Digital image processing and analysis
1. Image formation

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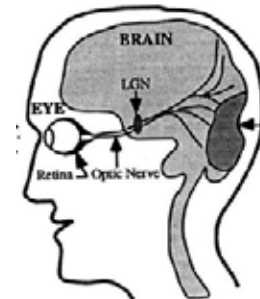| 228 | 224 | 216 | 204 | 199 | 202 | 207 | 197 | 207 | 215 | 207 | 208 | 204 | 198 | 184 | 192 |
218	206	199	200	207	210	208	202	212	218	215	210	201	188	174	197
200	200	203	204	204	199	197	207	210	203	196	191	194	193	193	198
209	219	221	211	201	203	213	200	200	190	188	184	193	197	203	205
223	225	223	208	186	176	176	173	176	171	178	180	194	201	212	198
200	191	184	167	127	76	42	63	63	57	68	81	112	136	156	169
212	214	182	91	41	49	49	38	40	42	40	37	38	50	61	95
216	198	136	65	60	62	24	34	41	46	42	36	34	37	40	42
205	181	141	101	96	84	46	40	48	50	40	34	37	38	33	35
181	150	128	96	64	44	33	38	49	46	34	32	43	45	37	37
193	153	100	65	48	39	36	36	44	42	32	35	46	46	34	34
197	159	90	62	56	48	44	43	44	38	29	32	41	40	31	30

In this lecture we shall find out about:

- Basics of visual perception

- Digital image acquisition
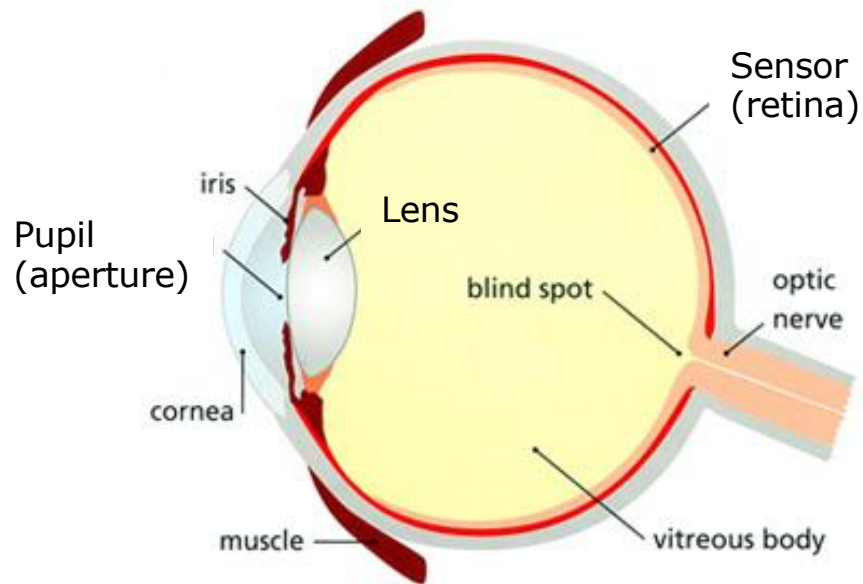
- Inside digital cameras

- Variety of maging devices
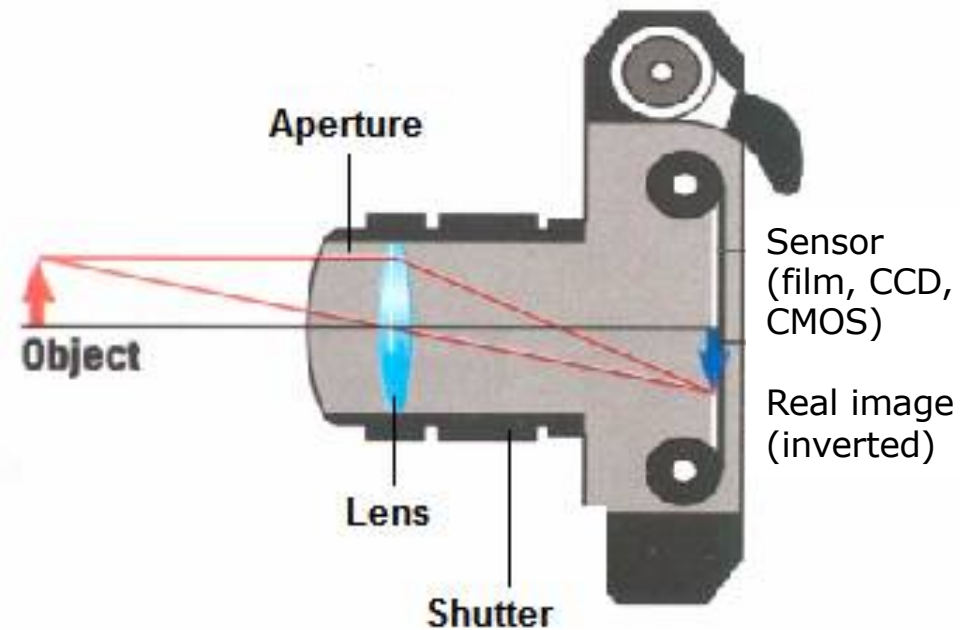
… and how these two compare

What does it mean to see?

