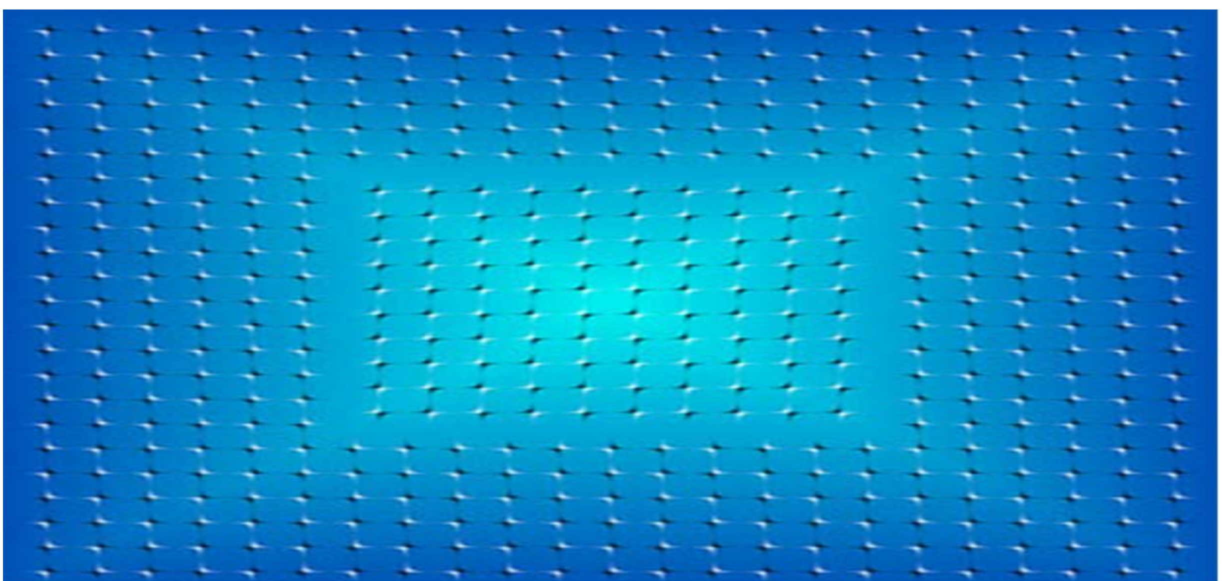
Image
Acquisition, Display, and Perception



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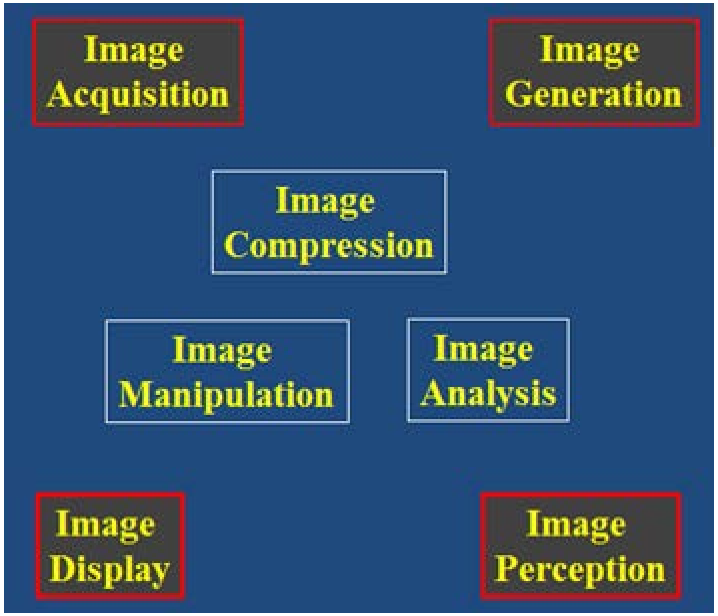
2015

Lecture Objectives

- Previously
  - History
  - Related fields
  - Application areas

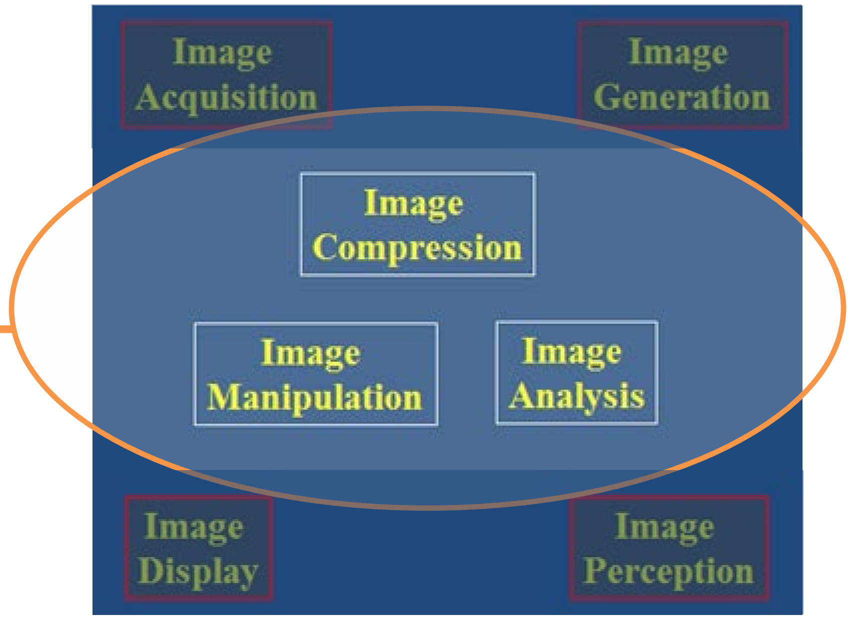
- Today
  - Image
    - Acquisition
    - Display
    - and Perception



Recall

- **Digital Image Processing (DIP)**
  - **Is *computer* manipulation of pictures, or images, that have been converted into numeric form**

  - Typical operations include
    - Image Compression
    - Image Warping
    - Contrast Enhancement
    - Blur Removal
    - Feature Extraction
    - Pattern Recognition



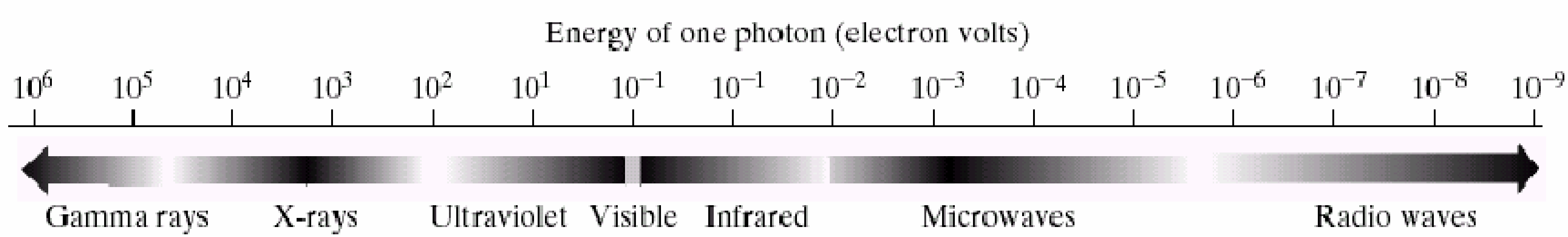
Recall: Image Processing **Goals**

- Image processing is
  a **subclass of signal processing specifically concerned with picture images**

  - Goals
    - To improve image quality for
      - human perception (subjective)
      - computer interpretation (objective)
    - Develop methods and applications
      - to compress images
      - to provide efficient storage and transmission

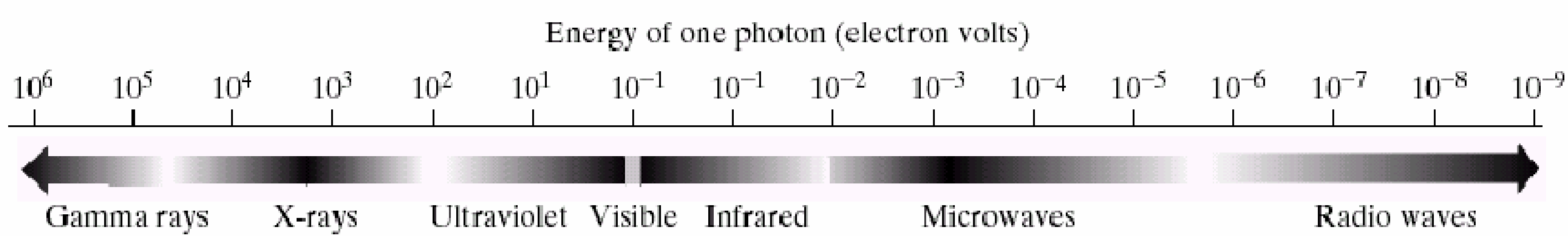
Sources of Images

- Principal source of images
  is the electromagnetic (EM) energy spectrum
  - EM waves are
    stream of massless (proton) particles
    each traveling in a wavelike pattern at the speed of light
    - Spectral bands are grouped by energy per photon
      - Gamma rays, X-rays, UV, Visible, Infrared, Micro, Radio…



Physical Aspects of Acquisition

- Improvements extend beyond human eyes
  - From visible spectrum to non-visible EM power spectrum
  - From close-distance sensing to remote sensing

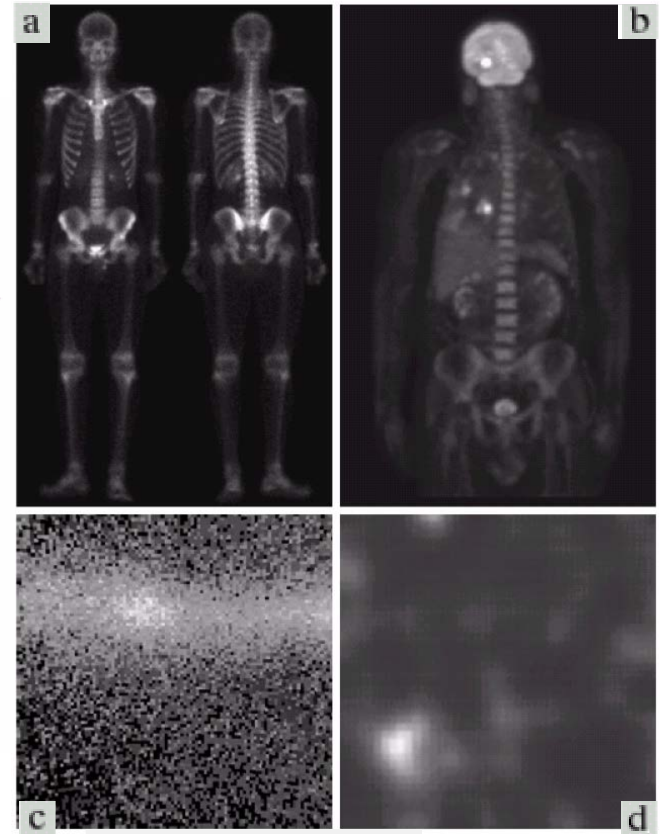


Gamma-Ray Imaging

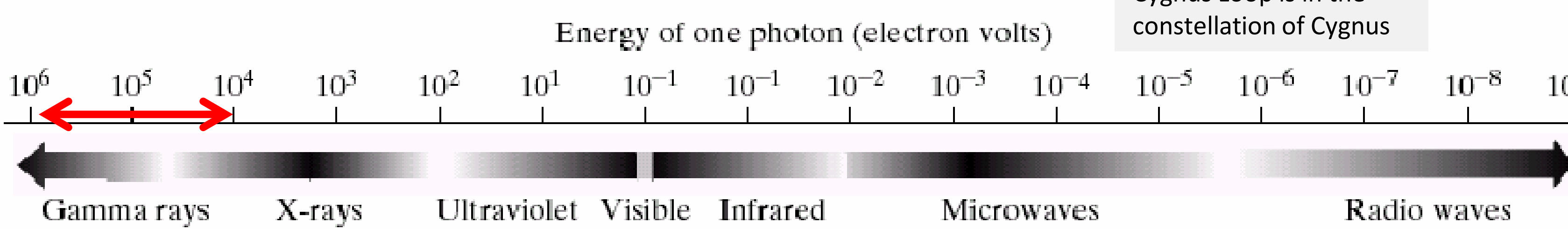
- Used in
  - Astronomy and Medicine

- Medicine
  - Positron Emission Tomography
  - Radioactive isotope injected into patient
    - Emits gamma rays as it decays
    - Allowing creation of medical images via detectors

FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of Michigan.)



Cygnus Loop is in the constellation of Cygnus



X-Ray Imaging

- Oldest source of EM radiation for imaging
  - CAT scans
  - angiograms
  - industrial inspection of circuit boards

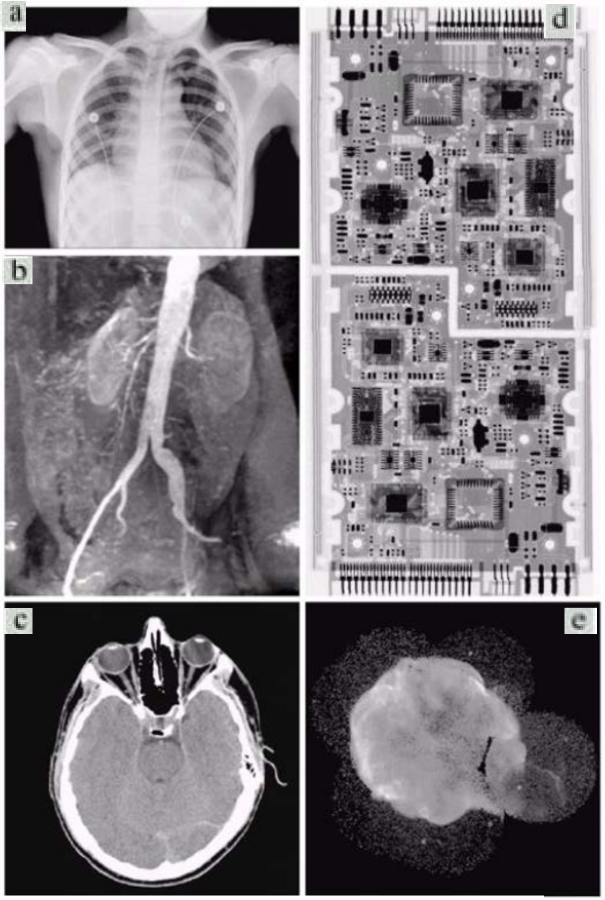
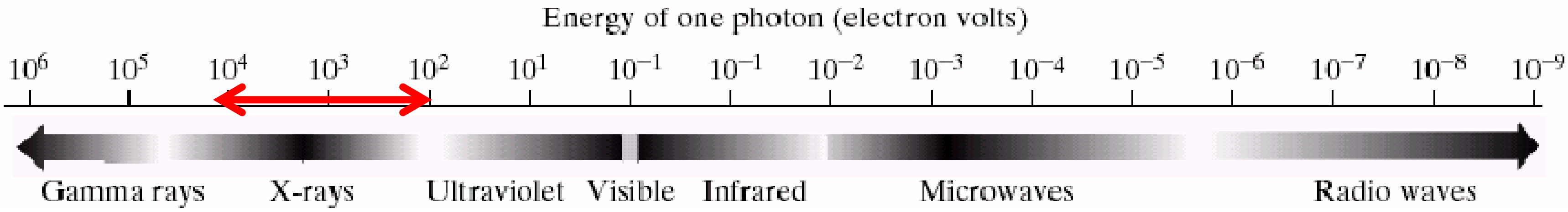


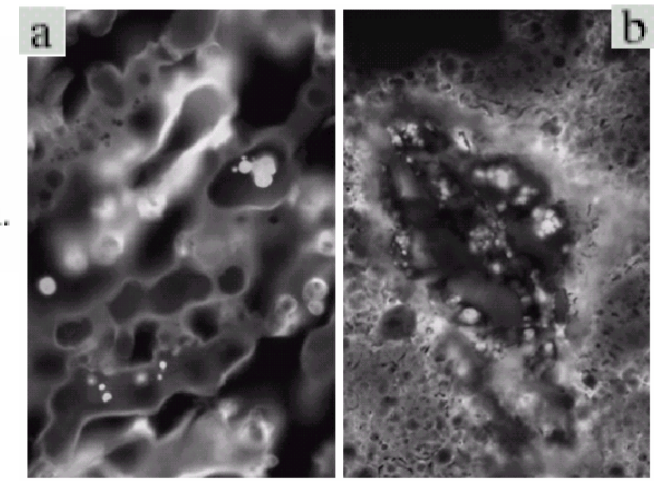
FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, (d) Mr. Joseph E. Pascente, Lixi, Inc., and (e) NASA.)

