ELEG404/604: Digital Imaging & Photography

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Introduction

Course Objectives & Structure

Digital imaging is everywhere at the heart of science, medicine, entertainment, engineering, and communications. This course provides an introduction to mathematical tools for the analysis and processing of digital images.

Course Structure:

- Weekly lectures [notes: https://www.eecis.udel.edu/∼arce/courses/digitalimgproc/]
- Homework & computer assignments [20%]
- Midterms & Final examination [80%]
- No cell phone or Laptop use in class

Textbook:

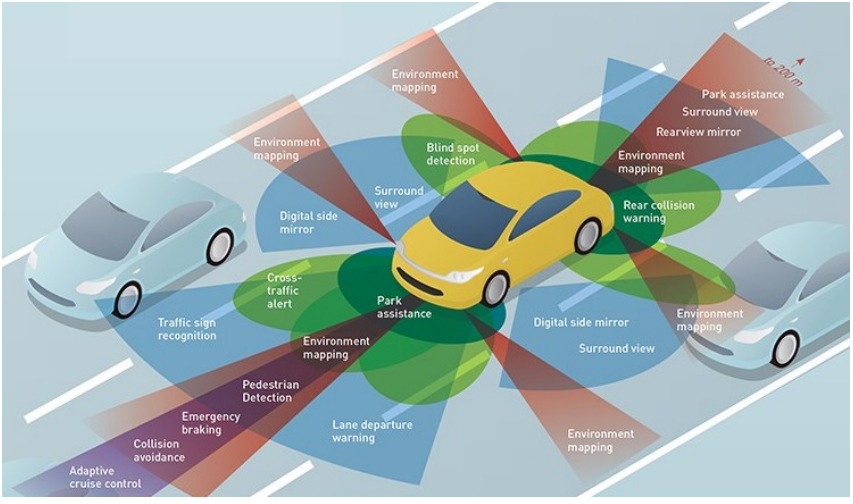
- R. Gonzalez and R. Woods. Digital Image Processing. 4th Ed. Prentice Hall.

Imaging: Key for Future Technology

Rise of the robots.

Boston Dynamics

Self-Driving Cars



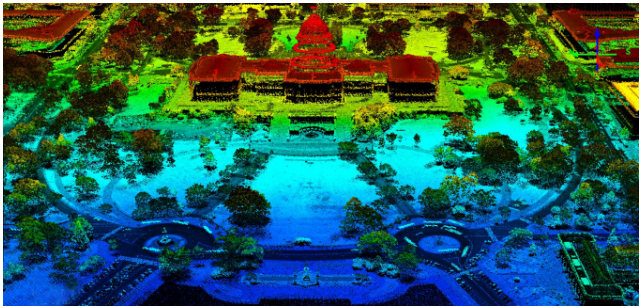
Long-range radar Ultrasound Short/medium-range radar

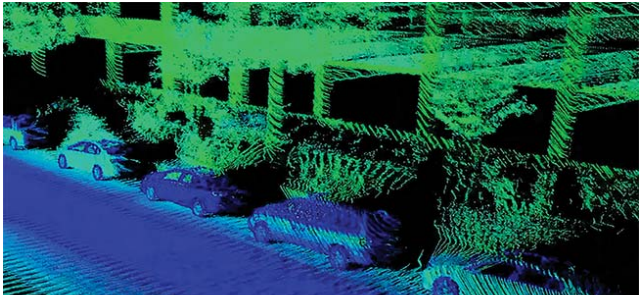
Optical Cameras Lidar

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

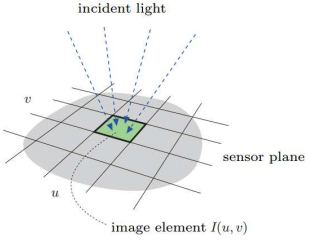
Left: iPhone XS. Right: Pixel 3 Night Sight.

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

Introduction

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

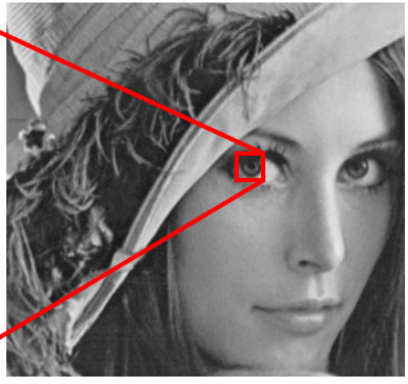
- An image may be defined as a function $f(x,y)$, where (x,y) are spatial coordinates and $f(x,y)$ is the intensity
- When x, y and f are all finite, discrete quantities the image is called a digital image
- Each $f(x,y)$ are referred to as picture elements, image elements, pels or pixels



What is an image?

In Digital Image Processing, an image is a matrix of numbers.

12	12	11	13	12
12	13	10	12	11
13	12	11	14	10
11	14	12	13	12
12	13	13	14	10

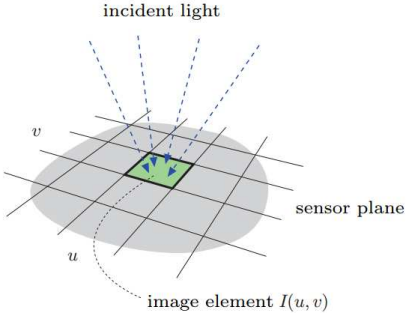


Each individual number in this matrix is a picture element or PIXEL.

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

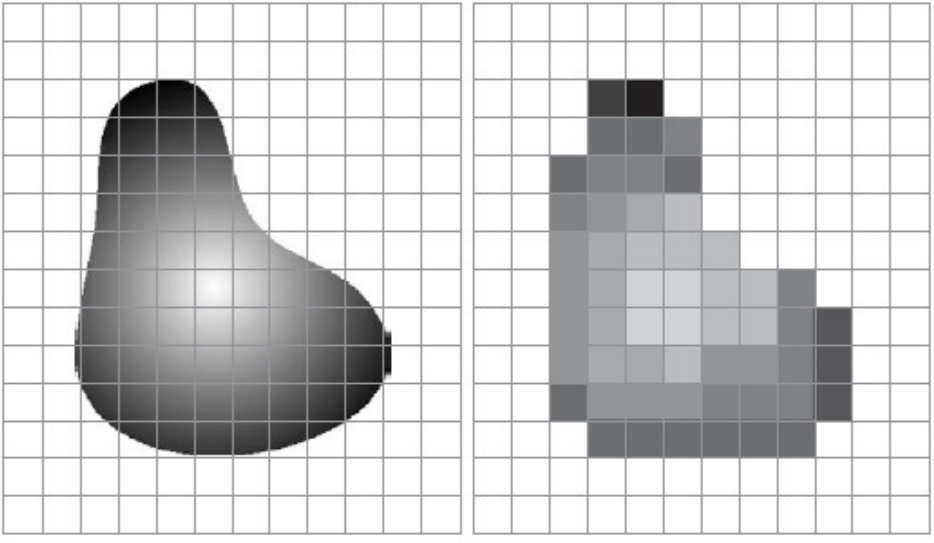


Going Digital

- 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 ···
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

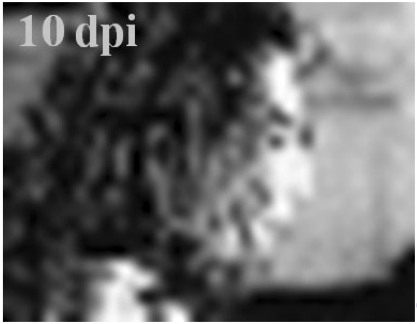


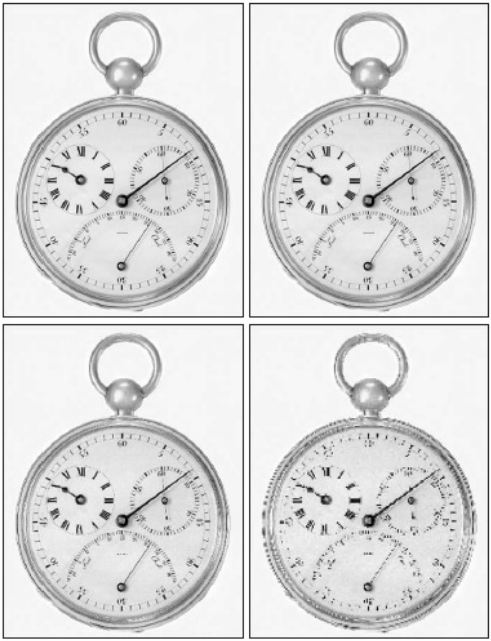
a b

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

Resolution

Is the amount of detail per unit area in an image.