- The eye
  - Sensor based on light

- Making use of the sensed data
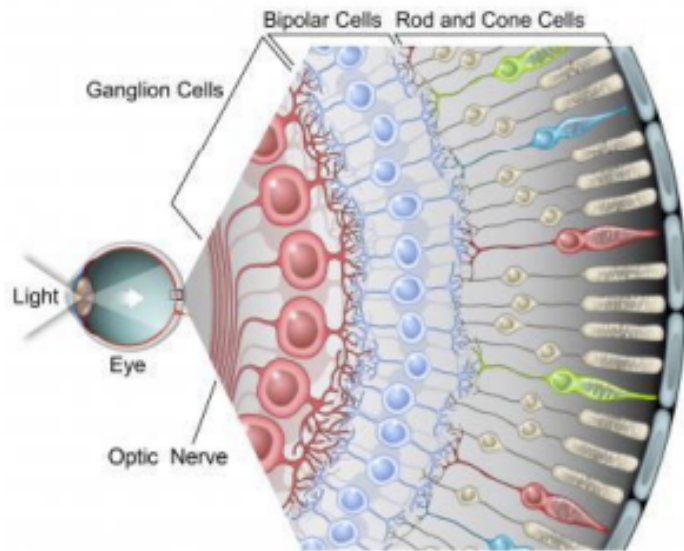 - Internal representation
  - Interpretation

Optical pathway

Pupil (aperture)

Sensor (retina)
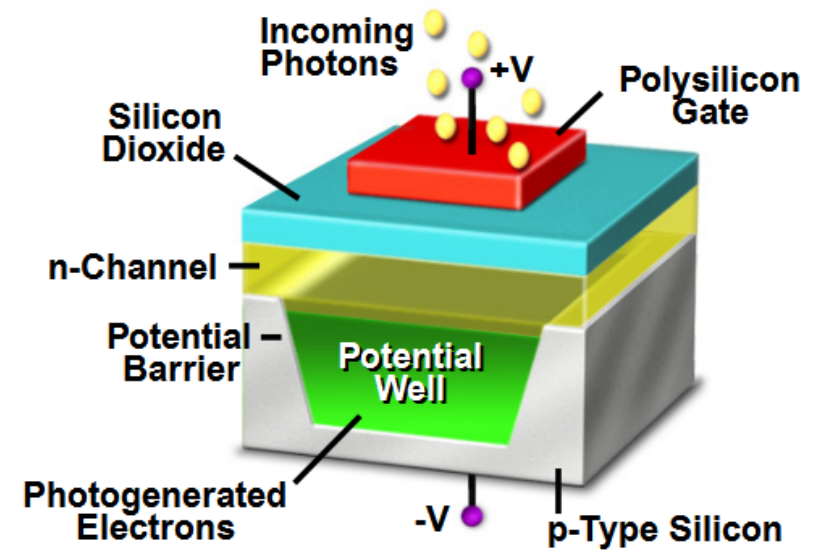
Lens

iris

cornea

muscle

blind spot

vitreous body

optic nerve

https://www.moorfields.nhs.uk/content/anatomy-eye

Aperture

Object

Lens

Shutter

Sensor (film, CCD, CMOS)

Real image (inverted)

From [2]

Photons are carriers of light

Sensors

Retina

Bipolar Cells Rod and Cone Cells

Ganglion Cells

Light

Eye

Optic Nerve

From [5]

Photosensor

Incoming Photons   +V   Polysilicon Gate

Silicon Dioxide

n-Channel

Potential Barrier   Potential Well

Photogenerated Electrons   -V   p-Type Silicon

From [3]

Sensors

Retina
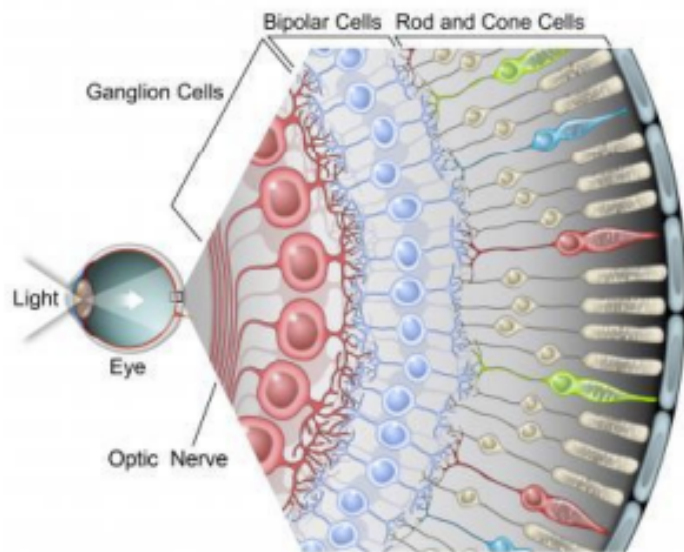
Cones
detect detail and colour, central, 6 million

Rods
sensitive to light & motion, off-centre, 120 million
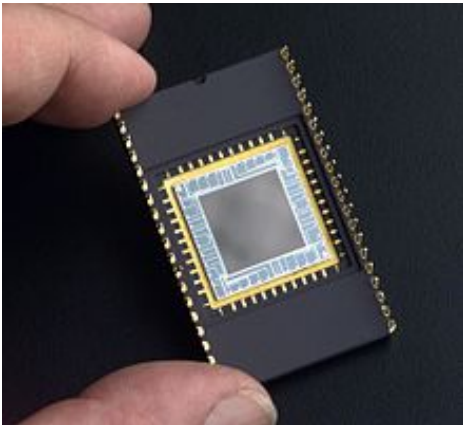
Fovea
densely packed with cones, fine detail, uniform resolution

