Welcome!

CS-E5520 Advanced Computer Graphics
Spring 2019

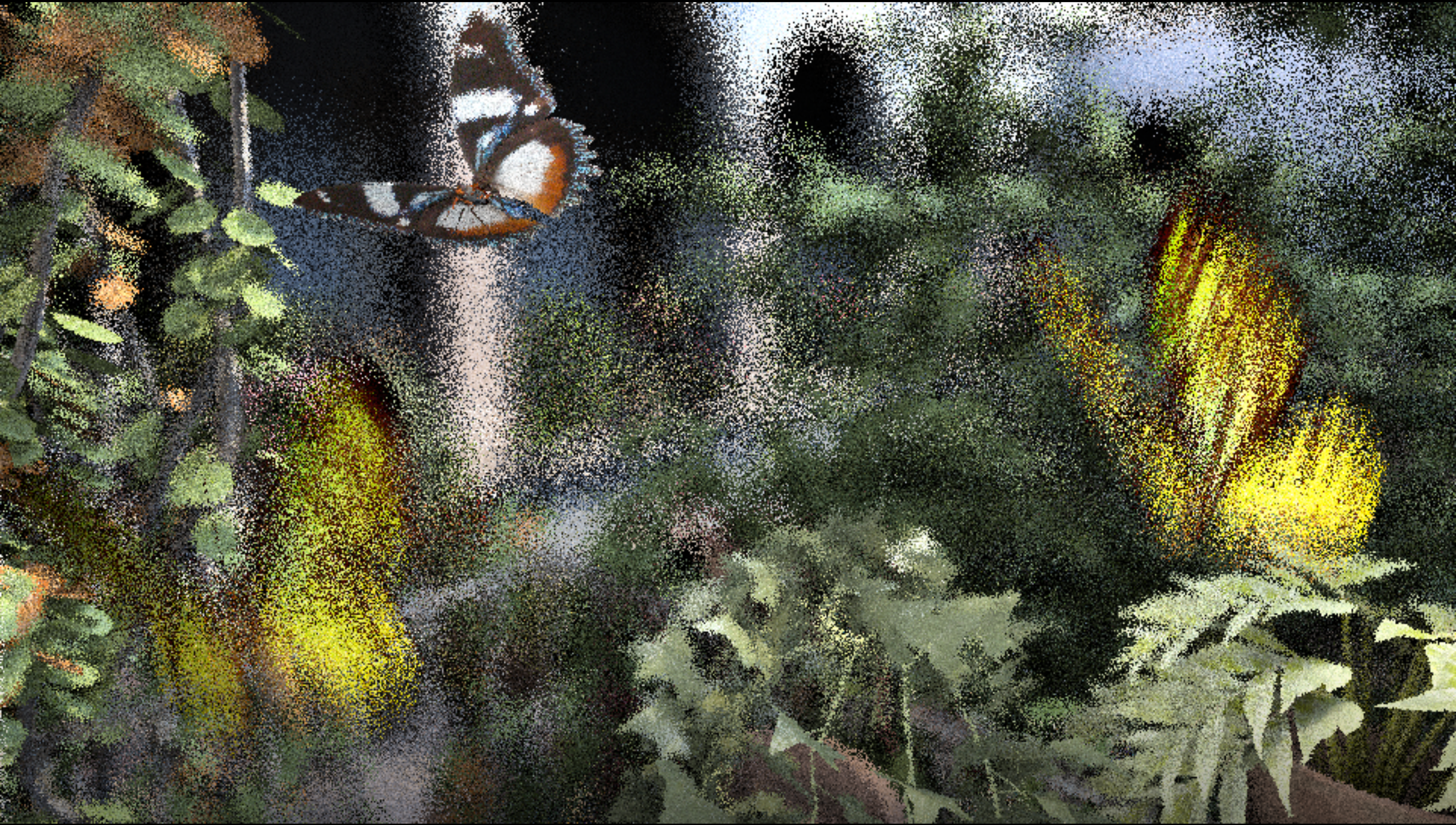
Jaakko Lehtinen, w/ TAs Pauli Kemppinen, Lauri Aarnio, & Ville Ollikainen

~1 quadrillion (10^{15}) FLOPs

Lehtinen et al. 2011

1000x fewer FLOPs

Lehtinen et al. 2011



Lehtinen et al. 2011

Smarter reconstruction from the **same input**

Lehtinen et al. 2011

Smarter reconstruction from the **same input**

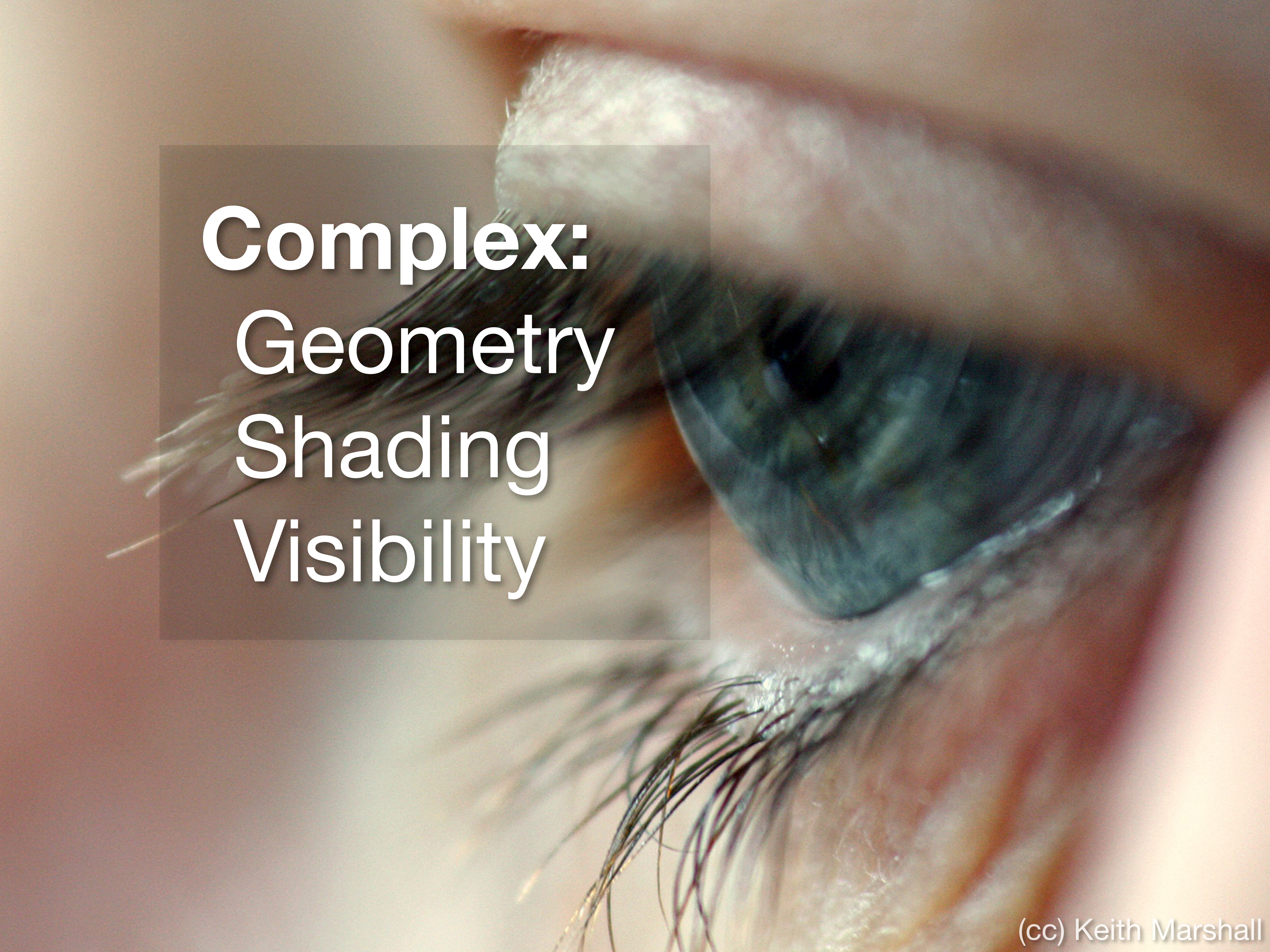
REMEDY

Massachusetts Institute of Technology

REMEDY

NVIDIA®

(cc) Keith Marshall


Complex:
Geometry
Shading
Visibility
(cc) Keith Marshall

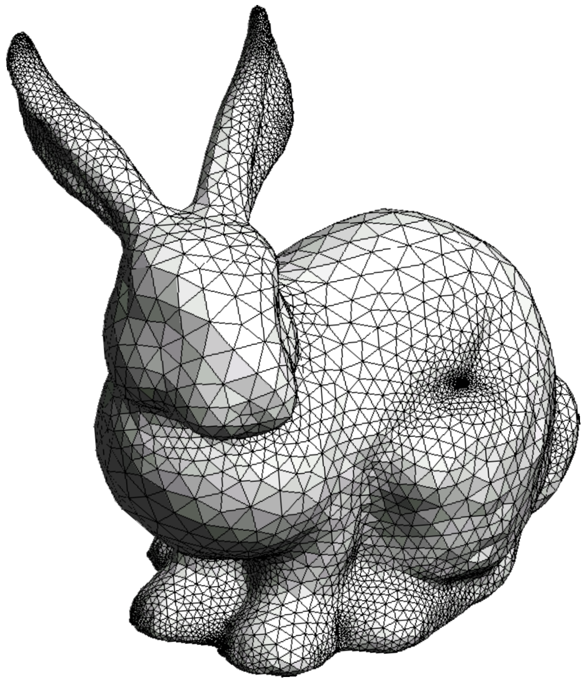
Rendering:

Compute what's visible.

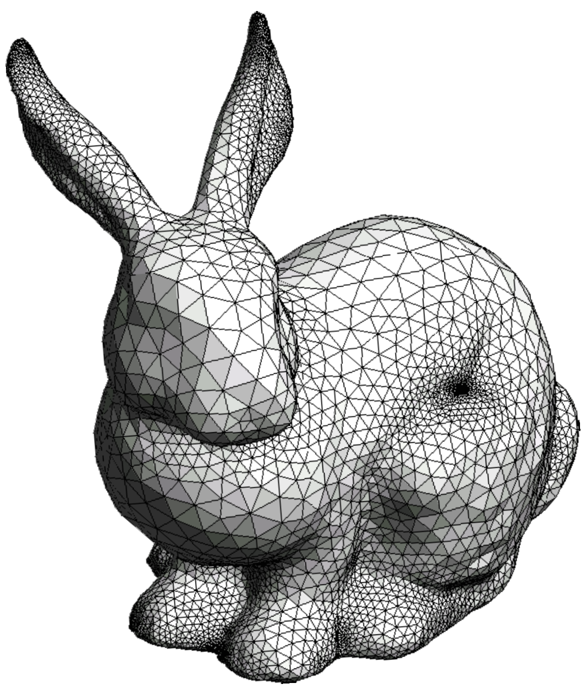
Compute what color it is.

What color it is:

Determined by interaction of light and matter.