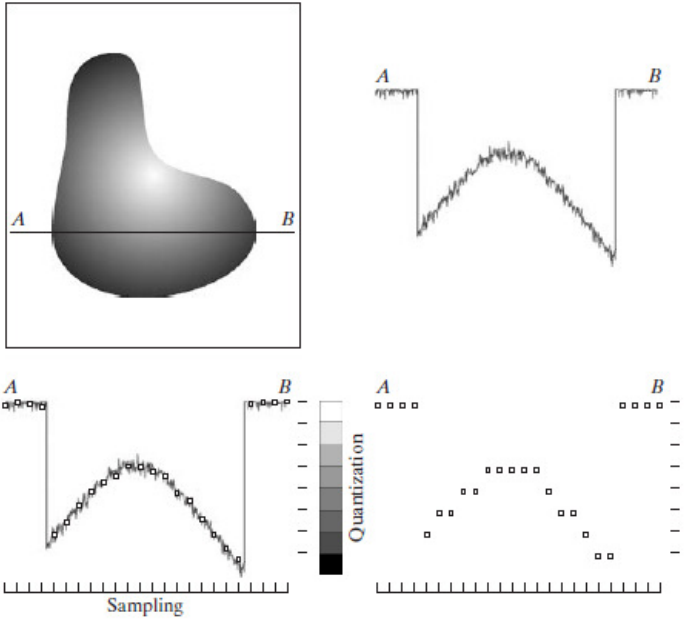




a b
c d

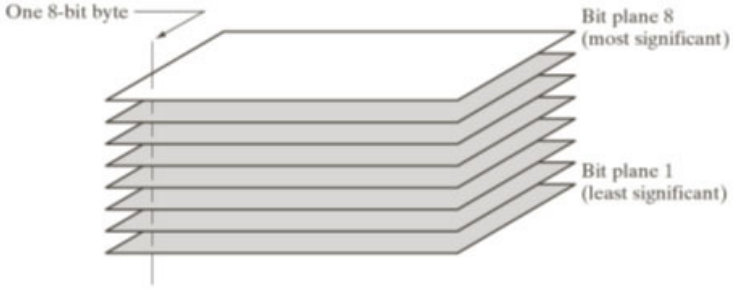
Intensity Image

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



a b
c d

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.

a b c

FIGURE 3.15 Images reconstructed using (a) bit planes 8 and 7; (b) bit planes 8, 7, and 6; and (c) bit planes 8, 7, 6, and 5. Compare (c) with Fig. 3.14(a).

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

Pixel Values

Color Images:

Chan.	*Bits/Pix.*	*Range*	*Use*
3	24	$[0...255]^3$	RGB, universal: photo, scan, print
3	36	$[0...4095]^3$	RGB, high quality: photo, scan, print
3	42	$[0...16383]^3$	RGB, professional: photo, scan, print
4	32	$[0...255]^4$	CMYK, digital prepress

Special Images:

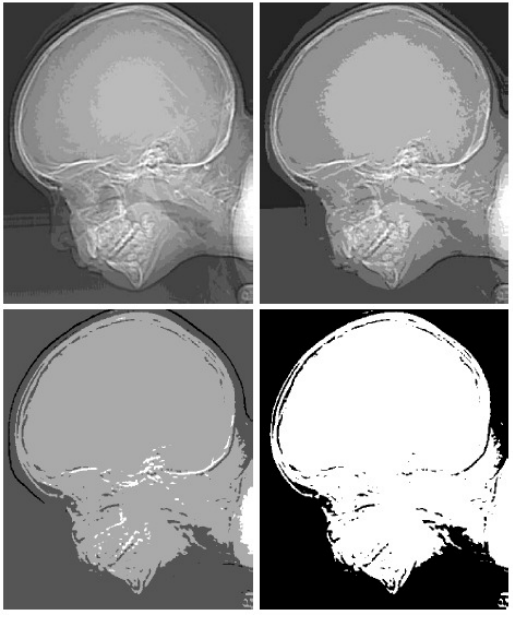
Chan.	*Bits/Pix.*	*Range*	*Use*
1	16	$-32768...32767$	Whole numbers pos./neg., increased range
1	32	$\pm 3.4 \cdot 10^{38}$	Floating point: medicine, astronomy
1	64	$\pm 1.8 \cdot 10^{308}$	Floating point: internal processing

Quantization

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

a b
c d

FIGURE 2.21
(a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 intensity levels, while keeping the image size constant.

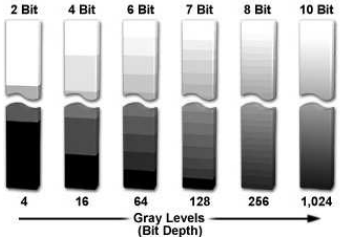


e f
g h

FIGURE 2.21 (*Continued*) (e)–(h) Image displayed in 16, 8, 4, and 2 intensity levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

Grayscale images

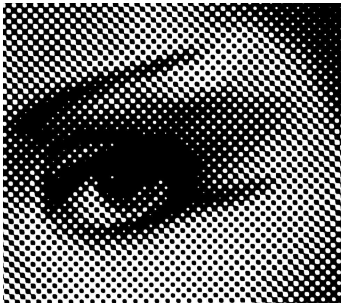
- Grayscale images consist of a single channel that represent the intensity, brightness, or density of the images.
- Whole integers in the range of $[0 \cdots 2k-1]$ are used.
- Typical grayscale images use $k = 8$ bits per pixel and intensity values in the range of $[0 \cdots 255]$, where the value 0 represents the minimum brightness (black) and 255 the maximum brightness (white).



8 bit

Binary images

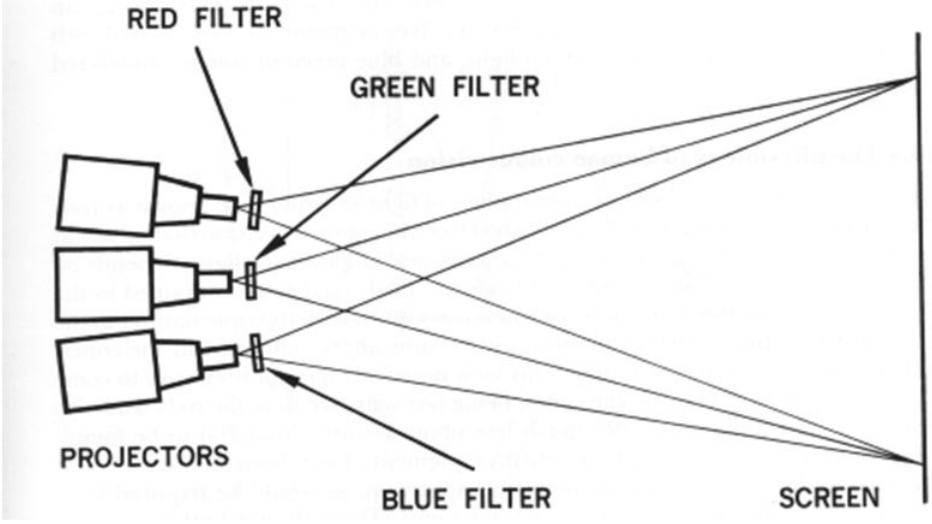
- Binary image pixels can take on one of two values, black or white.
- These values are encoded using a single bit (0/1) per pixel.
- Used for representing line graphics, archiving documents, encoding fax transmissions, and by many printers.



