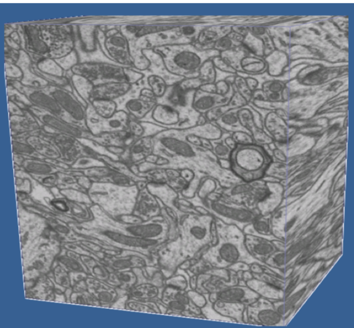
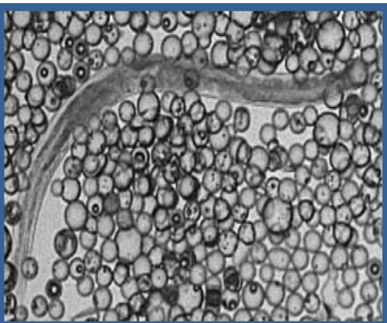
Introduction to Signal and Image Processing

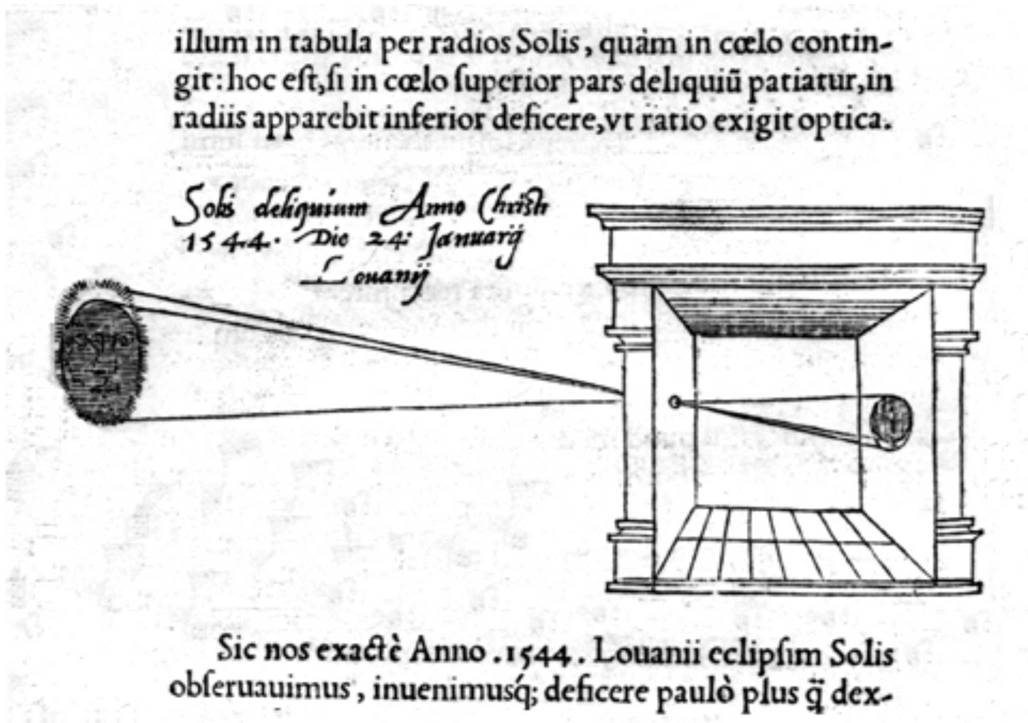
Spring 2019

Lecture 1:
Image formation & basics





Camera Obscura



"When images of illuminated objects ... penetrate through a small hole into a very dark room ... you will see [on the opposite wall] these objects in their proper form and color, reduced in size ... in a reversed position, owing to the intersection of the rays". *Da Vinci*

http://www.acmi.net.au/AIC/CAMERA_OBSCURA.html (Russell Naughton)

Slide credit: David Jacobs

Camera Obscura

Jetty at Margate England, 1898.

http://brightbytes.com/cosite/collection2.html (Jack and Beverly Wilgus)

Slide credit: David Jacobs

First known photograph

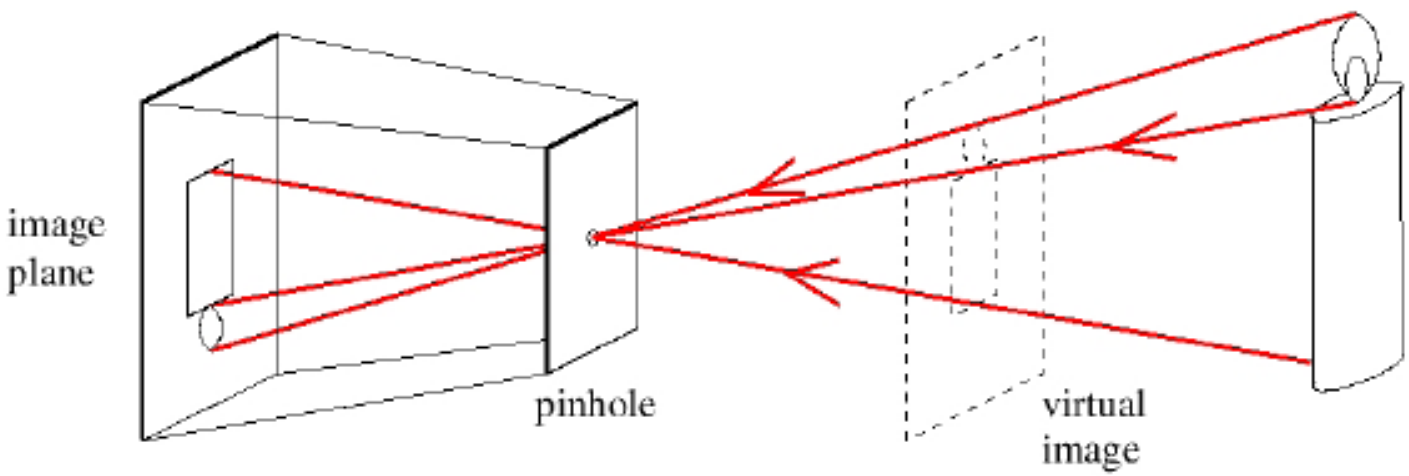
La table servie

Forsyth & Ponce Figure 1.16

Credit: Nicéphore Niepce, 1822

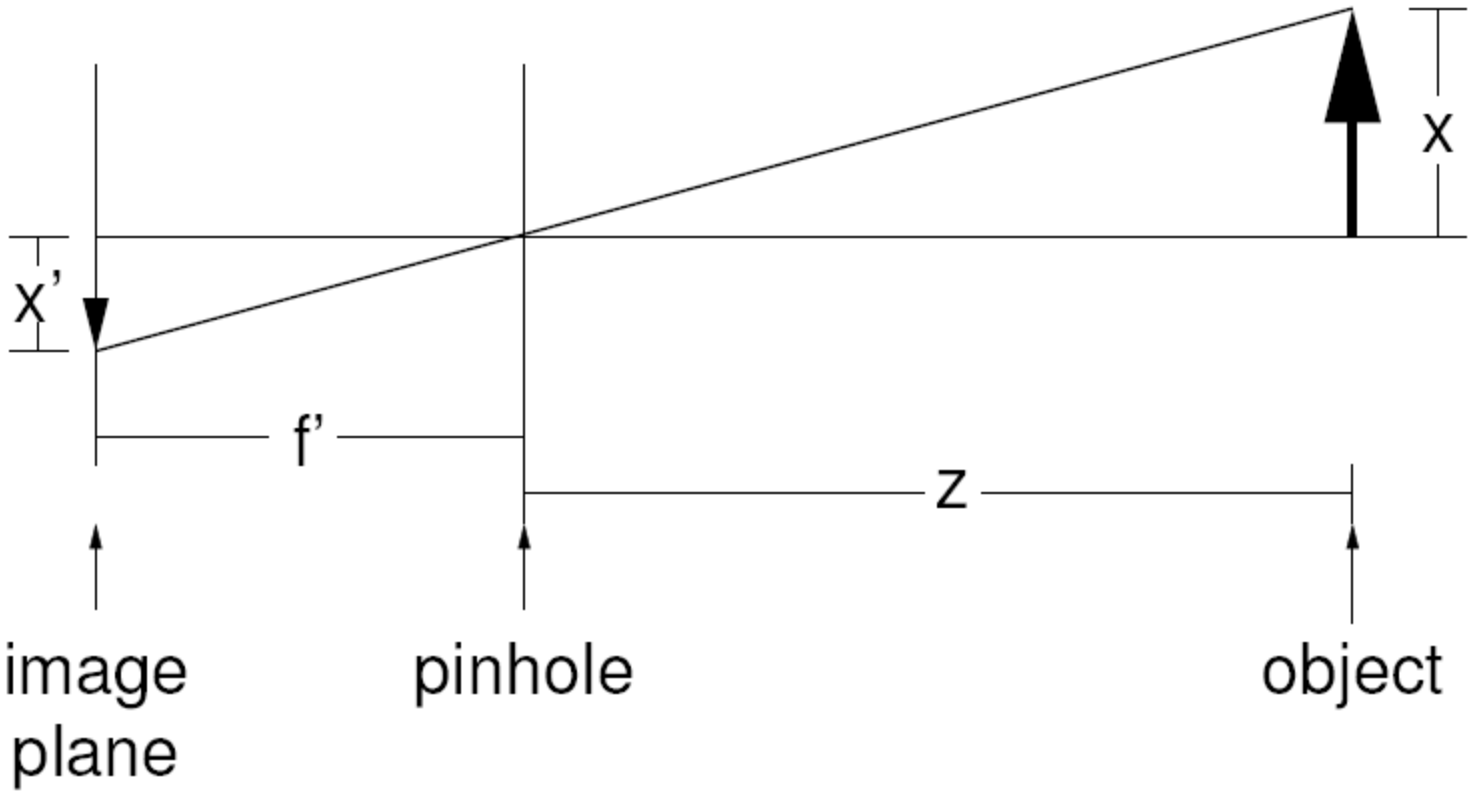
Pinhole cameras

- Pinhole camera - box with a small hole in it
- Image is upside down, but not mirrored left-to-right
- **Question:** Why does a mirror reverse left-to-right but not top-to-bottom?



