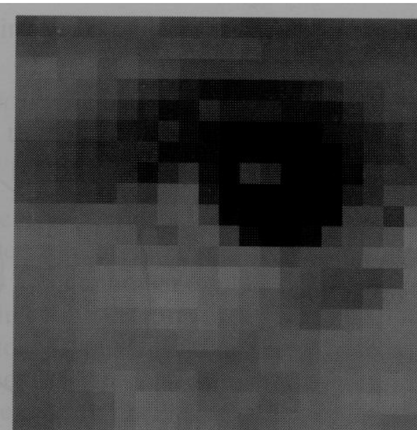
Digital Image Representation

How are images represented in the computer?



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133	129	140	142	146	159	167	165	154	151	146	141	147	154	156	160	161	157	153	154

- A signal is a *function* depending on some variables with physical meaning.
- Signals can be
  - one-dimensional (e.g., dependent on time),
  - two-dimensional (e.g., images dependent on two co-ordinates in a plane),
  - three-dimensional (e.g., describing an object in space),
  - or higher-dimensional.

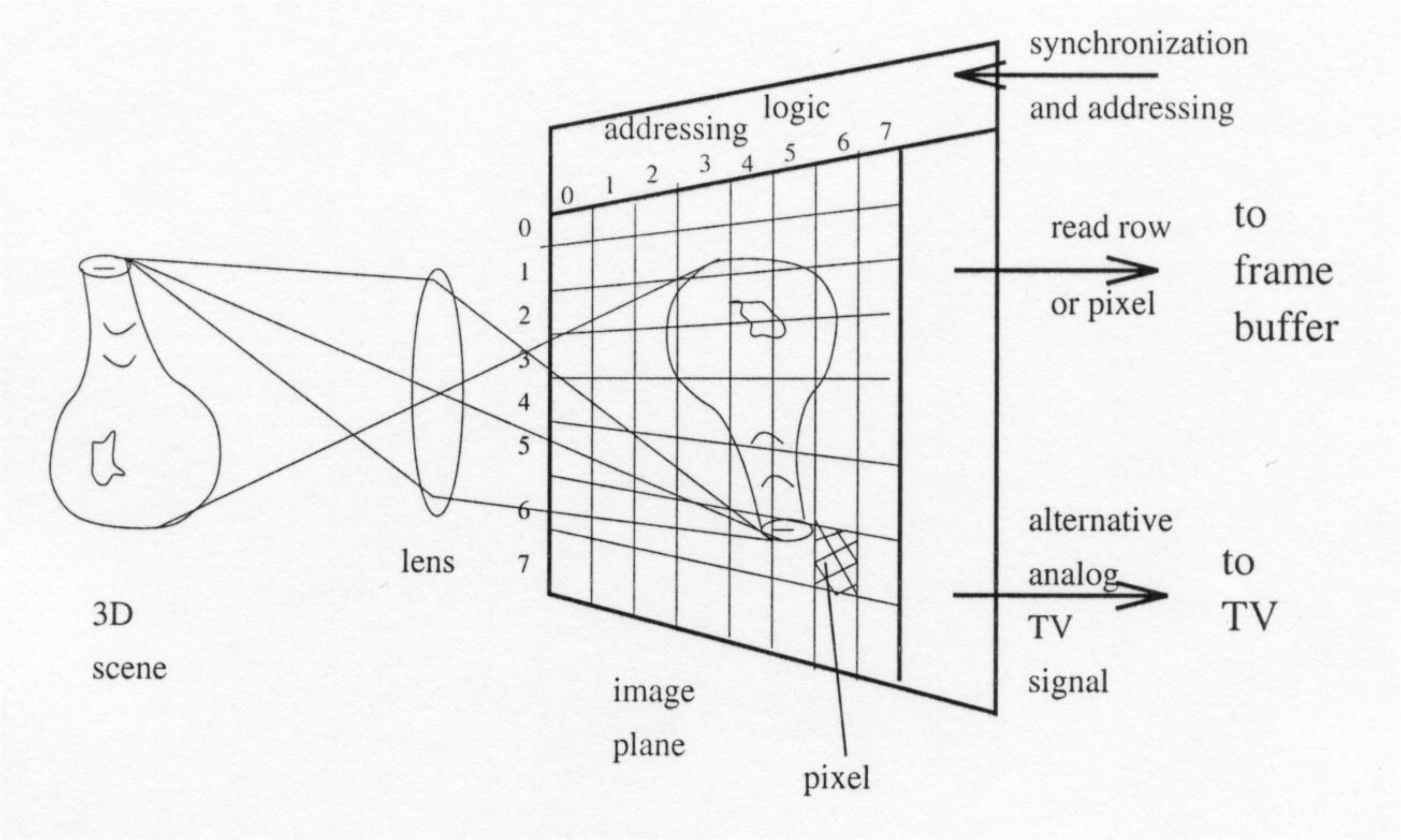
- A scalar function may be sufficient to describe a monochromatic (單色的) image, while vector functions are to represent, for example, color images consisting of three component colors.