Printing Example

RGB Image

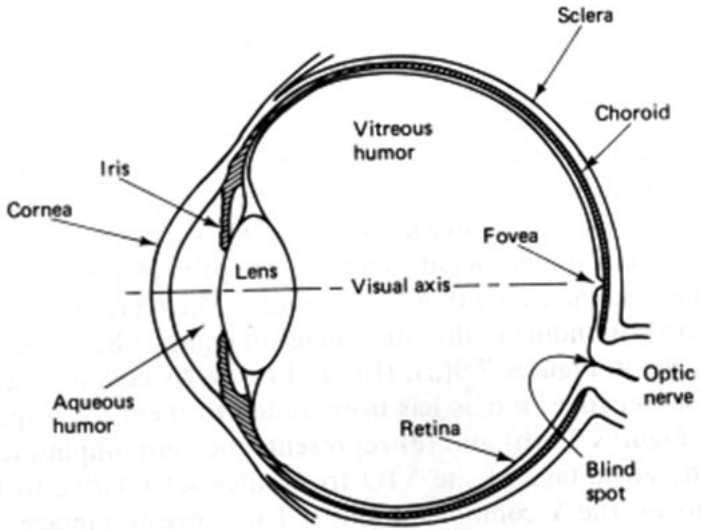
In a Red-Green-Blue (RGB) image, all colors are made by mixing the primary colors red, green and blue.



RGB Image

Why Red, Green and Blue

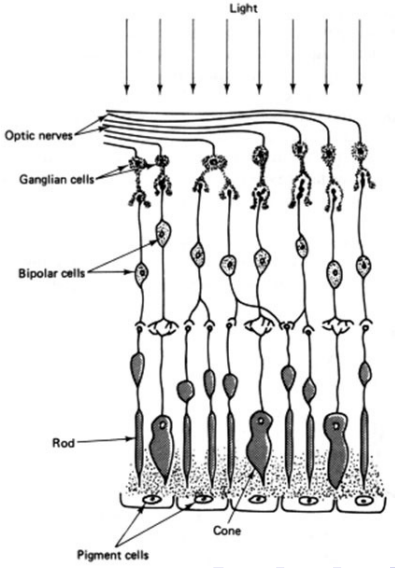
Human retina contains two types of light sensitive cells.



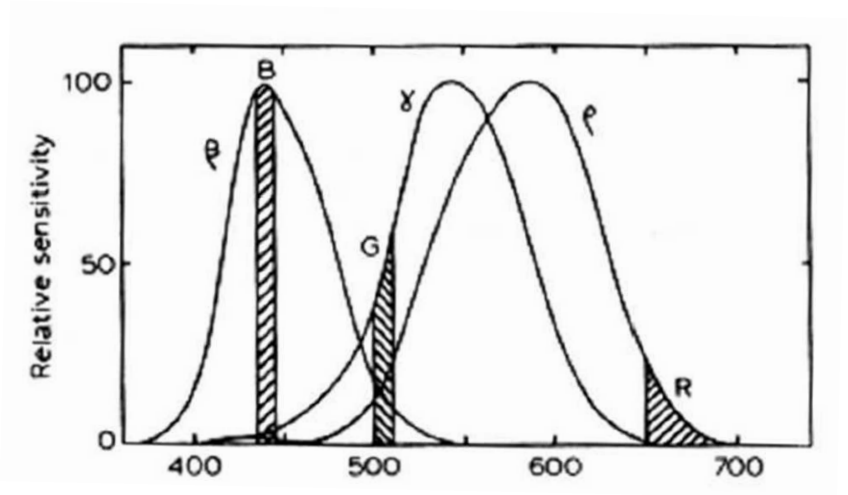
Why Red, Green and Blue

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

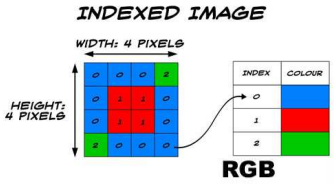


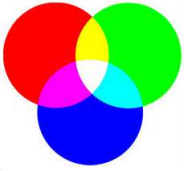
Light sensitive curves for the red, green and blue sensitive cones.

4K LED displays

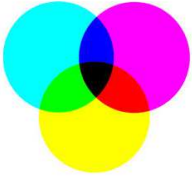
Color images

- Color images encode primary colors red, green, and blue (RGB), making use of 8 bits per component.
- In digital prepress there are images that use subtractive color models with four color components, CMYK (Cyan-Magenta-Yellow-Black).
- The difference between an indexed image and a true color image is the number of different colors (fewer for an indexed image.)





CMYK



Indexed Image

In an indexed image, the number is an index into a look-up table.

Image Sensing

Interest in digital image processing 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, surveilance, consumer electronics.
  - Imaging machines cover almost the entire EM spectrum