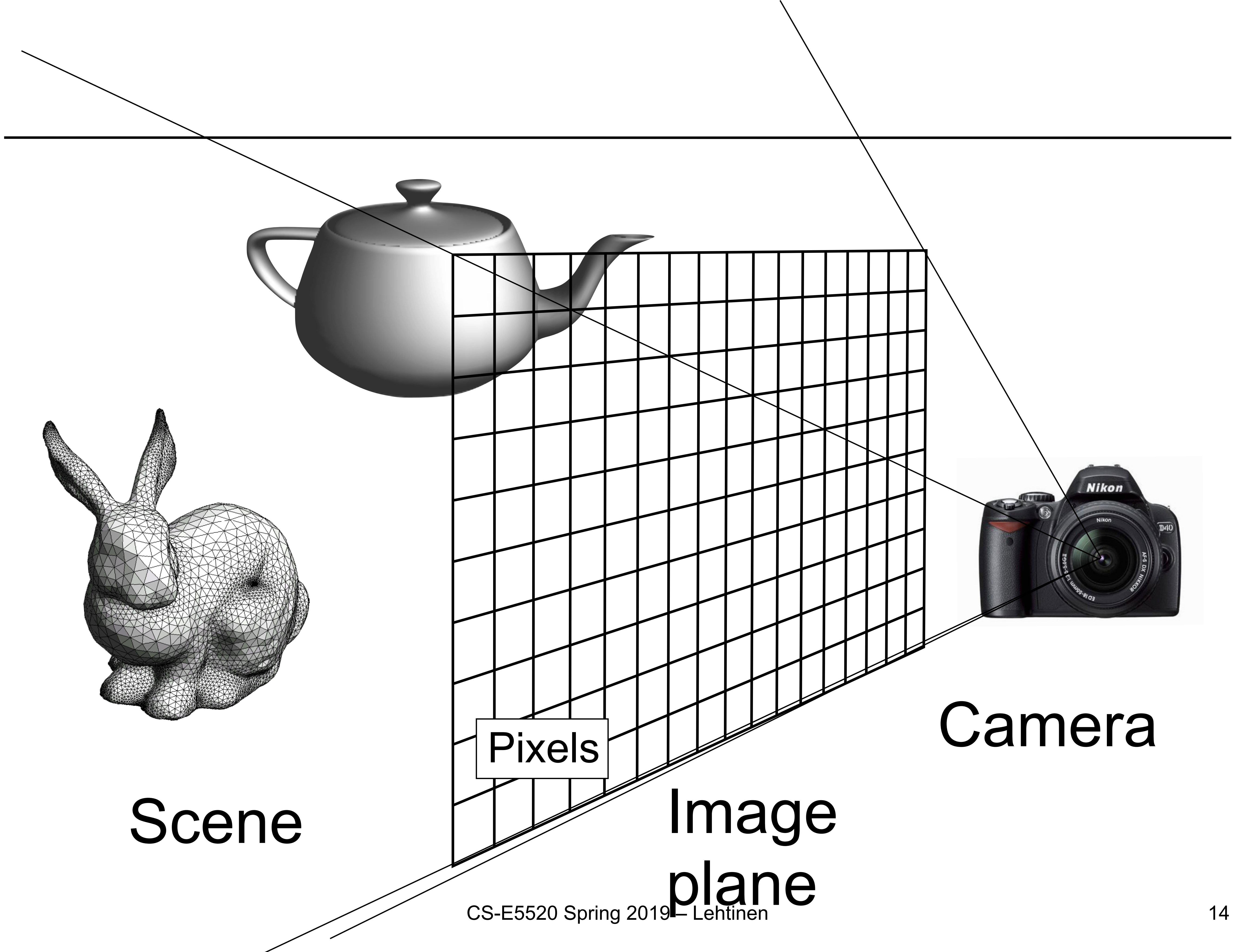


Scene

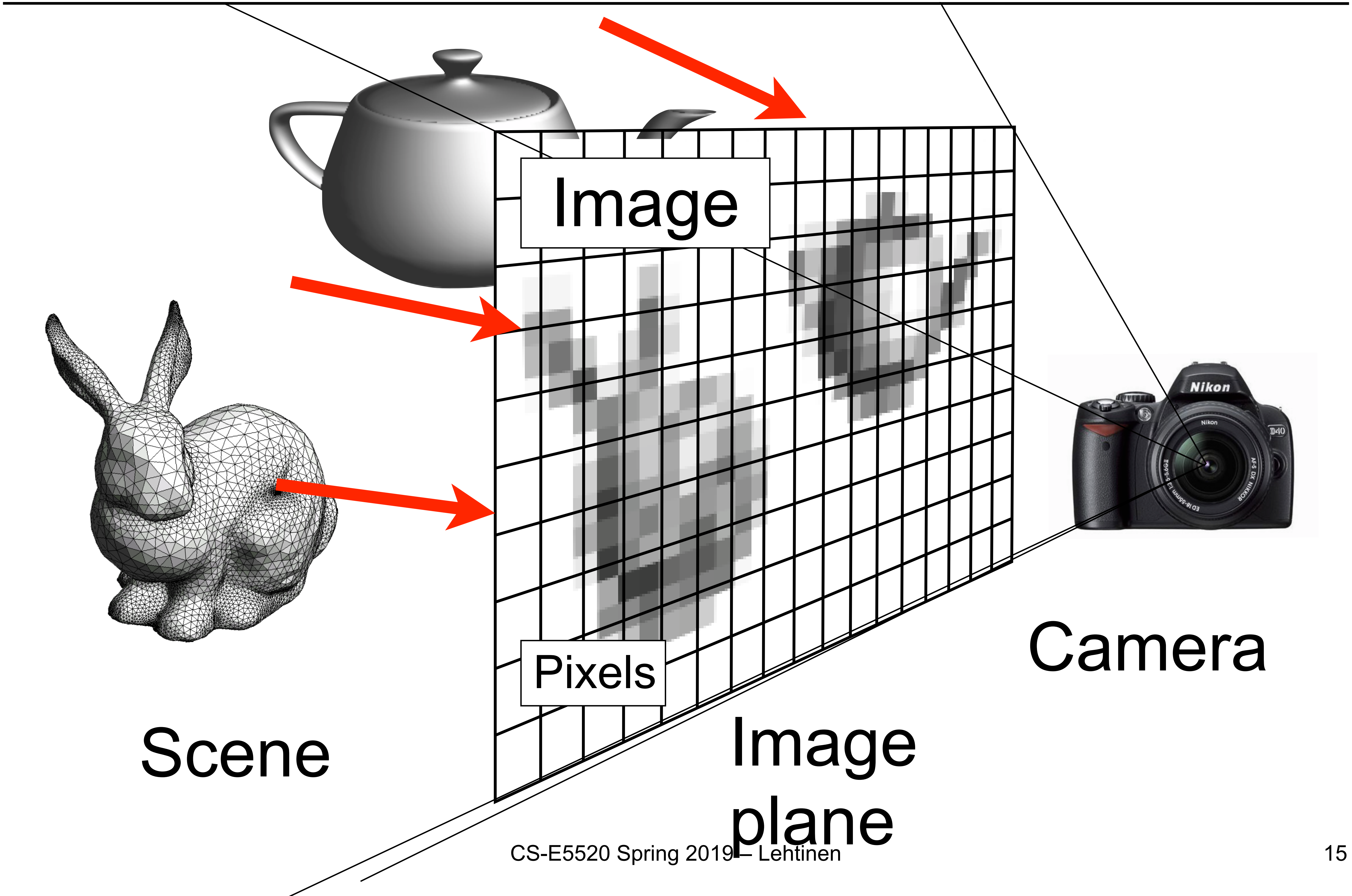


Camera

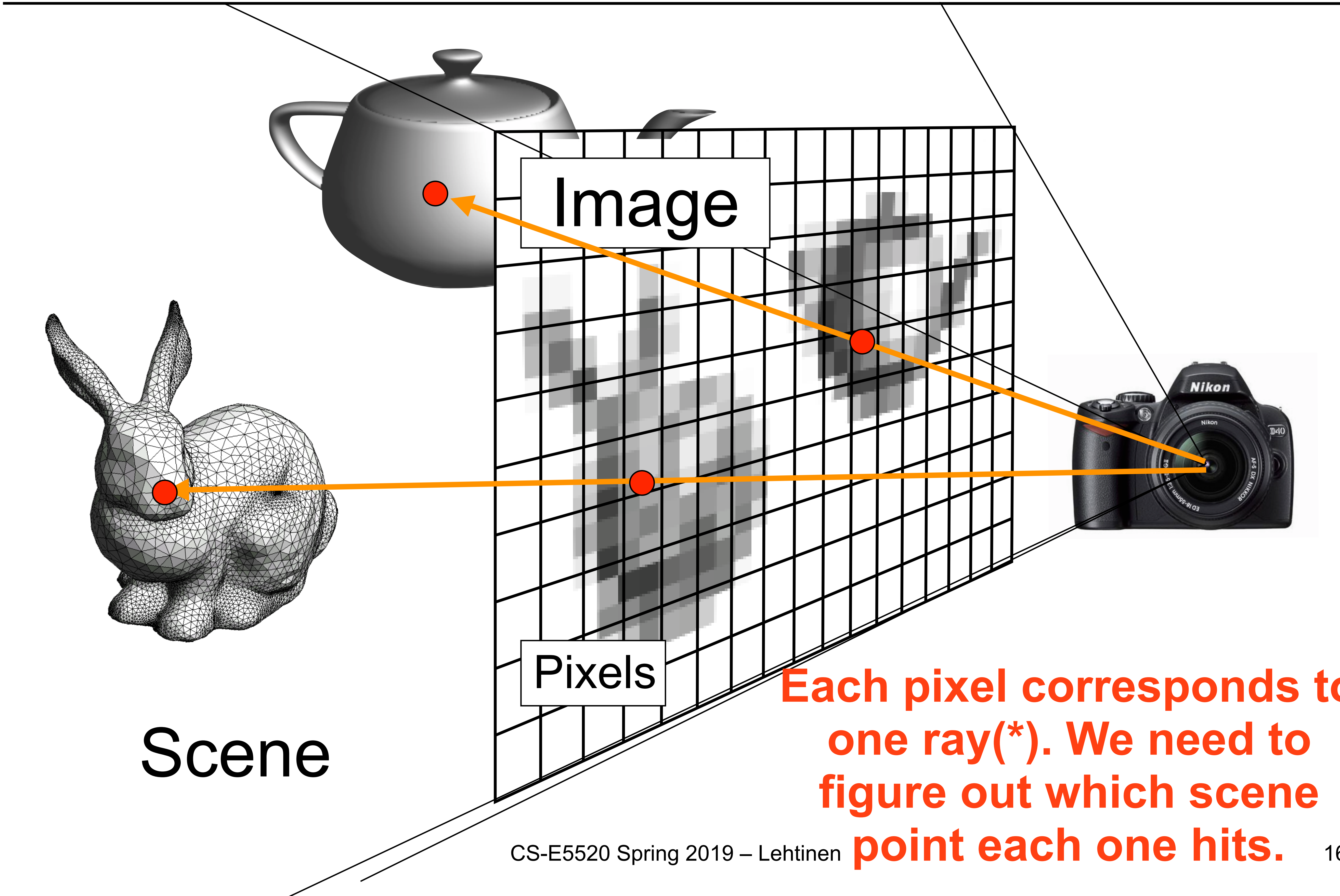
Scene


Pixels
Camera
Scene
Image
plane

Rendering = Scene to Image

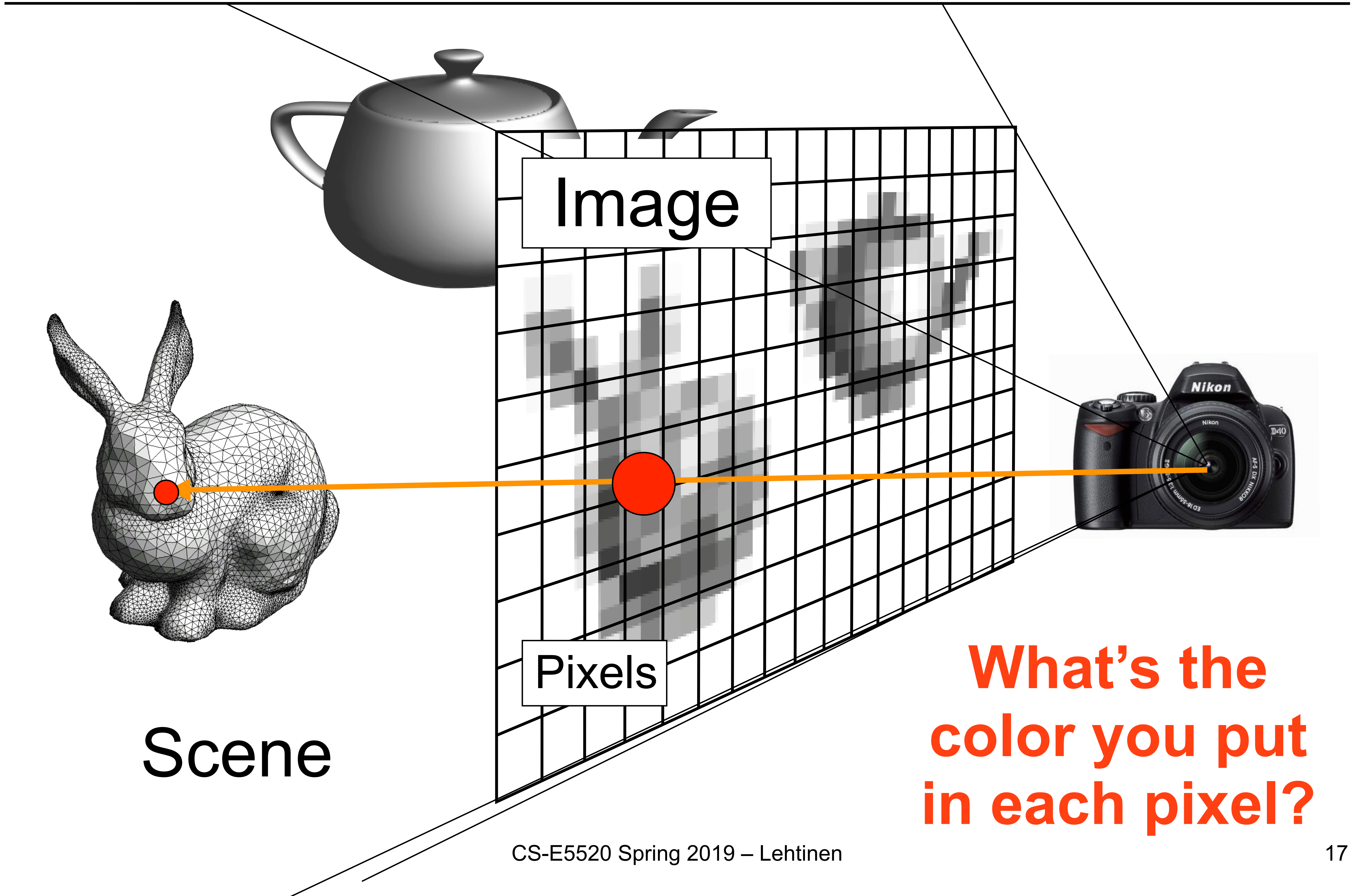


Rendering – Pinhole Camera



Each pixel corresponds to one ray(*). We need to figure out which scene point each one hits.

Rendering



What's the color you put in each pixel?

