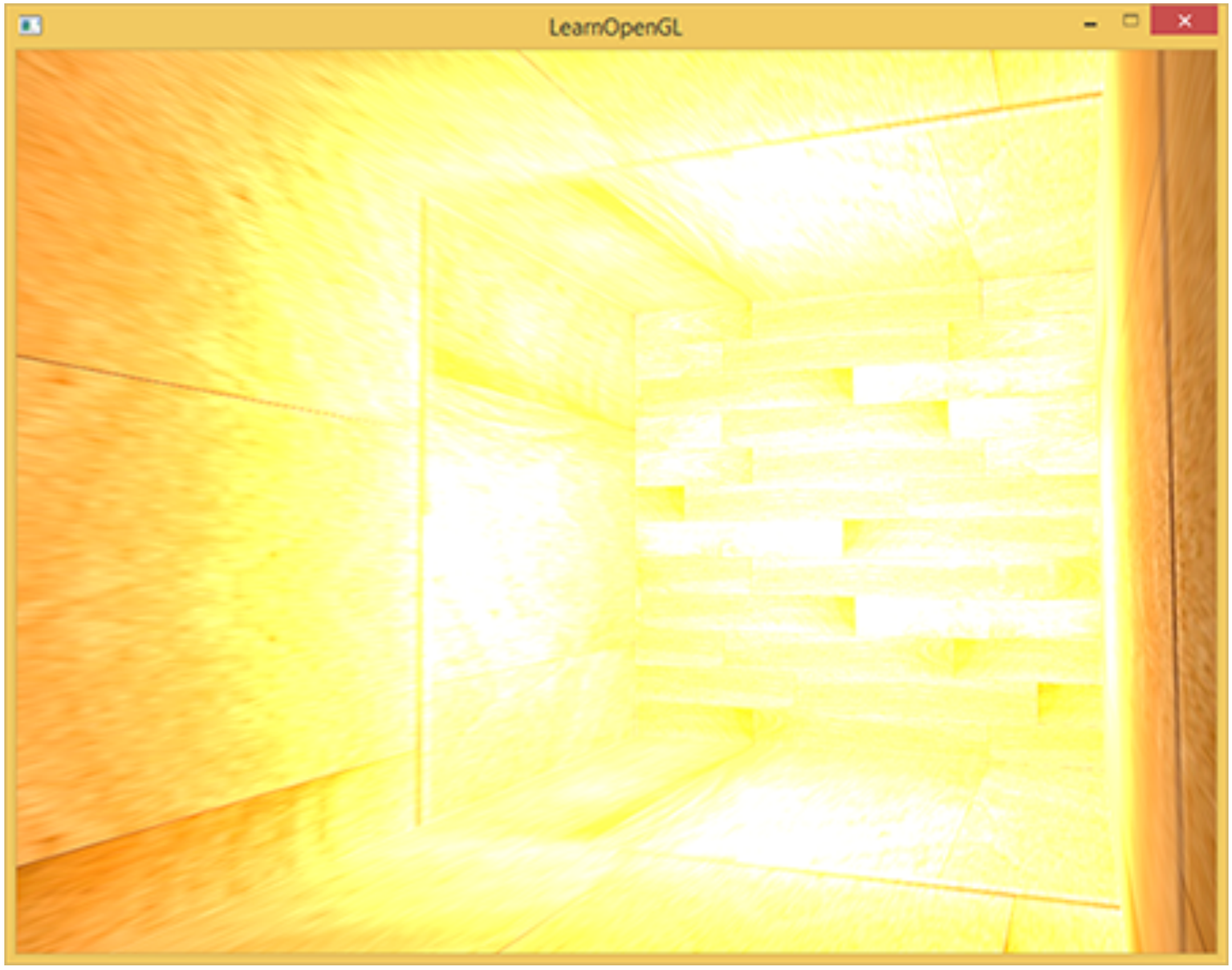
CS 300: Advanced Computer Graphics
High Dynamic Range Rendering

Pushpak Karnick

Problem: Too many lights are bright



What is HDR?

Computer Graphics Pipeline

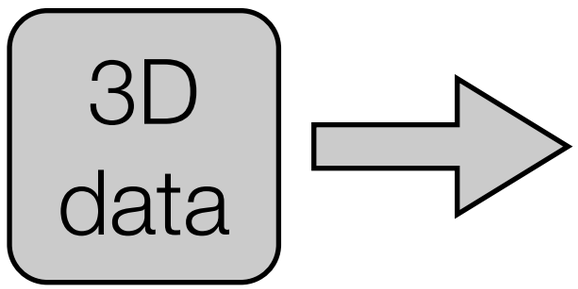
What is HDR?

Computer Graphics Pipeline

3D data

What is HDR?

Computer Graphics Pipeline



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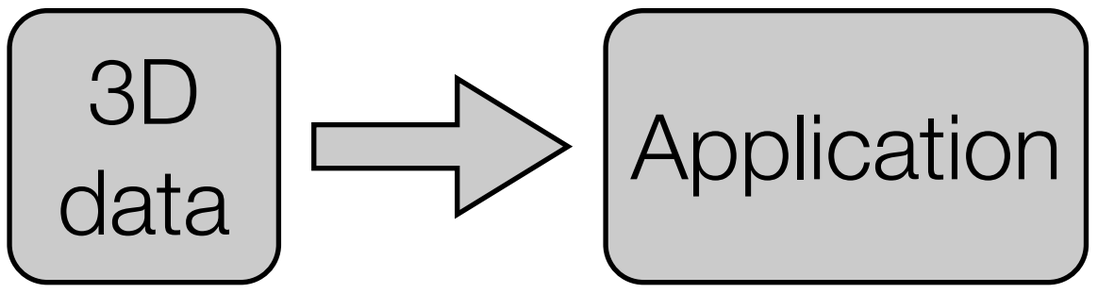

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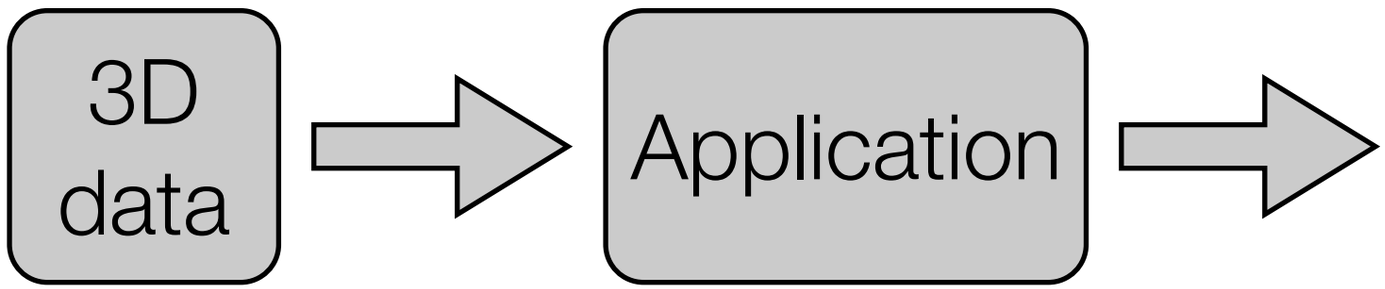

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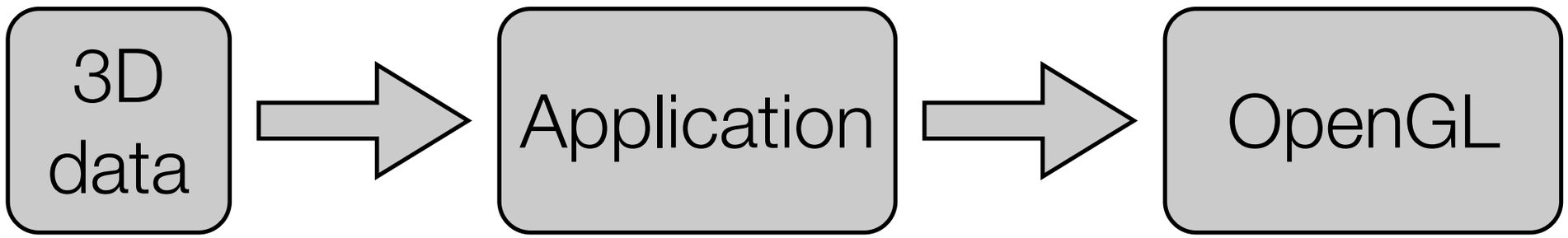

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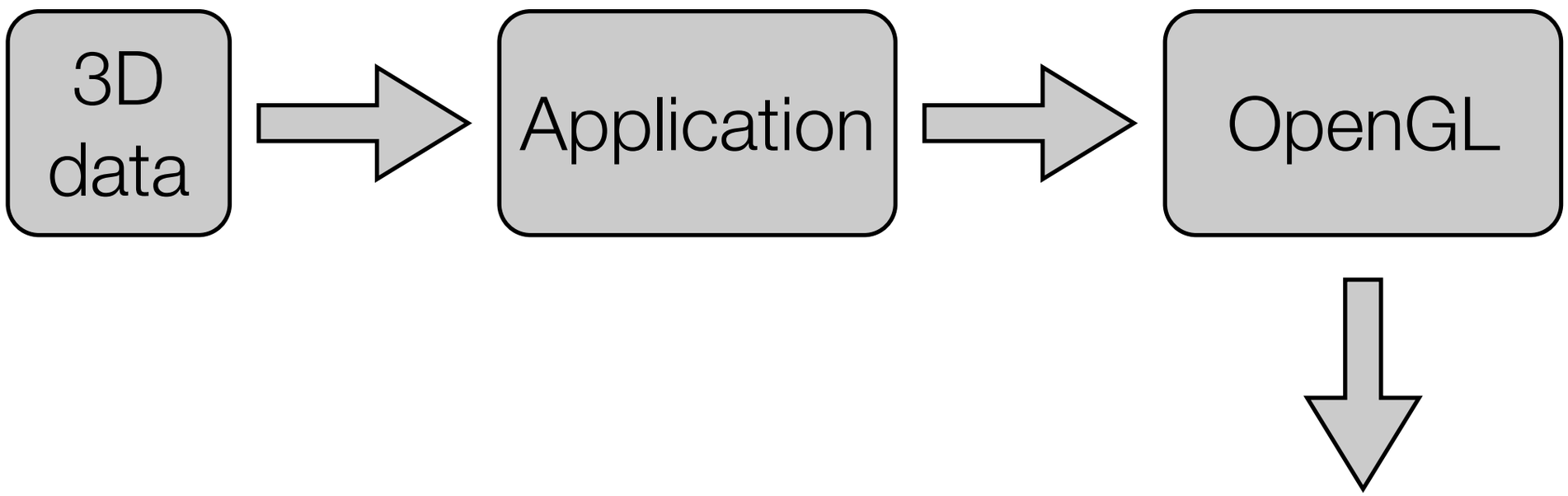

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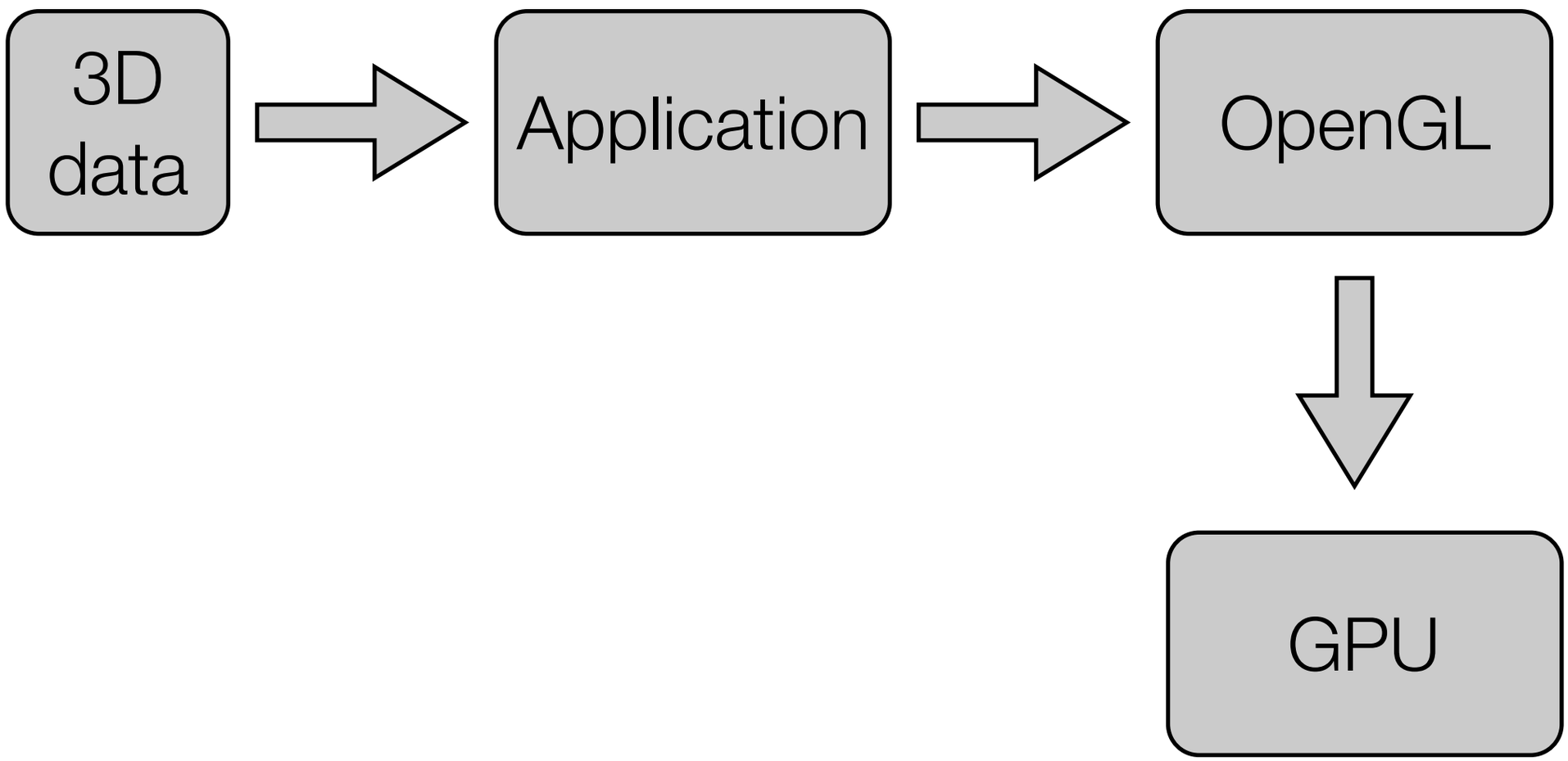

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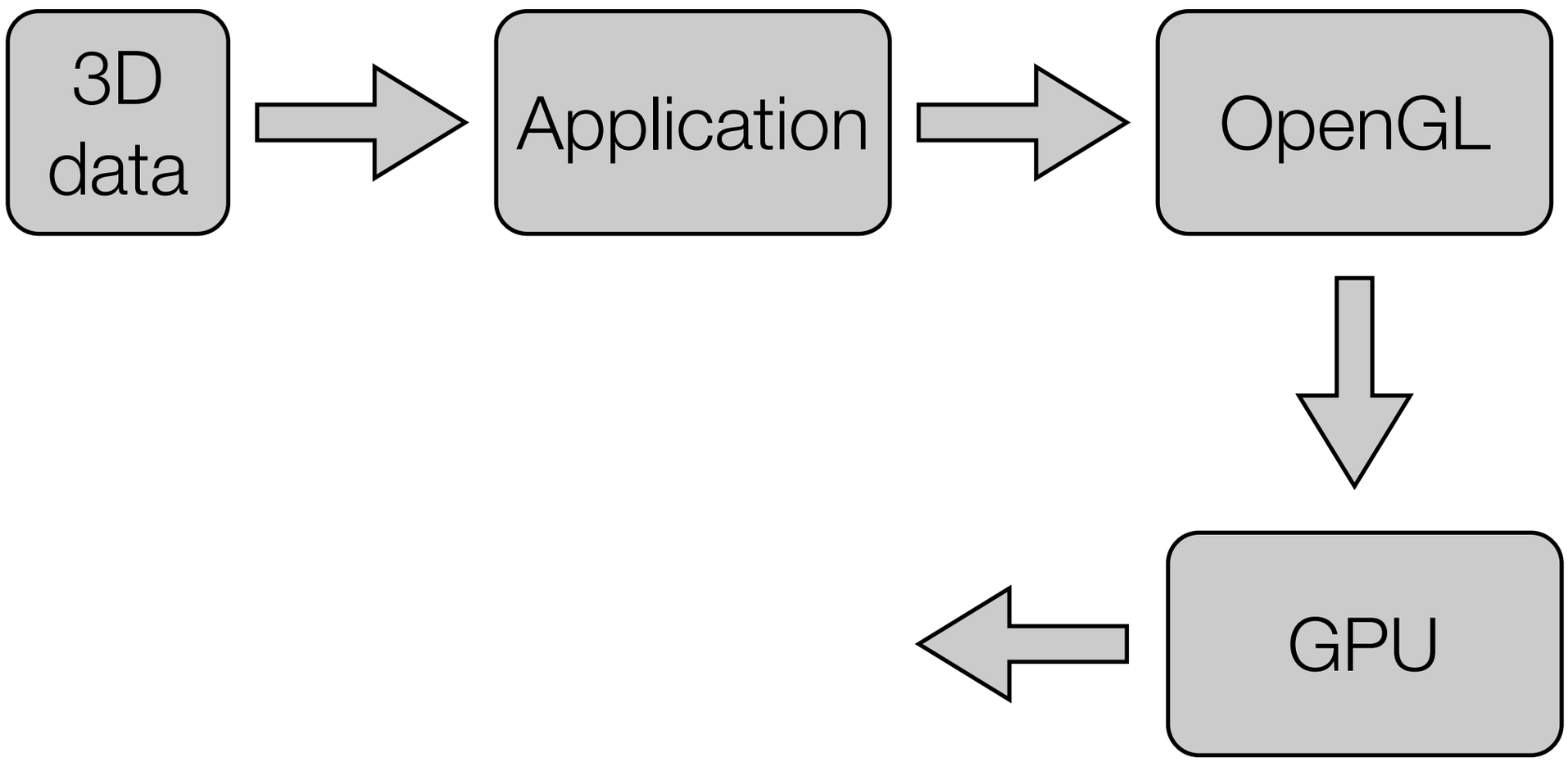

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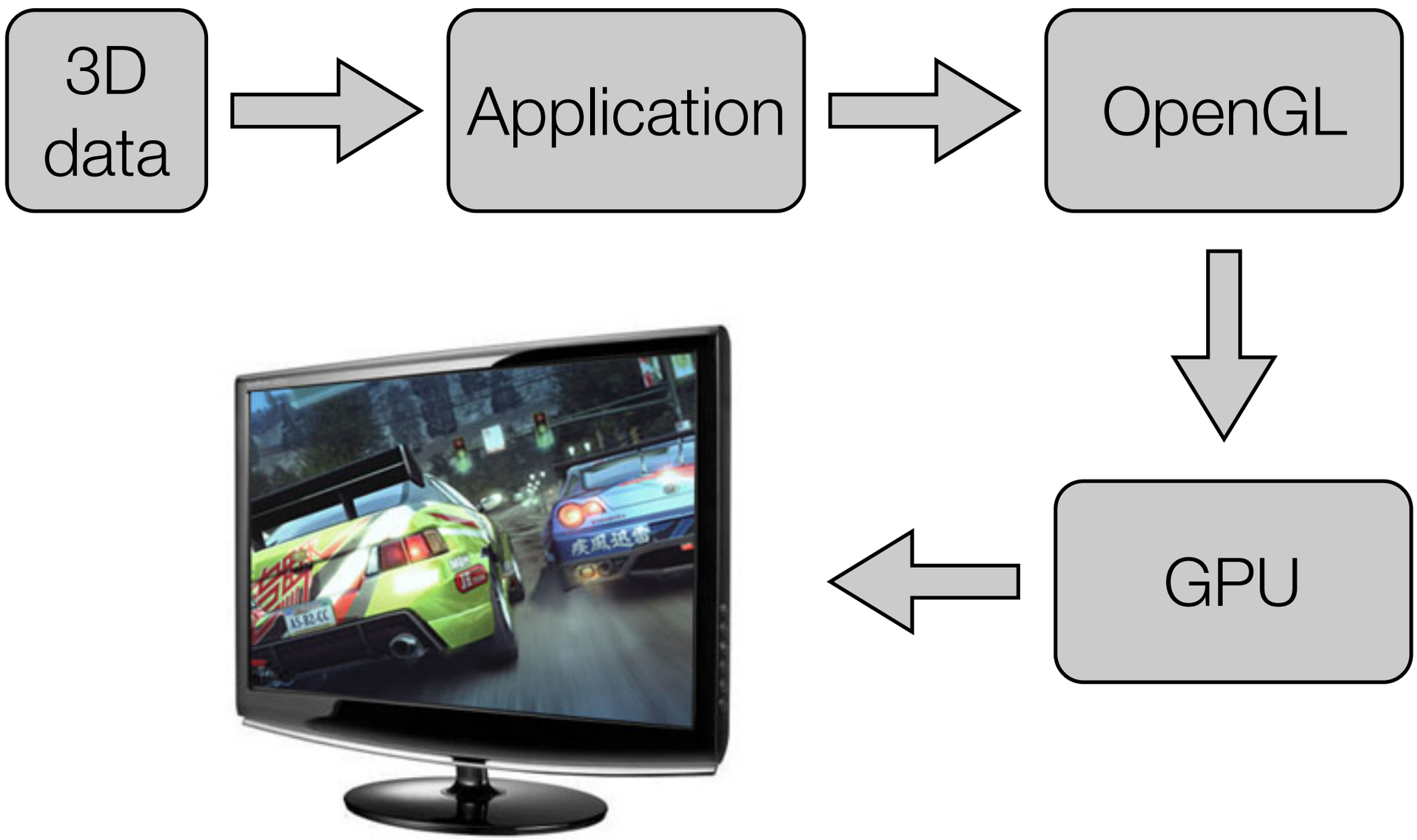

Framebuffer Format

- Brightest and darkest portions in a scene
- Highlights and shadows in real world
- 24-bit RGB, 8-bits per channel
- Min value : 0
- Max value : 255

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Contrast Ratio

- Ratio of maximum intensity to minimum intensity of **displayed** color values
  - Usually, the minimum is 1, not zero
- Hence, for 8-bit images
  - Contrast ratio per channel (intensity) is 256:1
- Compare to
  - Real world - 100,000 : 1

Capping out

- How to display “real-world” color and contrast on a display device with limited contrast ratio?

