TNM087
Image Processing and Analysis

Reiner Lenz
2015

Lectures and Labs

There are 12 lectures:

lecture.pdf

and 8x2hrs labs

labs.pdf

Course info

Organisation
The course consists of 12 lectures and 8 lab sessions (2 hours each)

Staff
Reiner Lenz (examiner, lectures)
Ehsan Miandji (Labs)
Saghi Hajisharif (Labs)
Gabriel Eilertsen (Labs)

Literature:
- Gonzalez, Woods ”Digital Image Processing”, 3rd edition, Pearson
- Szeliski ” Computer Vision: Algorithms and Applications”
  Springer or pdf at http://szeliski.org/Book

Examination
Lab reports/code, written exam

All written communication via Lisam!!!

Course info

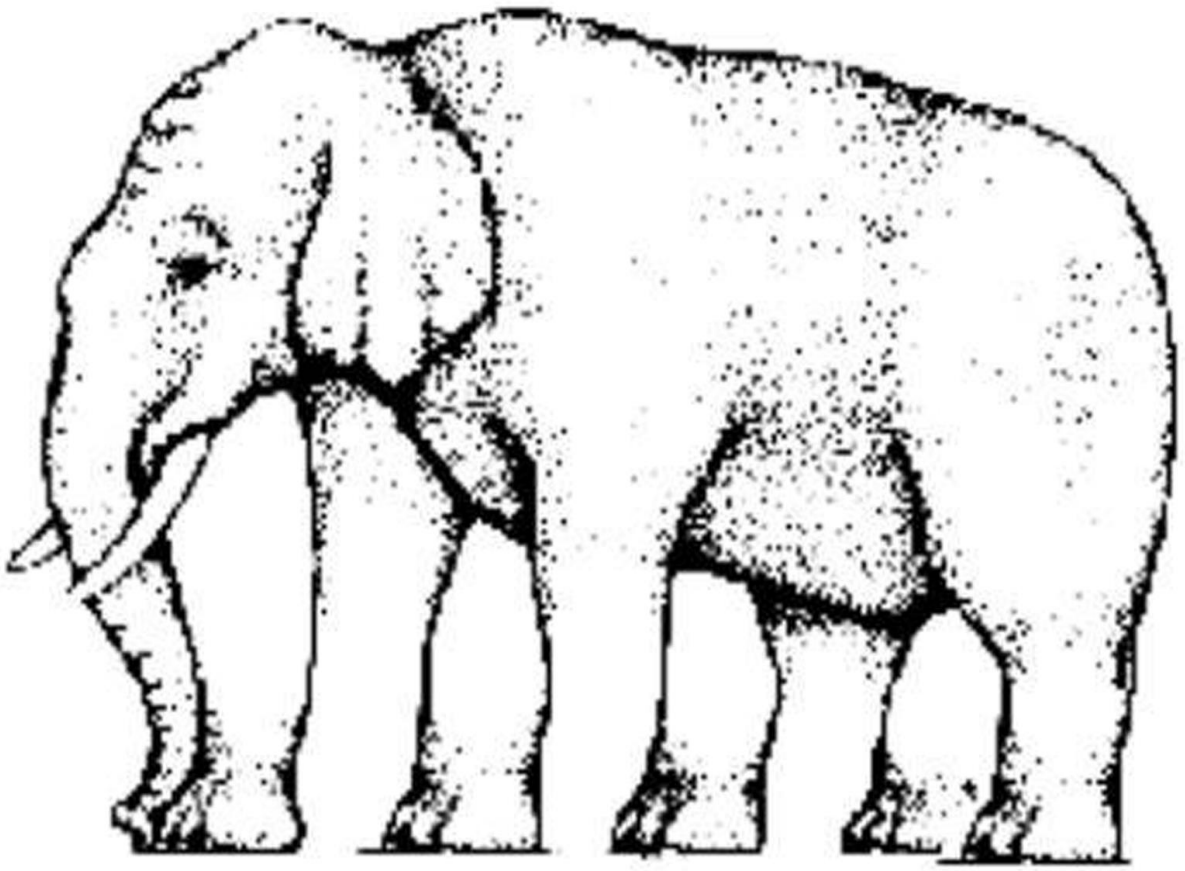
Some Topics

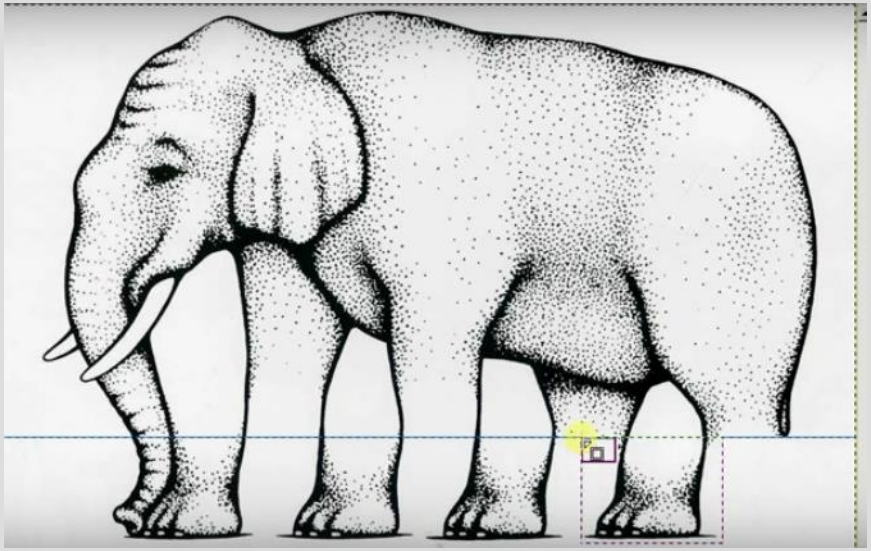
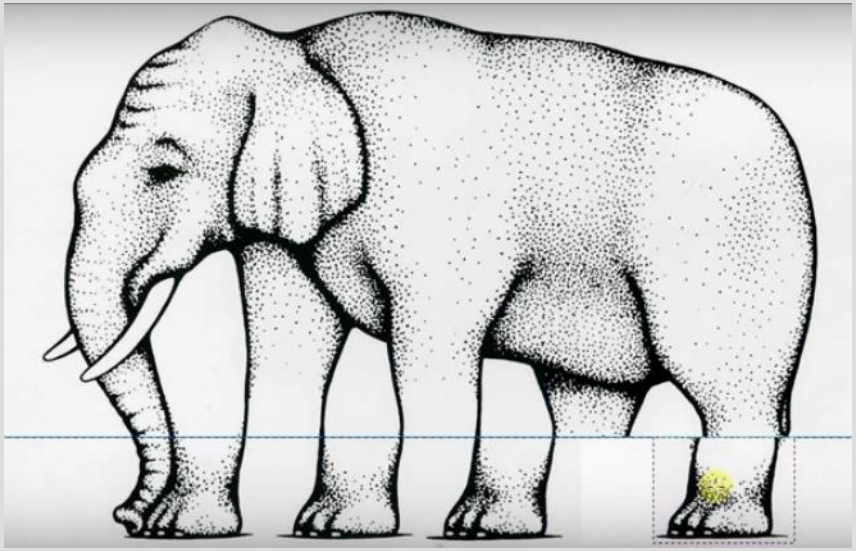
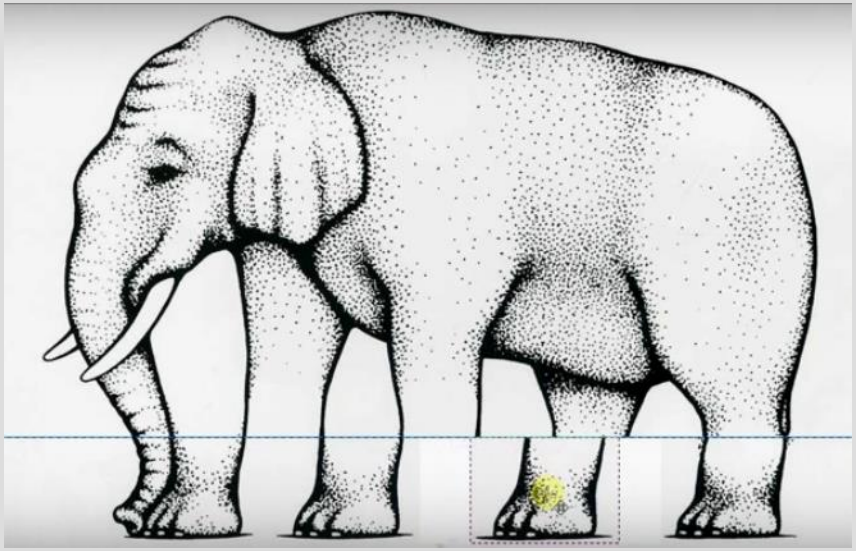
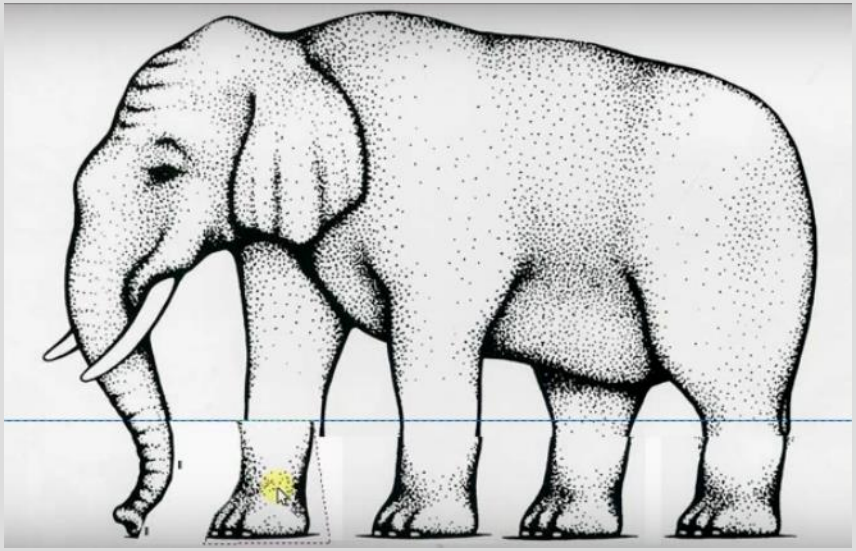
1. Introduction
2. Basic facts about cameras
3. High dynamic range
4. Images as 2D signals, basic operations
5. Filtering in the spatial domain
6. The Fourier transform, filtering in the frequency domain
7. Image restoration, morphological operations
8. Morphological operations
9. Color
10. Segmentation
11. Representation, Pattern recognition

Human vision

- Our vision system occupies a large part of the brain!
- Our interpretation of the image in our eyes is based on our experiences of the world around us.

How many legs?