Rendering

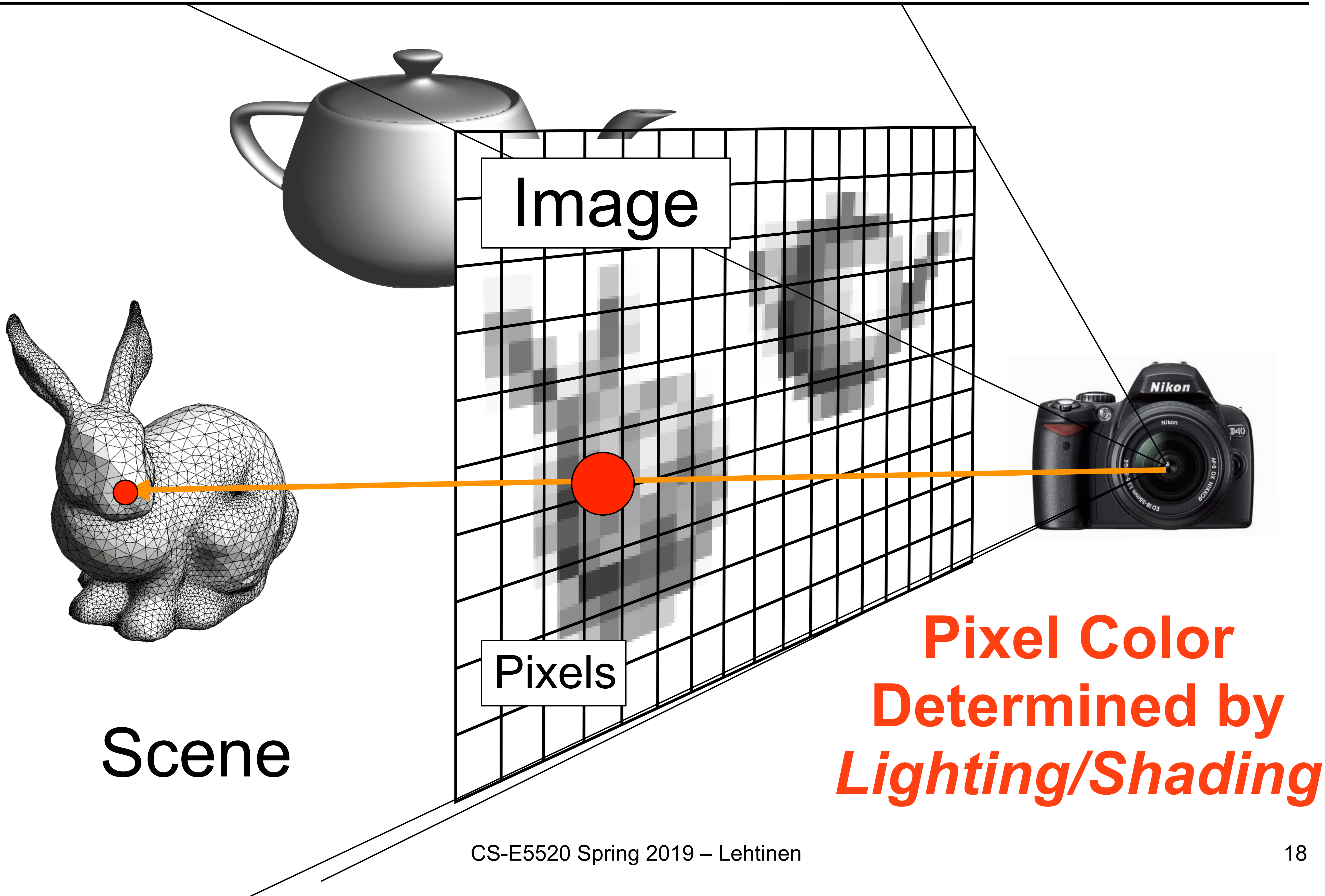
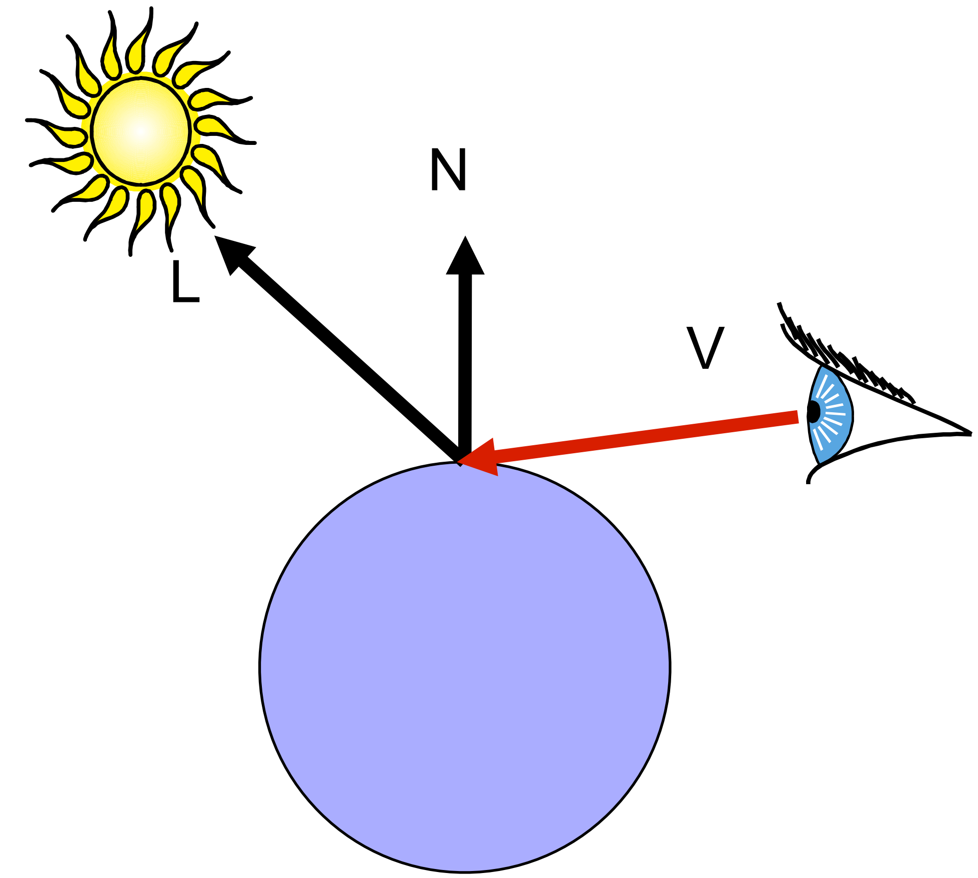
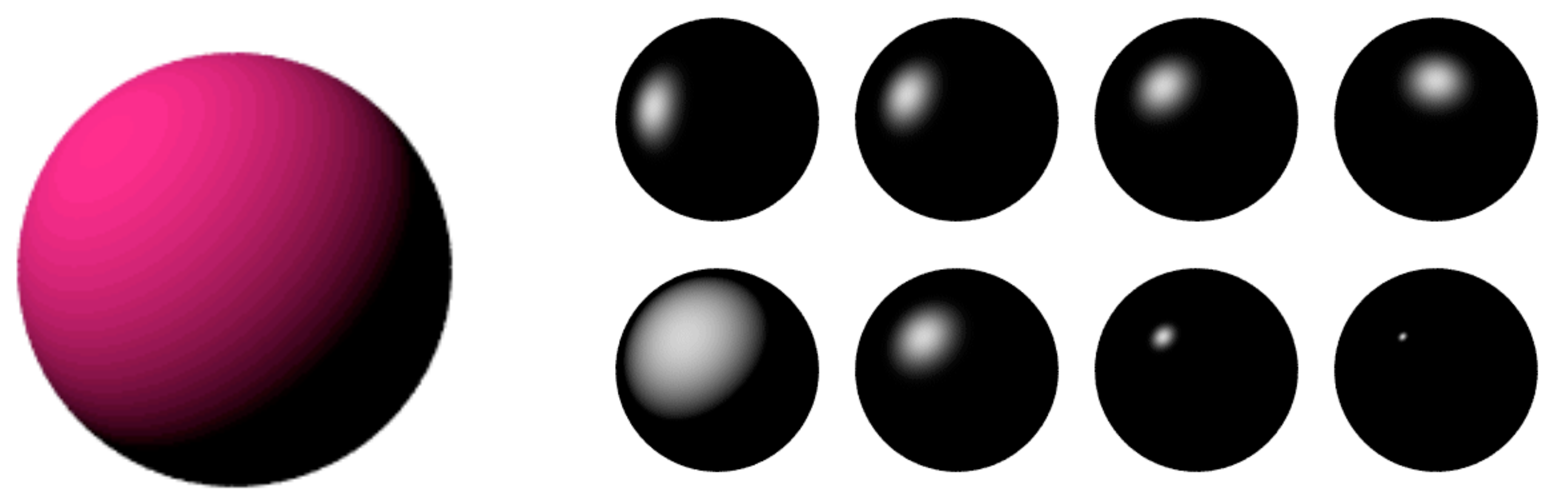


Image
Pixels
Scene
Nikon
Pixel Color
Determined by
Lighting/Shading

Shading = What Surfaces Look Like

- Surface/Scene Properties
  - surface normal
  - direction to light
  - viewpoint
- Material Properties
  - Diffuse (matte)
  - Specular (shiny)
  - …
- Light properties
  - Position
  - Intensity, ...
- Much more!





Diffuse sphere

Specular spheres

Interlude

Reflectance Capture By Parametric Texture Synthesis

Miika Aittala Timo Aila Jaakko Lehtinen

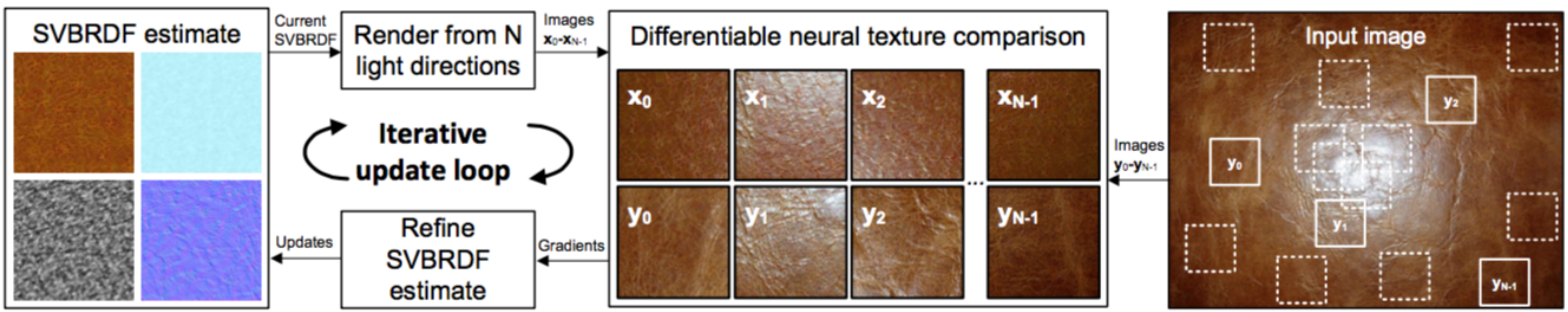


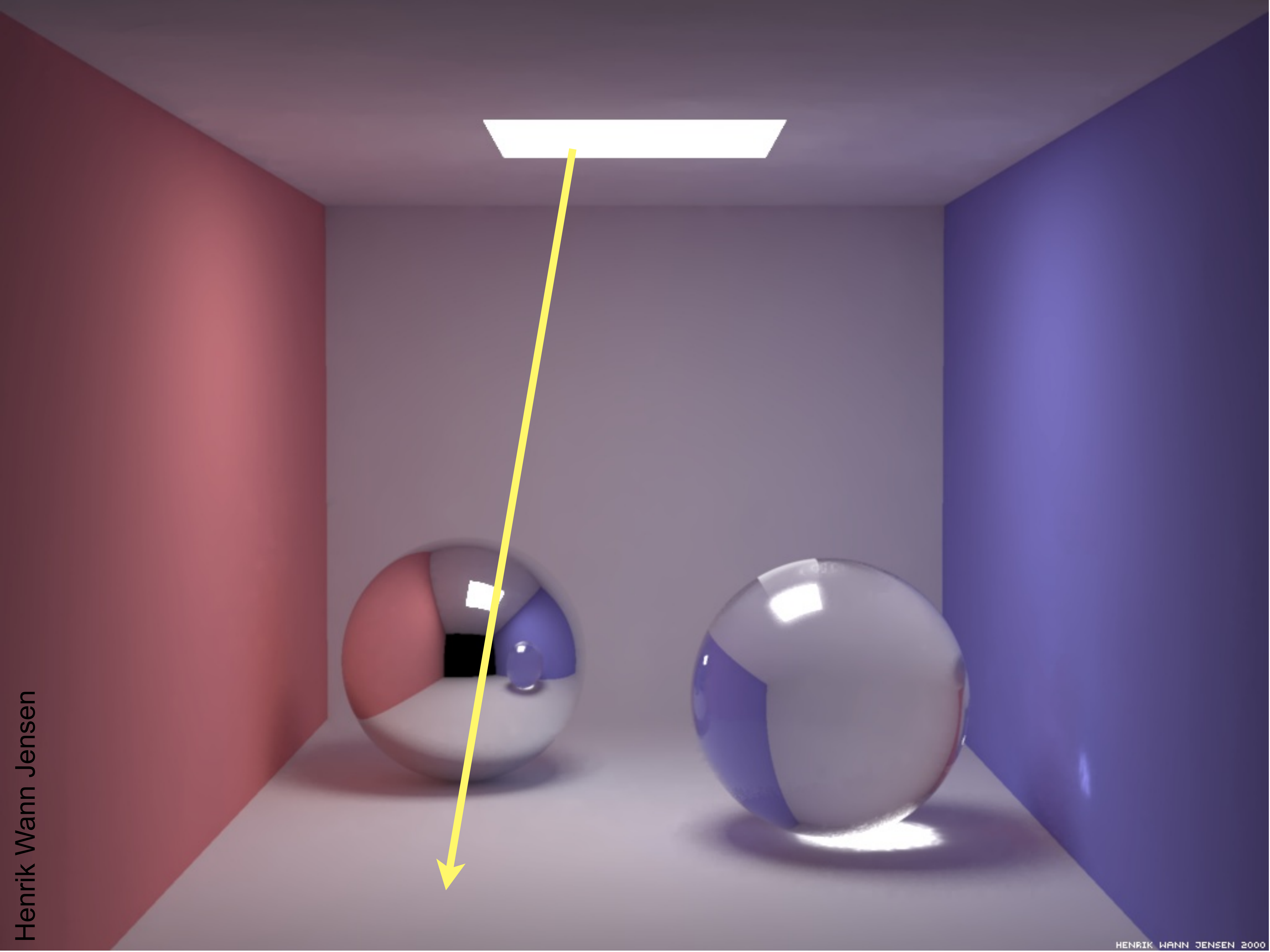
Figure 1: *Our algorithm synthesizes a spatially varying BRDF that closely matches the input flash image when rendered from different lighting directions. The optimization process iteratively updates the current estimate based on neural network-based texture statistics comparisons that are able to ignore the precise pixel arrangement inside image tiles. This snapshot is from an early stage of the optimization.*

Image Synthesis is Radiative Transport

$$\omega \cdot \nabla_x L(x,\omega) = \epsilon(x,\omega) - \sigma_t(x) L(x,\omega) + \sigma_s(x) \int_{4\pi} p(x,\omega,\omega')\, L(x,\omega')\, \mathrm{d}\omega'$$

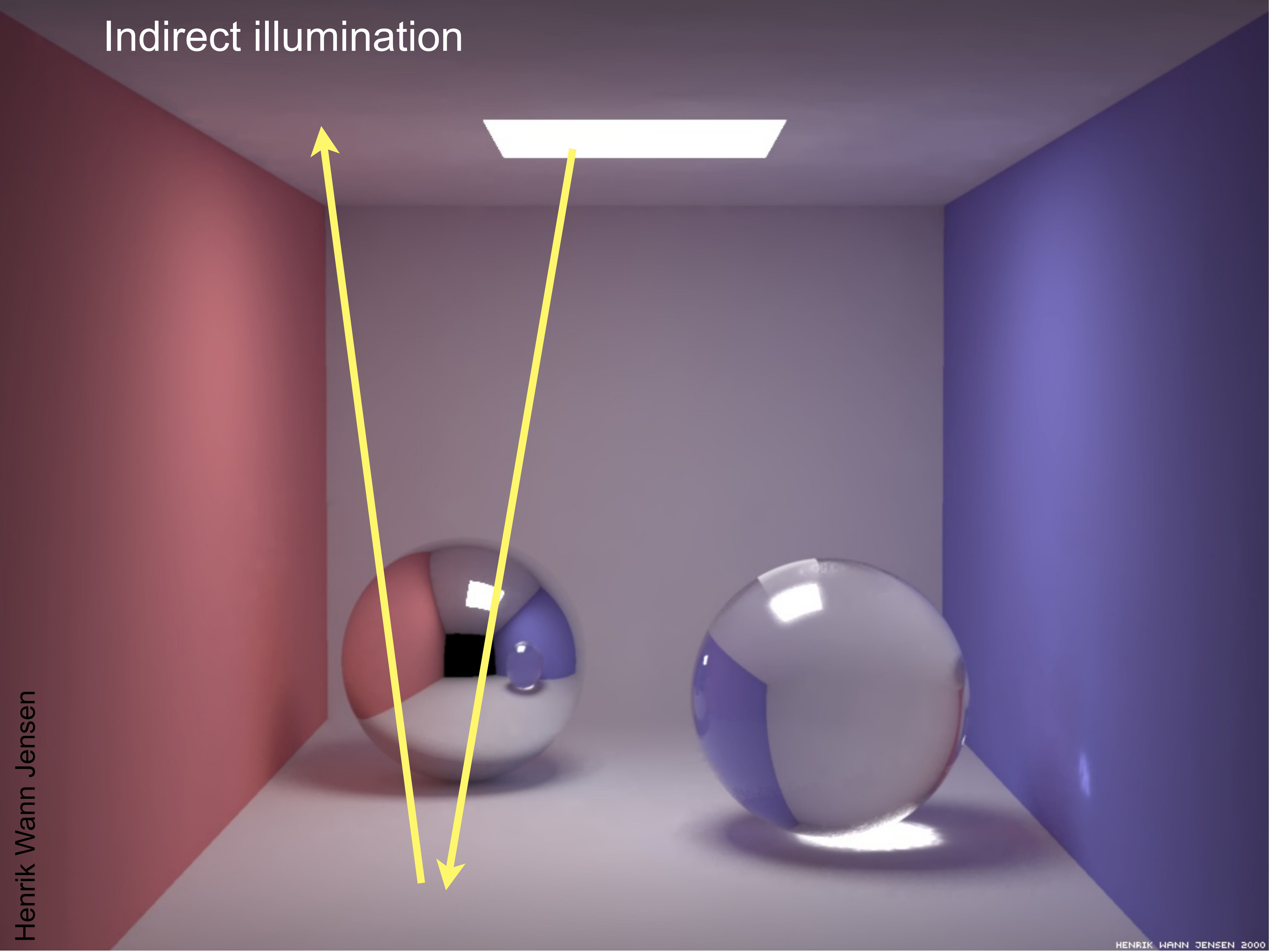
"Volumetric Rendering Equation"