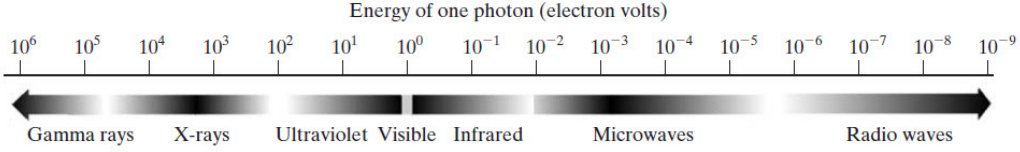
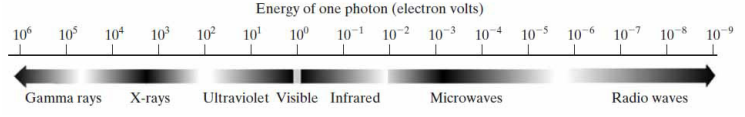
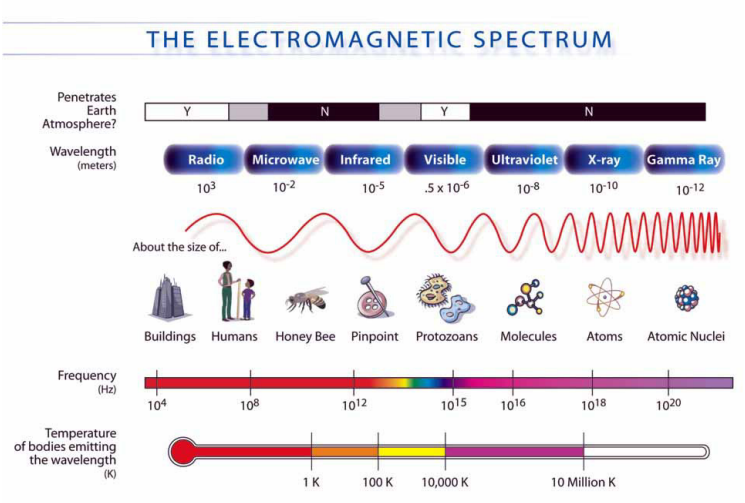
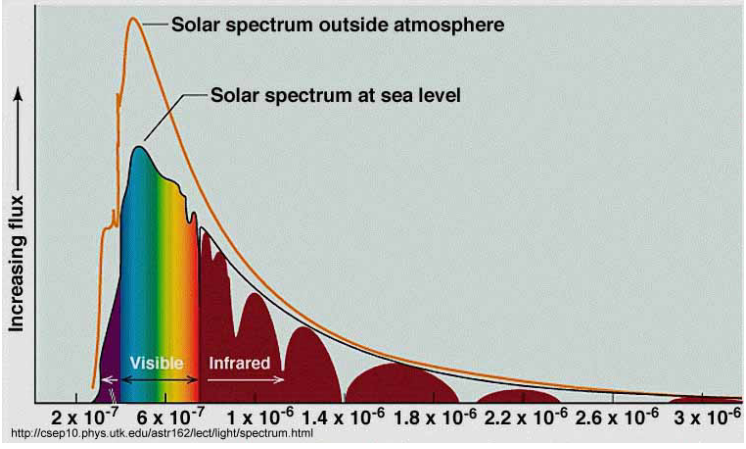
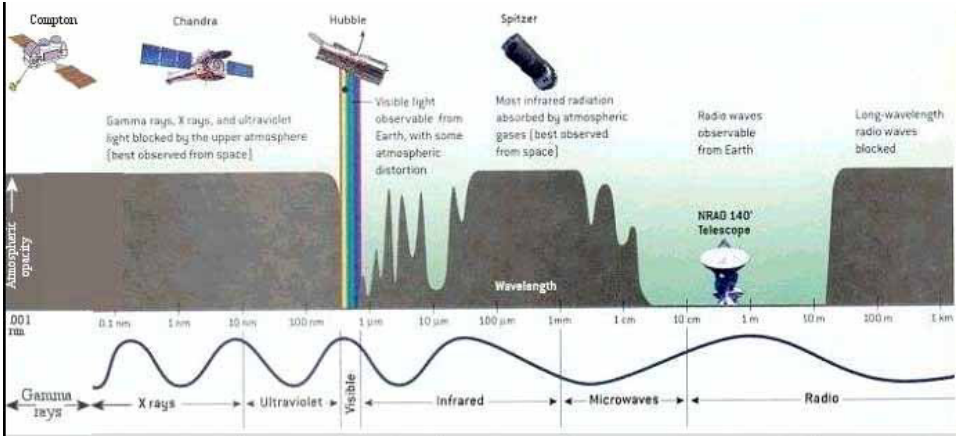


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

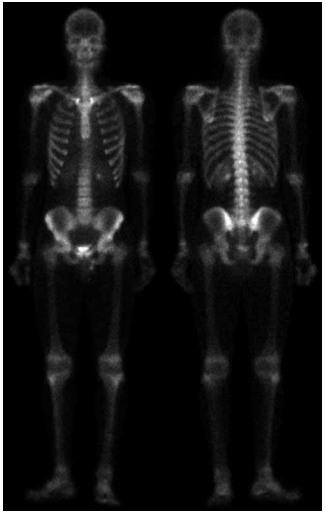

Energy of one photon (electron volts)
10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}
Gamma rays
X-rays
Ultraviolet
Visible
Infrared
Microwaves
Radio waves

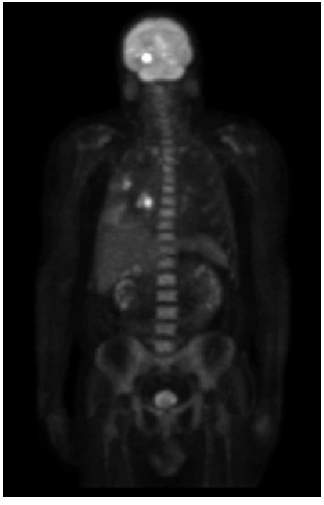

THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^{-2}
10^{-5}
$.5 \times 10^{-6}$
10^{-8}
10^{-10}
10^{-12}
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic 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

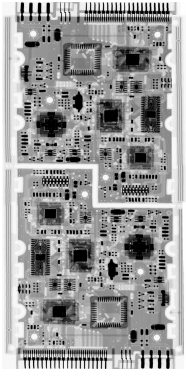




- Gamma-Ray imaging: radioactive isotope in patient emits gamma rays as it decays.

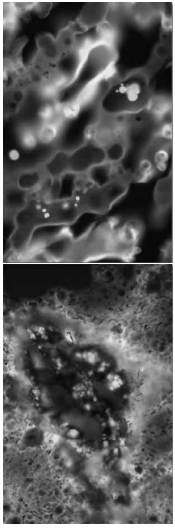
X-ray Imaging

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



Imaging in the ultraviolet band

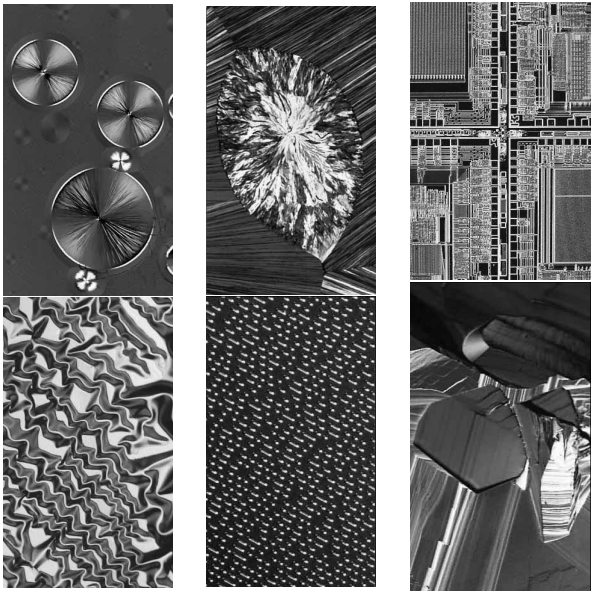
- Fluorescent microscopy
- UV photon collides with electron in fluorescent atom, elevates electron to a higher energy electron then emits light at lower energy when it relaxes.

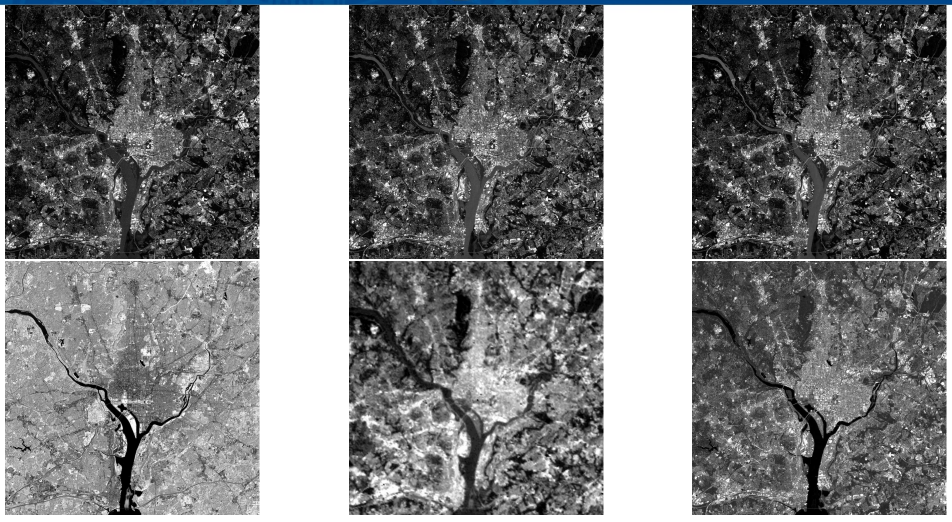


Color-coded surgery:
https:www.ted.comtalksquyen_nguyen_color_coded_surgery?languageēn

Imaging in the visible and infrared band

- Microscopy at various scales



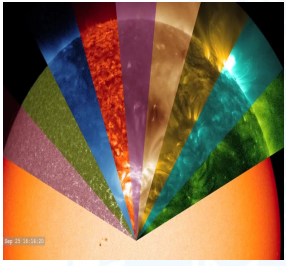


Remote sensing and spectral imaging

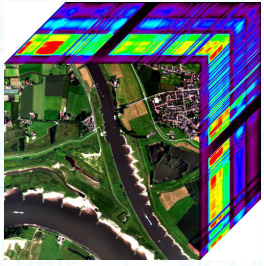
- Same scene at various bands.
- Visible through IR (450nm - 2000nm).