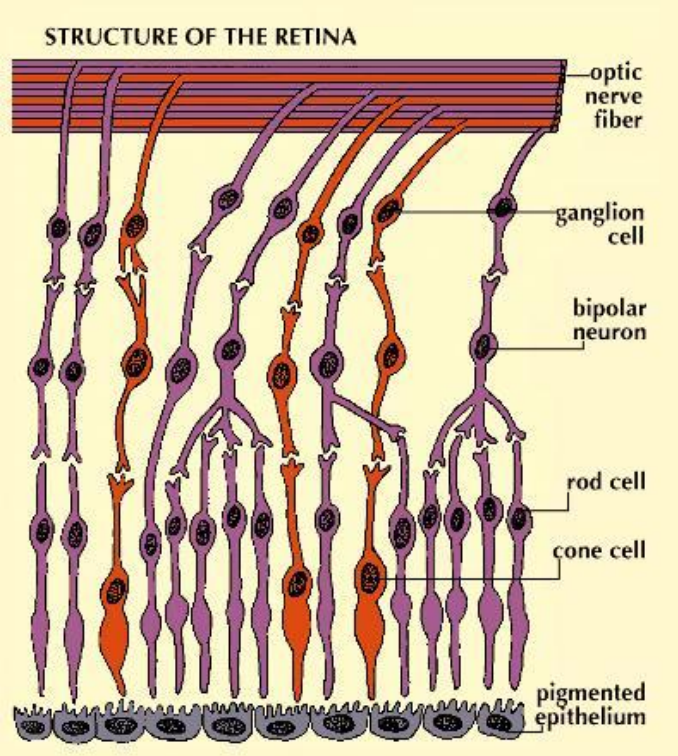
http://cogpsy.info/perception/the-elephant-illusion-shepard/

Low-Level / High-Level

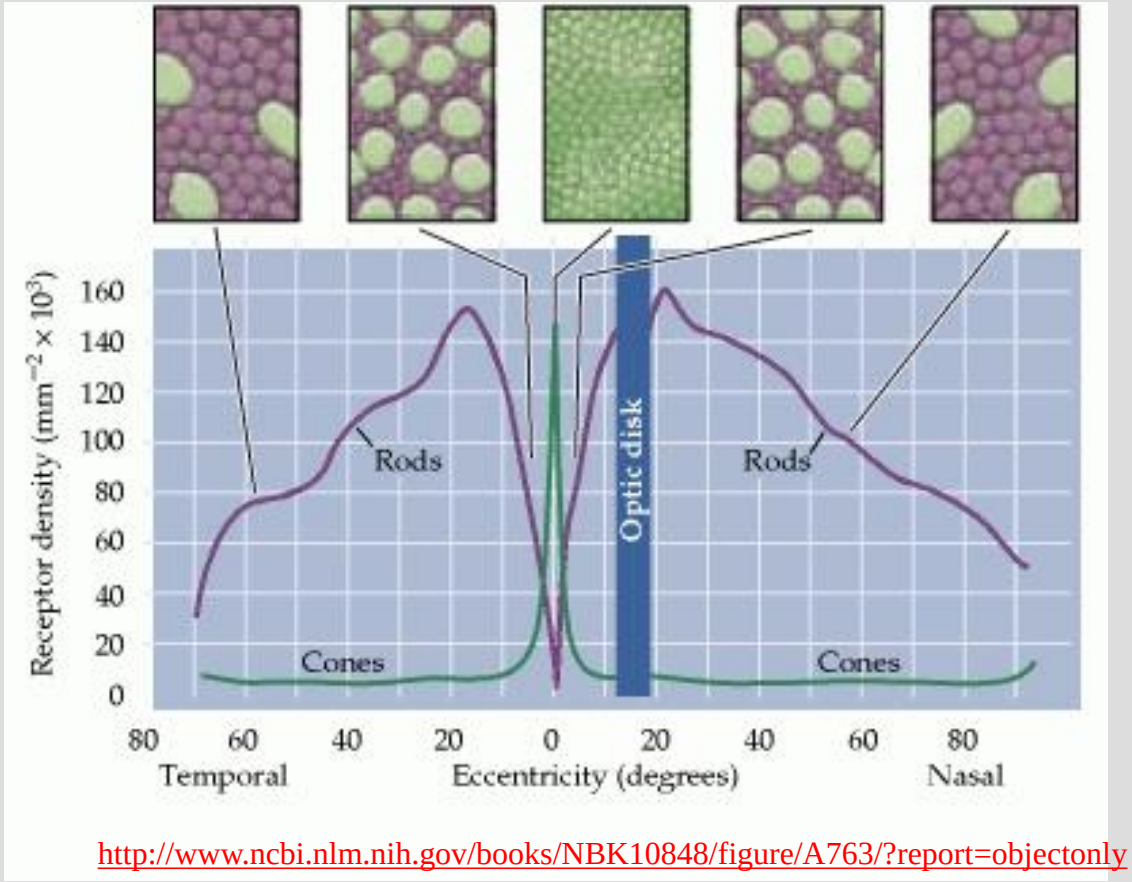
The elephant illusion is an example of figure-ground separation which is a high level effect

Low-level vision = optics, measurement, cameras, eyes …
High-level vision = understanding, interpretation, action …

Rods and Cones



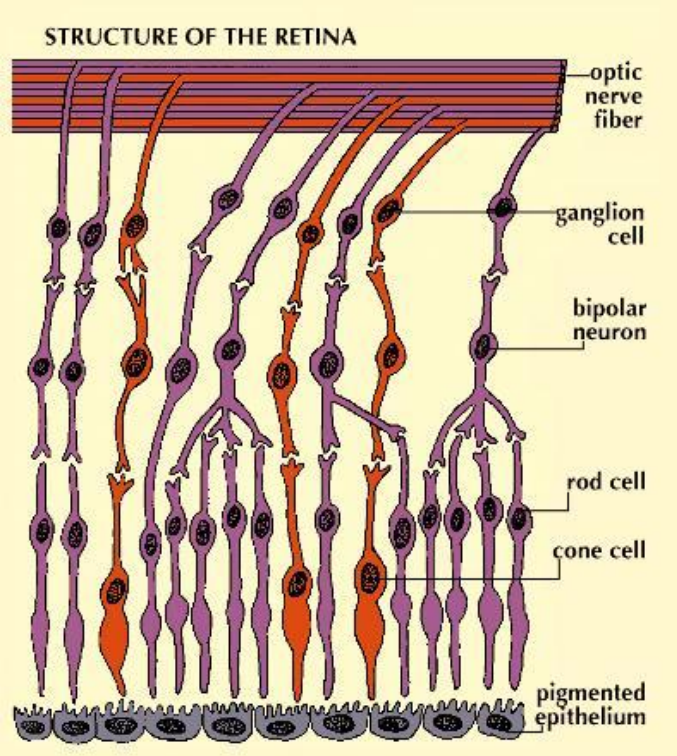
Encyclopedia Britannica, Inc.



http://www.ncbi.nlm.nih.gov/books/NBK10848/figure/A763/?report=objectonly

Distribution of rods and cones in the human retina. Graph illustrates that cones are present at a low density throughout the retina, with a sharp peak in the center of the fovea. Conversely, rods are present at high density throughout most of the retina, with a sharp decline in the fovea. Boxes at top illustrate the appearance of cross sections through the outer segments of the photoreceptors at different eccentricities. The increased density of cones in the fovea is accompanied by a striking reduction in the diameter of their outer segments.

Light Transport in the Retina



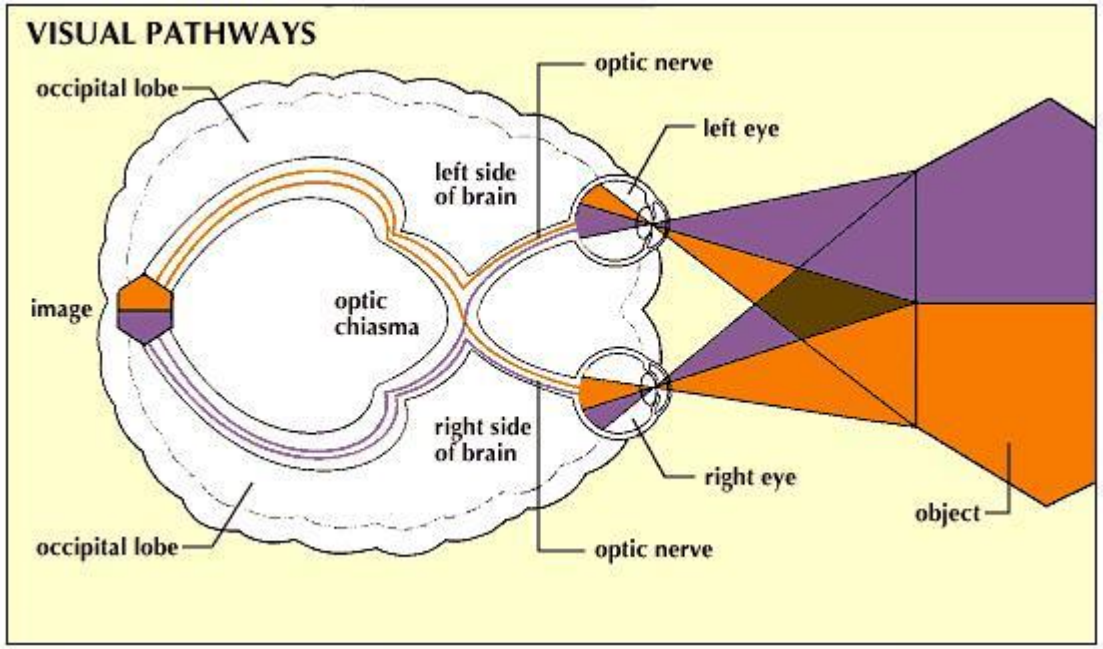
The arrangement of the retina makes it necessary for light to pass through the layers not sensitive to light first before it reaches the light-sensitive rods and cones. The optical disadvantages of this arrangement are largely overcome by the development of the fovea centralis, a localized region of the retina, close to the optic axis of the eye, where the inner layers of the retina are absent. The result is a depression, the foveal pit, where light has an almost unrestricted passage to the light-sensitive cells.

