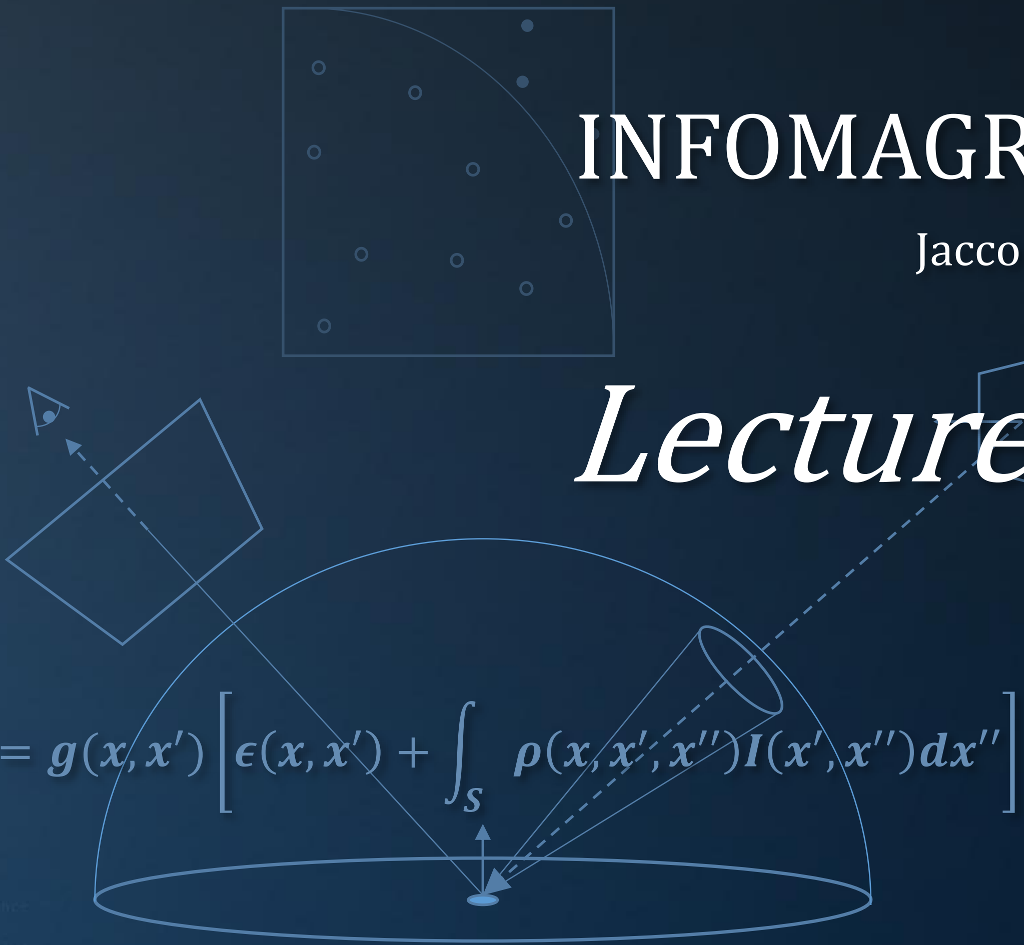
INFOMAGR – Advanced Graphics

Jacco Bikker - November 2021 - February 2022

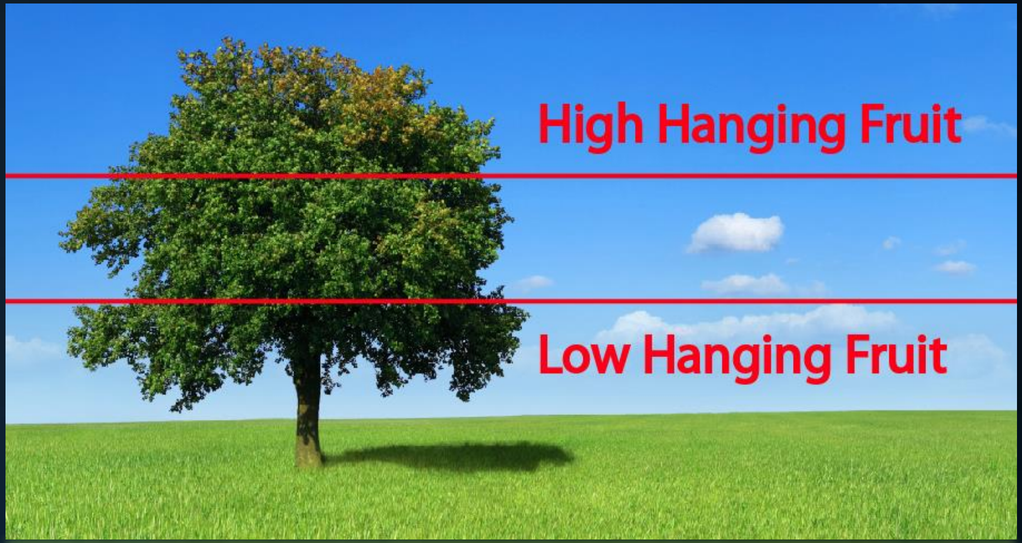
Lecture 11 - "Various"

Welcome!



Today's Agenda:

- Gamma Correction
- Depth of Field
- Skybox
- Spots, IES Profiles
- Microfacets



Gamma Correction

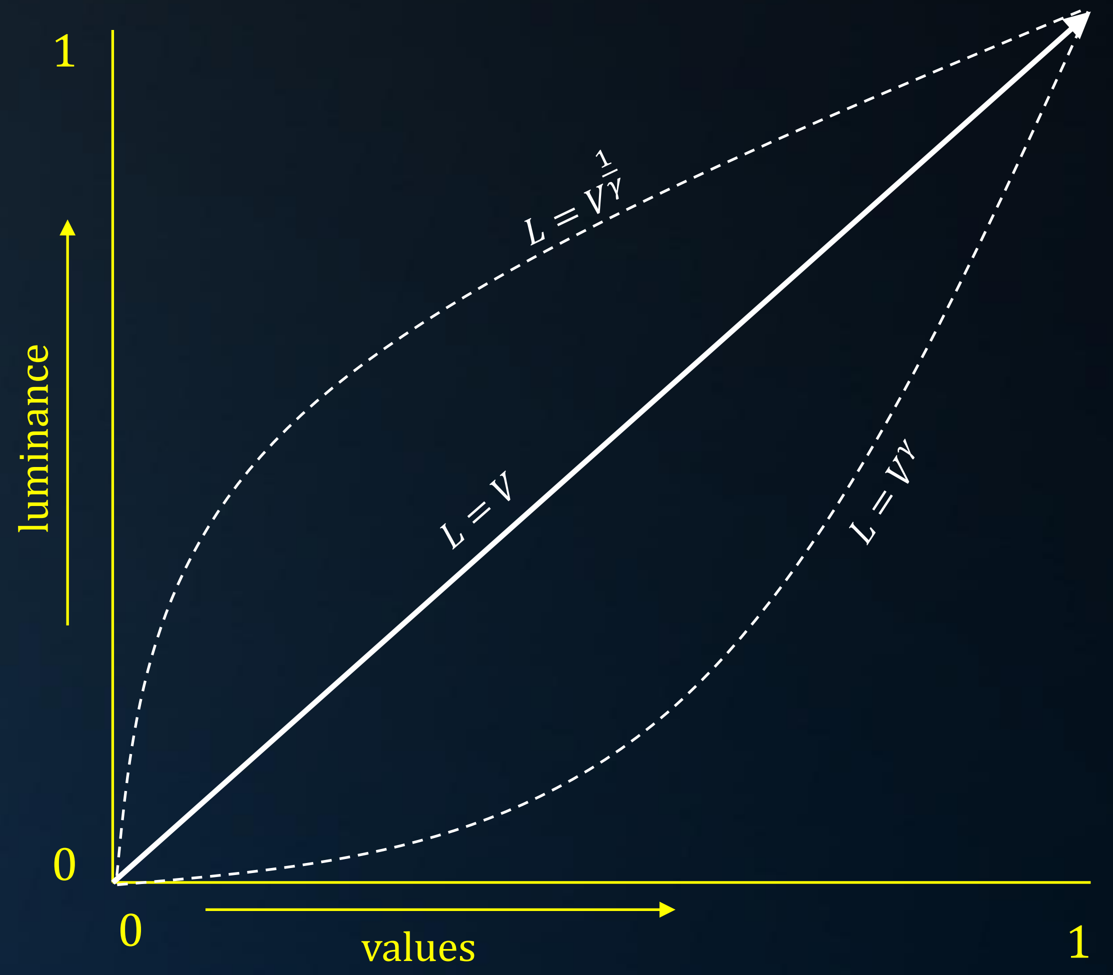
Human Eye

Digital representation of intensities is discrete: for ARGB32, we have 256 levels for red, green and blue.

The human eye is more sensitive to differences in luminance for dark shades. When encoding luminance, it is advantageous to have more detail in the lower regions, e.g.:

$$L = V^{\gamma} \;\Rightarrow\; V = L^{\frac{1}{\gamma}}$$

For the human eye, $\gamma = 2.33$ is optimal*.



*: Ebner & Fairchild, Development and testing of a color space (IPT) with improved hue uniformity, 1998.

Gamma Correction

CRT Power Response

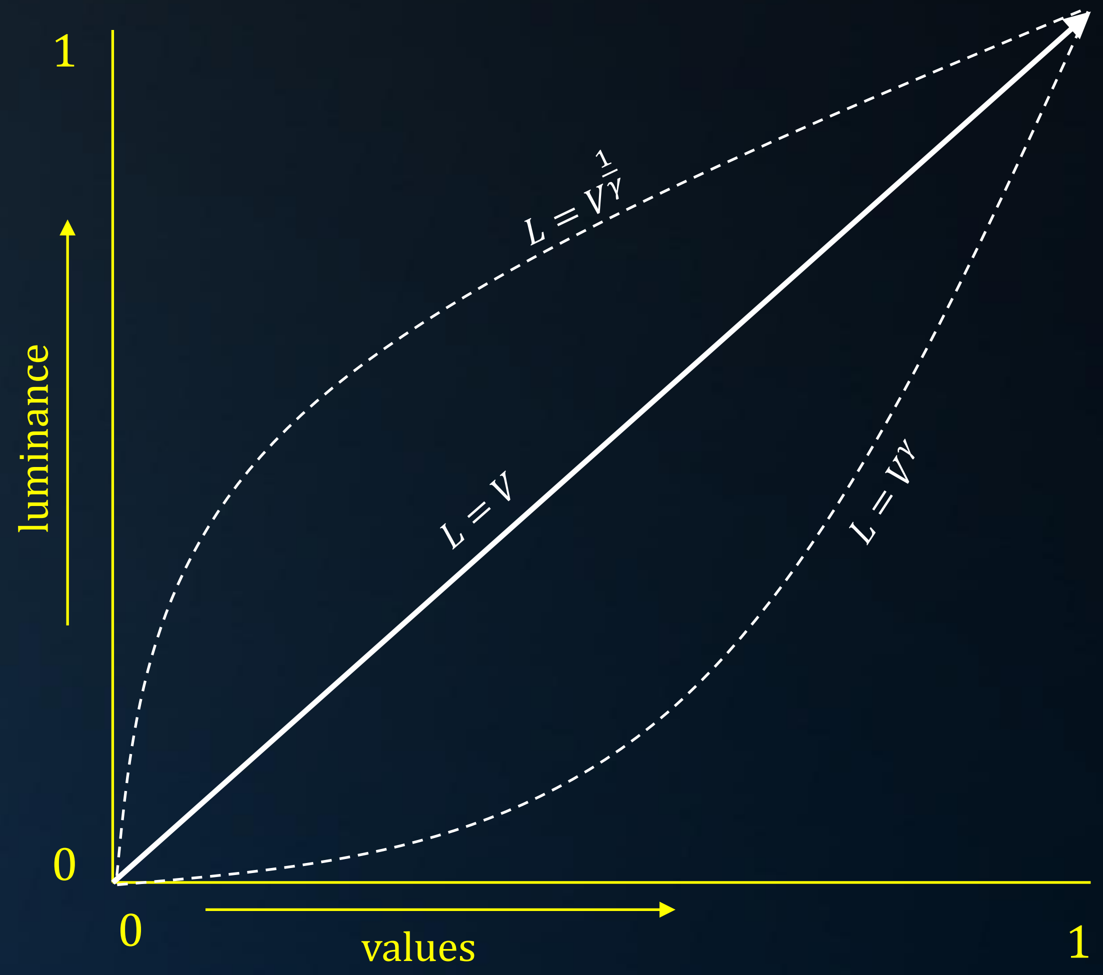
A classic CRT display converts incoming data to luminance in a non-linear way.

$$L = V^{\gamma} \quad \Rightarrow \quad V = L^{\frac{1}{\gamma}}$$

For a typical monitor, $\gamma = 2.2$.

In other words:

- If we encode our luminance using $V = L^{\frac{1}{\gamma}}$, it will be linear on the monitor.
- At the same time, this yields a distribution that has more detail for darker shades, which suits the human eye.



Gamma Correction

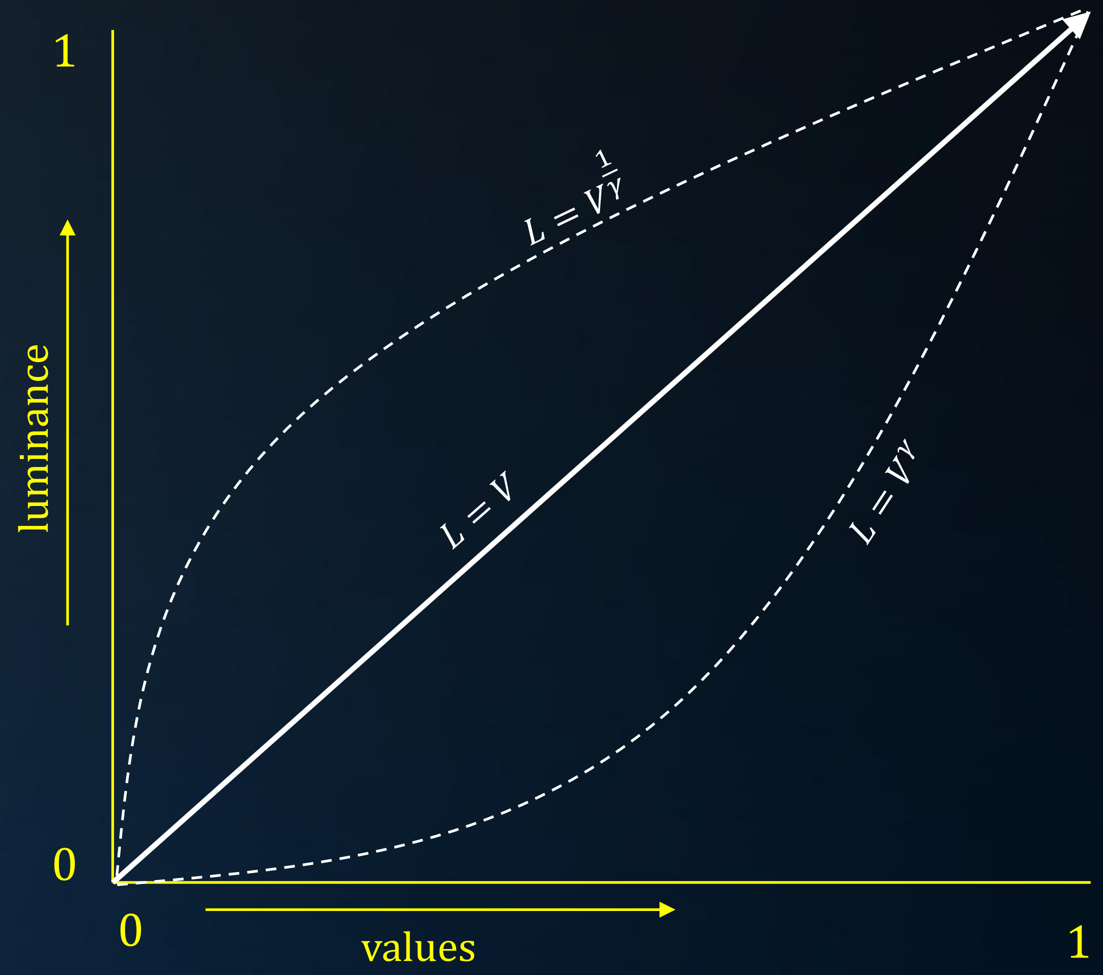
Practical Gamma Correction

To ensure linear response of the monitor to our synthesized images, we feed the monitor adjusted data:

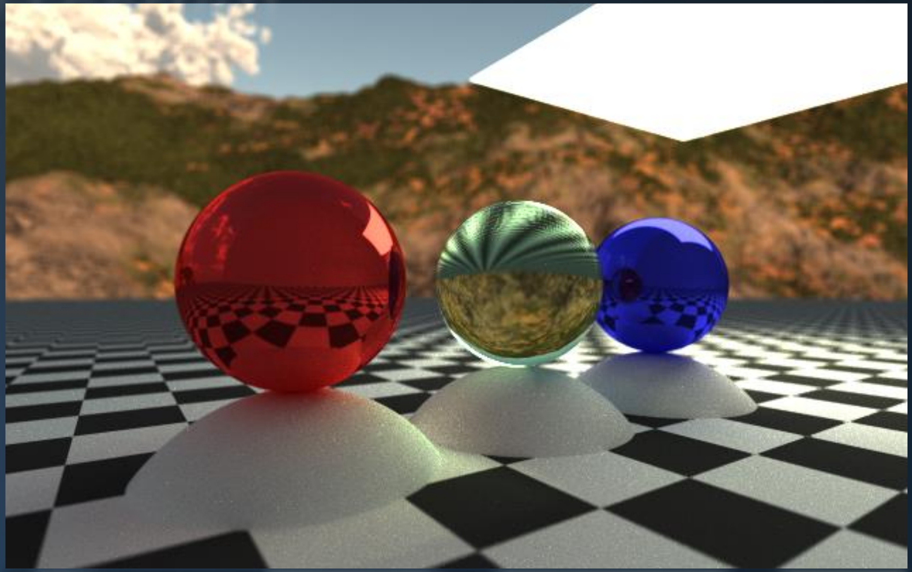
$$V = L^{1/2.2} \quad \approx \quad \sqrt{L}$$

What happens if we don't do this?

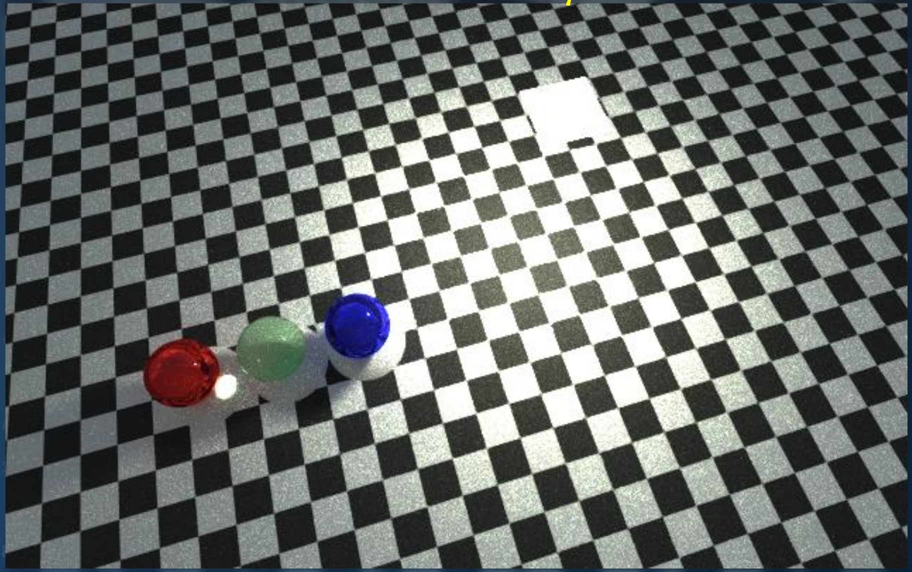
1. L will be $V^{2.2}$; the image will be too dark.
2. A linear gradient will become a quadratic gradient; a quadratic gradient will become a cubic gradient ➔ your lights will appear to have a very small area of influence.

