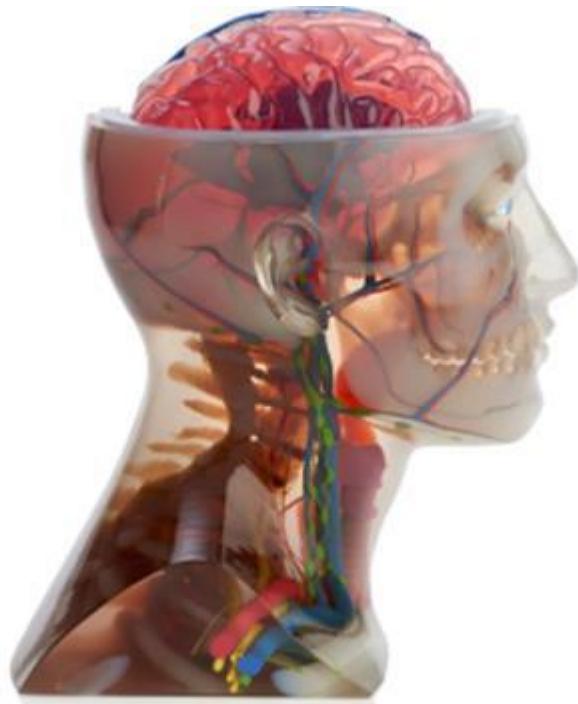
# 3D printing

- **3D model**
  - CSG, triangle-mesh, ...
  - STL format
- **Rasterization into a volume**
  - “Slicer” software
  - similar to 2D rasterization
  - Design of support materials
- **Geometric optimization**
  - Structural integrity, balance
  - Stiffness simulation
- **Appearance optimization**
  - Color, transparency, roughness, ...





Stratasys J750 full color





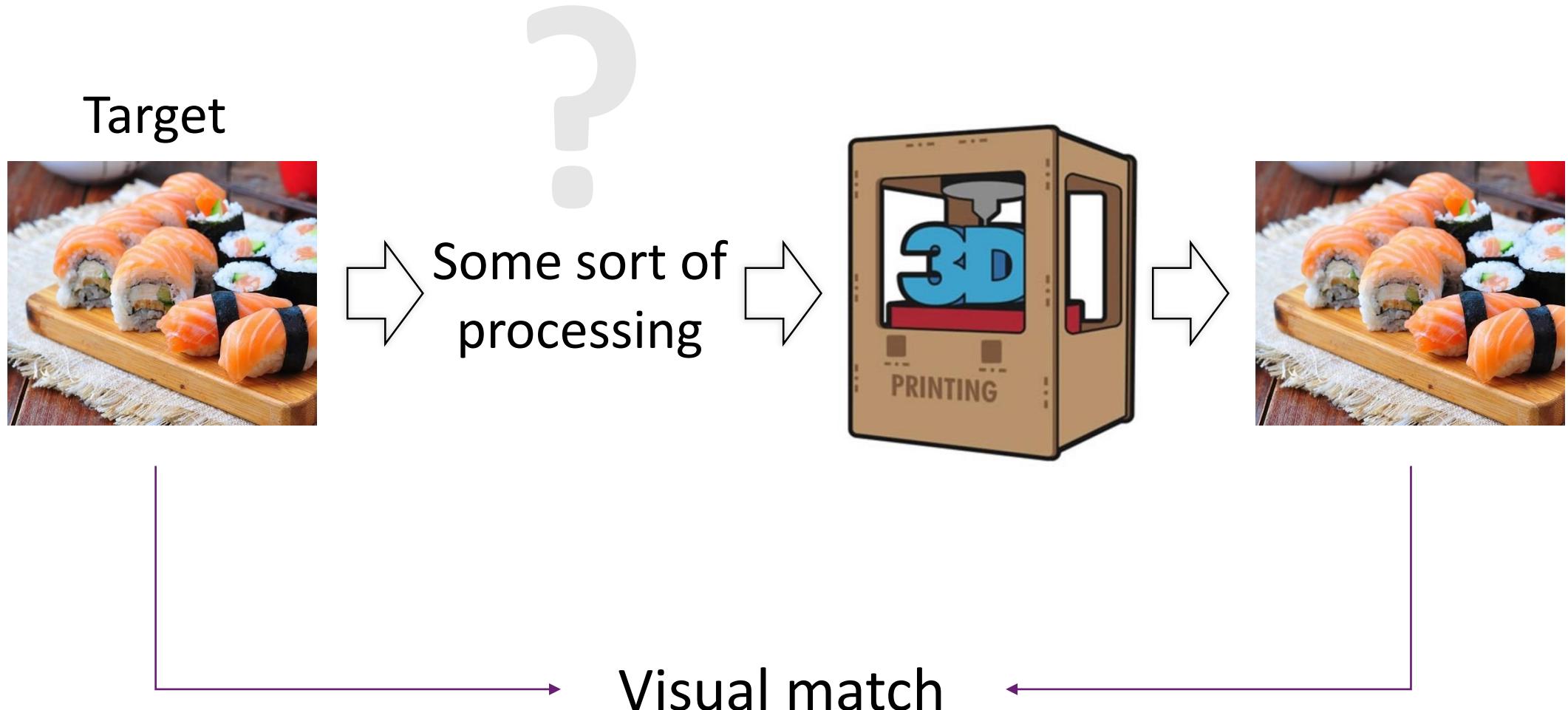
# Does the 3D printed sushi look like real sushi?