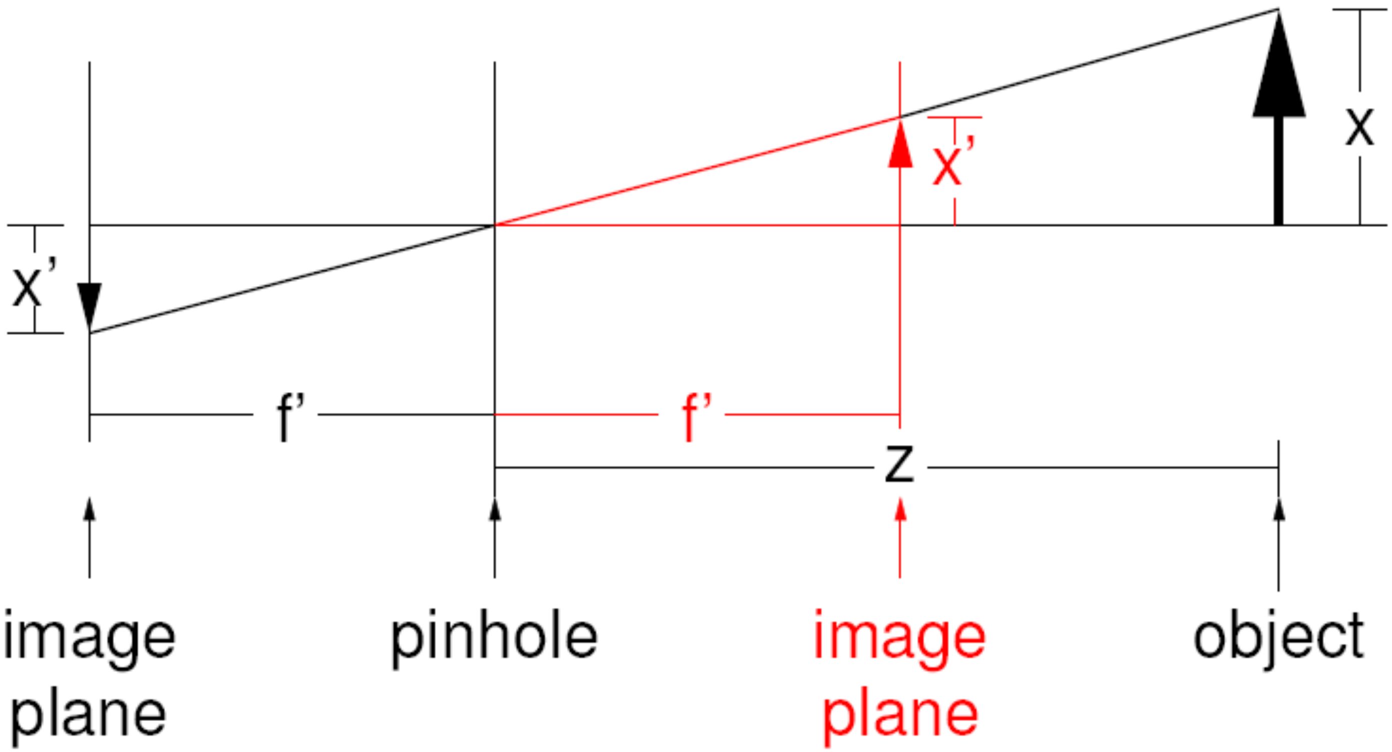
Forsyth & Ponce Figure 1.2

Pinhole camera in 2D



$$X' = (f' / Z)\,X$$

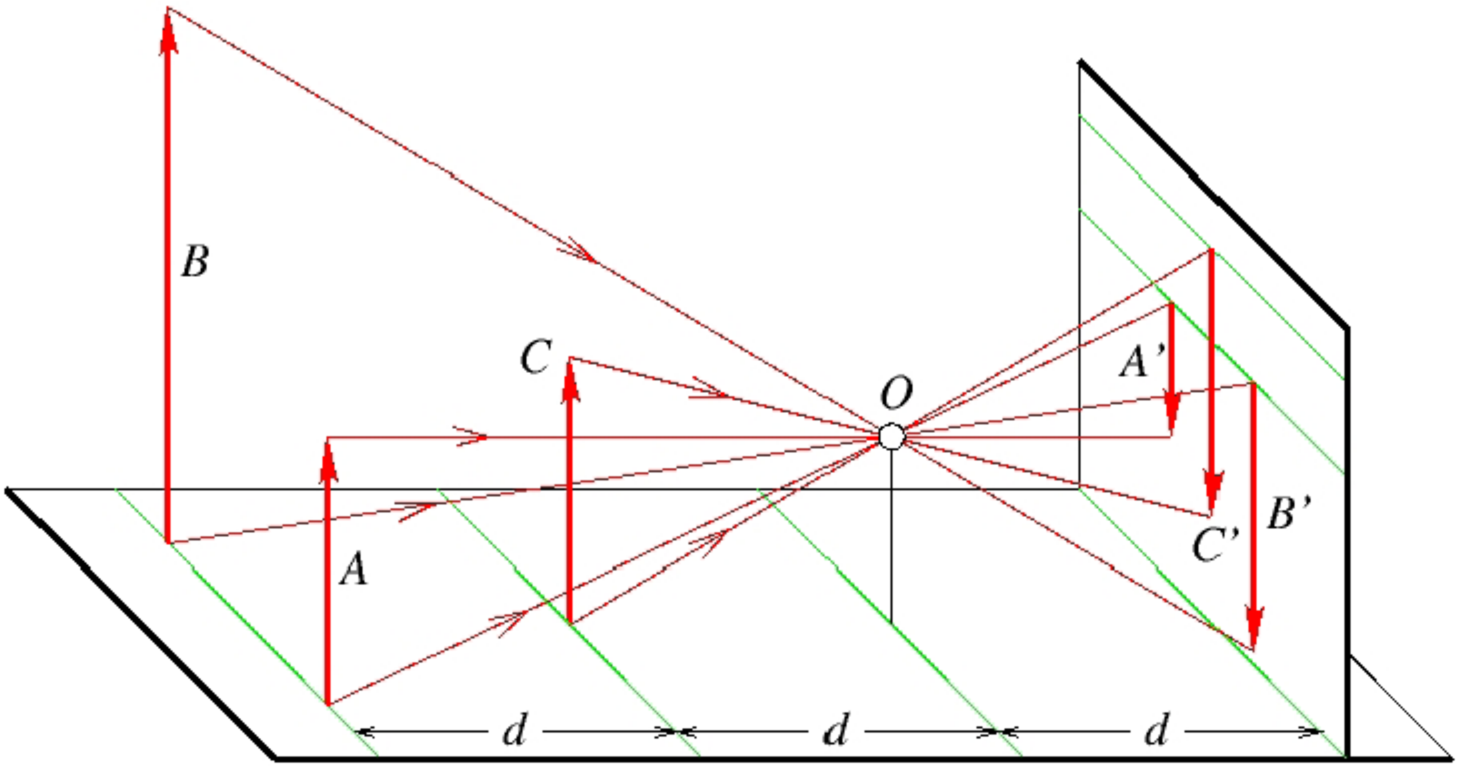
Pinhole camera in 2D (with reflected image plane)



The image is the same after reflection of the image plane, except that image is the right way up!

Distant objects are smaller

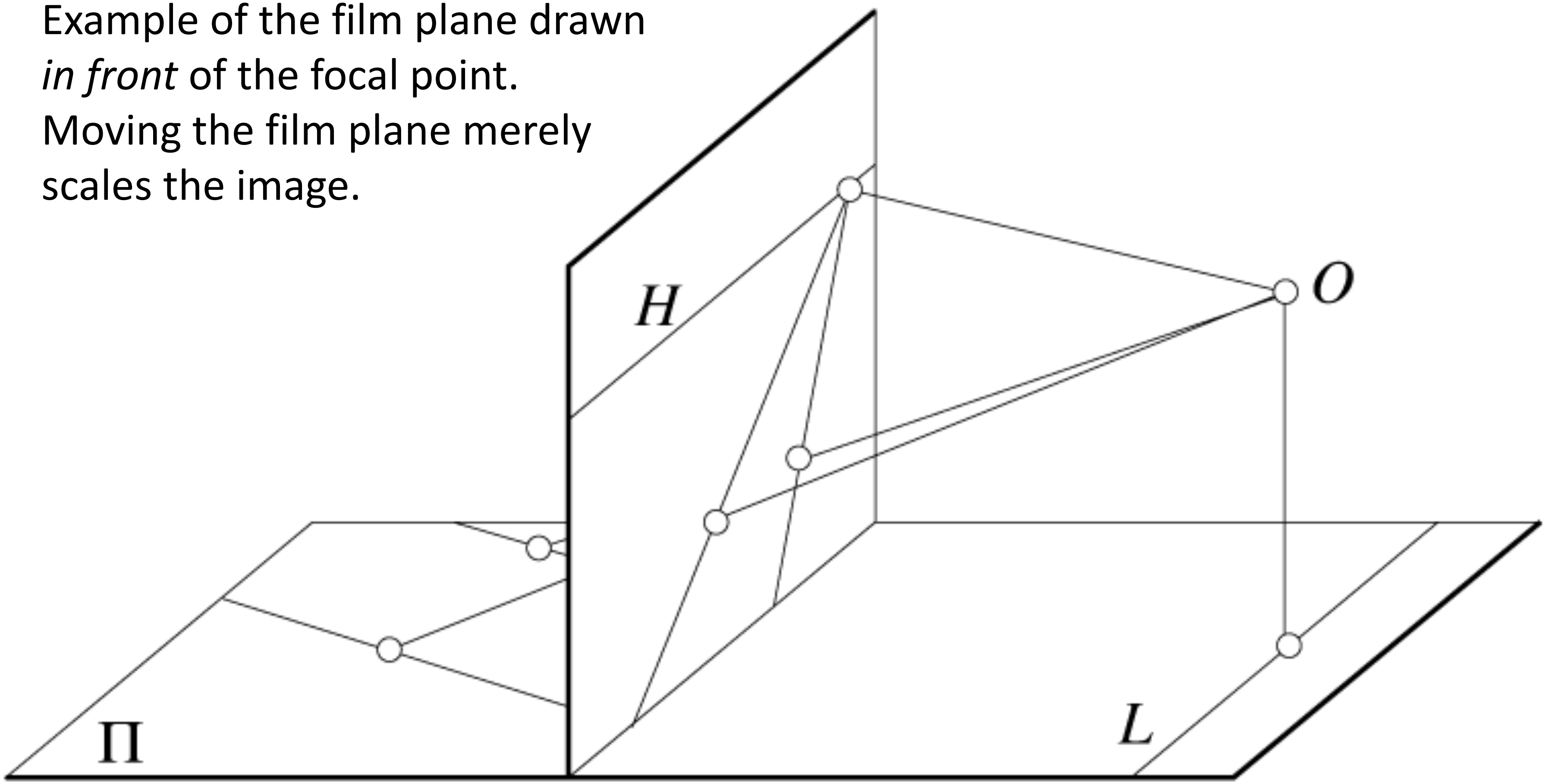
Size is inversely proportional to distance.



Forsyth & Ponce Figure 1.3a

Parallel lines meet

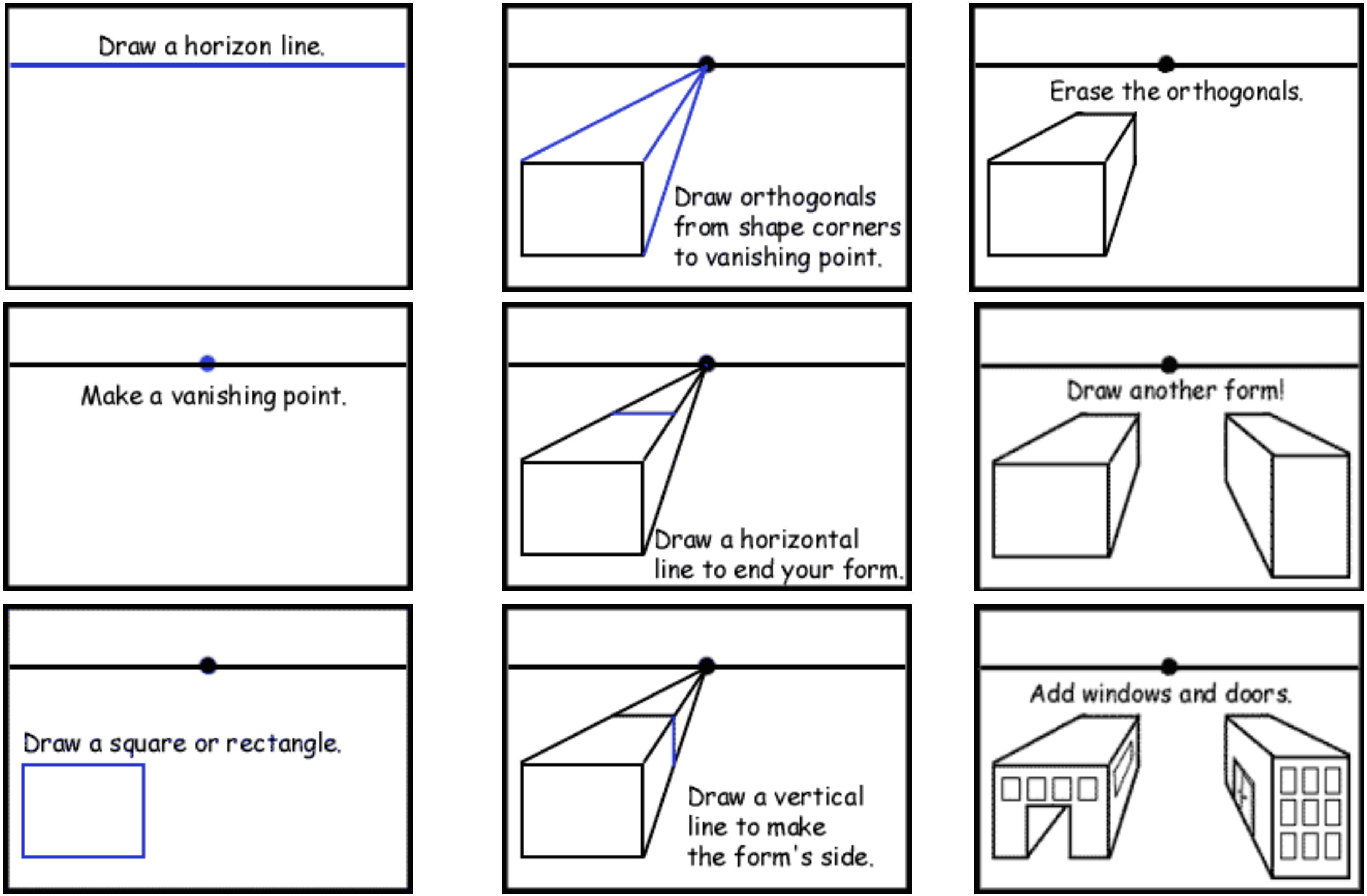
Example of the film plane drawn *in front* of the focal point. Moving the film plane merely scales the image.



