EE 584
MACHINE VISION

Introduction

Relation with other areas
Image Formation & Sensing
Projections
Brightness
Lenses
Image Sensing

METU EE 584 Lecture Notes by A.Aydin ALATAN © 2012

Introduction

- Vision is the most powerful sense
- Vision is the most complicated sense

- The purpose of a general *machine/computer/robot vision* system is to produce a symbolic description of what is being imaged.

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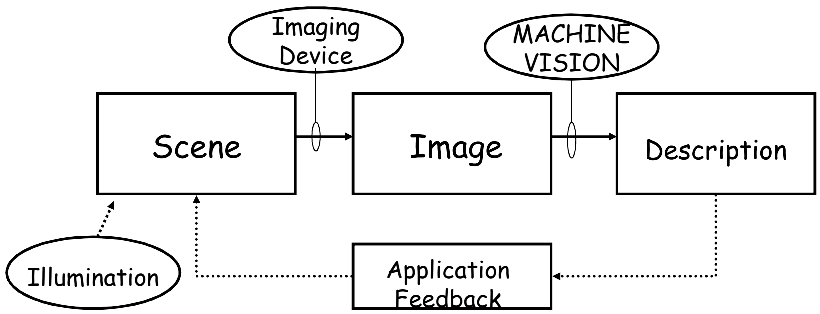
Machine Vision System

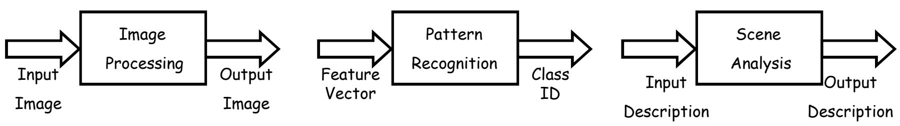
- A typical machine vision system :



Machine vision should be based on complete understanding of image formation

Relation to other fields :

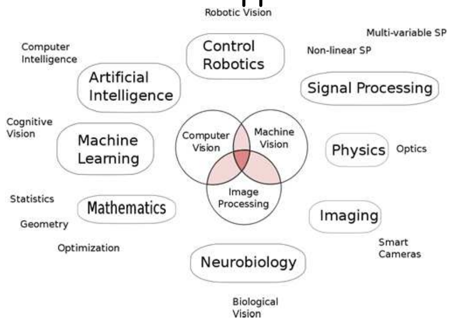
- 4 important related fields :
  - Imaging (science on creating all kinds of images)
  - Image processing
  - Pattern recognition
  - Scene analysis



None of them provides a solution to the problem "developing symbolic descriptions from images".

Relation to other fields :

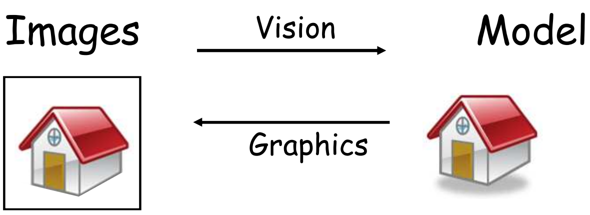
- Machine vision vs Computer vision:
  - Two terms can be used interchangeably
  - Machine vision → more constraints on the environment and focus on (industrial) applications
  - Computer vision → more generic in terms of content and applications



This course is about fundamentals of *vision* research

Image from http://en.wikipedia.org/wiki/Computer_vision

Vision and Graphics



Inverse problems: analysis and synthesis.

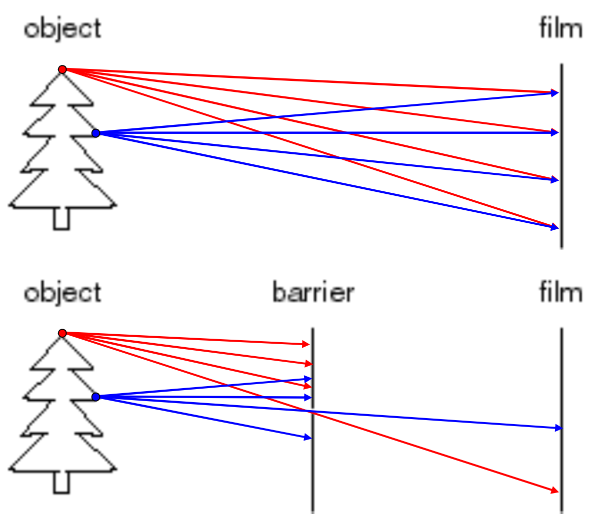
slide from Computer Vision Lecture Notes Trevor Darrell

Image Formation

- Projection of 3-D world onto 2-D image plane

- Two crucial questions :
  - What determines the *position* of a 3-D object point on the 2-D image plane?
  - What determines the *brightness* of a 3-D object point on the 2-D image plane?