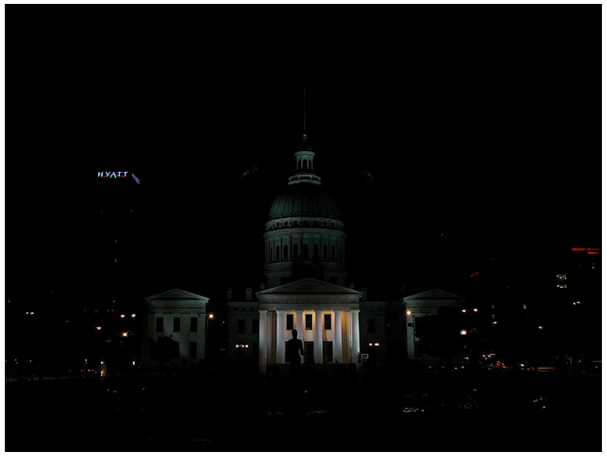
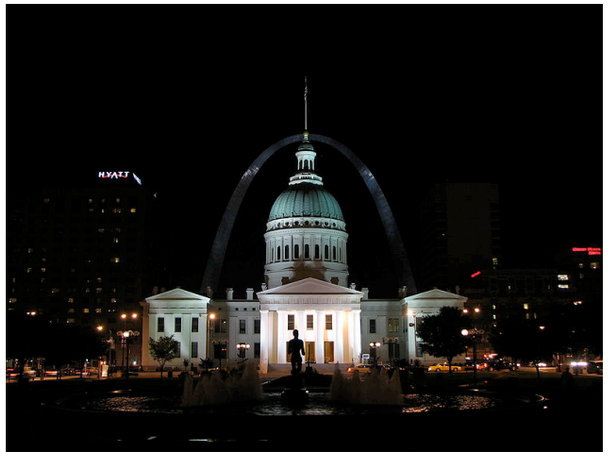
- High Dynamic Range (HDR) methods
  - High Dynamic Range Imaging - creating real-world images
  - High Dynamic Range Rendering - displaying real-world contrast ratio on commodity monitors

High Dynamic Range (HDR) Imaging




Images courtesy
wikipedia.org

High Dynamic Range (HDR) Imaging


Images courtesy
wikipedia.org

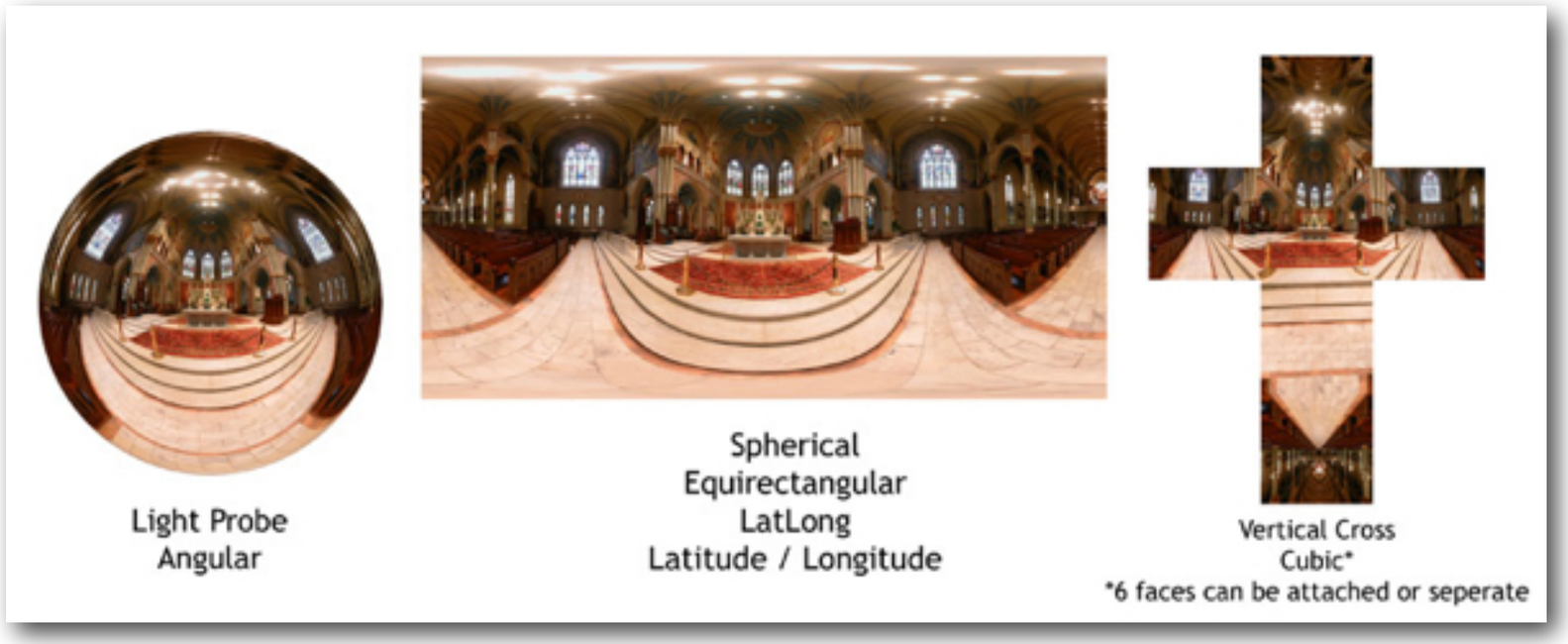
HDR output

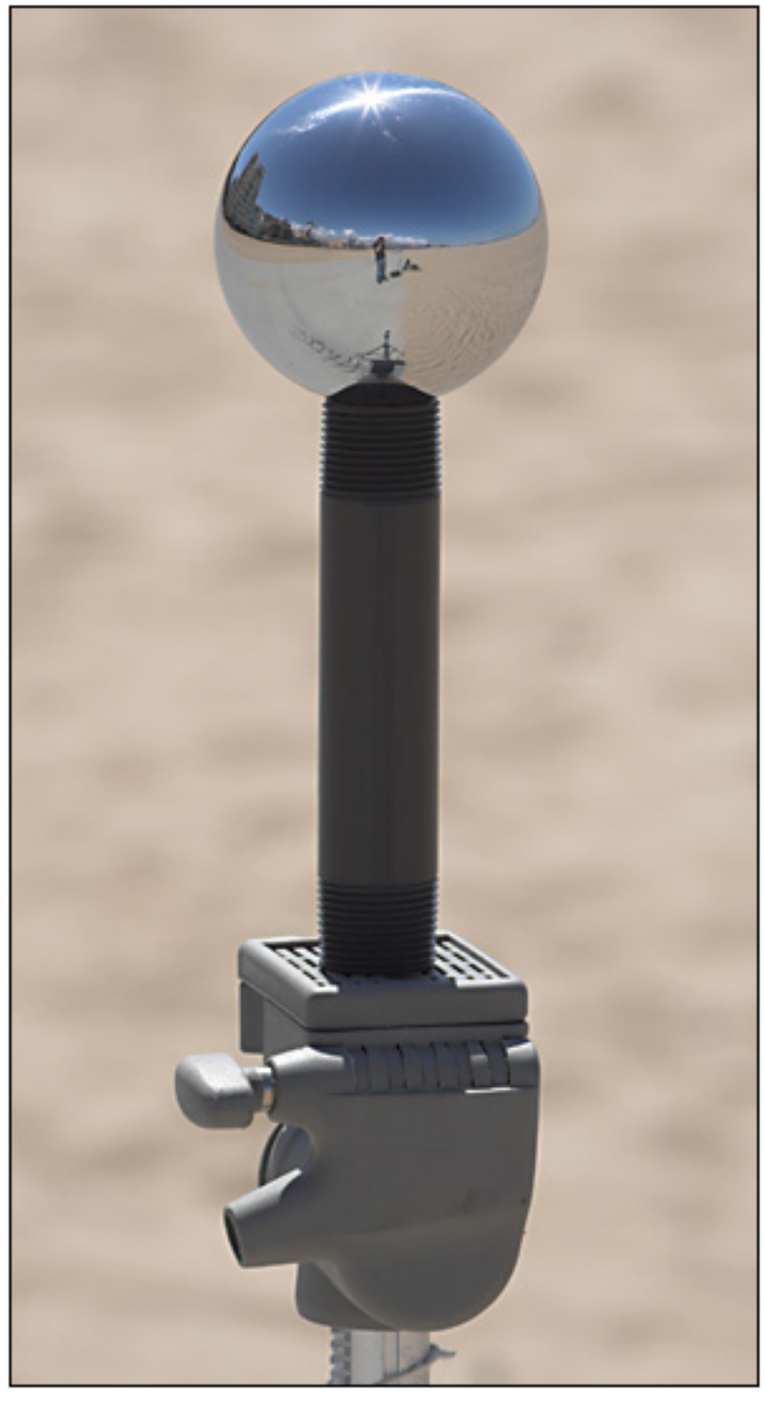
HDR output

Light Probes

- Data collected from real-world
- Similar to earlier approach (merge multi-exposure photographs)
- Combined into an HDR image (Radiance image, *.hdr)

HDR Panoramic Light-Image

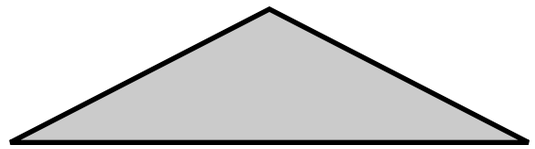




www.hdrlabs.com

CG Pipeline Revisited

CG Pipeline Revisited



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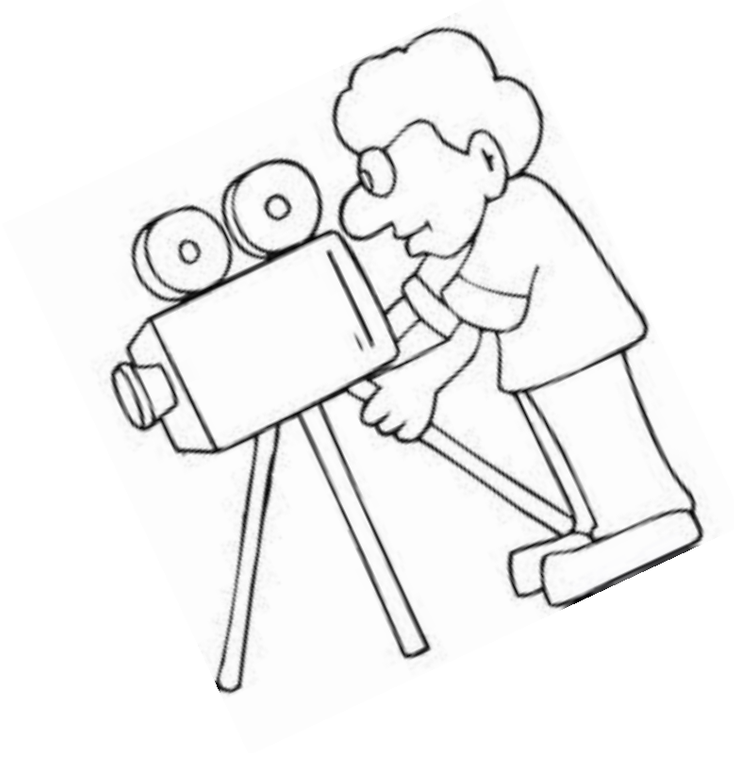

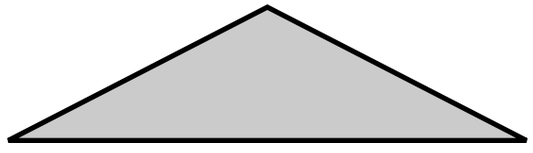

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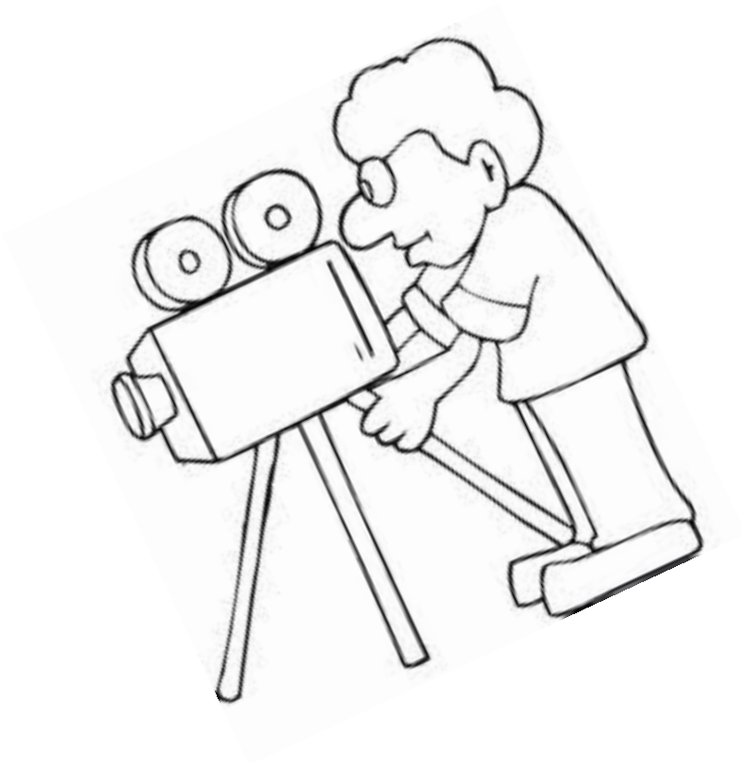

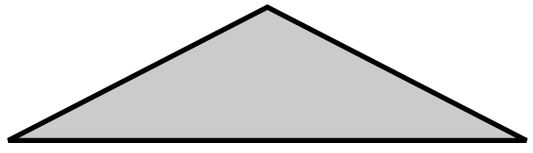

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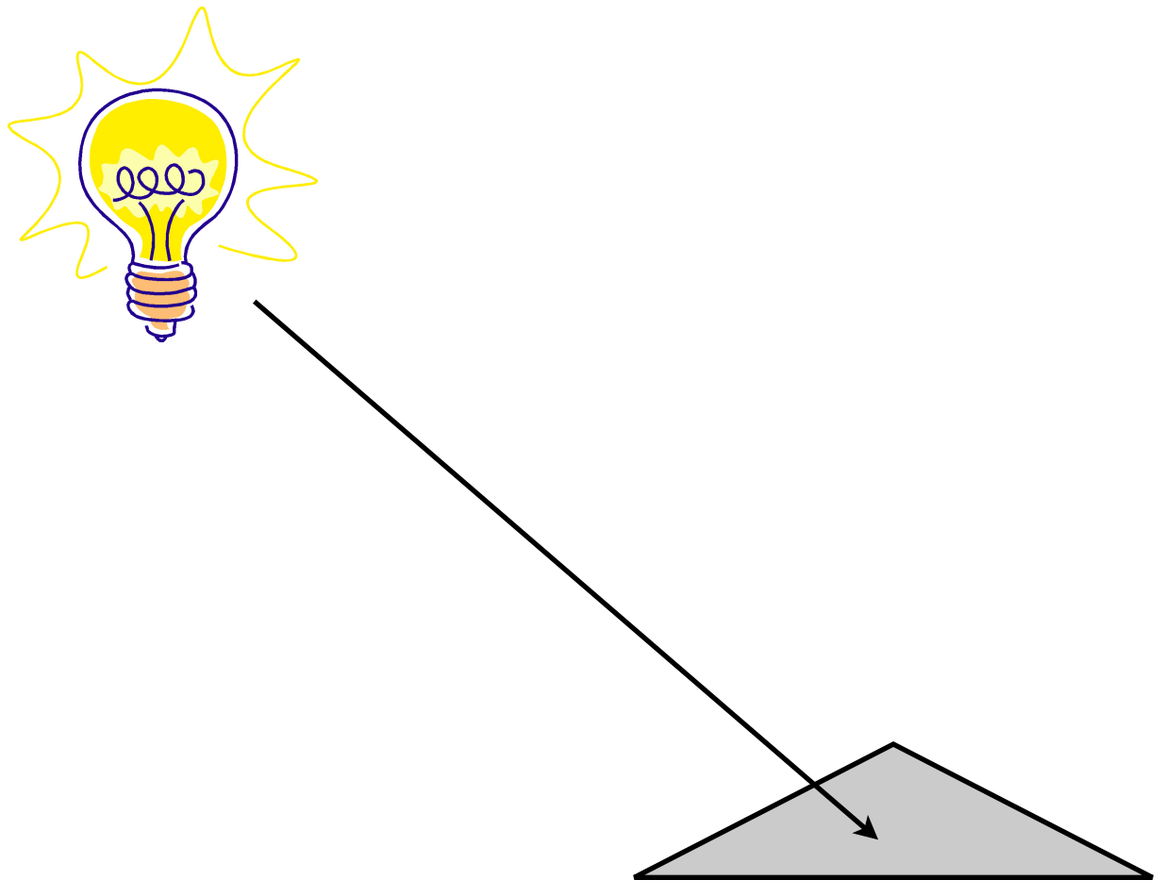

