Camera & Color

Overview

- Pinhole camera model
- Projective geometry
- Vanishing points and lines
- Projection matrix
- Cameras with Lenses
- Color
- Digital image

Book: Hartley 6.1, Szeliski 2.1.5, 2.2, 2.3

The trip of Light

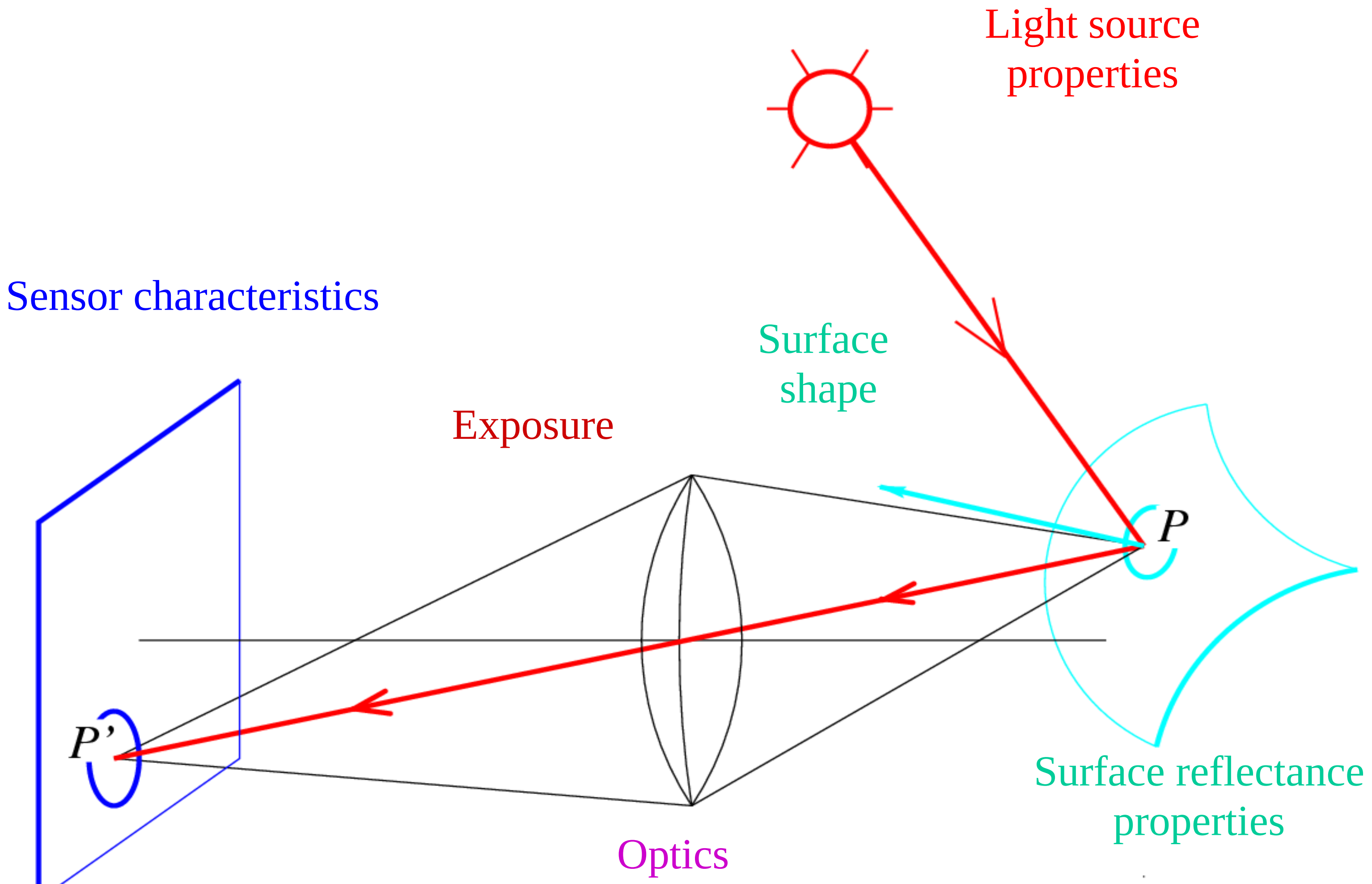
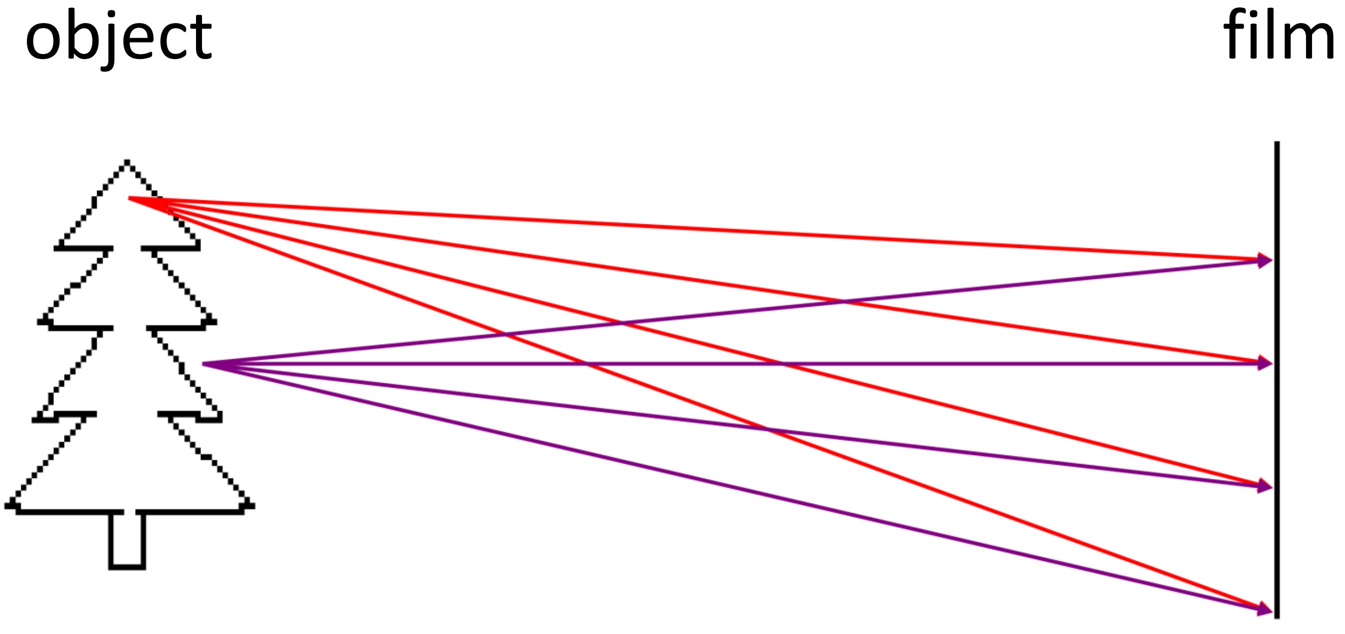
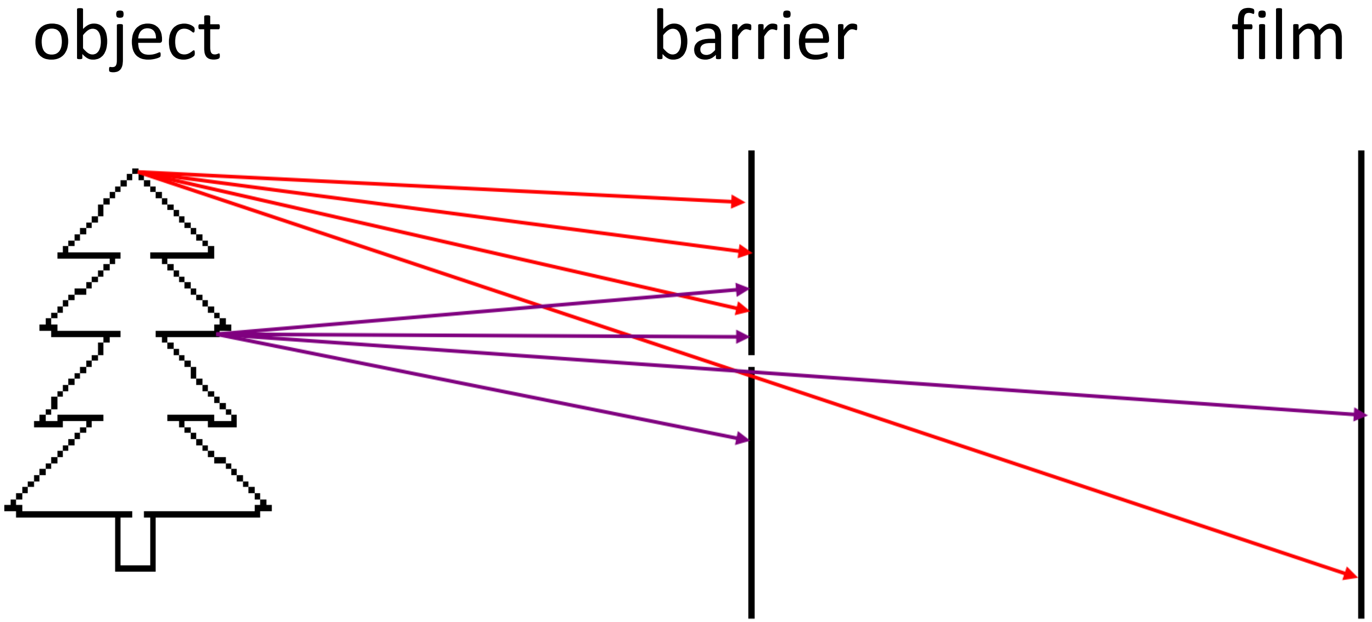


Image Formation

Let's design a camera.
Is this going to work?

