Image Formation

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Image Formation: Luminance

- Light is emitted by light source
- Light is reflected from objects
- Reflected light is sensed by eye or by camera

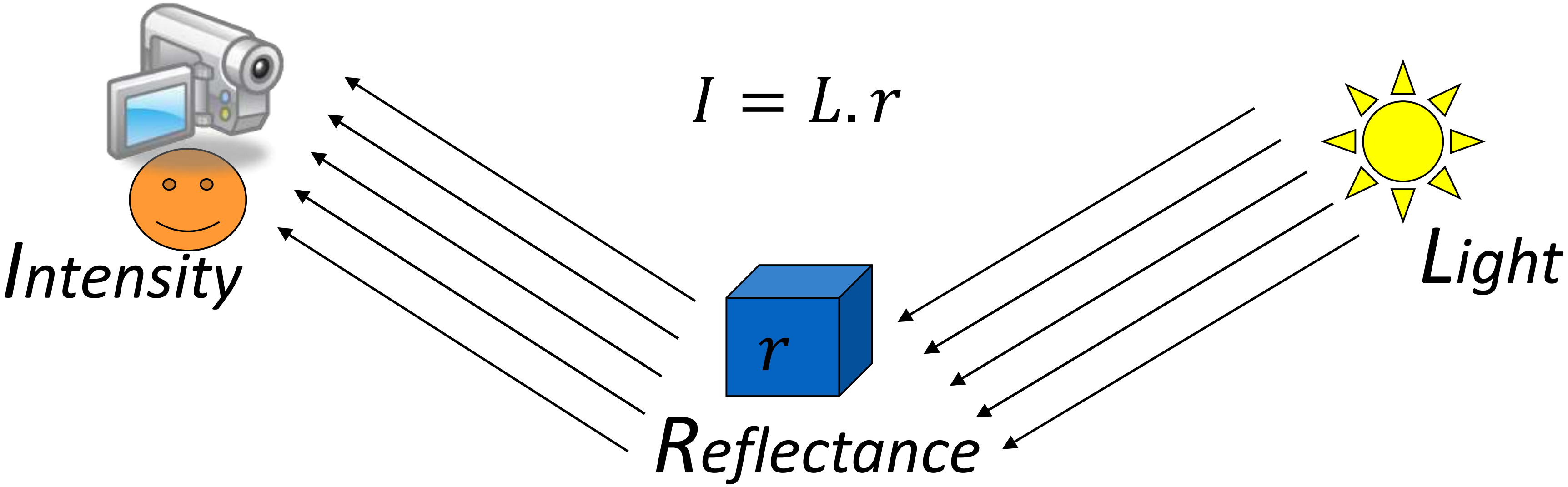

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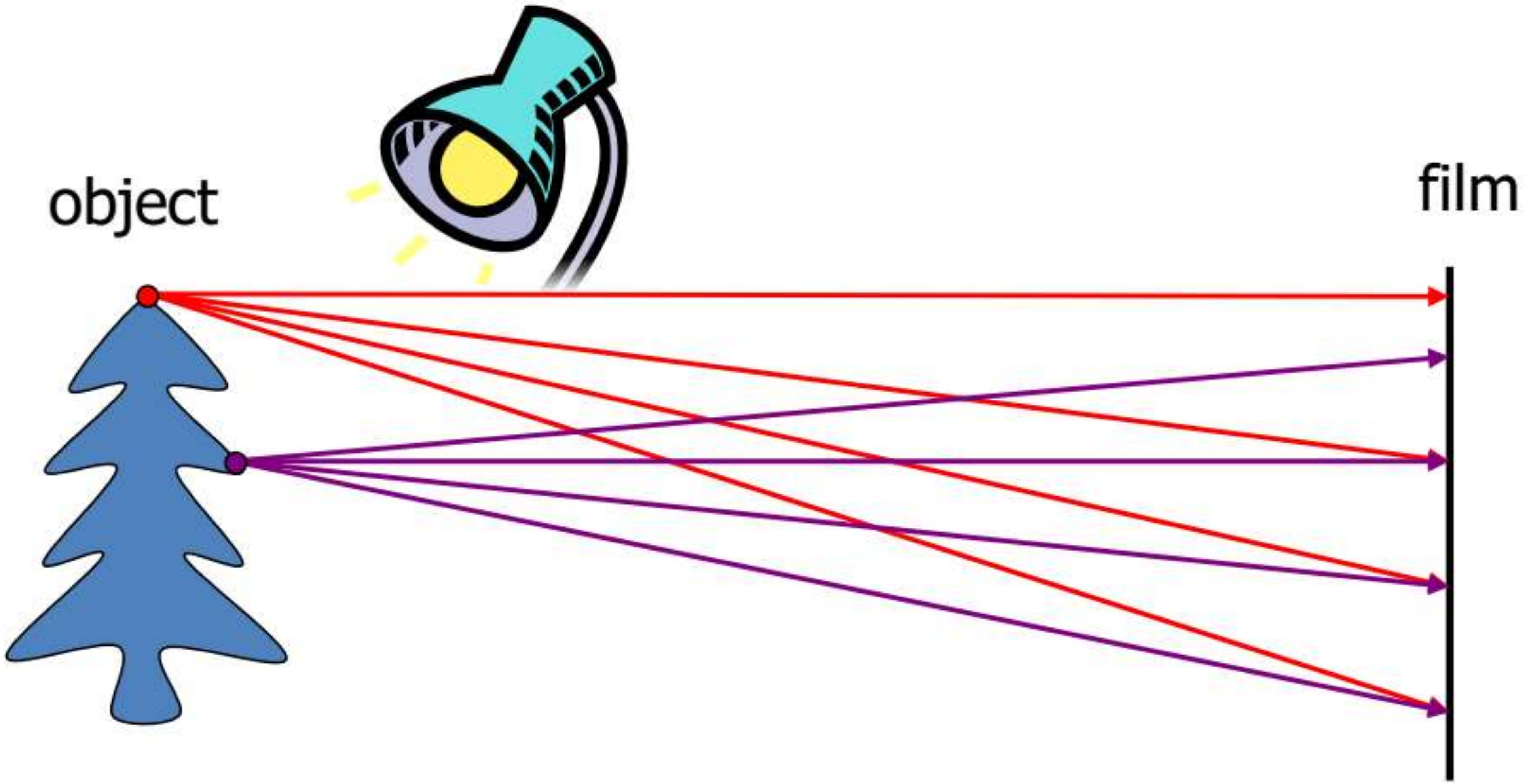
Image Capture

- Place a piece of film in front of an object: Do we get a reasonable image?



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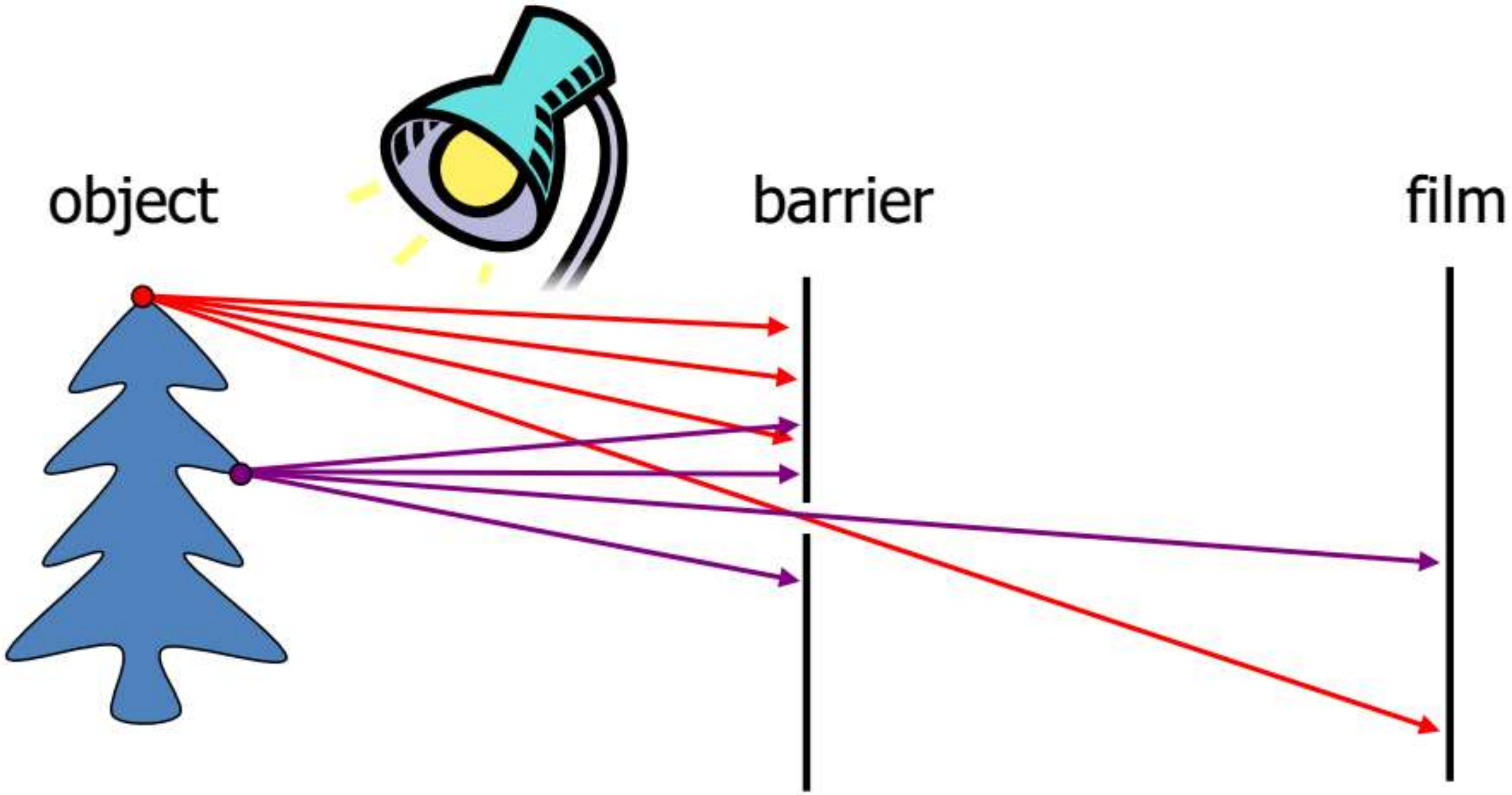
Pinhole camera

- Add a barrier to block off most of the rays
  - This reduces blurring
  - The opening is known as the aperture



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Effects of the Aperture Size

- In an ideal pinhole, only one ray of light reaches each point on the film
  - The image can be very dim
- Making aperture bigger makes the image blurry