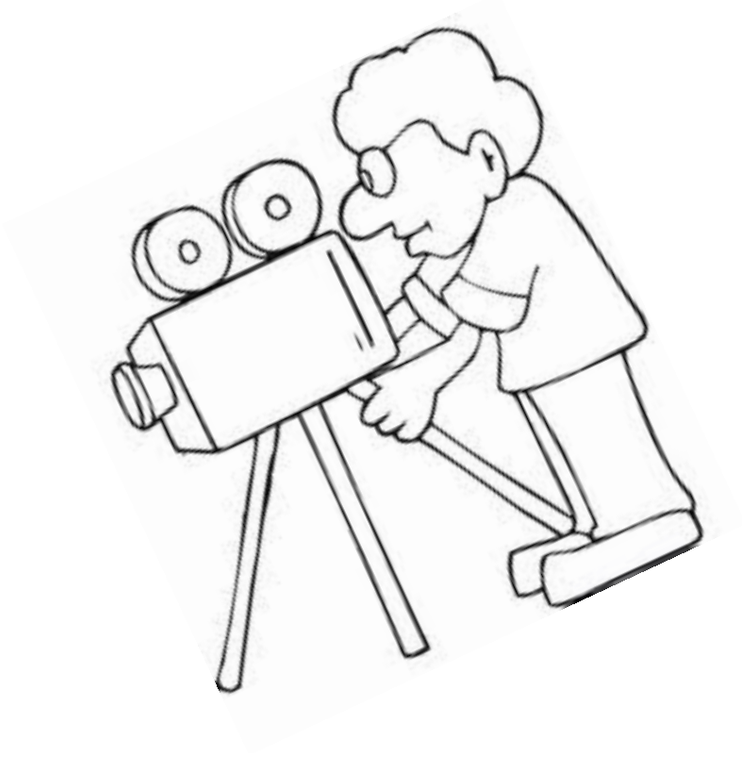

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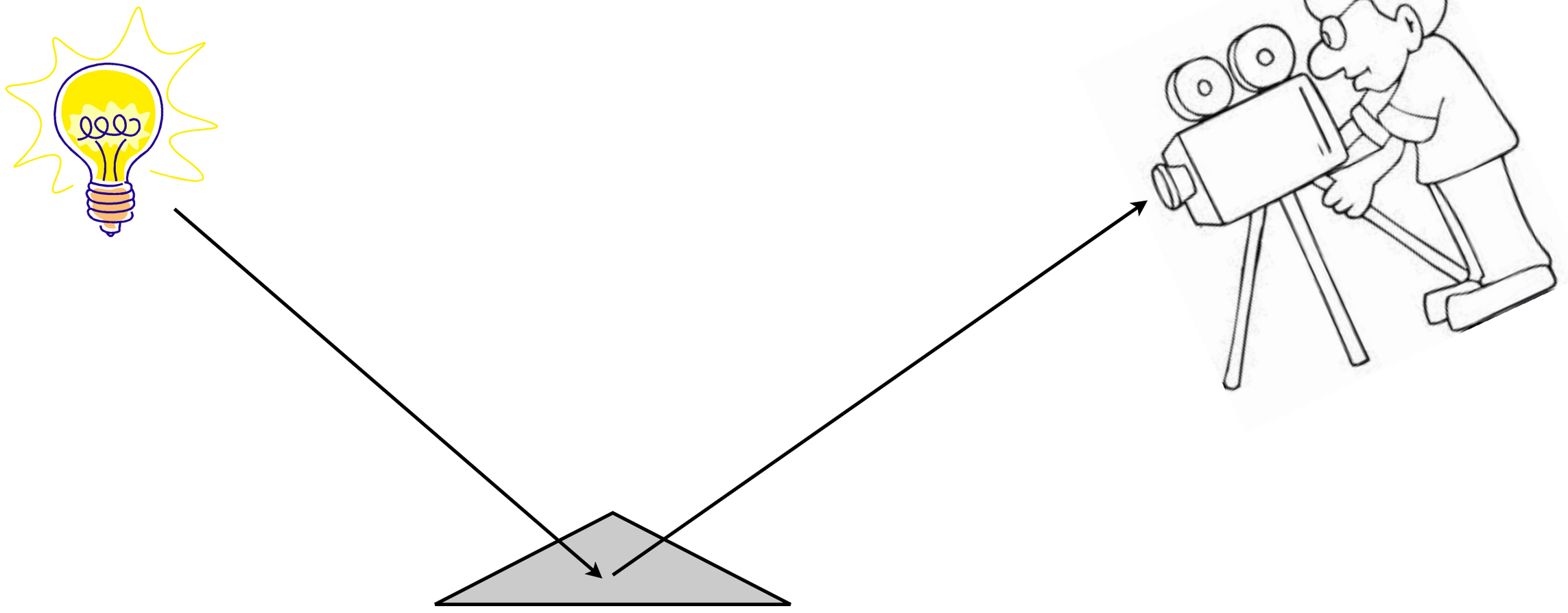

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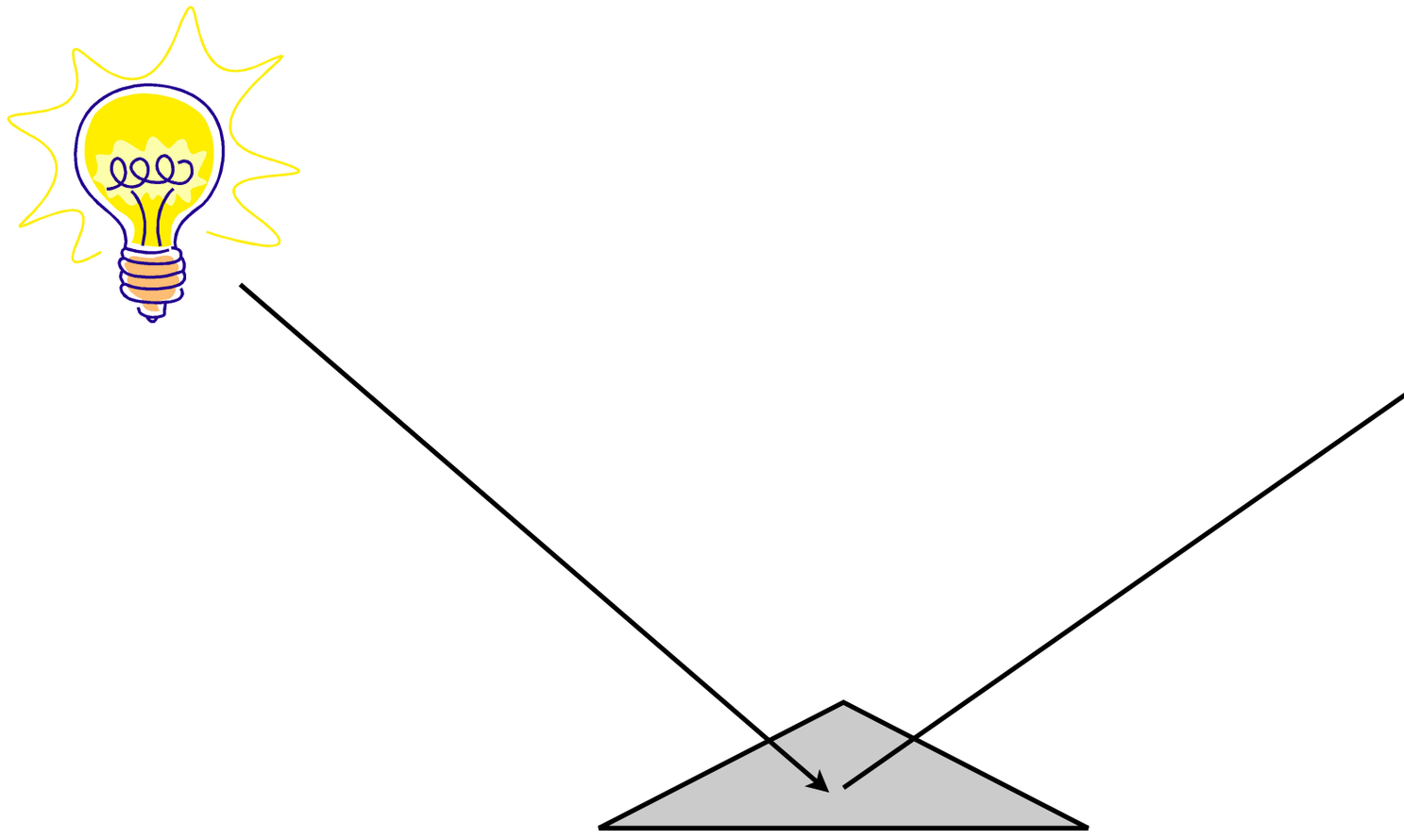
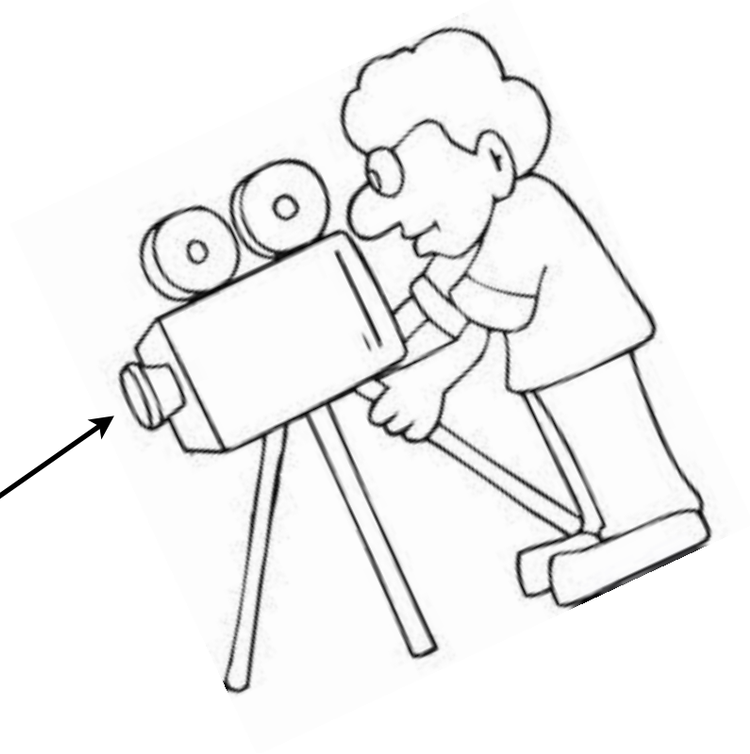
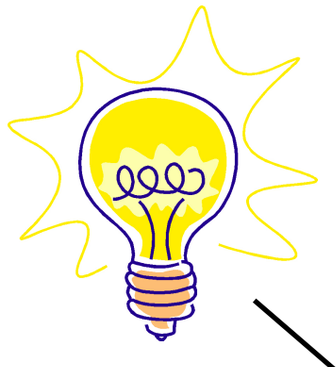


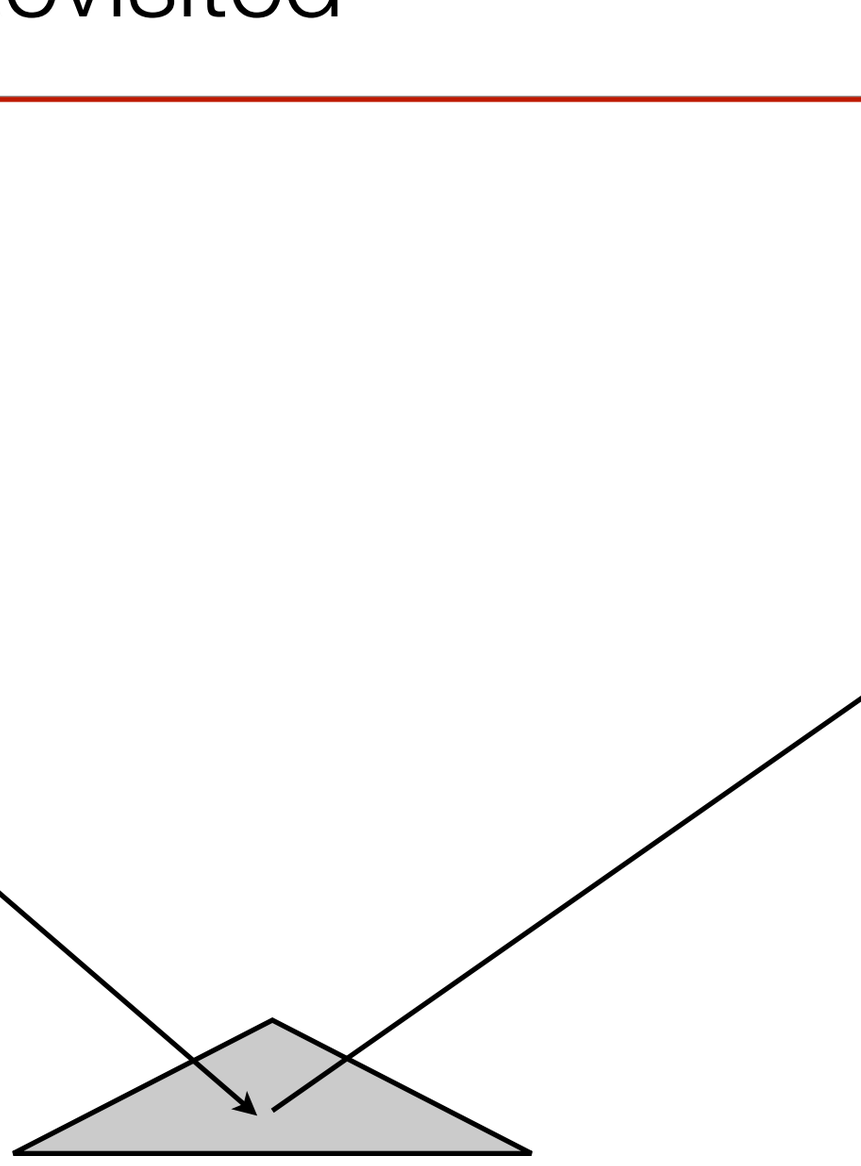


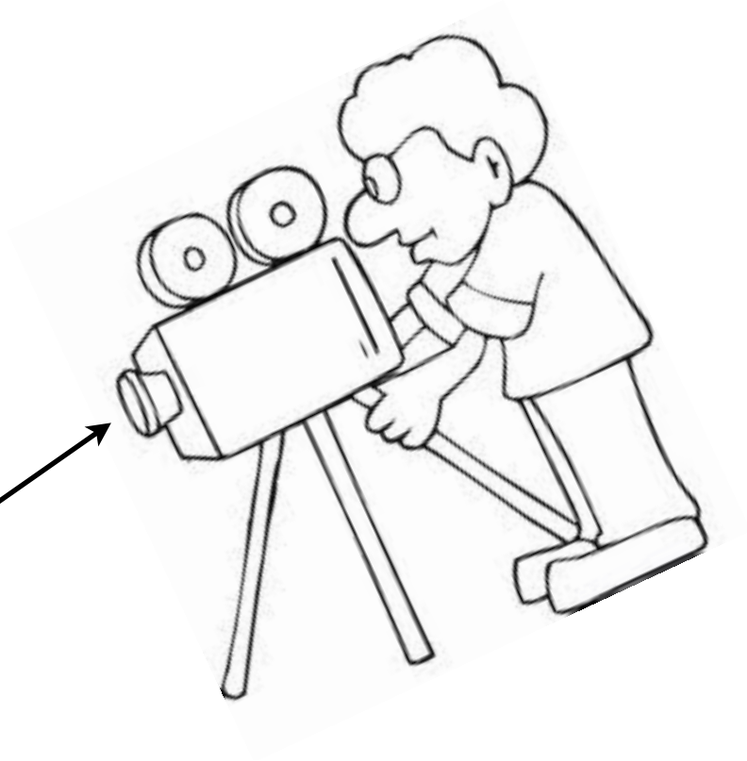
Film
Analog Medium
Higher contrast ratio

CG Pipeline Revisited



Radiance
“Real” values
floating point
representation





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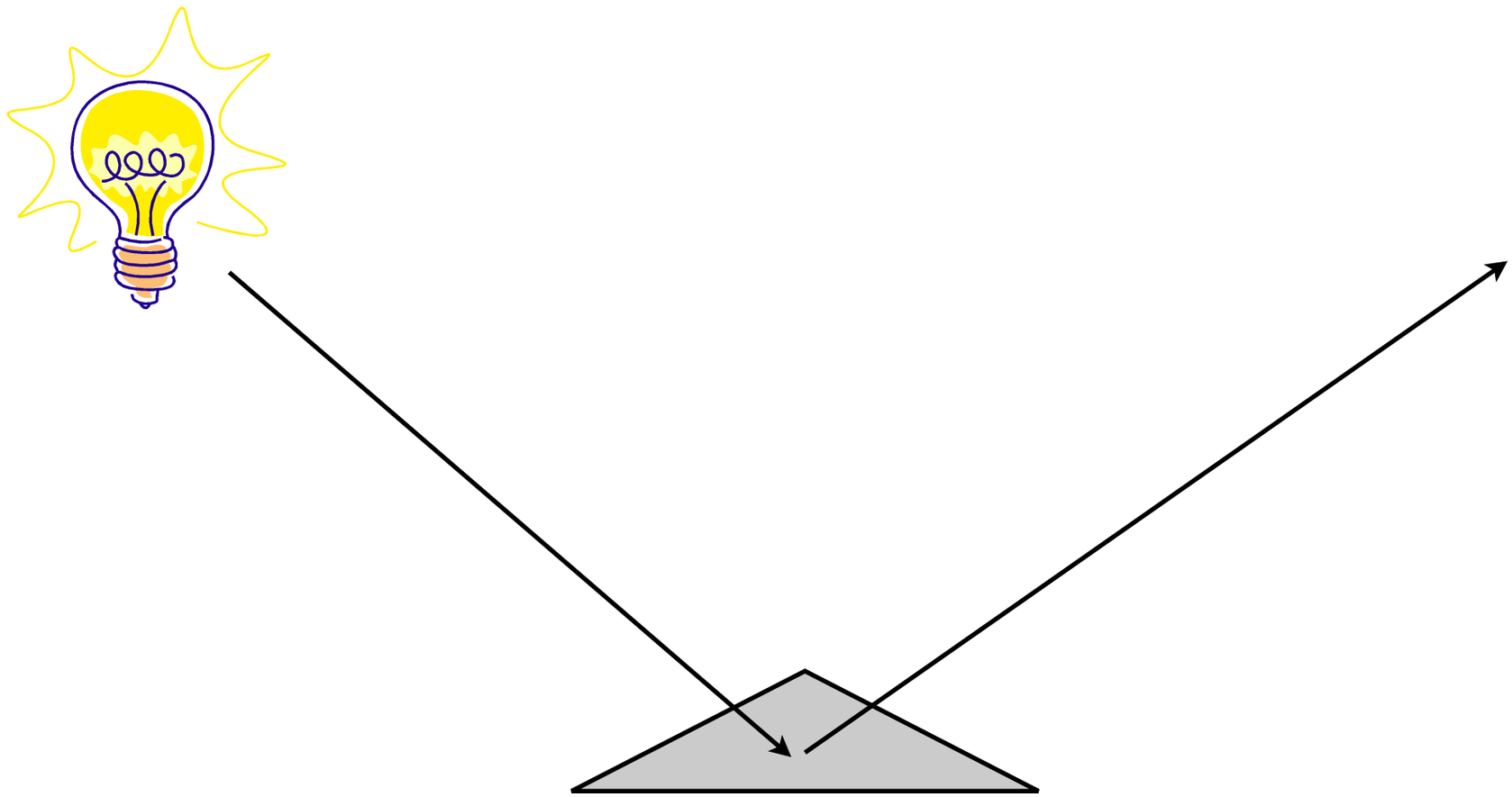