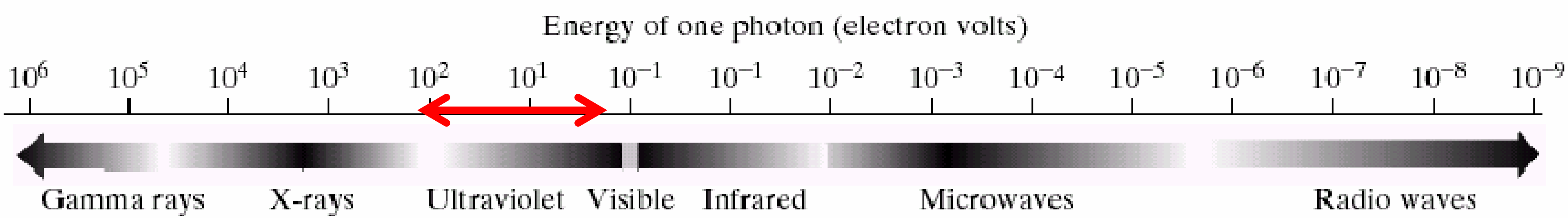


Ultraviolet Imaging

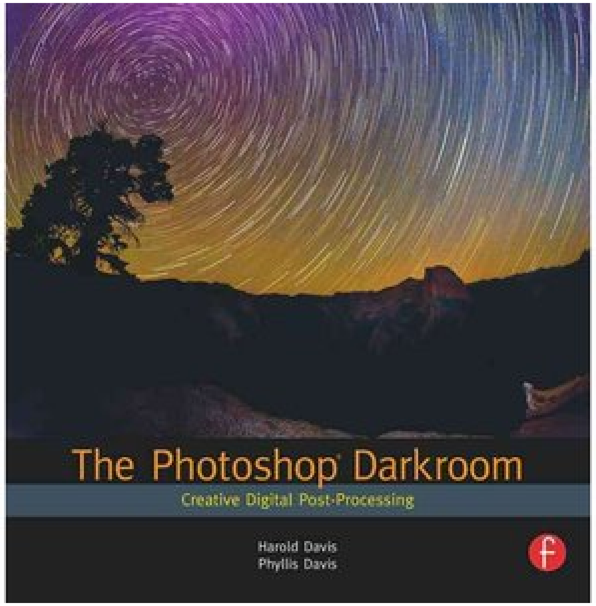
- Used for
  - lithography
  - industrial inspection
  - biological imaging
  - astronomy
  - lasers
  - flourescence microscopy
    - Shown to the right
    - Photon of UV light collides with electron of fluorescent material to elevate its energy
    - As energy falls it emits red light

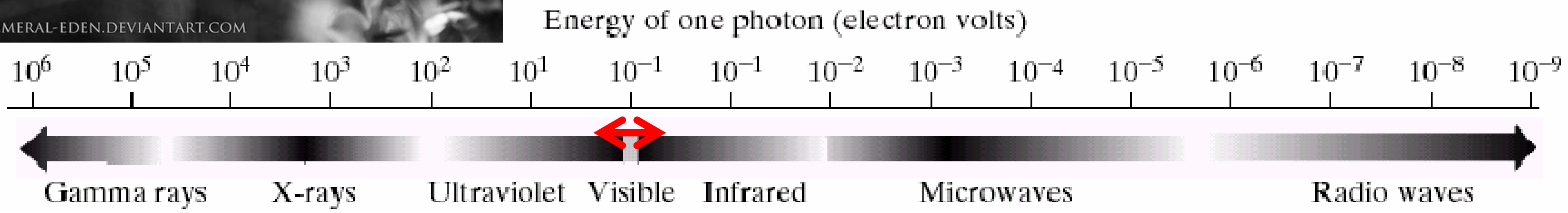
FIGURE 1.8 Examples of ultraviolet imaging. (a) Normal corn. (b) Smut corn. (Images courtesy of (a) and (b) Dr. Michael W. Davidson, Florida State University.)



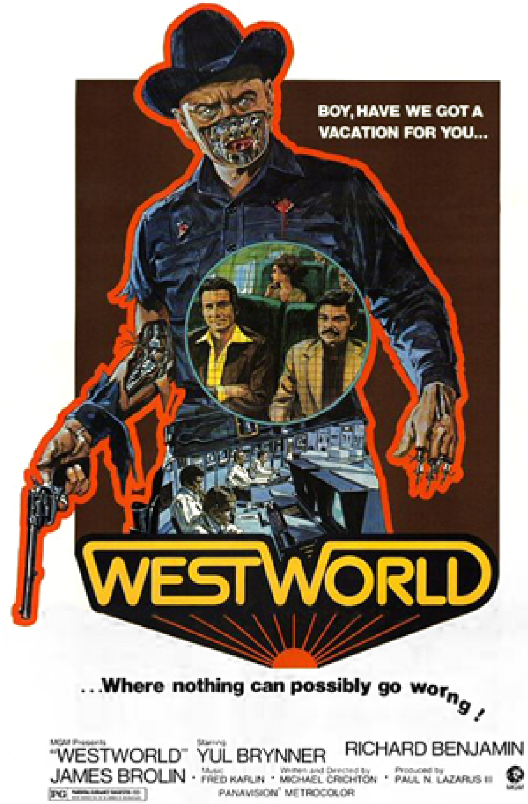


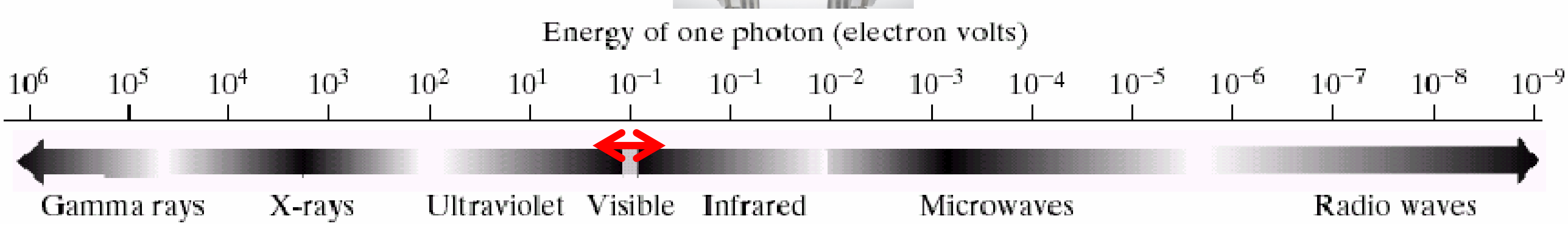
Visible Imaging: Photography



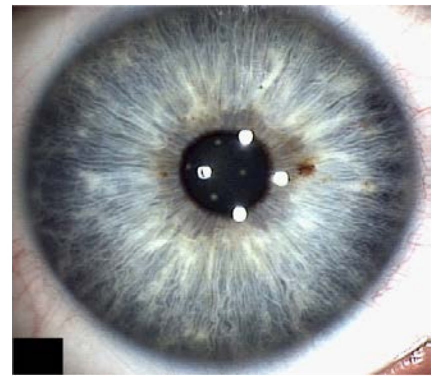


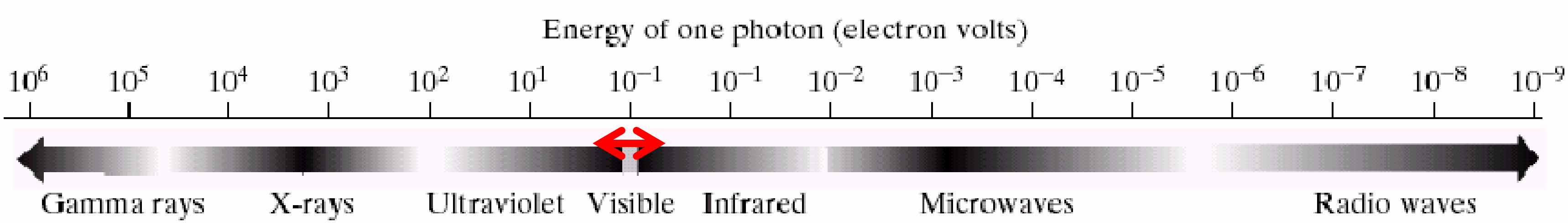
Visible Imaging: Motion Pictures



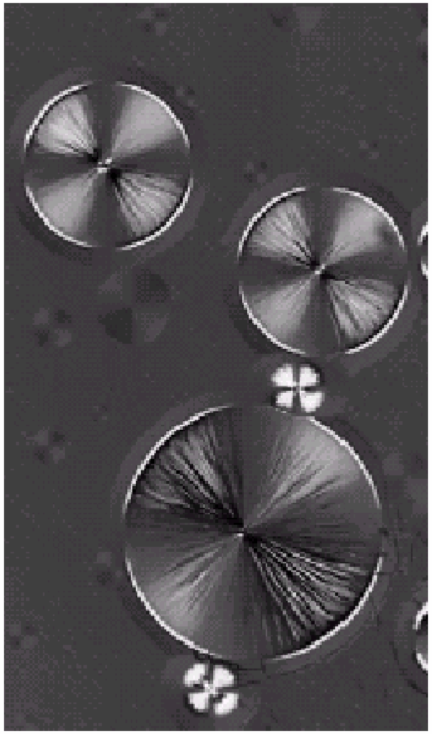


Visible Imaging: Biometrics & Forensics

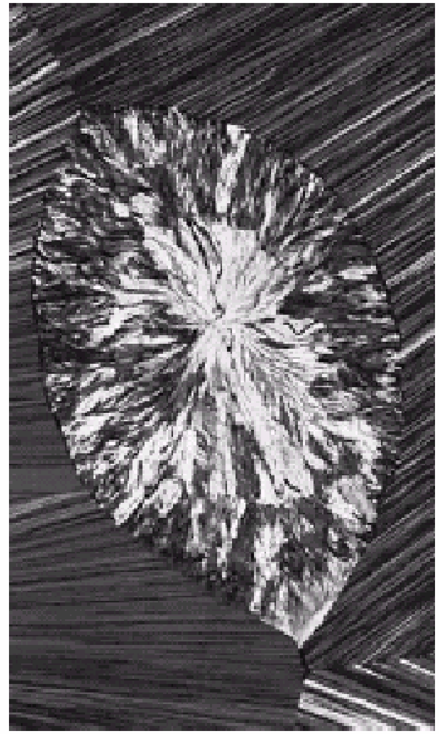




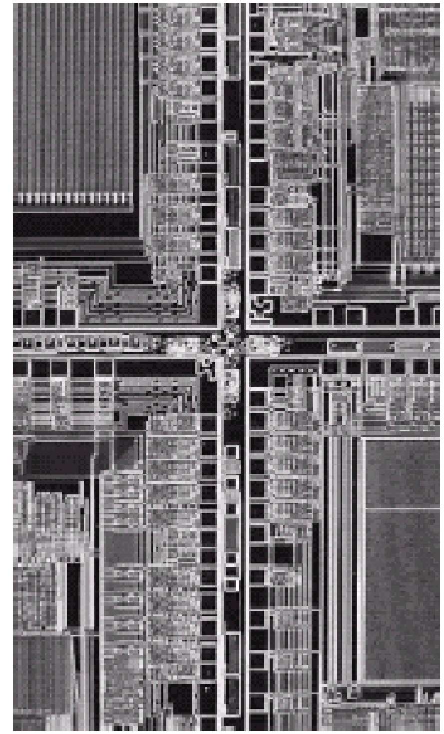
Visible Imaging: Light Microscopy



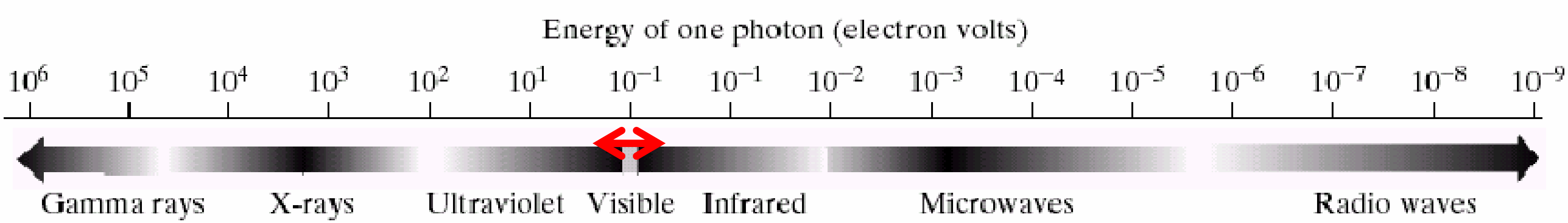
Taxol (250x)



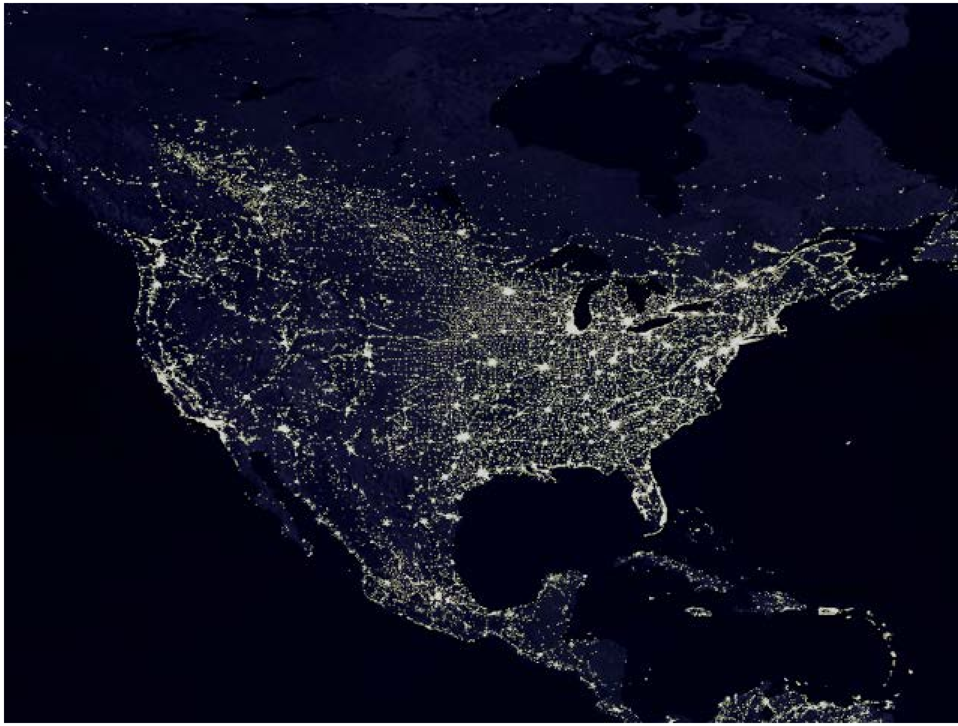
Cholesterol (40x)



Microprocessor (60x)



Visible Imaging: Remote Sensing



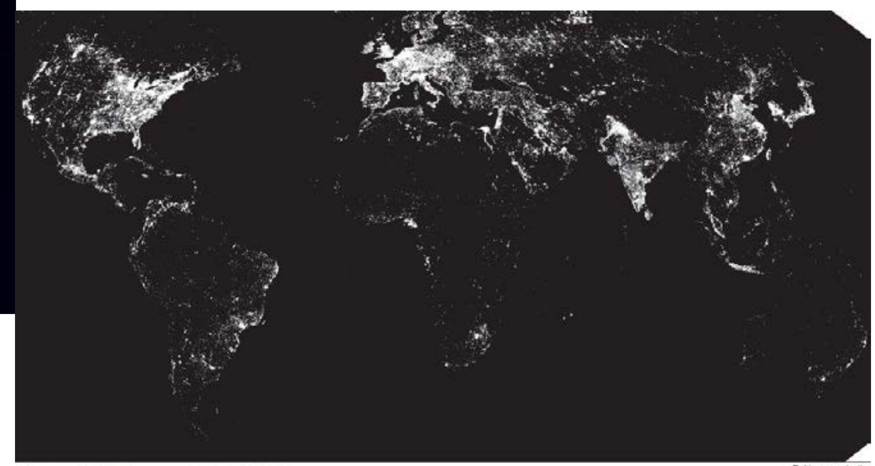
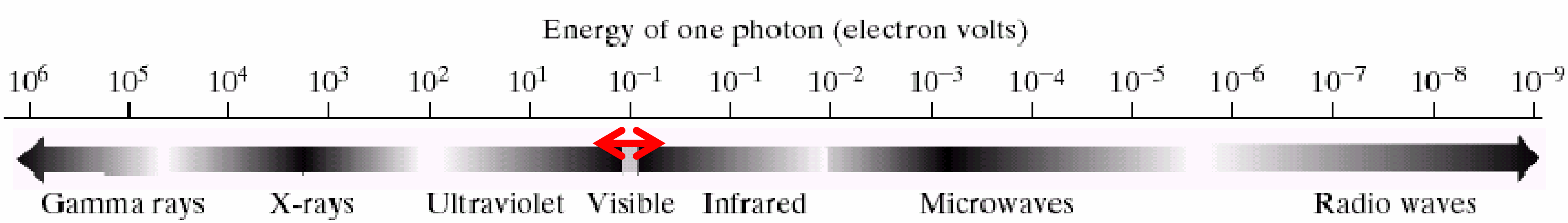


Figure 1: Lights at night, 2008



Infrared (thermal) Imaging

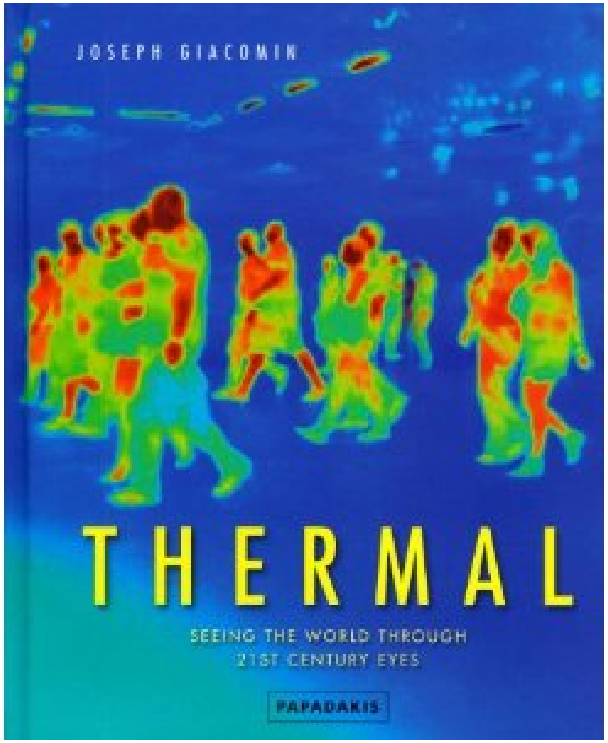
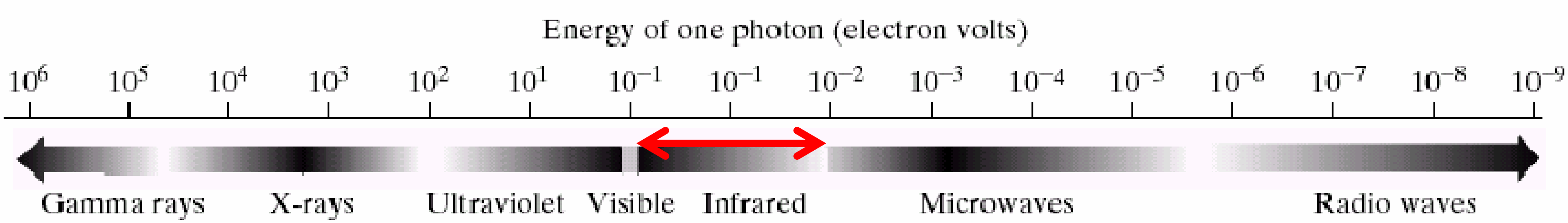


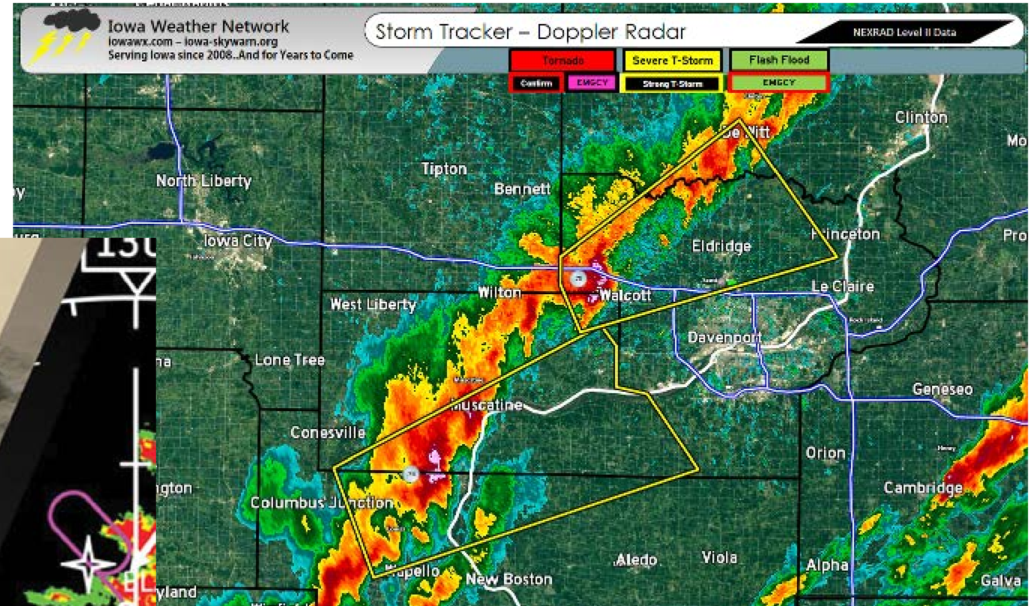
TABLE 1.1 Thematic bands in NASA's LANDSAT satellite.

