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http://www.dais.unive.it/~auce/smm2015-16/

Computer Science Applications to Cultural Heritage

Digital imaging

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Academic year 2018/2019

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Digital imaging & CH

Digital imaging-driven cultural heritage preservation is gaining more and more interest in the scientific community

Examples of content that can be naturally studied with digital imaging solutions:

- Paintings
- Frescoes
- antique photographic prints,
- old books
- handwritten documents
- ...

Digital imaging & CH

The **digitalization** of these treasures opens up the possibility of using **image processing and analysis techniques** to preserve this heritage for future generations and to augment it with accessory information for its enjoyment and use.

Different topics and applications:

- Visual content acquisition and digitization
- indexation of visual databases
- Image restoration and analysis
- Digital watermarking

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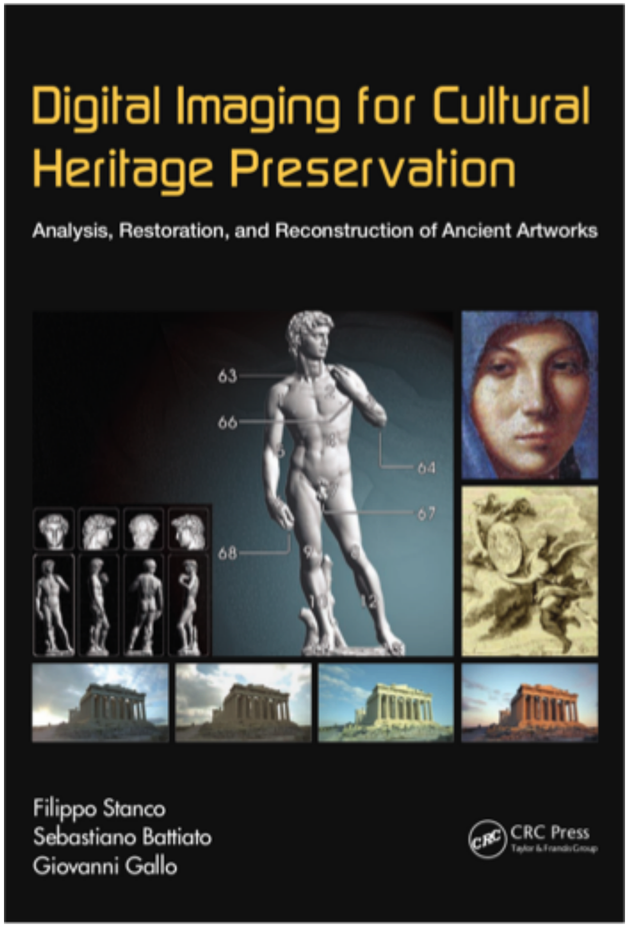
Suggested reading

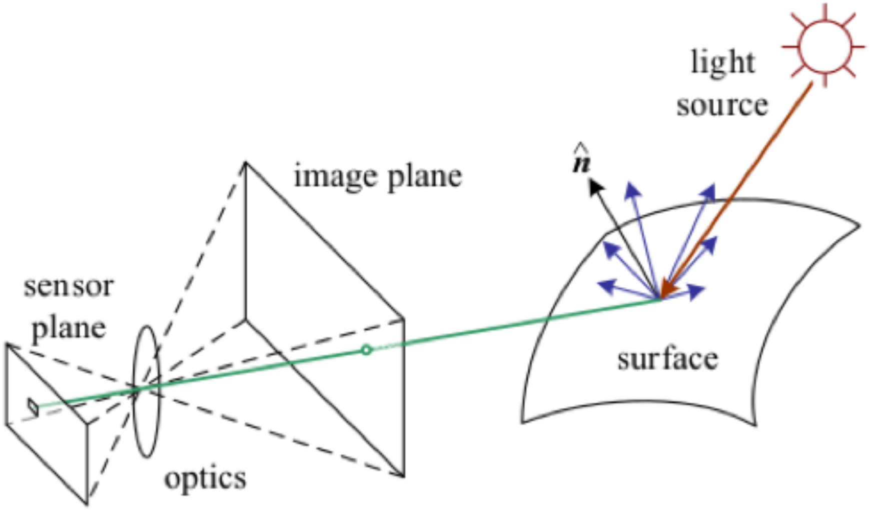


Filippo Stanco, Sebastiano Battiato, Giovanni Gallo, *“Digital Imaging for Cultural Heritage Preservation”*, CRC Press, 2017, ISBN 9781138073791

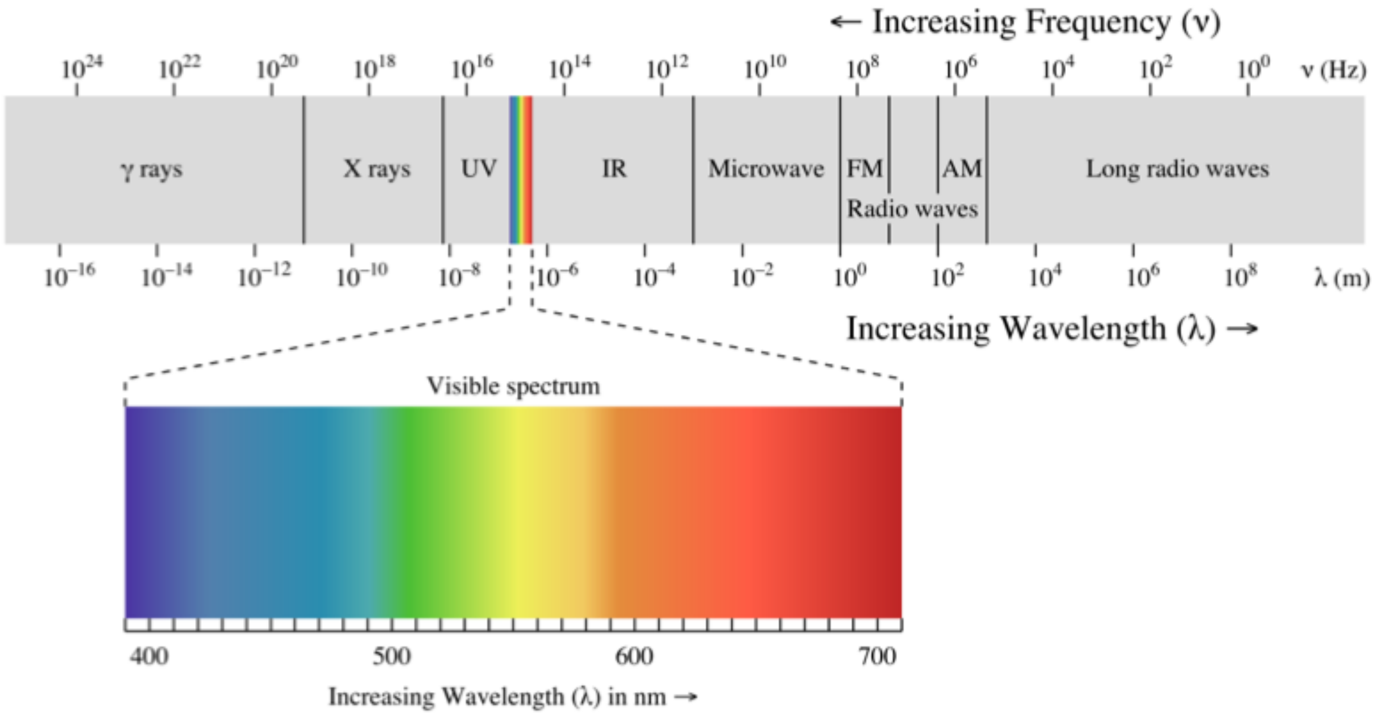
All starts with light...

To being able to see any image based content (like a painting, an old book, etc.) our eyes or a digital camera needs to capture the **light radiation** reflected from the object surface

To produce an image, a scene must be illuminated with one or more light sources



Visible light is part of electromagnetic spectrum



The electromagnetic spectrum can be expressed in terms of wavelength (**λ**) or frequency (**ν**)

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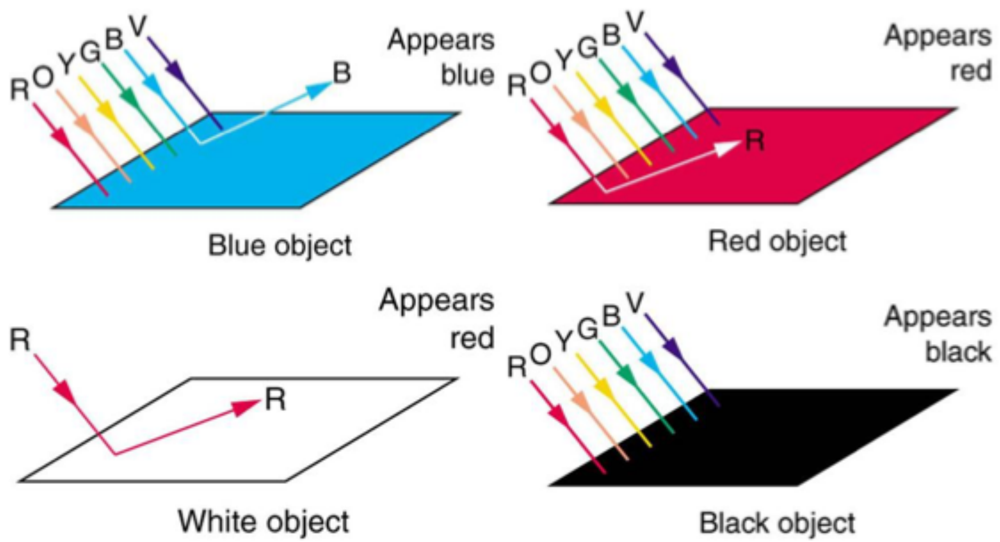
Color Fundamentals

The colors that humans and animals perceive in an object are determined by the nature of the light (wavelength) reflected from the object

- A body that favors reflectance in a limited range of the visible spectrum exhibits some shades of color



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Color and brightness

- A white object reflects light uniformly among visible wavelengths
- Green objects reflect light primarily in the 500-570 nm range

Quantities that are usually used to describe a light source:

1. Radiance
2. Luminance
3. Brightness

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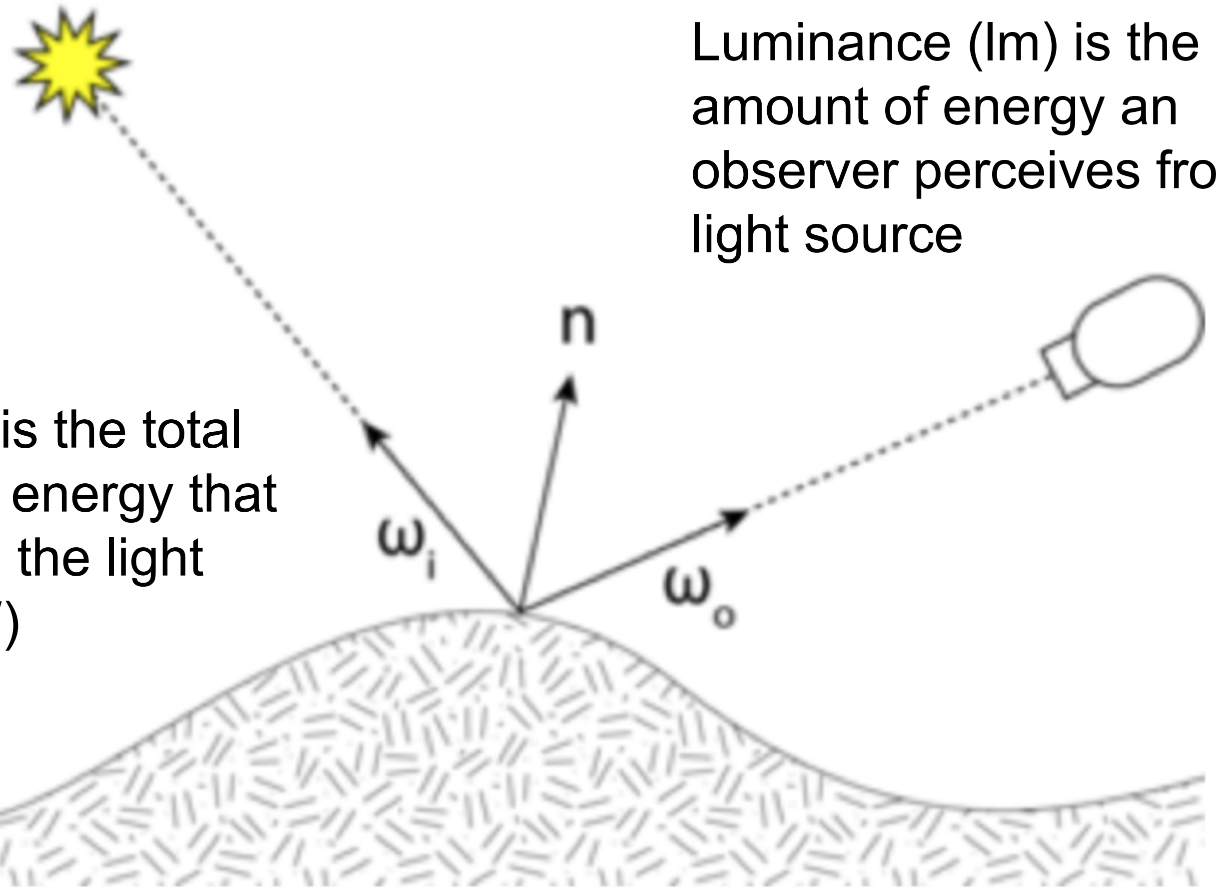
Light quantities

Luminance (lm) is the amount of energy an observer perceives from a light source



Radiance is the total amount of energy that flows from the light source (W)

Brightness

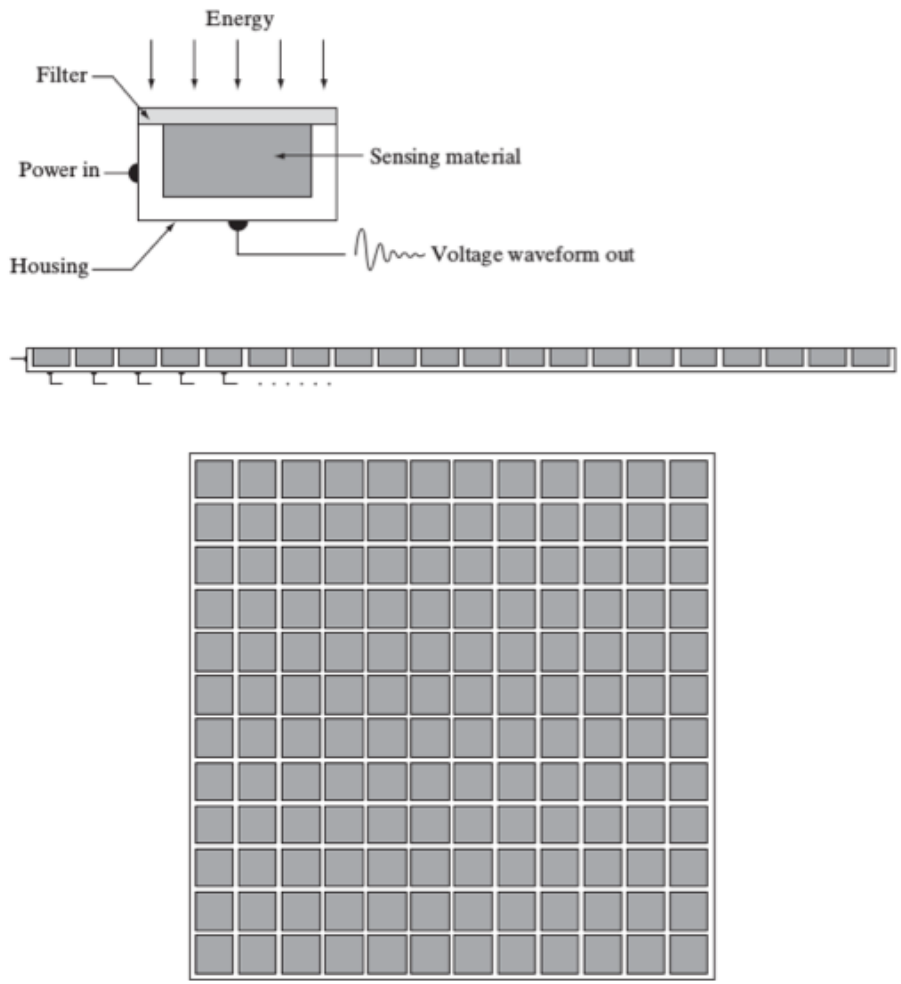
Brightness is a **subjective descriptor** of light "intensity" and is one of the key factors in describing color sensation