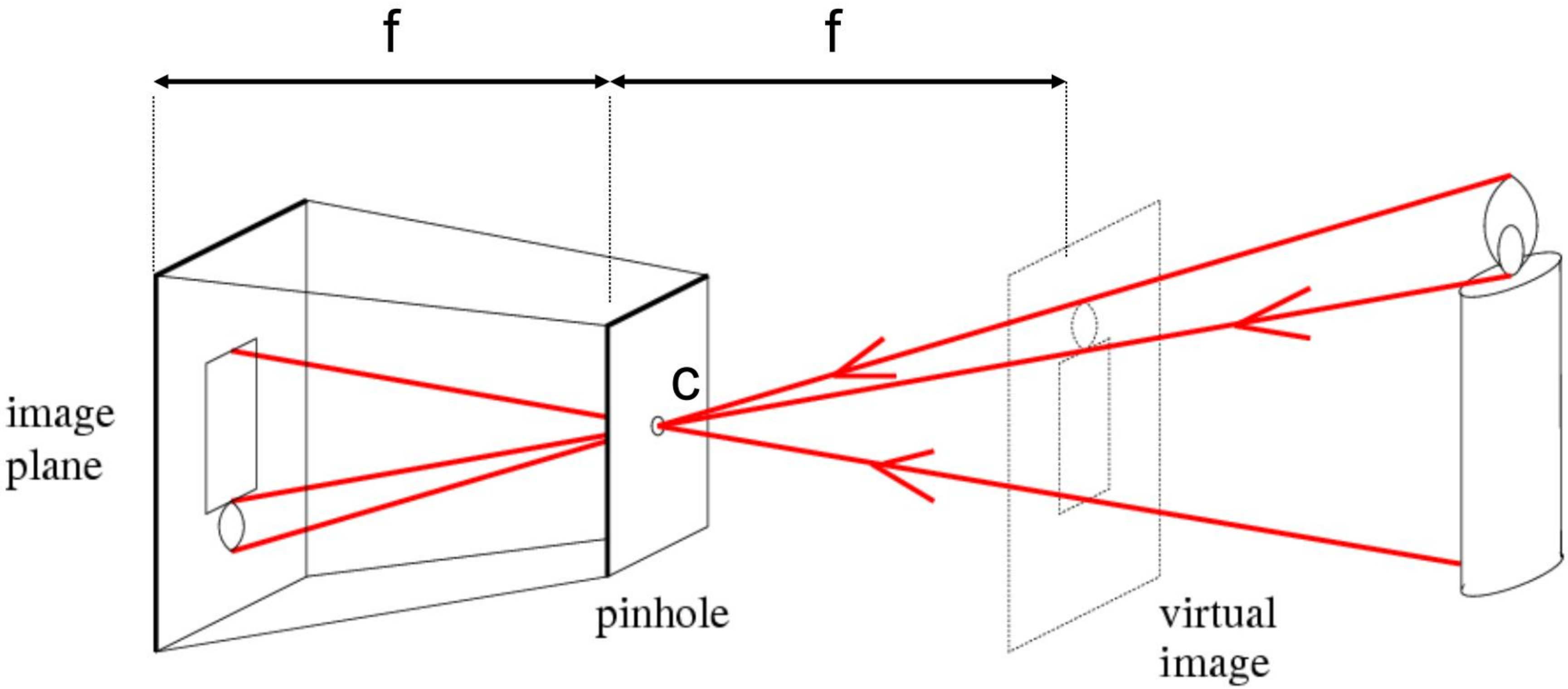


Pinhole Camera



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

Pinhole Camera



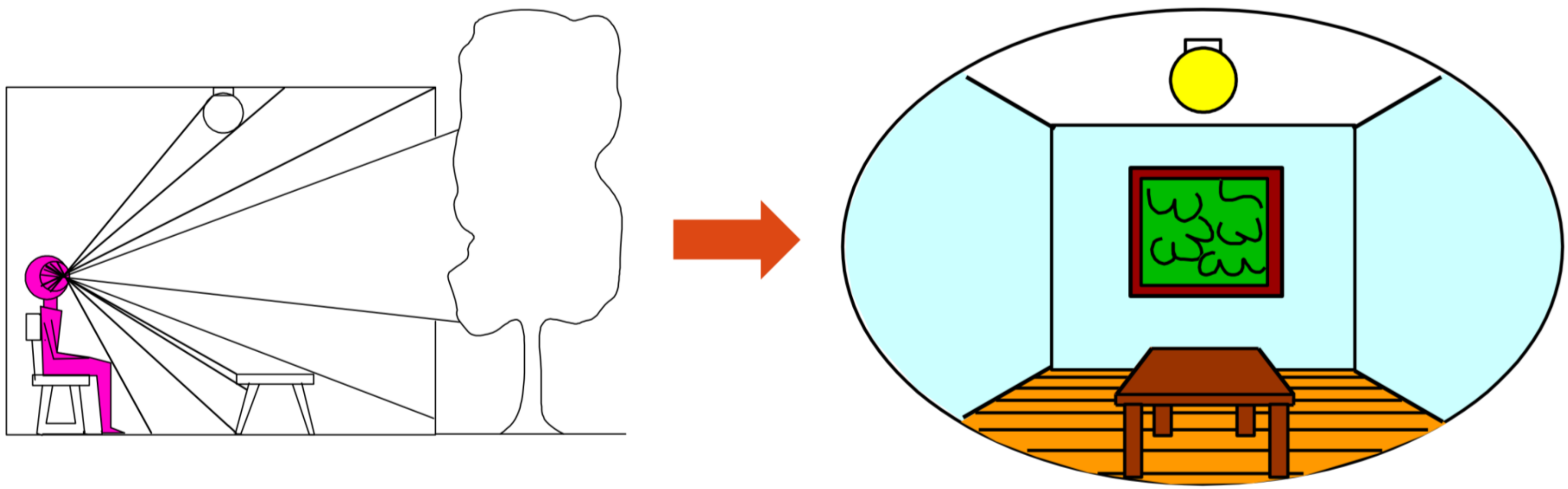
f = focal length

c = camera center

Dimensionality Reduction – 3D to 2D

3D world

2D image



Point of

observation

Projection Illusion

Projection Illusion

Projective Geometry

Lost Properties

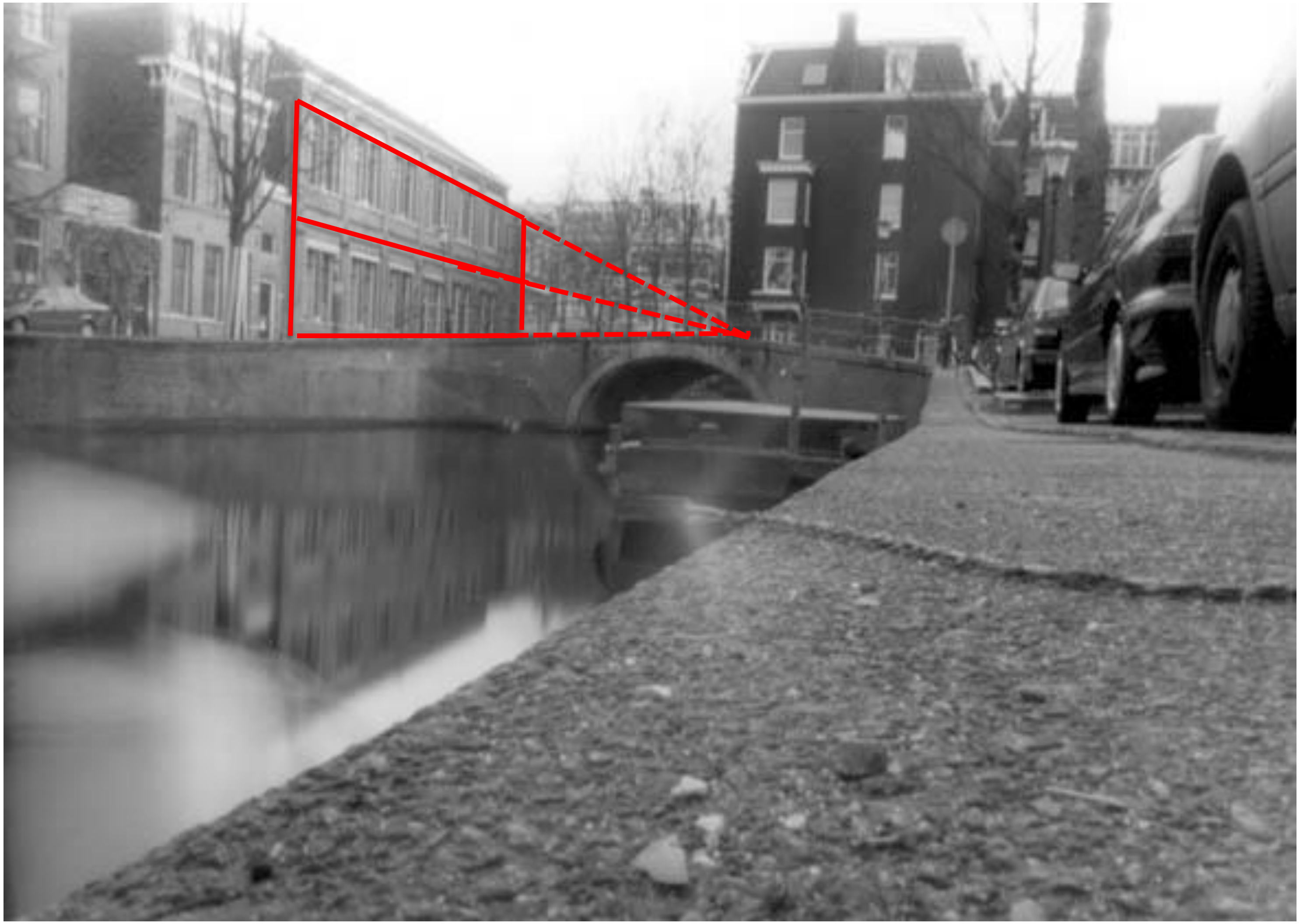
- Length (size)
- Angles
- Shape

Invariant Properties

- Straight Lines

Projective Geometry

Angles-Shape

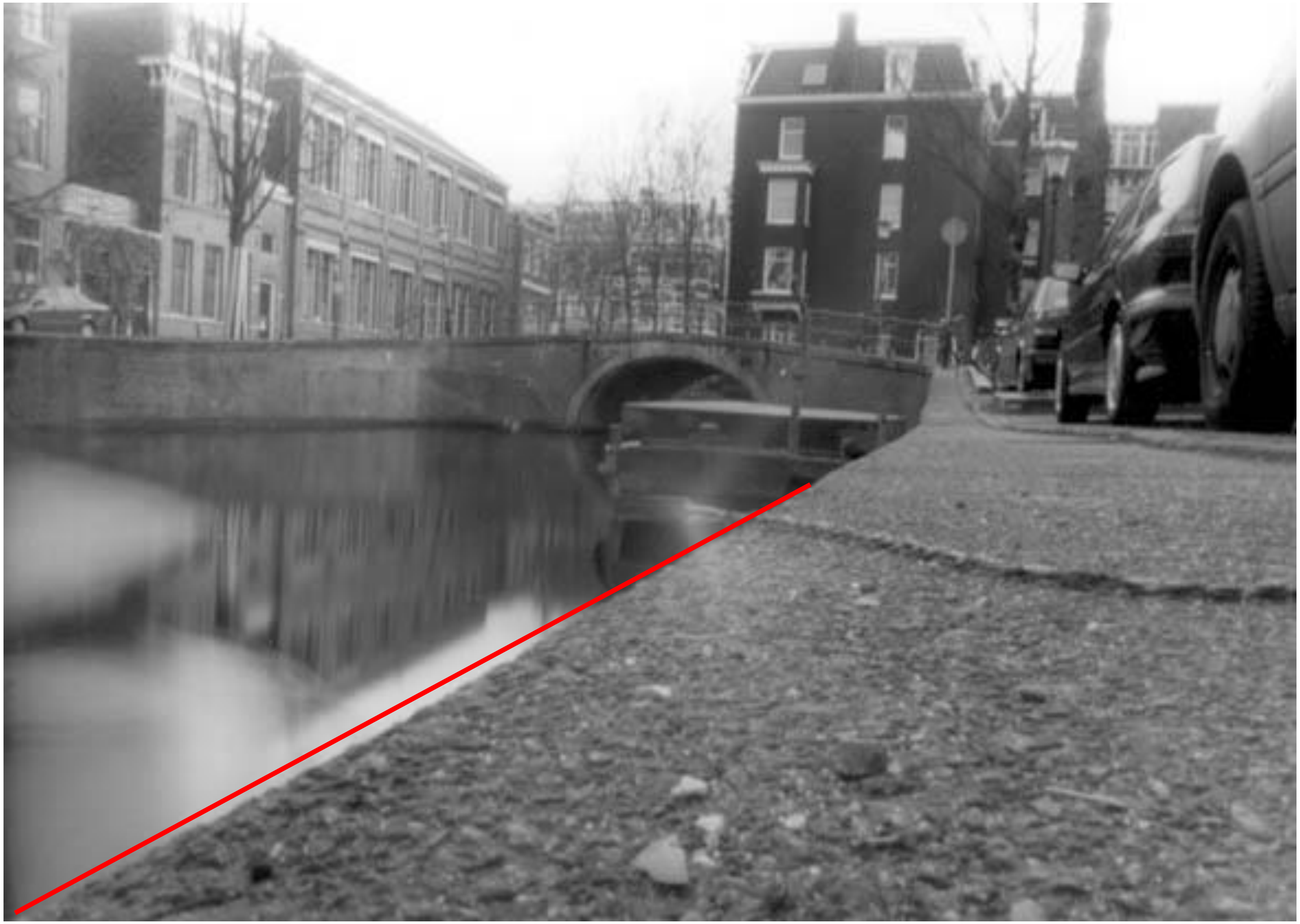


Projective Geometry

Length-Size

Projective Geometry

Straight Lines

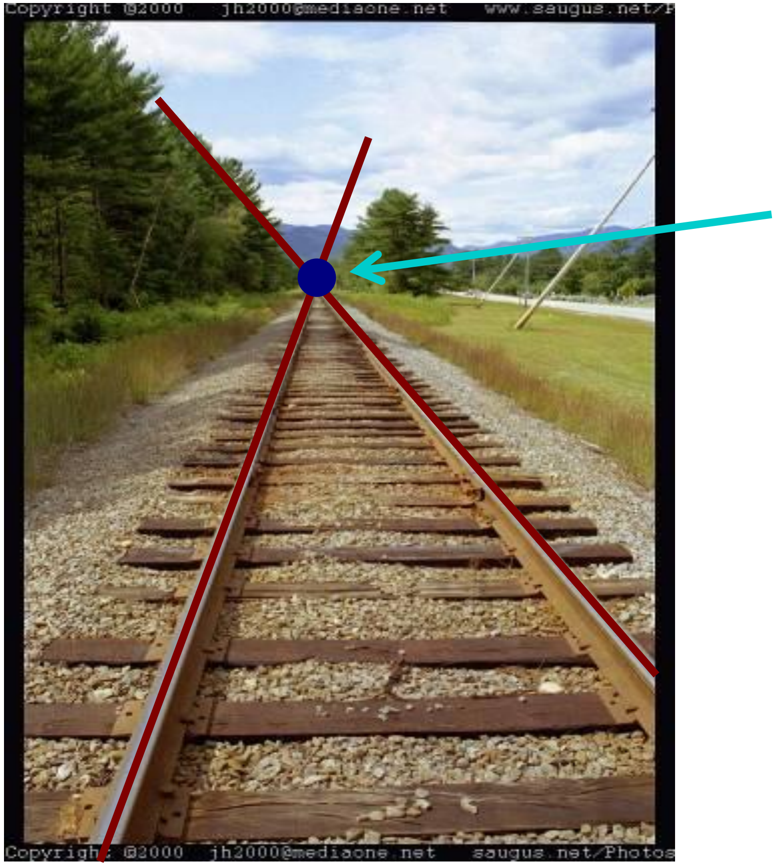


Projection Properties

- Many-to-one: any point along the same ray map to the same point in the image.
- Points → Points
- Lines → Lines
  - Line through the camera center projects to a point.
- Planes → Planes
  - Plane through the camera center projects to a line.

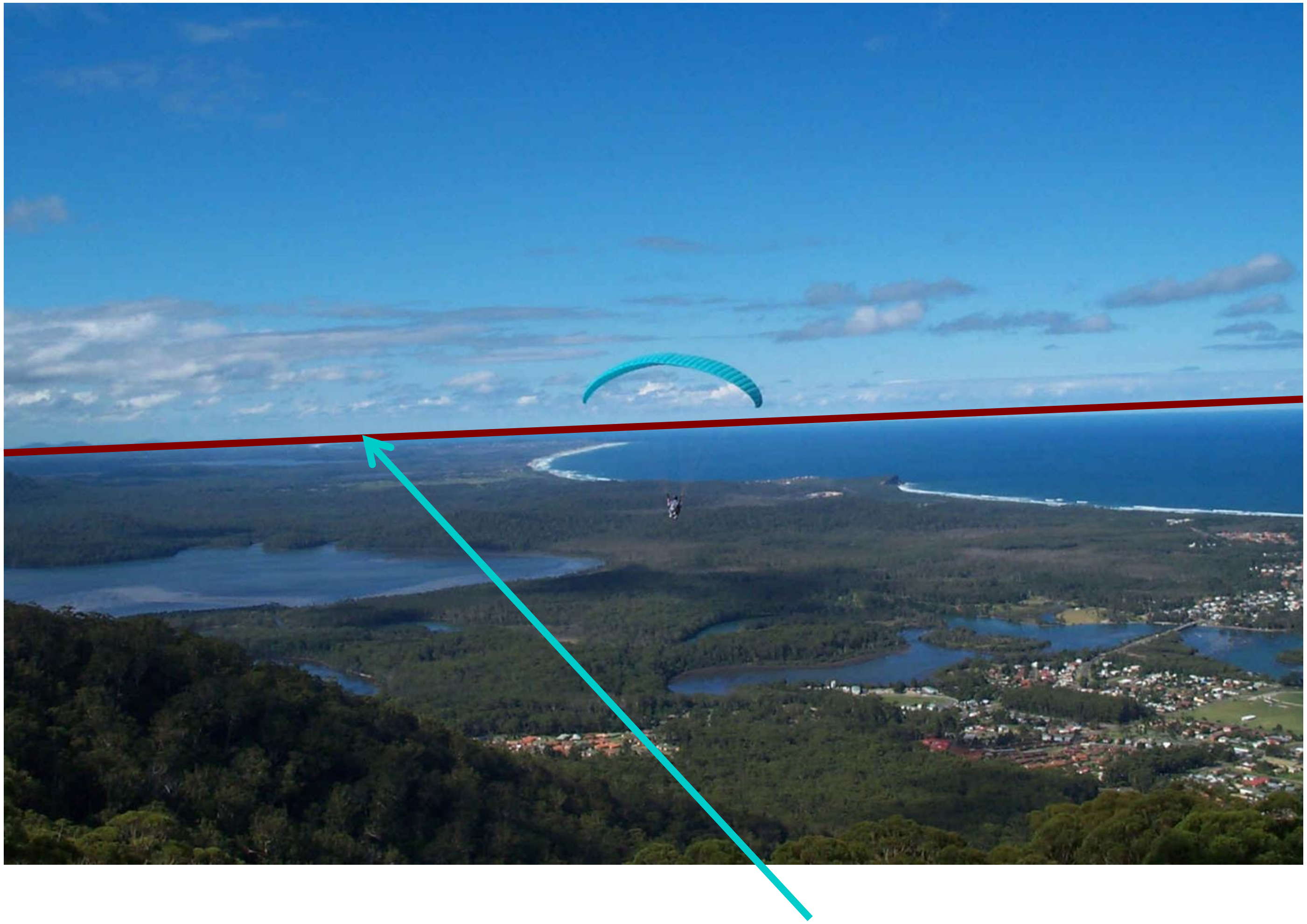
Vanishing Points

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



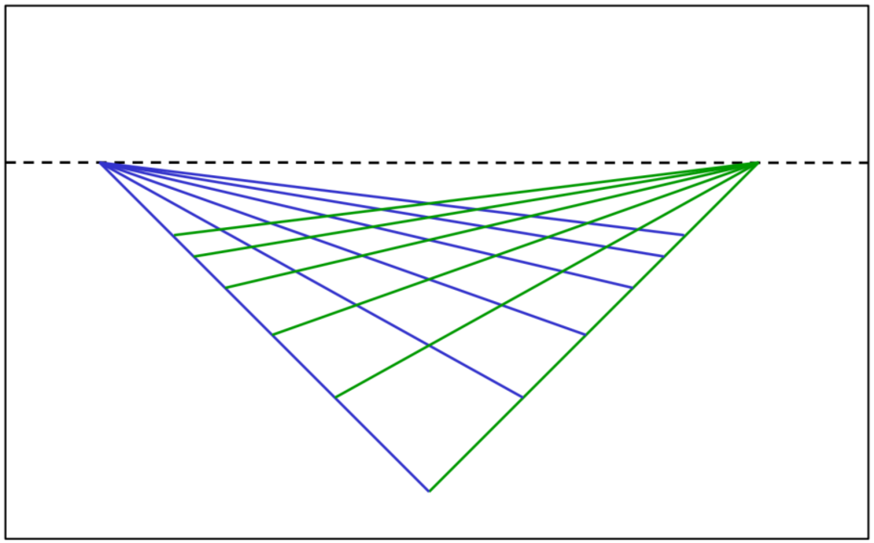
Vanishing Lines

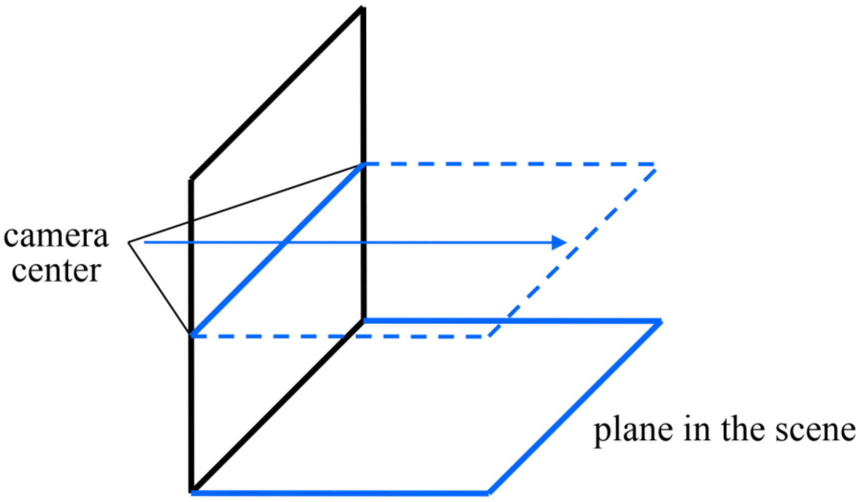
Planes in the world form a "vanishing line" in the image.