Pathways

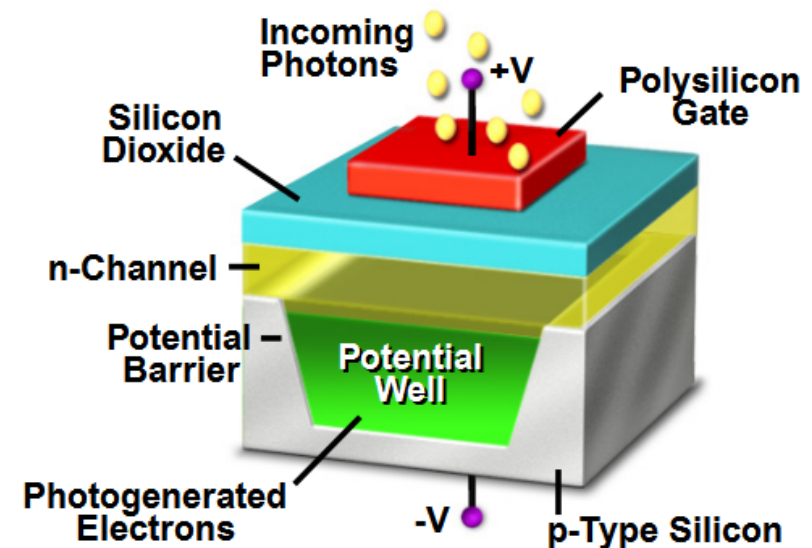The visual projection pathway

Polyak, 1957
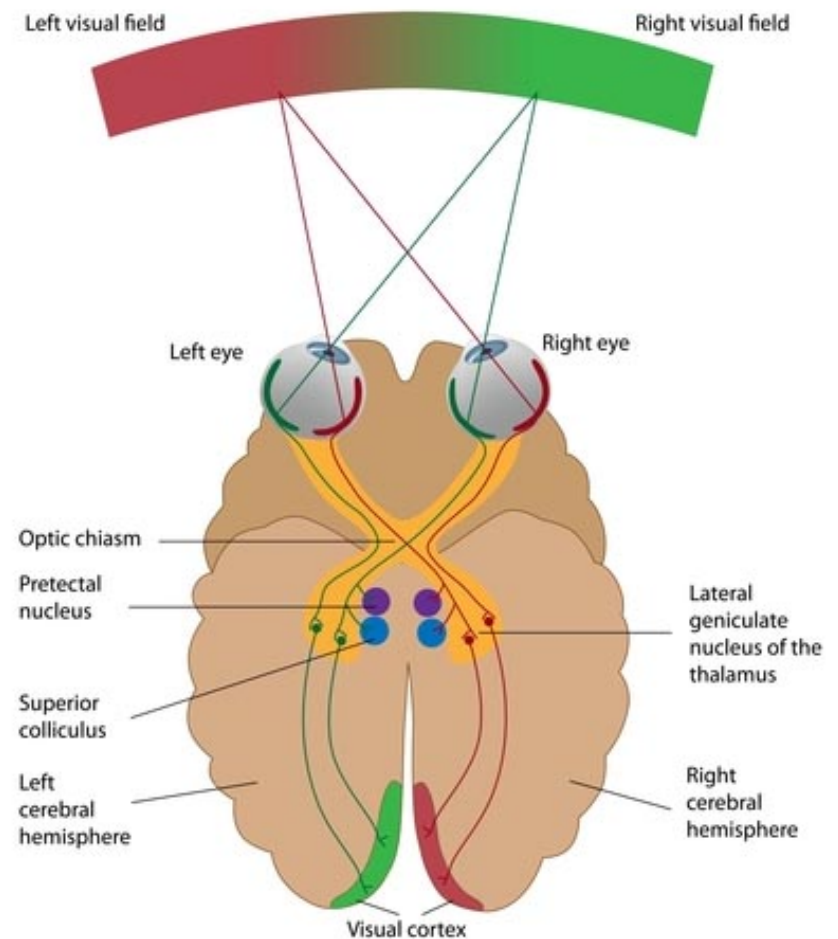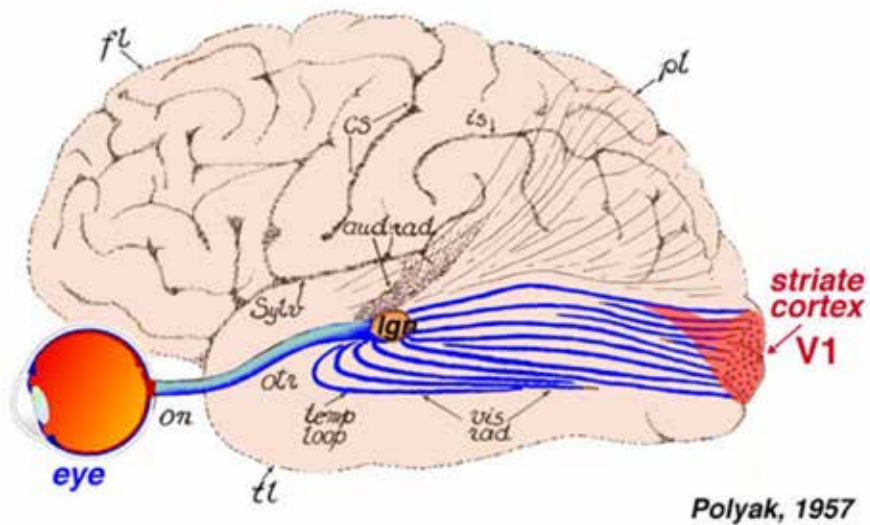
Sensors

Sensor chip

An array of light sensitive elements (photosensors = pixels)

Up to 10 megapixels (10 million) Uniform distribution
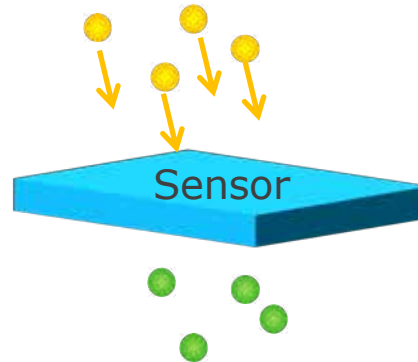
Physical size: ½ to 1 inch