Luminance of the inner square is exactly the same. Perceived brightness is different

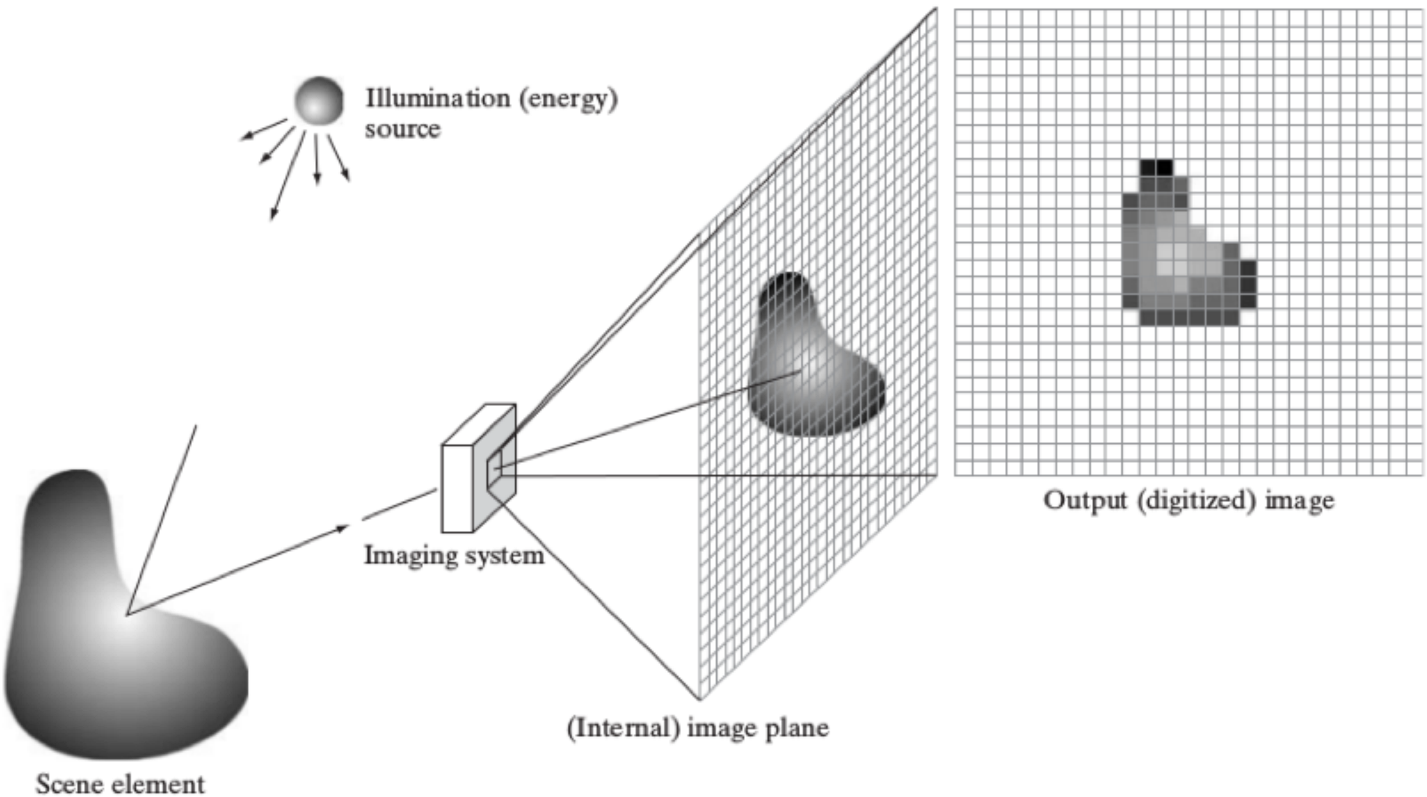
Image sensing

Incoming light radiation reflected from a 3D scene is transformed to a voltage by an imaging sensor that is sensible to a certain range of wavelengths.

Usually, sensors are arranged in linear or 2D arrays



Imaging process



The sensor array, coincident with the focal plane of the lens, produces outputs proportional to the integral of the light received at each sensor for a certain amount of time

Image digitization

A continuous analog image is converted into a digital one through a process of **sampling** and **quantization**

Sampling:

Reduces the image domain to a finite set of spatial coordinates

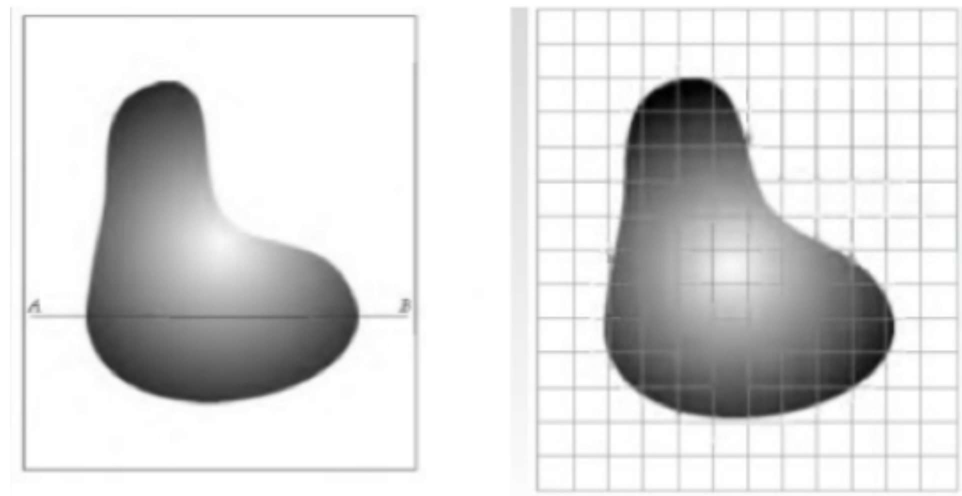
$$\mathbb{R}^2 \rightarrow M \times N$$

Quantization:

Reduces the sensor response (function codomain) to a finite set of values

$$\mathbb{R} \rightarrow [0, 1 \ldots 2^b]$$

Sampling



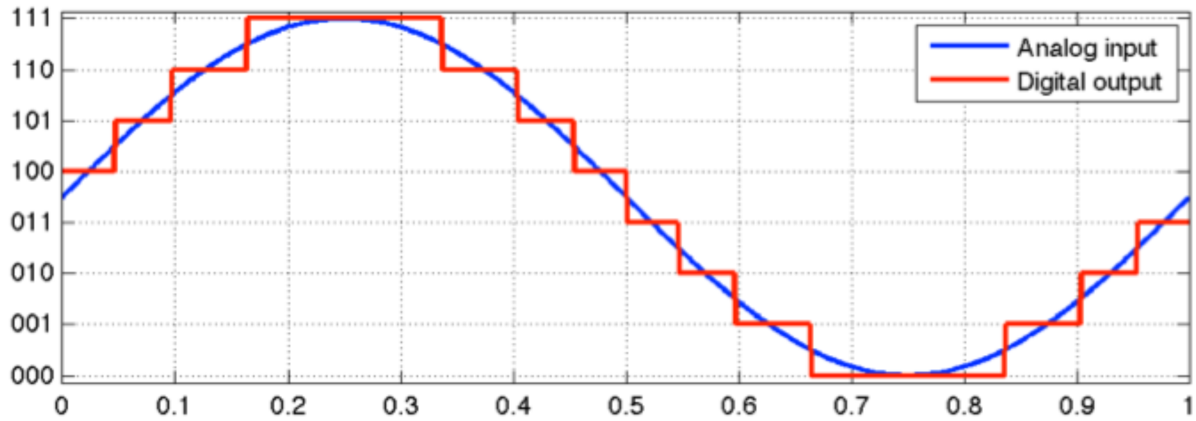
To sample the continuous image domain into a finite set of values we usually consider an equispaced grid of values in a given area (matrix). This follows the regular arrangement of cells in a CMOS or CCD sensor.

Each sample is called a **pixel**

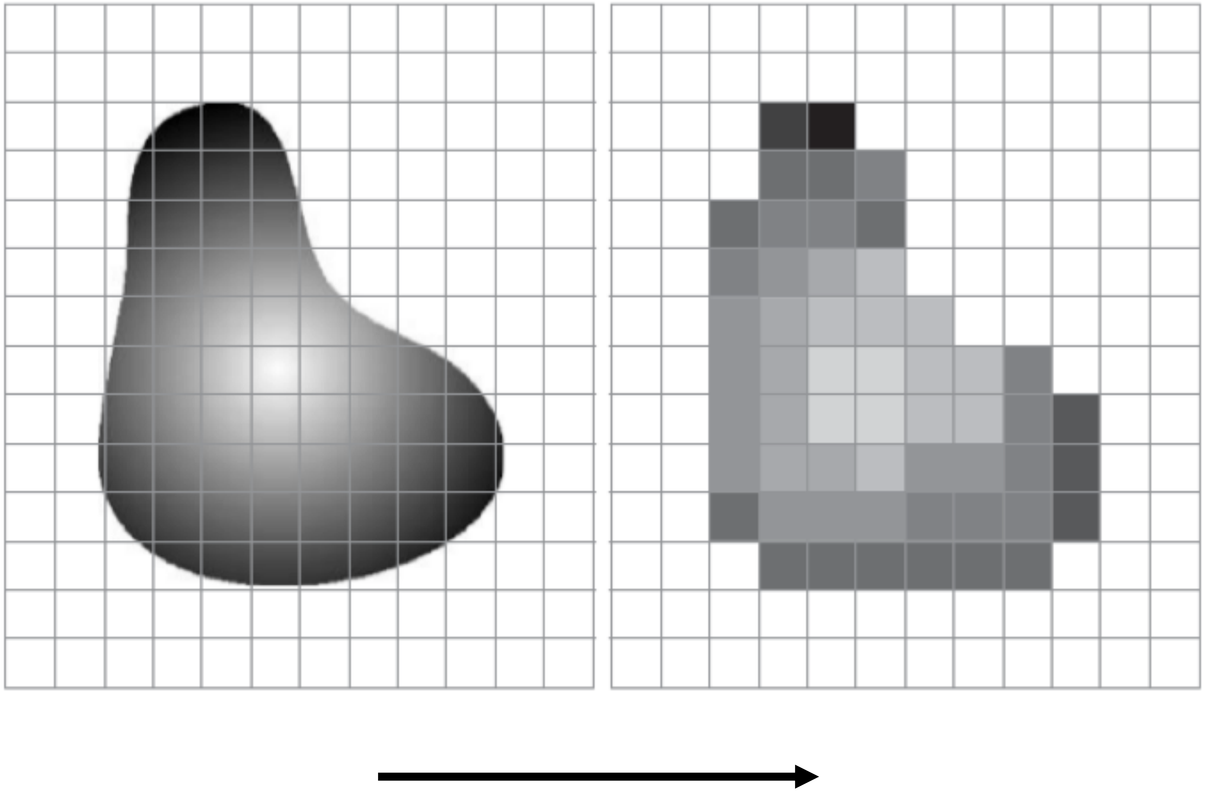
Quantization

The intensity (output) of the function must also be discretized (quantized) in a finite set of values to be used in a computer.

Image codomain is divided into a set of values and each f(x,y) is rounded to the closest one



Sampling and Quantization



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Digital Images

The digitization process requires that decisions be made regarding the matrix size M,N and the number L (usually a power of 2) of quantized intensity levels.

M,N are related to the **spatial resolution** of an image

L is related to the **intensity resolution**

Spatial resolution

Spatial resolution is a measure of the smallest discernible detail in an image

Usually defined as dots (pixels) per unit distance

NOTE: to be meaningful, measures of spatial resolution must be stated with respect to spatial units.

A 1024x1024 pixel image is not meaningful without stating the spatial dimensions encompassed by the image (the size of each pixel in the 3D world)

Spatial resolution


a. Landsat ETM+ b. ATLAS c. QuickBird

The number of pixels of an image directly affect spatial resolution only with comparable lenses and if the subjects are taken at the same distance

Spatial resolution

1250 dpi

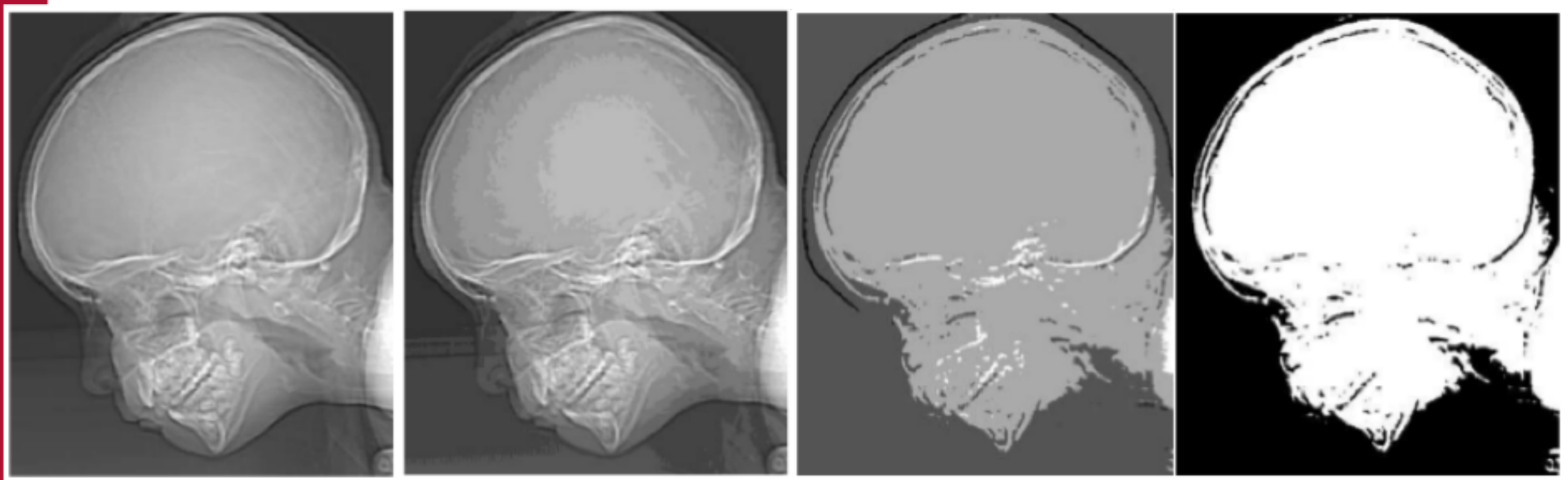
300 dpi

72 dpi

Intensity resolution

Intensity resolution refers to the smallest discernible change in intensity level.

Usually it is a power of 2 (8 bits most common)



256 levels | 16 levels | 4 levels | 2 levels

Dynamic Range/Contrast

The **dynamic range** of an imaging system is the *ratio* of the maximum measurable intensity to the minimum detectable intensity level.

- Depends by the number of bits we use (intensity resolution) and establish the lowest and highest intensity levels that a system can represent

Similarly, with **contrast** we define the *difference* between the highest and the lowest intensity level of an image.

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Dynamic Range/Contrast

Human eye has a dynamic range of about 10^9!

Even if we use techniques to acquire images at high dynamic range we will probably won't be able to display it on a computer screen...

Compromises have to be done in the acquisition process to either discard dark details or saturate heavily illuminated areas

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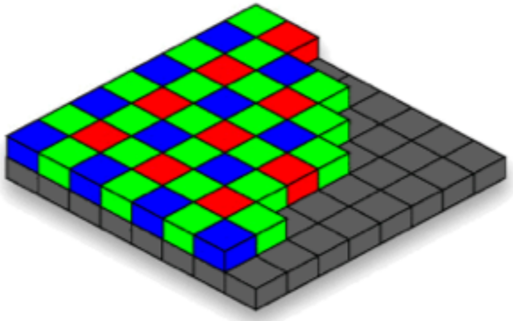
Dynamic Range/Contrast

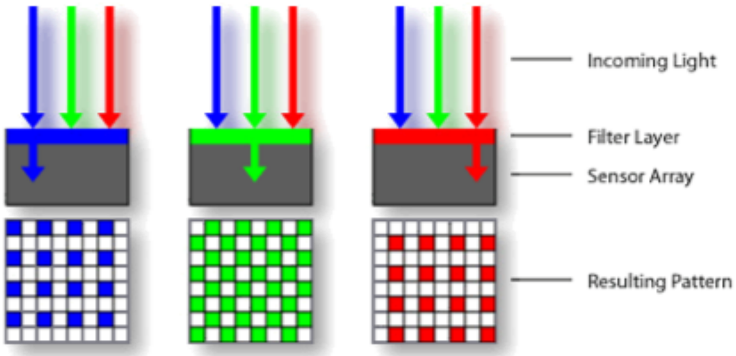
Color Imaging

Each sensing cell in a digital camera acquire light intensity at a broad range of different wavelengths

Color digital cameras use a color filter array (CFA), where alternating sensors are covered by different colored filters.