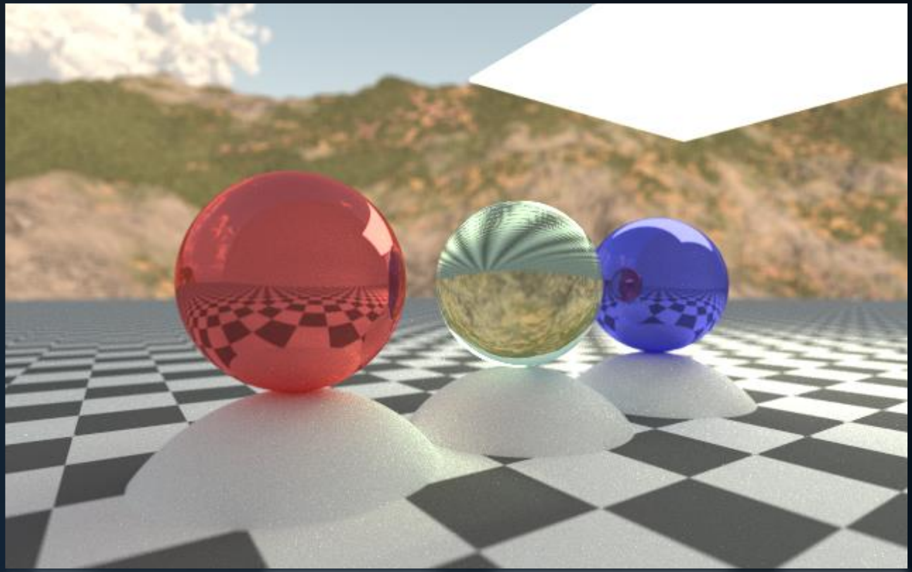


Gamma Correction

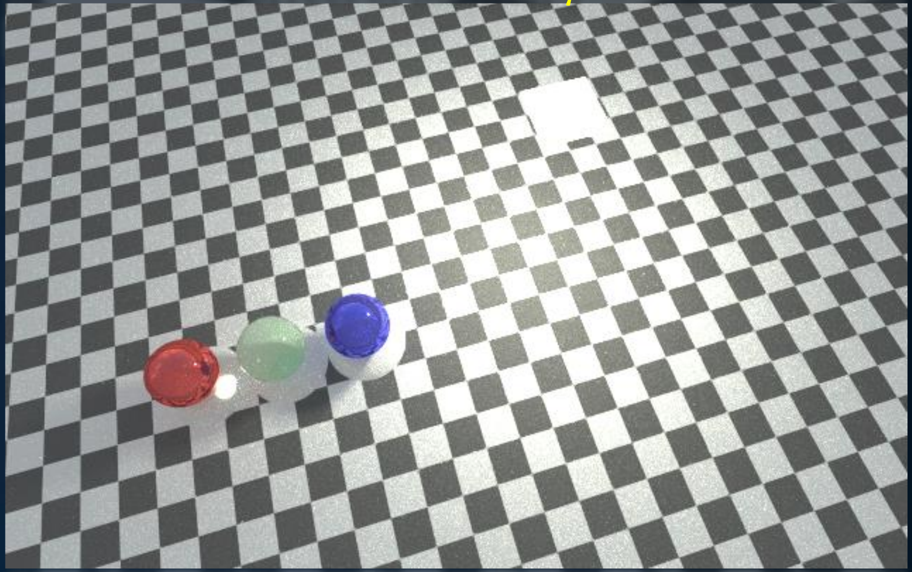


Correct of monitor $\gamma = 1.0$





Correct of monitor $\gamma = 2.2$



Gamma Correction

Legacy

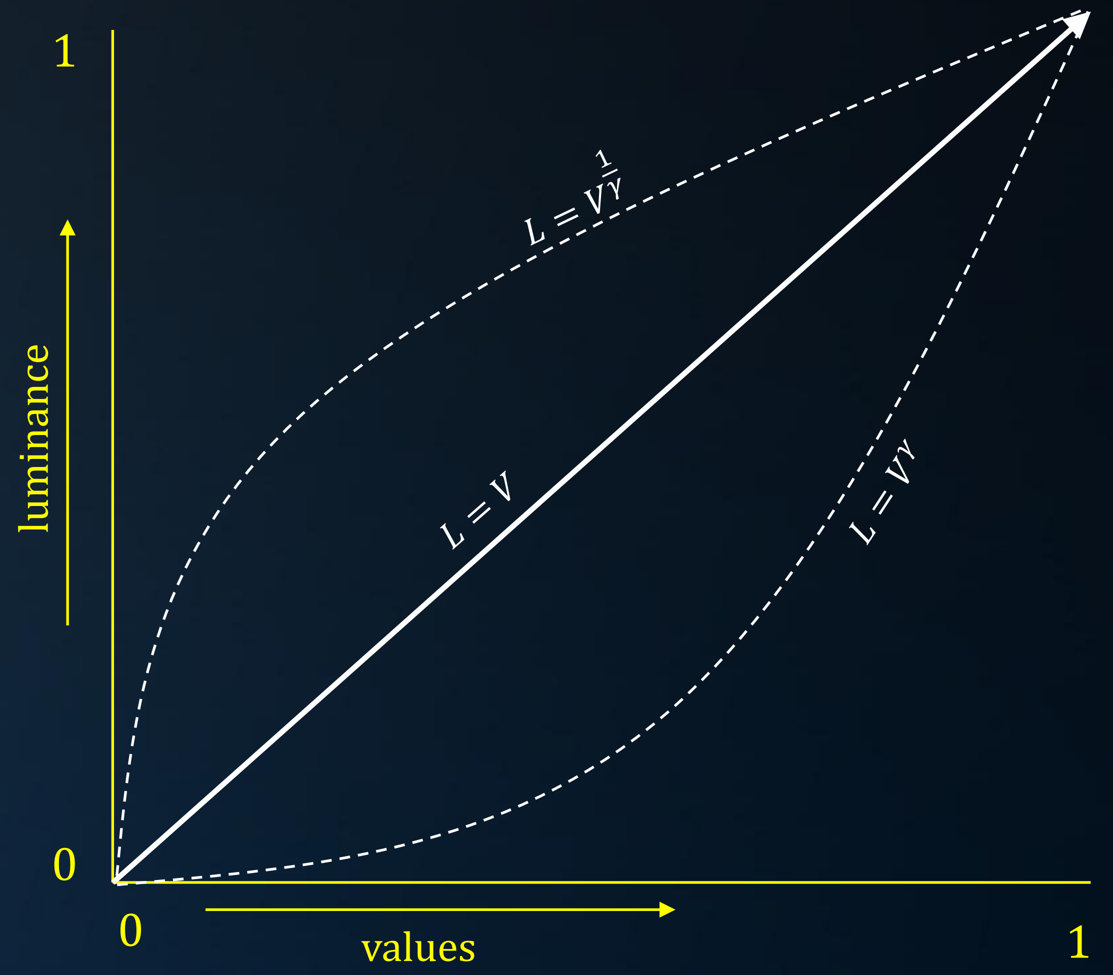
The response of a CRT is $L = V^{2.2}$; what about modern screens?

Typical laptop / desktop screens have a linear response, but expect applications to provide $\sqrt{L}$ data… So V is modified (in hardware, or by the driver): $V = V^2$.

$$L \Rightarrow \sqrt{L} \Rightarrow L^2$$

Not all screens take this legacy into account; especially beamers will often use $\gamma = 1$.

Gamma correct only if the hardware or video driver expects it!

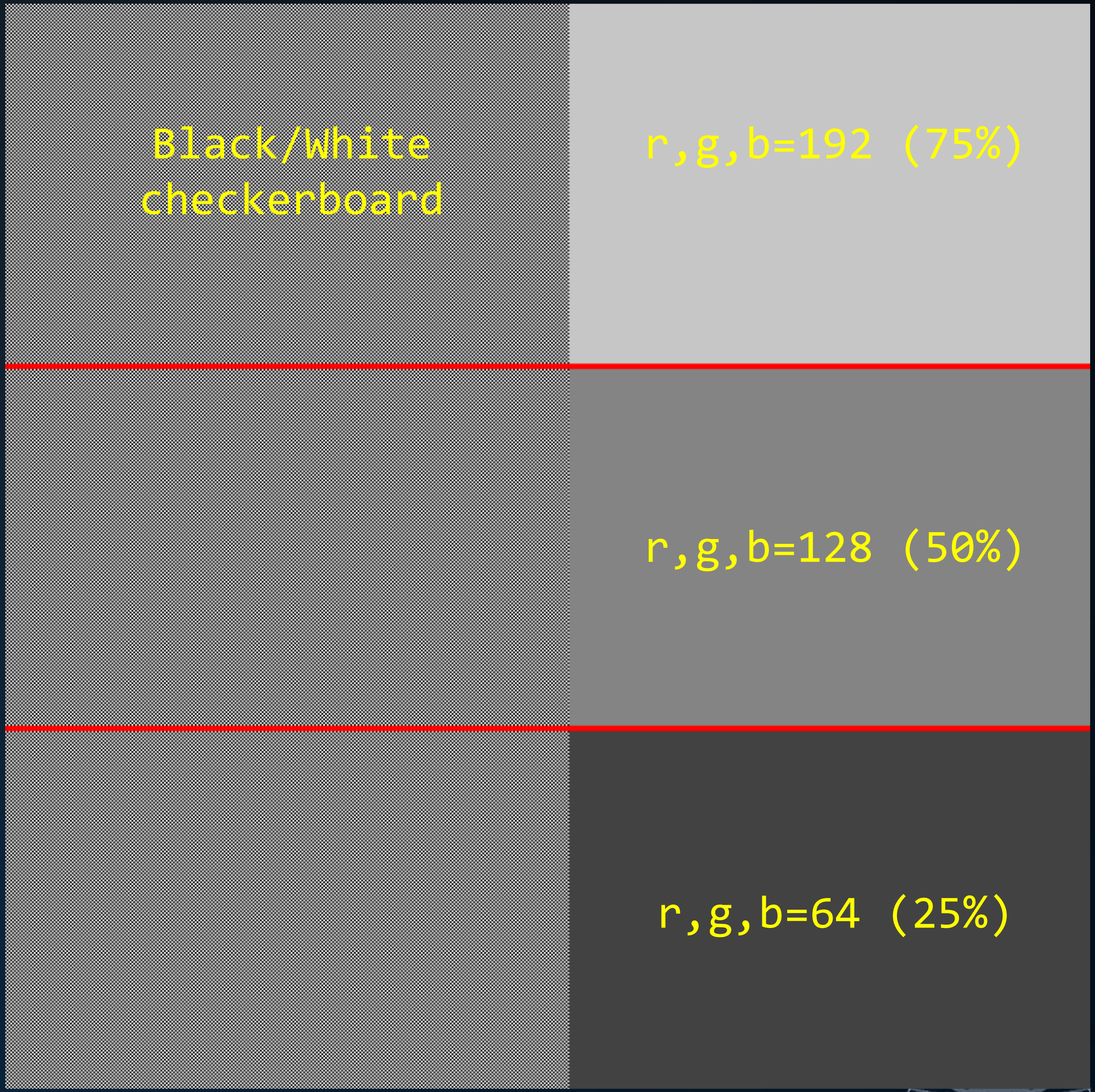


Gamma Correction

Gamma Corrected Or Not?

Open gamma.gif using the windows image previewer, and zoom to the smallest level (1:1). Which bar in the right column is most similar in brightness to the right column?

	$\gamma=1$	$\gamma=2$
75%	0.75	0.56
50%	0.50	0.25
25%	0.25	0.06



Gamma Correction

Consequences

How are your digital photos / DVD movies stored?

1. With gamma correction, ready to be sent to a display device that expects $\sqrt{L}$
2. Without gamma correction, expecting the image viewer to apply $\sqrt{L}$

For jpegs and mpeg video, the answer is 1: these images are already gamma corrected.

➔ Your textures may require conversion to linear space:

$$L = V^2$$

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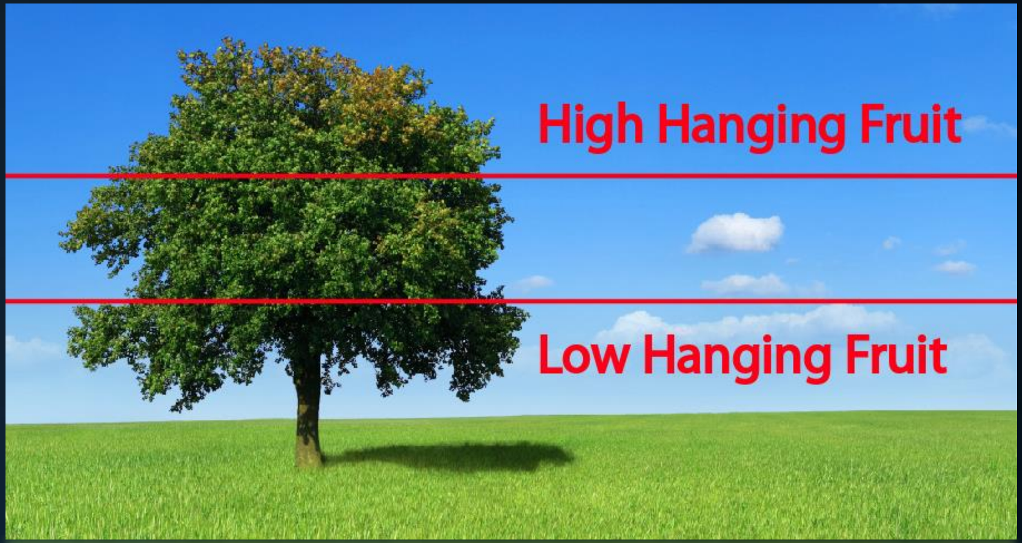
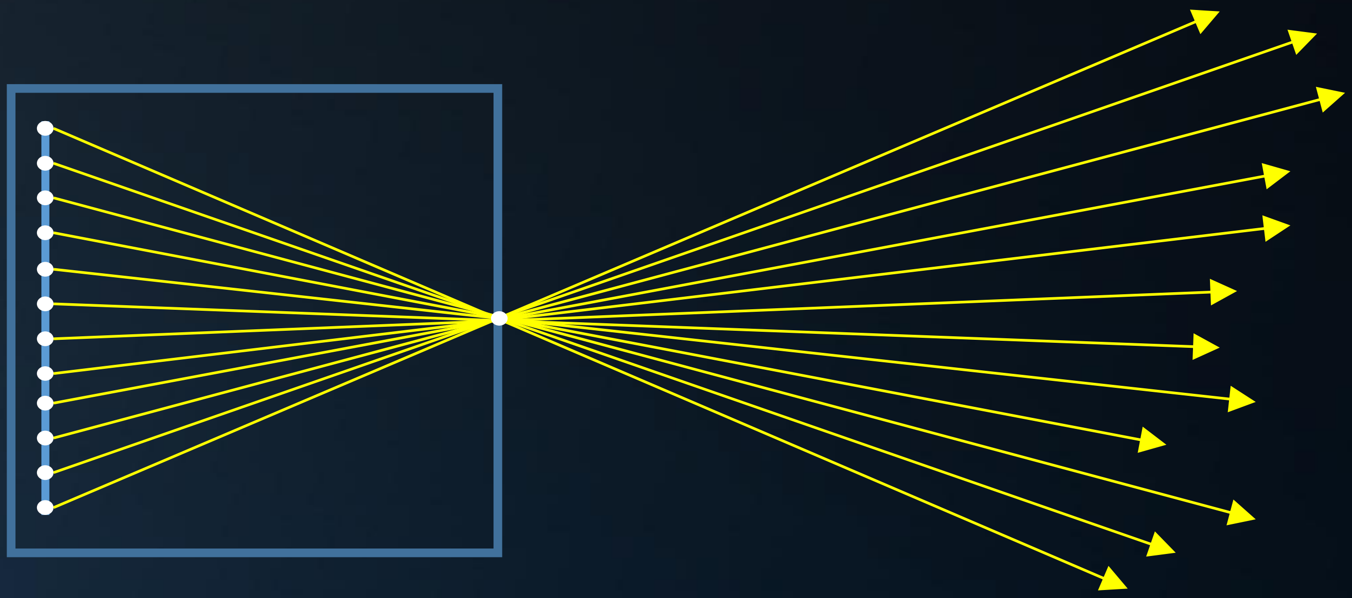
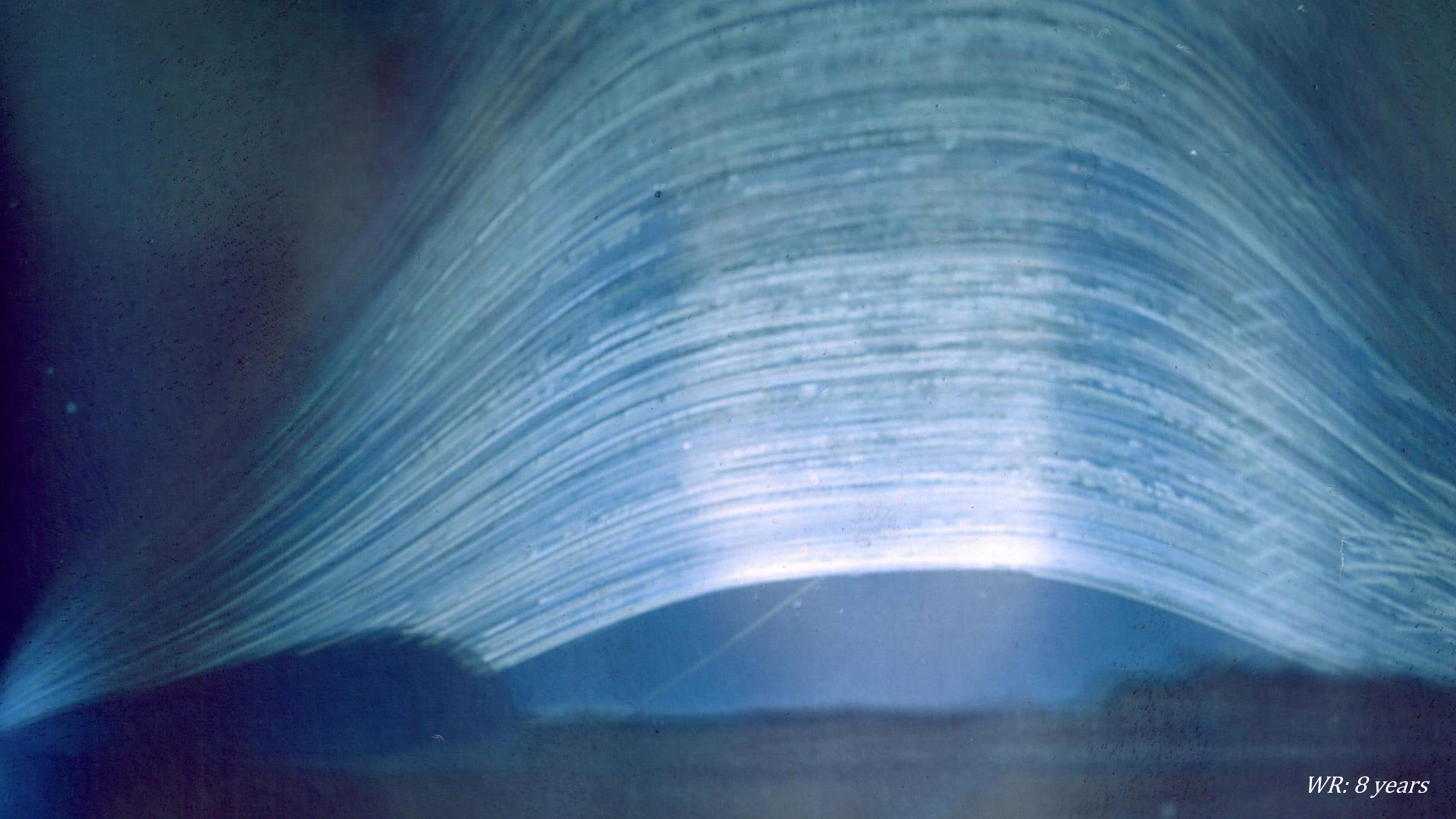


