ELEG404/604: Imaging & Deep Learning

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Introduction

Course Objectives & Structure

Imaging is everywhere at the heart of science, medicine, entertainment, engineering and communications. This course provides and introduction to mathematical and deep learning tools for image sensing and processing.

Course Structure:

- Weekly lectures [notes: eecis.udel.edu/∼arce/courses/digitalimgproc/].
- Homework & computer assignments [20%].
- 2 Midterms [40%].
- Final Exam [20%].
- Project [20%].

Textbook:

- Class notes and reference articles.

TA Information:

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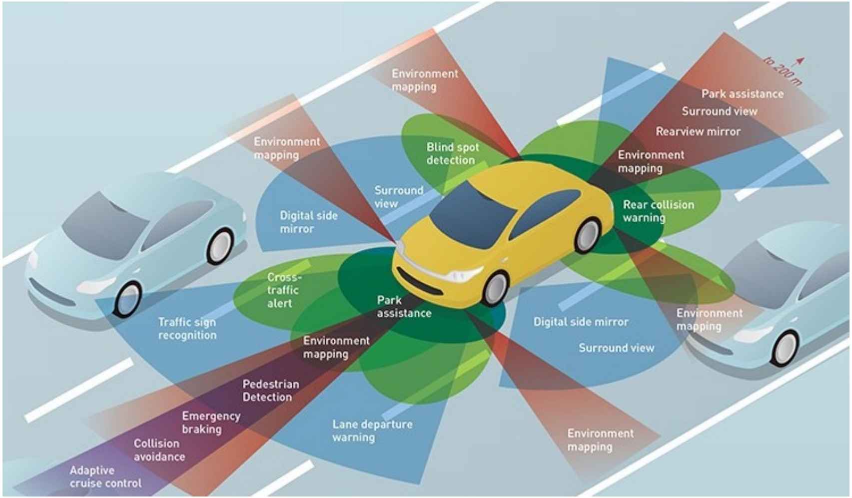
- aramjai@udel.edu
- Office Hours: Wednesday 3-5pm
- Evans Hall 204

Imaging: Key for Future Technology

Rise of the robots.

Boston Dynamics

Self-Driving Cars



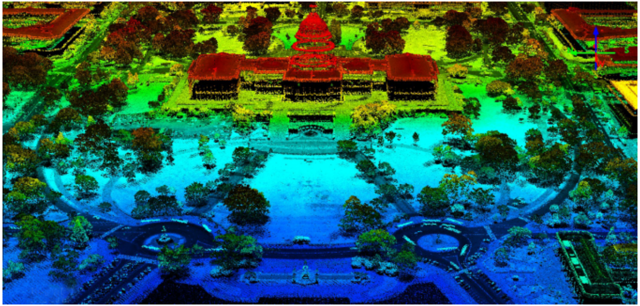
Long-range radar   Ultrasound   Short/medium-range radar

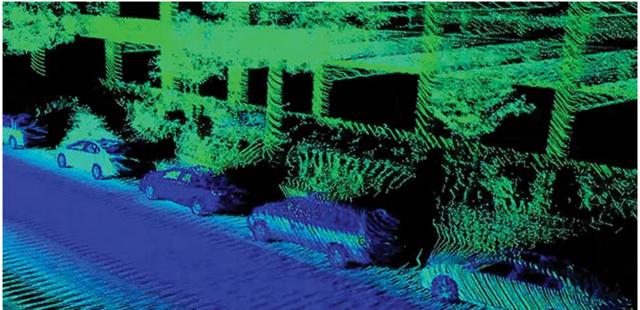
Optical Cameras   Lidar

Imaging: Self-Driving Cars

- Long-range radar: Microwave at 77 GHz has low resolution. Measure speed and detect vehicles 200 m away.
- Ultrasound: Short range. Identify close objects, e.g. parking.
- Short/medium-range radar: 24-GHz. Detects velocity and distance.
- Optical Cameras: Good spatial resolution, but cannot measure distance or velocity. Rely on external light.
- Lidar: Emits short pulses in steerable and tightly focused beam, measuring a million points a second. Detect objects at 200-300. Measures velocity directly. High resolution. High cost.

Lidar





Imaging: Smart Phones

Imaging: Smart Phones

New sensing:

Multiple lenses and AI software. Instantly recognize different scenes and situations for maximum photo quality.

Night Sight: Seeing in the Dark on Pixel Phones

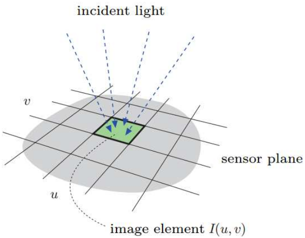
Left: iPhone XS. Right: Pixel 3 Night Sight.

Photographs in very low light, even in light so dim you can't see much. It does not uses flash.

Introduction

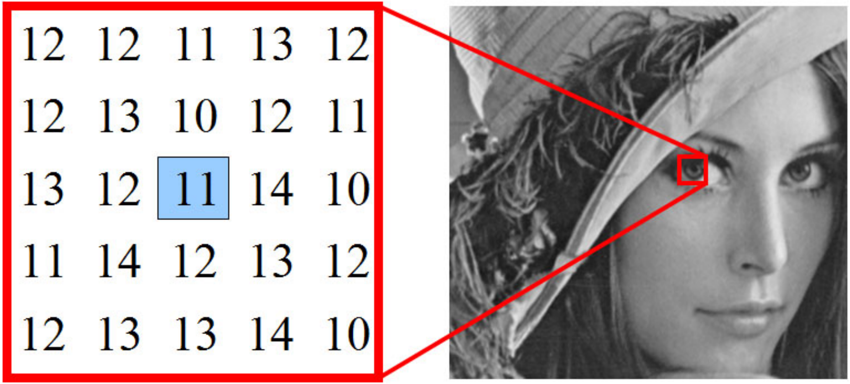
Digital imaging refers to processing of digital images by means of a computer.

- An image may be defined as a function $f(x, y)$, where (x, y) are spatial coordinates and $f(x, y)$ is the intensity
- When x, y and f are all finite, discrete quantities the image is called a digital image
- Each $f(x, y)$ are referred to as picture elements, image elements, pels or pixels



What is an image?

An image is a matrix of numbers.

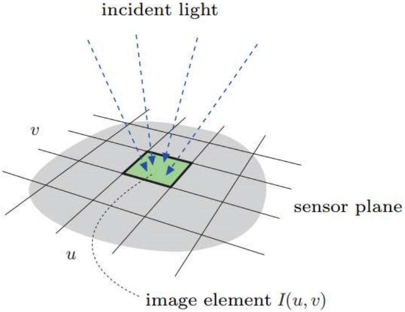


Each individual number in this matrix is a picture element or PIXEL.

Going Digital

Projection on the image plane of a camera is a two-dimensional, time-dependent, continuous distribution of light energy. To convert this image into a digital image, 3 steps are necessary:

- Spatial sampling
- Temporal sampling
- Quantization of pixel values

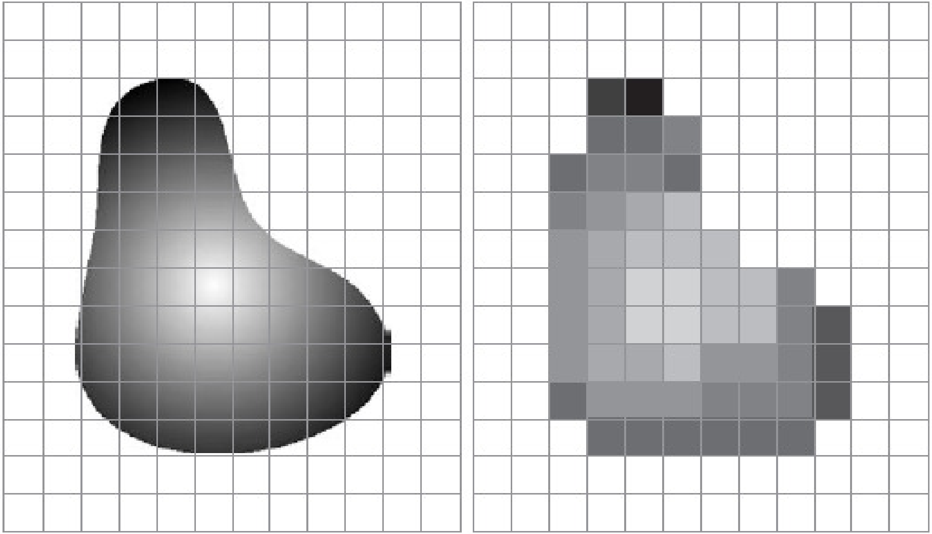


Going Digital

- Spatial sampling: Conversion of the continuous signal to its discrete representation.
- Temporal sampling: Integrates at regular intervals the amount of light incident on each individual sensor element.
- Quantization of pixel values: Image values on the computer they are commonly converted to an integer scale

$F(x, y)$

148	123	52	107	123	162	172	123	64	89	⋯
147	130	92	95	98	130	171	155	169	163	⋯
141	118	121	148	117	107	144	137	136	134	⋯
82	106	93	172	149	131	138	114	113	129	⋯
57	101	72	54	109	111	104	135	106	125	⋯
138	135	114	82	121	110	34	76	101	111	⋯
138	102	128	159	168	147	116	129	124	117	⋯
113	89	89	109	106	126	114	150	164	145	⋯
120	121	123	87	85	70	119	64	79	127	⋯
145	141	143	134	111	124	117	113	64	112	⋯
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	



a b

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Intensity Image

In a intensity image, the number corresponds to a shade of gray.