More in the Encyclopedia Britannicaat e

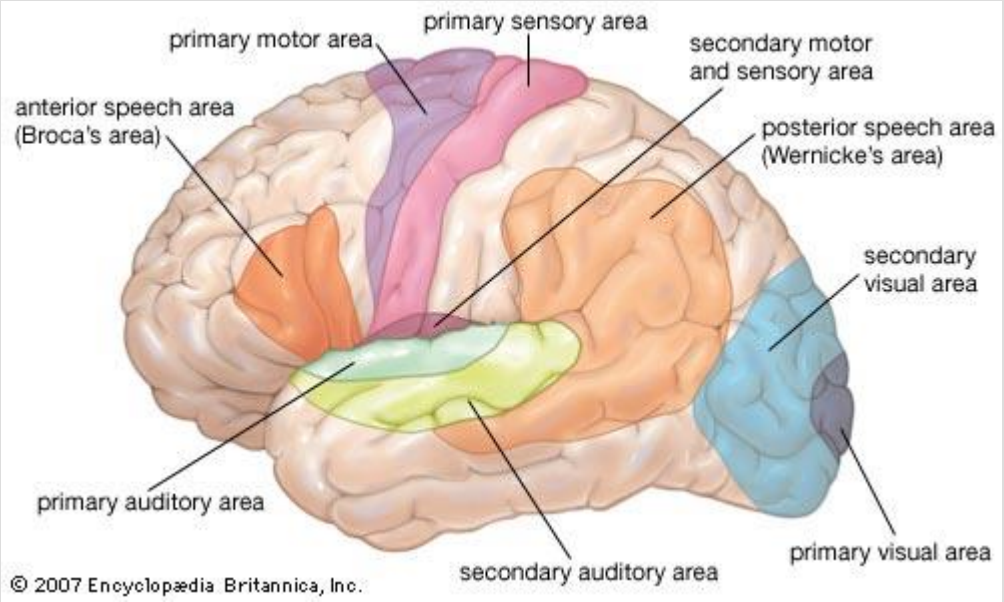
The eye

- Retina of the human eye: $<1cm^2$, thickness ~0.5 mm
- The retina contains $\sim10^8$ neurons (sensors).
- The optical nerve delivers data to the brain after data reduction in the retina (100:1)
- Each of the 10^6 output nerves transmit signals from one specific area on the retina.
- The data encodes light intensity differences in space and time.

The Eye and the Brain



http://www.britannica.com.lt.ltag.bibl.liu.se



http://www.britannica.com.lt.ltag.bibl.liu.se

Eyes in Animals (I)

Pinhole Eyes:
Nautilus: These organisms have eyes that are large, about 10 mm across, with millions of photoreceptors. They also have muscles that move the eyes and pupils that can vary in diameter, from 0.4–2.8 mm, with light intensity.
http://www.britannica.com.lt.ltag.bibl.liu.se

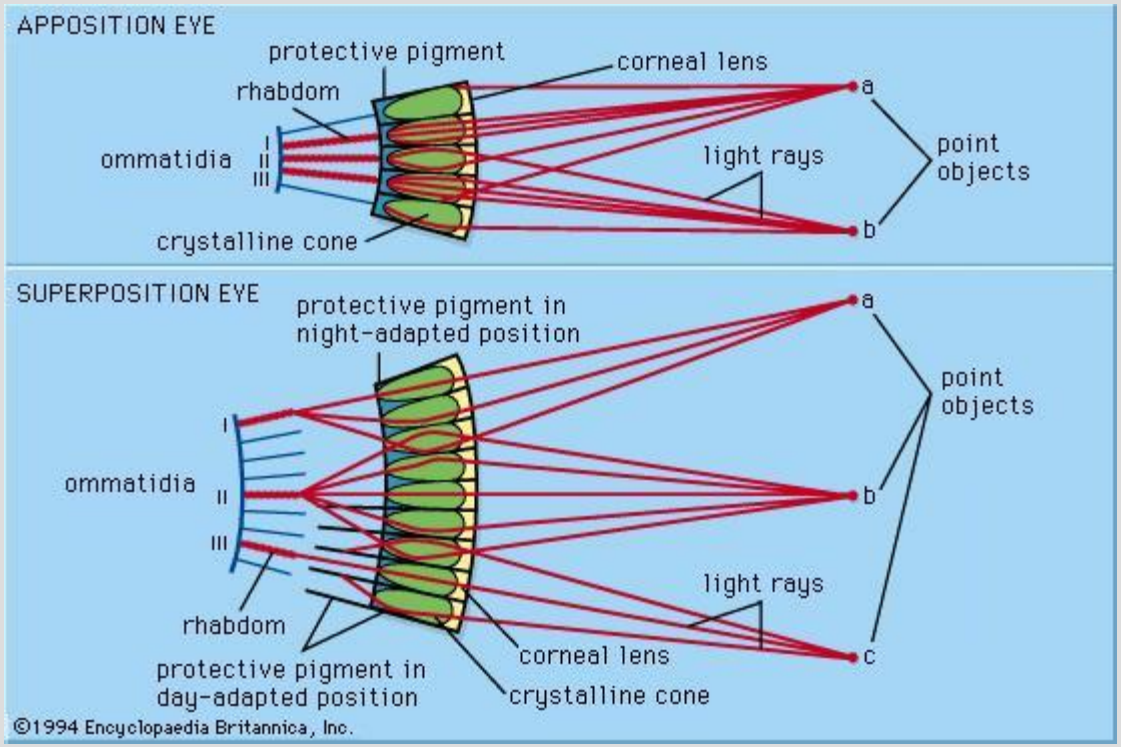
Eyes in Animals (II)

Spiders typically have eight eyes, two of which, the principal eyes, point forward and are used in tasks such as the recognition of members of their own species.

Jumping spiders have the best vision of any spider group, and their principal eyes can resolve a few minutes of arc, which is many times better than the eyes of the insects on which they prey. The eyes of jumping spiders are also unusual in that the retinas scan to and fro across the image while the spider identifies the nature of its target.

http://www.britannica.com.lt.ltag.bibl.liu.se

Eyes in Animals (III)



Compound eyes are made up of many optical elements arranged around the outside of a convex supporting structure. They fall into two broad categories with fundamentally different optical mechanisms.

In apposition compound eyes each lens with its associated photoreceptors is an independent unit (the ommatidium), which views the light from a small region of the outside world. In superposition eyes the optical elements do not act independently; instead, they act together to produce a single erect image lying deep in the eye. In this respect they have more in common with single-chambered eyes, even though the way the image is produced is quite different.

http://www.britannica.com.lt.ltag.bibl.liu.se

Facet Eyes

The number of ommatidia in apposition eyes varies from a handful, as in primitive wingless insects and some ants, to as many as 30,000 in each eye of some dragonflies (order Odonata). The housefly has 3,000 ommatidia per eye, and the vinegar fly (or fruit fly) has 700 per eye.

http://www.britannica.com.lt.ltag.bibl.liu.se

Lund Vision Group

Fast Recognition

Short video 11 sec
First gray then after about 5 sec
VERY SHORT 2 images side-by-side
one person(s) – one landscape type

Im 1	Im 2

As soon as you see the person(s)
raise your left hand when you see them in position Im1
raise your right hand when you see them in position Im2

Fast Recognition

Snakes have long been of interest to us above and beyond the attention we give to other wild animals. The attributes of snakes and our relationships with them have been topics of discussion in fields as disparate as religion, philosophy, anthropology, psychology, primatology, and herpetology (1, 2). Ochre and eggshells dated to as early as 75,000 y ago and found with cross-hatched and ladder-shaped lines (3, 4) resemble the dorsal and ventral scale patterns of snakes. As the only natural objects with those characteristics, snakes may have been among the first models used in representational imagery created by modern humans. Our interest in snakes may have originated much further back in time; our primate lineage has had a long and complex evolutionary history with snakes as competitors, predators, and prey (1). The position of primates as prey of snakes has, in fact, been argued to have constituted strong selection favoring the evolution of the ability to detect snakes quickly as a means of avoiding them, beginning with the earliest primates (2, 5). Across primate species, ages, and (human) cultures, snakes are indeed detected visually more quickly than innocuous stimuli, even in cluttered scenes (6–11). Physiological responses reveal that humans are also able to detect snakes visually even before becoming consciously aware of them (12). Although the visual system must be involved in the preferential ability to detect snakes rapidly and preconsciously or automatically, the neurological basis for this ability has not yet been elucidated, perhaps because an evolutionary perspective is rarely incorporated in neuroscientific studies. Our study helps to fill this interdisciplinary gap by investigating the responses of neurons to snakes and other natural stimuli that may have acted as selective pressures on primates in the past.

Snake Detection Theory

Quan Van Le, Lynne A. Isbell, Jumpei Matsumoto, Minh Nguyen, Etsuro Hori, Rafael S. Maior, Carlos Tomaz, Anh Hai Tran, Taketoshi Ono, and Hisao Nishijo

Pulvinar neurons reveal neurobiological evidence of past selection for rapid detection of snakes

PNAS 2013 : 1312648110v1-201312648.

Human Vision = Sensor + Brain

Vision is a dynamical process with spatial and temporal adaptation

Focal changes by changing the form of the lens

Strange Things can Happen

Strange Things can Happen

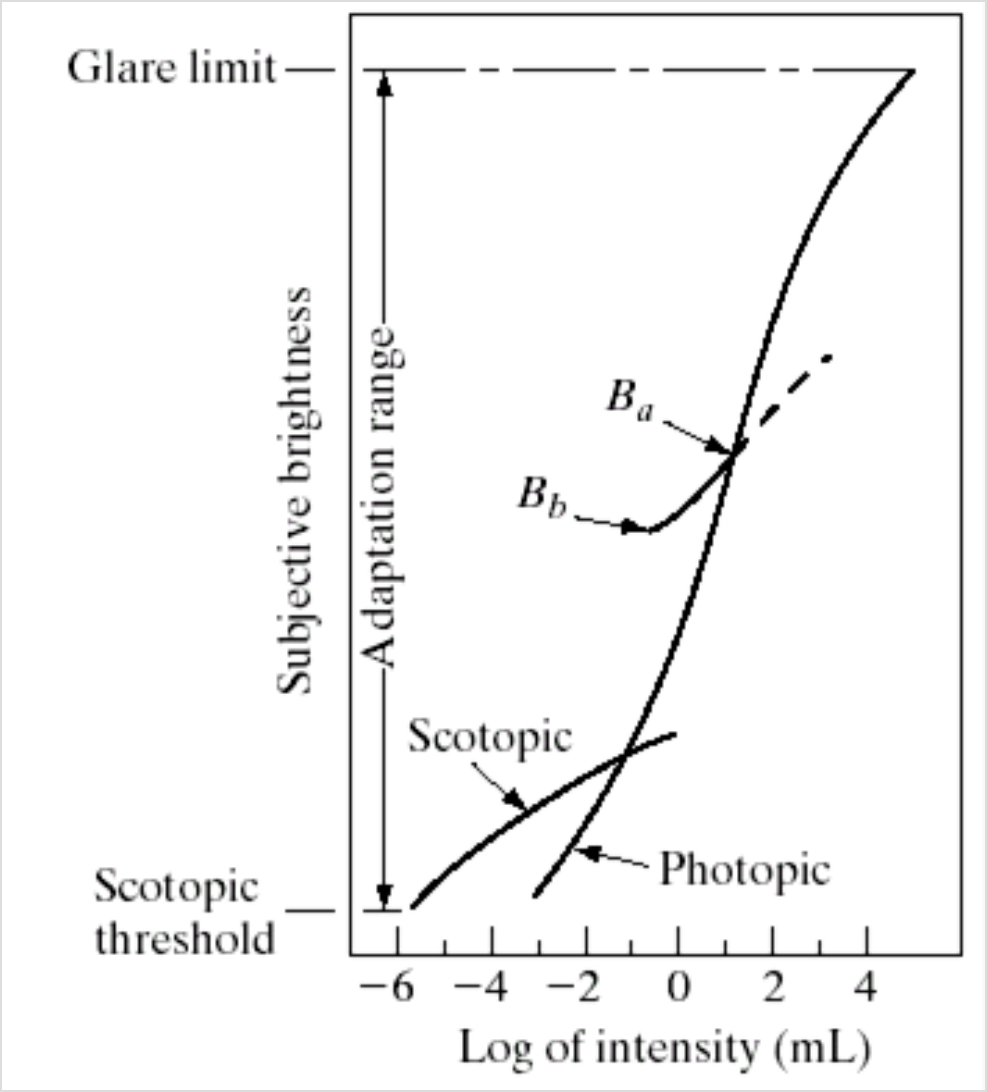
Sensitivity of the eye

A common jpeg image has R, G and B values
in the range 0…255

A raw image may have 2^{12} or 2^{14} different levels

Human vision has a range of
10^{10} intensity levels with adaptation

Sensitivity of the Eye



Scotopic: rods (dim light vision)

