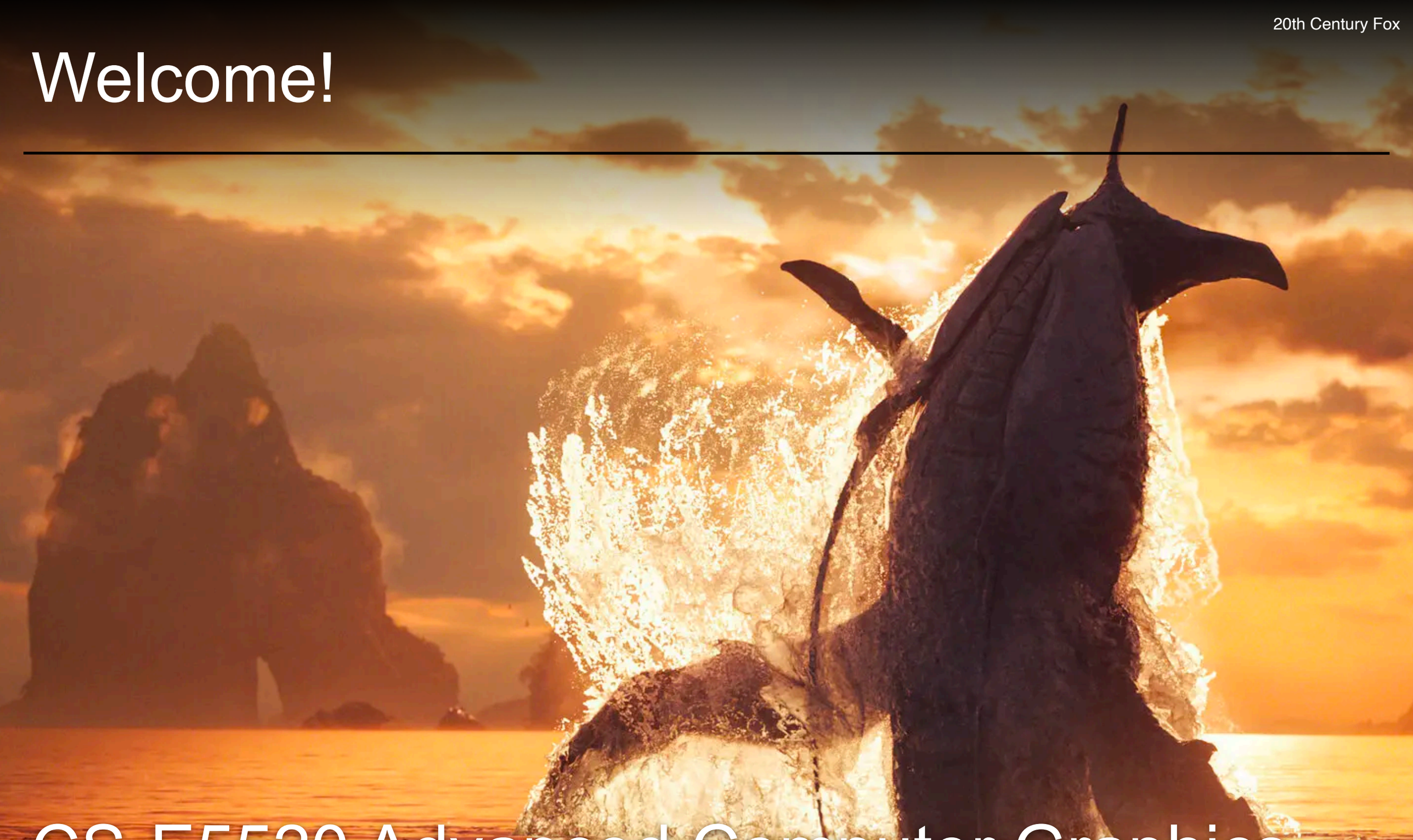
Welcome!



CS-E5520 Advanced Computer Graphics

Spring 2023

Jaakko Lehtinen & TAs Pauli Kemppinen and Heikki Timonen

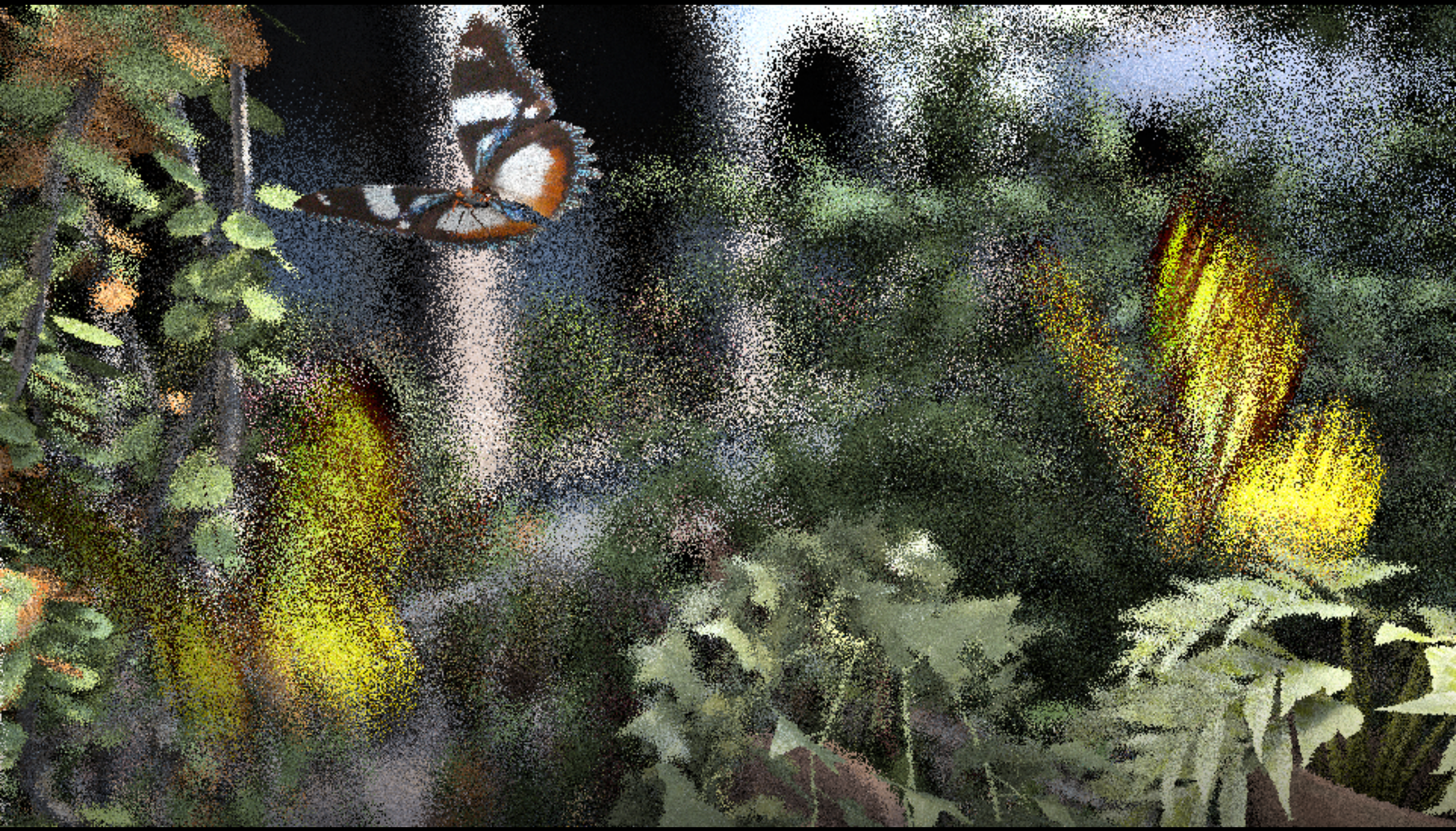
NVIDIA

~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®

Complex:
Geometry
Shading
Visibility

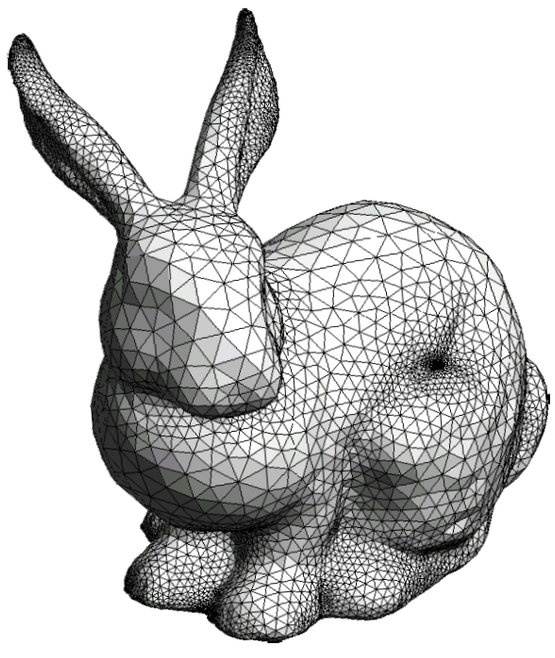
Rendering:

Compute what's visible.

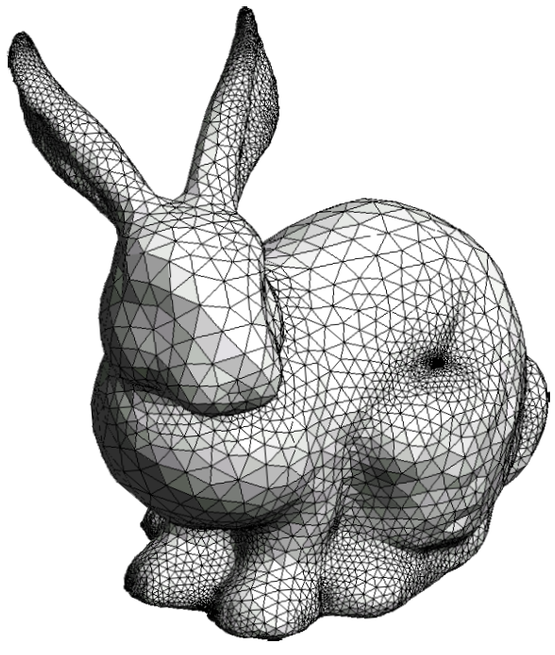
Compute what color it is.

What color it is:

Determined by interaction of light and matter.