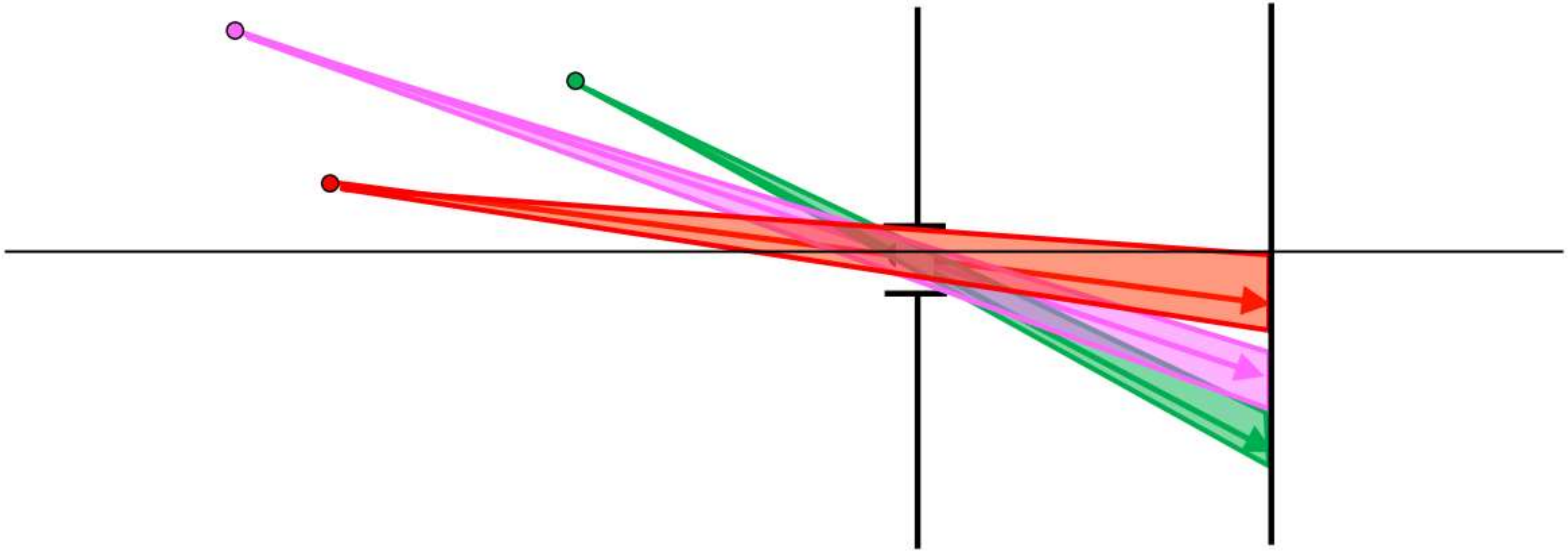

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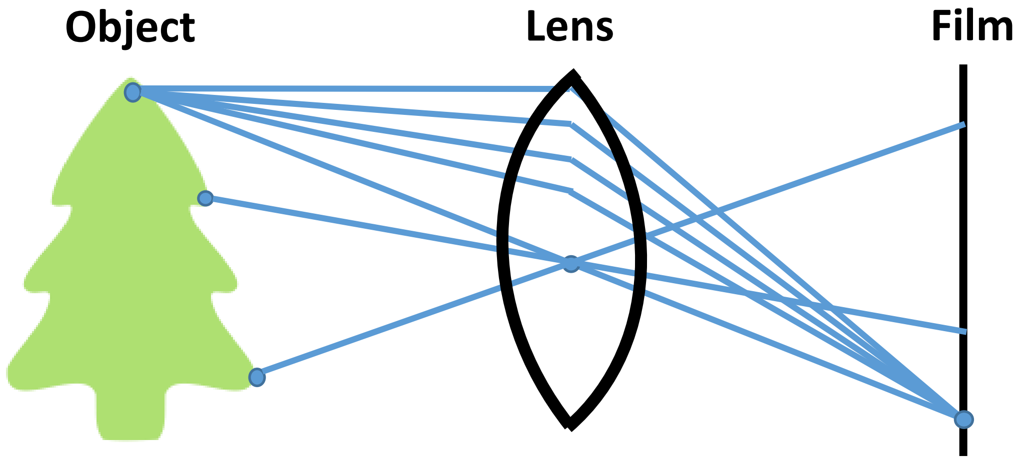
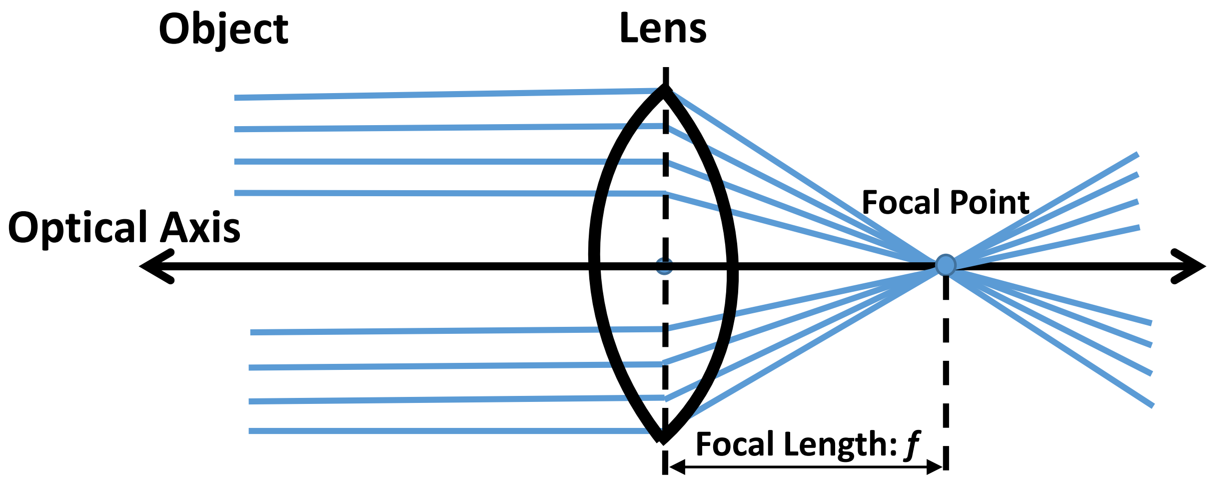
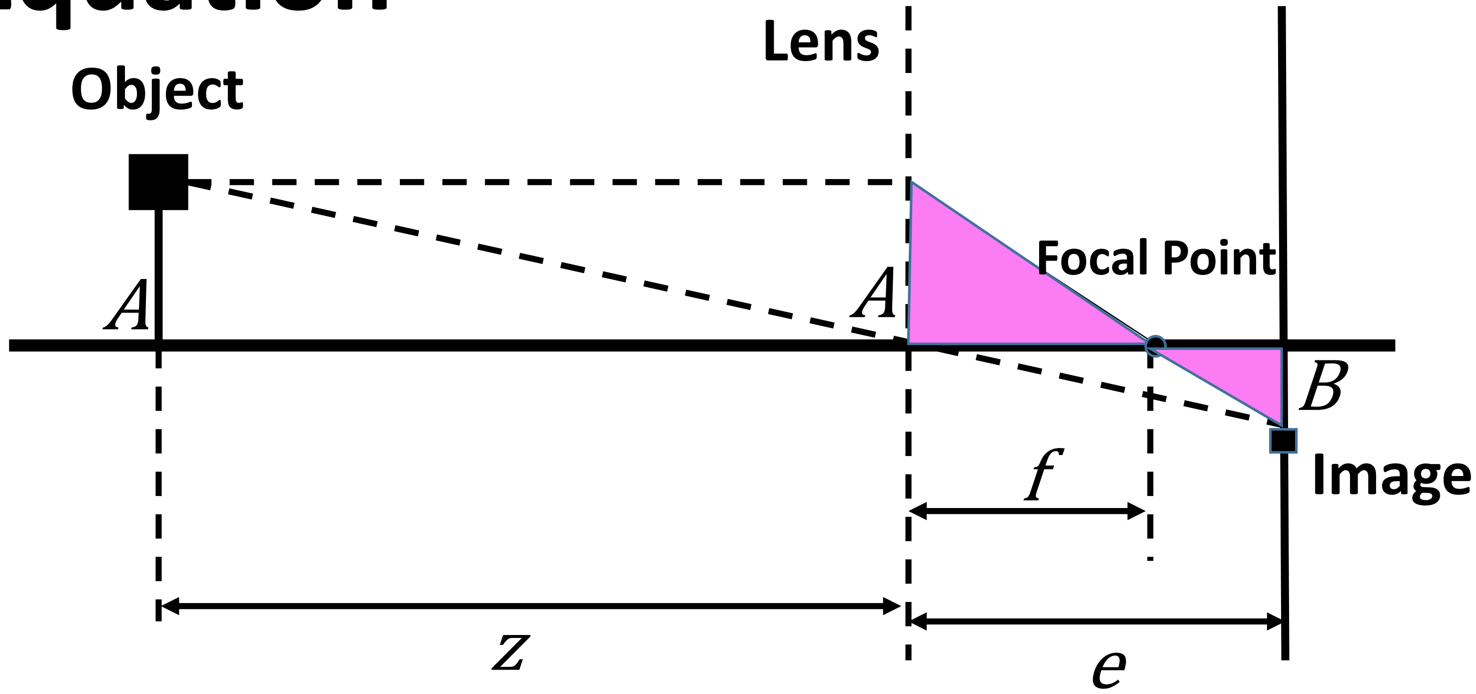
Image Capturing using a Converging Lens

- A lens focuses light onto the film.
- Rays passing through the 'Optical Center' are not deviated.
- All rays parallel to the 'Optical Axis' converge at the 'Focal Point'.





Thin Lens Equation



- Similar Triangles

$$\frac{B}{A} = \frac{e}{z}$$

$$\frac{B}{A} = \frac{e-f}{f} = \frac{e}{f} - 1$$

$$\frac{e}{f} - 1 = \frac{e}{z} \quad \Rightarrow \quad \frac{1}{f} = \frac{1}{z} + \frac{1}{e}$$

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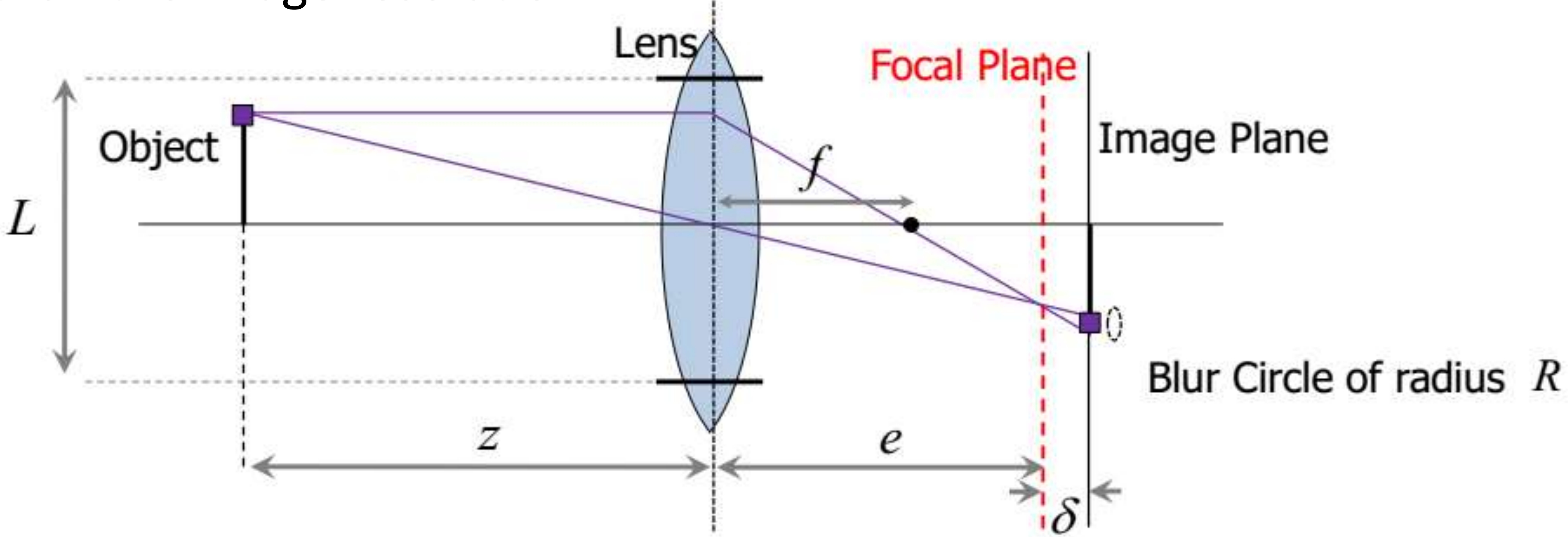
Blur Circle

- Object is out of focus ⇒ Blur Circle has radius: $R = \frac{L\delta}{2e}$
- A minimal L (pinhole) gives minimal R
- To capture a 'good' image, adjust camera settings, such that R remains smaller than the image resolution



Focus and Depth of Field (DOF)

- Although a lens can precisely focus at only one distance at a time, the decrease in sharpness is gradual on each side of the focused distance, so that within the DOF, the un-sharpness is ‘imperceptible’ under normal viewing conditions (depends upon pixel width: usually less than a pixel)
- Depth of field (DOF) is the distance between the nearest and farthest objects in a scene that appear acceptably sharp in an image.

