Realistic / Advanced Image Synthesis

Tutorial Week #2

Fall 2019

Topics for today

I. Camera view

II. Rendering loops

III. Getting started with the assignments

Teaching assistants

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Tutorials

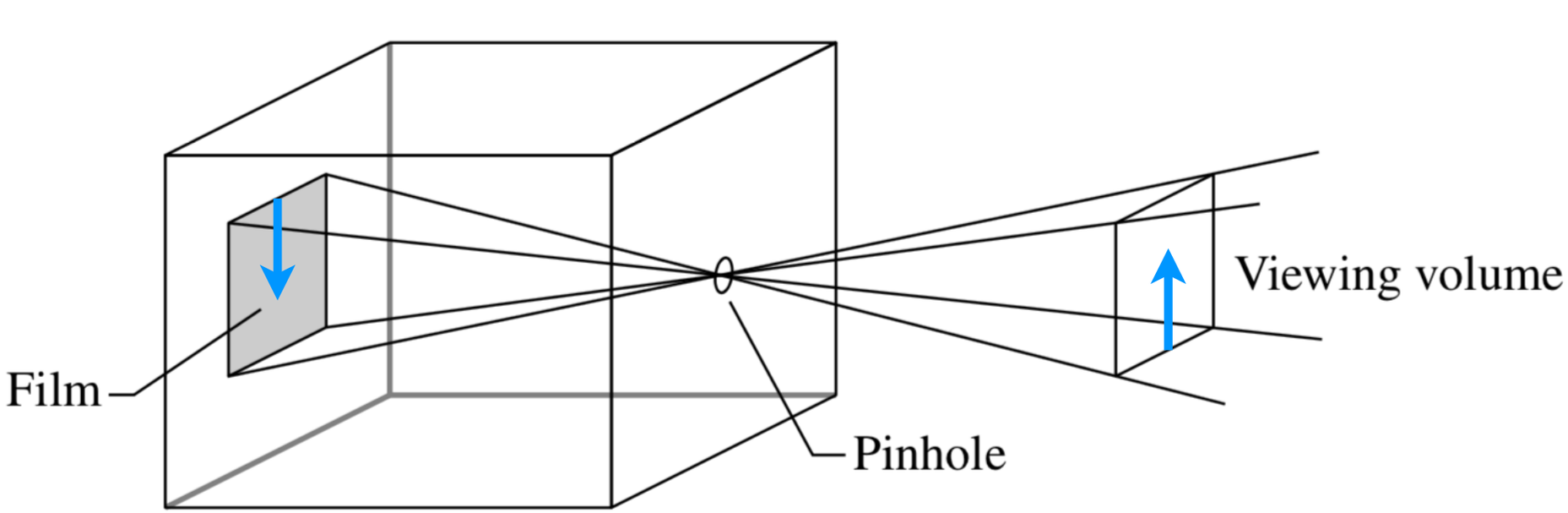
- Complement the lectures
- Answer your questions
- **Help you with the assignment code**
- But… don’t expect us to magically solve your coding bugs!

Camera view


LENS MADE IN JAPAN
UTO SEARS 1:1.7 f=50mm
Φ77mm
CANON EF LENS
24mm 1:1.4 L
MACRO
AUTO 28mm 1:2.8
CPC
CCT
903813

Pinhole camera

- Infinitely small aperture, hence the name
- Defined with position, up vector and look-at vector

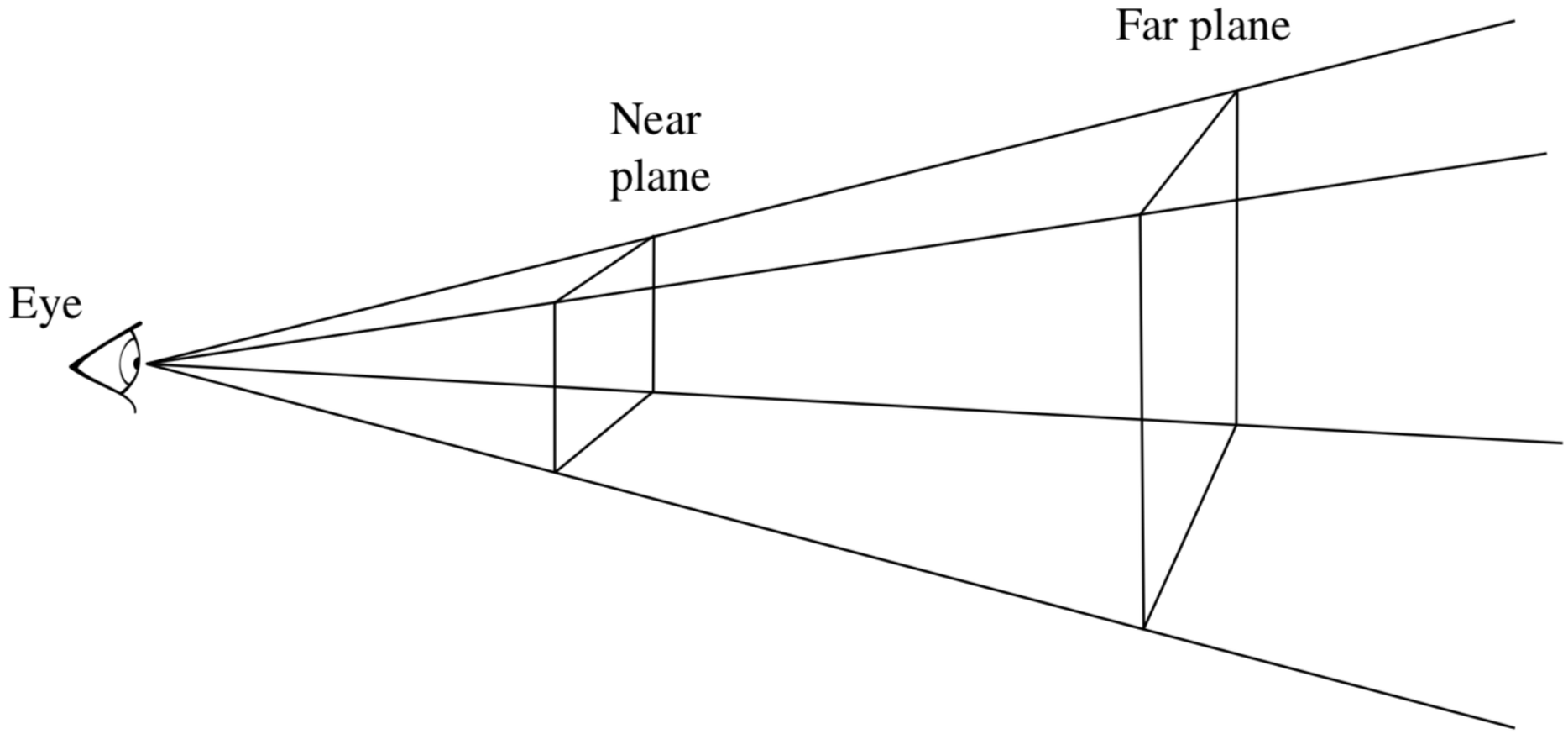


Pinhole camera IRL

- Hole in a cardboard box to see solar eclipses

Pinhole camera

- Simulate pinhole by placing film *in front of* hole
- *Hole* is what we call *eye* in rendering



Pinhole camera

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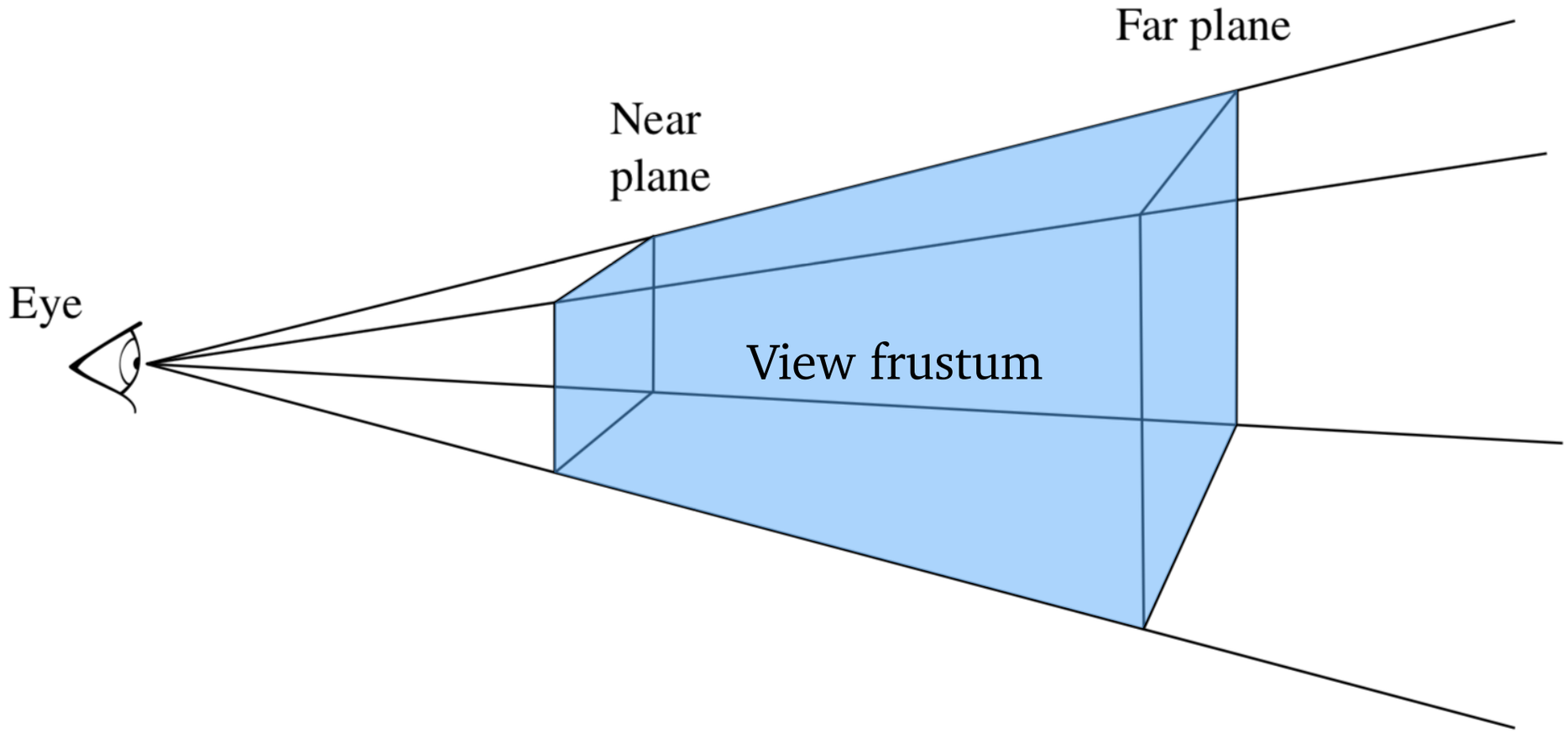


Coordinate spaces

- **Object space**

  Coordinate system in which geometric primitives are defined

- **World space**

  Standard frame that all other spaces are defined in terms of.