Vanishing Line

Vanishing Lines





- Horizon: vanishing line of the ground plane

Homogeneous Coordinates

Converting to *homogeneous* coordinates

$$(x, y) \Rightarrow \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

homogeneous image coordinates

$$(x, y, z) \Rightarrow \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

homogeneous scene coordinates

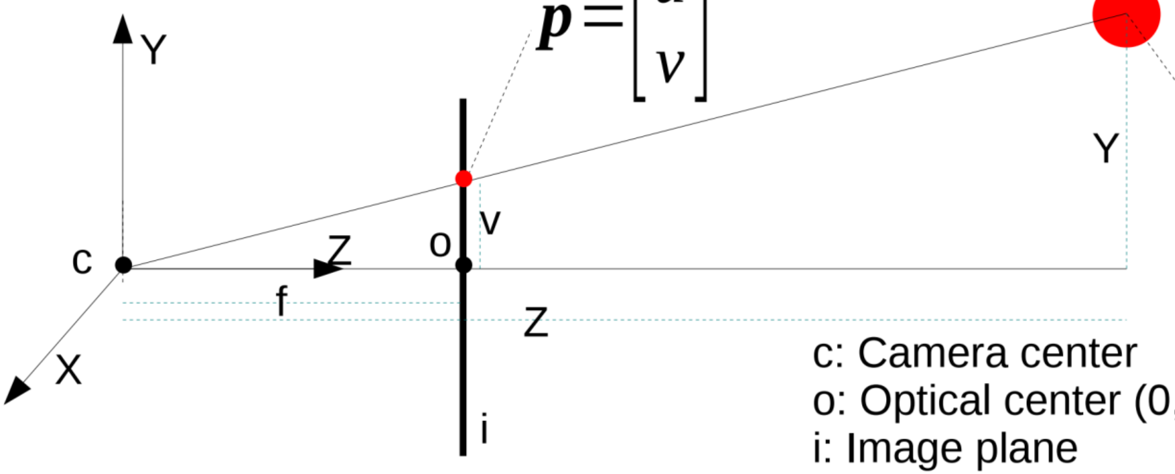
Converting *from* homogeneous coordinates

$$\begin{bmatrix} x \\ y \\ w \end{bmatrix} \Rightarrow (x/w, y/w)$$

$$\begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix} \Rightarrow (x/w, y/w, z/w)$$

Projection

3D World Coordinates to 2D Image Coordinates



$$\boldsymbol{p} = \begin{bmatrix} u \\ v \end{bmatrix}$$

$$\boldsymbol{P} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

c: Camera center
o: Optical center (0,0)
i: Image plane

Intrinsic Assumptions

- Unit aspect ratio
- Optical center at (0,0)

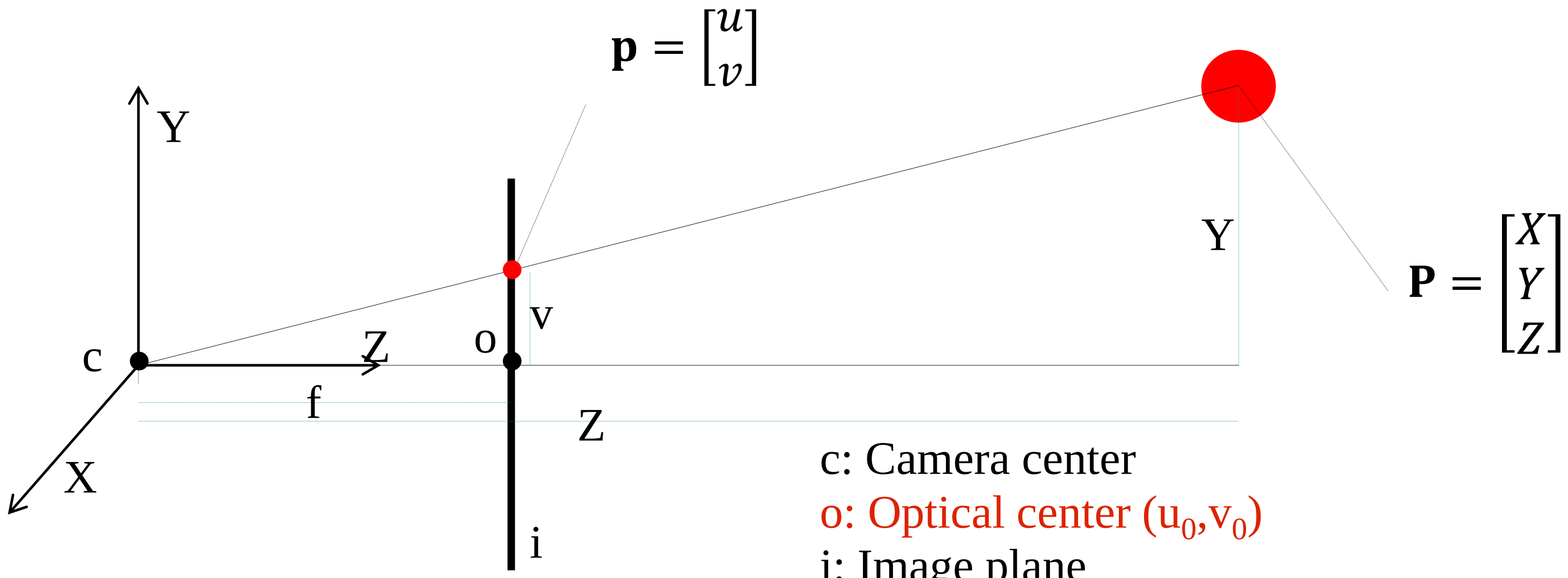
Extrinsic Assumptions

- No rotation
- Camera at (0,0,0)

Projection Matrix:

$$w\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Projection Matrix



If the position of the optical center is at (u_0,v_0):

K:intrinsic matrix

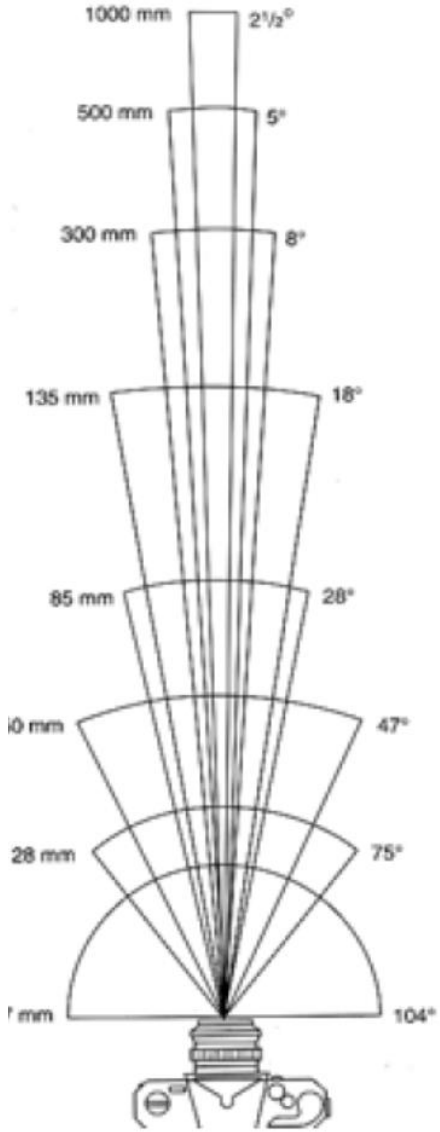
$$w\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & u_0 & 0 \\ 0 & f & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

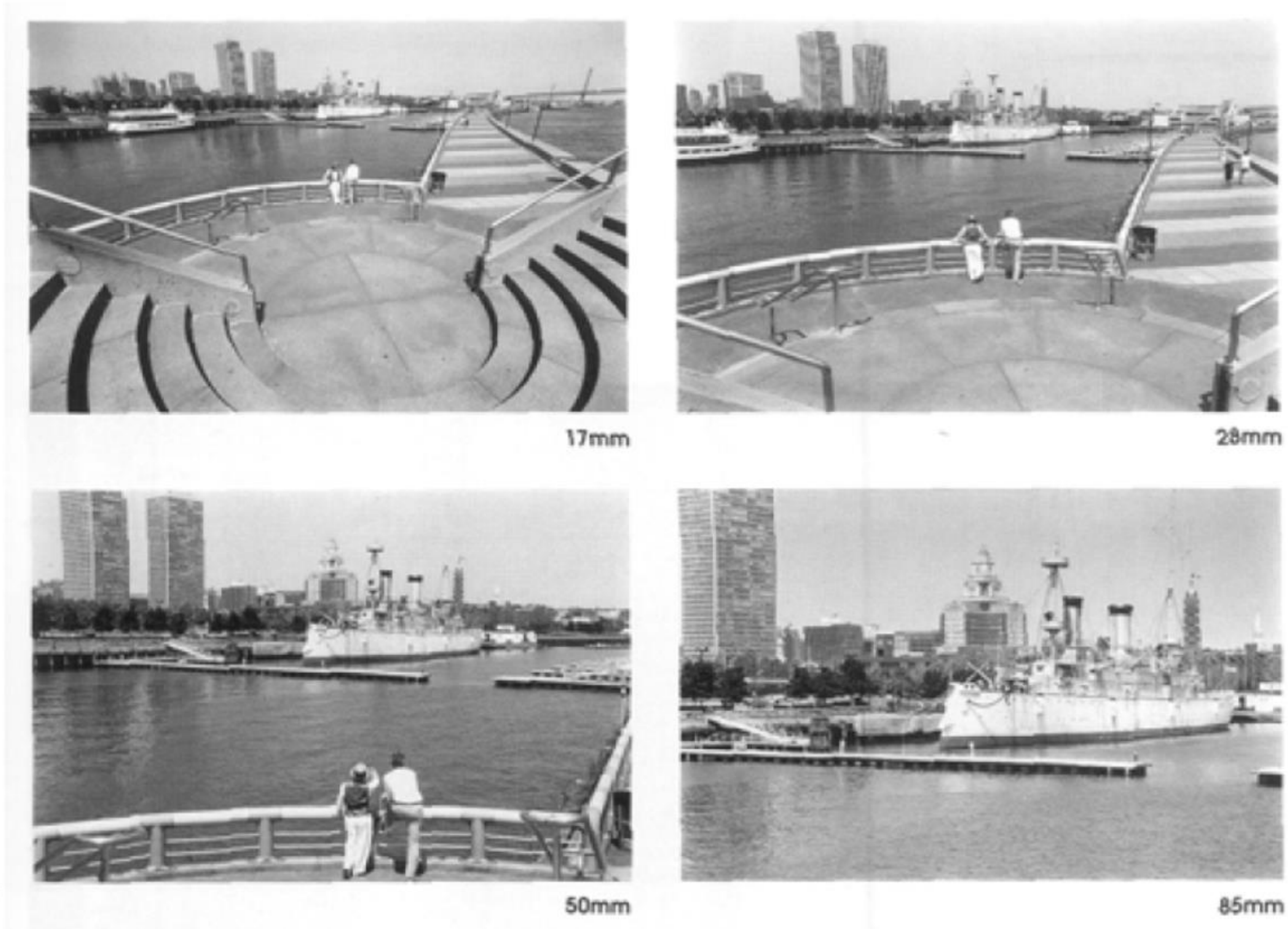
$\mathbf{x} = \mathbf{K}[\mathbf{I}\,\mathbf{0}]\mathbf{X}$

Rotation (**R**), Translation (**t**)

