thrive
SIGGRAPH2019
LOS ANGELES • 28 JULY – 1 AUGUST

Dissertation award talk:

TOWARDS ULTIMATE REALISM IN RENDERING

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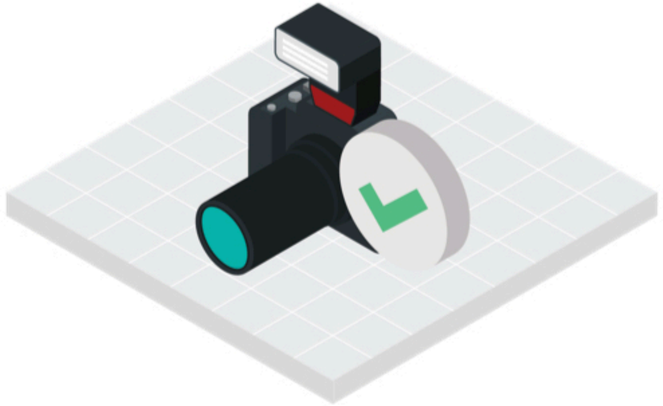
UC Santa Barbara (Assistant Professor, 2018 -)



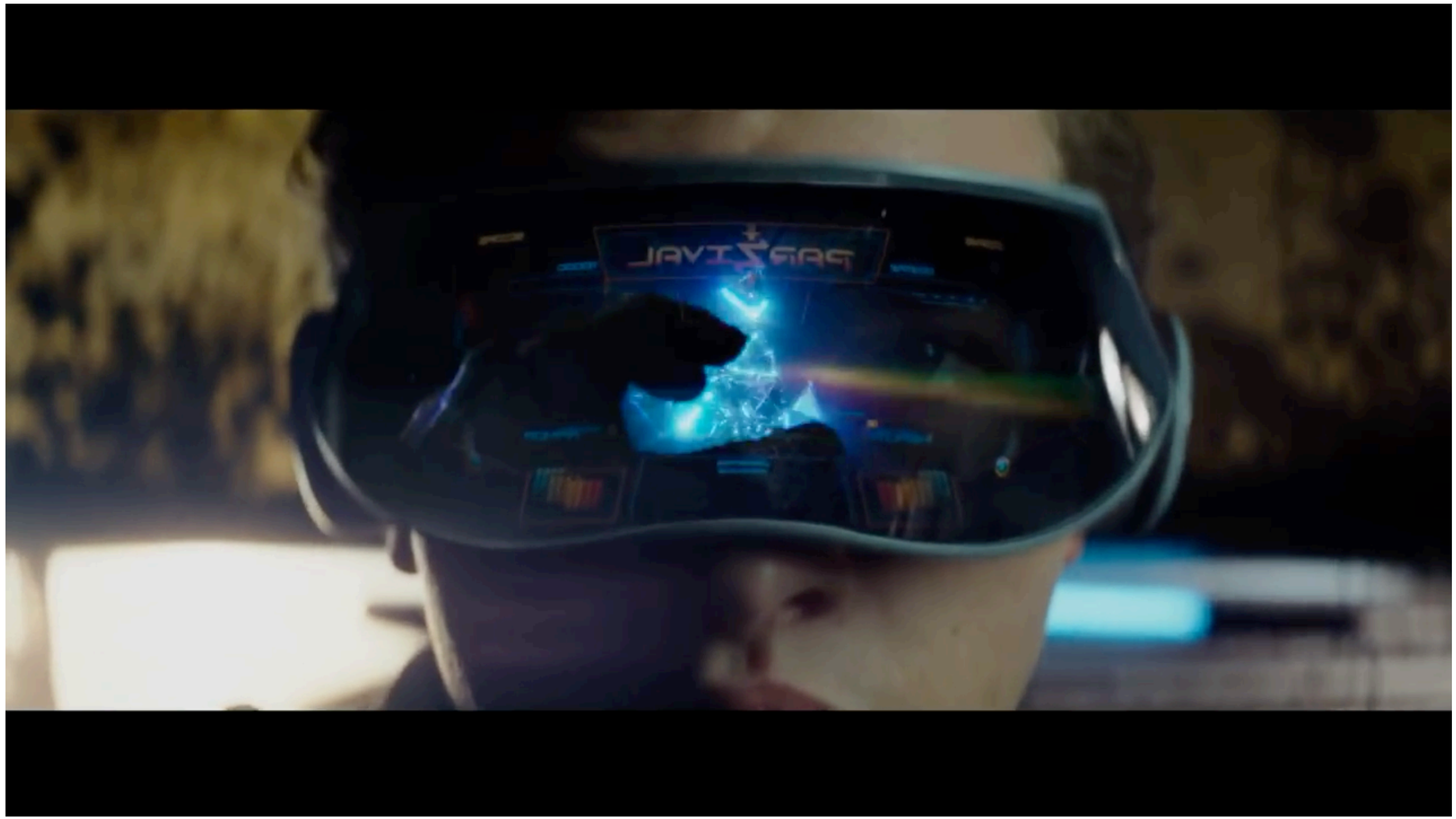
PHOTOGRAPHY & RECORDING ENCOURAGED

WHAT IS ULTIMATE REALISM?

WHAT IS ULTIMATE REALISM?

The Matrix (1999 movie)

WHAT IS ULTIMATE REALISM?



Ready Player One (2018 movie)

ULTIMATE REALISM == A NEW WORLD

What is ultimate realism in Computer Graphics?

ULTIMATE REALISM IN COMPUTER GRAPHICS?

- One must not be able to distinguish the Computer Generated Imagery (CGI) from reality / photos
  - This is known as **(photo)realism**

- One must be able to interact with everything
  - It includes senses such as touch and smell
  - Visually, this indicates **real-time performance / speed**

WHAT HAVE I CONTRIBUTED TO ULTIMATE REALISM?

Or, what's in my dissertation?