# New problem: “Realistic appearance fabrication”



# Appearance fabrication



Example of our 3D printing research:

## **SCATTERING-AWARE TEXTURE REPRODUCTION IN 3D PRINTING**

# Textured 3D prints



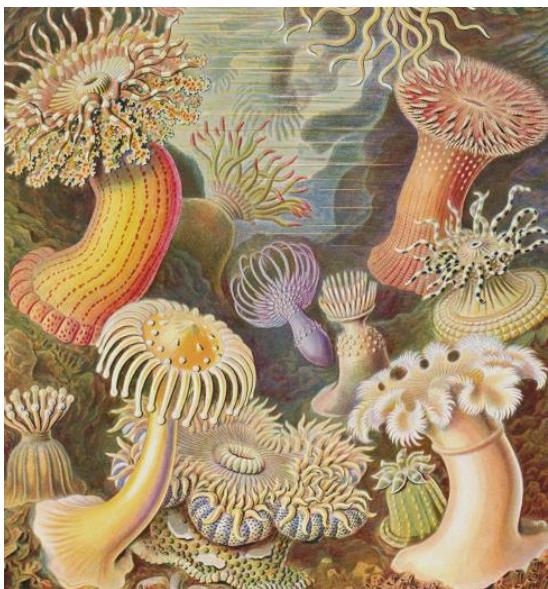
# Translucency blurs textures



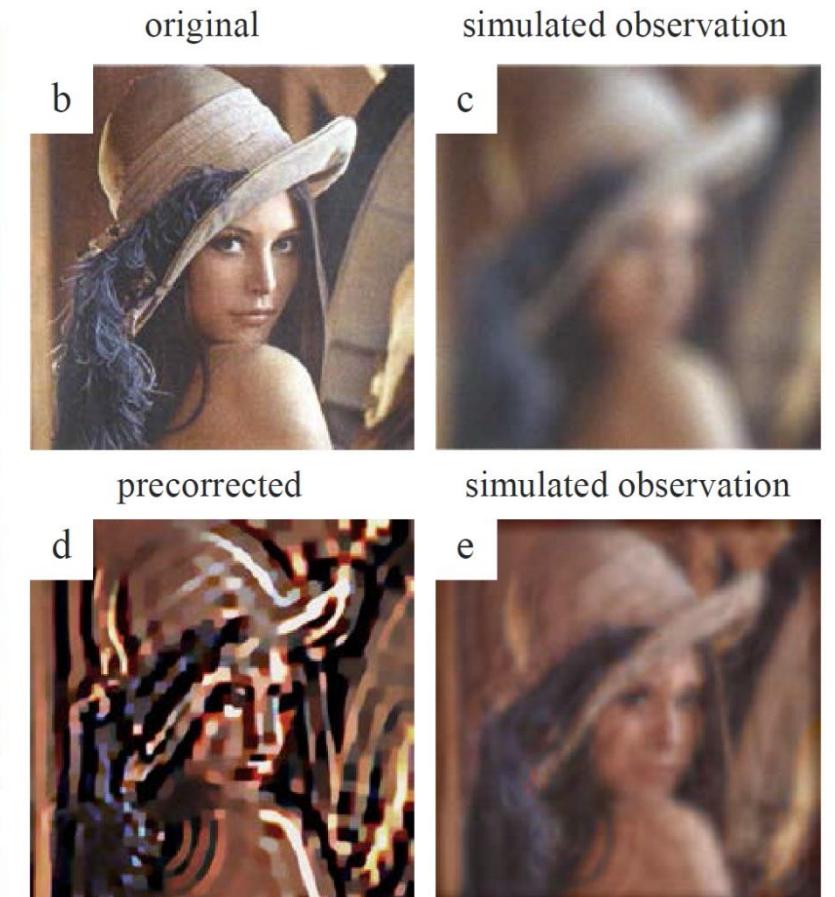
Target



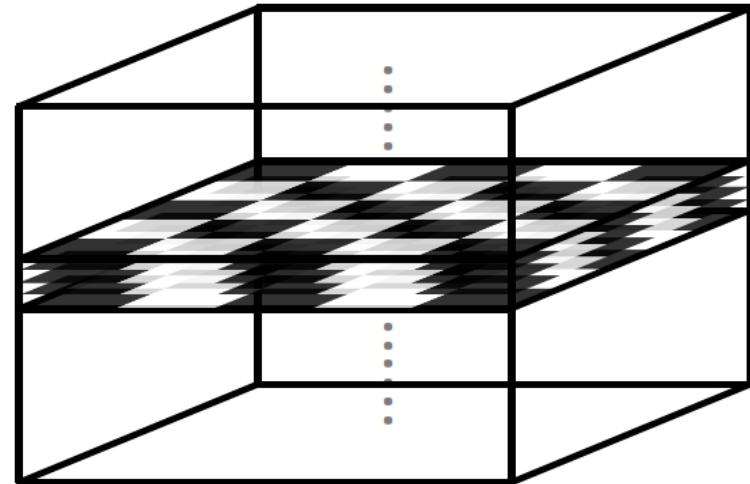
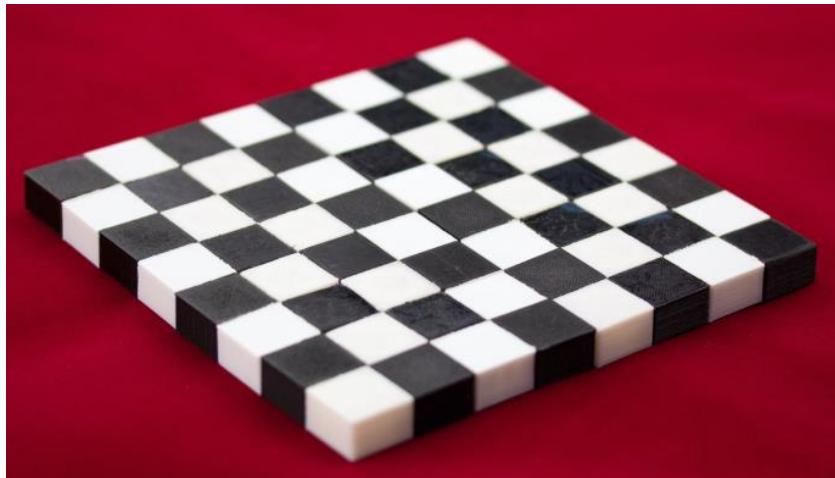
Default print