$\mathbf{x} = \mathbf{K}[\mathbf{R}\mathbf{t}]\mathbf{X}$

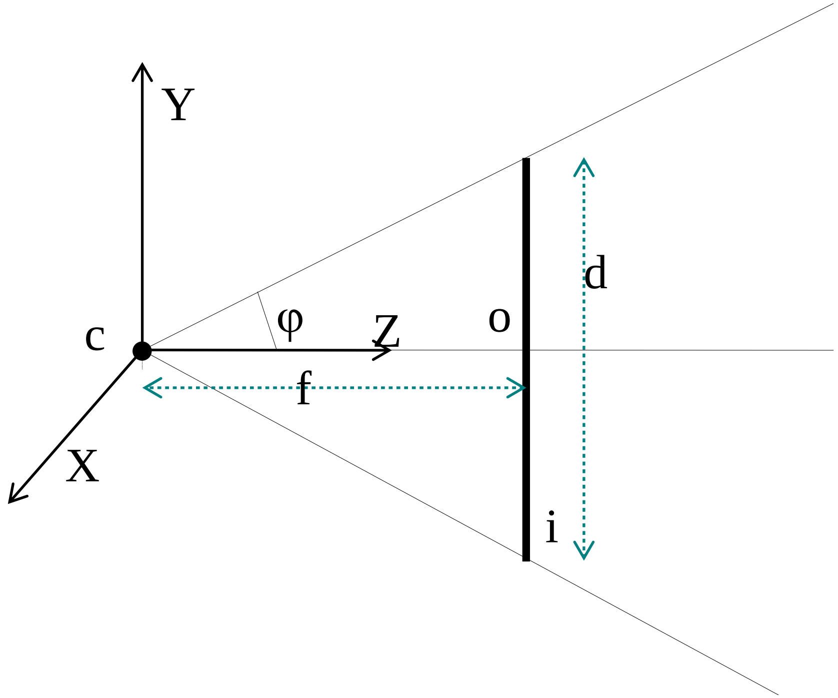
Field of View



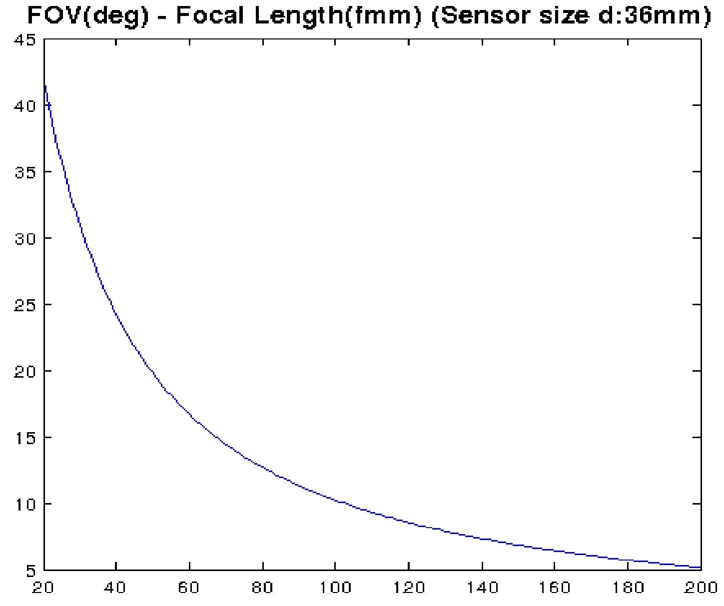


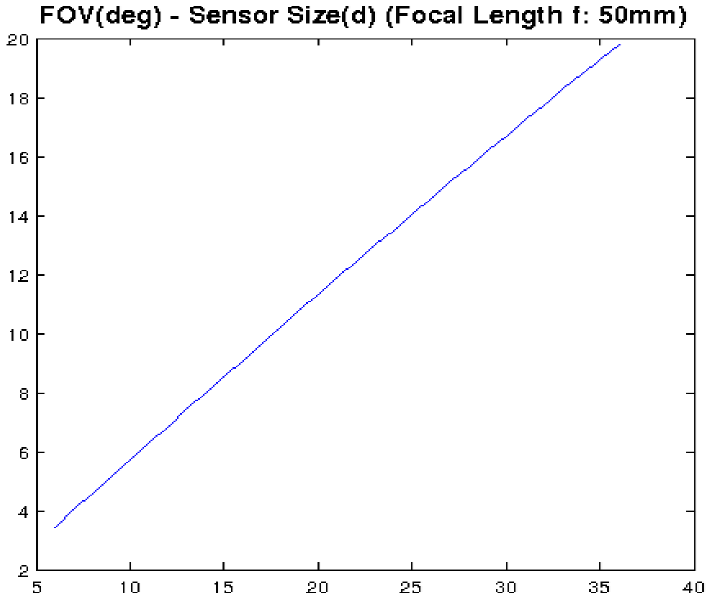
From London and Upton

Field of View

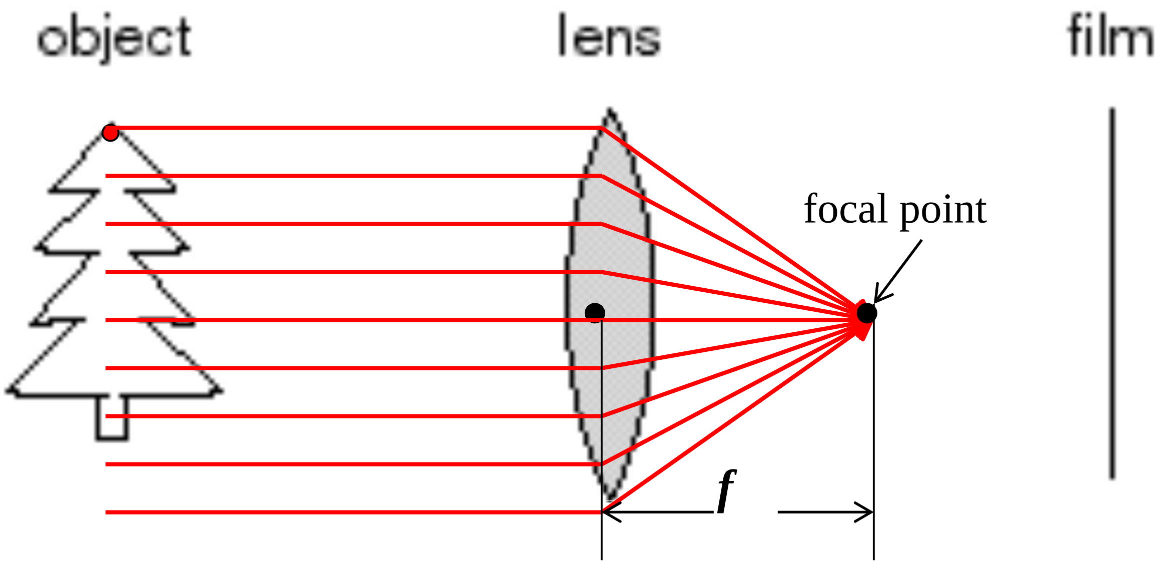


$$\phi = \tan^{-1}(d/2f)$$



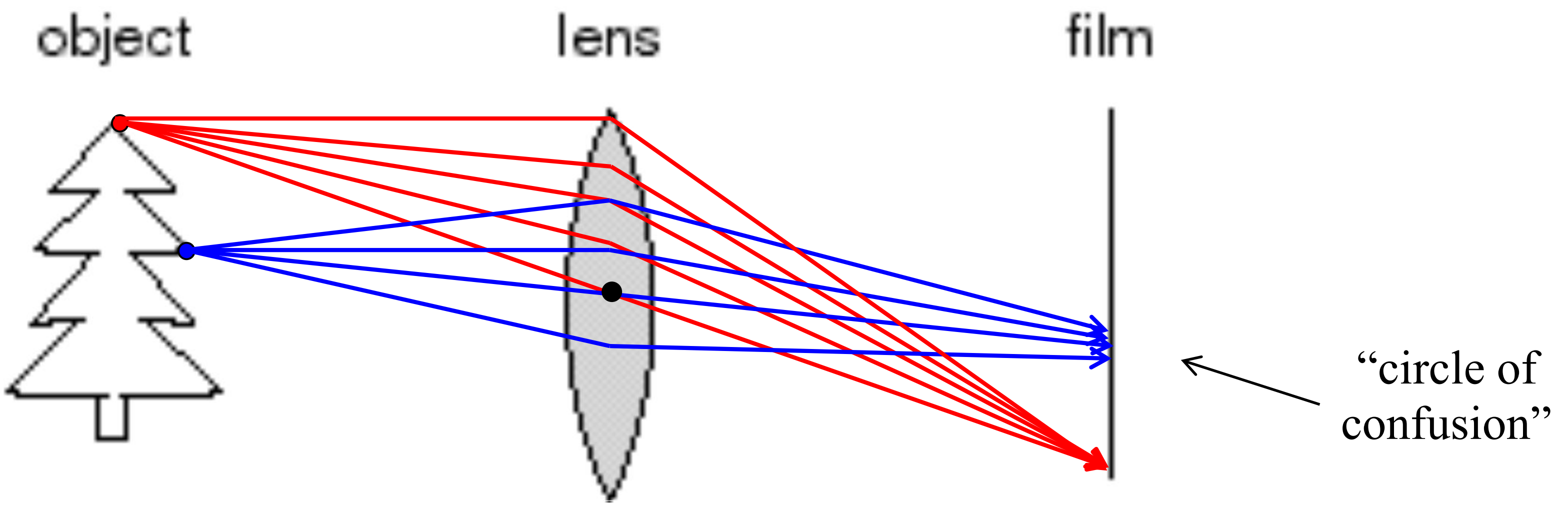


Lenses



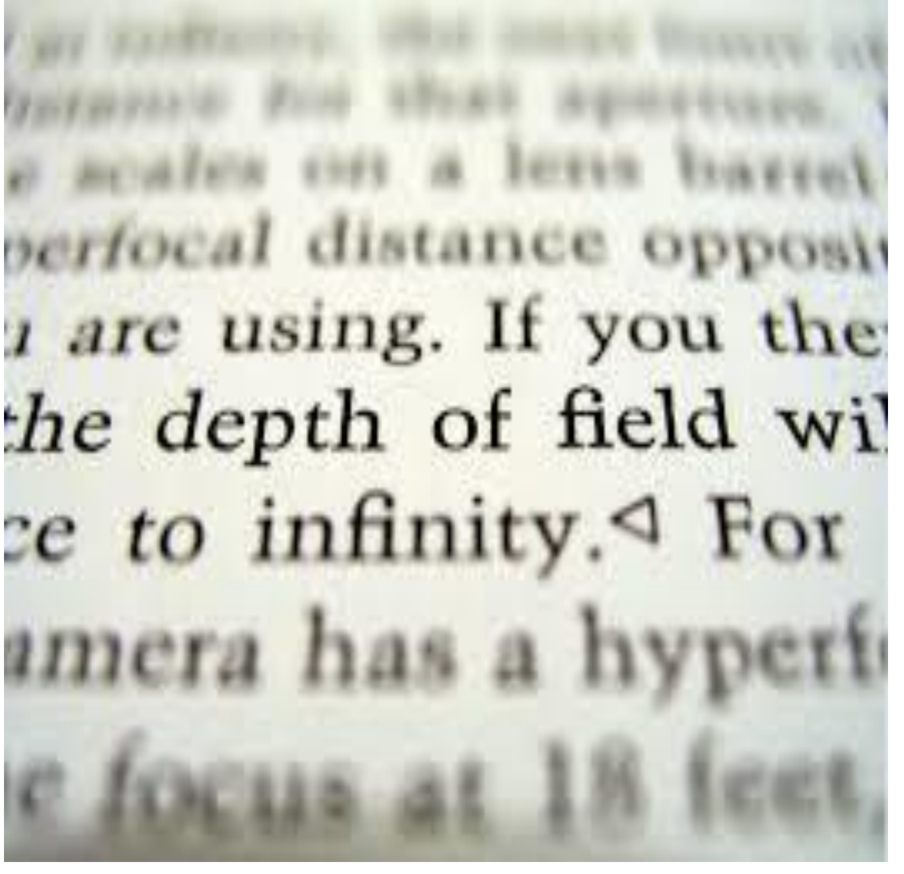
A lens focuses light onto the film.

Lens Focus

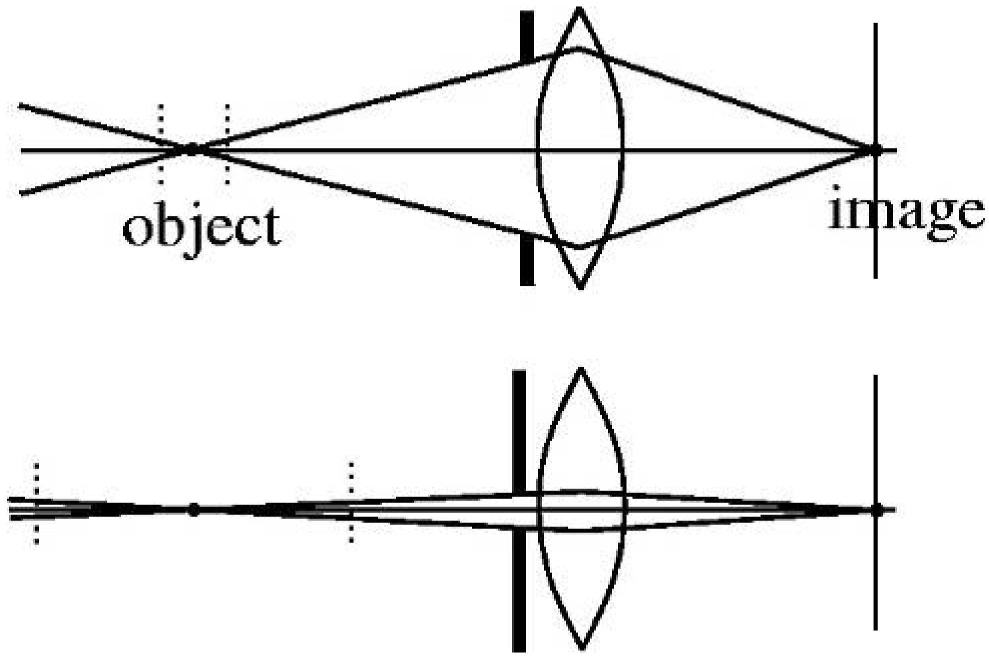


There is a specific distance at which objects are "in focus".

Lens Focus – Depth of Field



Depth of Field and Aperture

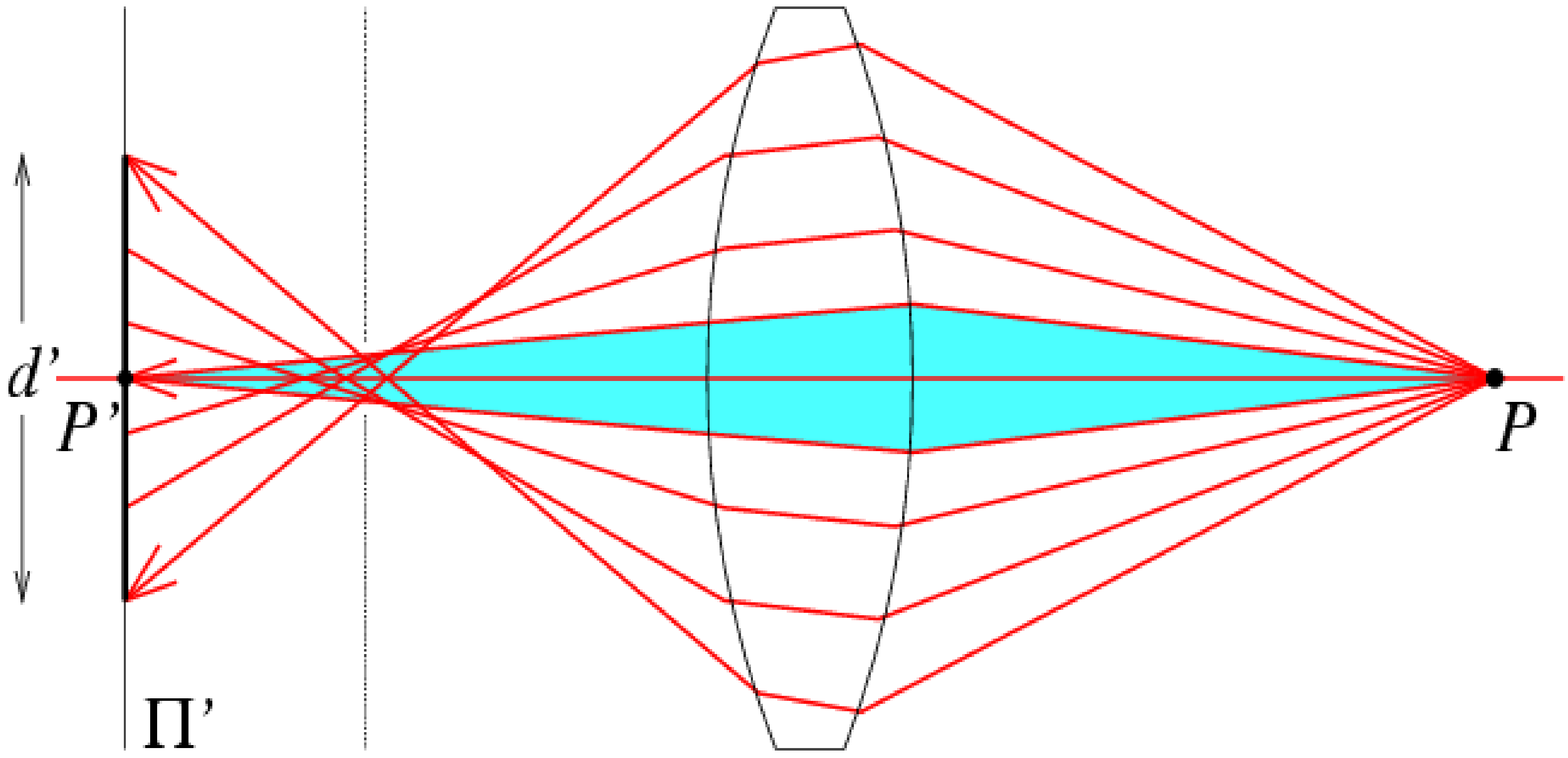


Changing the aperture size affects depth of field

- A smaller aperture increases the range in which the object is approximately in focus
- But small aperture reduces amount of light – need to increase exposure