Photosensor

Incoming Photons
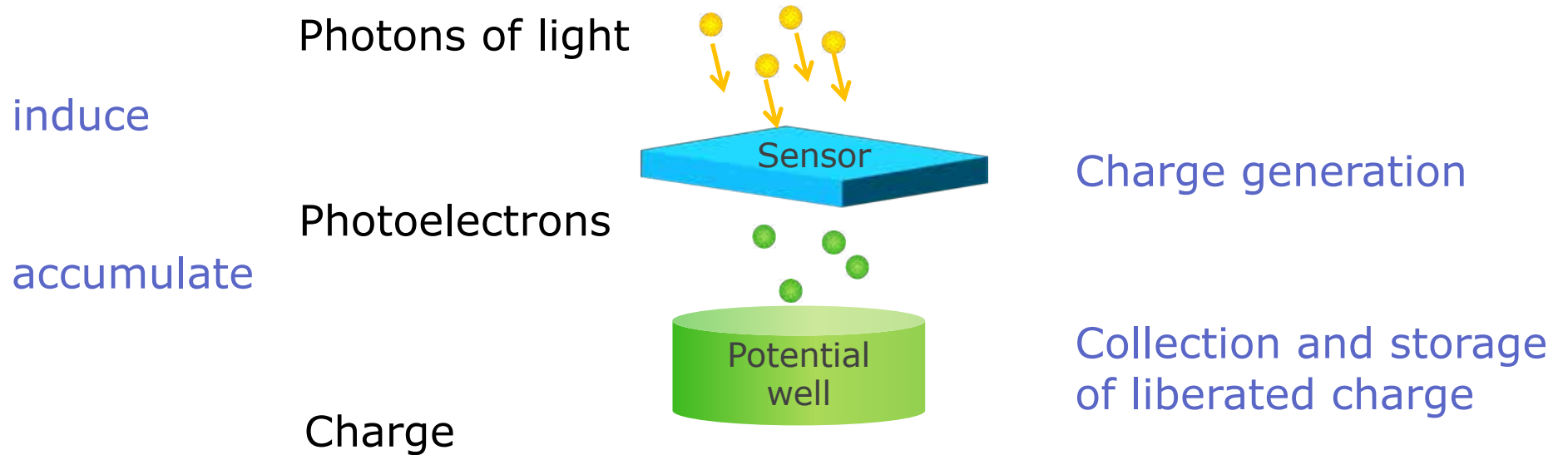+V
Polysilicon Gate
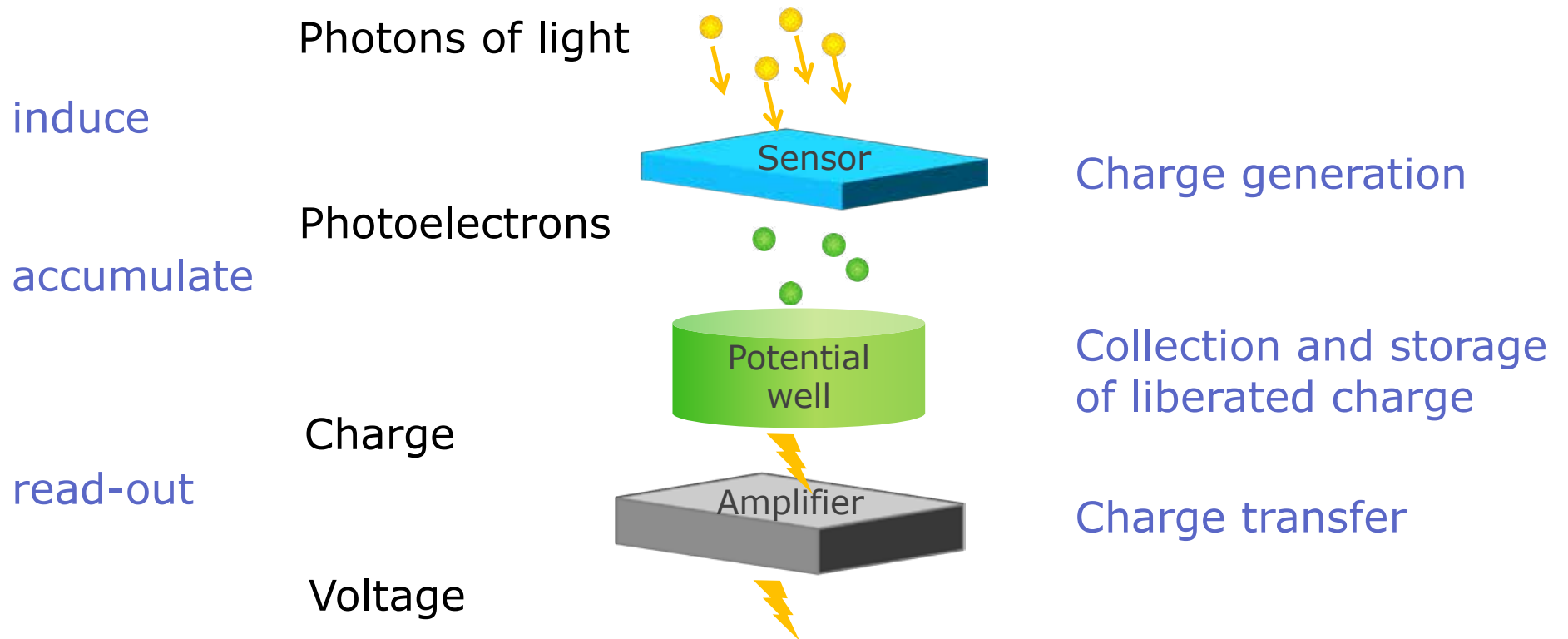Silicon Dioxide
n-Channel
Potential Barrier
Potential Well
Photogenerated Electrons
-V
p-Type Silicon