MY DISSERTATION

High level goal: **realism** and **speed**

detailed rendering

appearance modeling

Interactive ray tracing

PART I: DETAILED RENDERING

Photorealism for known but difficult details

detailed rendering (from microstructures)

appearance modeling

interactive ray tracing

RENDERING IS POWERFUL TODAY

Car rendered in NVIDIA Iray

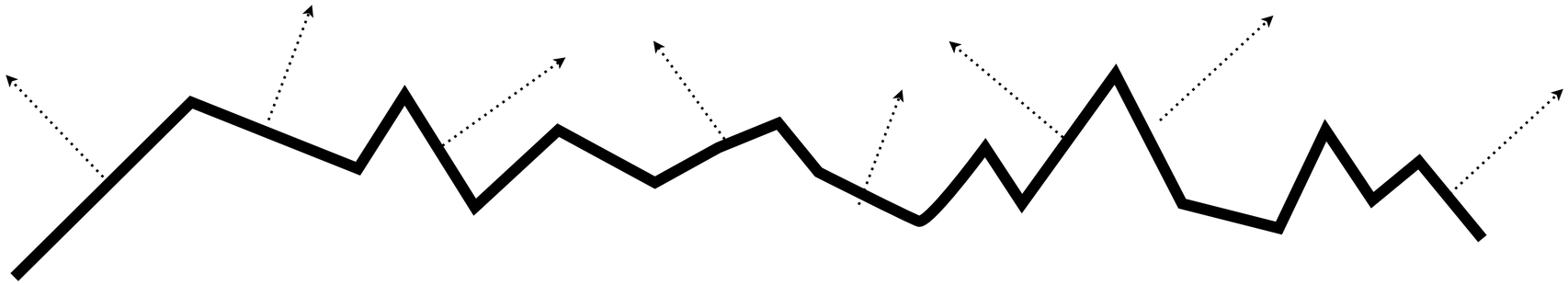
Mouse rendered in
Autodesk 3DS Max

BUT REAL WORLD IS MORE COMPLICATED

Real photograph of a car

Real video of a mouse

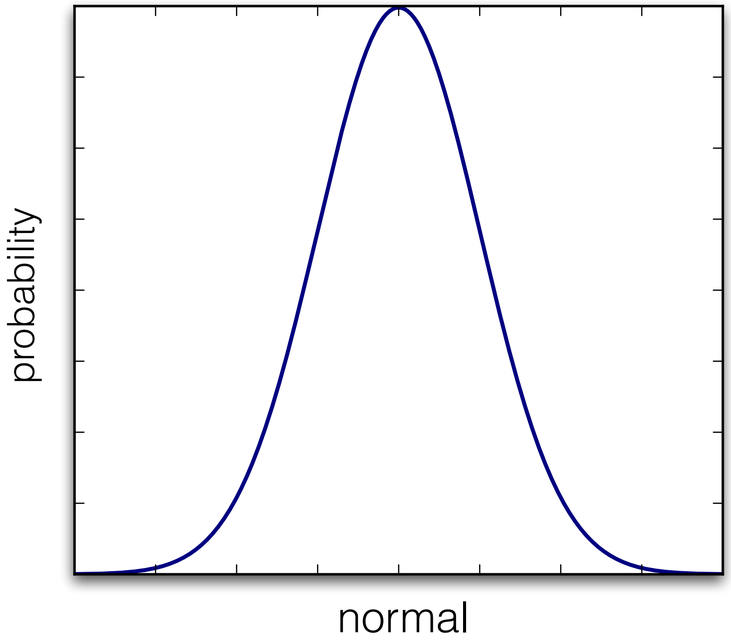
A CLOSE LOOK AT A SURFACE



Surface = Specular microfacets + Different normals

NORMAL DISTRIBUTION: IDEAL VS. REAL

Normal Distribution Function (NDF)



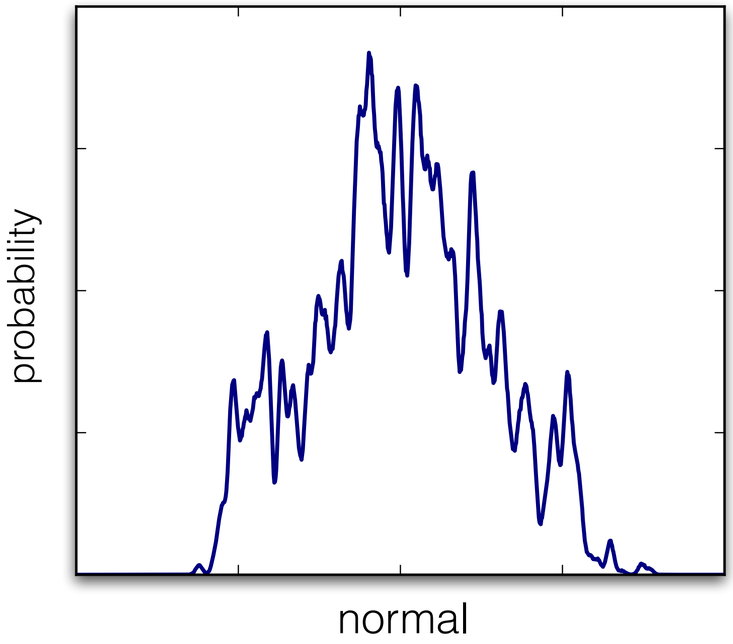
What we have previously
(**statistics**)

Smooth
distribution

Smooth
appearance

NORMAL DISTRIBUTION: IDEAL VS. ACTUAL

Normal Distribution Function (NDF)



What we have now
(**actual distribution**)