Lens flaws: Spherical aberration

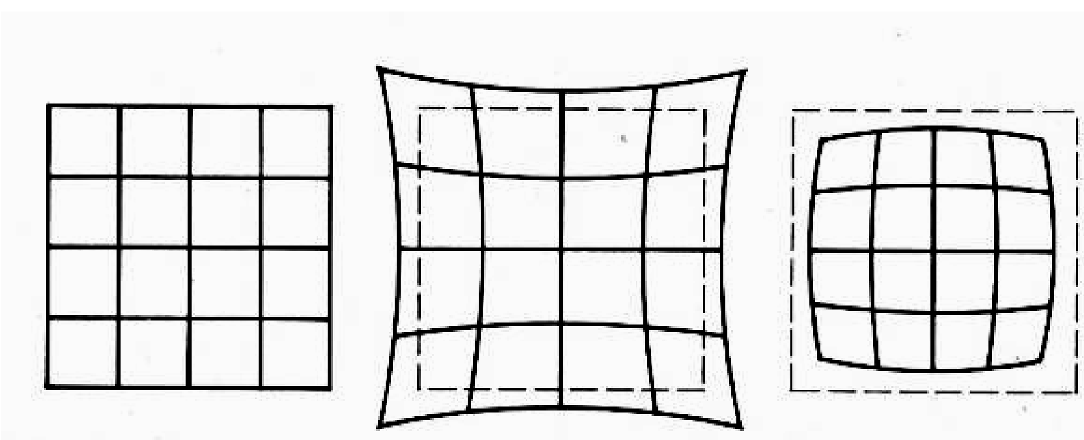
Rays farther from the optical axis focus closer.



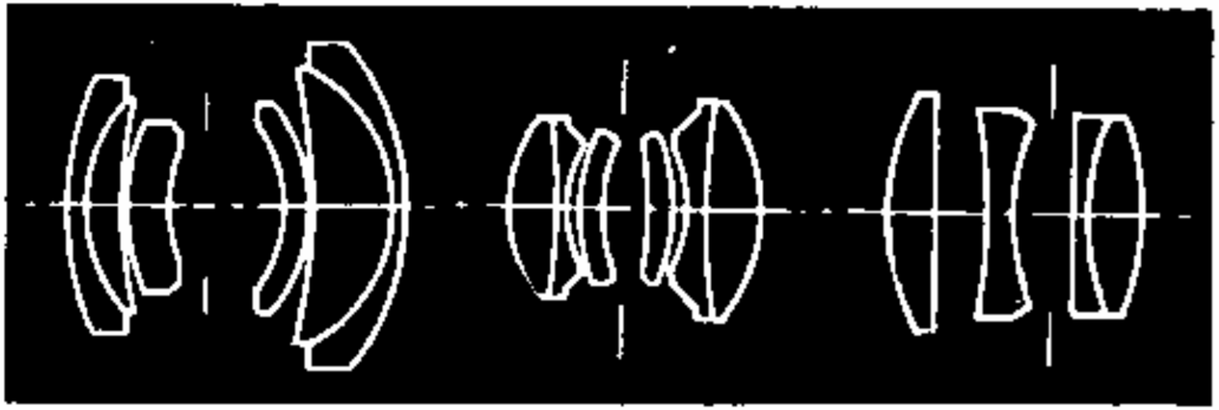
Lens flaws: Vingetting

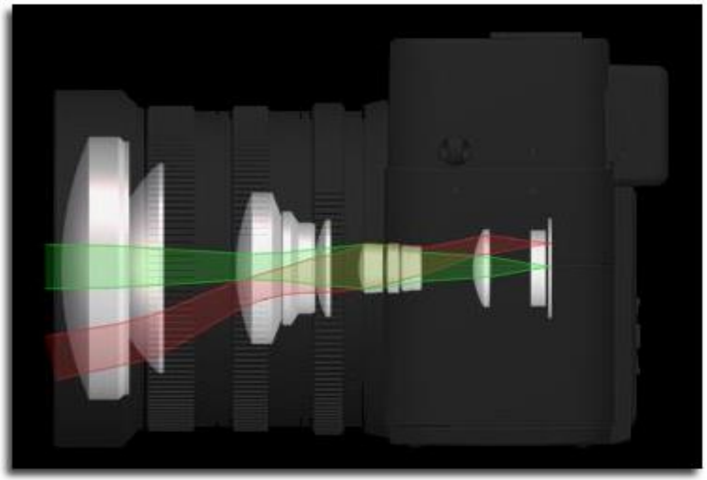
Radial Distortion

- Caused by imperfect lenses
- Deviations are most noticeable on the edges.

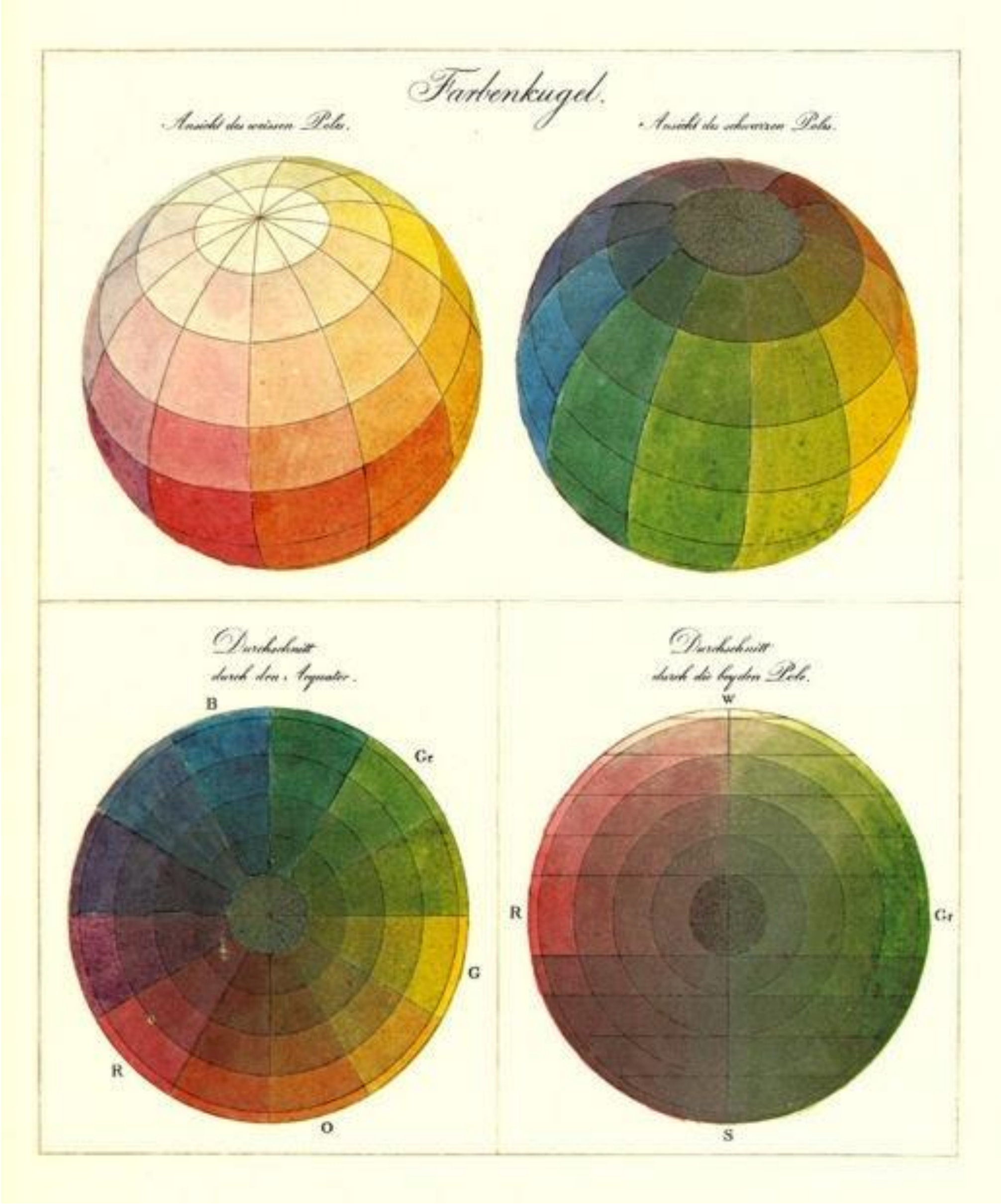


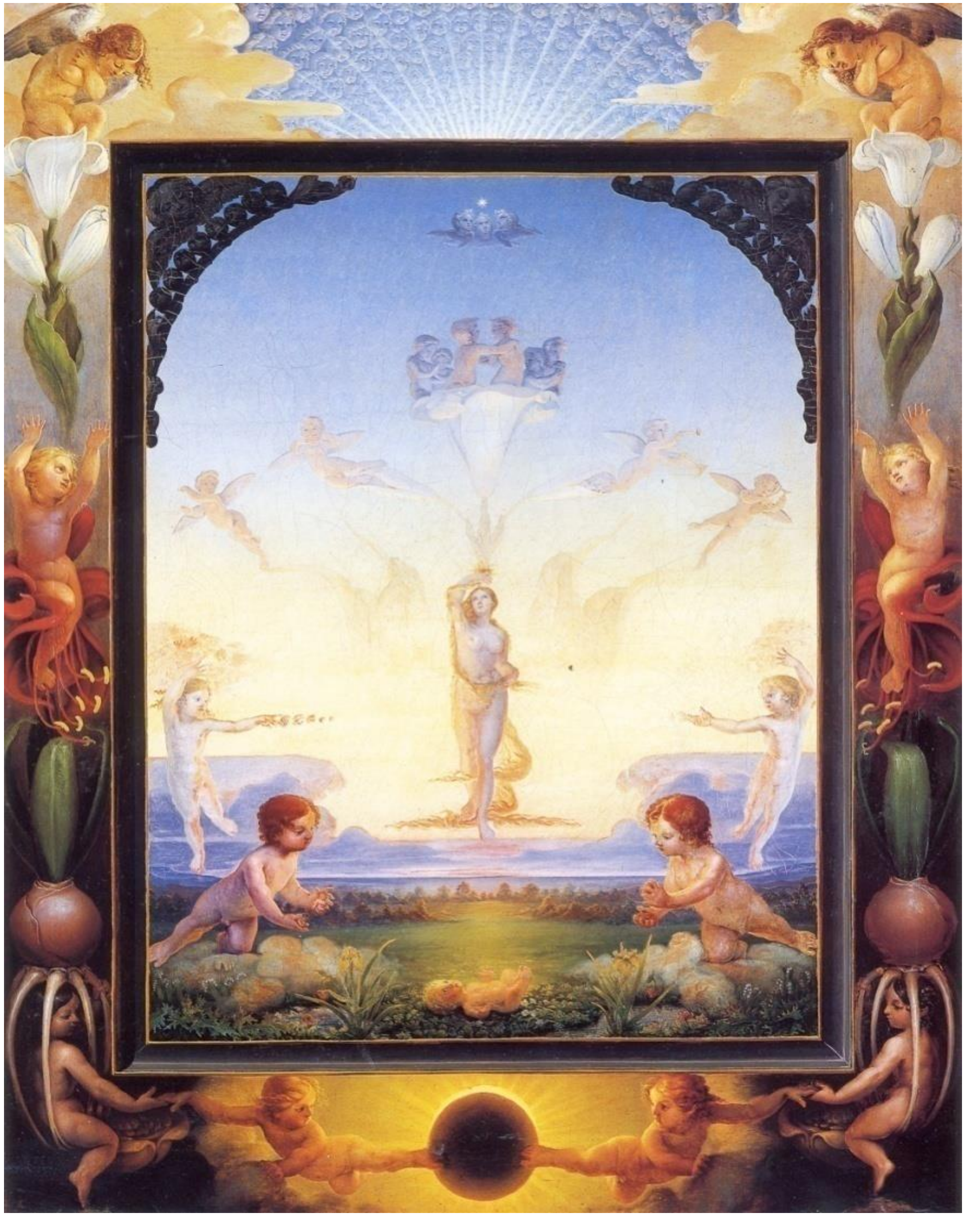
Real Lenses





Color


Farbenkugel.
Ansicht des weissen Pols.
Ansicht des schwarzen Pols.
Durchschnitt durch den Aequator.
Durchschnitt durch die beyden Pole.
B
Gr
G
O
R
W
R
Gr
S



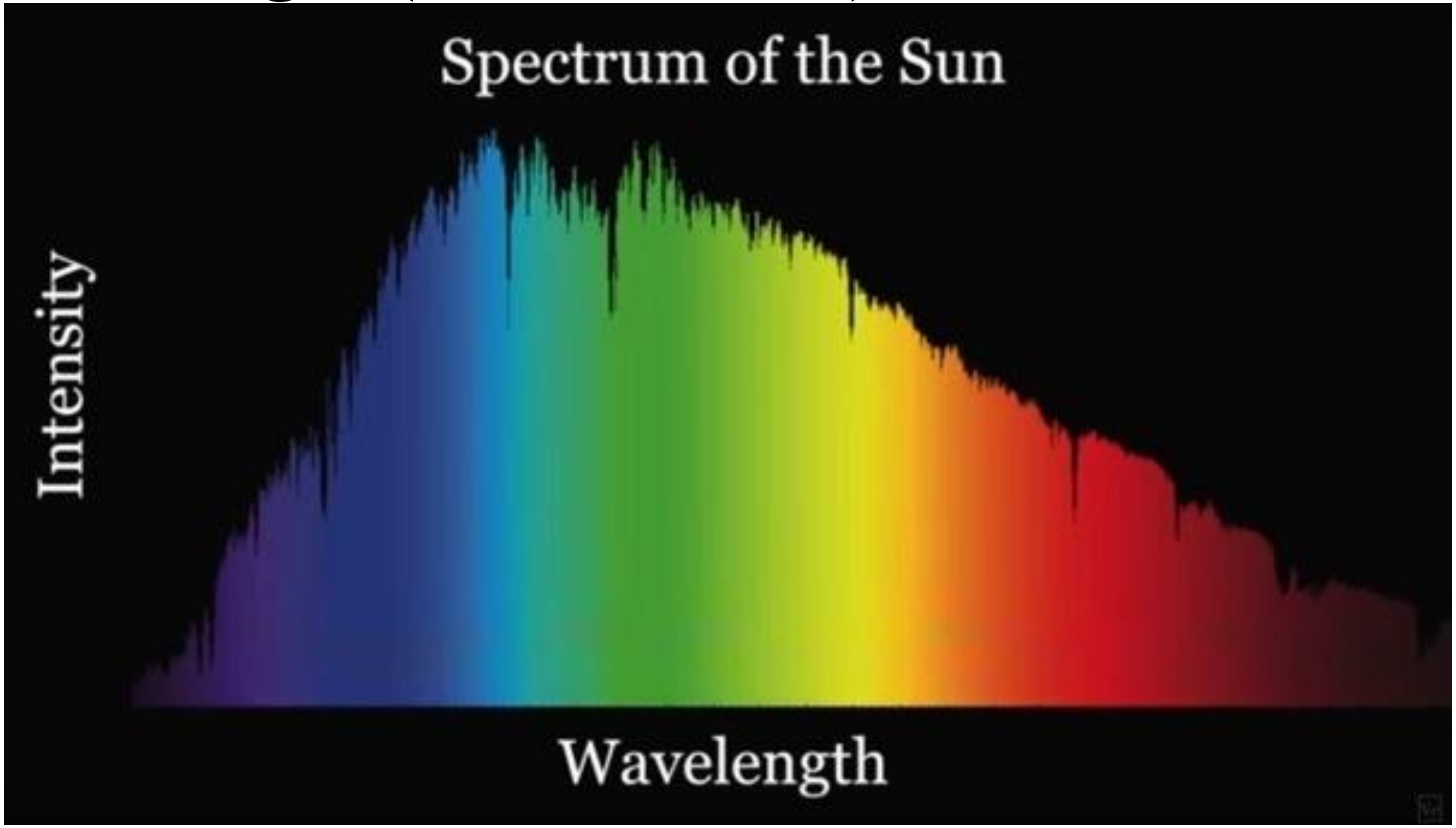
What is color?