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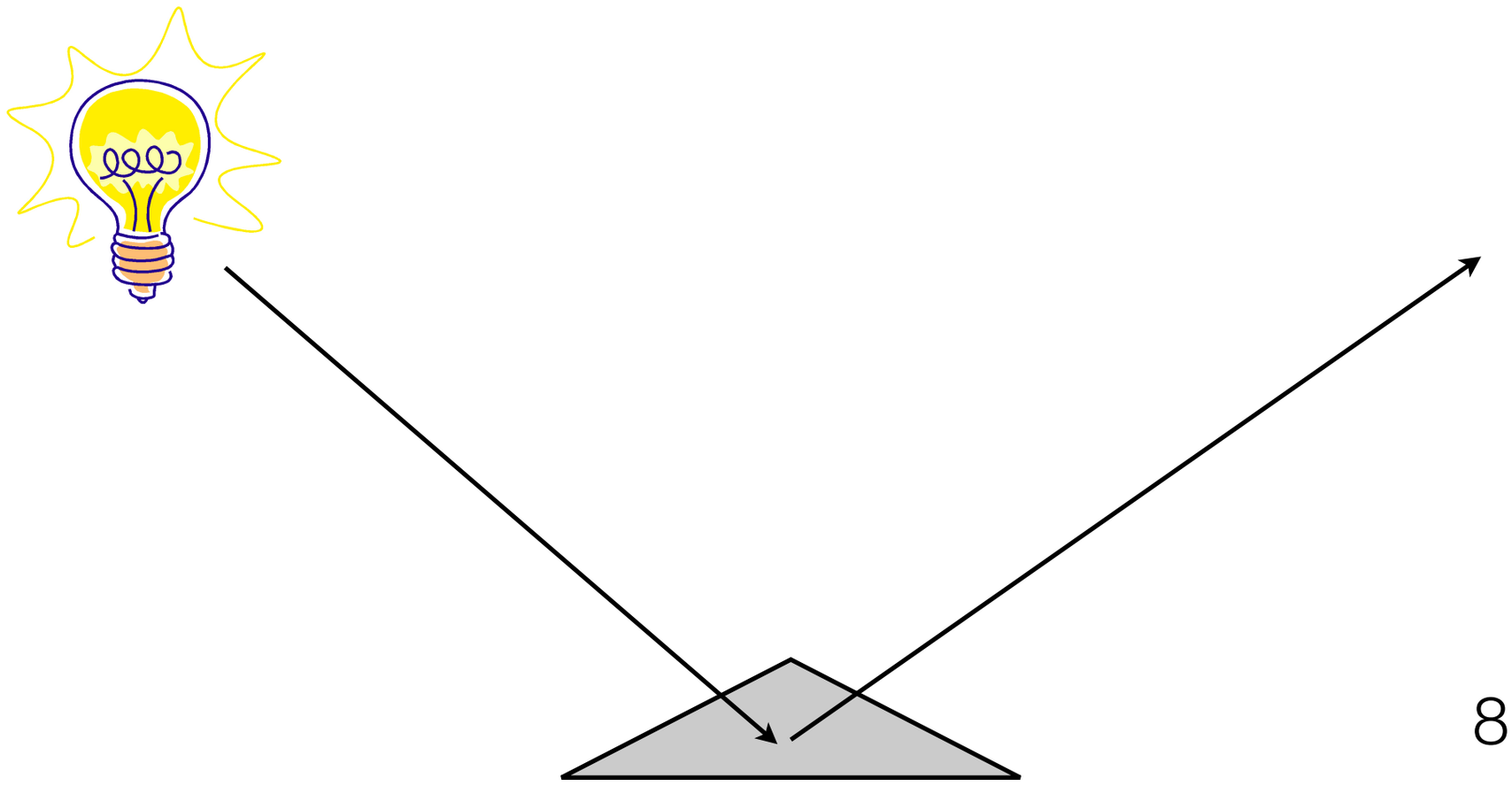
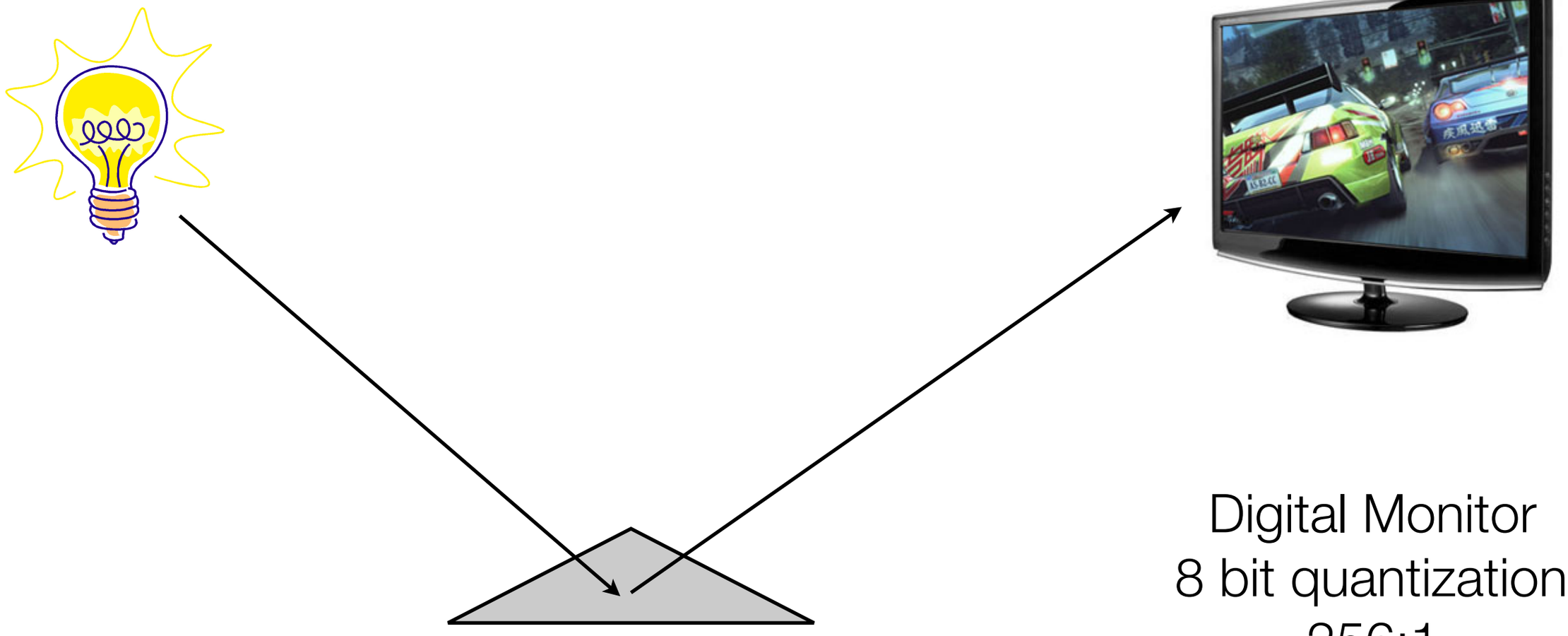


Digital Monitor
8 bit quantization
256:1

CG Pipeline Revisited



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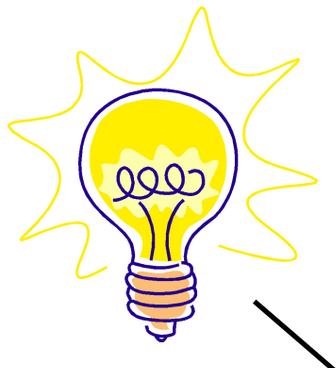
256:1

CG Pipeline Revisited



Digital Lights
8 bit quantization
3 wavelengths
256:1

Digital Monitor
8 bit quantization
256:1

HDR Pipeline Motivation

- How to use real-world data (i.e. floating point values) for our lighting calculations?

- Ordinary framebuffer is integer-based representation with 256:1 contrast ratio

- What if our output of the fragment shader could be floating point instead of integers?

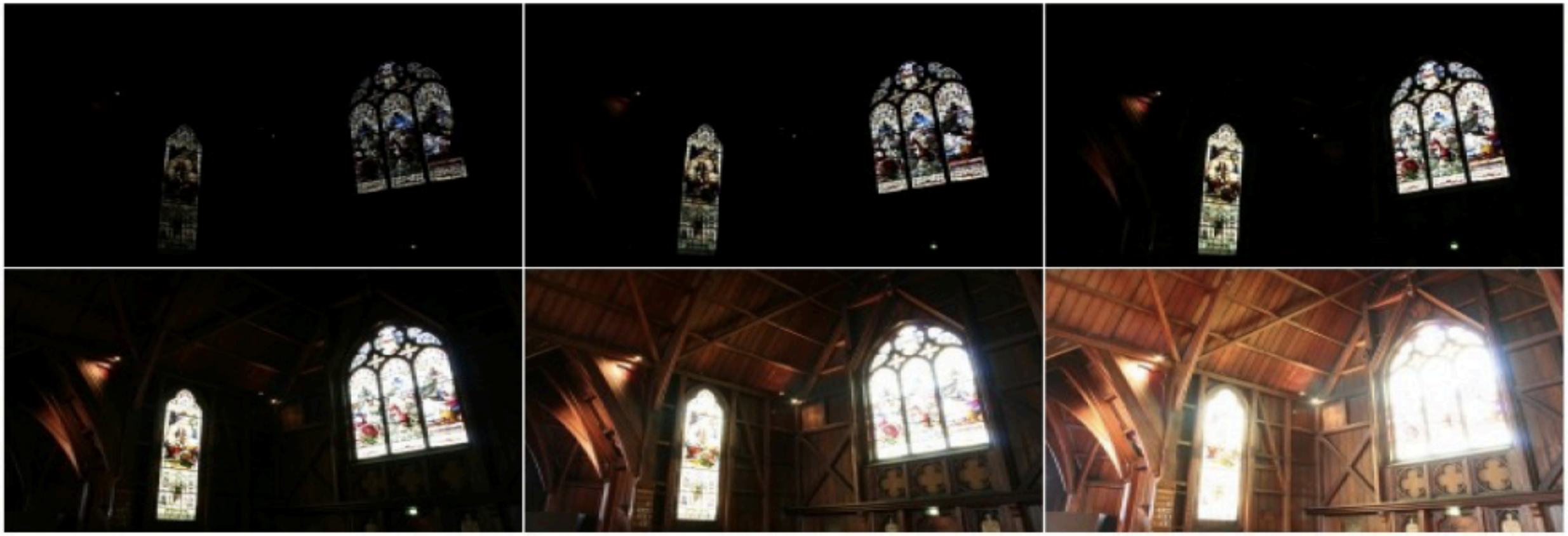
  - Floating point render targets

  - Framebuffer Objects (FBOs)

HDR

- Two types of operations in practice
- HDRI - High Dynamic Range Imaging
  - Applied in photography and image processing
- HDR(R) - High Dynamic Range Rendering
  - Used to display larger contrast ratio data on a lower contrast ratio medium
  - For e.g. FBO to monitor screen

HDR Imaging

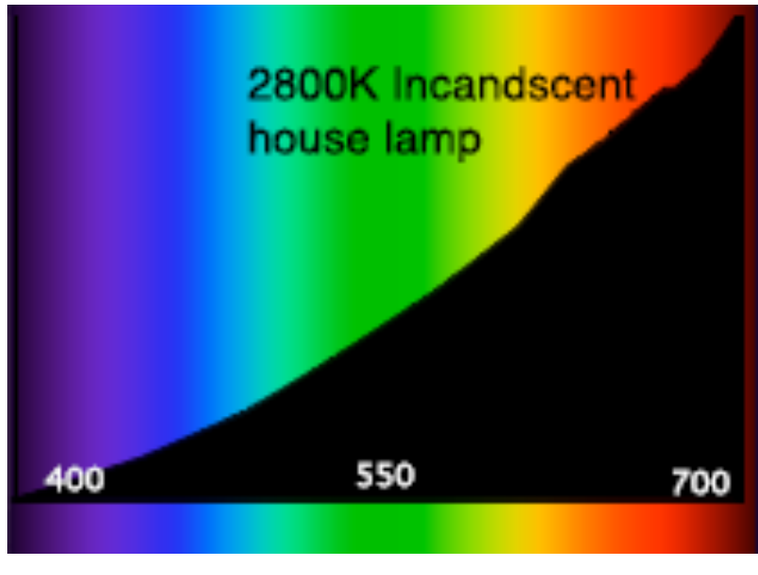


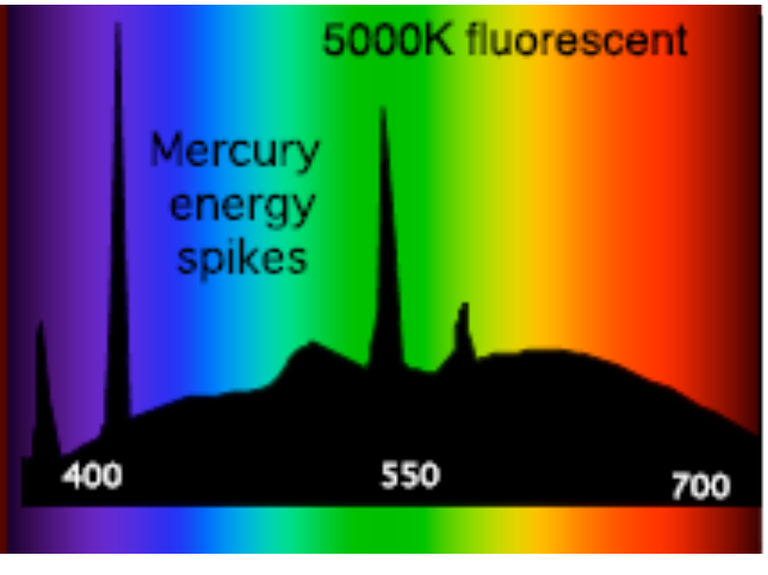

3
138
331
62


3
138
331
62

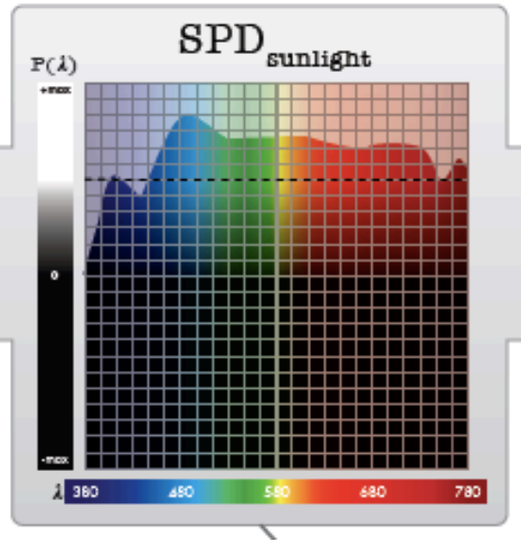
How to obtain HDR lights?

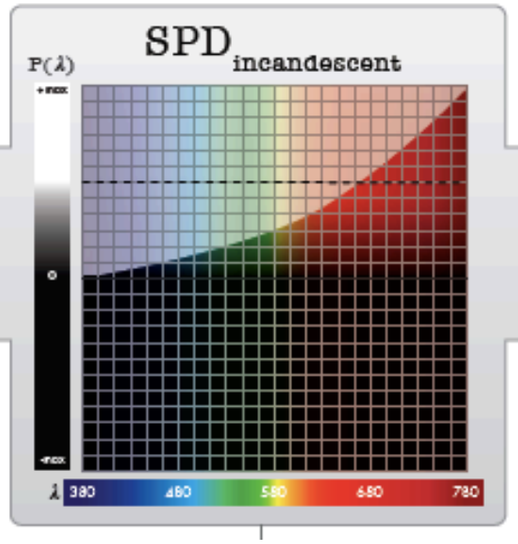
- Spectral Distribution Function

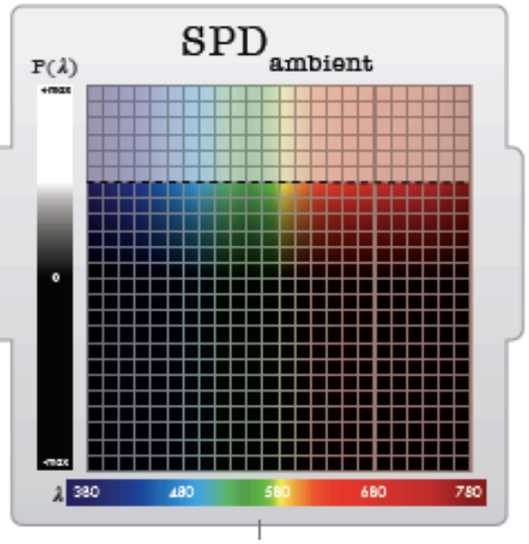




Sample Light Sources







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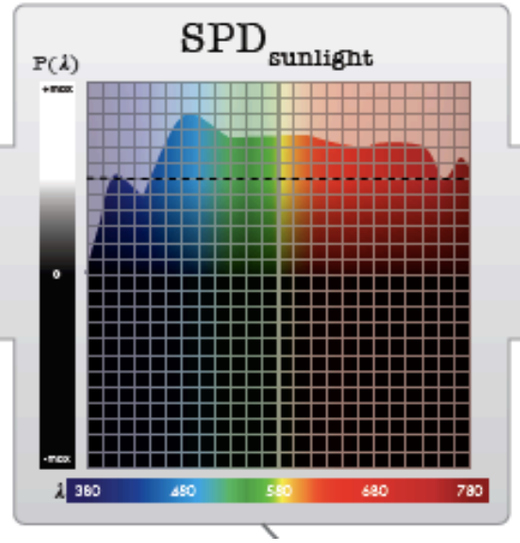
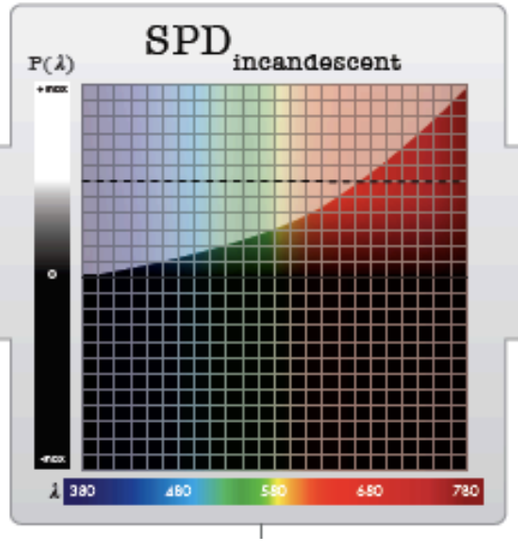
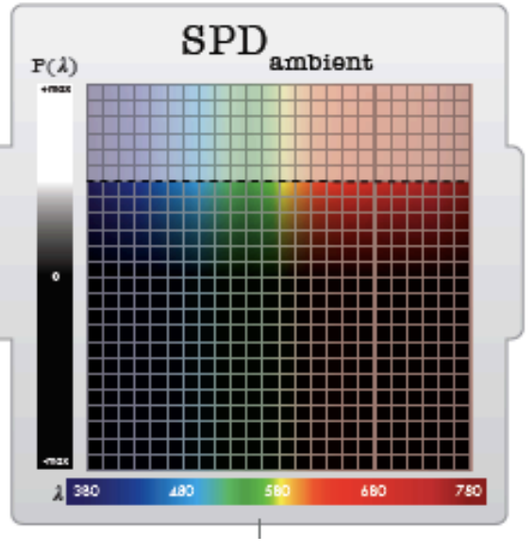
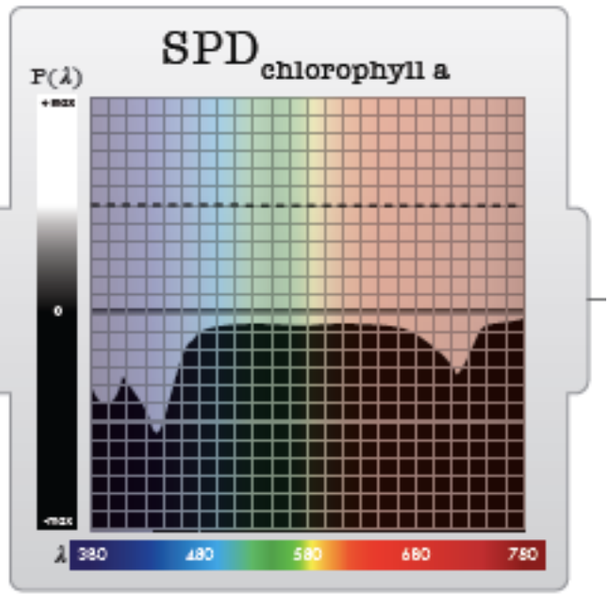






Sample Material



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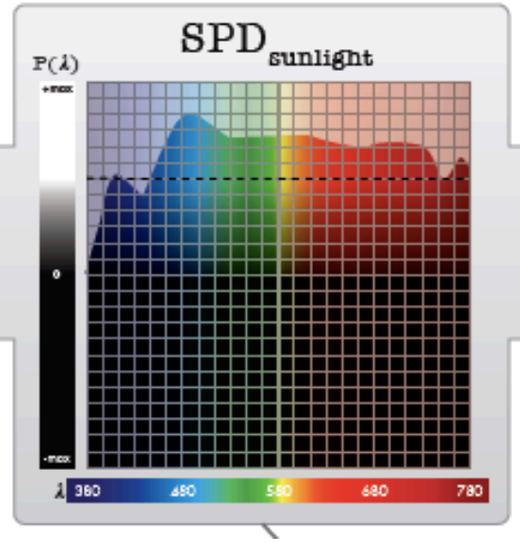