Image Formation



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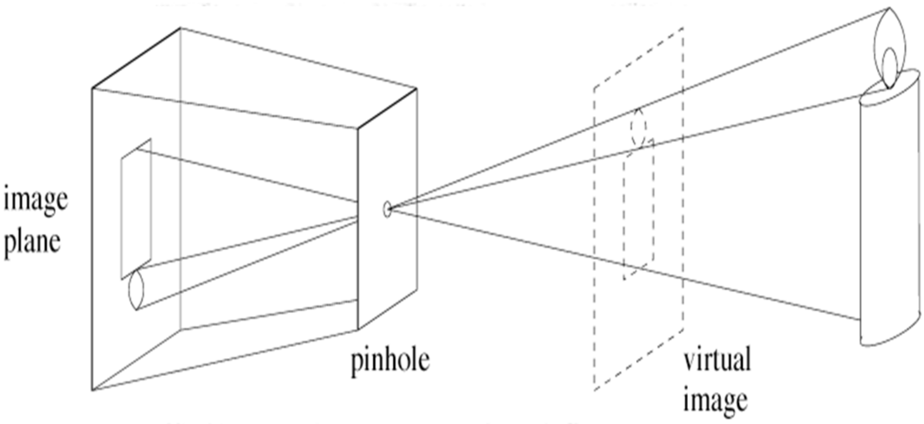
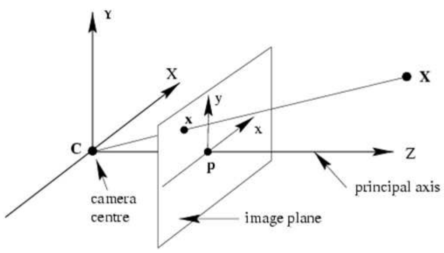
Camera Models