# Precorrection for optical aberrations

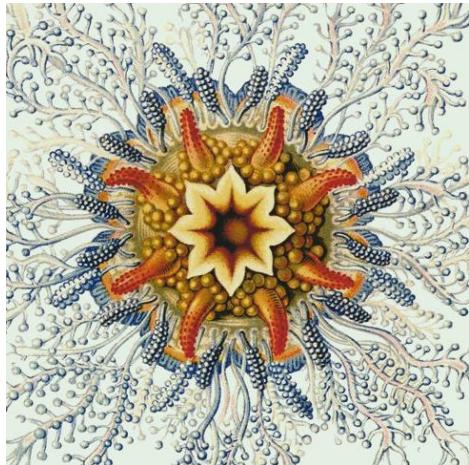


# 3D print is not just a flat image

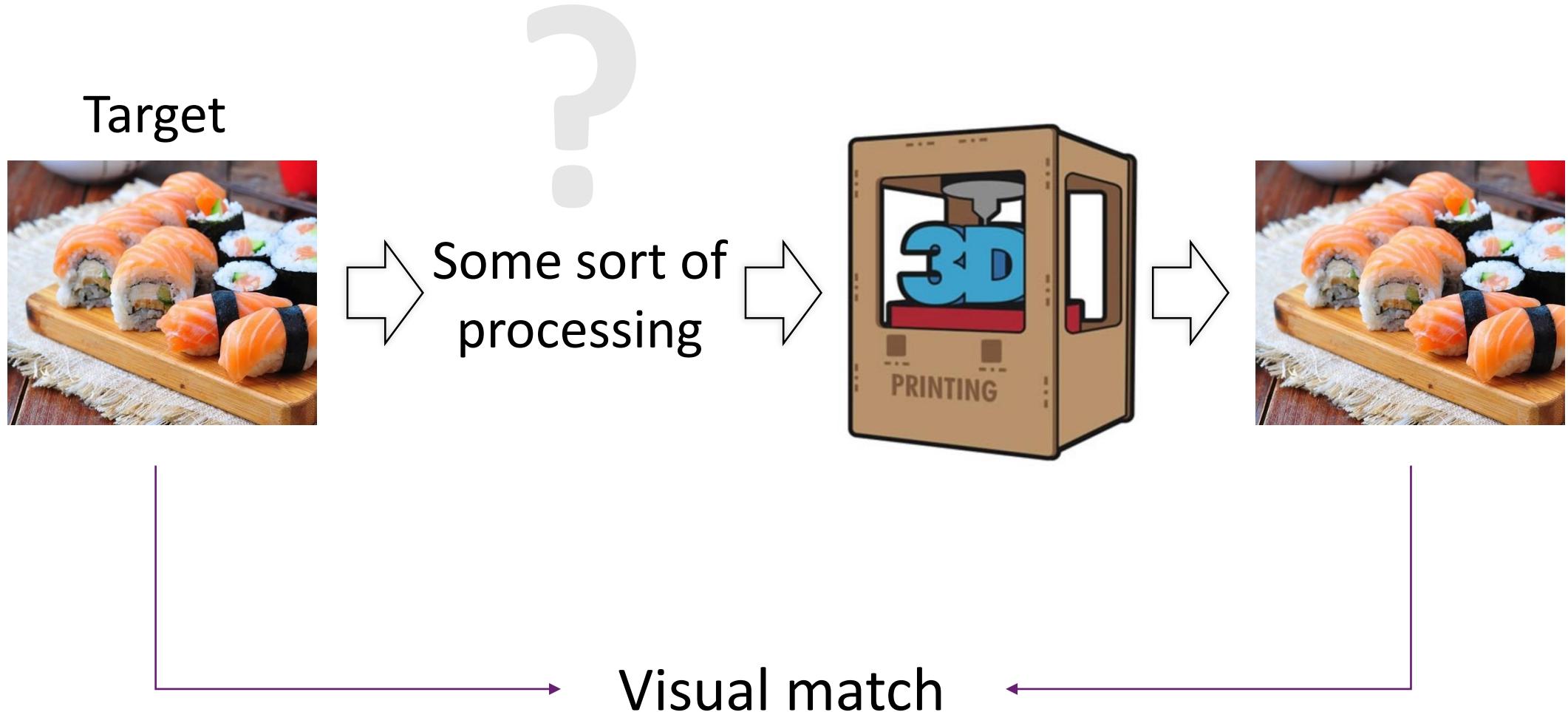


# Iterative precorrection process

Target

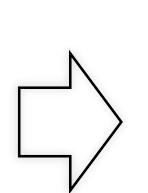
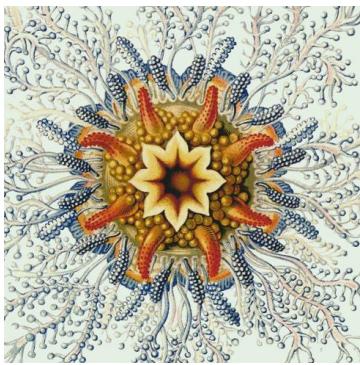