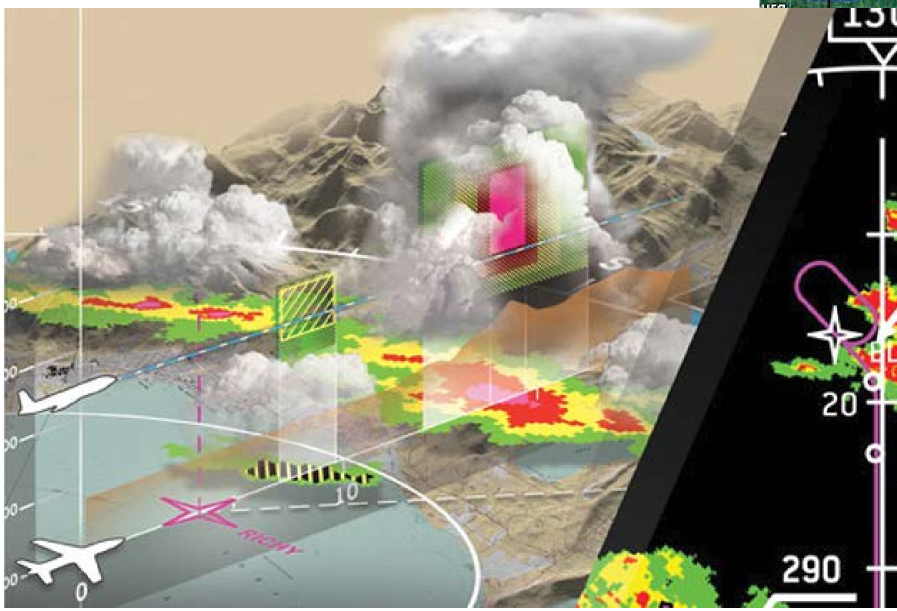
Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

Rhett Allain
http://www.wired.com/2014/10/seek-thermal-infrared-camera-iphone-android/

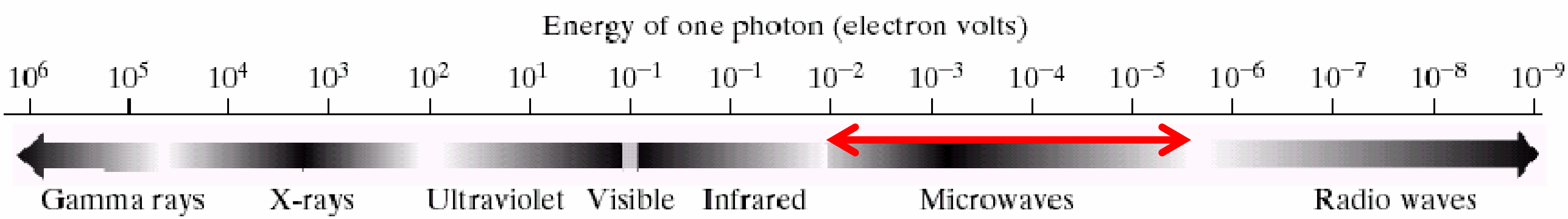


Microwave Imaging: Radar

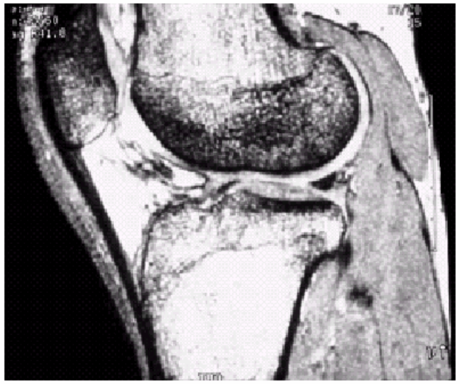


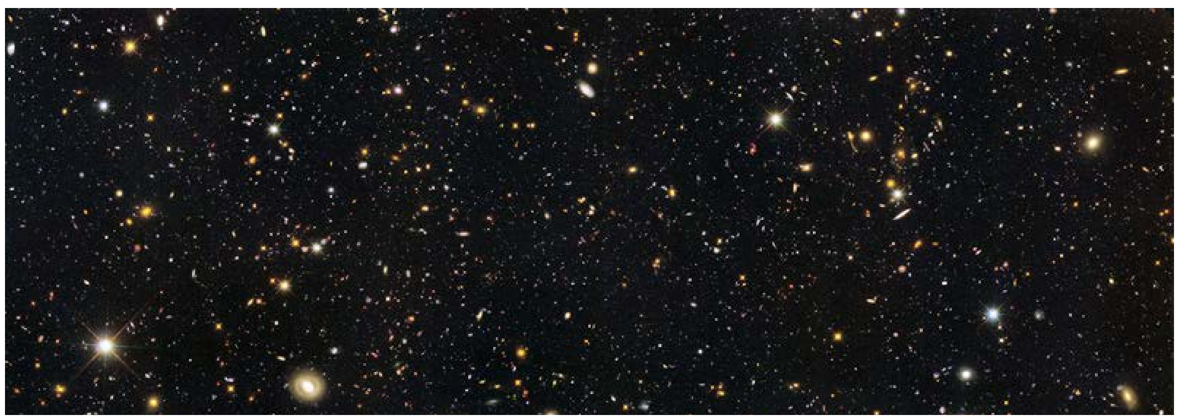


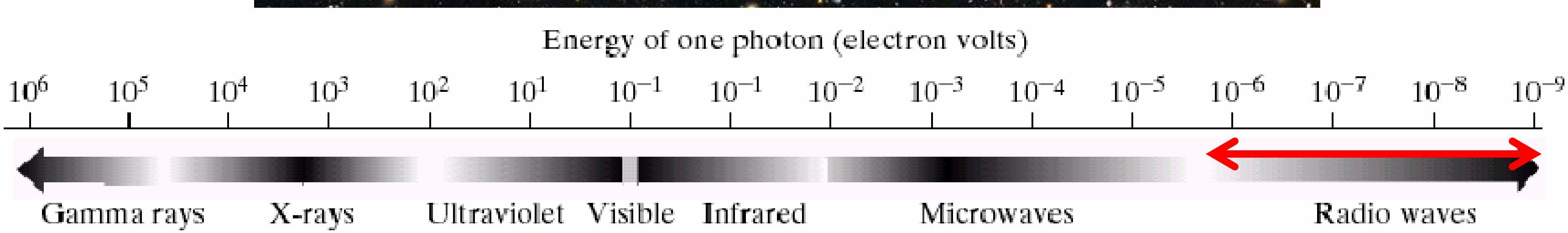
Rockwell Collins: Weather Radar Threat Tracking System



Radio Wave Imaging: MRI and Astronomy

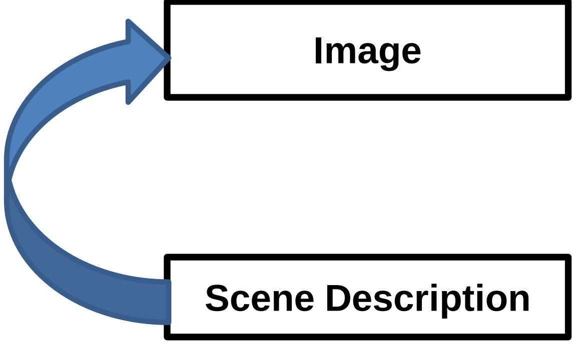






Non-EM Imaging Sources

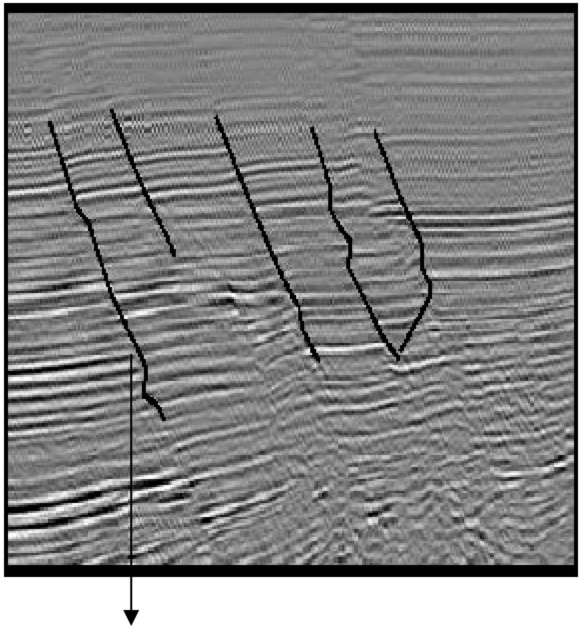
- Acoustic Imaging
  - Translate sound waves into image signals
    - Ultrasounds, Seismic…
- Electron Microscopy
  - Shine a beam of electrons through specimen
- Synthetic Images in Computer Graphics
  - Computer generated
    - Non-existent in the real world
    - Graphics, Games, Digital Art…



Acoustic Imaging

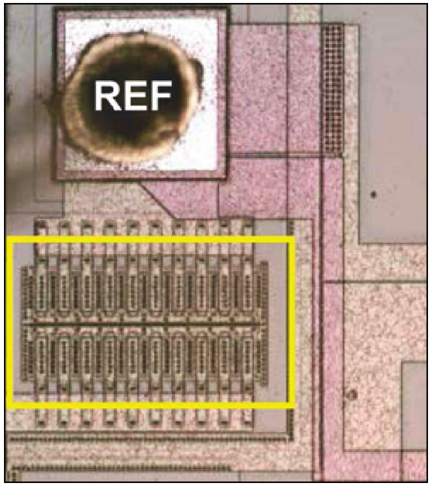
visible

seismic

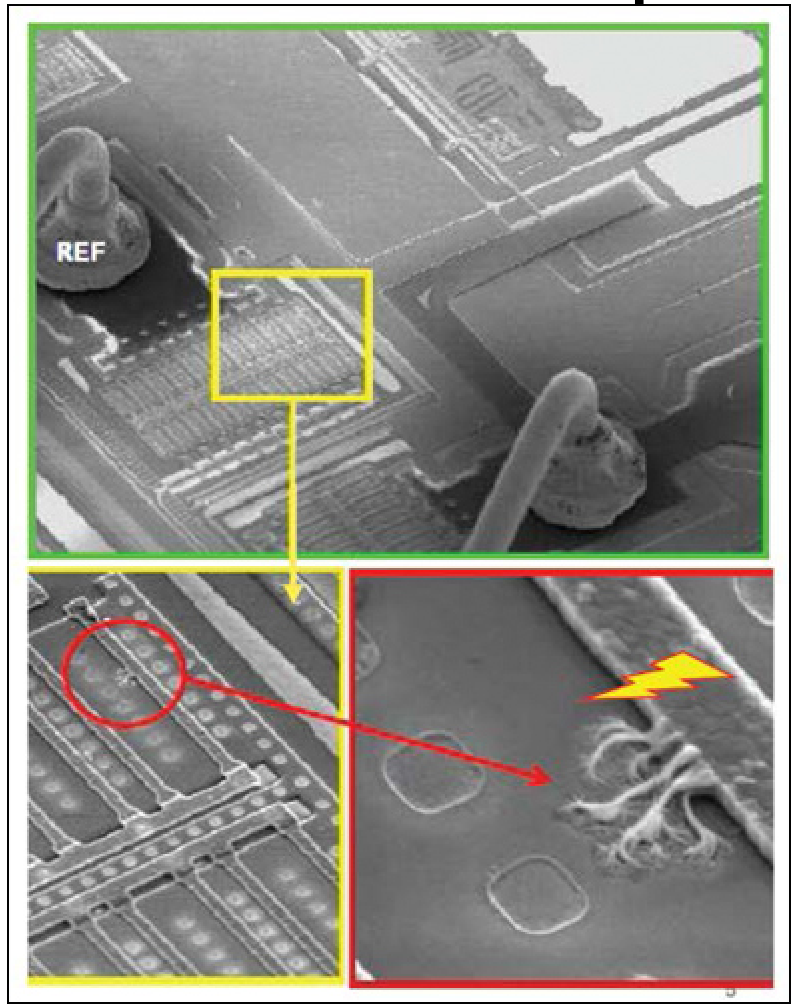


potential locations of oil/gas

Electron Microscope



visible image



Same circuit under electron microscope
Shows damage from electrical overstress

Images from: http://www.maximintegrated.com/en/app-notes/index.mvp/id/4491

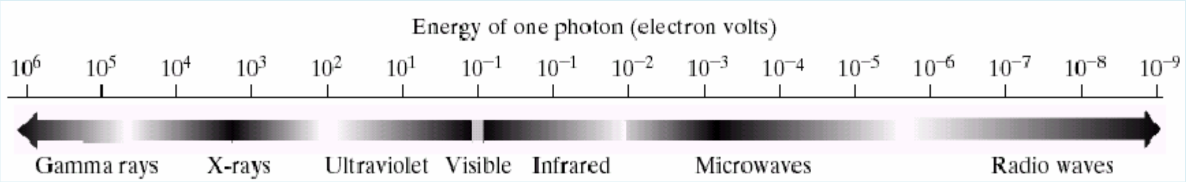
Cartoon Images

3. Scoobert Doo

Images from Video Games

Summary: Acquisition & Generation

- Sources
  - Electromagnetic (EM) spectrums



  - Acoustic Imaging
    - EX: Ultrasounds, Seismic Imaging…
  - Electron Microscopy
  - Synthetic Images
    - Computer Generated
      - Graphics, Games, Digital Art…