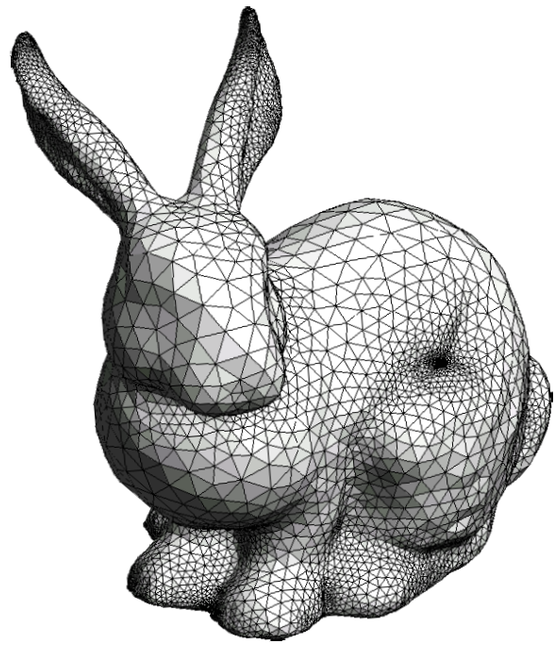


Scene

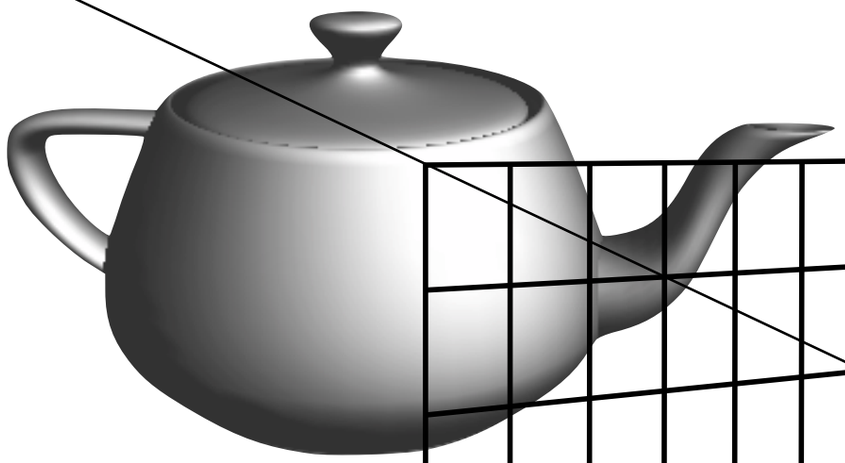


Scene

Camera



Scene

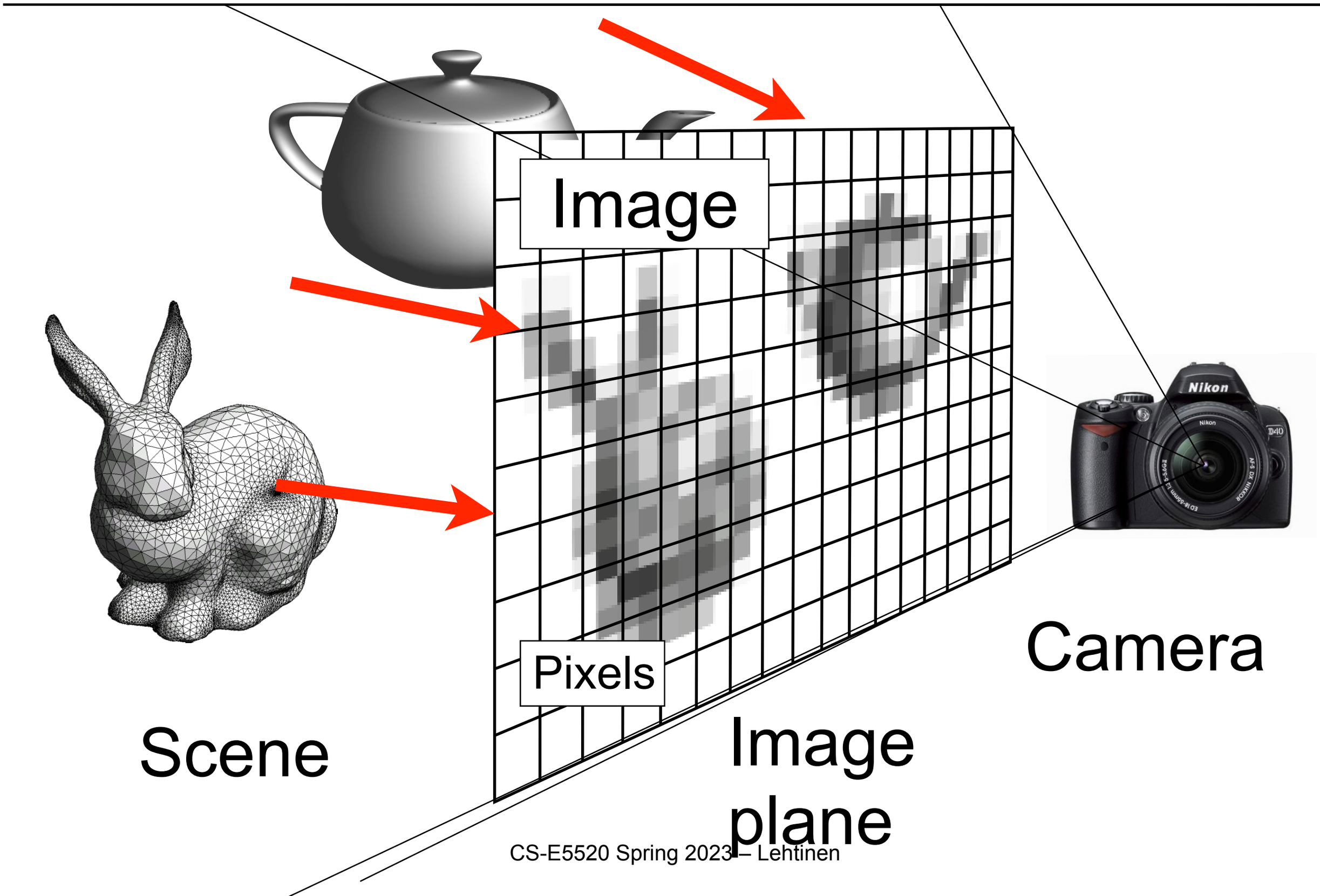


Pixels

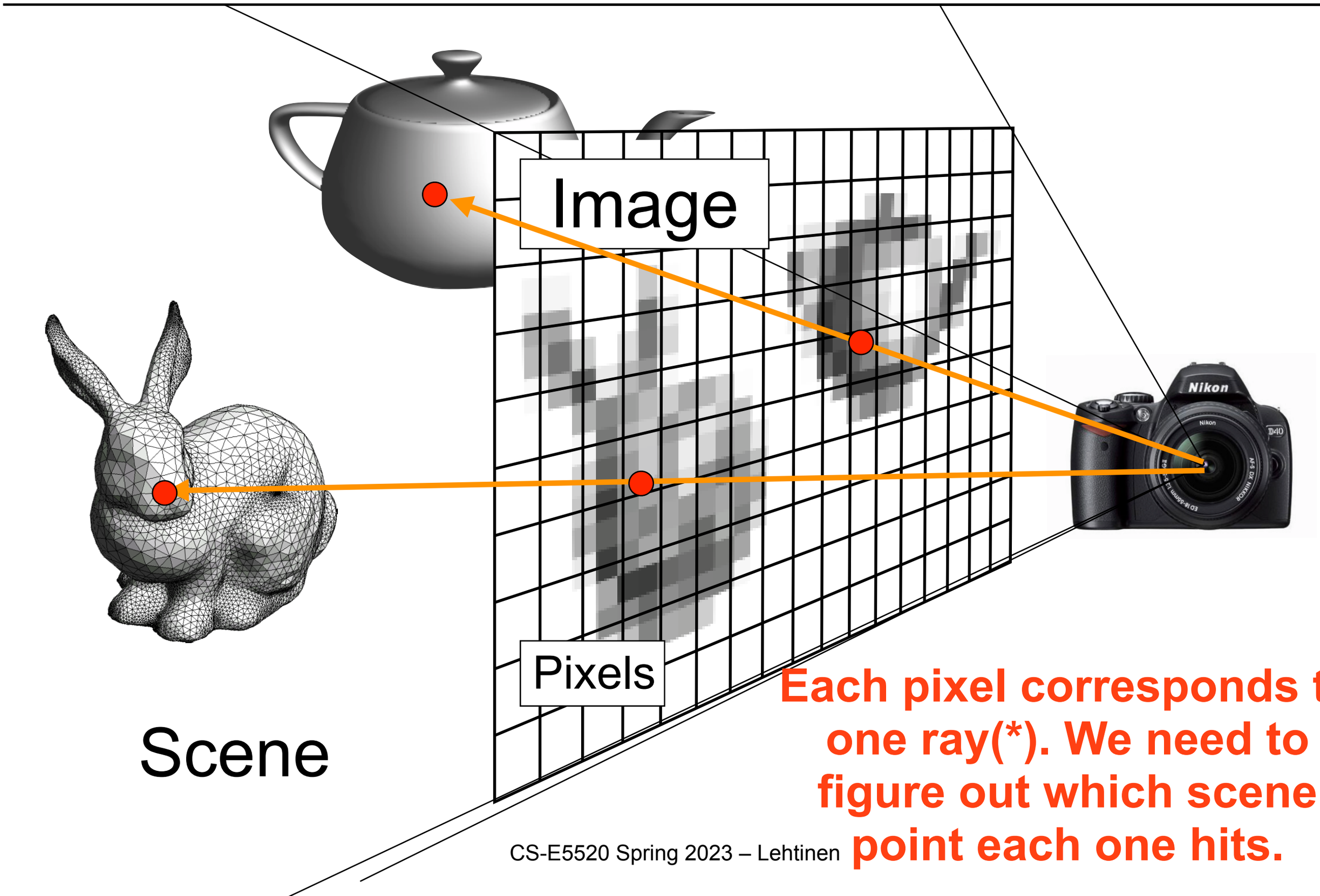
Image plane

Camera

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

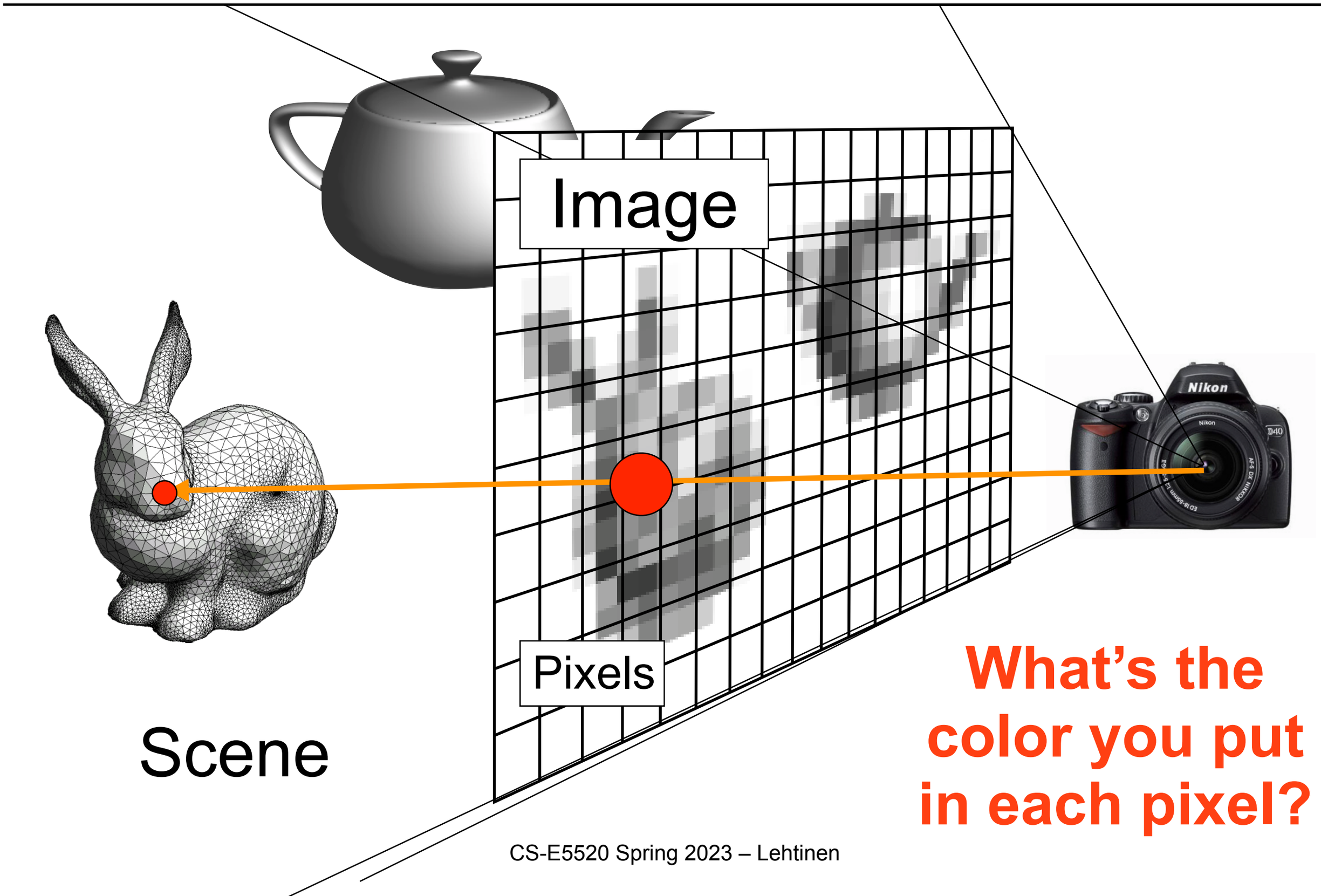


Image
Pixels
Scene
Nikon
What's the color you put in each pixel?