Photopic: cones (color vision)

Range of intensity levels: 10^{10} with adaptation

Only a few at given Adaptation level

Weber-Fechner Law

Intensity = physical property; stimulus
Brightness = subjective perception of intensity

Brightness = f(log(Intensity))

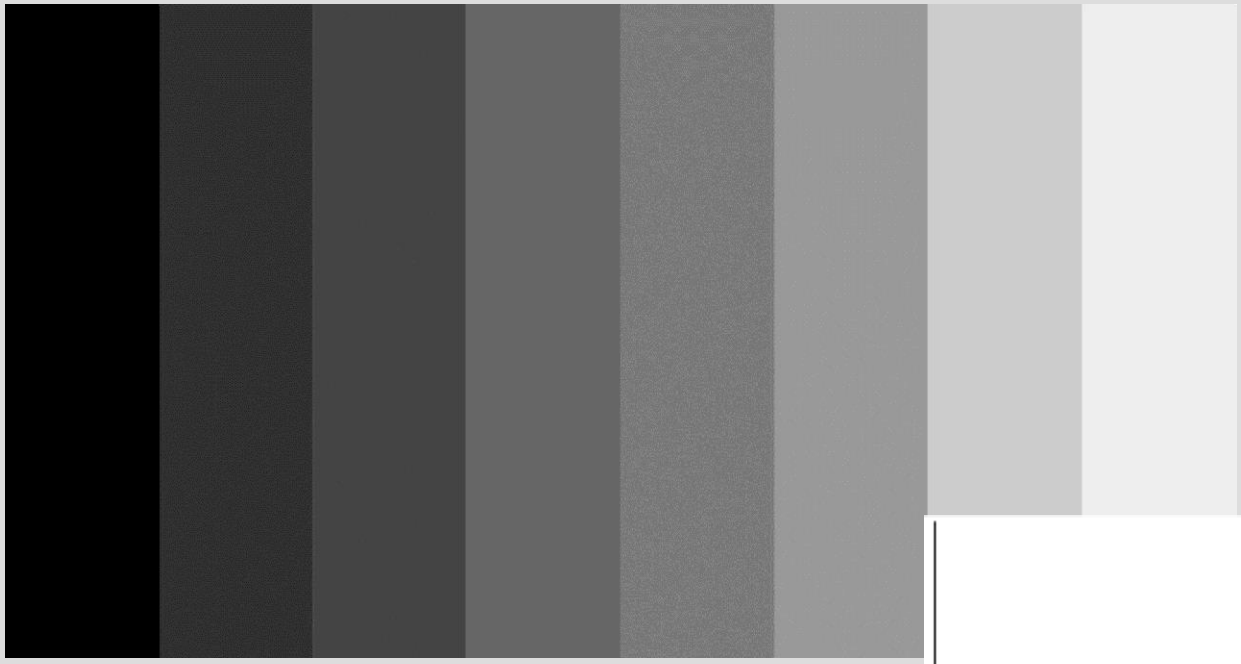
General rule:

Perception = f(log(stimulus))

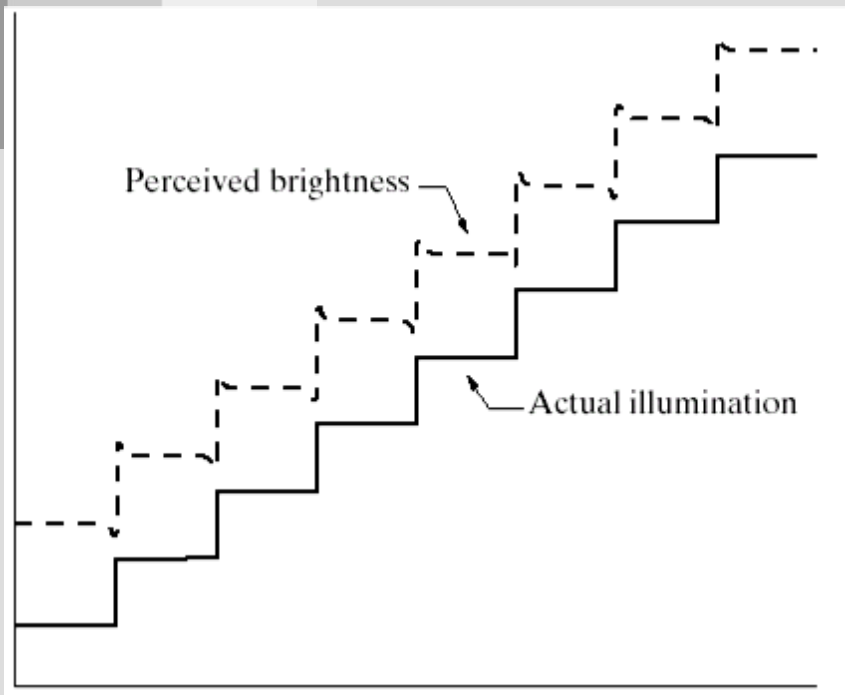
Also:

Discrimination at high intensities is better than at low (Weber ratio)