  Each primitive has an object-to-world transformation

- **Camera space**

  New coordinate system with origin at camera eye

  Negative z-axis = Viewing direction

  y-axis = Up direction

Camera matrices

- **Model matrix** (Identity in this course)

  Acts on the vertices of the object in local coordinates.

  Model = Translation · Rotation · Scale (of your actual mesh)

- **View matrix**

  World-to-camera transform that puts the camera at the center of the space

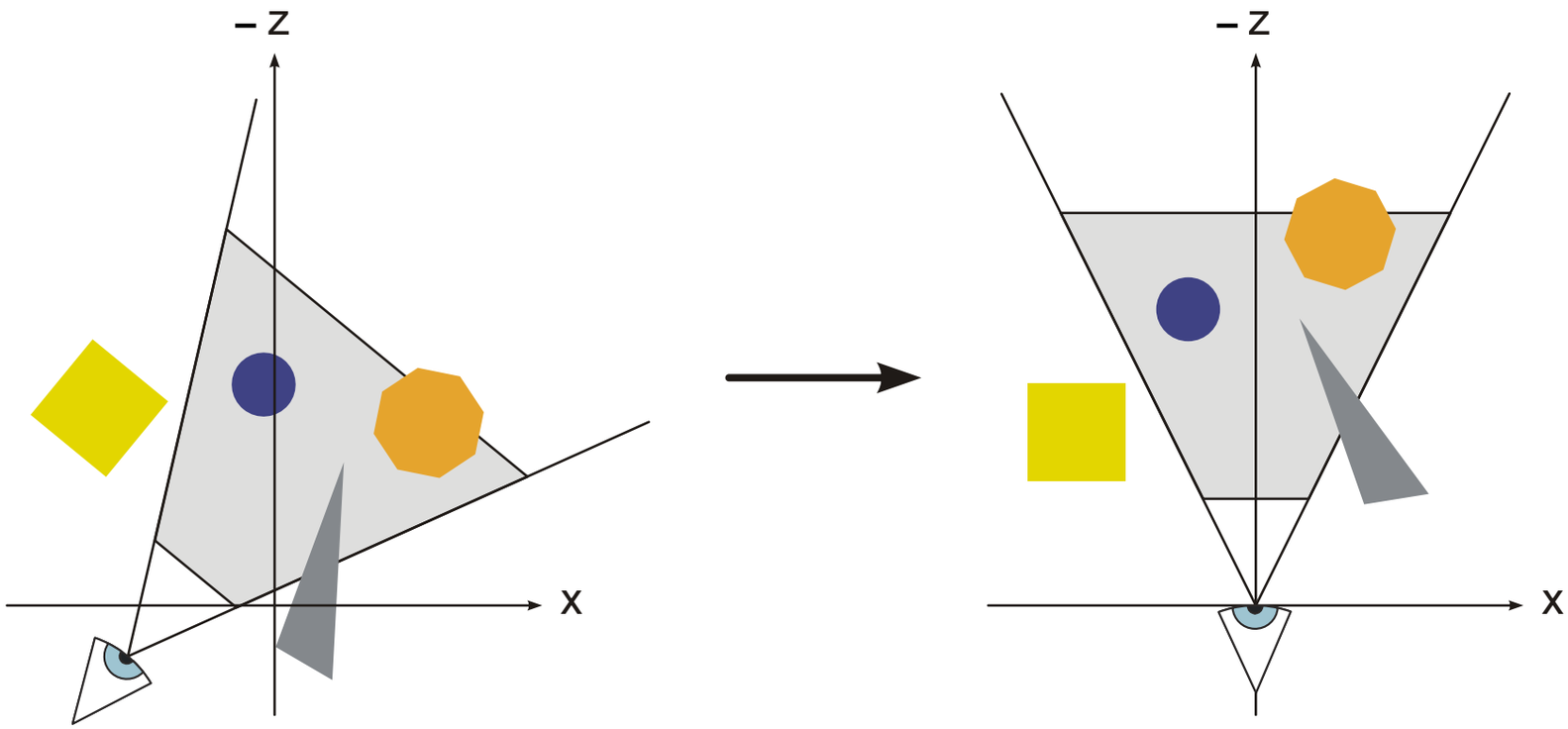
- **Projection matrix**

  Perspective transform from camera space to clip coordinates.

  Simulates how we perceive things IRL

View matrix

- Moves the world so that camera is at origin
- Expressed as a 4×4 transformation matrix

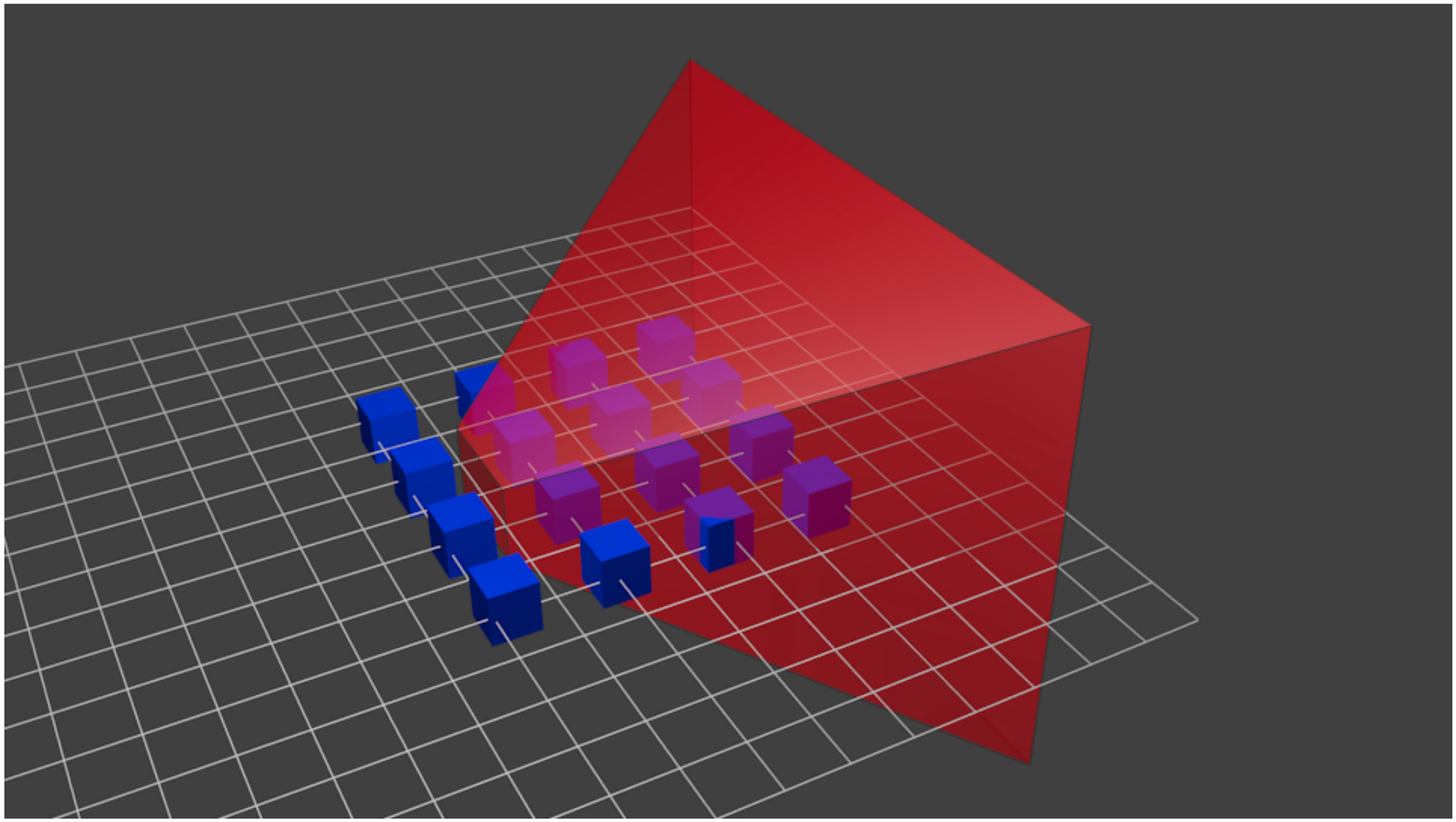


Projection matrix

- Transforms view frustum (truncated pyramid) into unit cube
- Expressed as a 4×4 projection matrix
- After transformation, models are said to be in *clip coordinates*