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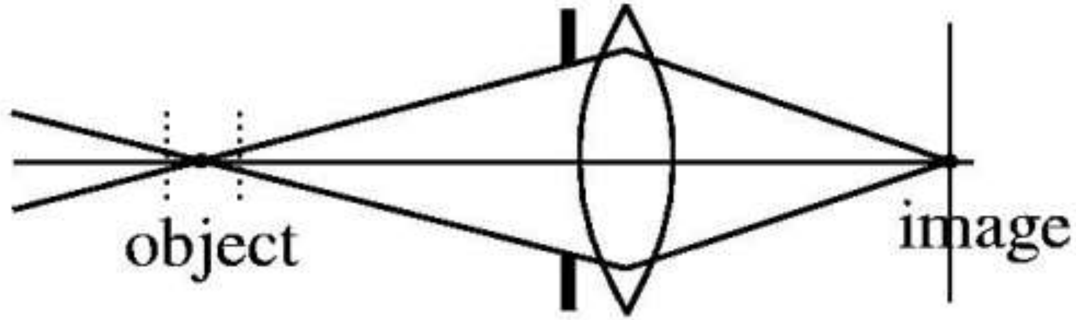
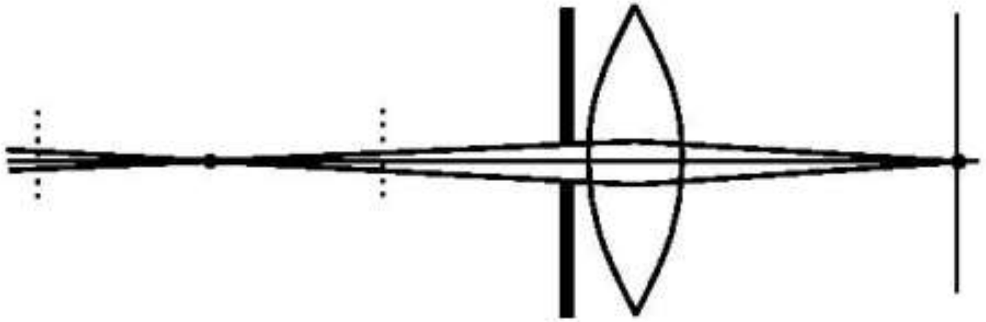
DOF and Aperture

- How does the aperture affect the depth of field?
- A smaller aperture increases the range in which the object appears approximately in focus but reduces the amount of light into the camera





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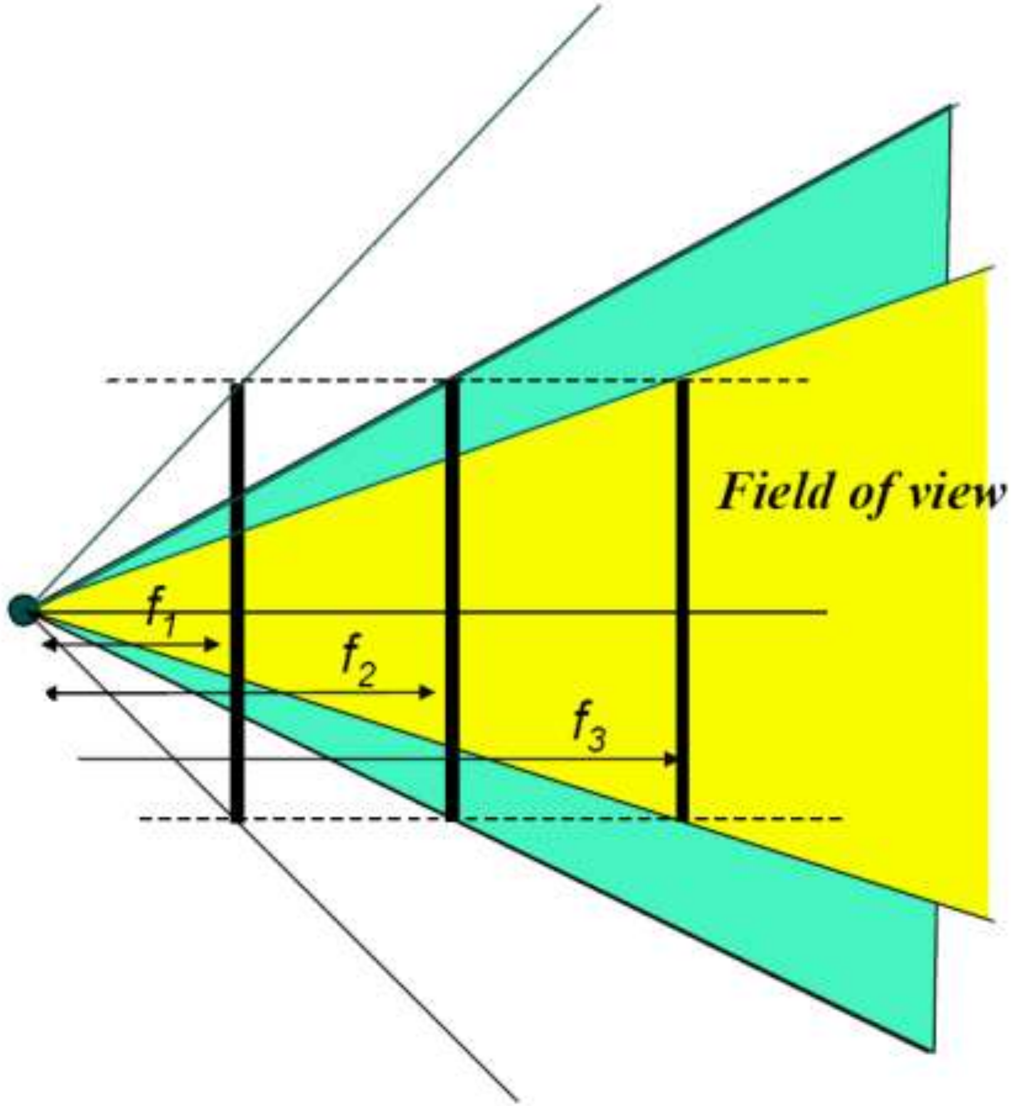
Focal Length and Field of View (FOV)

- As f gets smaller, image becomes more wide angle
  - more world points project onto the finite image plane

- As f gets larger, image becomes more narrow angle
  - smaller part of the world projects onto the finite image plane



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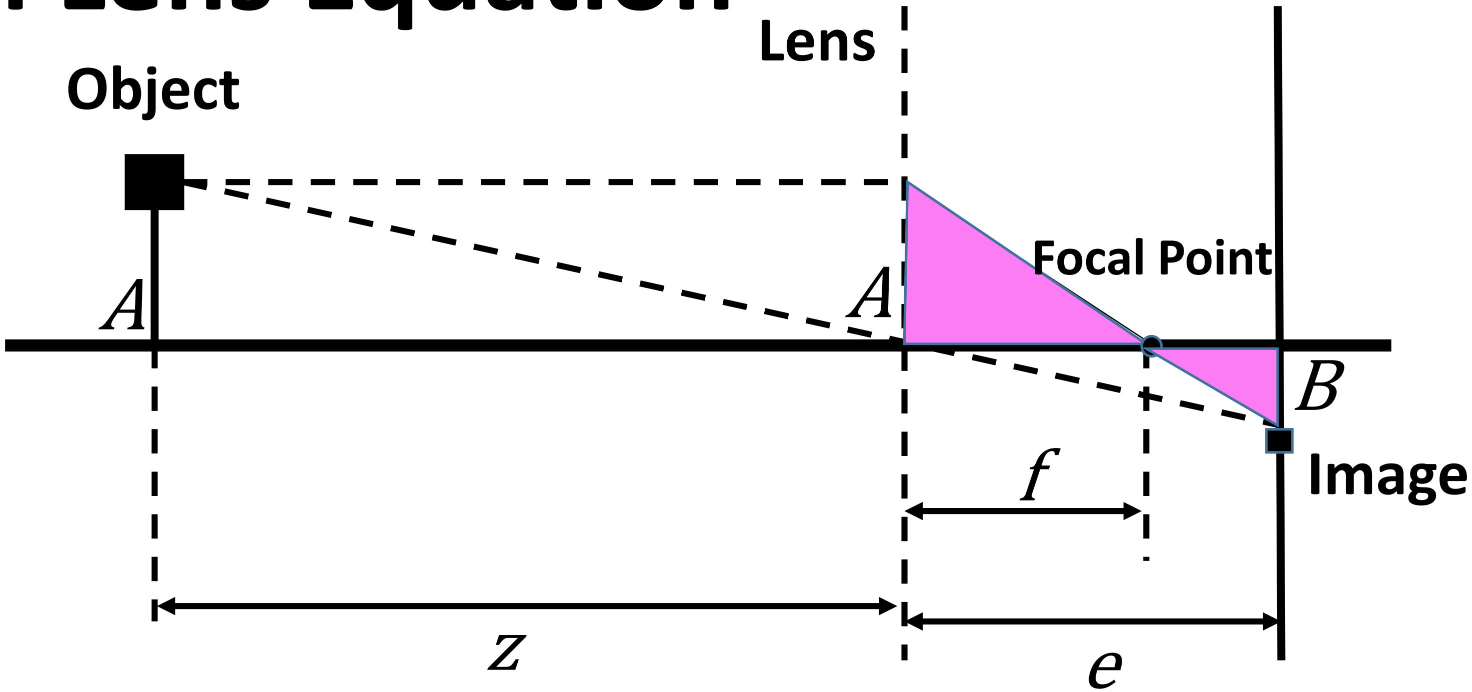
Recall: Thin Lens Equation



- Similar Triangles

$$\left.\begin{aligned} \frac{B}{A} &= \frac{e}{z} \\ \frac{B}{A} = \frac{e-f}{f} &= \frac{e}{f} - 1 \end{aligned}\right\} \quad \frac{e}{f} - 1 = \frac{e}{z} \quad \Rightarrow \quad \frac{1}{f} = \frac{1}{z} + \frac{1}{e}$$

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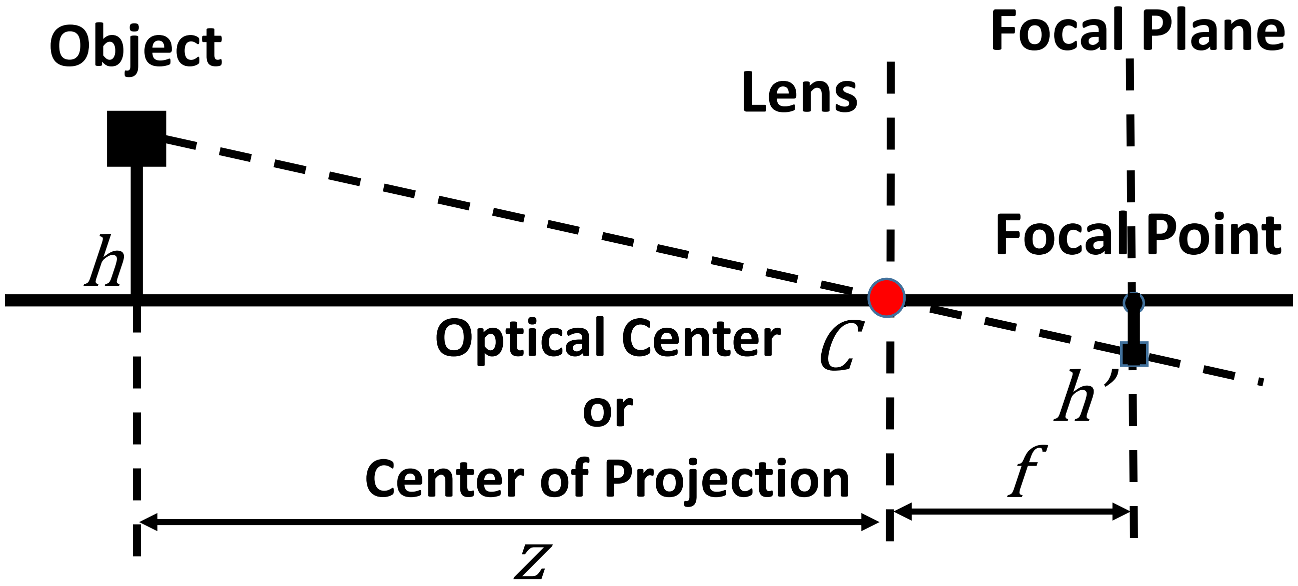
Pinhole Approximation

- What happens if $z \gg f$?
- We need to adjust the image plane such that objects at infinity are in focus.

$$\frac{1}{f} = \underbrace{\boxed{\frac{1}{z}}}_{} + \frac{1}{e} \Rightarrow \frac{1}{f} \approx \frac{1}{e} \Rightarrow f \approx e$$

$$\overset{= 0}{\boxed{\tfrac{1}{z}}}$$

$$\frac{h'}{h} = \frac{f}{z} \Rightarrow h' = \frac{f}{z} h$$



- The dependence of the apparent size of an object on its depth (i.e. distance from the camera) is known as **perspective**

Perspective Effects

- Far away objects appear smaller

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Perspective Effects

- Parallel lines in the world intersect in the image at a "vanishing point"

Color

Colorimetry

- Light is **Electromagnetic Energy** in the 400nm to 700nm wavelength.