Rendering

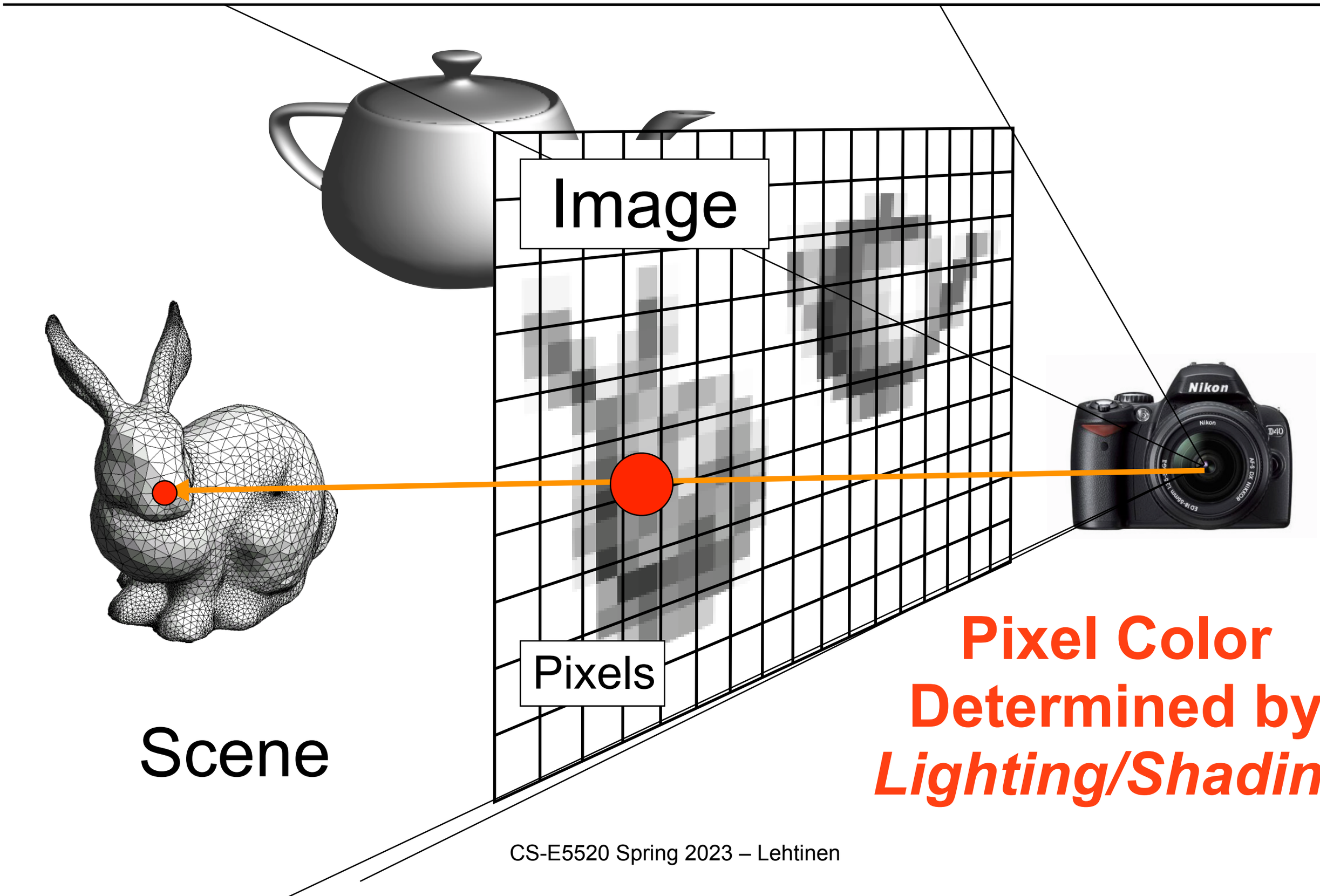
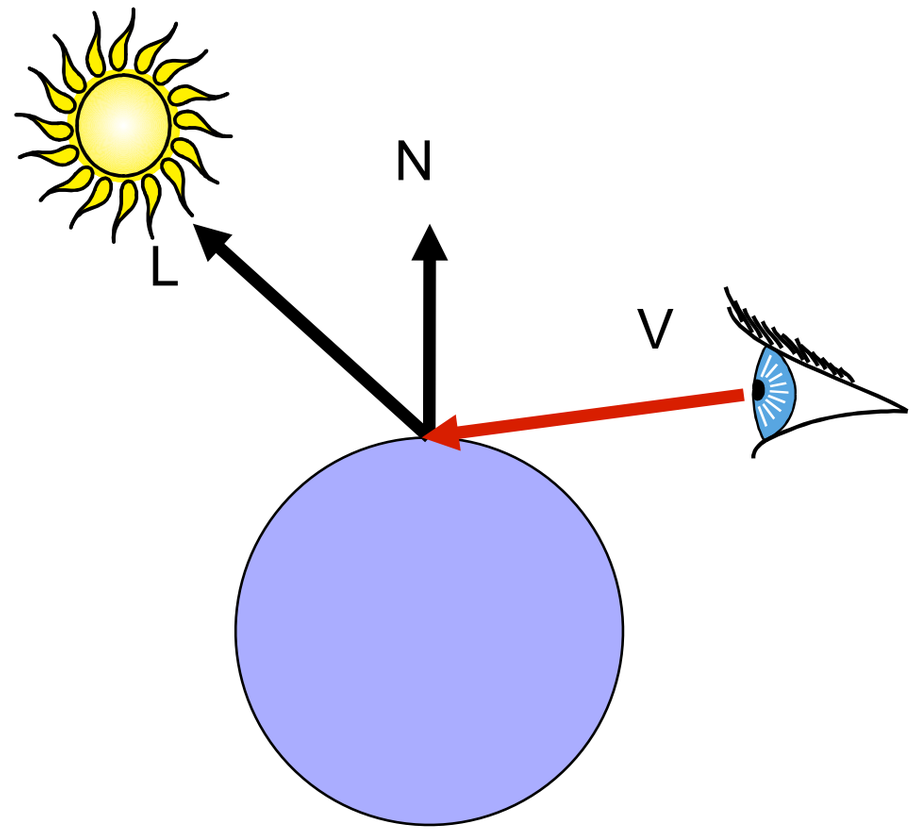


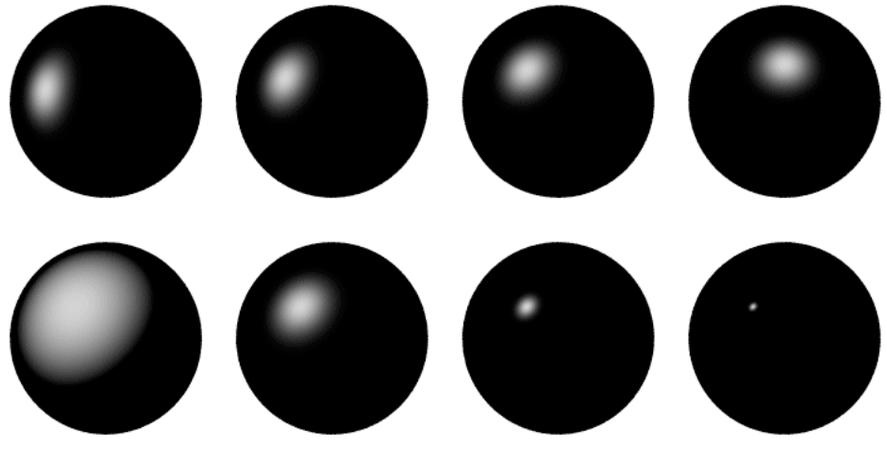
Image
Pixels
Scene
Nikon
Pixel Color
Determined by
Lighting/Shading

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 (link to paper)

Reflectance Capture By Parametric Texture Synthesis

Miika Aittala Timo Aila Jaakko Lehtinen

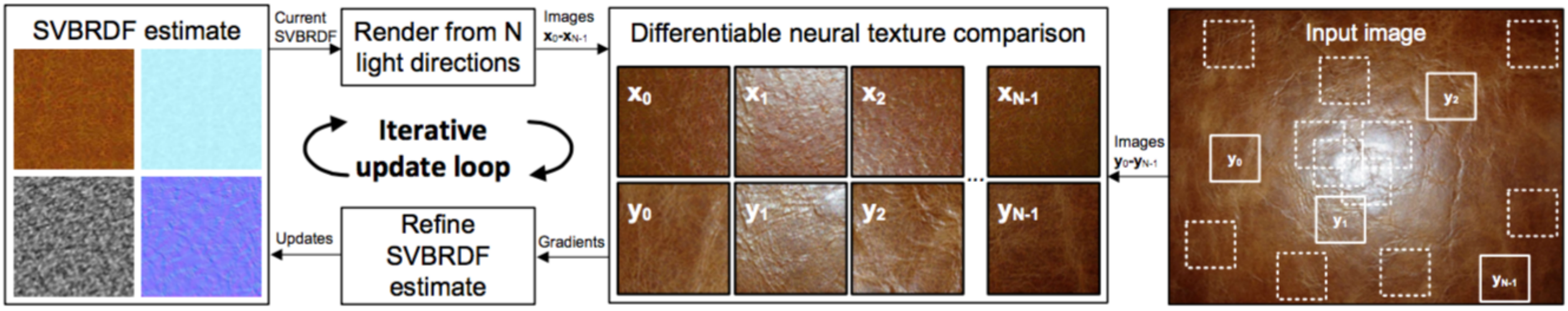


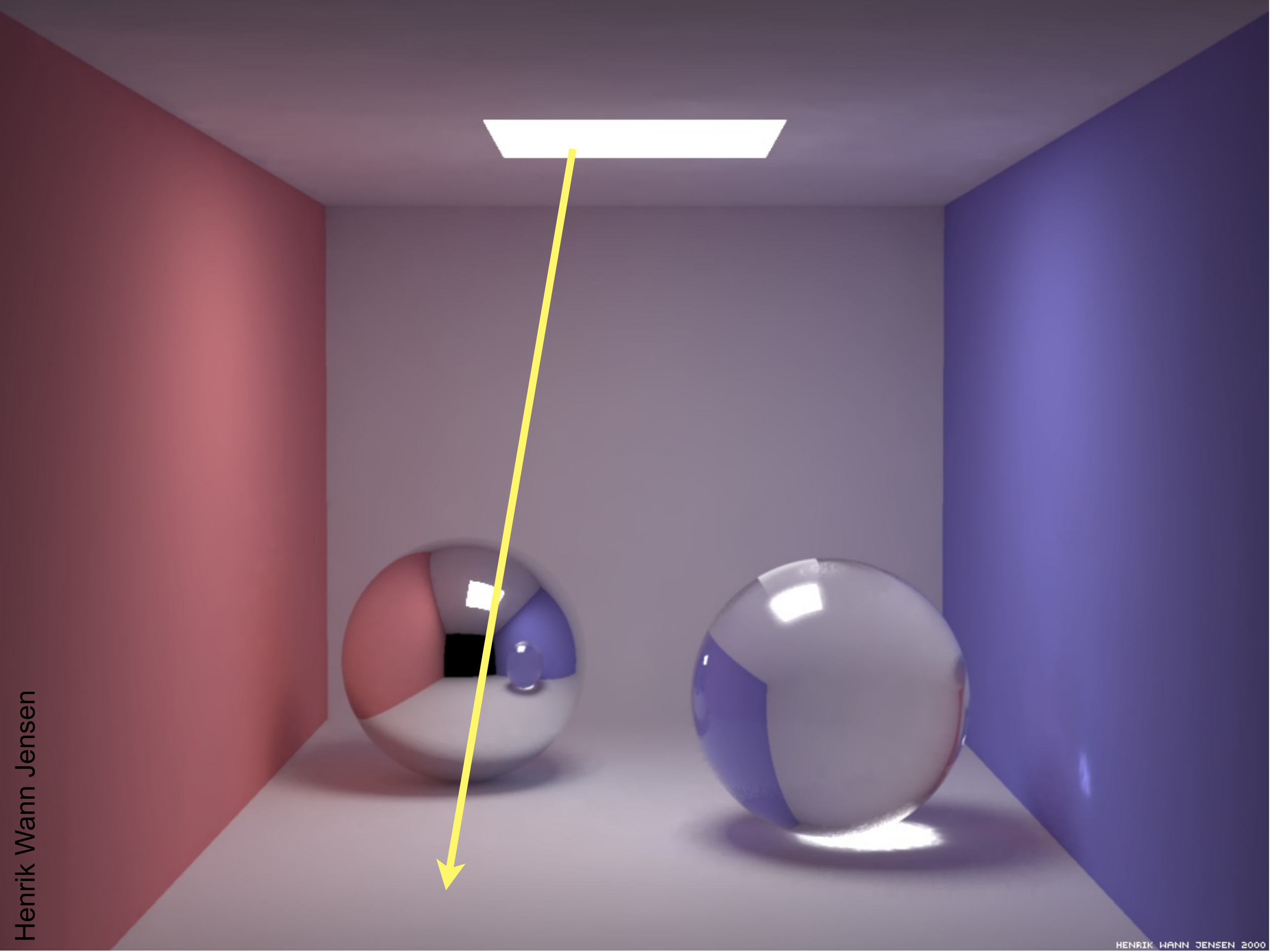
Figure 1: *Our algorithm synthesizes a spatially varying BRDF that closely matches the input flash image when rendered from different lighting directions. The optimization process iteratively updates the current estimate based on neural network-based texture statistics comparisons that are able to ignore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