# Appearance fabrication

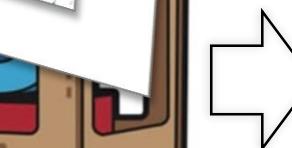
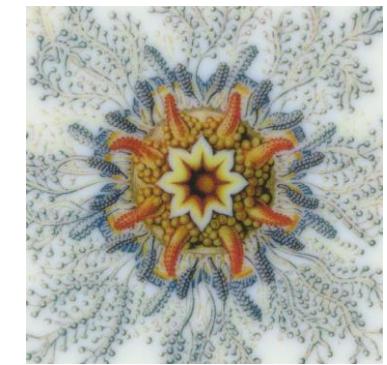
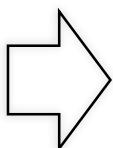
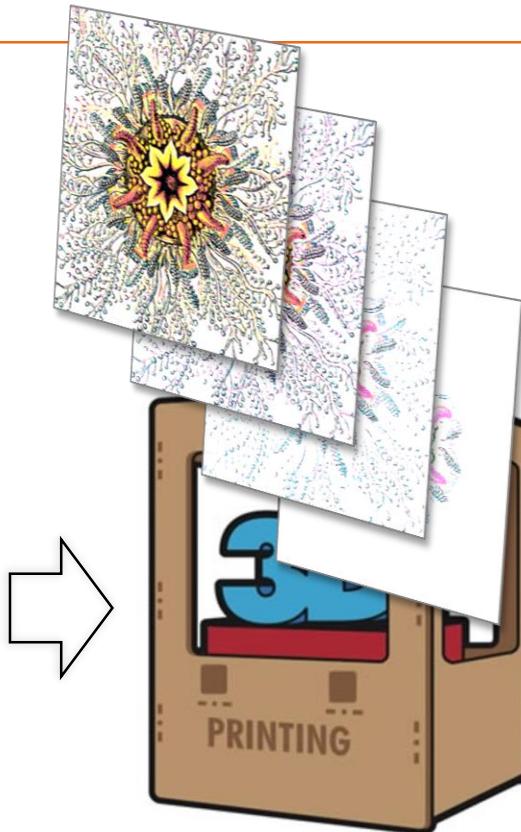