Image formation

- There are two parts to the image formation process:
  - The ***geometry of image formation***, which determines where in the image plane the projection of a point in the scene will be located.
  - The ***physics of light***, which determines the brightness of a point in the image plane as a function of illumination and surface properties.

CCD (Charged-Coupled Device)(電荷耦合器) cameras

- Tiny solid state cells **convert light energy into electrical charge**.
- The image plane acts as a digital memory that can be read row by row by a computer.


synchronization
and addressing
addressing logic
0 1 2 3 4 5 6 7
0
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6
7
read row
or pixel
to
frame
buffer
alternative
analog
TV
signal
to
TV
3D
scene
lens
image
plane
pixel

- The ***image*** can be modeled by a continuous function of two or three variables;
- arguments are co-ordinates ***x, y*** in a plane, while if images change in time a third variable ***t*** might be added.
- The image function values correspond to the brightness at image points.

- The image on the human eye retina or on a TV camera sensor is intrinsically (本質上) 2D.
- We shall call such a 2D image bearing information about brightness points an ***intensity image***

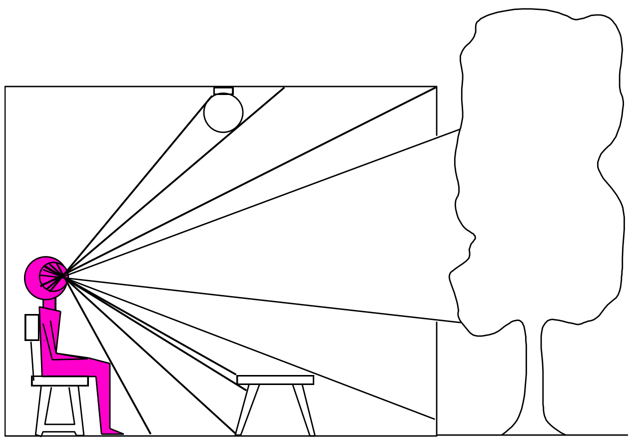
- The real world which surrounds us is intrinsically 3D.
- The 2D intensity image is the result of a perspective projection (透視投影) of the 3D scene.

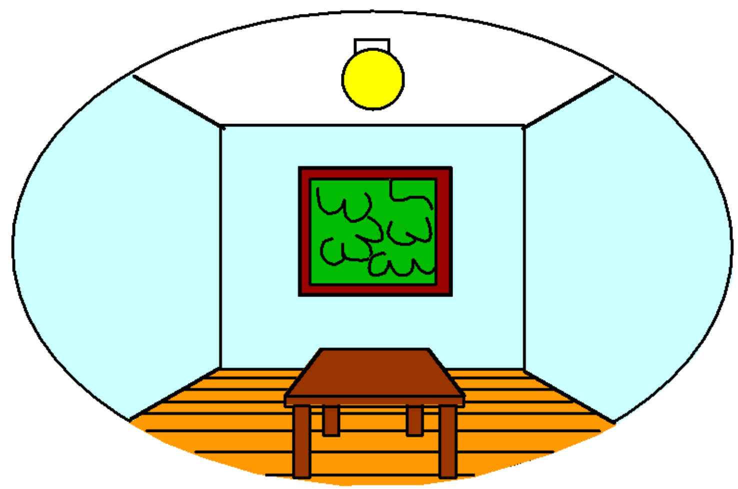
- When 3D objects are mapped into the camera plane by perspective projection a lot of information disappears as such a transformation is not one-to-one.
- Recognizing or reconstructing objects in a 3D scene from one image is an ill-posed problem.