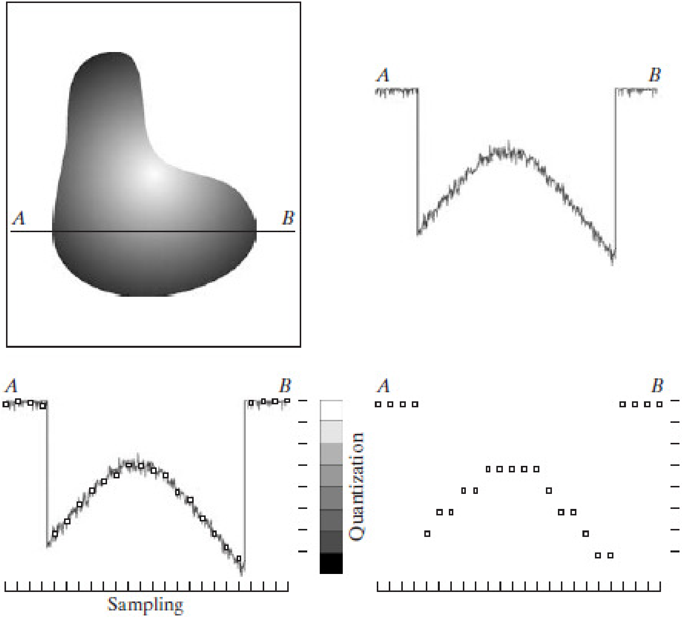
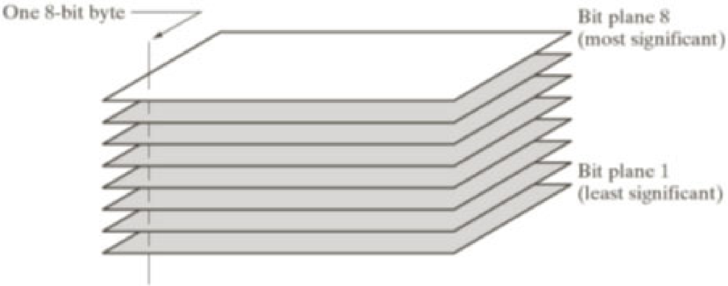


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.



Bit-plane representation of an 8-bit image.

a	b	c
d	e	f
g	h	i

FIGURE 3.14 (a) An 8-bit gray-scale image of size 500 × 1192 pixels. (b) through (i) Bit planes 1 through 8, with bit plane 1 corresponding to the least significant bit. Each bit plane is a binary image.

Pixel Values

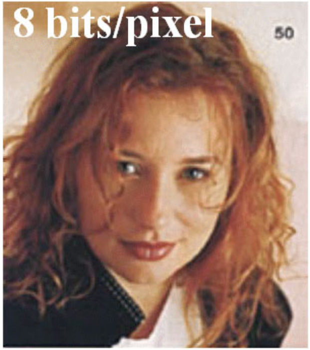
Information within an image element depends on the data type used to represent it. A pixel can be represented by any of 2^k different values. Common image types:

Grayscale (Intensity Images):

Chan.	*Bits/Pix.*	*Range*	*Use*
1	1	0...1	Binary image: document, illustration, fax
1	8	0...255	Universal: photo, scan, print
1	12	0...4095	High quality: photo, scan, print
1	14	0...16383	Professional: photo, scan, print
1	16	0...65535	Highest quality: medicine, astronomy

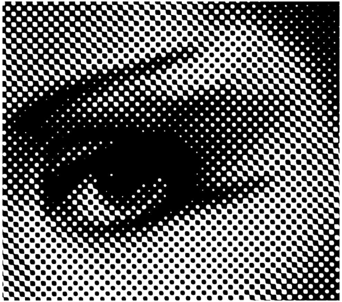
Quantization

How many different colors are needed to represent a particular image?



Binary images

- Binary image pixels can take on one of two values, black or white.
- These values are encoded using a single bit (0/1) per pixel.
- Used for representing line graphics, archiving documents, encoding fax transmissions, and by many printers.



Printing Example

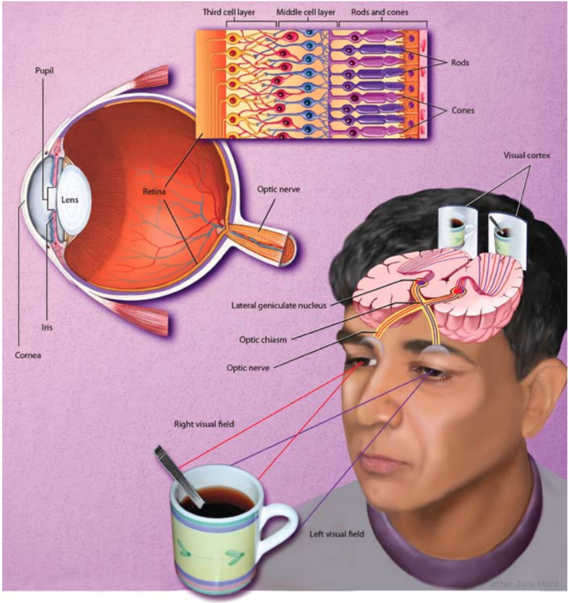
RGB Image

RED

GREEN

BLUE

Why Red, Green and Blue

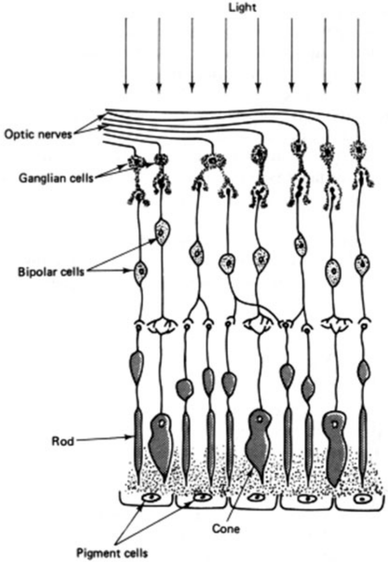


Human retina contains two types of light sensitive cells.

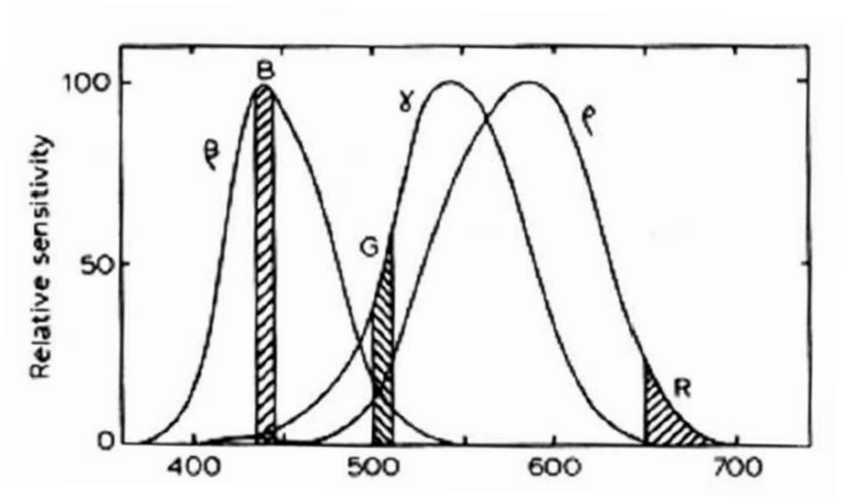
Why Red, Green and Blue

Human retina contains two types of light sensitive cells.