Image Synthesis is Radiative Transport

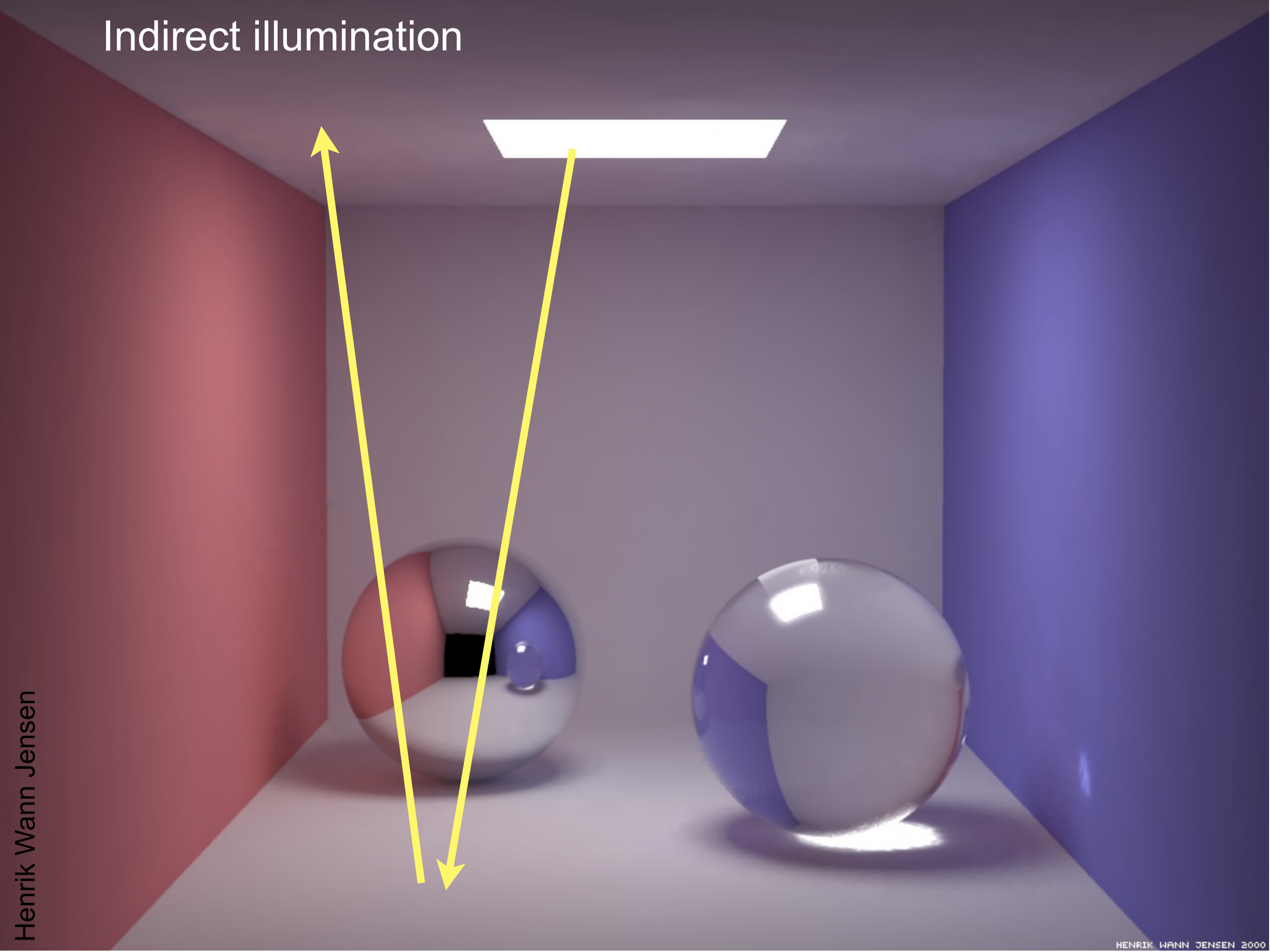
$$\omega \cdot \nabla_x L(x,\omega) = \epsilon(x,\omega)$$
$$-\sigma_t(x) L(x,\omega)$$
$$+\sigma_s(x) \int_{4\pi} p(x,\omega,\omega')\, L(x,\omega')\, \mathrm{d}\omega'$$

“Volumetric Rendering Equation”

= Radiative Transport Equation (Chandrasekhar, 1960)