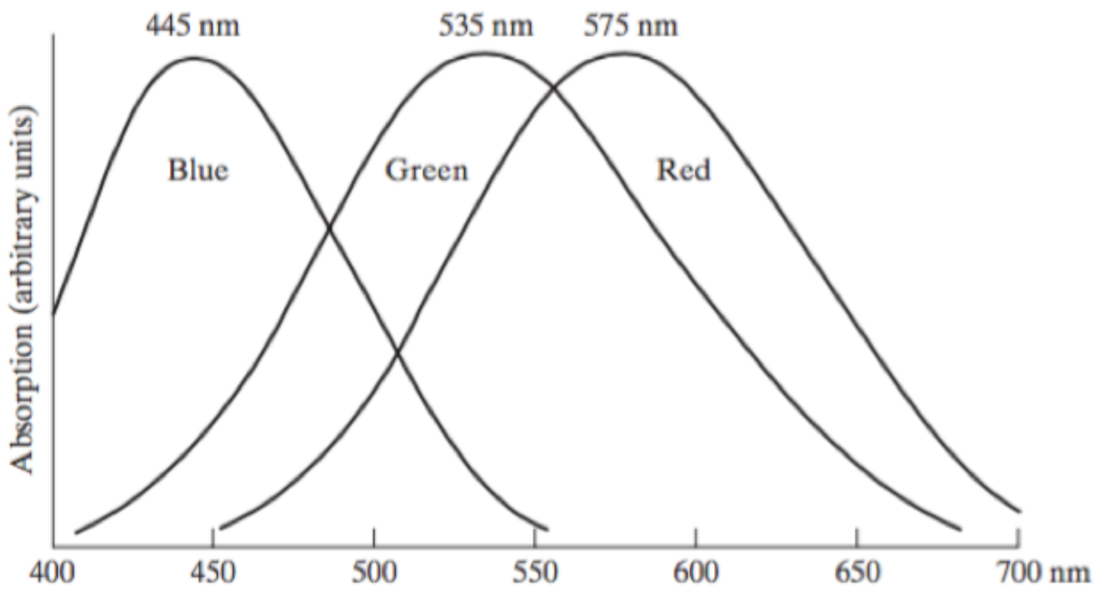
The most commonly used pattern in color cameras today is the **Bayer pattern**



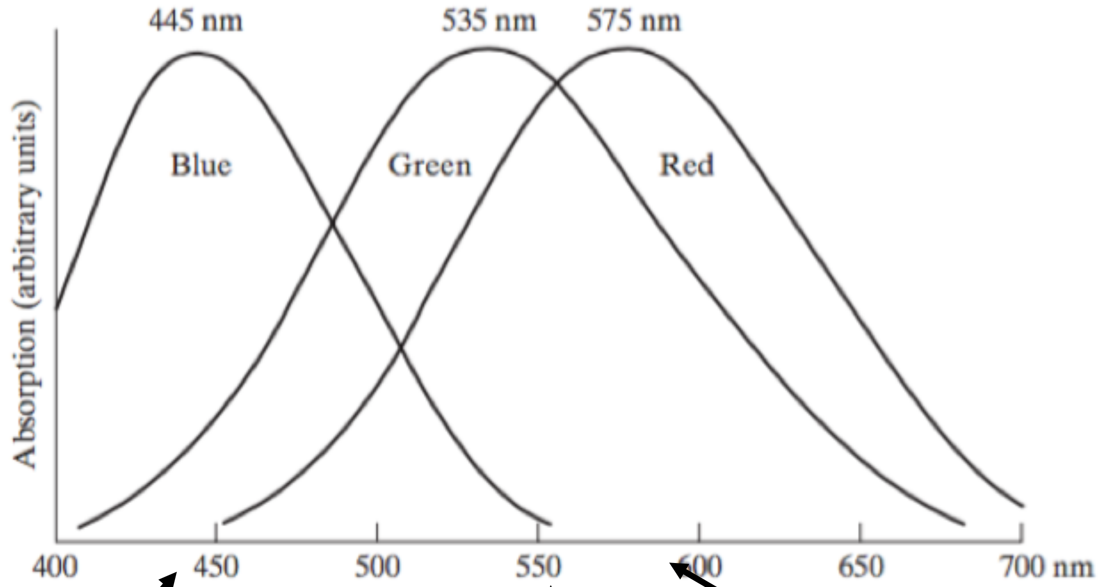
Similar to human vision

Human Vision

Physiologic research showed that in the human cornea there are three types of receptors for daylight vision (cones) sensible in different ways to the various frequencies of the electromagnetic radiation



Human Vision

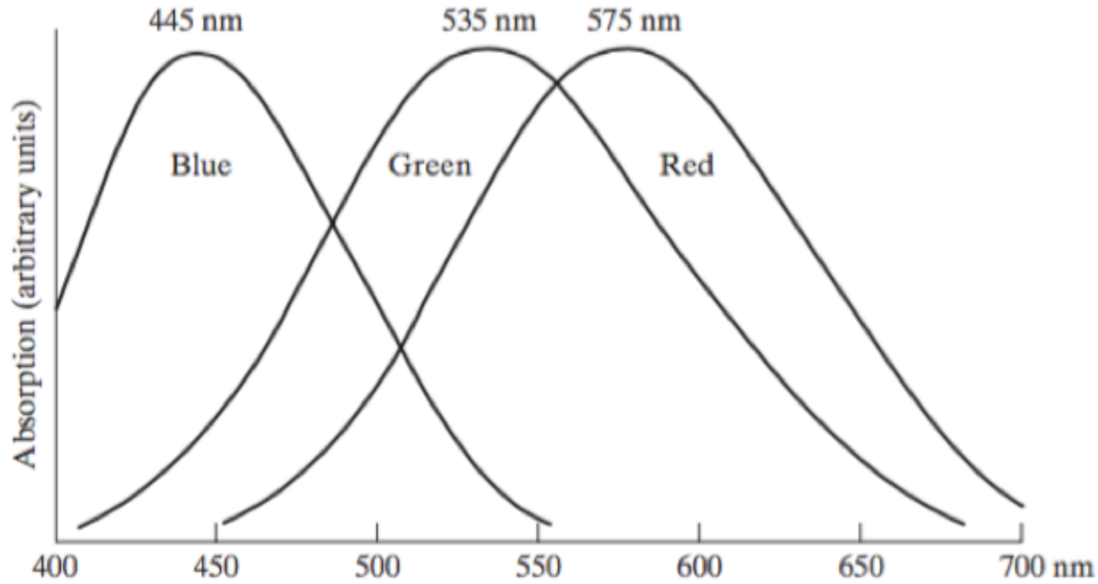


2% of the cones are sensitive to blue light (but are the most sensible)

33% of the cones are sensitive to green light

65% of the cones are sensitive to red light

Human Vision

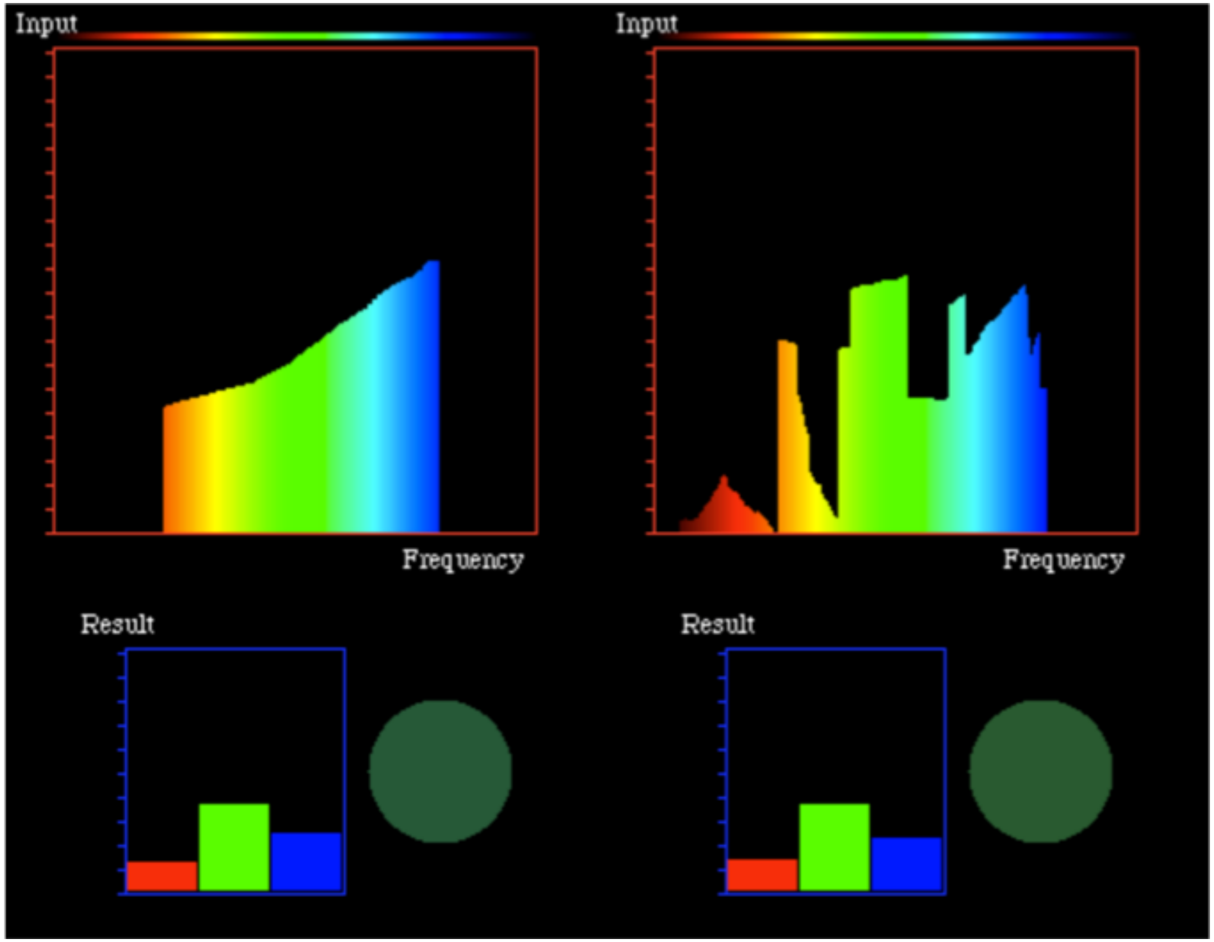


Our perception of colors is the result of the simultaneous stimulus (tri-stimulus) of the 3 different classes of cones

- Two lights with different spectra that produce the same response from these 3 types of receptors are perceived being of the same color.

Metamers

Colour stimuli that have different spectral radiant power distributions but are perceived as identical for a given observer.



Color characteristics

The characteristics generally used to distinguish one color from another are **brightness**, **hue**, and **saturation**.

Brightness: achromatic notion of intensity

Hue: dominant wavelength in a mixture of light waves (represents dominant color as perceived by an observer)

Saturation: the “relative purity” or the amount of white light mixed with a hue

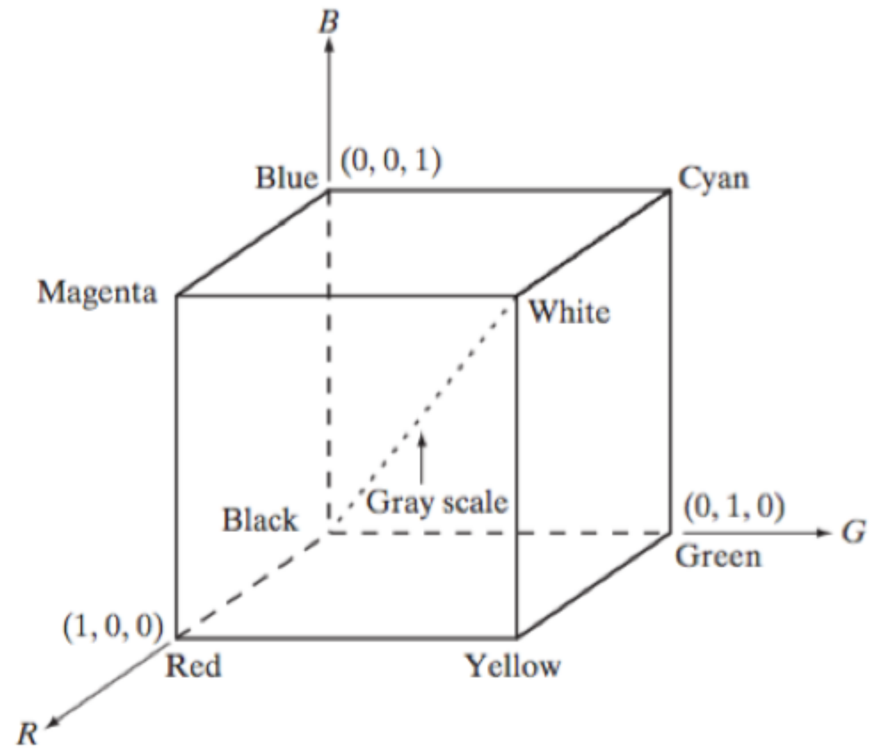
Color spaces

A color image is usually digitized by representing the color of each pixel in a suitable **color space**.

In other words, any color is stored and visualized by combining contributions of a finite number (usually 3 or 4) of “pure colors” (with a fixed wavelength) assuming an **additive** or **subtractive** mixing.

For example: an **RGB** color image stores the intensity and color of each pixel as a triplet of 3 numbers, which specify the amount of red (~700nm), green (~546nm) and blue (~435nm) respectively.