= Radiative Transport Equation (Chandrasekhar, 1960)



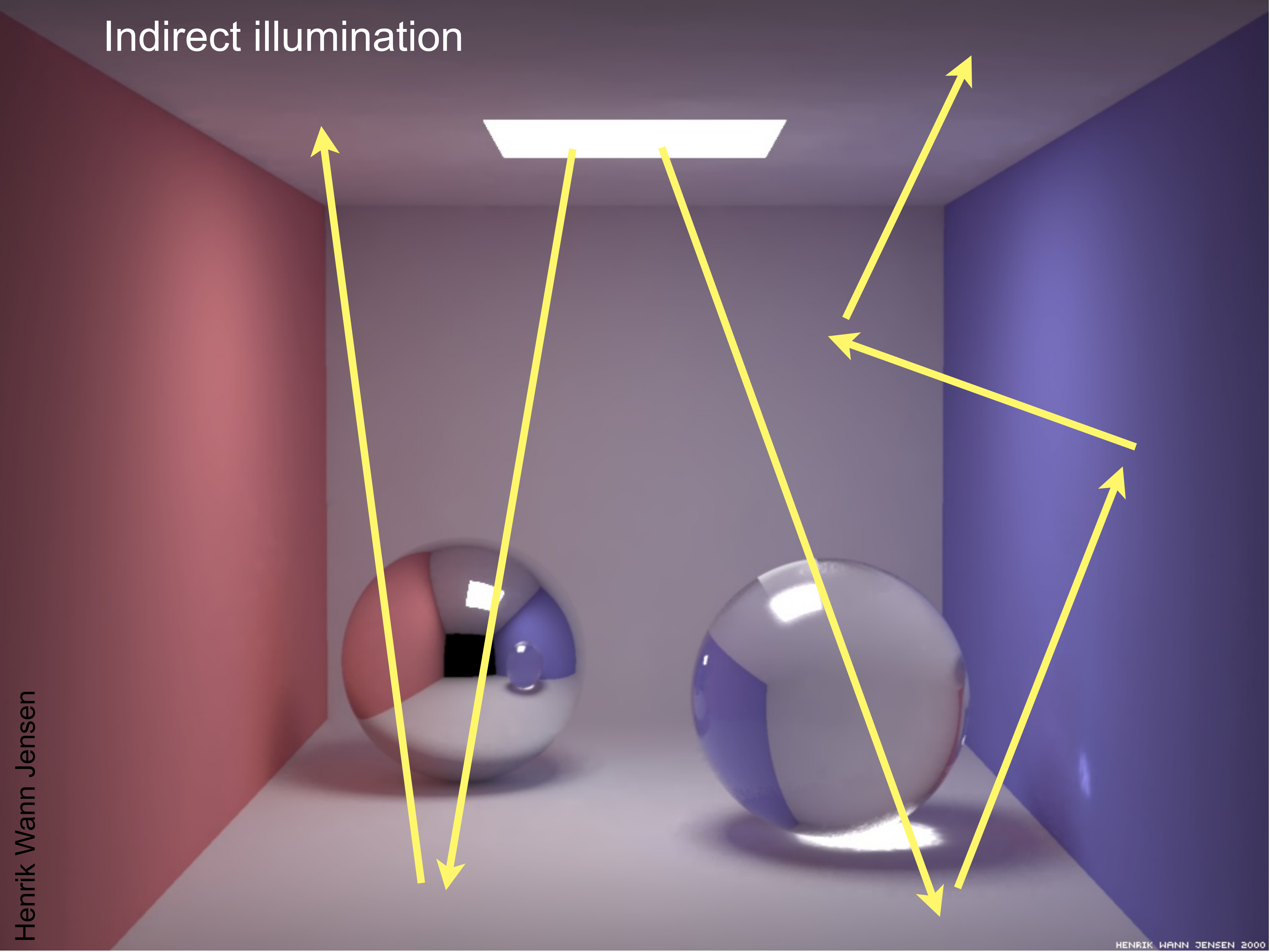
Henrik Wann Jensen

Indirect illumination



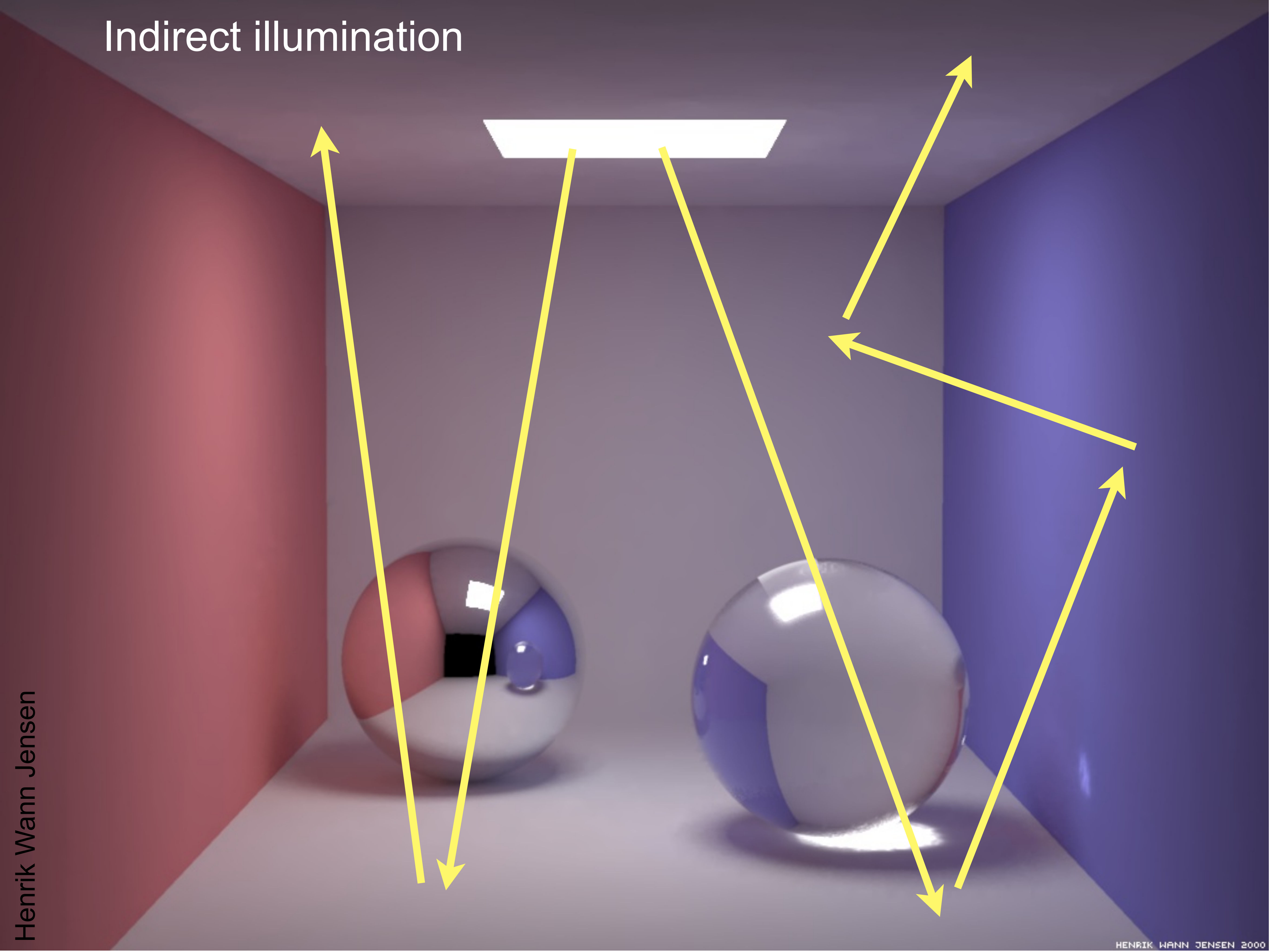
Henrik Wann Jensen

Indirect illumination

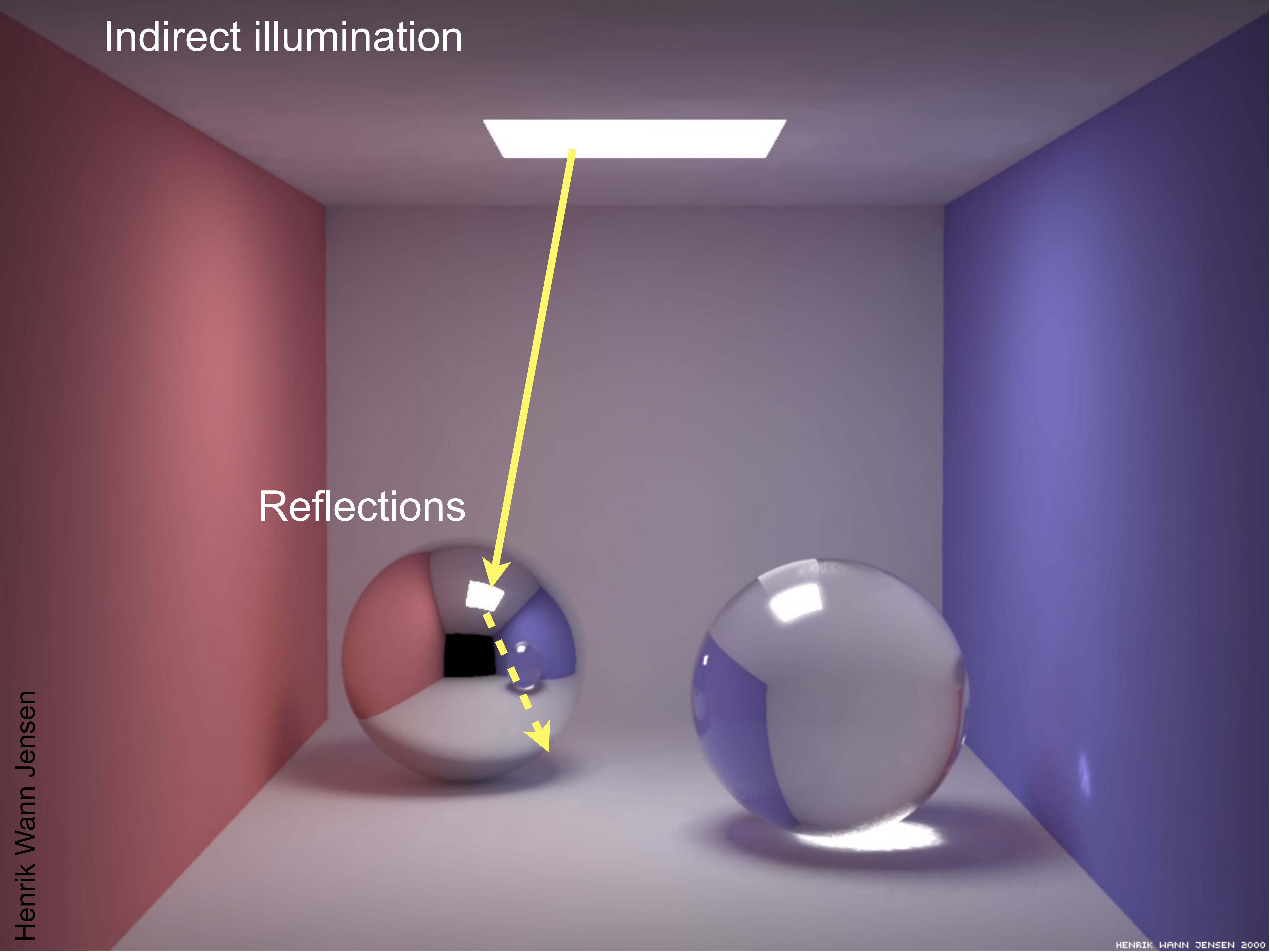


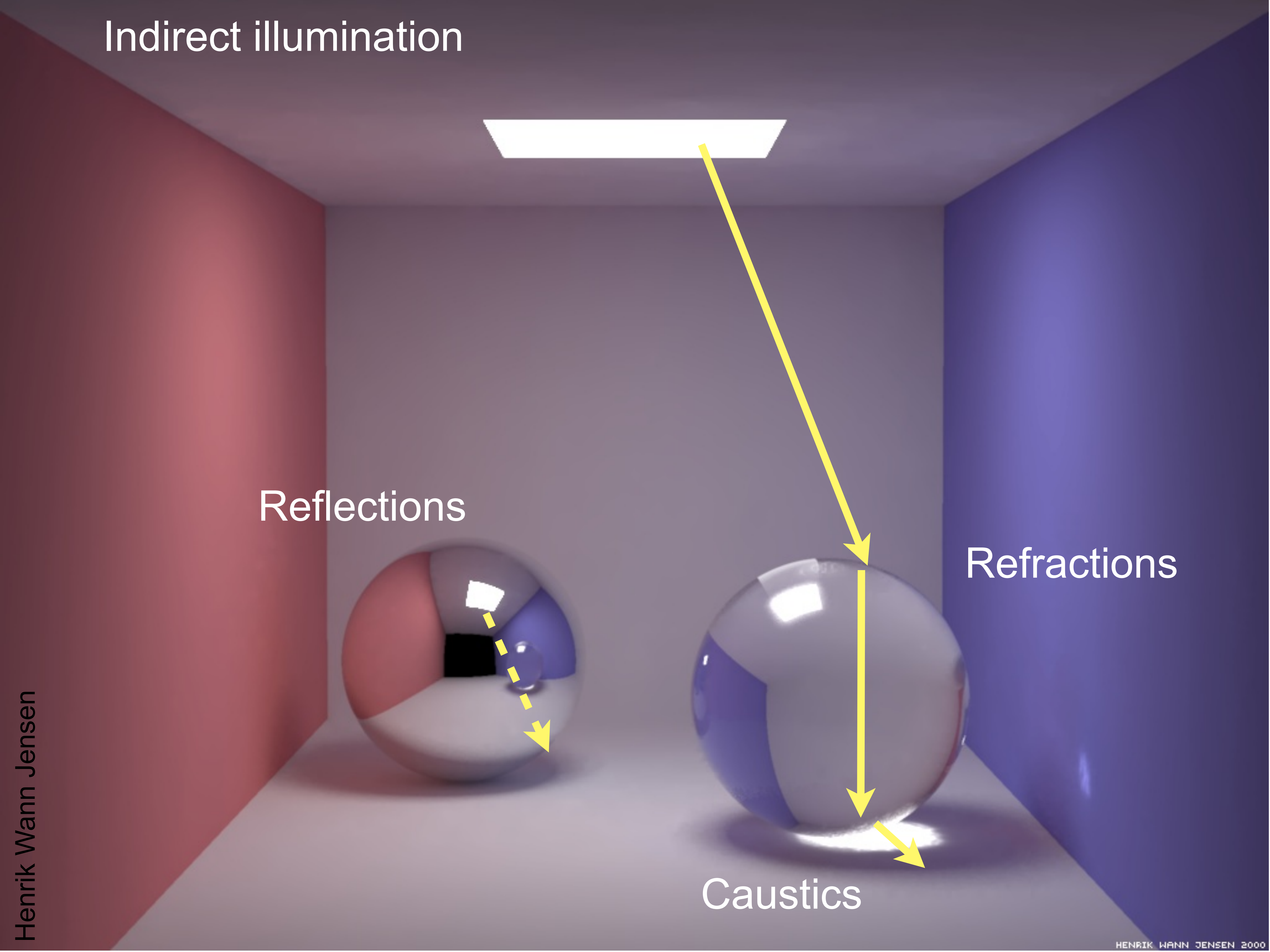
Henrik Wann Jensen

Indirect illumination



Henrik Wann Jensen


Indirect illumination
Reflections
Henrik Wann Jensen
HENRIK WANN JENSEN 2000

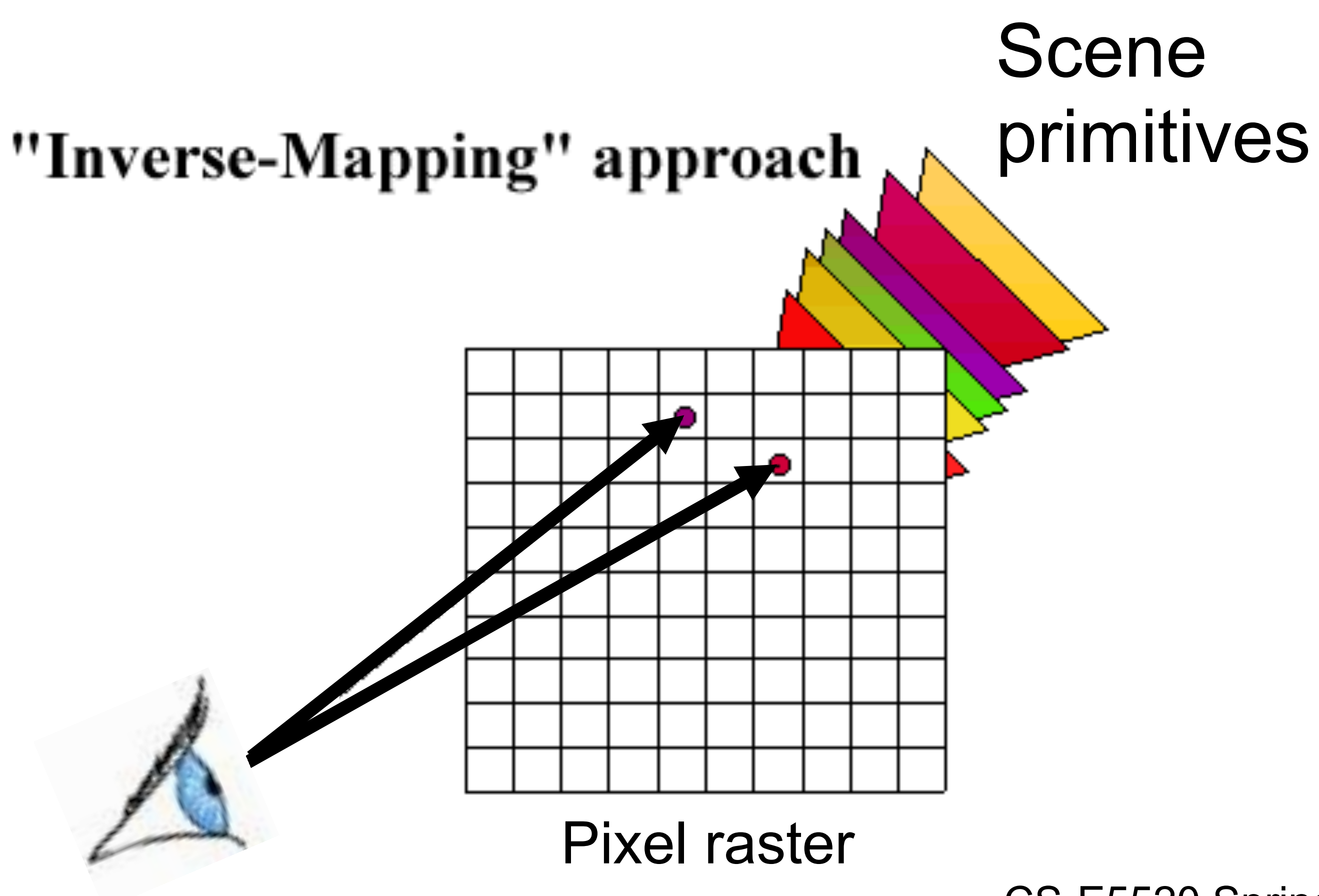