- Pure or **Monochromatic Light** is perceived as one color in the range violet-indigo-blue-green-yellow-orange-red of the rainbow.

- The amount of energy present at each wavelength is represented by the **Spectral Energy Distribution** of the light.

Source: https://www.mat.univie.ac.at/~kriegl/Skripten/CG/node8.html

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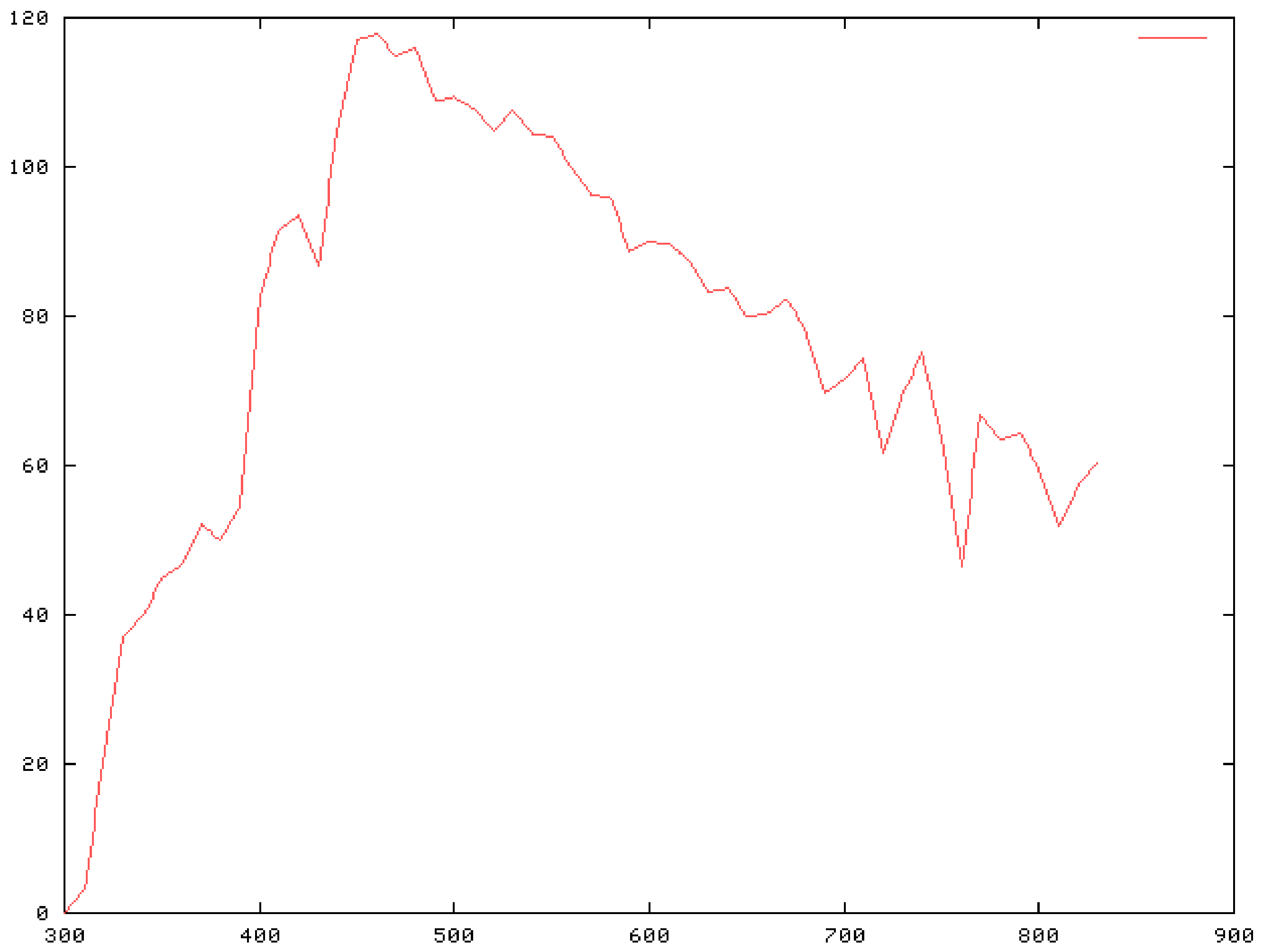
Colorimetry

- The spectral-energy-distributions of sunlight (what we call white light) is as shown on the right.

- Note: The dominant wavelength is not necessarily that with largest spectral component.



Source: https://www.mat.univie.ac.at/~kriegl/Skripten/CG/node8.html

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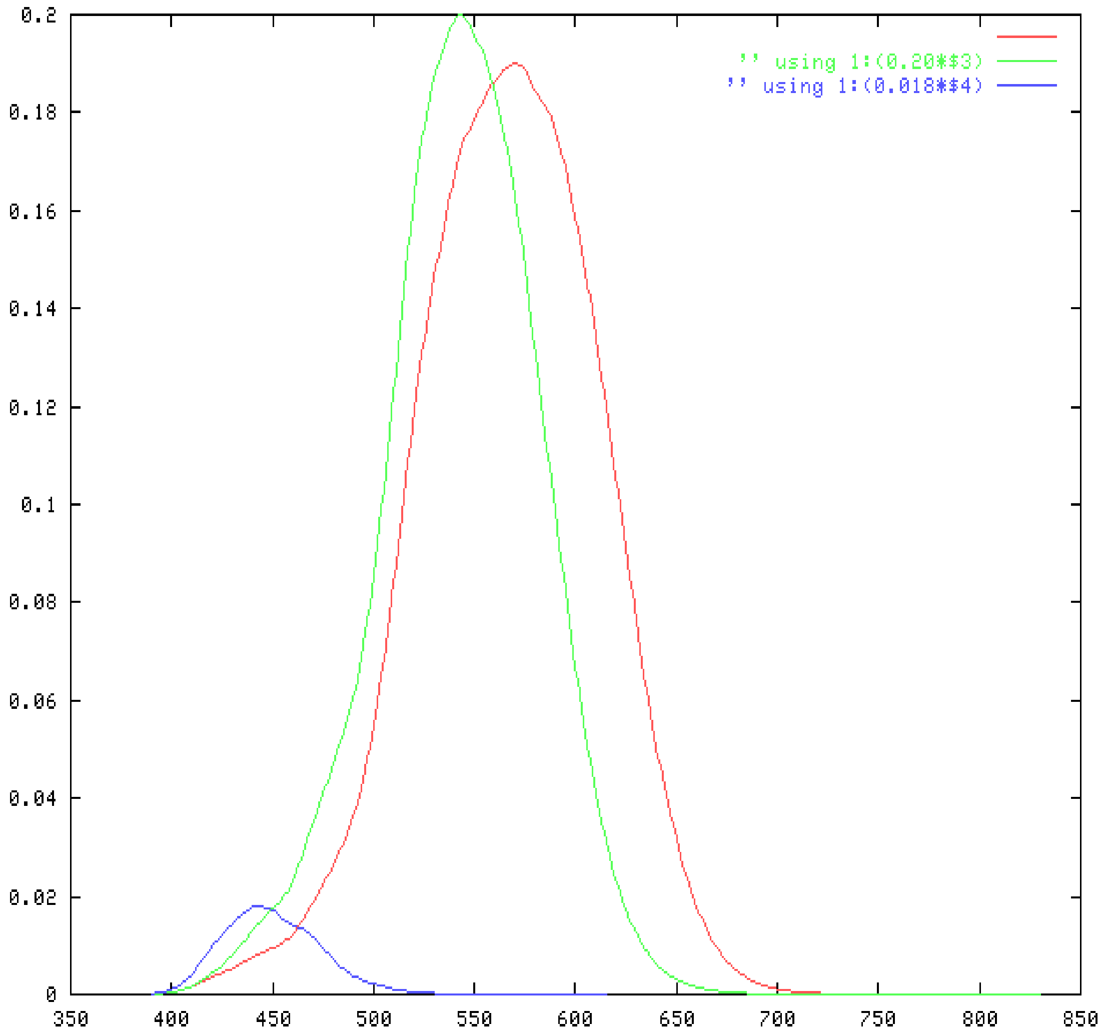
Color and Human Eye

- The human retina has 3 kind of color sensors (called **cones**) with approx. peak sensitivity at red, green and blue.
- The spectral response function R, G and B of these cones to monochromatic light is on the right.
- Response to blue light is less strong. The sensitivity peaks of R and G are in the yellow range.



Source: https://www.mat.univie.ac.at/~kriegl/Skripten/CG/node8.html

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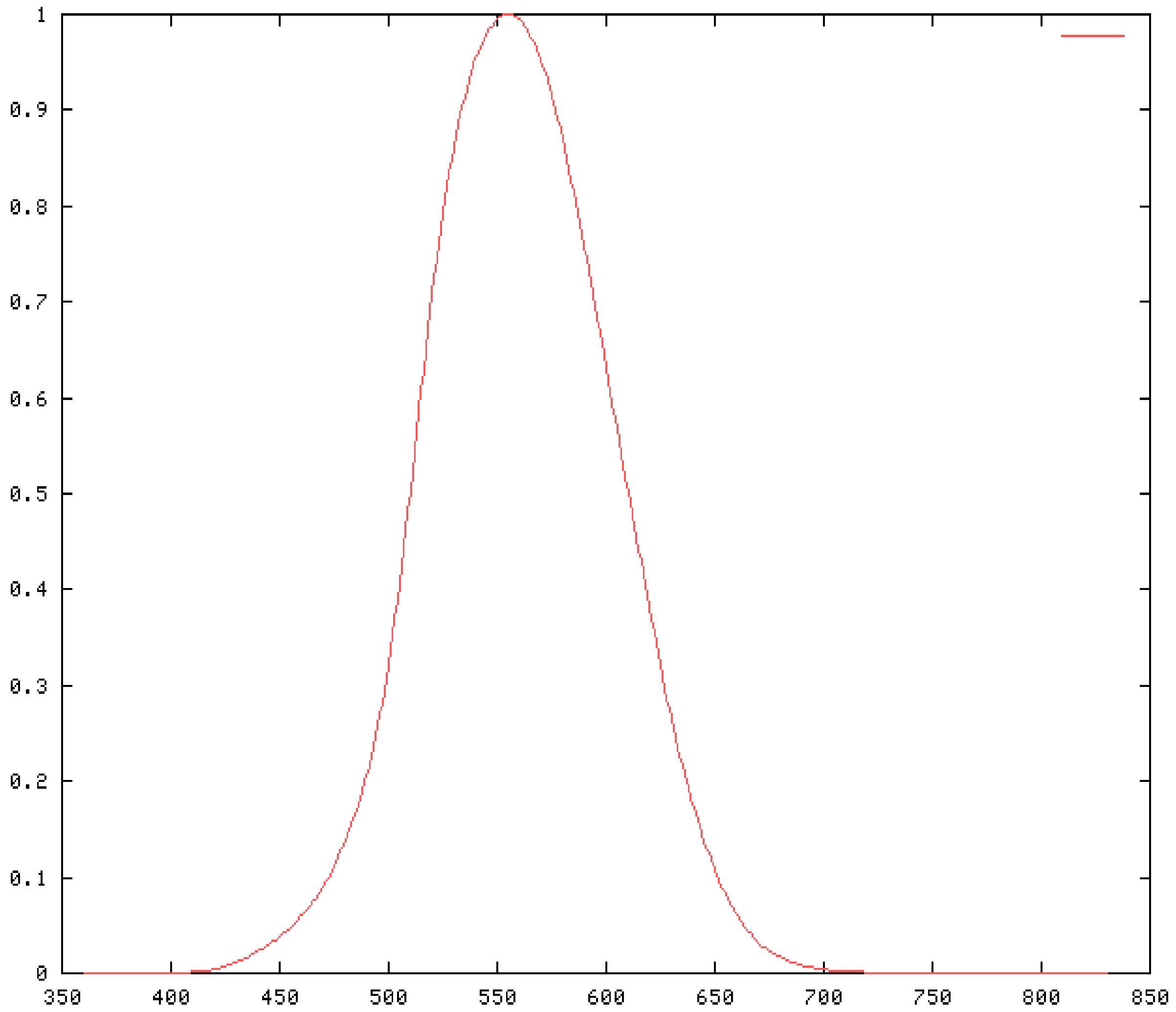
Color Sensitivity

- Luminous efficiency function (the eye's response to light of constant luminance at a given wavelength) corresponds to the sum of the R, G, and B spectral response curves.