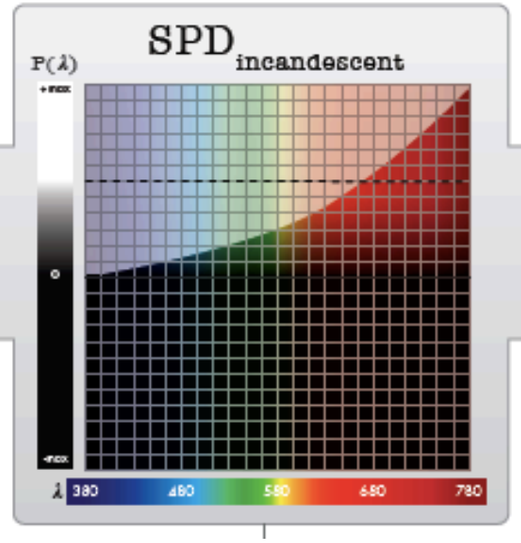

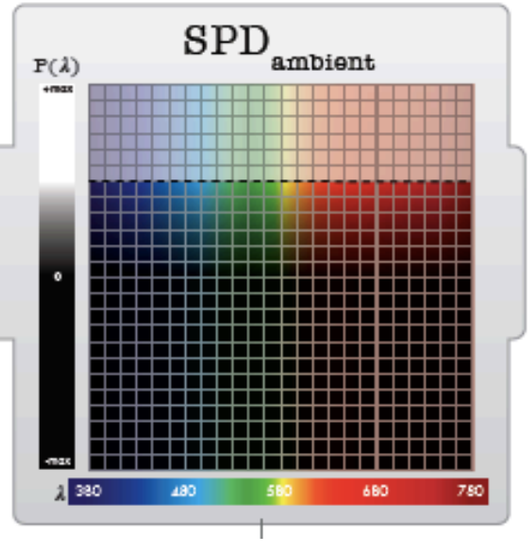

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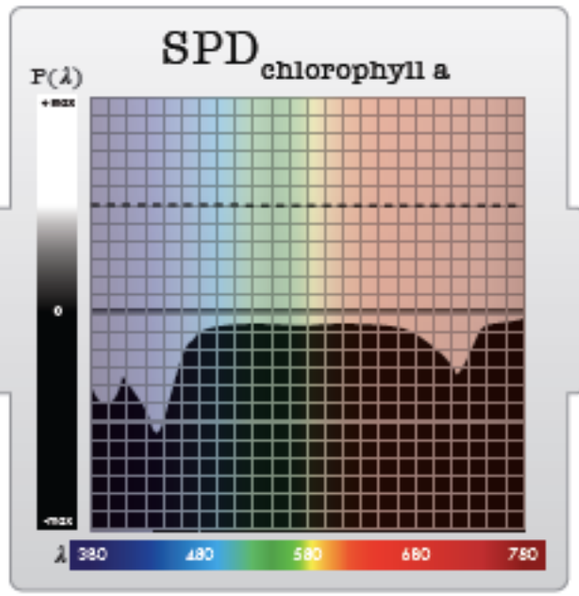

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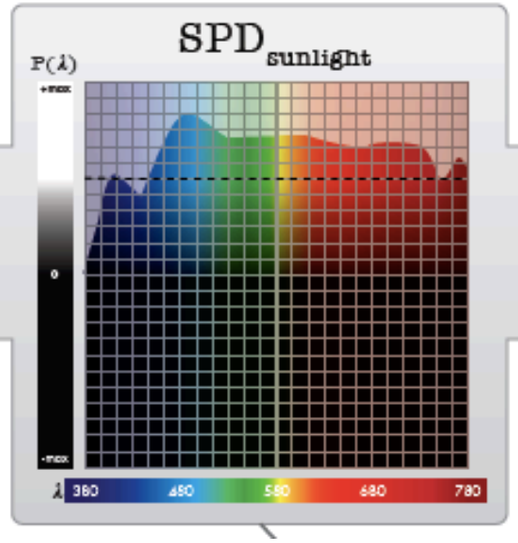
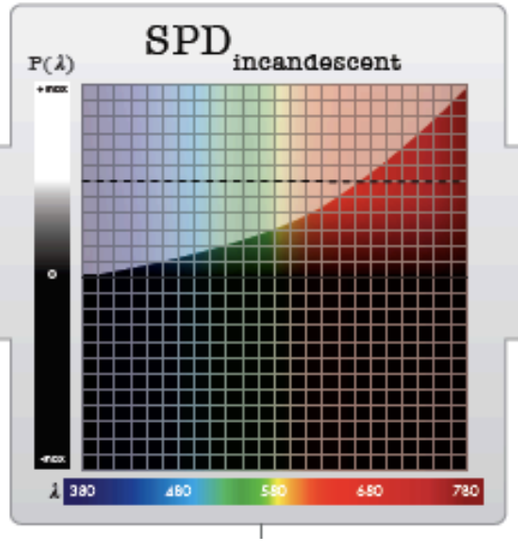
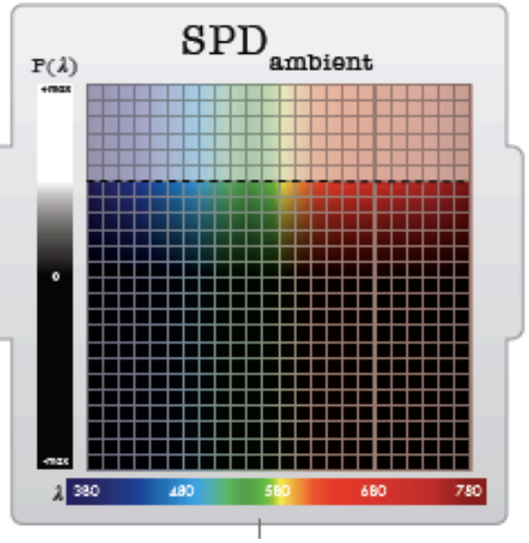
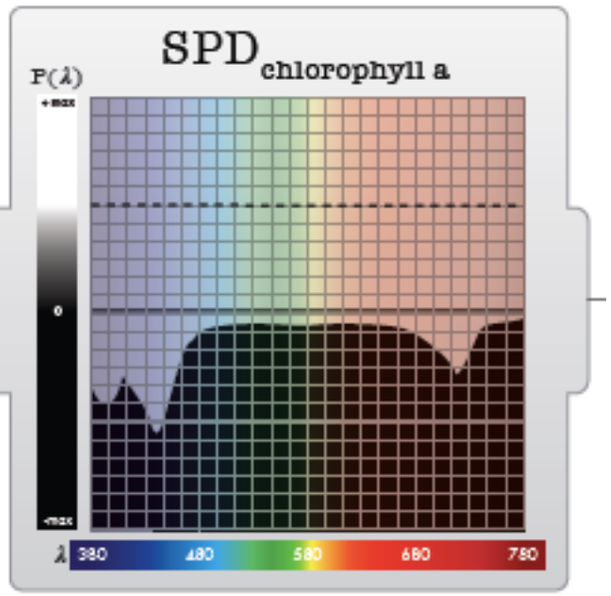


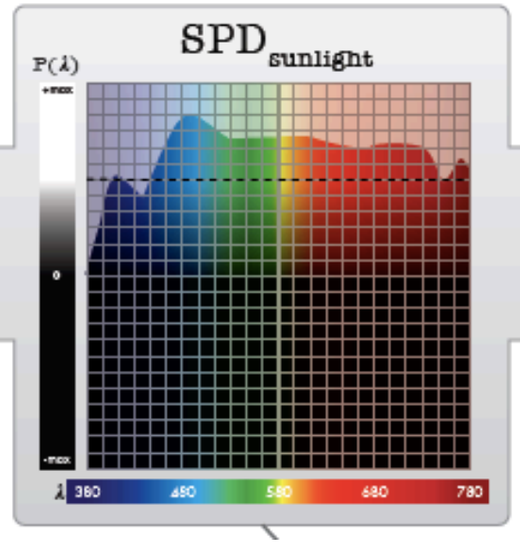


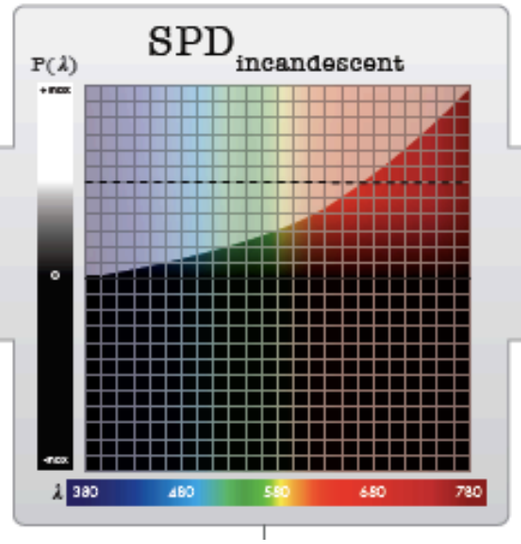


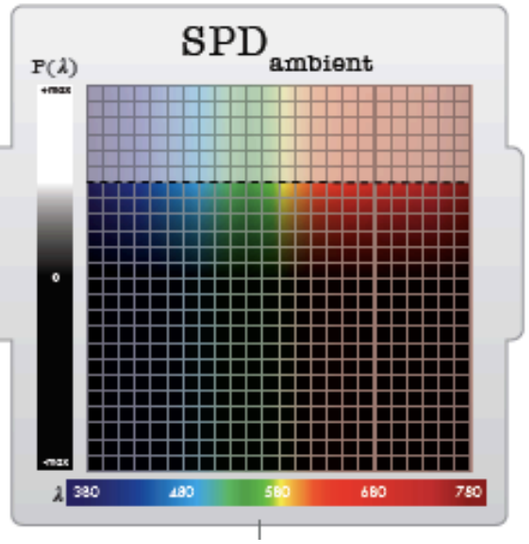
Sample Material



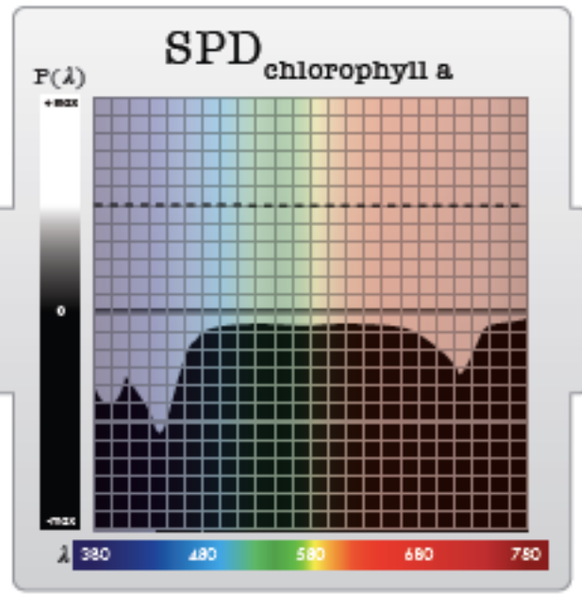
Sample Light Sources





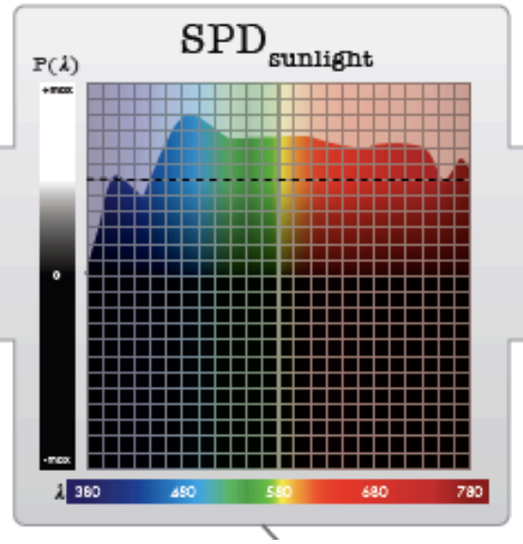


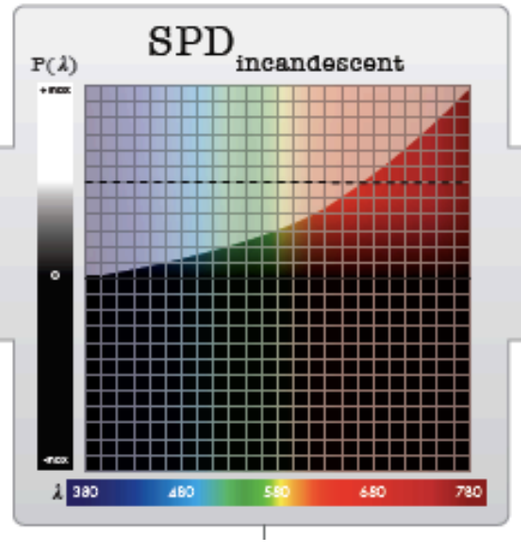
Sample Material

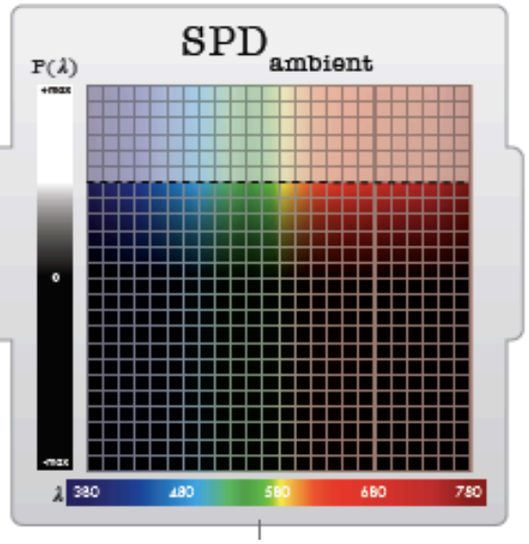


Illumination shader

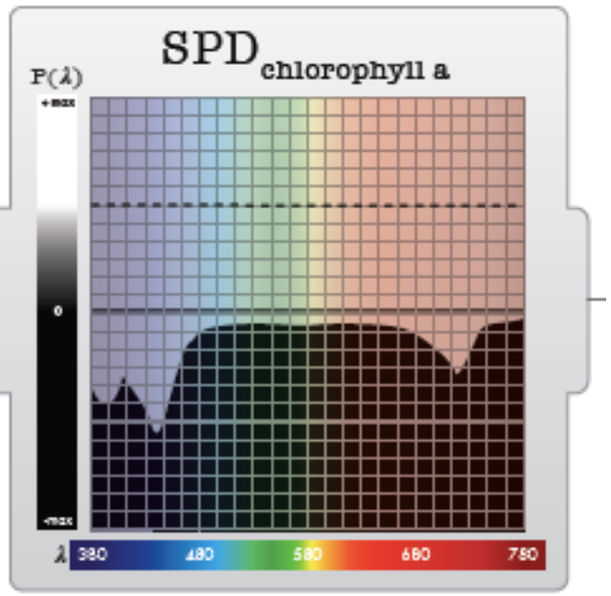
Sample Light Sources



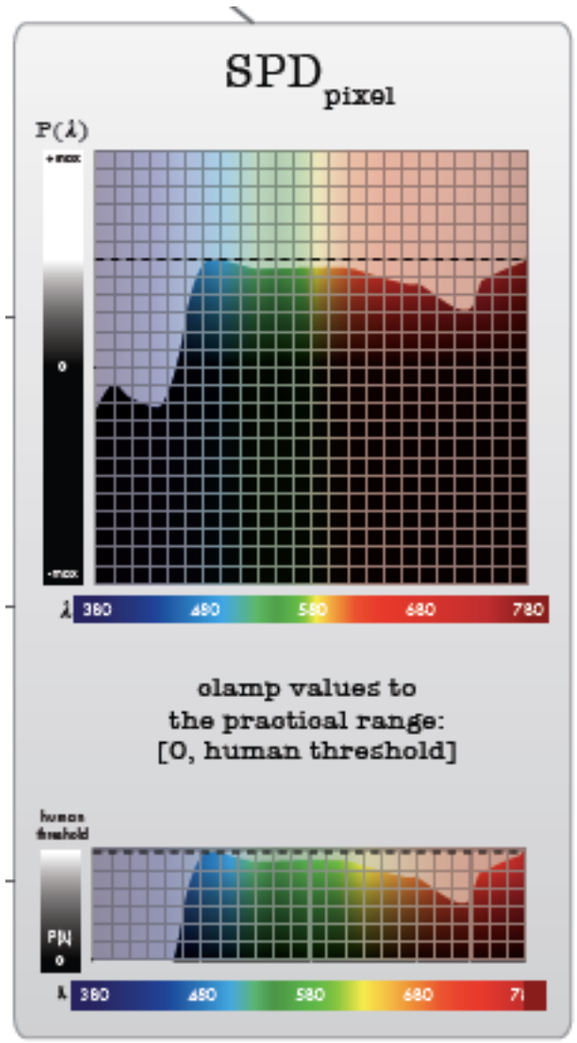


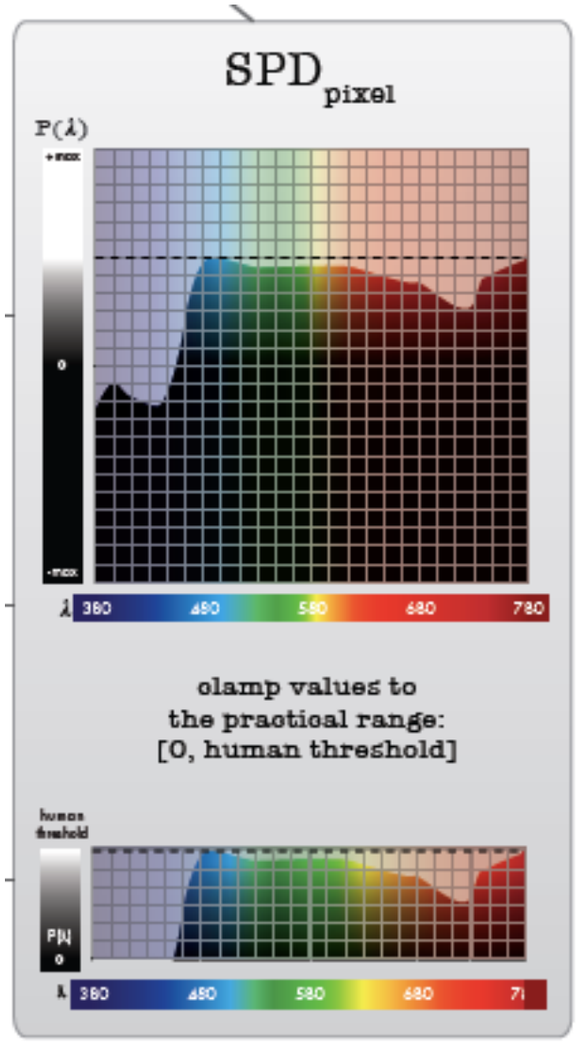


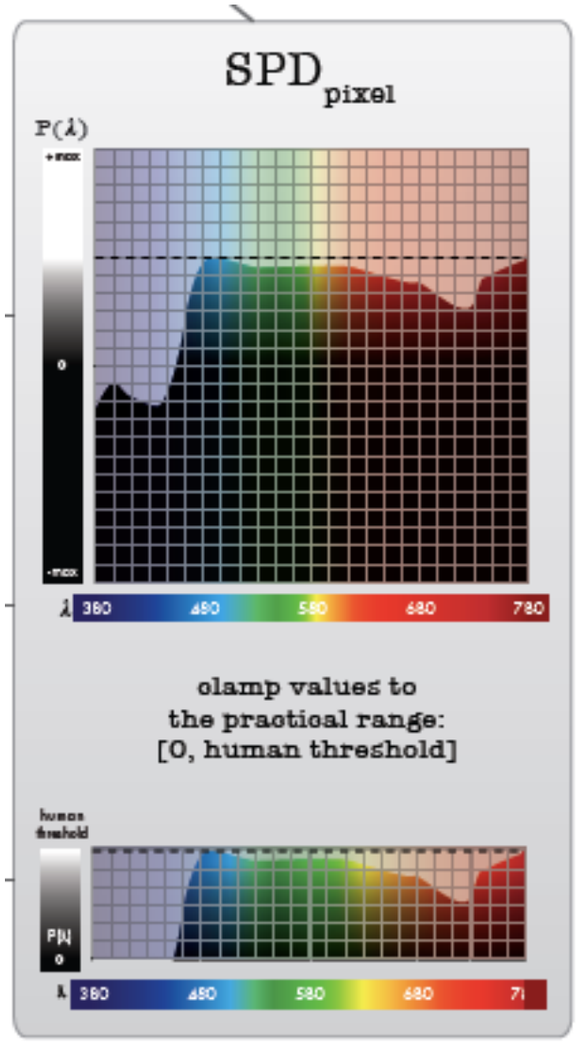
Sample Material



Illumination shader




SPD pixel
P(λ)
+max
0
-max
λ 380 480 580 680 780
clamp values to
the practical range:
[0, human threshold]
human threshold
PW
0
λ 380 480 580 680