- Color is the result of interaction between physical light in the environment and our visual system
- Color is a psychological property of our visual experiences when we look at objects and lights, not a physical property of those objects or lights (S. Palmer, Vision Science: Photons to Phenomenology)

Wassily Kandinsky, Murnau Street with Women, 1908

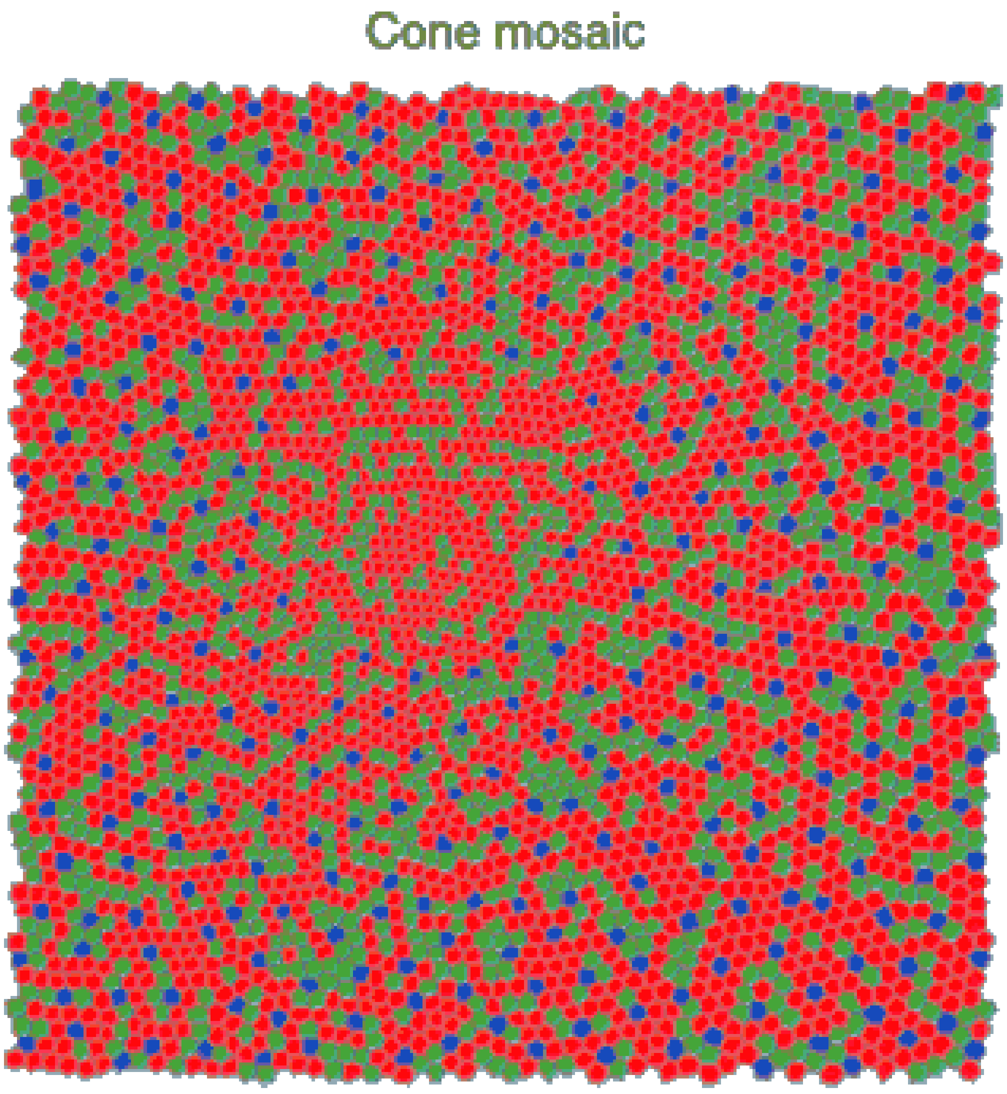
Physics of Light

A source of light can be described physically by its spectrum: the amount of energy emitted at each wavelength (~400-700nm).

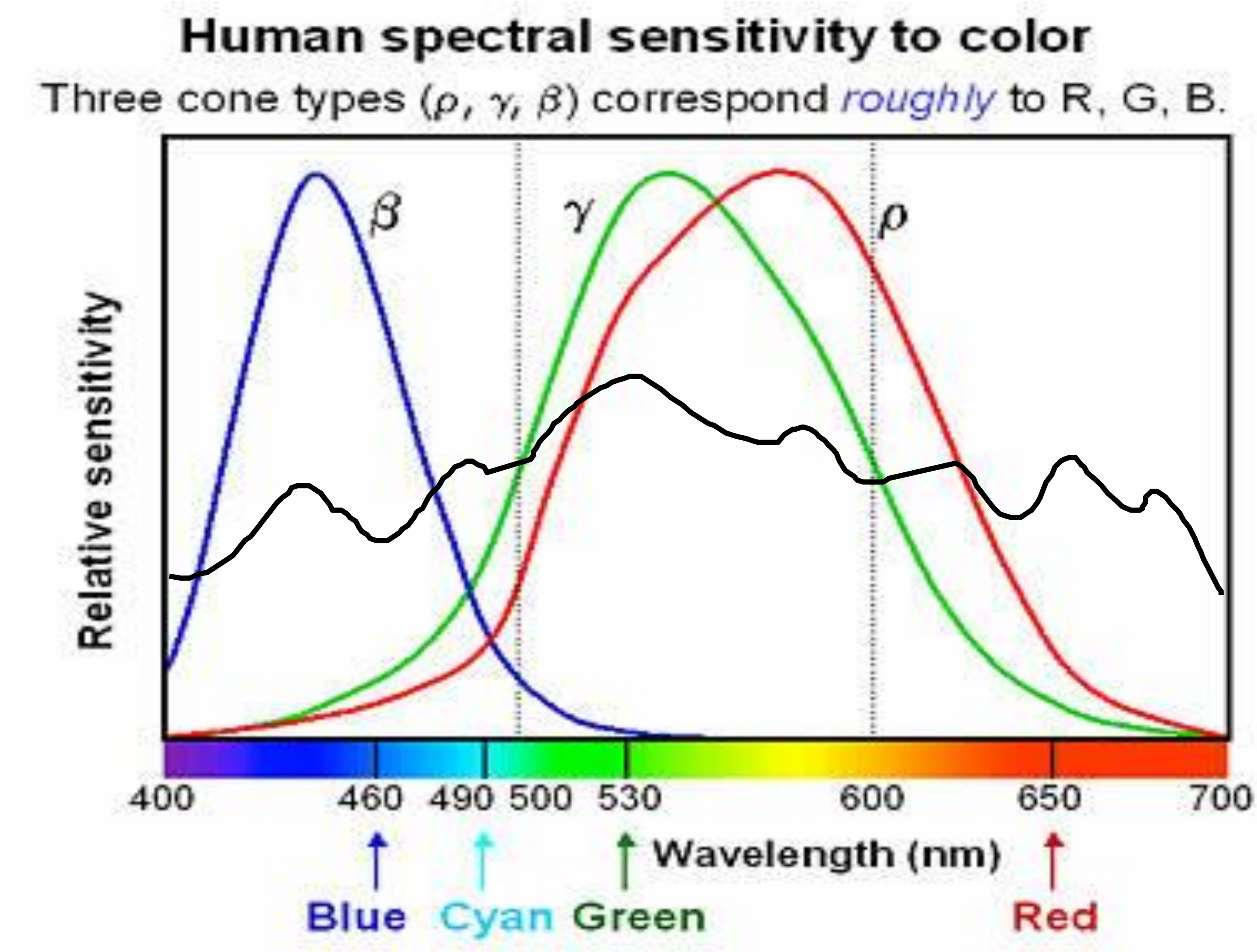


Color Perception by Humans

- Photoreceptor cells: Rods and cones on the retina.
- Rods provide black and white vision.
- Cones provide color vision.
- 3 kind of cones.

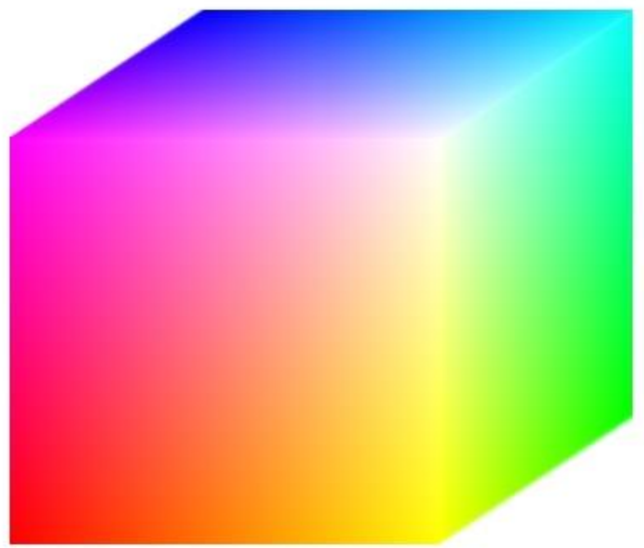


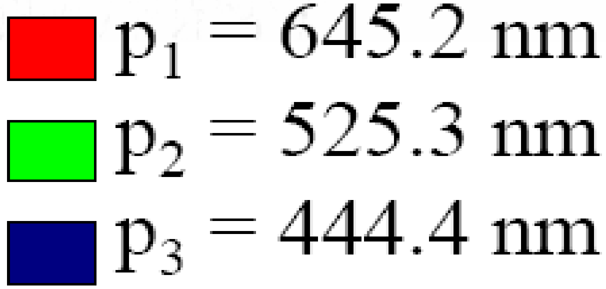
Color Perception by Humans



Rods and cones act as filters on the spectrum: To get the output of a filter, multiply its response curve by the spectrum, integrate over all wavelengths

RGB Color Space

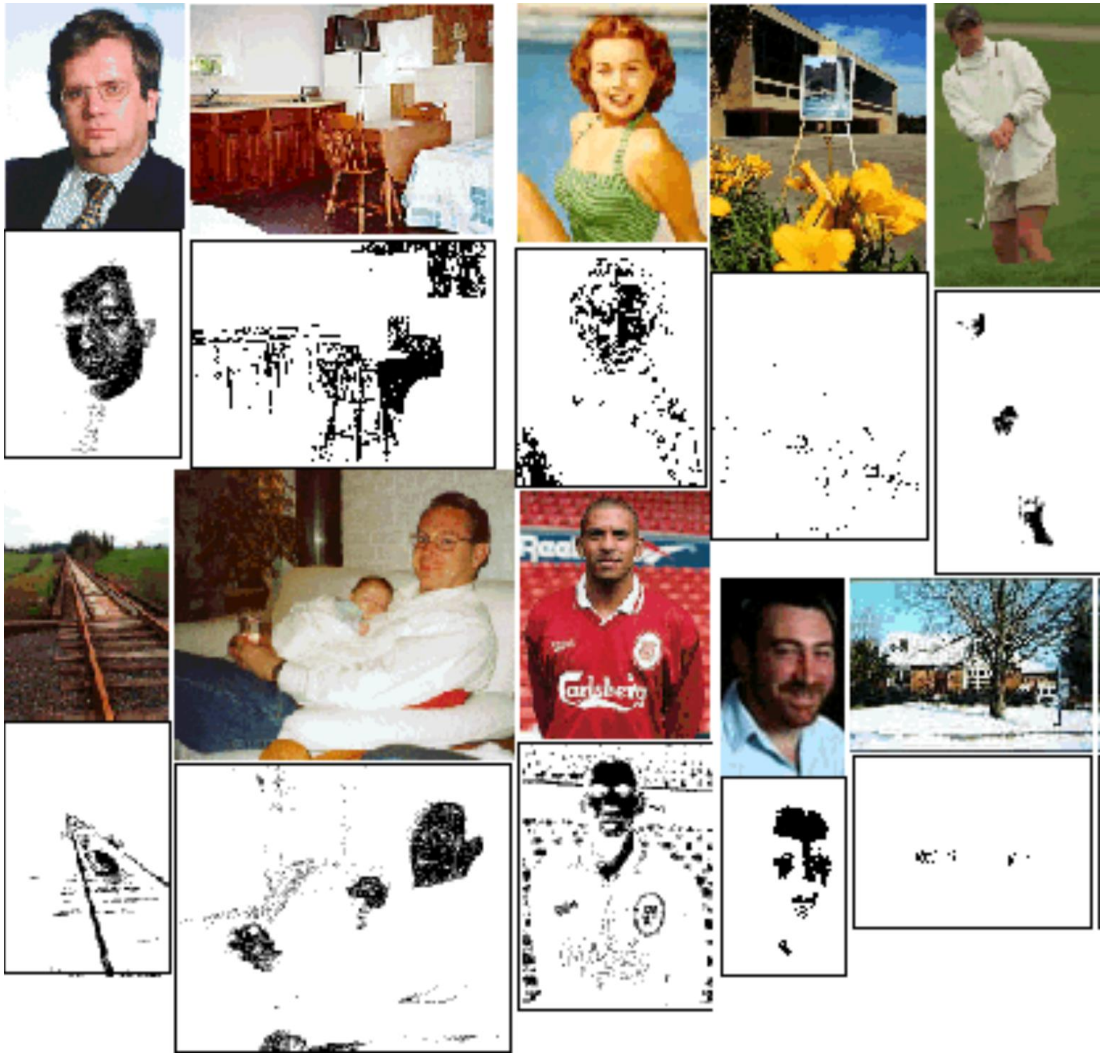




- Additive color model.
- Each pixel is characterized by a value for each of the three components: (v_r, v_g, v_b).
- Examples:
  - Black: (0,0,0)
  - Gray: (v,v,v)
  - White: $(v_{max}, v_{max}, v_{max})$