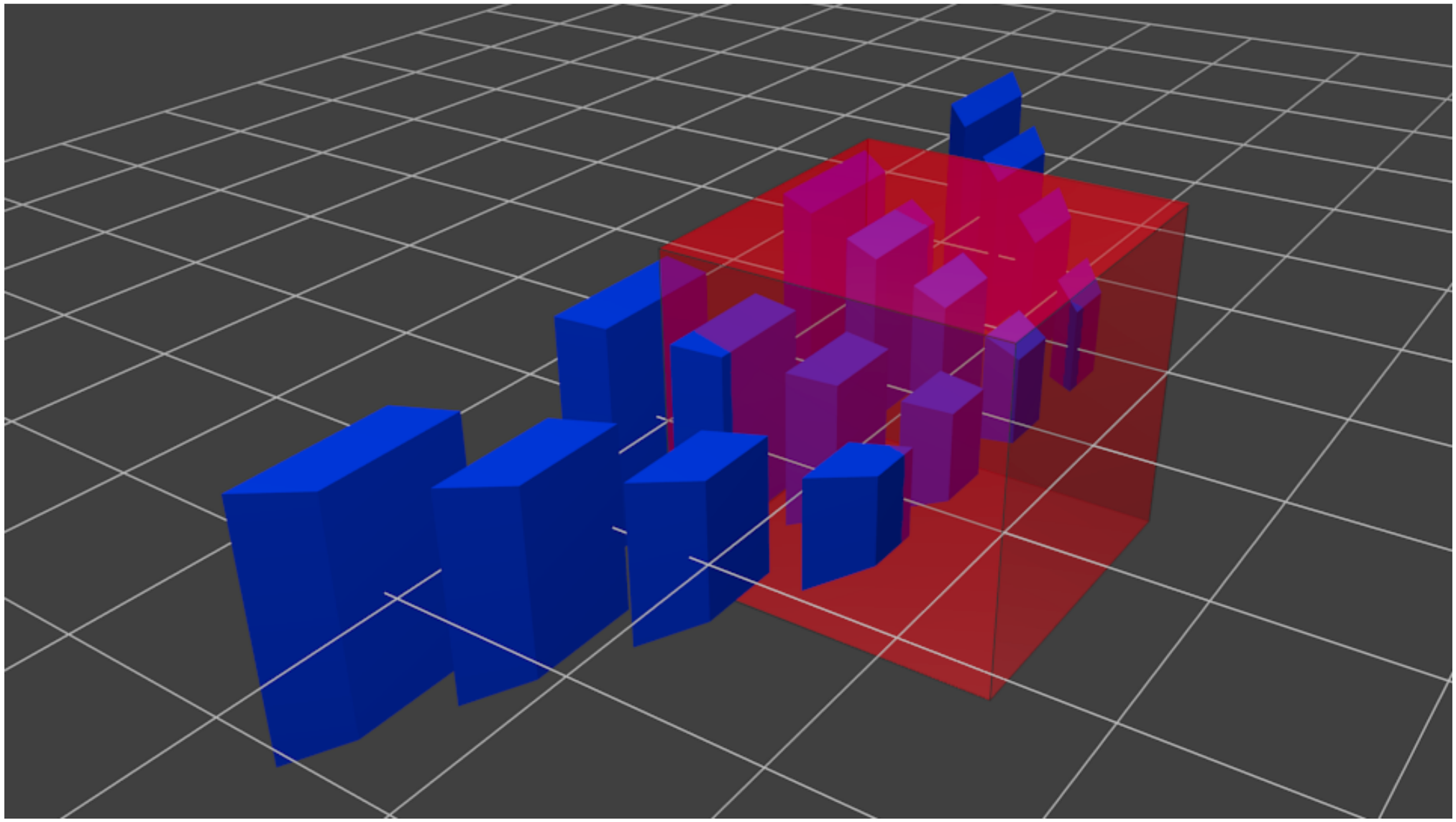
Camera view

Projection matrix



Before (camera space)

Projection matrix



After (clip coordinates)

Further readings

- **Offline**

  PBRT3 Chapter 6.1 *Projective camera models*

- **Real-time**

  RTR4 Chapter 4.7 *Projections*

  Good tutorial (includes the previous images for the projection matrix): http://www.opengl-tutorial.org/beginners-tutorials/tutorial-3-matrices

Offline rendering loop

Image source: Pixar's Coco

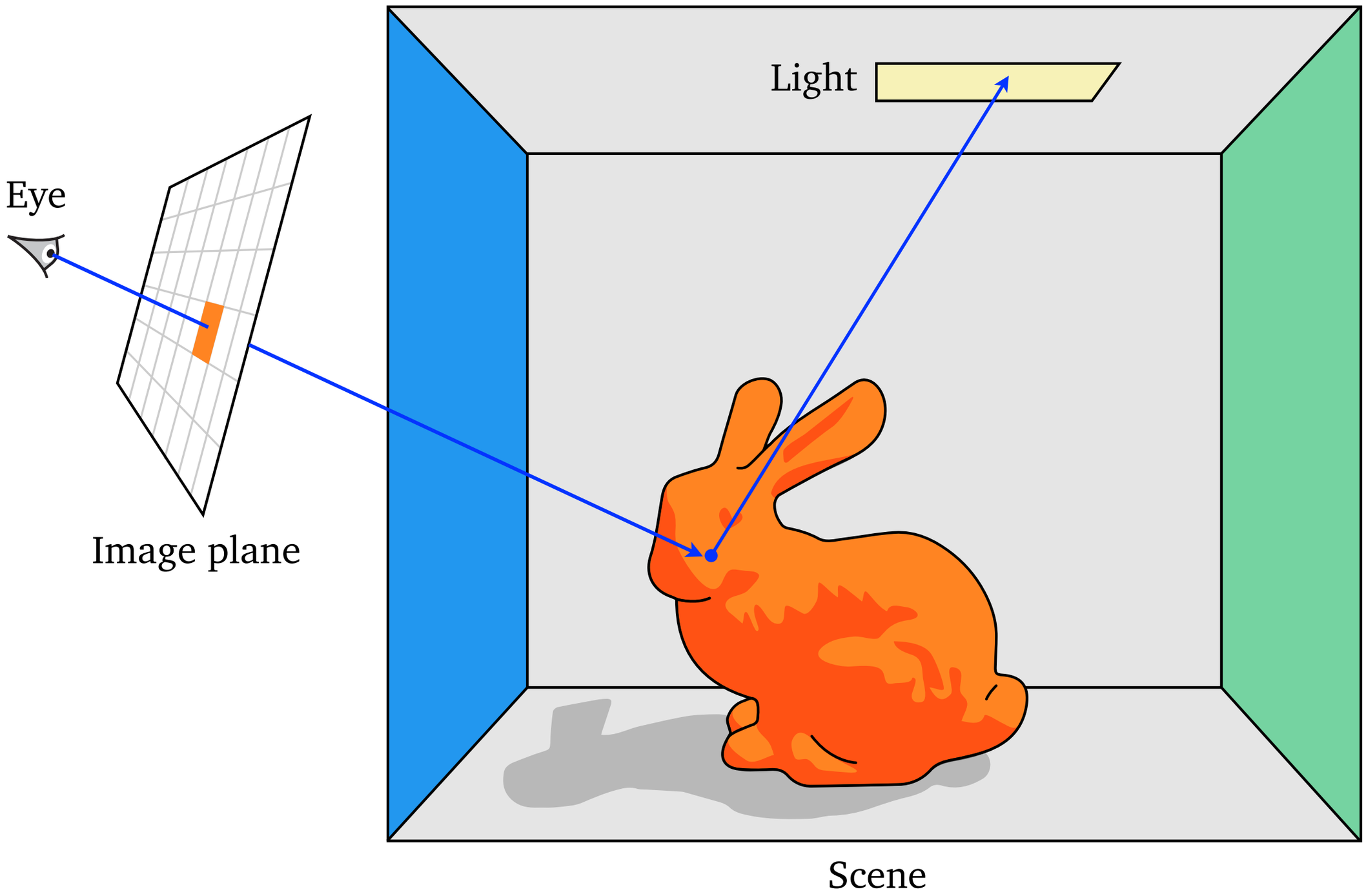
Offline rendering loop

Ray tracing 101

1. Shoot rays from eye through each pixel of the image plane
2. Hit a surface, retrieve its reflectance property (normal, colour, etc.)
3. Evaluate light contribution (and possibly recurse)
4. ???
5. Profit