Vanishing points

- each set of parallel lines meets at a different point
  - The *vanishing point* for this direction
- Sets of parallel lines on the same plane lead to *collinear* vanishing points.
  - The line is called the *horizon* for that plane
- Good ways to spot faked images
  - scale and perspective don’t work
  - vanishing points behave badly

Vanishing points



Properties of perspective projection

- Points project to: points
- Lines project to: lines
- Planes project: images
- Angles are / are not preserved?
- Degenerate cases
  - Line through focal point projects to a point.
  - Plane through focal point projects to line

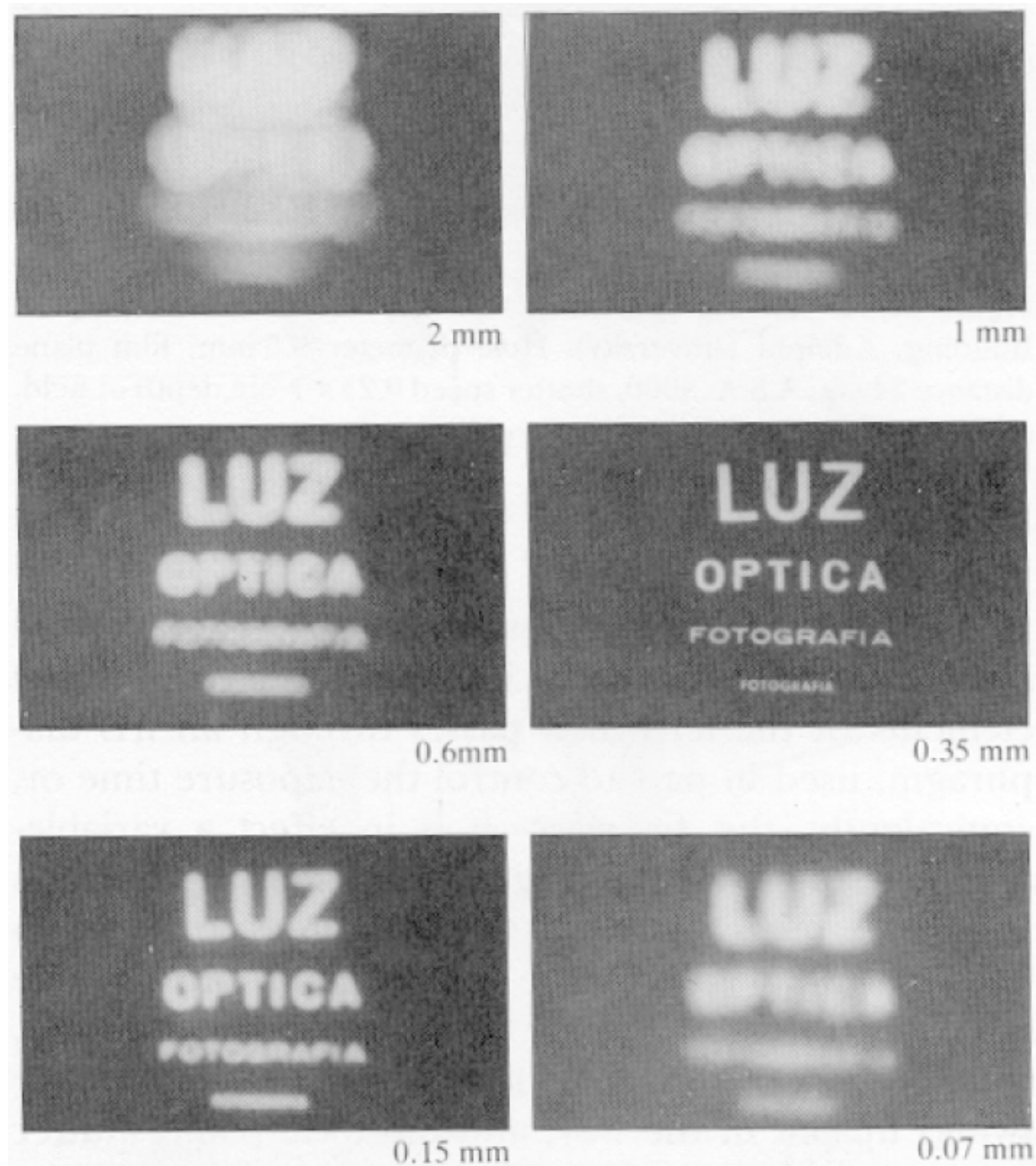
Pinhole limitations

Why not use pinhole cameras?

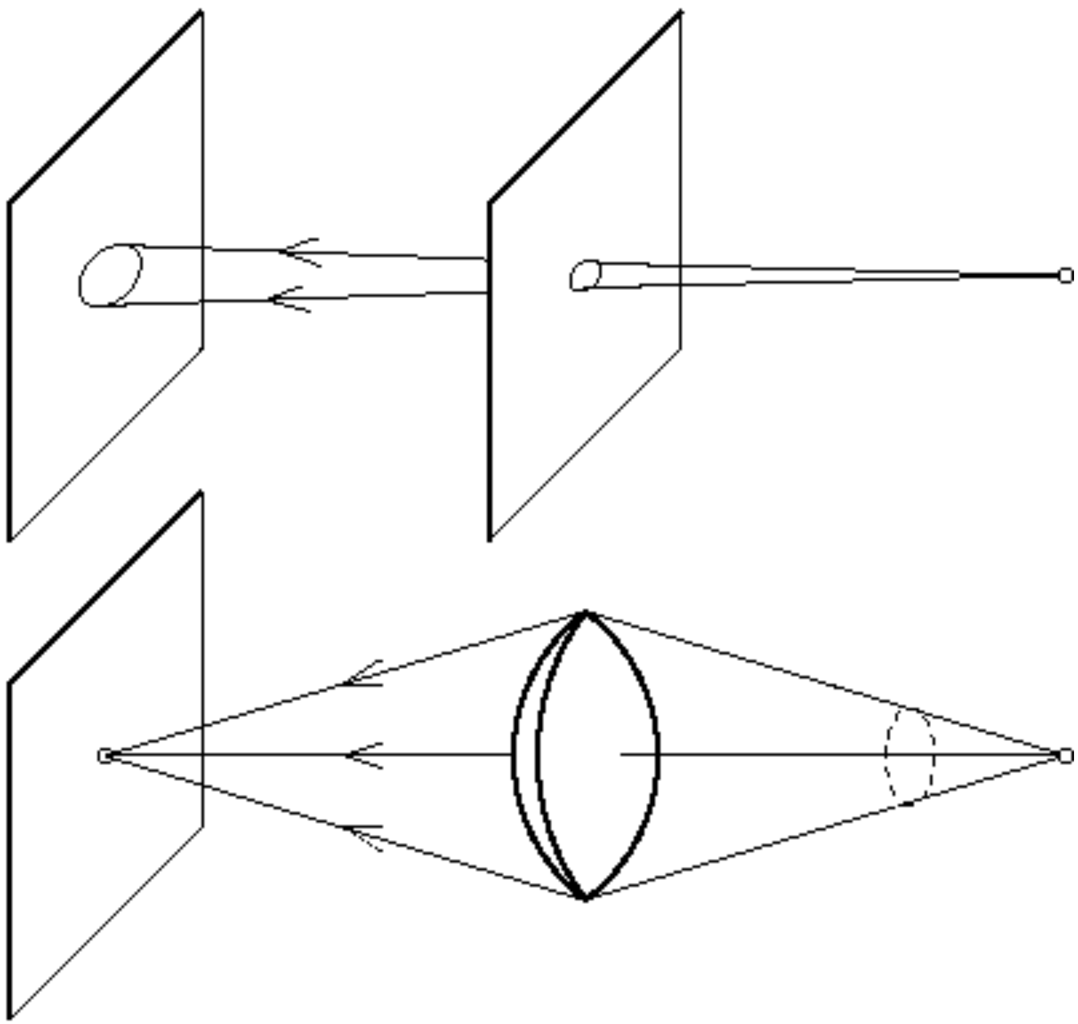
If pinhole is too big - many directions are averaged, blurring the image

Pinhole too small- diffraction effects blur the image

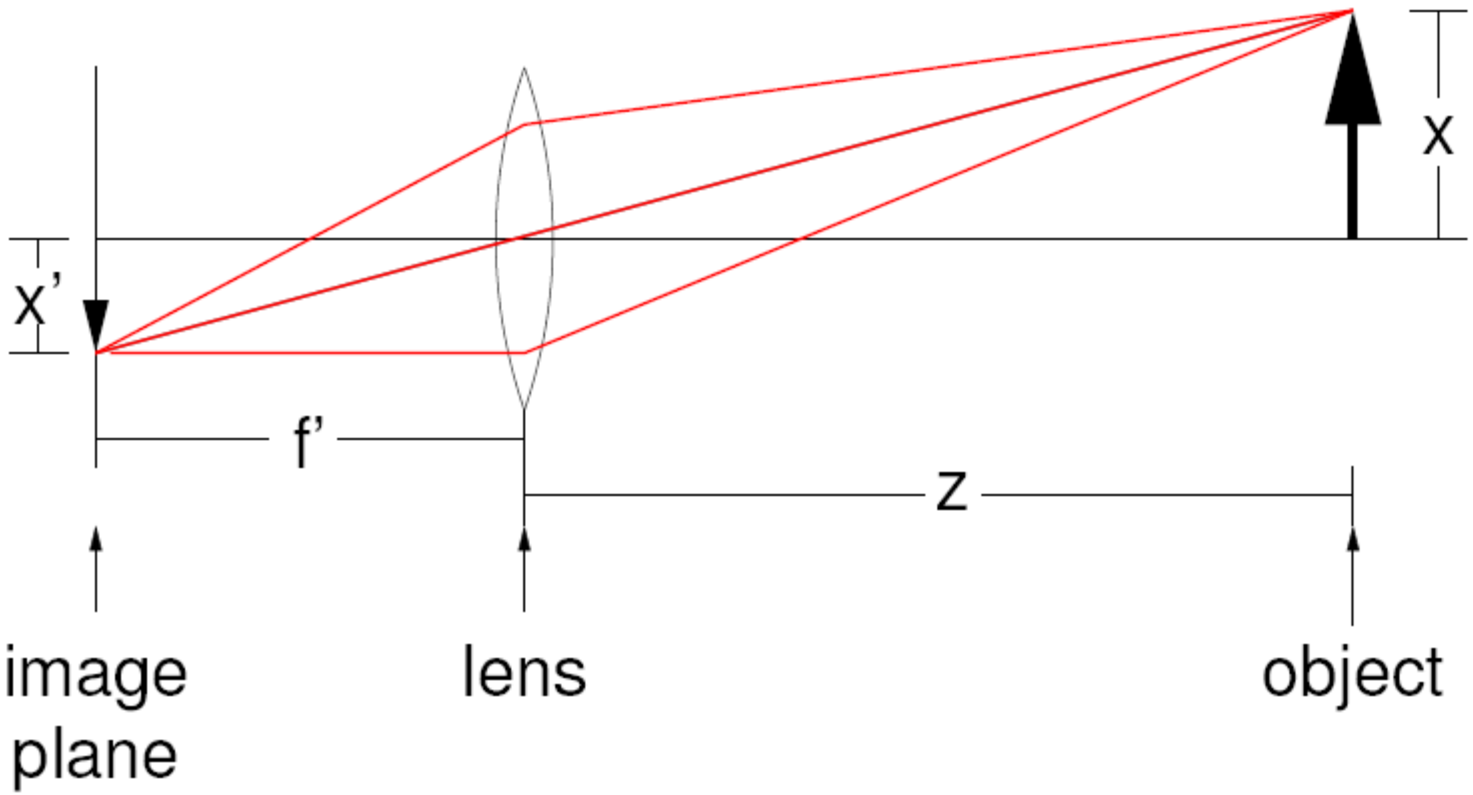
Generally, pinhole cameras are *dark*, because a very small set of rays from a particular point hits the screen.