So Far

Image Acquisition

Image Generation

Image Compression

Image Manipulation

Image Analysis

Image Display

Image Perception

Moving On

Image Acquisition

Image Generation

Image Compression

Image Manipulation

Image Analysis

Now Onto These

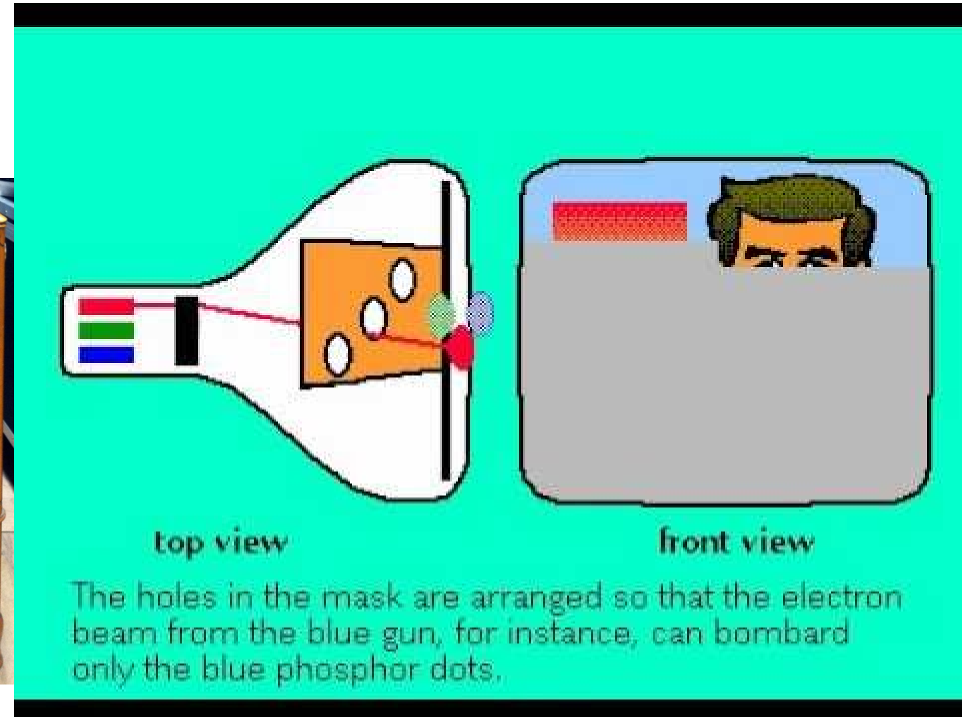
Image Display

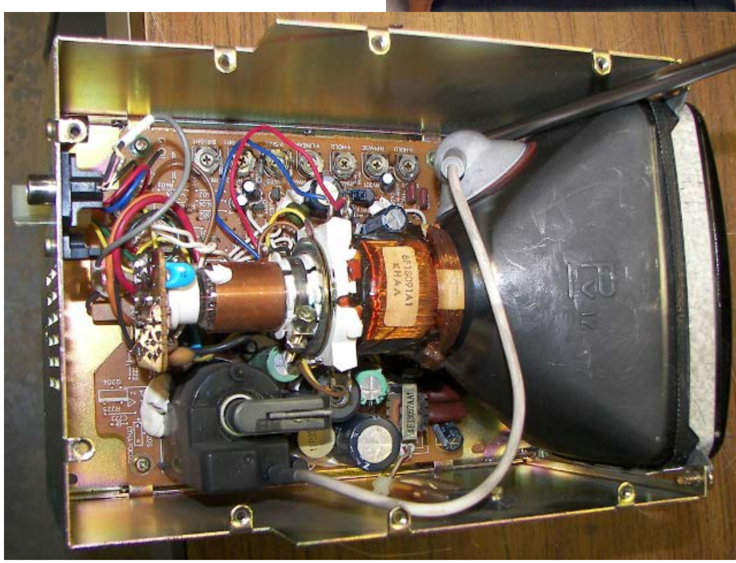
Image Perception

Image Display

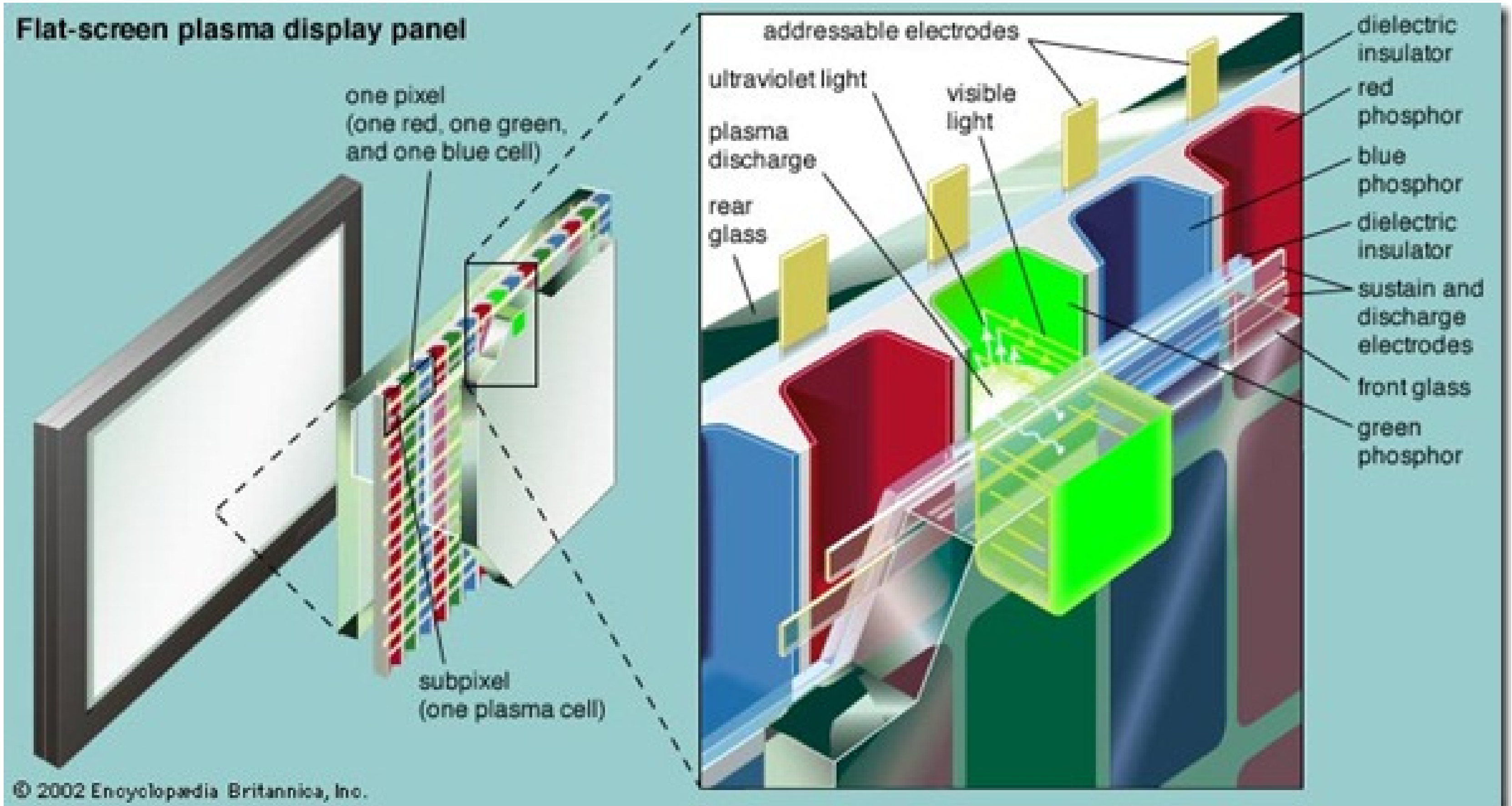
- Many types of display devices
  - For Digital Images
    - CRT, Plasma, LCD, LED…
    - HDTV, display wall…
    - Tablet, Cell phone, Gameboy…
    - Stereoscopic 3D

CRT Monitors and TVs





Plasma TVs

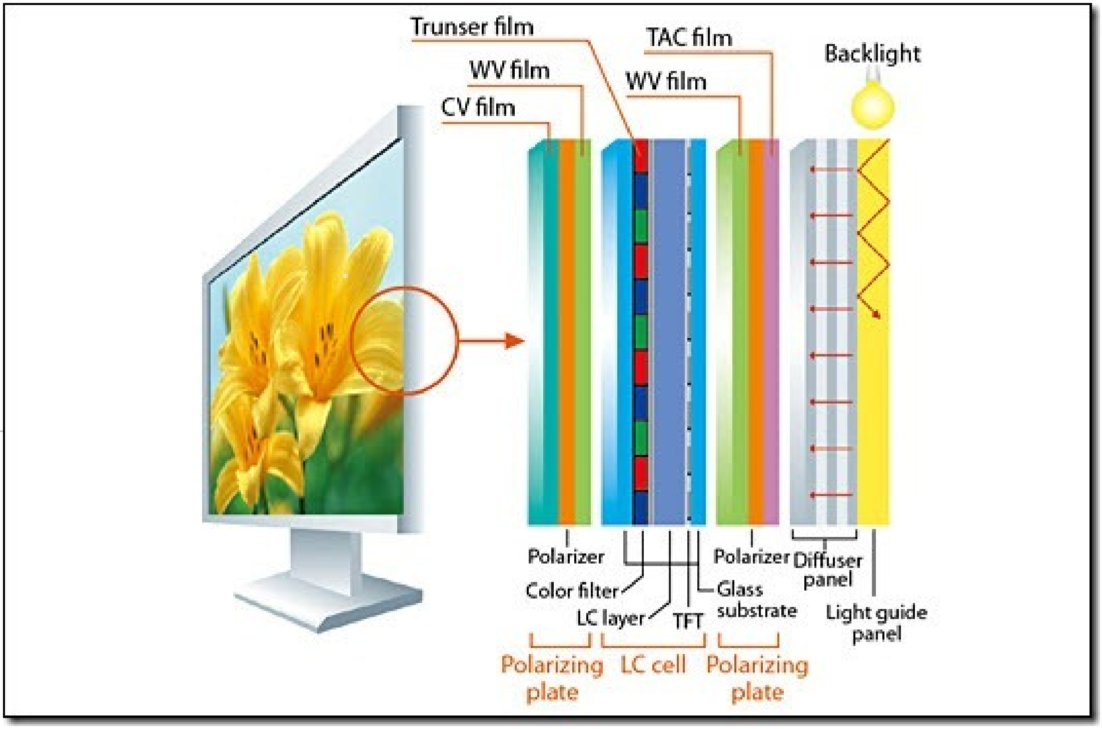


- Array of light emitting gas cells sandwiched between 2 glass sheets
  - Requires a glass panel, but no “external” light source

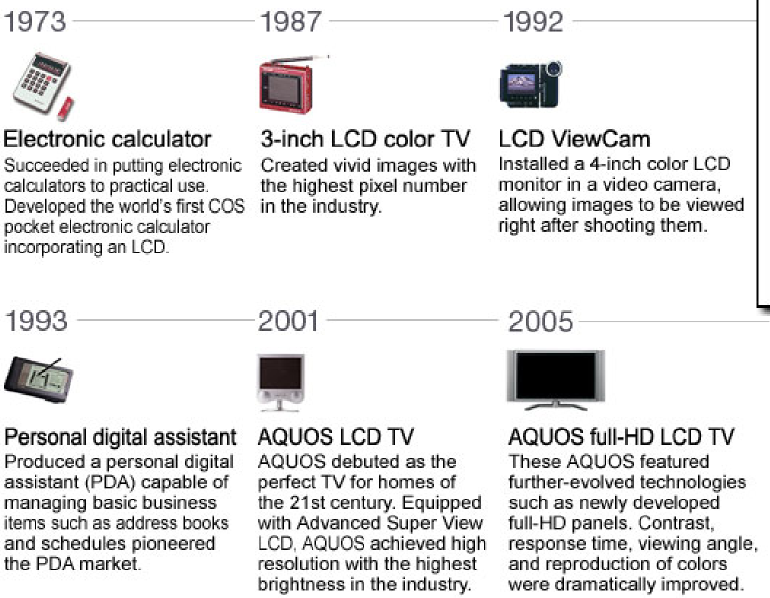
http://www.guidingtech.com/26940/led-lcd-plasma-difference/

LCD: Liquid Crystal Display

http://mybroadband.co.za/news/gadgets/59323-cool-tech-deals-this-weekend-4.html/attachment/lg-32-inch-full-hd-lcd-tv



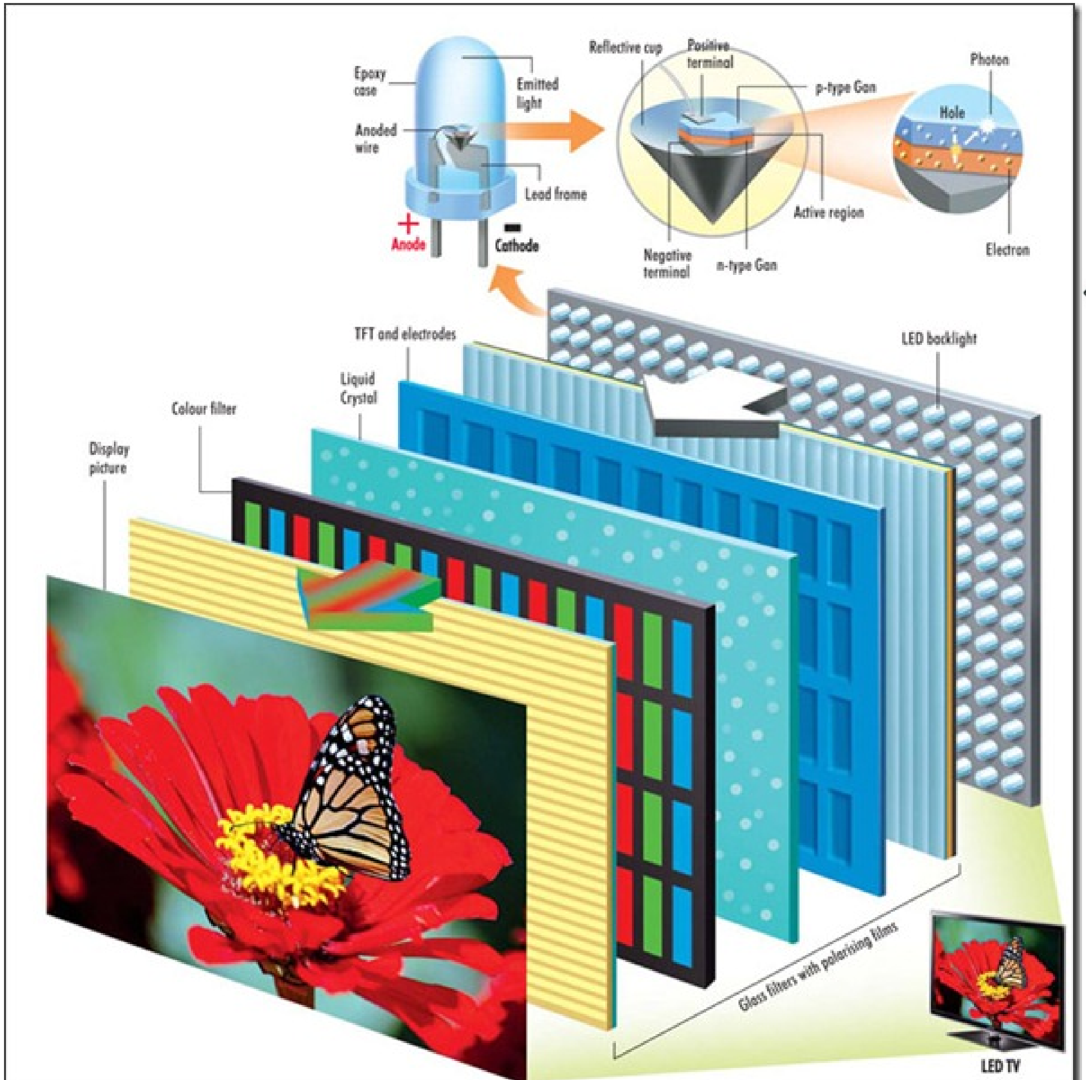
http://www.guidingtech.com/26940/led-lcd-plasma-difference/



Sharp's History of LCD development

http://www.sharp.net.au/articles/lcd-televisions/why-sharp-lcd-tv/

LED: Light Emitting Diode



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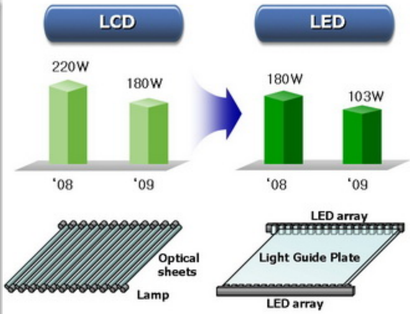


LED TVs draw much lower current than LCD TVs,

thus resulting in lower power consumption

https://commons.wikimedia.org/wiki/

Transparent LCD

Hisense: Transparent 3D TV, 2013

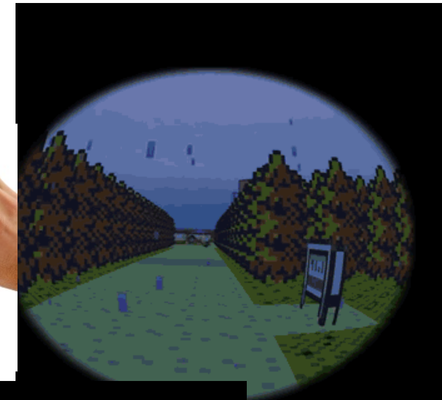
http://www.bbc.com/news/technology-20957845

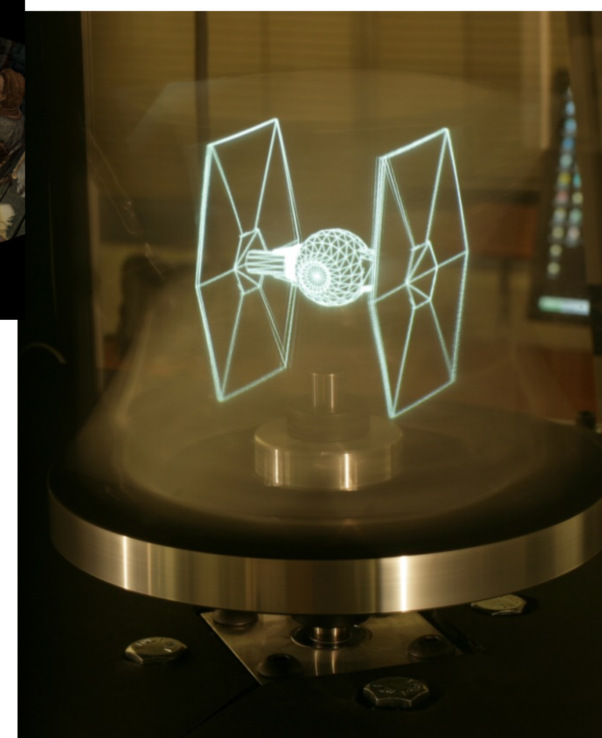
http://www.applianceretailer.com.au/2013/01/kvvntjtalp/#.VcJkgPmXoXE