SPD pixel
P(λ)
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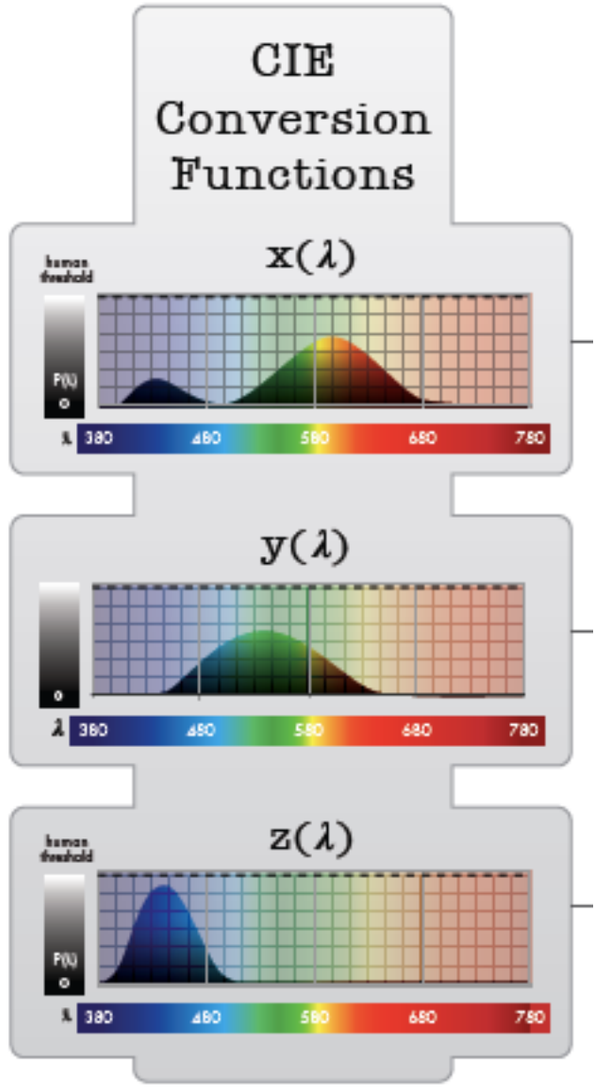
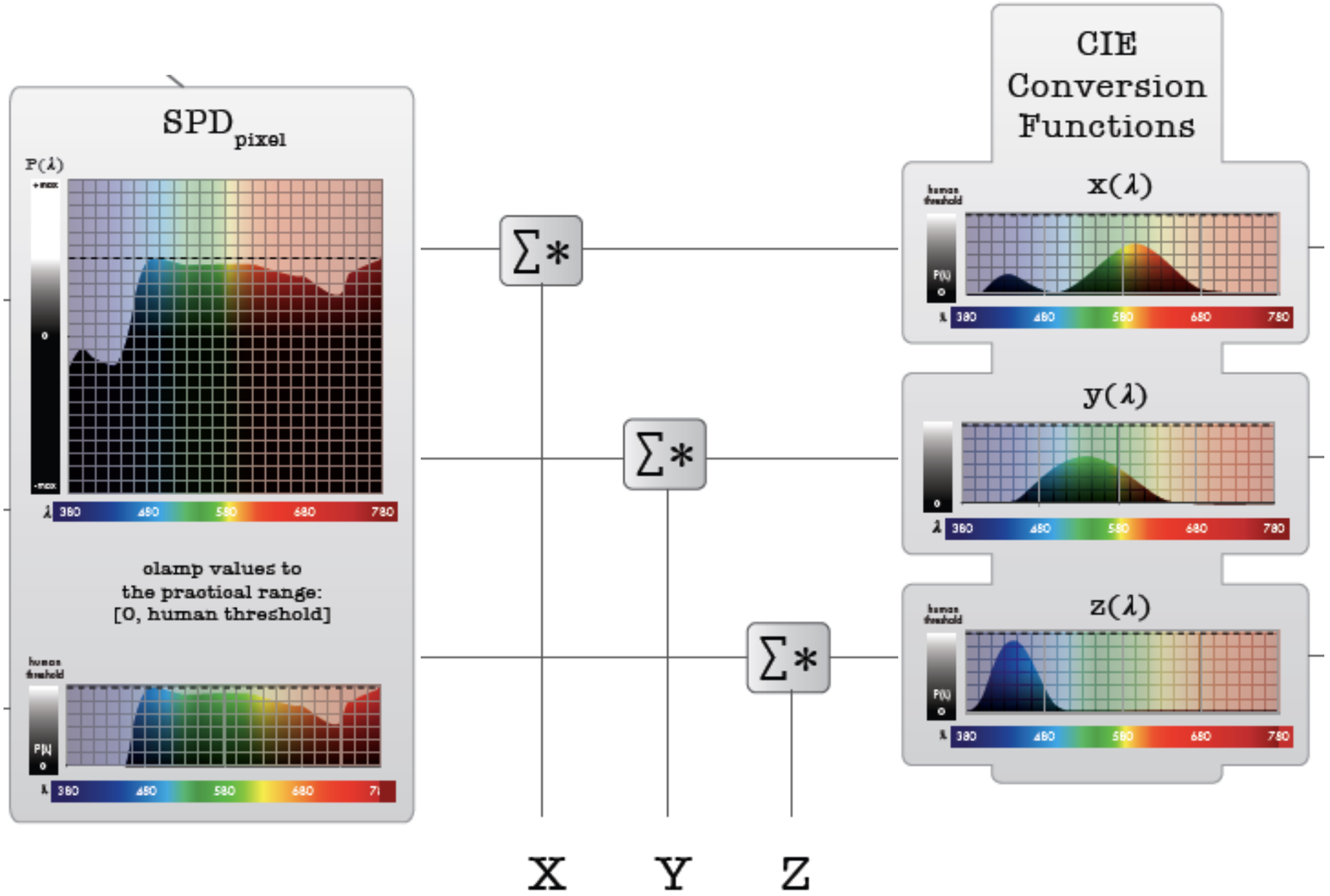
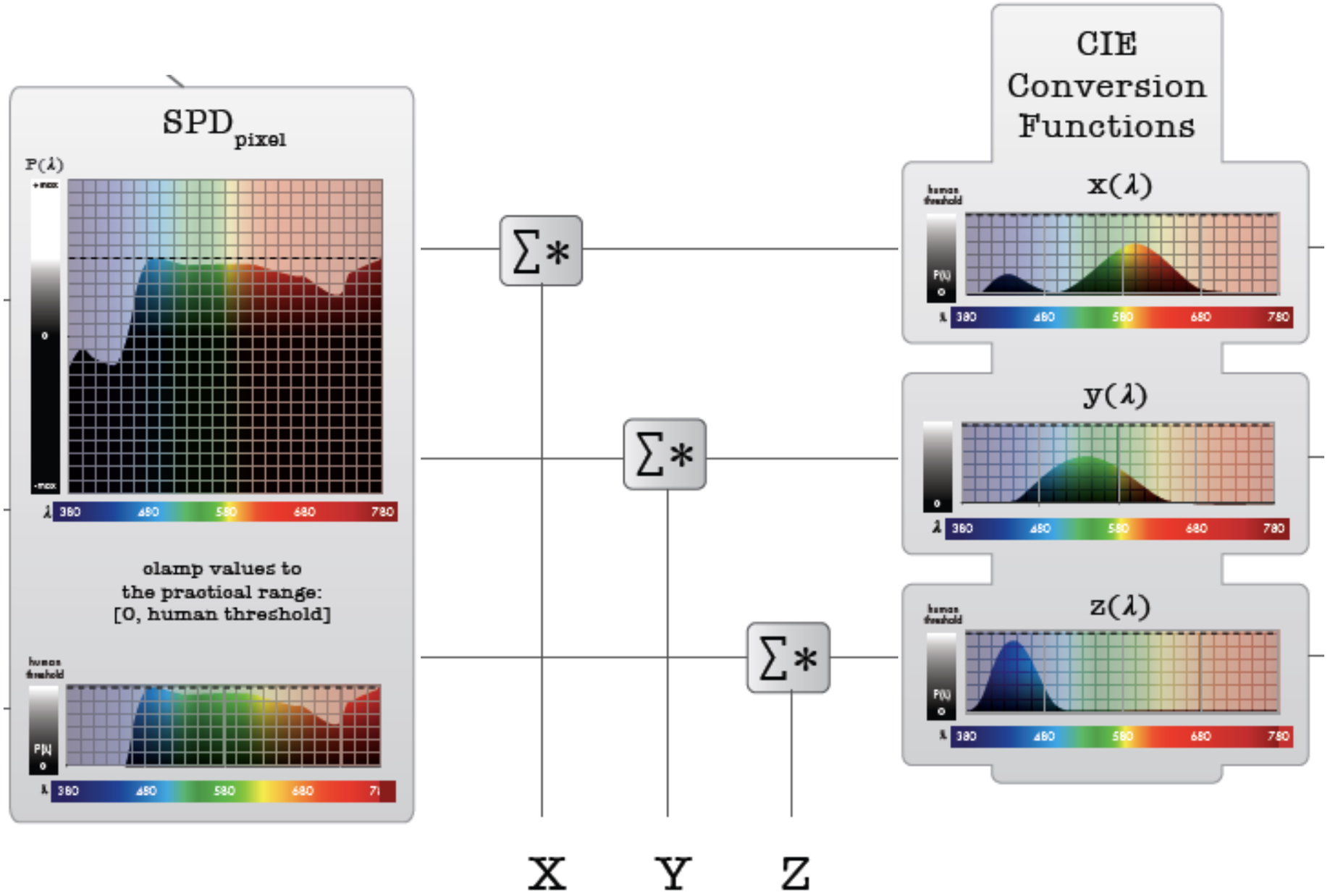
0
-max
λ 380 480 580 680 780
clamp values to
the practical range:
[0, human threshold]
human threshold
P(λ)
0
λ 380 480 580 680 7


CIE
Conversion
Functions
x(λ)
human threshold
P(λ)
0
λ 380 480 580 680 780
y(λ)
0
λ 380 480 580 680 780
z(λ)
human threshold
P(λ)
0
λ 380 480 580 680 780

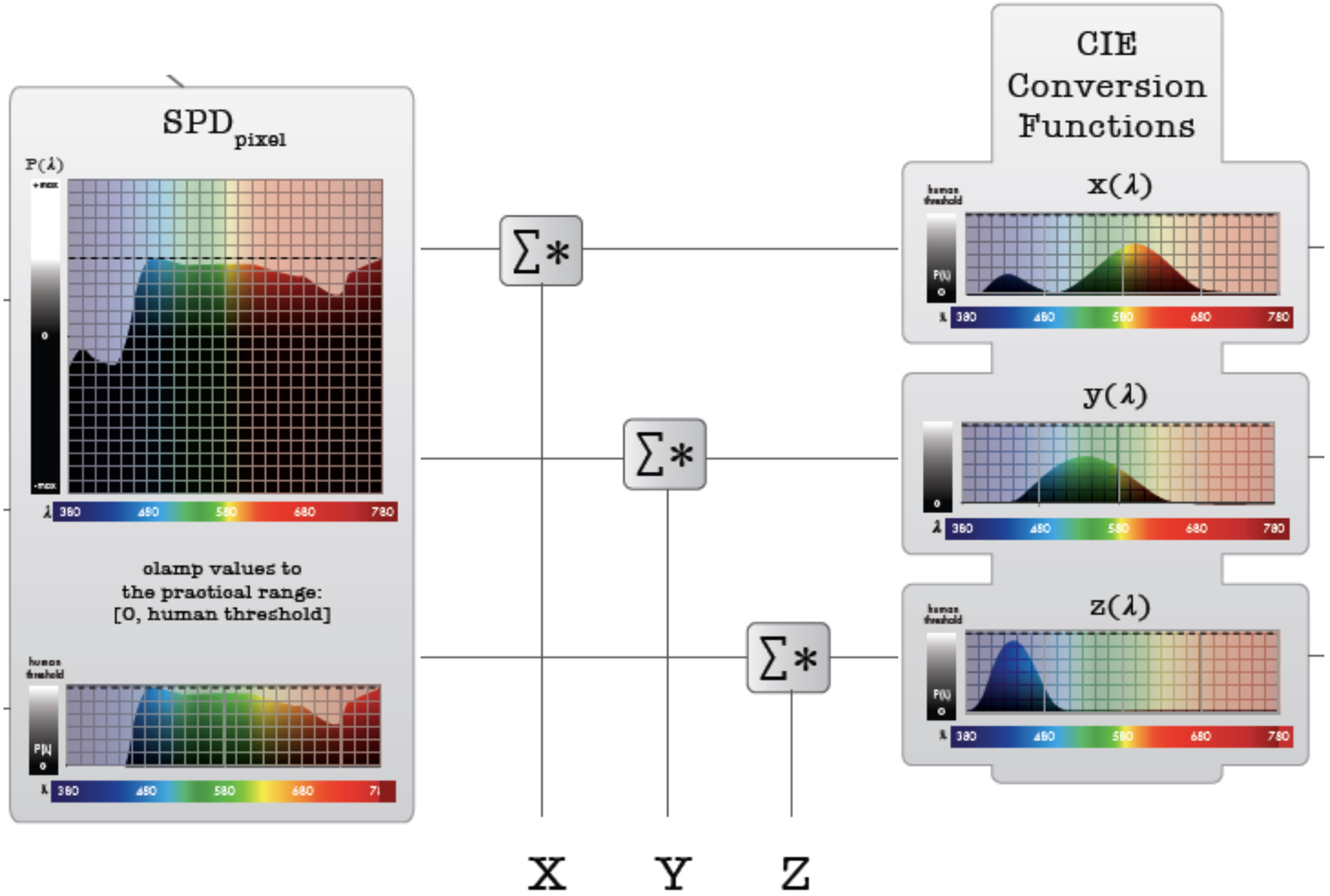

SPD pixel
P(λ)
+max
0
-max
λ 380 480 580 680 780
clamp values to
the practical range:
[0, human threshold]
human threshold
P(λ)
0
λ 380 480 580 680
∑*
∑*
∑*
X
Y
Z
CIE
Conversion
Functions
x(λ)
human threshold
P(λ)
0
λ 380 480 580 680 780
y(λ)
0
λ 380 480 580 680 780
z(λ)
human threshold
P(λ)
0
λ 380 480 580 680 780



$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z}$$



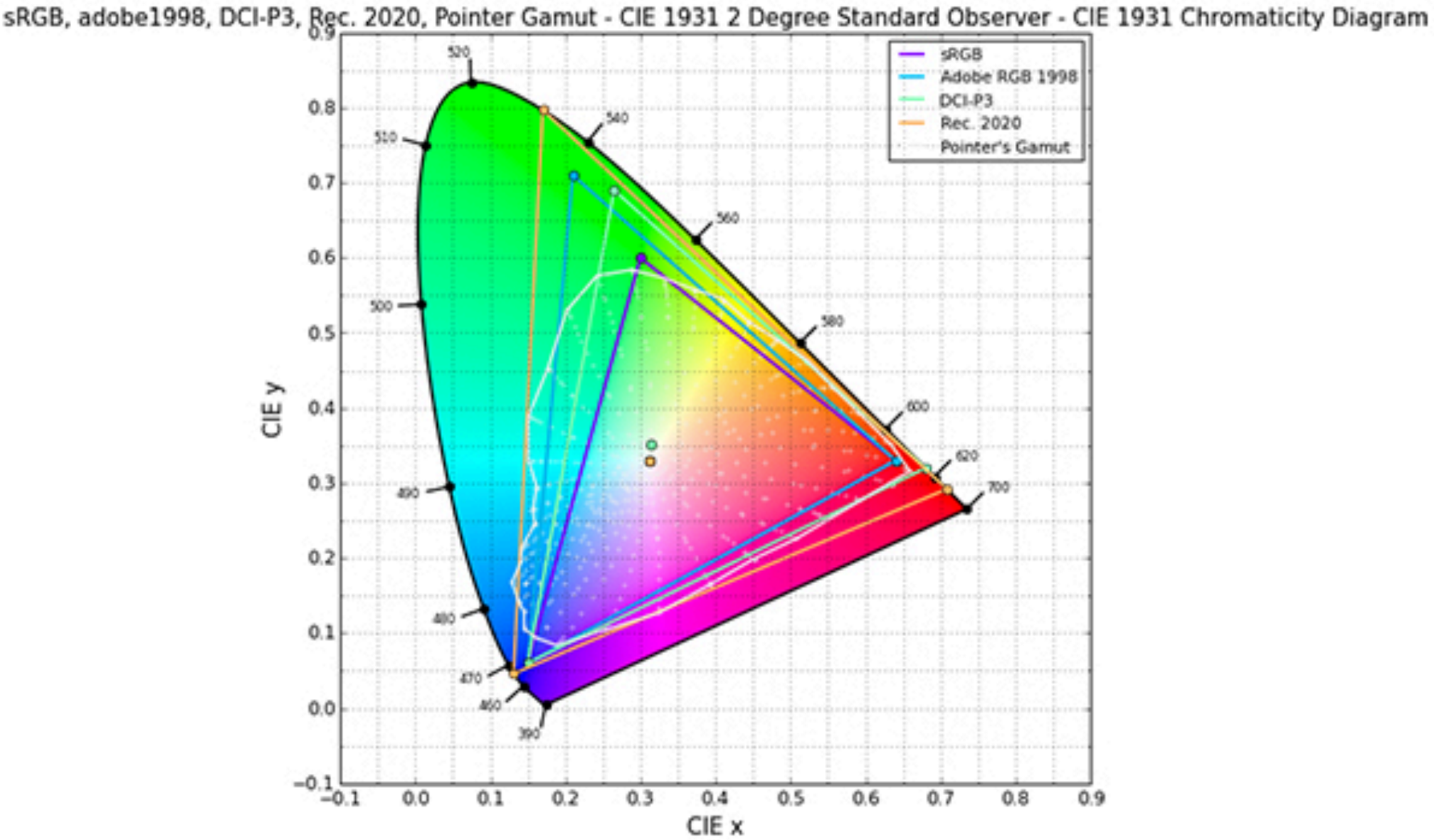
Pixel
RGB values

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

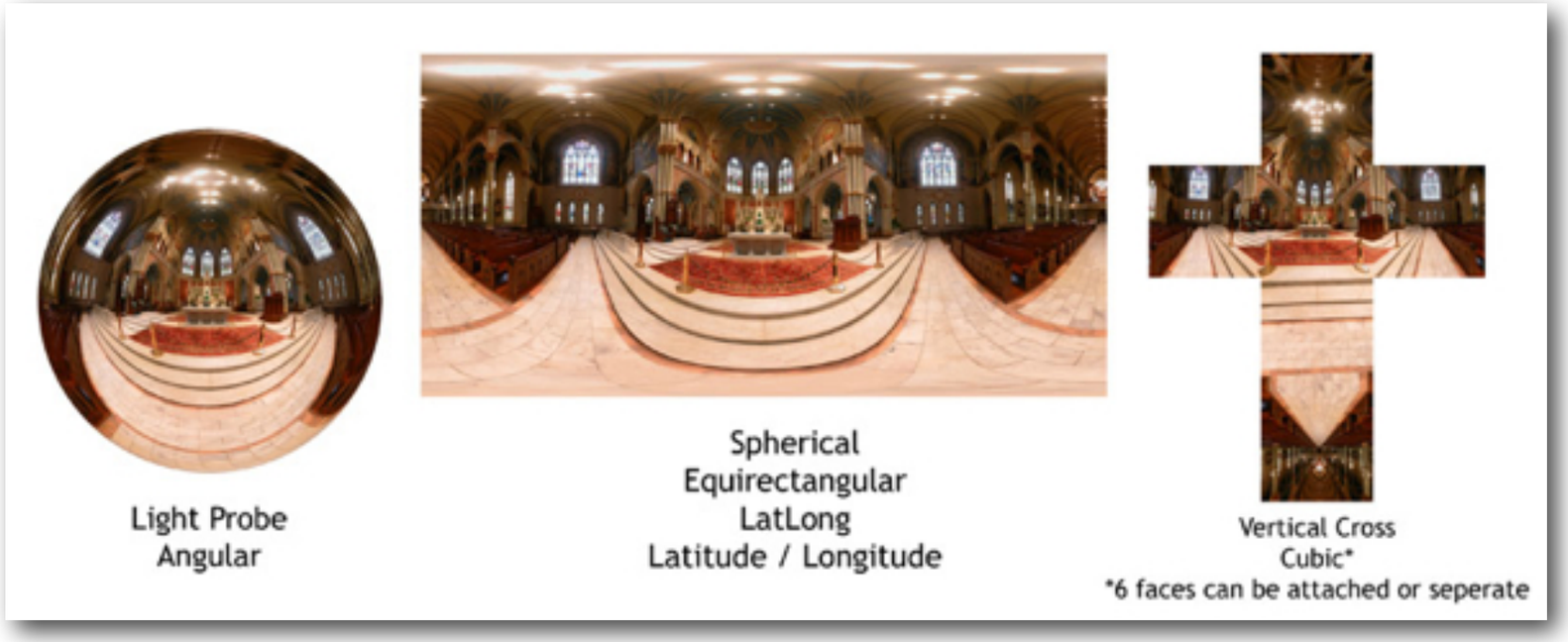
How many colors can we represent?



