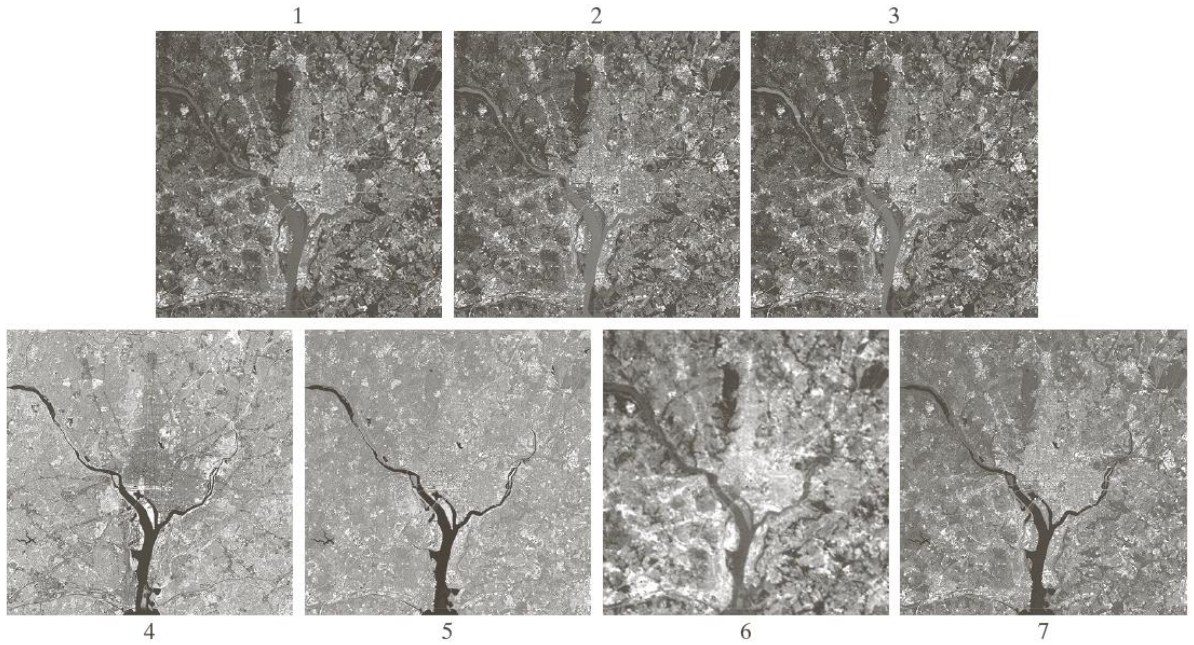
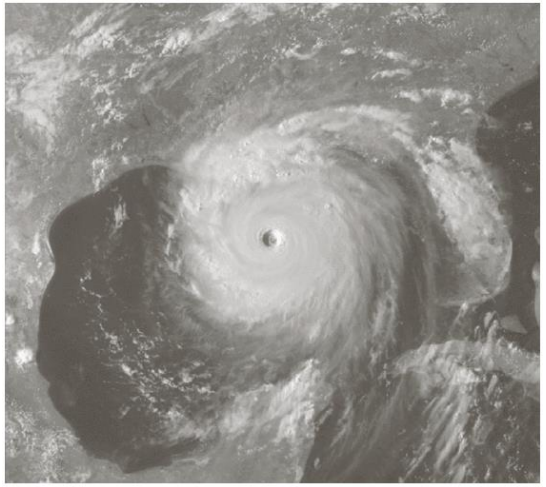
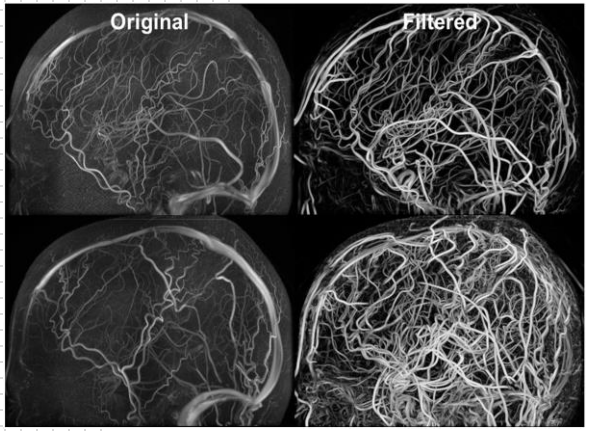
Recap of the previous lesson

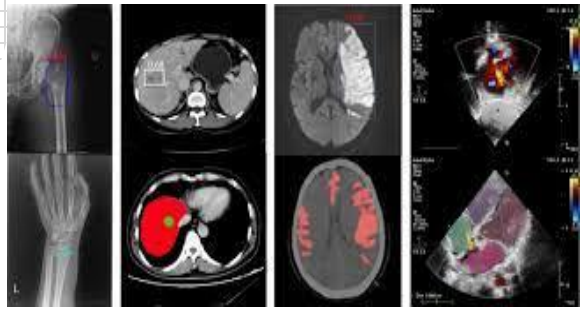
From the satellite

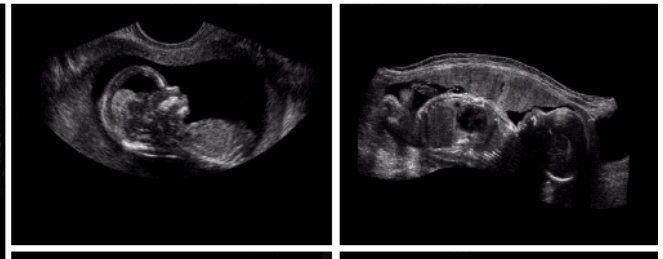


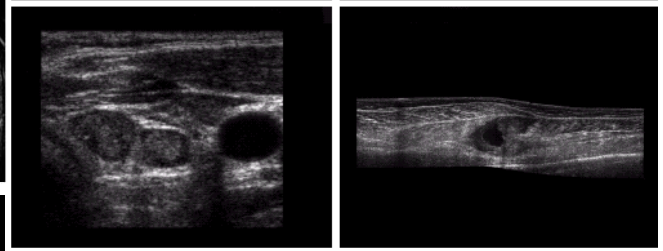


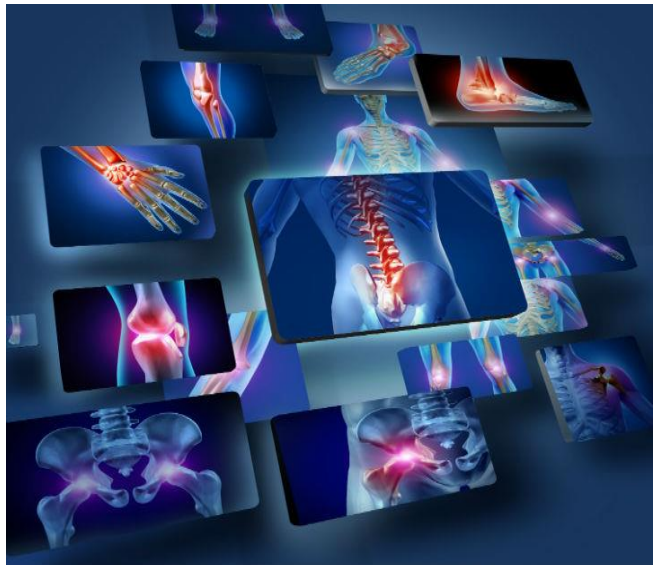
Medical

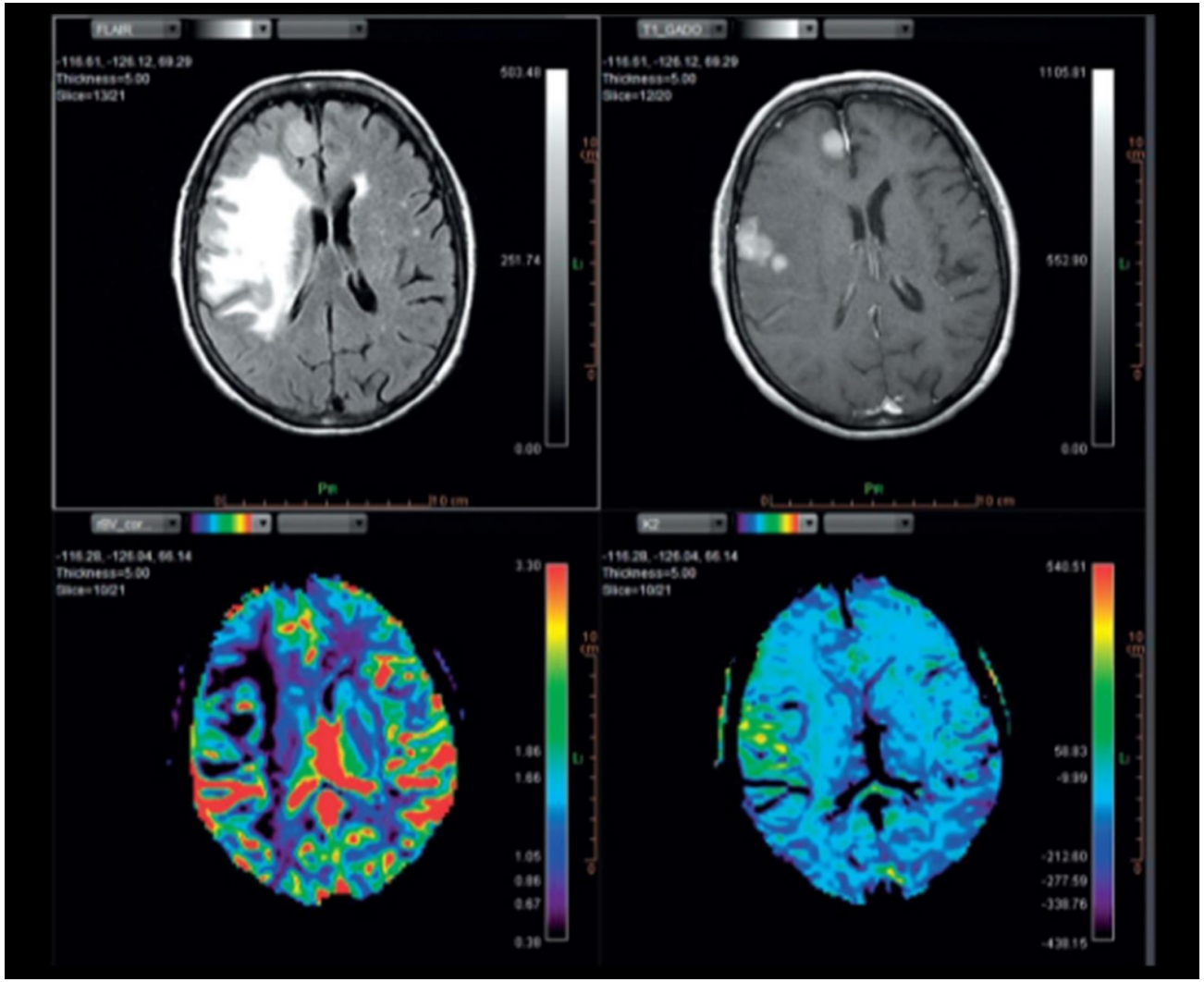




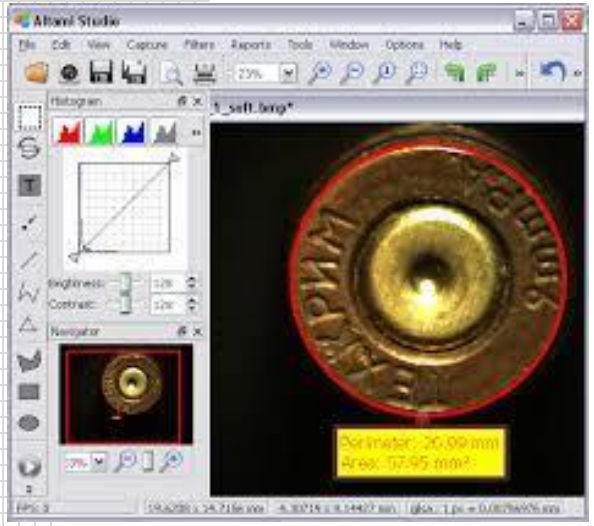








Forensics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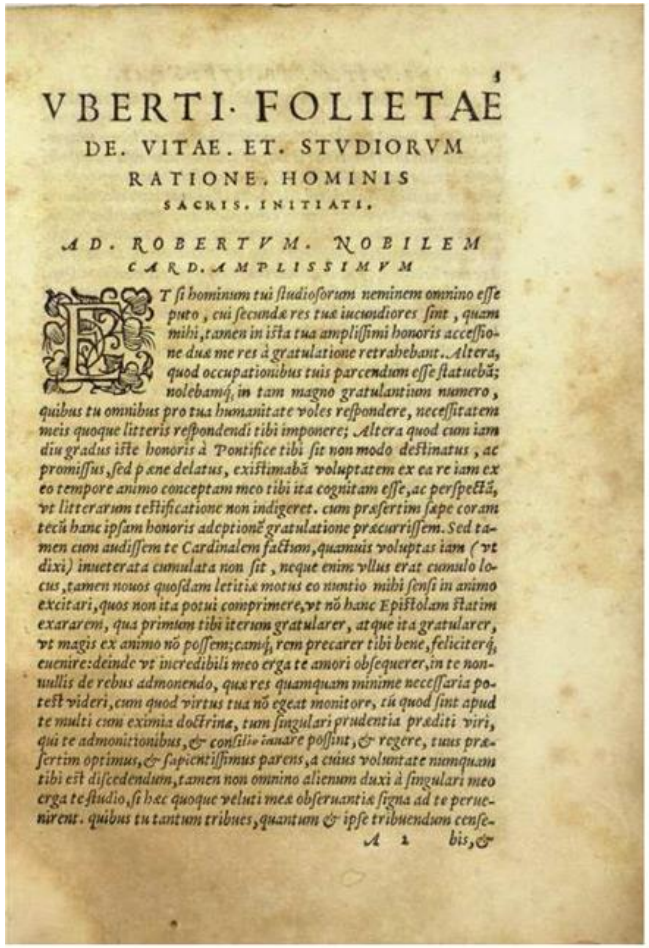
For cultural heritage



VBERTI· FOLIETAE

DE. VITAE. ET. STVDIORVM

RATIONE. HOMINIS

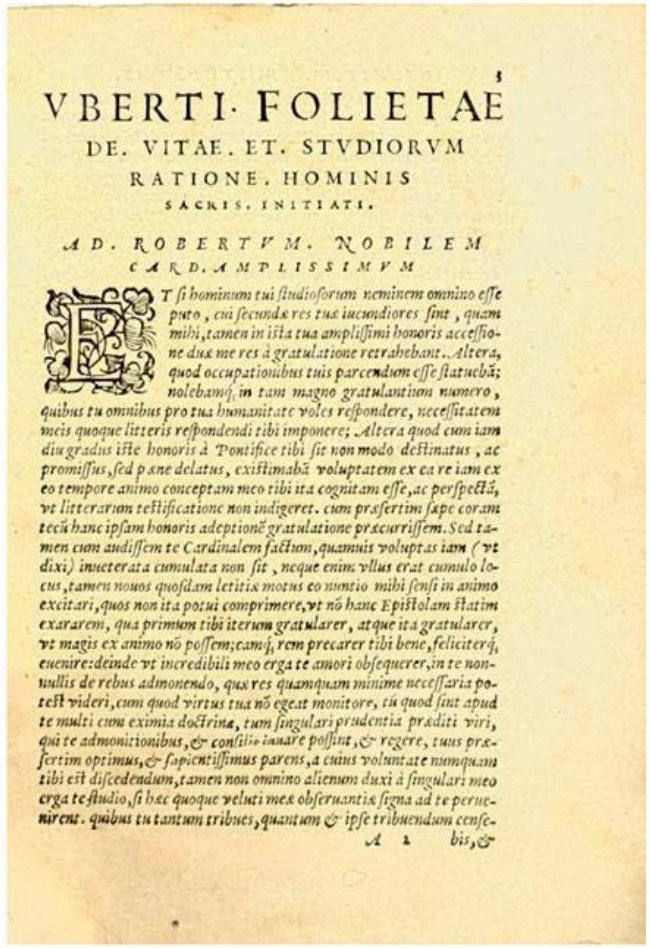
SACRIS. INITIATI.