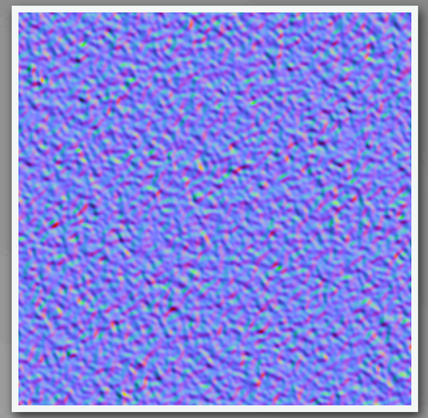
Actual distribution

More realistic appearance

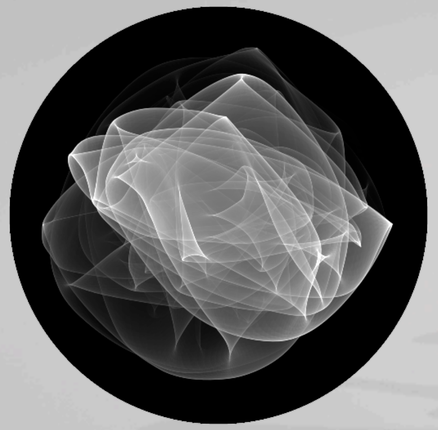
Actual distribution

More realistic appearance

Defining the details



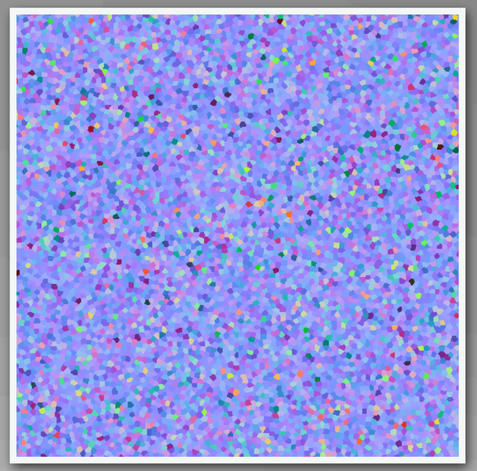
normal map



NDF

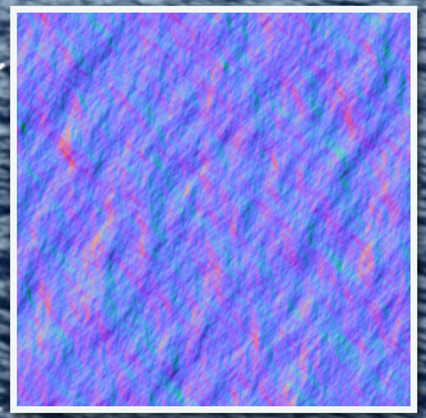
Normal map resolution:

≈ 200K x 200K



SIGGRAPH 2014
technical paper trailer

Metallic flakes



Ocean waves

HOW TO RENDER THE DETAILS?

$$D(\mathbf{s}) = \int_{\mathbb{R}^2} G_p(\mathbf{u})\delta(n(\mathbf{u}) - \mathbf{s})d\mathbf{u}$$

HOW TO RENDER THE DETAILS?

$$R_k(\boldsymbol{s}) = B_{2D}(\boldsymbol{s};\boldsymbol{m}_k,l_k)\,\xi_2\,e^{-\frac{i2\pi\xi_3}{\lambda}H(\boldsymbol{s})} \approx l_k^2 G_{2D}(\boldsymbol{s};\boldsymbol{\mu}_k,\sigma_k)\,\xi_2\,e^{-\frac{i2\pi\xi_3}{\lambda}\left(\alpha_k+\boldsymbol{H'}(\boldsymbol{m}_k)\cdot\boldsymbol{s}\right)}$$

$$\cdots \qquad G_i(u,s) = c_i \underbrace{\exp\left(-\frac{(u-u_i)^2}{2\sigma_h^2}\right)}_{\text{position band}} \underbrace{\exp\left(-\frac{(s-n(u_i))^2}{2\sigma_r^2}\right)}_{\text{normal band}}$$

$$\cdots \qquad \text{experf}(a,b,x_0,x_1) = \int_{x_0}^{x_1} \exp(-a(x-b)^2)\text{erf}(x)dx$$

$$\Sigma_i^{-1} = \frac{1}{\sigma_h^2}\begin{pmatrix}\mathbf{I} & \mathbf{0}\\ \mathbf{0} & \mathbf{0}\end{pmatrix} + \frac{1}{\sigma_r^2}\begin{pmatrix}\mathbf{J}^T\mathbf{J} & -\mathbf{J}^T\\ -\mathbf{J} & \mathbf{I}\end{pmatrix}$$

$$D(\mathbf{s}) = \int_{\mathbb{R}^2} G_p(\mathbf{u})\delta(n(\mathbf{u})-\mathbf{s})d\mathbf{u}$$

$$f_r(\boldsymbol{\omega}_i,\boldsymbol{\omega}_o) = \frac{\xi_1}{A_c}\left|\int_{\bar{S}_c} R^\star(\boldsymbol{s})\,e^{-i\frac{2\pi}{\lambda}(\bar{\boldsymbol{\psi}}\cdot\boldsymbol{s})}\,d\boldsymbol{s}\right|^2 \qquad \cdots$$

$$R^\star(\boldsymbol{s}) = w(\boldsymbol{s}-\boldsymbol{x}_c)R(\boldsymbol{s})$$

$$G_c[\mathcal{P},\mathbf{s}](\mathbf{x},\mathbf{y}) = G_p(\mathbf{x})G_r(\mathbf{y}-\mathbf{s})$$

$$\mathcal{F}[g(\boldsymbol{s};\boldsymbol{\mu},\sigma,\boldsymbol{a})](\boldsymbol{v}) = e^{-i2\pi(\boldsymbol{\mu}\cdot(\boldsymbol{v}+\boldsymbol{a}))}\,e^{-2\pi^2\sigma^2\|\boldsymbol{v}+\boldsymbol{a}\|^2} = \frac{1}{2\pi\sigma^2}e^{-i2\pi(\boldsymbol{\mu}\cdot\boldsymbol{a})}\,g\left(\boldsymbol{v};-\boldsymbol{a},\frac{1}{2\pi\sigma},\boldsymbol{\mu}\right)$$