The reason for lenses

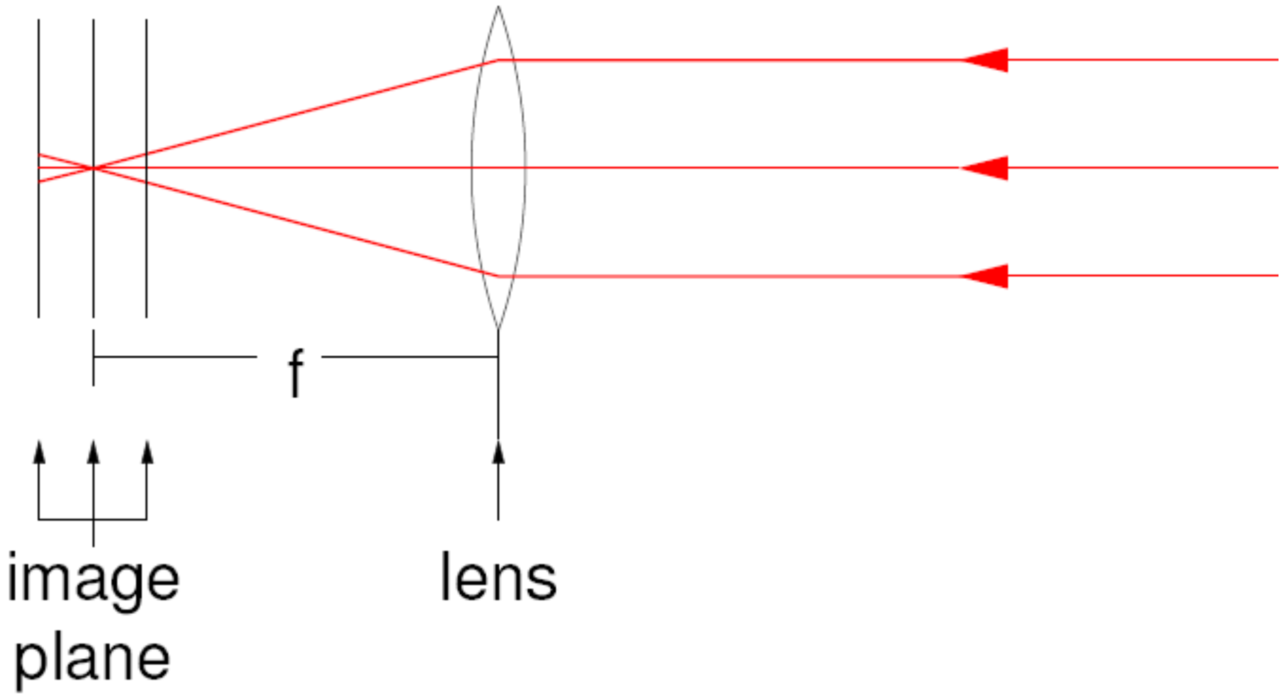


Pinhole model with a single lens



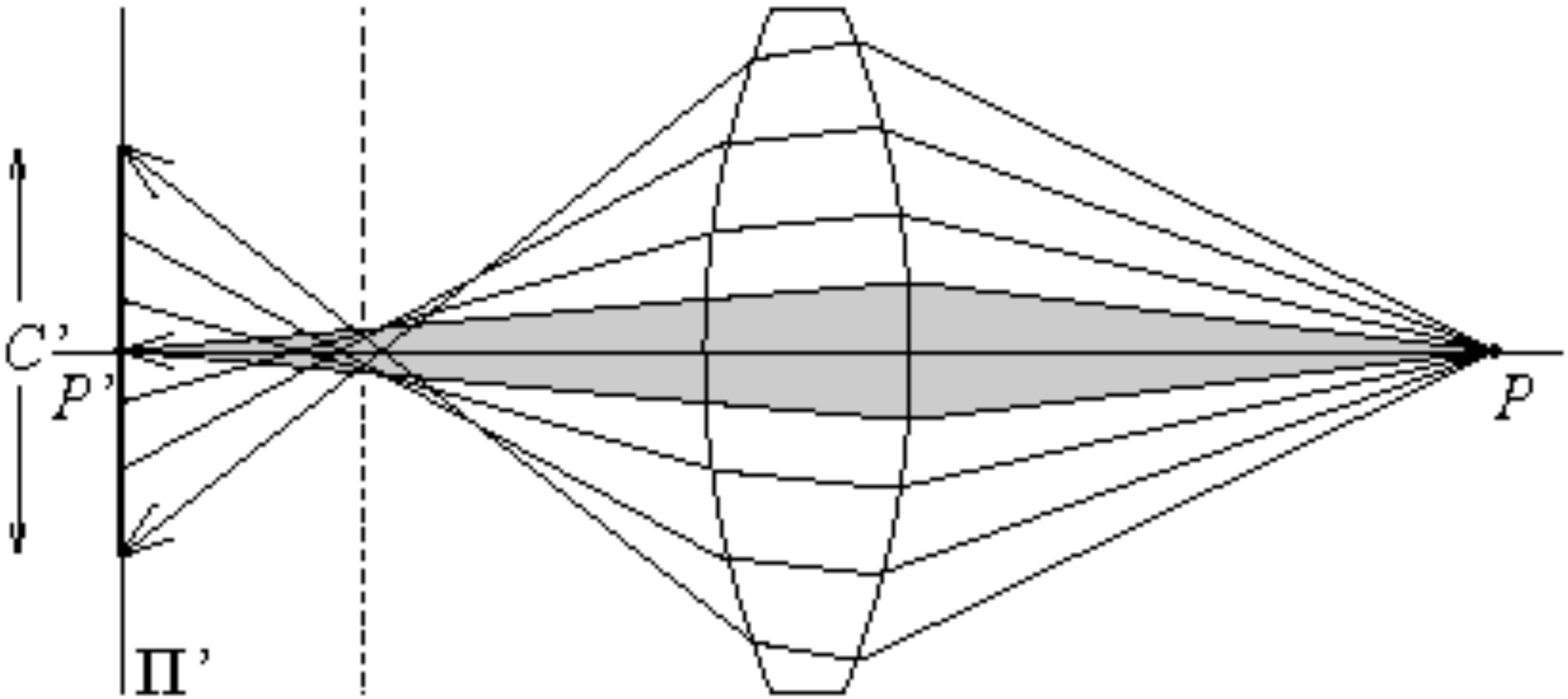
A lens follows the pinhole model for objects that are in focus.

An out-of-focus lens



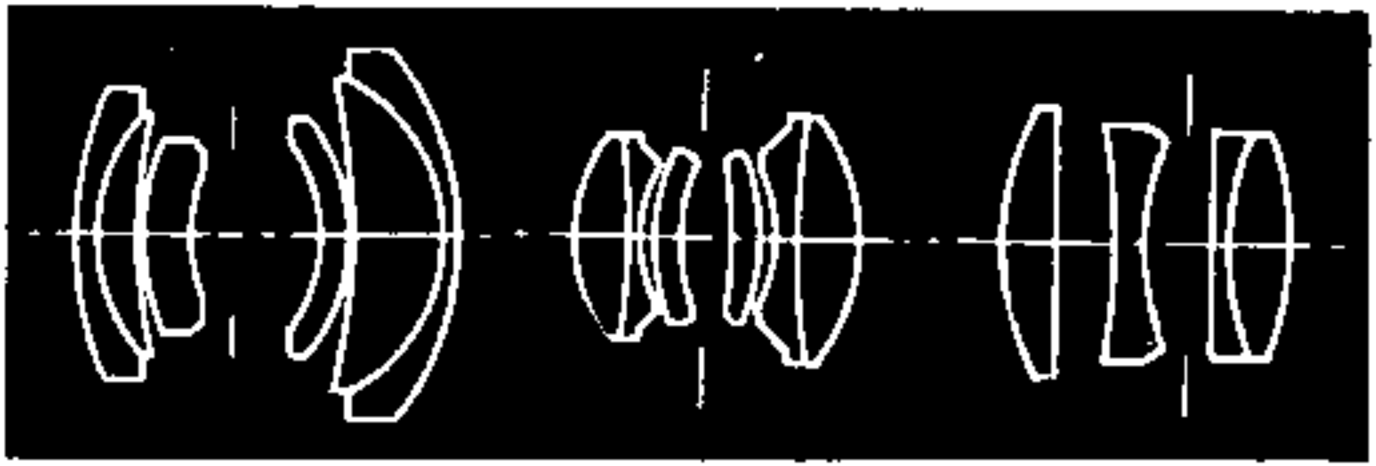
An image plane at the wrong distance means that rays from different parts of the lens create a blurred region (the "point spread function").

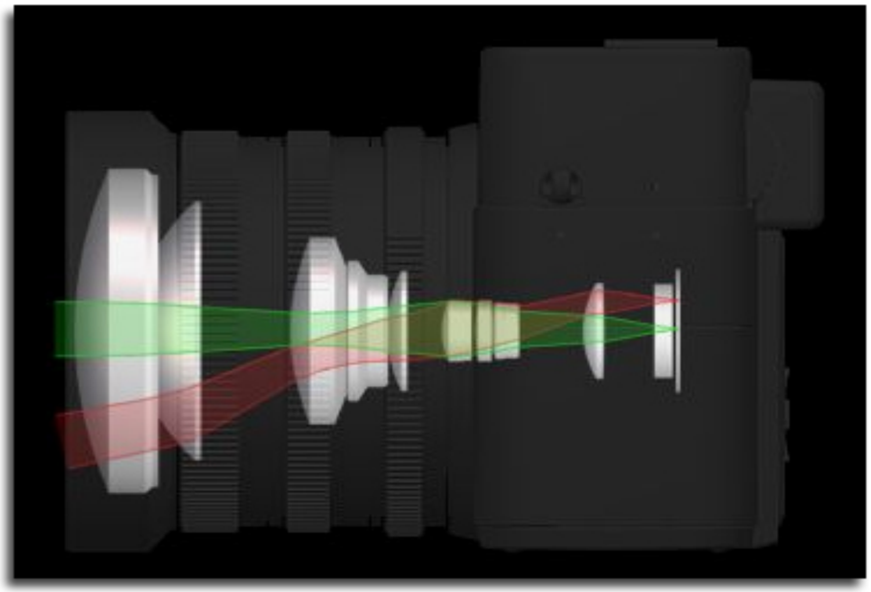
Spherical aberration



Historically, spherical lenses were the only easy shape to manufacture, but are not correct for perfect focus.

Lens systems

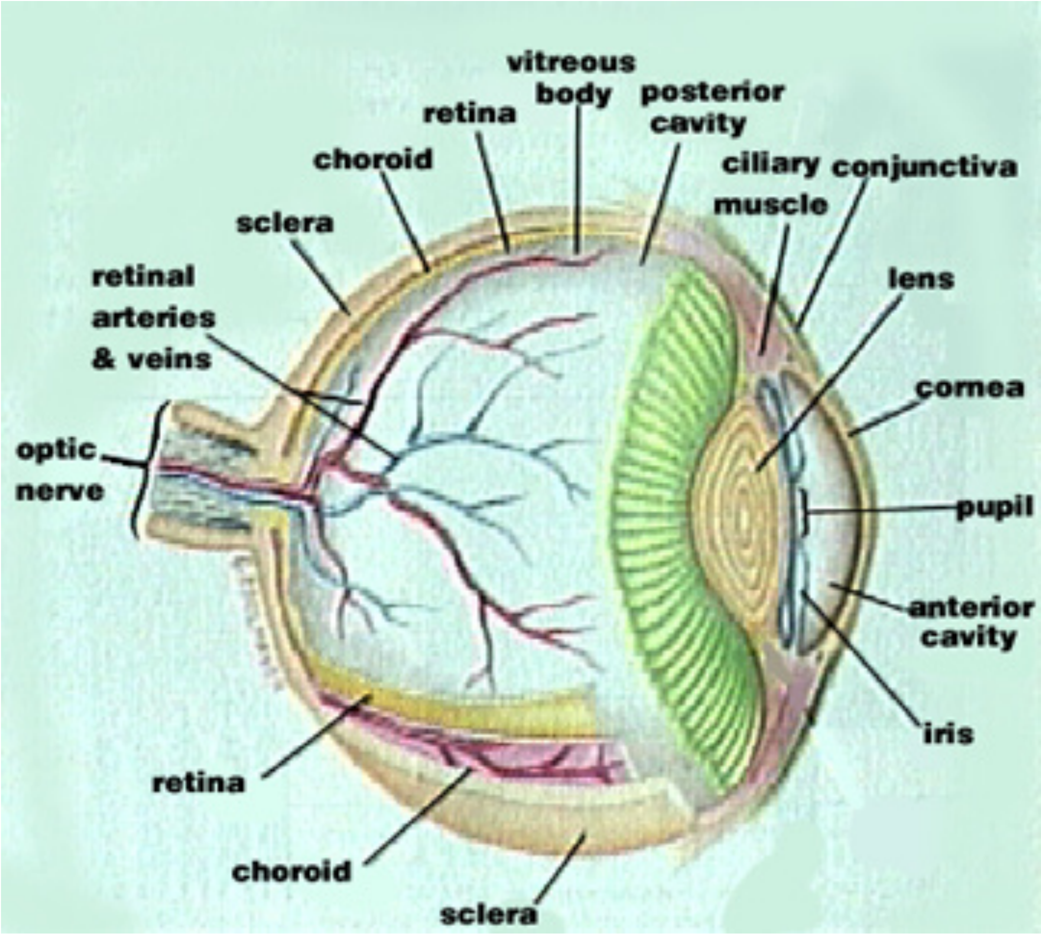




- A good camera lens may contain 15 elements and cost a thousand dollars
- The best modern lenses may contain aspherical elements

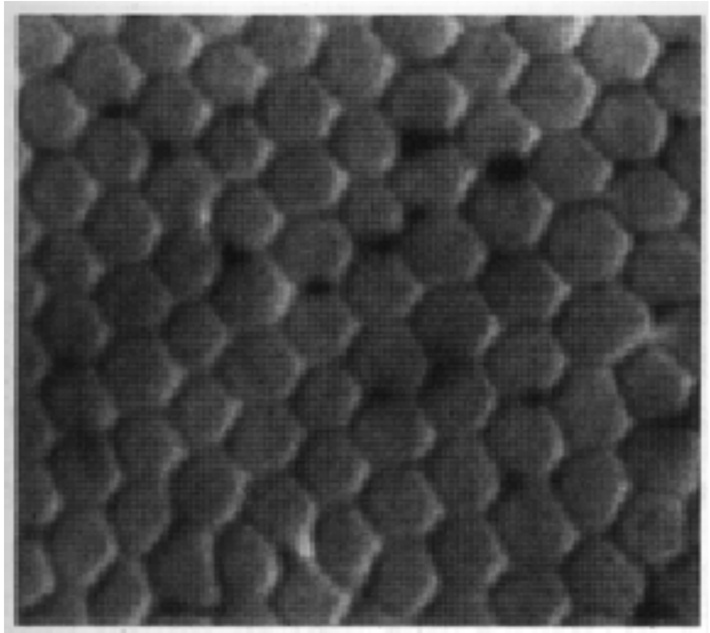
Human Eye

- The eye has an iris like a camera
- Focusing is done by changing shape of lens
- Retina contains cones (mostly used) and rods (for low light)
- The fovea is small region of high resolution containing mostly cones
- Optic nerve: 1 million flexible fibres