AD. ROBERTVM. NOBILEM

CARD. AMPLISSIMVM

ET si hominum tui studiosorum neminem omnino esse puto, cui secundæ res tuæ iucundiores sint, quam mihi, tamen in ista tua amplissimi honoris accessione duæ me res à gratulatione retrahebant. Altera, quod occupationibus tuis parcendum esse statuebã; nolebamq; in tam magno gratulantium numero, quibus tu omnibus pro tua humanitate voles respondere, necessitatem meis quoque litteris respondendi tibi imponere; Altera quod cum iam diu gradus iste honoris à Pontifice tibi sit non modo destinatus, ac promissus, sed pene delatus, existimabã voluptatem ex ea re iam ex eo tempore animo conceptam meo tibi ita cognitam esse, ac perspectã, vt litterarum testificatione non indigeret. cum præsertim sæpe coram tecũ hanc ipsam honoris adeptionẽ gratulatione præcurrissem. Sed tamen cum audissem te Cardinalem factum, quamuis voluptas iam (vt dixi) inueterata cumulata non sit, neque enim vllus erat cumulo locus, tamen nouos quosdam letitiæ motus eo nuntio mihi sensi in animo excitari, quos non ita potui comprimere, vt nõ hanc Epistolam statim exararem, qua primum tibi iterum gratularer, atque ita gratularer, vt magis ex animo nõ possem; camq; rem precarer tibi bene, feliciterq; euenire: deinde vt incredibili meo erga te amori obsequerer, in te nonnullis de rebus admonendo, quæ res quamquam minime necessaria potest videri, cum quod virtus tua nõ egeat monitore, tũ quod sint apud te multi cum eximia doctrina, tum singulari prudentia præditi viri, qui te admonitionibus, & consilio iuuare possint, & regere, tuus præsertim optimus, & sapientissimus parens, a cuius voluntate numquam tibi est discedendum, tamen non omnino alienum duxi à singulari meo erga te studio, si hæc quoque veluti meæ obseruantiæ signa ad te perue-

A 2 bis, &



VBERTI· FOLIETAE

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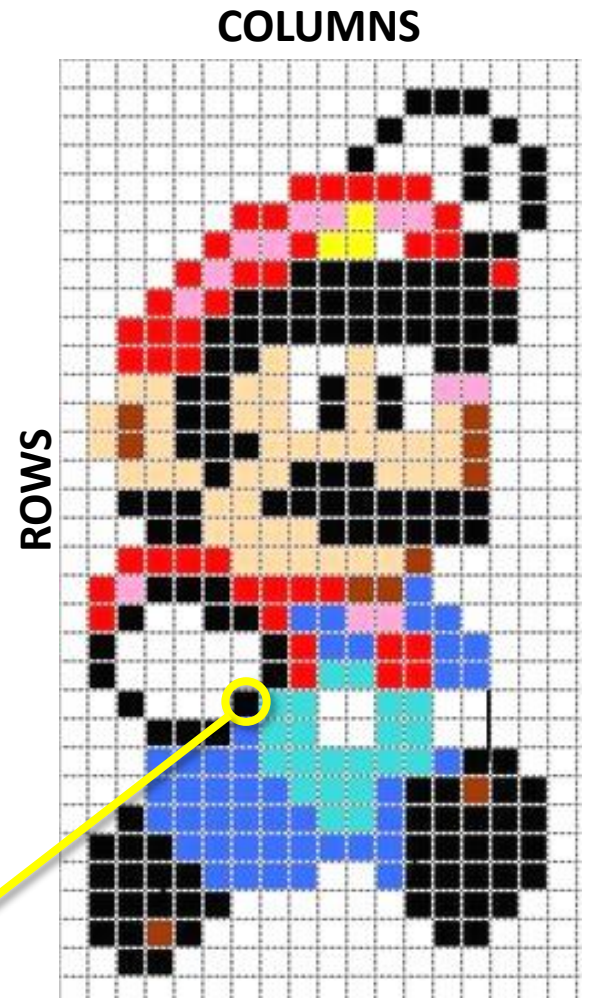
A 2 bis, &

What is a digital image?

Definizione

A monochromatic digital image is a matrix I = f(x,y) of discrete values of light intensity (gray levels), consisting of M*N pixels (picture elements, sometimes called pel), each of which has a value belonging to the interval [0, L-1] L being the possible levels of intensity (or gray levels).

All the operations that can be done on matrices can be done on an image



Pixel (PICTURE ELEMENT)

Comparison

Raster

Pro

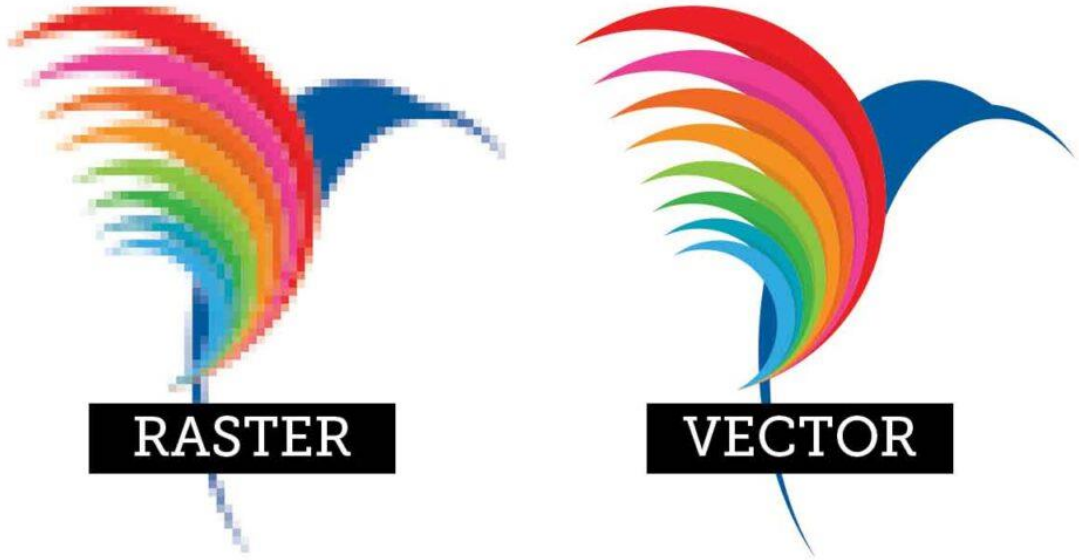
Photorealism

Web-based standards

Cons:

No semantic description.

Large size



Vector

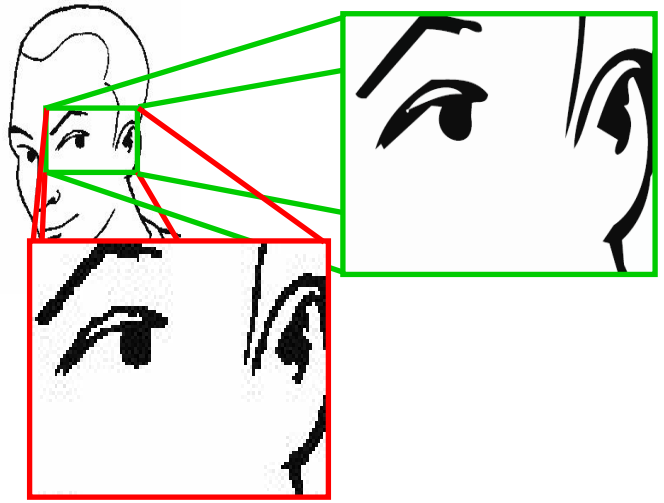
Pro

Transformations on the plane are simple (Zooming, Scaling, Rotating)

Cons:

Not photorealistic

Proprietary vector formats



Vettoriale

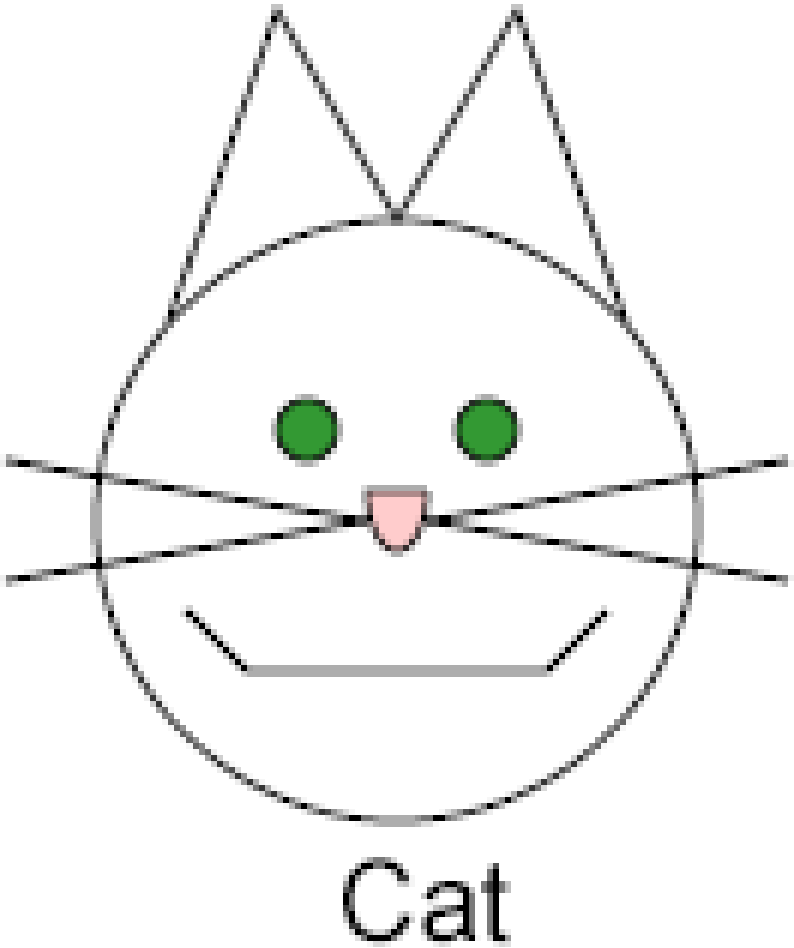
Raster

Un esempio concreto di scalabilità

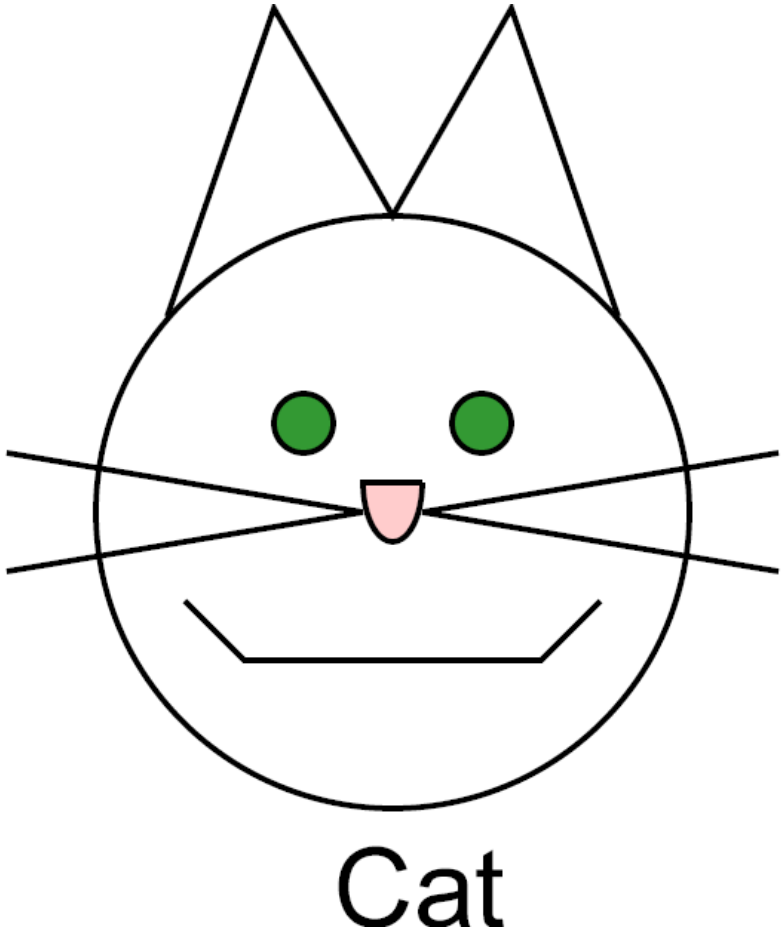
Raster
(140x170)

Vector
(140x170)

Raster 2x



Vector 2x



Types of images - **Black and white**

- **1 bit per pixel**
- At position **(i,j)** there will be either value **0** or value **1**

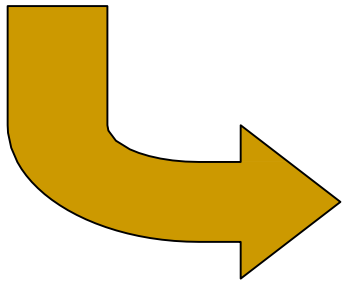
Types of images - Greyscale

- **8 bit per pixel**
- At position **(i,j)** there will be a value between **[0, 255]**

Types of images – Color (e.g. RGB)

- **8 bit per canale**. Since there are 3 channels I will have **24 bit**
- At position **(i,j)** there will be a triplet of the type **(x, y, z)** with x, y, z taking values between **[0, 255]**

RGB images: actually ...



Operations on Images and Matrices

- A raster digital image can be represented by a matrix;
- All the operations that can be done on matrices can be done on an image.
- Such operations do not necessarily make logical sense. For example, what does it mean to multiply two images from a visual point of view?
- What is the range of values after such operations?

Product

- WARNING: The row-by-column product rule applies to matrices, whereas in image processing it is used to do the dot product between two matrices, that is, the **point-to-point product** of the **corresponding elements**.

row-by-column product rule

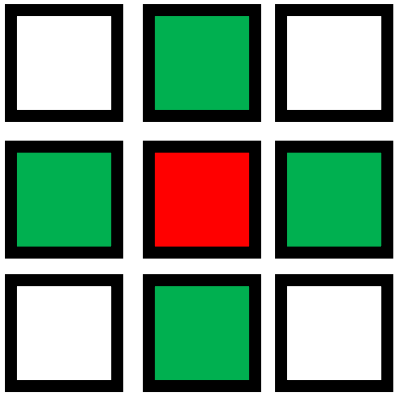
$$\begin{bmatrix} 1 & 0 & 2 \\ -1 & 3 & 1 \end{bmatrix} \times \begin{bmatrix} 3 & 1 \\ 2 & 1 \\ 1 & 0 \end{bmatrix} = \begin{bmatrix} (1\times 3+0\times 2+2\times 1) & (1\times 1+0\times 1+2\times 0) \\ (-1\times 3+3\times 2+1\times 1) & (-1\times 1+3\times 1+1\times 0) \end{bmatrix} = \begin{bmatrix} 5 & 1 \\ 4 & 2 \end{bmatrix}$$

Image product

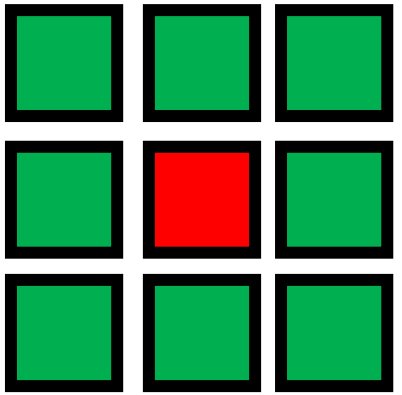
$$\begin{bmatrix} 1 & 2 \\ 3 & -1 \end{bmatrix} \cdot \begin{bmatrix} -3 & 0 \\ 1 & 4 \end{bmatrix} = \begin{bmatrix} -3 & 0 \\ 3 & -4 \end{bmatrix}$$

Neighborhood N_p

- The 4 connected neighbors of a given pixel are those to its left and right and those above and below it.



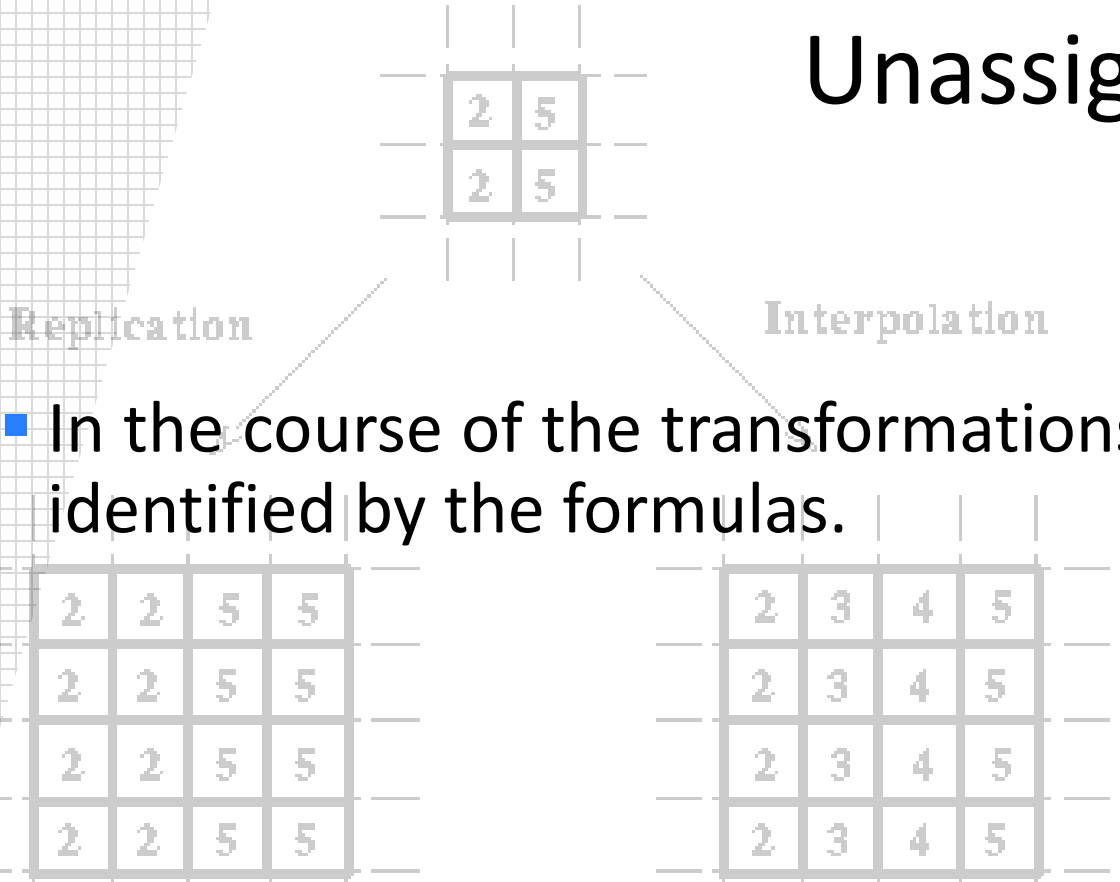
- Neighbors 8 connected are those 4 connected to which the 4 diagonal pixels are added.