Indirect illumination
Reflections
Refractions
Caustics
Henrik Wann Jensen
HENRIK WANN JENSEN 2000

Ray Casting vs. Rasterization

Ray Casting

```
For each pixel (ray)
  For each object
    Does ray hit object?
```

Keep closest hit

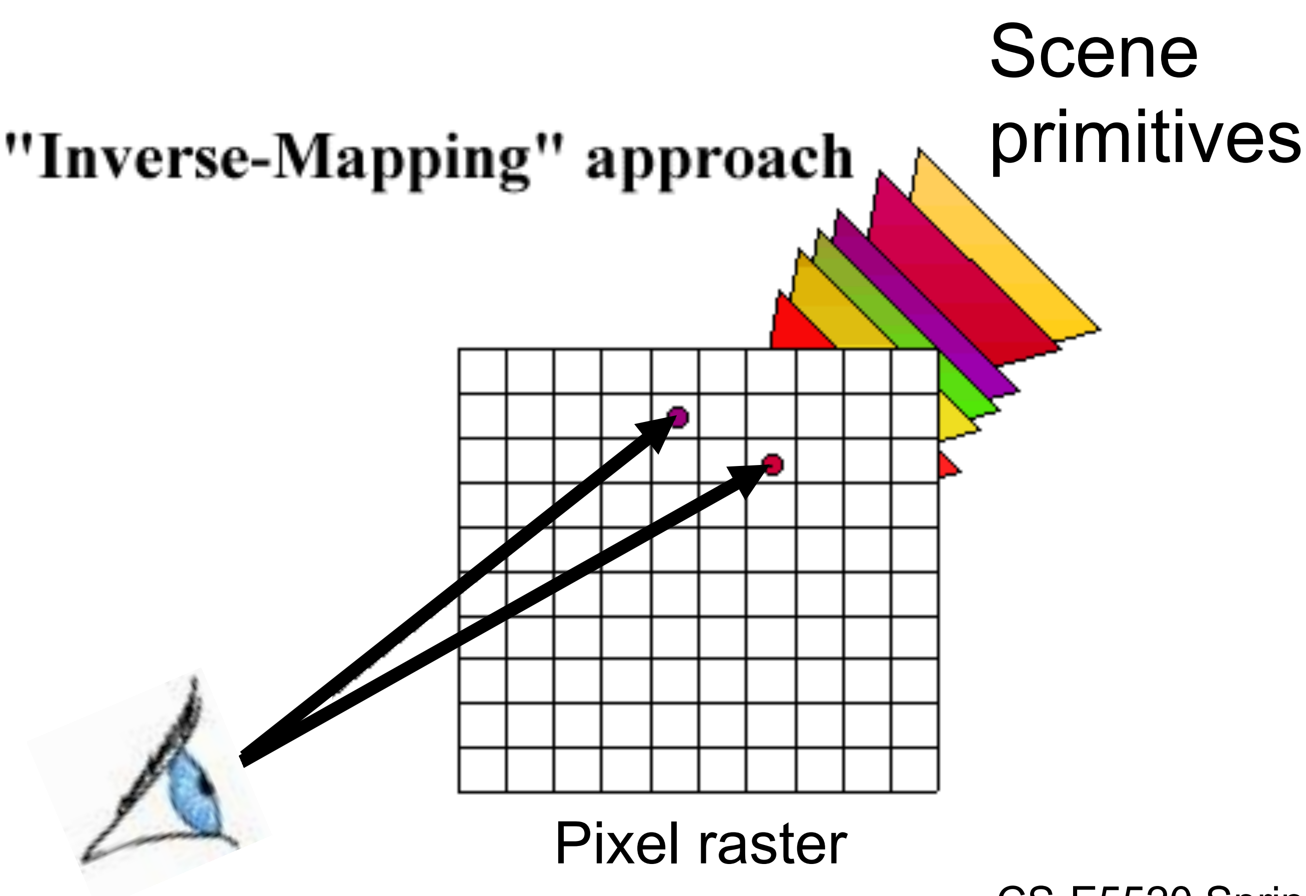


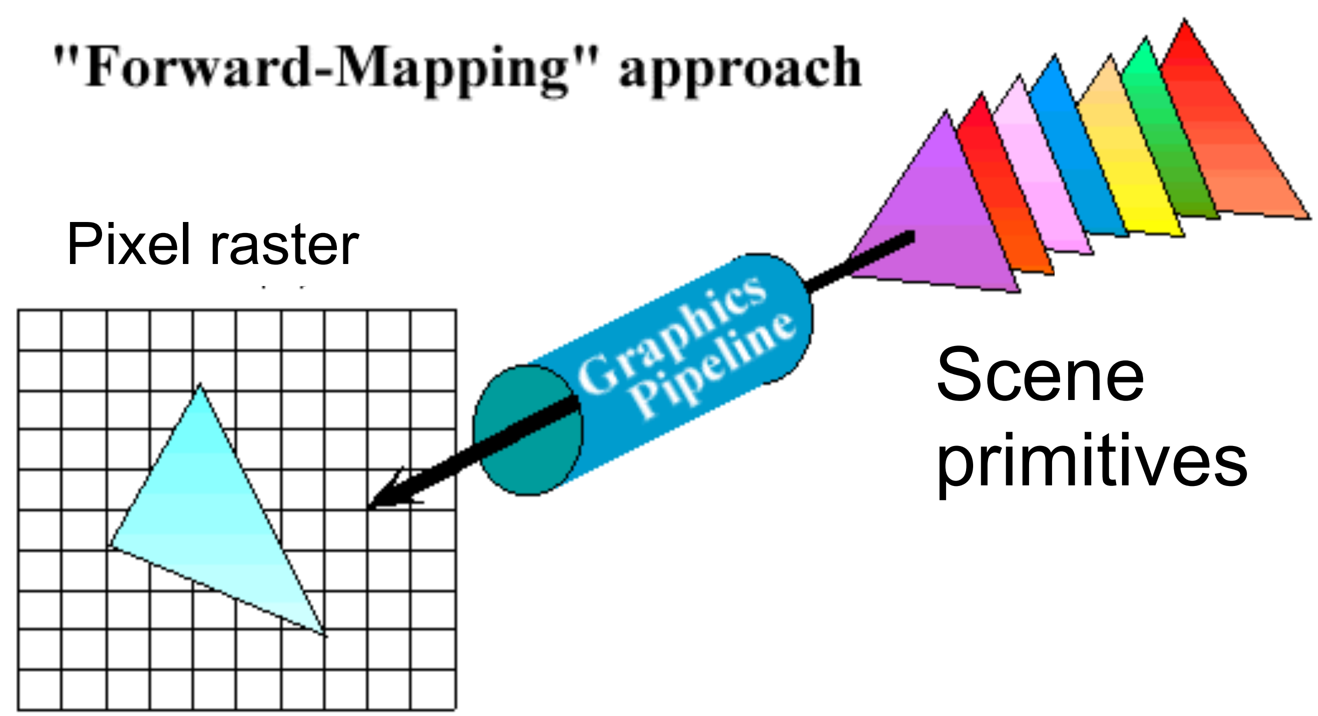
Ray Casting vs. Rasterization

Ray Casting	Rasterization

For each pixel (ray)
  For each object
    Does ray hit object?
	For each triangle
	  For each pixel
	    Does triangle cover pixel?