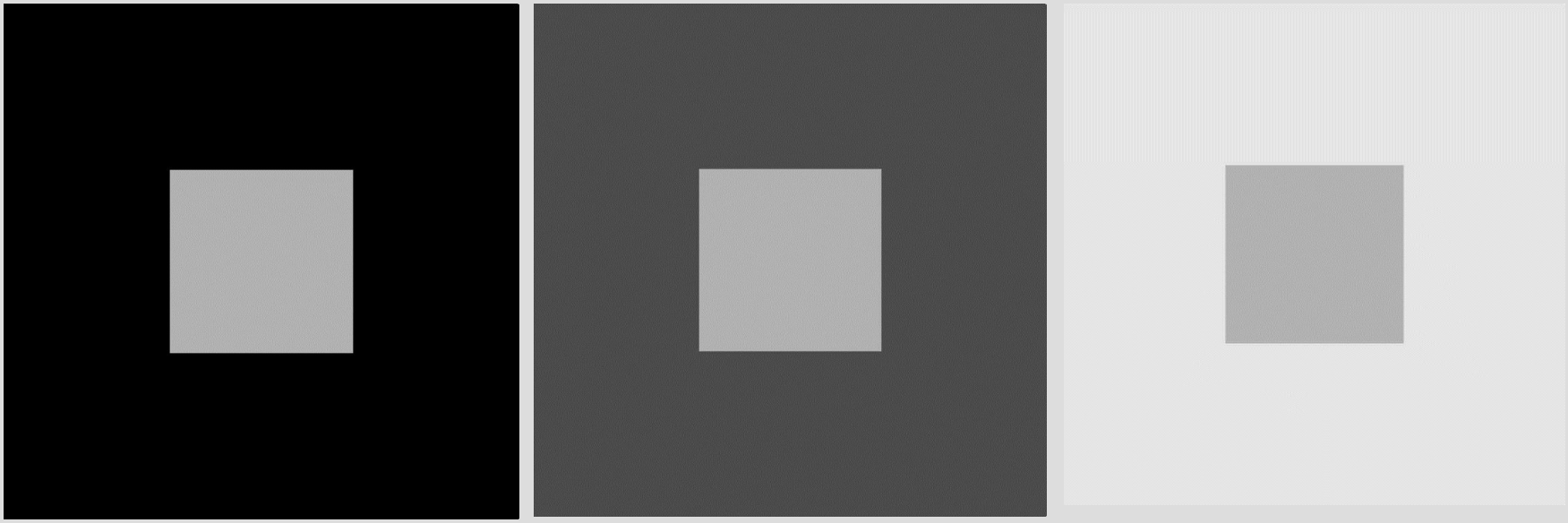
Sensitivity of the eye



Mach-band

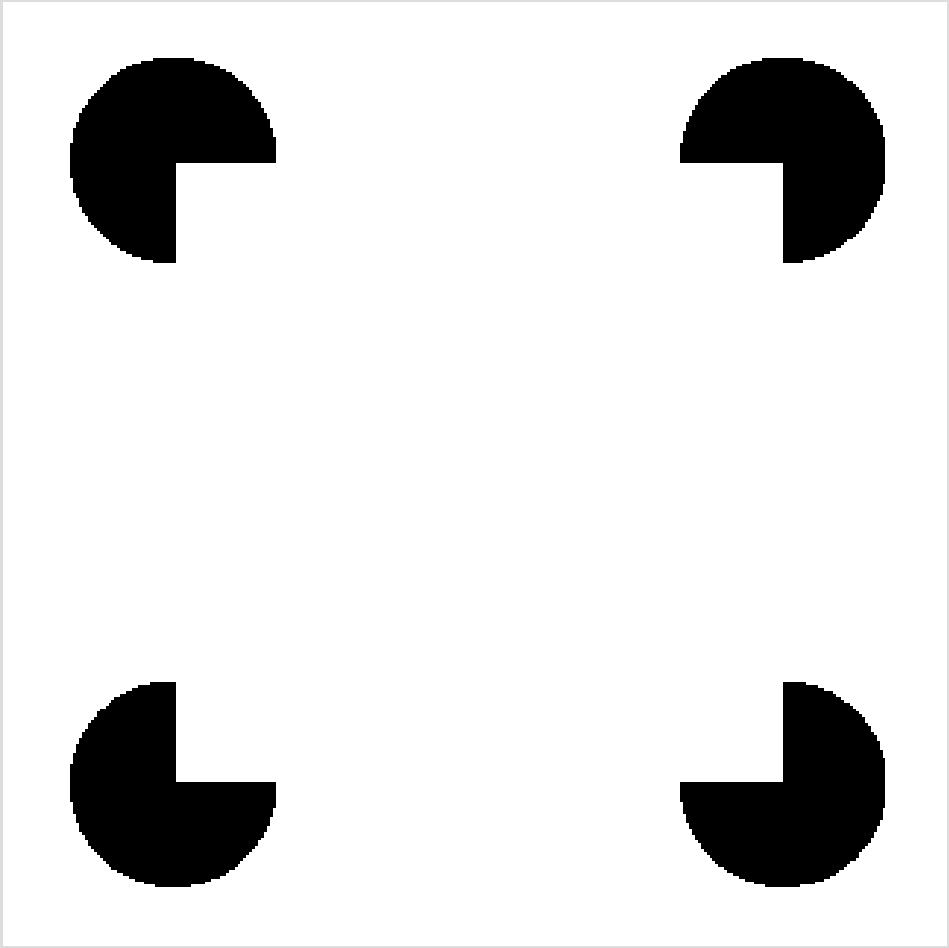


Sensitivity of the eye

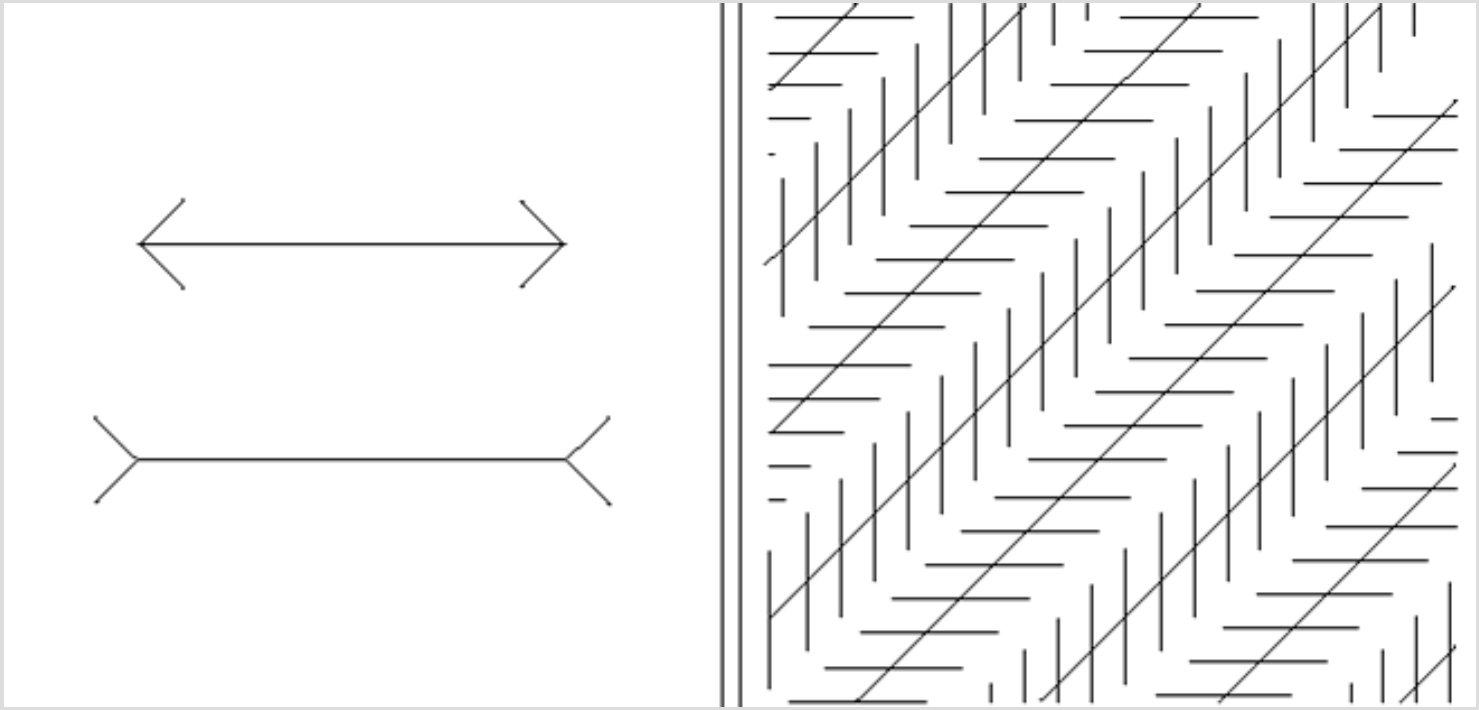


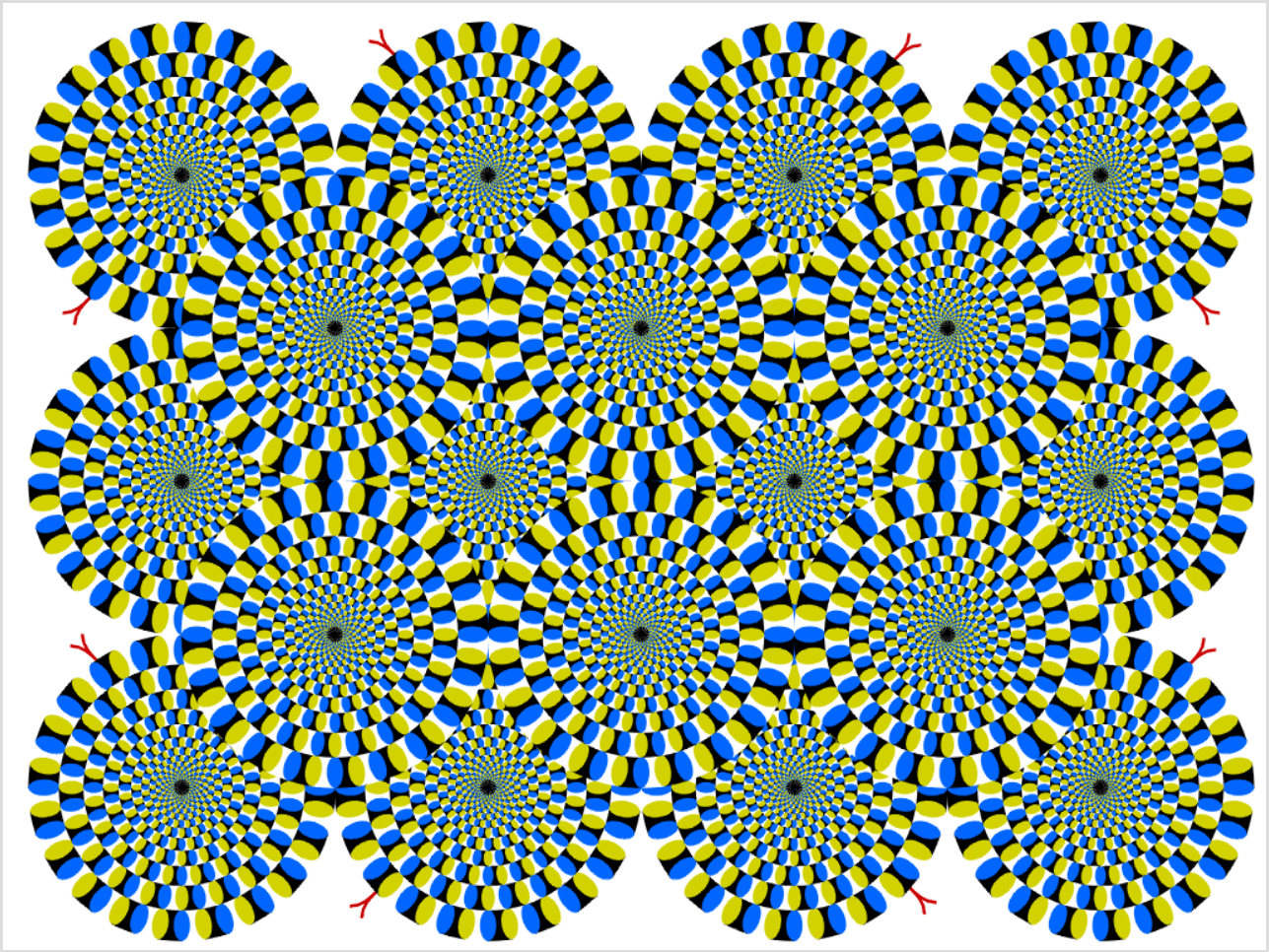
Simultaneous contrast

Optical illusion



Optical illusion





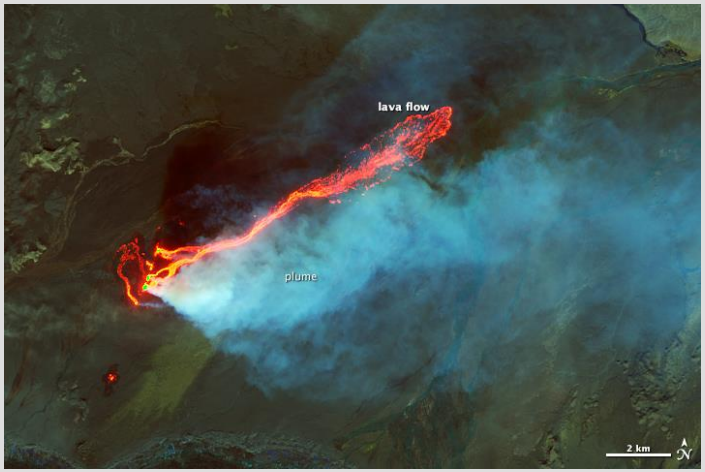
Akiyoshi's illusion pages

Guardian: 1. Jan. 2013

1. **Self-driving cars**
   May 2012, Nevada had licensed them
2. **Augmented reality**
   overlaying information about what you are seeing in your field of view
3. **Superfast mobile broadband**
   really fast connections – great for video and games
4. **Flexible phone screens**
   Nobody's quite sure what to use them for, though
5. **Measure yourself**
   Possibly by relaying your results to their Google Glasses