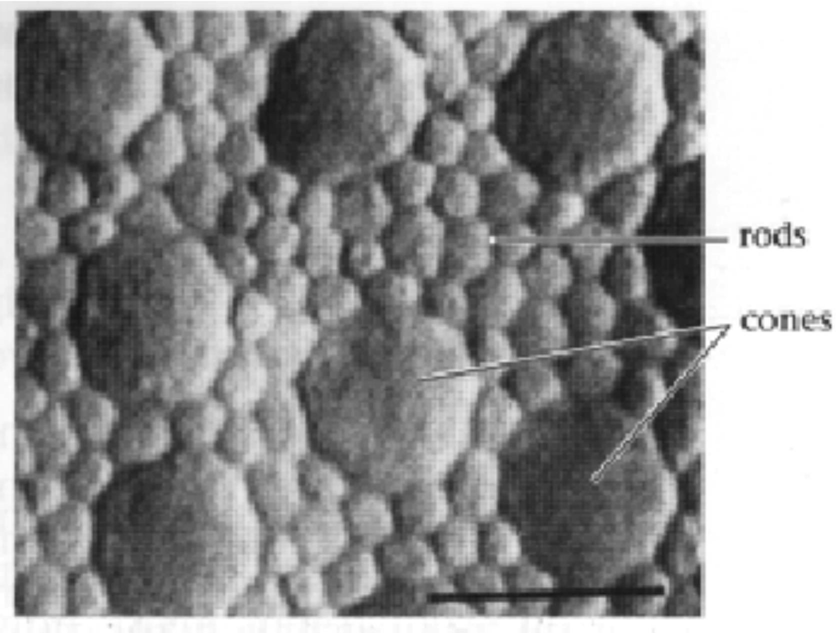


http://www.cas.vanderbilt.edu/bsci111b/eye/human-eye.jpg

Human Photoreceptors

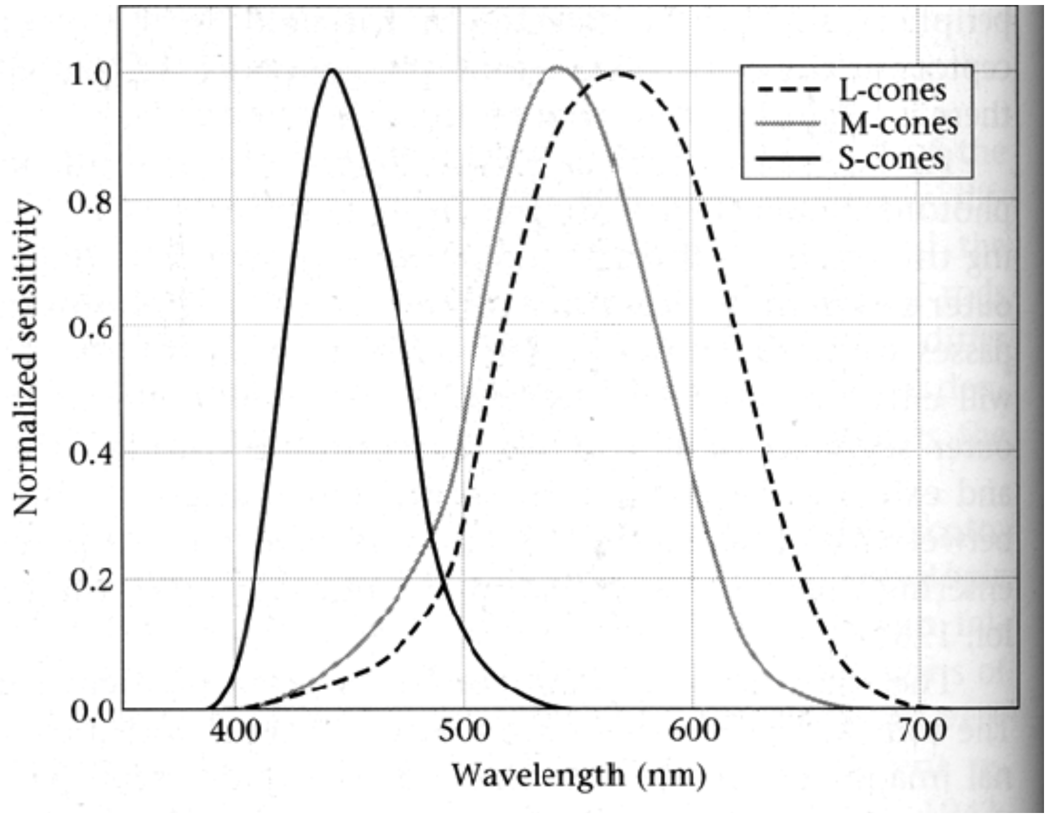


Fovea



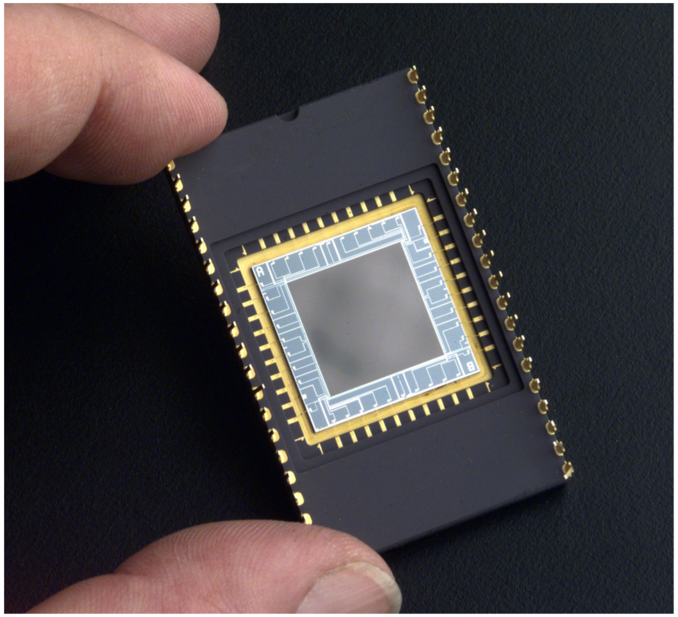
Periphery

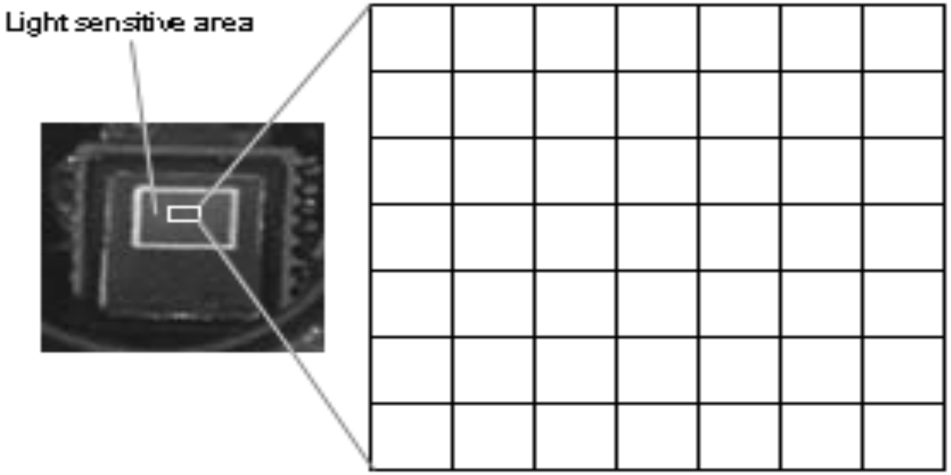
Human Cone Sensitivities



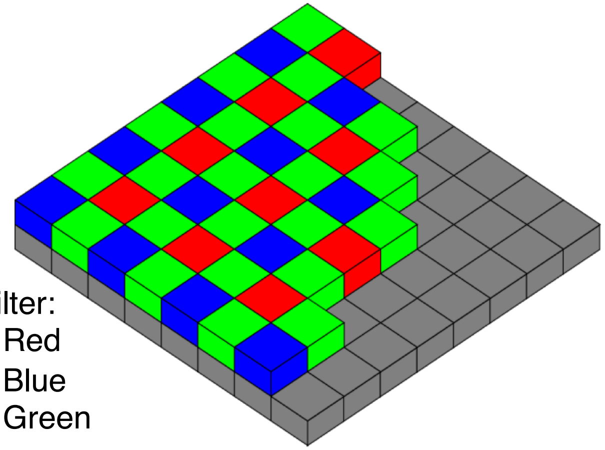
- Spectral sensitivity of L, M, S (red, green, blue) cones in human eye

CCD Cameras





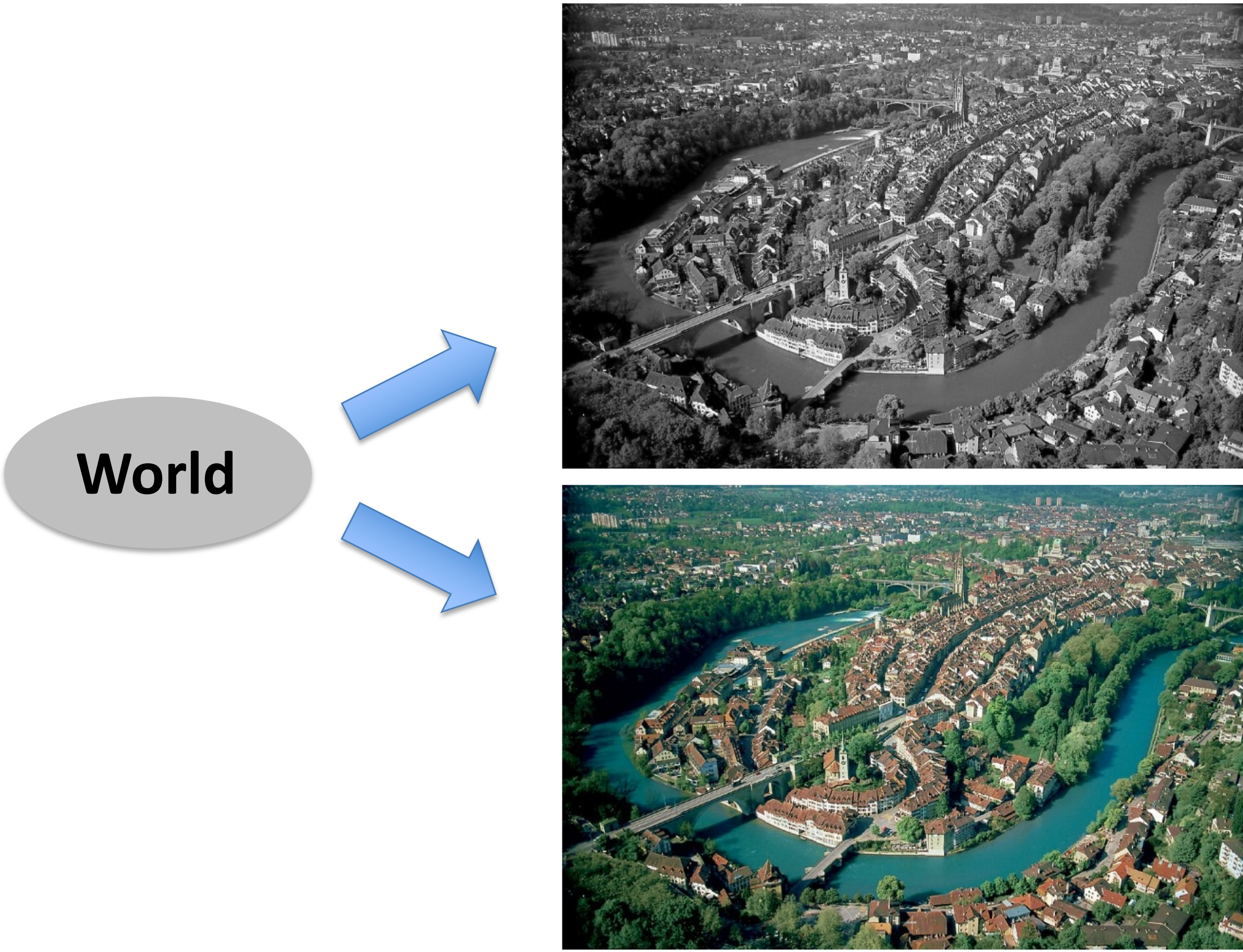
http://huizen.ddsw.nl/bewoners/maan/imaging/camera/ccd1.gif



Bayer filter:
- 25% Red
- 25% Blue
- 50% Green

Smith and Boyle: Nobel prize winners in Physics 2009

From world to digital image



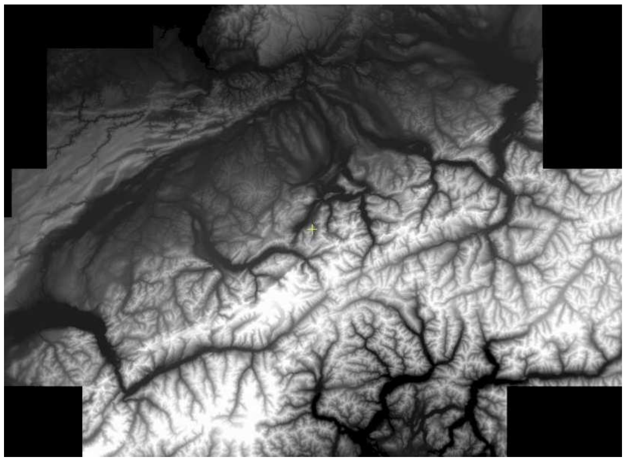
From world to digital image

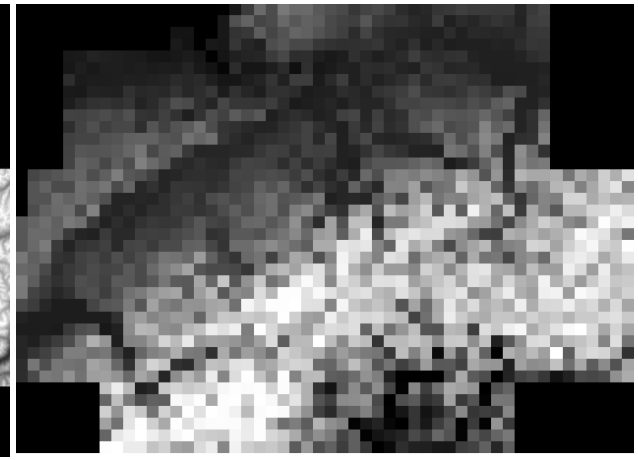
Light source incidence (illumination)

Light reflected (reflectance)