Pros/Cons of This Approach

- Generates very realistic looking images (in theory)
- Cumbersome to set up
  - How about using a “readymade” lighting information
    - Light probes!!
      - Already in floating point format (*.hdr files)

Using Light Probes as Environment Maps



Steps to implement HDR (Rendering) in OpenGL

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- Create an FBO

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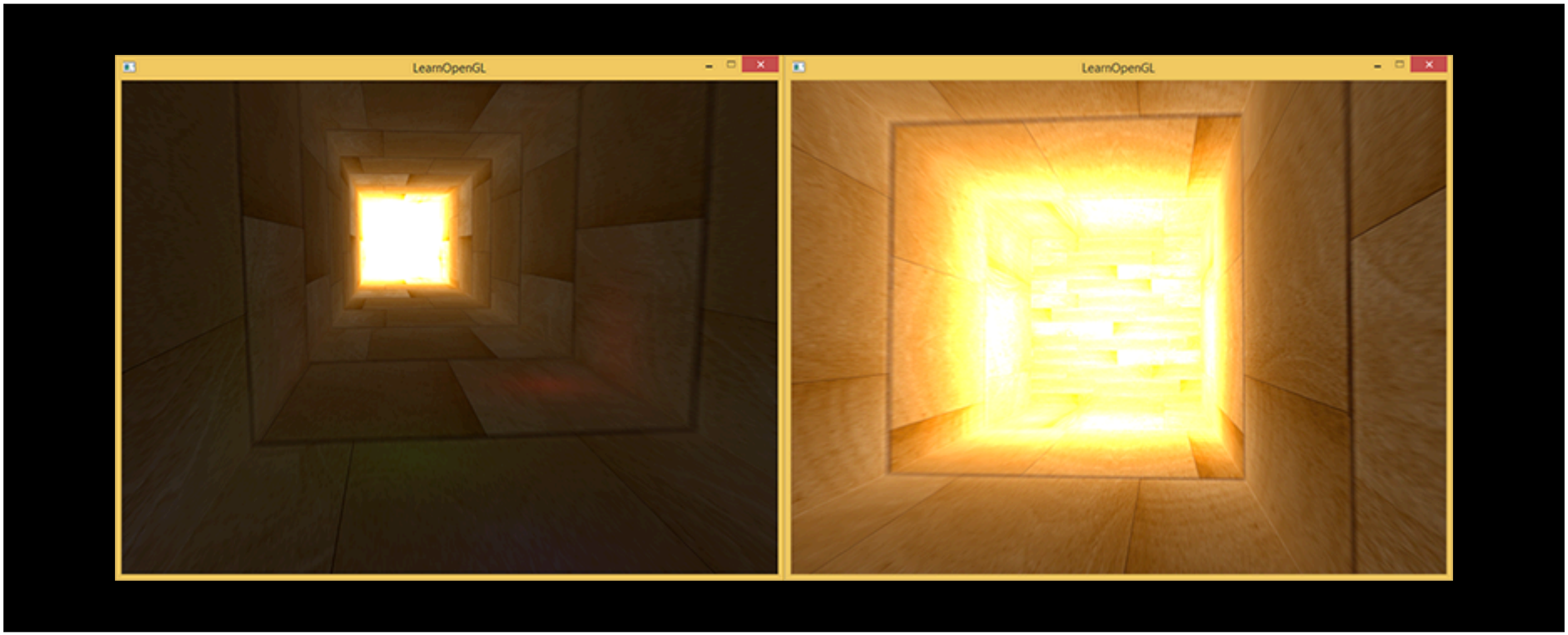
- The resulting values are also floating point per fragment
- Are we done? Not yet

Code Example

```
#version 330 core
out vec4 color;
in vec2 TexCoords;

// Output generated using FBO,
// now used as lookup texture

uniform sampler2D hdrBuffer;

void main()
{
    vec3 hdrColor = texture(hdrBuffer, TexCoords).rgb;
    color = vec4(hdrColor, 1.0);
}
```

Sample output



4 point lights
L1= (200.0, 200.0, 200.0)
L2=(1.0, 0.0, 0.0)
L3=(0.0, 0.0, 0.2)
L4=(0.0, 0.1, 0.0)

HDR --> LDR aka Tone Mapping

- Our render target contains HDR values (contrast ratio > 256:1)
- Eventually, we need to display the current frame on screen (256:1)
- Convert HDR values to LDR values using a Tone Mapping Operator

$$L = \frac{Y}{(Y+1)}$$

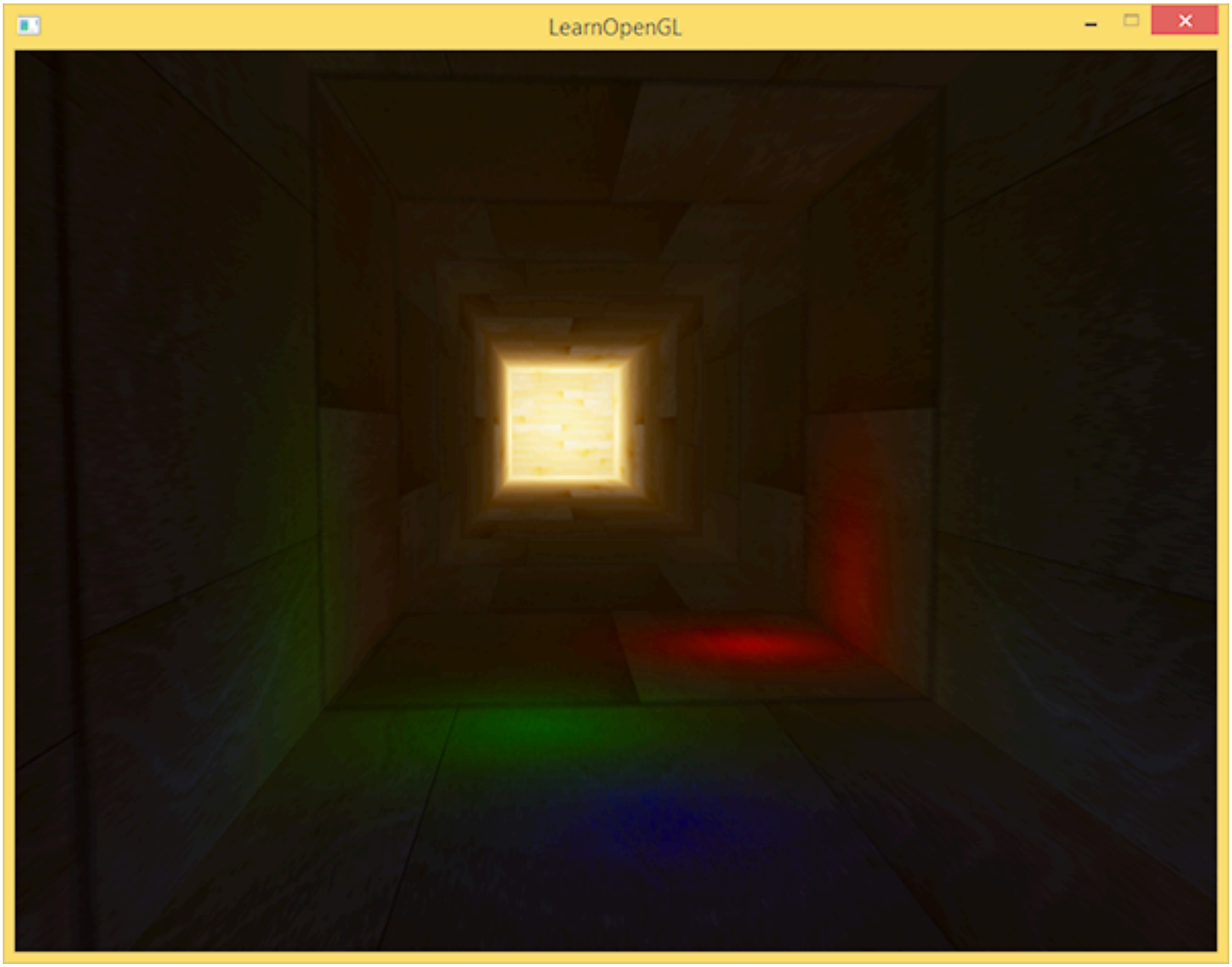
This operator will map value from [0; inf) to [0;1)

http://www.mpi-inf.mpg.de/resources/tmo/

Code Version 2.0

```
#version 330 core
out vec4 color;
in vec2 TexCoords;

void main()
{
    const float gamma = 2.2;
    vec3 hdrColor = texture(hdrBuffer, TexCoords).rgb;

    // Reinhard tone mapping
    vec3 mapped = hdrColor / (hdrColor + vec3(1.0));

    // Gamma correction
    mapped = pow(mapped, vec3(1.0 / gamma));

    color = vec4(mapped, 1.0);
}
```

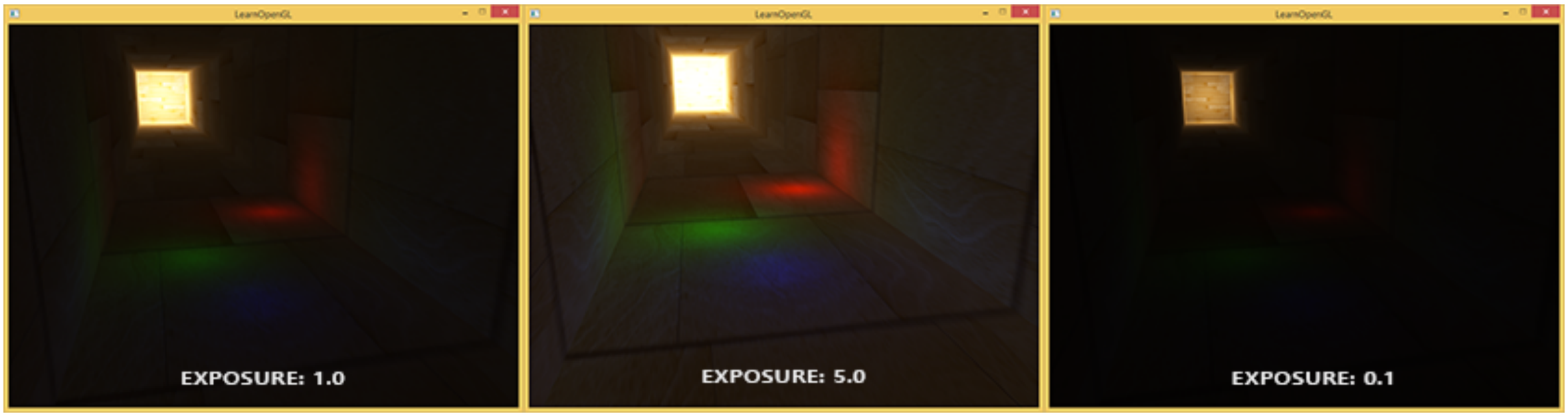
Output



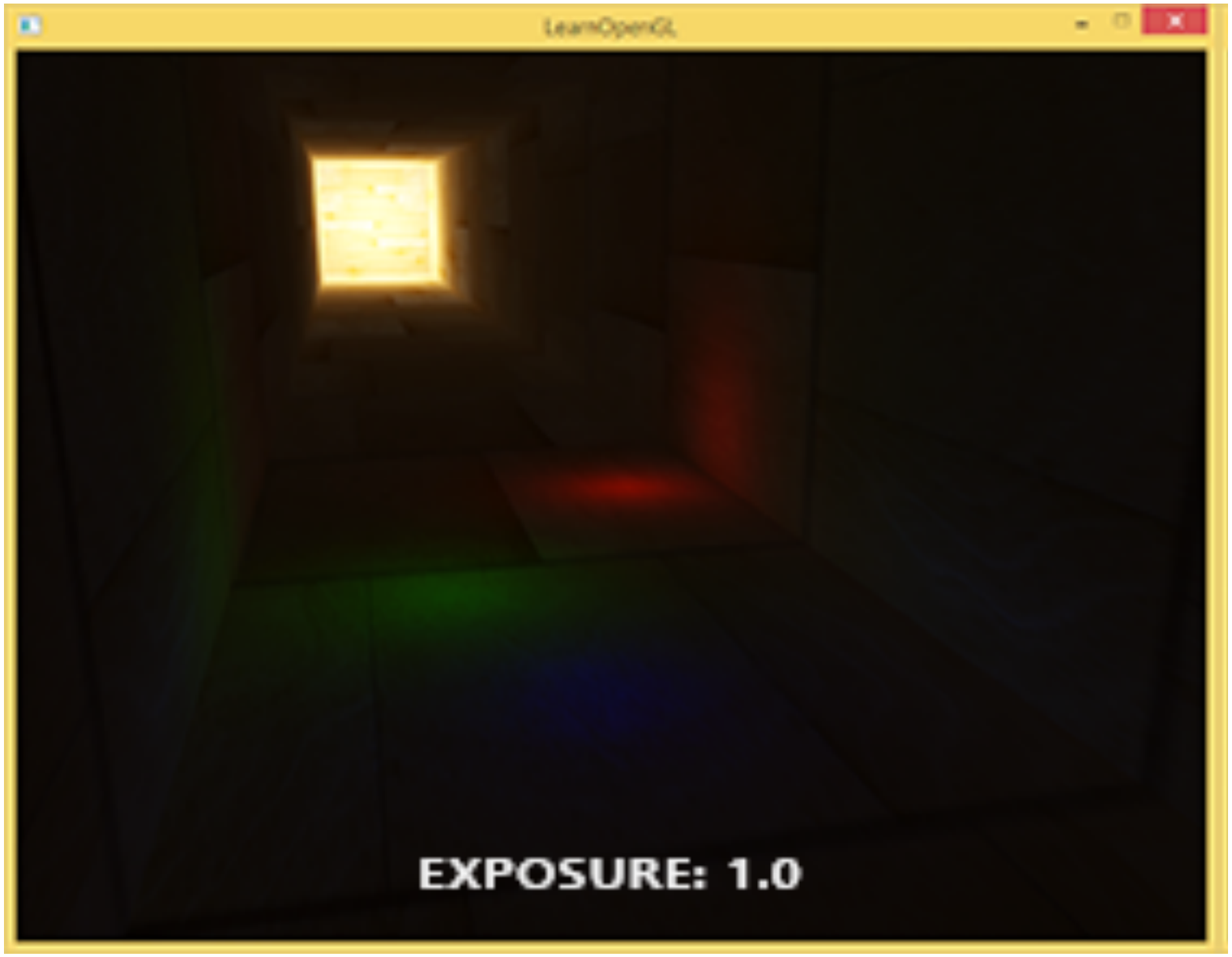
Adding exposure

```
#version 330 core
out vec4 color;
in vec2 TexCoords;
uniform float exposure
void main()
{
    const float gamma = 2.2;
    vec3 hdrColor = texture(hdrBuffer, TexCoords).rgb;

    // Exposure-based tone mapping
    vec3 mapped = vec3(1.0) - exp( -hdrColor * exposure );

    // Gamma correction
    mapped = pow(mapped, vec3(1.0 / gamma));

    color = vec4(mapped, 1.0);
}
```

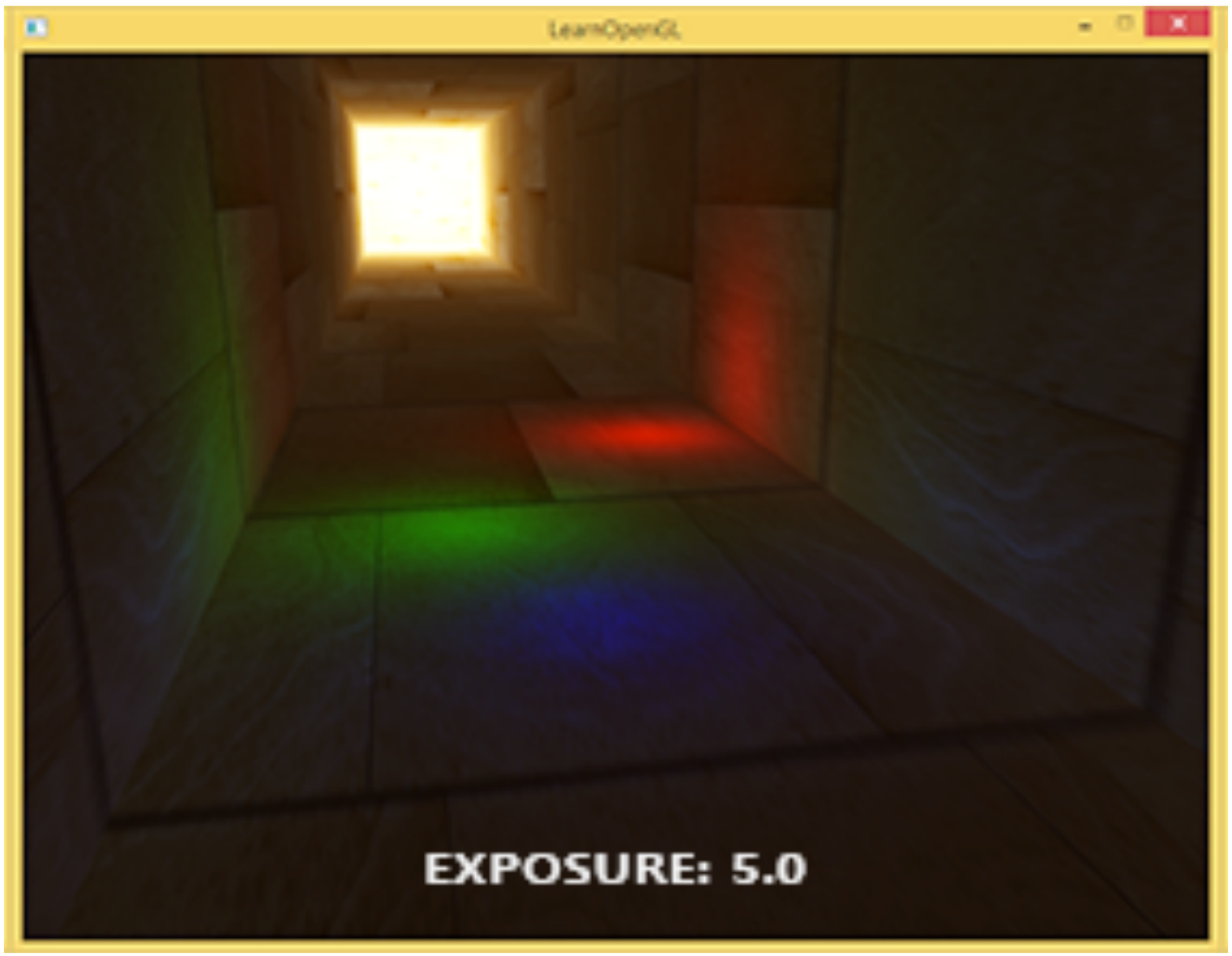
Output


LearnOpenGL
EXPOSURE: 1.0
LearnOpenGL
EXPOSURE: 5.0
LearnOpenGL
EXPOSURE: 0.1

Exposure = 1.0



Exposure = 5.0 (overexposed)



Exposure = 0.1 (underexposed)

More “Optimizations” aka Hacks

- A scene with values between [0,256) looks very flat and dull

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Images from Farcry

More “Optimizations” aka Hacks

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Bloom Effect!!!