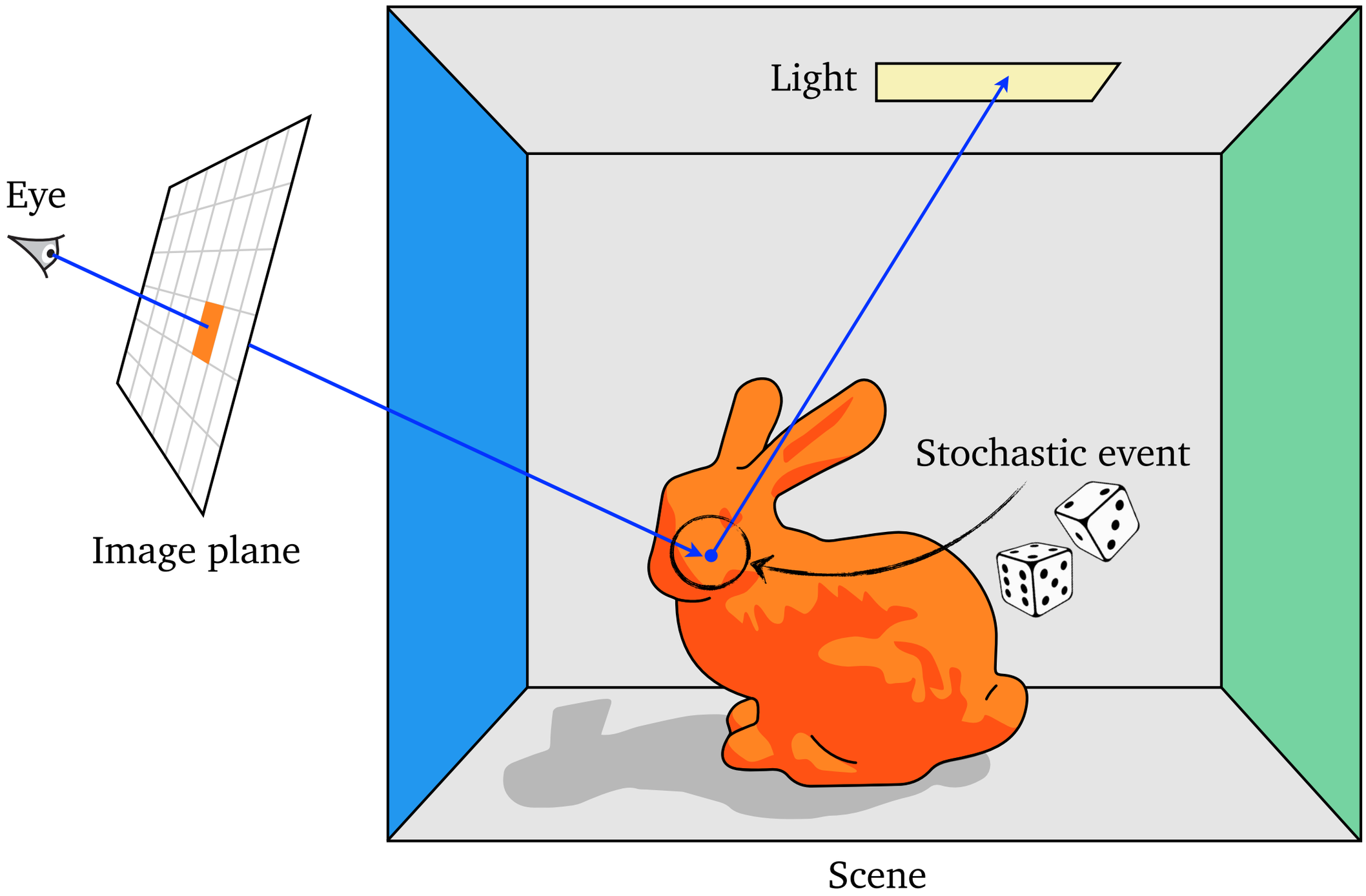
Offline rendering loop

Ray tracing 101

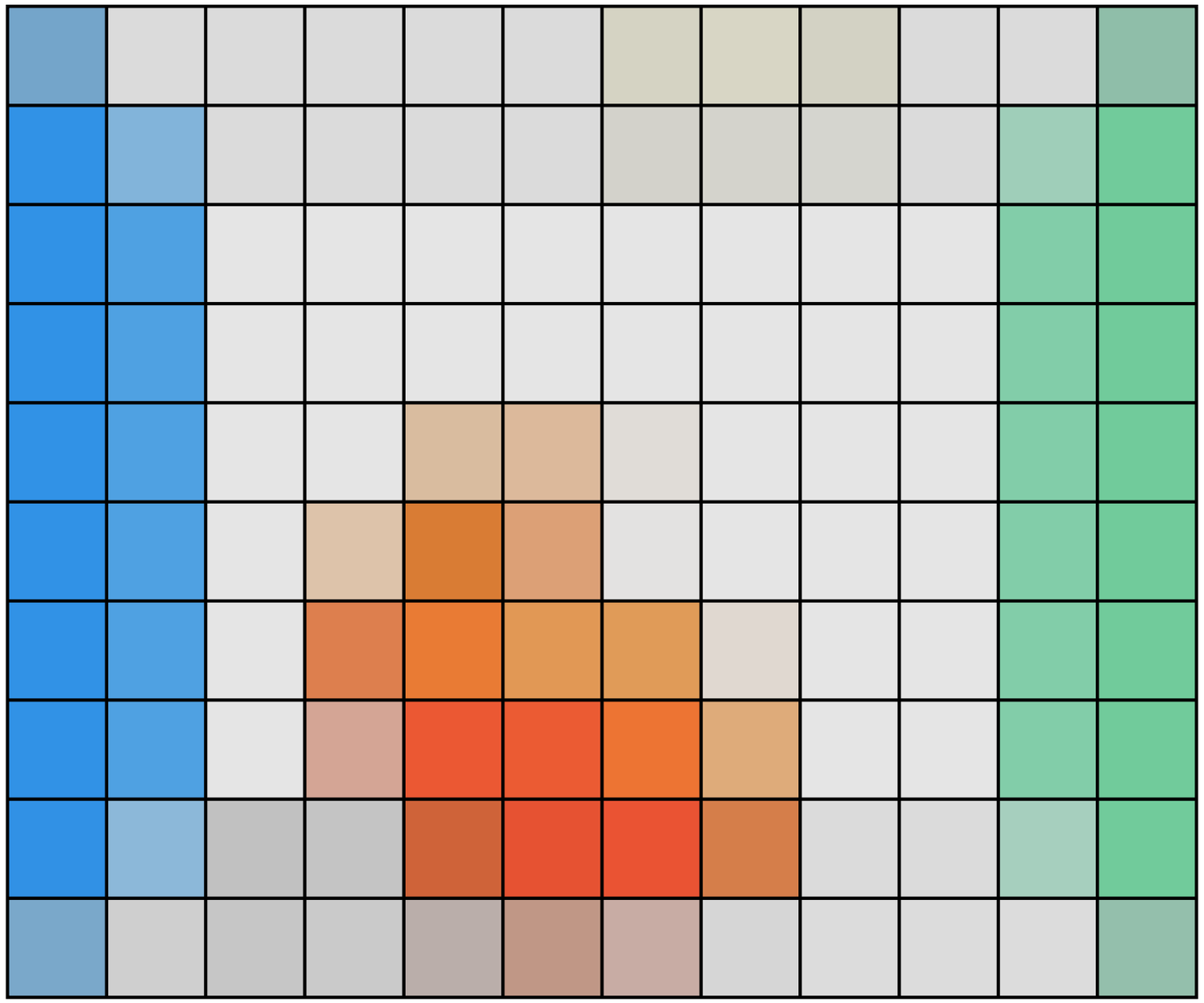


Offline rendering loop

Ray tracing 101

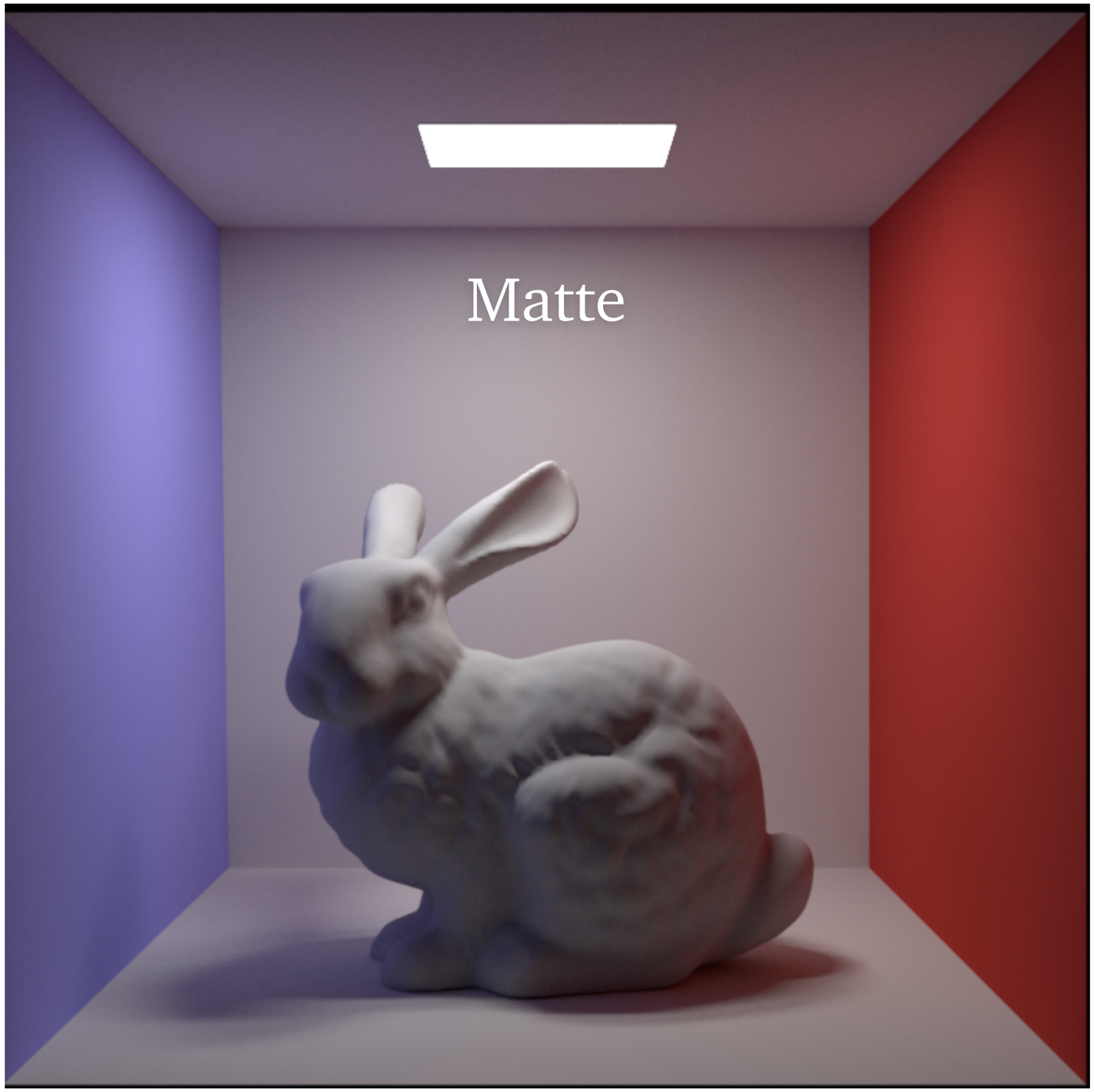


Ray tracing 101

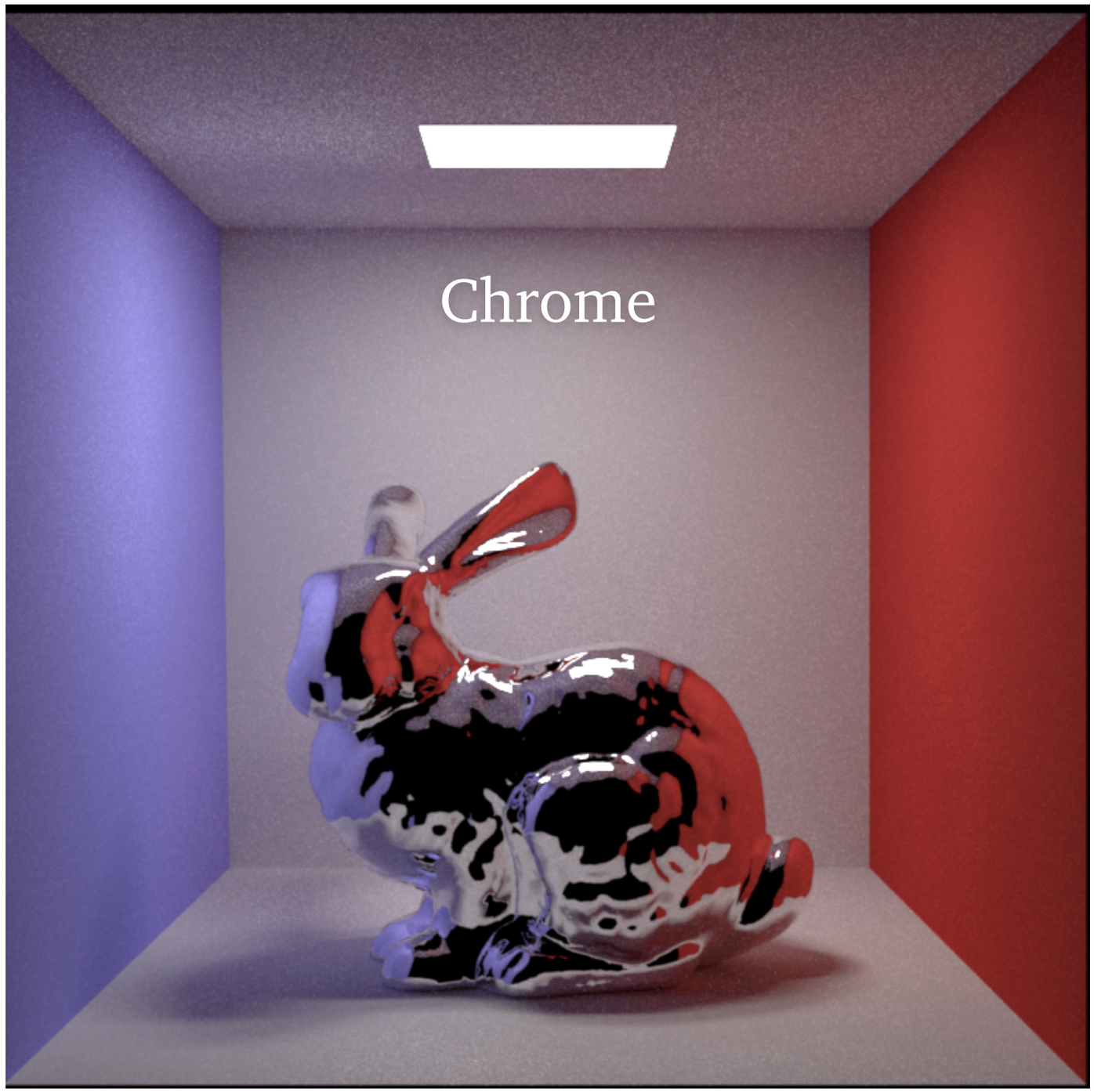


Low-res image (after ray traced)