Image sampling and quantization

Sampling





Quantization

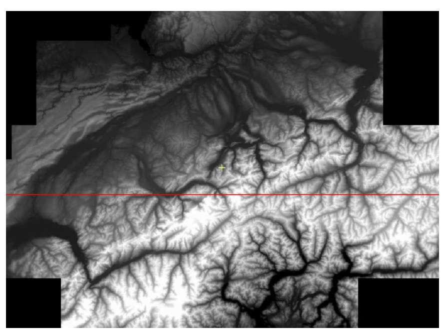


Fig 2.35 Height profile of Switzerland

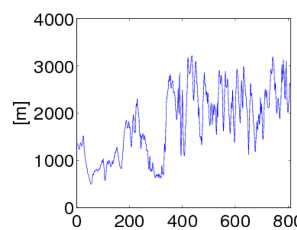


Fig 2.36 Height profile along the red line

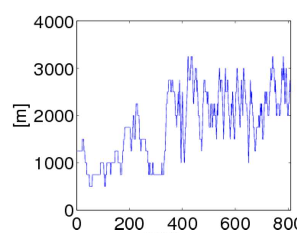
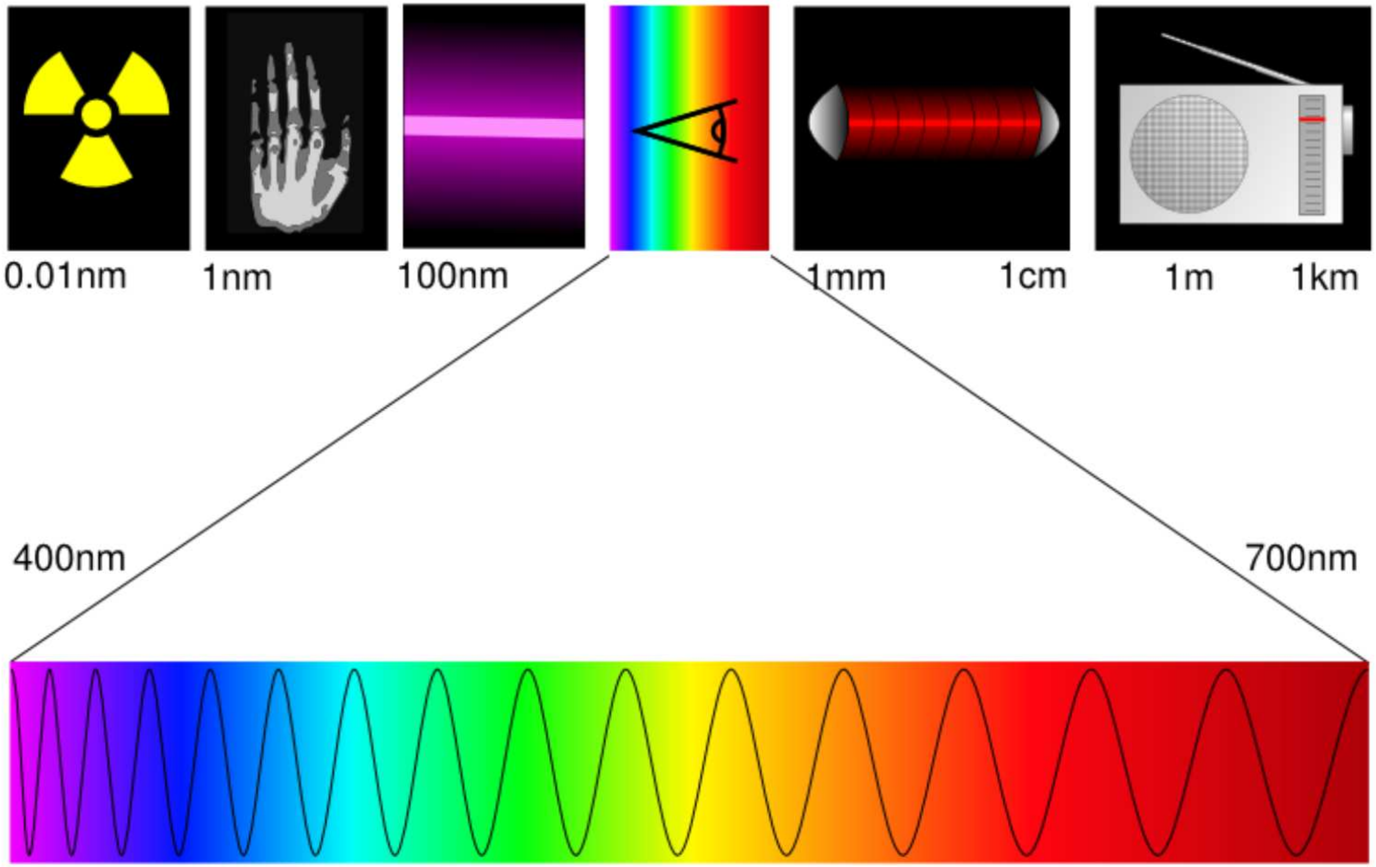


Fig 2.37 Quantised 250 m height profile of the red line

Slide from P. Cattin

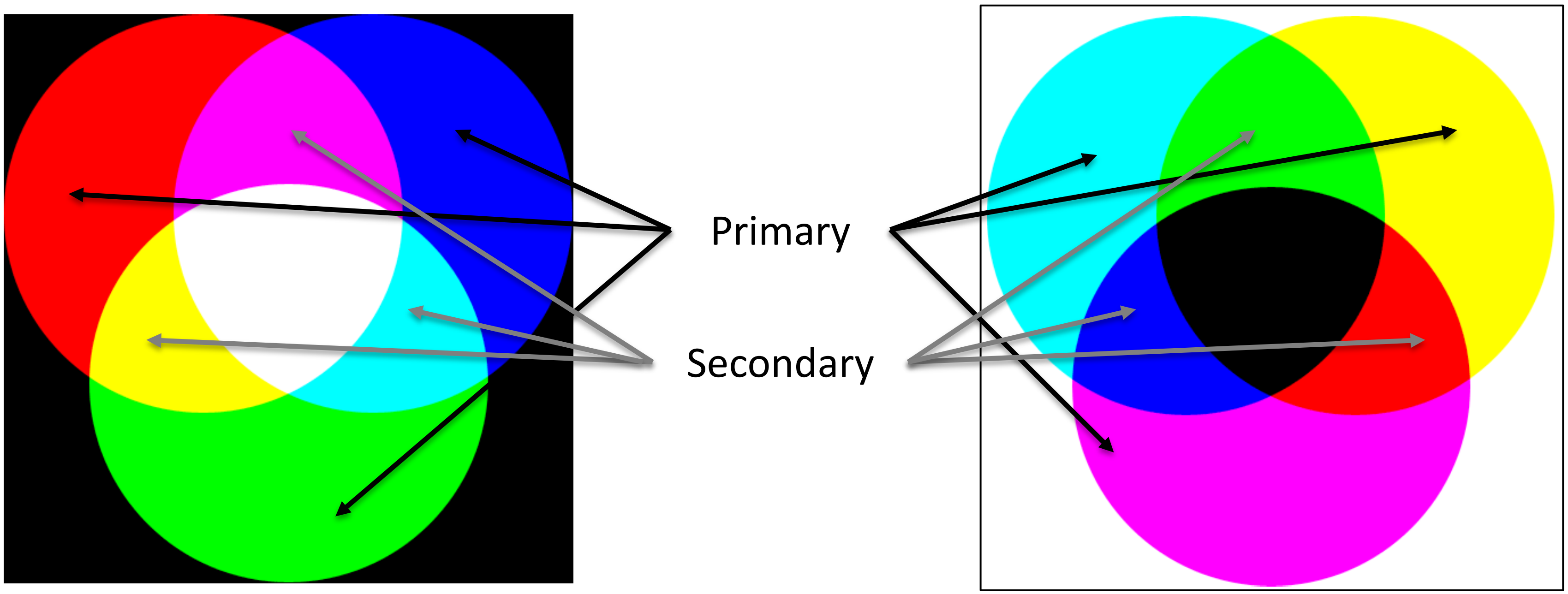
Color Perception



Additive and Subtractive colors mixing

Additive mixing

Subtractive mixing



Projector lighting

Concept behind printers

Color models

Original image

Red channel

Green channel

Blue channel

A bit of notation

Some important color models: HSV

The HSV (Hue, Saturation, Value) colour model, also known as HSB (Hue, Saturation, Brightness), is considerably closer than the RGB system to the way in which humans experience and describe colour sensations. It defines the colour space in terms of three components:

- Hue: defines the pure colour and ranges from $[0, 360°]$
- Saturation: is the *vibrancy* or a measure for the degree to which a pure colour is diluted by white light. It ranges from $[0, 100\%]$
- Value: the brightness of the colour in the range of $[0, 1]$

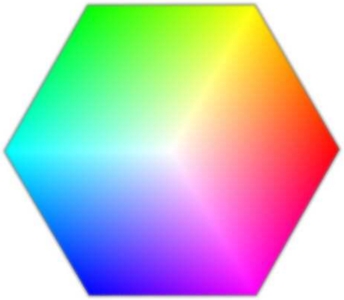


Fig 2.24: HSV colour hexagon

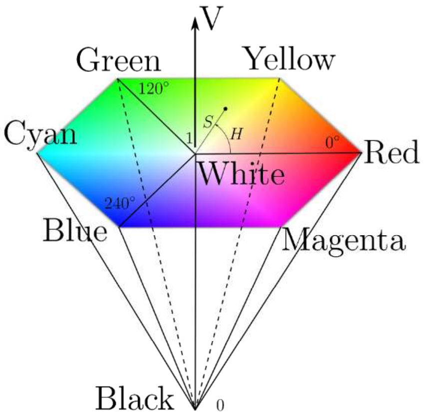


Fig 2.25: HSV hexagonal cone

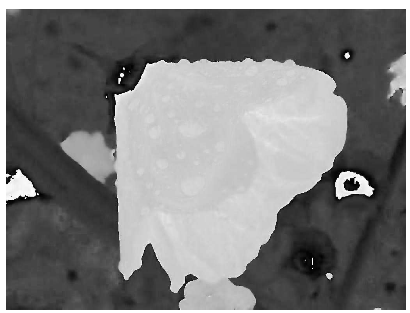
Color models

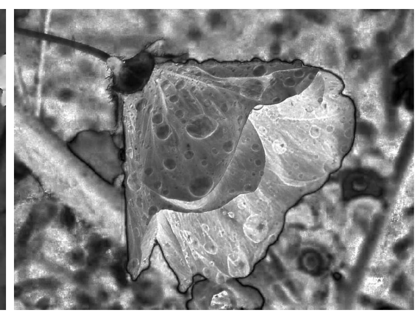

Original image


Red channel


Green channel


Blue channel


Hue channel


Saturation channel


Intensity channel

Some important color models: RGB to HSV conversion

Given the RGB values with R, G, and B normalised to $[0, 1]$, $MAX = \max(R, G, B)$, and $MIN = \min(R, G, B)$ the HSI values can be determined with the following rules:

1. $H = \begin{cases} \text{undefined, often } 0 & \text{if } MAX = MIN \\ 60 \cdot (0 + \frac{G-B}{MAX-MIN}) & \text{if } R = MAX \\ 60 \cdot (2 + \frac{B-R}{MAX-MIN}) & \text{if } G = MAX \\ 60 \cdot (4 + \frac{R-G}{MAX-MIN}) & \text{if } B = MAX \end{cases}$

2. $\text{if}(H < 0)\ H = H + 360$

3. $S = \begin{cases} 0 & \text{if } MAX = 0 \\ 100 \cdot \frac{MAX-MIN}{MAX} & \text{otherwise} \end{cases}$

4. $V = 100 \cdot MAX$

The resulting H lies in the interval $[0, 360°]$, S and V in the interval $[0, 100\%]$.

Some important color models: HSI

The HSI (Hue, Saturation, Intensity) colour model, also known as HSL (Hue, Saturation, Luminosity/Luminance), is in contrast to HSV drawn as a colour cone, a colour hexcone or as a sphere. Both systems are non-linear deformations of the RGB colour cube. HSI spans the colour space in terms of three parameters:

- Hue: defines the pure colour and ranges from $[0, 360°]$
- Saturation: is a measure for the degree to which a pure colour is diluted by white light. It ranges from $[0, 100\%]$
- I: intensity of the colour in the range of $[0, 1]$