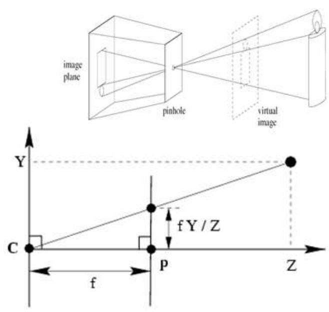
- Pinhole camera model



Camera Models

- Pinhole camera model

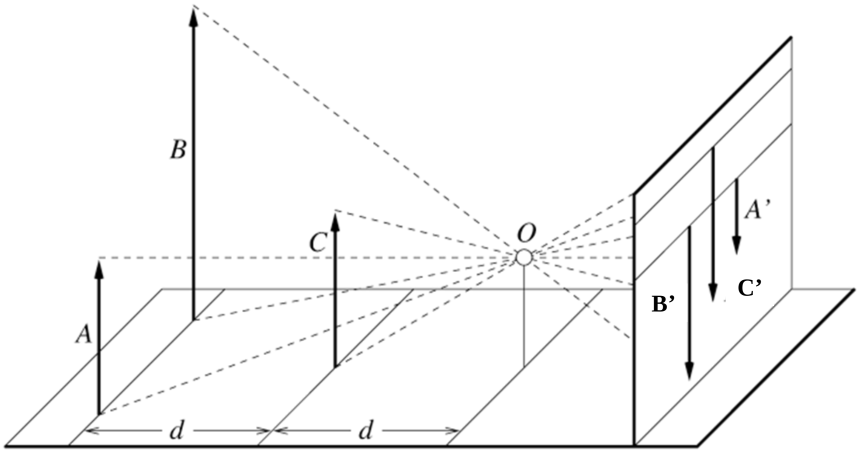




$$x = f\frac{X}{Z},\ y = f\frac{Y}{Z}$$

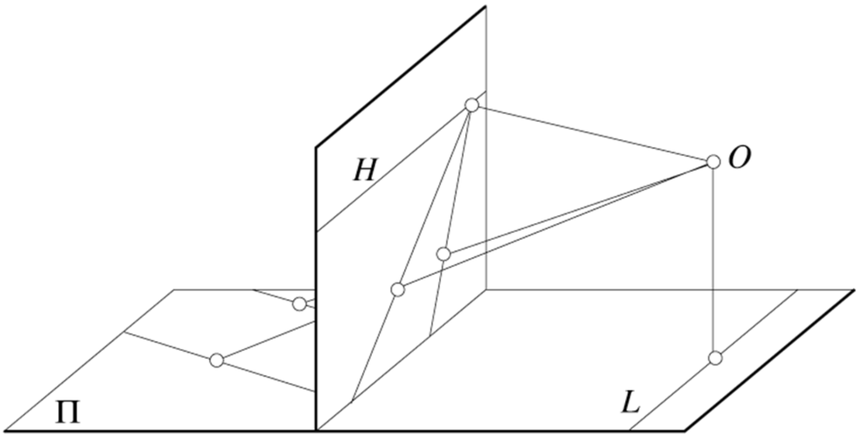
Camera Models

- In pin-hole camera, distant objects are observed smaller



Camera Models

- In pin-hole camera, parallel lines meet



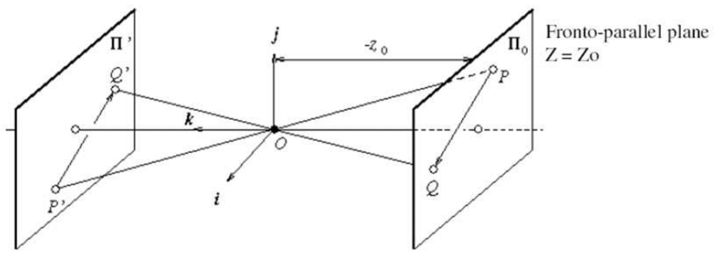
Perspective Projection

$$x = f\frac{X}{Z}, \; y = f\frac{Y}{Z}$$

- Pin-hole camera model is called *perspective projection*
- It is also possible to make approximations to perspective projection
  - Affine : Scene points are planar
  - Weak-perspective : Scene is approximated by a plane and assumed to be far away from camera
  - Orthographic : Scene is approximated to be planar and far away from camera and camera distance does not change

Affine Projection

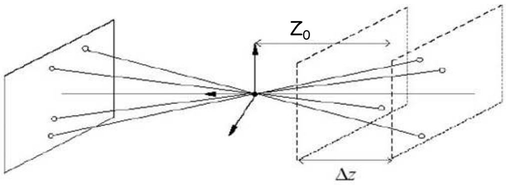
- If all scene points are on a plane



$$x = -f\frac{X}{Z_0}, \; y = -f\frac{Y}{Z_0} \quad \Rightarrow m \equiv \frac{f}{Z_0} \quad \Rightarrow x = -mX, \; y = -mY$$

Weak-perspective Projection

- Now, <u>assume</u> all scene points are on a plane

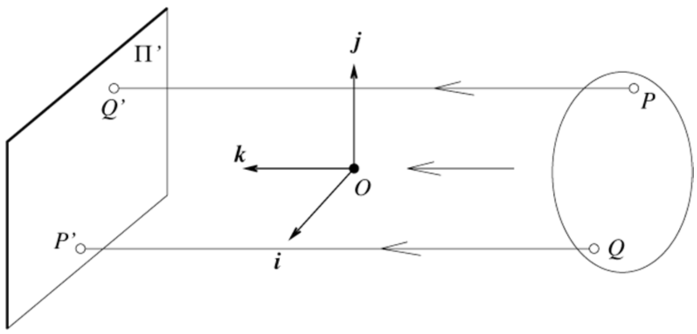


$$x \cong -f\frac{X}{Z_0}\,,\; y \cong -f\frac{Y}{Z_0} \quad \Rightarrow x \cong -mX\,,\; y \cong -mY$$

- This assumption can only be justified, if *scene depth range* is small compared to average distance from camera
  - Δz is small wrt Z_0