Depth of Field

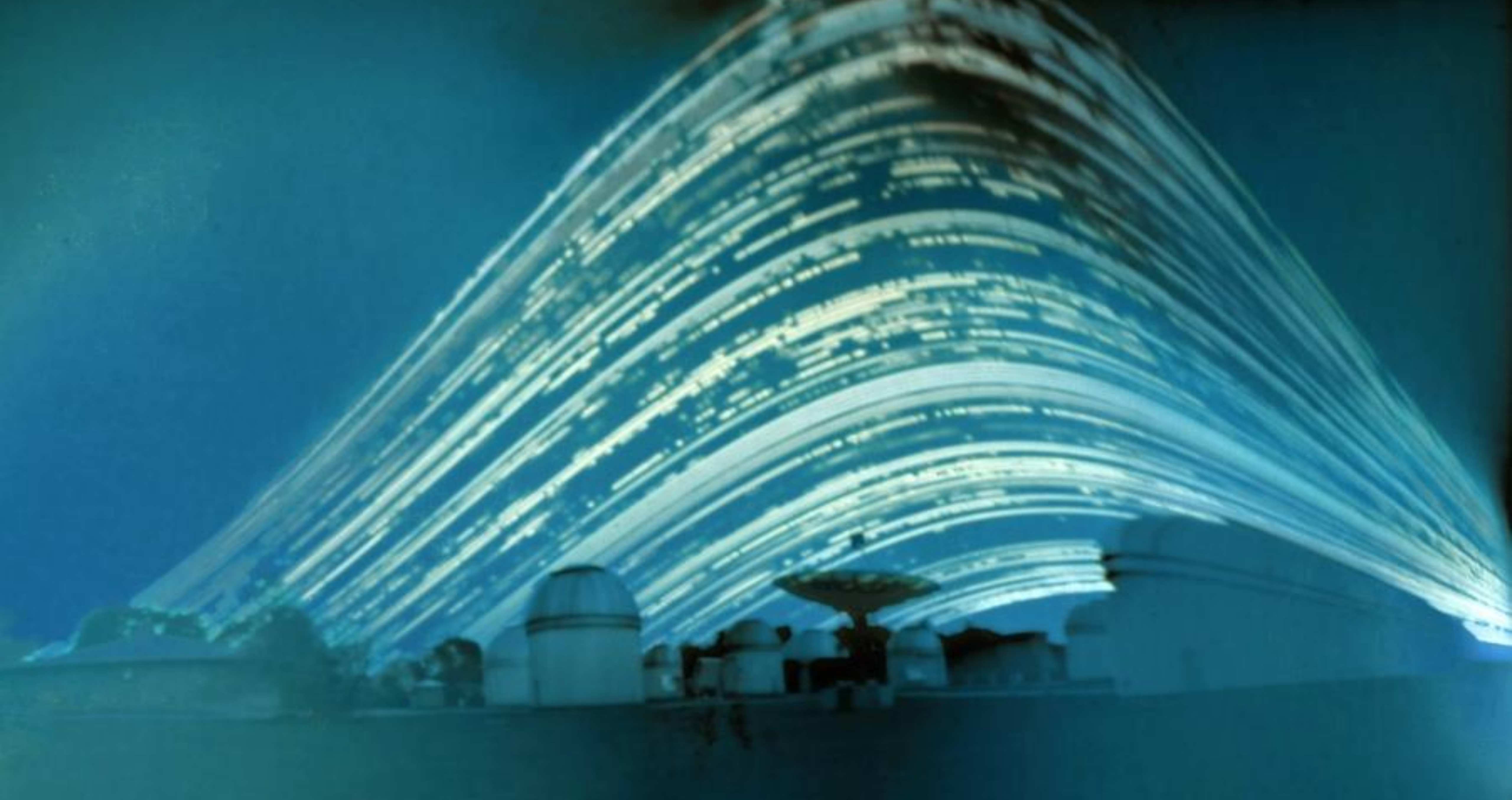
Focus

A pinhole camera ensures that each pixel receives light from a single direction.





WR: 8 years



https://www.thisiscolossal.com/2020/12/longest-exposure-photograph

6 months

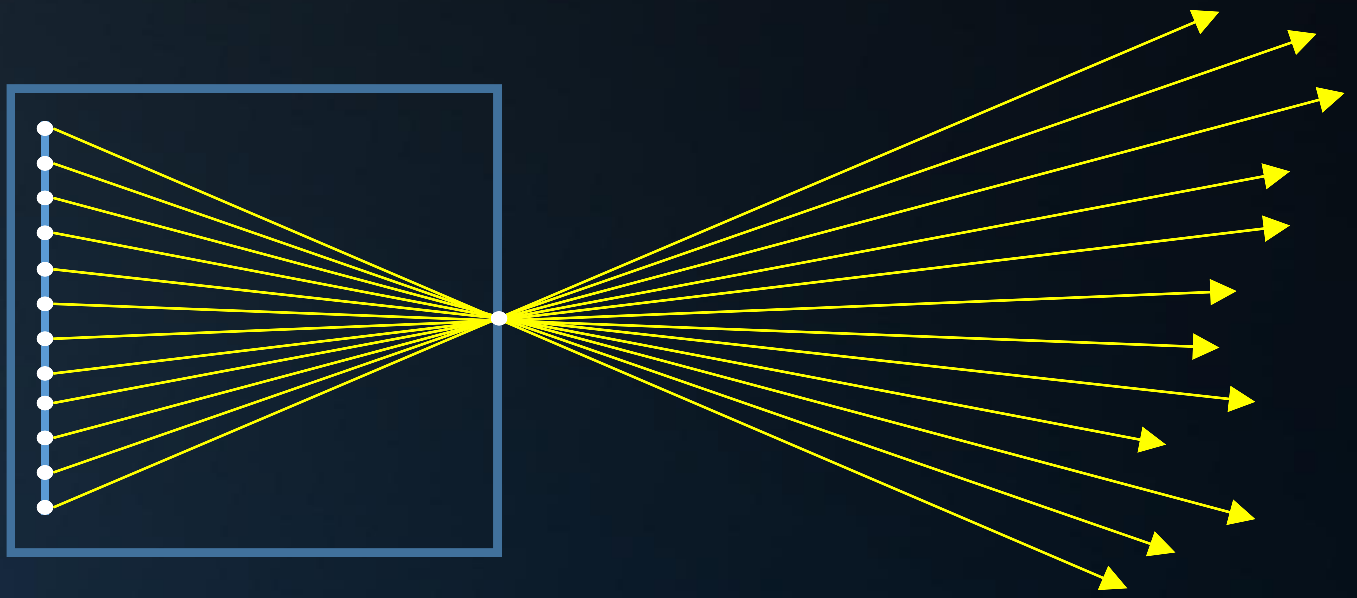
Depth of Field

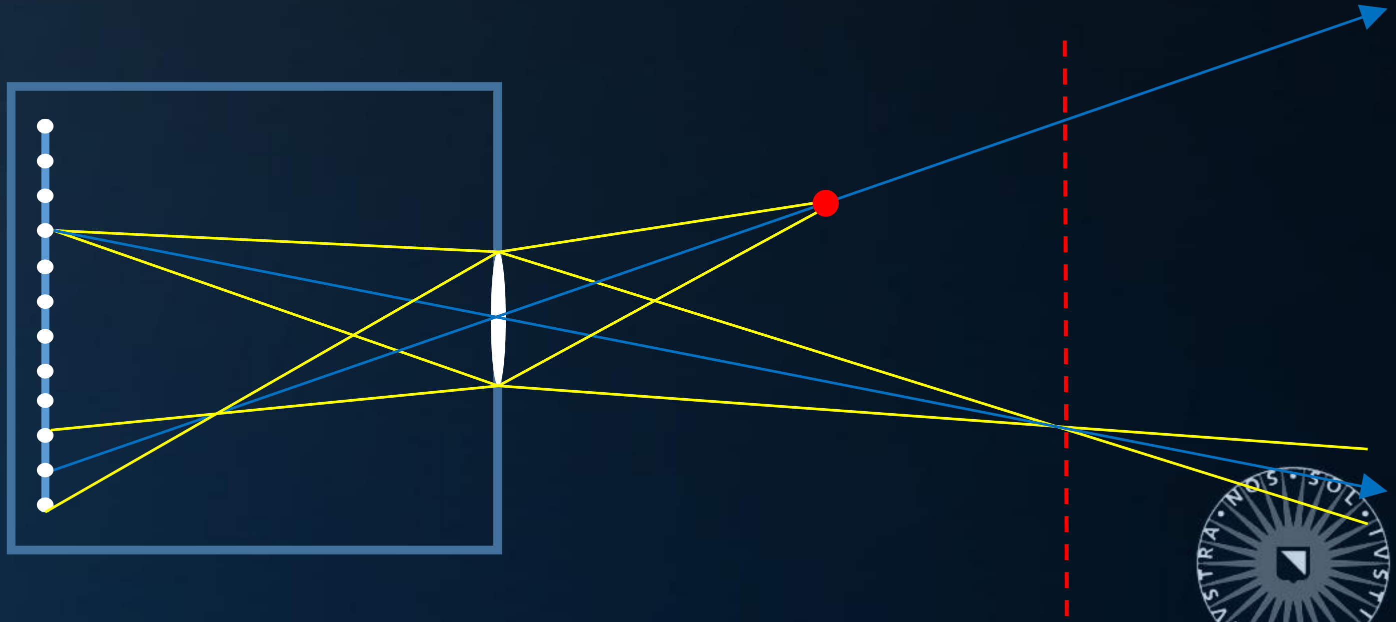
Focus

A pinhole camera ensures that each pixel receives light from a single direction.

For a true pinhole, the amount of light is zero.

Actual cameras use a lens system to direct a limited set of directions to each pixel.



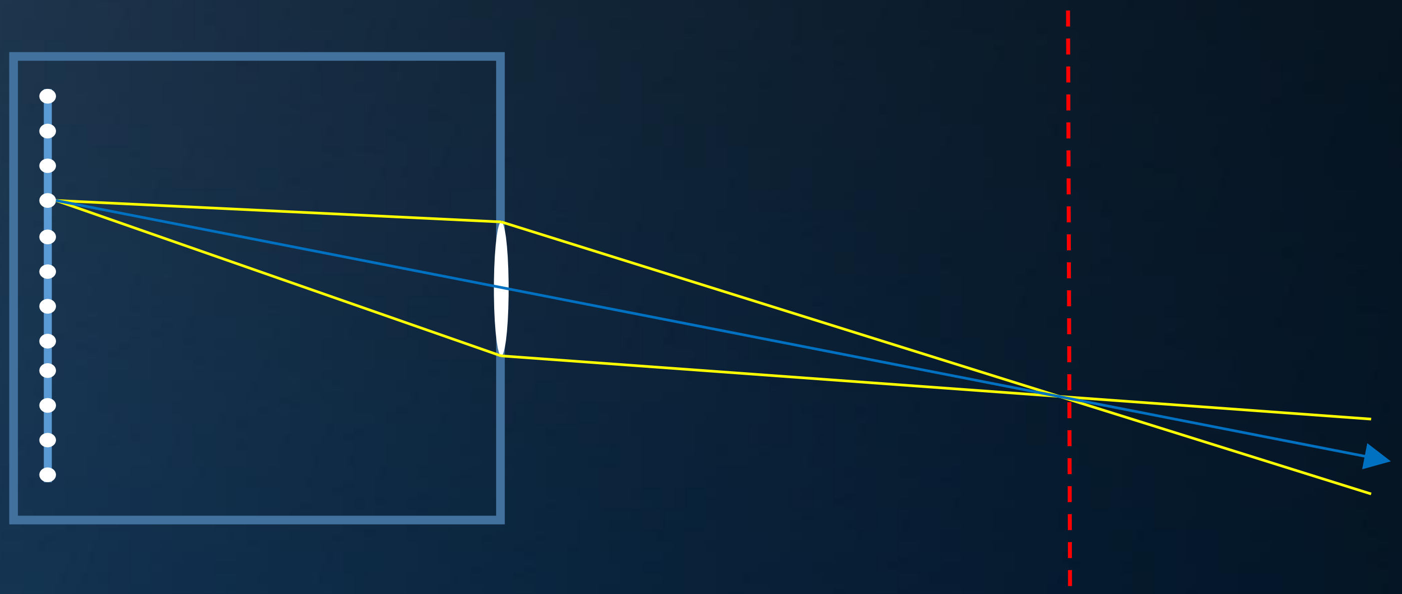


Depth of Field

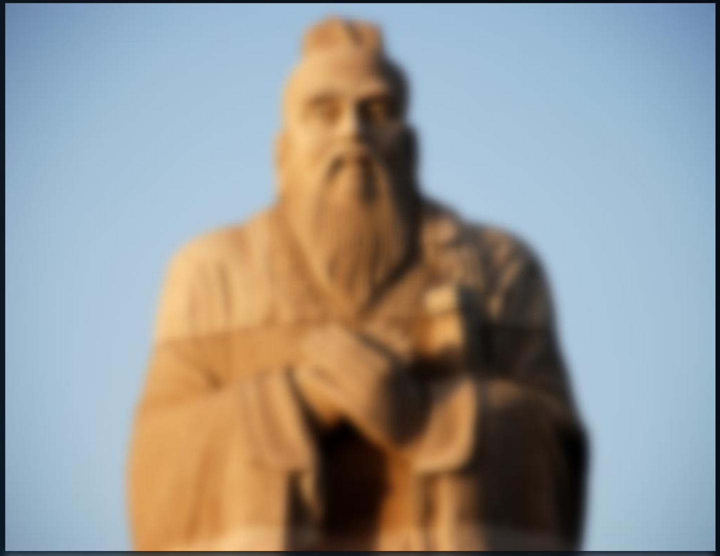
Focus

Objects on the focal plane appear in focus:

Light reflected from these objects to the lens end up on a single pixel on the film.



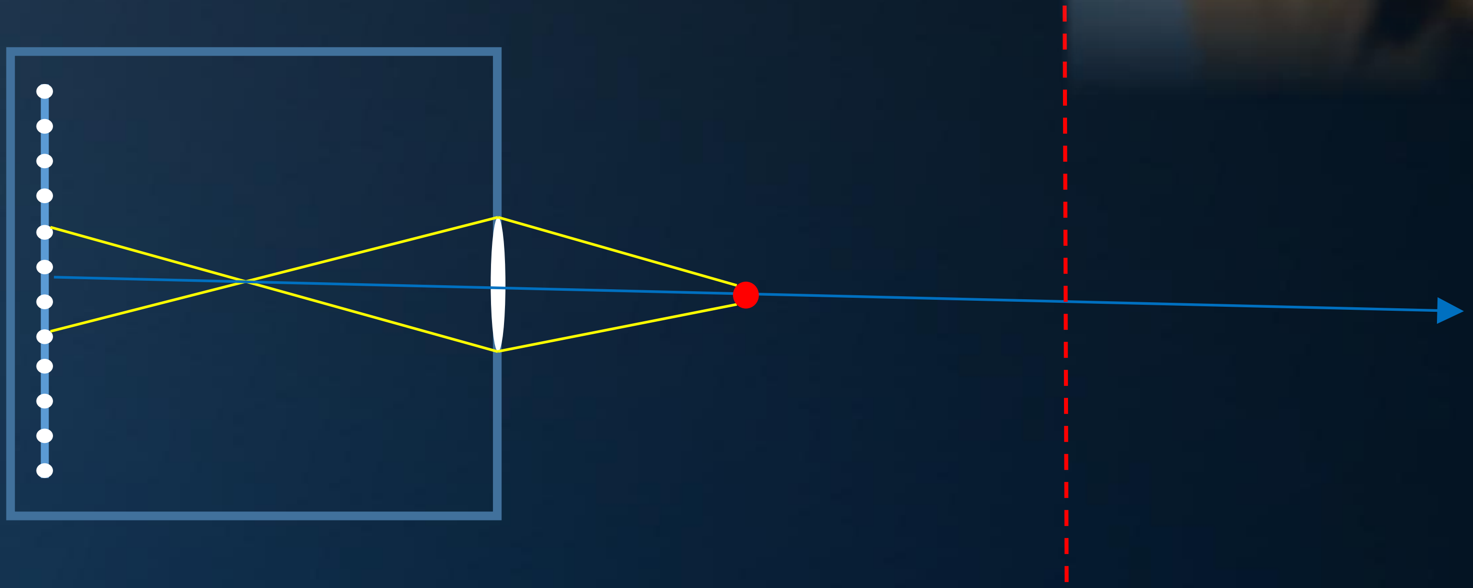
Depth of Field



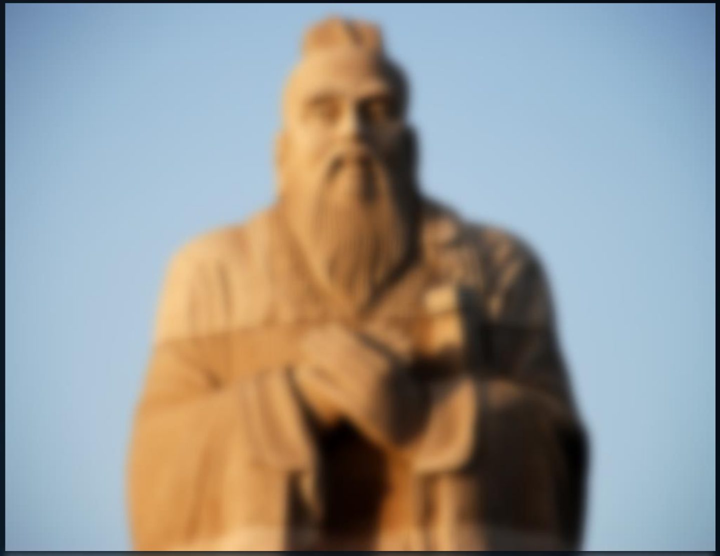
Focus

Objects before the focal plane appear out of focus:

Light reflected from these objects is spread out over several pixels on the film (the ‘circle of confusion’).