- Human eye seems to be most sensitive to the green hues.



Source: https://www.mat.univie.ac.at/~kriegl/Skripten/CG/node8.html

Reproducing Color

- Every human eye distinguishable color can be produced by a additive mixture of red, green and blue. This is the principle of color reproduction.

Experimental RGB Mix Identification:

- The observer would alter the brightness of each of the three primary beams until a match to the test color was observed.

Source: https://www.mat.univie.ac.at/~kriegl/Skripten/CG/node8.html

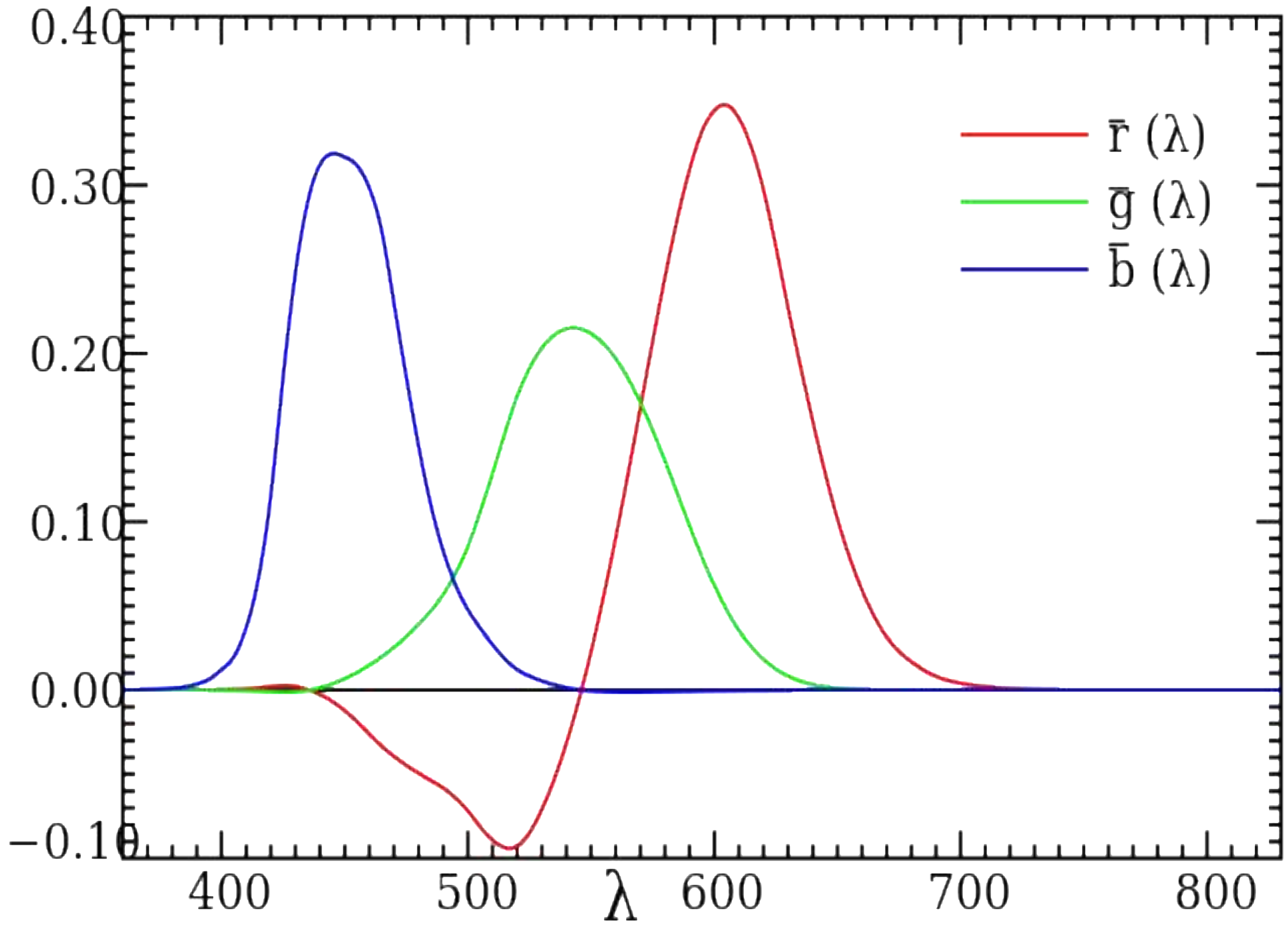
Reproducing Color

- Not all test colors could be matched using this technique.
- When this was the case, a variable amount of one of the primaries could be added to the test color, and a match with the remaining two primaries was carried out with the variable color spot.
- For these cases, the amount of the primary added to the test color was considered to be a negative value. In this way, the entire range of human color perception could be covered.

Source: https://www.mat.univie.ac.at/~kriegl/Skripten/CG/node8.html

Reproducing Color

- Negative values of red in the range from 450nm to 525nm.
- This amount of red has to be added to the given color in order that this new color can be matched by the described values of G and B.
- Certain colors **can not** be produced by R-G-B-mixes



Source: https://www.mat.univie.ac.at/~kriegl/Skripten/CG/node8.html

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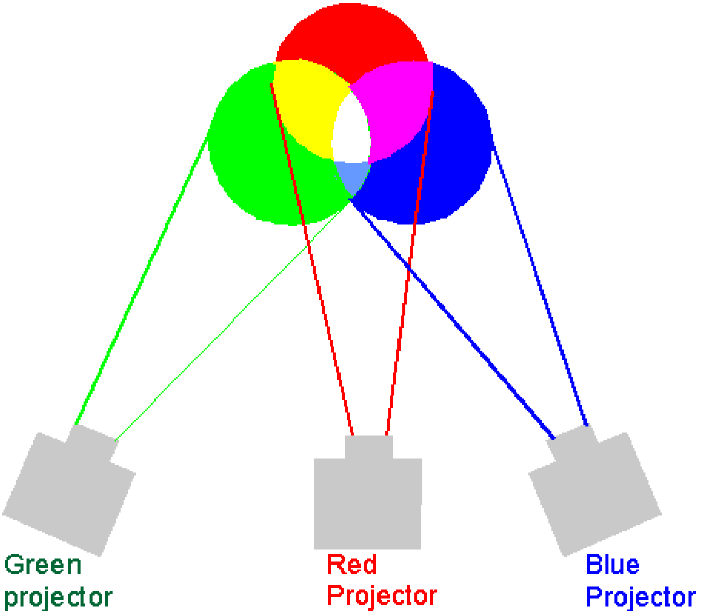
Color Models

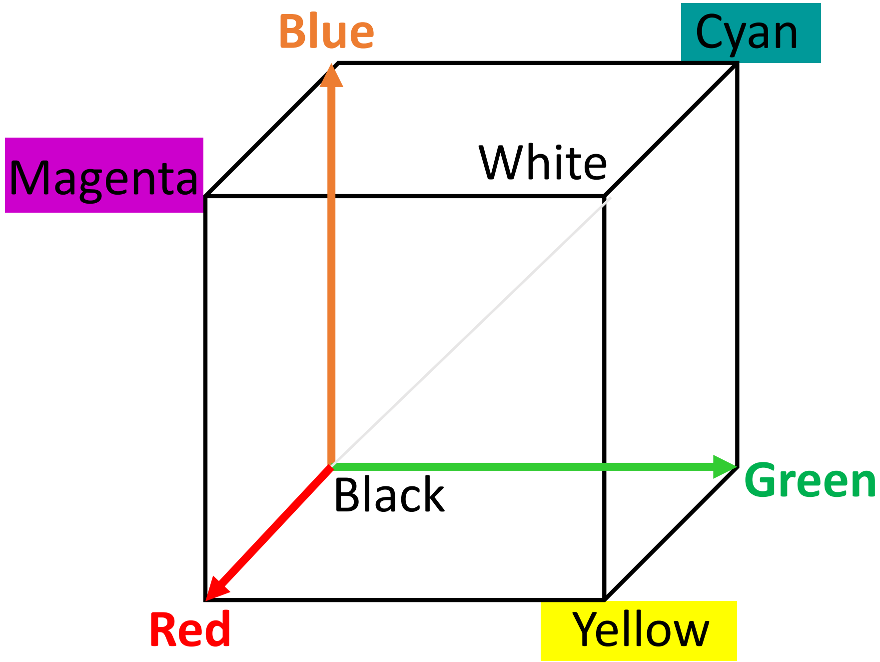
- $\text{color} = xR + yG + zB = \begin{bmatrix} x & y & z \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$

- $\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = 1 - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$

- LUV, HSV, …

- Gray





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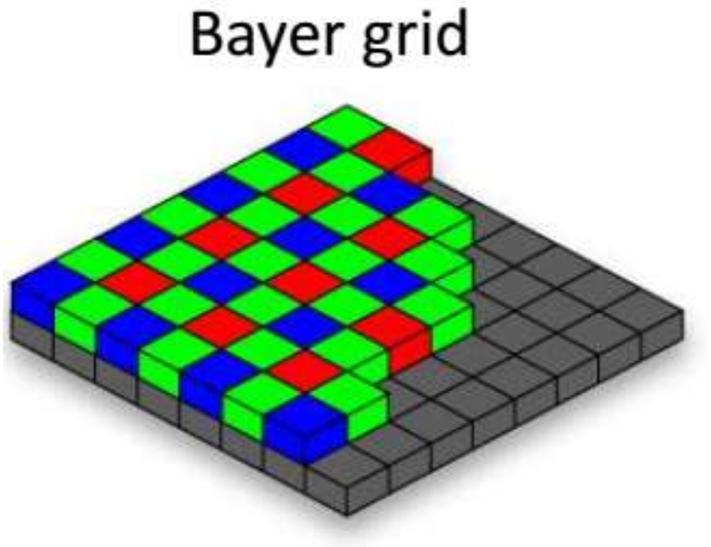
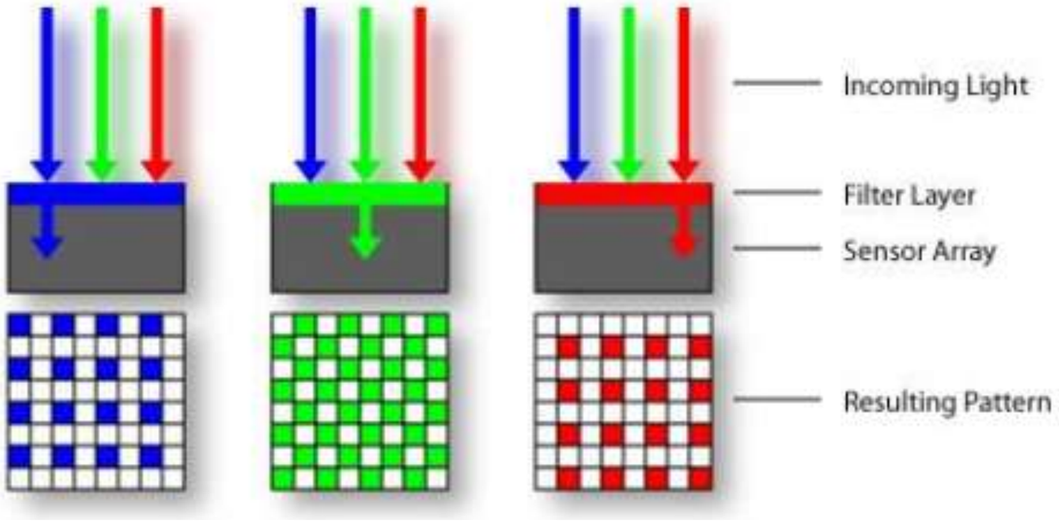
Color Sensing in Digital Cameras

- The Bayer pattern (Bayer 1976) places green filters over half of the sensors (in a checkerboard pattern), and red and blue filters over the remaining ones.