- RODS-sensitive to light intensity, sees only in gray-scale.
- Cones-see color. Red light, green light and Blue light sensitive cones.



Why Red, Green and Blue



Light sensitive curves for the red, green and blue sensitive cones.

Image Sensing

Interest in digital imaging methods stems from two main applications:

- Improvement of pictorial information for human interpretation
  - Vision is the most advanced of human senses
  - Limited to visual band of EM spectrum
- Processing of image data for medicine, science, surveilance, consumer electronics.
  - Imaging machines cover almost the entire EM spectrum

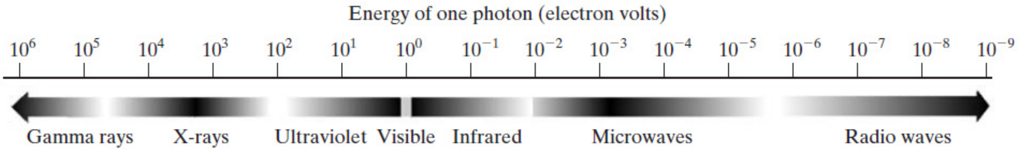
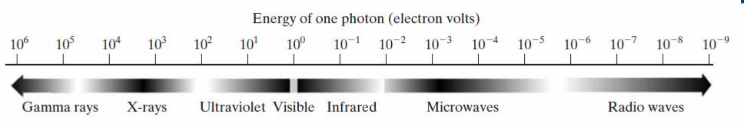
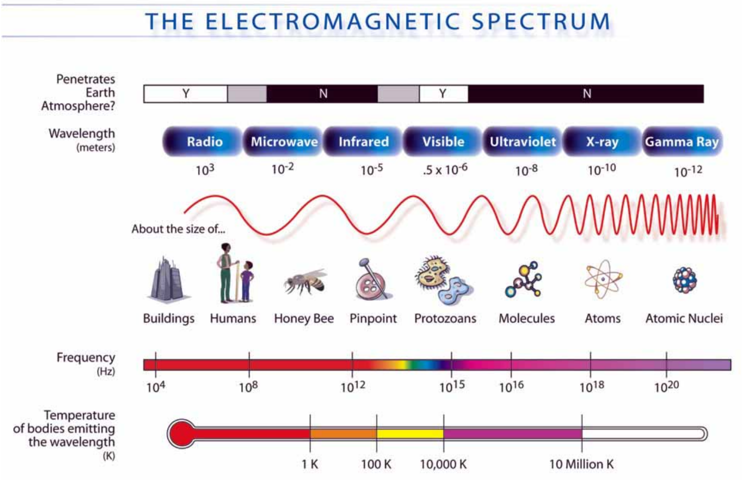
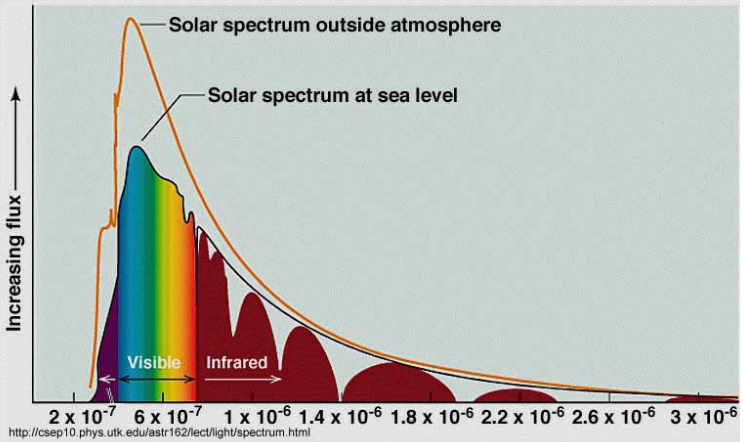
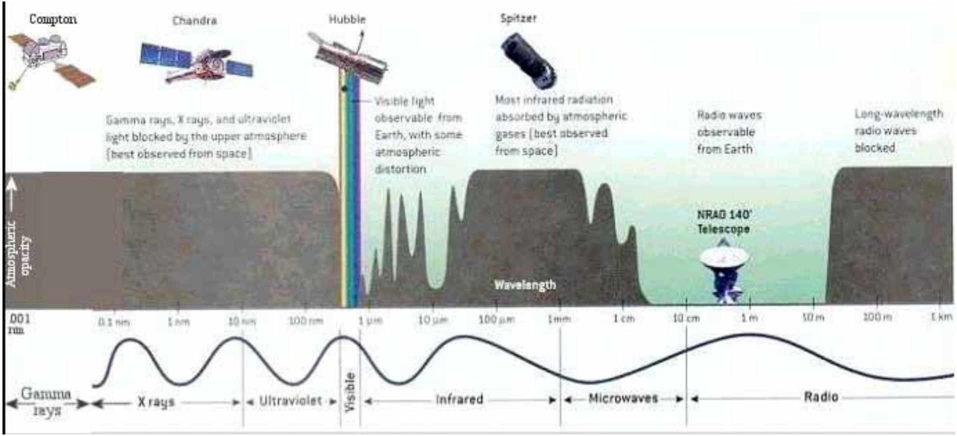


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

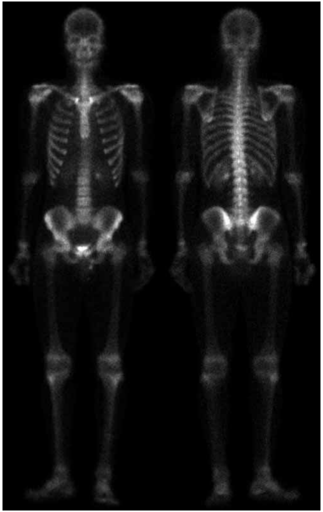

Energy of one photon (electron volts)
10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9
Gamma rays
X-rays
Ultraviolet
Visible
Infrared
Microwaves
Radio waves

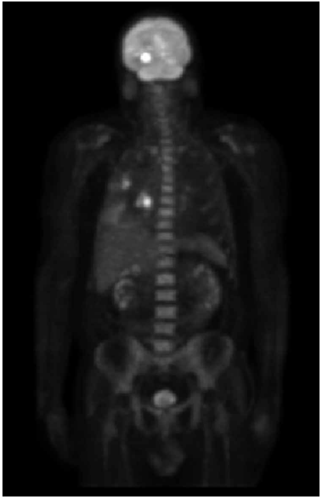

THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^-2
10^-5
.5 x 10^-6
10^-8
10^-10
10^-12
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K


Solar spectrum outside atmosphere
Solar spectrum at sea level
Increasing flux
Visible
Infrared
2 x 10-7
6 x 10-7
1 x 10-6
1.4 x 10-6
1.8 x 10-6
2.2 x 10-6
2.6 x 10-6
3 x 10-6
http://csep10.phys.utk.edu/astr162/lect/light/spectrum.html


Compton
Chandra
Hubble
Spitzer
Gamma rays, X rays, and ultraviolet light blocked by the upper atmosphere (best observed from space)
Visible light observable from Earth, with some atmospheric distortion
Most infrared radiation absorbed by atmospheric gases (best observed from space)
Radio waves observable from Earth
Long-wavelength radio waves blocked
NRAO 140' Telescope
Atmospheric opacity
Wavelength
.001 nm
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Gamma rays
X rays
Ultraviolet
Visible
Infrared
Microwaves
Radio

Applications



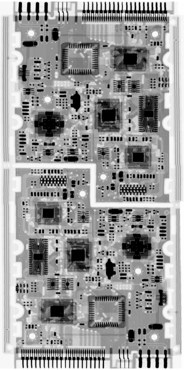


- Gamma-Ray imaging: radioactive isotope in patient emits gamma rays as it decays.