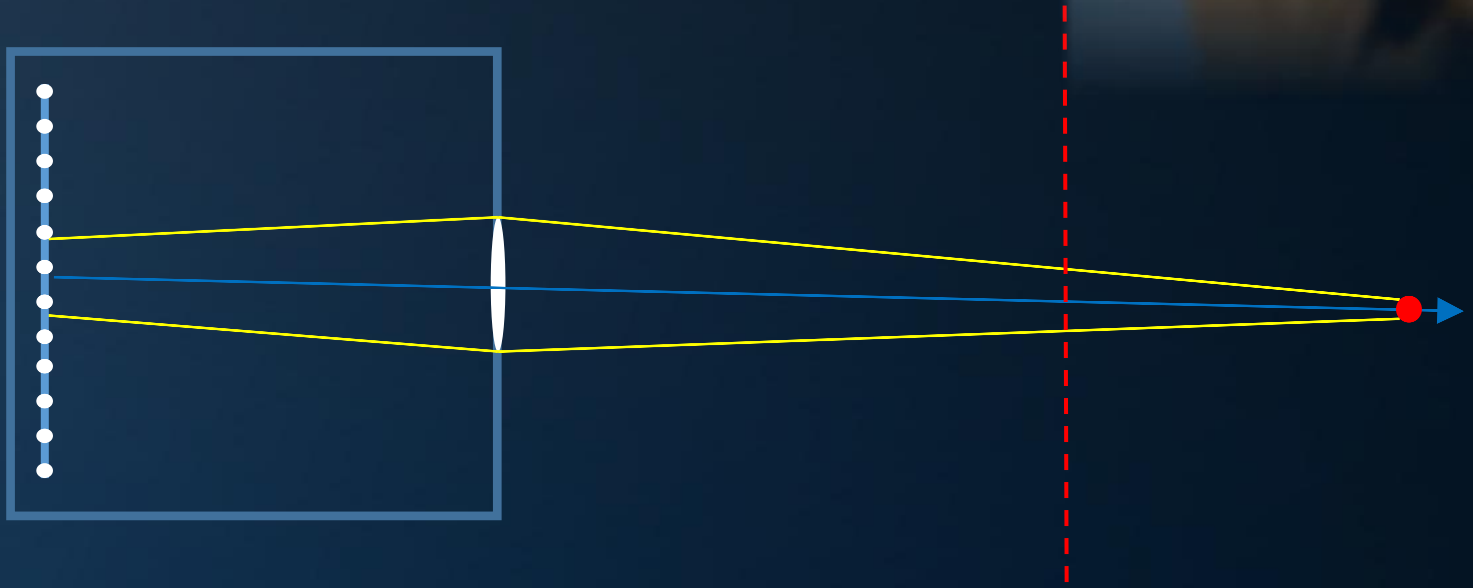
Depth of Field



Focus

Objects beyond the focal plane also appear out of focus:

Light reflected from these objects is again spread out over several pixels on the film.

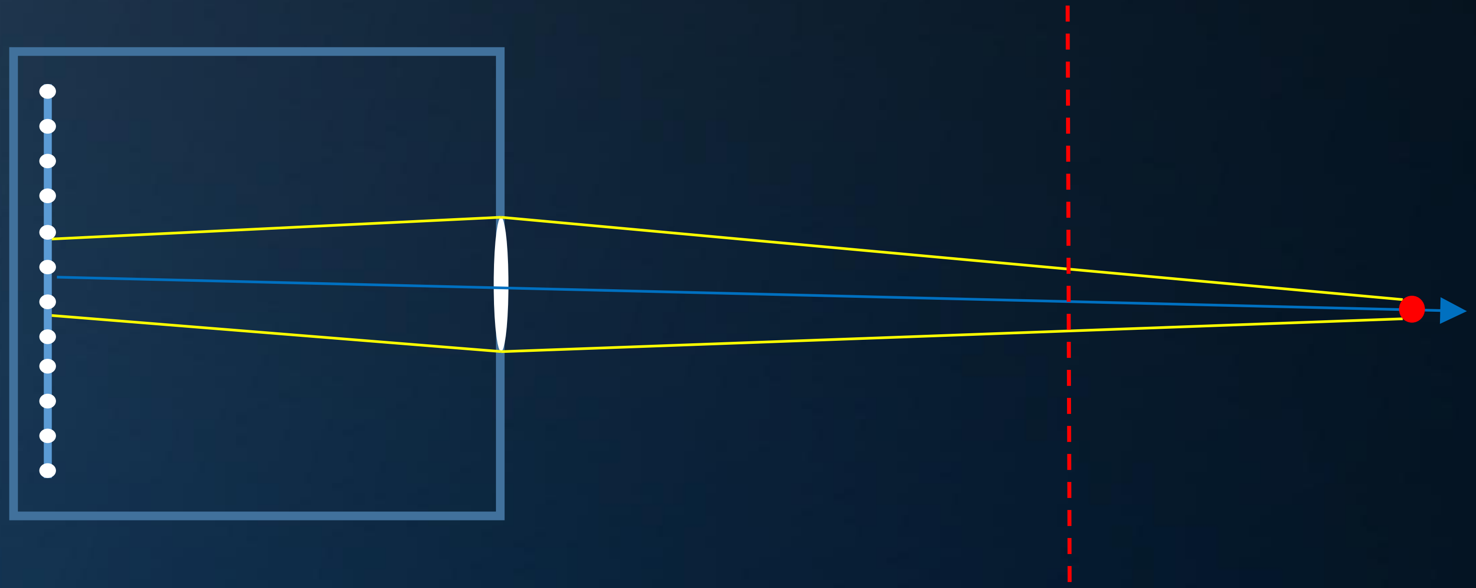


Depth of Field

Circle of Confusion

Ray tracing depth of field:

Spreading out the energy returned by a single ray over multiple pixels within the circle of confusion.



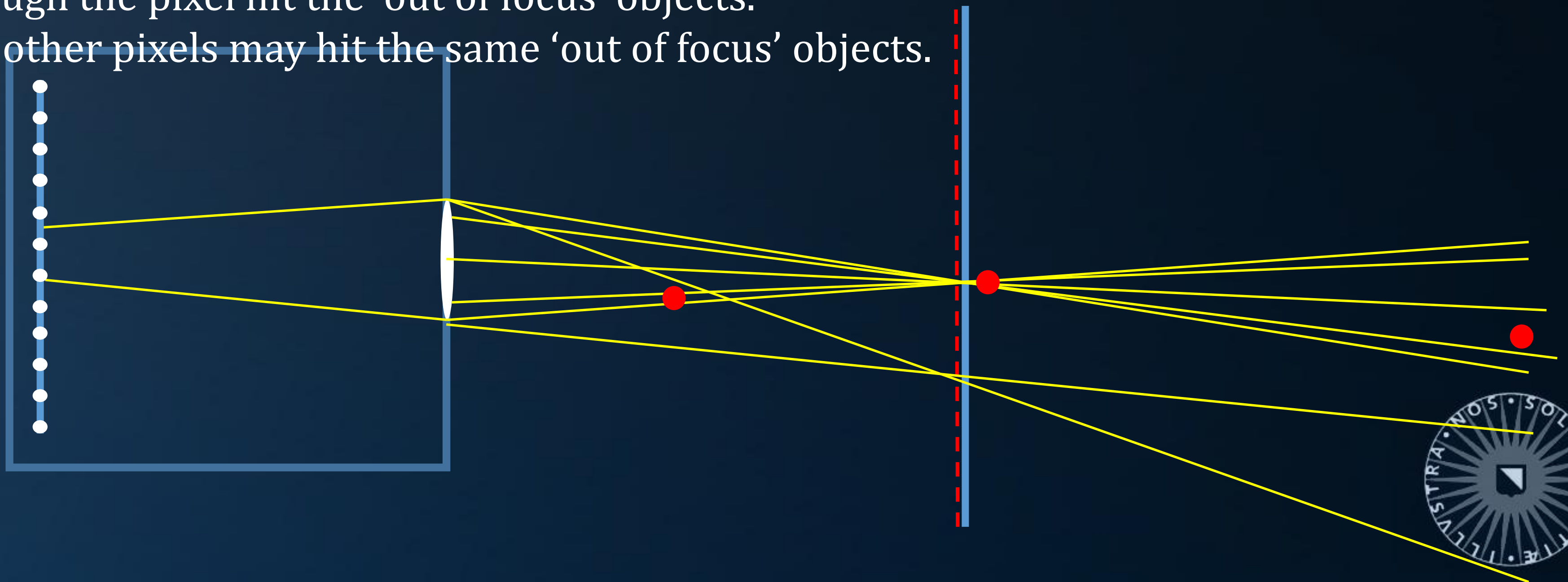
Depth of Field

Circle of Confusion

Efficient depth of field:

We place the virtual screen plane at the focal distance (from the lens).
Rays are generated on the lens, and extend through each pixel.

- All rays through the pixel will hit the object near the focal plane;
- Few rays through the pixel hit the 'out of focus' objects.
- Rays through other pixels may hit the same 'out of focus' objects.



Depth of Field

Generating Primary Rays

Placing the virtual screen plane at the focal distance:

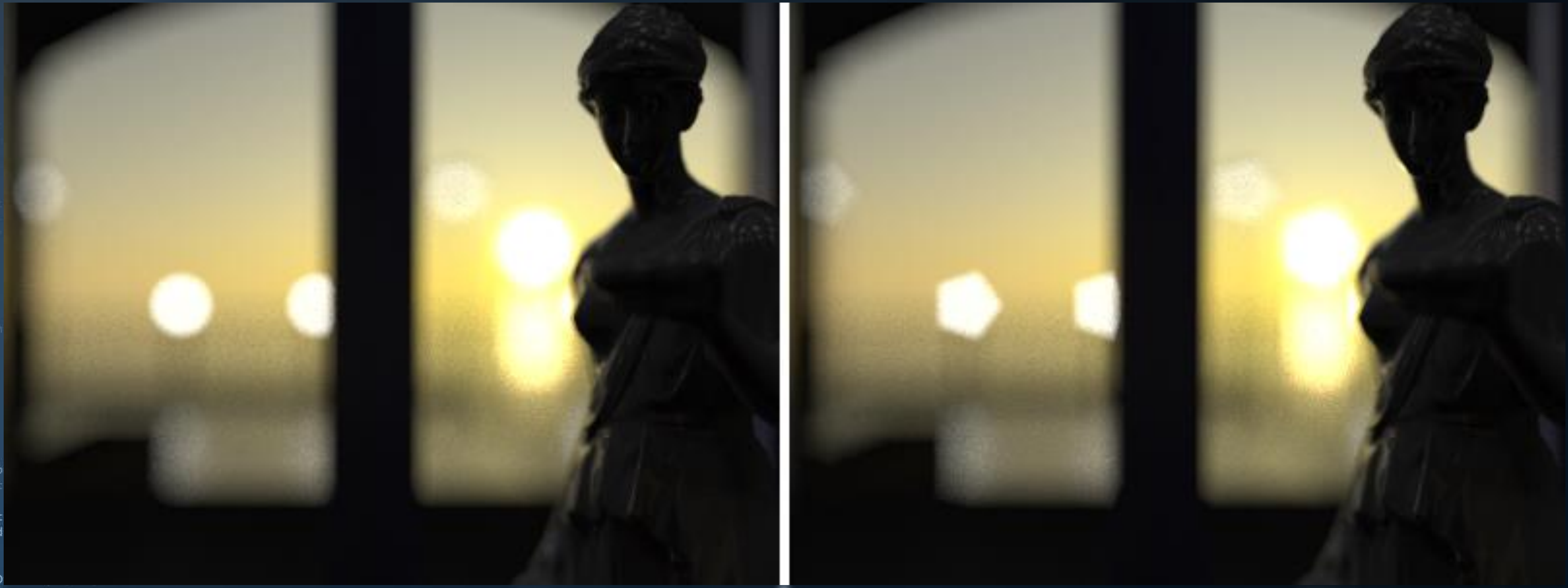
Recall that a 2×2 square at distance d yielded a FOV that could be adjusted by changing d.

We can adjust d without changing FOV by scaling the square and d by the same factor.

Random point on the lens: generate an (ideally uniform) random point on a disc. This is non-trivial; see Global Illumination Compendium, 19a or b. Alternatively, you can use rejection sampling.

Also nice: replace the disc with a regular n-gon.

Depth of Field



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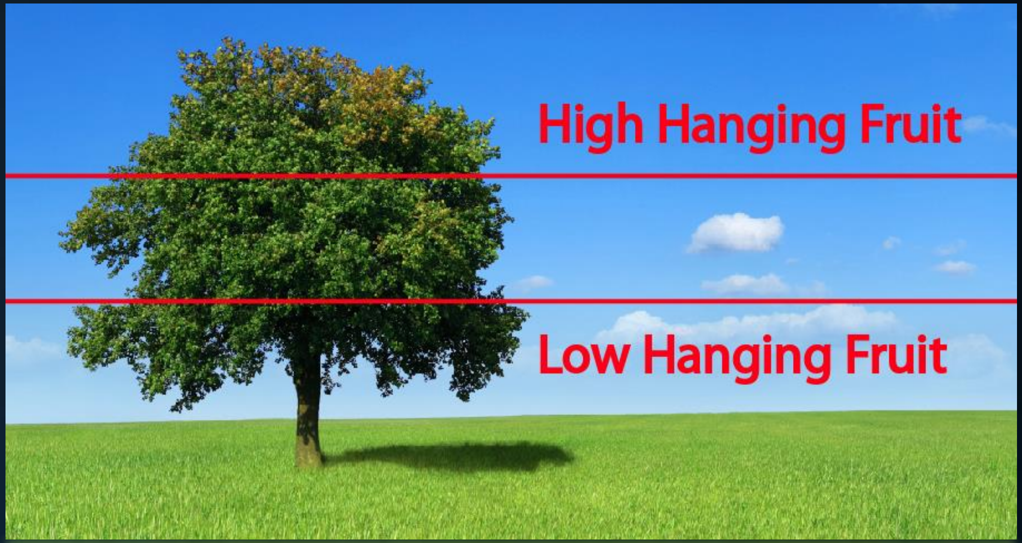
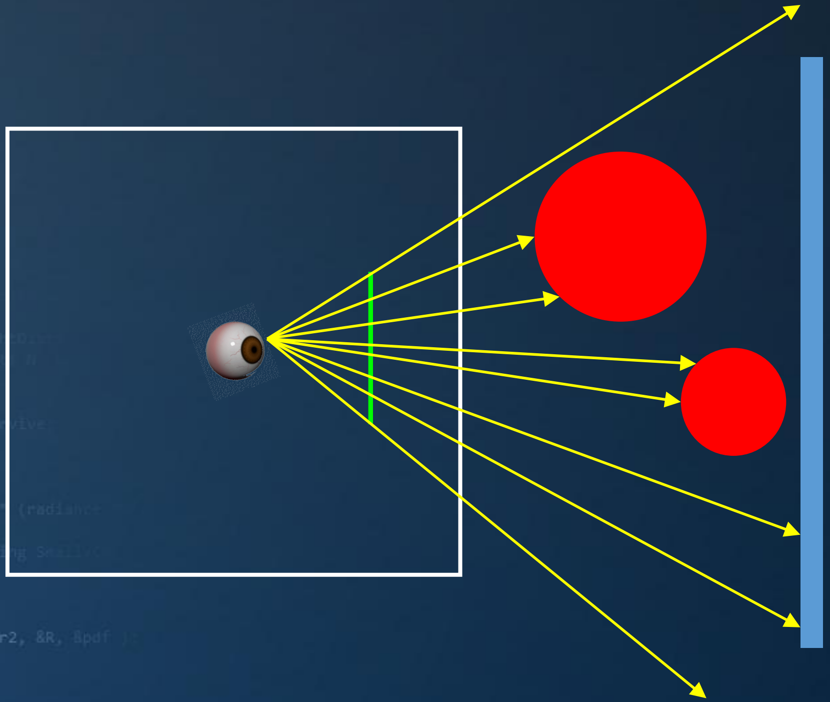
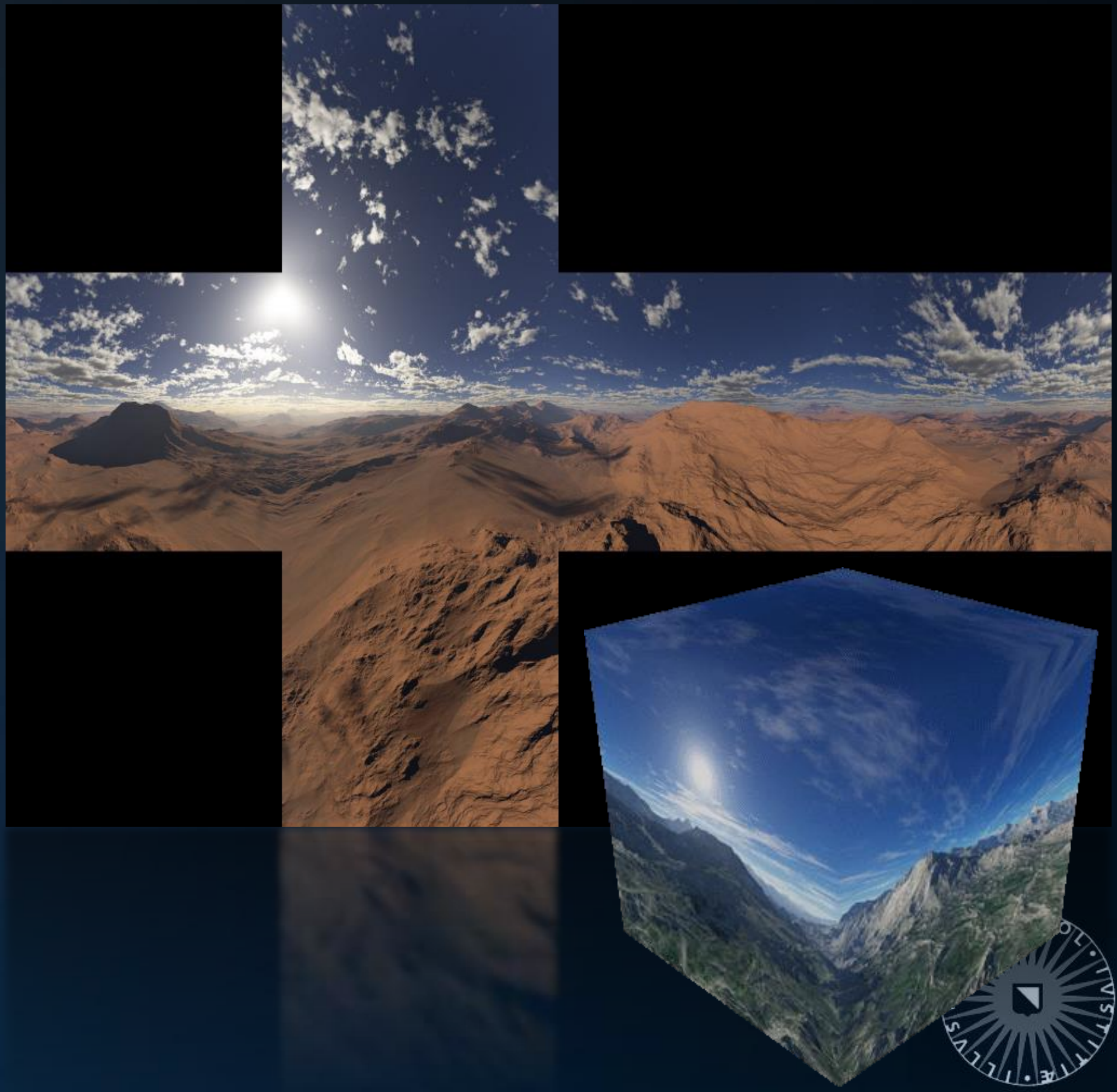


Skybox

Environment Imposter

Many games use a skybox to simulate distant geometry without actually storing this geometry.