RGB color space



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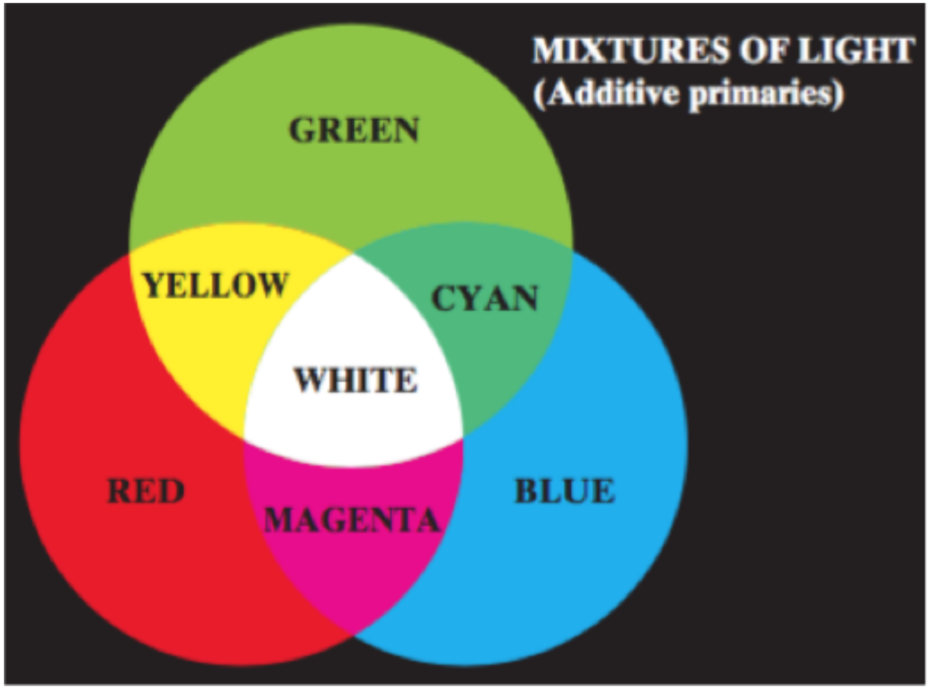
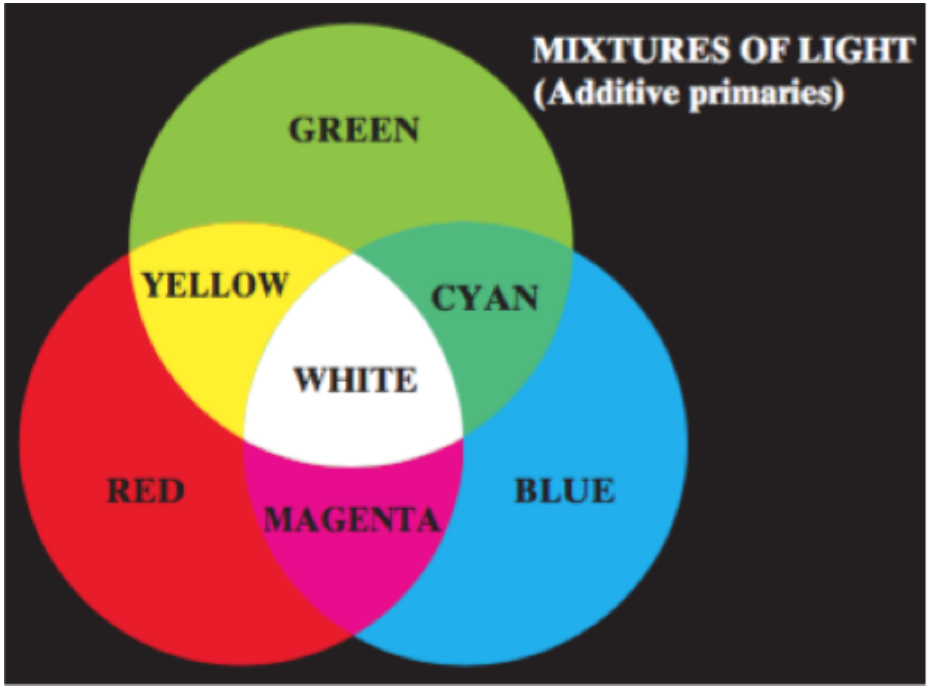
RGB Additive mixing model



3 monochromatic lights with the R,G,B primary colors respectively can be mixed together (added) to produce what are called **secondary colors**

RGB additive mixing model



This is the basic technology behind LCD screens which use polarized filters to block or pass light through the screen

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RGB is device-dependant

RGB and other similar color spaces (HSV,YUV,etc) **depend on the properties of the devices** used for display:

- Different devices reproduce a given RGB value differently since the response of each color element vary from manufacturer to manufacturer
- An RGB triplet does not define the same *color* across devices
- What primaries to use? Different standards:
  - sRGB
  - Adobe RGB
  - etc

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RGB & human vision

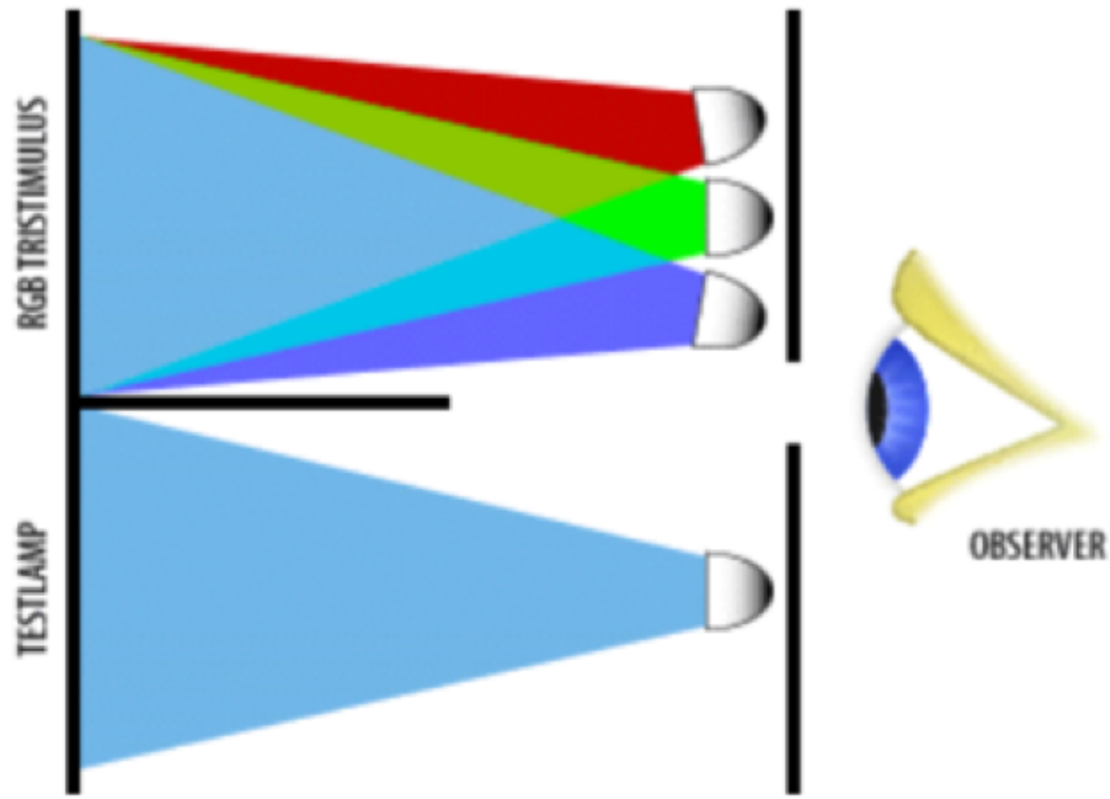
The composition of the primary colors by RGB additive synthesis cannot generate all colors perceivable by the human vision

- RGB primaries do not correspond exactly to the retina cones sensitivity
- some colors perceived by the eye can not be obtained just by mixing RGB primaries

How can we measure that?

1. Choose the primaries (ex: red=700.0 nm, green= 546.1 nm, blue=435.8 nm)
2. Use "color matching" to find each triplet associated to a pure wavelength

Color matching

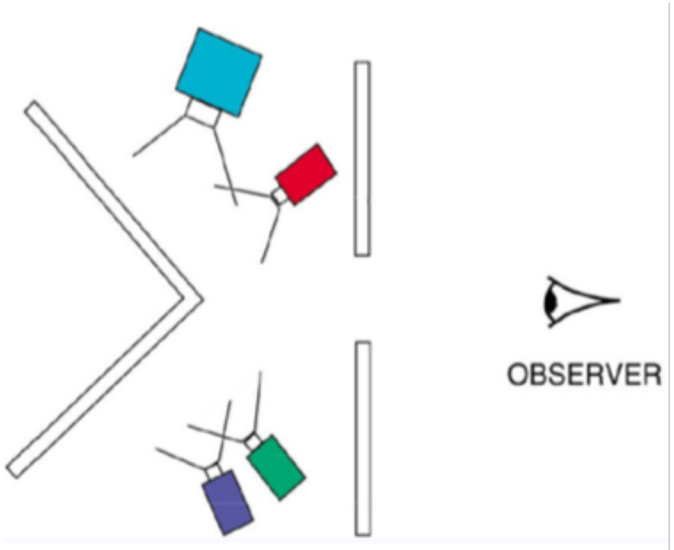


Color matching

Almost all colors can be matched this way, except some shades between blue and green that cannot be reproduced!

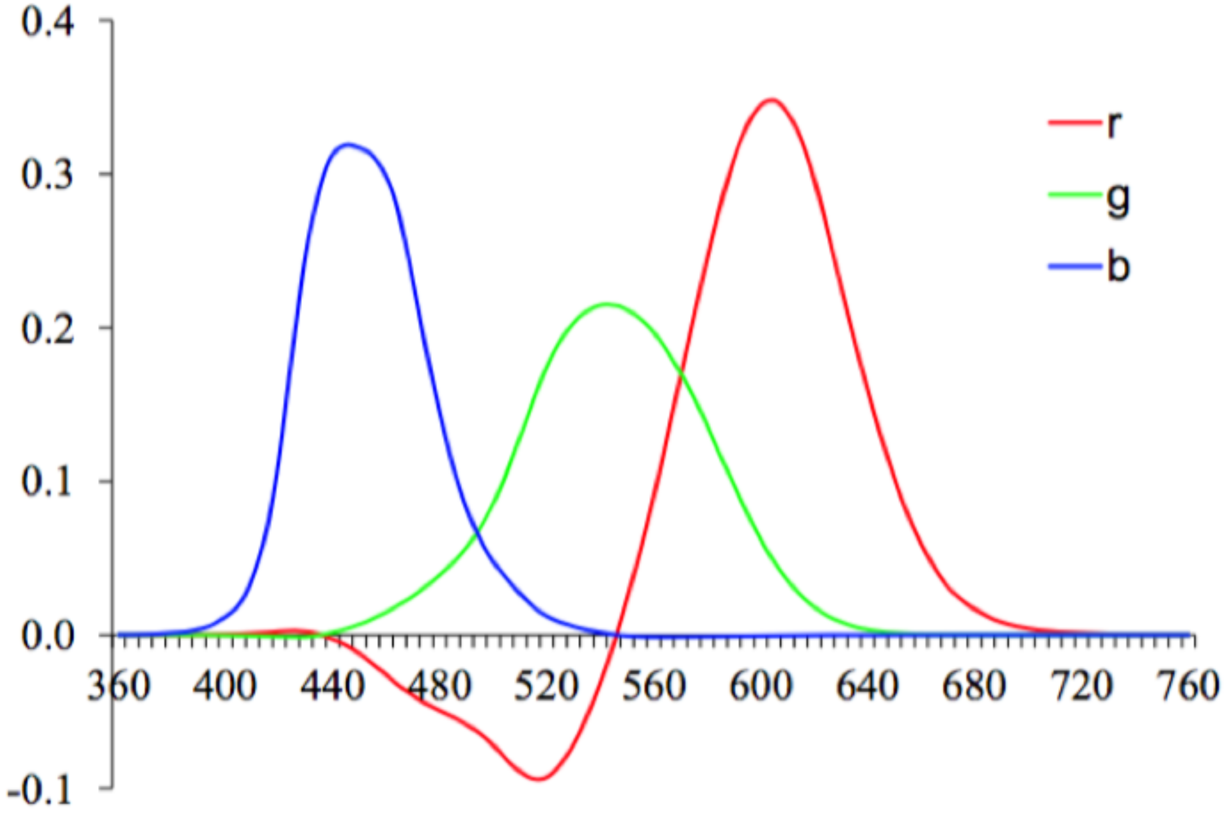
If we add some red to the test light, than we can match it using only green and blue:

- We need a negative amount of red to obtain certain colors!



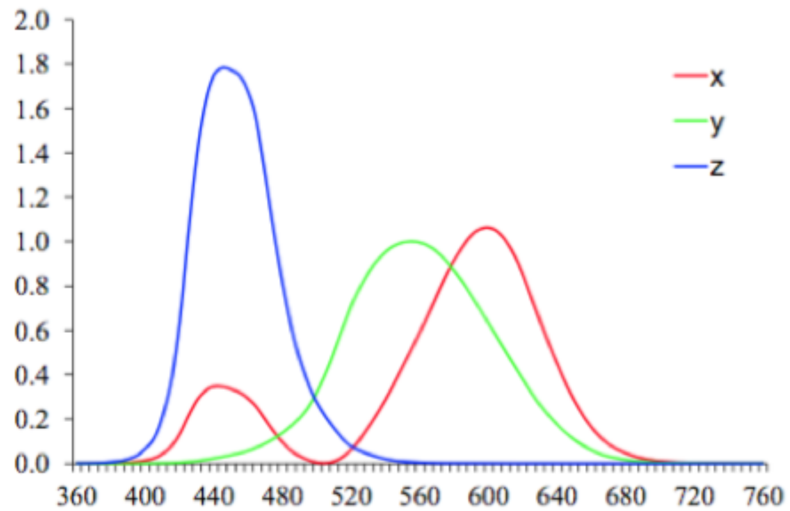
Color matching

Resulting color matching function:



XYZ Color Space

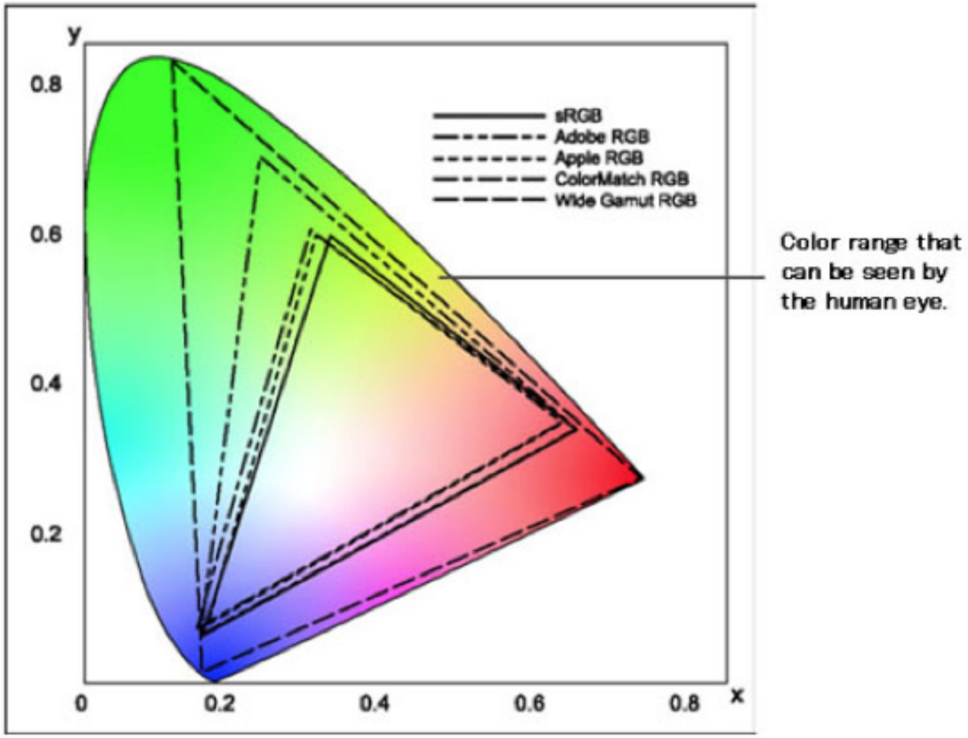
To overcome the problem of mixing negative amount of red light, **CIE Standard** defined a new color space created by the combination of 3 virtual (non monocromatic) colors: X Y Z.