Ray tracing 101

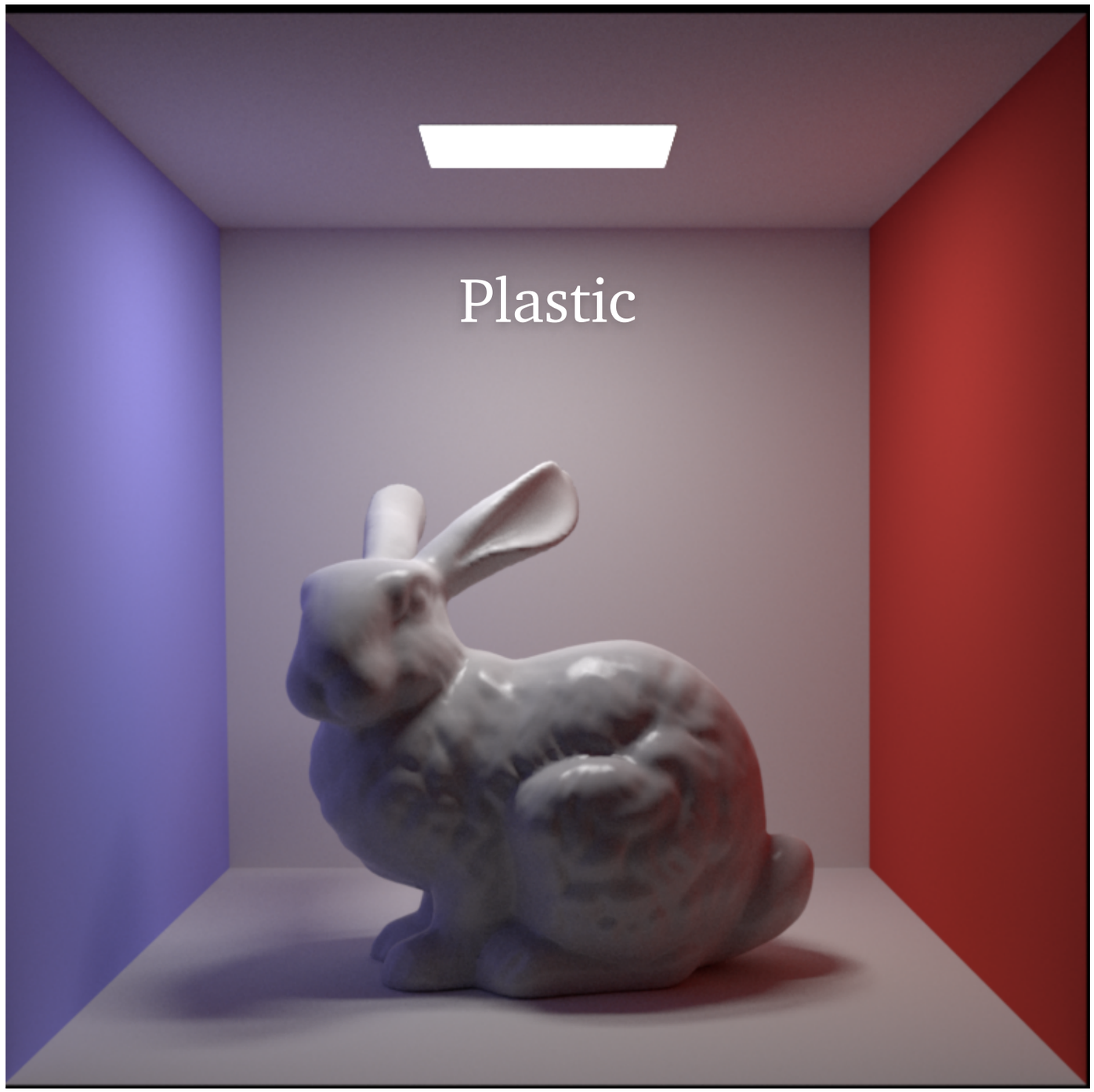


Ray tracing 101

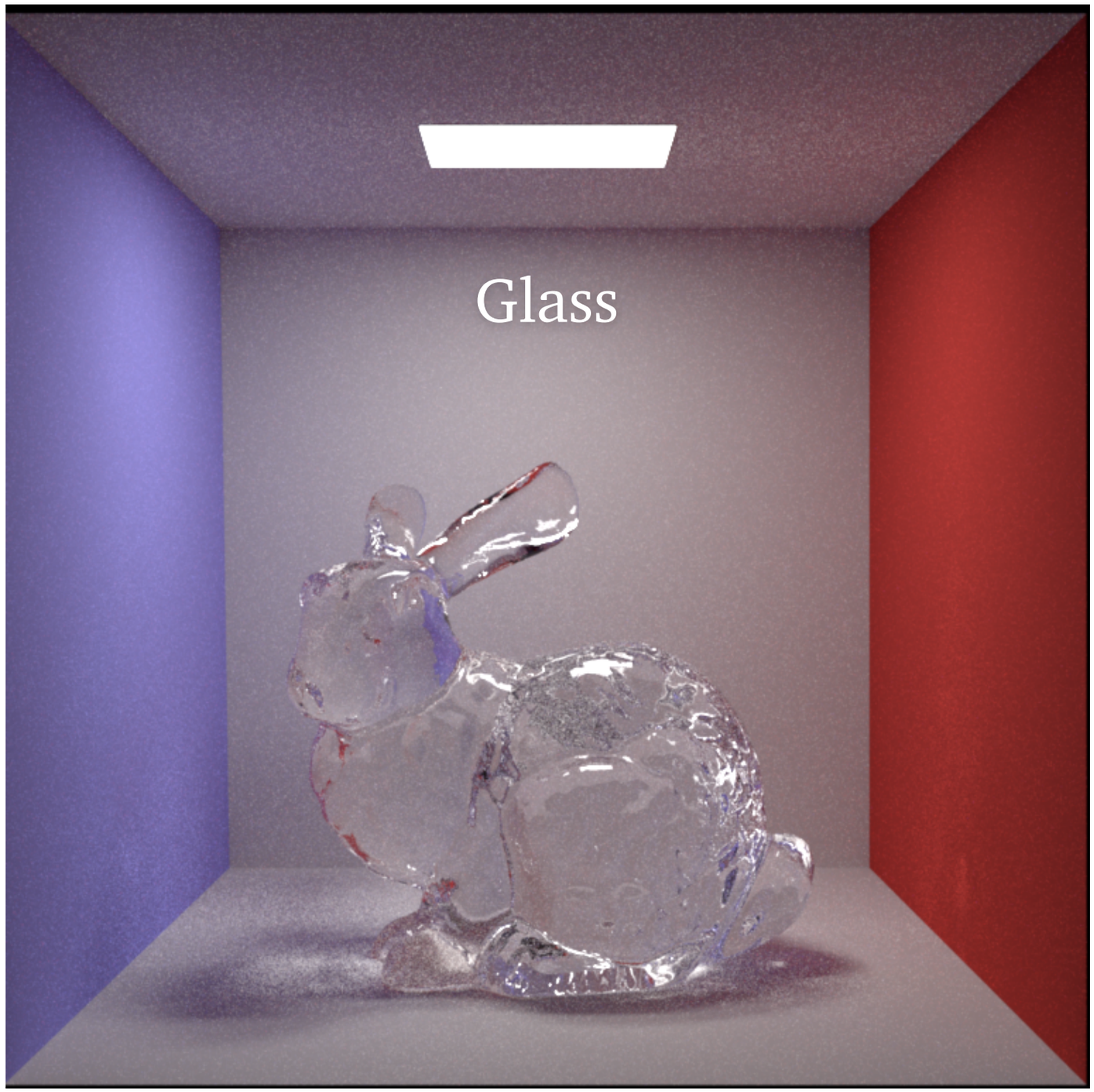


Offline rendering loop

Ray tracing 101



Ray tracing 101

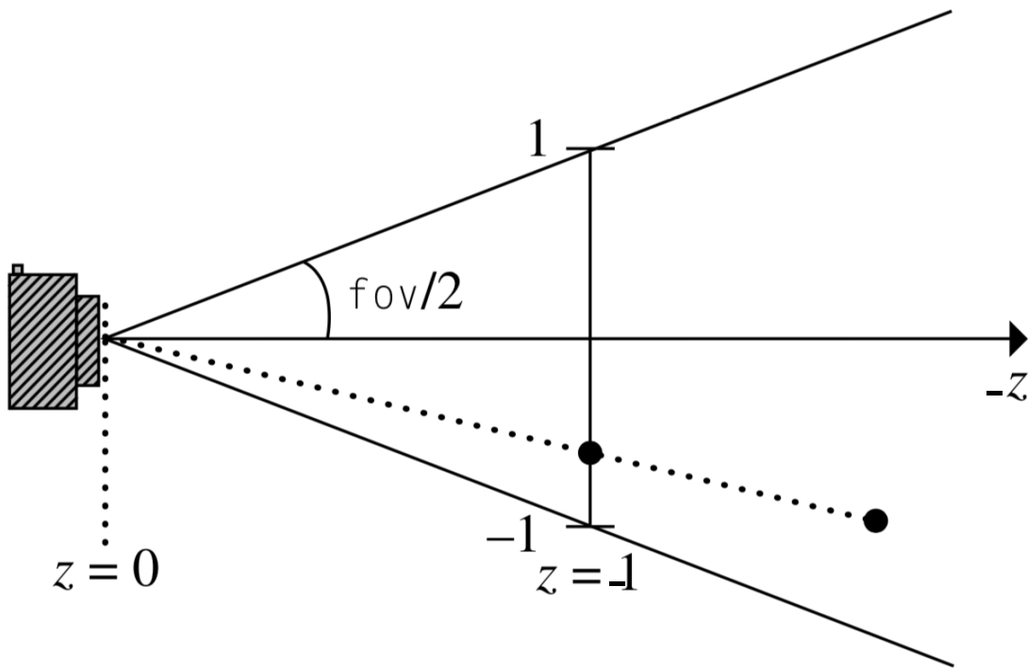


Field of view

- Pixel location should be in the interval [-1, 1]
- Account for FOV by scaling the pixel location:

```
scaling = tan(deg2rad(fov) / 2.f);
```

- Adjust film dimension by scaling x-axis by aspect ratio (w/h)



Field of view

- TinyRender uses *vertical* FOV
- Seems counterintuitive as we usually prefer landscape mode in photography
- Arbitrary choice to match camera settings of reference scenes, so just roll with it

View matrix

- Use OpenGL Mathematics:

```
glm::mat4 inverseView =
    glm::inverse(glm::lookAt(eye, at, up));
```

- Gives you the matrix in *row major order*

- To map a ray from camera to world spaces:

1. Augment to homogeneous coordinates (4D)
2. Multiply by inverse view matrix *on the left*

Offline rendering loop

Ray tracing pseudocode

```
// Compute camera settings
// Clear image RGB buffer & instantiate sampler

for (x = 0; x < width; ++x) {
    for (y = 0; y < height; ++y) {
        (px, py) = getPixelLoc(x, y, width, height);
        dir = toWorld(px, py);
        ray = Ray(camera.o, dir);
        pixelColor = integrator->render(ray, sampler);
        splatOnScreen(x, y, pixelColor);
    }
}
```

Offline rendering loop

Ray tracing pseudocode

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}
```

Generating rays

- Different ways to sample ray through pixel:
  - Single ray through pixel center (A1.1)
  - Single ray through random position on pixel
  - Multiple rays through pixel center
  - Multiple rays through random position on pixel (A1.2, *supersampling*)

Real-time rendering loop

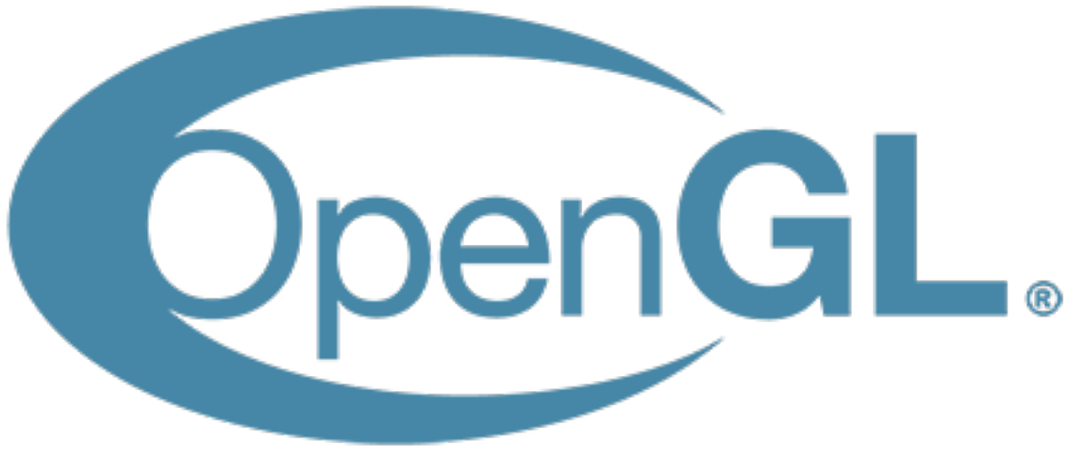
Image source: Naughty Dog's Uncharted 4

OpenGL 101

- OpenGL is an API to access the GPU
- This course uses a relatively modern version (3.3)
- Good references:
  - Official docs: http://docs.gl
  - Shaderific: http://www.shaderific.com/glsl

OpenGL 101

- GL = State Machine + Buffers
- Data is passed through *buffers*