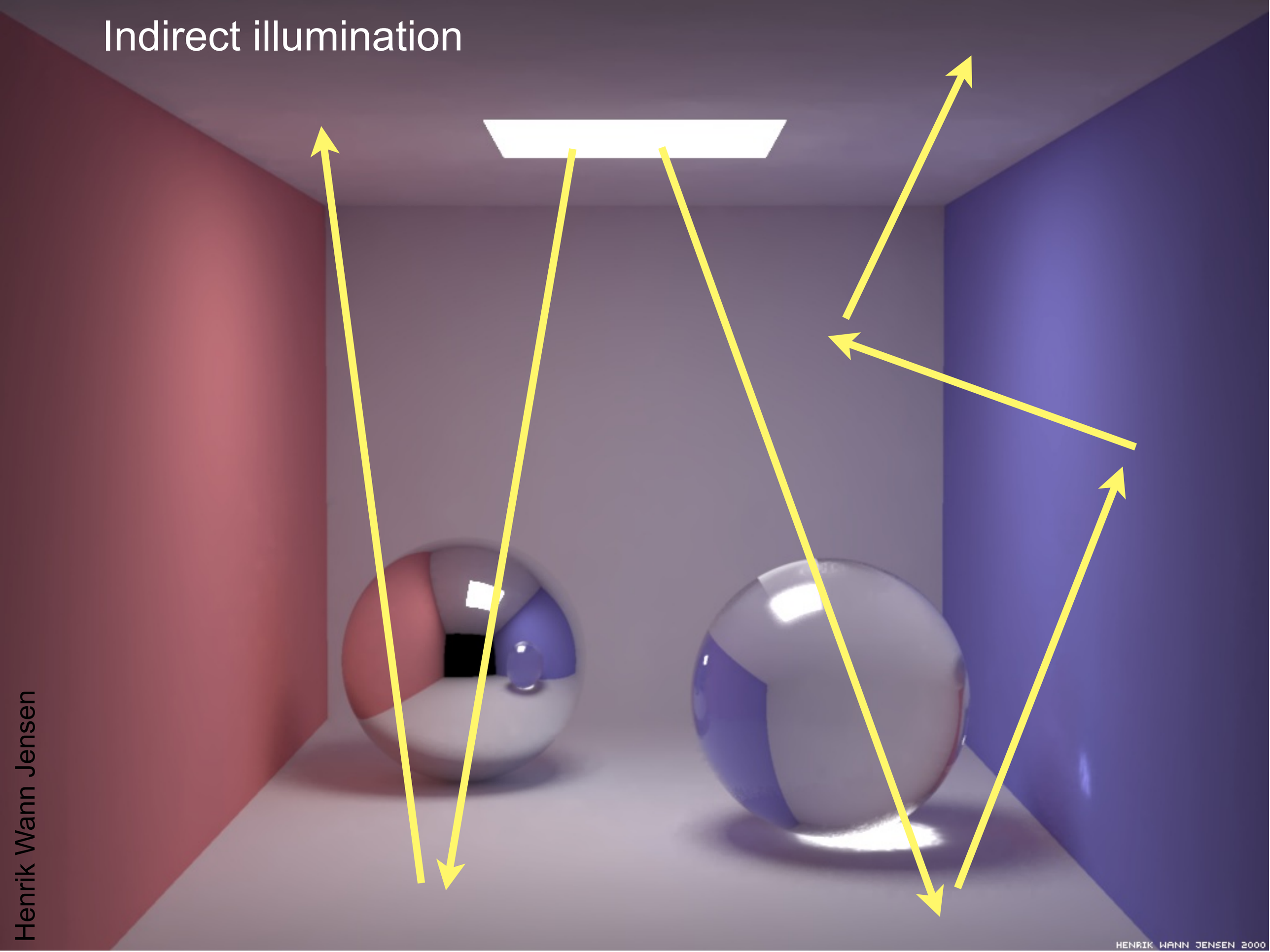

Henrik Wann Jensen
HENRIK WANN JENSEN 2000

Indirect illumination

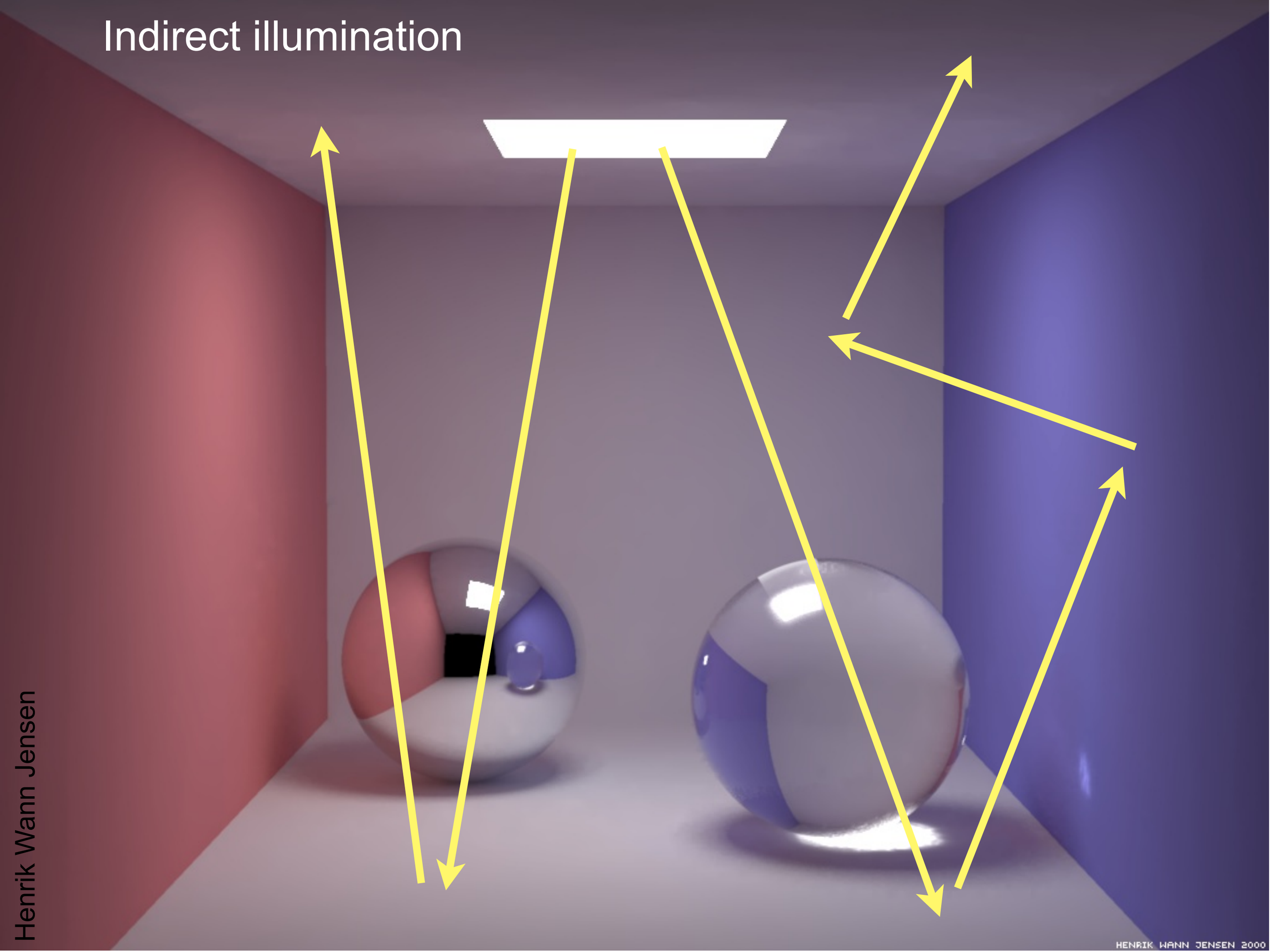


Henrik Wann Jensen

Indirect illumination



Indirect illumination

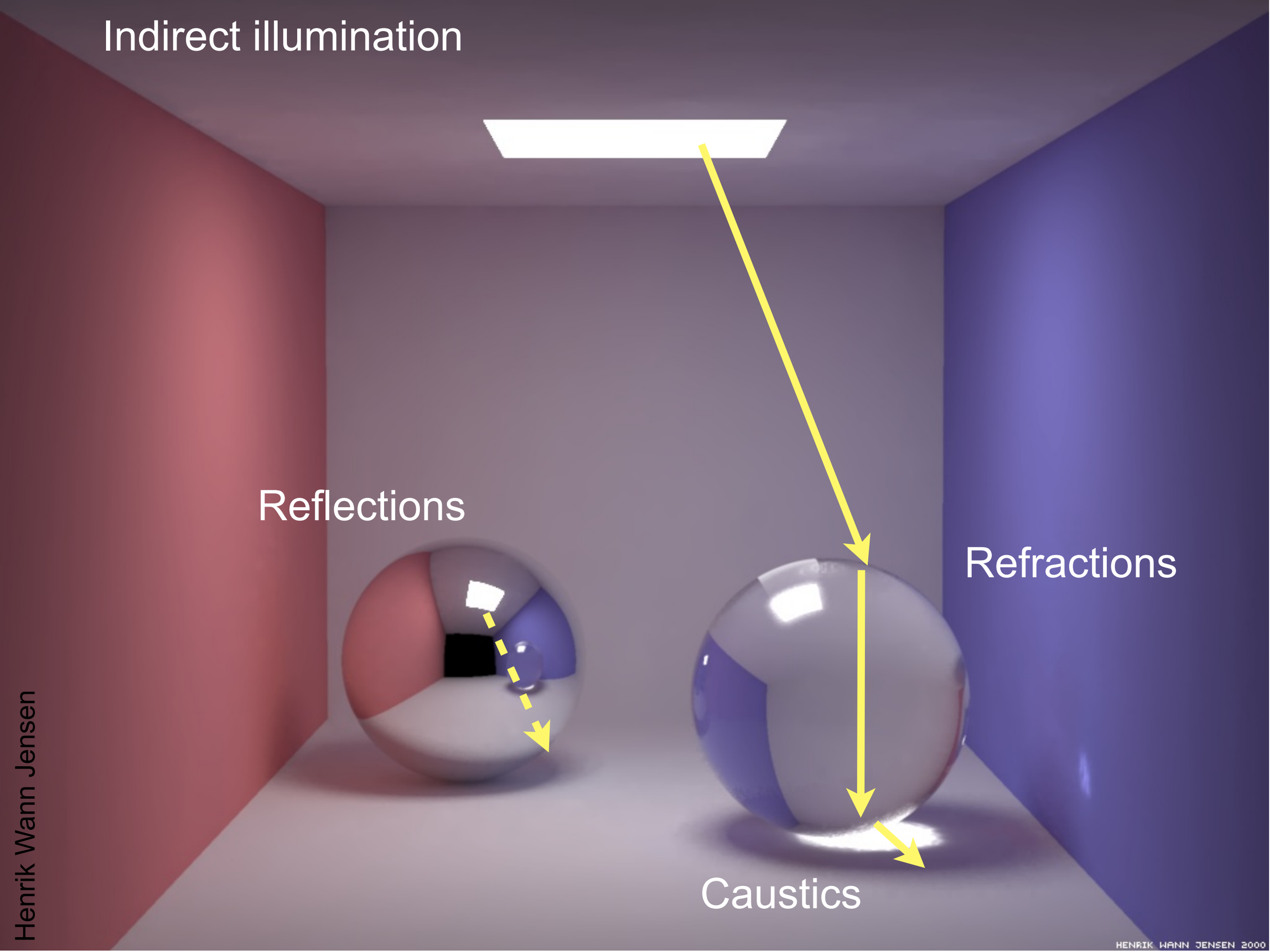


Indirect illumination

Reflections

Henrik Wann Jensen

Indirect illumination

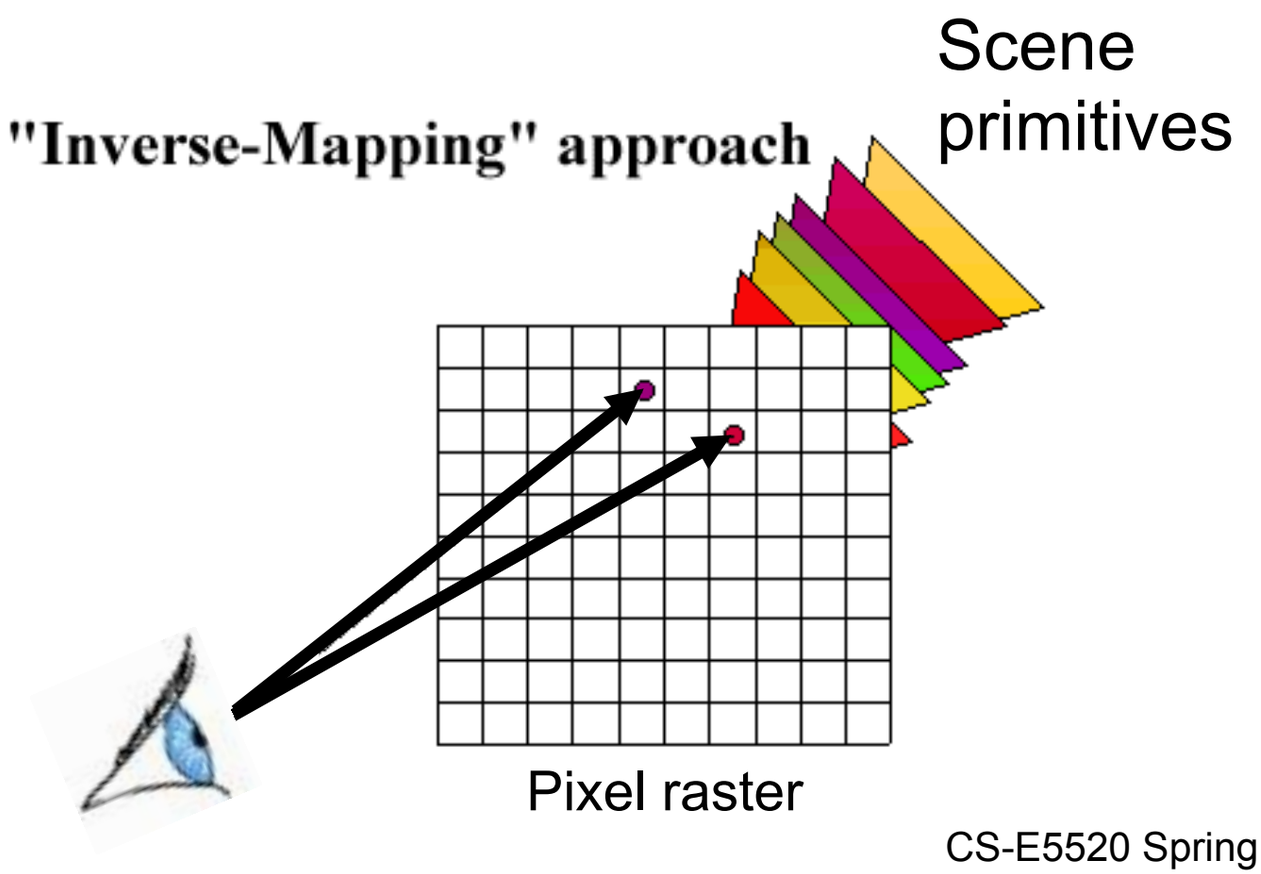


Ray Casting vs. Rasterization

Ray Casting

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

Keep closest hit



Ray Casting vs. Rasterization

Ray Casting