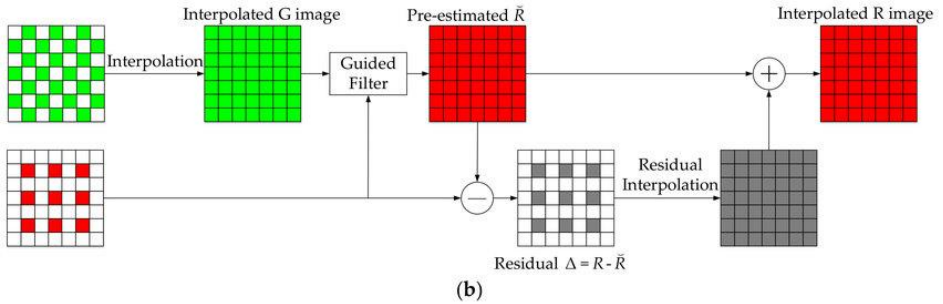
Affine operations

Transformation Name	Affine Matrix, T	Coordinate Equations	Example
Identity	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v$ $y = w$	
Scaling	$\begin{bmatrix} c_x & 0 & 0 \\ 0 & c_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = c_x v$ $y = c_y w$	
Rotation	$\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v\cos\theta - w\sin\theta$ $y = v\sin\theta + w\cos\theta$	
Translation	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ t_x & t_y & 1 \end{bmatrix}$	$x = v + t_x$ $y = w + t_y$	
Shear (vertical)	$\begin{bmatrix} 1 & 0 & 0 \\ s_v & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v + s_v w$ $y = w$	
Shear (horizontal)	$\begin{bmatrix} 1 & s_h & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v$ $y = s_h v + w$	

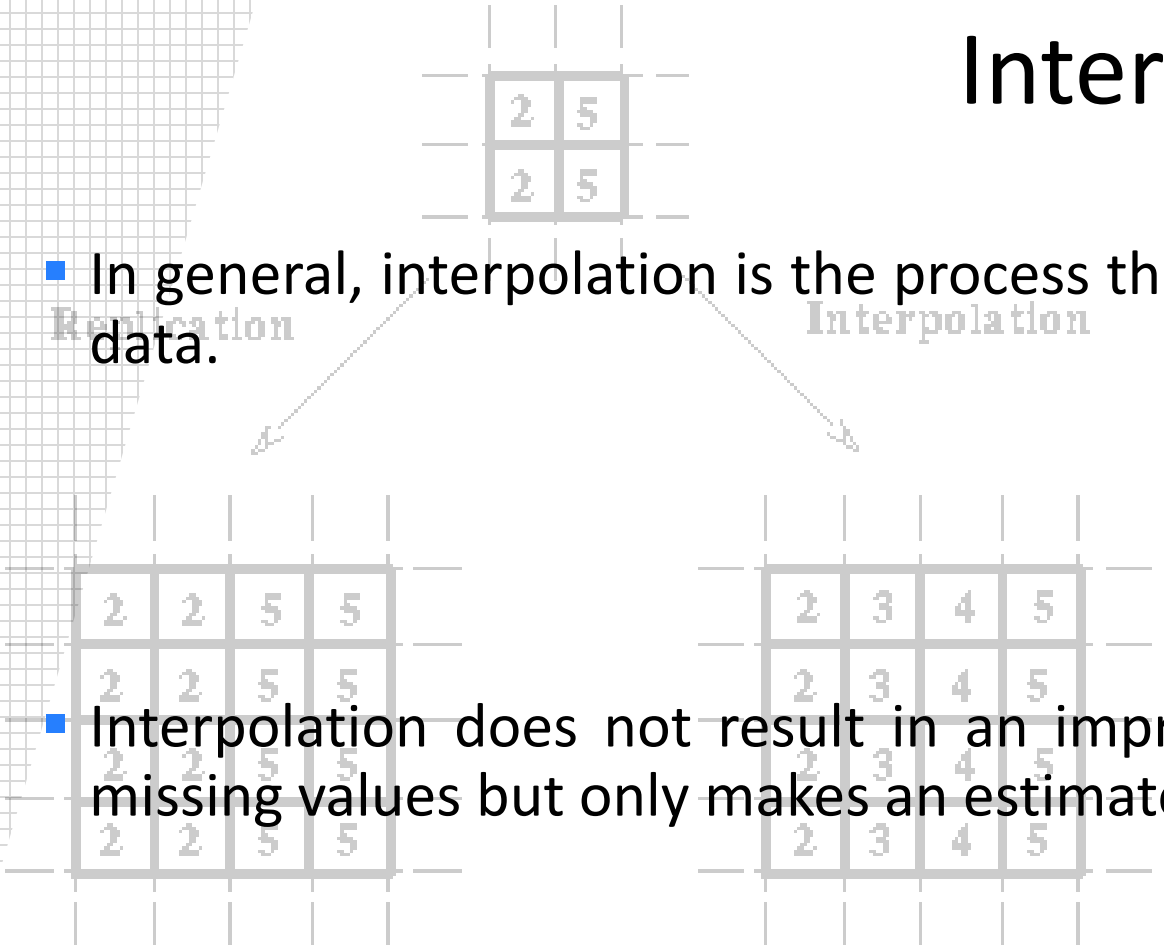
Unassigned values



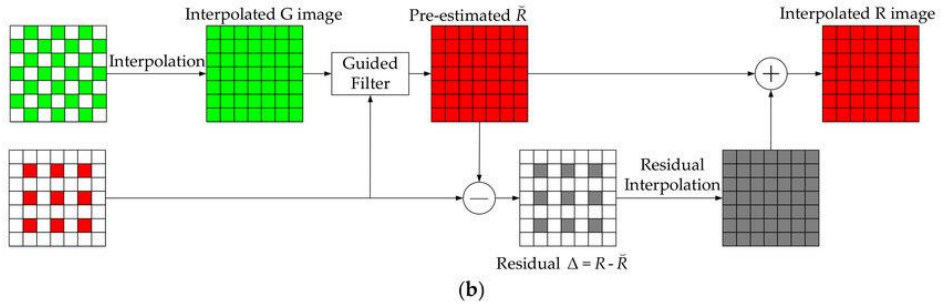
- In the course of the transformations, there may be pixel values that are never identified by the formulas.
- An interpolation process is applied for them.



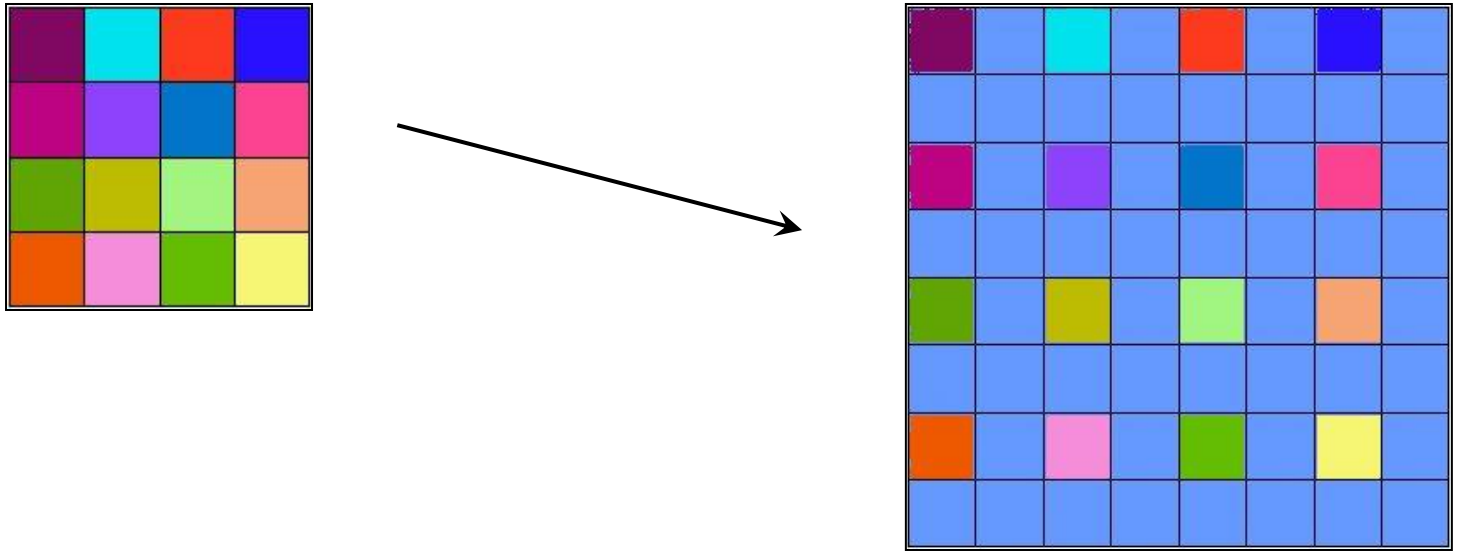
Interpolation



- In general, interpolation is the process that starting from real data estimates the unknown data.
- Interpolation does not result in an improvement in image quality as if it "regains" the missing values but only makes an estimate of the unknown values.



Zooming in (2x)



After placing the already known values, it is necessary to estimate the values in the empty areas.

Various types of interpolation

There are several types of interpolation:

- Nearest neighbor (or replication)
- Bilinear
- Bicubic
- Others ...

Replication Interpolation

(a)

(b)

Bilinear Interpolation

(a)

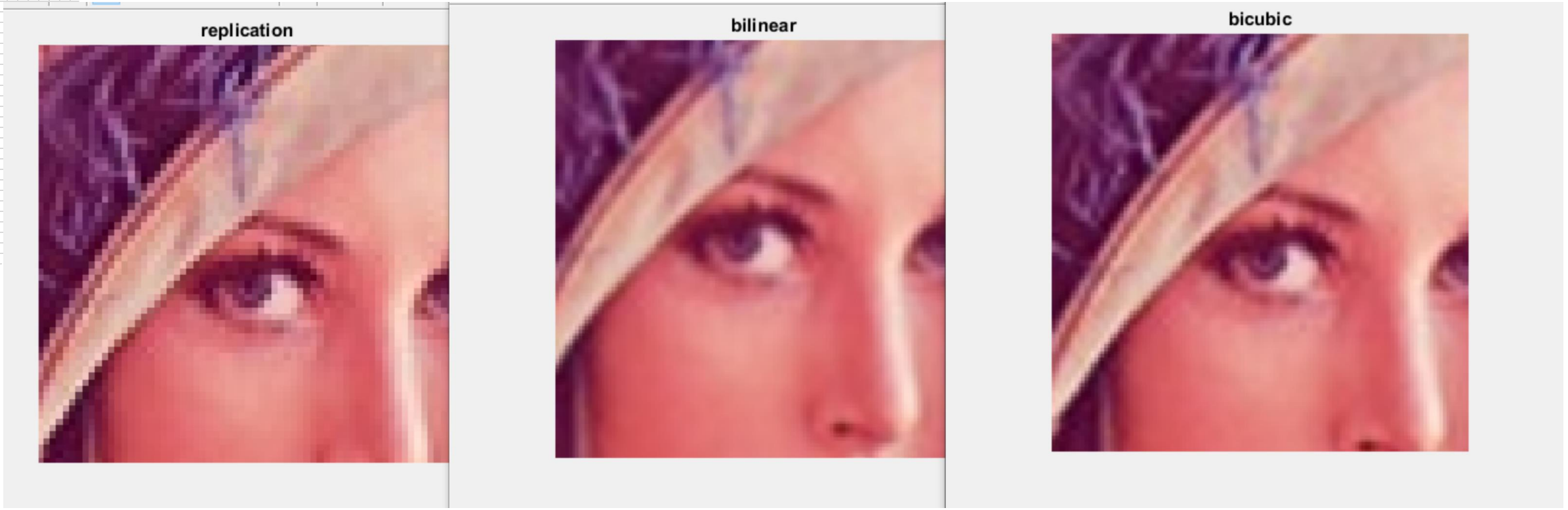
(b)

Bicubic Interpolation

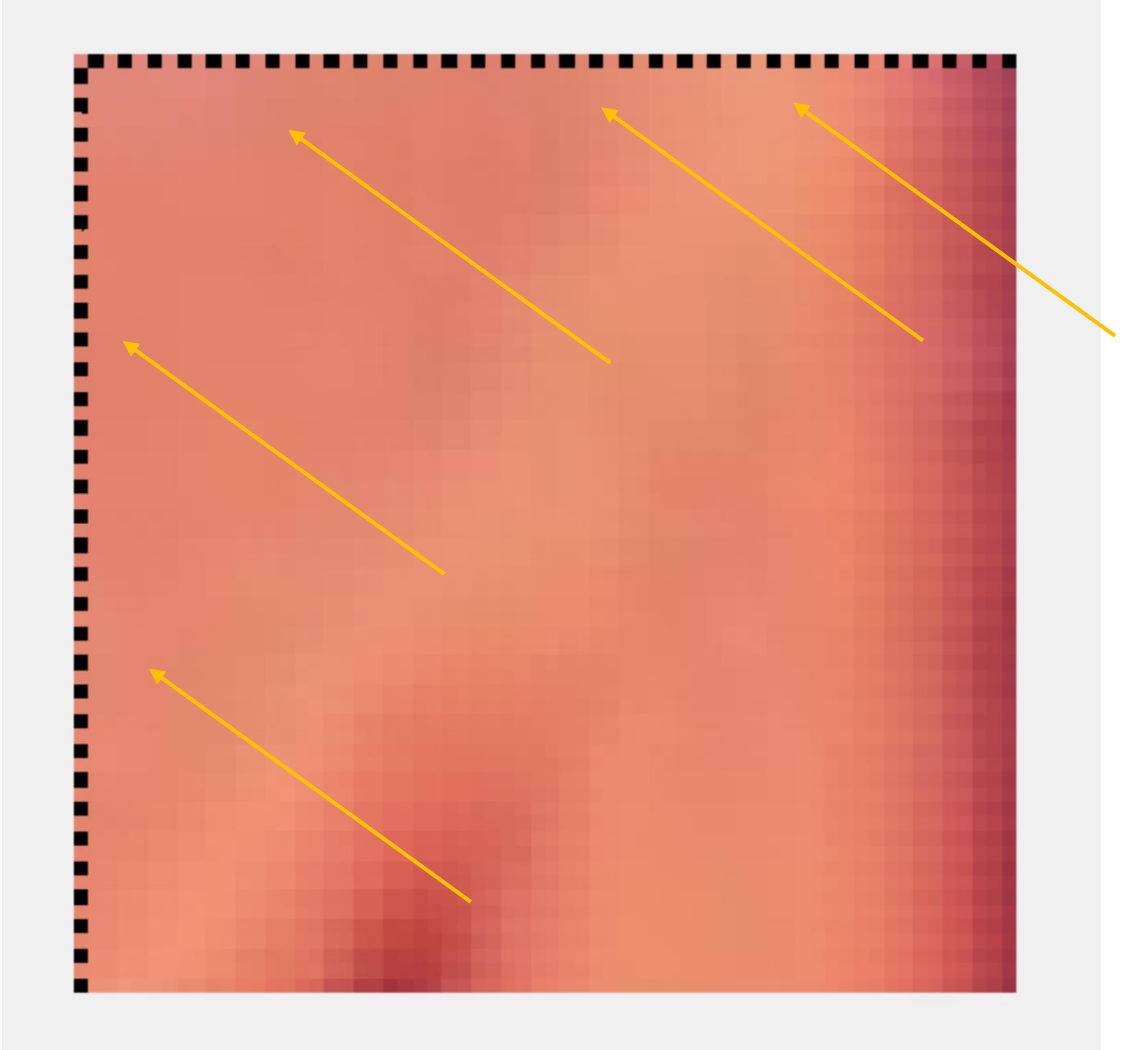
(a)

(b)

Replication, Bilinear and Bicubic - Example



The problem



Consider only the central areas of the image.