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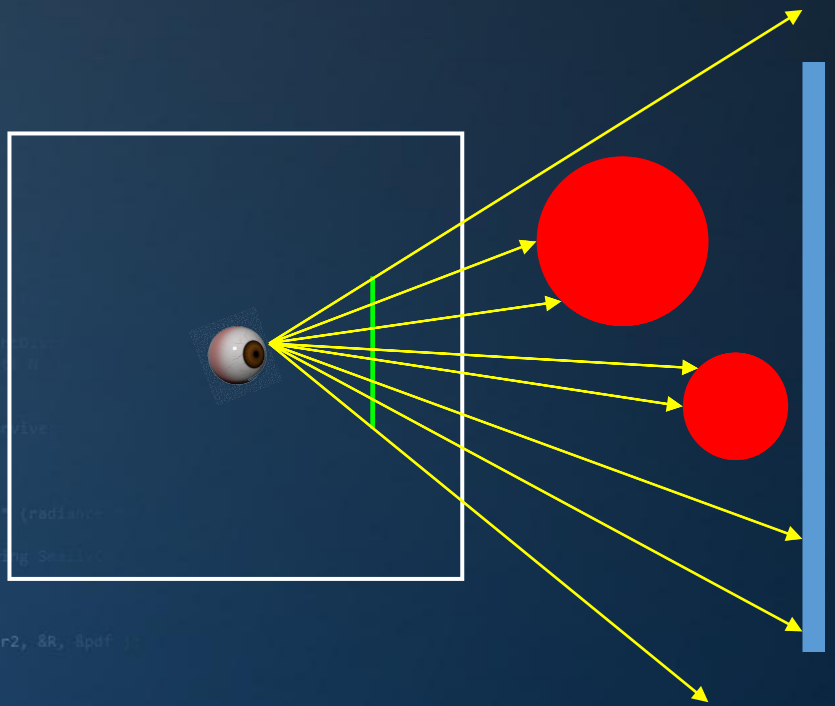
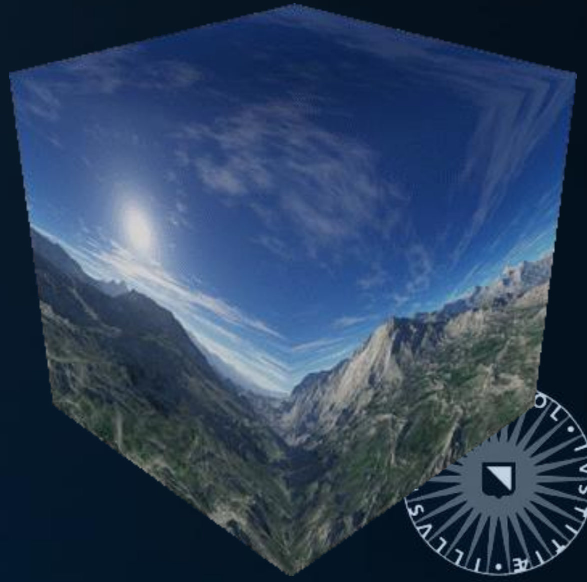


The skybox is a 1 × 1 × 1 box centered around the camera: assuming the sky is at an 'infinite' distance, the location of the camera inside this box is irrelevant.

Which face of the cubemap we need to use, and where it is hit by a ray is determined on ray direction alone.



Skybox

High Dynamic Range

Instead of using a skybox, we can also use an equirectangular mapping, which maps azimuth to u and elevation to v:

$$\theta = \pi(u-1), \varphi = \pi\, v; \;\; u = [0,2], \;\; v = [0,1].$$

Converting polar coordinates to a unit vector:

$$\vec{D} = \begin{pmatrix} sin(\varphi)sin(\theta) \\ cos(\varphi) \\ -sin(\varphi)cos(\theta) \end{pmatrix}$$

Reverse:

$$u, v = \begin{pmatrix} 1 + atan2(D_x, -D_z) / \pi \\ acos(D_y) / \pi \end{pmatrix}$$

Skybox

High Dynamic Range

You can find HDR panoramas on Paul Debevec's page:

http://gl.ict.usc.edu/Data/HighResProbes

Note:

A HDR skydome can be used as a light source.

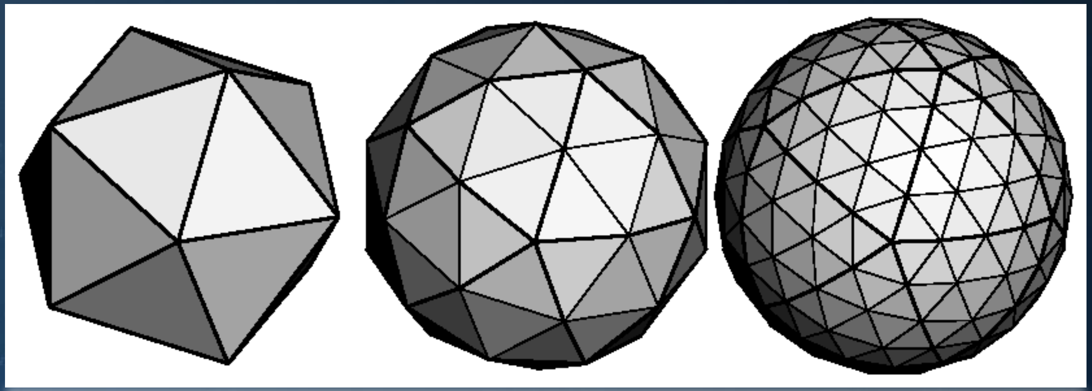
Skybox

Next Event Estimation for Skydomes

Useful trick:

Use the original skydome only for rays that stumble upon it.

For next event estimation, use a tessellated (hemi)sphere; assign to each triangle the average skydome color for the directions it covers.



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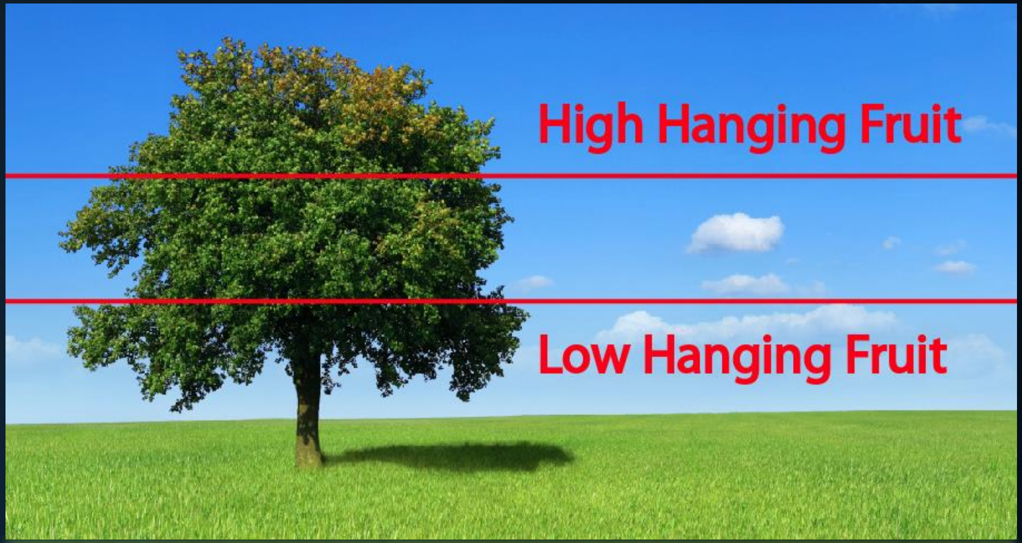
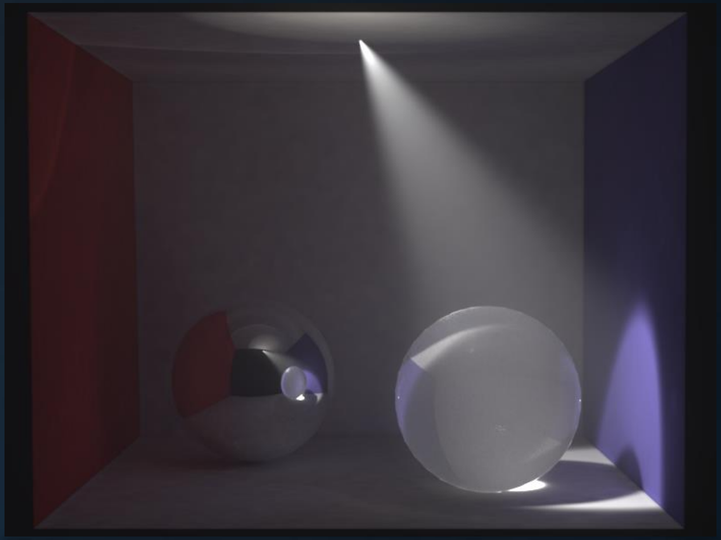


Spots & IES

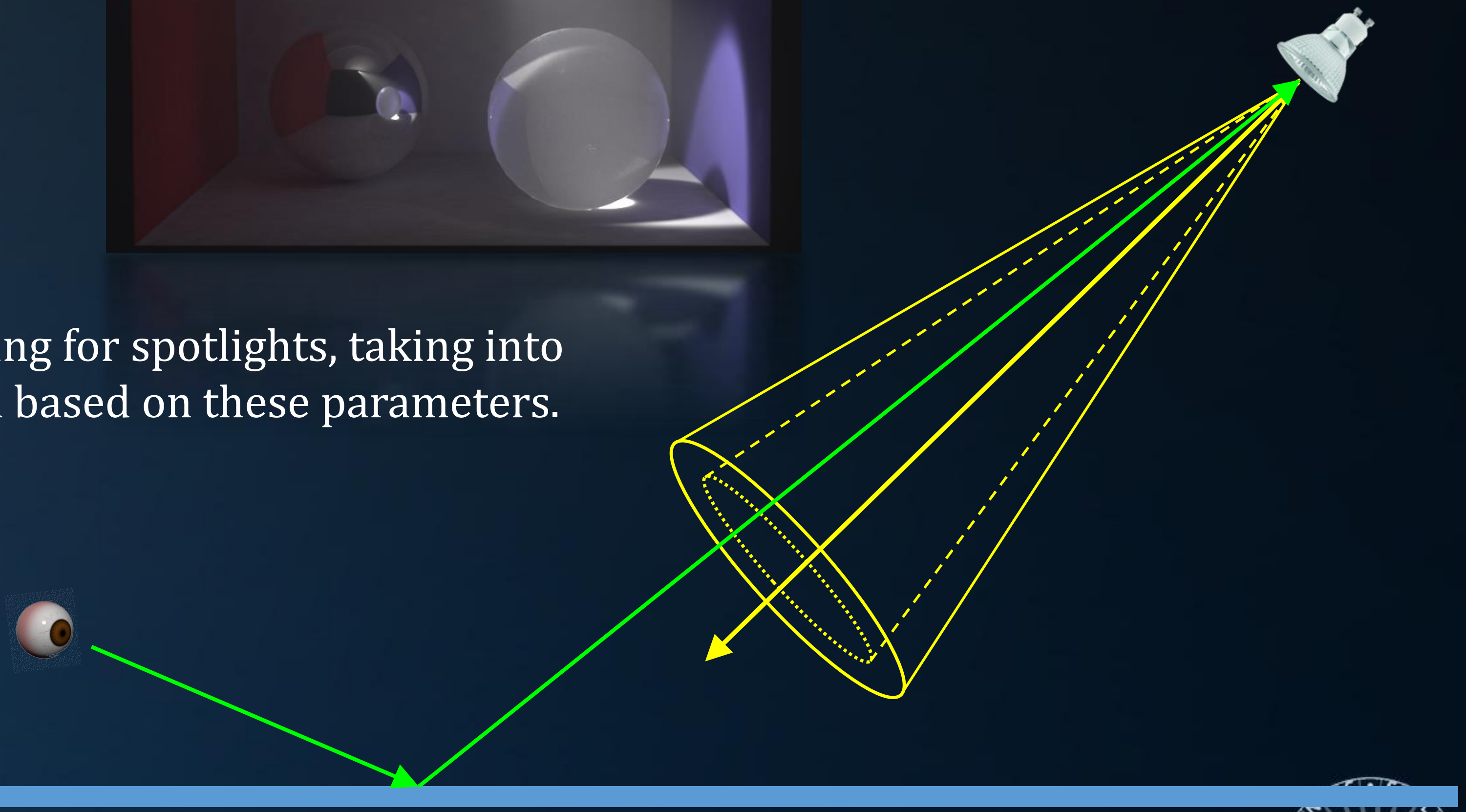


Ray Tracing Spotlights

Spotlight parameters:

- Brightness
- Position, direction
- Inner angle, outer angle

We can use importance sampling for spotlights, taking into account potential contribution based on these parameters.

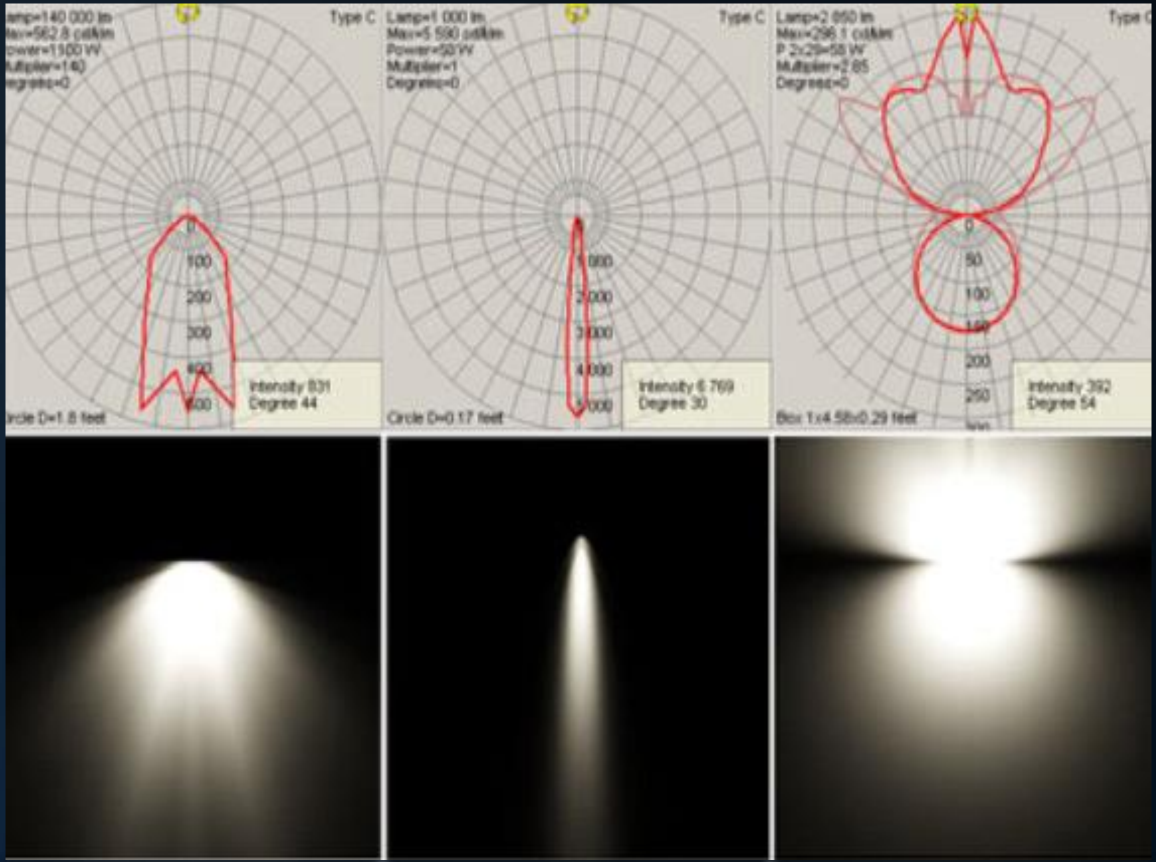


Spots & IES

IES Profiles

Photometric data for light sources:
Measurement of the distribution of light intensity.

Can be used in e.g. 3DS Max to model lights in virtual scenes.



Spots & IES

Format specification:
http://lumen.iee.put.poznan.pl/kw/iesna.txt

```
IESNA:LM-63-1995
[TEST]    21307
[MANUFAC]ECLIPSE LIGHTING - PENDANT LUMINAIRE
[LUMCAT]ME-XL1-QL165-277VOLT
[LUMINAIRE]WHITE PLASTIC TUBE WITH TOP AND BOTTOM OPEN
[LAMP]ONE PHILIPS 165 WATT INDUCTION LAMP
[LAMPCAT]QL165W/840. LUMEN RATING = 8289 LMS.
[OTHER]ONE PHILIPS QL165W S/1 GENERATOR OPERATING AT 277 VAC AND 147 WATTS
TILT=NONE
1  8289   1   73  1   1  1   -1.00   0.00   1.92  1  1
 147.0000
0 2.5 5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30 32.5 35 37.5
40 42.5 45 47.5 50 52.5 55 57.5 60 62.5 65 67.5 70 72.5 75
77.5 80 82.5 85 87.5 90 92.5 95 97.5 100 102.5 105 107.5 110
112.5 115 117.5 120 122.5 125 127.5 130 132.5 135 137.5 140
142.5 145 147.5 150 152.5 155 157.5 160 162.5 165 167.5 170
172.5 175 177.5 180
0
   879.2   897.2   941.6   1001.1   1060.8   1116.3   1165.3   1171.1   1131.6   1064.3
   986.6   910.8   845.1   792.7    760.3    745.7    735.6    724.5    714.6    703.8
   693.0   683.0   675.6   672.1    672.0    673.9    675.9    677.6    679.3    680.9
   682.3   682.9   682.7   681.2    678.5    676.6    680.7    684.8    683.3    680.9
   676.9   671.2   664.1   655.9    646.6    636.3    625.0    612.7    599.6    586.1
   572.3   558.1   544.0   530.5    517.8    506.6    496.4    486.5    477.0    469.6
   470.0   482.8   502.2   520.6    526.0    496.0    414.4    315.6    235.7    169.7
   108.4    59.4    35.8
```