Orthographic Projection

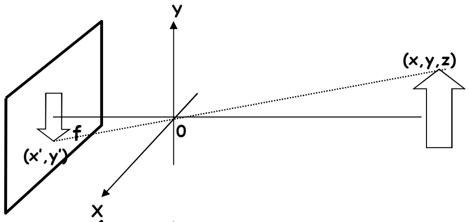
- If scene depth range is small wrt average depth <u>and</u> camera distance remain at a <u>constant distance</u> (i.e. Z_0 is contant)
  - Choose m=-1 ➔ x=X , y=Y



Projections : Summary

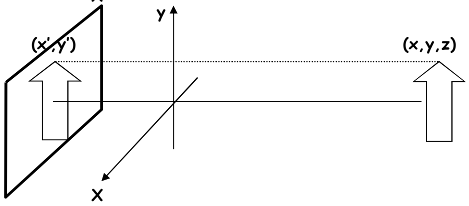
Perspective :

$$x' = f\frac{x}{z}, y' = f\frac{y}{z}$$



Orthographic :

$$x' = x, y' = y$$

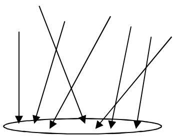


Perspective projection is a more realistic projection for (pin-hole) camera recordings

If *depth range* is small compared to average distance from the camera, orthographic is also a good approximation

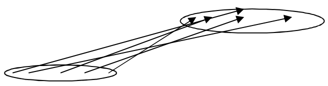
Brightness :

Two different brightness concepts :



- **Image brightness** : *irradiance*

  Light power per unit area <u>falling</u> on a (image) surface



- **Scene brightness** : *radiance*

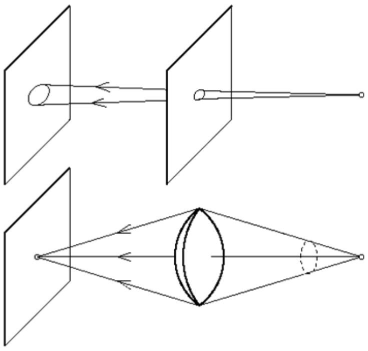
  Light power per unit area <u>emitted</u> into a solid angle from a (object) surface

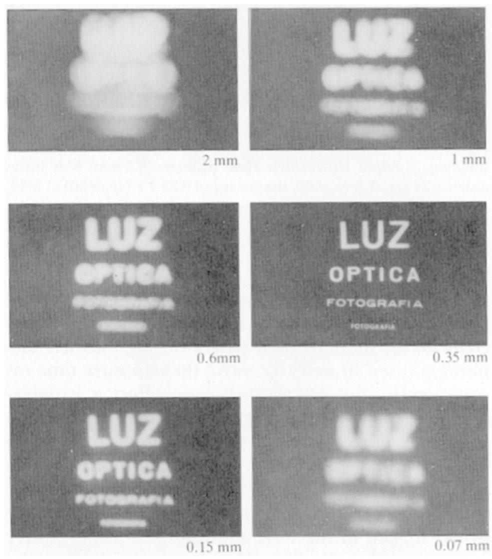
Image and scene brightness are proportional to each other

Pinhole camera needs non-zero diameter for enough light

Lenses :

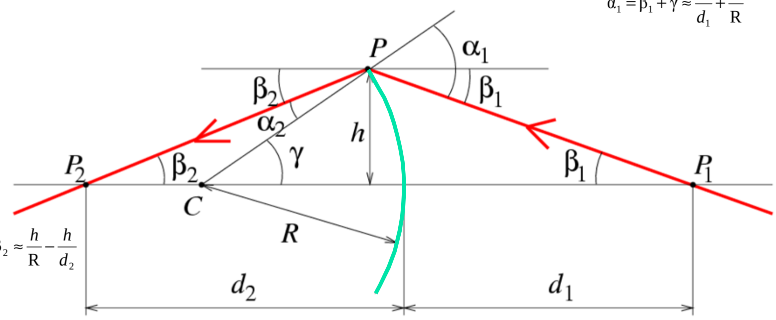
A pin-hole camera needs light





Lenses : Paraxial (or first-order) optics

$$\alpha_1 = \beta_1 + \gamma \approx \frac{h}{d_1} + \frac{h}{R}$$



$$\alpha_2 = \gamma - \beta_2 \approx \frac{h}{R} - \frac{h}{d_2}$$

Snell's law:

$$n_1 \sin \alpha_1 = n_2 \sin \alpha_2$$

Small angles:

$$n_1 \alpha_1 \approx n_2 \alpha_2$$

$$n_1\left(\frac{h}{d_1} + \frac{h}{R}\right) = n_2\left(\frac{h}{R} - \frac{h}{d_2}\right)$$

$$\frac{n_1}{d_1} + \frac{n_2}{d_2} = \frac{n_2 - n_1}{R}$$

Note that the relation is independent of β_1 and β_2 → all rays pass from *P1*, also pass *P2*.