- RGB values at a pixel estimated using neighboring individual sensor values (demosaicing)





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Digital Pictures

- A Matrix of numbers (Greylevel image)
- A Matrix of triplets (RGB Color, etc.)

1	2	3	4	5	6	7	8	9	10	9	8	7	6	5
2	4	5	6	7	8	9	10	11	12	11	10	9	8	7
3	5	6	7	8	9	10	11	12	13	12	11	10	9	8
4	6	7	8	9	10	11	12	13	14	13	12	11	10	9
5	7	8	9	10	11	12	13	14	15	14	13	12	11	10
6	8	9	10	11	12	13	14	15	16	15	14	13	12	11
7	9	10	11	12	13	14	15	16	17	16	15	14	13	12
8	10	11	12	13	14	15	16	17	18	17	16	15	14	13
9	11	12	13	14	15	16	17	18	19	18	17	16	15	14
10	12	13	14	15	16	17	18	19	20	19	18	17	16	15
9	11	12	13	14	15	16	17	18	19	18	17	16	15	14
8	10	11	12	13	14	15	16	17	18	17	16	15	14	13
7	9	10	11	12	13	14	15	16	17	16	15	14	13	12
6	8	9	10	11	12	13	14	15	16	15	14	13	12	11
5	7	8	9	10	11	12	13	14	15	14	13	12	11	10
4	6	7	8	9	10	11	12	13	14	13	12	11	10	9
3	5	6	7	8	9	10	11	12	13	12	11	10	9	8
2	4	5	6	7	8	9	10	11	12	11	10	9	8	7
1	3	4	5	6	7	8	9	10	11	10	9	8	7	6

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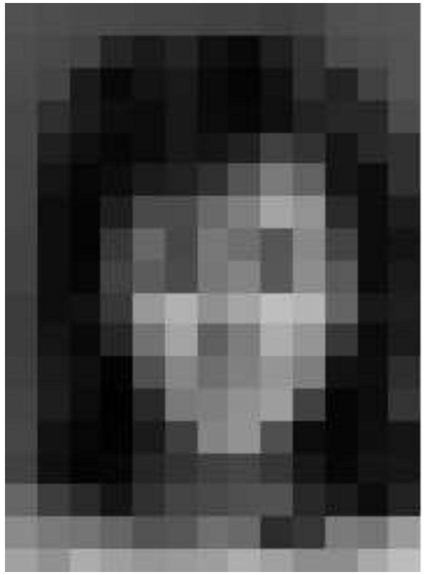
Image Sampling

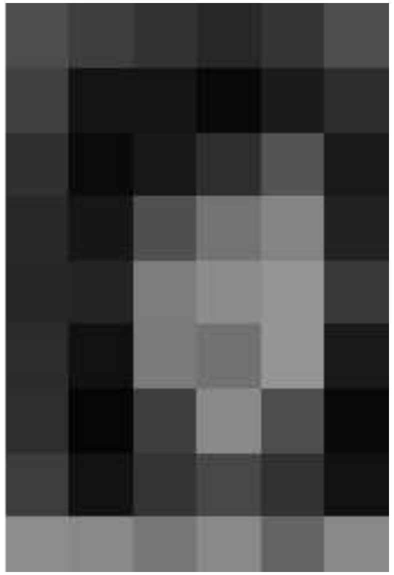
- Sampling the Image Plane
  - Finite number of Pixels
  - Do we always want maximum number of pixels?

Original

X 1/4



X 1/16



X 1/32

Operations on Color Histogram

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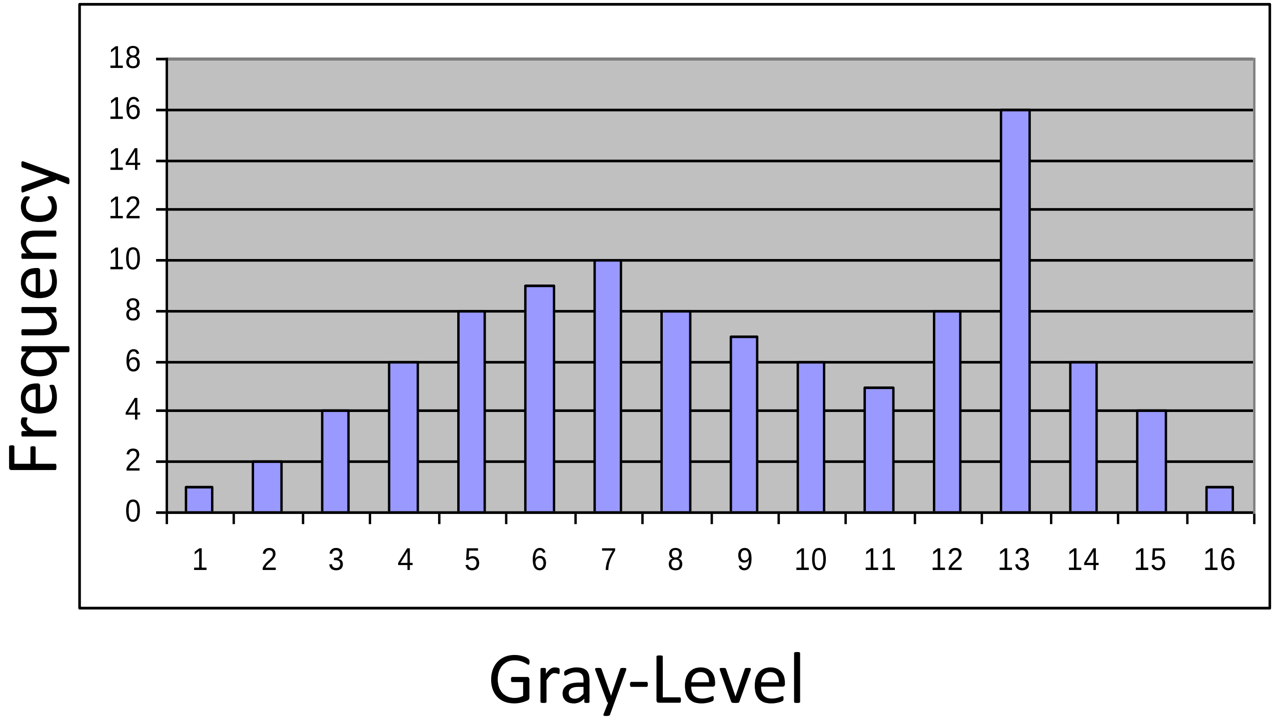
The Histogram

- Frequency counting of gray levels or colors



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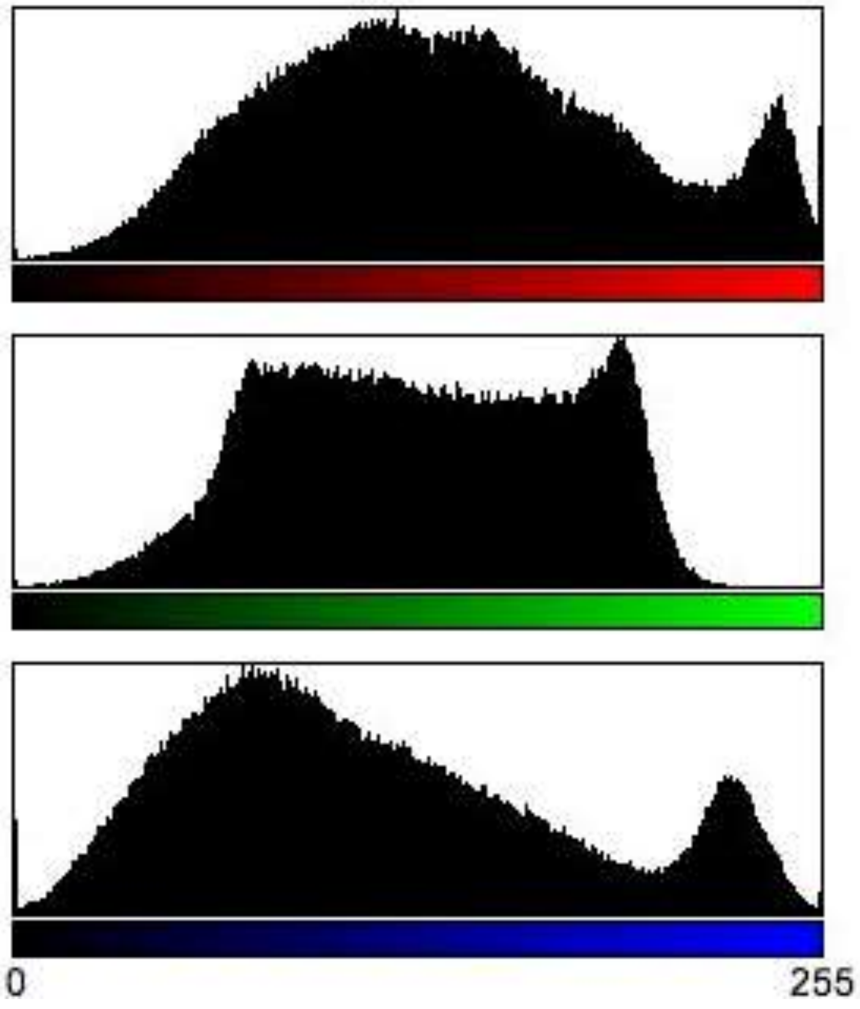
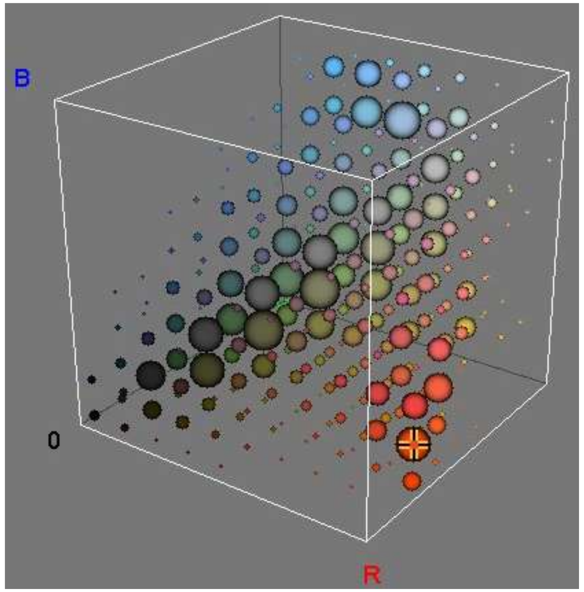
Histogram - Example





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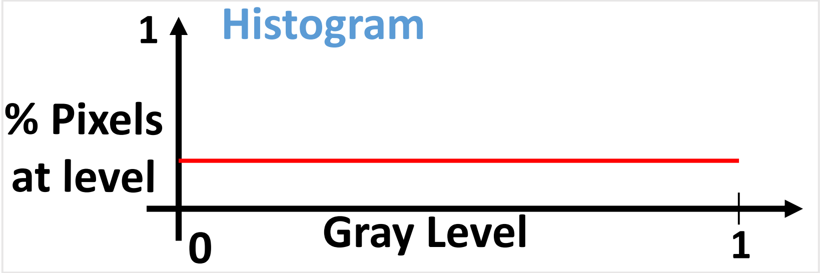
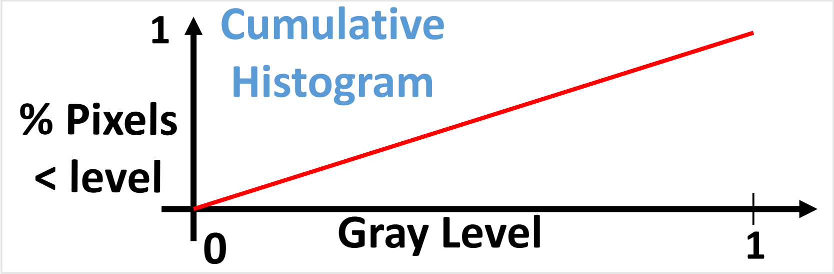
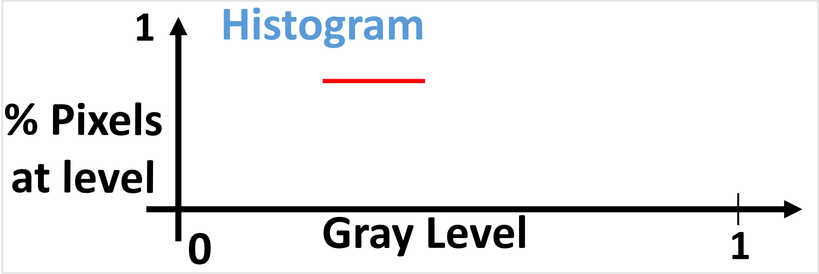
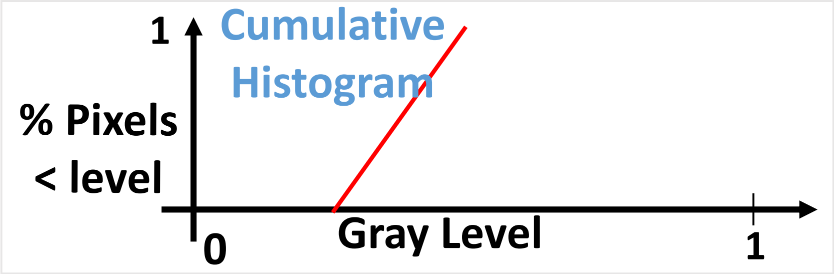
Histogram Equalization