Pathways

Photons of light

induce

Photoelectrons

Sensor

Charge generation

Pathways

Photons of light

induce

Sensor

Charge generation

Photoelectrons

accumulate

Potential
well

Collection and storage
of liberated charge

Charge

Pathways

Photons of light

induce

Photoelectrons

accumulate

Charge

read-out

Voltage

Sensor

Potential well

Amplifier

Charge generation

Collection and storage of liberated charge

Charge transfer

Pathways

Photons of light

induce

Sensor — Charge generation

Photoelectrons

accumulate

Potential well — Collection and storage of liberated charge

Charge

read-out

Amplifier — Charge transfer

Voltage

ADC

digitise — Charge measurement

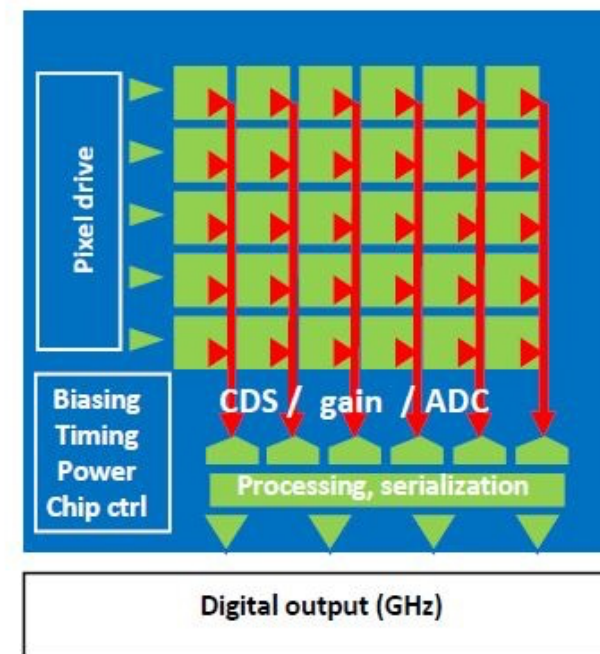Numerical values

ADC=Analogue-to-Digital Converter

Sensor arrays

Charge-coupled-device (CCD)
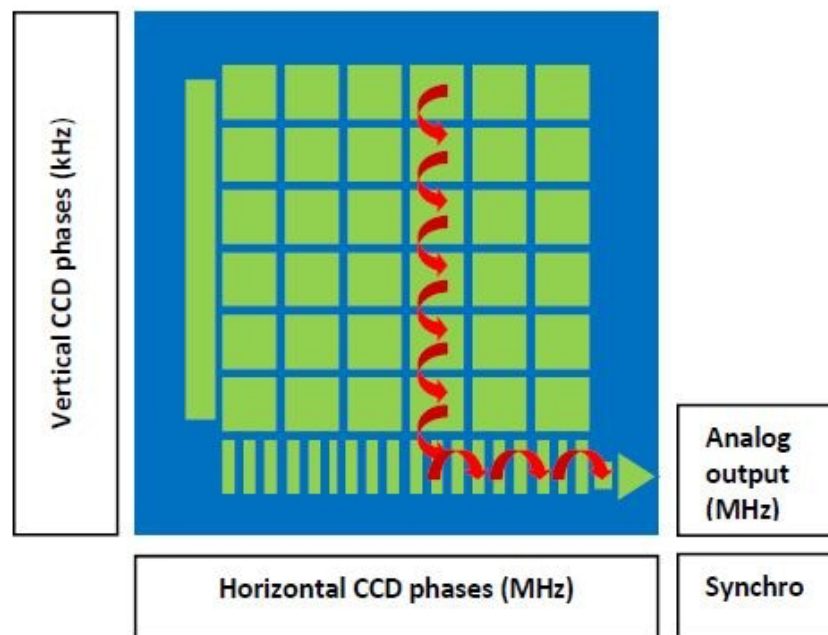
The charges from a CCD move across the array photosensor by photosensor until they reach the external amplifier units.

Complementary metal–oxide–semiconductor (CMOS)

Photosensors are positioned inside 'wells'. Between the wells is circuitry associated with the amplifier units. Each sensor has its own amplifier.
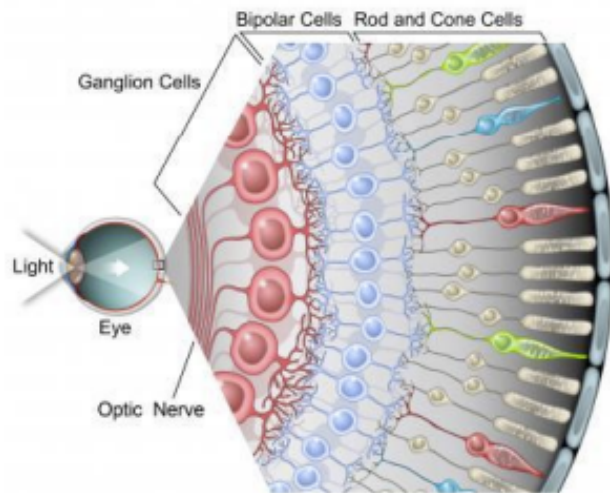
Sensor arrays

CCD vs. CMOS   **Dallmeier**

Charge-coupled-device (CCD)

- High sensitivity
- High resolution
- Low noise level
- Lower speed
- Complex electronics

Complementary metal–oxide–semiconductor (CMOS)

- Lower sensitivity
- Moderate resolution
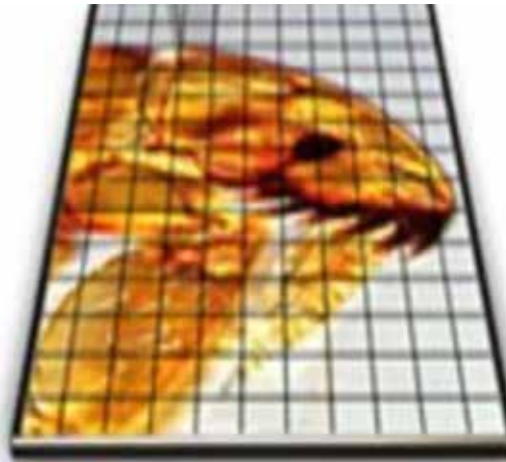- Higher noise level
- High speed
- Simpler electronics