- In this case, the values at the edges are not calculated

input

1	2	3
4	5	6
7	8	9

output

1	1.5	2	2.5	3	
2.5	3	3.5	4	4.5	
4	4.5	5	5.5	6	
5.5	6	6.5	7	7.5	
7	7.5	8	8.5	9	

After doing the calculations replicate the last rows and columns

- In this case to do the calculations we replicate the values in the "isolated" rows and columns

input

1	2	3
4	5	6
7	8	9

output

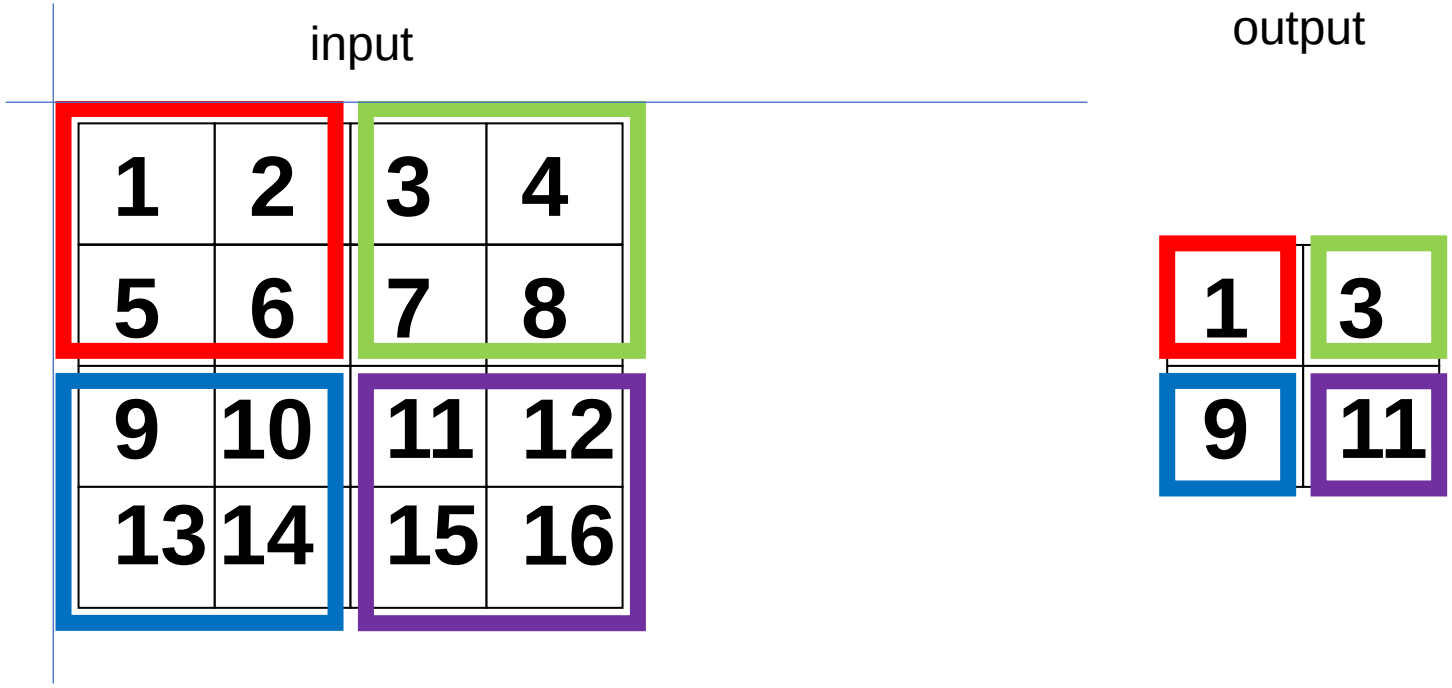
1	1.5	2	2.5	3	3
2.5	3	3.5	4	4.5	4.5
4	4.5	5	5.5	6	6
5.5	6	6.5	7	7.5	7.5
7	7.5	8	8.5	9	9
7	7.5	8	8.5	9	9

Zooming out

- If zooming is done with a number less than 1, you get an image smaller than the original.
- If I reduce an image, I have a process called "decimation."
- Given an mxn image with a zooming out of 0.5 you will get an m/2 × n/2 image.

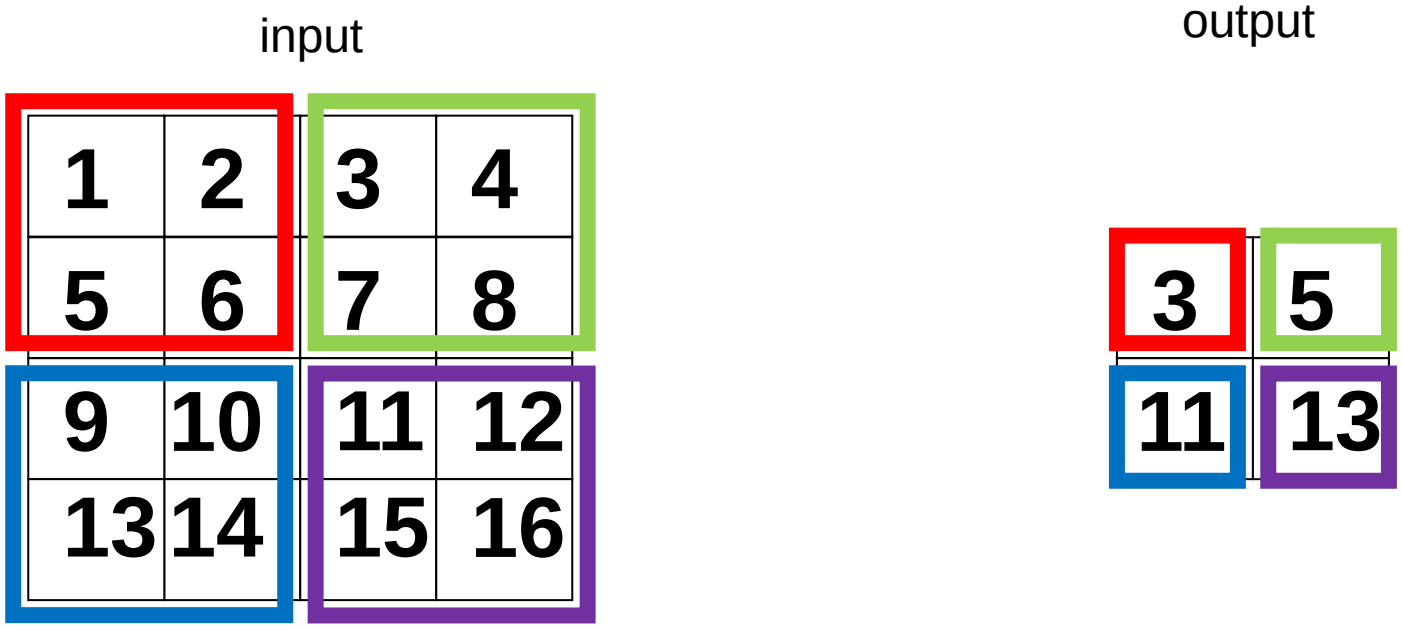
Decimation: method 1

- Every four pixels one is chosen.



Decimation: method 2

- Of four pixels, the average value is calculated.



Estimating the quality of an algorithm

- ***MSE***: (**Mean Square Error**) this parameter is used to estimate the mean square error between two images; the lower this index is, the smaller the difference between the images.

- ***PSNR***: (**Peak Signal to NoiseRatio**) parameter to measure the quality of a compressed image compared to the original, it depends on the difference between the encoded image and the original image. The higher its value, the greater the "similarity" to the original.

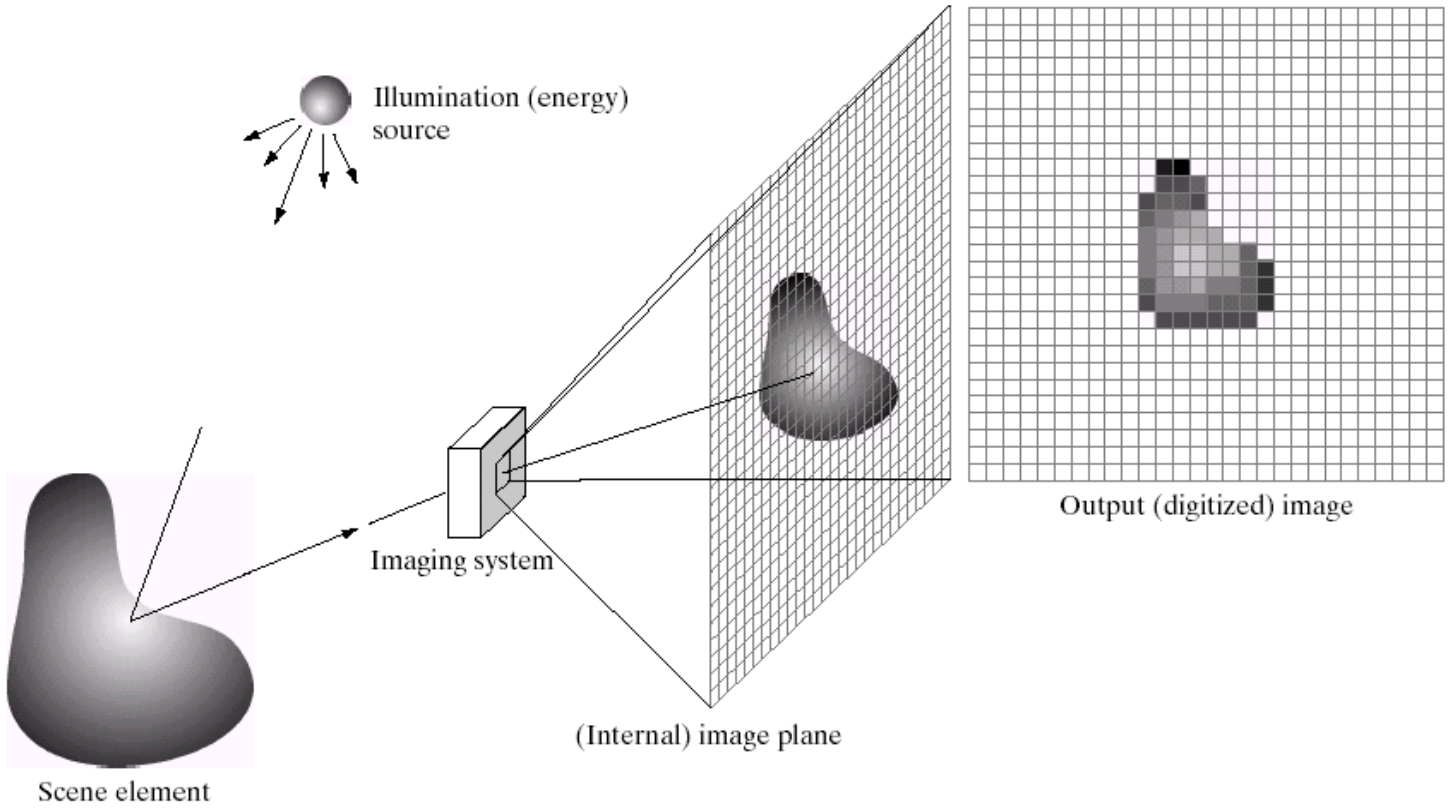
Digital image acquisition

Digital image acquisition

- When light hits an object, part of it is absorbed and part of it is reflected.
- That which is reflected gives rise to the perceived color.
- To create a digital image, it is essential that such reflected light be captured by a sensor and processed.

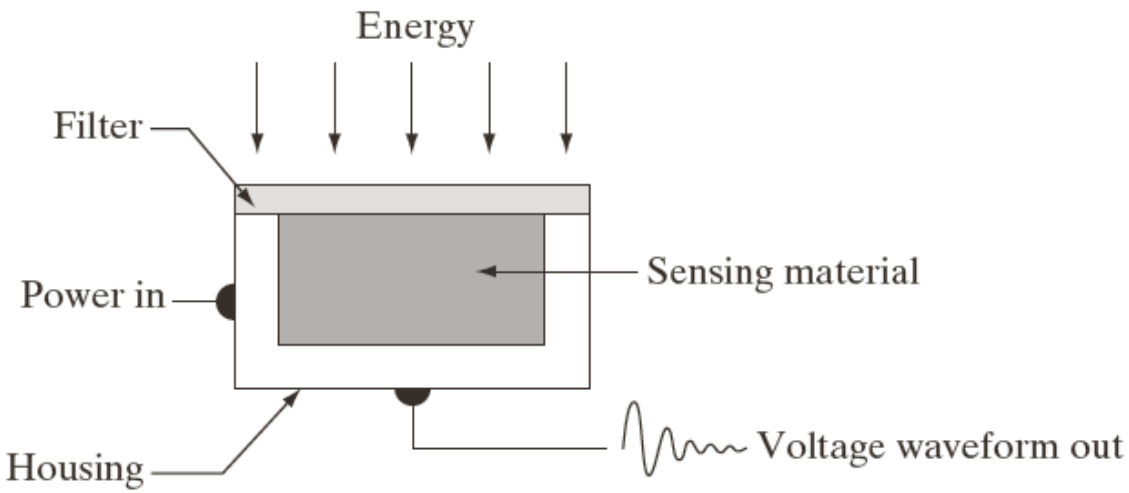
How to capture an image

- When light hits an object, part of it is absorbed and part of it is reflected.
- That which is reflected gives rise to the perceived color.
- To create a digital image, it is essential that such reflected light be captured by a sensor and processed.



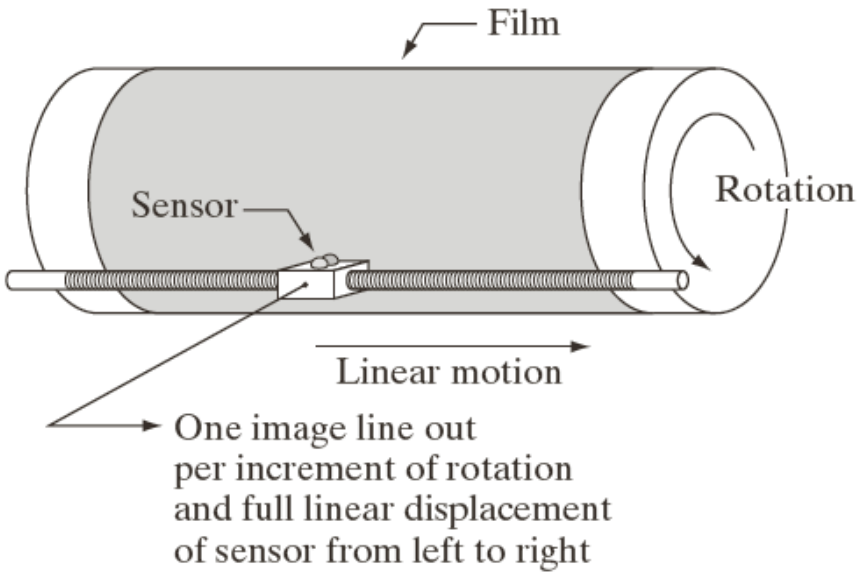
Sensor

- Energy striking the sensor is converted into an electrical pulse by the sensor, which is made of an especially light-sensitive material. This electrical pulse is subsequently digitized.



Single sensor

- Scanners use a single sensor that is moved along the source to be digitized.



2D array sensors

- In digital cameras, the sensors are arranged in an array.
- It is not necessary to move the sensor, as in previous cases, to scan.
- The most common sensors of this type are CCDs

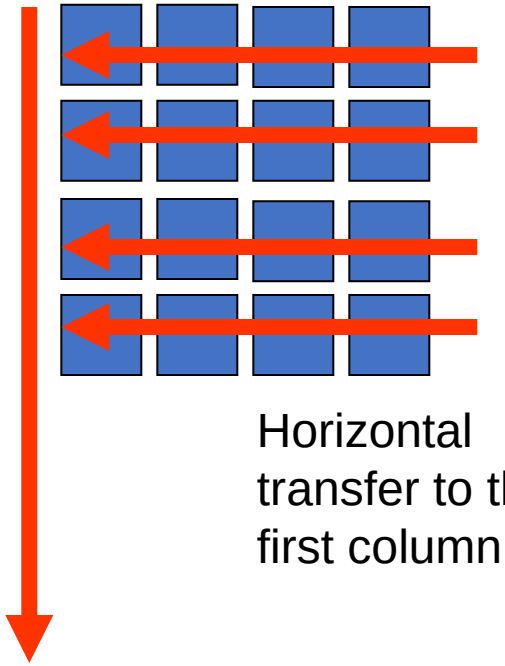
CCD: Charged Coupled Device

- These are electronic devices that when hit by photons take on a positive charge.
- CCD cells cannot charge beyond a certain limit-they are buckets of water that cannot fill beyond their capacity (over-saturation phenomenon).
- The number of cells per exposure area is a camera quality parameter measured in MEGAPIXELs

CCD: the measurement scheme

After charges have been acquired from an array of cells they must be transferred to a digital memory. The scanning is done in C phases, one phase for each column of the matrix.

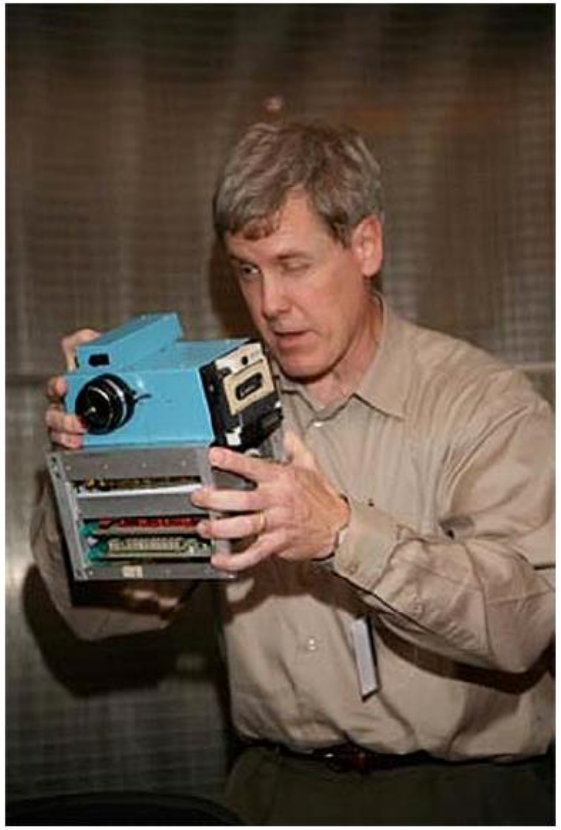
At each stage the first column of the matrix is transferred to memory, at the same time all elements (from the second column onward) are transferred from their column to the previous one.



December 1975, Steven Sasson, an electrical engineer at Eastman Kodak Co., in Rochester, N.Y., became the first person to pick up a digital camera and take a picture.

Prototype Digital Camera of 1975

- Weight of 4 Kg
- Resolution of 0.01 megapixels
- Images of 100 x 100 pixels
- Storage on cassette
- Storage time of one shot on cassette: 23 seconds.