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

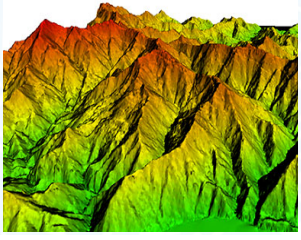


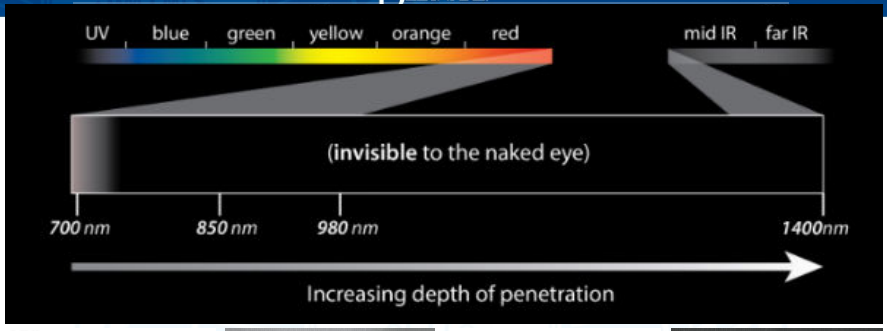
Spectral Imaging

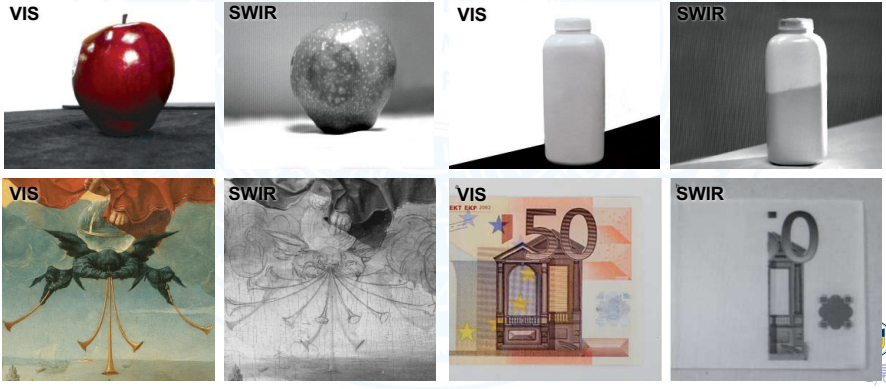


Hyperspectral Imaging

Depth Maps

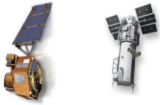



UV
blue
green
yellow
orange
red
mid IR
far IR
(invisible to the naked eye)
700 nm
850 nm
980 nm
1400nm
Increasing depth of penetration