Sensor connectivity

Human retina

CCD chip
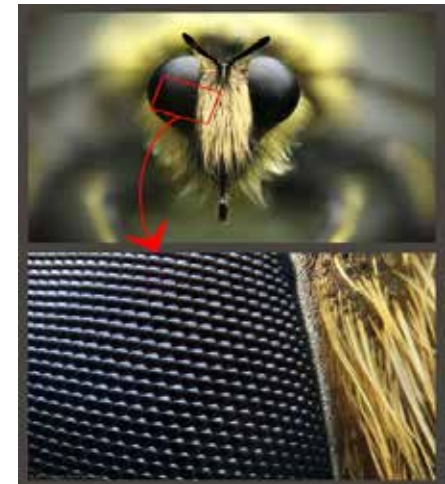pixel array

Insect
compound eye

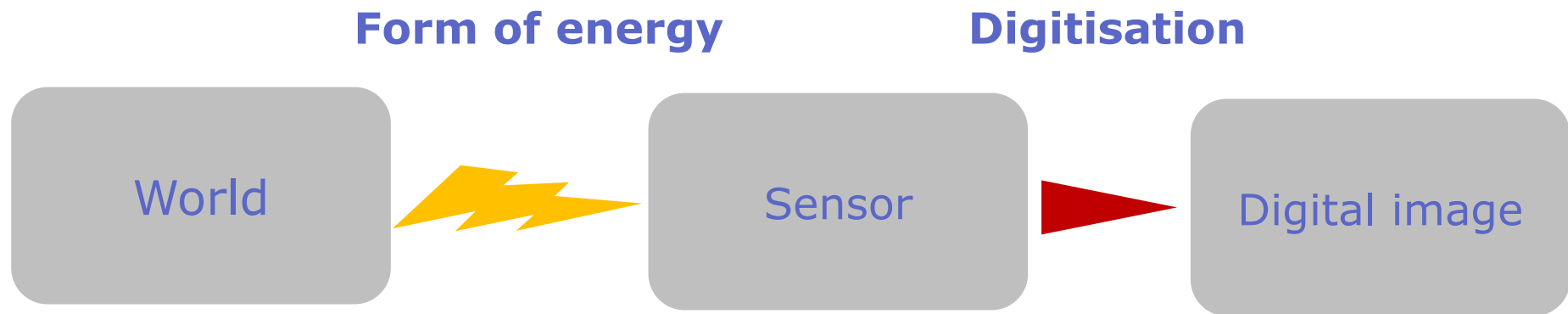http://hamamatsu.magnet.fsu.edu/
articles/scanningformats.html

https://blog.nmacro.com

High connectivity

Separate sensors

Imaging devices
General principles

Form of energy   **Digitisation**
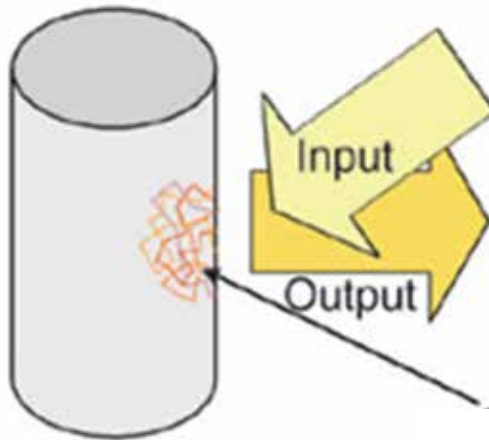
World → Sensor → Digital image

- Electromagnetic waves
  - Light
  - X-ray
  - etc
- Magnetic resonance
- Sound
- Particles
- Fields (e.g. biomagnetic)

Imaging devices
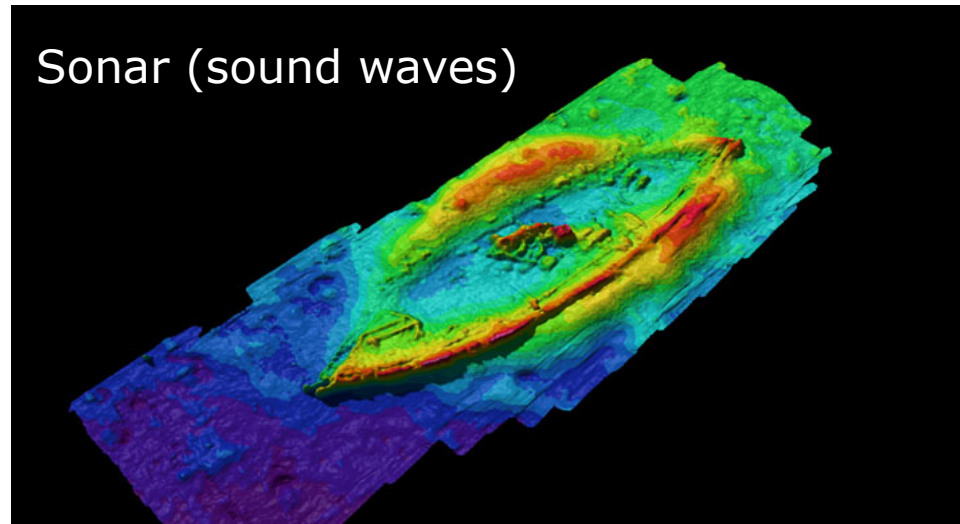## Inputs and outputs

Reflectance (echo)

Looking and listening to light: the evolution of whole-body photonic imaging
Ntziachristos et al. Nature Biotechnology 23, 313 - 320 (2005)
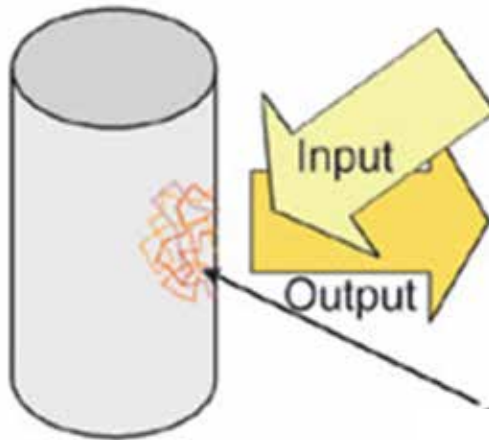
Ultrasound (sound waves)

Sonar (sound waves)