slide from Computer Vision Lecture Notes by Marc Pollefeys

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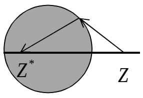
Lenses : Thin Lenses

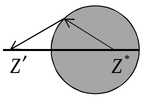
spherical lens surfaces;
thickness << radii; same refractive index on both sides

$$\boxed{\frac{n_1}{d_1}+\frac{n_2}{d_2}=\frac{n_2-n_1}{R}}$$

$$\frac{1}{Z}+\frac{n}{Z^*}=\frac{n-1}{R}$$

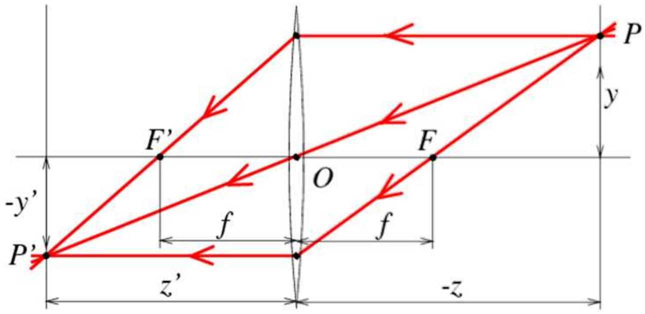


$$\frac{n}{Z^*}+\frac{1}{Z'}=\frac{1-n}{R}$$



$$\frac{n}{Z^*}=\frac{n-1}{R}-\frac{1}{Z} \qquad \frac{n}{Z^*}=\frac{1-n}{R}-\frac{1}{Z'}$$

$$\frac{n-1}{R}-\frac{1-n}{R}=\frac{1}{Z}-\frac{1}{Z'}$$



$$\boxed{\frac{1}{z'}-\frac{1}{z}=\frac{1}{f}} \quad \text{and} \quad \boxed{f=\frac{R}{2(n-1)}}$$

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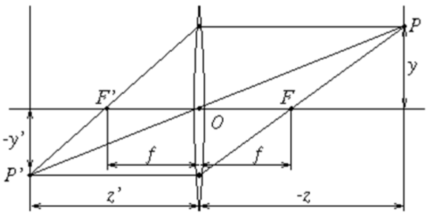
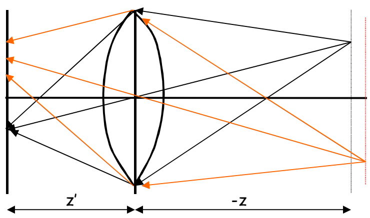
Lenses :

An ideal thin lens produces the same projection with a pinhole camera, plus some finite amount of light.



$$\frac{1}{z'}+\frac{1}{-z}=\frac{1}{f}$$

Once you focus for one distance z, points on other distances will be blurred.



Lenses : Deviations from the lens model

3 assumptions :

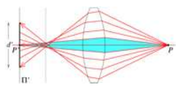
1. all rays from a point are focused onto 1 image point
2. all image points in a single plane
3. magnification is constant

deviations from this ideal are *aberrations*

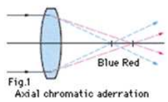
2 types of aberrations:

geometrical : small for paraxial rays

study through 3rd order optics $\sin(\theta) \approx \theta - \frac{\theta^3}{6}$

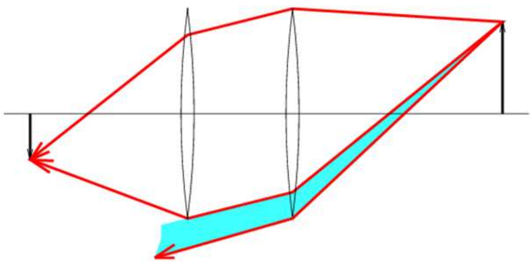


chromatic : refractive index function of wavelength



Lenses :