Dimensionality Reduction Machine (3D to 2D)

3D world

2D image





Point of observation

Projection can be tricky…

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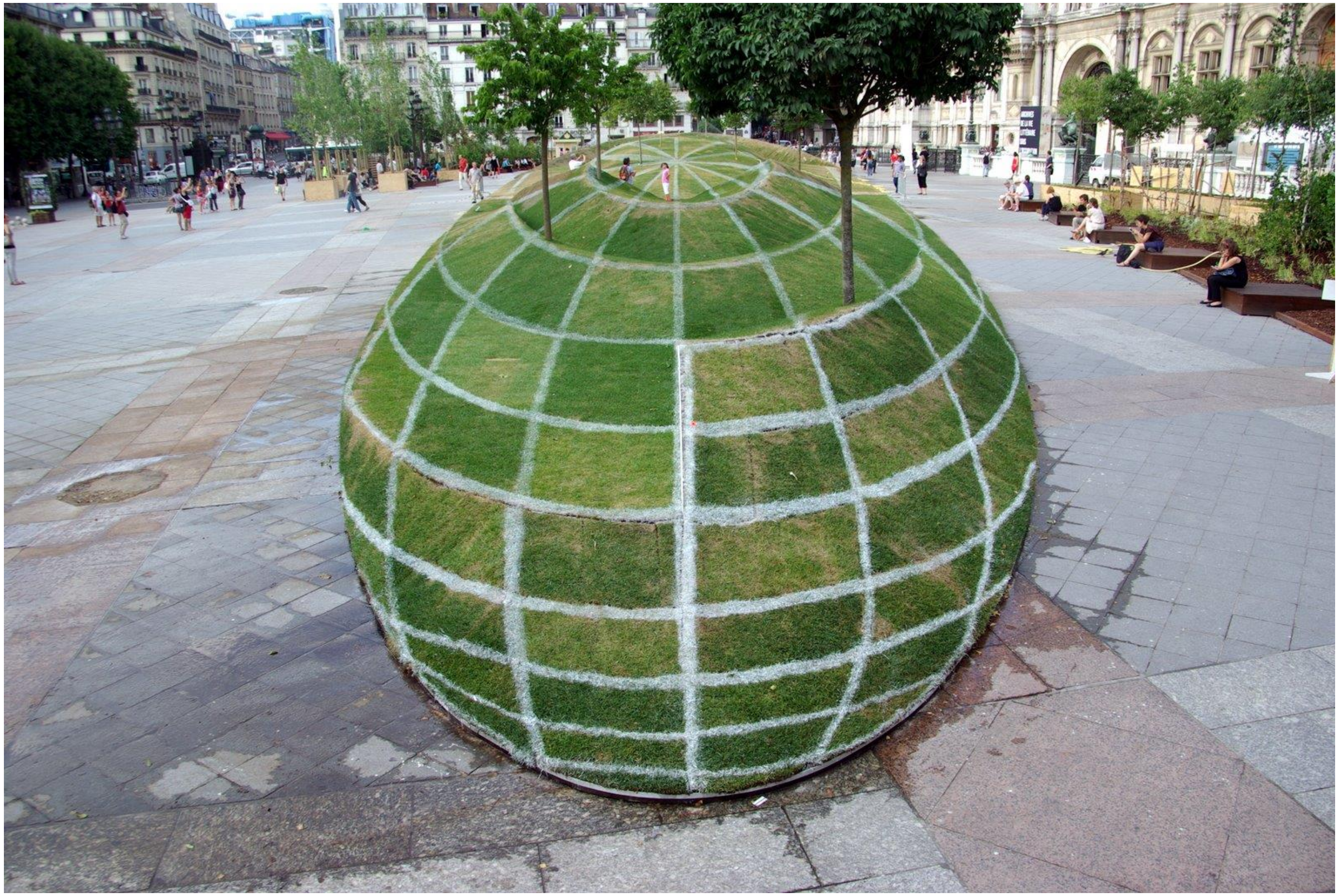
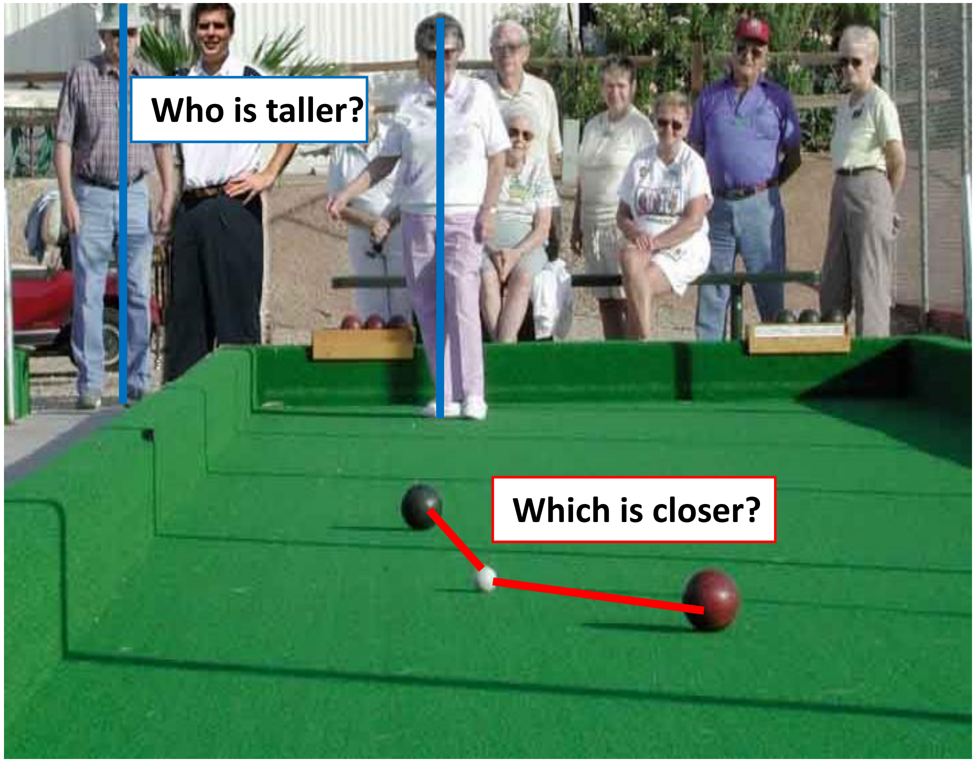