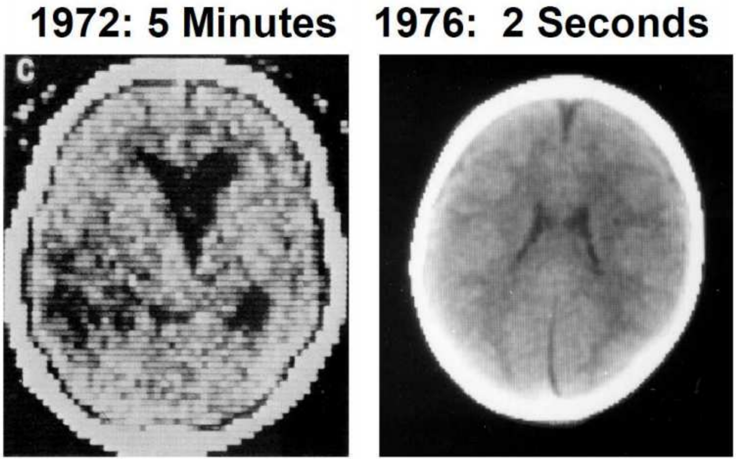
X-ray Imaging

- X-rays.
- Angiogram.
- CAT scans (Housefield and Cormmack 1979 - Nobel prize in medicine).
- Industrial inspection.
- Astronomy.



2^{nd} and 3^{rd} CT Generations

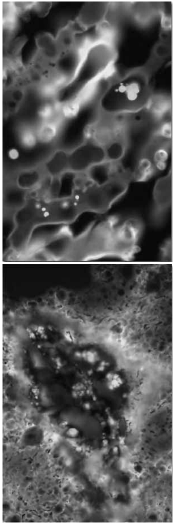


2G

3G

Imaging in the ultraviolet band

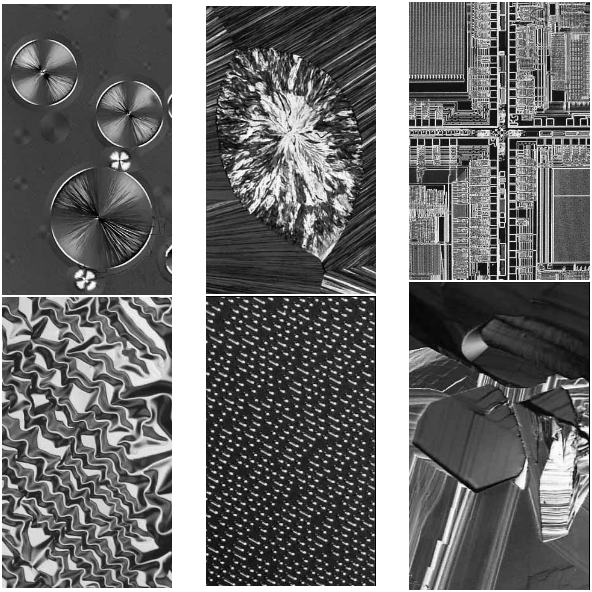
- Fluorescent microscopy
- UV photon collides with electron in fluorescent atom, elevates electron to a higher energy electron then emits light at lower energy when it relaxes.

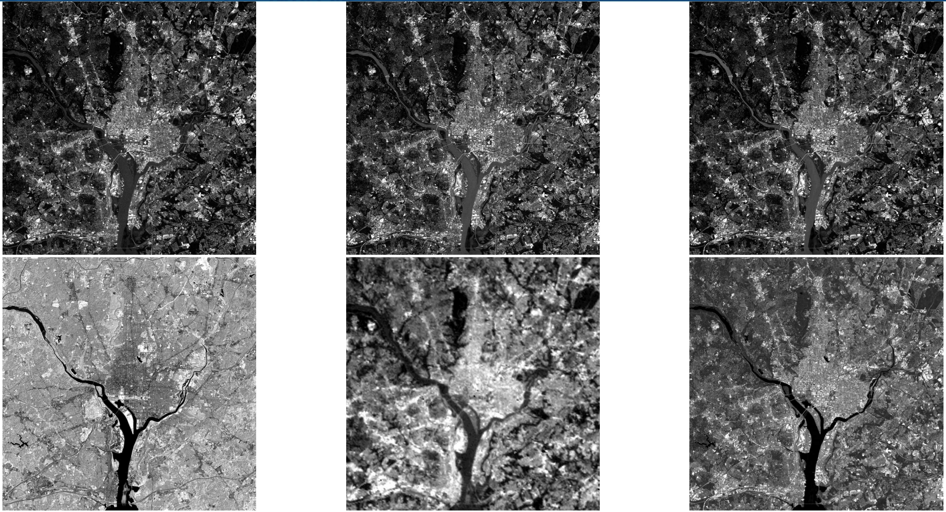


Color-coded surgery:
https:www.ted.comtalksquyen_nguyen_color_coded_surgery?languageēn

Imaging in the visible and infrared band

- Microscopy at various scales



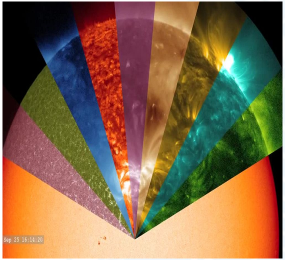


Remote sensing and spectral imaging

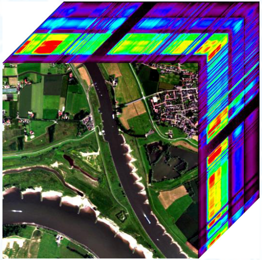
- Same scene at various bands.
- Visible through IR (450nm - 2000nm).

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

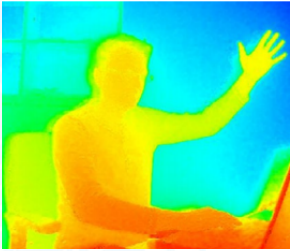
Multimodal Imaging



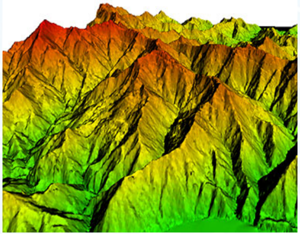
Spectral Imaging

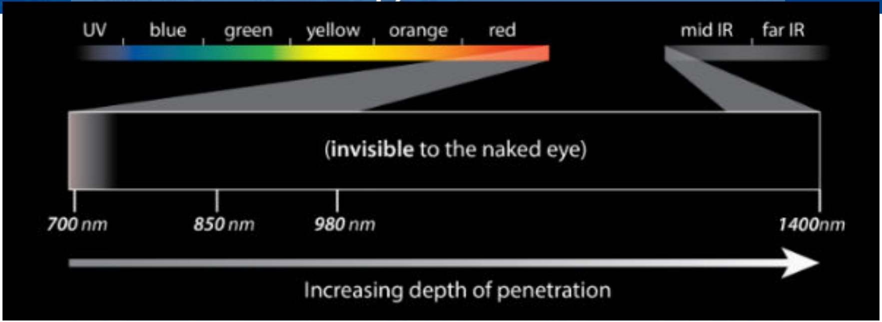


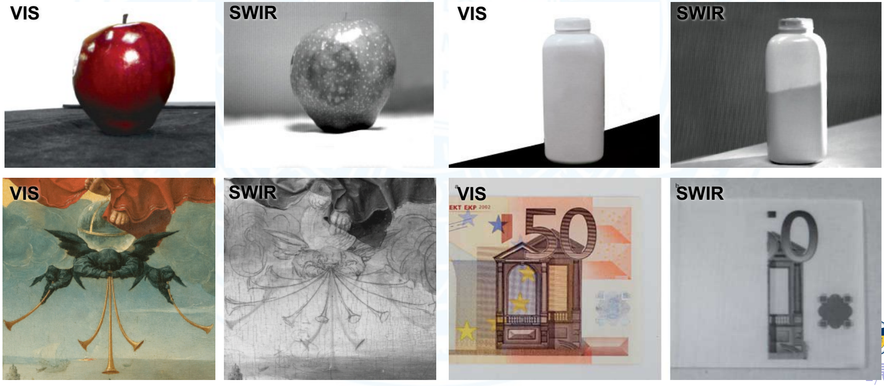
Hyperspectral Imaging



Depth Maps

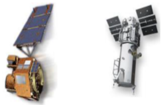



UV
blue
green
yellow
orange
red
mid IR
far IR
(invisible to the naked eye)
700 nm
850 nm
980 nm
1400nm
Increasing depth of penetration