Vignetting : Brightness drop in image periphery for compound lenses



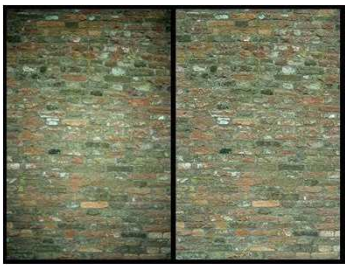
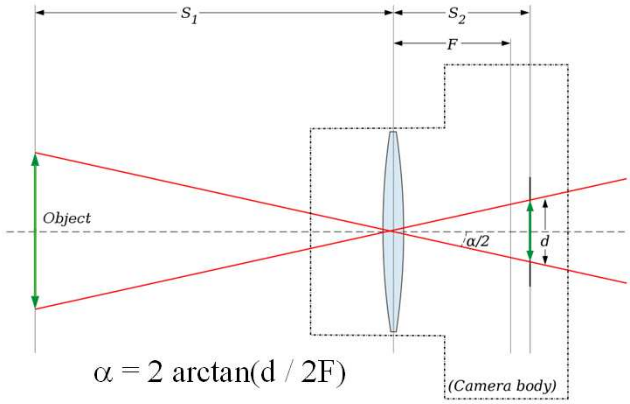


Figure from http://www.vanwalree.com/optics/vignetting.html

Camera Field of View

Angular measure of the portion of 3D space seen by the camera

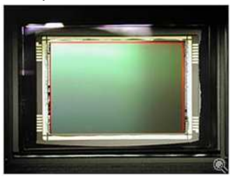


$$\alpha = 2 \arctan(d / 2F)$$

Image from http://en.wikipedia.org/wiki/Angle_of_view

Image Sensing :

Light photons striking a suitable (vacuum or semi-conductor device) surface generate electron-hole pairs which are measured to determine the irradiance.



Quantum efficiency : ratio of electron flux to incident photon flux & depends on energy (wavelength) of photon

Solid-state devices almost ideal for some wavelengths

Photographic films have poor quantum efficiency

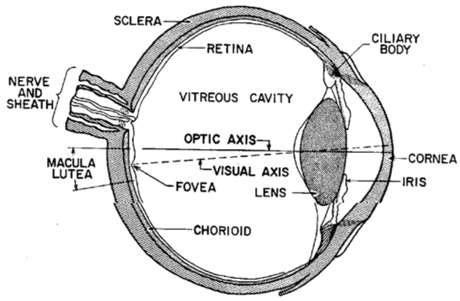
Quantization of Image

Electrons should be measured/averaged at some predefined regions on the image sensor -> Spatial quantization

These regions can be square, rectangular or hexagonal

Each predefined region represents a *pixel* (picture element) location and the quantized values are *pixel* values (usually 0 to 255)

The Human Eye



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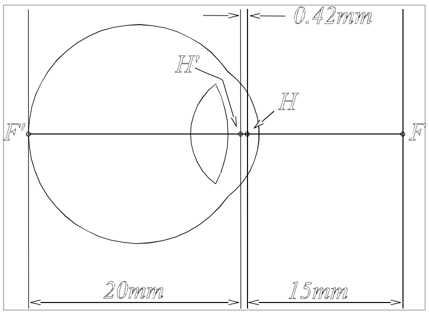
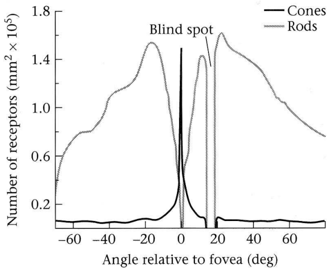


Helmoltz's Schematic Eye

The distribution of rods and cones across the retina



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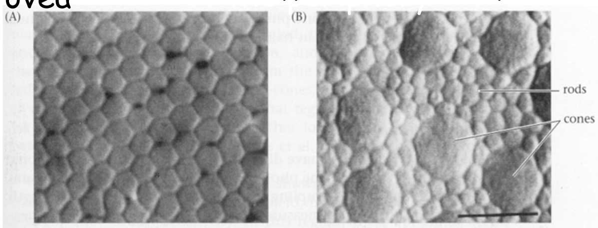
Cones in the fovea

3 types of cones that yield color perception



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