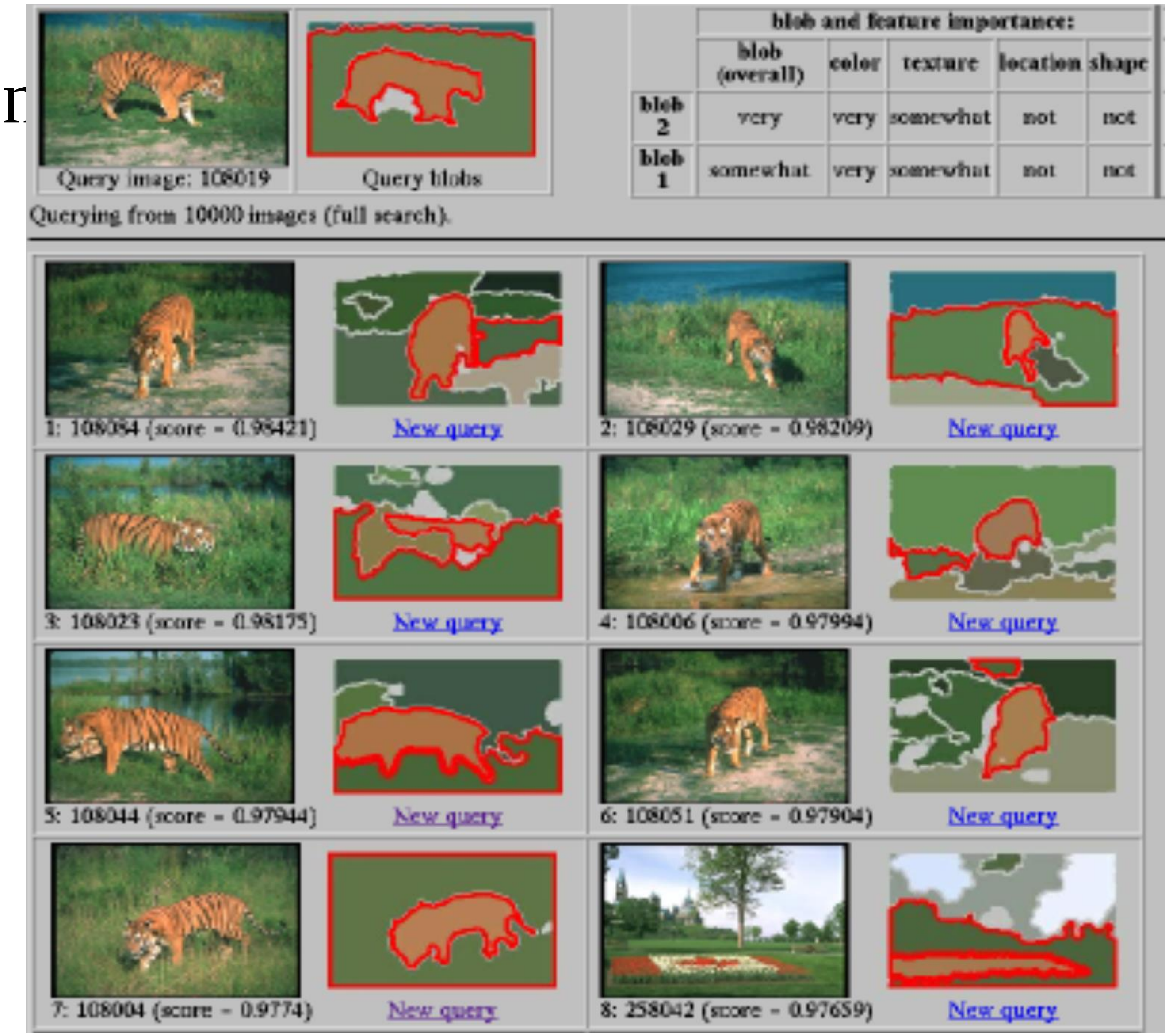
Uses of Color in Computer Vision

Skin Detection



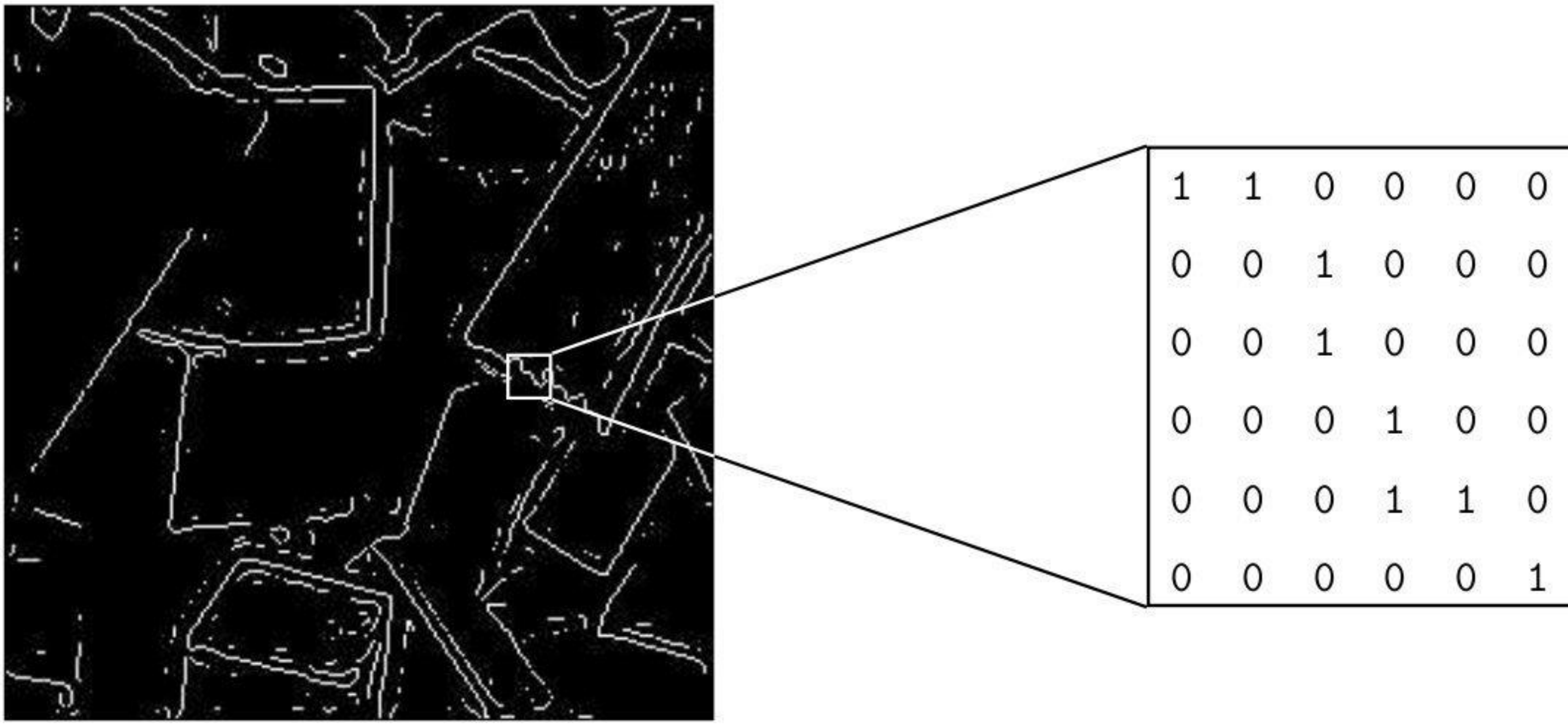
Uses of Color in Computer Vision

Image Segmentation and Retrieval



Digital Camera

Digital Image - Binary



Digital Image - Grayscale

230	229	232	234	235	232	148
237	236	236	234	233	234	152
255	255	255	251	230	236	161
99	90	67	37	94	247	130
222	152	255	129	129	246	132
154	199	255	150	189	241	147
216	132	162	163	170	239	122

Digital Image - Color

49	55	56	57	52	53
58	60	60	58	55	57
58	58	54	53	55	56
83	78	72	69	68	69
88	91	91	84	83	82
69	76	83	78	76	75
61	69	73	78	76	76

Red

64	76	82	79	78	78
93	93	91	91	86	86
88	82	88	90	88	89
125	119	113	108	111	110
137	136	132	128	126	120
105	108	114	114	118	113
96	103	112	108	111	107

Green

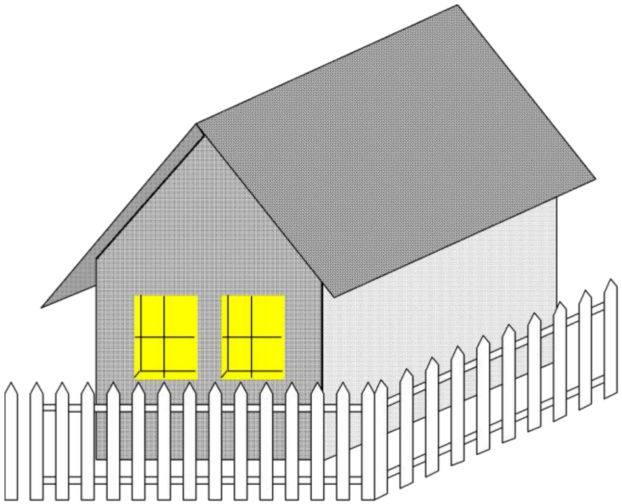
66	80	77	80	87	77
81	93	96	99	86	85
83	83	91	94	92	88
135	128	126	112	107	106
141	129	129	117	115	101
95	99	109	108	112	109
84	93	107	101	105	102

Blue

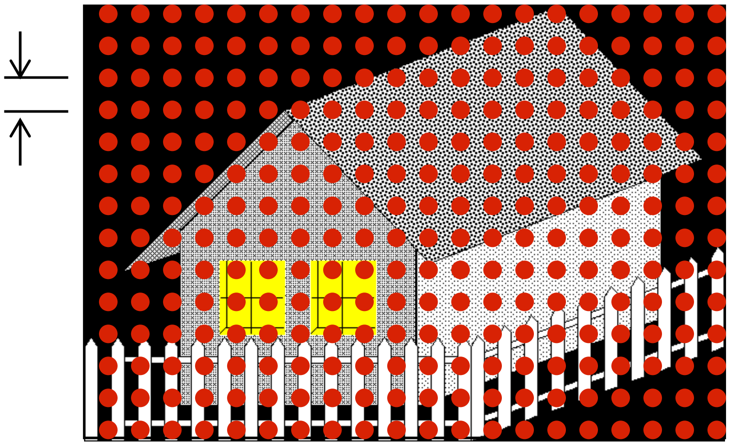
Digitization

- Digital camera, scanner.
- Quality depends on:
  - Spatial Sampling (image resolution, number of pixels).
  - Depth (number of intensity values).

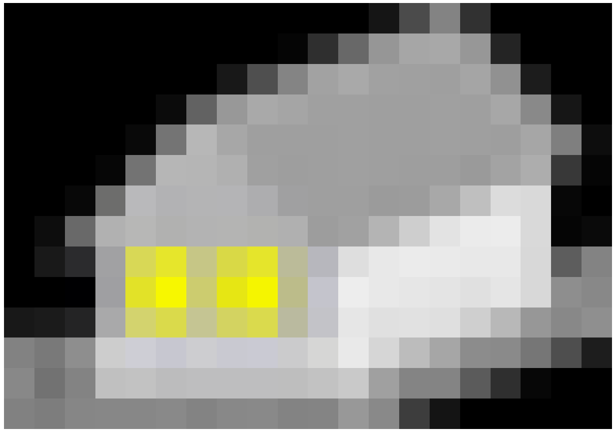
Digitization – Spatial Sampling



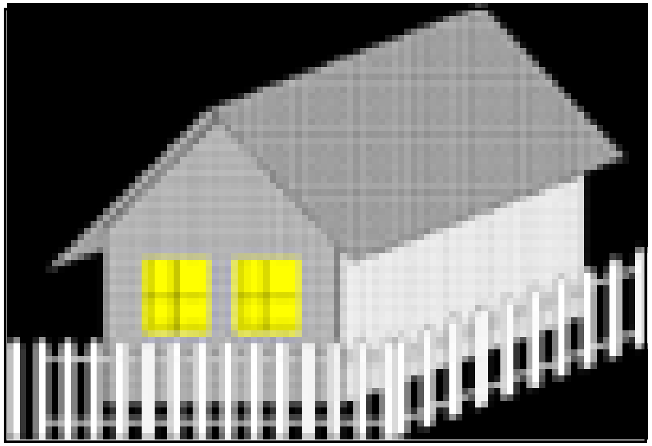
Initial image



Sampling points



Coarse sampling

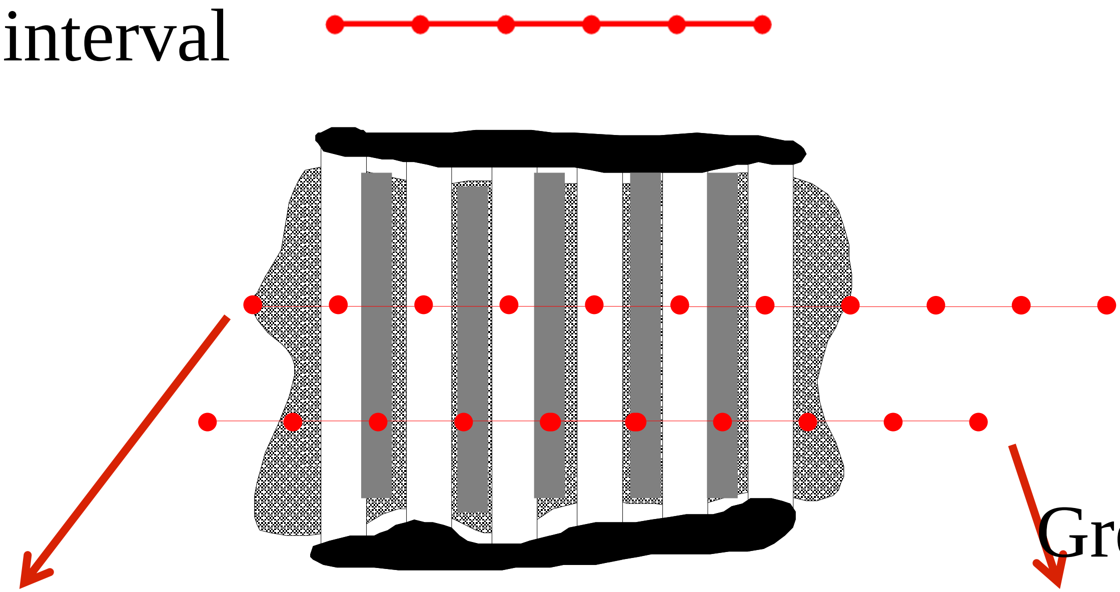


Dense sampling

Sampling Interval

Look at the fence:

Sampling interval



White image!

Grey image!