VIS
SWIR
VIS
SWIR
VIS
SWIR
VIS
SWIR

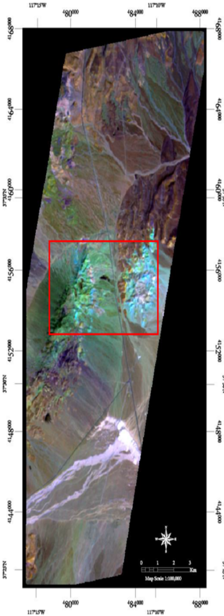
HYPERION AND WV3 FUSION

Cuprite, Nevada, US

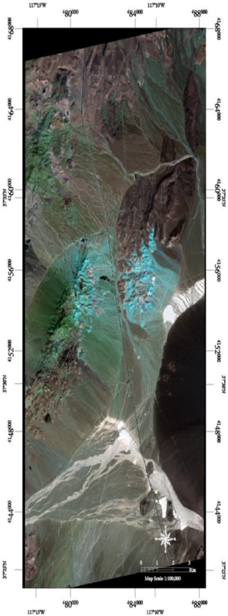


© DigitalGlobe

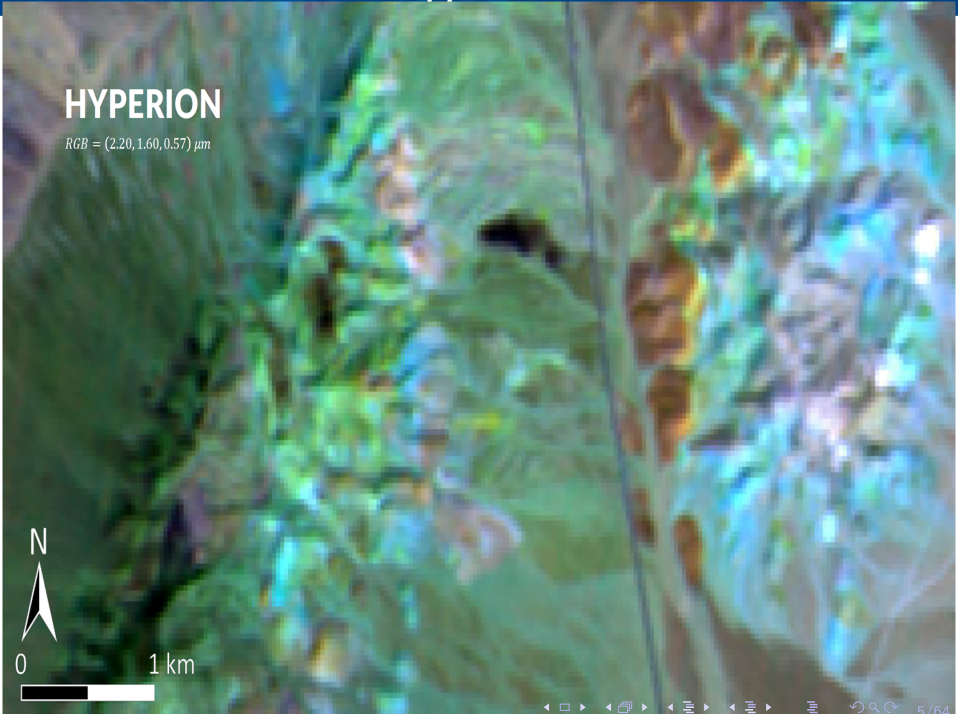
		Hyperion	WorldView-3
Number of bands	VNIR	50 (70)	8
	SWIR	117 (172)	8
GSD (m)	VNIR	30	1.24
	SWIR	30	7.5 (3.7)
Swath width (km)		7.7	13.1

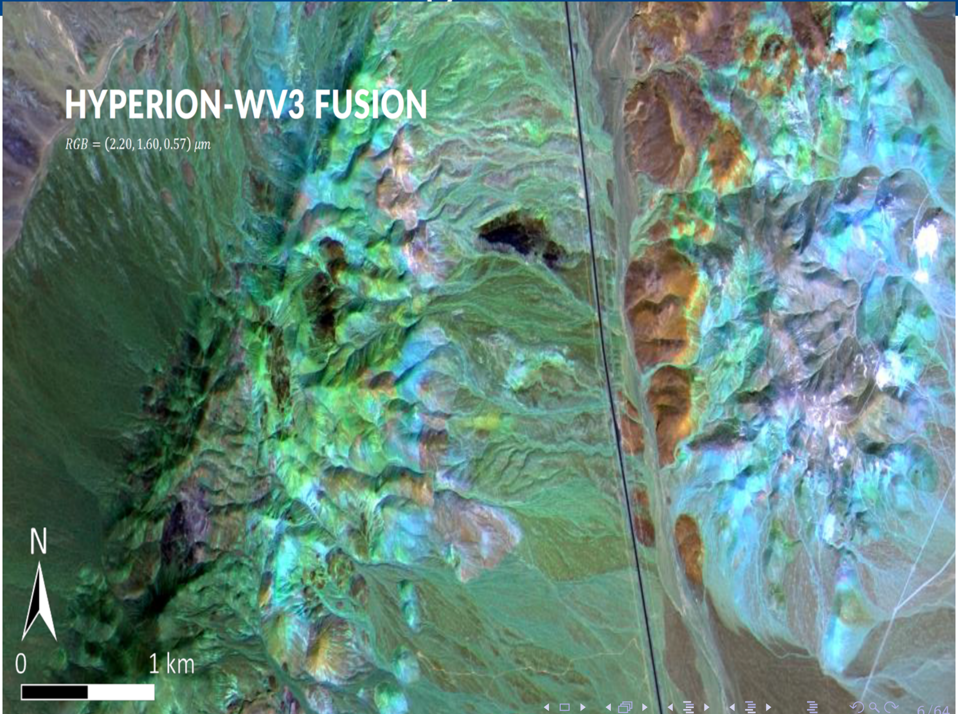


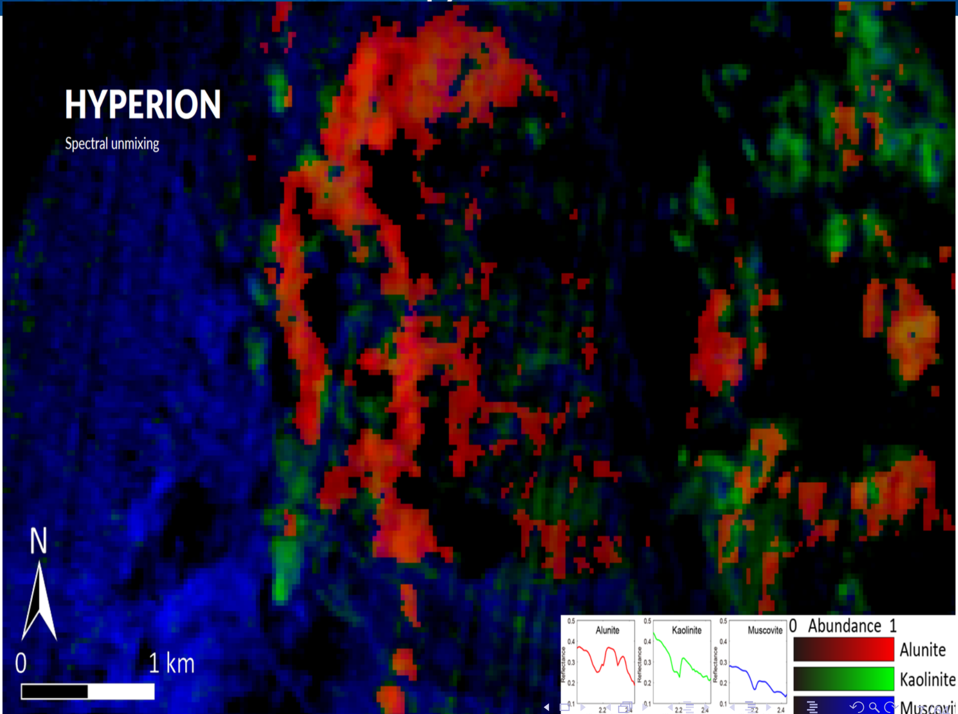
Color composite of Hyperion
$RGB = (2.20, 1.60, 0.57)\ \mu m$
2011-09-19