Keep closest hit	**Keep closest hit**





Ray Casting vs. Rasterization

Ray Casting

```
For each pixel (ray)
   For each object
      Does ray hit object?
```

Keep closest hit

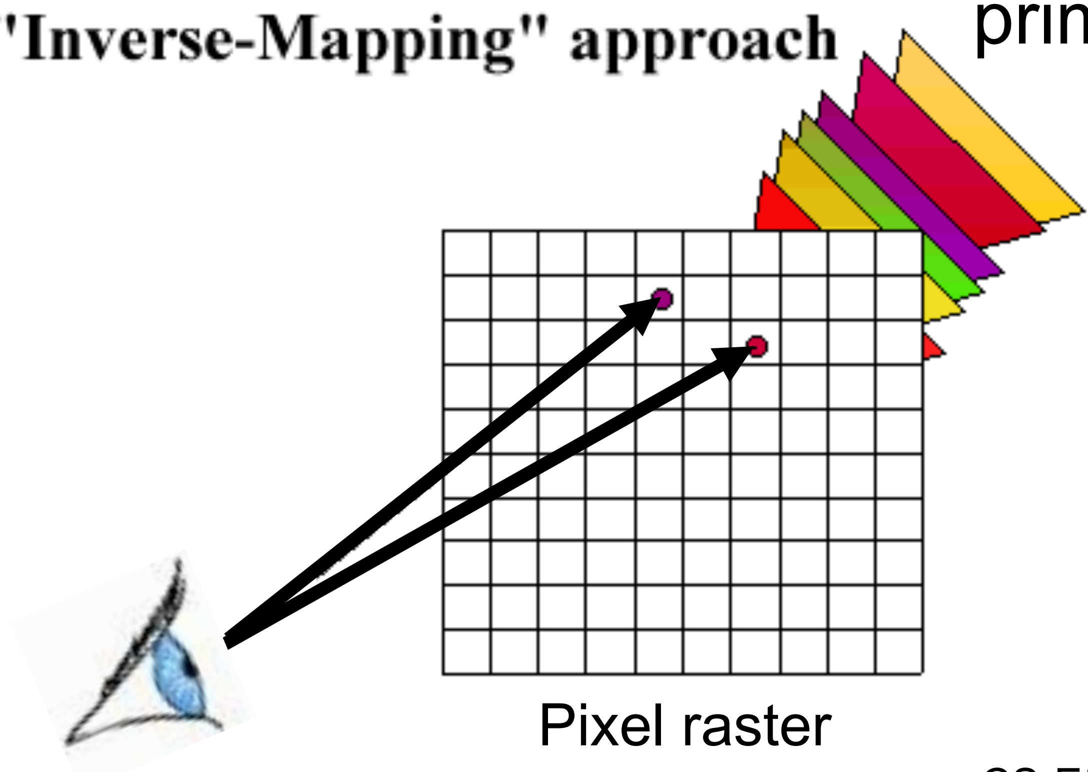
Rasterization

```
For each triangle
   For each pixel
      Does triangle cover pixel?
```

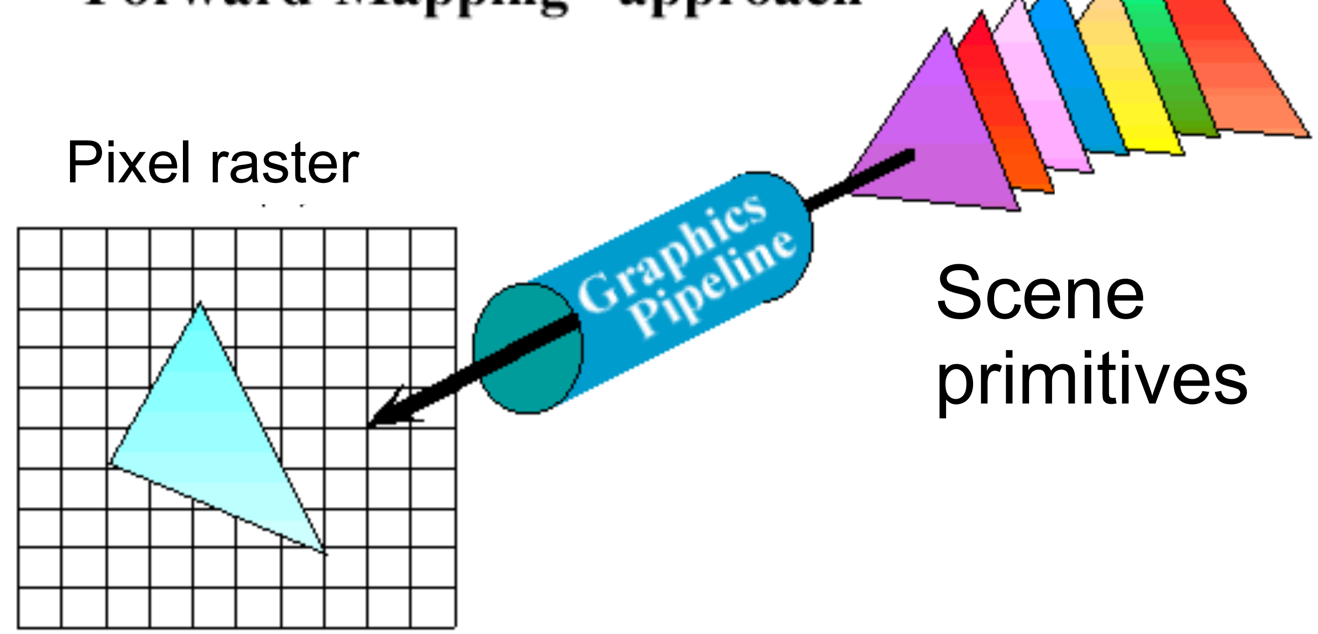
Keep closest hit

It's just a different order of the loops!

"Inverse-Mapping" approach



"Forward-Mapping" approach



Ray Tracing

- Advantages
  - Generality: can render anything that can be intersected with a ray
  - Easily allows recursion (shadows, reflections, etc.)

- Disadvantages
  - Harder to implement in hardware (less computation coherence, must fit entire scene in memory, worse memory behavior)
    - Not such a big point any more given general purpose GPUs
  - Has traditionally been too slow for interactive applications..
  - **..but today, interactive ray tracing is reality!**

Ray Casting / Tracing

- Advantages
  - Generality: can render anything that can be intersected with a ray
  - Easily allows recursion (shadows, reflections, etc.)

Our focus in this class

- Disadvantages
  - Harder to implement in hardware (less computation coherence, must fit entire scene in memory, worse memory behavior)
    - Not such a big point any more given general purpose GPUs
  - Has traditionally been too slow for interactive applications..
  - **..but today, interactive ray tracing is reality!**

Lehtinen et al. 2008

Video:
Temporal Gradient-Domain Path Tracing (Kettunen et al. 2016)

Markus Otto/Winzenrender, Rendered using Maxwell

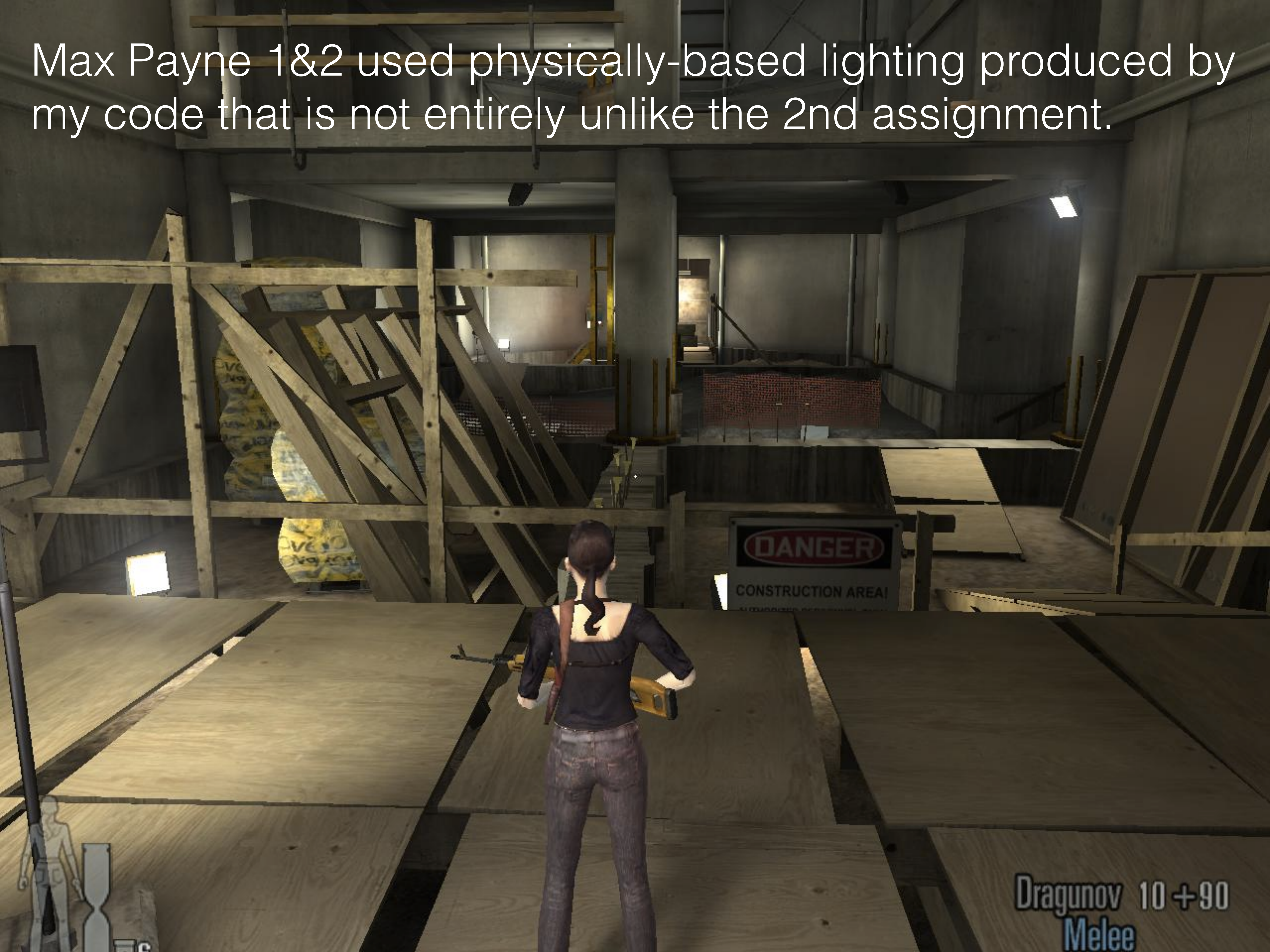
Stack Studios, Rendered using Maxwell

New Line Cinema

Also Real-Time (video)

– Hedman, Karras, Lehtinen 2016. "Sequential Monte Carlo Instant Radiosity", Proc. SIGGRAPH Symposium on Interactive 3D Graphics and Games 2016

Max Payne 1&2 used physically-based lighting produced by my code that is not entirely unlike the 2nd assignment.




Questions?
Call of Duty: Modern Warfare 2 by Infinity Ward

Class Topics

- Efficient Ray Tracing
  - Basis for everything
- The Rendering Equation...
  - The single most important equation in graphics
  - Radiometry (how light is measured)
- ... and how to solve it
  - The bulk of the class and your assignments
  - Monte Carlo methods, Finite Element Methods (FEM)

[Lehtinen et al. 2008]

You Will Code a Lot

- Four assignments
  - Accelerated ray tracer: Build and use a Bounding Volume Hierarchy, Soft Shadows, Ambient Occlusion
  - Radiosity: Compute diffuse global illumination at vertices, display interactively using OpenGL
    - What I did for Max Payne 1&2, except we used textures
  - Instant radiosity: The Real-Time Technique I just showed
  - Path Tracing (Monte Carlo Global Illumination)
    - Lots of extensions available for almost unbounded extra credit

- Still time to make suggestions!

[Lehtinen et al. 2008]

C3100

E5520

Practical Details: Assignments

- Less starter code than in intro class
  - you will use **your own ray tracer in all of the assignments**
    - Well, in the first one you write it
    - If you fail, we'll provide a binary library you can link against, but this will impose a maximum on your score
  - Framework still there, don't worry

[Lehtinen et al. 2008]

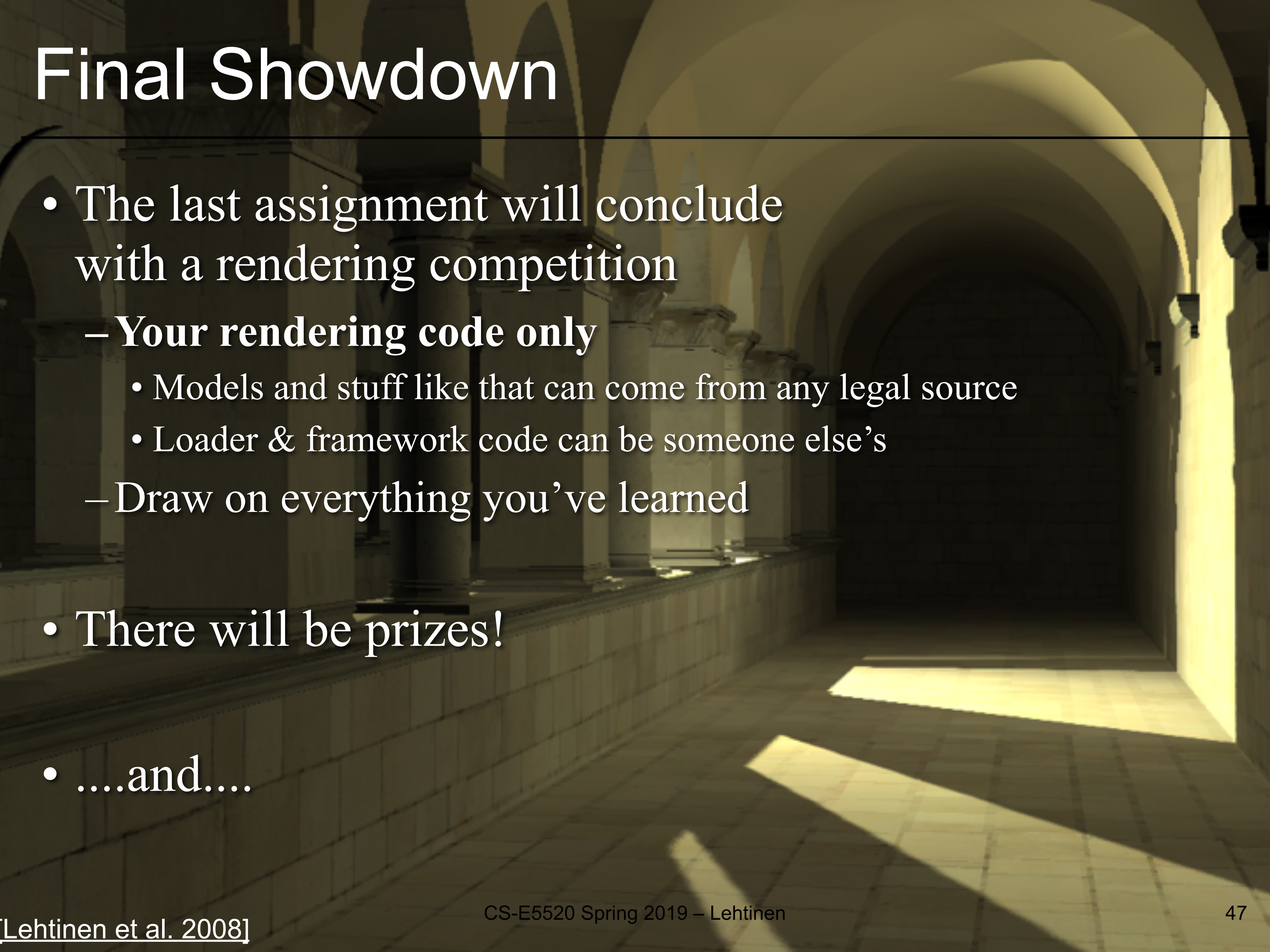
Practical Details: Assignments

- One-person projects
  - Code yourself, BUT talking to others highly encouraged
- MyCourses online message board for discussions and helping others
- MyCourses is the official communications channel

- Grading
  - 90% of grade based on assignments
  - 10% on participation (MyCourses Forums)
    - Yes, we really encourage this

[Lehtinen et al. 2008]

Final Showdown



- The last assignment will conclude with a rendering competition
  - **Your rendering code only**
    - Models and stuff like that can come from any legal source
    - Loader & framework code can be someone else's
  - Draw on everything you've learned

- There will be prizes!