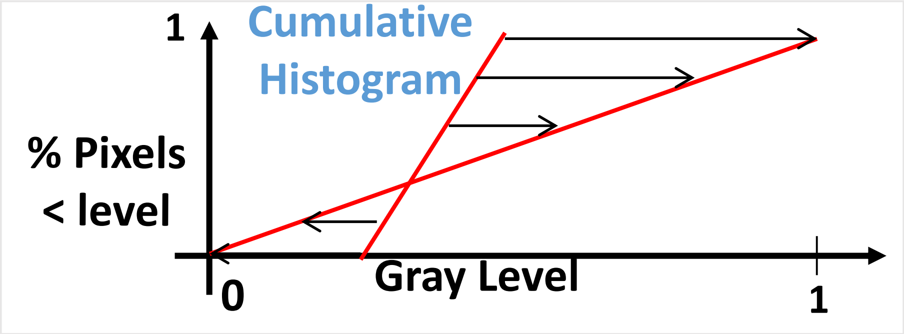
- Equal usage of all gray levels











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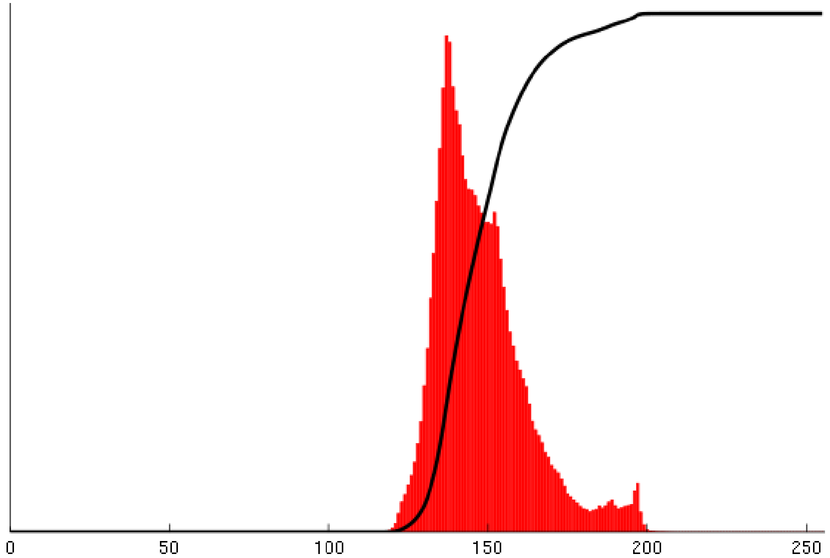
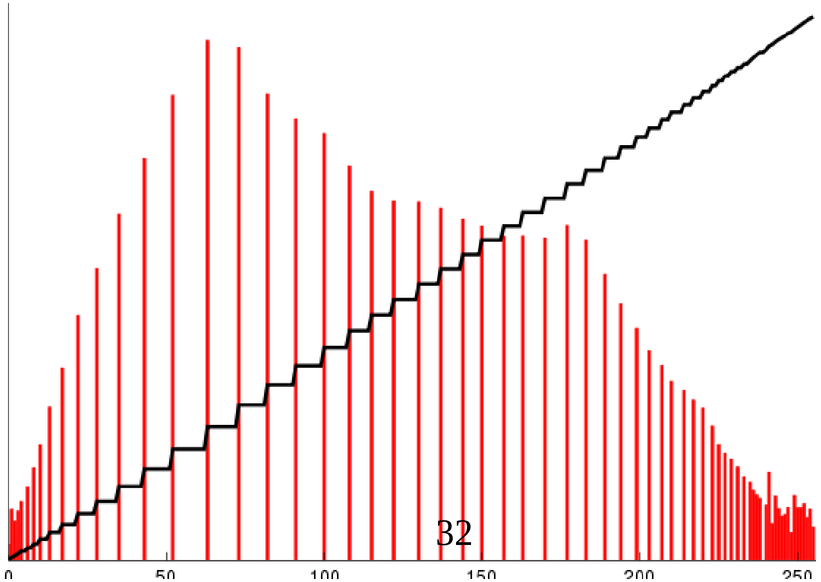
Histogram Equalization





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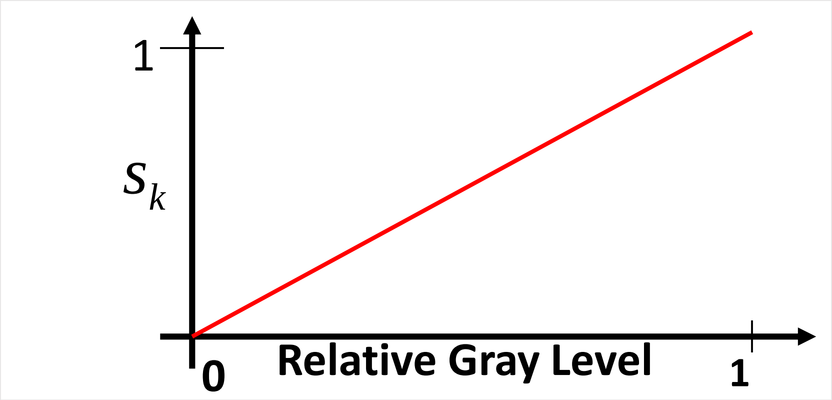
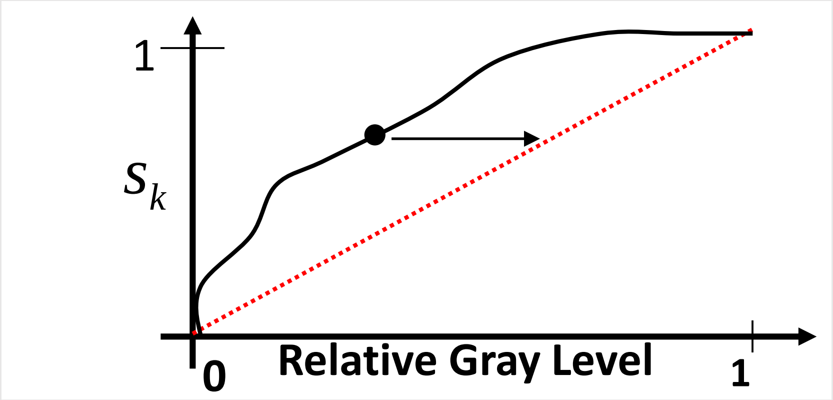
Histogram Equalization





1. Given image $I(x, y)$, create a histogram H:

$$\forall\, x, y: \; H(I(x,y)) = H(I(x,y)) + 1$$

2. Create cumulative histogram $S(k)$:

$$S(0) = H(0); \; S(k+1) = S(k) + H(k+1)$$

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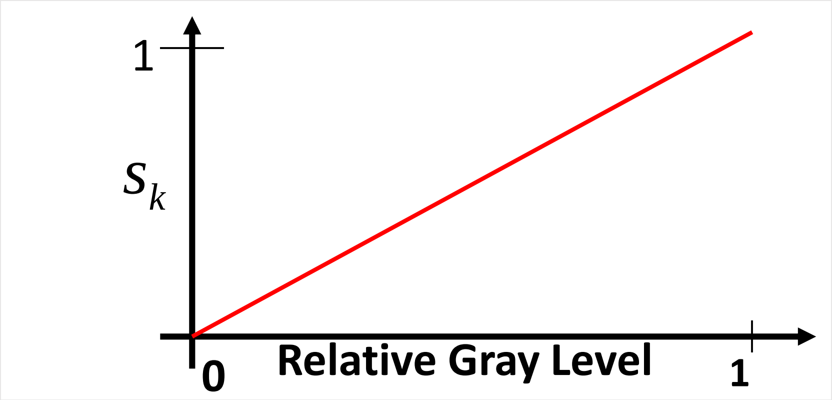
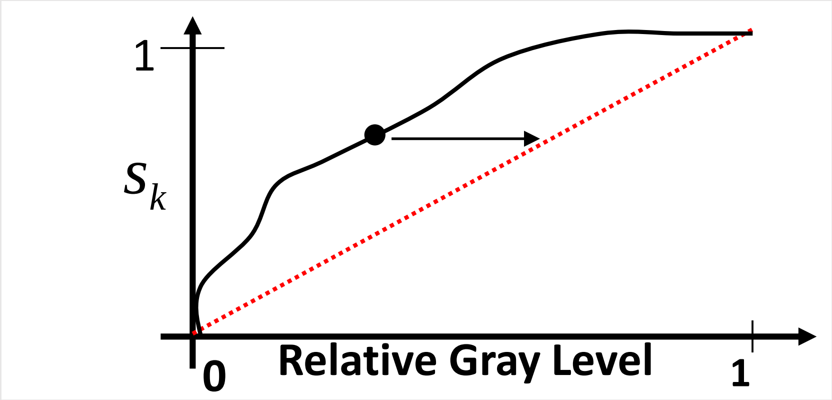
Histogram Equalization





Let m be first index for which $S(m) \neq 0$

3. Create **Look Up Table (LUT)** $T(k)$:

$$T(k) = \{ [S(k) - S(m)] / [S(255) - S(m)] \} * 255$$

4. Apply LUT T to I, get equalized image J

$$J(x, y) = T(I(x, y))$$

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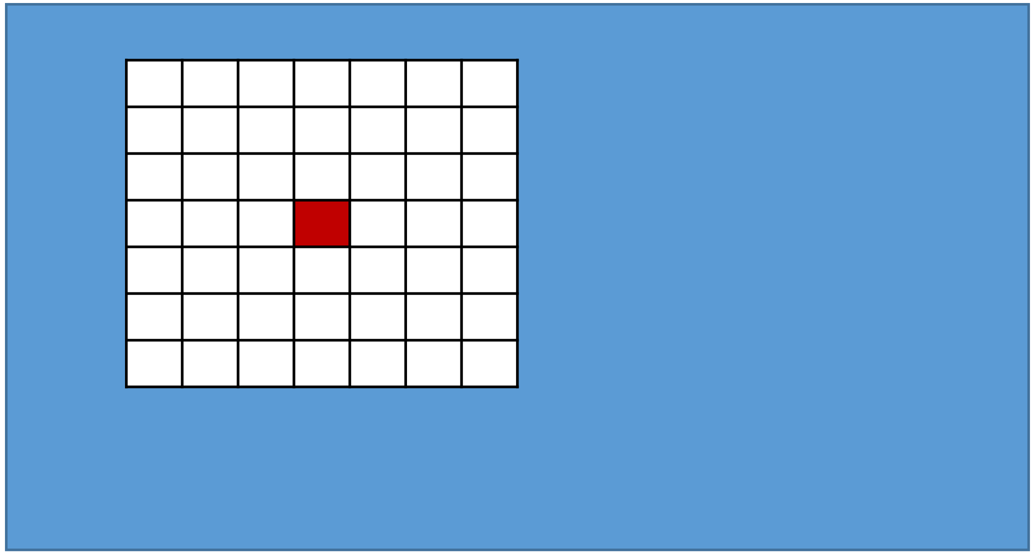
Adaptive Histogram Equalization