Multispectral – Planets - …

Many spectral bands

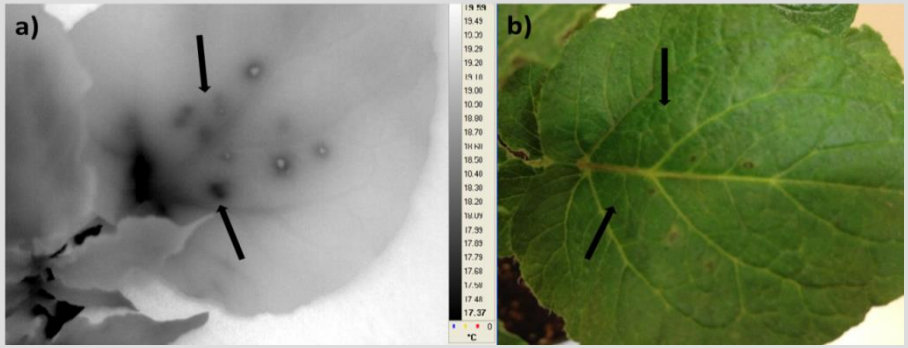


GeoEye-1 details the size of 41 cm
Google 50 cm

Charon: Moon of Pluto

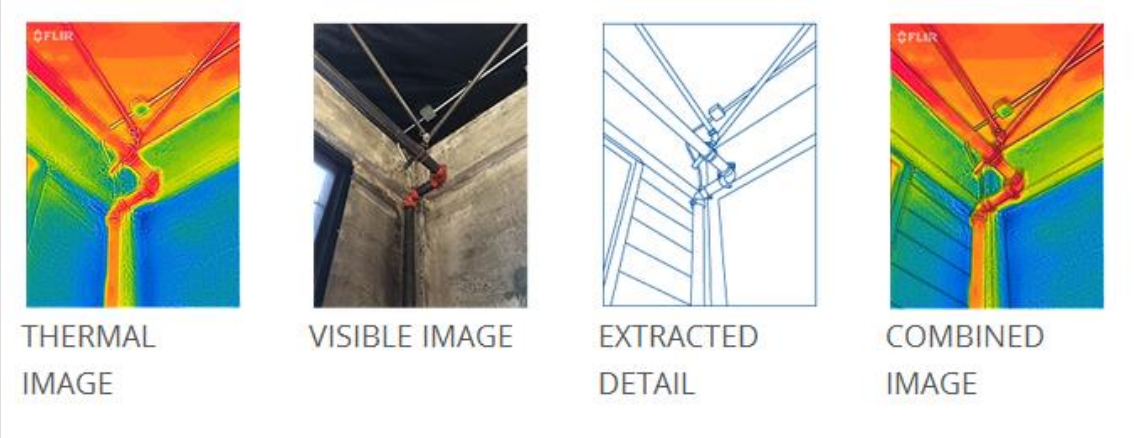
InfraRed (IR) Images

Cameras sensitive to very long wavelength radiation measures temperature



In image (**a**), taken with IR- camera, arrows indicate early plant response to attack by potato viruses which are invisible in image (**b**) taken with a digital camera.
Small necrosis visible in the image (a) and (b) has the highest temperature while encircling tissue has lower leaf temperature than the undamaged parts of the potato leaf (a).

IR for Mobile Phones



Flir-One http://www.flir.com/flirone

Application areas for image processing

- Cameras
- Scanners
- Graphic arts: color correction, halftoning
- Satellite images
- Medical images (X-ray, ultrasound, microscopy,MRI)
- Digital film production
- Search (Google, Bing, Facebook,...)
- Mobile

Cameras are cheap and therefore we have cameras everywhere

Title of a course

Image and video processing: From Mars to Hollywood with a stop at the hospital

Some Nobel Prizes

- Roentgen (X-Rays) 1901
- Lippmann (Photography) 1908
- von Laue (Diffraction) 1914
- Gabor (Holography) 1971
- Cormack & Hounsfield (Tomography) 1979
- Klug, (Microscopy) 1984
- Ruska (Electron Microscope) 1986
- Binning &Rohrer (Scanning Tunneling Microscope) 1986
- Betzig, Heil, Moerner (Microscopy) 2014

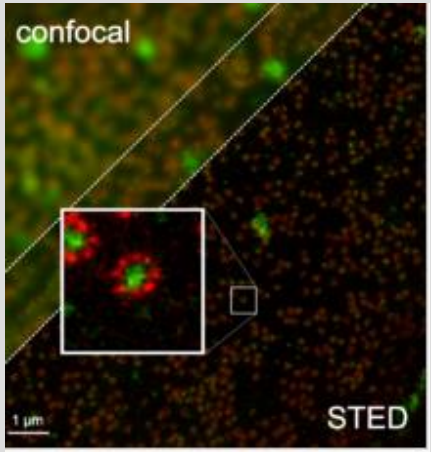
Nobel Prize in Chemistry 2014

"for the development of super-resolved fluorescence microscopy"

Ernst Abbe's formula for the diffraction limit, set in stone at a monument in Jena.

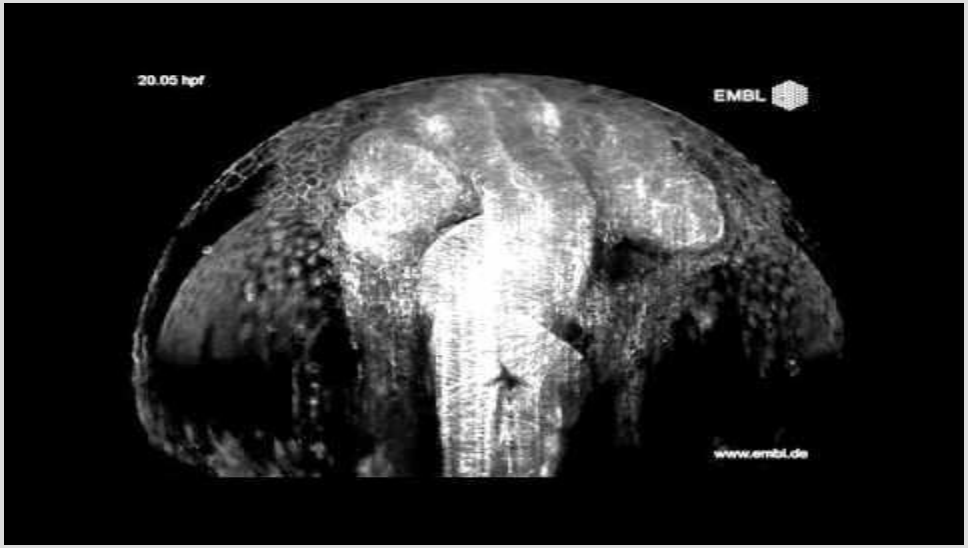
Stimulated emission depletion (STED) microscopy

http://en.wikipedia.org/wiki/STED_microscopy



Comparison of confocal microscopy and STED microscopy. This shows the improved resolution of STED microscopy over traditional techniques.

Light Sheet Microscopy



scientificamerican: new-microscope-enables-movies-of-embryos/

Terminology

Some research and application areas that involve processing and analysis of images:

- Image Enhancement
- Image Restoration
- Imaging
- Image Analysis
- Computer Vision
- Pattern Recognition

Image enhancement

Create an image that is perceived as ”better” in some sense by a human observer, for instance thru:

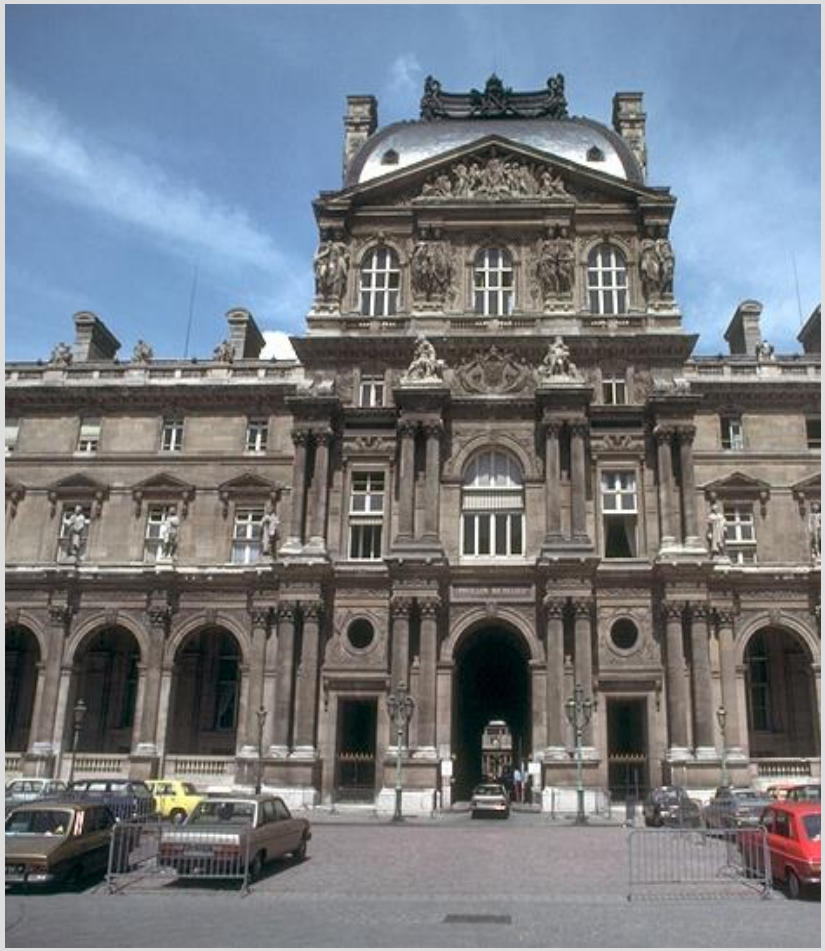
- change of tone
- color correction
- sharpening
- retouch
- …..

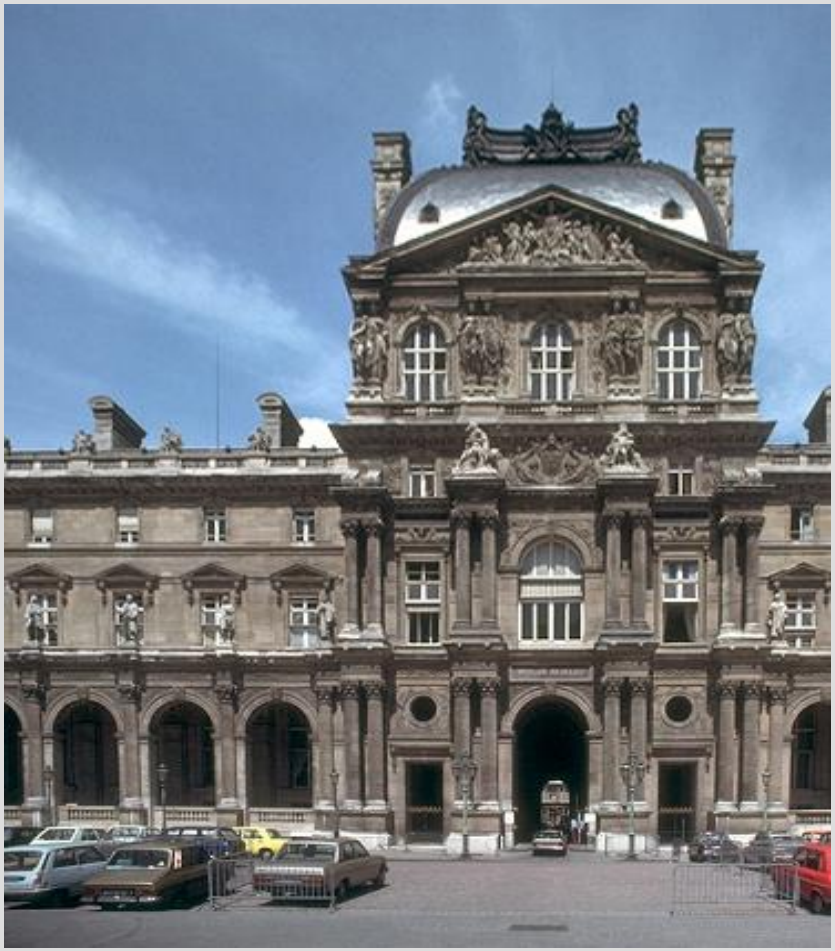
} Photoshop!