Lumens

Horizontal angles

Vertical angle

Candela values

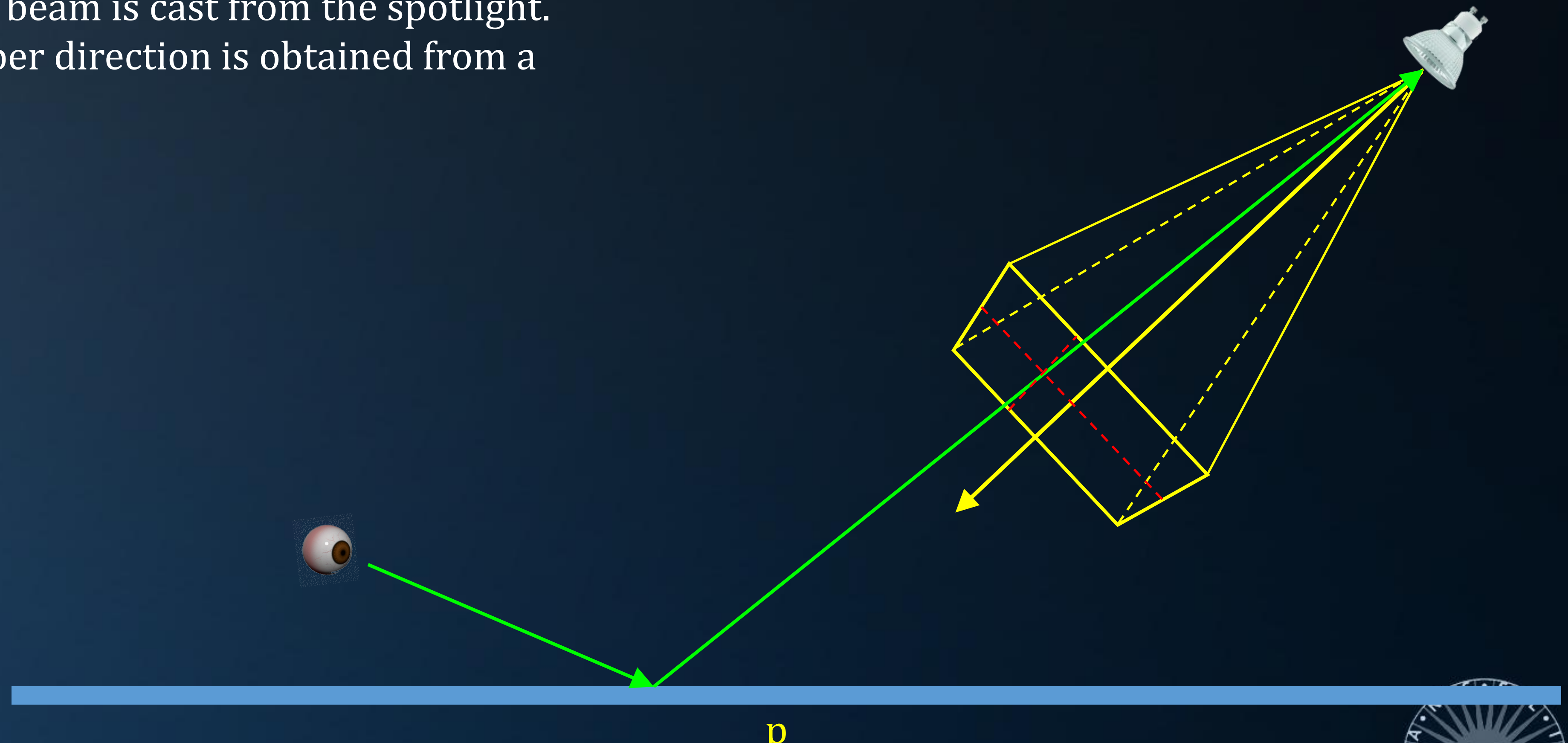

UNREAL ENGINE

Spots & IES

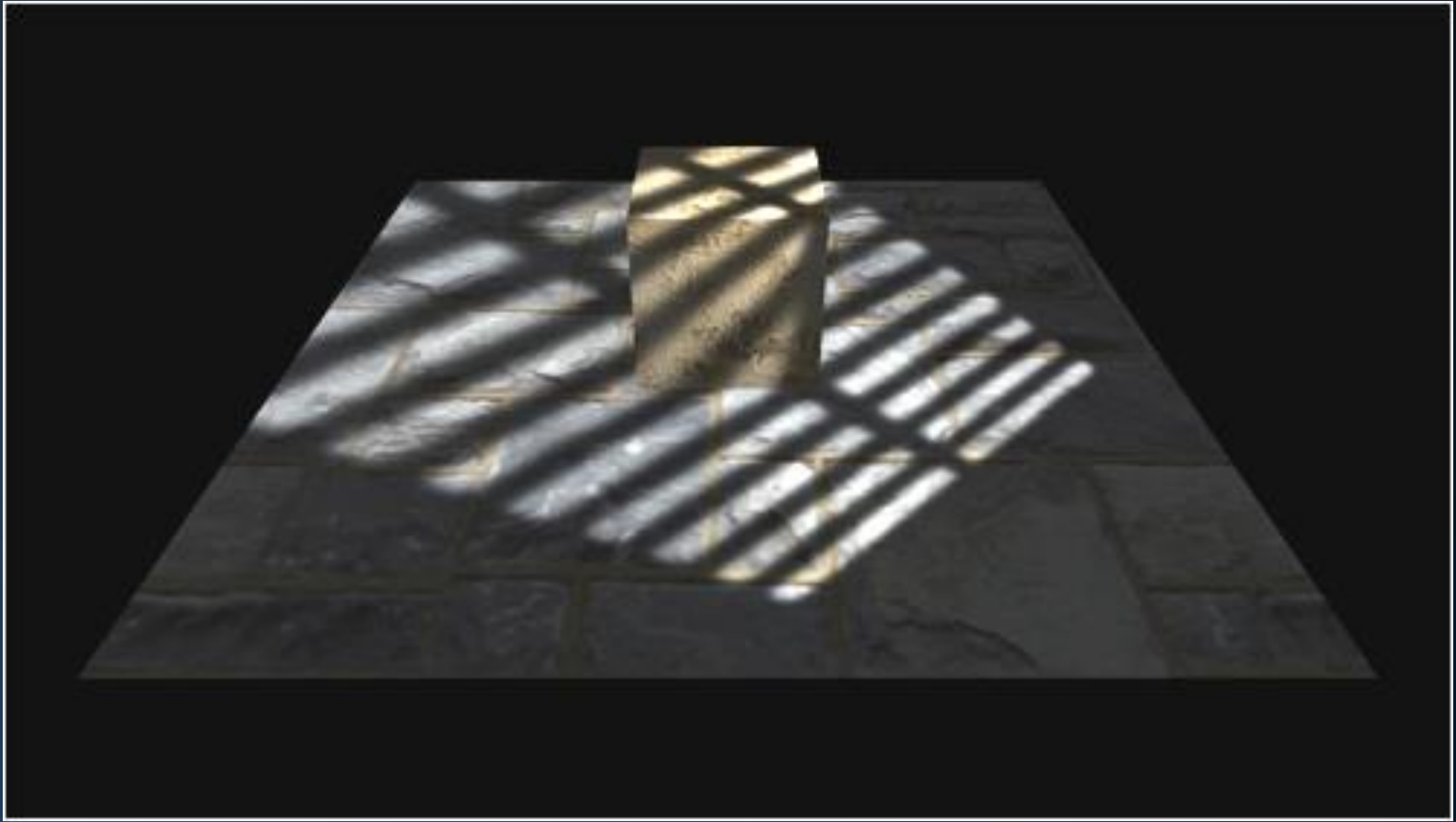
Projective Spotlight

A rectangular beam is cast from the spotlight. Illumination per direction is obtained from a bitmap.

$$u, v = ?$$



Spots & IES



Spots & IES

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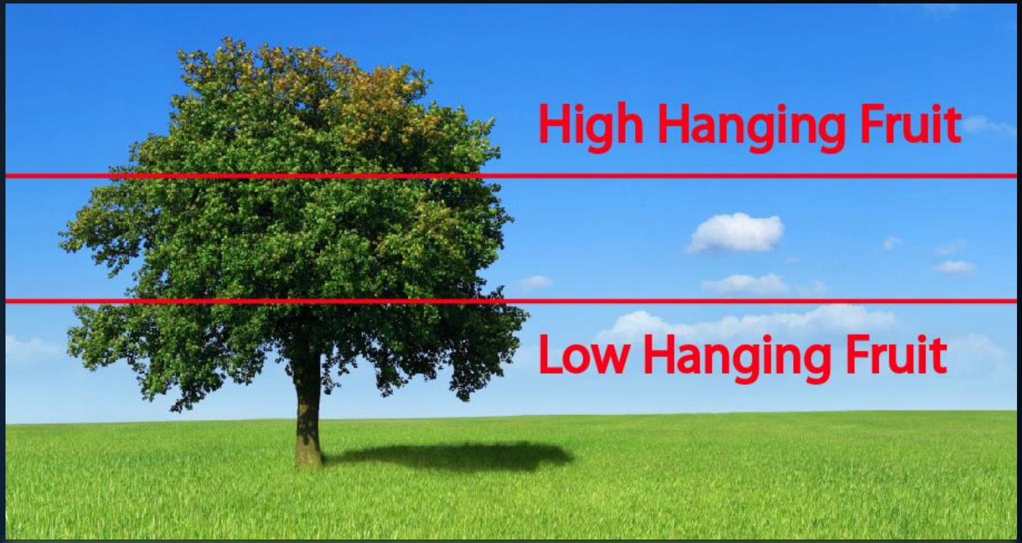


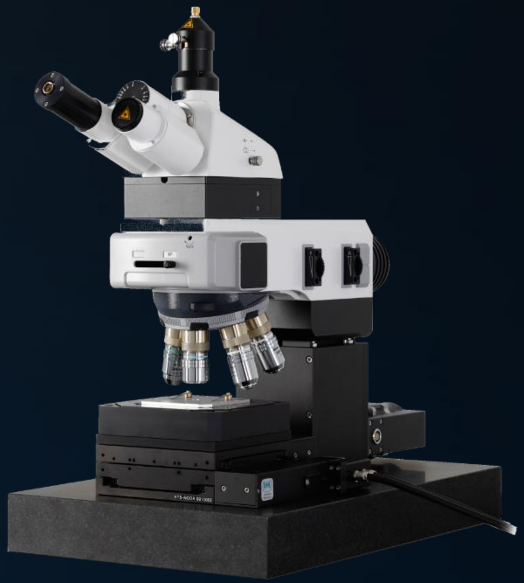
Microfacet

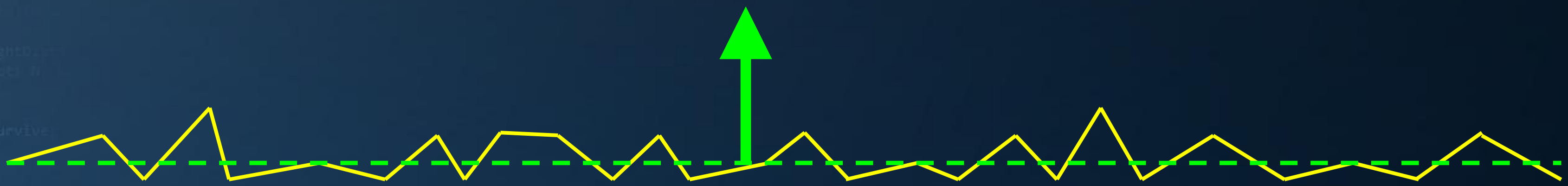
BRDFs Without Issues

We have two BRDFs without problems:

1. The Lambertian BRDF
2. The pure specular BRDF

These are physically plausible and can be sampled. The PDF is also clear.



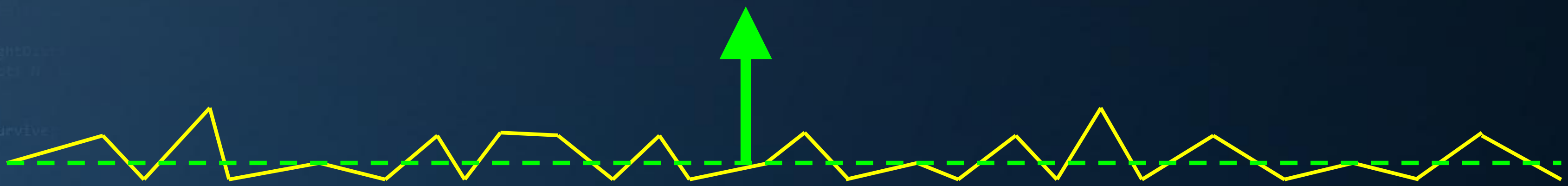


Microfacet

Microfacet BRDFs*

We can simulate a broad range of materials if we assume:
at a microscopic level, the material consists of tiny specular fragments.

- If the fragment orientations are chaotic, the material appears diffuse.
- If the fragment orientations are all the same, the material appears specular.
- Different but similar orientations yield glossy materials.



*: Torrance & Sparrow, Theory for Off-Specular Reflection from Roughened Surfaces. 1967.

Microfacet

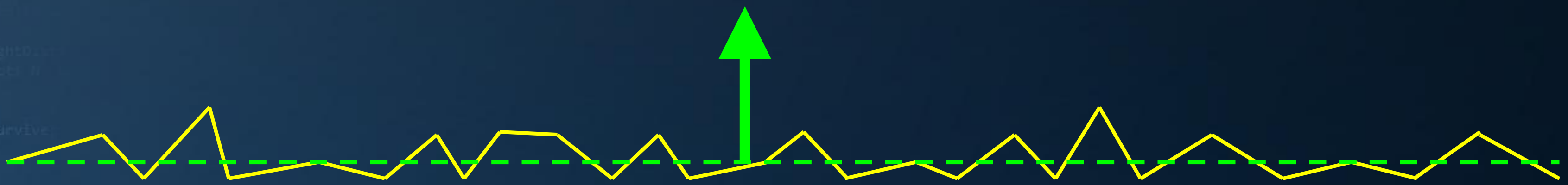
Microfacet BRDFs*

The Microfacet BRDF:

$$f_r(\vec{L},\vec{V}) = \frac{F(\vec{L},\vec{V})G(\vec{L},\vec{V},\vec{H})D(\vec{H})}{4(\vec{N}\cdot\vec{L})(\vec{N}\cdot\vec{V})}$$

Ingredients:

1. Normal distribution D
2. Geometry term G
3. Fresnel term F
4. Normalization



Microfacet

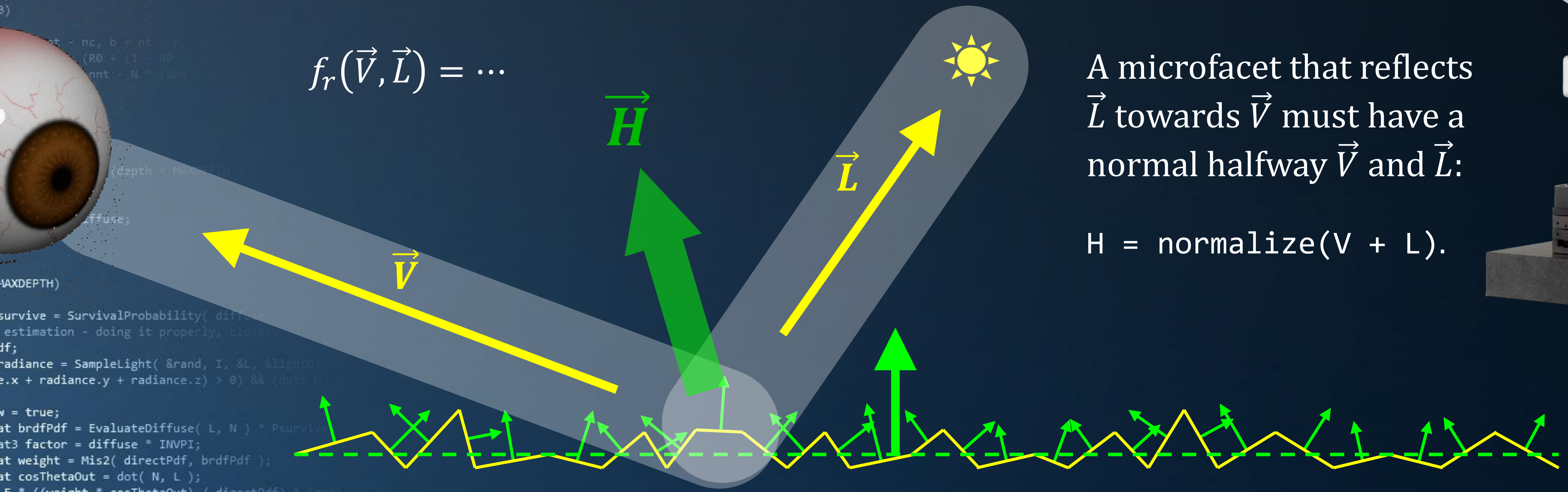
$$f_r(x, \theta_i, \theta_o) = \frac{L_o(x, \theta_o)}{L_i(x, \theta_i)\cos\theta_i}$$

Normal Distribution

Microfacet BRDF, ingredient 1: $D(\vec{H})$ ➔ the *normal distribution function.*

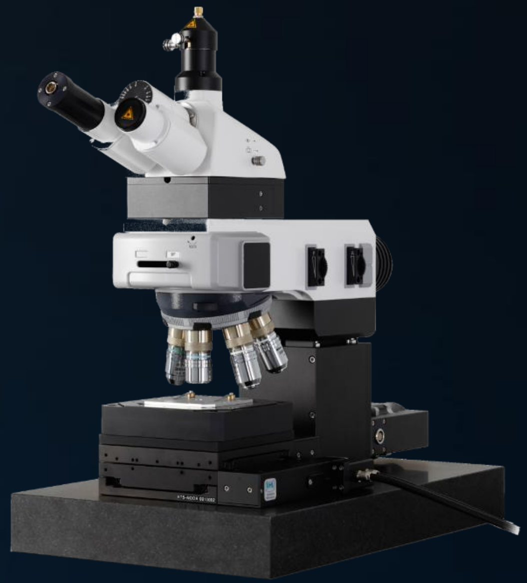
Parameter $\vec{H}$: the halfway vector:

$$f_r(\vec{V}, \vec{L}) = \cdots$$



A microfacet that reflects $\vec{L}$ towards $\vec{V}$ must have a normal halfway $\vec{V}$ and $\vec{L}$:

```
H = normalize(V + L).
```



Microfacet

Normal Distribution

Intuitive choices for D:

$D(\vec{H}) = C$: microfacet normals are equally distributed ➔ diffuse material.

$D(\vec{H}) = \begin{cases} \infty, for \vec{H} = (0,0,1) \\ 0, otherwise \end{cases}$: all microfacet normals are (0,0,1) ➔ pure specular.

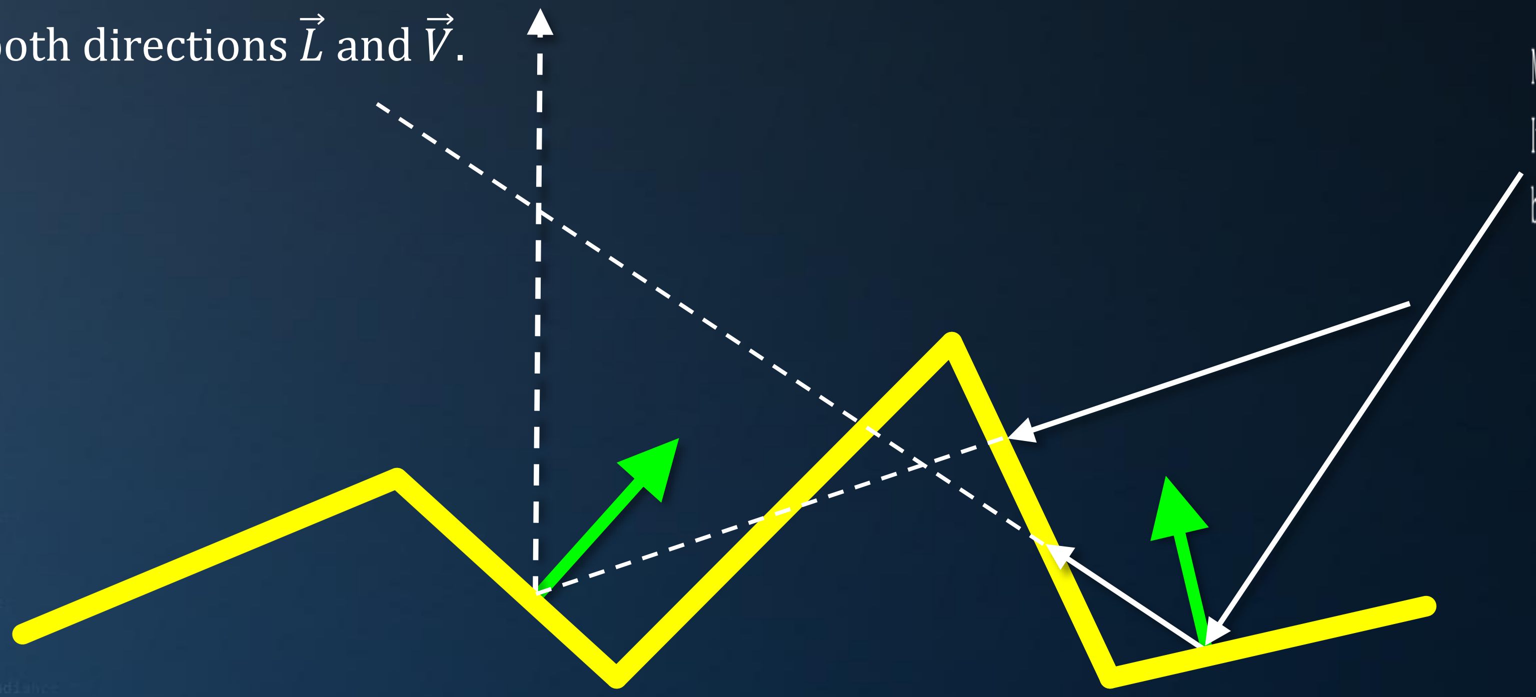
Good practical choice for D: the Blinn-Phong distribution;

$$D(\vec{H}) = \frac{\alpha + 2}{2\pi} \underline{(\vec{N} \cdot \vec{H})}^{\alpha}$$

Microfacet

Geometry Term

Microfacet BRDF, ingredient 2: $G(\vec{V},\vec{L},\vec{H})$ ➔ the *geometry term.*
It describes what fraction of a microsurface with normal $\vec{H}$ is visible in both directions $\vec{L}$ and $\vec{V}$.