Rendered using wave optics [Yan 2018]


control
option
command


fn
control
option
command

PART II: APPEARANCE MODELING

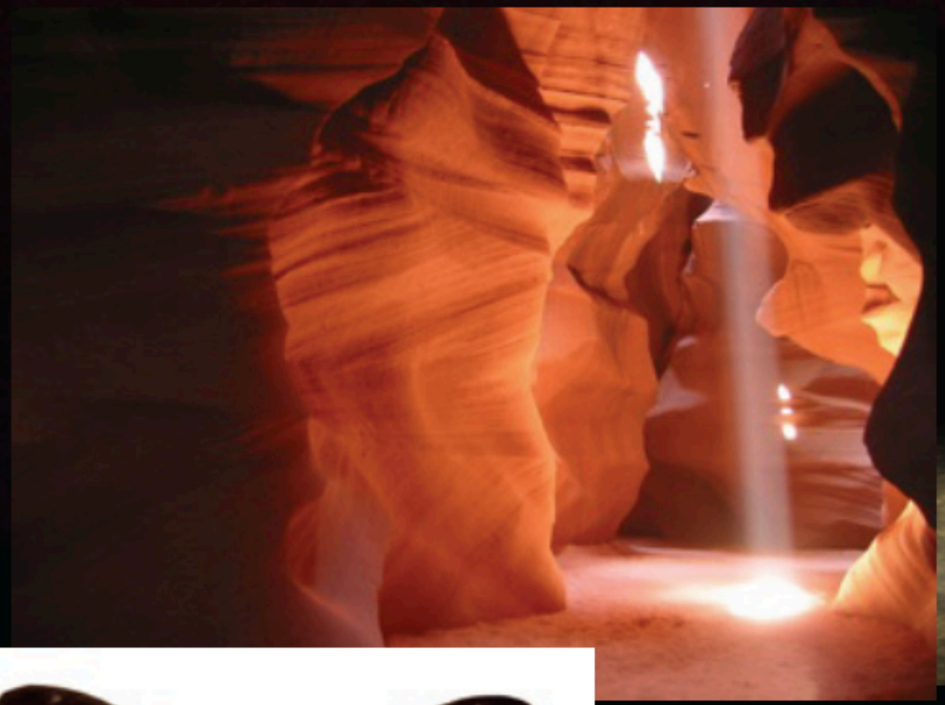
Photorealism for **unknown** materials

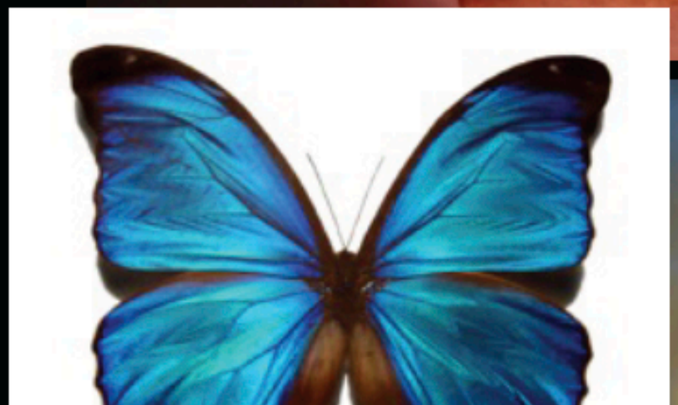
detailed rendering

appearance modeling (hair / fur rendering)

interactive ray tracing

The Appearance of Natural Materials





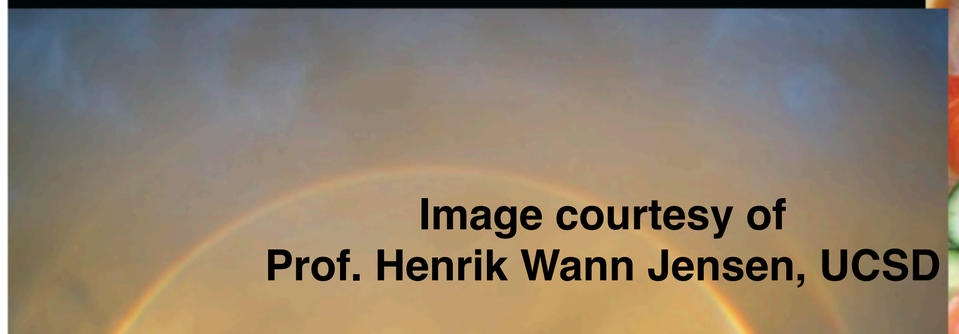


Image courtesy of
Prof. Henrik Wann Jensen, UCSD

HAIR REFLECTANCE MODELS

- Actively developing

[Marschner 03]

[Zinke 07]

[d’Eon 11]

[Chiang 16]

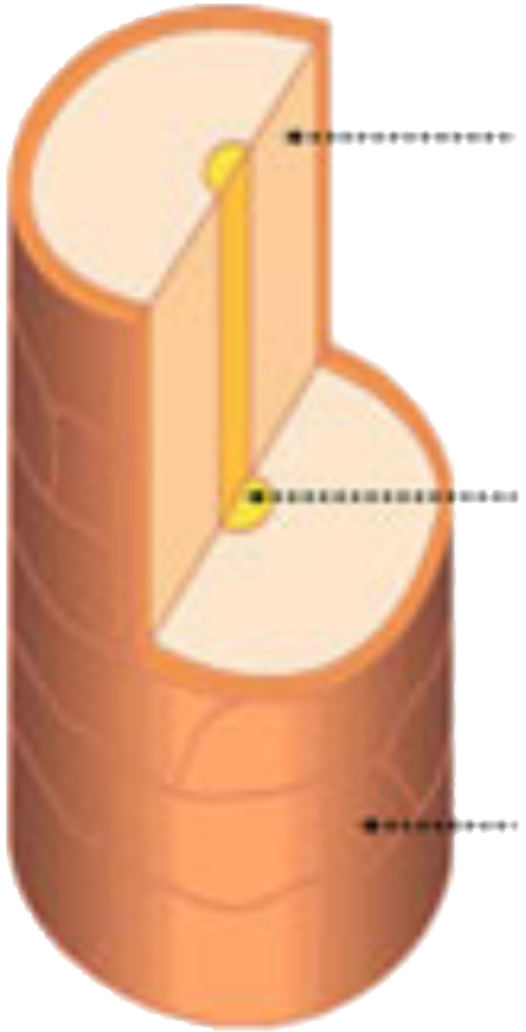
FUR REFLECTANCE — AS HUMAN HAIR

- Cannot represent diffusive and saturated appearance

Rendered as human hair
[Marschner 03]