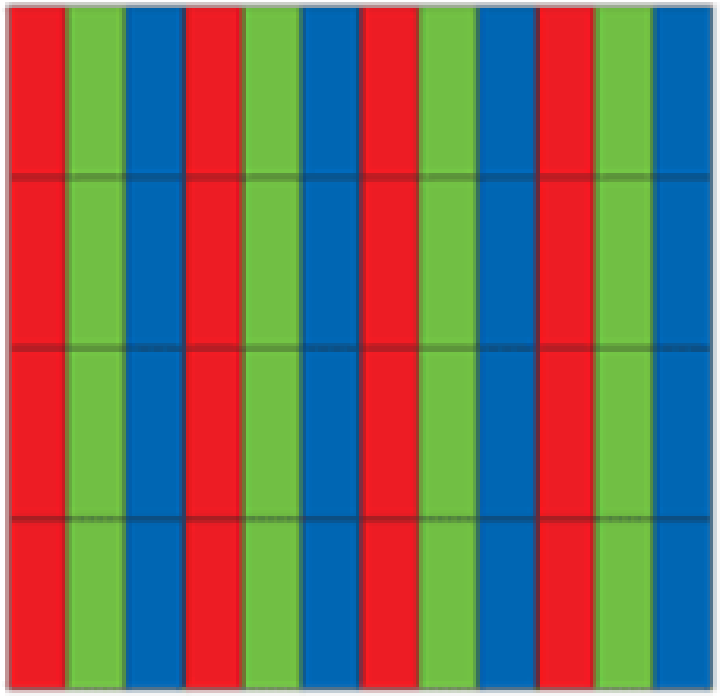
- The final test was in December 1975: Sasson convinced one of his assistants to pose for him. The machine took 23 seconds to record the image on the audio cassette and another 23 seconds to be displayed on a regular television. The result? Only the silhouette of hair could be glimpsed but, after a little calibration to the electronics, the assistant's face was immediately visible.

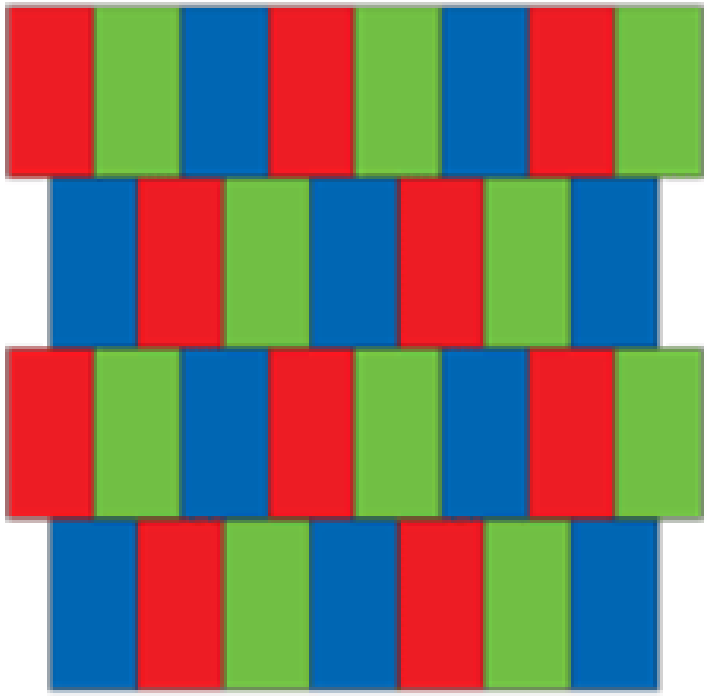
This is considered the first official photo taken with the "Kodak."

CFA: Color Filter Array

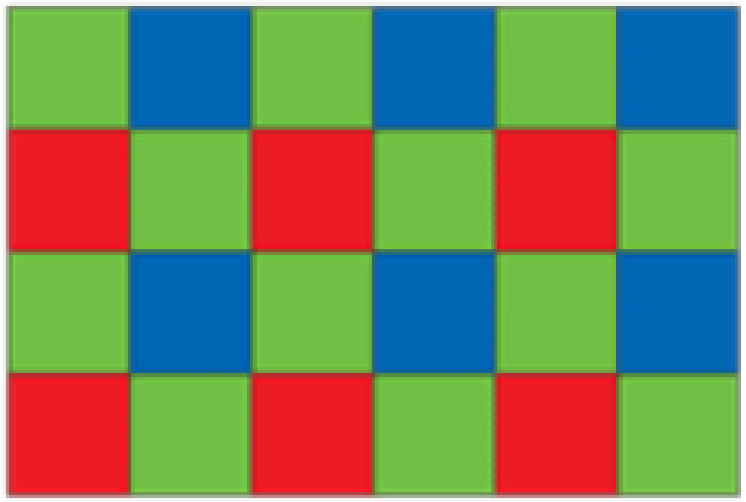
- Since each cell will store **only one color** at a time and not a triad, it is necessary to choose what is the optimal storage pattern (CFA).
- The two missing colors to complete the triad will be obtained by interpolation from neighboring pixels (Color Interpolation).
- The degree of accuracy of the result depends on how sophisticated the interpolation method is.

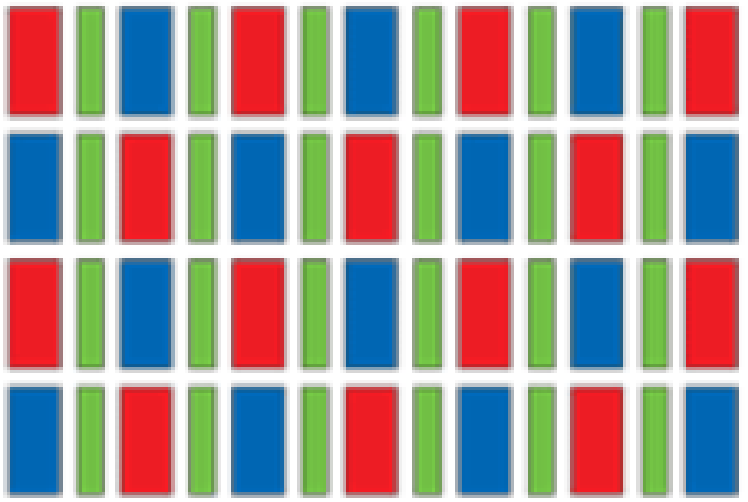
Possible models of CFA



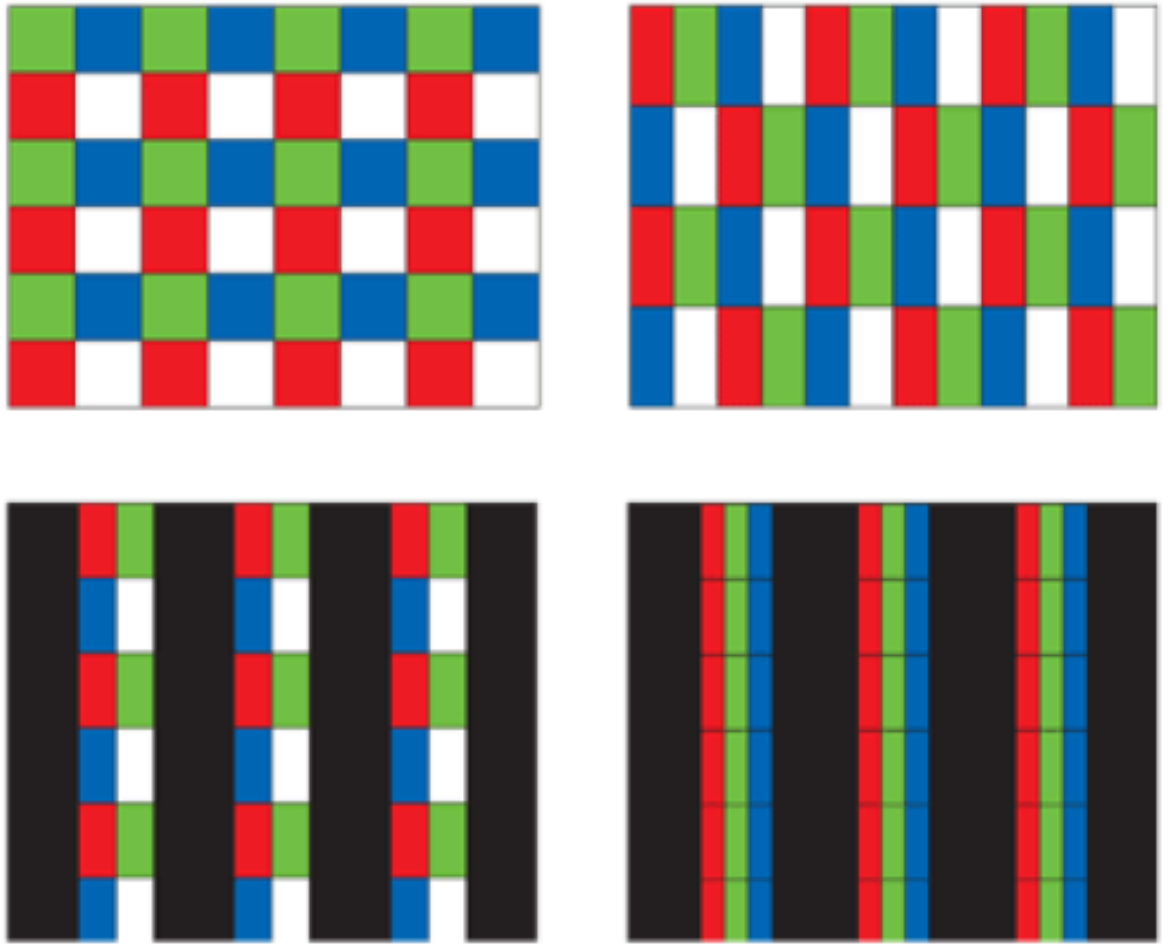


Possible models of CFA



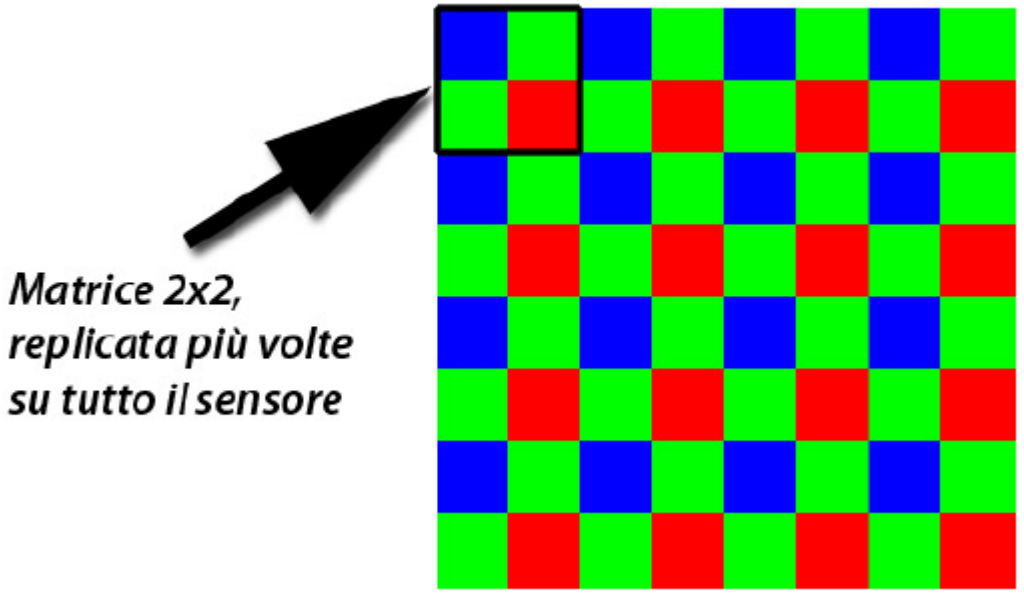


Possible models of CFA



Which one is the best? The Bayer Pattern

- The most widely used scheme is the BAYER PATTERN. It was proposed in 1976 by Byce Bayer and used since 1980 in all electronic devices.
- It has a 1:2:1 ratio for R:G:B, where the green pixels are arranged on "diagonals.“
- It favors measurements in the green channel because it is the most important for human perception.
- A Bayer Pattern image is stored in the "raw" format.



Notebook No. U203

RESEARCH LABORATORIES
EASTMAN KODAK COMPANY

Date May 24, 1974

1

Problem: Providing color in a ~~CCD~~ camera using photosensor array

Suppose a camera uses an m x n array of photodetectors to record a picture. How should color be recorded?

One way is to superimpose over the array of photosensors an array of filters or other optical system such that different elements record different colors. For example, we might use the following arrangement:

G	R	G	R	G	R
B	G	B	G	B	G
G	R	G	R	G	R
B	G	B	G	B	G
G	R	G	R	G	R

½ of elements are green in checkerboard pattern

¼ elements each are red and blue in rectangular arrangements

Each of the red, green, and blue records are sampled in regular arrays, with twice as many points for green, which is most important to sharpness. Such regular arrays are easy to filter to avoid evidence of sampling artifacts in final display.

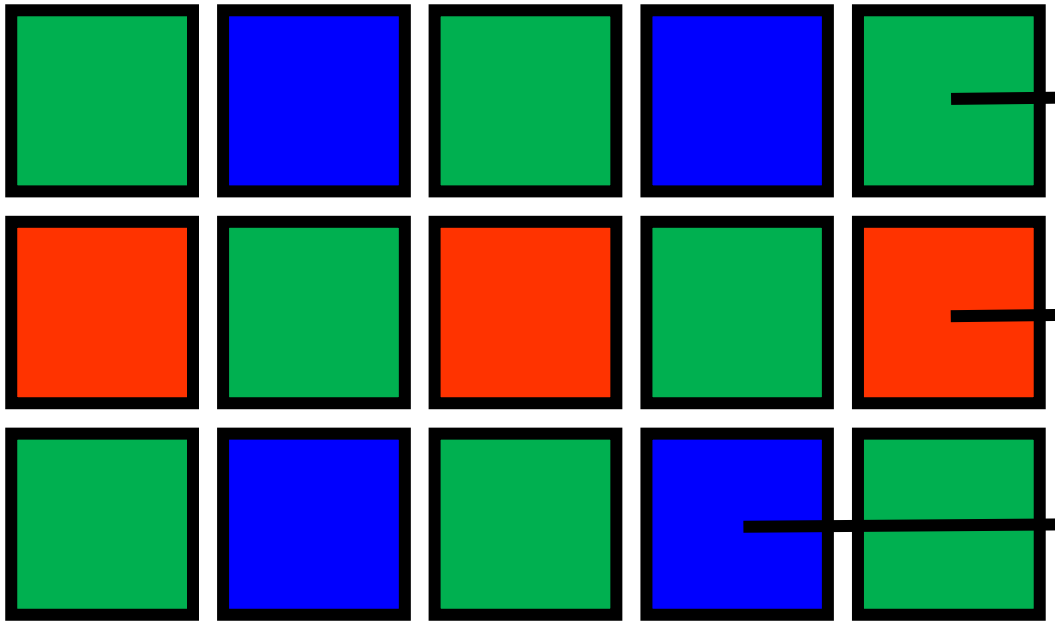
KP 15226-B I.P.S.

Signature Bryce E. Bayer

The foregoing disclosed to me on 5/28 19 74 Joyce Olson Witness

Bayer Pattern

If for each pixel, only one color component is stored, all others will have to be obtained by interpolation from neighboring pixels.