# Appearance fabrication

Target

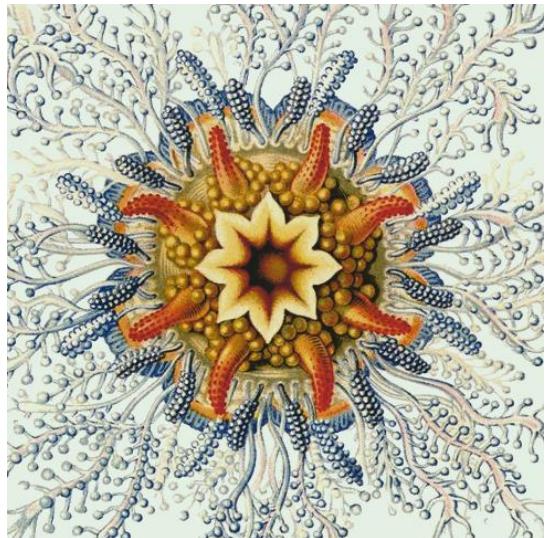


Our  
iterative  
precorrection

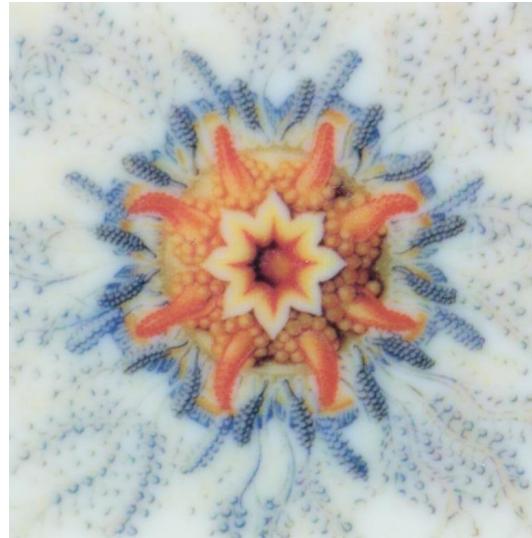


# More results

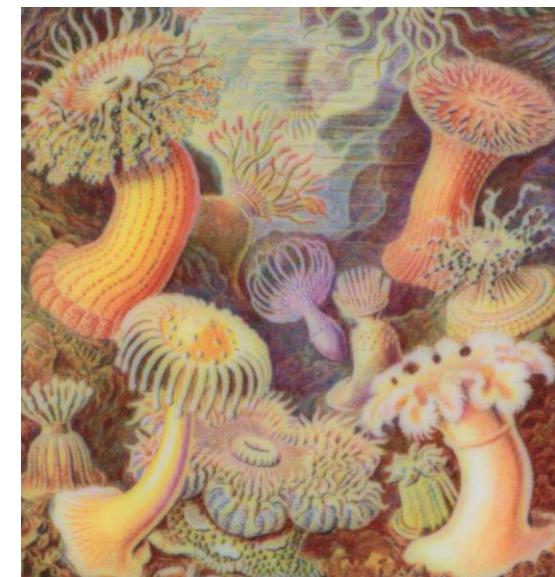
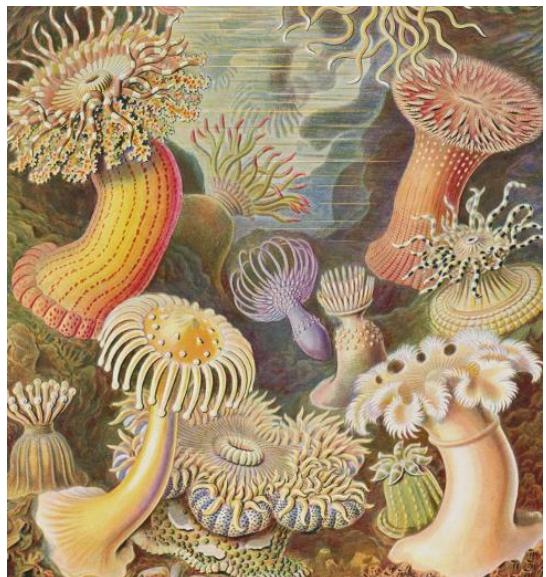
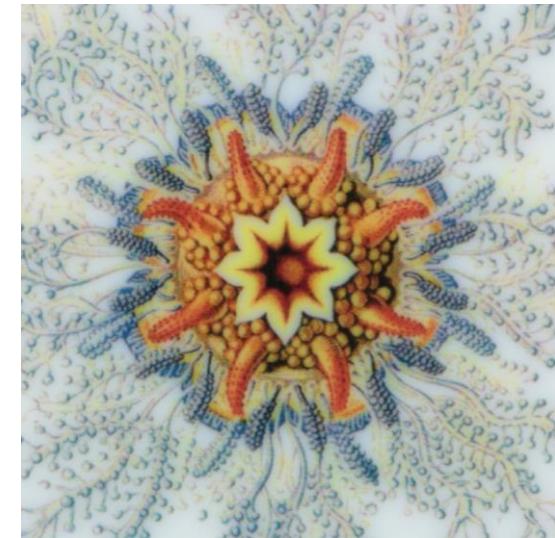
Target



Default print

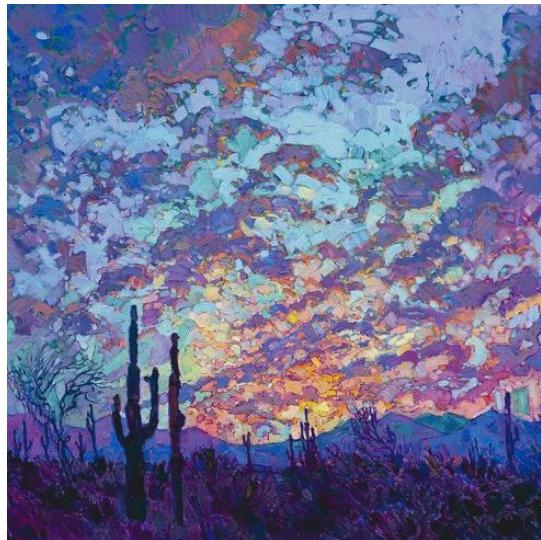


Our result



# More results

Target



Default print



Our result



## Student brněnského VUT navrhl a vyrobil protetické oko na 3D tiskárně

9. 8. 2018

Již dlouhá léta pracují protetici na tom, aby umělé oči, které slouží jako náhrady při zrakových postiženích, vypadaly co nejrealističtěji. Strojně vyráběné oční náhrady jsou stále velkou výzvou. Zrakově postižený student VUT v Brně, Ondřej Vocílka, letos přišel s revolučním nápadem vyrobit oční protézu pomocí 3D tisku. A u MCAE Systems našel tu nejhodnější 3D tiskárnu - Stratasys J750 s technologií PolyJet.



Přednáška o technologiích 3D tisku na FSI VUT v Brně Ondřeje Vocílku zaujala natolik, že začal přemýšlet o jejím využití při výrobě oftalmologických protéz a jak by je bylo možné co nejvíce přizpůsobit pacientům. Po dohodě s přednášejícím se začal tomuto tématu věnovat ve své bakalářské práci.

Standardně se oční protézy vyrábí ručně ze skla či akrylátu, a tak estetický dojem celé protézy závisí zejména na zkušenostech a šikovnosti protetika. Nejnáročnější částí ruční výroby je duhovka, protože se musí co nejvíce podobat zdravému oku pacienta. Toho je však konvenčními způsoby obtížně dosáhnout.

Ondřej se své práci zabývá výrobou prototypu oční protézy pomocí 3D tisku na bázi modelu získaného skenováním své ručně vyrobené starší protézy z PMMA. Model byl modifikován v programu 3ds Max 2017. Tímto postupem bylo vymodelováno jádro oční protézy s texturou, která byla vytvořena z fotografie oka. Vytisklé jádro oční protézy bylo dále zalito čirým akrylátem, aby se vytvořil zdravotně nezávadný povrch.