VIS
SWIR
VIS
SWIR
VIS
SWIR
VIS
SWIR

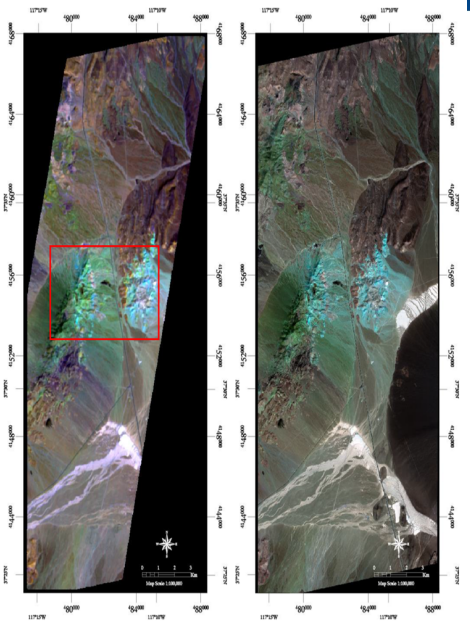
HYPERION AND WV3 FUSION

Cuprite, Nevada, US



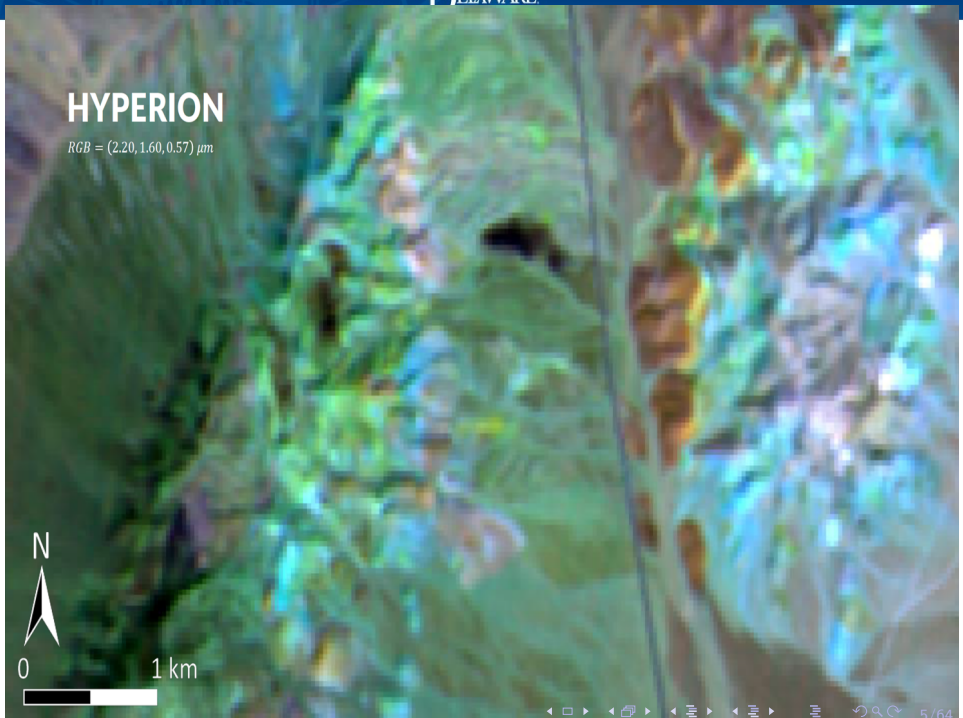
© DigitalGlobe

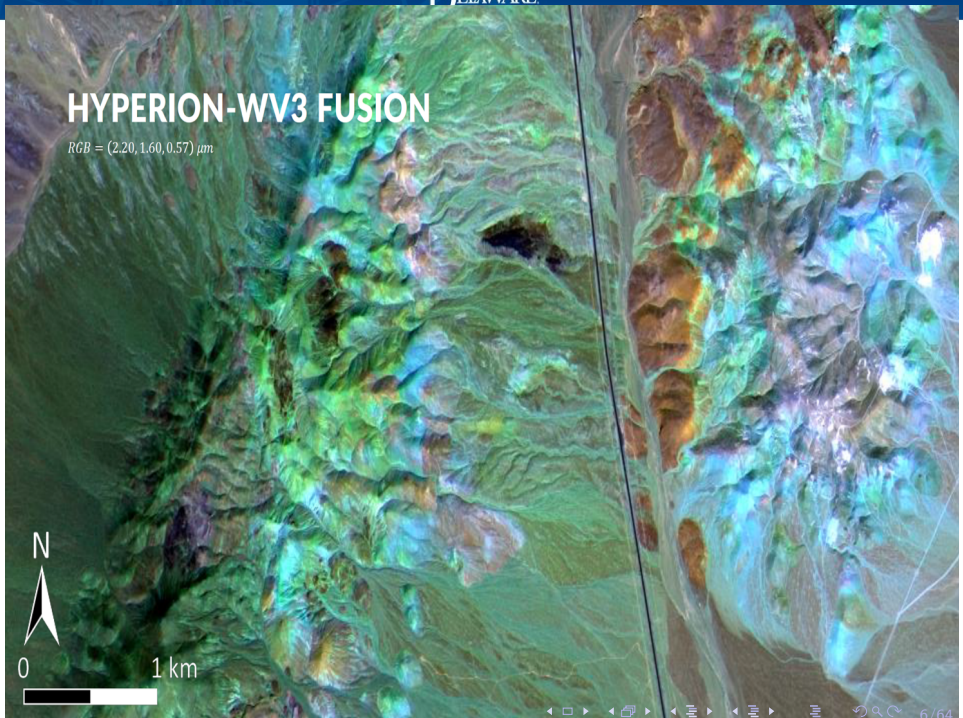
		Hyperion	WorldView-3
Number of bands	VNIR	50 (70)	8
	SWIR	117 (172)	8
GSD (m)	VNIR	30	1.24
	SWIR	30	7.5 (3.7)
Swath width (km)		7.7	13.1

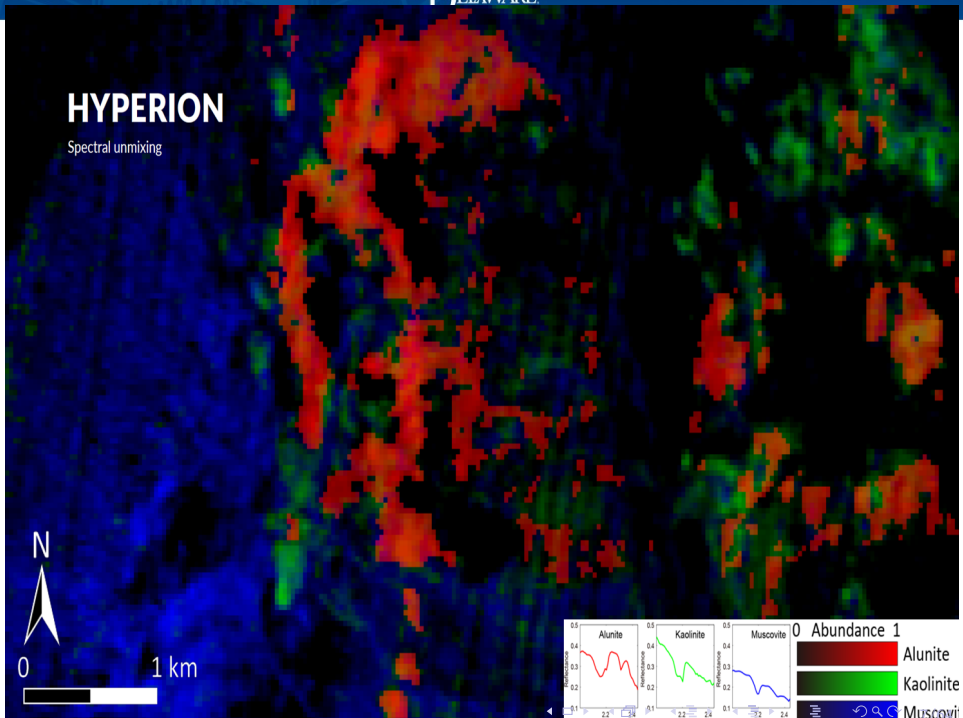


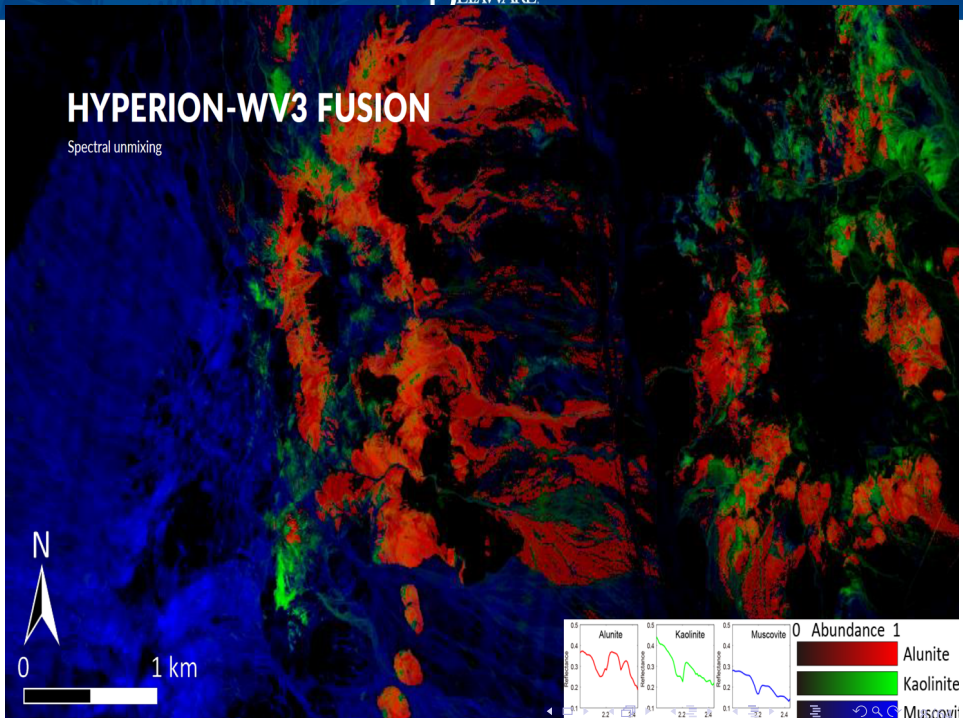
Color composite of Hyperion
$RGB = (2.20, 1.60, 0.57)\ \mu m$
2011-09-19