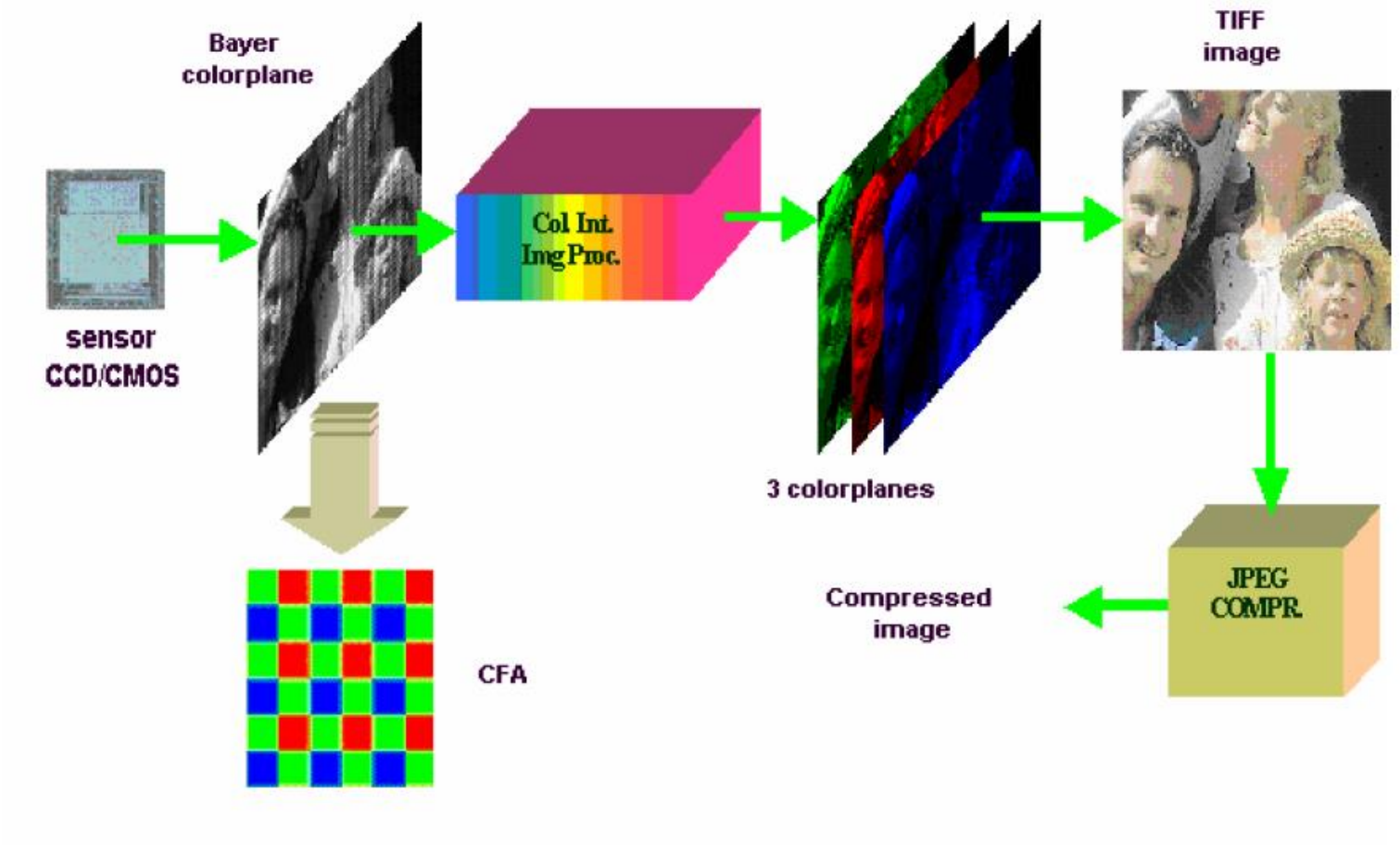


The R and B value for this pixel are obtained by "interpolation" from neighboring values

The G and B value for this pixel are obtained by "interpolation" from neighboring values

Il valore R e G per questo pixel sono ottenuti per “interpolazione” dai valori vicini

In more detail



Other CFA models being tested (from a scientific paper)

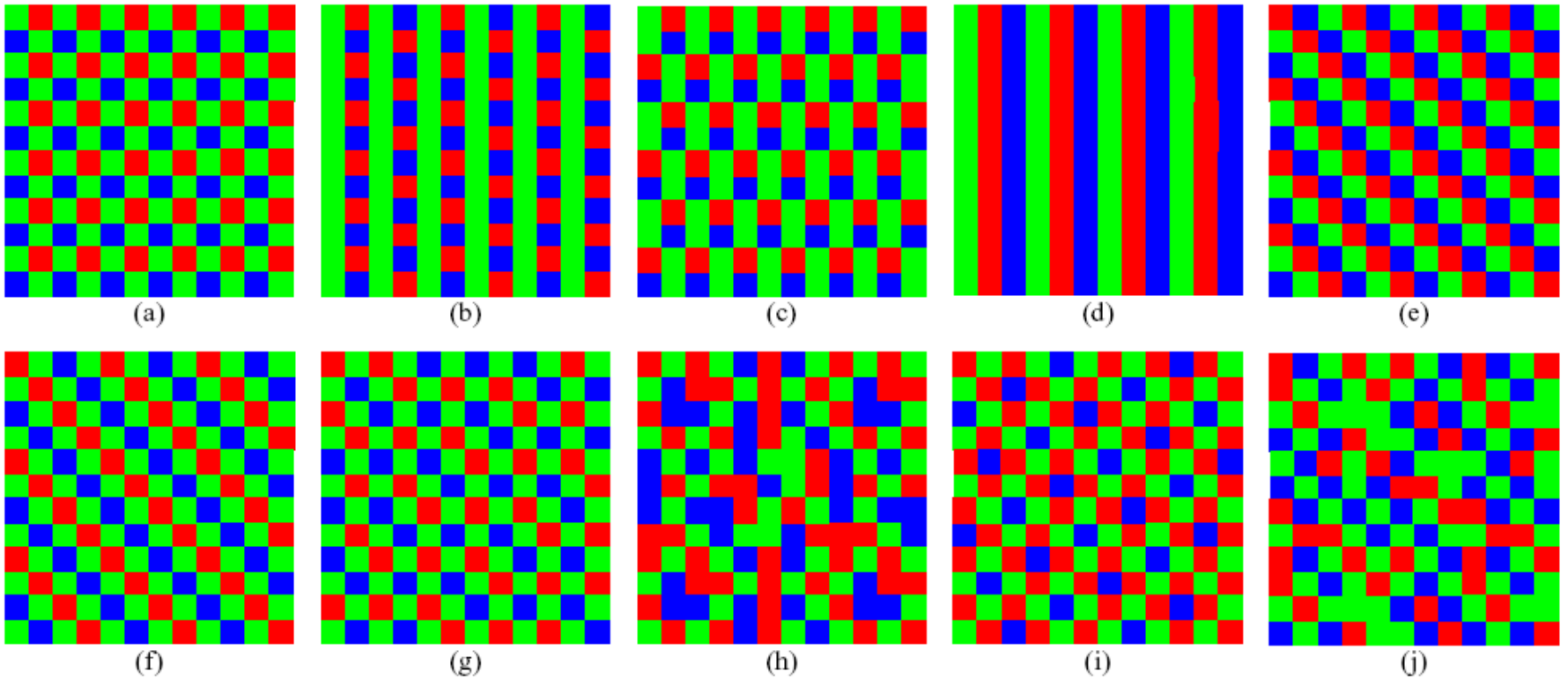
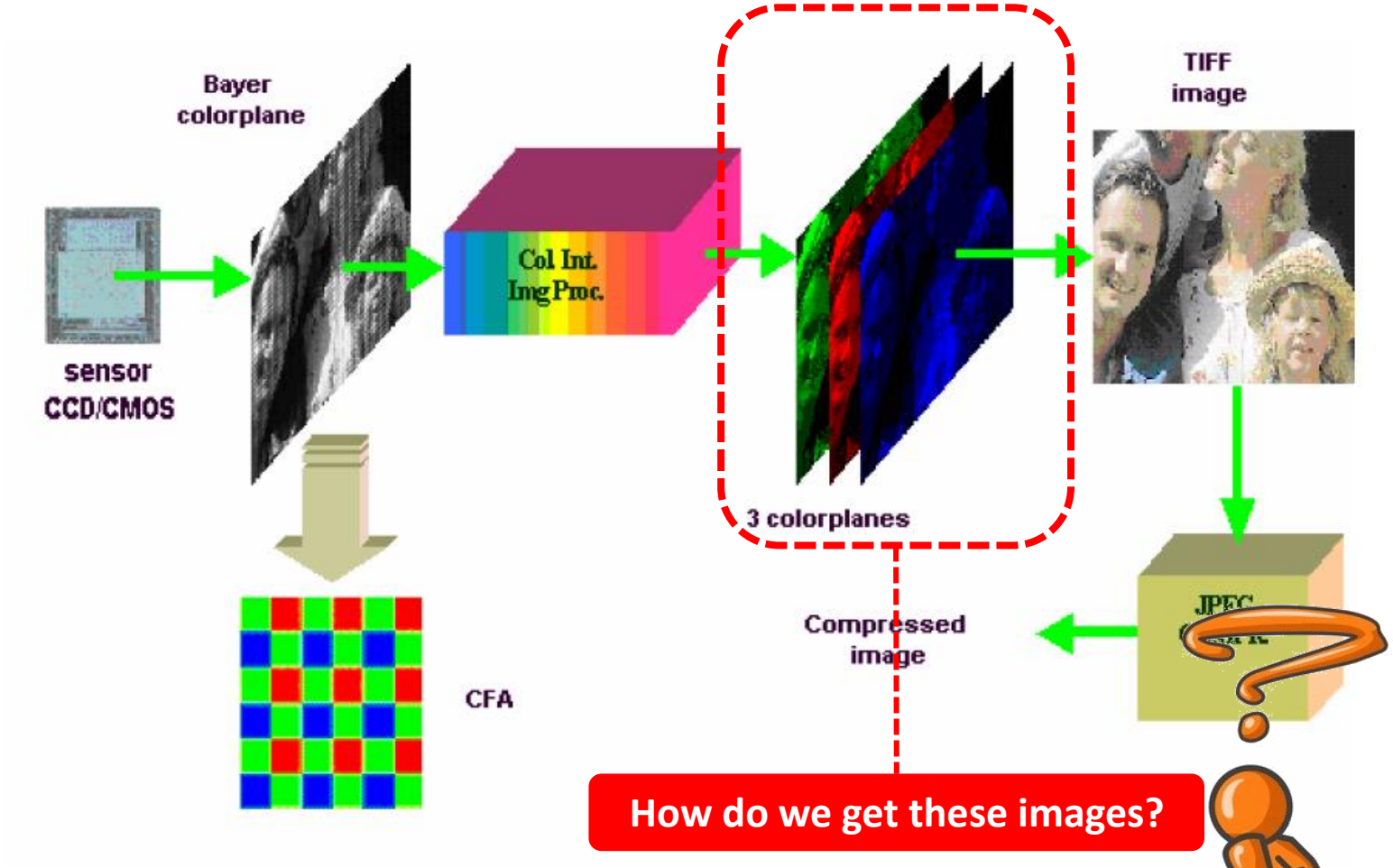


Fig. 2. RGB CFAs: (a) Bayer CFA [10], (b) Yamanaka CFA [11], (c) proposed here CFA, (d) vertical stripe CFA [12], (e) diagonal stripe CFA [12], (f) modified Bayer CFA [12], (g-i) pseudo-random CFA [12], (j) HVS-based CFA [13].

We have a problem to solve...



Color Interpolation

- The array of data released by the sensor can be displayed as an image. In this case a grayscale image would be seen.
- Retaining only one component of the color triad results in viewing the image as if it were composed of a mosaic.
- To obtain a color image, one must proceed with a color interpolation algorithm that derives the missing values for each individual triad from the surrounding data.
- Because the mosaic effect disappears from the color image, the color interpolation algorithm is also called a "demosaicking" algorithm.

Bayer pattern

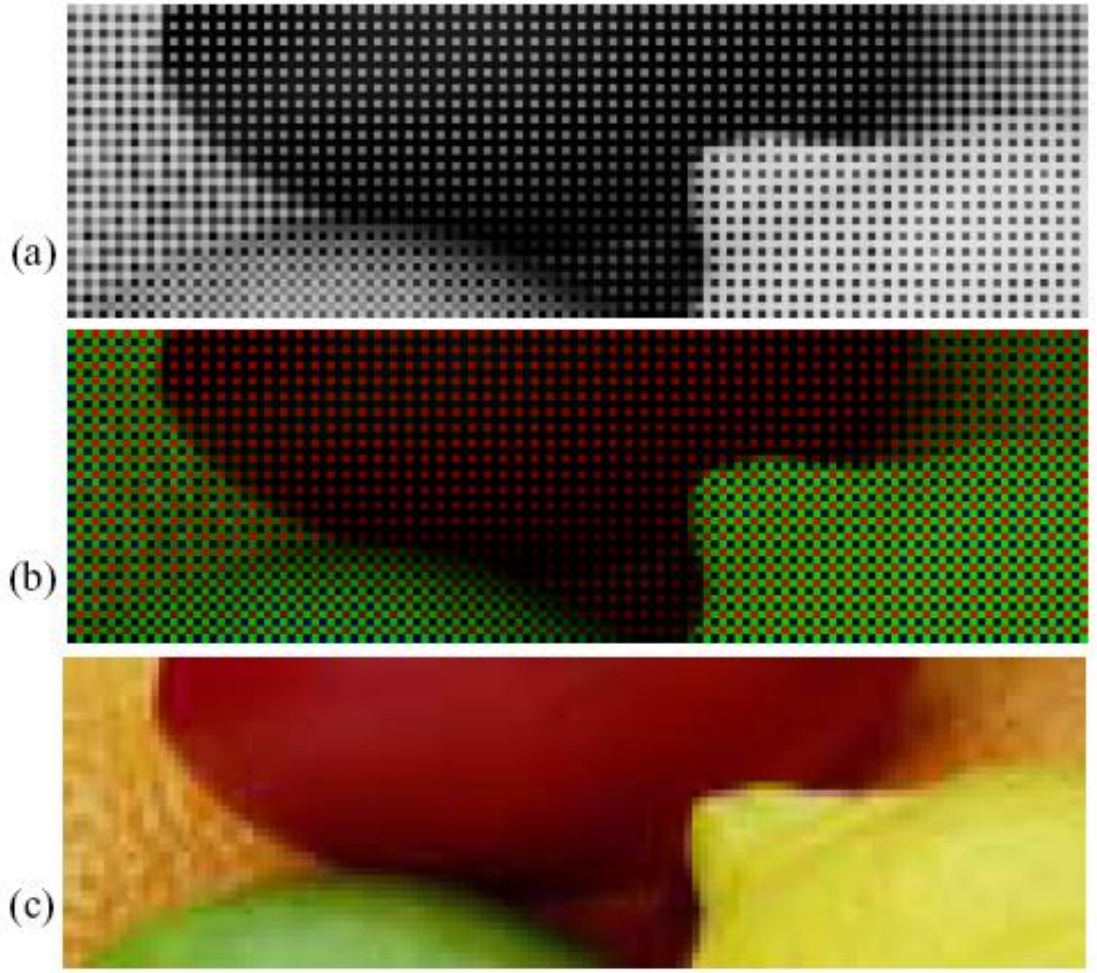
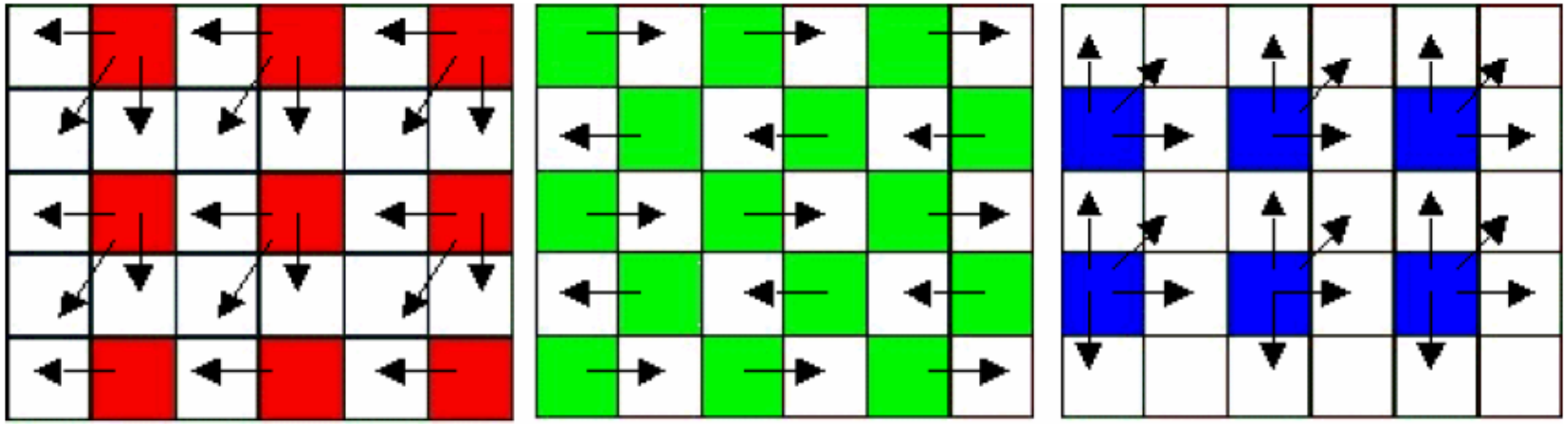


Fig. 1. Single-sensor imaging: (a) mosaic-like gray-scale CFA image, (b) color variant of the CFA image, (c) demosaicked full-color image.