- For each pixel
  - Compute Equalization LUT in local region
  - Transform by LUT only the center pixel
- Go to next pixel



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Adaptive Histogram Equalization

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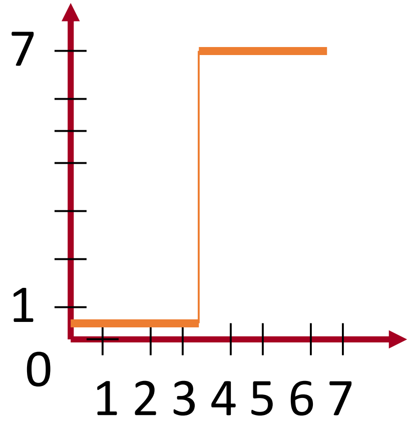
Other Operations with LUT

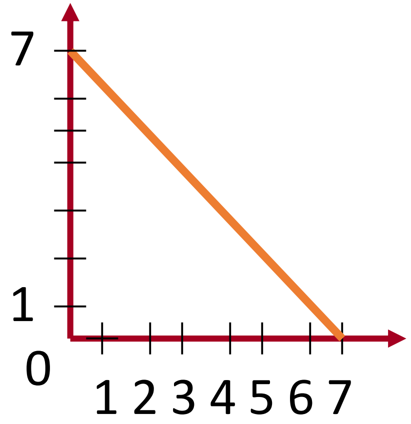
- Threshold

In	0	1	2	3	4	5	6	7
Out	0	0	0	0	7	7	7	7



- Negative

In	0	1	2	3	4	5	6	7
Out	7	6	5	4	3	2	1	0



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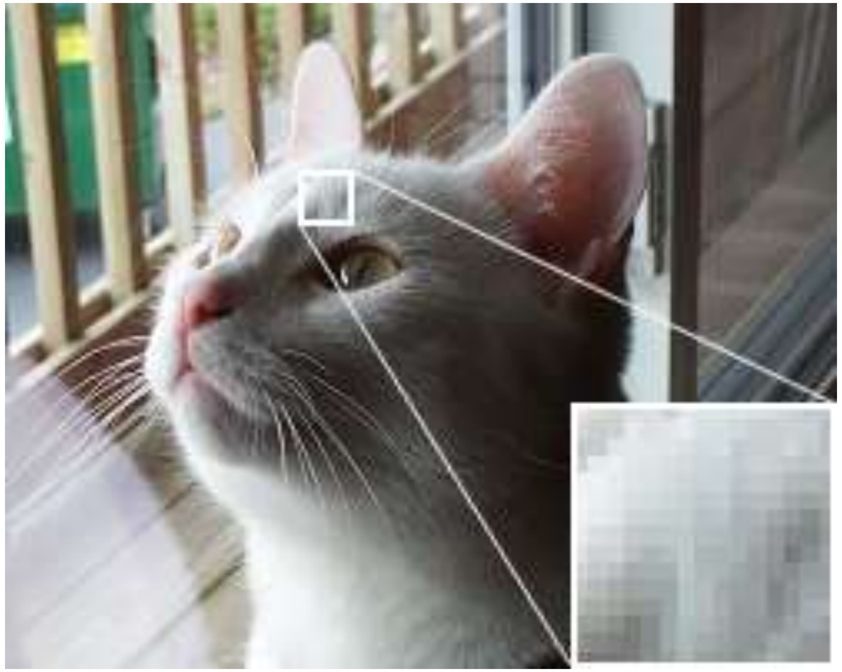
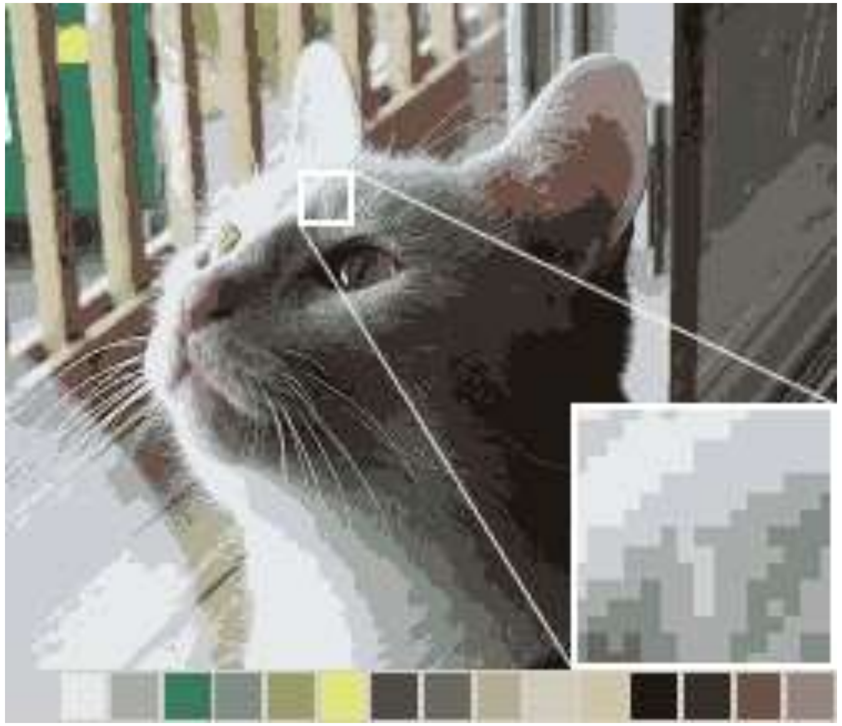
Color Quantization



24-bit RGB color



Optimal 16 colors (4 bits)

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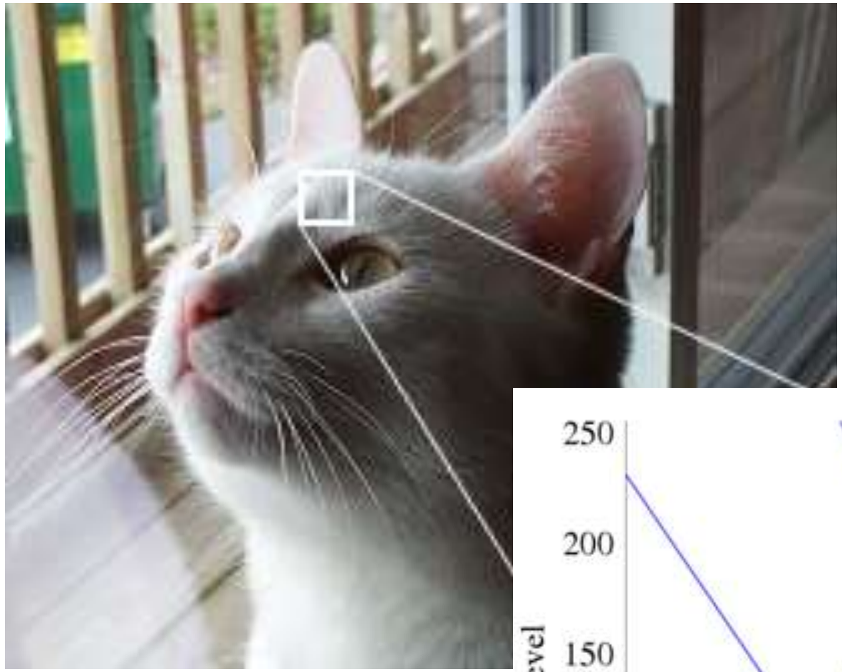
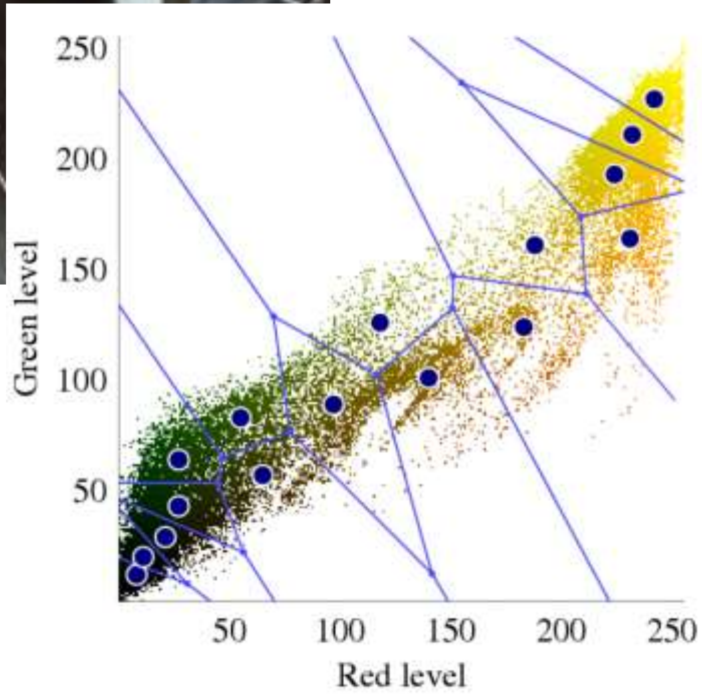
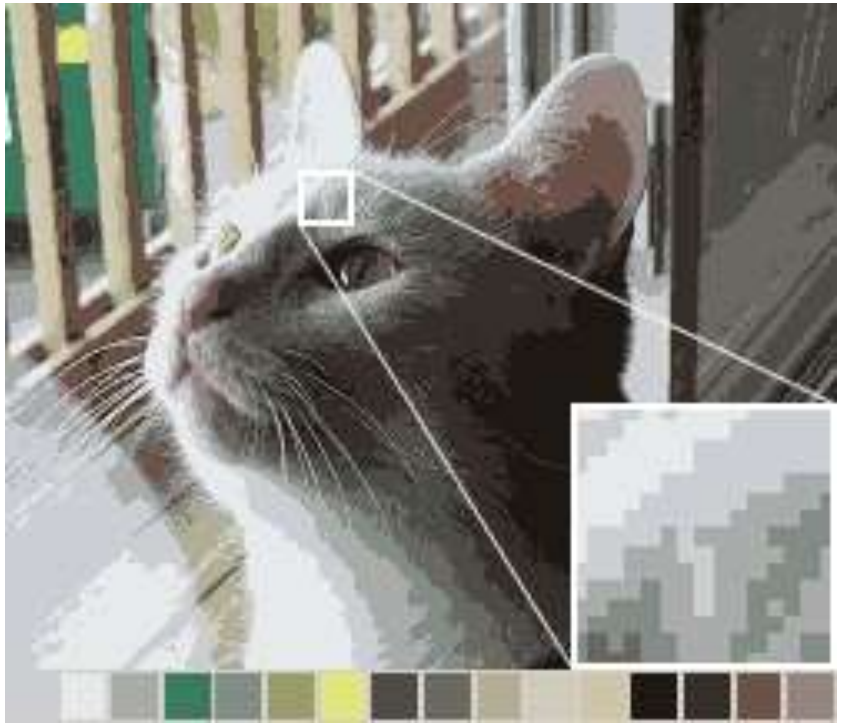
Color Quantization





24-bit RGB



Optimal 16 colors (4 bits)

Chetan Arora
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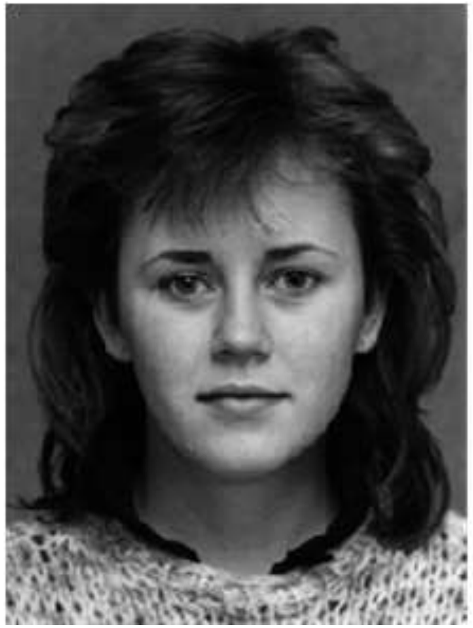
Color/Gray Level Quantization

- Quantizing the color/gray-level
  - Finite number of colors



256 Levels

8 Levels

4 Levels

2 Levels