Samsung: Solar-Powered
LCD Transparent TV, March 2011

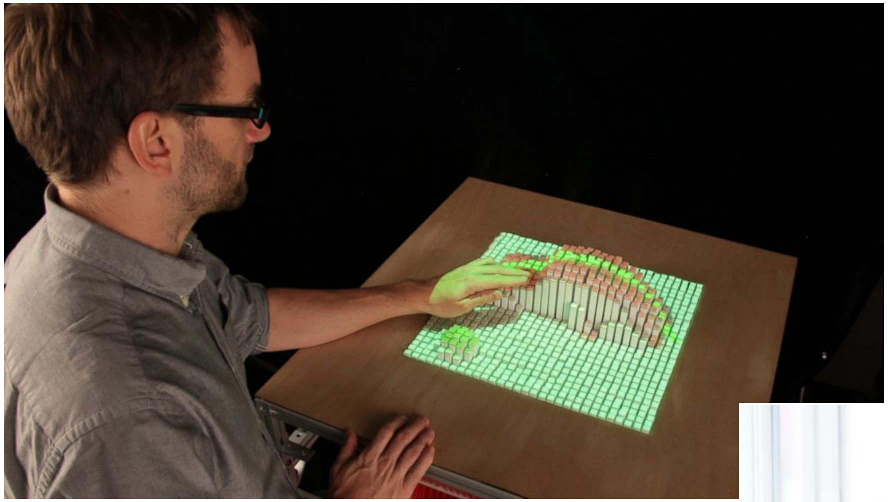
http://inhabitat.com/samsung-unveils-solar-powered-zero-energy-transparent-tv/

Various VR and 3D Displays





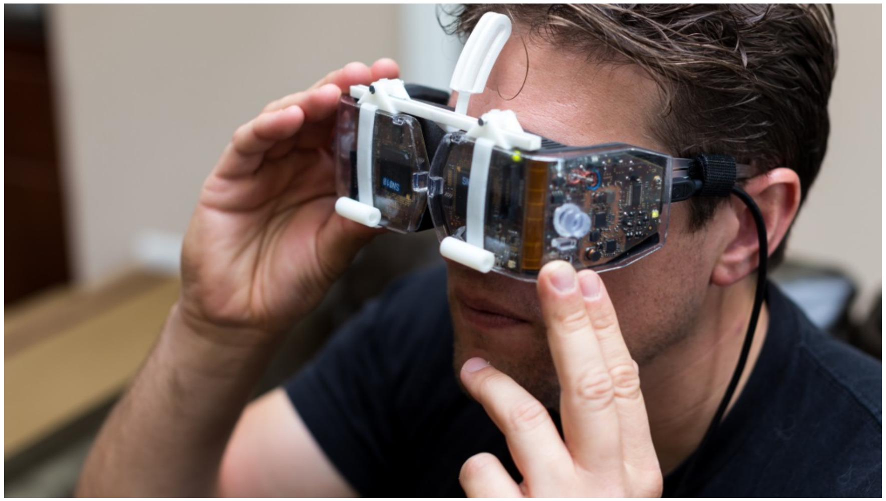
More VR and 3D



http://abcnews.go.com/Technology/3d-display-physically-touch/story?id=20891750

http://www.firestarters.nl/nl/detail/general_article/9x-haptische-technologie

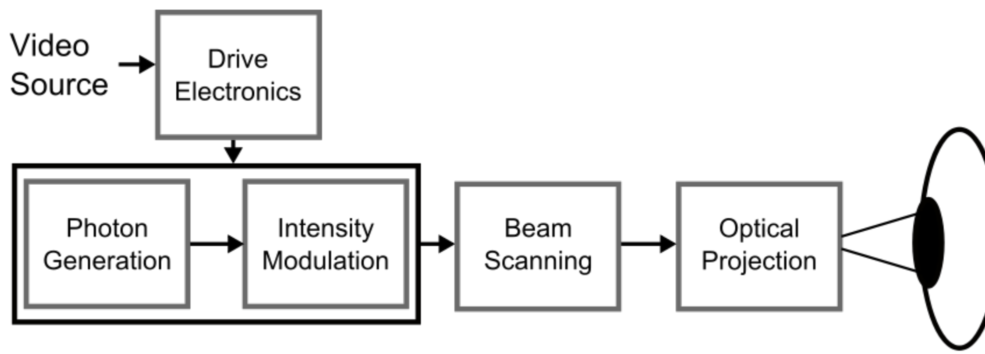
Virtual Retinal Display



http://www.tested.com/tech/459020-hands-avegants-virtual-retinal-display-prototype/

AIRScouter

http://vandrico.com/wearables/device/air-scouter



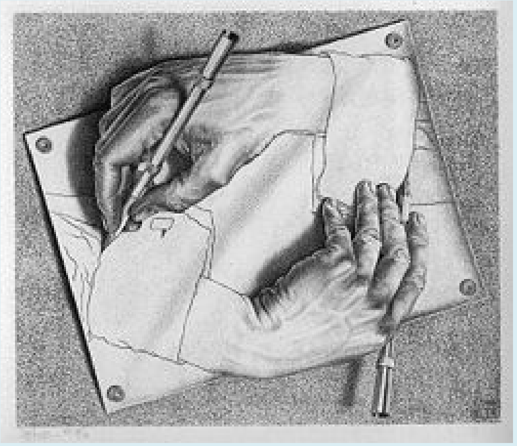
- Virtual Retinal Display
  - aka Retinal Scan Display or Retinal Projector
    - Draw a raster display directly on the retina of the eye

Images for the Blind

http://blitab.com/

Display Summary

- Many types of display devices
  - Each has unique features and requirements



- Digital Images
  must "appear correct"
  on all of these
  - Standards help
  - Yet
    - The same image may not inherently display correctly
    - Adjustments (image processing) may be required

- Human Perception adds complications

Perception and the Human Eye

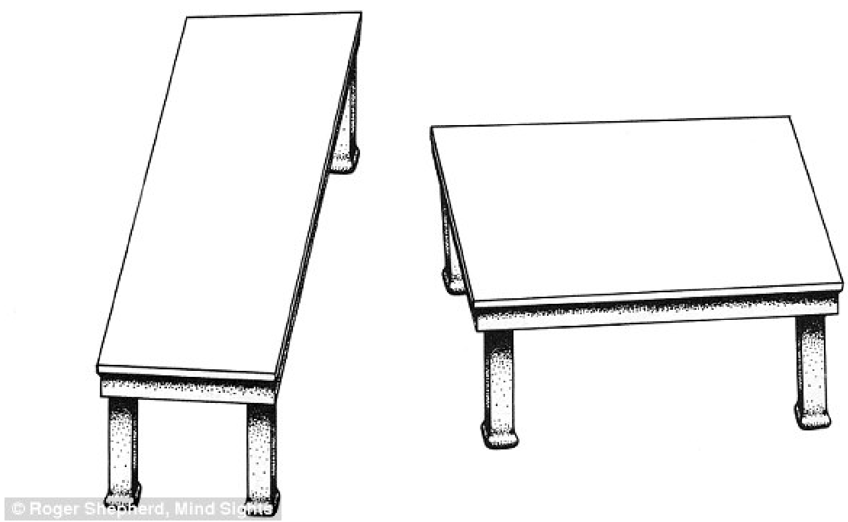
- We use our eyes to observe and evaluate images

- We should understand how our eyes work
  - What intensity differences can we distinguish?
  - What is the spatial resolution of our eye?
  - How accurately do we estimate length and area?
  - How do we sense colors?
  - By which features can we detect/distinguish objects?

- Gain in Understanding by Examining “oddities”

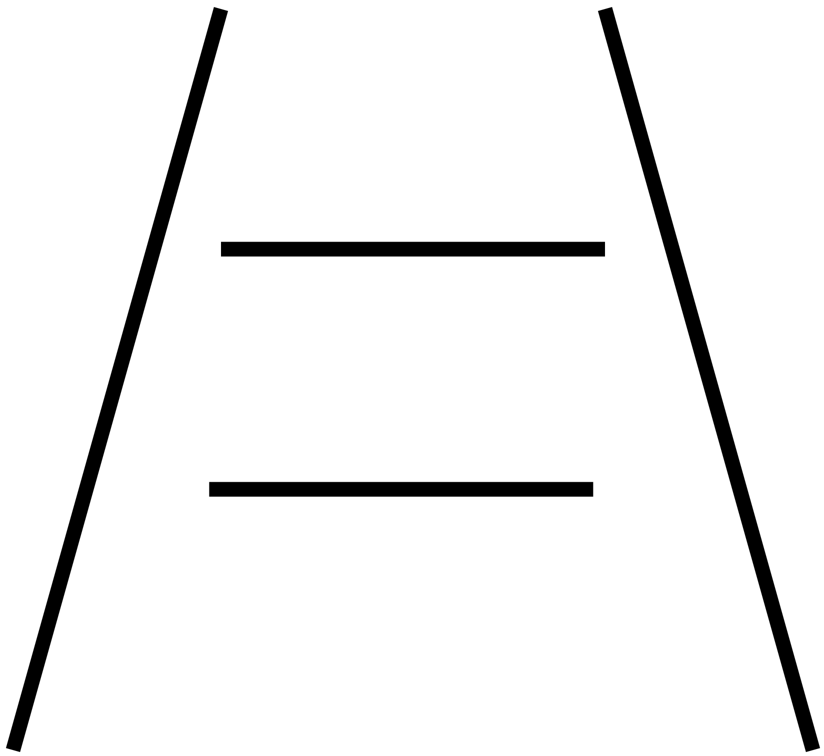
Comparative Length

- Same Length
  - Vertical may appear longer



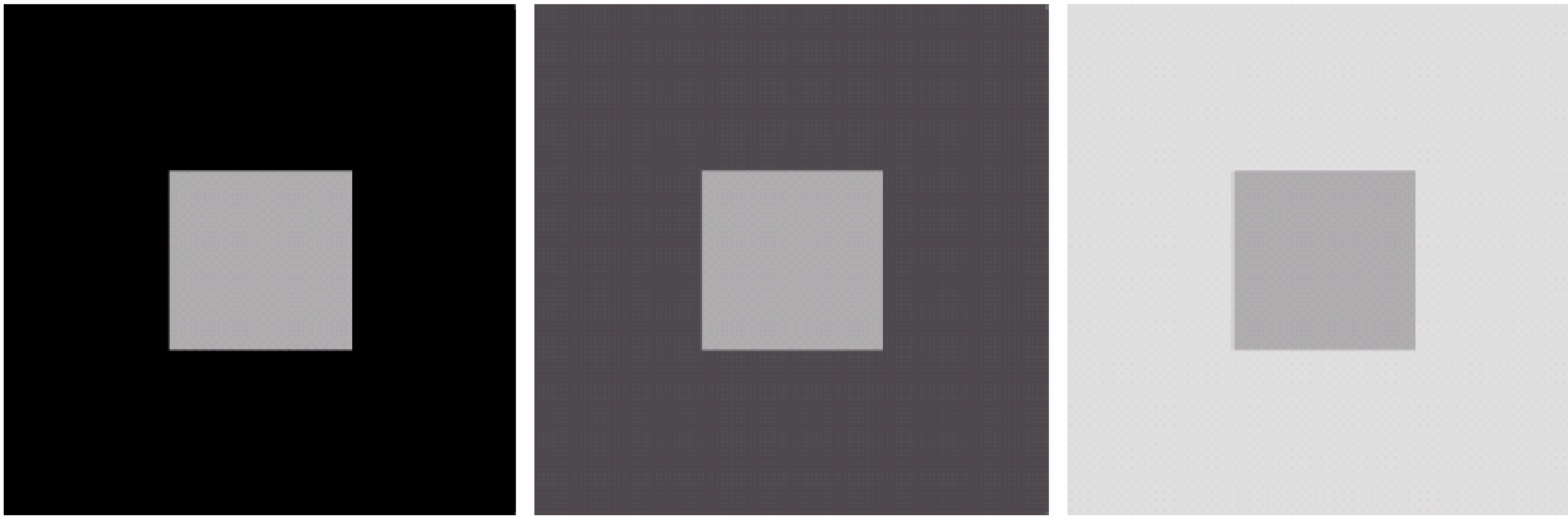
- Table tops are same size

Comparative Length 2

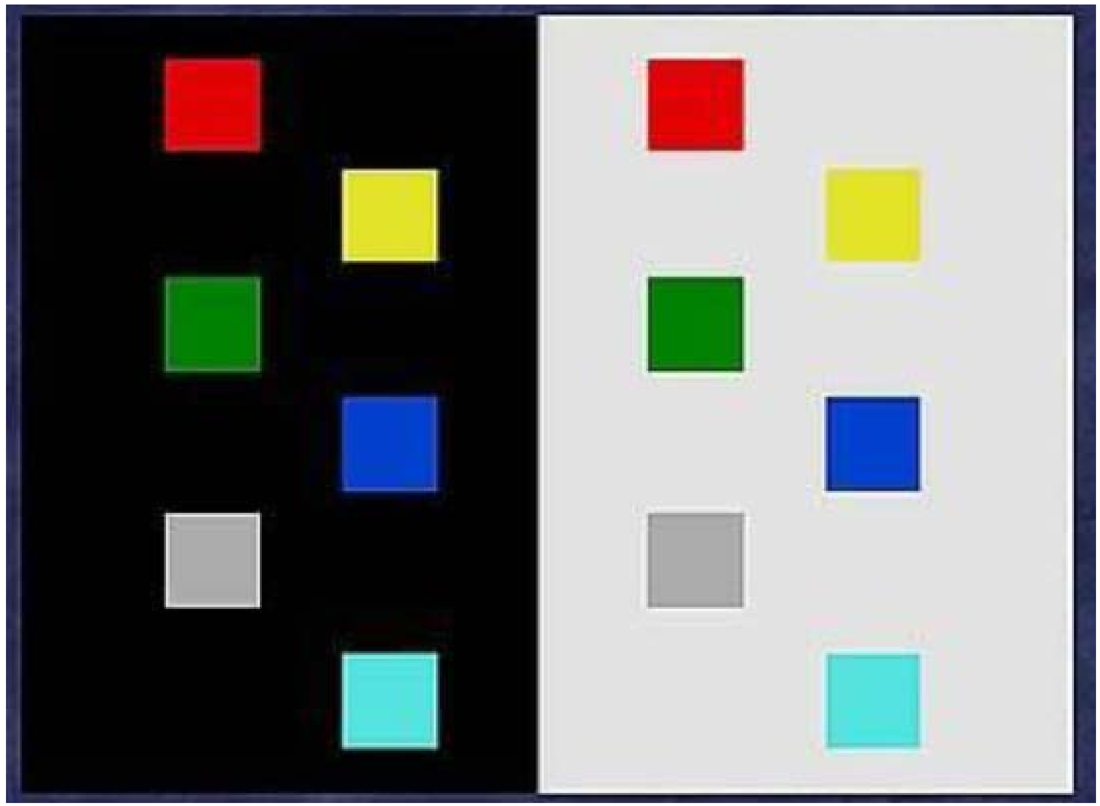


- Horizontal Lines are same length
  - Upper line may appear longer

Simultaneous Contrast: Light vs Dark



Similar Perception Errors in Color



Ambiguous Images

Duck or Rabbit?

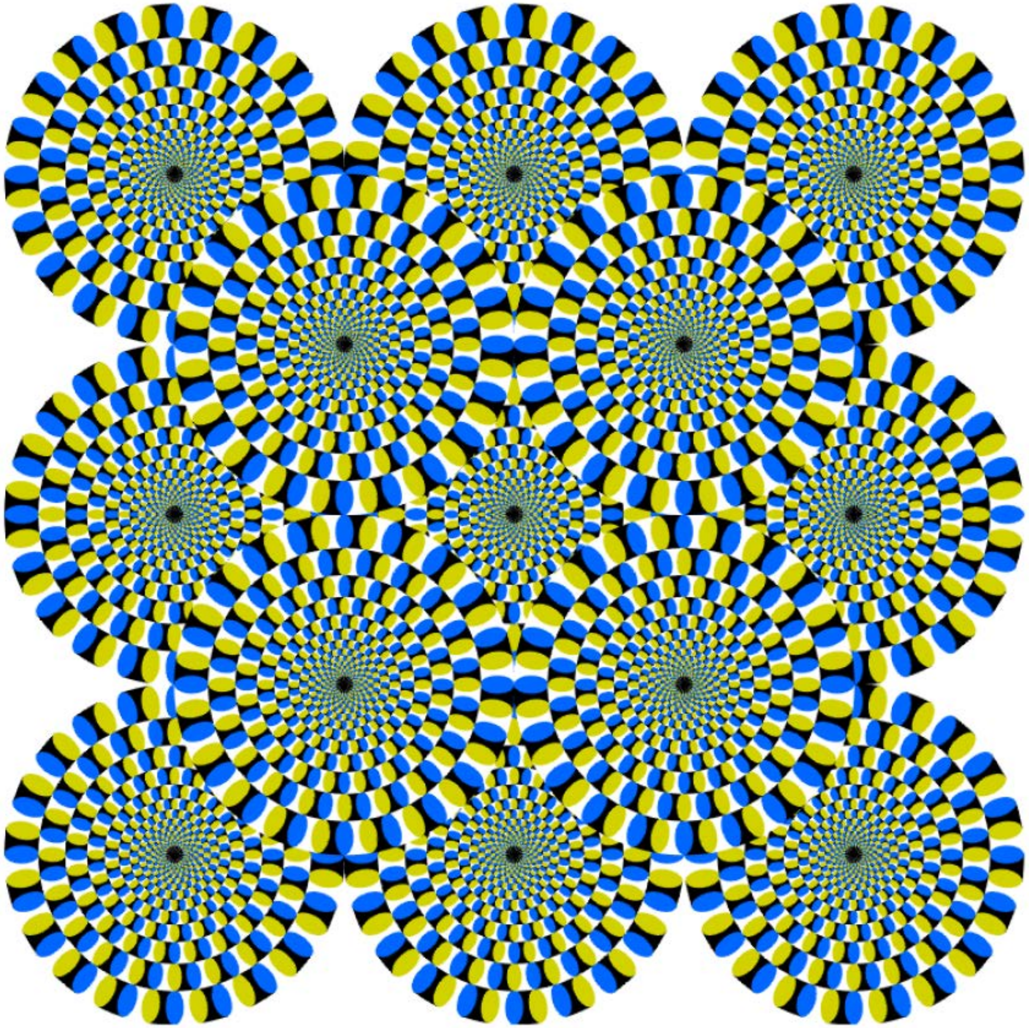
Seal or Donkey?

Thatcher

- Eyes and mouth are inverted
  - But you don’t notice when the entire image is upside down
    - because the mouth and eyes are “correct” then

Rotation Illusion

- Rotation occurs in relation to eye motion
- Effect stops if you fixate your eyes
- Rotation direction depends on polarity of the luminance steps
- Asymmetric luminance steps are required to trigger motion detectors
  - in eye/brain



Closer "Look"

- Why do these oddities occur?