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

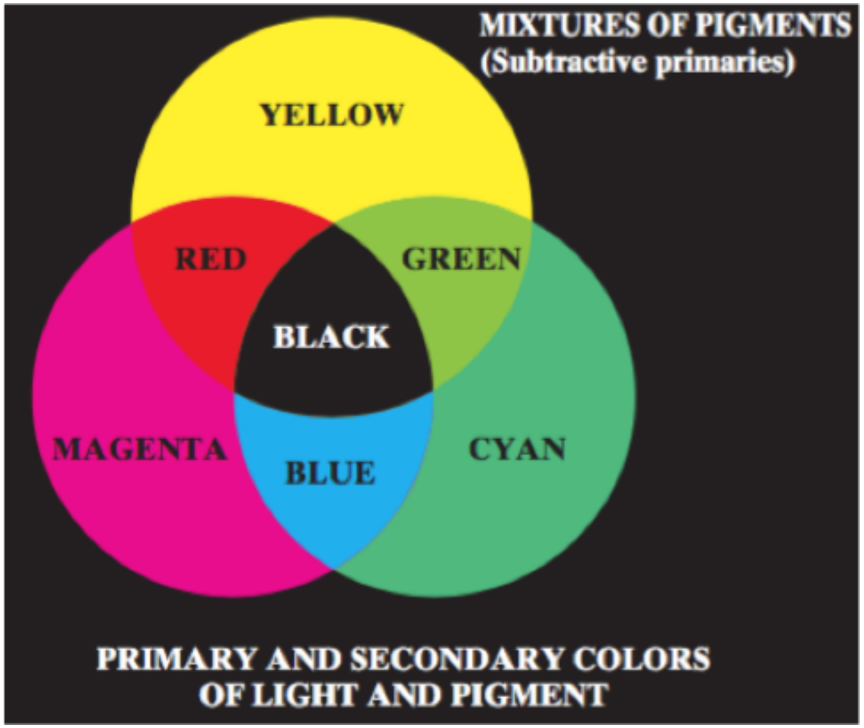
Color Gamut

Any device that reproduces colors by mixing a fixed set of basic colors can only reproduce the colors within the convex envelope of their basis



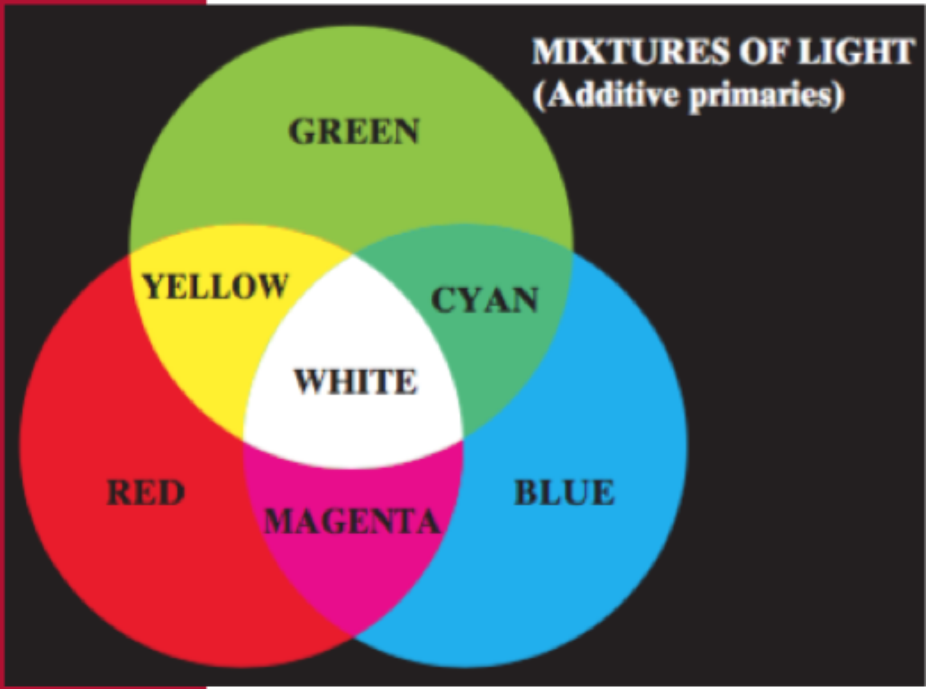
The area of the envelope measures the quantity of reproducible colors and is called **Gamut**

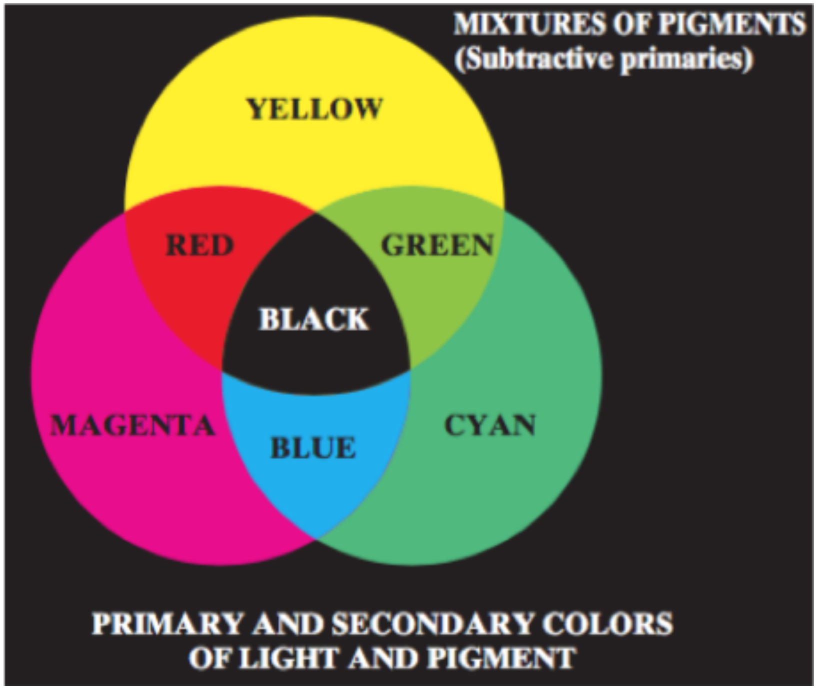
Subtractive mixing: CMY(K)



When talking about pigments, it is useful to reason by means of subtractive synthesis. In this model, a primary color is defined as one that subtracts or absorbs a primary color of light and reflects or transmits the other two

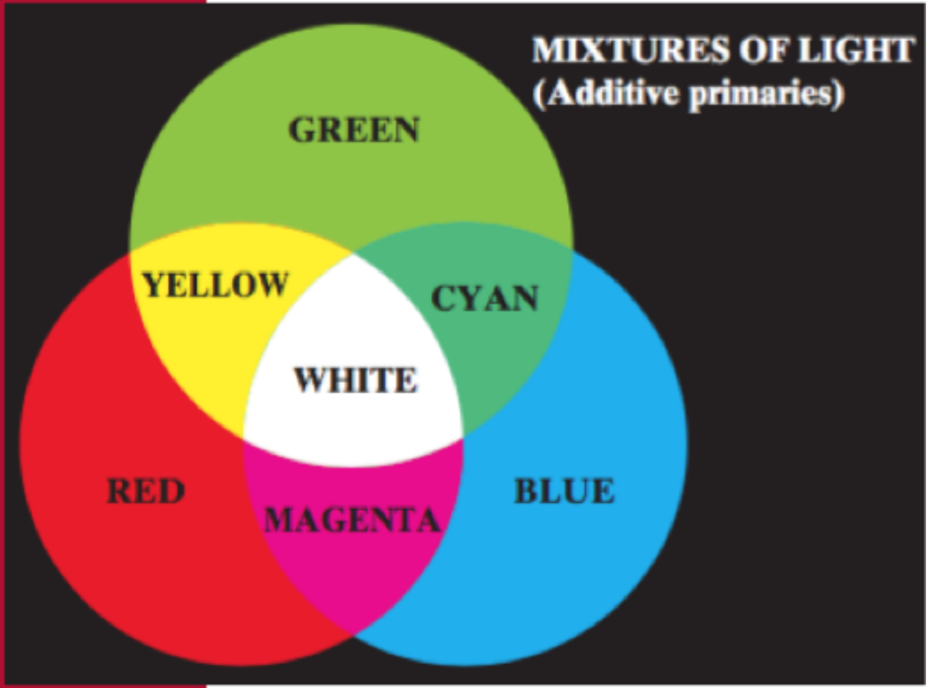
Subtractive mixing: CMY(K)

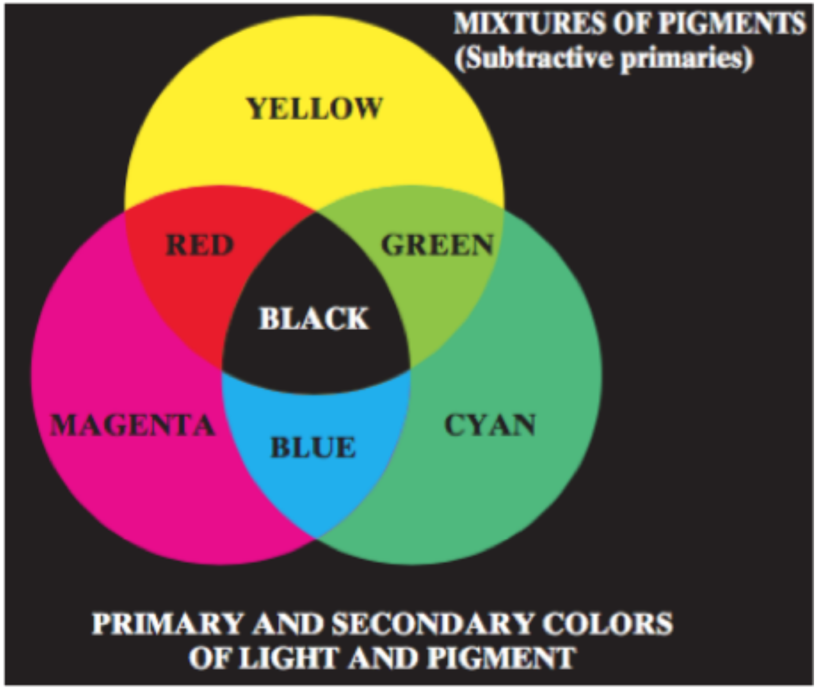




For example, yellow completely absorbs blue and reflects red and green. Hence, mixing yellow (absorbing blue) with cyan (absorbing red) transmits only green

Subtractive mixing: CMY(K)





Odd fact: The secondary color "magenta" is not in the spectrum of colors (ie. there is no single wavelength associated to magenta that is always a result of red-blue mix).Our brain interpolates the two signals to produce the sensation of magenta

Additive vs. Subtractive

The composition of the primary colors for subtractive CMYK synthesis does not produce a color range completely equivalent to the RGB additive synthesis

- reflective surfaces behave differently from light emitting sources
- printing technology with inks and pigments has practical limits that prevent the production of the full range of visible colors

Storing images

Once digitized, an image can be represented by a grid of pixels. Each pixel defines the characteristics of the captured light in a defined color space.

When storing a digital image in a computer we have different possible choices on the way the data is physically represented in memory, which usually also contain:

- The resolution of the image (number of rows and columns)
- Its color space
- The number of bits used to store each color
- Details on the **compression algorithm** to be used

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Image compression

Image compression aims to reduce the space required for their storage, reducing also the time needed for transmission.

Usually an image is compressed for storage but it must be decompressed before usage

Compression can retain or not the full content of the original data:

- **lossless compression** (reversible), exploits the redundancy in data encoding
- **lossy compression** (irreversible), exploits the redundancy in data use (perception)

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Lossless example: RLE

Run-length encoding (RLE) is an example of lossless compression.

Simple idea:

represents sequences of the same value with a counter of the repeated value

Example:

Suppose that 0 is the value of a black pixel and 1 is a value of white

0 0 0 0 0 0 0	**1 1 1**	**0 0 0 0 0**	**1 1 1 1 1**

7 0 3 1 5 0 5 1

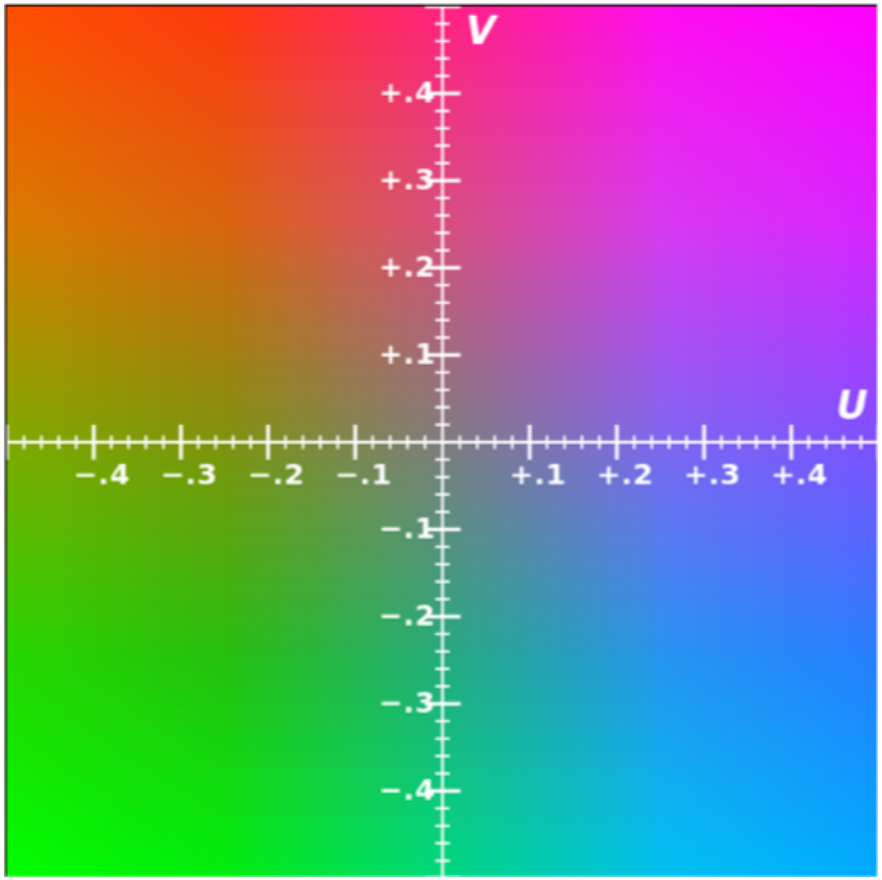
Lossy example: Chroma subsampling

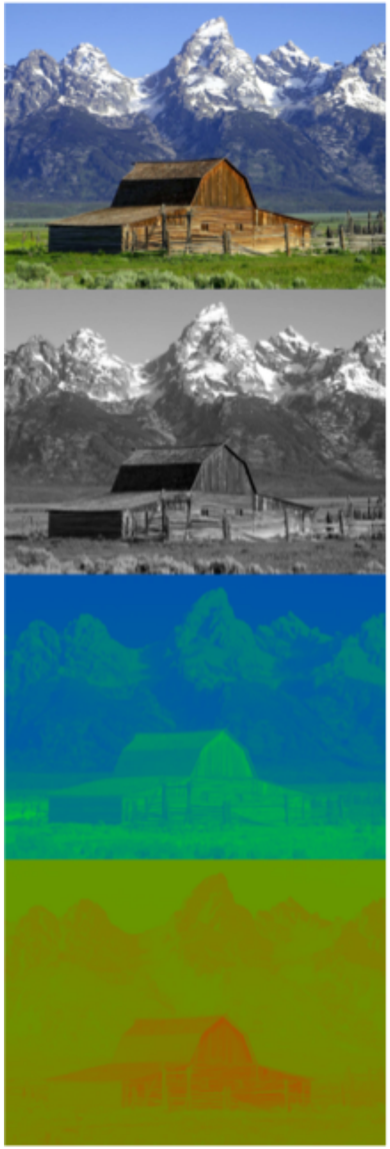
The human perception of brightness variations is more accurate than the perception of color variations

If the luminance information is represented with greater accuracy than chrominance information we will observe no significant difference (although some information will be forever lost in the process)

Chroma subsampling works by first representing the image into luminance and chrominance components (YUV color space), then by reducing the spatial resolution of the chrominance image

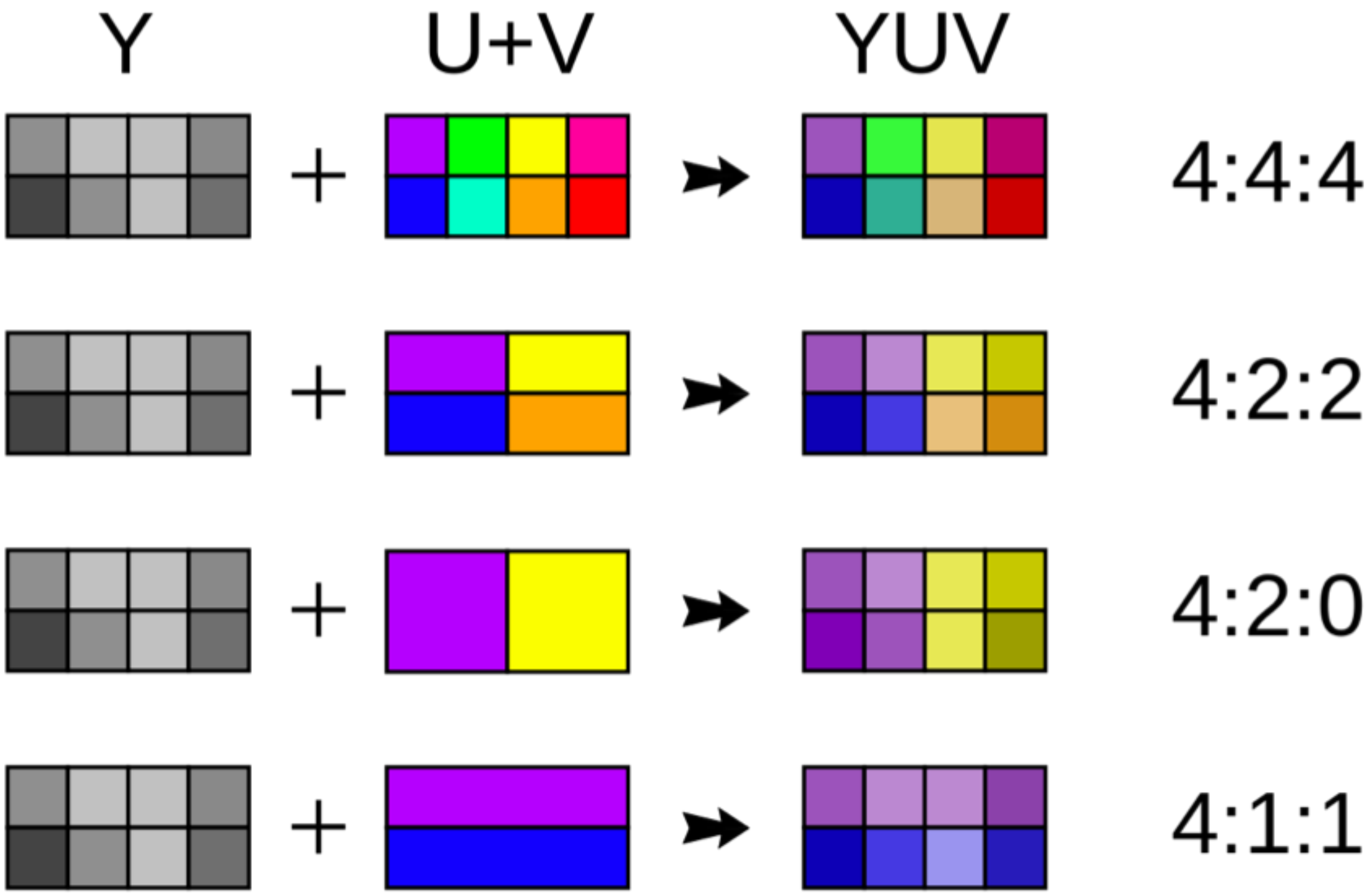
YUV color space





Similar to HSI but the color vector is parametrized by uv components instead by hue (angle) saturation (length)