- Commands are then used to change the *state* of the machine



Modern GL pipeline

1. Initialize buffers
2. For each frame:
    a) Bind buffers (tell GPU which VAO/VBO to use)
    b) Update uniforms
    c) Draw call
3. Clean up memory

GL Buffers

- **Screen buffer**

  Where all the pixels are written

- **Vertex Buffer Object (VBO)**

  Where vertex attributes (position, normal, colour, etc.) are stored

- **Vertex Array Object (VAO)**

- **Other buffers**

  Framebuffer Object (FBO)

  Buffer Texture

GL Buffers

- They are used the same way:

    1. Create buffer
    2. Bind buffer (to use it)
    3. Fill buffer with data

Rasterization (in one slide)

- Process of converting a continuous object to a discrete representation on a raster (pixel) grid
- At a high-level:

1. Take triangles
2. Figure out which pixels they cover
3. Perform some computation on these pixels

Programmable rasterization pipeline

Vertex data in

- Transformations & shading → **[Vertex processing]**

Transformed vertex data

- Convert to pixels → **[Clipping & rasterization]**

Fragments with interpolated data

- Visibility & shading → **[Fragment processing]**

Frame buffer

- User output → **[Display]**

So, what do I code?

- Render pass that actually calls the shaders
- GLSL shaders:
  - Vertex shader (`.vs` file)
  - Fragment shader (`.fs` file)

Vertex shader

- Done at every vertex (hence the name)
- Means that it can manipulate attributes of vertices (position, normal, etc.)
- Comes earlier in the graphics pipeline

Fragment shader

- Comes *after* the vertex shader
- And *after* the rasterization step
- Takes care of how the pixels between the vertices look
- Interpolated between the defined vertices following specific rules to *fill in* the fragments

Shader logic

- Vertex shader will relay some information to the fragment shader (`out`)
- **Vertex shader**
  Transform triangles to match camera view by setting `gl_Position`, and retrieve necessary information for shading
- **Fragment shader**
  Compute the actual colour of the pixel using whatever info passed from the vertex shader

MVP Matrix

- Use GLSL uniforms:

```
gl_Position = projection * view * model
              * vec4(position, 1.0);
```

- That's it. Field of view is handled by the code for the real-time part

TinyRender

General information

- Minimalistic rendering engine written in C++11
- Cross-platform (Windows, Linux and macOS)
- Both offline and real-time rendering frameworks

- Written by us (the TAs)
- Second year using it, hopefully bug-free™
- But, signal any important bug by email if you find one…

What you'll be able to render

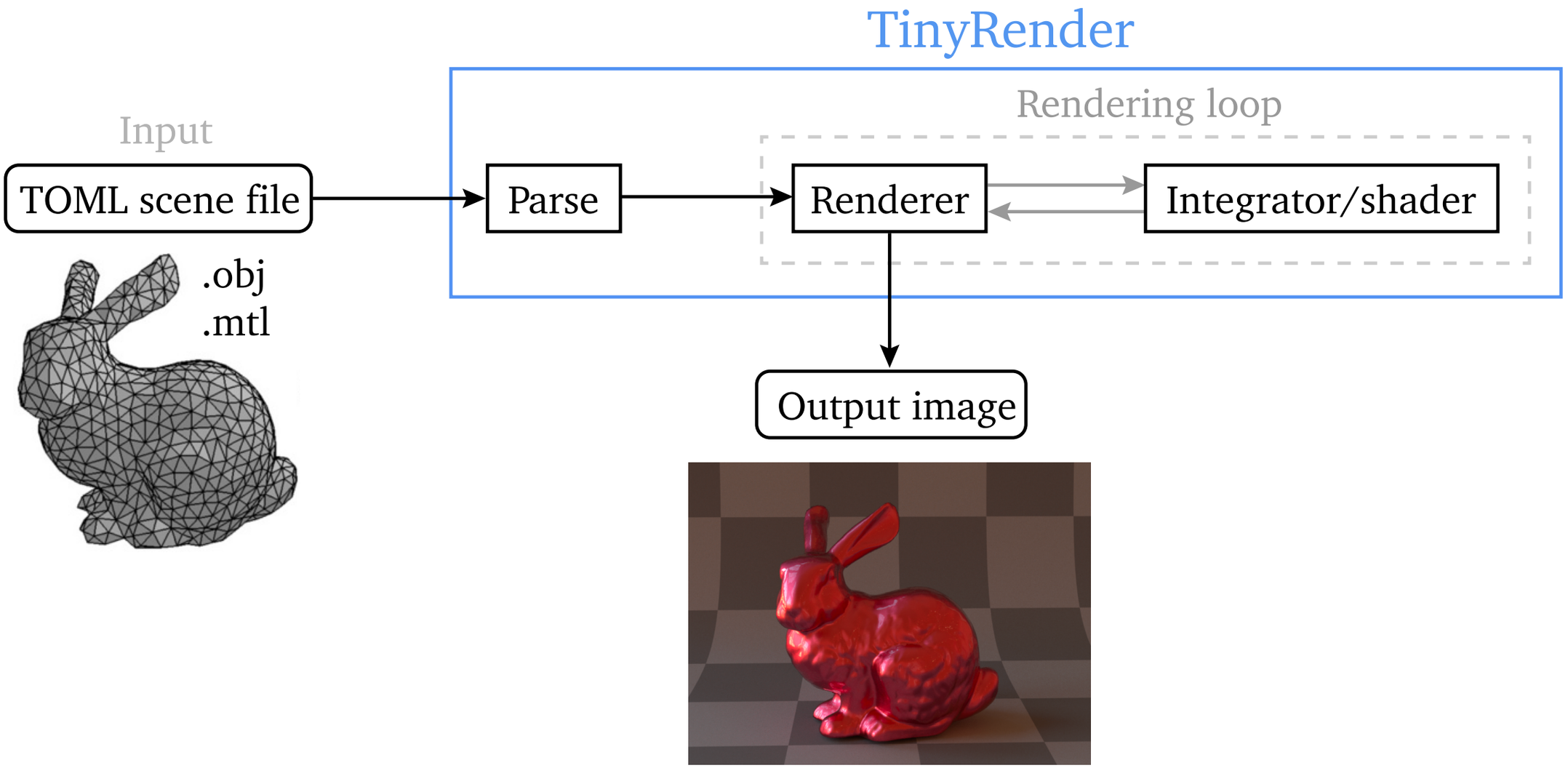
Rendered with path tracer from A5

And with a few tweaks…

Gold

Brushed glass

Overview of the codebase



Codebase repository

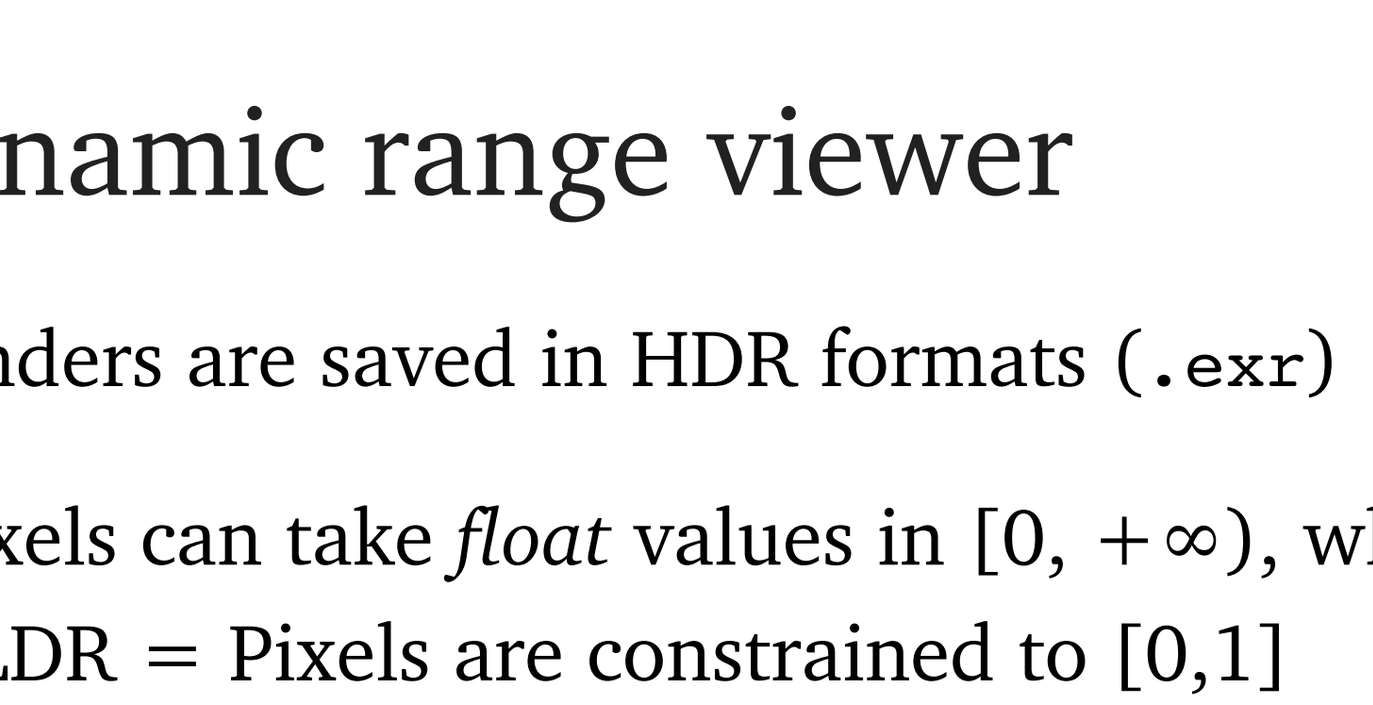
- Code available through a public Git repo
- Allows TAs to push modifications for upcoming assignments, bug fixes, etc. in a seamless way
- If you don’t know Git, you will have to learn the very basics
- Only have to sync with master branch a handful of times throughout the semester

Building instructions

- All details can be found in the Read-me document
- Requires a few things to be installed beforehand
- If you want to compile TinyRender in the command-line under Ubuntu 14, you have every right to do so. **But,** we are *not* going to help you
- Do **NOT** upgrade to macOS Catelina when it comes out: may break the build and it will be **YOURS** to fix