- We have some ideas…

Human Perception

- **Human Eye**
- Lightness Perception
- Brightness
- Contrast
- Illusions

Human Eye

Image from:
http://webvision.med.utah.edu/anatomy.html

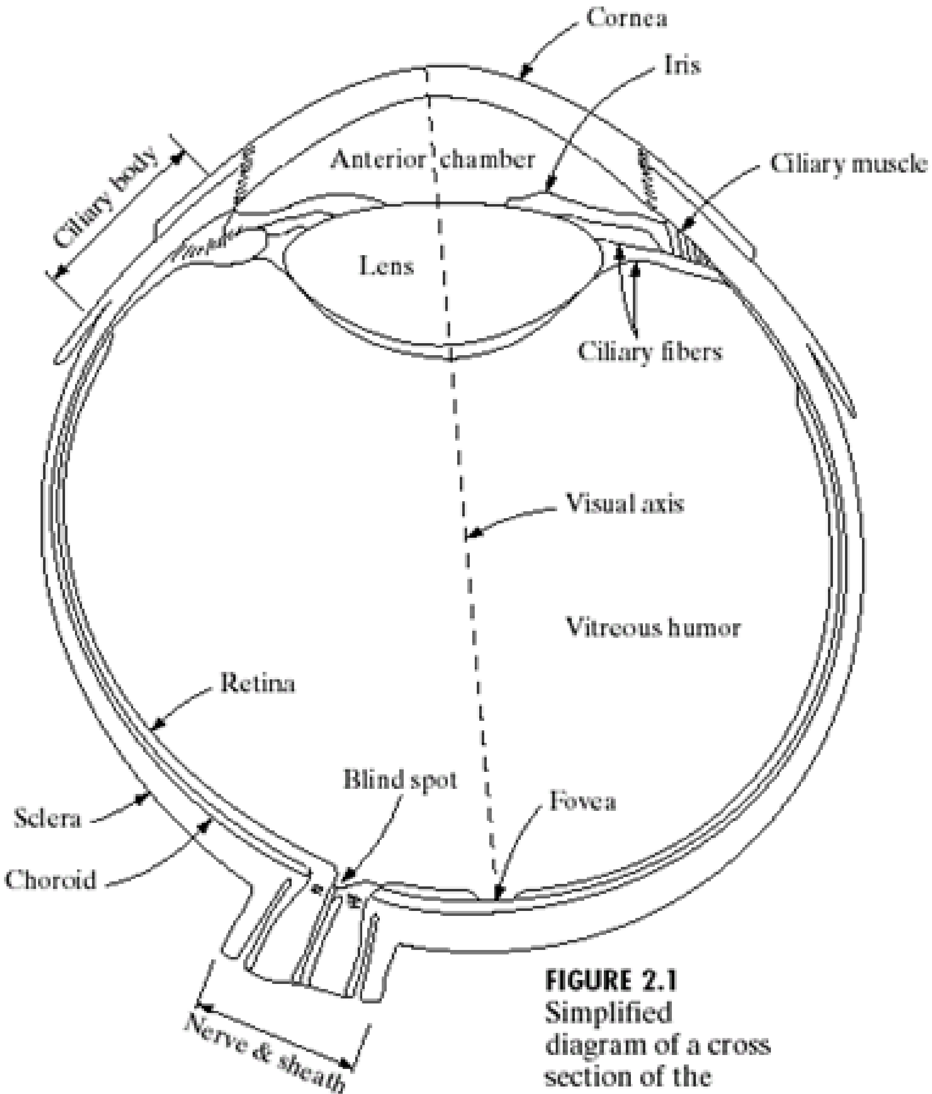
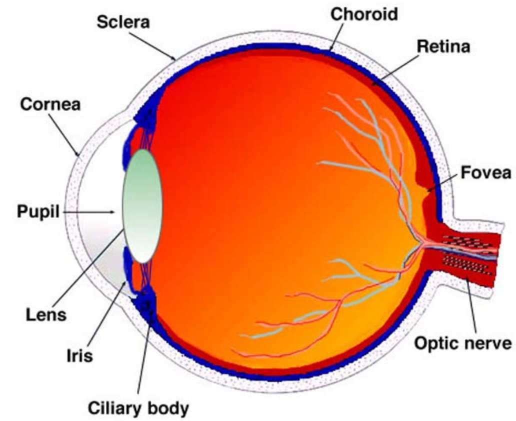


FIGURE 2.1 Simplified diagram of a cross section of the human eye.



Three membranes enclose the eye:
Cornea and sclera, Choroid, Retina

ciliary body

iris diaphragm

Pupil size: 2-8mm

Eye color: melanin (pigment) in iris

Retina

- When the eye is properly focused, light from an outside object is imaged on the retina

- **Two** classes of **receptors** are located over the surface of retina: cones and rods
  - **Cone**: 6-7 million in each eye, central part of retina (fovea) and highly sensitive to **color**
  - **Rod**: 75-150 million, all over the retina surface and sensitive to low levels of **illumination**

Rods and Cones

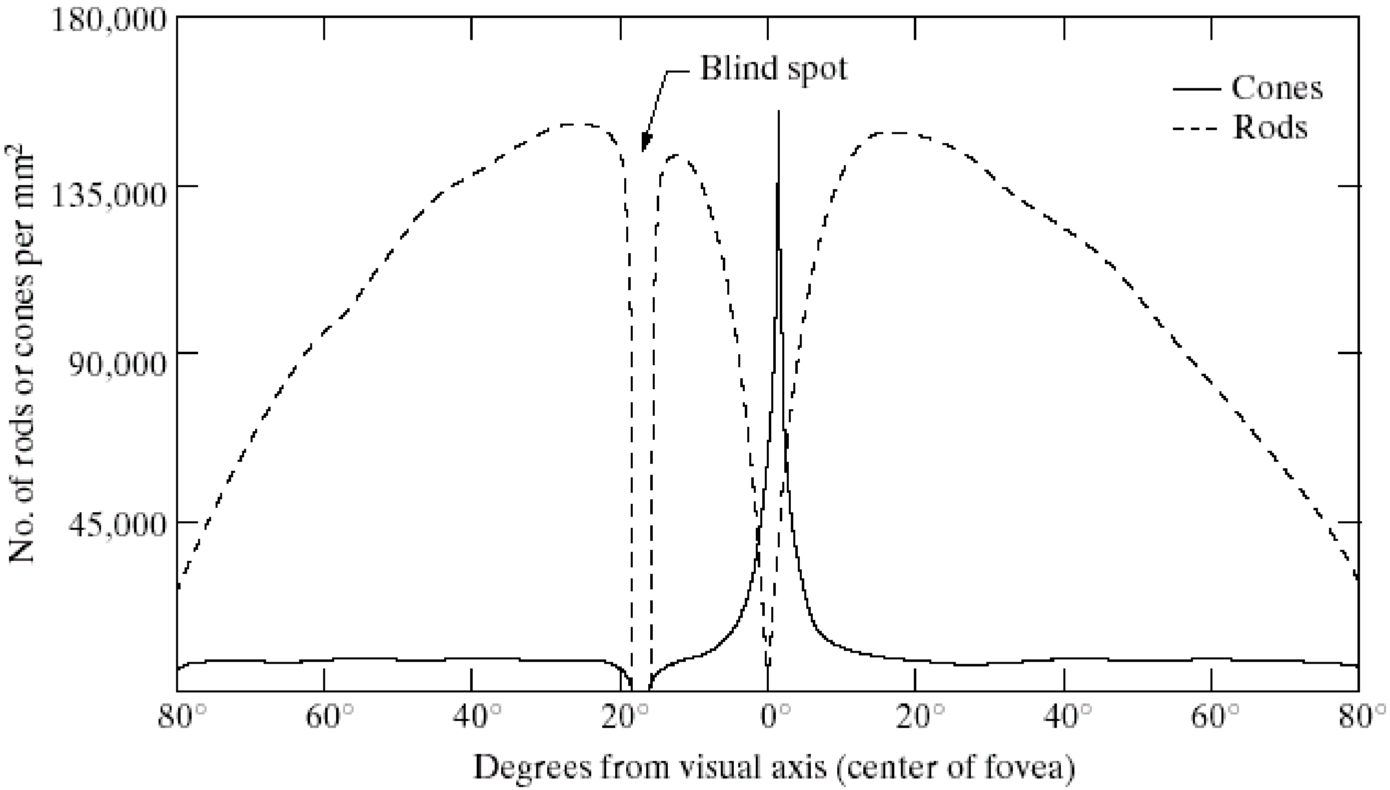
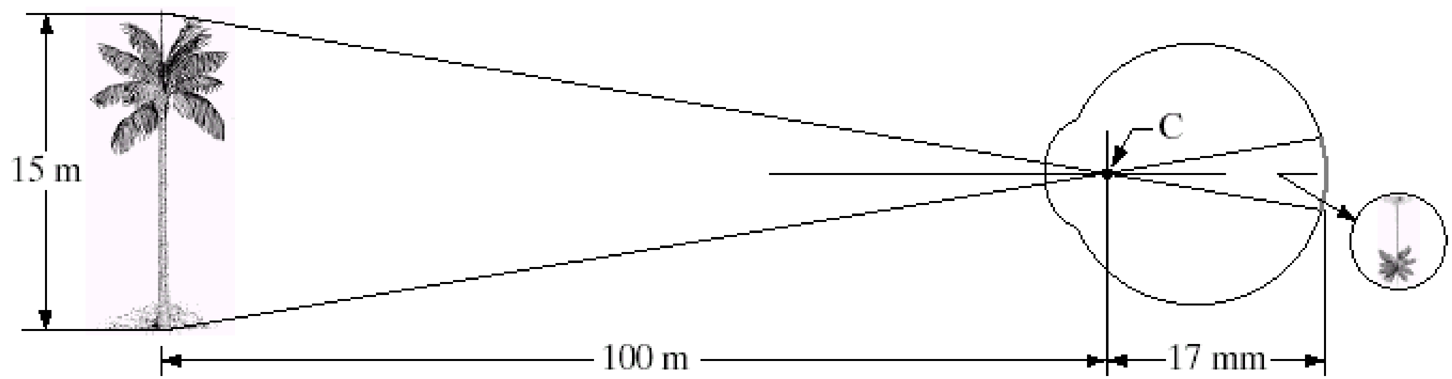


FIGURE 2.2 Distribution of rods and cones in the retina.

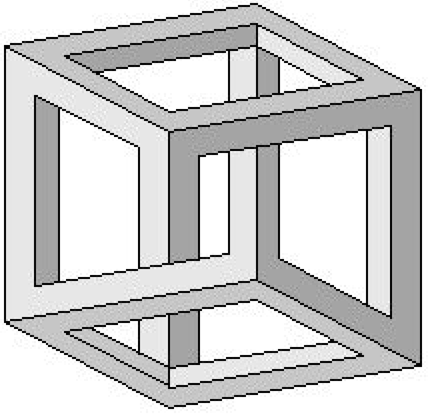
Image Formation in the Eye

FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.



Human Perception

- Human Eye
- **Lightness Perception**
- Brightness
- Contrast
- Illusions



Perception of Lightness

- *Luminance* is the amount of visible light that comes to the eye from a surface

- ***Illuminance*** is the amount of light incident on a surface

- ***Reflectance*** is the proportion of incident light that is reflected from a surface
  - Varies from 0% to 100%
    - 0% is ideal black
    - 100% is ideal white.
    - In practice,
      average black paint is about 5% and average white paint about 85%.

Math: Image Formation Model

- Image Formation Model

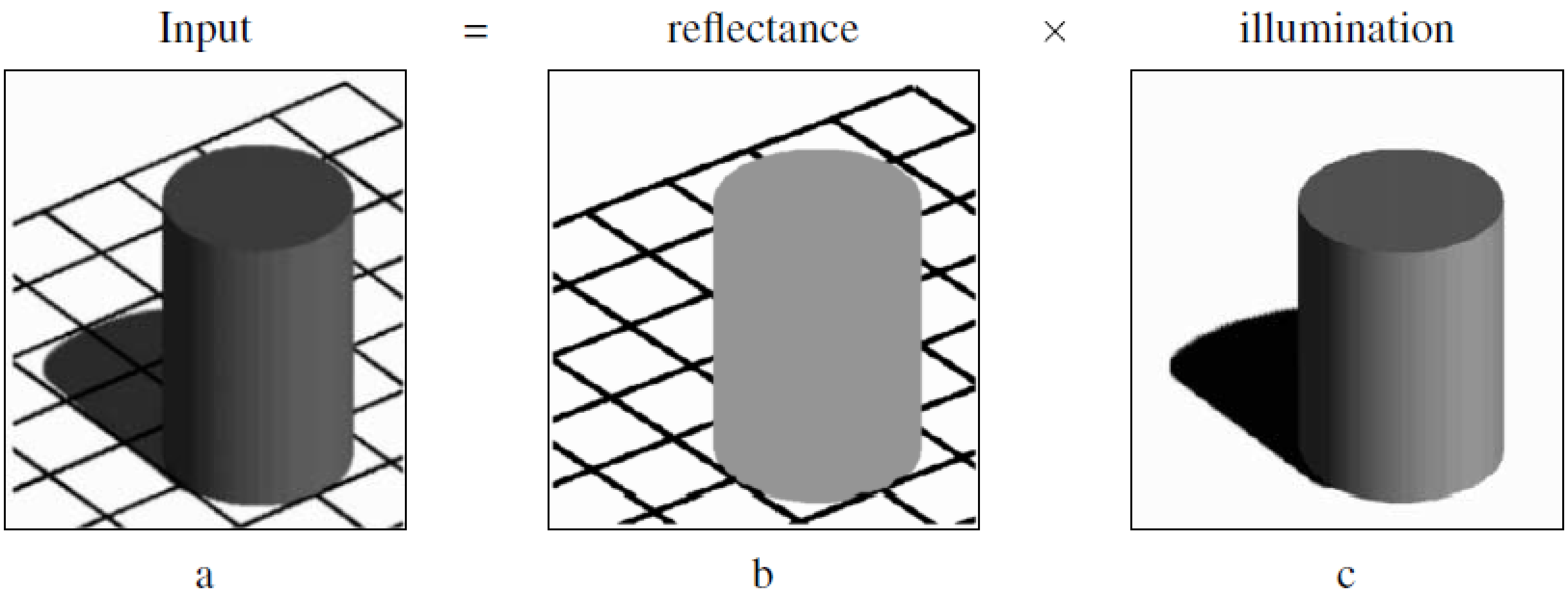
$$f(x,y) = i(x,y) * r(x,y) + n(x, y)$$

$f(x, y)$	$0 < f(x, y) < \infty$	***Intensity*** which is proportional to the energy radiated by a physical source
$i(x, y)$	$0 < i(x, y) < \infty$	***illumination*** is amount of source illumination incident on the scene being viewed
$r(x, y)$	$0 < r(x, y) < 1$	***reflectance*** is the amount of illumination reflected by objects in the scene
$n(x, y)$		***noise*** is various measurement errors

nature of $i(x, y)$ is determined by the illumination source (light source)

nature of $r(x, y)$ is determined by the object(s) in the scene

Formation Model: Example



f(x,y)

r(x,y)

object props

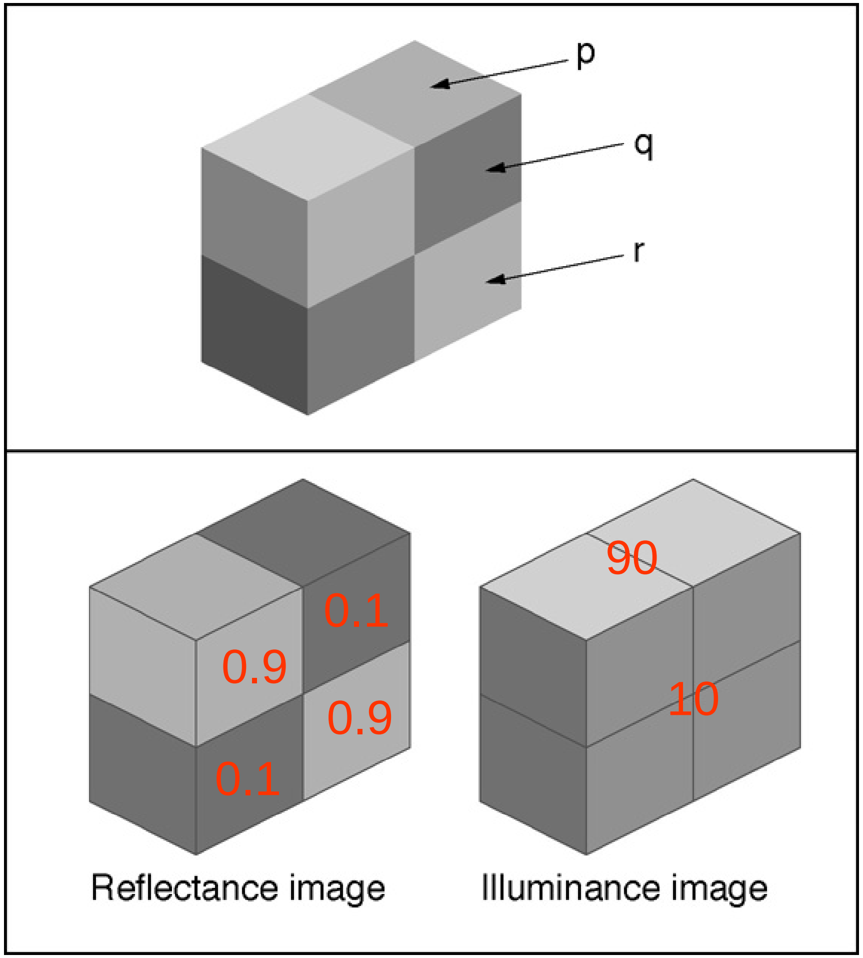
i(x,y)

lighting props

Question:
How to separate r(x,y) and i(x,y) from f(x,y)?
For Answer: Google "intrinsic images"

Images from: *Deriving intrinsic images from image sequences*, Yair Weiss, 2001

Illustration: Checker-Block

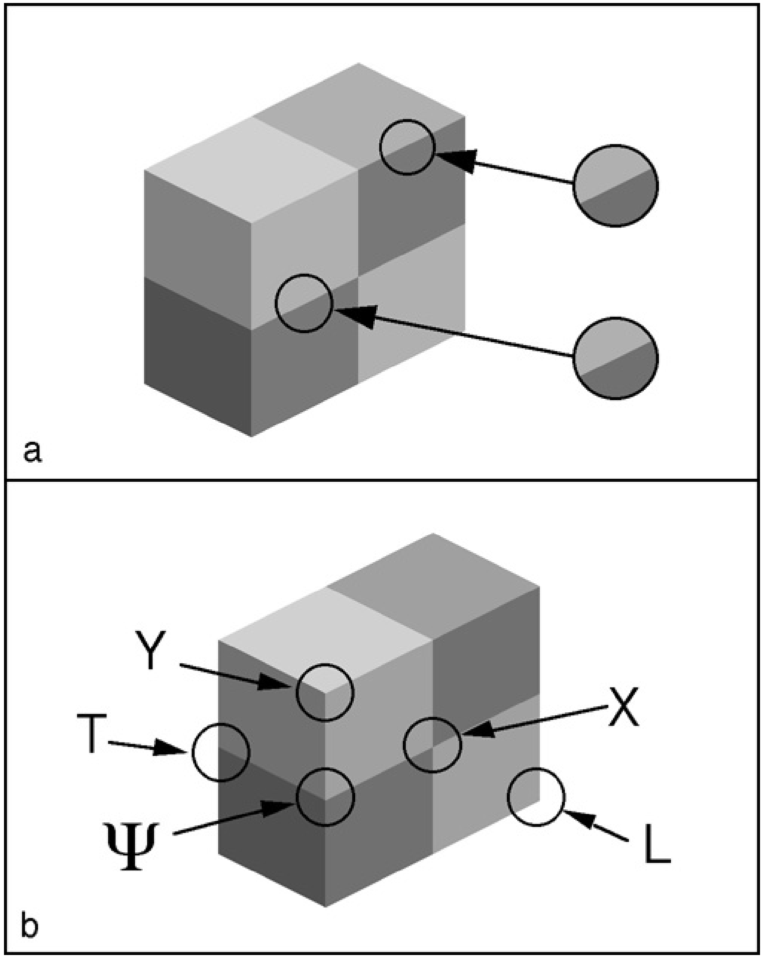


Patches p and q have the same reflectance, but different luminances.