Image restoration

Create an image that correctly presents the scene that the camera saw. This often requires a model of the camera regarding photometric and geometric distortion.

Image reconstruction





Correction of geometric distorsion

Photosynth / GigaPixels / Computational Photography / ...

- photosynth.net
- Abandonedamerica
- GigaPan-Billions of Pixels
- http://www.mit.edu/~velten/press/content/
- ...

Imaging

Imaging is the art of using a sensor (e.g. a camera) to capture an image. Images can be created from data from sensors that are not primarily image forming, such as

- *Computed Tomography (CT)*
- *Magnetic Resonance Imaging (MRI)*

These techniques are primarily used in medical diagnosis.

HDR

Normal exposure time (Auto)

Shorter exposure time

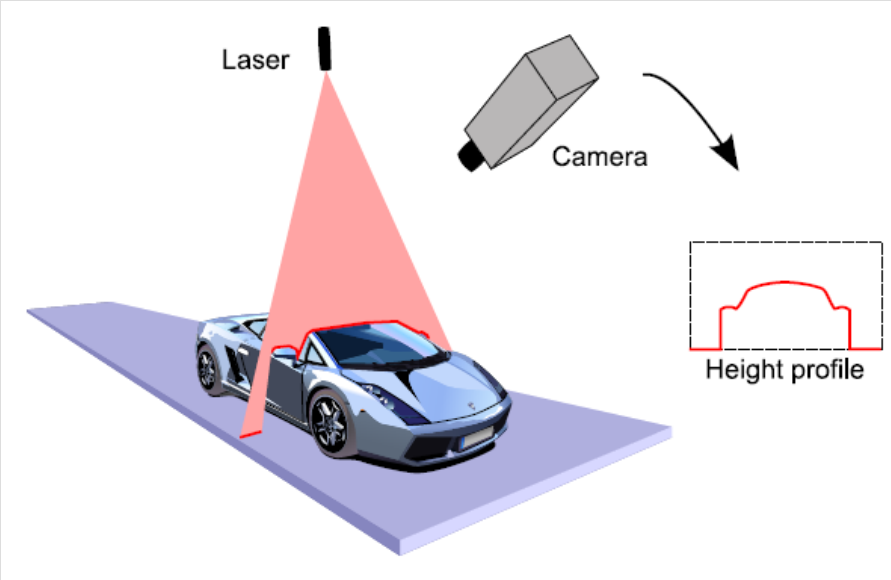
Longer exposure time

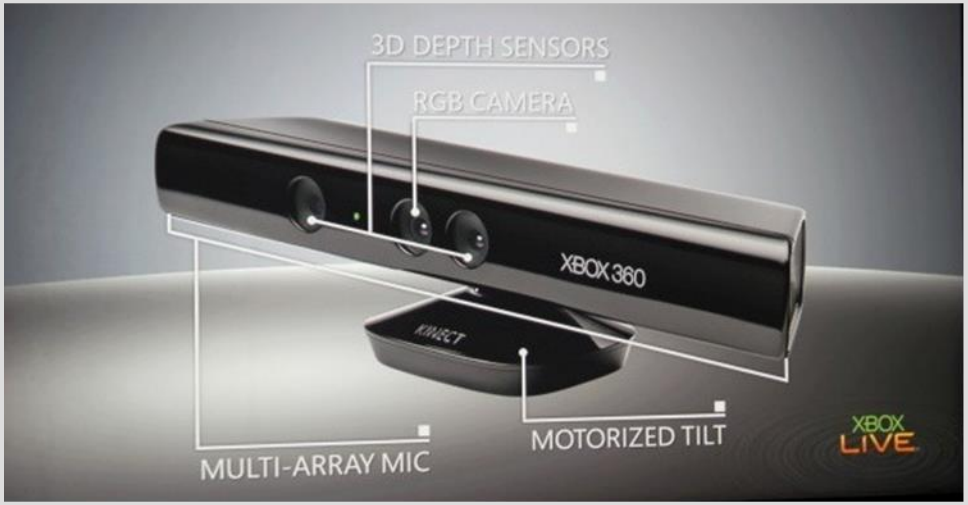
Result

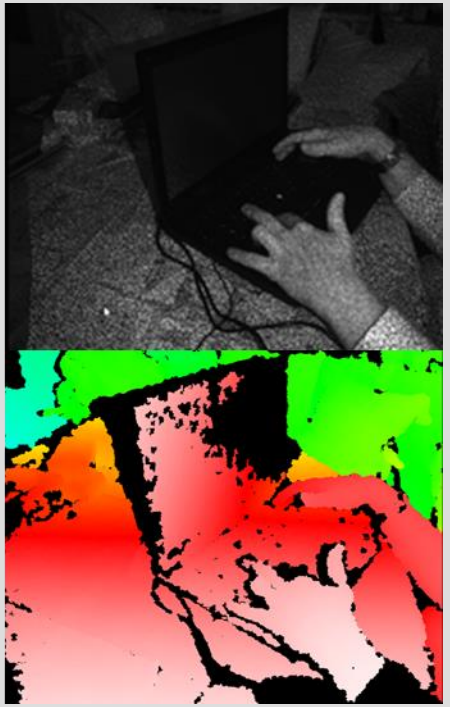
HDR

Result

Laser Range Cameras

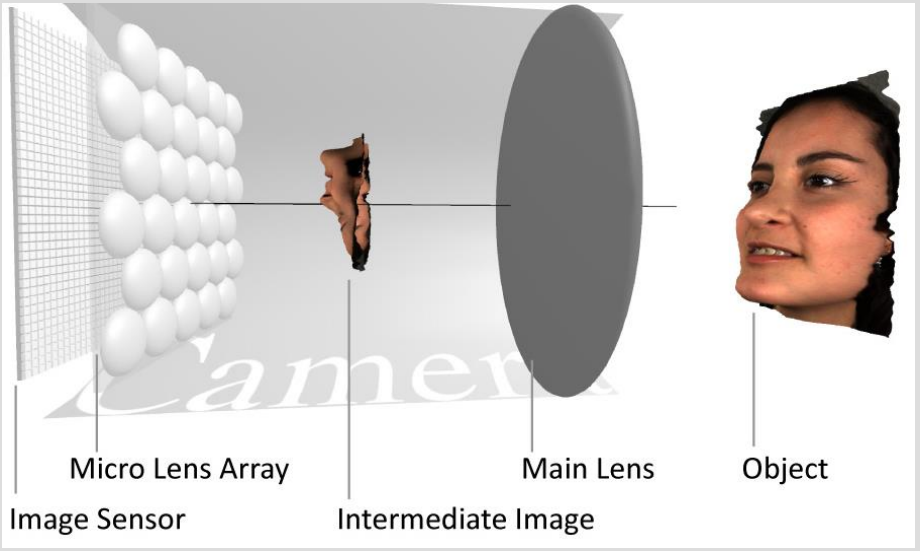






Light-Field Cameras

Possible to focus after shooting



https://en.wikipedia.org/wiki/Light-field_camera

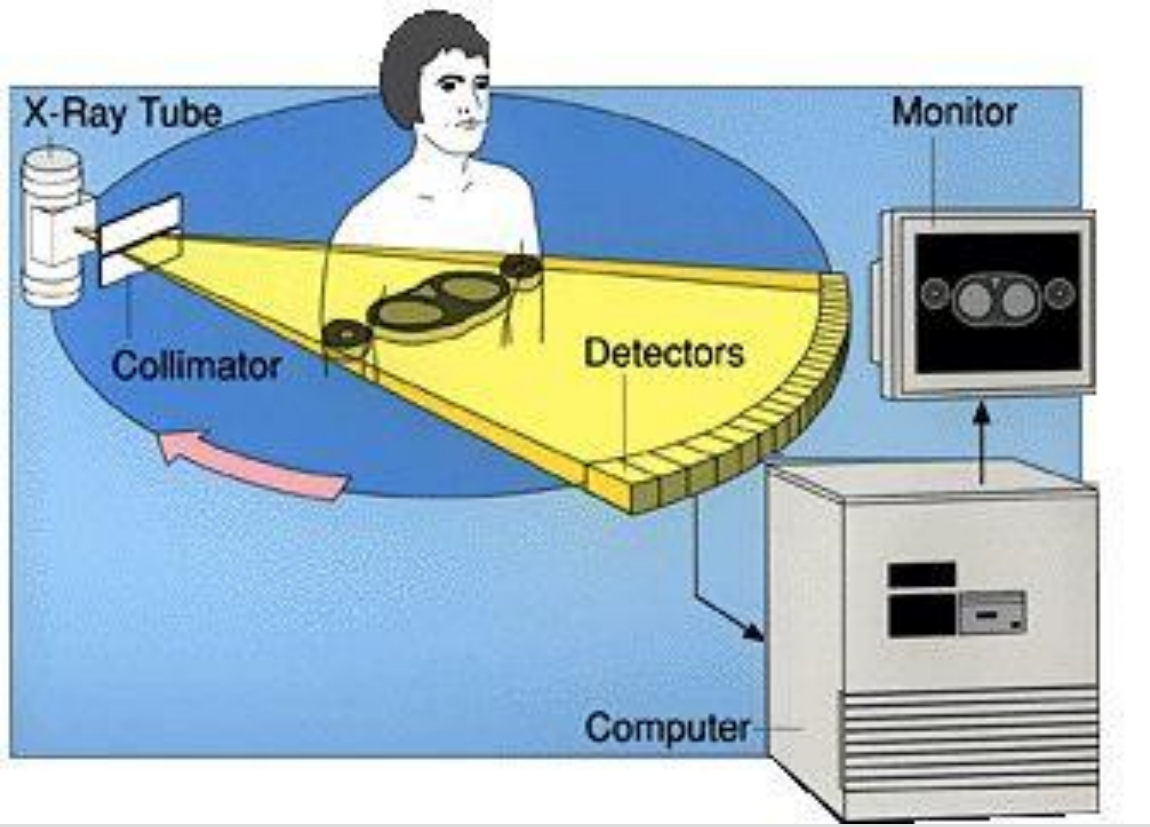
Multi-Cameras

L16: Computational photography
http://light.co/camera

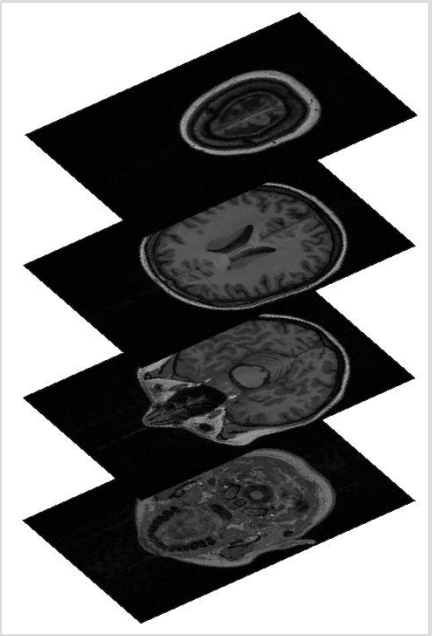
The rectangular black camera can capture images of up to 52 megapixels. Unlike most cameras, which use just one lens and image sensor, the L16 will squeeze in 16 camera modules with three different focal lengths—five 35-millimeter ones, five 70-millimeter ones, and six 150-millimeter ones. Each of the camera modules will have a 13-megapixel image sensor. The cameras will simultaneously snap their own shots from different perspectives when you take a picture, and software will combine them automatically into one image that mimics what you'd get from a DSLR camera with a large lens attached to it.
http://www.technologyreview.com/news/542121/a-high-end-camera-in-a-small-package/