Rendered as animal fur
[Yan 15]

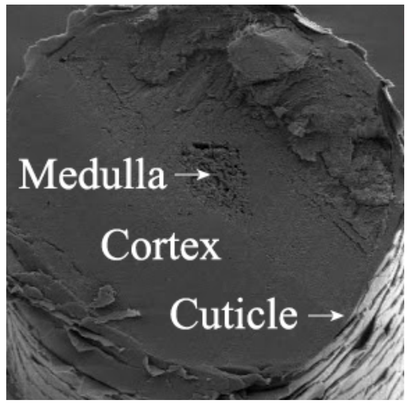
MAIN DIFFERENCE — MEDULLA

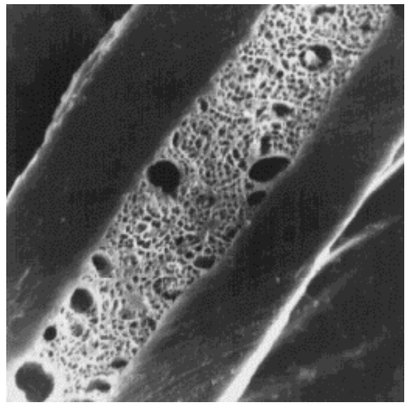


Cortex
- Contains pigments
- Absorbs light

Medulla
- Complex structure
- **Scatters light**

Cuticle

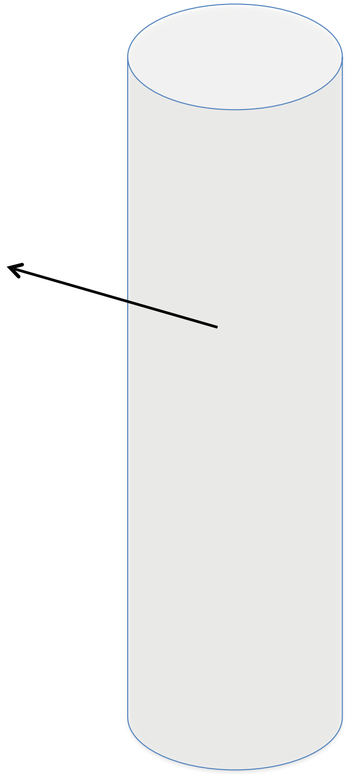




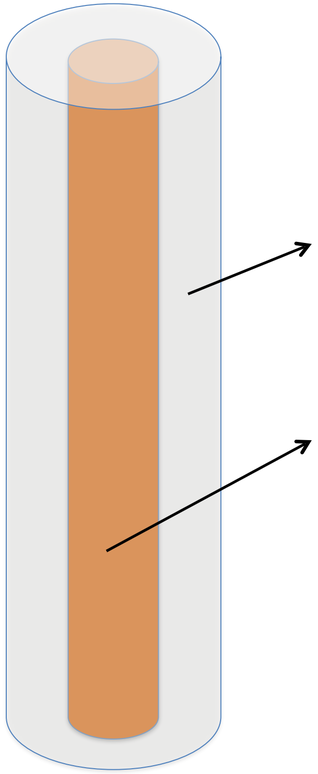
Microscopic images
(Top: human, Bottom: Cougar)

FUR REFLECTANCE MODEL

Cortex
(absorbs)



Hair Model
[Marschner 03]



Cortex
(absorbs)

Medulla
(scatters)

Double Cylinder
Model

[Yan 2015, 2017]

IMPORTANCE OF MEDULLA

Increasing medulla size

600,000 fur fibers
1024 samples / pixel
36.9 min / frame

SIGGRAPH 2017
technical paper trailer
[Yan et al. 15, 17]


260,000 fur fibers
1024 samples / pixel
14.1 min / frame
[Yan et al.17]