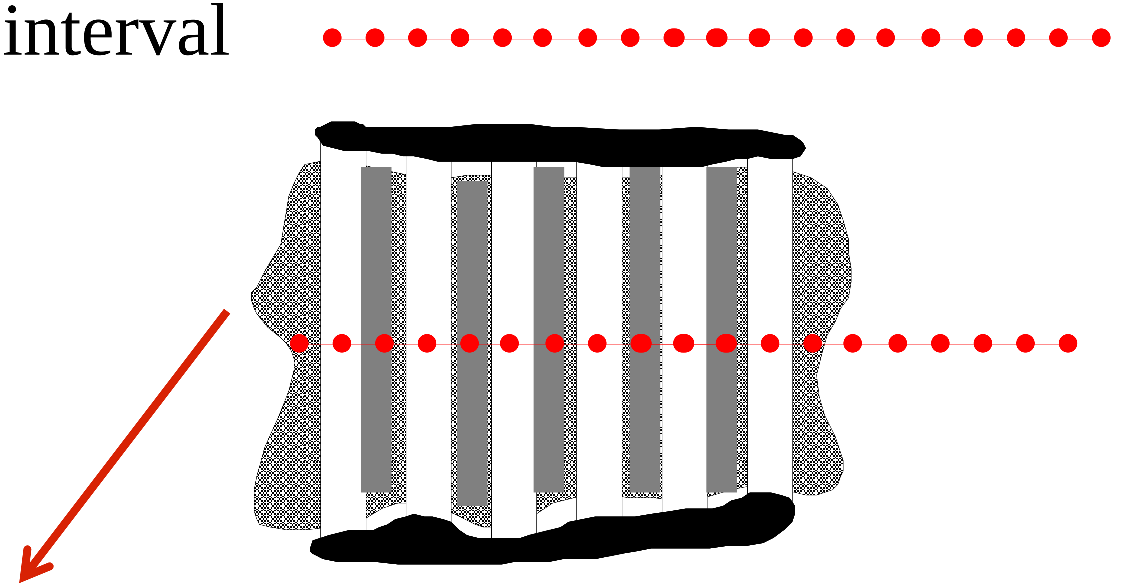
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100

40	40	40	40	40	40
40	40	40	40	40	40
40	40	40	40	40	40
40	40	40	40	40	40

Sampling Interval

Look at the fence:

Sampling interval



40	100	40	100	40
40	100	40	100	40
40	100	40	100	40
40	100	40	100	40

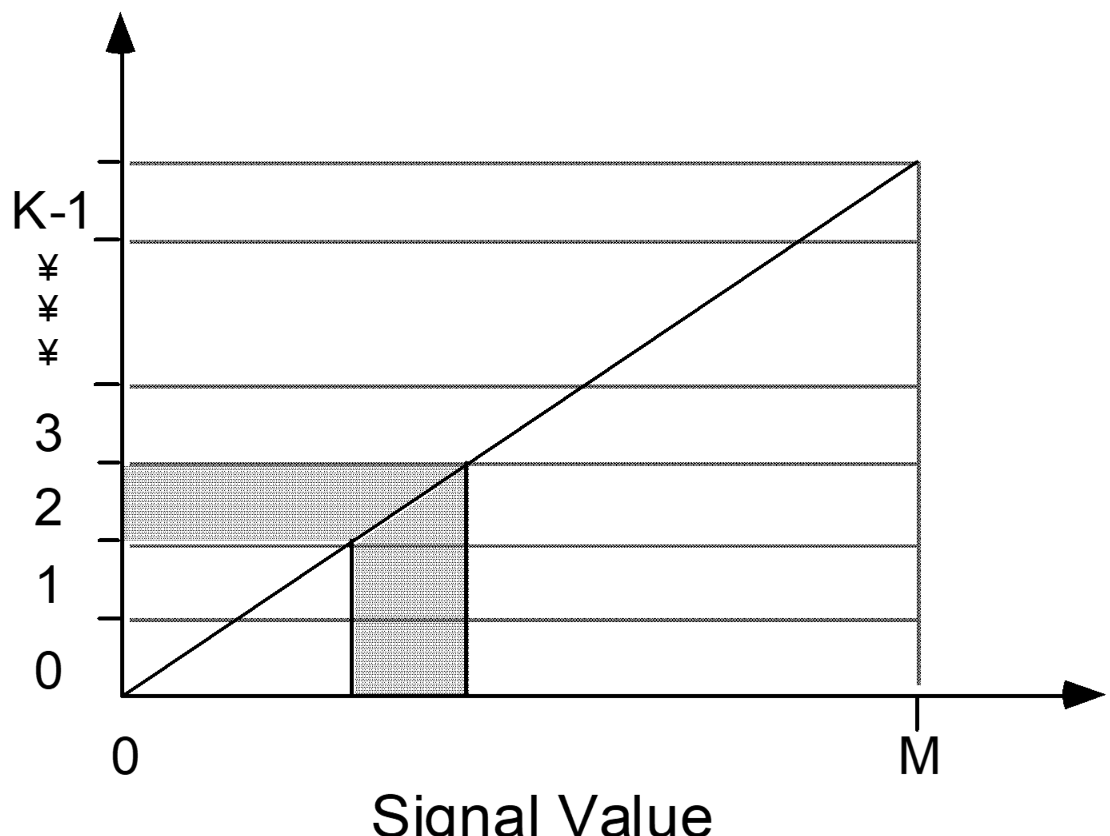
Now the fence is visible!

Sampling Theorem

If the width of the thinest structure is **d**, then the sampling interval should be smaller than **d/2**.

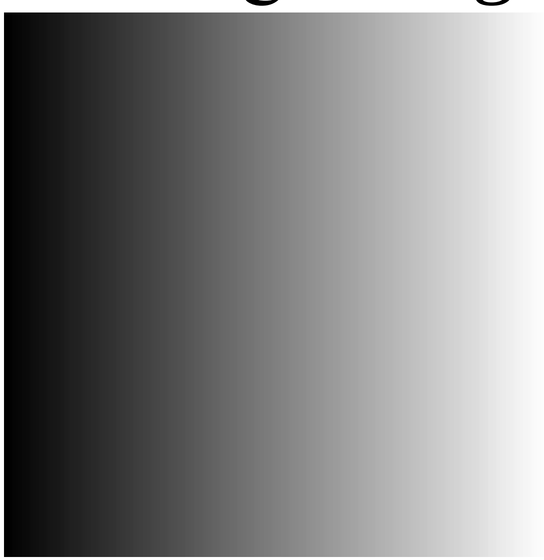
Image Quantization

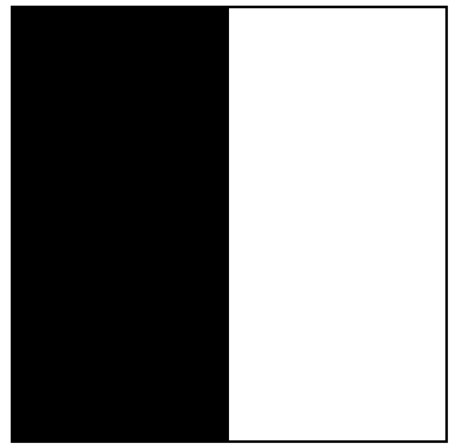
- Determines the value of each sample.
- Mapping between analog continuous values and **K** digital quantized values.



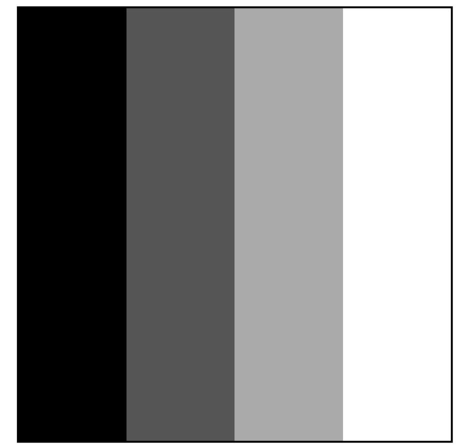
Selection of K – Gray Scale Image

“Analog” image

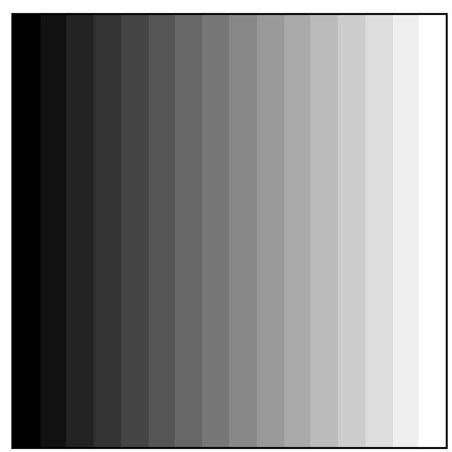




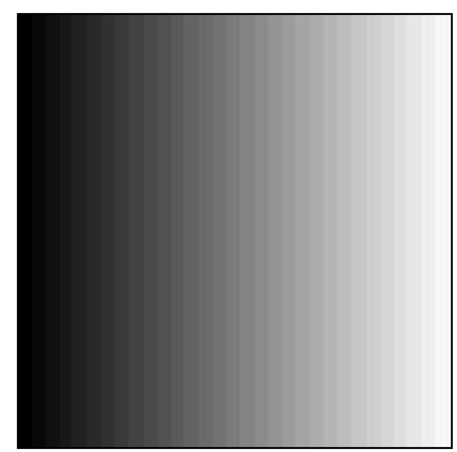
K=2



K=4



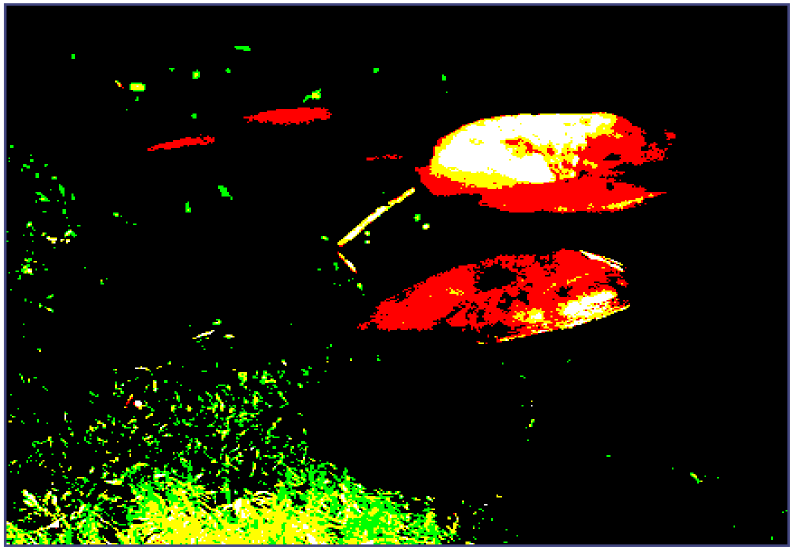
K=16



K=32

Selection of K - Color Image

"Analog" Image



K=2 (for each color)

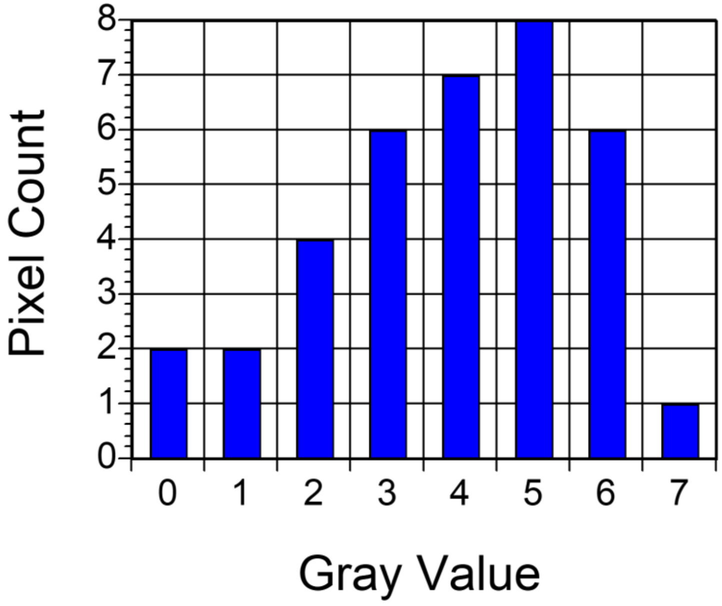
K=4 (for each color)

Loss during Quantization

Loss during Spatial Sampling

Image Histogram **H**

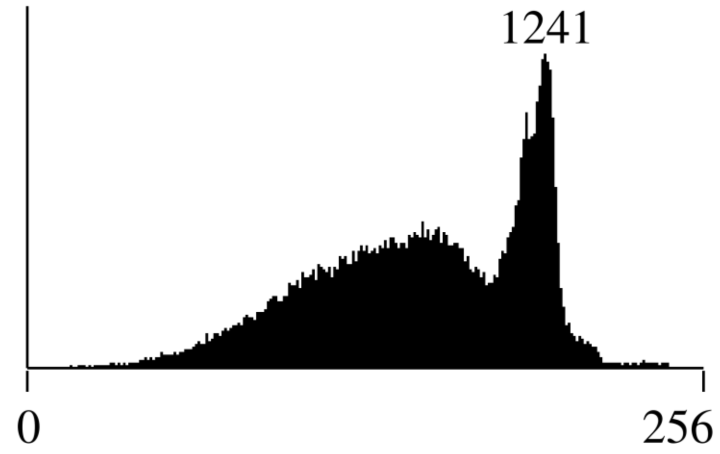
- *H(i)* is the number of image pixels that have the value *i*.

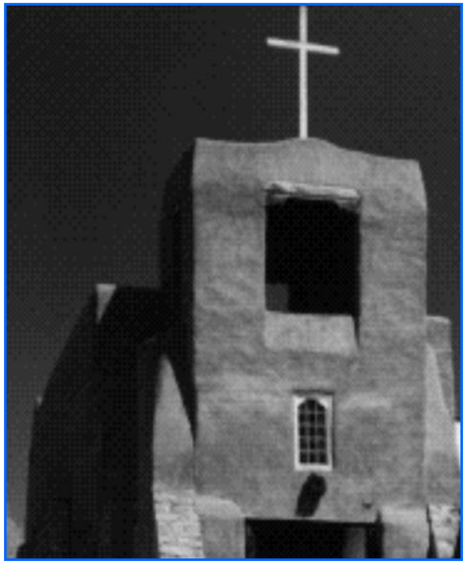


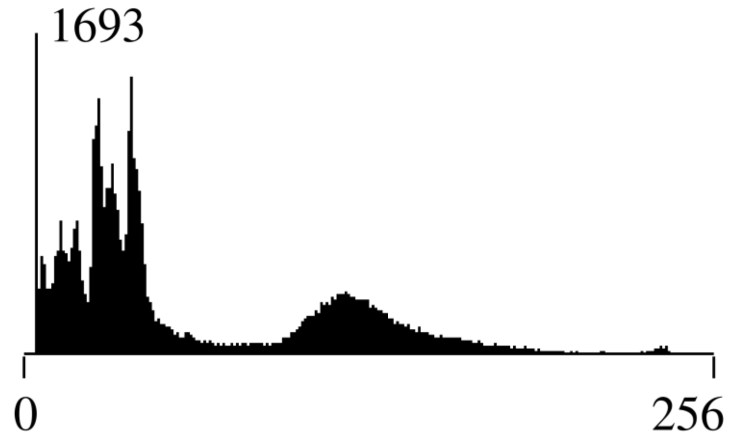
For a MxN image:

$$\sum_{i=I_{\min}}^{I_{\max}} H(i) = MN$$

Histogram Examples







? Questions ?