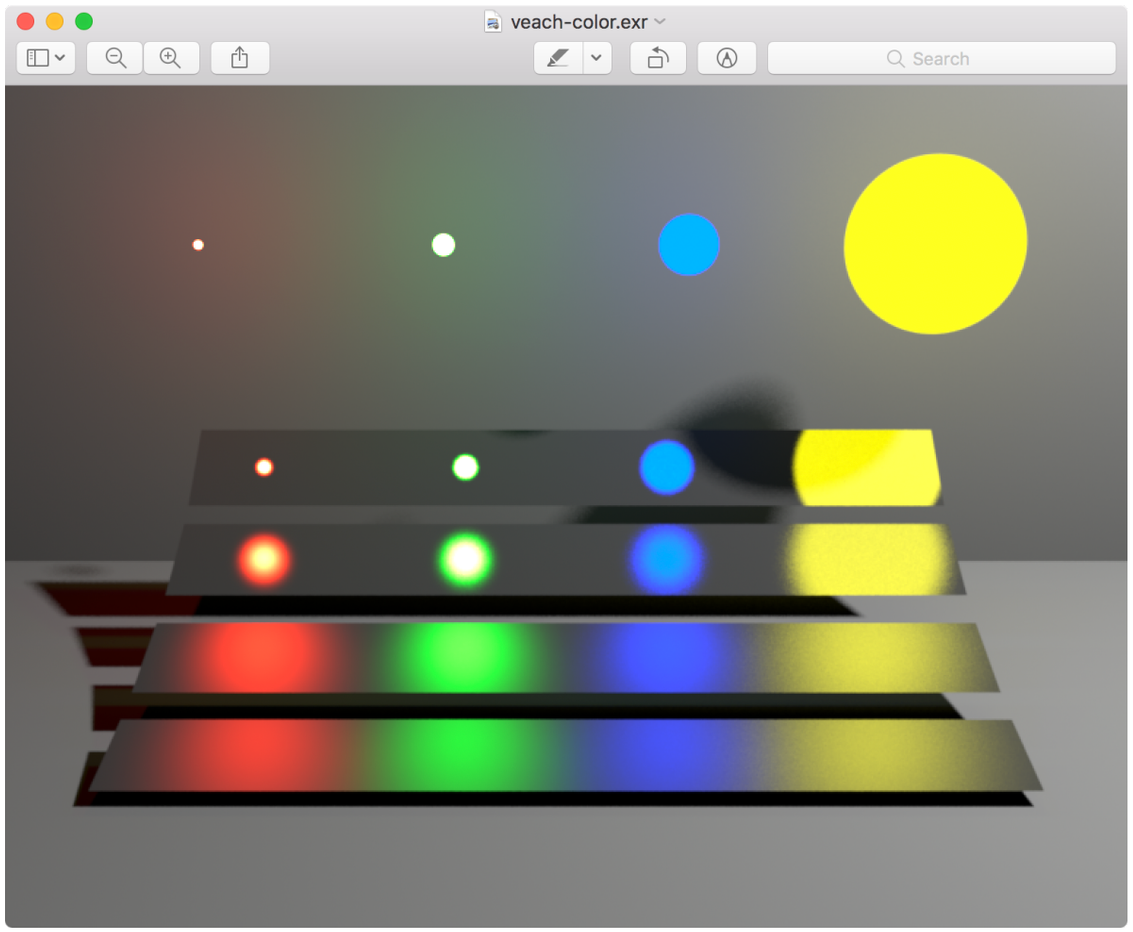
High dynamic range viewer

- Offline renders are saved in HDR formats (`.exr`)
- HDR = Pixels can take *float* values in $[0, +\infty)$, whereas standard LDR = Pixels are constrained to [0,1]
- Requires HDR viewer software (*e.g.* tev, HDRView)

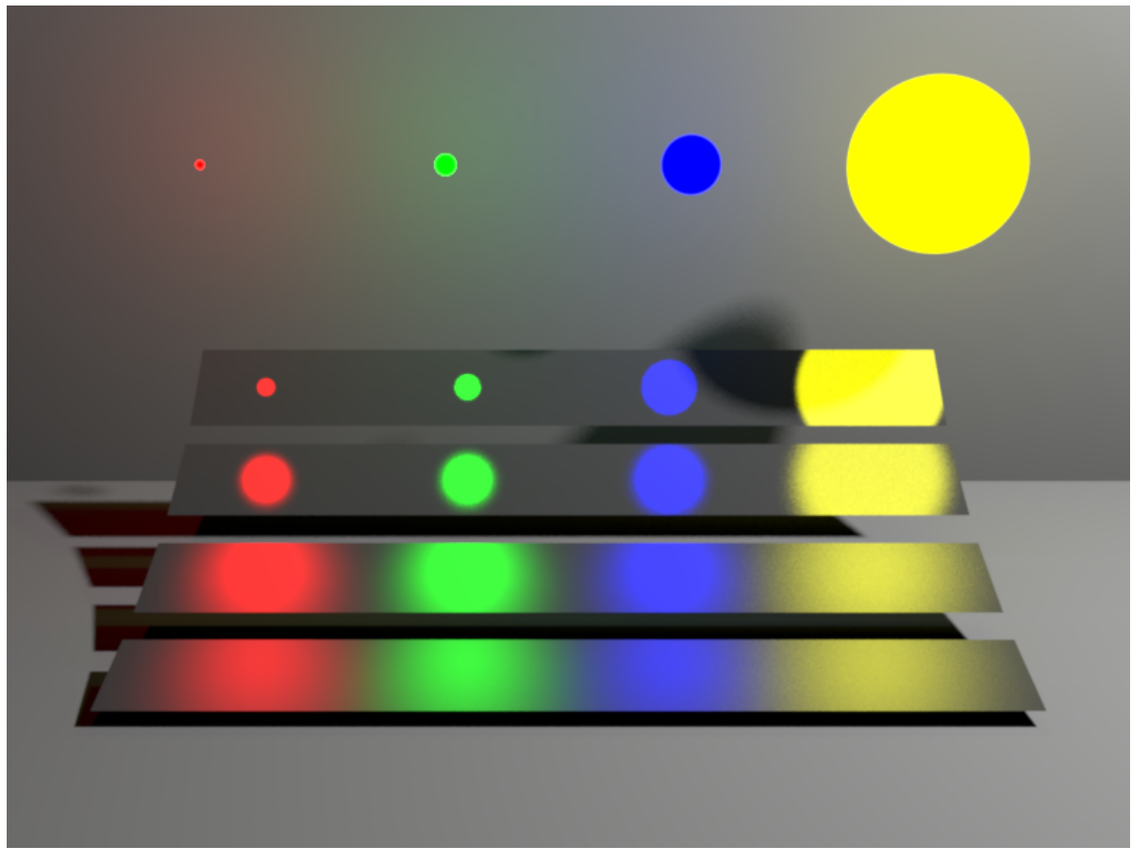


tev

Tonemapping and why it matters

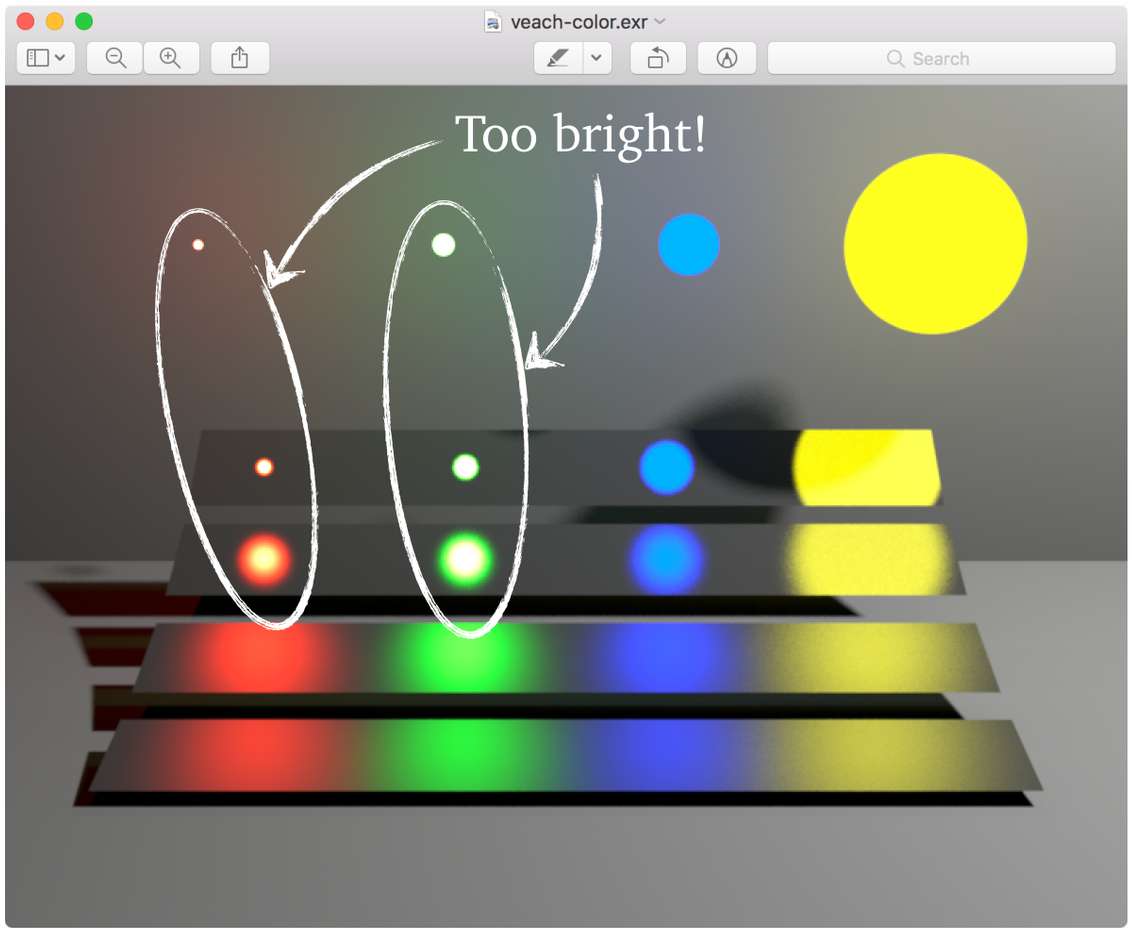


Wrong tonemap (Preview on macOS)



Correct tonemap

Tonemapping and why it matters



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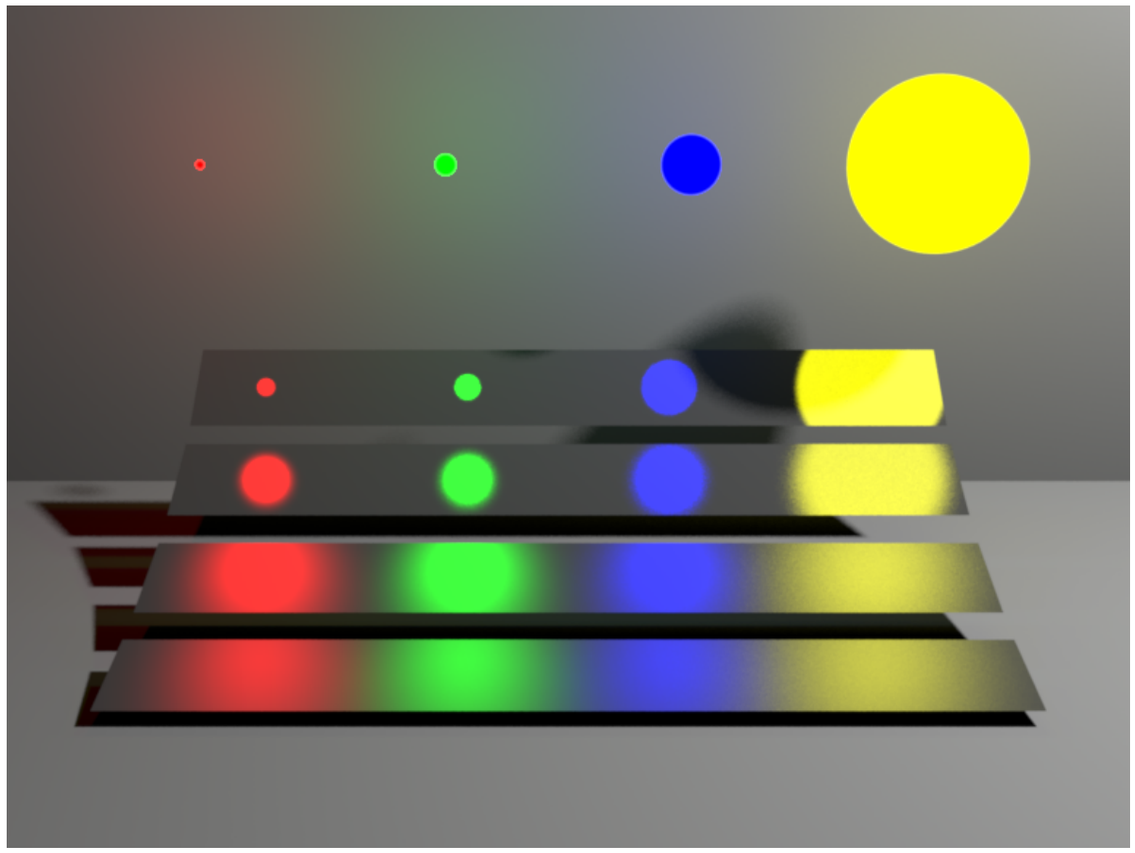

Correct tonemap

Important notes

- 3000+ lines of code: you will have to learn how to navigate the code base, *don't be scared*
- All assignments use TinyRender and you will have to recycle code across them
- Incremental level of difficulty, but some assignments are more important than others. **A1 is one of them**
- You are encouraged to discuss the assignments with your peers, but sharing code or images is *strictly forbidden*
- **This includes Github!**

Important notes

- Come to tutorials: TA's office hours = tutorials
- Use discussion board to ask questions
- Assignment deadlines **include** render times
- Submissions must follow a **strict** structure
- If you want to pursue grad studies in rendering, first step is doing well in this course!

Questions?