Samotná výroba jádra oční náhrady byla realizována na [3D tiskárně Stratasys J750](#) s technologií aditivní výroby **PolyJet** [*technologie pro přesný 3D tisk modelů nanášením fotopolymeru a jeho vytvrzováním UV zářením*]. Tato tiskárna je díky svým možnostem ideální pro takto náročný tisk. Zde do procesu vstupuje MCAE Systems, která 3D tiskárny značky Stratasys nabízí na českém a slovenském trhu.

<https://www.mcae.cz/cs/student-brnenskeho-vut-navrhl-vyrobil-proteticke-oko-3d-tiskarne/>

# What's next?





**Computer  
Graphics  
Charles  
University**



CGG BBQ



2015  
**HiVisComp**





# Khronos Prague Meetup



9  
OCT

Tuesday, October 9, 2018

## Let's talk about 3D graphics development vol.4



Hosted by Ondřej Smrž  
From [Khronos Prague Meetup](#)  
Public group



The Vulkan logo, featuring the word "Vulkan." in a bold, red, sans-serif font. A stylized red swoosh or wave graphic starts from the top left and curves over the letter "V", extending towards the right side of the word.

- **CGB = Computer graphics beer**
  - Roughly once a month in a pub in Prague
- **CGBBQ = Computer graphics barbecue**
  - Once a year in May
- **CG seminar**
- **HiVisComp**
  - Every winter (includes skiing), gathering of computer graphics enthusiasts from Czech Republic, Slovakia and elsewhere
  - <http://www.hiviscomp.cz/>
- **CESCG**
  - Student research
  - Slovakia, Austria, Czech rep., Hungary, DE, FR, apod.
  - <http://www.hiviscomp.cz/>



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# Light

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- Computer Graphics Group • Charles University, Prague • [cgg.mff.cuni.cz](http://cgg.mff.cuni.cz) •

# Different approaches to rendering

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- **Phenomenological**
  - Traditional, “old” computer graphics
  - E.g. Phong shading model, colors between 0 and 1, etc.
- **Physically-based**
  - Based on a proper mathematical formulation
  - Rendering algorithms = numerical methods for solving the rendering equation
  - Radiance values between 0 and infinity

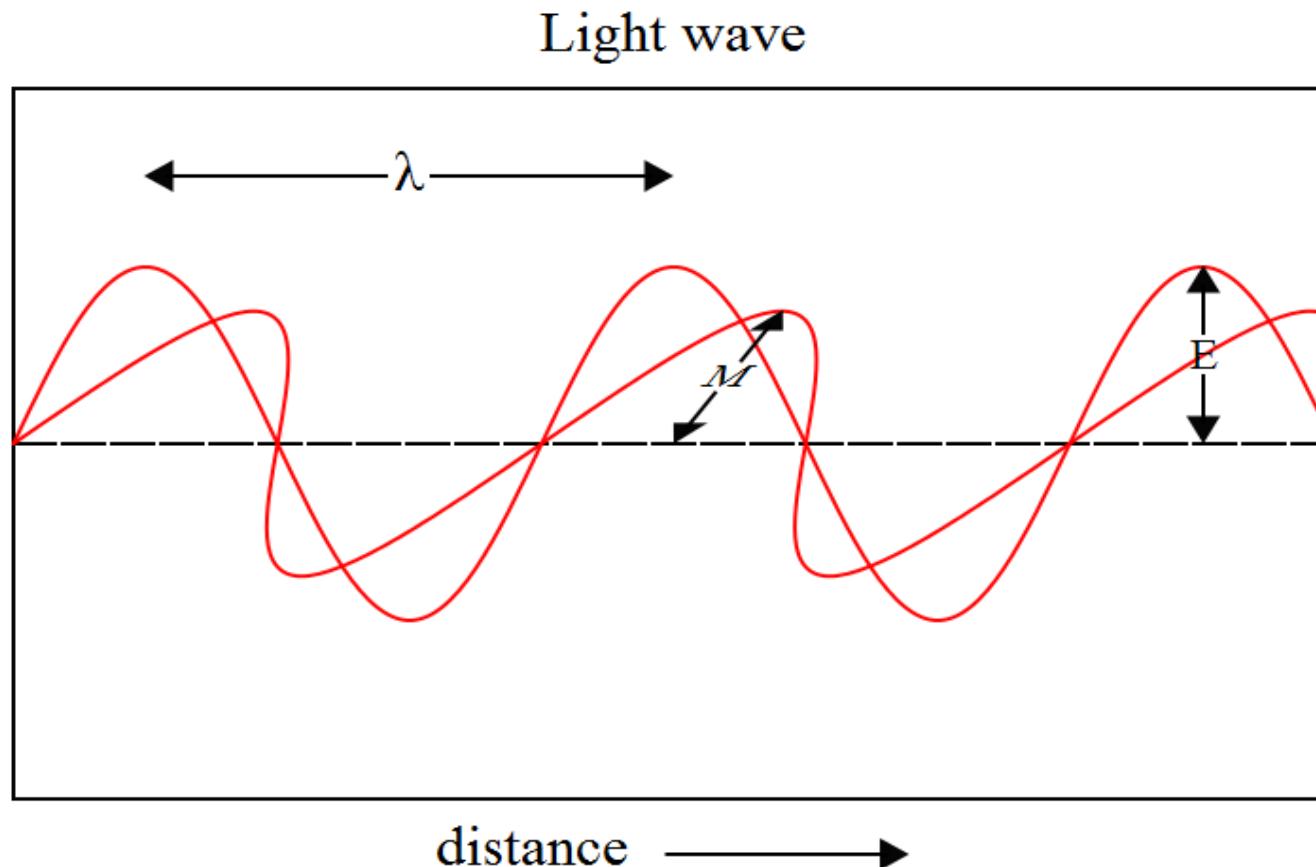
# Mathematical model

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- Image synthesis (rendering) = light transport simulation
- We need a **mathematical model** for light
- Formulation of the model = choice of level of detail
  - No need to model the behavior of every single photon
  - Need simplifying assumptions