- ....and....

[Lehtinen et al. 2008]

2013 Juror

Luca Fascione
Rendering Research Lead
Weta Digital

2014 Juror

Eric Tabellion
Principal Rendering Engineer
DreamWorks Animation

2015-16 Juror

Christophe Hery
Global Tech and Research TD
Pixar Research

2017 Juror

Marcos Fajardo
Founder & CEO
Solid Angle, Makers of Arnold

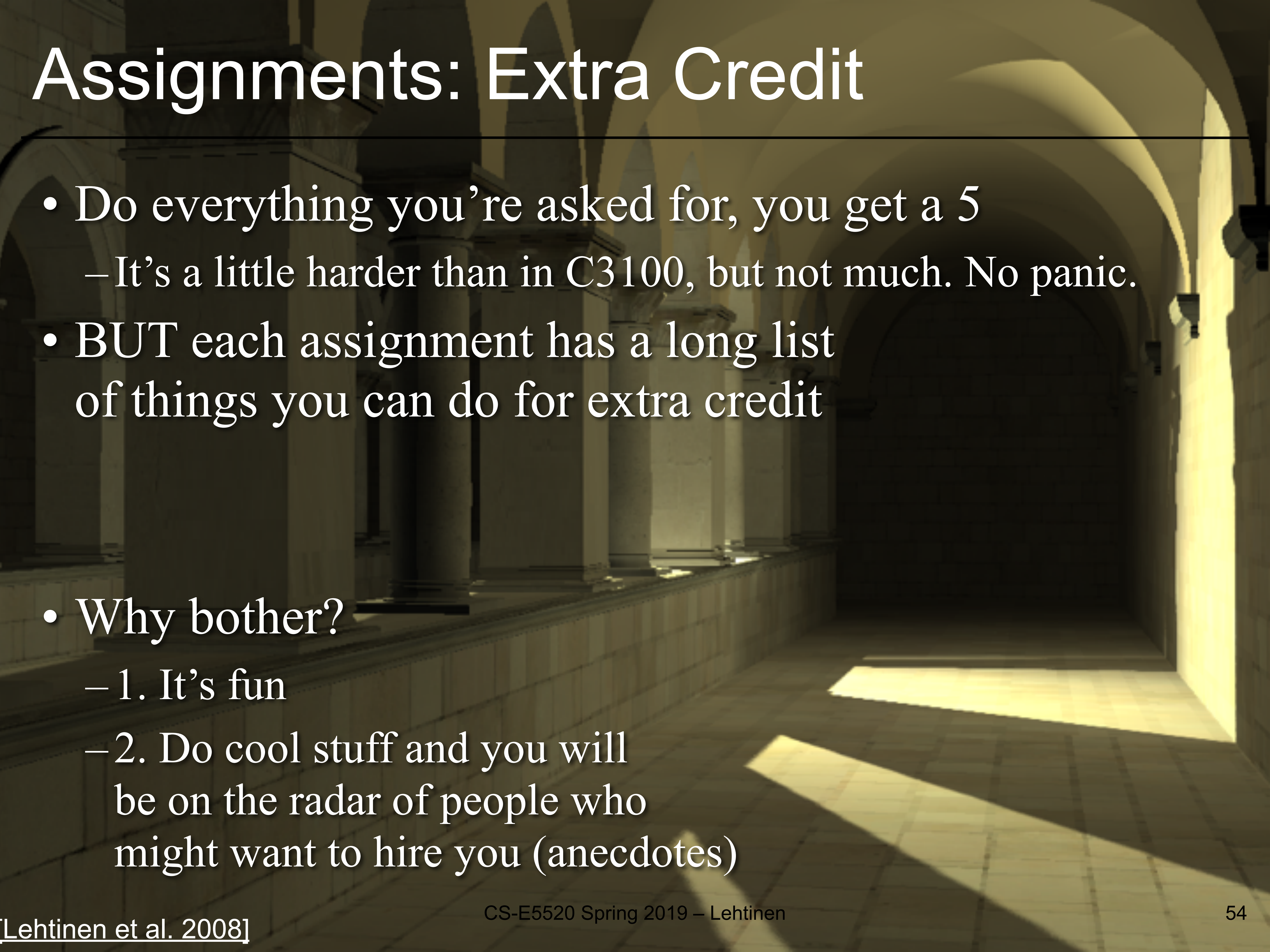
Some examples from Stanford

Saket Pankar and Bo Zhu modeled and simulated water, foam, and sand to render this scene.

Some examples from Stanford

Ben Mildenhall used subsurface scattering and volume rendering to generate candles and flames.

Assignments: Extra Credit



- Do everything you're asked for, you get a 5
  - It's a little harder than in C3100, but not much. No panic.
- BUT each assignment has a long list of things you can do for extra credit
- Why bother?
  - 1. It's fun
  - 2. Do cool stuff and you will be on the radar of people who might want to hire you (anecdotes)

[Lehtinen et al. 2008]

Up to YOU

No Upper Limit

Practical Details: Assignments

- **Deadlines are absolute**: 0 if not on time
  - If you need extra time, must ask for it 1 week in advance
- Coding environment: MS Visual Studio 2017
  - Same environment as CS-C3100 this past fall
- You must turn in code that compiles in Y338
  - You can code on your own setup, but always make sure it compiles and runs in the classroom!
- Always turn in README file where you tell us how long the assignment took, who you collaborated with, what was unclear/difficult, etc.

[Lehtinen et al. 2008]

Tentative Schedule 2019

- Assignment 1: Fast Ray Tracing, DL 17.2.
- Assignment 2: Radiosity, DL 10.3.
- Assignment 3: Instant Radiosity, DL 7.4.
- Assignment 4 + Rendering Compo, DL 5.5.
- **MyCourses is the definitive schedule!**
- Lectures not necessarily every week (will try to keep up with assignments), will post info ahead of time
- Schedule subject to change,
  will notify well in advance

[Lehtinen et al. 2008]

Practical Details: Admin

- Class email: cs-e5520@aalto.fi
  - ***All teacher communication through there!***
- TAs
  - Pauli Kemppinen, Ville Ollikainen, Lauri Aarnio
- Exercise sessions Y338 Mondays 11-14
  - Not mandatory
  - TAs will be there to help, and you can chat with classmates
- To see me, come to my office hours
  - Wednesdays 10-11 at room B308, Aalto CS building
  - Exceptions posted on my webpage

[Lehtinen et al. 2008]

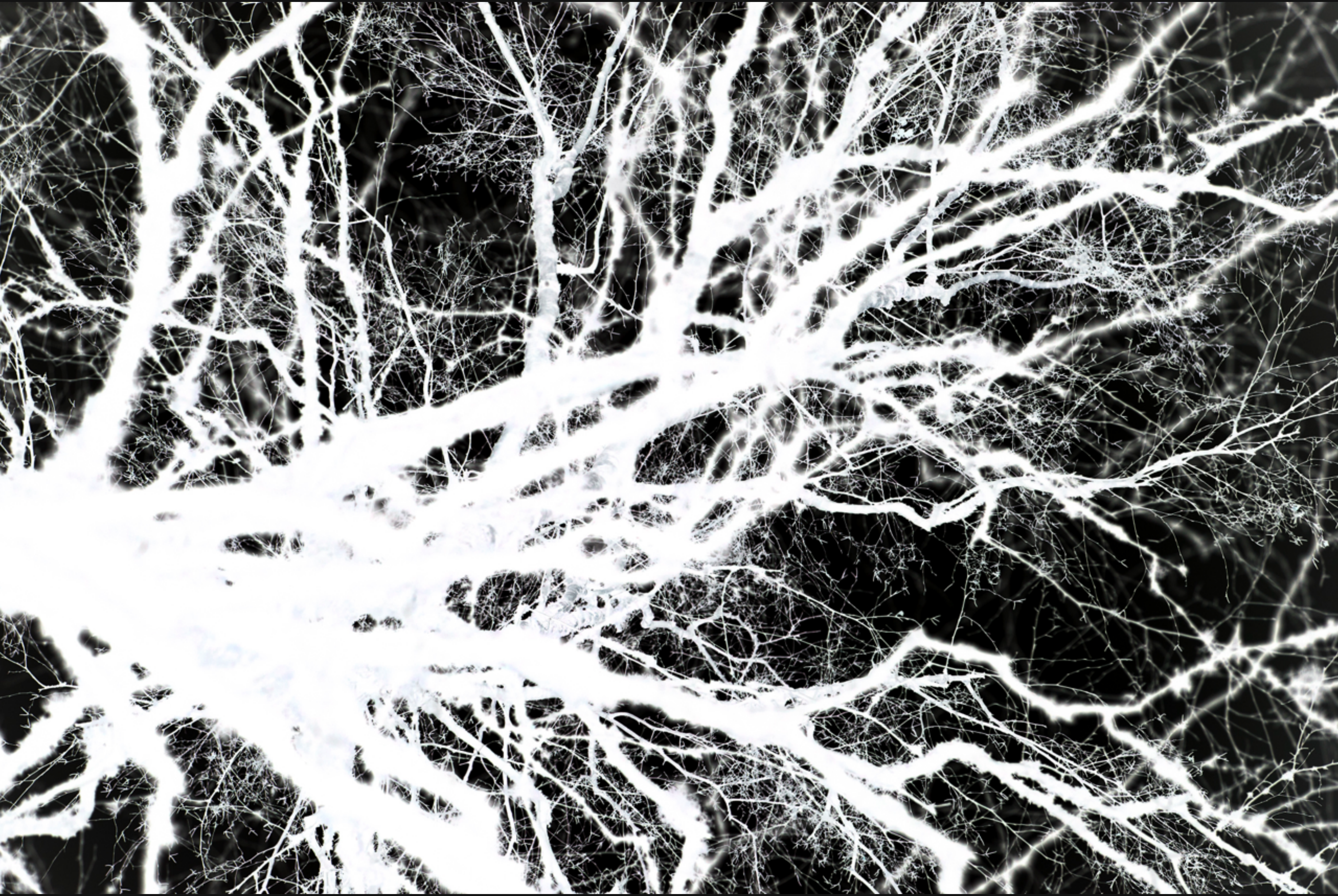
Practical Details: Admin

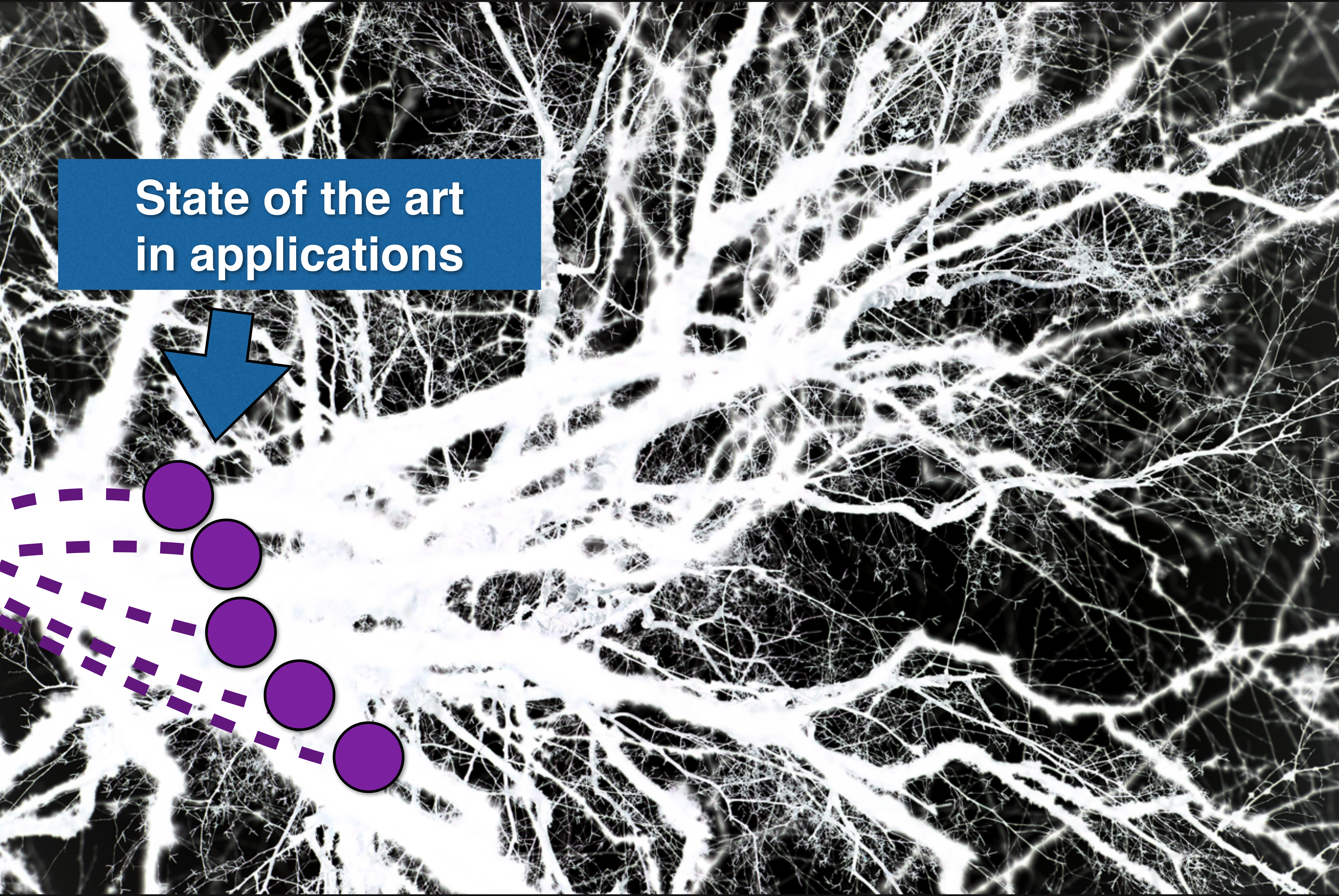
- This is the 7th time this class is run
- Lecture schedule (how many in total) not set in stone
  - Will have industry visitors
  - etc.

- Will communicate basic requirements clearly, but lots of extra material will be available.