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

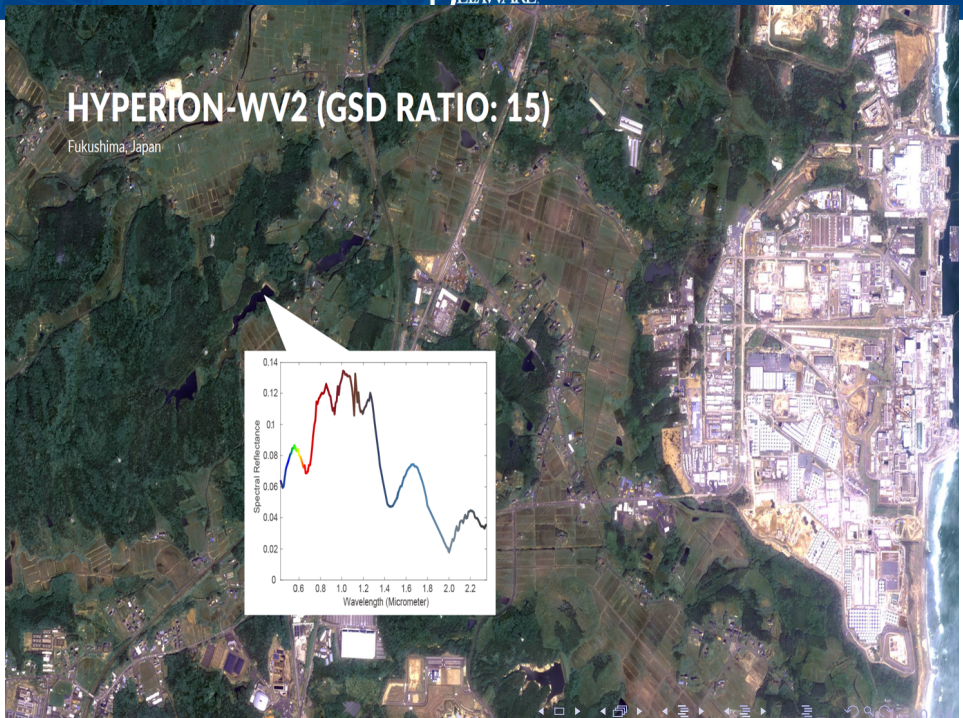

HYPERION
RGB = (2.20, 1.60, 0.57) μm
N
0
1 km


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
Reflectance
0 Abundance 1
Alunite
Kaolinite
Muscovit


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


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)

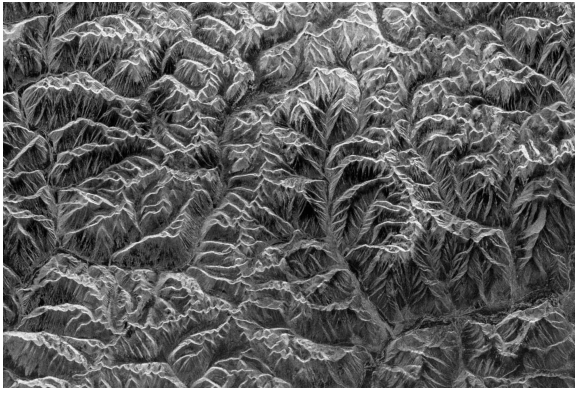
Medical Spectral Imaging

Night-time lights of the world

- IR imaging (1000 - 13400 nm).

Visible band imaging

- Applications in biometrics, authentication and surveillance.



Microwave radar imaging

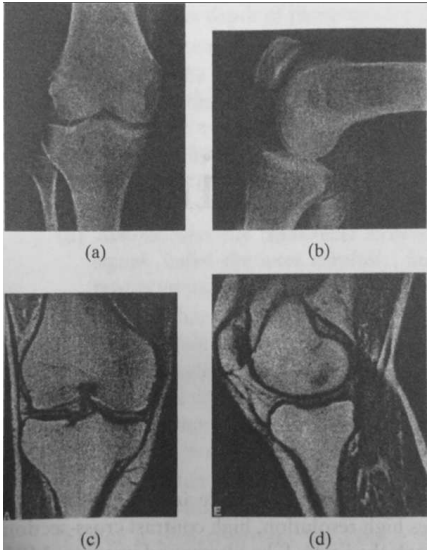
- Active imaging
- Antenna arrays instead of cameras

Magnetic Resonance Imaging

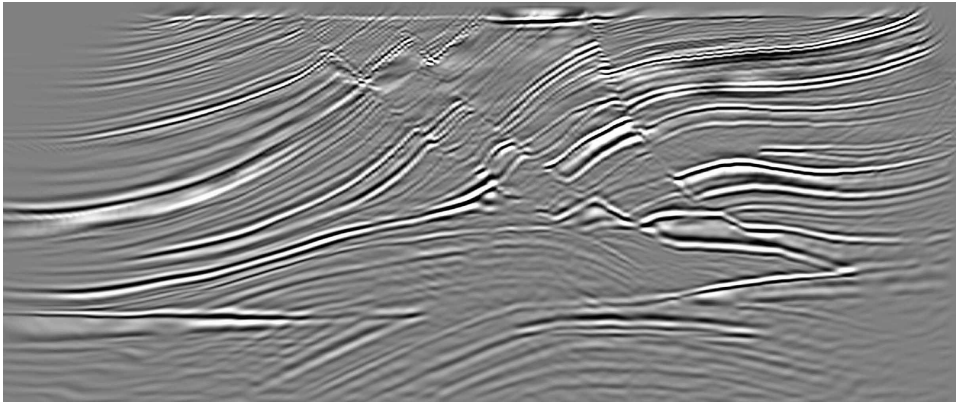
X-ray CT vs MRI

Comparison of projection radioagraphy and MRI of the knee:

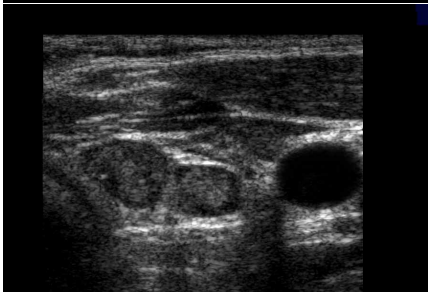
- a Anterior projection radiograph
- b Lateral projection radiograph
- c Coronal MRI
- d Sagittal MRI

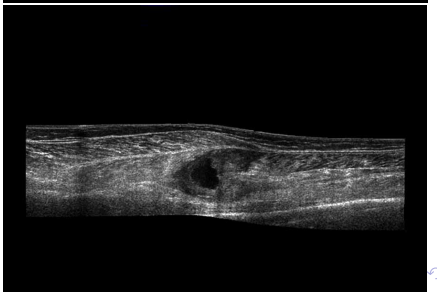


Geological Seismic Exploration (100 Hz)

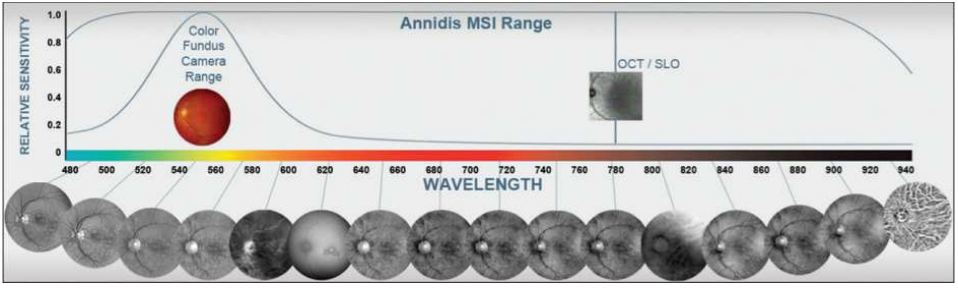


Ultrasound imaging (1-5Mhz)





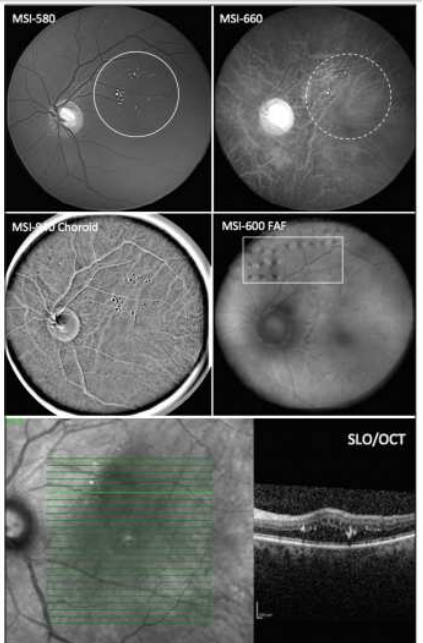
Multiple-wavelength imaging of the retina and choroid



A bell shaped blue curve represents the sensitivity of the human eye and the spectrum used by traditional digital fundus cameras with a peak at 555 nm.