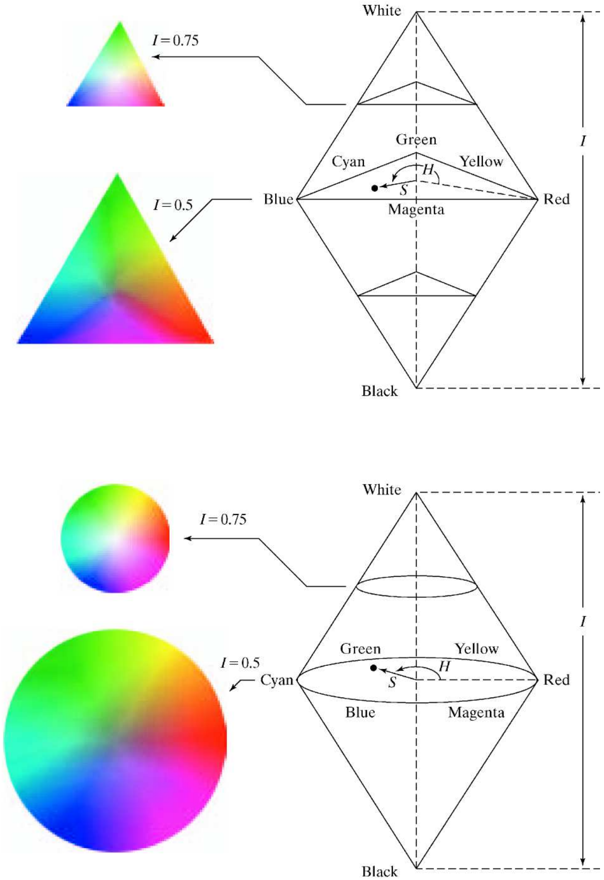


Fig 2.26: HSI Colour model

Some important color models: RGB to HSI conversion

Given an image in RGB colour format, the H, S, I components can be obtained using the following equations:

$$H = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases}$$ with

$$\theta = \cos^{-1}\left\{\frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}}\right\}$$

$$S = 1 - \frac{3}{R+G+B}[\min(R,G,B)]$$

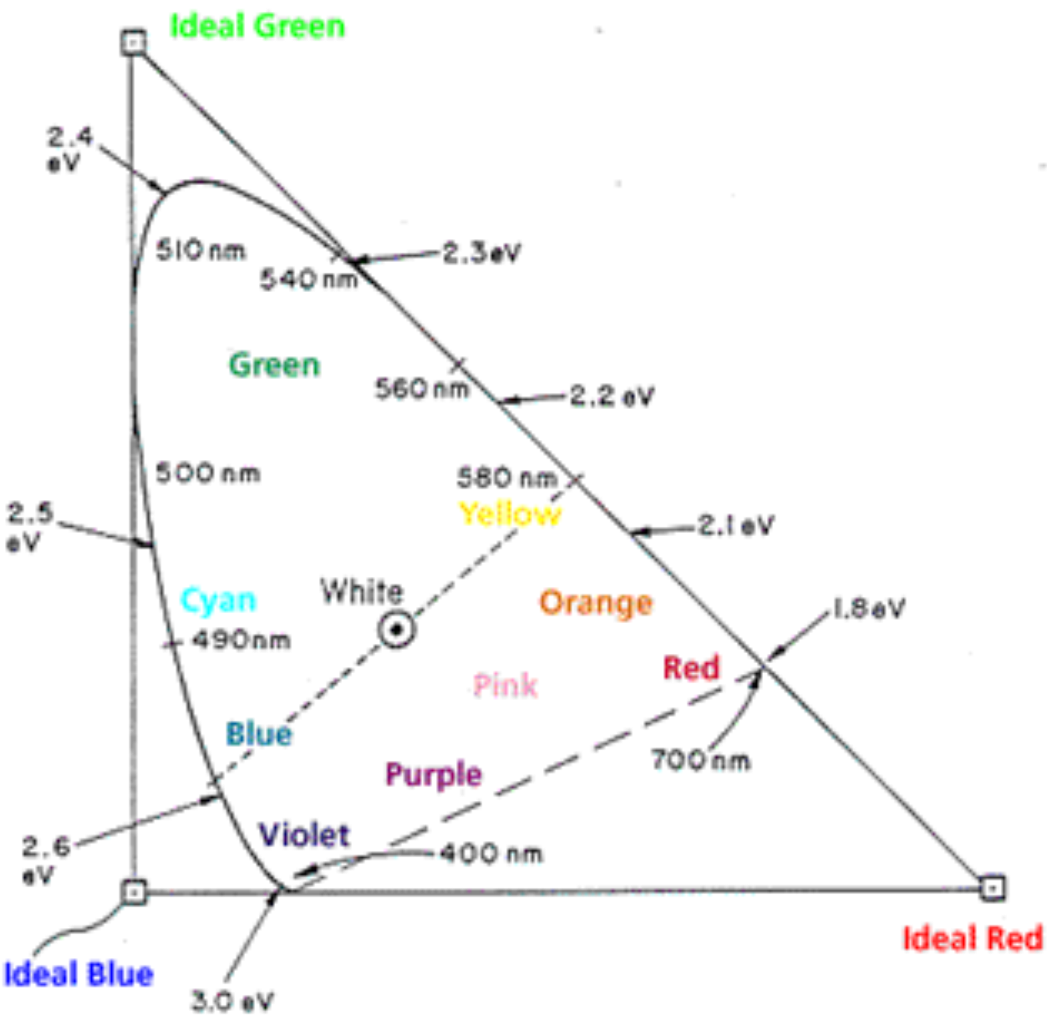
$$I = \frac{1}{3}(R+G+B)$$

It is assumed that the RGB values have been normalised to the range $[0,1]$, and that the angle θ is measured with respect to the red axis of the HSI space. Hue H can be normalised to the range $[0,1]$ by dividing by $360°$.

Slide from P. Cattin

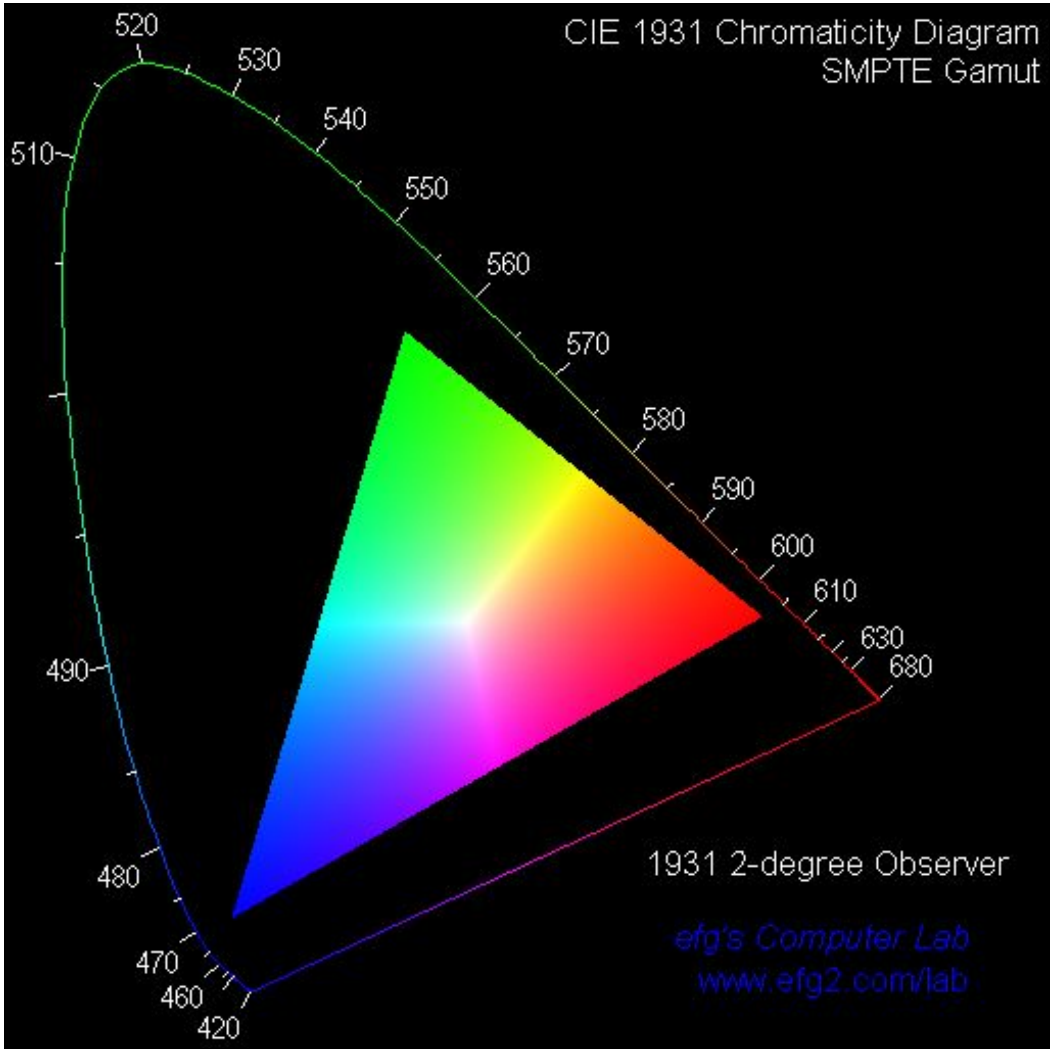
CIE color space

Primaries are imaginary, but have other convenient properties. Colour coordinates are (X,Y,Z), where X is the amount of the X primary, etc.



- White is in the center, with saturation increasing towards the boundary
- Mixing two colored lights creates colors on a straight line
- Mixing 3 colors creates colors within a triangle
- Curved edge means there are no 3 actual lights that can create all colors that humans perceive!

RGB colour Space in the CIE space

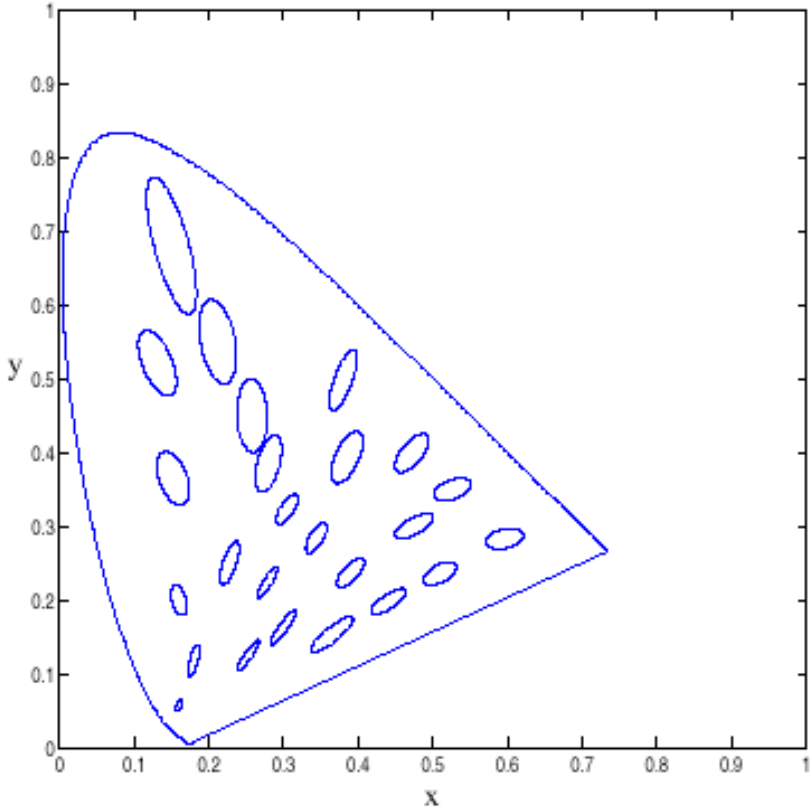


The colours that can be displayed on a typical computer monitor (phosphor limitations keep the space quite small)

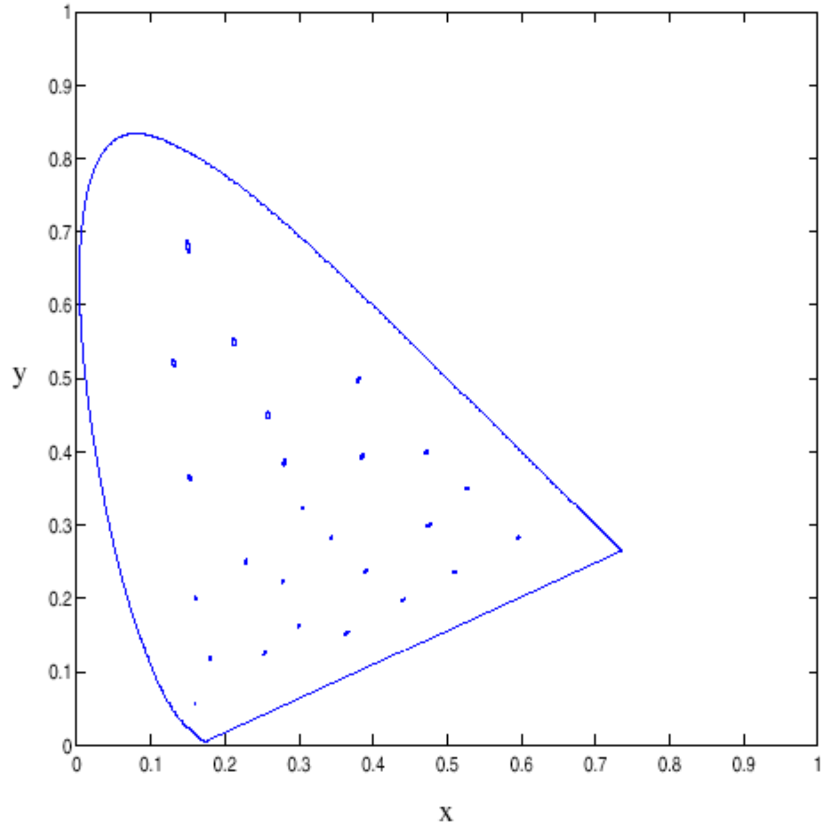
Uniform colour spaces

- McAdam ellipses (next slide) demonstrate that differences in x,y are a poor guide to differences in colour
  - Each ellipse shows colours that are perceived to be the same
- Construct colour spaces so that differences in coordinates are a good guide to differences in colour.