Geometry Term

Microfacet BRDF, ingredient 2: $G(\vec{V},\vec{L},\vec{H})$ ➔ the *geometry term.*
It describes what fraction of a microsurface with normal $\vec{H}$ is visible in both directions $\vec{L}$ and $\vec{V}$.

Microfacet

Geometry Term

Intuitive choice for G:

$G(\vec{V},\vec{L},\vec{H}) = 1$: no occlusion.

Good practical choice for G*:

$$G(\vec{V},\vec{L},\vec{H}) = \min\left(1, \min\left(\frac{2(\vec{N}\cdot\vec{H})(\vec{N}\cdot\vec{V})}{\vec{V}\cdot\vec{H}}, \frac{2(\vec{N}\cdot\vec{H})(\vec{N}\cdot\vec{L})}{\vec{V}\cdot\vec{H}}\right)\right)$$

*: Physically Based Rendering, page 455

Microfacet

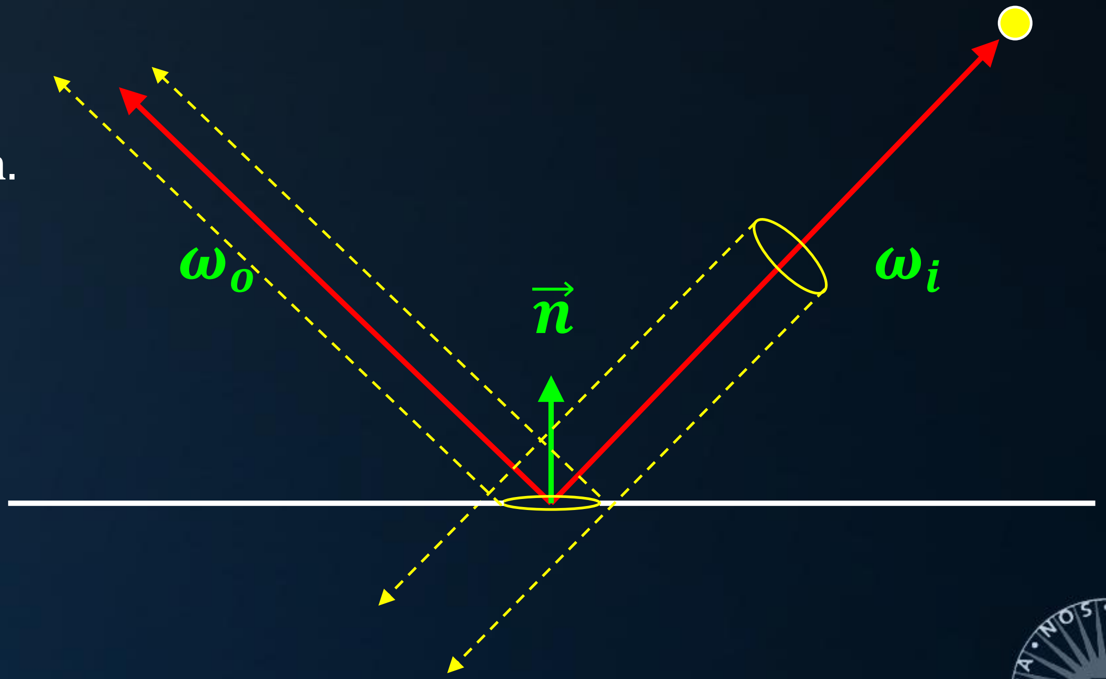
Fresnel Term

Microfacet BRDF, ingredient 3: $F(\vec{L}, \vec{H})$ ➔ the *Fresnel term.*

So far, we assumed that the light reflected by a specular surface is only modulated by the material color.

This is not true for dielectrics: here we use the Fresnel equations to determine reflection.

In nature, Fresnel does not just apply to dielectrics.



Microfacet

Fresnel Term

Iron is specular, but reflectivity differs depending on incident angle.

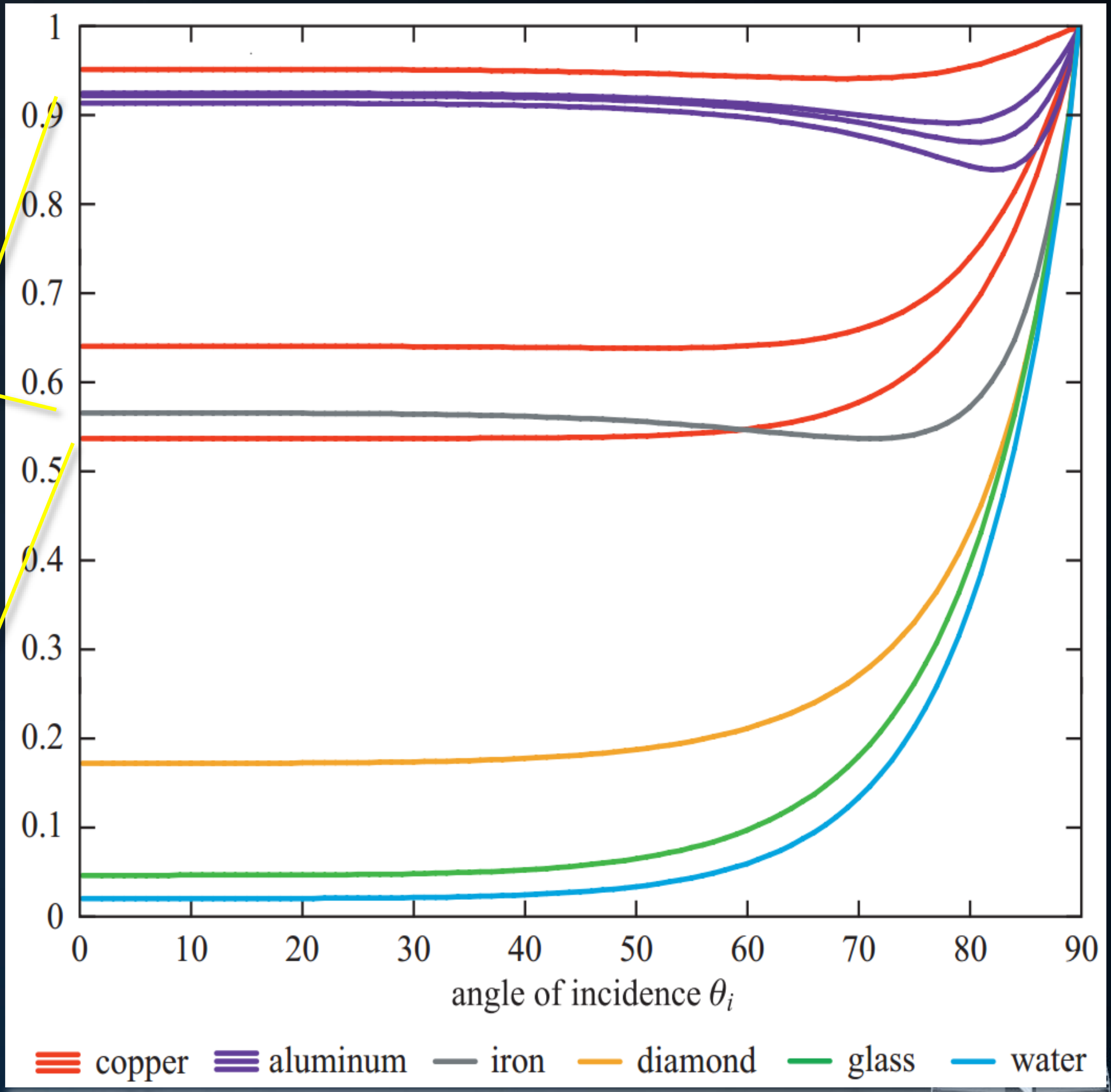
Aluminum is even more interesting: reflectivity depends on wavelength. The three lines in the graph:

Top: blue, middle: green, bottom: red.

Copper takes this to extremes: at grazing angles, it appears white. The lines in the graph:

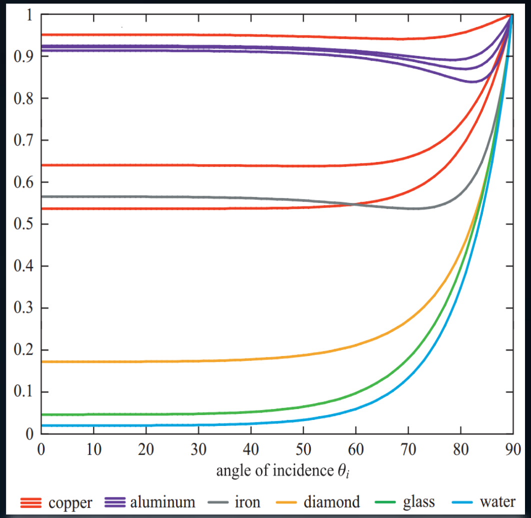
Top: red, middle: green, bottom: blue.

(hence its reddish appearance)



From “Real-time Rendering, 3rd edition, A. K. Peters.

Microfacet



Fresnel Term

For Fresnel, we use Schlick's approximation:

$$F_r = k_{specular} + (1 - k_{specular})(1 - (\vec{L} \cdot \vec{H}))^5$$

Note that this is calculated per color channel ($k_{specular}$ is an rgb triplet).

Values for $k_{specular}$ for various materials:

Iron	0.56, 0.57, 0.58
Copper	0.95, 0.64, 0.54
Gold	1.00, 0.71, 0.29
Aluminum	0.91, 0.92, 0.92
Silver	0.95, 0.93, 0.88

Microfacet

Bringing it All Together

The Microfacet BRDF:

$$f_r(\vec{L},\vec{V}) = \frac{F(\vec{L},\vec{V})G(\vec{L},\vec{V},\vec{H})D(\vec{H})}{4(\vec{N}\cdot\vec{L})(\vec{N}\cdot\vec{V})}$$

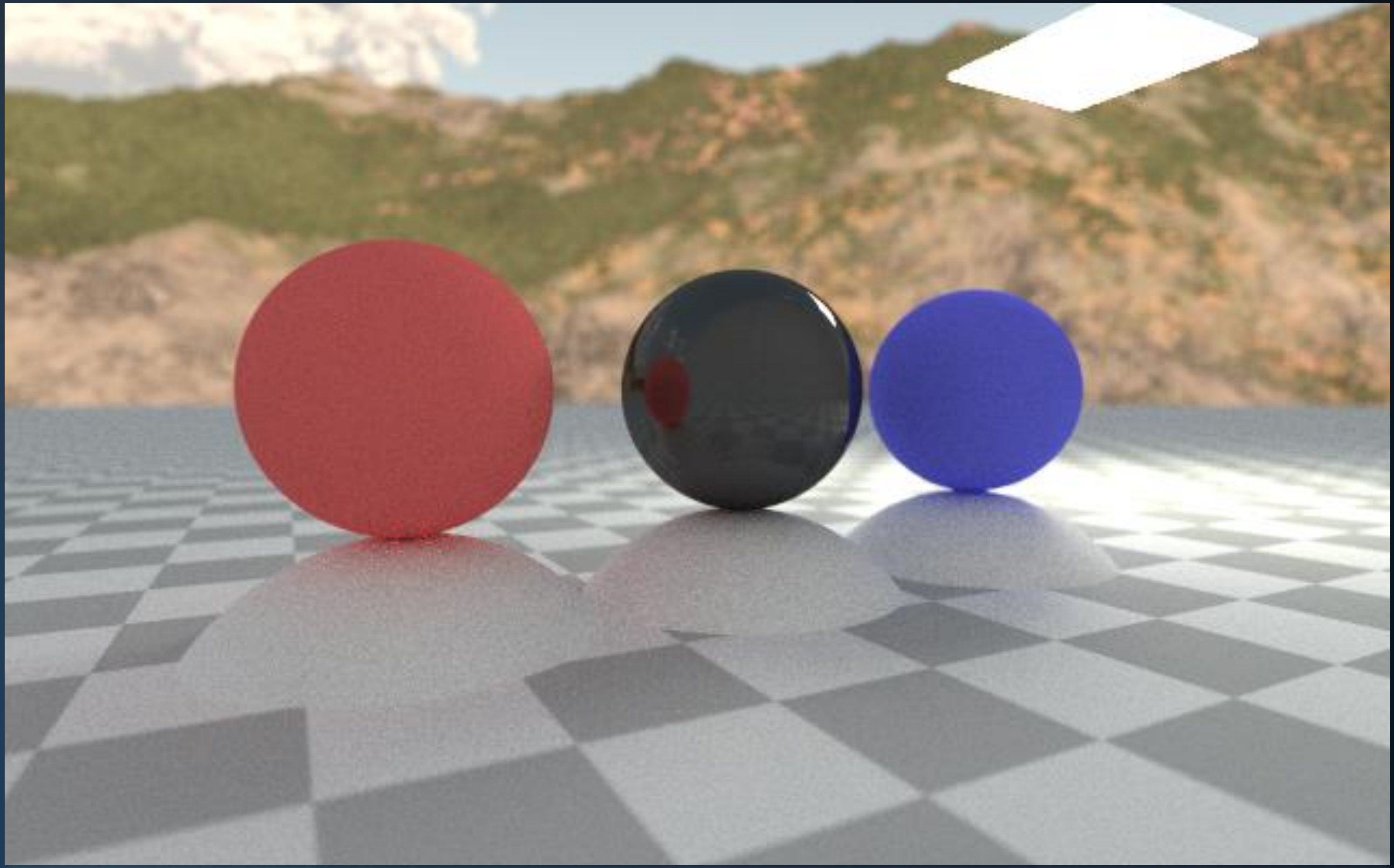
$$D(\vec{H}) = \frac{\alpha+2}{2\pi}\underline{(\vec{N}\cdot\vec{H})}^{\alpha}$$

$$G(\vec{V},\vec{L},\vec{H}) = \min\left(1, \min\left(\frac{2(\vec{N}\cdot\vec{H})(\vec{N}\cdot\vec{V})}{\underline{\vec{V}\cdot\vec{H}}}, \frac{2(\vec{N}\cdot\vec{H})(\vec{N}\cdot\vec{L})}{\underline{\vec{V}\cdot\vec{H}}}\right)\right)$$

$$F_r = k_{specular} + (1-k_{specular})(1-(\vec{L}\cdot\vec{H}))^5$$

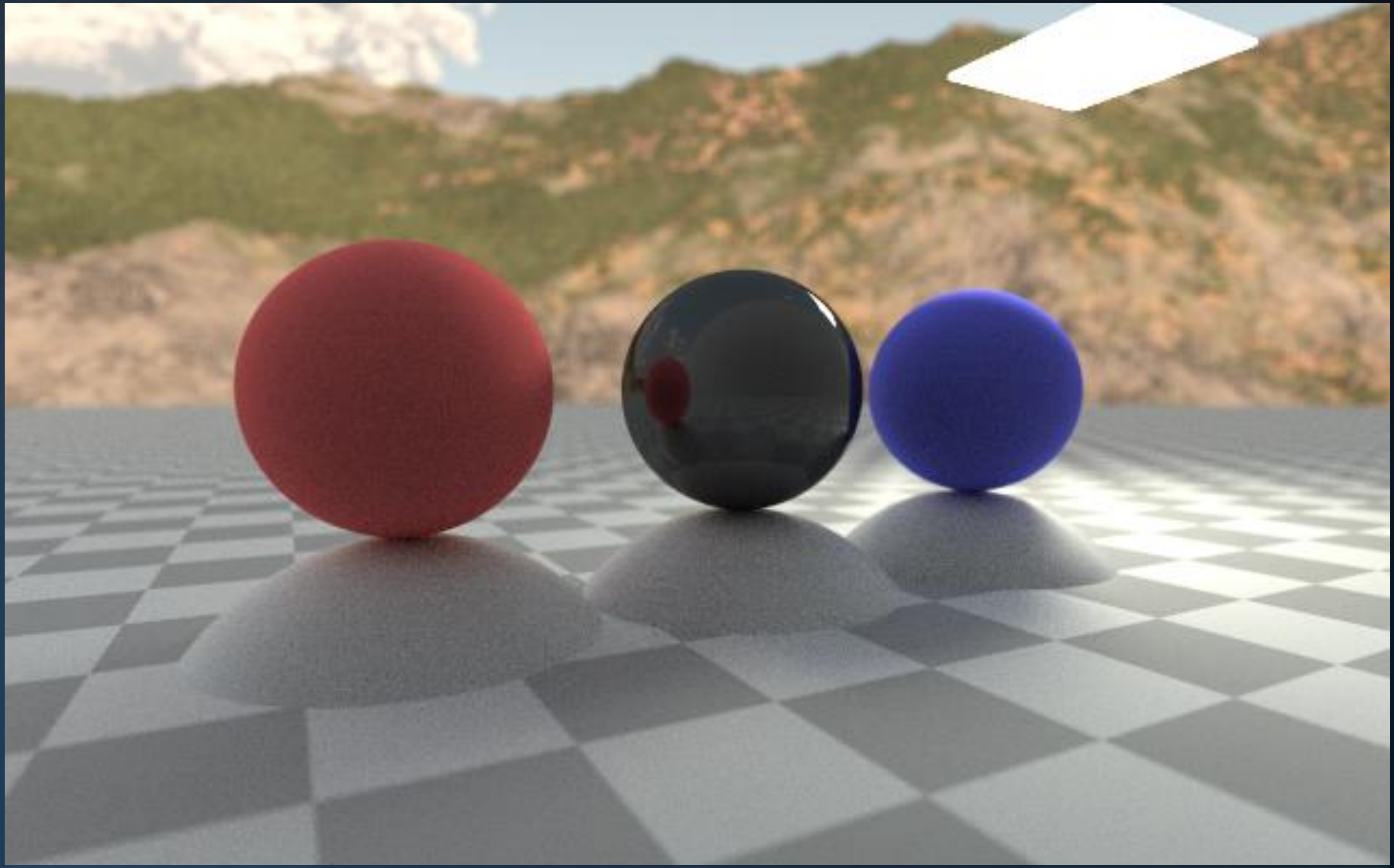
For a full derivation of the denominator of the BRDF, see Physically Based Rendering, section 8.4.2.