[Lehtinen et al. 2008]

Concluding remarks:
The Role of Research

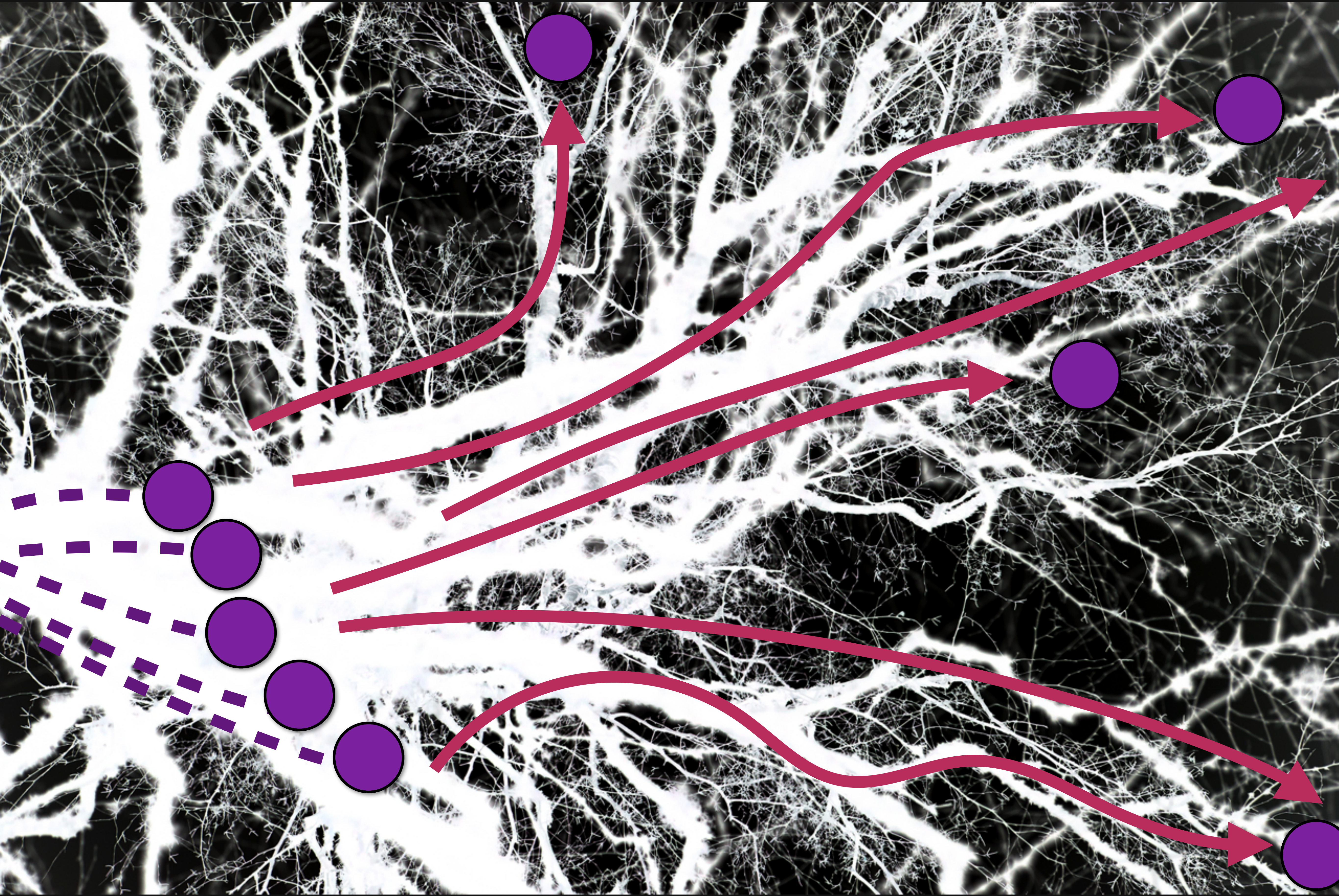


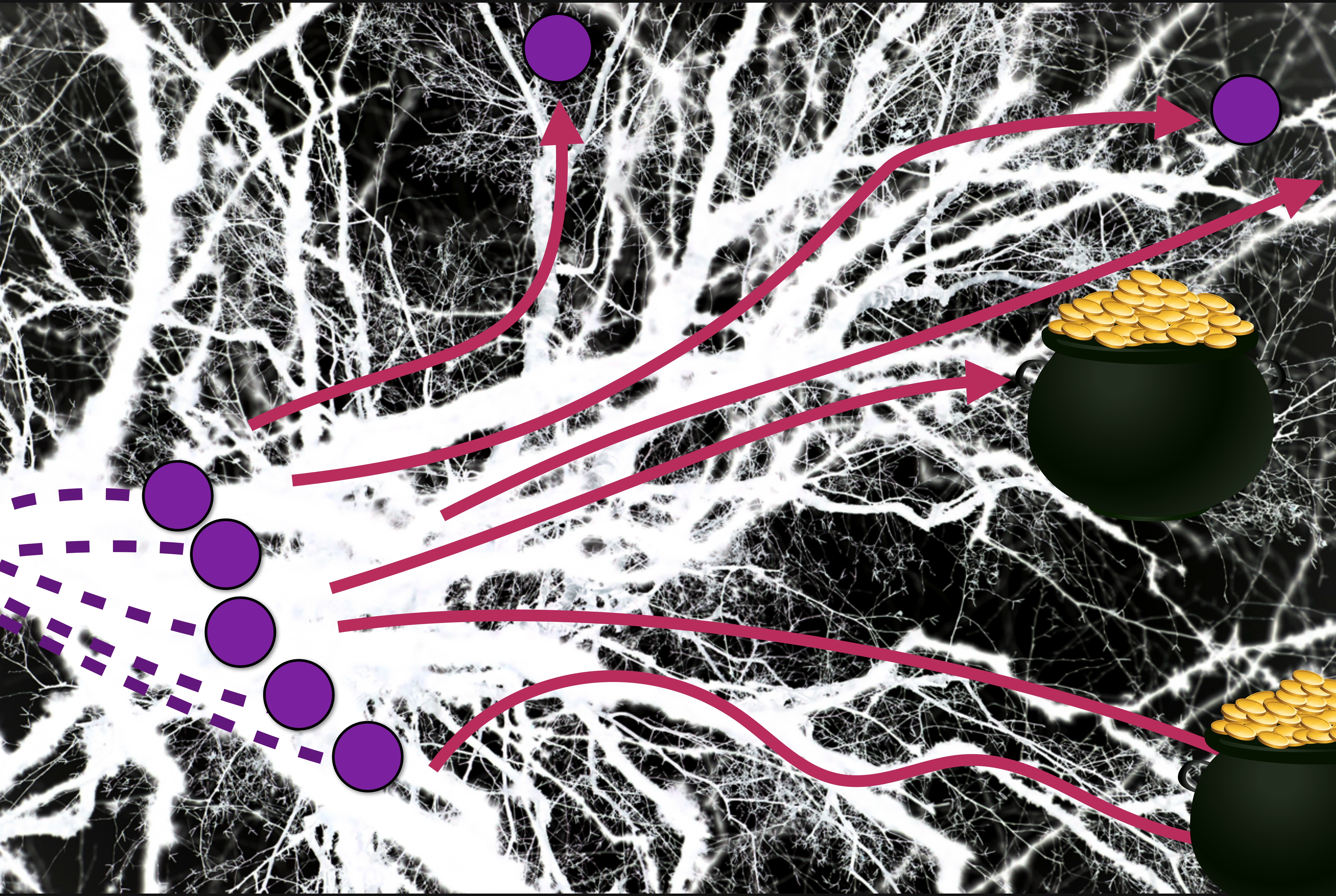

State of the art
in applications

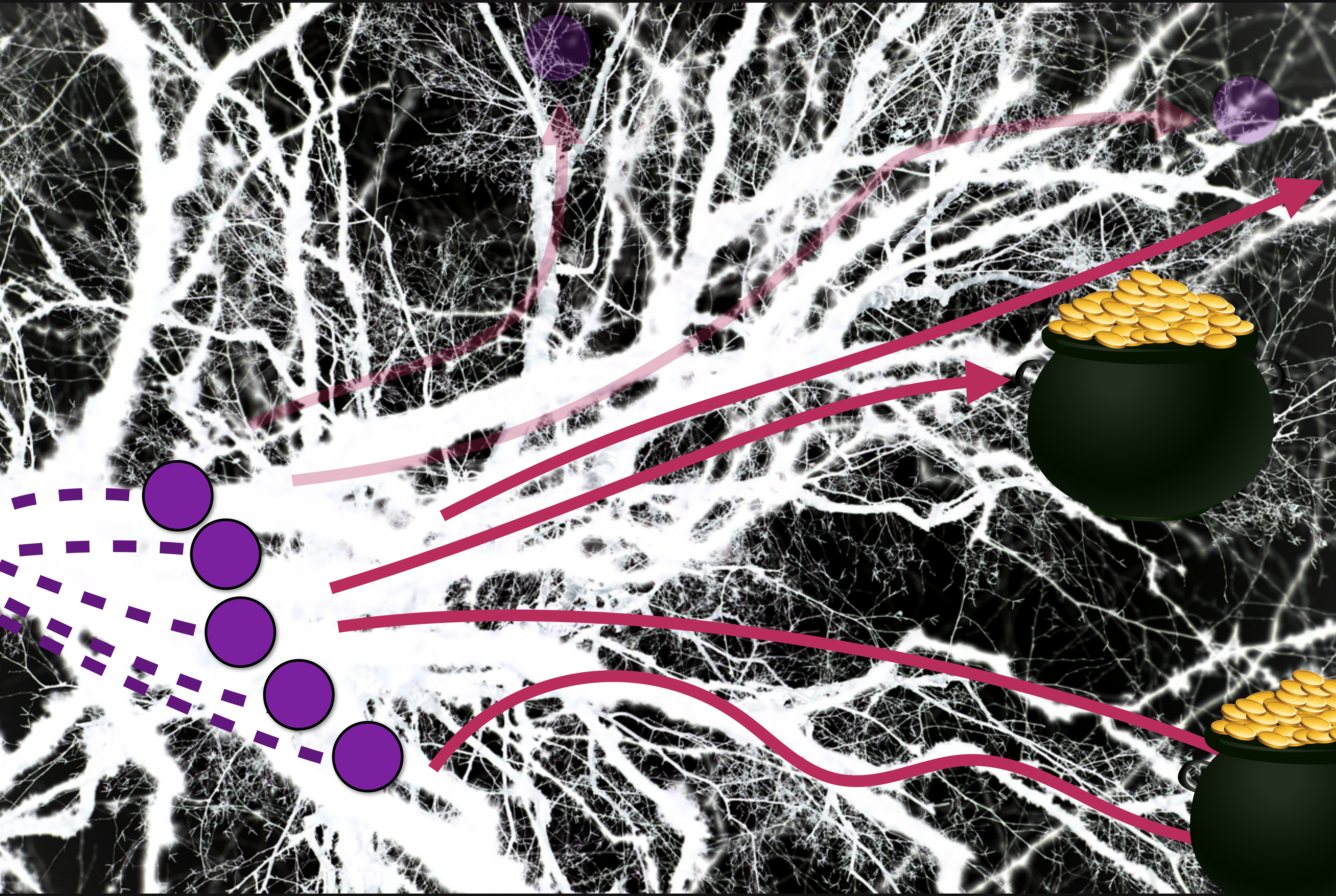
Reality: if you just focus on what's possible today, you suffer from serious myopia

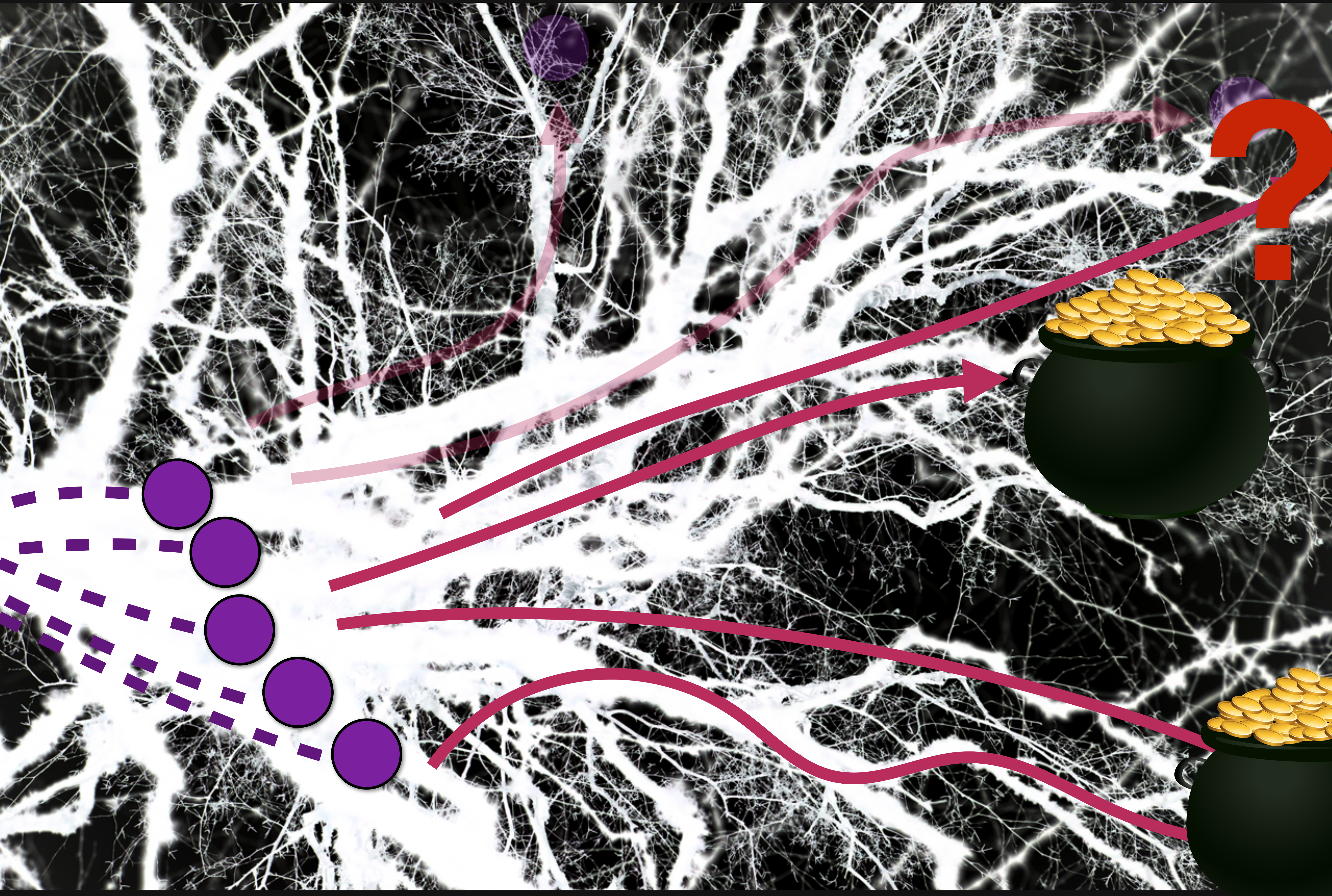
Reality: if you just focus on what's possible today, you suffer from serious myopia

The role of research is…









Almost everything you learn in university
is a product of peer-reviewed, published academic research.

(In CS, also the industry participates in the academic forum.)

Adapted from original by New Line Cinema (?)

You can google ahead for
“rendering equation”, “radiance”

Journey Starts Next Wednesday