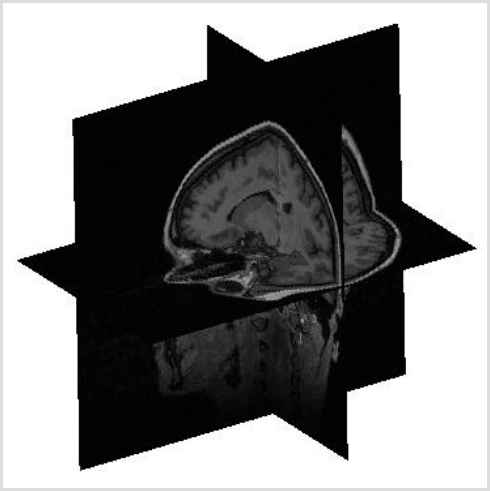
Computed Tomography (CT)

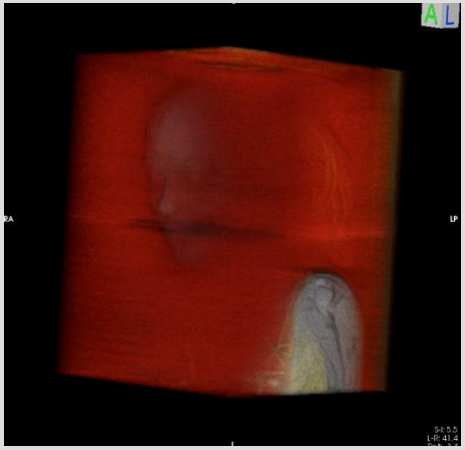
- Used in medical diagnosis and non-destructive industrial inspection
- A sequence of X-Ray projections is used to reconstruct a slice through the object



Visualization of 3D Data

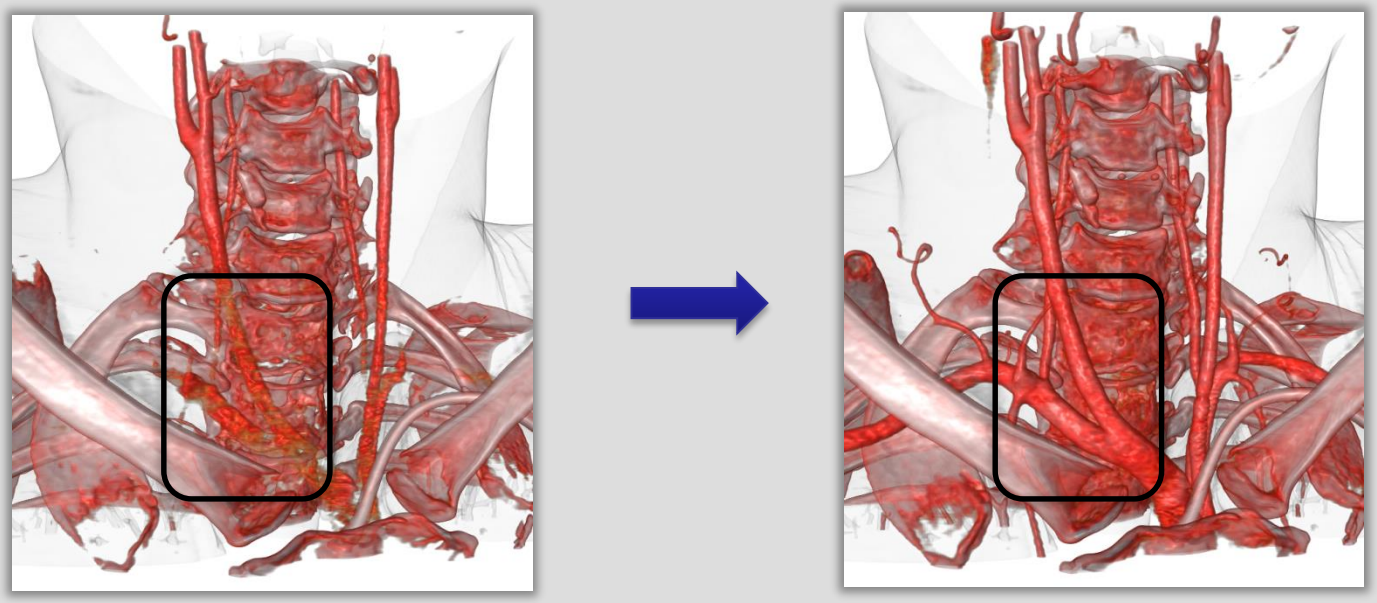






Blood vessel visualization

- Locally adapted visualization of blood vessel lumen
  - Automatic
  - Adapts to contrast agent concentration



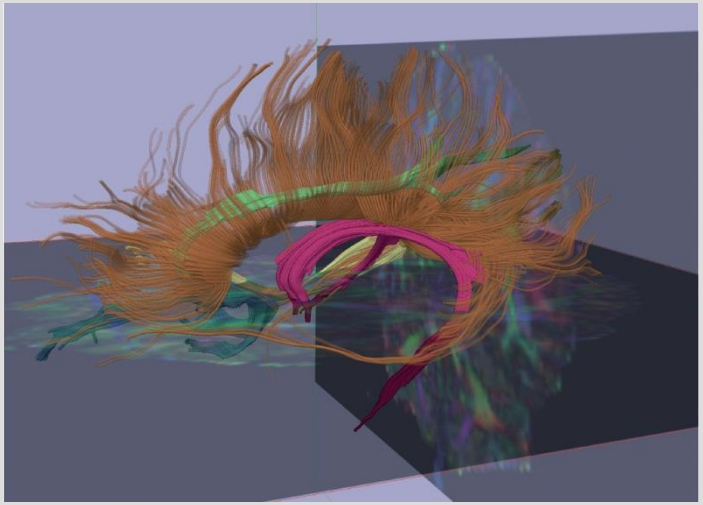
Standard

Our Method

Magnetic Resonance Imaging (MRI)

- A strong magnet, microwave transmitters and receivers
- Based on spin resonance of atom nuclei
- Often the reconstructed slices basically show the density distribution of hydrogen atoms in the object

Magnetic Resonance Imaging (MRI)

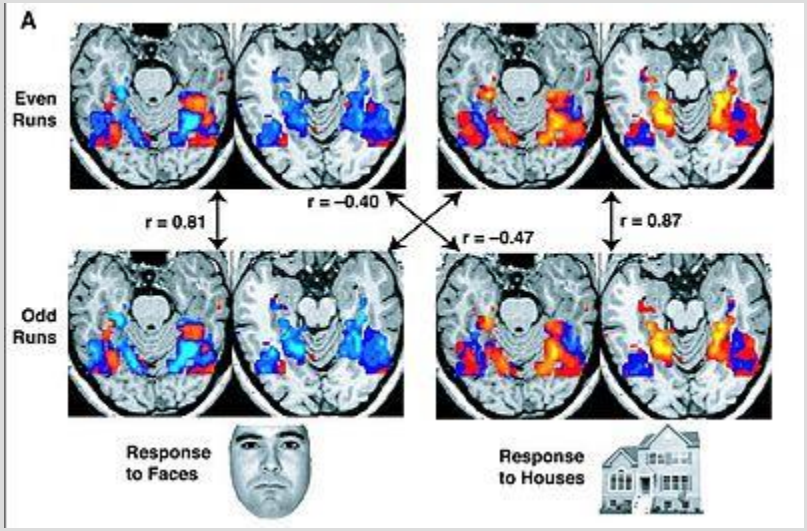


This image shows several major white matter fiber bundles identified through diffusion tensor imaging

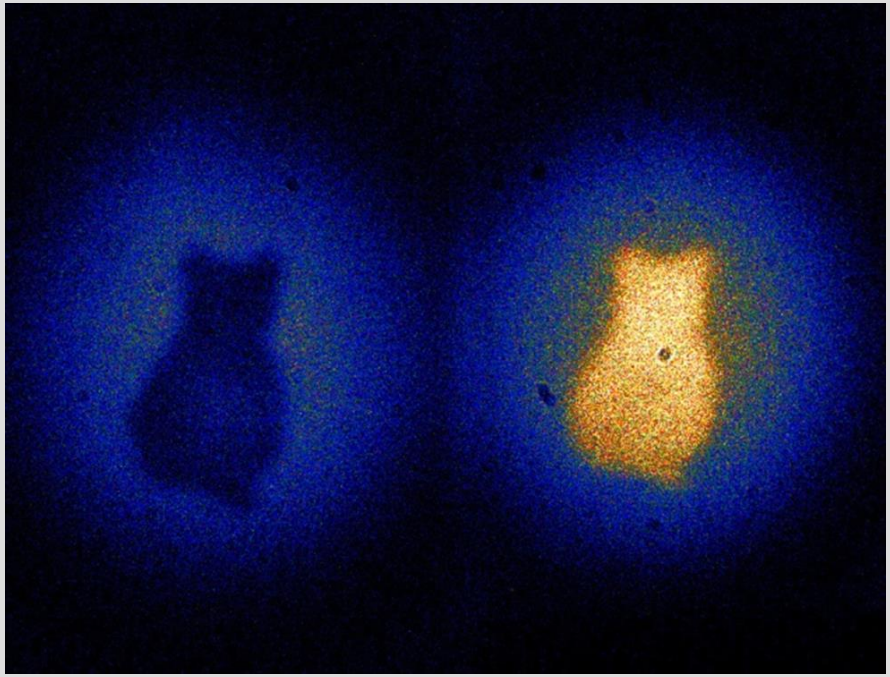
Shenton ME, Kubicki M. Structural brain imaging in schizophrenia

Magnetic resonance angiography studies without using contrast agents

Image Like Information



http://en.wikipedia.org/wiki/Functional_magnetic_resonance_imaging



Entangled photons make a picture from a paradox

Quantum imaging outlines objects with light that does not interact with them.

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Physicists have devised a way to take pictures using light that has not interacted with the object being photographed.

http://www.nature.com/nature/journal/v512/n7515/full/nature13586.html