Microfacet



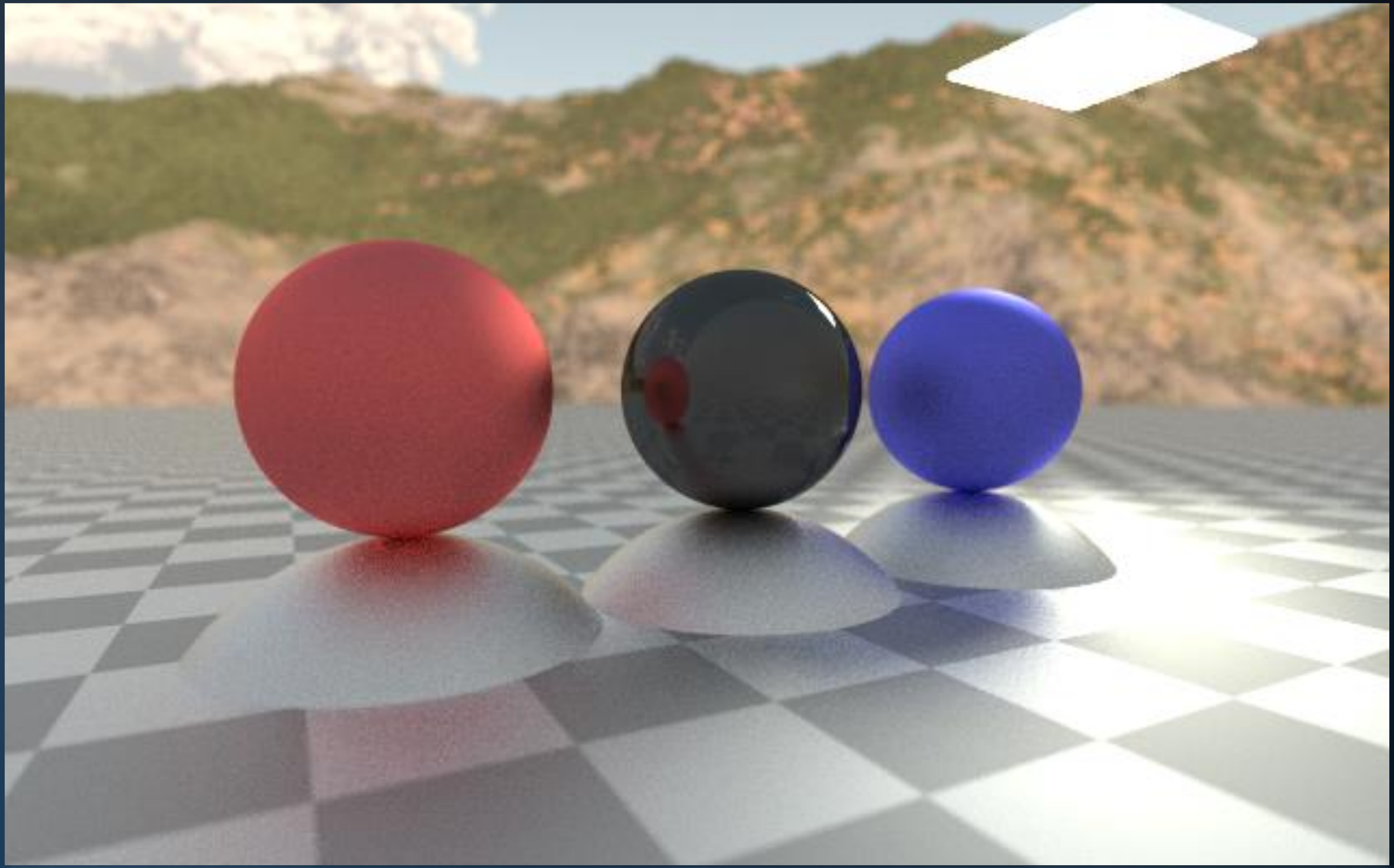
Lambertian BRDF

Microfacet



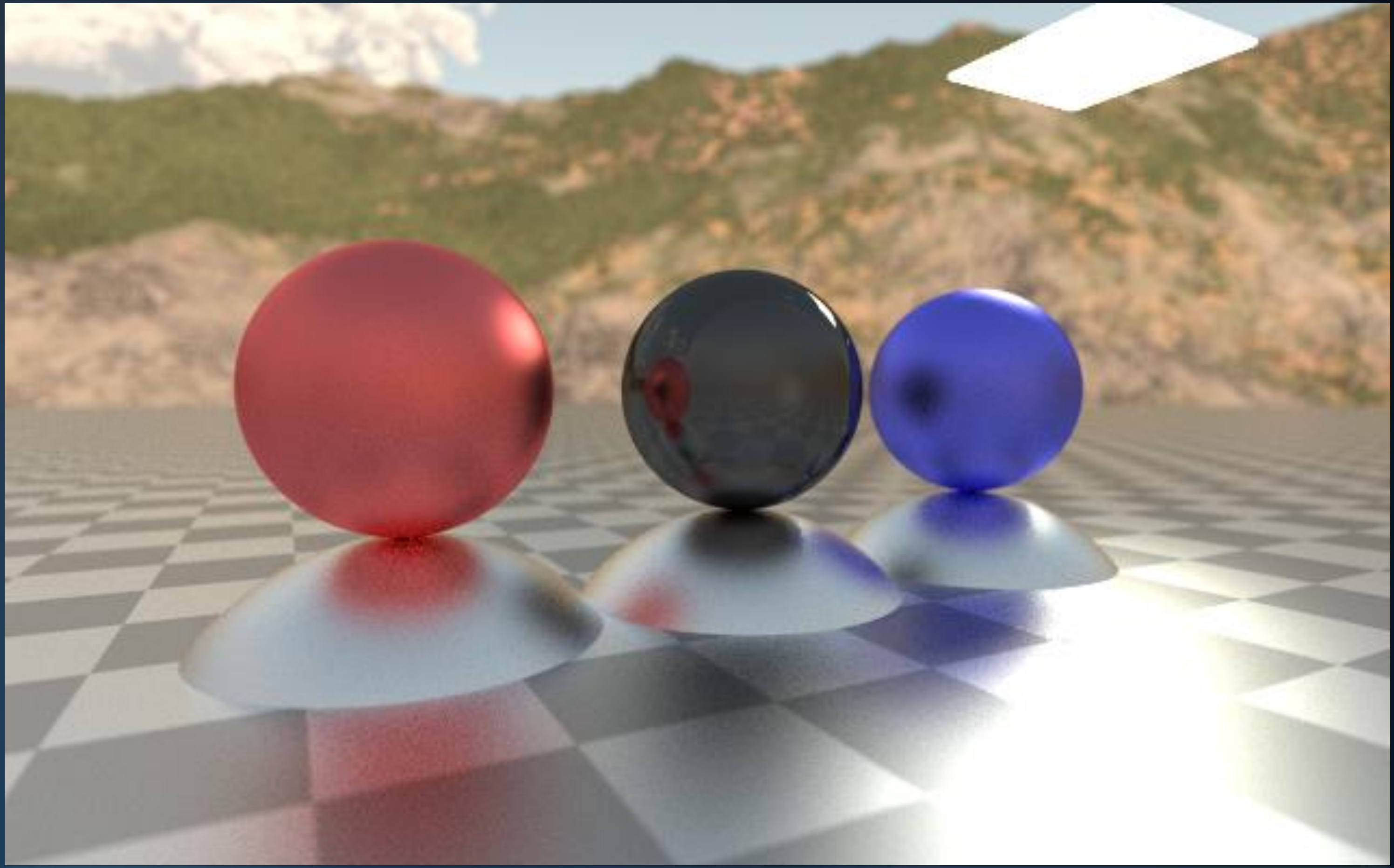
Blinn-Phong Microfacet BRDF, $\alpha=1$

Microfacet



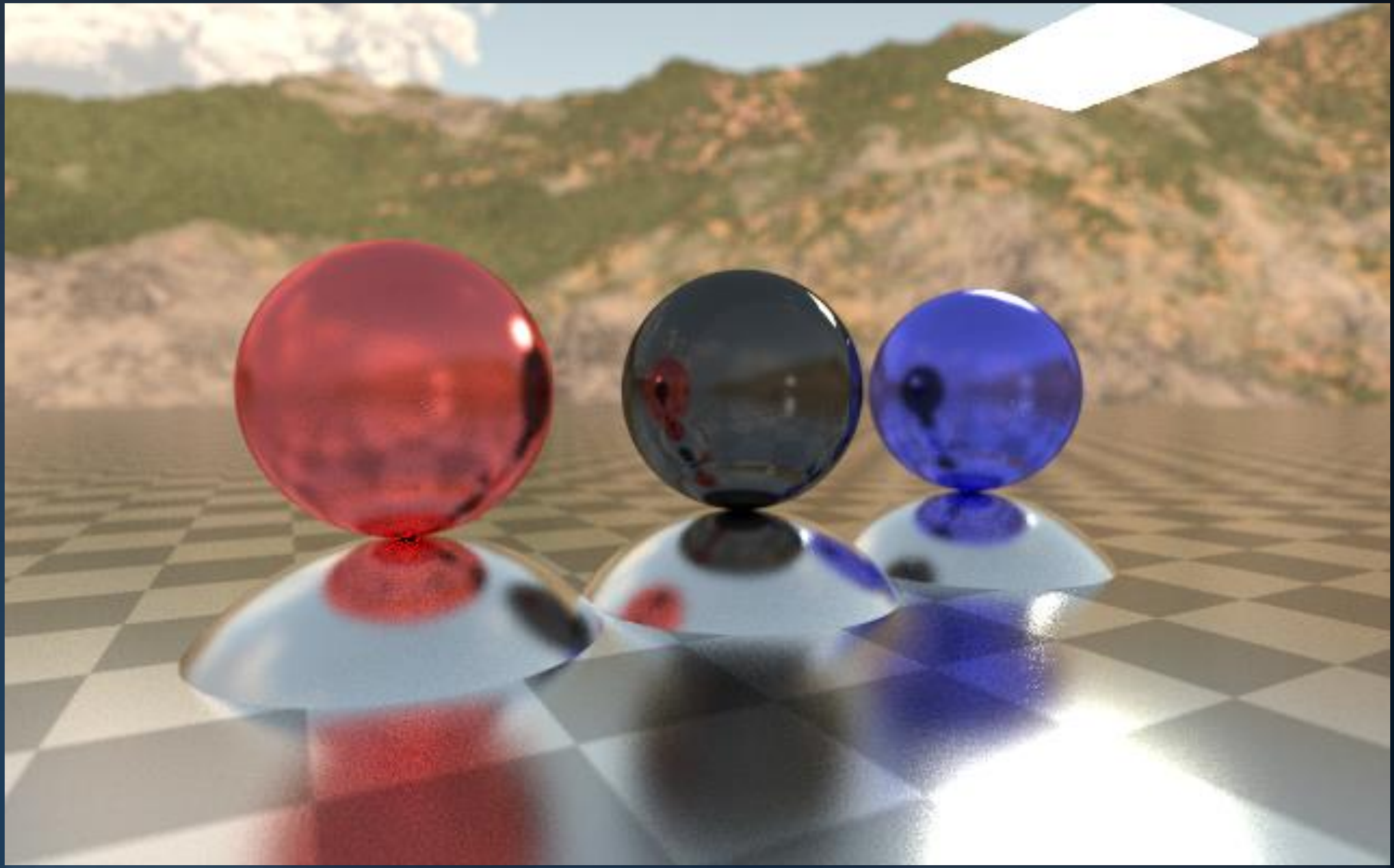
Blinn-Phong Microfacet BRDF, α=10

Microfacet



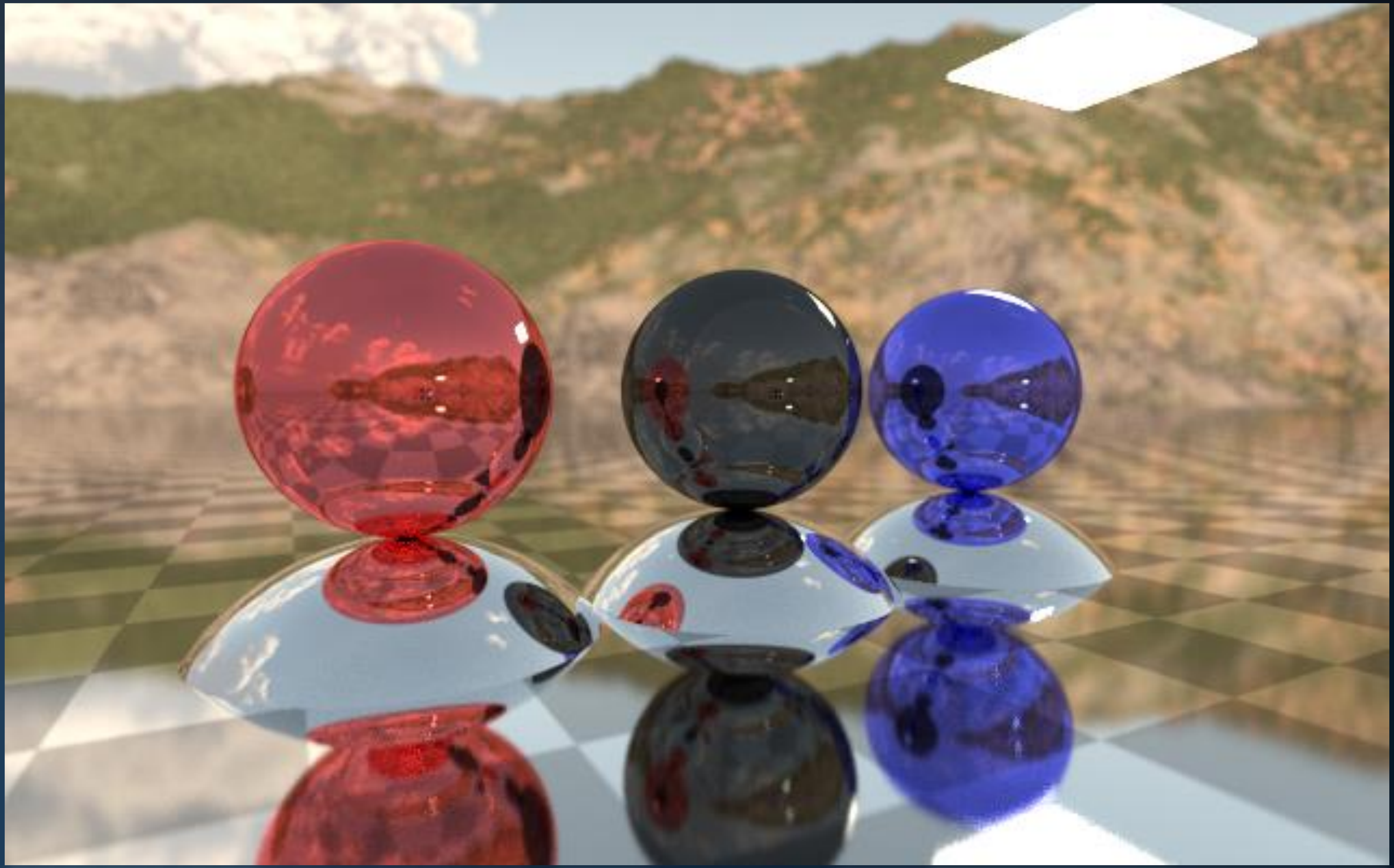
Blinn-Phong Microfacet BRDF, α=50

Microfacet



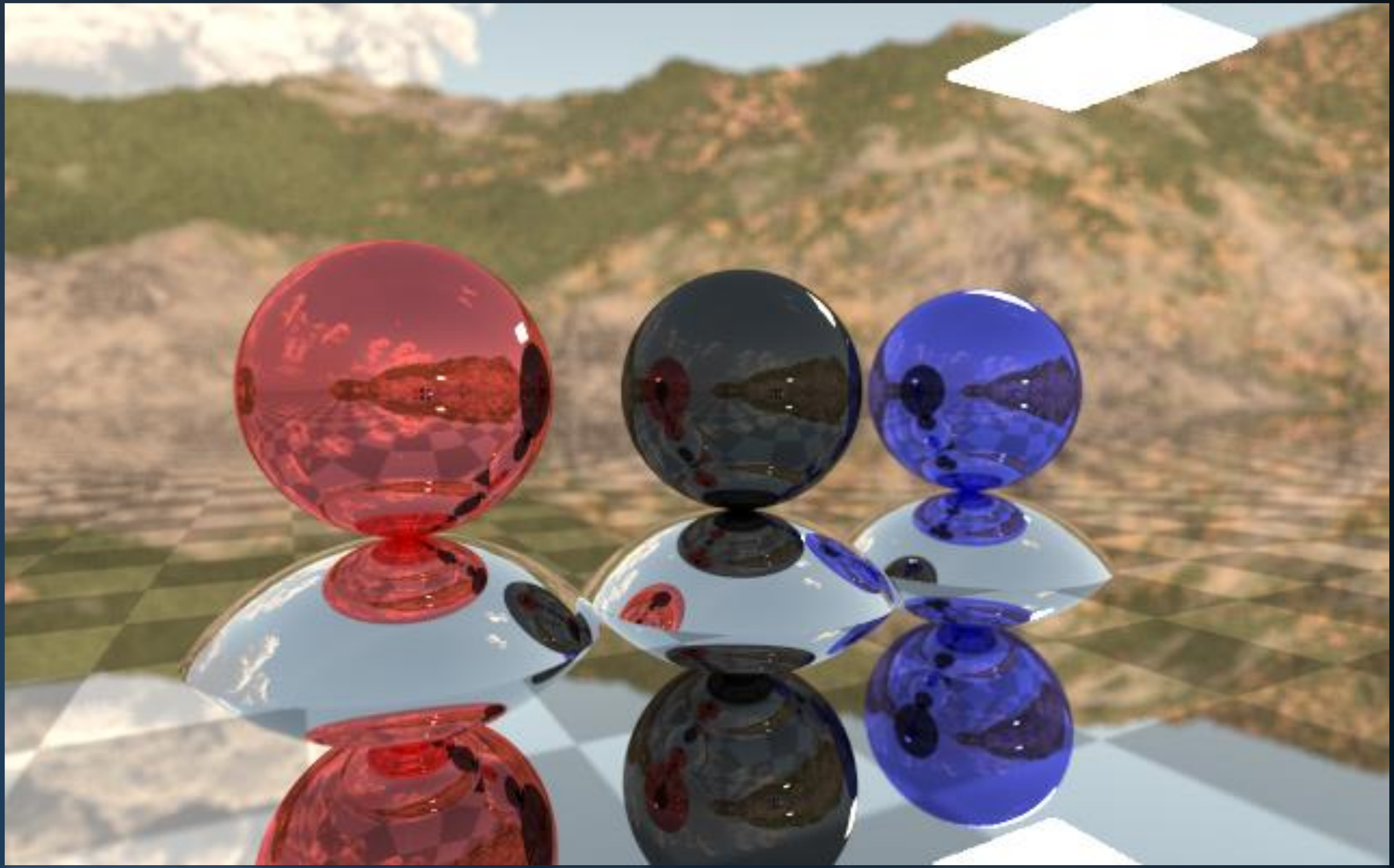
Blinn-Phong Microfacet BRDF, α=500

Microfacet



Blinn-Phong Microfacet BRDF, α=50000

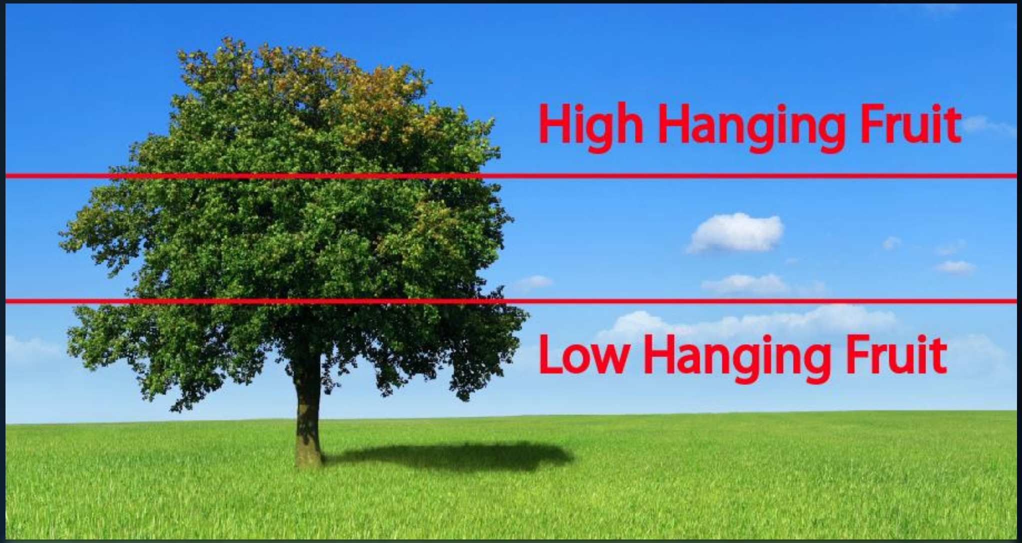
Microfacet



Specular BRDF

Today's Agenda:

- Gamma Correction
- Depth of Field
- Skybox
- Spots, IES Profiles
- Microfacets



INFOMAGR – Advanced Graphics

Jacco Bikker - November 2021 - February 2022

END of “Various”

next: Assignment 2 deadline, then: Christmas Break