War for the Planet of the Apes, 2017 movie

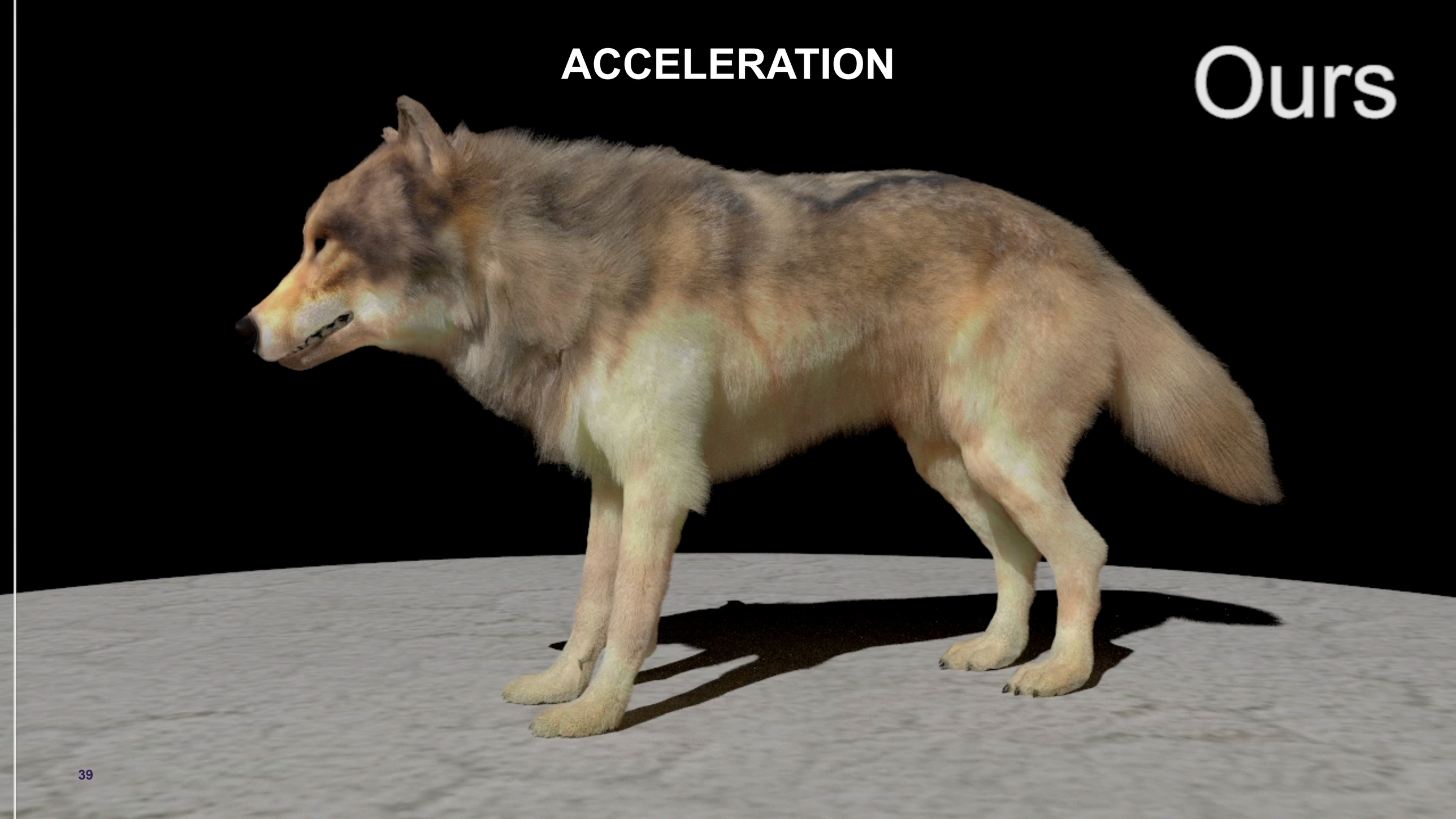
2018 Oscar Nominee for Best Visual Effects

ACCELERATION

world’s fuzziest bunny

Very similar!

ACCELERATION



PART III: INTERACTIVE RAY TRACING

Real-time performance

detailed rendering

appearance modeling

Interactive ray tracing

MOTIVATION: RAY TRACING VS. RASTERIZATION

- Rasterization: fast, less realistic

Buggy, from PlayerUnknown's Battlegrounds (PC game)