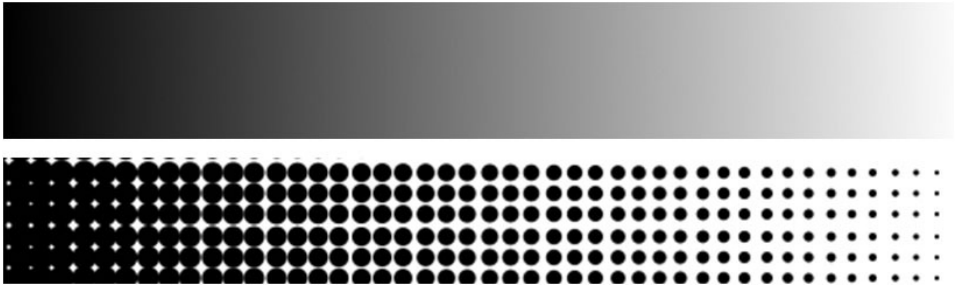
Multiple-wavelength imaging of the retina and choroid

Multiple dot-and-blot hemorrhages seen with MSI-580. Diabetic macular edema centrally, as evidenced by the blurry area surrounded by hard exudates in the MSI-660 image. The MSI-940 image shows damage to the choroidal structure.



Spatial Dithering

Represent a continuous tone image with only black and white pixels.



Spatial Dithering

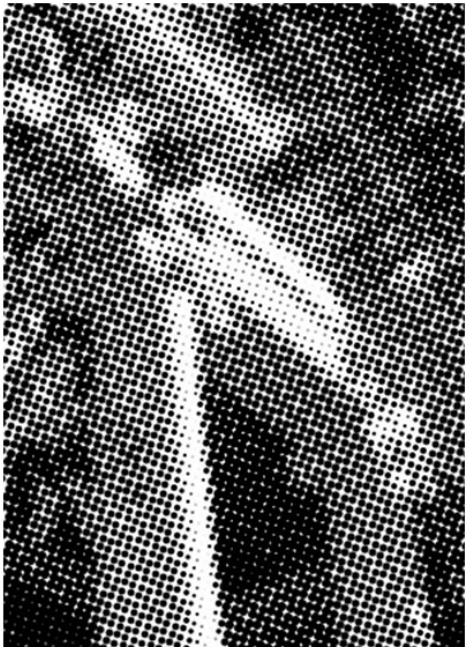
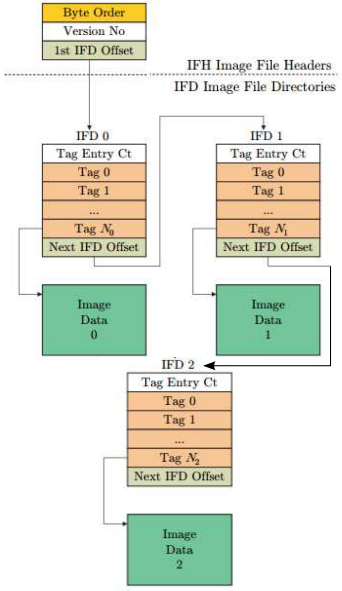


Image File Formats

- Most early (1985) software developers created a new custom file format for each new application they developed.-> Incompatible file formats.
- Criteria to consider when selecting an appropiate file format:
  - Type of image: i.e. binary, grayscale, color, scan.
  - Maximum image size
  - Storage size and compression
  - Compatibility
  - Application Domain: Print, Web, film, computer graphics, medicine.

Tagged Image File Format (TIFF)

- Developed by Aldus by Microsoft and now Adobe.
- Supports grayscale, indexed, and true color images.
- A TIFF file can contain a number of images with different properties.
- It is possible to store a number of variations of an image in different sizes and representations together in a single TIFF file.
- Currently no Web browser supports TIFF



Graphics Interchange Format (GIF)

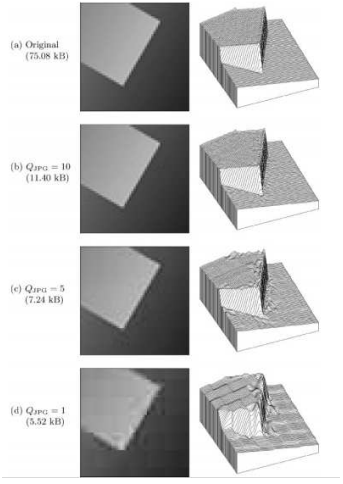
- Designed by CompuServe (1986) to encode the rich line graphics.
- Widely used format for representing images on the Web.
- Supports indexed color at multiple bit depths, LZW compression, interlaced image loading, and short animations.
- Does not support true color images.
- GIF supports color palletes in the range of $2 \cdots 256$.

Portable Network Graphics (PNG)

- Supports true color images (with up to 3×16 bits/pixel), grayscale (with up to 16 bits/pixel), indexed (with up to 256 colors).
- Includes an alpha channel for transparency with a maximum width of 16 bits.
- Allows images of up to 230×230 pixels.
- Supports lossless compression by means of a variation of PKZIP (Phil Katz's ZIP).
- Does not support animations or multiple images per file.

JPEG

- Defines a compression method for continuous grayscale and color images.
- Developed by the Joint Photographic Experts Group (JPEG) with goal of achieving an average data reduction of a factor of 1:16 and was established in 1990 as ISO Standard IS-10918.
- Today it is the most widely used image file format
- Does not perform well on images such as line drawings.



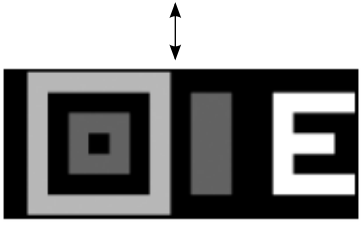
Windows Bitmap (BMP)

- Simple, and under Windows widely used, file format supporting grayscale, indexed, and true color images.
- It also supports binary images, but not in an efficient manner since each pixel is stored using an entire byte.

Portable Bitmap Format (PBM)

- Series of simple file formats that can be optionally saved in a human-readable text format easily read and edited using a text editor.
- PBM is widely used under Unix and supports: PBM (portable bitmap) for binary bitmaps, PGM (portable graymap) for grayscale images, and PNM (portable any map) for color images

```
P2
# oie.pgm
17 7
255
0 13 13 13 13 13 13 13  0  0  0  0  0  0  0  0  0
0 13  0  0  0  0  0 13  0  7  7  0  0 81 81 81 81
0 13  0  7  7  7  0 13  0  7  7  0  0 81  0  0  0
0 13  0  7  0  7  0 13  0  7  7  0  0 81 81 81  0
0 13  0  7  7  7  0 13  0  7  7  0  0 81  0  0  0
0 13  0  0  0  0  0 13  0  7  7  0  0 81 81 81 81
0 13 13 13 13 13 13 13  0  0  0  0  0  0  0  0  0
```



Additional File Formats

For most practical applications

- TIFF: Universal format supporting a wide variety of uncompressed images.
- JPEG/JFIF: Digital color photos when storage. size is a concern
- PNG or GIF: Image is destined for use on the Web.

In addition, there exist countless other file formats for special application areas, for example:

- RGB: Format from Silicon Graphics.
- RAS: Format from Sun Microsystems.
- TGA (Truevision Targa File Format): First 24-bit file format for PCs.
- XBM/XPM (X-Windows Bitmap/Pixmap): family of ASCIIencoded formats used in X-Windows and is similar to PBM/PGM.