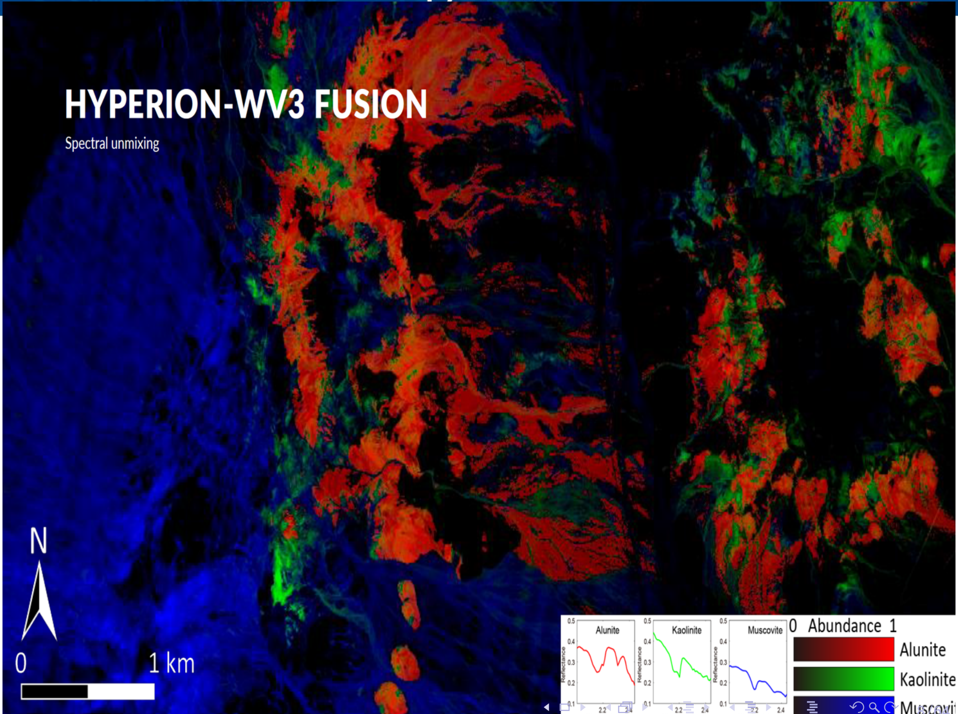


Color composite of WV3-SWIR
$RGB = (2.20, 1.57, 1.21)\ \mu m$
2014-09-19 © DigitalGlobe

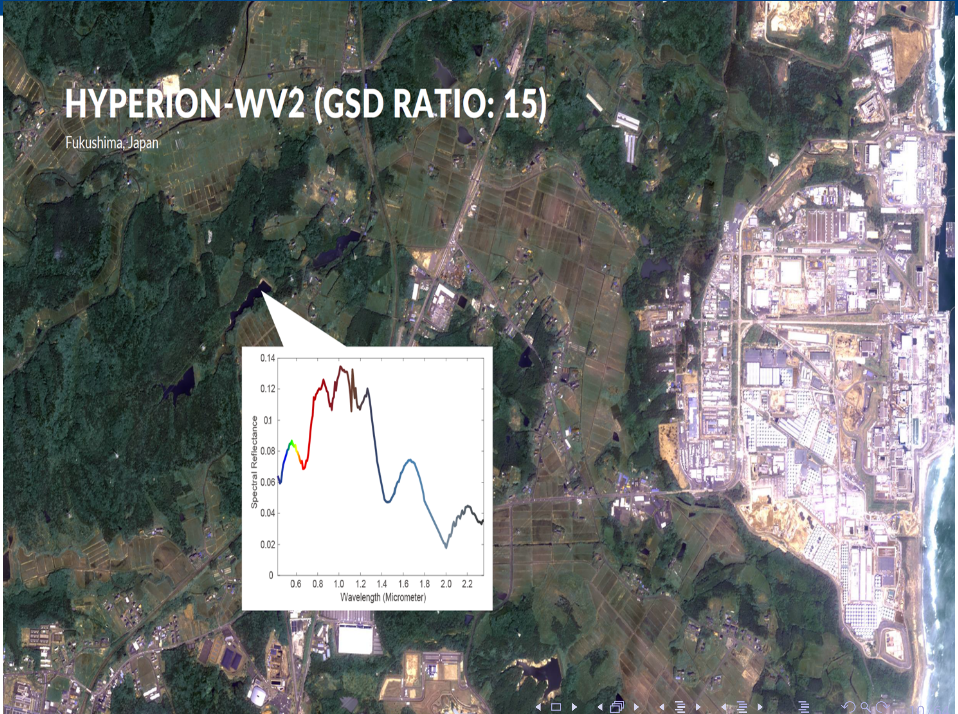

HYPERION
RGB = (2.20, 1.60, 0.57) μm
N
0
1 km


HYPERION-WV3 FUSION
RGB = (2.20, 1.60, 0.57) μm
N
0
1 km

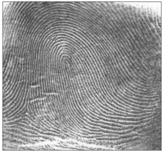

HYPERION
Spectral unmixing
N
0
1 km
Alunite
Kaolinite
Muscovite
0 Abundance 1
Alunite
Kaolinite


HYPERION-WV3 FUSION
Spectral unmixing
N
0
1 km
Alunite
Kaolinite
Muscovite
0 Abundance 1
Alunite
Kaolinite


HYPERION
Fukushima, Japan


HYPERION-WV2 (GSD RATIO: 15)
Fukushima, Japan
Spectral Reflectance
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2
Wavelength (Micrometer)

Medical Spectral Imaging



Visible band imaging

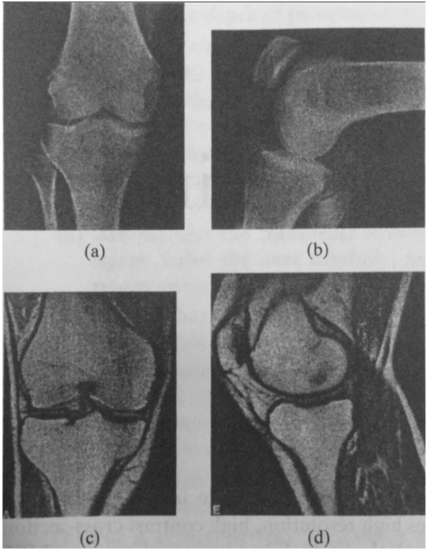
- Applications in biometrics, authentication and surveillance.

Magnetic Resonance Imaging

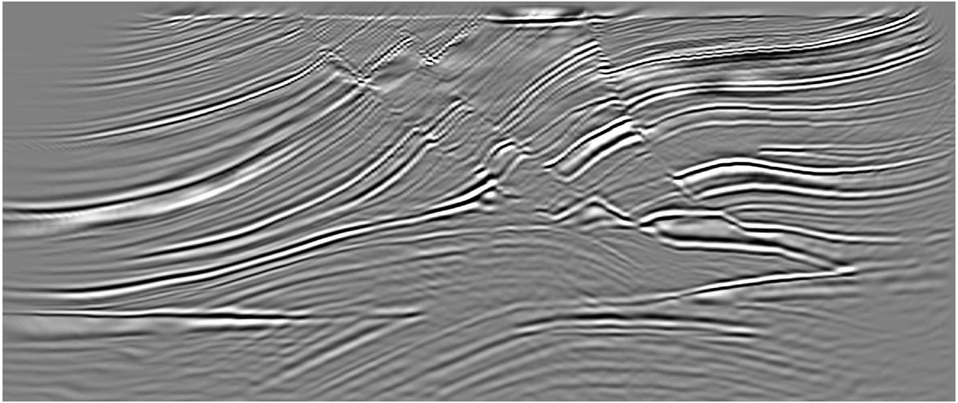
X-ray CT vs MRI

Comparison of projection radioagraphy and MRI of the knee:

- a Anterior projection radiograph
- b Lateral projection radiograph
- c Coronal MRI
- d Sagittal MRI

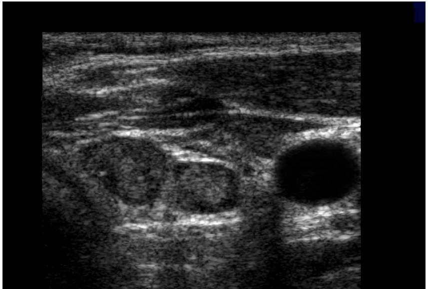
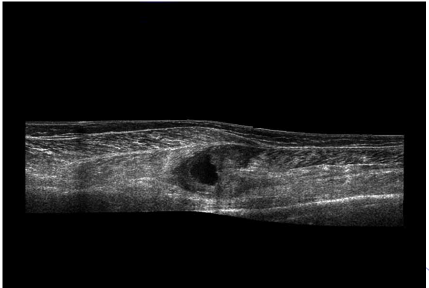


Geological Seismic Exploration (100 Hz)



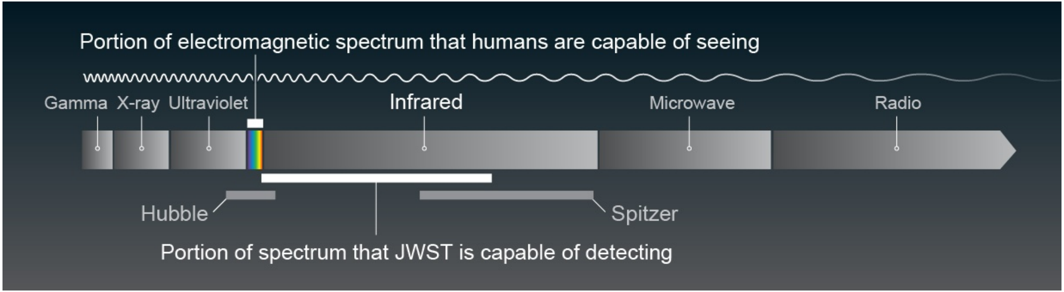
Ultrasound imaging (1-5Mhz)



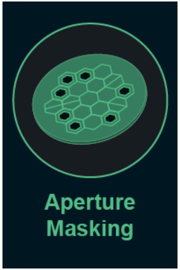
James Webb Space Telescope Imaging

- 10 Billion camera
- Can view objects too old in distance
- Can observe the first stars, the formation of the first galaxies, and atmospheric characterization of potentially habitable planets.