Lossy example: Chroma subsampling



Lossy example: Chroma subsampling

Original image

Chroma 4:1:1

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Image formats

Standard image formats:

GIF: 8 bit indexed colors, animation, transparency, was patented

PNG: lossless compression, alpha channel, extensible

JPEG: true color, photographic quality, lossy compression

TIFF: limited compression, dimensional specifications, standard for typographic/photo industry

Proprietary (mostly obsolete)

BMP: Windows bitmap, uncompressed/RLE

PICT: Apple, mixed bitmap/draw

PCD: Kodak photo, used by early Photo-CD

X-11: X-Windows bitmap, historical value

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GIF image format

GIF was the first standard format for image transmission over networks (BBS)

Features:

- Each pixel indexes a palette of 256 possible colors
- A transparent color can be defined
- Lossless compression (algorithm LZW)
- multiple images can be stored in the same file, presented as subregions of the whole image or as subsequent video frames
- Simple animations supported (each frame is automatically visualized after a timeout)

8-bit vs. 24-bit color images

In a color 24-bit image, each pixel is represented by three bytes, usually in RGB color-space (one byte per channel).

This format supports 256 × 256 × 256 possible combined colors, or a total of 16,777,216 possible colors.

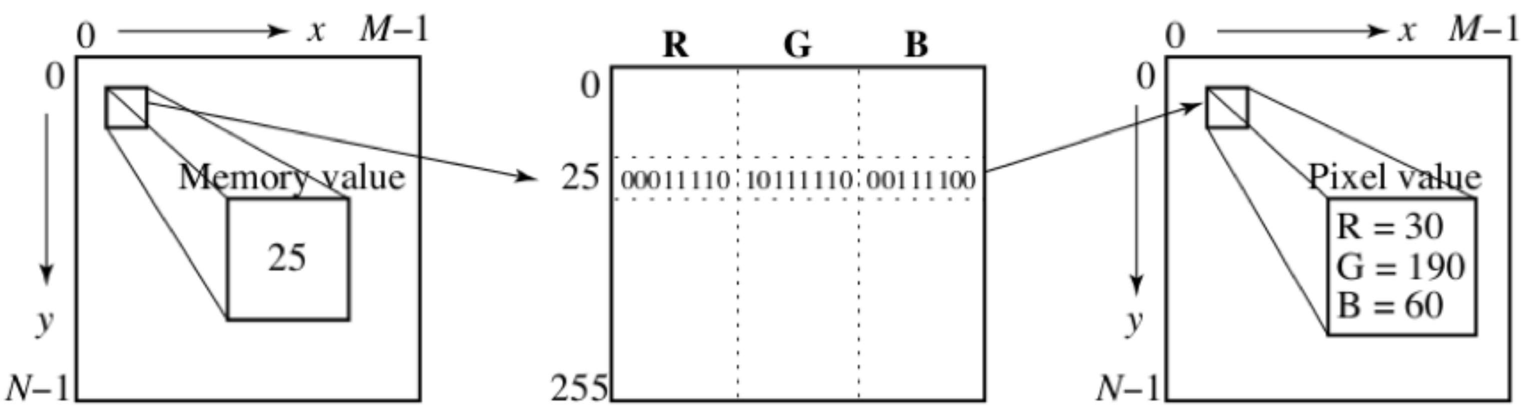
However, such flexibility does result in a storage penalty: A 640×480 24-bit color image would require 921.6 kB of storage without any compression.

GIF use the concept of a lookup table to store color information, using only 8-bits for each pixel. The same image mentioned above would require ~300kb

8-bit color lookup table

The image is composed by a set of bytes, each of which is actually an index into a table with 3-byte values that specify the color for a pixel with that lookup table index.

Eg: if a pixel stores the value 25, the meaning is to go to row 25 in a color lookup table (LUT).



LUT

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8-bit color lookup table

Original image

8-bit color
lookup table

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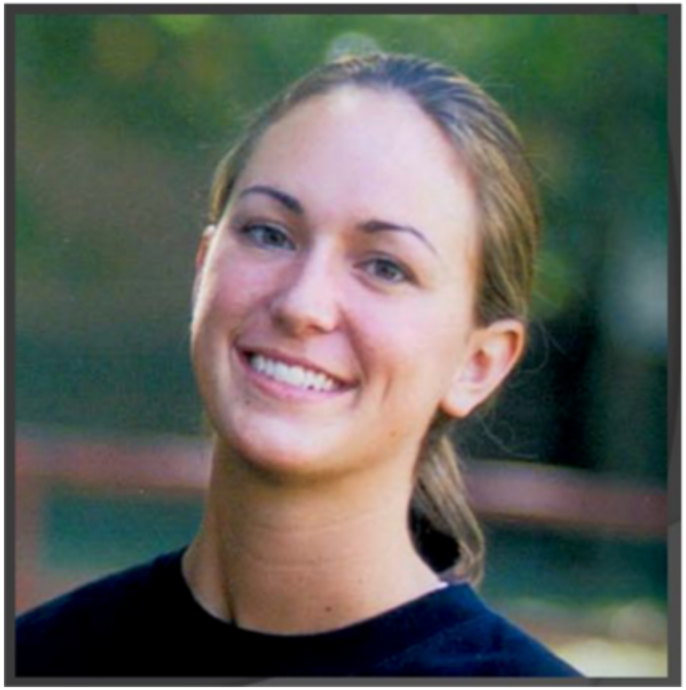
8-bit color lookup table



Original image

8-bit color
lookup table

Color dithering

Many techniques, collectively called dithering, have been developed to approximate a wider range of colors with a small color palette by using pixels of two or more colors to approximate in-between colors

32 colors, no dithering

32 colors, dithering

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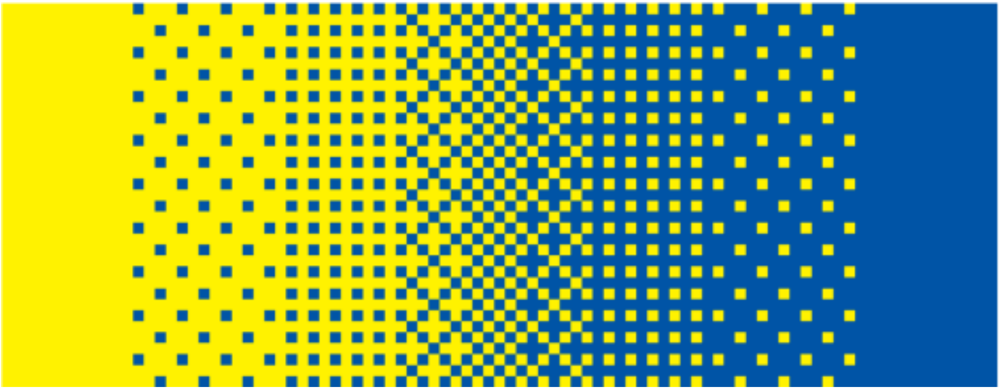
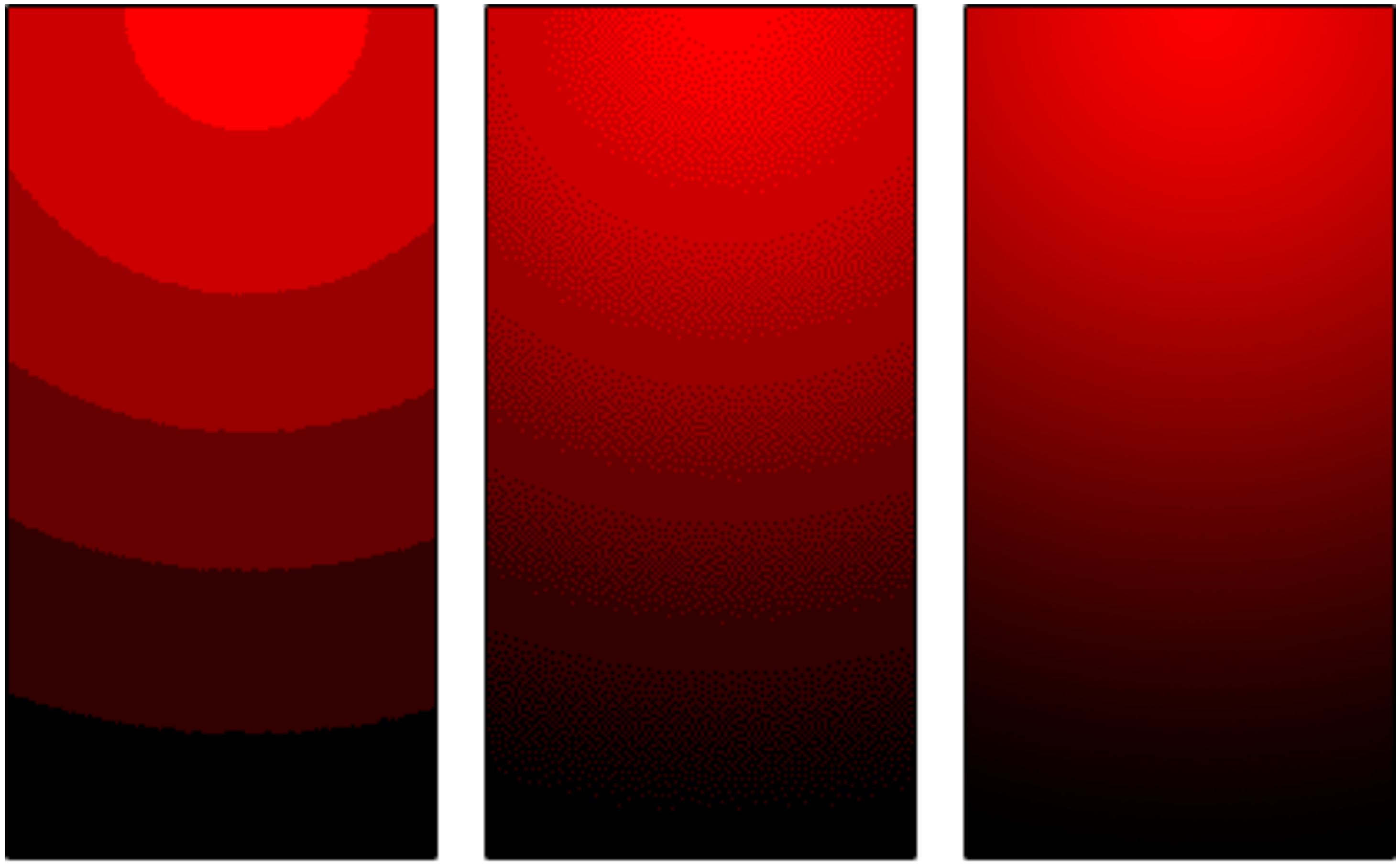
Color dithering

In a dithered image, colors that are not available in the palette are approximated by a diffusion of colored pixels from within the available palette.



- The human eye perceives the diffusion as a mixture of the colors within it
- By its nature, dithering introduces pattern into an image. If the image is viewed from a certain distance, the pattern should not be discernible to the human eye.

Color dithering



8-bit gradient | 8-bit gradient, dithered | 24-bit gradient

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GIF image format

When to use:

- Simple images with few distinct colors (like artificial images, graphics, logos)
- Lossless compression
- Compatibility with many systems
- Simple animations
- Transparent images (a pixel can be either transparent or not)

GIF is the worst choice in general for photographic images. 256 colors are usually too limited and the file is usually larger than the same 24-bit JPEG file.

GIF image format

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PNG image format

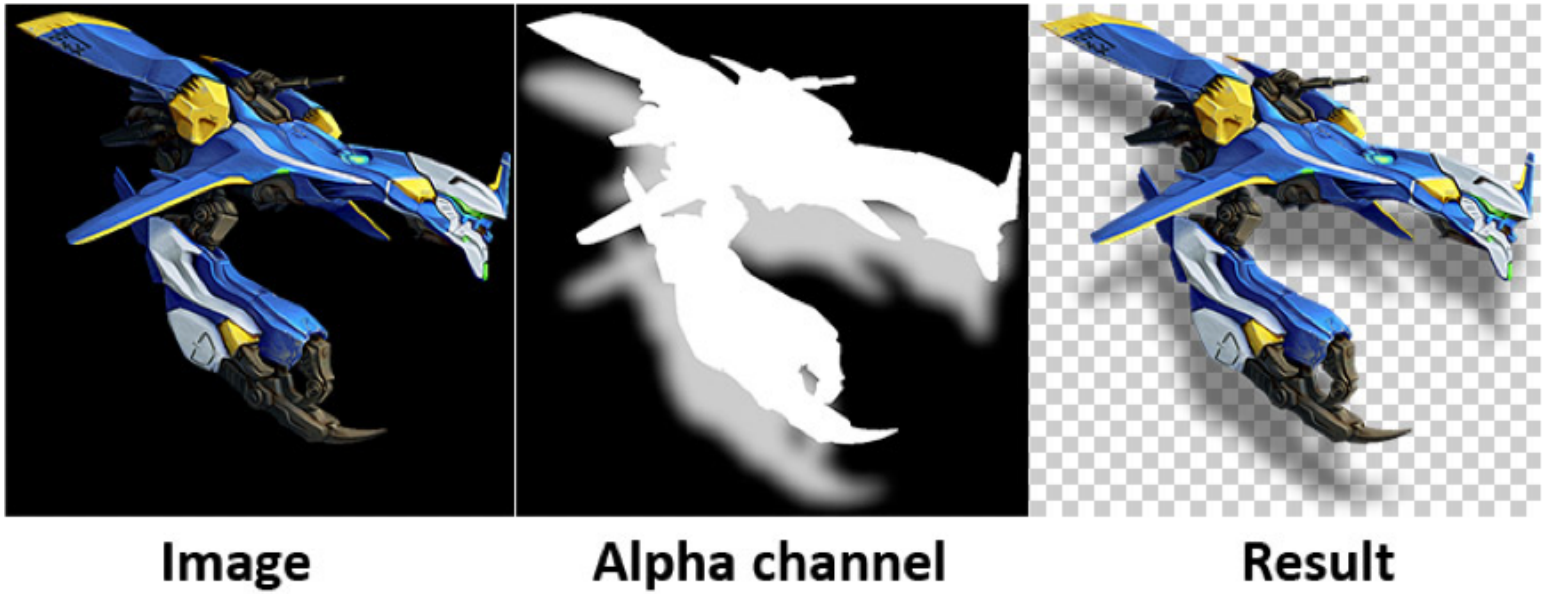
Extensible file format for lossless portable storage of raster images

- patent-free replacement for GIF
- supports indexed-color, grayscale, and true-color (24 bit color images)
- color depth ranges from 1 to 16 bits
- optional alpha channel for transparency
- Compression is better than GIF, but worse than JPEG
- vendor or application dependent information can be stored in image file
- efficient interlacing scheme for slow networks
- W3C recommendation
- privileged format on some platforms (e.g., Apple iOS)

Alpha compositing

Alpha compositing is the process of combining an image with a background to create the appearance of partial or full transparency.