Color interpolation: replication

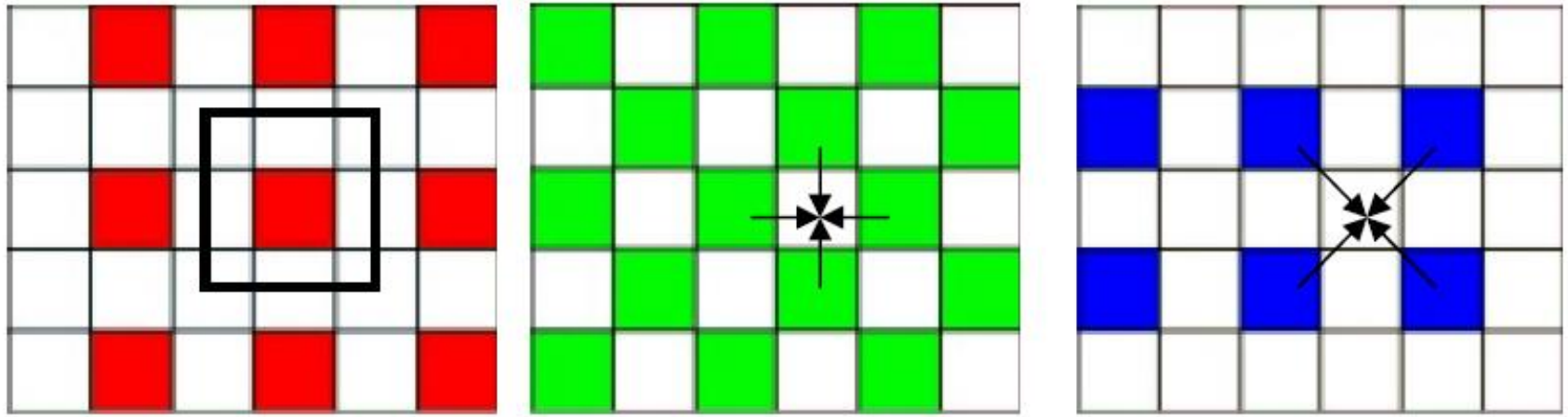
- For each individual pixel, the missing elements of the triad are copied from the surroundings.
- This technique is also called **"Nearest-neighbor interpolation."**



Color interpolation: bilinear about the information of R and missing G and B

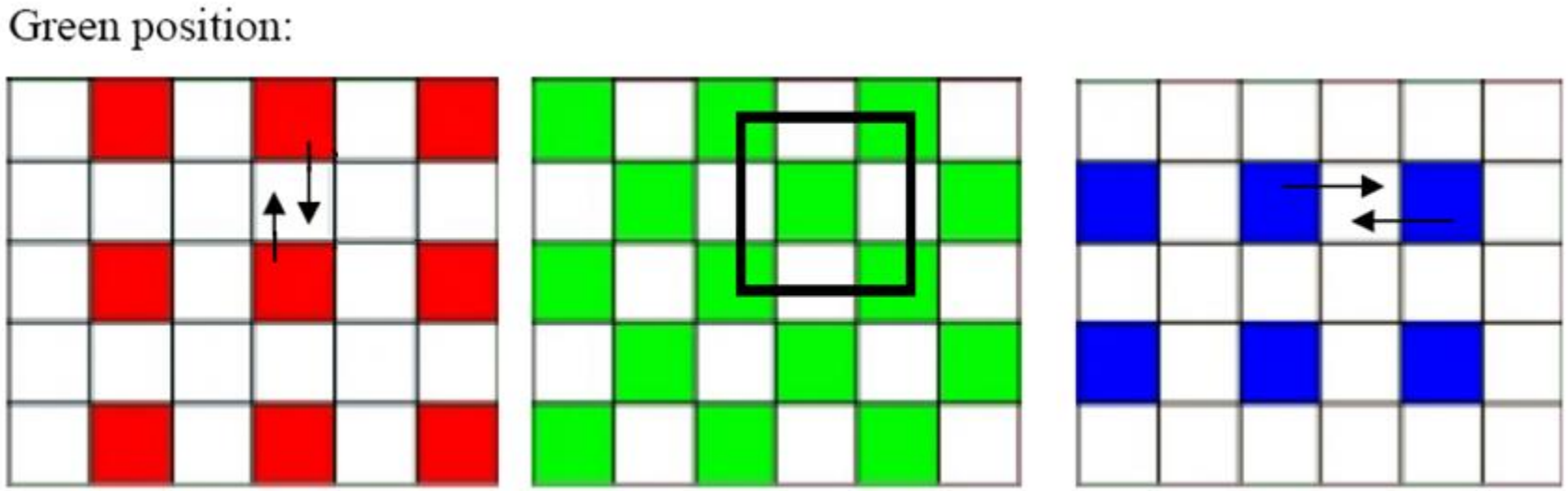
- In the matrix of R, nothing needs to be done.
- In G it is necessary to derive data from a neighborhood by selecting the 4 values released by the sensor.
- In B it is necessary to derive data from a neighborhood by selecting the 4 values released by the sensor.

Red position:



Color interpolation: bilinear about the information of G and missing R and B

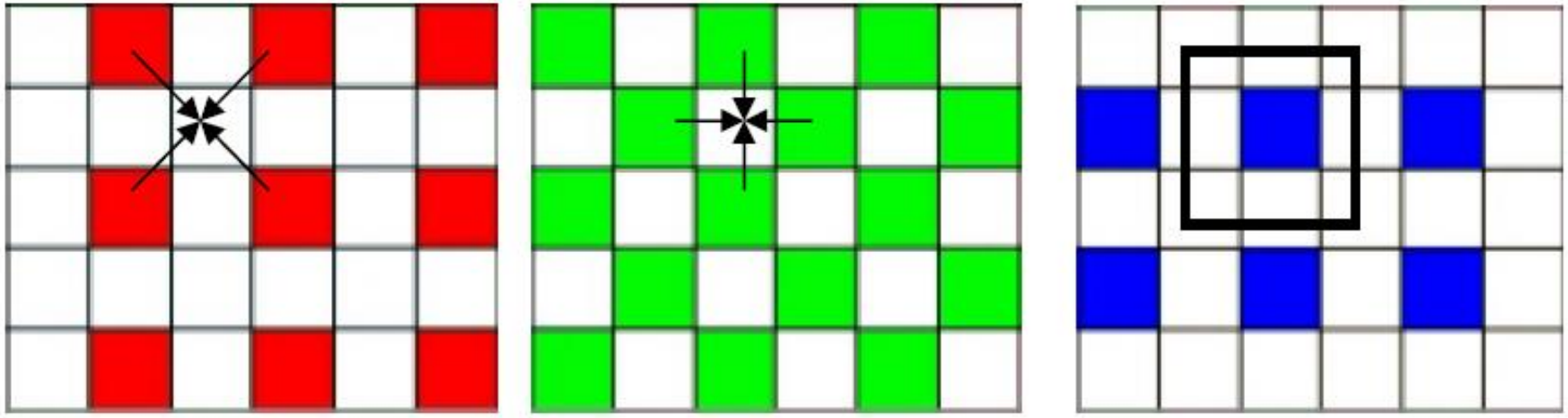
- In the matrix of G nothing has to be done.
- In R it is necessary to derive data from a neighborhood by selecting the 2 values released by the sensor.
- In B it is necessary to derive data from a neighborhood by selecting the 2 values released by the sensor.



Color interpolation: bilinear about the information of B and missing R and G

- In the matrix of B, nothing needs to be done.
- In R it is necessary to derive data from a neighborhood by selecting the 4 values released by the sensor.
- In G one needs to derive data from a neighborhood by selecting the 4 values released by the sensor.

Blue position:



Bilinear

- In bilinear interpolation, the four nearest pixels are used to estimate the intensity to be assigned to each new position. Suppose that (x, y) are the coordinates of the position to be assigned an intensity value and that **v(x, y)** equals the intensity value. For bilinear interpolation, the assigned value is obtained by the equation

$$v(x, y) = ax + by + cxy + d$$

Where the four coefficients are determined from the four equations in the four unknowns obtainable using the four pixels closest to the point (x, y).

- Bilinear interpolation produces better results than replication with a modest increase in computational complexity.

Bicubic

- Bicubic interpolation uses the sixteen pixels closest to the point. The intensity value assigned to the point (x, y) is obtained through the equation

$$v(x,y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} x^i y^j$$

- Where the sixteen coefficients are determined from sixteen equations in sixteen unknowns that can be written using the sixteen points closest to (x, y).
- Generally, bicubic interpolation preserves details better than bilinear interpolation. Bicubic interpolation is the standard technique used in commercial editing programs such as Adobe Photoshop and Corel Photopaint.

Results obtained using different color interpolation

 Ideale	 Bayer Pattern	 Replication
 Bilineare	 Bicubico	 Altro

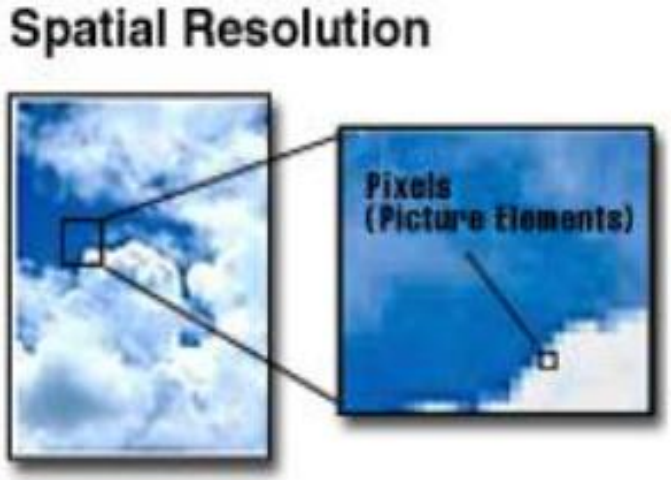
Resolution

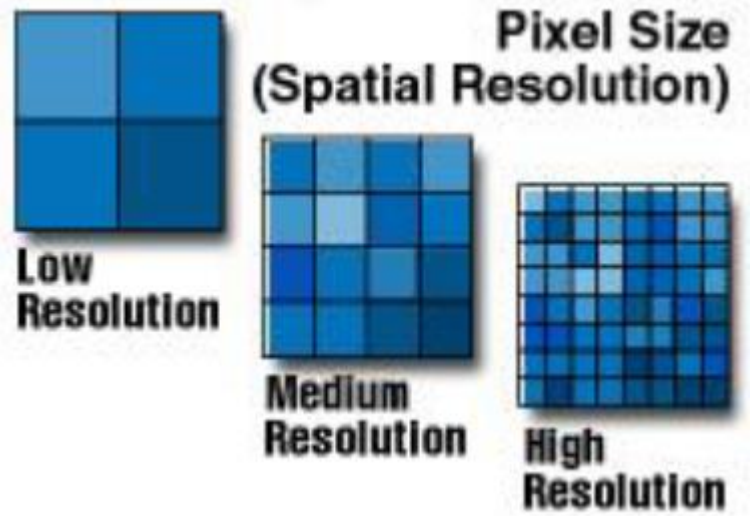

Store sign
Pedestrian
Street sign
Building
Other
Vehicle
Multimedia Data Modelling
Multimedia Data Modelling

Spatial Resolution

Definition

Spatial resolution refers to the specific number of information points (pixels - Picture Element) in an 'image.





Resolution in detail

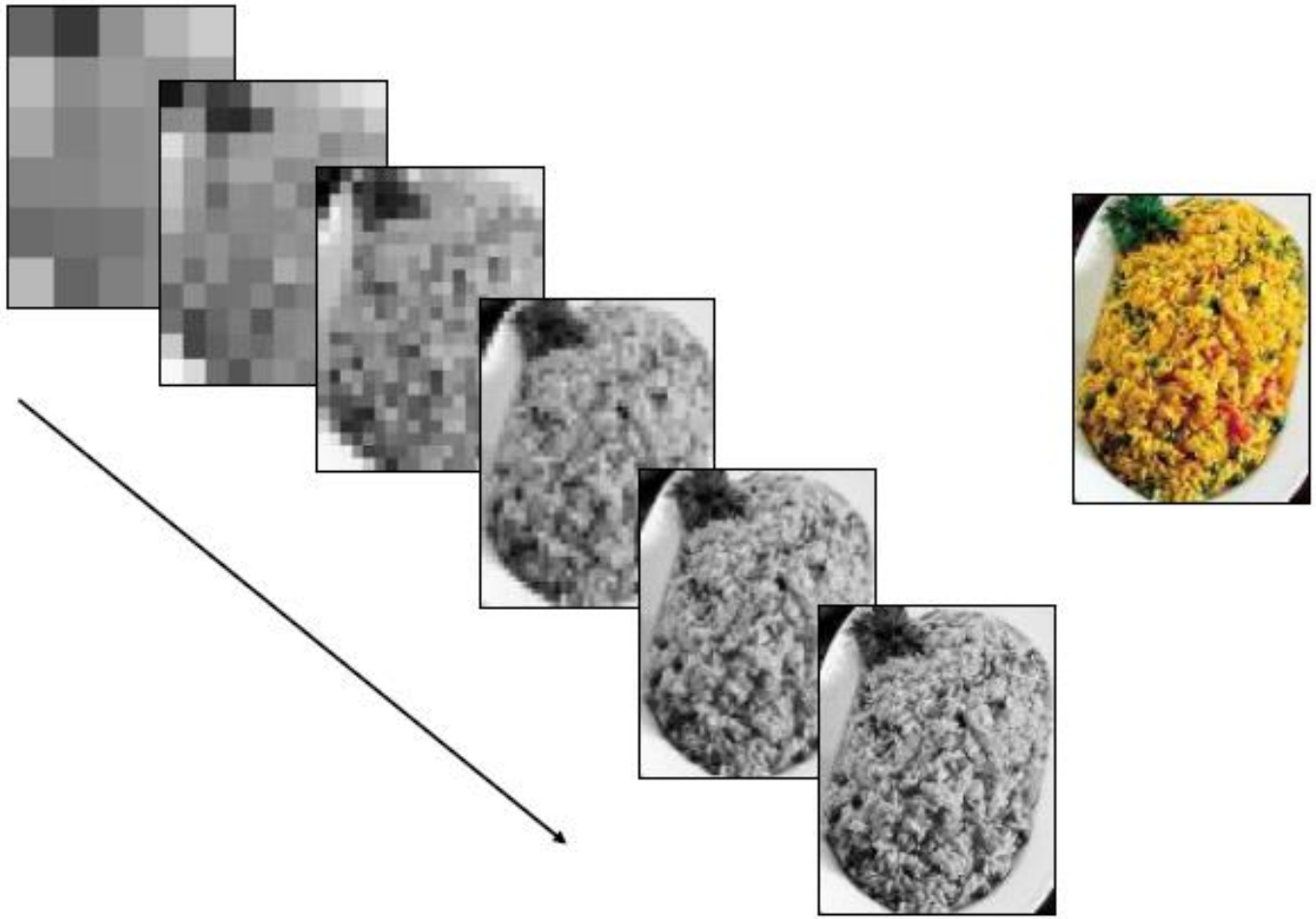
- **Definition**: resolution is defined as the number of pixels per unit of measurement.
- It can be measured **in pixels per centimeter**, or in **dots per inch (dpi).**
- It can also be expressed as the number of pixels over the entire image (e.g., 16- Megapixels).

Resolution

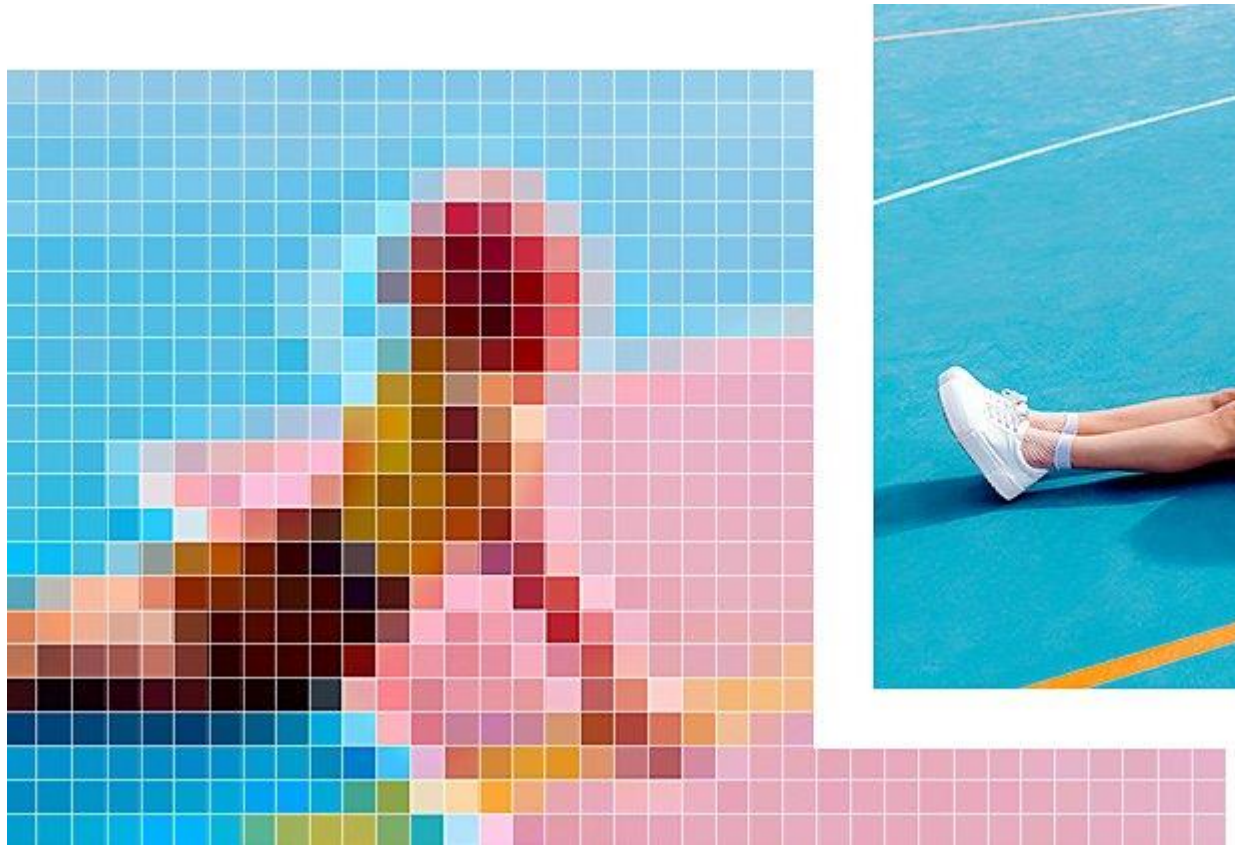
- **Resolution indicates the degree of quality of an image**

- A computer screen cannot show lines or drawings, only dots; if these are small enough, such that they are smaller than the resolution perceived by the human eye, the observer has the impression of seeing lines instead of aligned dots, and drawings instead of clusters of distinct dots.