# Light

- EM radiation (an EM wave propagating through space)



$\lambda$  = wave length

$E$  = amplitude of electric field

$M$  = amplitude of magnetic field

Image: Wikipedia

# Light

- Frequency of oscillations => wavelength => perceived color

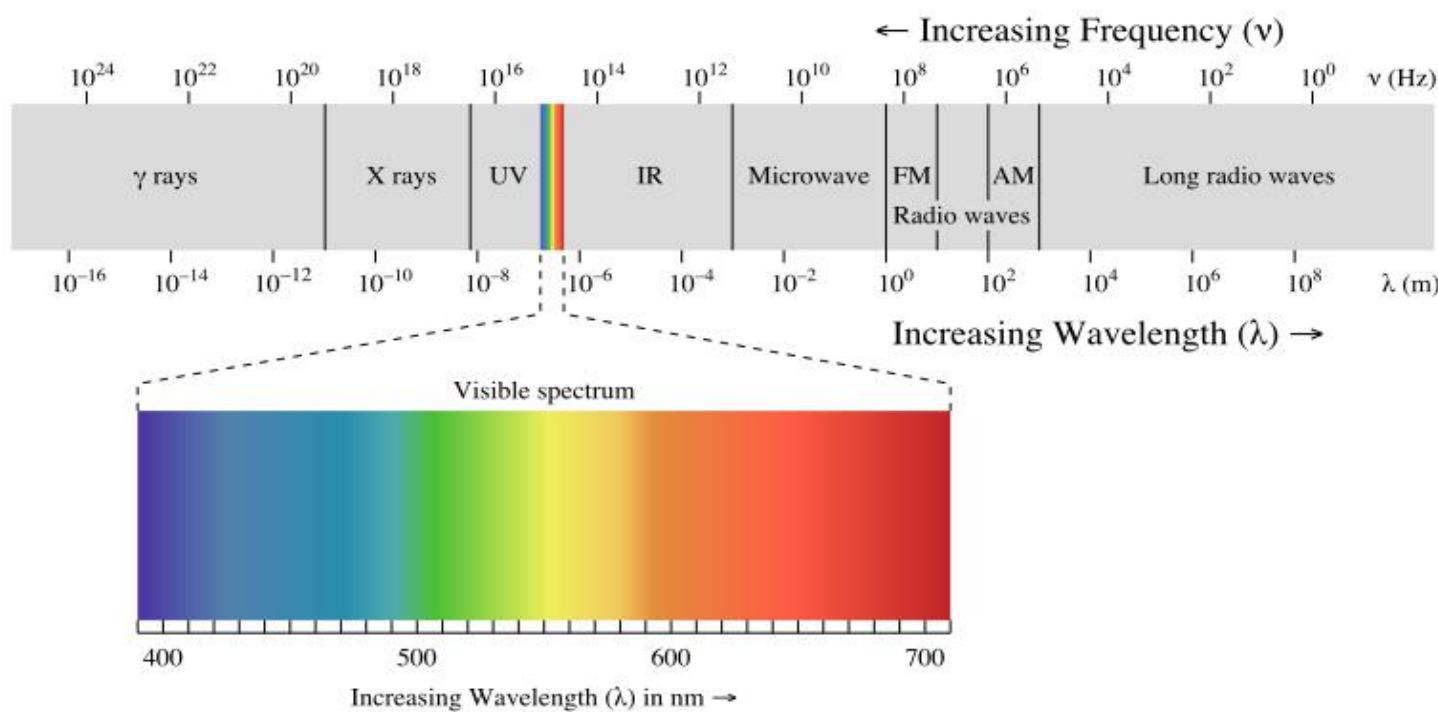


Image: Wikipedia

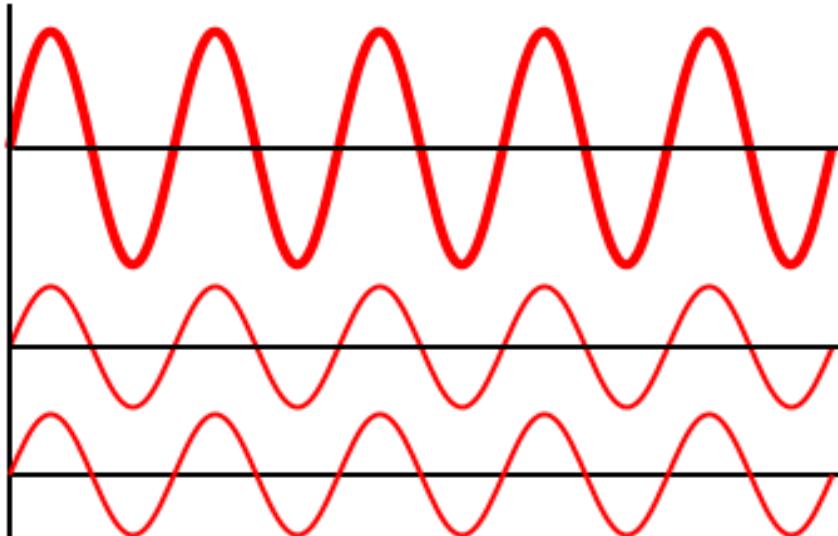
# Various kinds of optics

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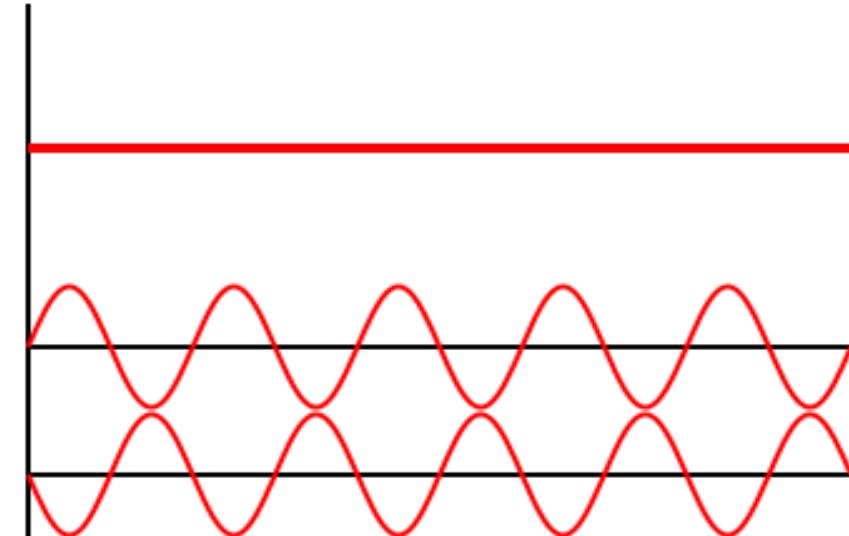
- **Geometry (ray) optics**
  - Most useful for rendering
  - Describes bulk, macroscopic effects of light
  - It is not a complete theory (Does not describe all observed phenomena, such as diffraction, interference etc.)
- **Wave optics** (light = E-M wave)
  - Important when describing interaction of light with objects of size on par with the light wavelength
  - Interference (soap bubbles), diffraction, dispersion
- **Quantum optics** (light = photons)
  - Necessary to describe interaction of light with atoms