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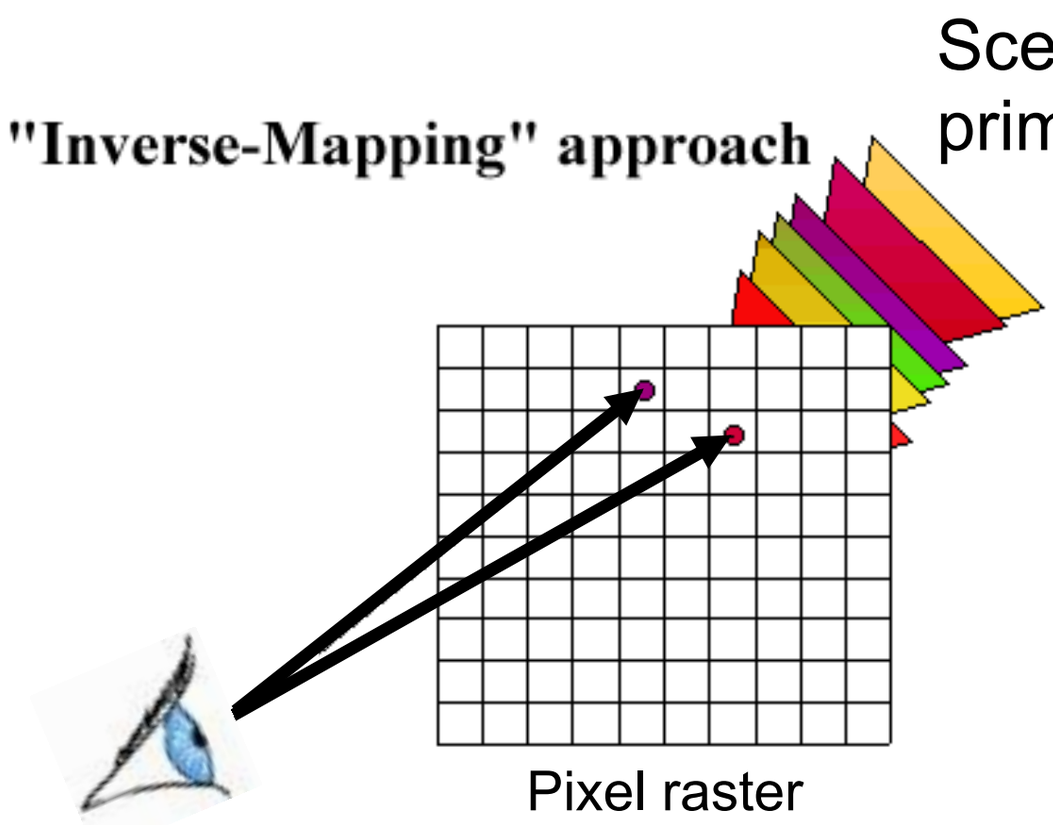
    Does ray hit object?
```

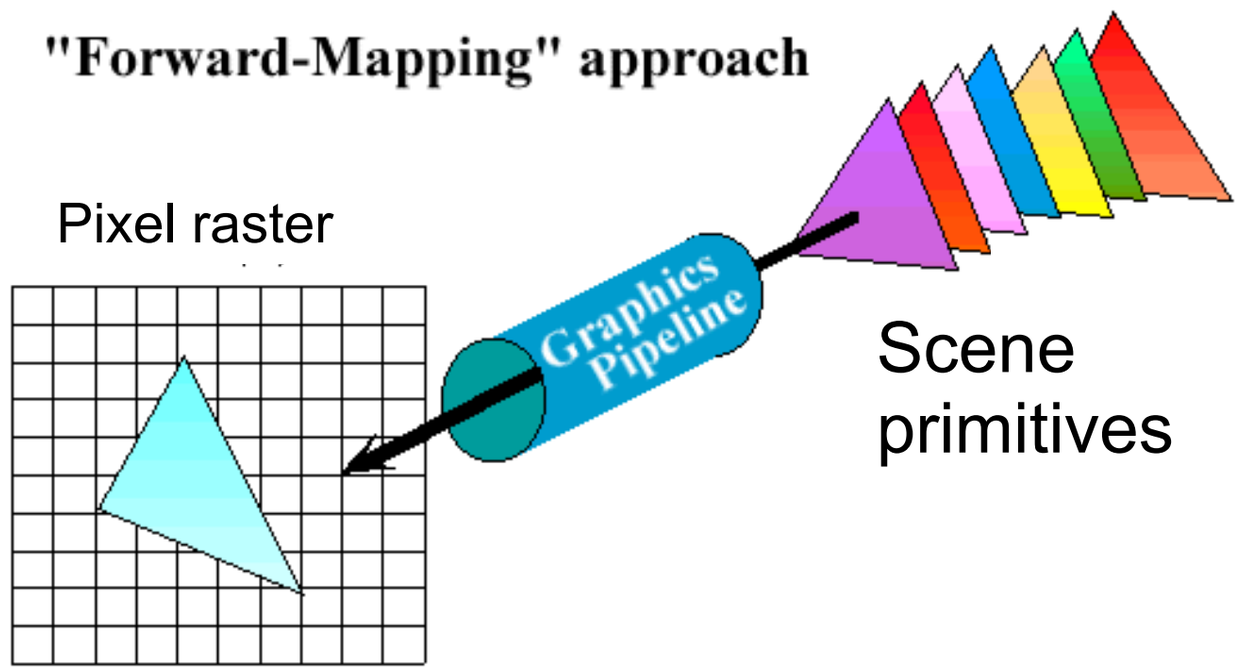
Keep closest hit

Rasterization

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

Keep closest hit





Ray Casting vs. Rasterization

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Keep closest hit

Rasterization

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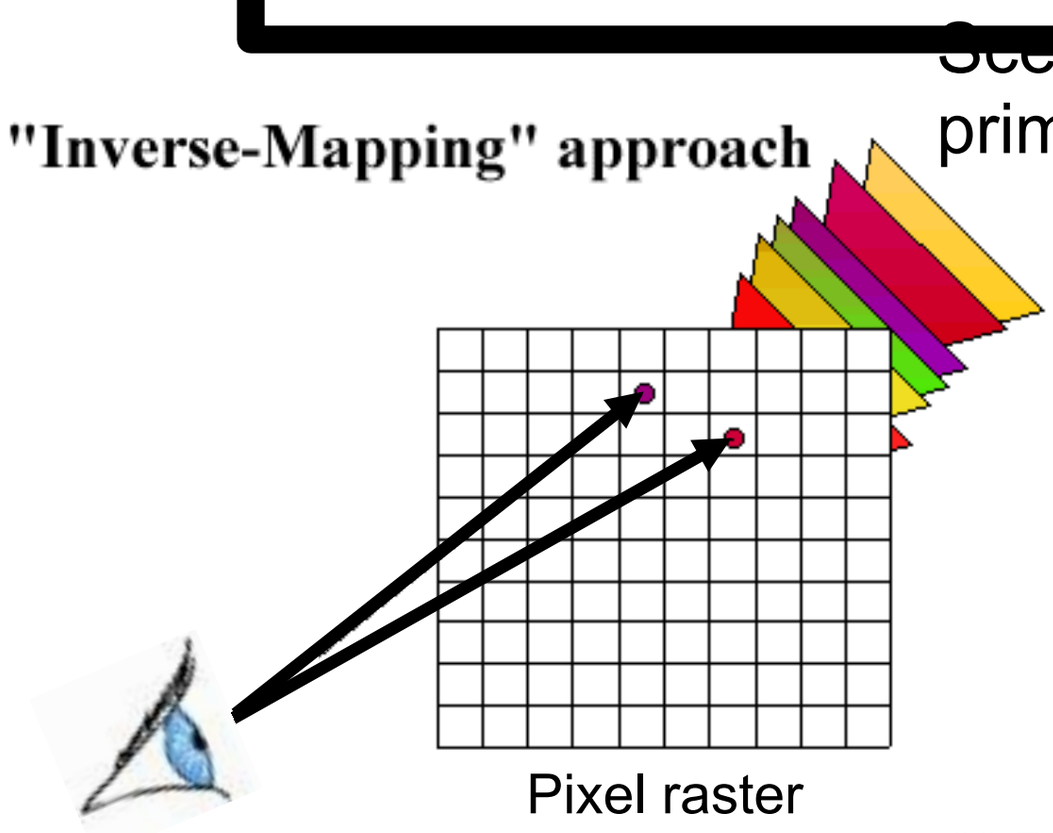
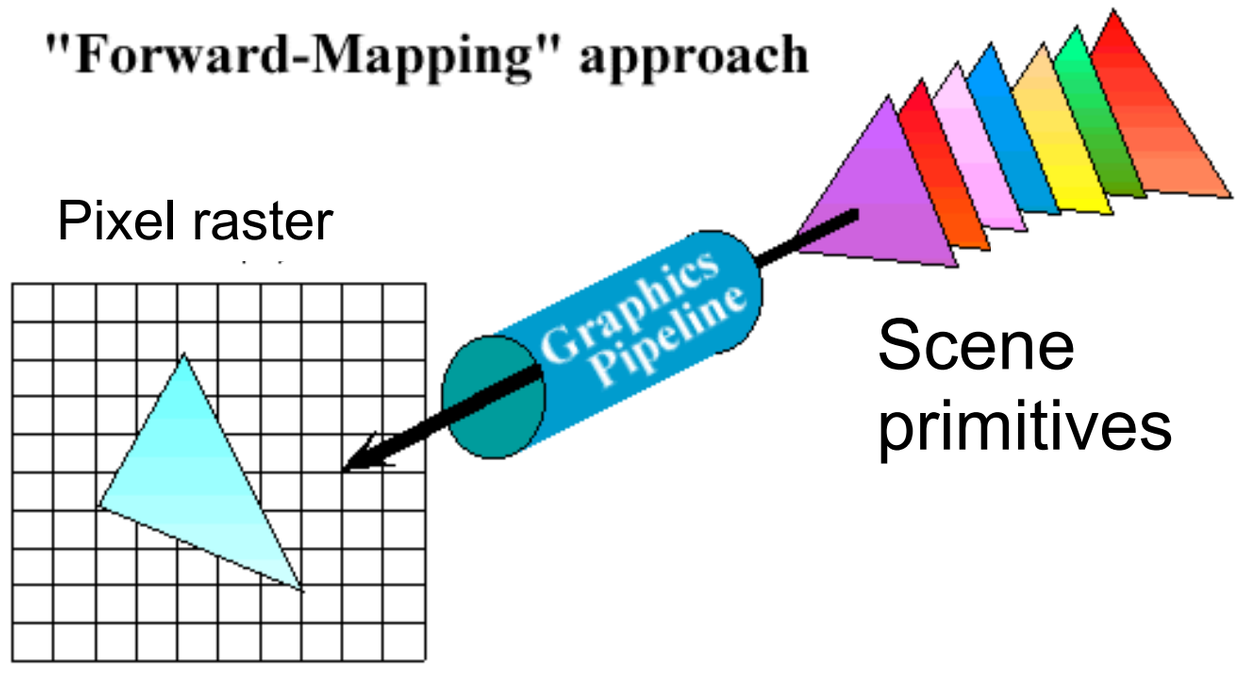
For each triangle
  For each pixel
    Does triangle cover pixel?
```