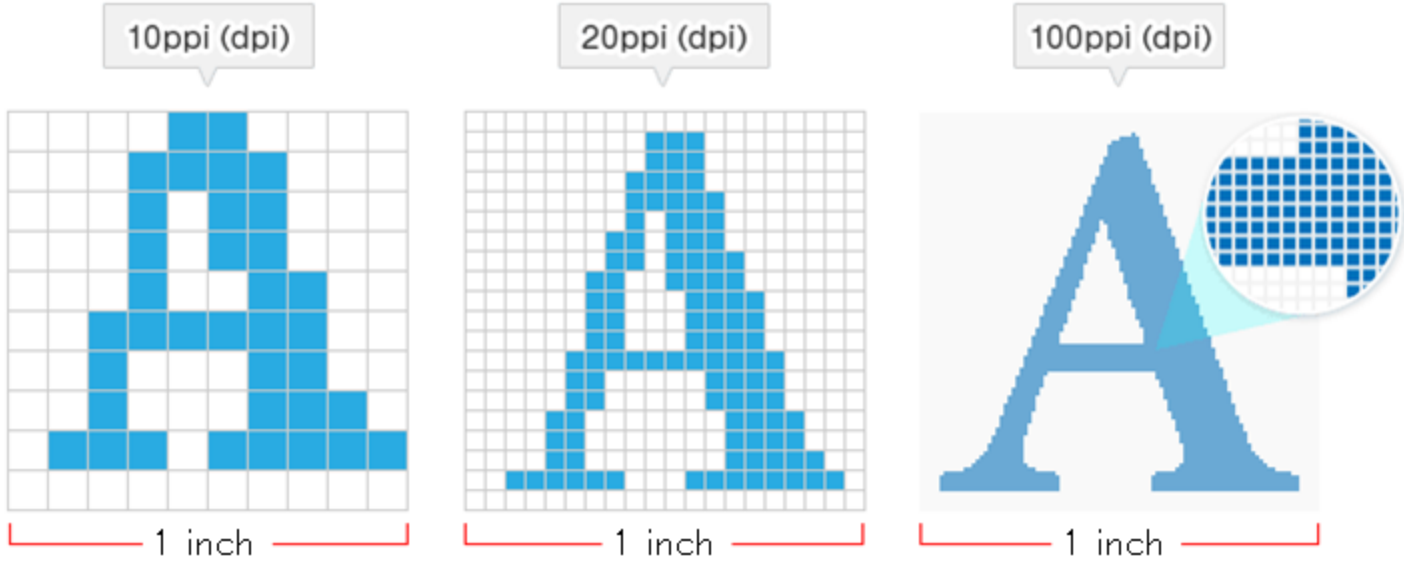
Spatial Resolution



Resolution

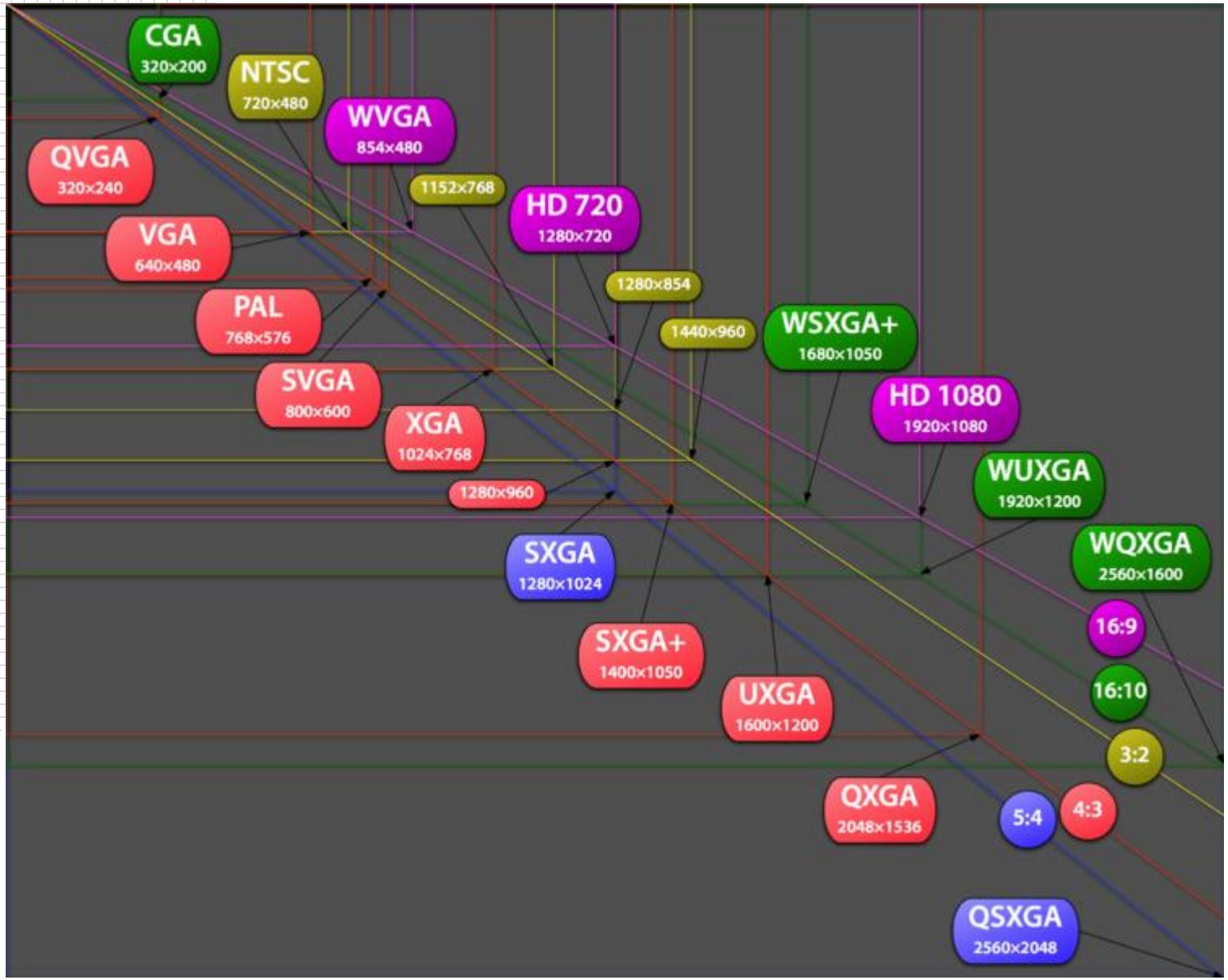


Resolution

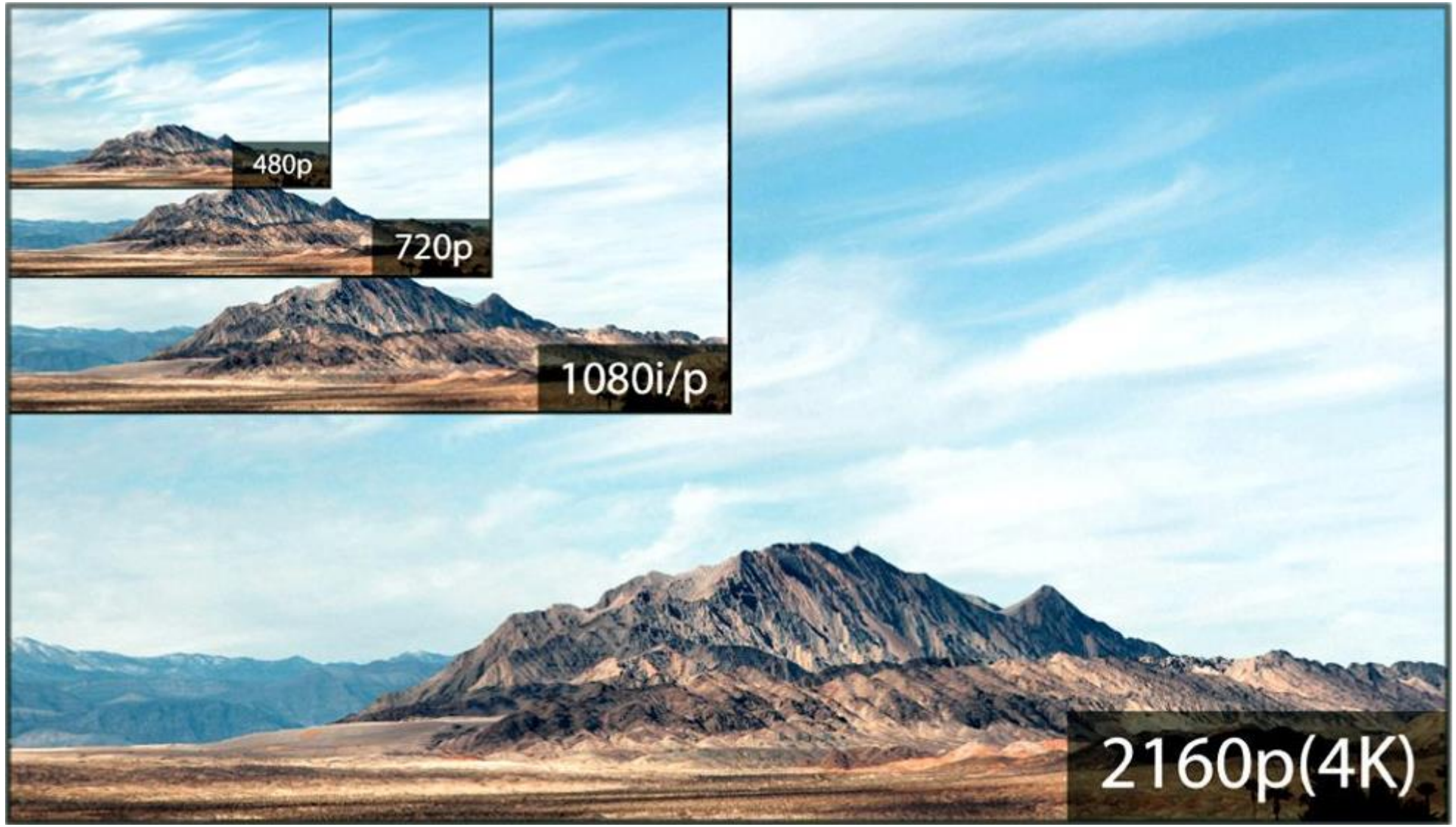


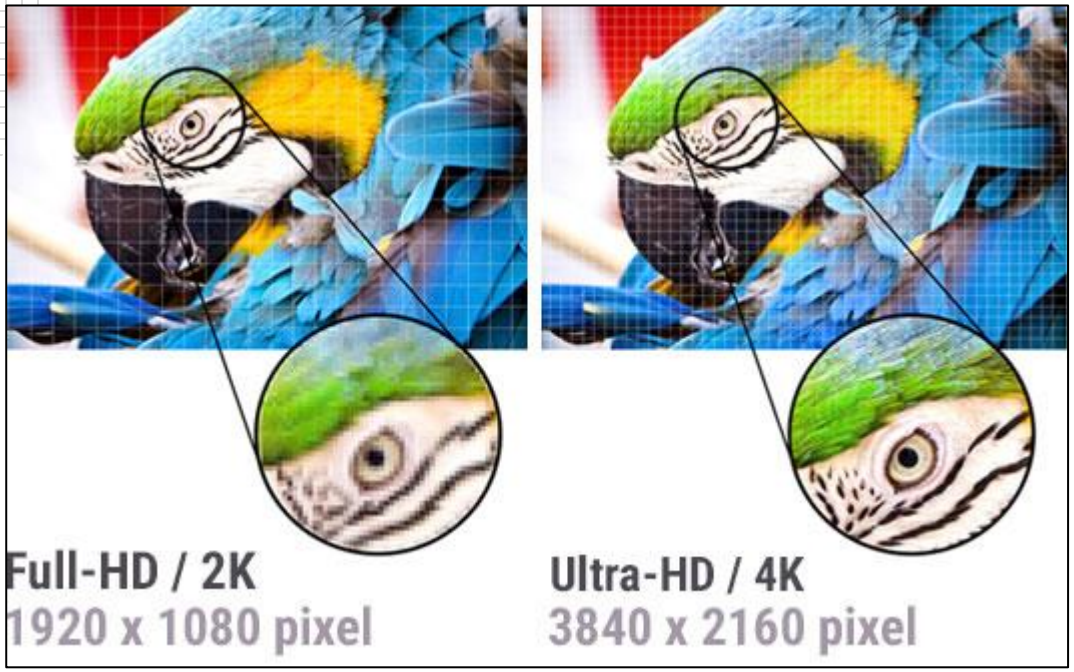
- Images born with a certain resolution must be displayed with the same resolution for maximum rendering.

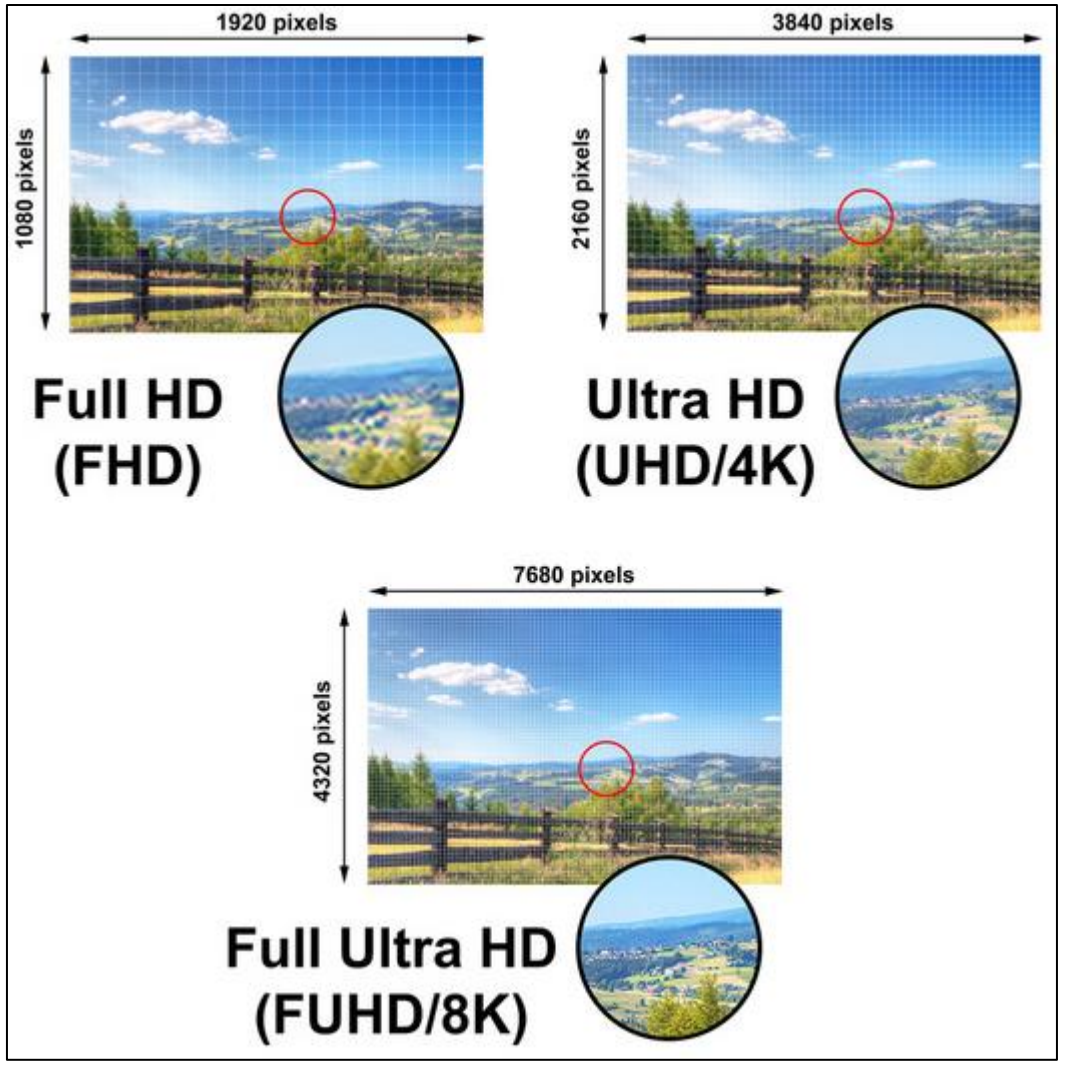
- The main standard sizes and their names are given in the following image (wikipedia).



Sigla	Definizione	Risoluzione	Rapporto
Quarter QVGA	QQVGA	160 x 120	4:3
CGA o Quarter VGA	CGA / QVGA	320 x 240	4:3
Half VGA	HVGA	640 x 240	8:3
Monocrome Display Adapter	MDA	720 x 350	
Enhanced Graphics Array	EGA	640 x 350	
Video Graphics Array	VGA	640 x 480	4:3
Super VGA	SVGA	800 x 600	4:3
Quad VGA	QVGA	1280 x 960	4:3
eXtended Graphics Array	XGA	1024 x 768	4:3
Super XGA	SXGA	1280 x 1024	5:4
Super XGA Plus	SXGA+	1400 x 1050	4:3
Ultra XGA	UXGA	1600 x 1200	4:3
Quad XGA	QXGA	2048 x 1536	4:3
Quad Ultra XGA	QUXGA	3200 x 2400	4:3
(*) Wide XGA	WXGA	1366 x 768	~16:9
(*) Wide XGA	WXGA	1280 x 800	16:10
(*) Wide XGA	WXGA	1280 x 720	16:9
Wide XGA Plus	WXGA+	1440 x 900	16:10
Wide Super XGA Plus	WSXGA+	1680 x 1050	16:10
Wide Ultra XGA	WUXGA	1920 x 1200	16:10


480p
720p
1080i/p
2160p(4K)


Full-HD / 2K
1920 x 1080 pixel
Ultra-HD / 4K
3840 x 2160 pixel


1920 pixels
1080 pixels
Full HD
(FHD)
3840 pixels
2160 pixels
Ultra HD
(UHD/4K)
7680 pixels
4320 pixels
Full Ultra HD
(FUHD/8K)

Resolution


Store sign
Pedestrian
Street sign
Building
Other
Vehicle
Multimedia Data Modelling
Multimedia Data Modelling