The JWST was designed to capture light with frequencies in the infrared range.

JWST - Six Data Collection Components

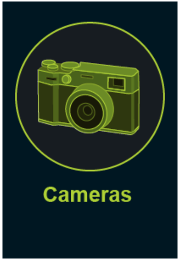


It allows combining data from multiple telescopes for higher resolution than a single lens can achieve

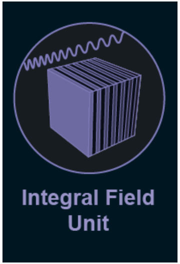
A grid of small doors can open or close to measure spectra from up to 100 points in a single frame

Coronagraphs are opaque circles that block bright starlight to let the weaker signals through

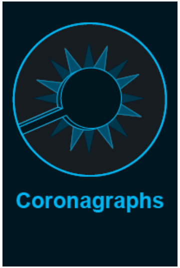
JWST - Six Data Collection Components



Two cameras capture light in the near-infrared range and one works in the mid-infrared

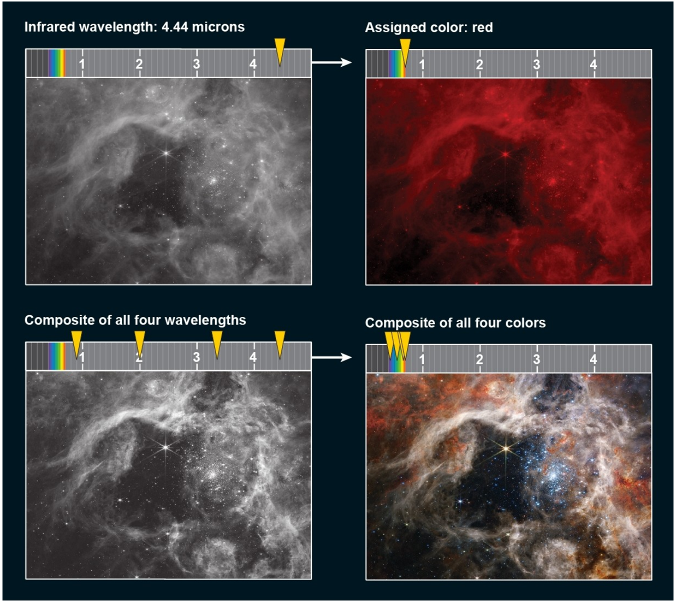


A combined camera and spectrograph captures an image, along with spectra for each pixel

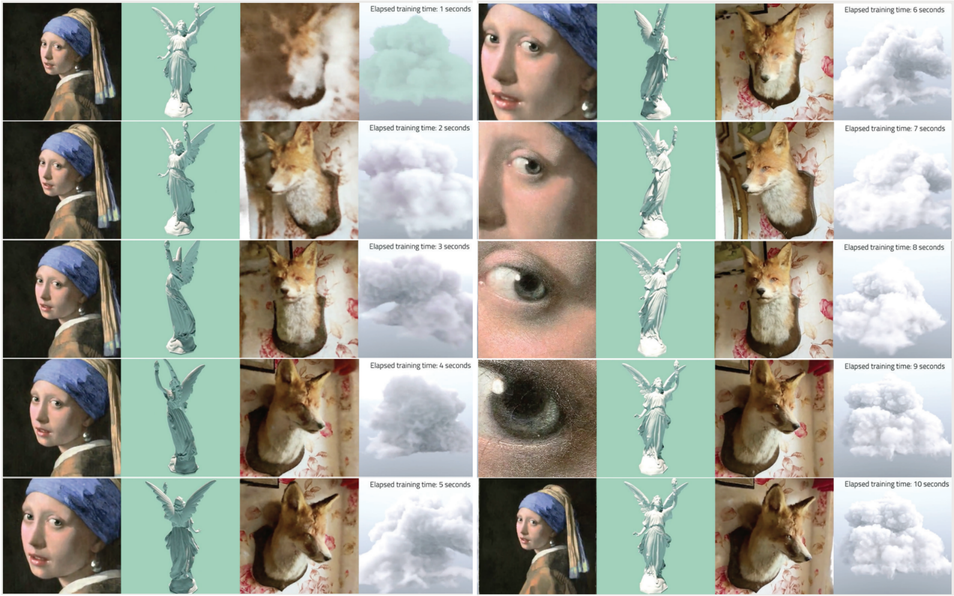


prisms separate incoming light into spectra to reveal the intensity of individual wavelengths

JWST - Image Composite

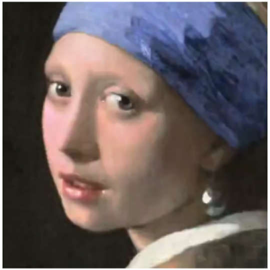


AI Computer Rendering



AI Computer Rendering

Neural gigapixel images



Gigapixel Image Generation

Neural SDF

Learns a signed distance function in 3D space whose zero level-set represents a 2D surface

NeRF

Reconstruct a volumetric radiance-and-density field from 2D Images

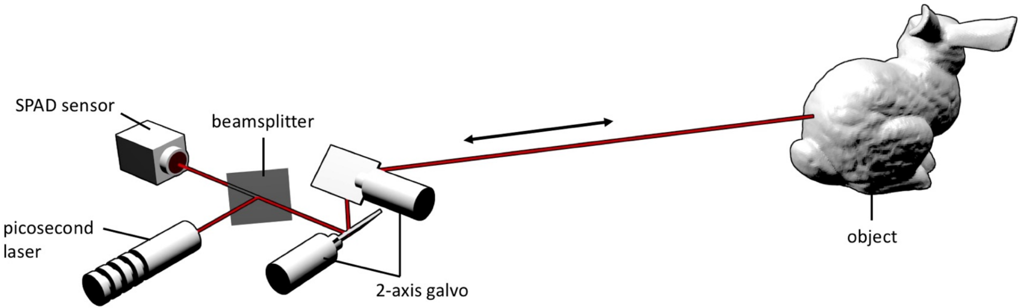
Neural volume

Learns a denoised radiance and density field directly from a volumetric path tracer