Keep closest hit

It's just a different order of the loops!





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

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  - **..but today, interactive ray tracing is reality!**

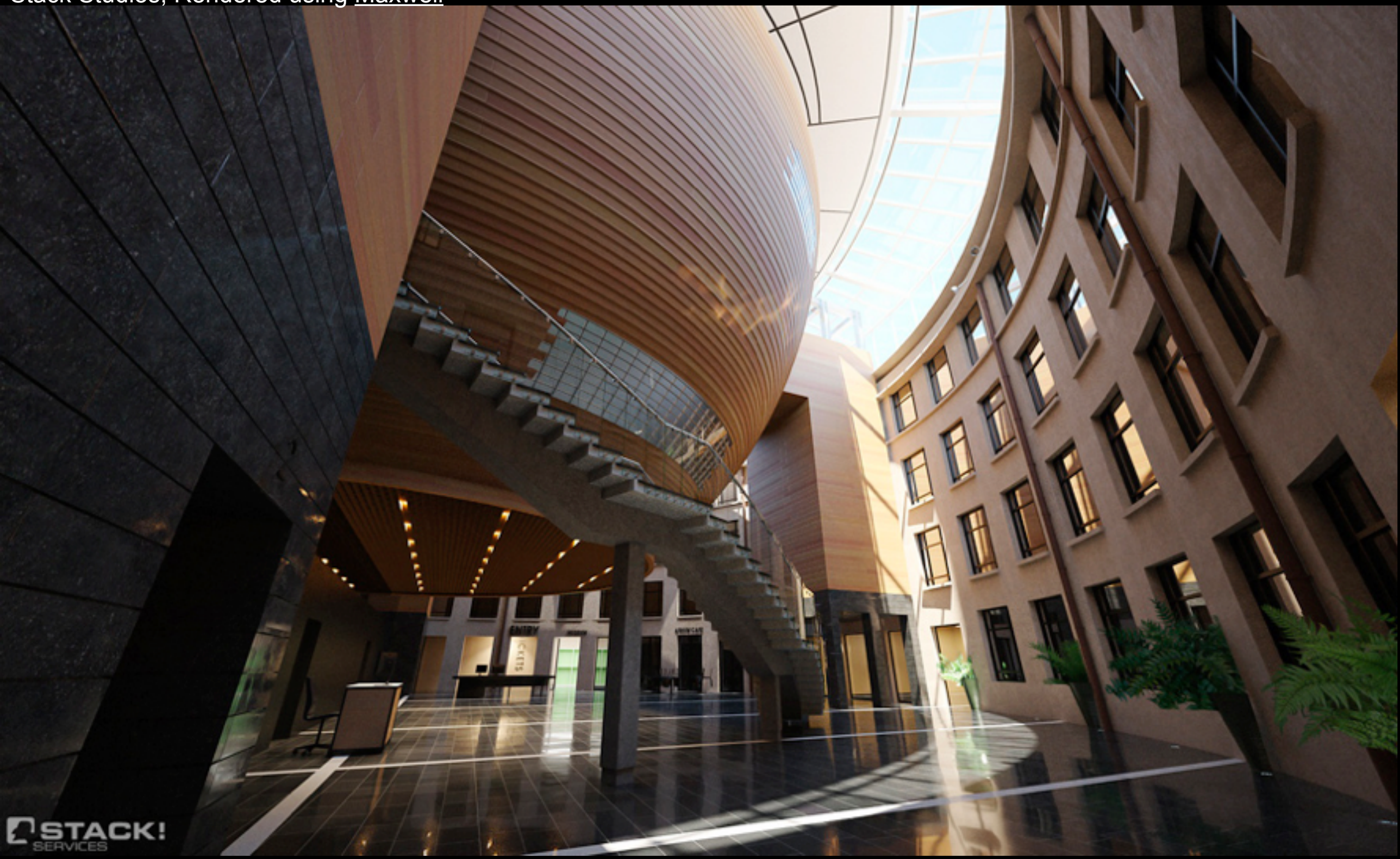
Our focus in this class

“Speed of Light”
Real-time ray tracing on an NVIDIA RTX GPU

“Marbles at Night” (**YouTube**)
Real-time ray tracing on an NVIDIA RTX GPU

Markus Otto/Winzenrender, Rendered using Maxwell

Stack Studios, Rendered using Maxwell

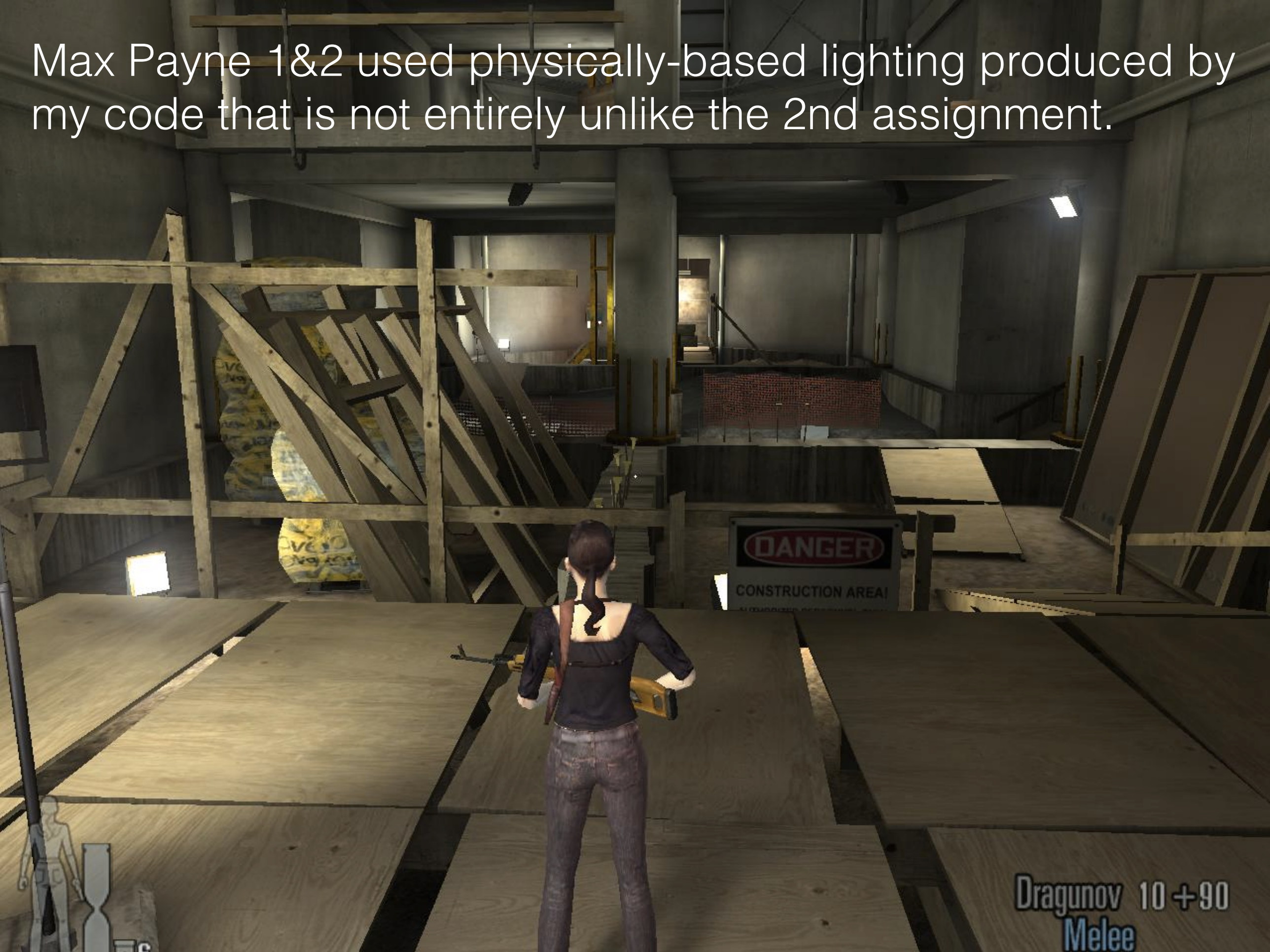


New Line Cinema

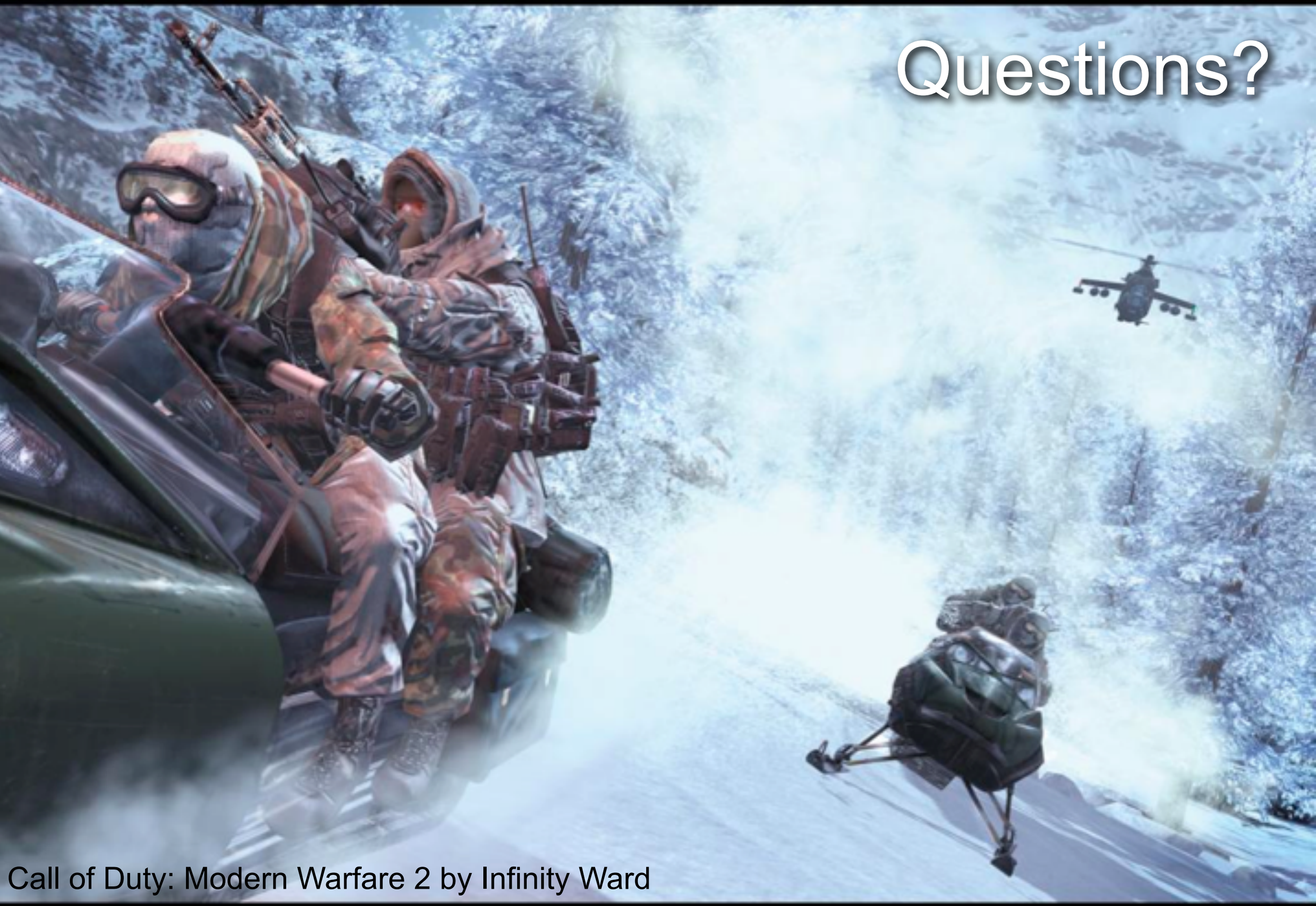
Also Real-Time using Traditional Methods (video@58s)

– 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

- Three 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
  - Path Tracing (Monte Carlo Global Illumination)
    - Lots of extensions available for almost unbounded extra credit

[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
- *New this year*: Slack for asking questions and giving answers related to assignments (link on MyCourses)
- MyCourses is the official communications channel

- Grading
  - 100% of grade based on assignments
  - Strong effort on helping others on Slack may get bonuses

[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

[Lehtinen et al. 2008]

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 2022
- You must turn in code that compiles in VDI "Windows 10 3D" instance
  - You can code on your own setup
- 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 2020

- Assignment 1: Fast Ray Tracing, DL 19.2.
- Assignment 2: Radiosity, DL 12.3.
- Assignment 4 + Rendering Compo, DL 7.5.
- **MyCourses is the definitive schedule!**
- Lectures will be mostly up front, will go out of sync with exercises

[Lehtinen et al. 2008]

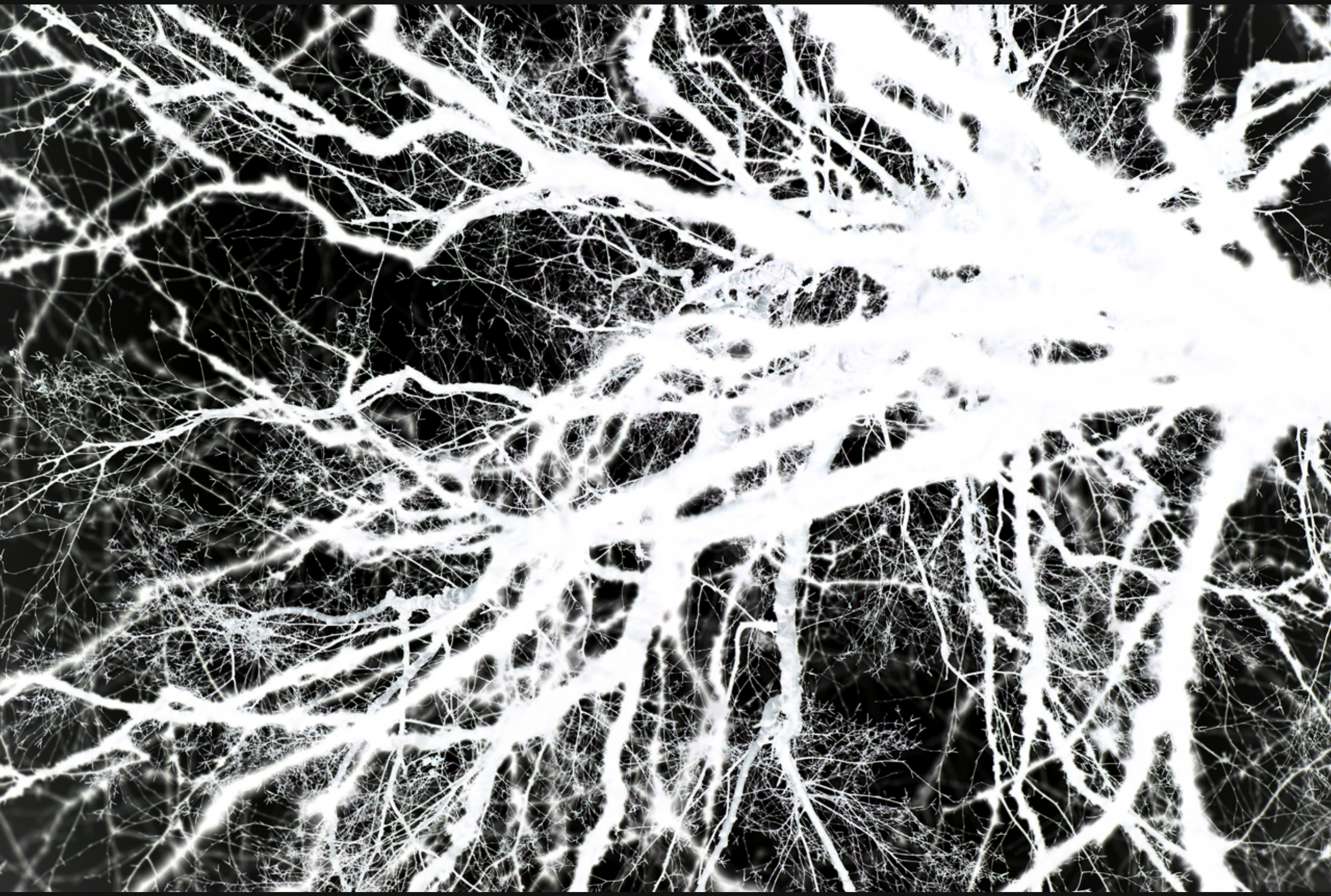
Practical Details: Admin

- Class email: cs-e5520@aalto.fi
  - ***All communication not related to assignments here!***
- TAs
  - Pauli Kemppinen, Heikki Timonen
  - Will patrol Slack

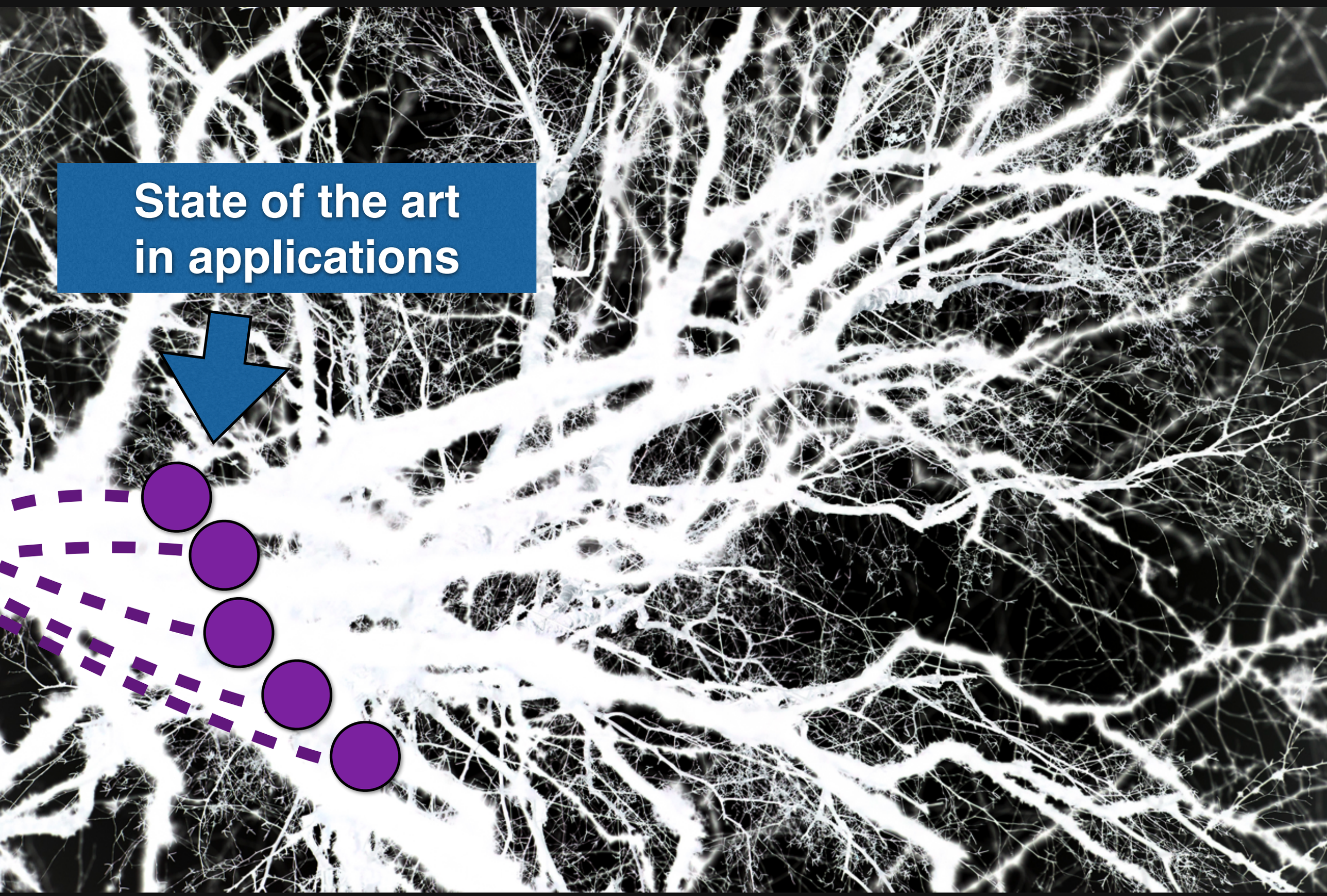
[Lehtinen et al. 2008]

Concluding remarks:

The Role of Research



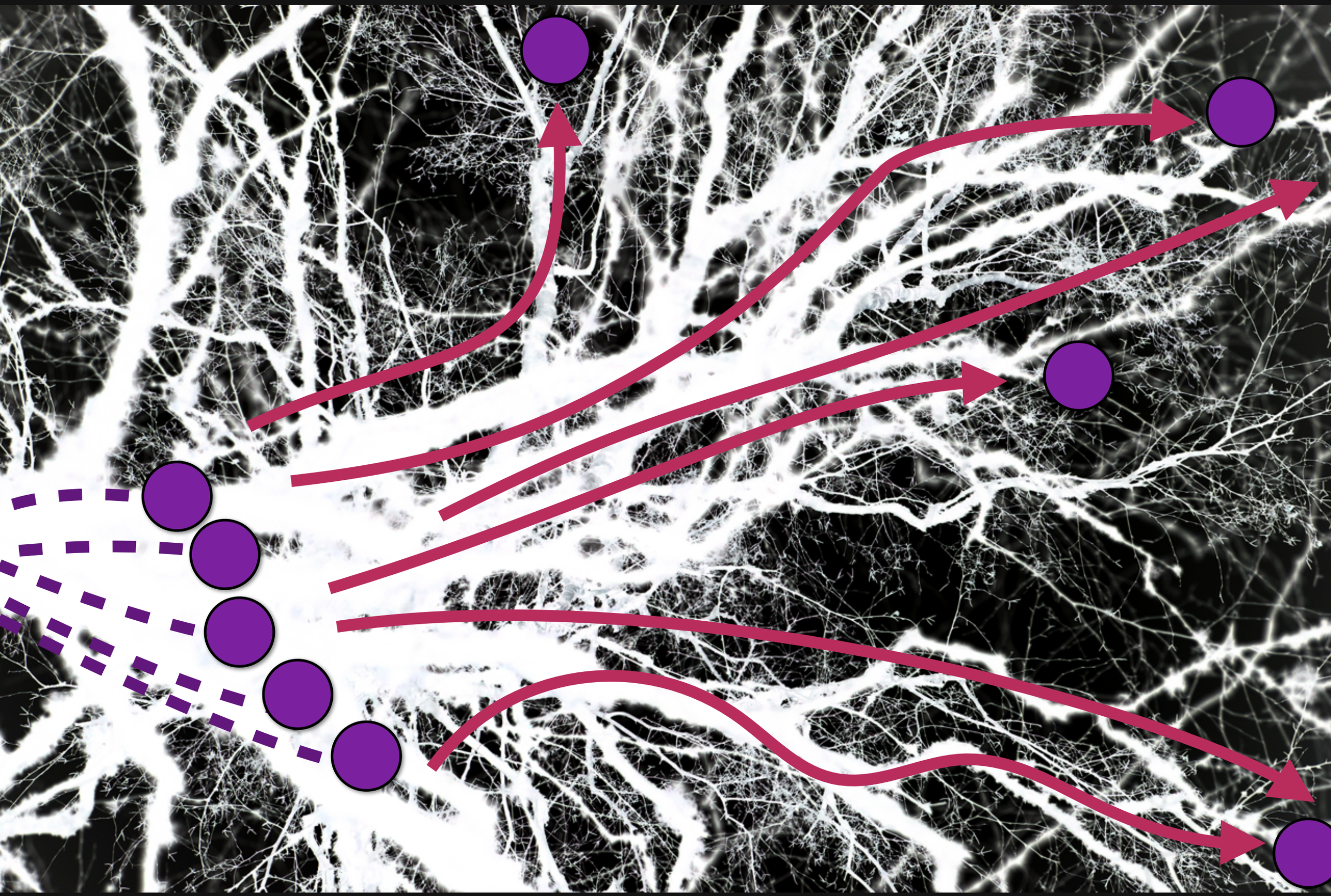
State of the art in applications

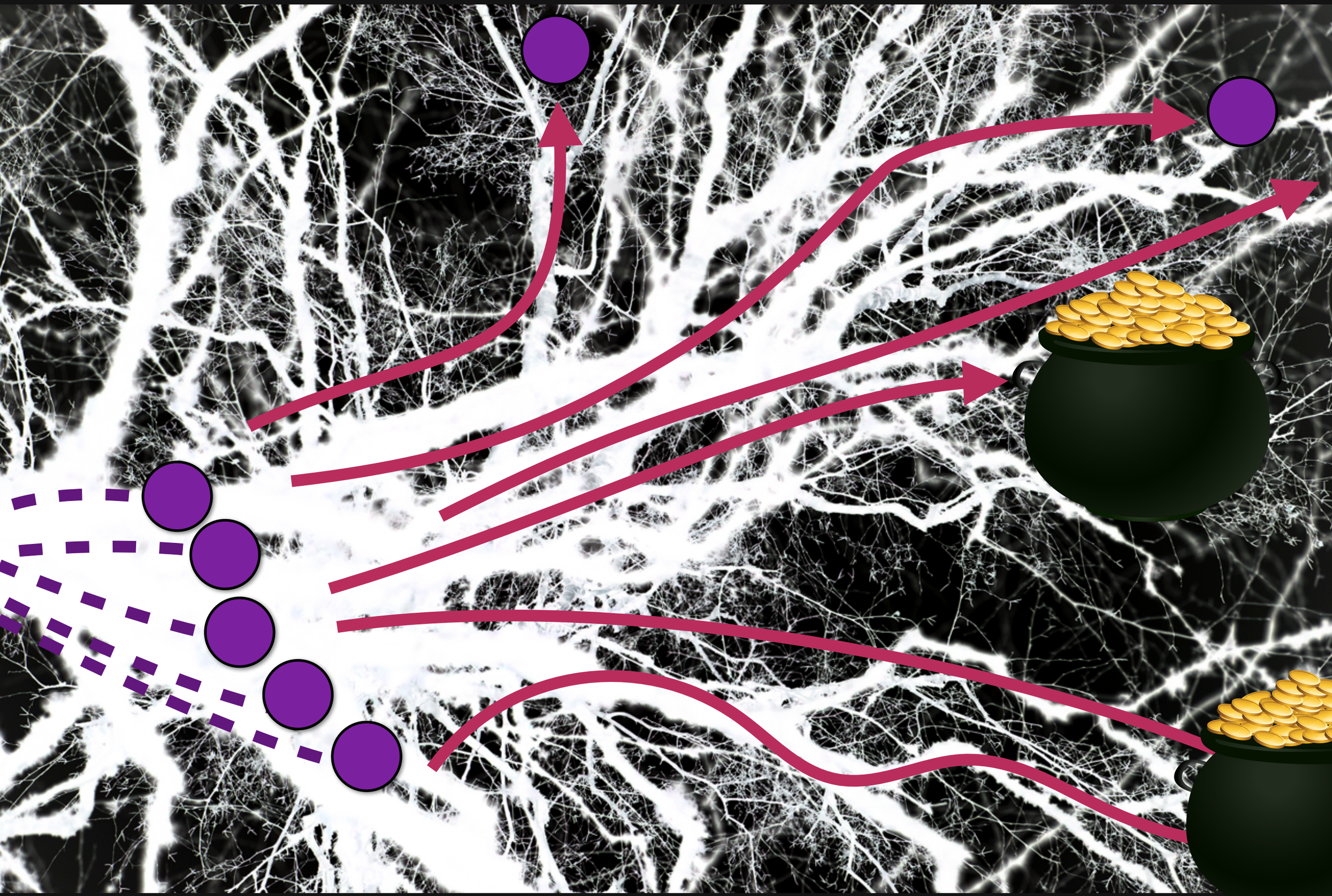


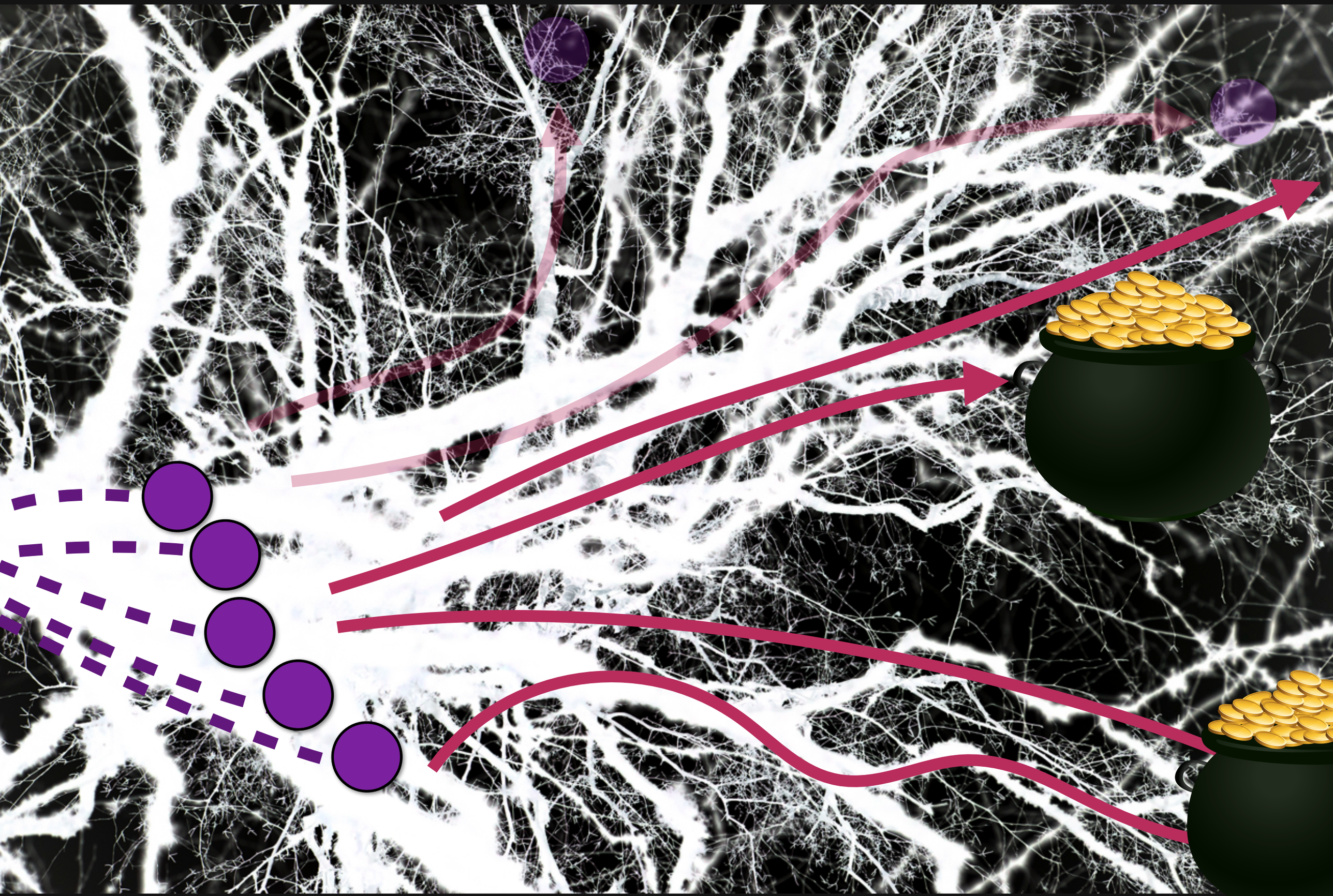
Reality: if you just focus on what's possible today, you suffer from serious myopia

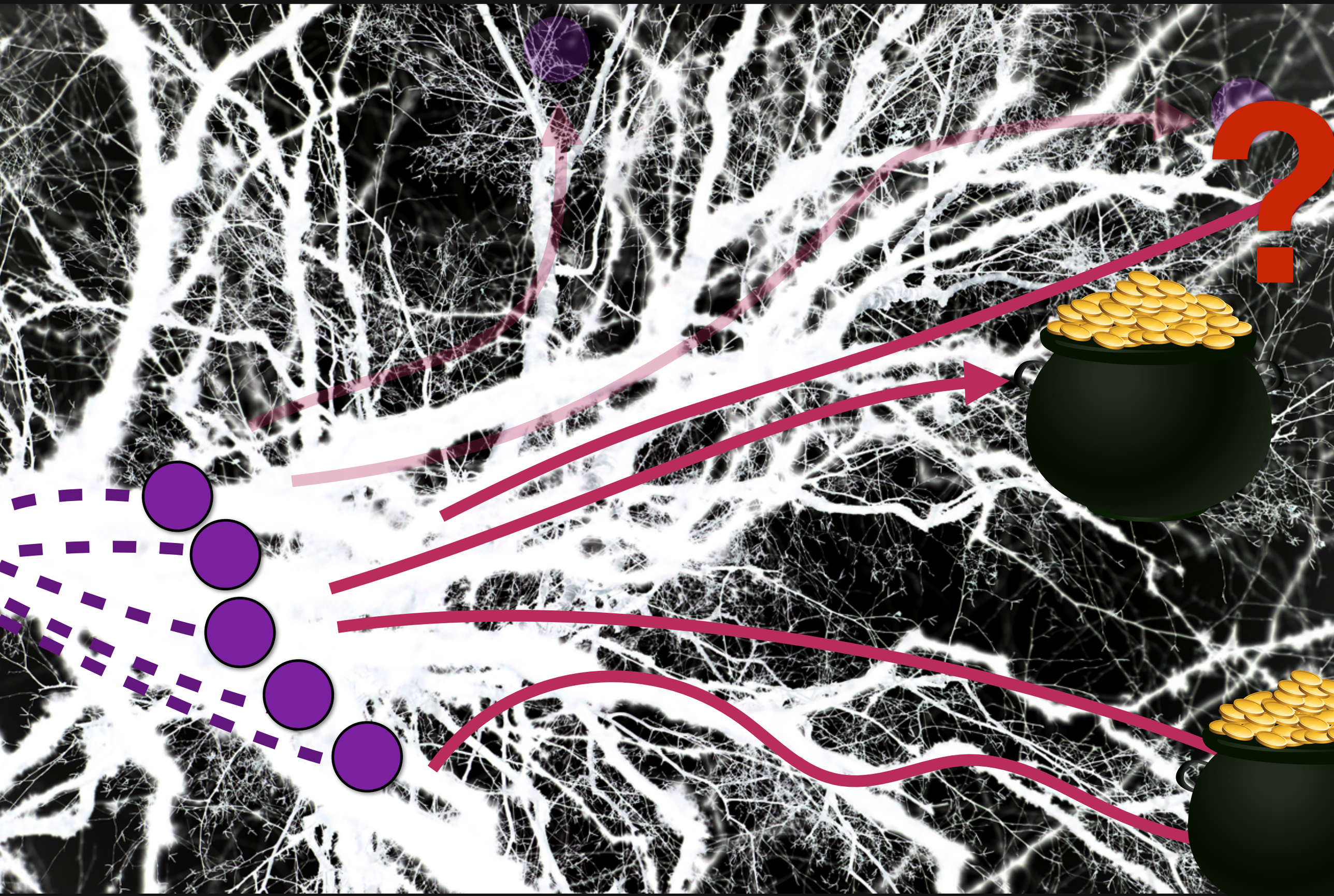
Reality: if you just focus on what's possible today, you suffer from serious myopia

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