Patches q and r have different reflectances and different luminances; they share the same illuminance.

Patches p and r happen to have the same luminance, because the lower reflectance of p is counterbalanced by its higher illuminance.

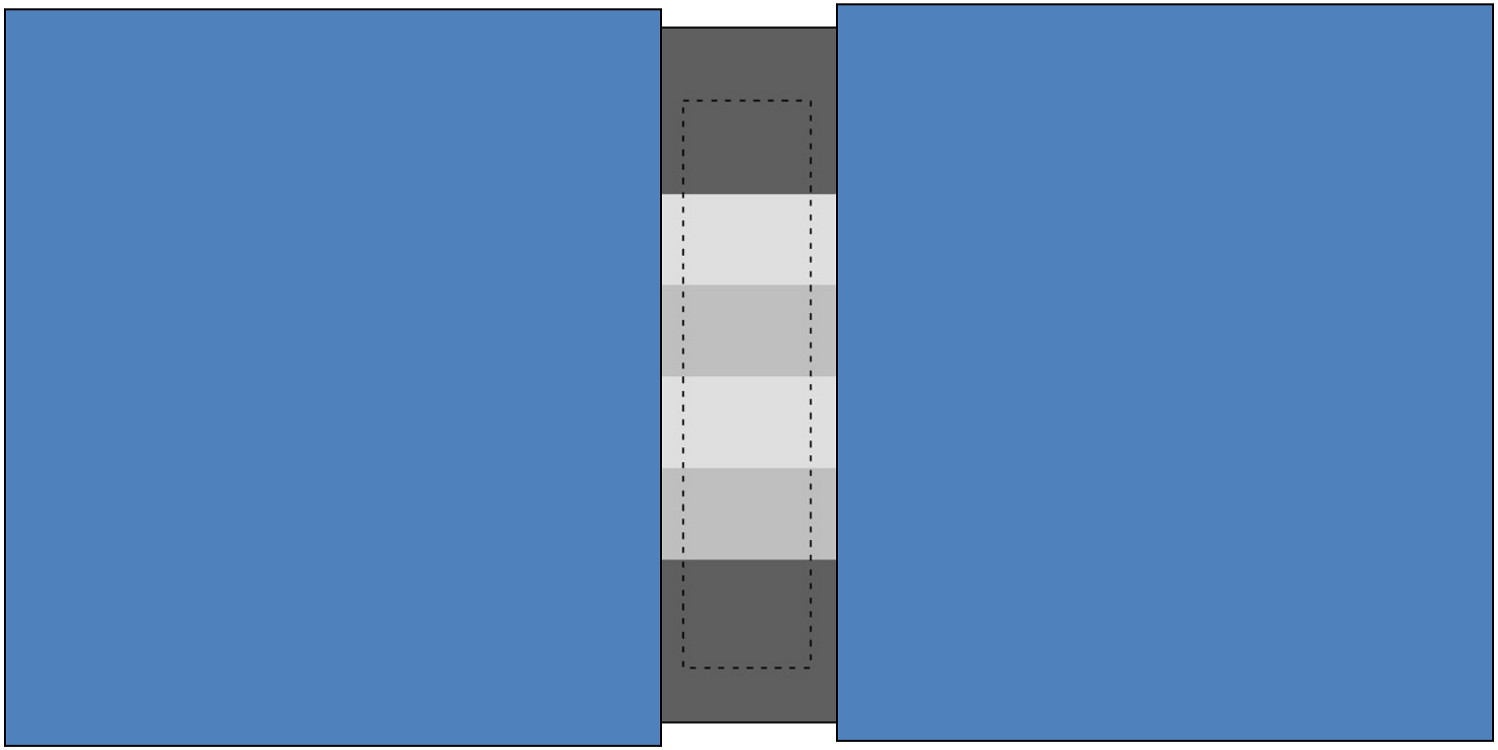
Visual Context



Importance of edges

Importance of corners

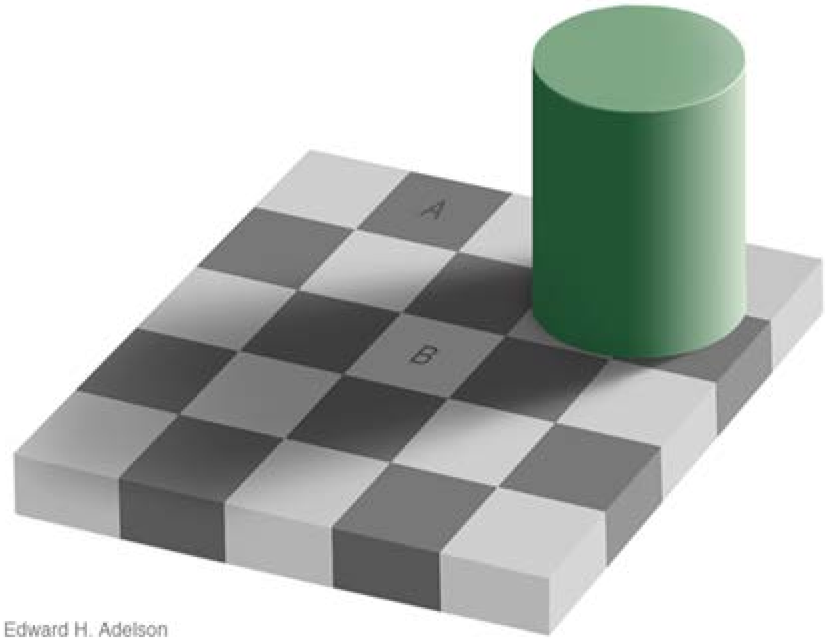
Lightness Illusion

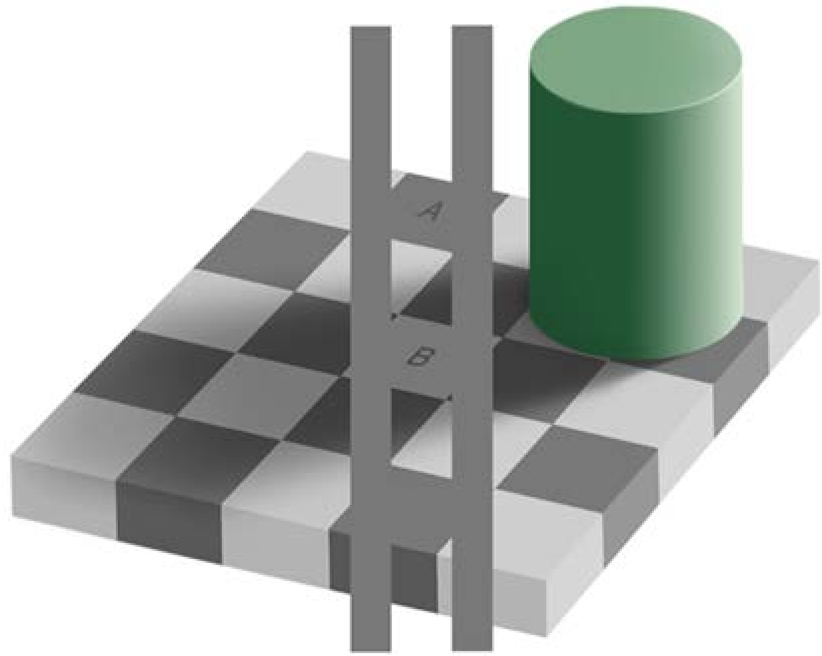


If we cover the left side and view the right, it appears that the stripes are due to different lighting on the stair steps (illumination).

If we cover the right side of the figure and view the left side, it appears that the stripes are due to paint (reflectance).

More Illusions





Squares A and B --- same value or different?

SAME

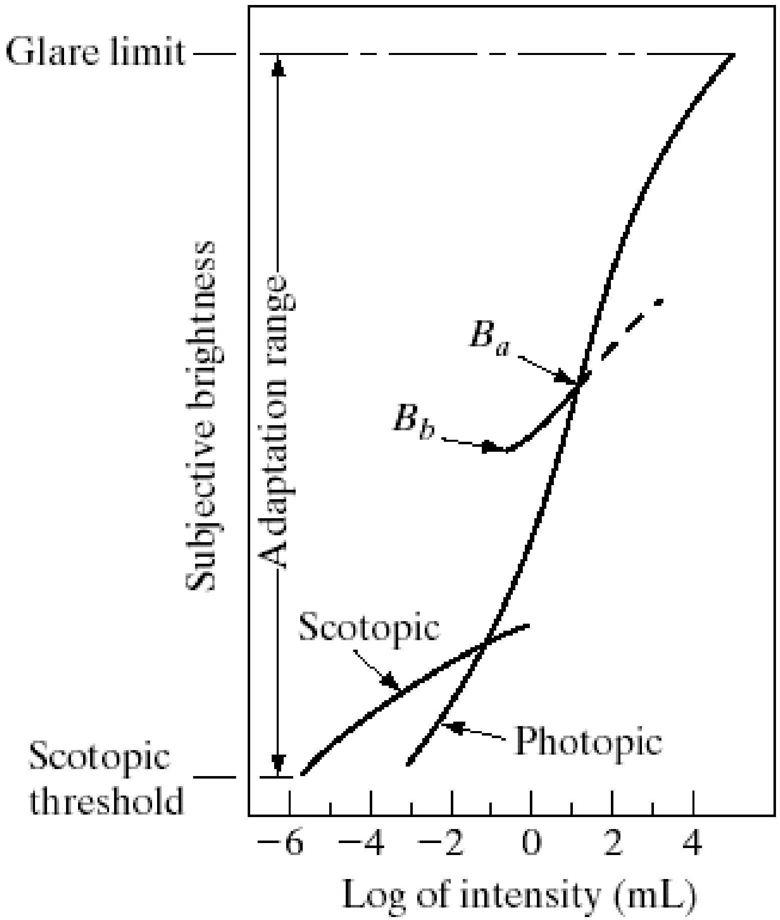
Human Perception

- Human Eye
- Lightness Perception
- **Brightness**
- Contrast
- Illusions

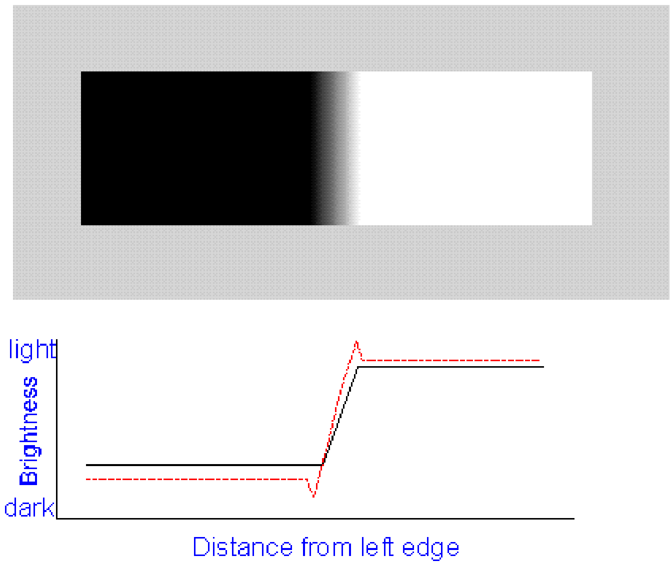
Brightness Adaptation

FIGURE 2.4
Range of subjective brightness sensations showing a particular adaptation level.

The **human** visual system **cannot operate simultaneously**, **over** such a **high dynamic range**
But **manages** such a large variation **by changing its overall sensitivity**,
a phenomenon called **"brightness adaptation"**



Mach Bands



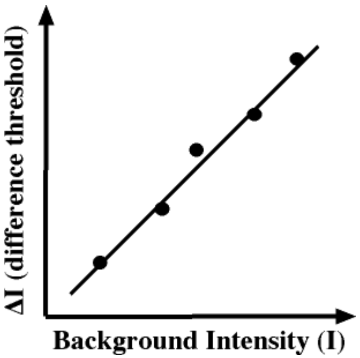
As soon as rectangles touch:
Contrast between them becomes more exaggerated

i.e. Dark band at top looks more dark when it touches the middle band

Image: Public Domain from Wikipedia

Brightness Discrimination

Weber ratio = $\Delta I / I$



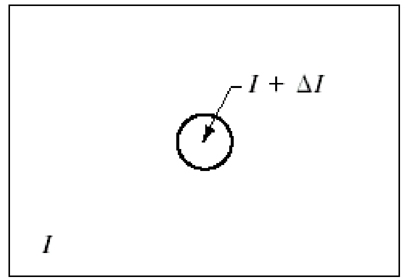
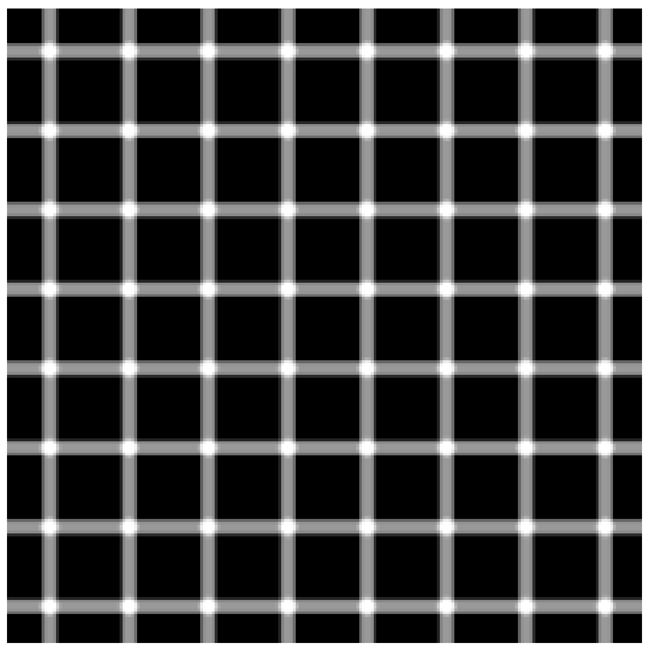


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Weber's Law
The ratio of the increment threshold to the background intensity is constant

$$\Delta I / I = K$$



bright white dots at intersection when you look directly at them,

black dots when you are not

Human Perception

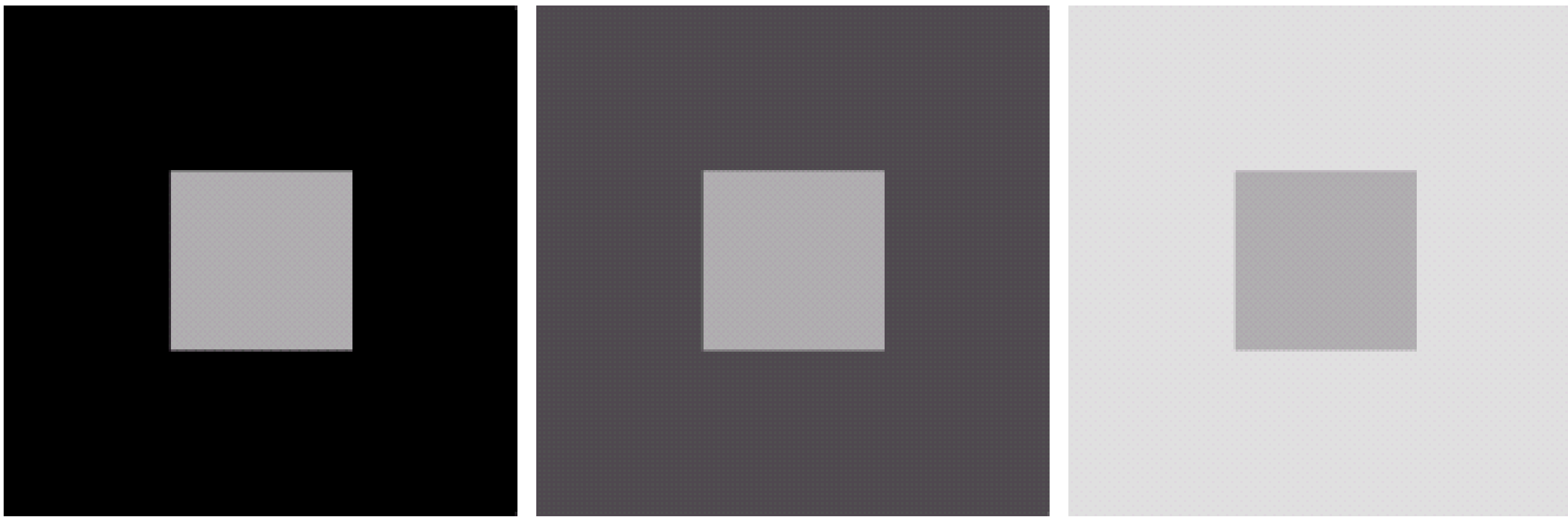
- Human Eye
- Lightness Perception
- Brightness
- **Contrast**
- Illusions