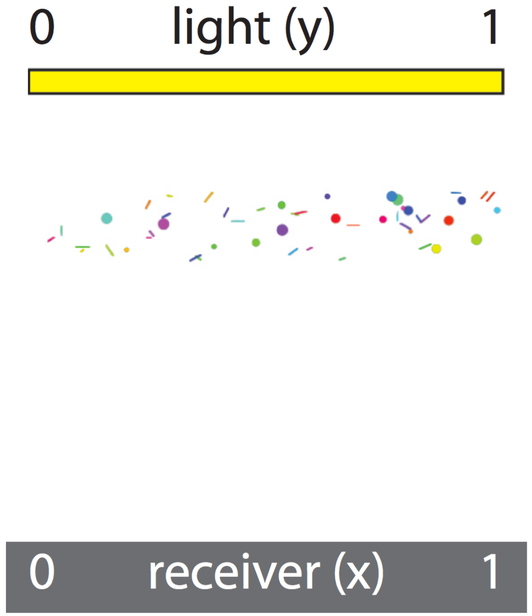
- Ray tracing: slow / noisy

Toyota 2000GT, from TurboSquid

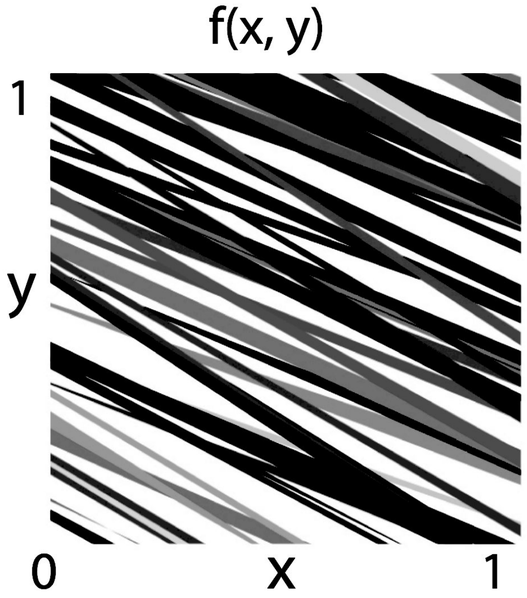
Ray Tracing + Filtering

Rendered by NVIDIA

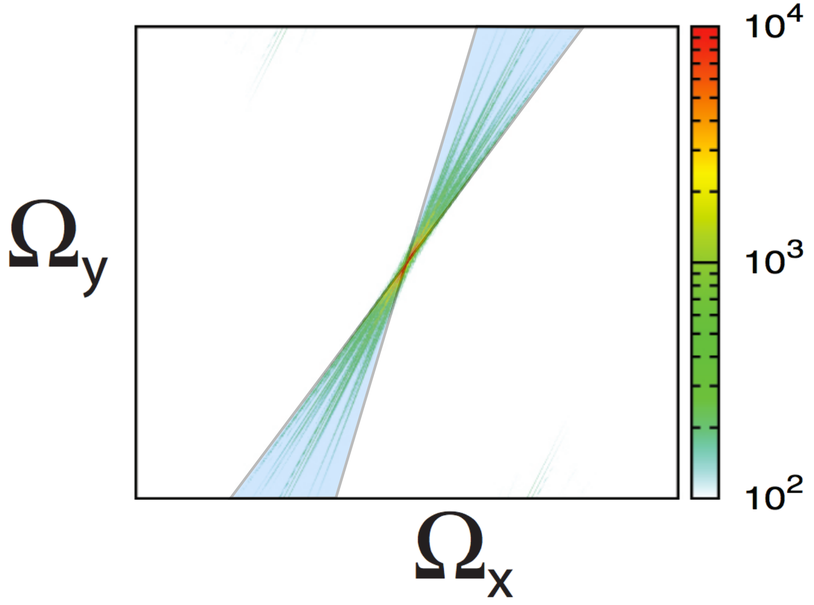
FREQUENCY ANALYSIS (OF SHADOWS)