Images from Farcry

Implementing a Smart Bloom

- Extract bright areas (threshold) from the HDR buffer
- Downsample and filter with a median filter
- Add (superimpose, in signal-speak) the blurred HDR buffers on the original

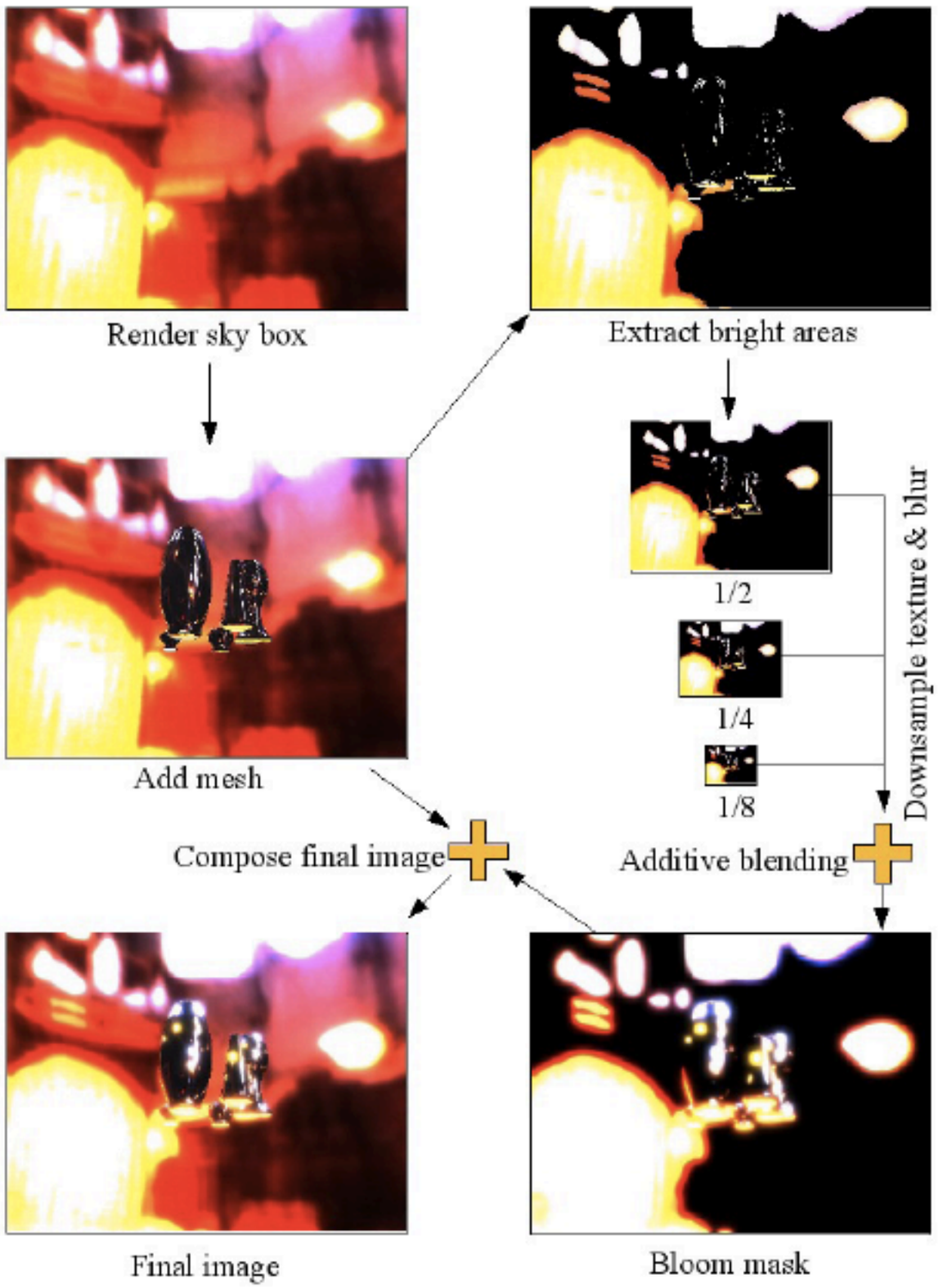
- Apply tone-mapping to this new blurred/bloomed buffer

$$Y = exposure \times \left(\frac{\left(\frac{exposure}{maxLuminance} + 1 \right)}{(exposure + 1)} \right)$$

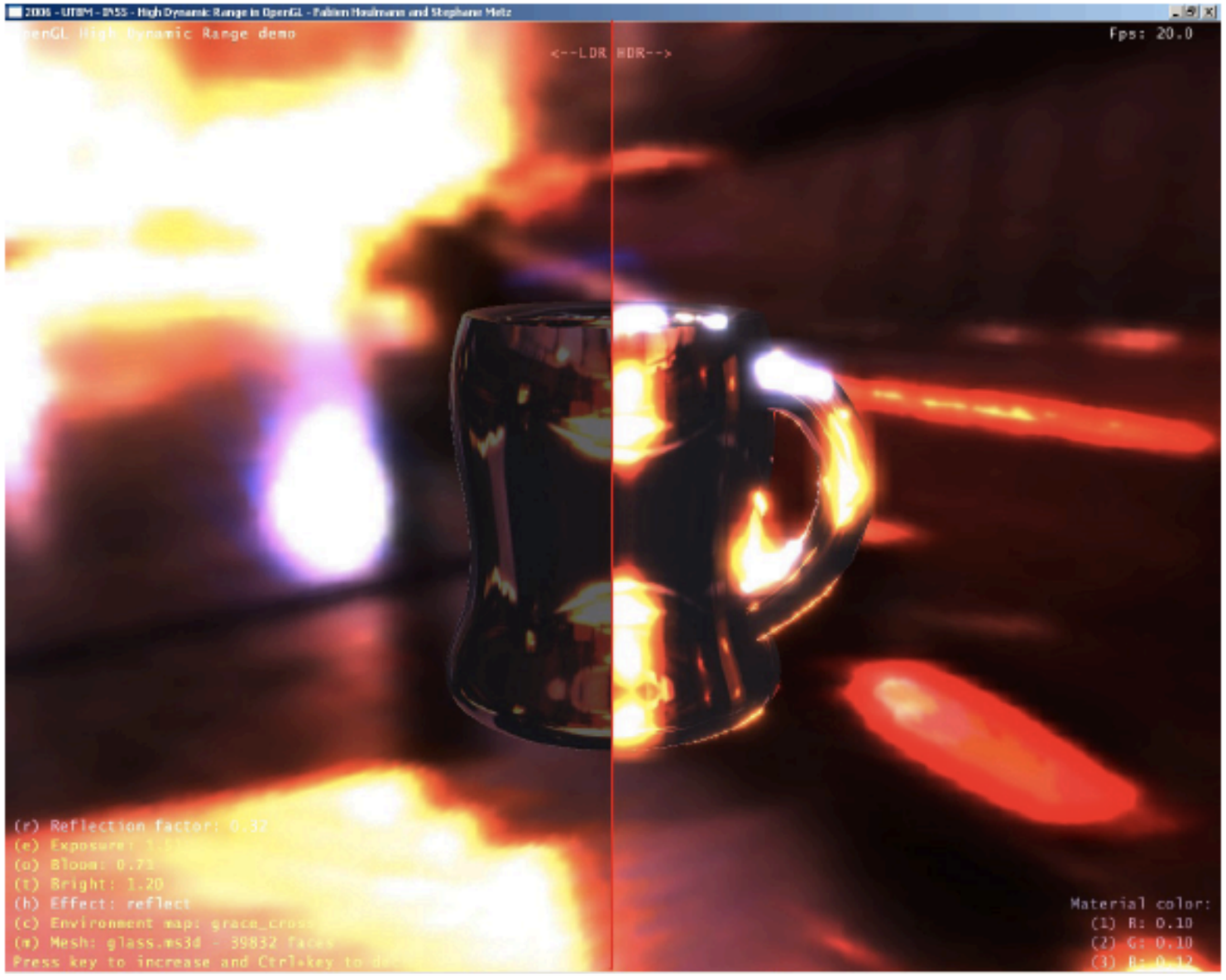
$$Y'_{601} = 0.30R + 0.59G + 0.11B$$

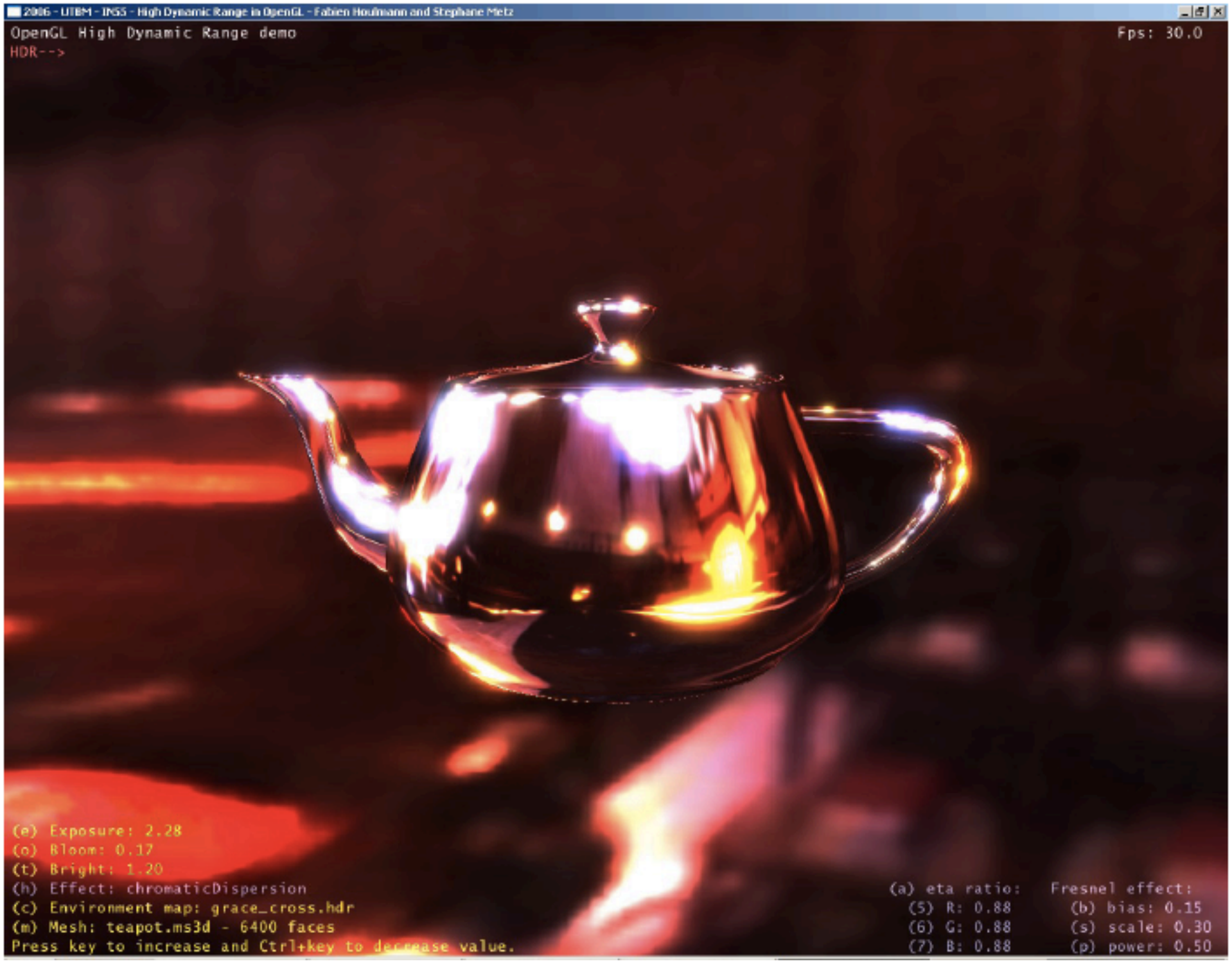
In GLSL

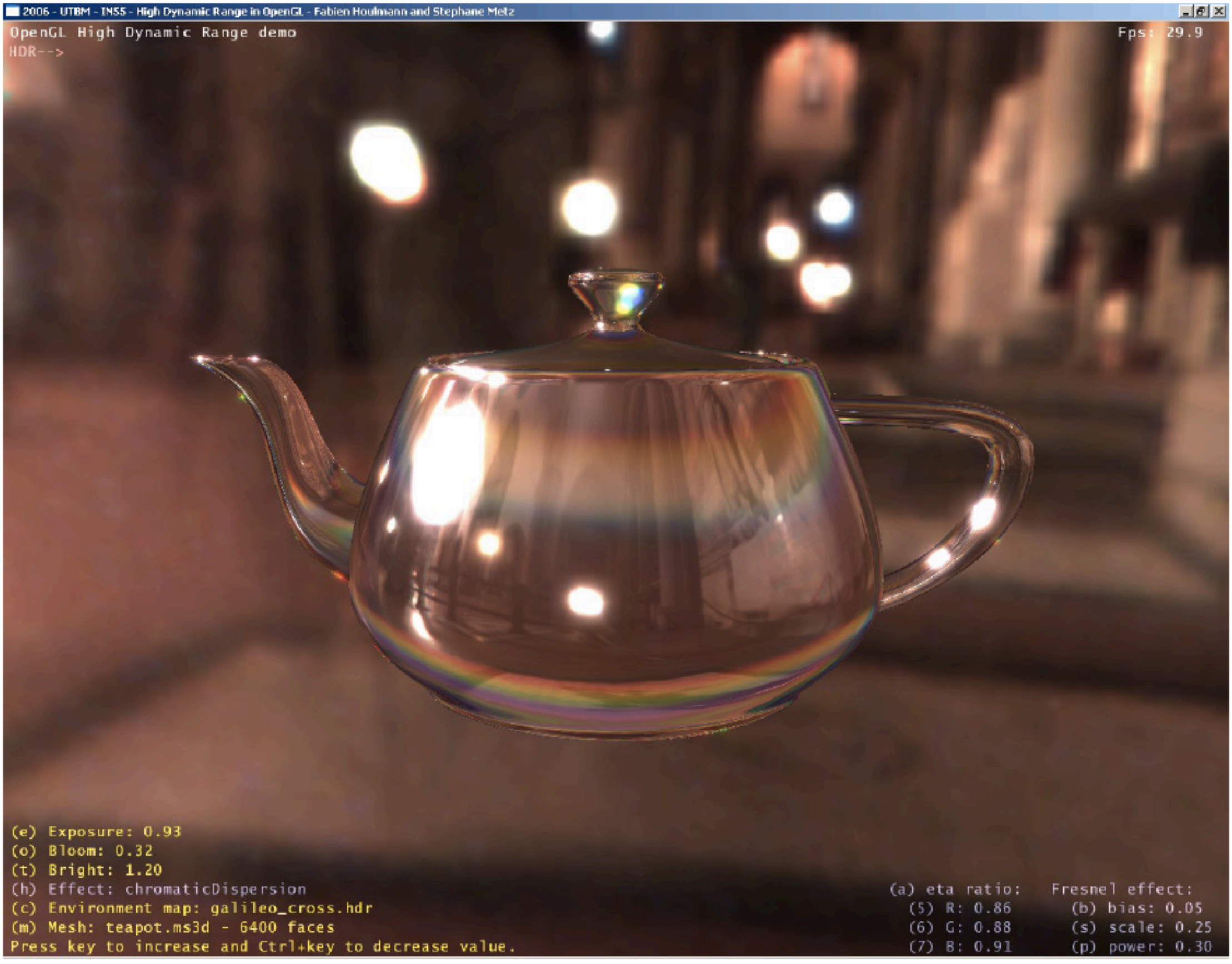
```
// render texture and bloom map
uniform sampler2D tex, bloom;
// Control exposure with this value
uniform float exposure;
// How much bloom to add
uniform float bloomFactor;
// Max bright
uniform float brightMax;

void main()
{
	vec2 st = gl_TexCoord[0].st;
	vec4 color = texture2D(tex, st);
	vec4 colorBloom = texture2D(bloom, st);

	// Add bloom to the image
	color += colorBloom * bloomFactor;

	// Perform tone-mapping
	float Y = dot(vec4(0.30, 0.59, 0.11, 0.0), color);
	float YD = exposure * (exposure/brightMax + 1.0) / (exposure + 1.0);
	color *= YD;

	gl_FragColor = color;
}
```


Render sky box
Extract bright areas
1/2
1/4
1/8
Downsample texture & blur
Add mesh
Compose final image
Additive blending
Final image
Bloom mask


High Dynamic Range demo
Fps: 23.0
<--LDR HDR-->
(e) Exposure: 1.09
(b) Bloom: 0.37
(t) Bright: 1.20
(h) Effect: chromaticDispersion
(c) Environment map: rnl_cross.hdr
(m) Mesh: car2.ms3d - 44000 faces
Press key to increase and Ctrl+key to decrease value.
(a) eta ratio:
(1) R: 0.80
(6) G: 0.80
(7) B: 0.80
Fresnel effect:
(b) bias: 0.20
(s) scale: 1.00
(p) power: 1.00


2006 - UTBM - INSS - High Dynamic Range in OpenGL - Fabien Houlmann and Stephane Metz
OpenGL High Dynamic Range demo
<--LDR HDR-->
Fps: 20.0
(r) Reflection factor: 0.32
(e) Exposure: 1.5
(o) Bloom: 0.71
(t) Bright: 1.20
(h) Effect: reflect
(c) Environment map: grace_cross
(m) Mesh: glass.ms3d - 39832 faces
Press key to increase and Ctrl+key to de
Material color:
(1) R: 0.10
(2) G: 0.10
(3) B: 0.12


2006 - LITBM - INSS - High Dynamic Range in OpenGL - Fabien Houlmann and Stephane Metz
OpenGL High Dynamic Range demo
HDR-->
Fps: 30.0
(e) Exposure: 2.28
(o) Bloom: 0.17
(t) Bright: 1.20
(h) Effect: chromaticDispersion
(c) Environment map: grace_cross.hdr
(m) Mesh: teapot.ms3d - 6400 faces
Press key to increase and Ctrl+key to decrease value.
(a) eta ratio:
(5) R: 0.88
(6) G: 0.88
(7) B: 0.88
Fresnel effect:
(b) bias: 0.15
(s) scale: 0.30
(p) power: 0.50


2006 - UTBM - IN55 - High Dynamic Range in OpenGL - Fabien Houlmann and Stephane Metz
OpenGL High Dynamic Range demo
Fps: 29.9
HDR-->
(e) Exposure: 0.93
(o) Bloom: 0.32
(t) Bright: 1.20
(h) Effect: chromaticDispersion
(c) Environment map: galileo_cross.hdr
(m) Mesh: teapot.ms3d - 6400 faces
Press key to increase and Ctrl+key to decrease value.
(a) eta ratio:
(5) R: 0.86
(6) G: 0.88
(7) B: 0.91
Fresnel effect:
(b) bias: 0.05
(s) scale: 0.25
(p) power: 0.30


Filmic tone mapping
No tone mapping
NAUGHTY DOG

References

- https://learnopengl.com/#!Advanced-Lighting/HDR
- “High Dynamic Range Rendering in OpenGL,” Fabian Houlmann & Stephane Metz
- Digital Image Processing, 3rd Edition, Gonzales & Woods
- www.hdrlabs.com
- Paul Debevec, USC (http://www.pauldebevec.com/)
  - Awarded Oscar for his work in relighting for “Avatar”
- SPD from Robert Campbell Farish, Digipen MSCS student