PNG supports alpha compositing in a per-pixel basis using an additional channel called alpha channel.



PNG compression

PNG uses a **lossless** compression strategy composed by a filtering stage followed by the “DEFLATE” data compression algorithm

- Can be freely used (permissive license)
- The filter step preprocesses the data (always with a reversible operation) to let the subsequent compression step more efficient
- Compared to formats with lossy compression such as JPEG, choosing a compression setting higher than average delays processing, but often does not result in a significantly smaller file size.

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PNG image format

When to use:

- All usages of GIF file format, but is patent free
- Lossless compression
- Transparent images with fine control on alpha channel
- Extensible, can hold application dependent information
- Supported by all browsers. Suggested use for the web

For its lossless compression, PNG in general offers better quality than JPEG images but with lower compression (thus the images are bigger).

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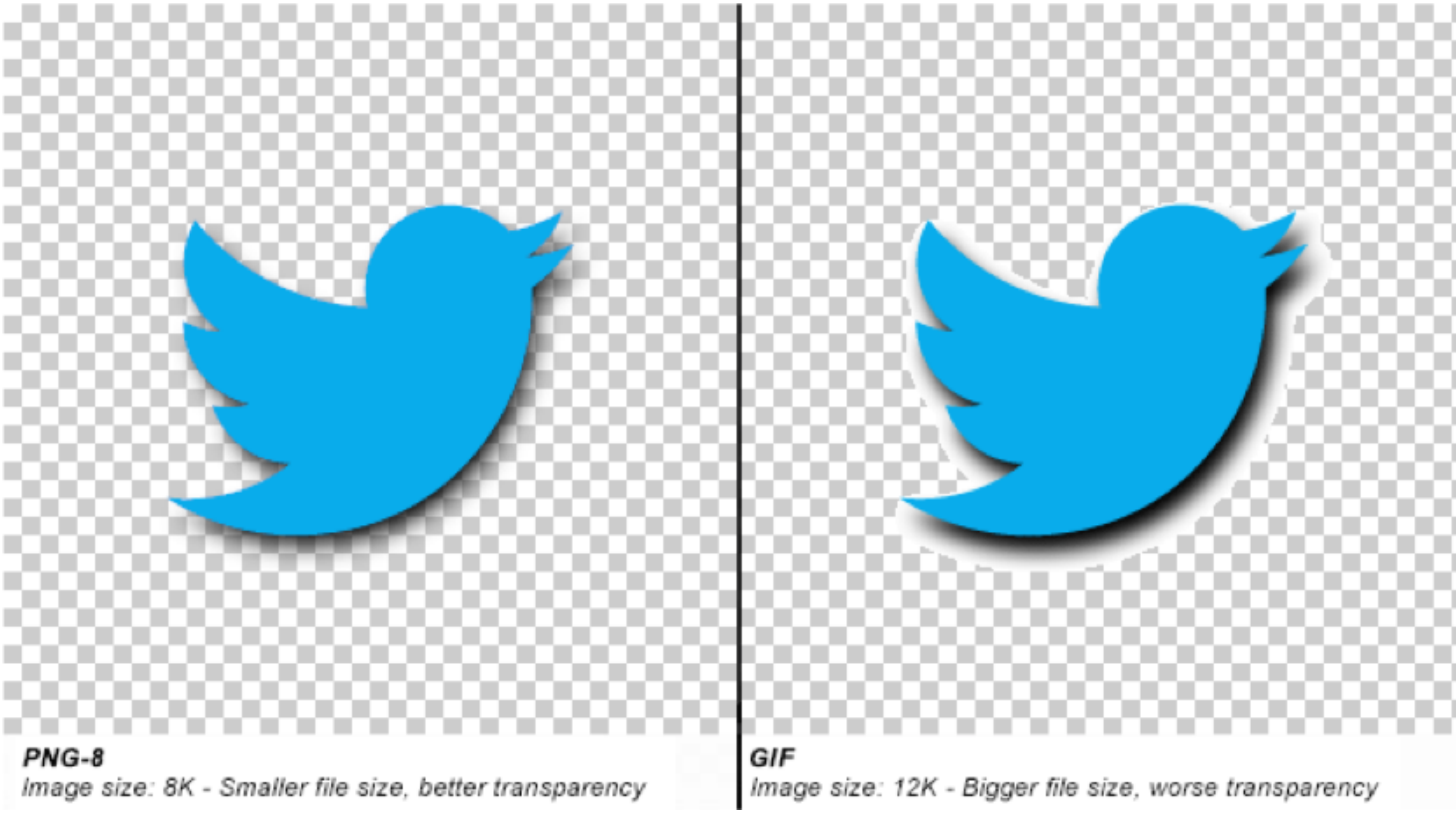
PNG image format



JPEG image format

Standard for photo image compression

High compression rate based on limitations of human vision system:

- small details in a photo image can be suppressed without visible notice
- frequency domain representation and YUV color scheme allows entropic compression algorithms to work better
- not suitable with line-art, geometric drawing, CAD-style images
- not suitable for scanned text
- Can support lossless compression, but in general it is used for its excellent lossy compression

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JPEG compression

The compression technique used in JPEG images is based on the inability of the human eye to distinguish small details in an image, even if recorded by a high quality camera

- In coding terms, details are represented by high frequency components, whatever color model is adopted
- the loss of detail can be accepted as long as the image meaning and quality is preserved in low frequency components
  - GOOD for photographic images, BAD for graphics (logos,etc)

JPEG compression

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First step:

Image is converted from RGB to YUV, the image is decomposed into 8x8 pixels blocks

Second step:

A Discrete Cosine Transformation (DCT) is applied to each block, generating an 8x8 matrix where each element represents the coefficient of a base frequency

Third step:

Coefficients are quantized according to a table. This causes the loss of information

JPEG compression

Fourth step:

The DC component of each block is coded with a differential encoding with respect to the previous block, typically obtaining small values

Fifth step:

The AC coefficients are linearized in diagonal order so that high frequency coefficients, mostly 0, are adjacent; a RLE encoding is then applied

Sixth step:

All the lists are further compressed (Huffman coding) and written to the file

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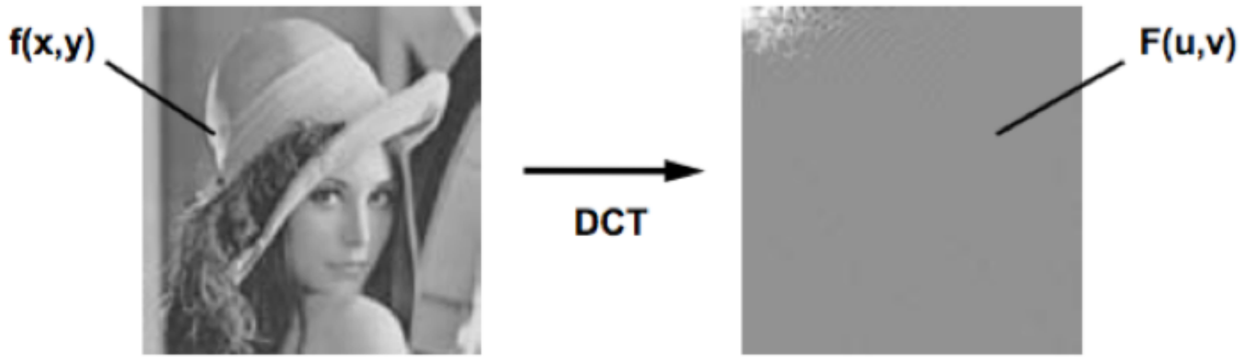
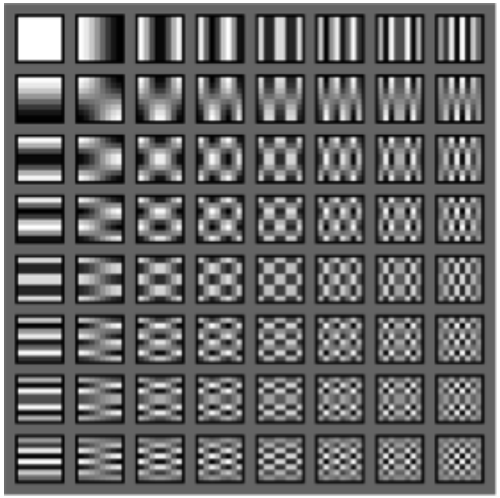
Discrete cosine transform



$$F(u,v) = \alpha(u)\alpha(v)\sum_{x=0}^{N}\sum_{y=0}^{N} f(x,y)\cos\left[\frac{\pi(2x+1)u}{2N}\right]\cos\left[\frac{\pi(2y+1)u}{2N}\right]$$



Discrete cosine transform

The cosine transform is invertible so the original image can be rebuilt by inverting the process.

The DCT coefficients quantization causes the image degradation

DCT Coefficients

150	80	40	14	4	2	1	0
92	75	36	10	6	1	0	0
52	38	26	8	7	4	0	0
12	8	6	4	2	1	0	0
4	3	2	0	0	0	0	0
2	2	1	1	0	0	0	0
1	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Quantized coefficients

150	80	20	4	1	0	0	0
92	75	18	3	1	0	0	0
26	19	13	2	1	0	0	0
3	2	2	1	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Quantization table

1	1	2	4	8	16	32	64
1	1	2	4	8	16	32	64
2	2	2	4	8	16	32	64
4	4	4	4	8	16	32	64
8	8	8	8	8	16	32	64
16	16	16	16	16	16	32	64
32	32	32	32	32	32	32	64
64	64	64	64	64	64	64	64

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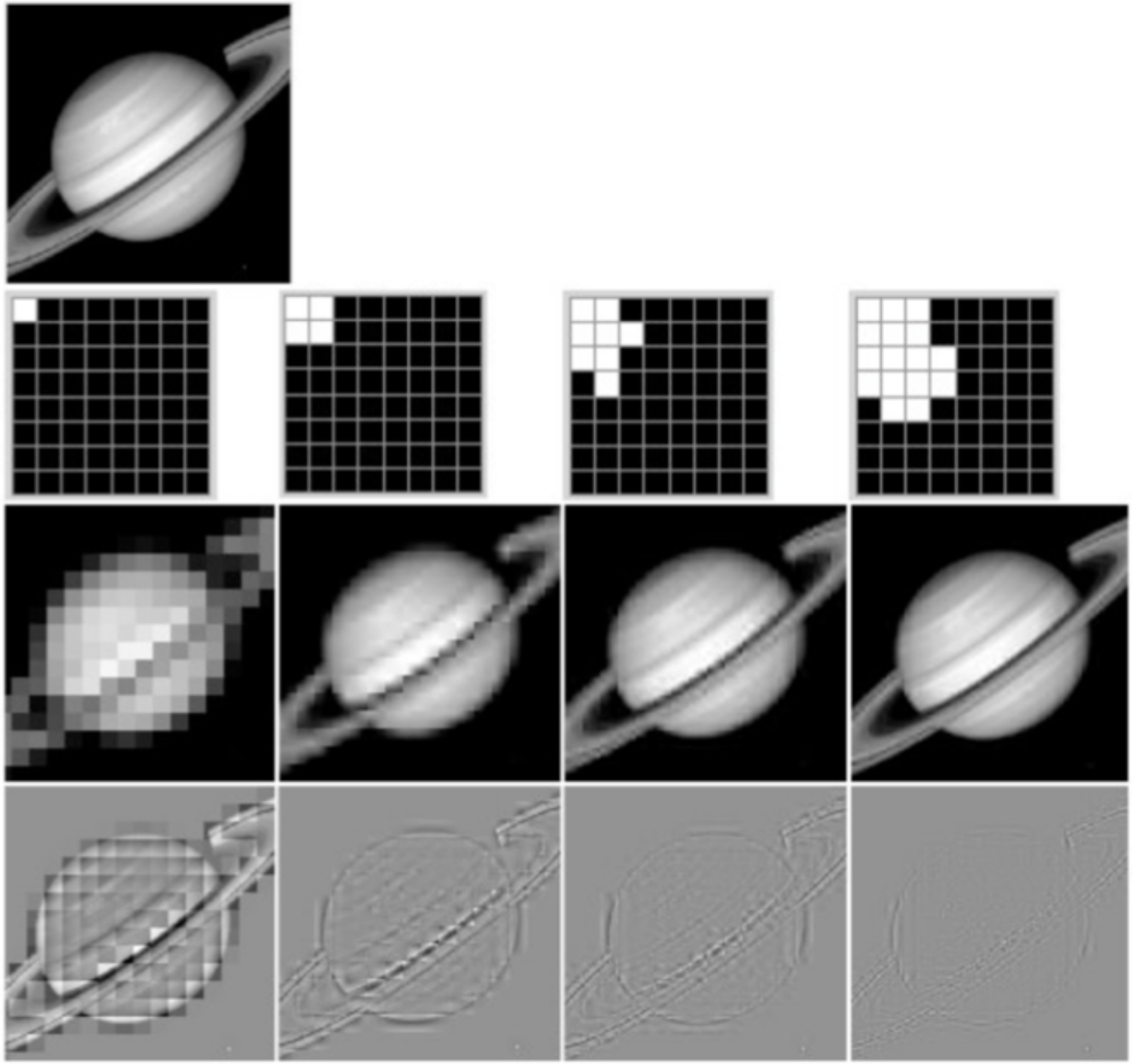
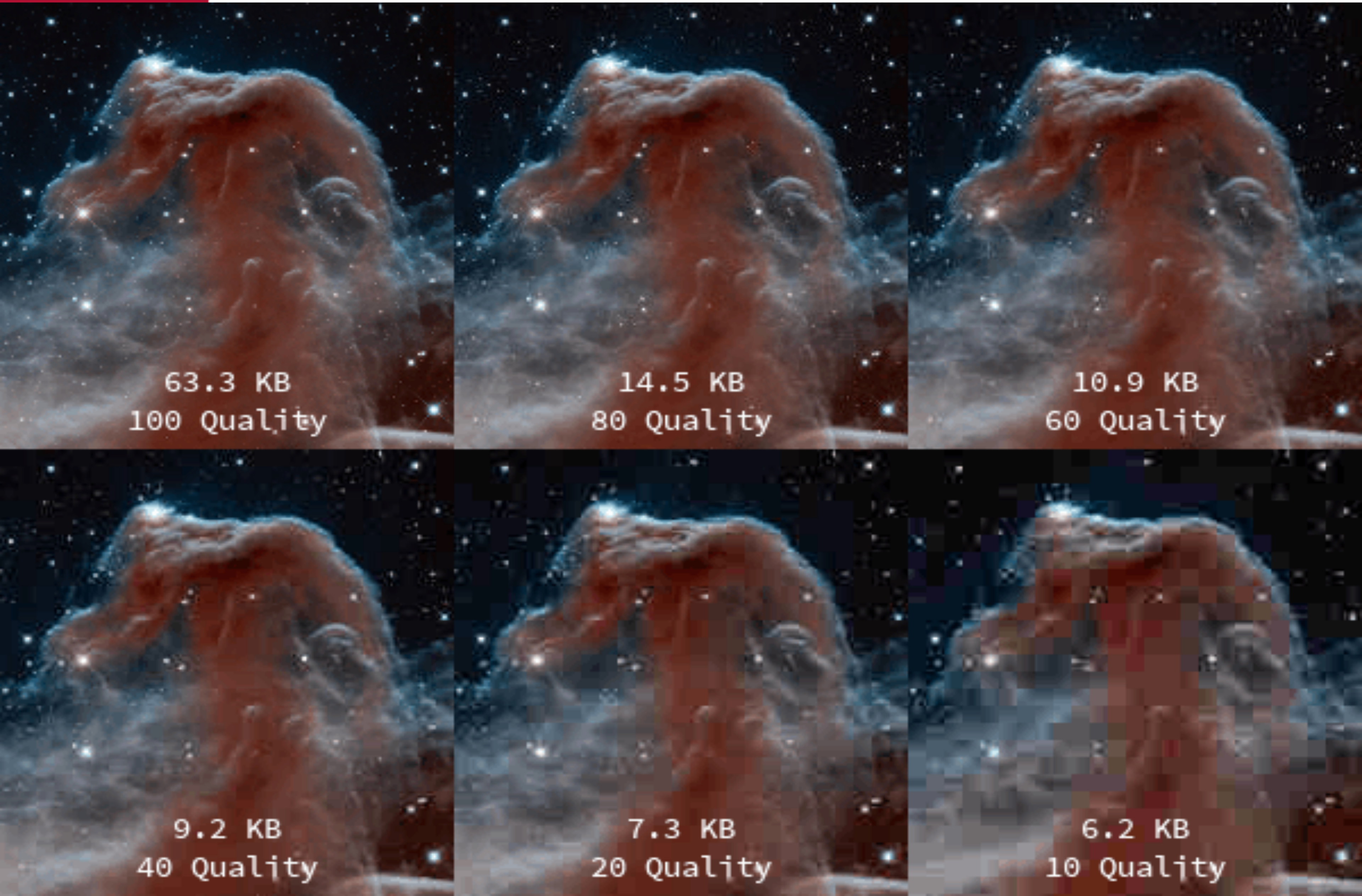
Effect of DCT quantization