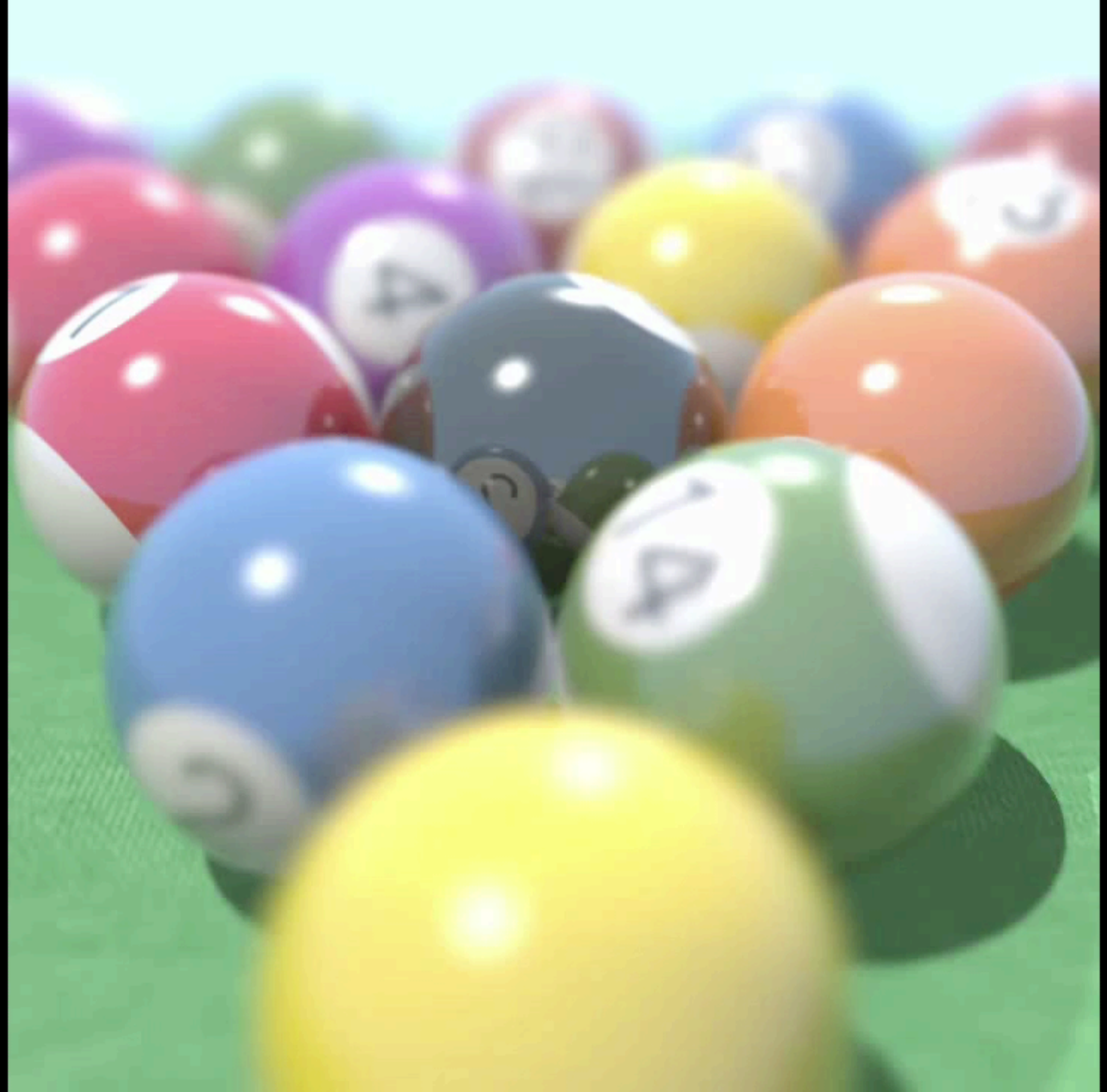
scene in flatland



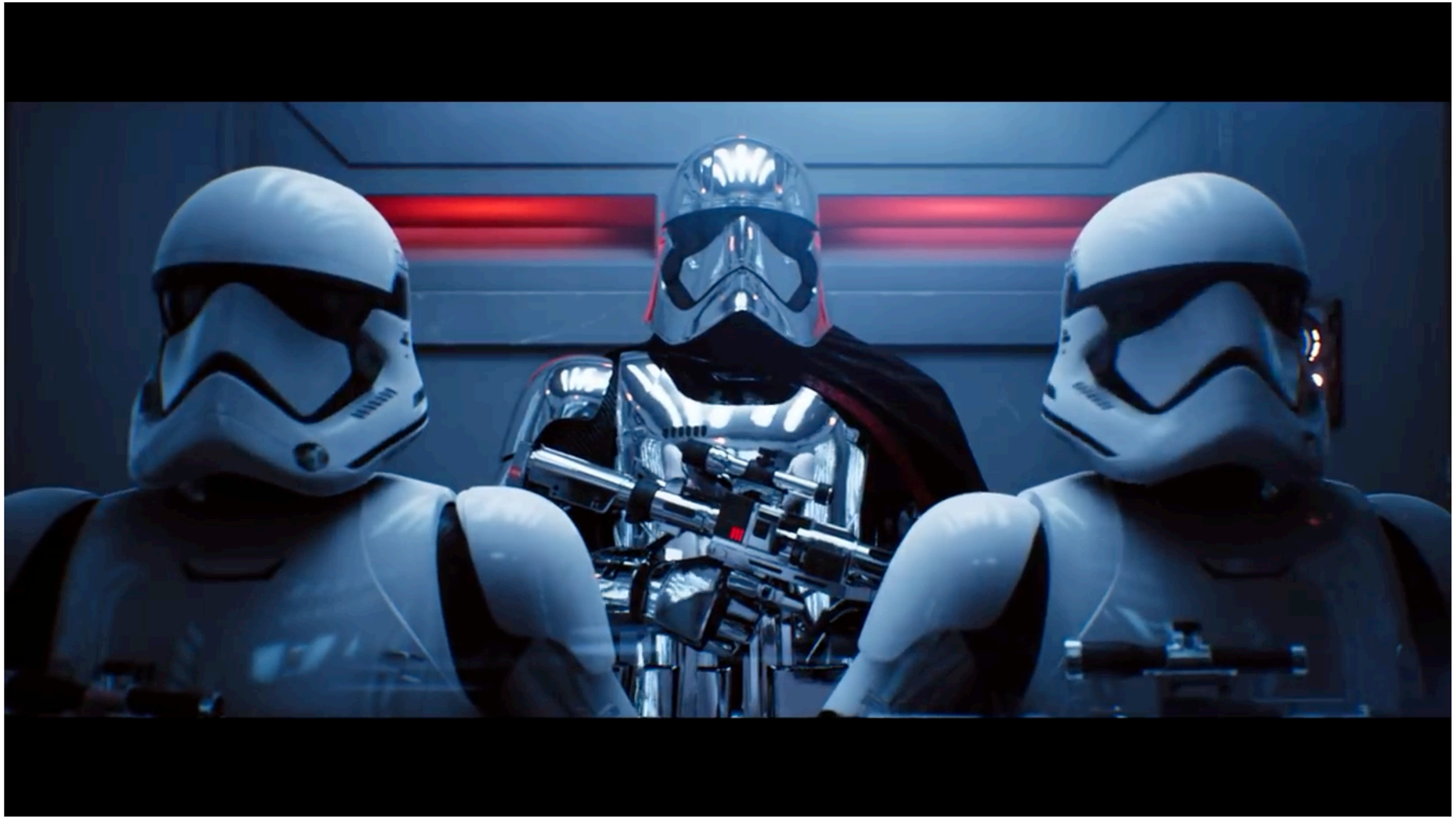
visibility function



Fourier spectrum



REAL-TIME RAY TRACING (RTRT)



(2018) - Real-Time Ray Tracing Demo, NVIDIA

WHAT'S NEXT TOWARDS ULTIMATE REALISM?

What's the future?

THE RENDERING EQUATION

- Almost every research field in CS has a "gold standard”
- In rendering, it is "the rendering equation”

$$L_o = L_e + \int_\Omega L_i f_r(\omega_i, \omega_o) \cos\theta_i \ \mathrm{d}\omega_i$$

TOWARDS ULTIMATE REALISM

- My rendering equation

Real-time / Offline
Light Transport

TOWARDS ULTIMATE REALISM

- My rendering equation

+

Real-time / Offline
Light Transport

Appearance
Modeling

TOWARDS ULTIMATE REALISM

My rendering equation


+

+


Real-time / Offline
Light Transport

Appearance
Modeling

Future
Display Equip.

TOWARDS ULTIMATE REALISM

My rendering equation


Real-time / Offline
Light Transport

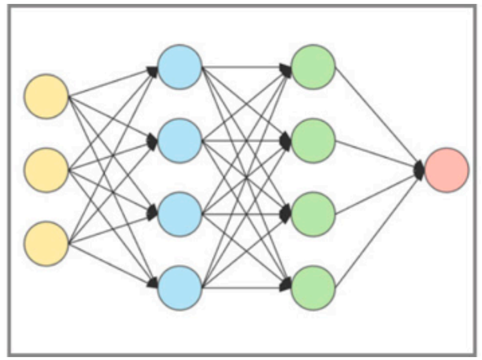
+


Appearance
Modeling

+


Future
Display Equip.

+


Emerging
Technology

TOWARDS ULTIMATE REALISM

My rendering equation


Real-time / Offline
Light Transport

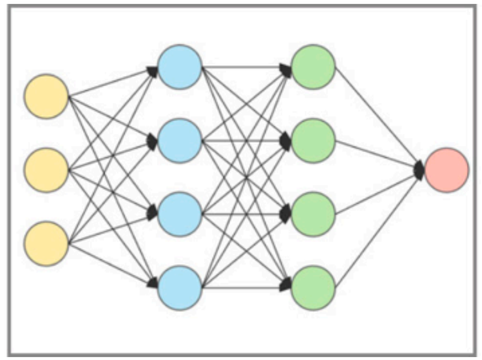
+


Appearance
Modeling

+


Future
Display Equip.

+


Emerging
Technology

=

Ultimate
Realism

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- Collaborators
  - Miloš Hašan, Steve Marschner, Henrik Wann Jensen, Fredo Durand, Bruce Walter, Soham Uday Mehta, Wenzel Jakob, Jason Lawrence, Chi-Wei Tseng, Alexandr Kuznetsov, Laurent Belcour, Derek Nowrouzezahrai, Lifan Wu, Zexiang Xu, and more!
- Industrial friends
  - NVIDIA, Adobe, Walt Disney Animation Studios, Weta Digital, Autodesk

Thank you!

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