Contrast Effects

- A **contrast effect is**
  - the **enhancement or diminishment**
    relative to the 'normal'
    of perception or cognition
    as a result of successive or simultaneous exposure
    to **a stimulus of lesser or greater value**

    - 'normal' here means
      the perception or cognition that would occur if the other stimulus was not present
      - i.e. what it would appear to be "normally"

Example: Simultaneous Contrast



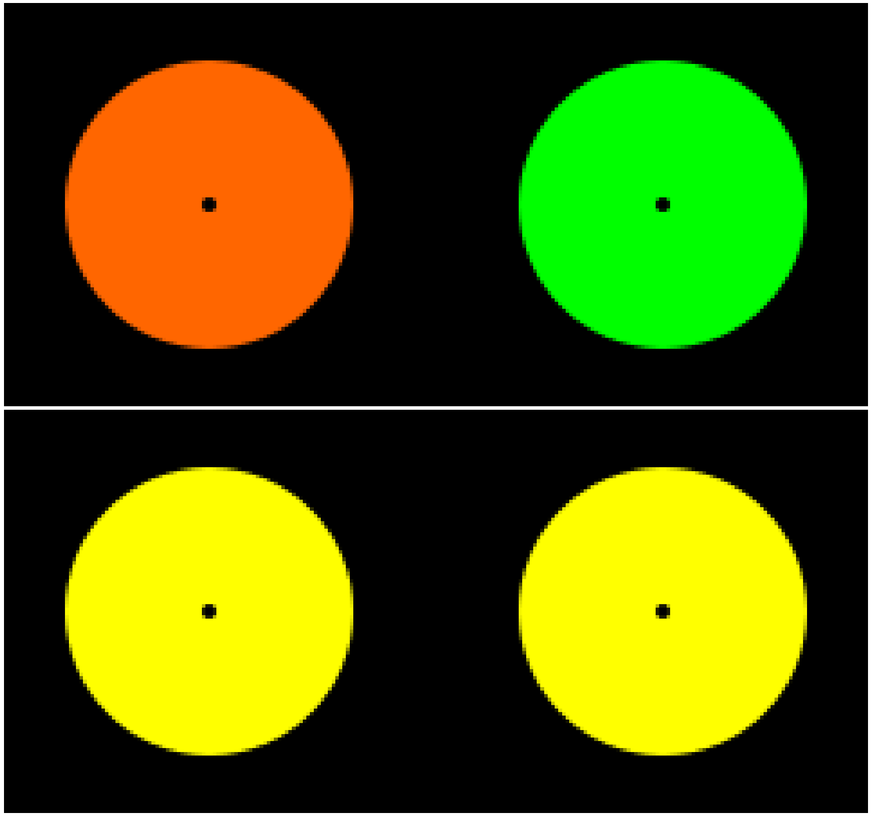
Same luminance but varying brightness (perceived luminance)

a b c

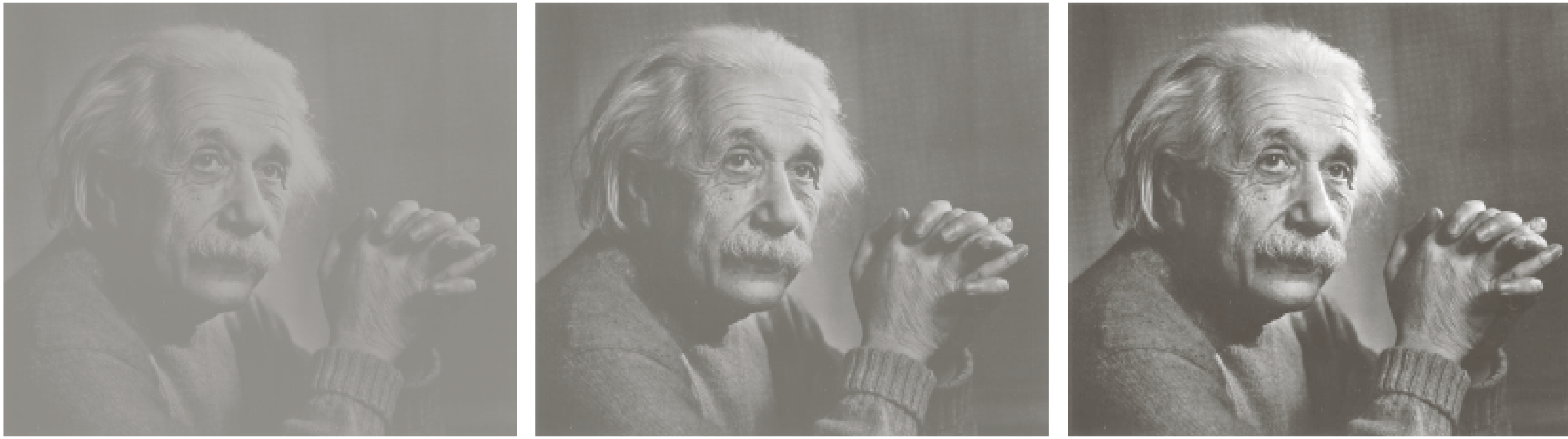
FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Example: Successive Contrast

- Stare at the dot in one of the two top circles
- Then look at bottom circles
  - They will appear different colors/shades (but are the same)



Common Issues with Contrast



a b c

FIGURE 2.41 Images exhibiting (a) low contrast, (b) medium contrast, and (c) high contrast.

Human Perception

- Human Eye
- Lightness Perception
- Brightness
- Contrast
- **Illusions**

Optical Illusions

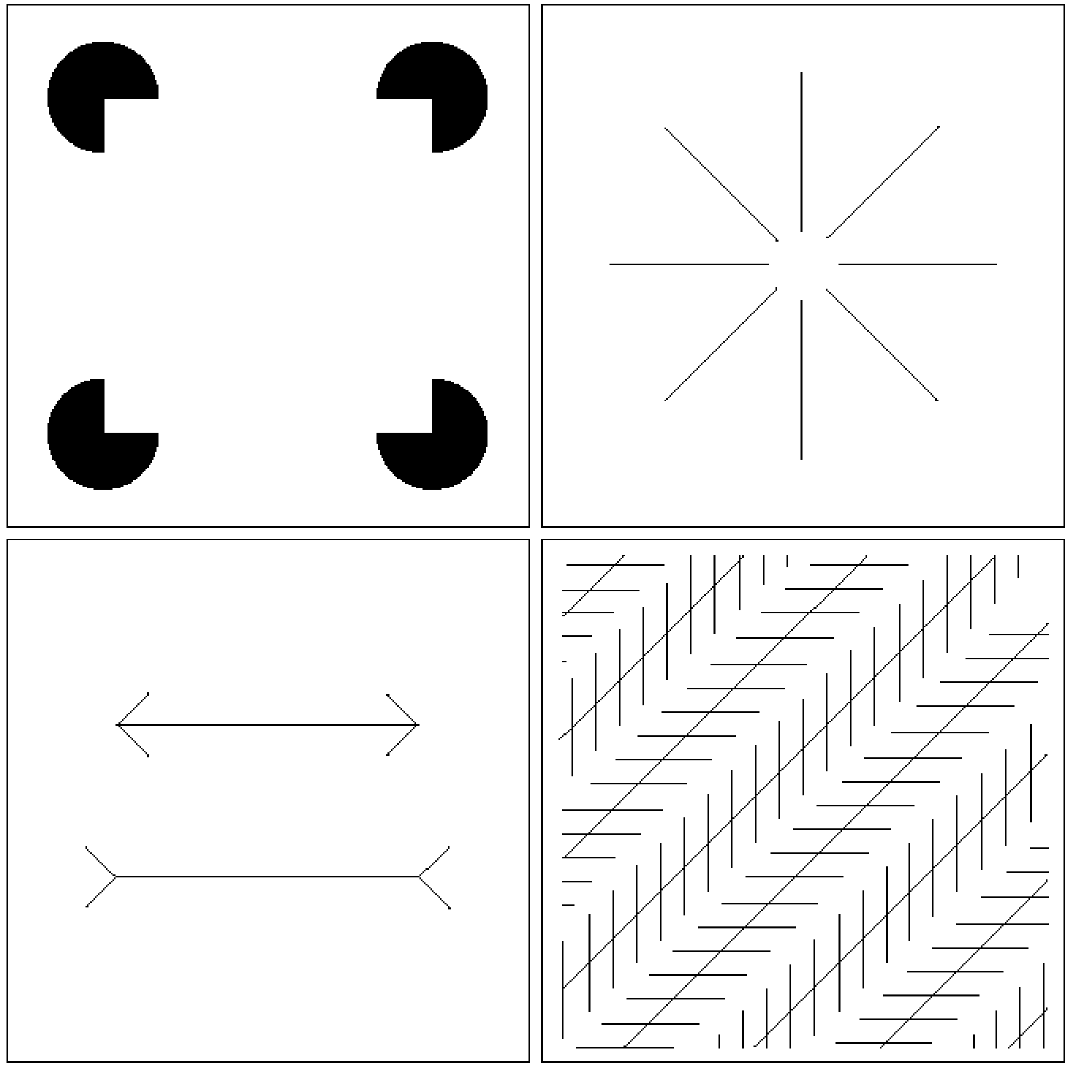


FIGURE 2.9 Some well-known optical illusions.

Lastly

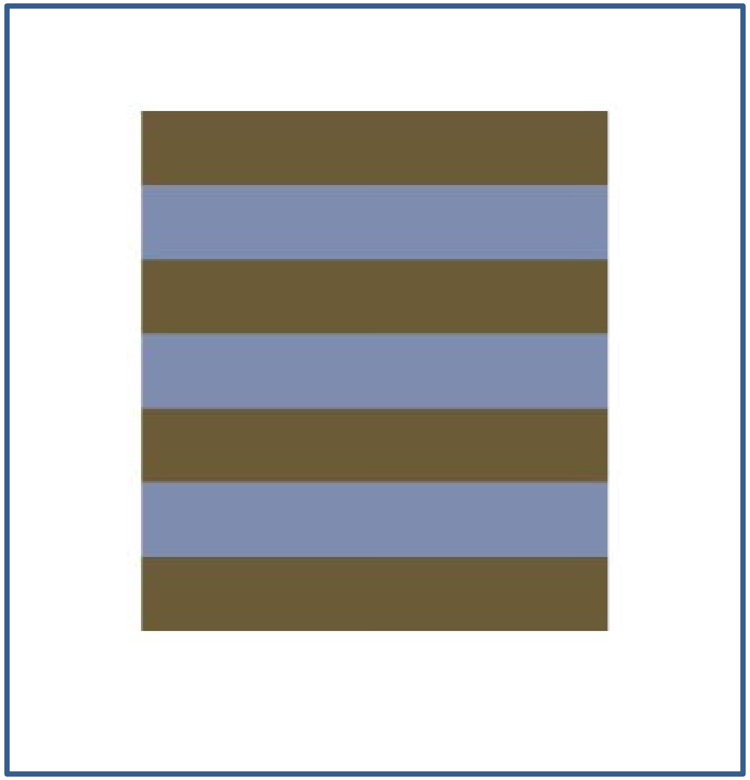
What color is this dress ?

Summary: Human Perception

- Human Eye
- Lightness Perception
- Brightness
- Contrast
- Illusions

Now we understand
the technical details of digital images
AND
how the images are perceived

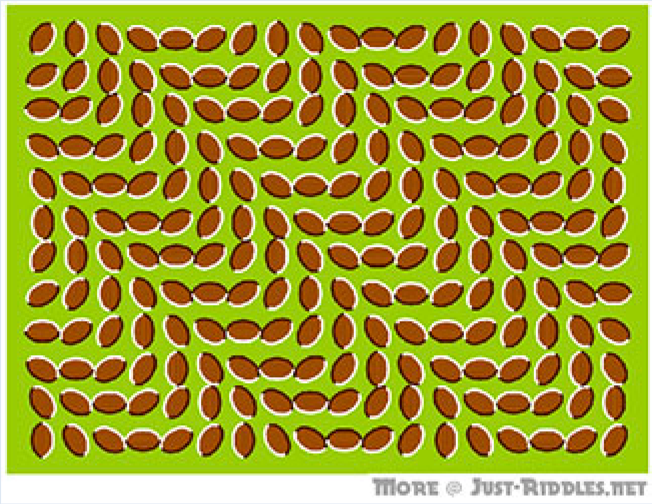
Next Time:
Let's start messing with them images =)



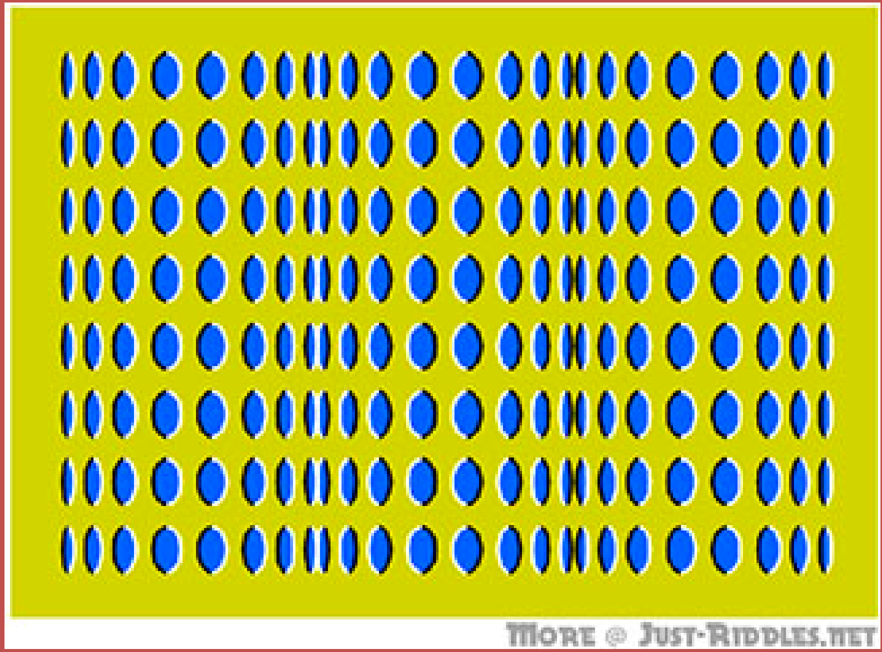
Questions?

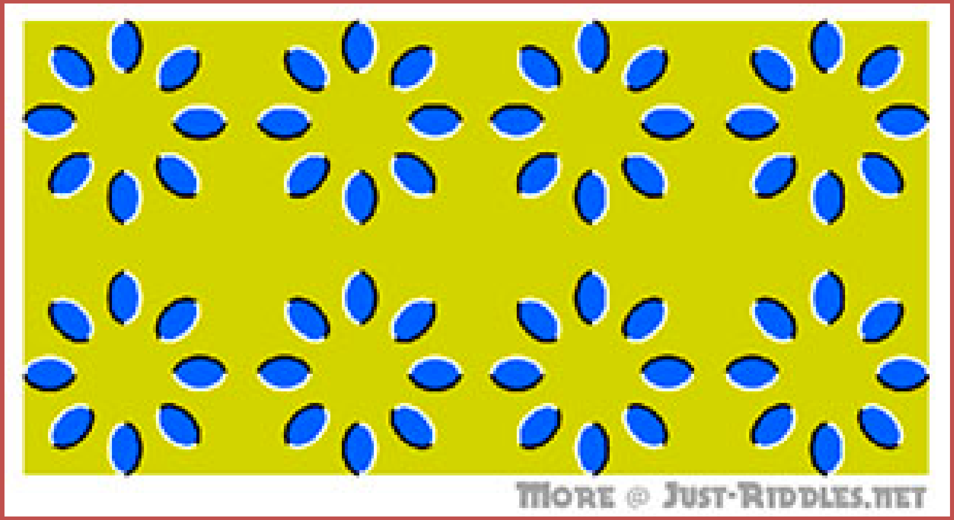
- Beyond D2L
  - Examples and information can be found online at:
    - *http://docdingle.com/teaching/cs.html*

    - *Continue to more stuff as needed*



Extra Reference Stuff Follows





Credits

- Much of the content derived/based on slides for use with the book:
  - *Digital Image Processing,* Gonzalez and Woods

- Some layout and presentation style derived/based on presentations by
  - Donald House, Texas A&M University, 1999
  - Bernd Girod, Stanford University, 2007
  - Shreekanth Mandayam, Rowan University, 2009
  - Igor Aizenberg, TAMUT, 2013
  - Xin Li, WVU, 2014
  - George Wolberg, City College of New York, 2015
  - Yao Wang and Zhu Liu, NYU-Poly, 2015
  - Sinisa Todorovic, Oregon State, 2015