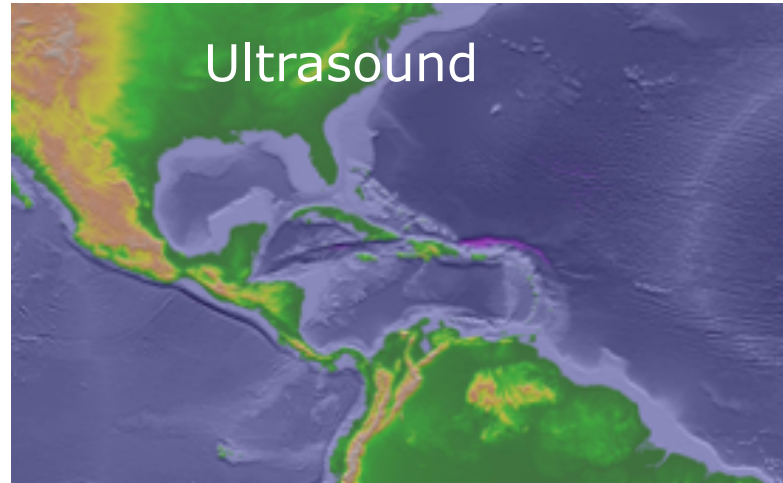https://www.archaeology.org/issues/116-1401/sidebars/1934-monterrey-wrecks-delgado-update

Imaging devices
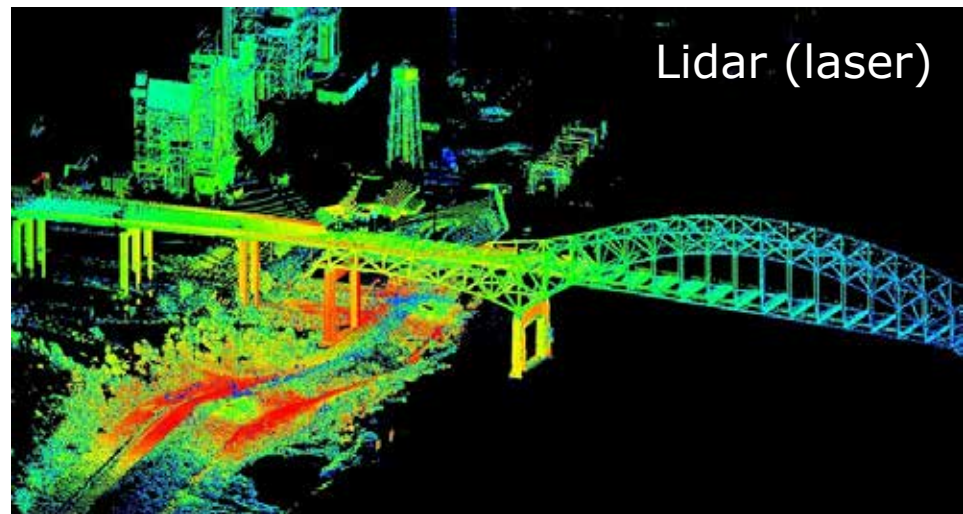# Inputs and outputs

Reflectance (echo)

Ultrasound

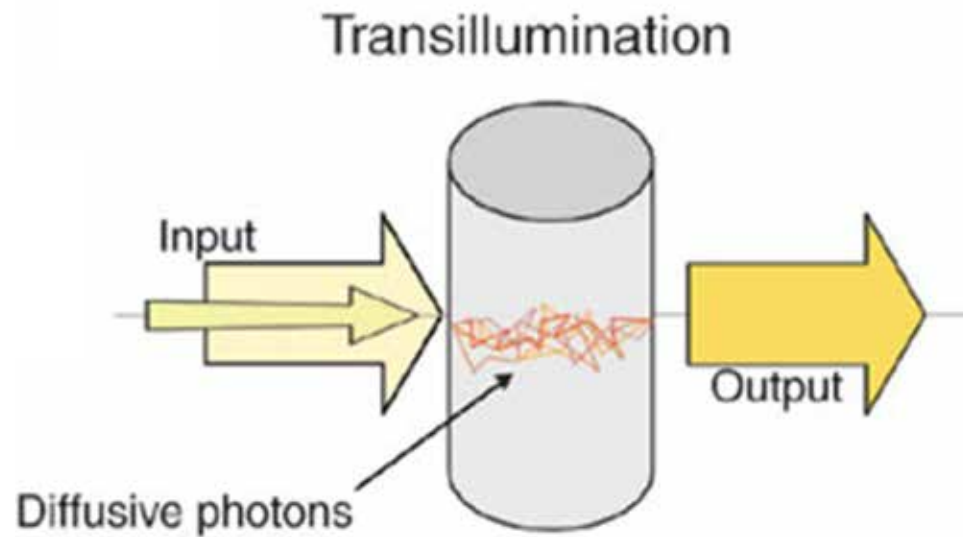https://www.ngdc.noaa.gov/mgg/topo/pictures/CARIBBEANebcolshade.jpg

Lidar (laser)

https://www.sciencenewsforstudents.org/article/explainer-what-are-lidar-radar-and-sonar
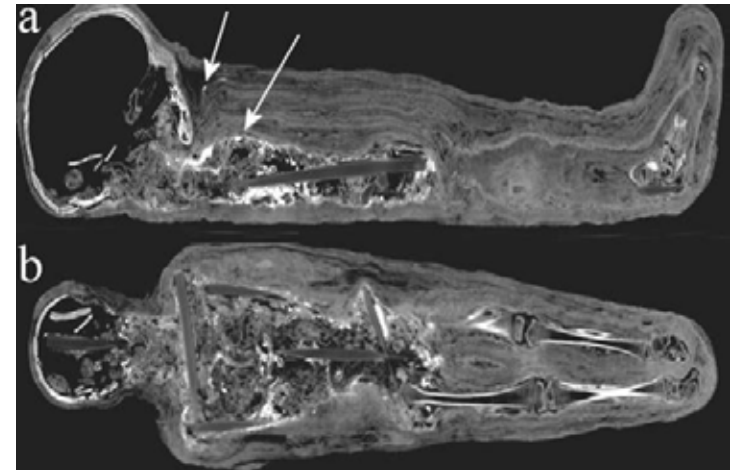
Imaging devices
Inputs and outputs