McAdam Ellipses



10 times actual size

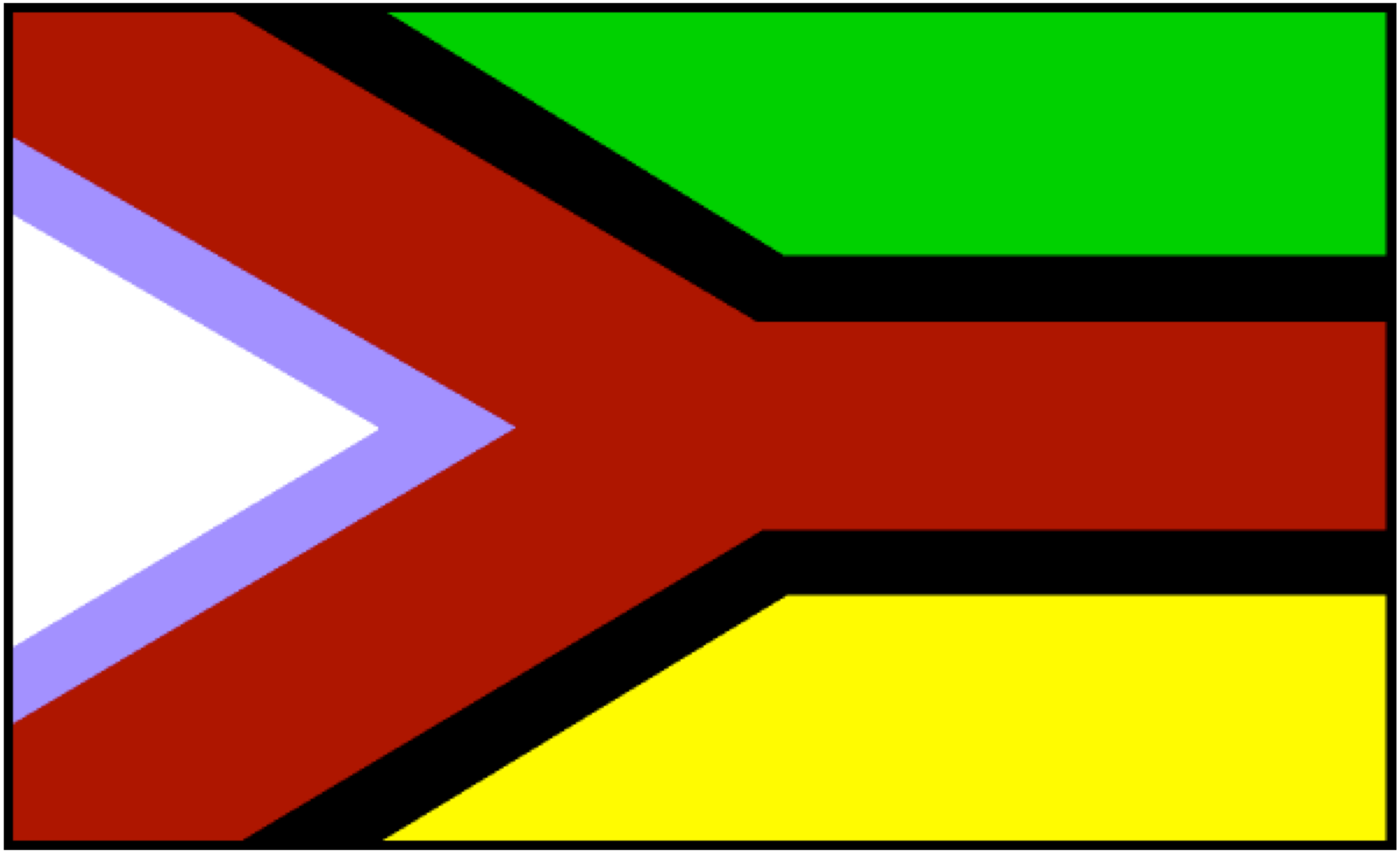


Actual size

Adaptation phenomena

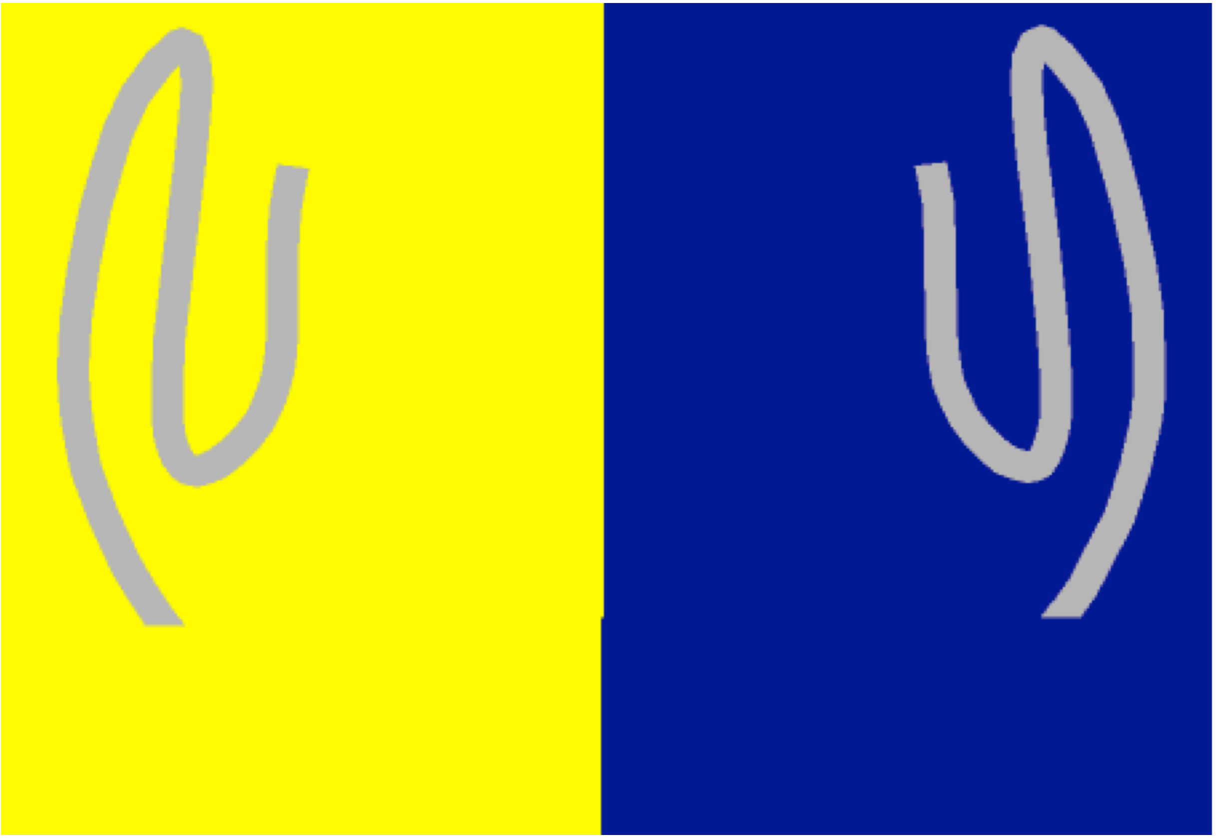
- The response of your colour system depends both on spatial contrast and what it has seen before (adaptation)
- This seems to be a result of coding constraints -- receptors appear to have an operating point that varies slowly over time, and to signal some sort of offset. One form of adaptation involves changing this operating point.
- Common example: walk inside from a bright day; everything looks dark for a bit, then takes its conventional brightness.

Adaptation phenomena

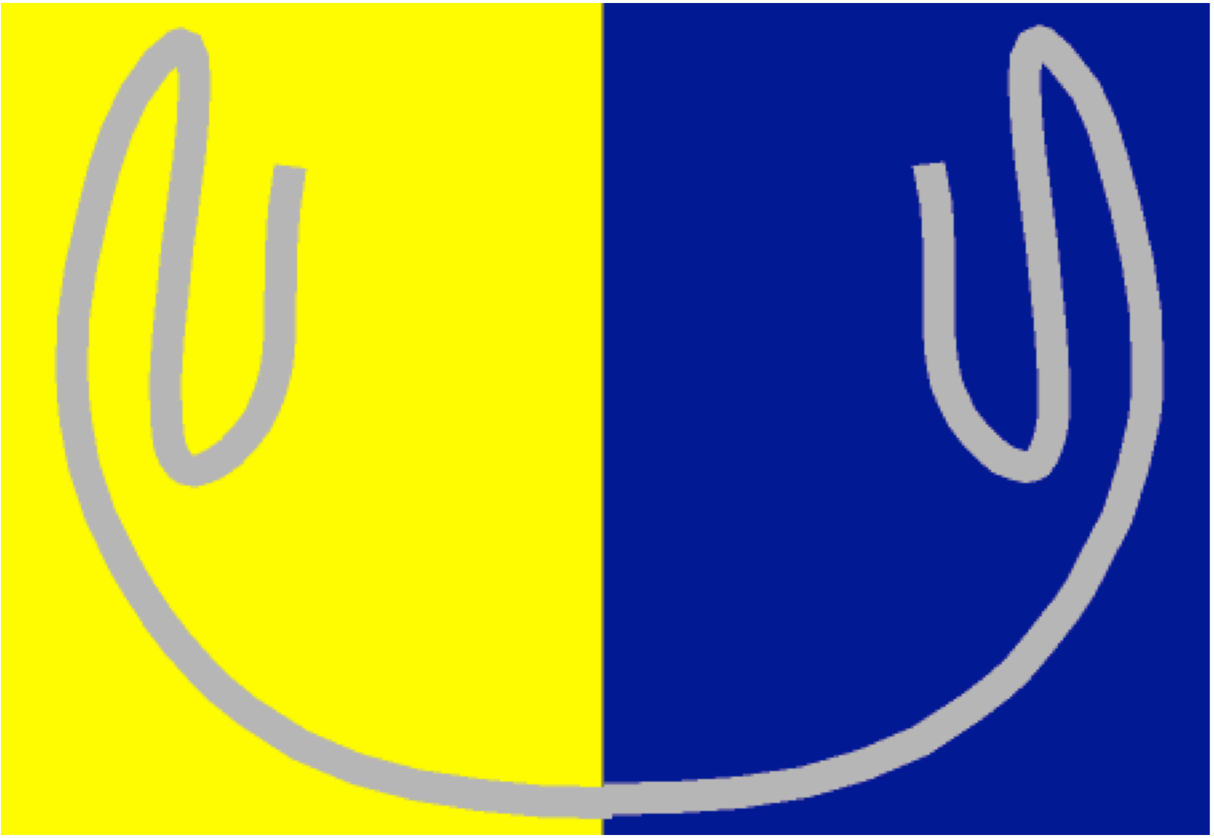


Adaptation phenomena

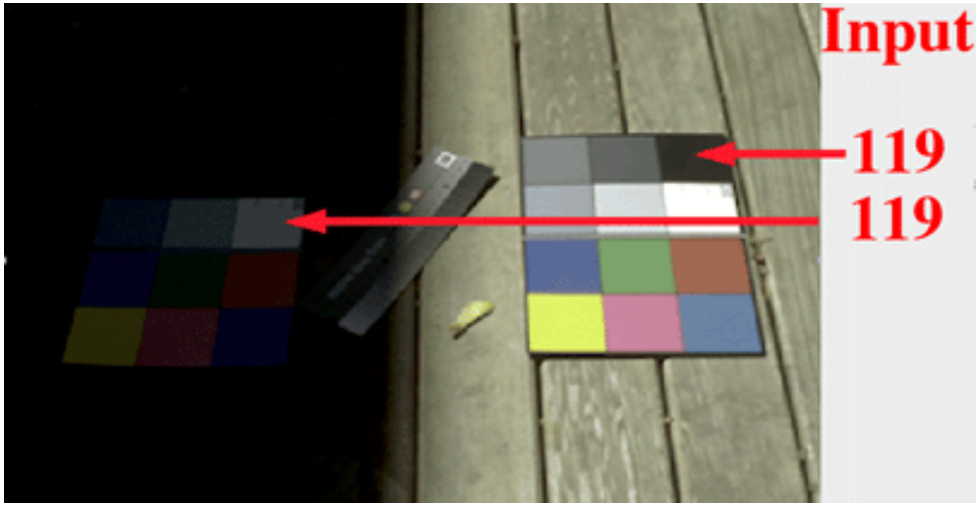
Adaptation phenomena

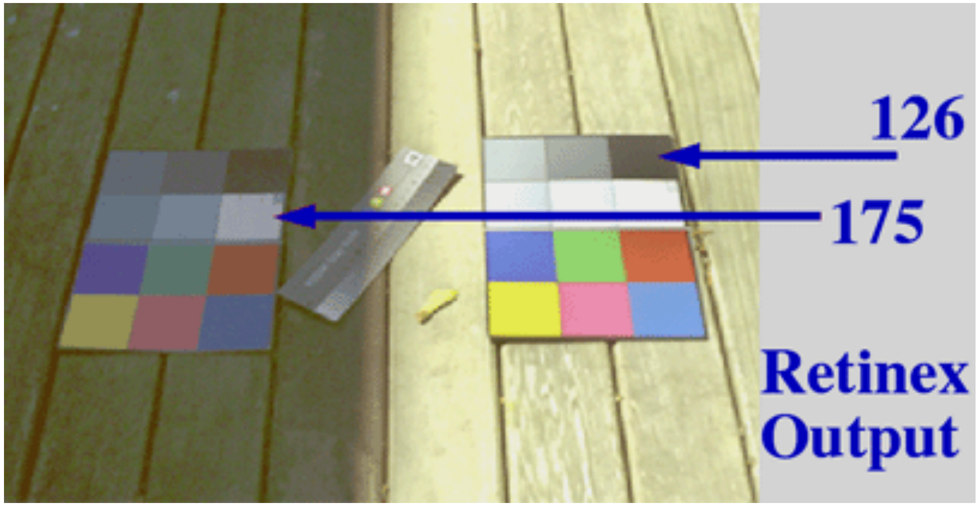


Adaptation phenomena



Adaptation phenomena





Mathematical operators

Some more operators we will need throughout the course:

- Distance measures
- Pixel relations
- Chamfer Algorithm

Chamfer Distance example