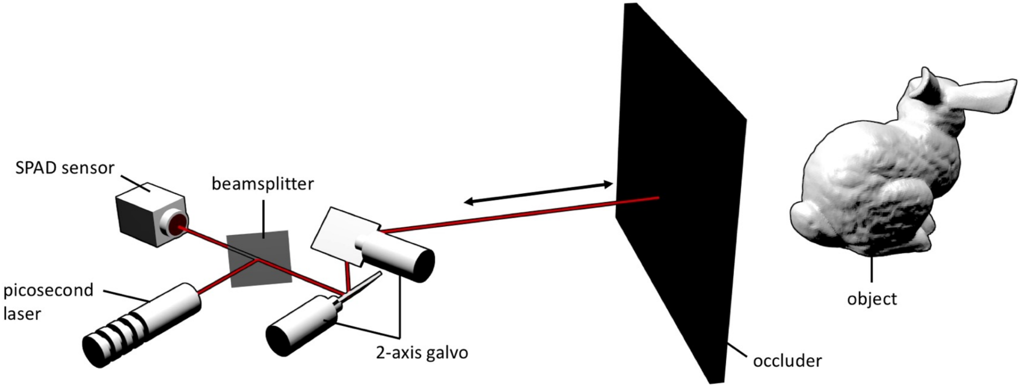
AI Computer Rendering

The quality of the scene becomes more precise as training proceeds. Video

Imaging Around the Corner



Imaging Around the Corner



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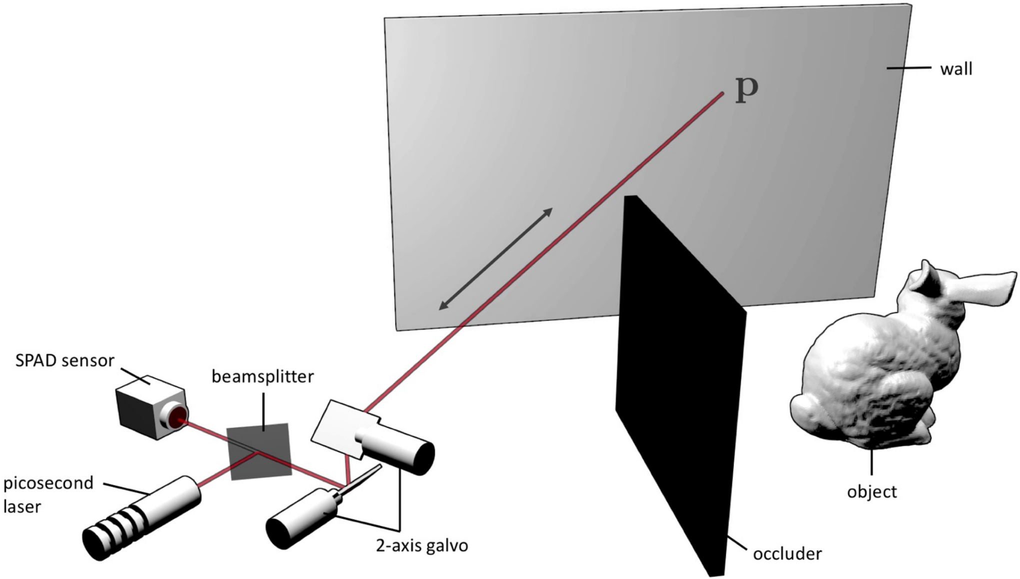

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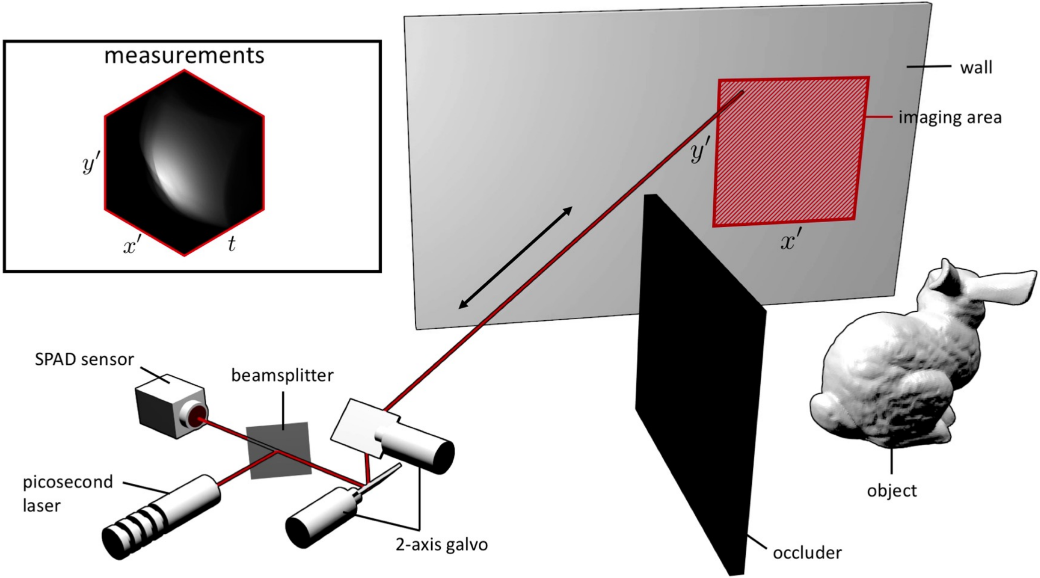

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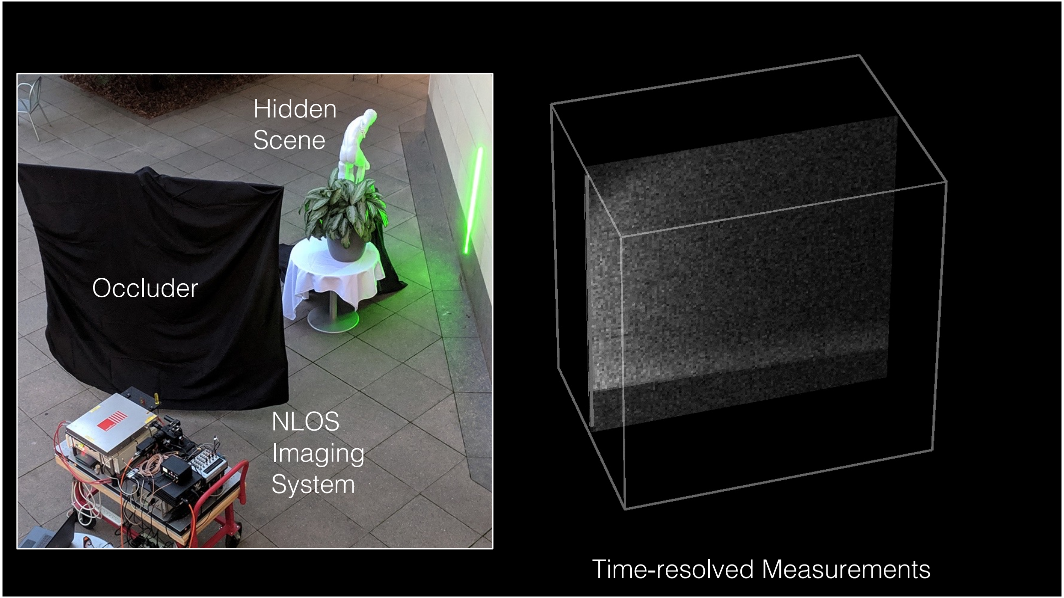
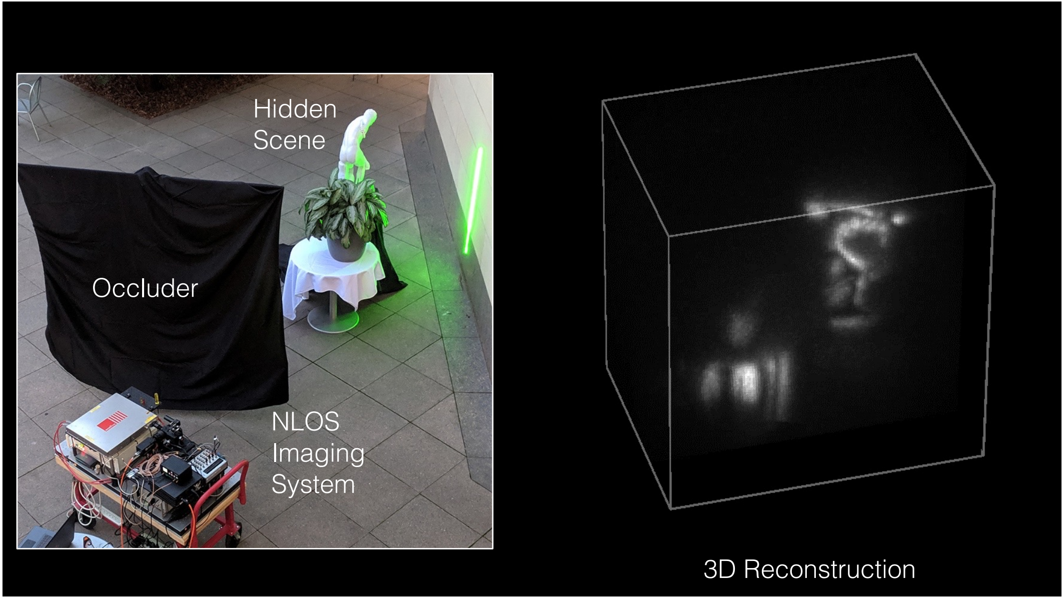


Imaging Around the Corner



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- Gonzales, R. C., & Wintz, P. (1987). Digital image processing. Addison-Wesley Longman Publishing Co., Inc..