Medical x-ray

Imaging devices
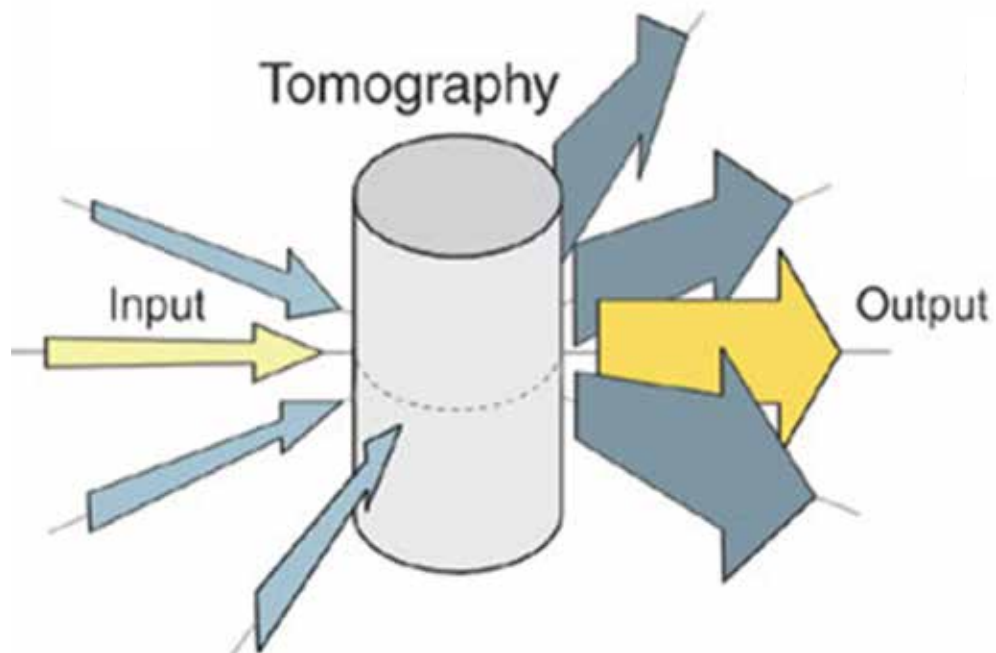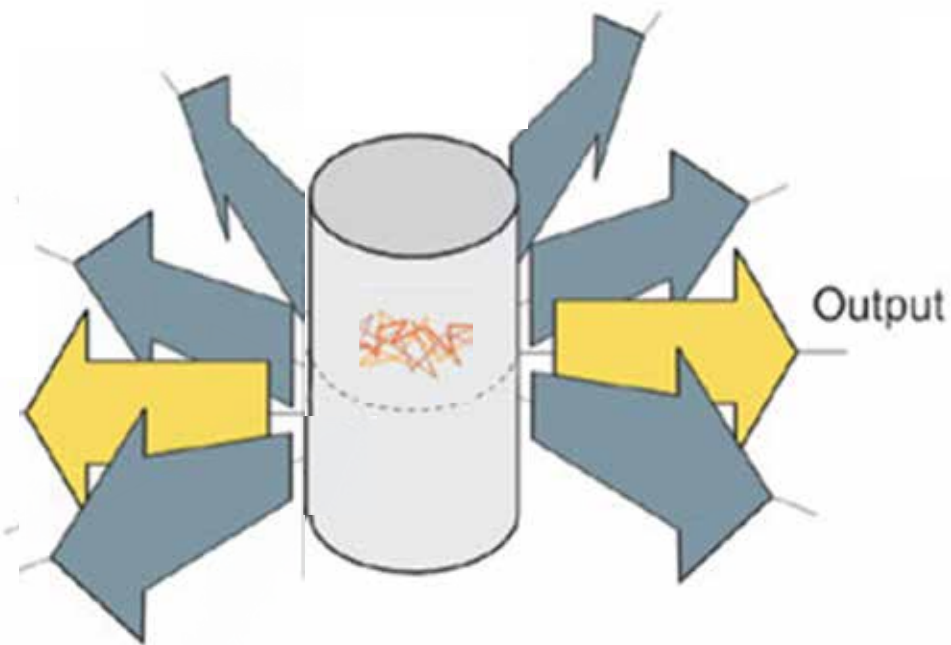## Data collection

Tomography

Input → Output

Computed tomography
(Egyptian mummy)

Imaging devices
Data collection

Output

Fluorescence
(coral)

http://www.microworldsphotography.com/Galleries/Marine-Fluorescence/i-XPdd4QT/A

In this lecture we have covered:

- Basics of visual perception

  … and how these two compare

- Digital image acquisition

- Inside digital cameras

- Imaging devices

Next lecture

What digital images are like

- Properties
  - **Computer representation** – pixels
  - **Sampling** – related to image coordinates
  - **Quantisation** – related to image values
- … and how they relate to image acquisition

Further reading

1. Human vision: Gregory, Richard L. *Eye and brain: The Psychology of Seeing*.
2. Camera optics: http://www.odec.ca/projects/2007/aust7k2/Index.htm
3. CCD: https://www.microscopyu.com/digital-imaging/introduction-to-charge-coupled-devices-ccds
4. https://www.microscopyu.com/digital-imaging/fundamentals-of-digital-imaging
5. https://en.wikipedia.org/wiki/Charge-coupled_device
6. Retina: http://wiki.bethanycrane.com/introducingtheeye
7. http://cpn.canon-europe.com/content/education/infobank/capturing_the_image/ccd_and_cmos_sensors.do
8. https://www.tel.com/museum/exhibition/principle/cmos.html
9. https://www.dpreview.com/articles/8095816568/sensorsizes