# Effects of the wave nature of light

- Interference



Constructive



Destructive

- Causes **iridescence** (structural coloration)

# Iridescence

- Thin-film interference
- Color changes with the observation angle



# Iridescence – Structural coloration

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- Biological tissues can have layers causing interferences



# Iridescence – Structural coloration



Img: <http://en.wikipedia.org/wiki/Iridescence>

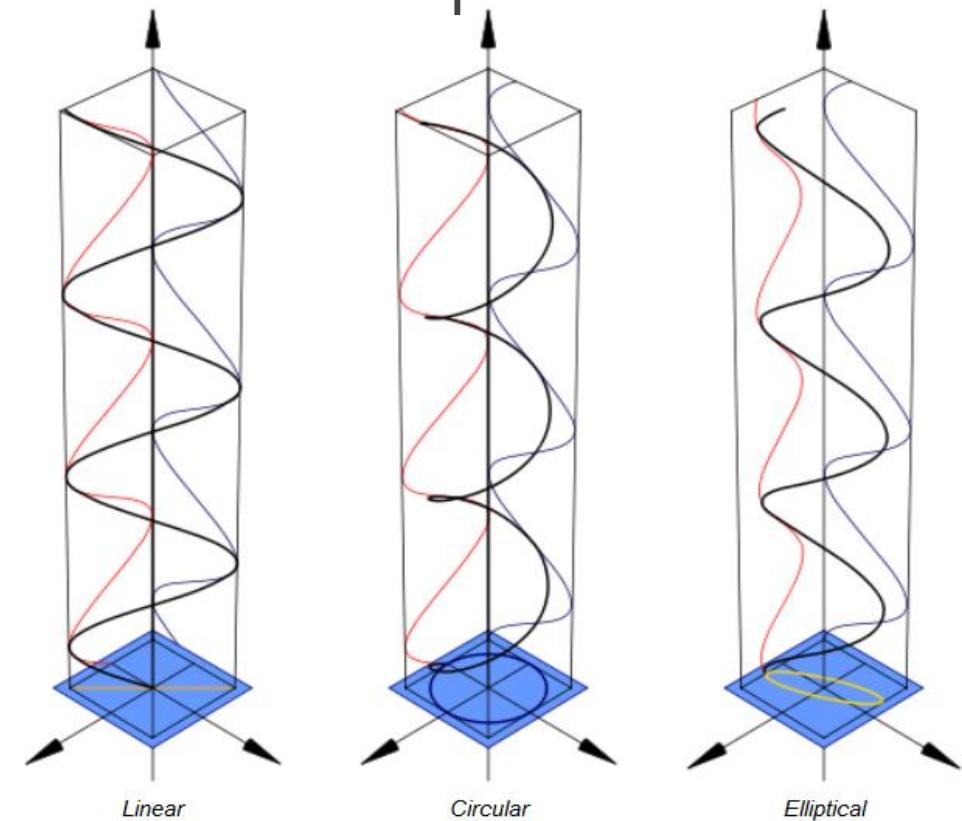
# Iridescence – Structural coloration



Img: <http://en.wikipedia.org/wiki/Iridescence>

# Polarization

- Preferential orientation of the E-M waves with respect to the direction of travel
- Unpolarized light – many waves with different polarization
- More in the “Predictive rendering” class



# Polarization

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- Skylight is partially polarized



- Specular reflections are polarized





# Thank you!

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