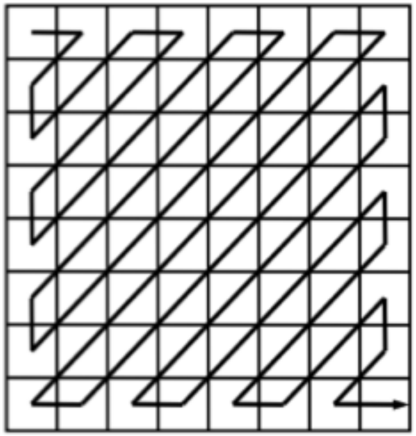
JPEG quality comparison



Effect of DCT quantization

Higher frequencies represent image details that can be removed without appreciable loss of information

- The DCT coefficient matrix is linearized diagonally



- The coefficients of higher frequencies are mostly zeros after the quantization
- RLE compression techniques is applied

JPEG encoding

JPEG defines four (alternative) coding schema:

- **sequential coding:** the immagine is coded in a single top-left to bottom-right scan
- **progressive coding:** DCT coefficients are grouped by frequency across all the image --> the image is progressively displayed with increasing quality and detail
- **hierarchical coding:** the image is sub-sampled and JPEG coded, then it is followed by the differences between the decoded and resampled image and the original image
- **lossless coding:** uses predictive techniques instead of DCT transform; each pixel is coded as a difference w.r.t. a function of adjacent pixels

JPEG image format

When to use:

- Photographic images with many colors and shades
- Precision in detail rendering is not mandatory
- Progressive transmission and rendering for slow networks and variable quality
- Most used standard for non professional photographic applications

JPEG is not a good format:

- To represent graphic, logos, written text
- When transparency is needed

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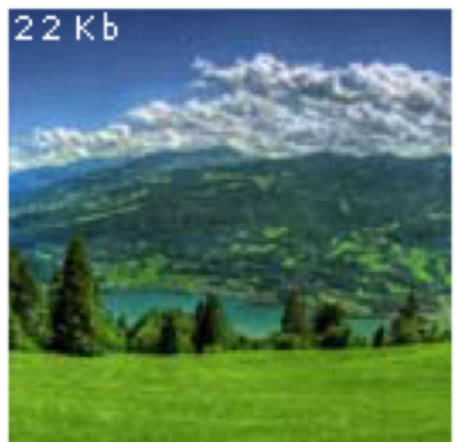
JPEG image format

PNG

Compressed
JPEG



TIFF image format

Standard format for professional high quality applications.

Standard since long time in typographic industry

- supports b/w, grayscale, indexed color and true color images
- the image file is divided into chunks, each of which has its own identifier (tag) and its own format
- contains physical size definition of image to preserve the format of the original when printing

Supports multiple compression formats:

- CCITT standard (~ fax) for b/w images
- JPEG for color images
- no compression for maximum fidelity

TIFF image format

When to use:

Photographic and typographic professional high quality applications

- format supported by digital cameras and scanners
- standard format printing industry for historical reasons

Allows full quality control through compression selection.

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Multispectral imaging

We have seen that we usually code color information according to 3 channels

- For example in the RGB space correspond to the red, green, and blue components of the image acquisition device

In recent years, the field of digital imaging has extended the traditional trichromatic RGB paradigm to more than three dimensions, introducing what is called spectral or **multispectral imaging**.

GOAL: acquire, process, reproduce and store images with a higher color quality

Multispectral imaging

For cultural heritage applications, there is the strong need to accomplish a faithful reproduction of the content across different devices or media. In other words, to provide a **consistent color reproduction** for different viewing conditions.

On the contrary, RGB images must be processed within the framework of colorimetry in order to accomplish faithful reproduction across different devices.

Color information captured with RGB devices cannot generate a fully accurate colorimetric representation due to the fact that **the sensitivities of the sensor employed do not correspond to those of the standard colorimetric observer**

Color balance

Image data acquired must be transformed to values that are appropriate for reproduction on a specific device.

Color correction is essential:

- The acquisition sensors do not match the “sensors” in the human eye
- The properties of the display medium must be accounted
- The ambient viewing conditions of the acquisition differ from the display viewing conditions

An important goal of this adjustment is to render specific colors (particularly neutral colors) correctly: **white balance**

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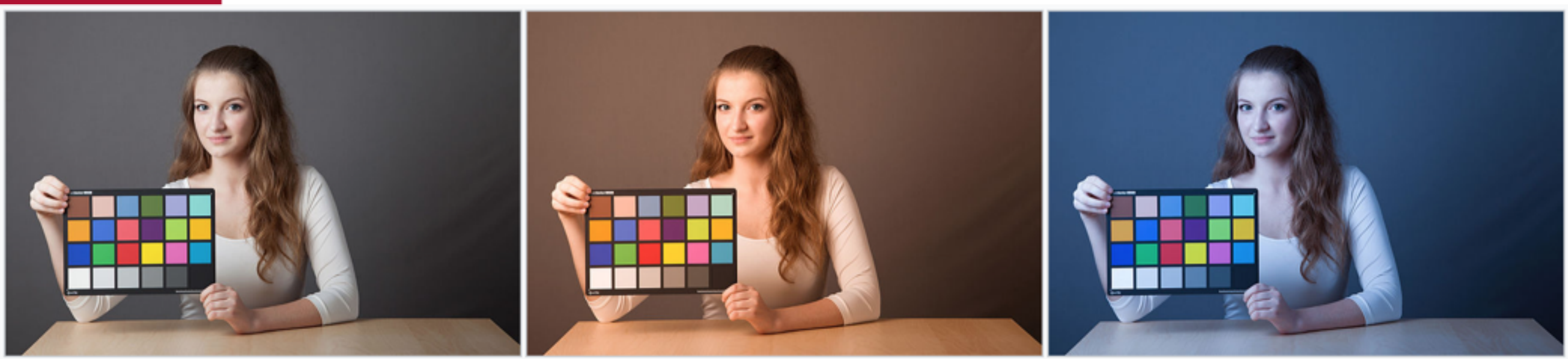
Color balance

Neutral light | Warm light | Cold light

Comparison of resulted colors as shot by the digital camera for different light qualities (color temperature): Neutral, Warm and Cold.[15]



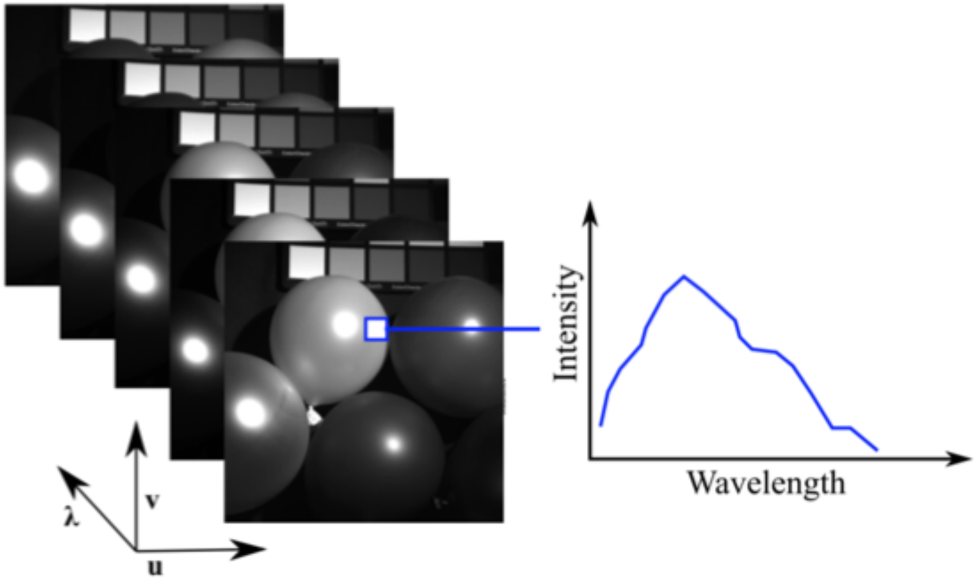
Setting: As shot | Setting: Cloudy | Setting: Tungsten

Example of different white balance settings on digital camera for Neutral light.[15]

Multispectral imaging

A multispectral imaging device directly samples the **radiance** of a scene at different bands of the wavelength spectrum (usually 8 up to 32 bands).

The data returned is a cube in which for each pixel a vector of real numbers encode the spectral response sampled at specific wavelengths



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Irradiance and Reflectance

Radiance is defined as the amount of energy that flows from a light source.

A fraction of the light incident on the surface being observed is reflected towards the camera and captured by the sensors. This fraction is called **Irradiance** and is a function of:

- The scene geometry (**shading**)
- The surface material (**reflectance**)

In multi-spectral imaging we are interested in the recovering of **reflectance** that is a physical characteristic of each material.

Reflectance models

Reflectance recovery requires modelling the influence of the **illumination** condition, the surface **geometry** and the **material** properties under study on the observed image irradiance

Reflectance models can be classified into three broad categories:

- Empirical (often used in practice)
- Physics-based
- phenomenological (semi-empirical).

Dichromatic model

Introduced by Shafer (1985), is the simplest reflection model that accounts for both diffuse and specular reflection:

$$I(u,\lambda) = g(u)L(\lambda)S(u,\lambda) + k(u)L(\lambda)$$

- Uniform illumination across the spatial domain
- Surface radiance is decomposed into a diffuse component and a specular one
- g(u) governs the proportion of diffuse light reflected from the object and depends on the surface geometry
- k(u) models the irregularities of the micro-facet structure that cause specularities in the scene

Multispectral imaging

Advantages:

- Each pixel represents a physical property (reflectance) defined on a per-wavelengths basis. It is thus independent from the acquisition device
- The multispectral image constitutes a fundamental physical description of the artifact, independent from the observer, which can be targeted to any desired description specific for a given observer and viewing conditions

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Multispectral imaging

Advantages:

- Multispectral images can also show details in the artifacts that are hard to see, if not impossible to detect, in RGB images. (For example in the near-infrared bands)
- It is quite straightforward to produce a correspondent colorimetric version of a multispectral image once viewing conditions are assigned. (the reverse is not possible)

Multispectral camera

Usually multispectral cameras rely on a standard B/W digital camera and a set of colored filters

Filters can be fixed or composed by device whose spectral transmission can be electronically controlled through the application of voltage or acoustic signal

Narrow-band vs. Wide-band

In **narrow-band** systems, the device's sensors are sensitive to a very narrow wavelength interval or the light sources employed show a very narrow emission spectrum.

- Easy to deal with, complex hardware and/or environment conditions

In **wide-band** systems each sensor is sensitive to light energy in a large wavelength interval.

- Require a correlation method learned from a suitable training set to relate the output from the multispectral camera at some pixel with the reflectance spectrum of the corresponding surface point in the scene

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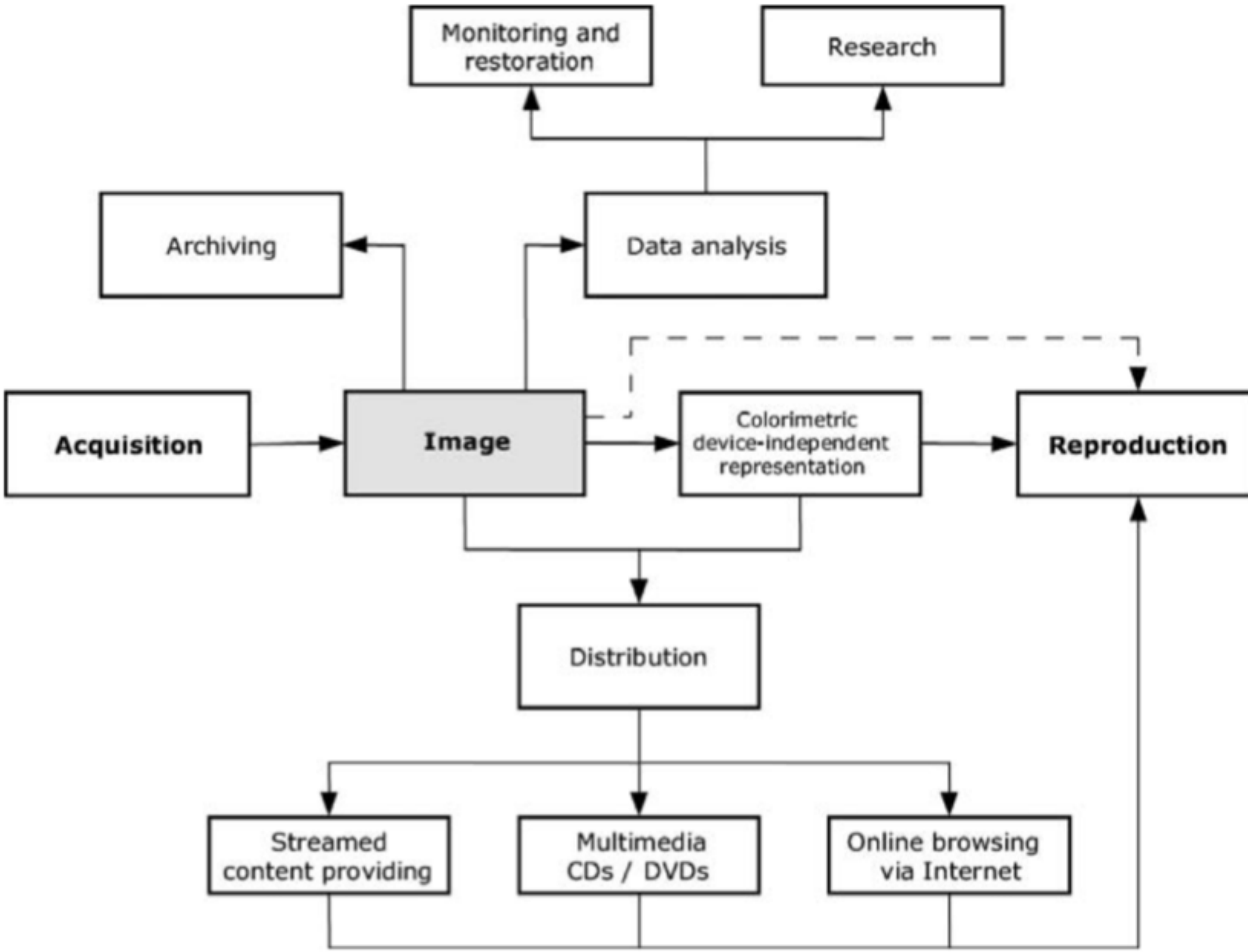
Multispectral imaging in CH



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Multispectral imaging in CH

First steps toward the full digitization of cultural heritage artefacts had been the adoption of multispectral images acquired with fixed viewpoint and fixed lighting position.

VASARI Project (http://users.ecs.soton.ac.uk/km/projs/vasari/)

Aim: Develop a colorimetric scanner system for direct digital imaging of paintings. (years 1989-92)

The proposed system was able to digitize high-resolution multispectral images (six bands) moving a CCD camera and acquiring multiple shots

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Multispectral imaging in CH

Multispectral imaging for pigment analysis:

- H. Maitre, F. Schmitt, J.-P. Crettez, Y. Wu, and J. Y. Hardeberg, "Spectrophotometric image analysis of fine art paintings," in Proc. IS&T/SID 4th Color Imaging Conference: Color Science, Systems and Applications, pp. 50–53, 1996.

- F. M. P. B. Ferreira, P. Fiadeiro, S. Nascimento, V. de Almeida, M. Pereira, and J. Bernardo, "Spectral characterization of a hyperspectral system for imaging of large art paintings," in CGIV 2006 – Third European Conference on Color in Graphics, Imaging and Vision., pp. 350–354, 2006.