Projection can be tricky…

Projective Geometry

What is lost?

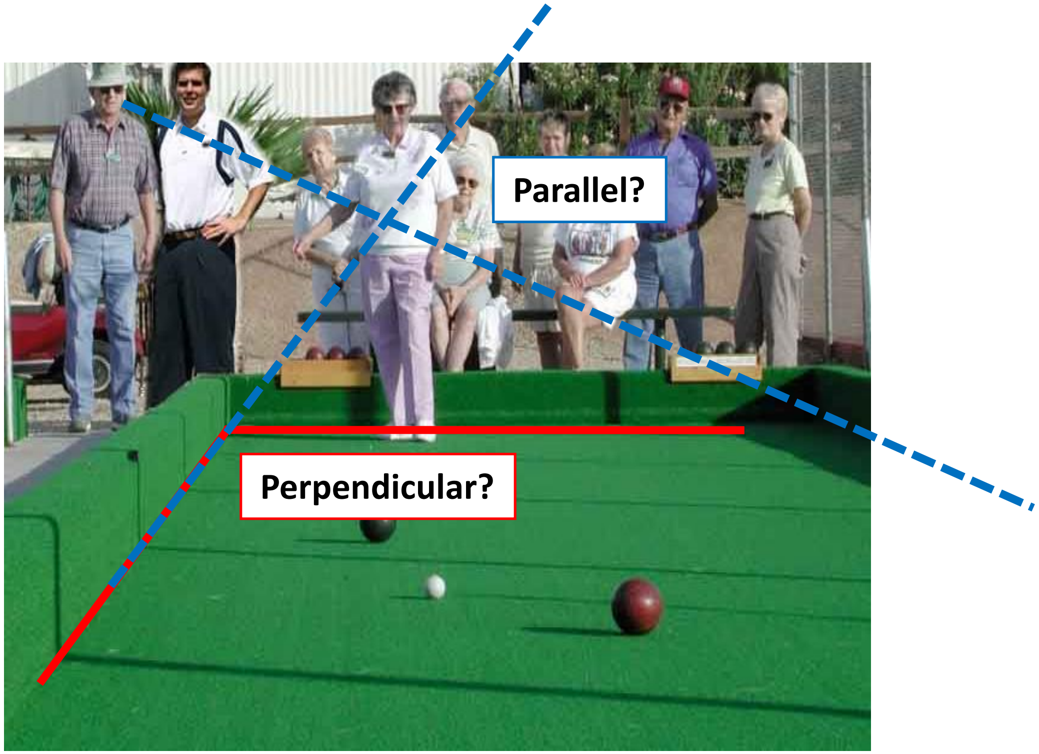
- Length



Projective Geometry

What is lost?

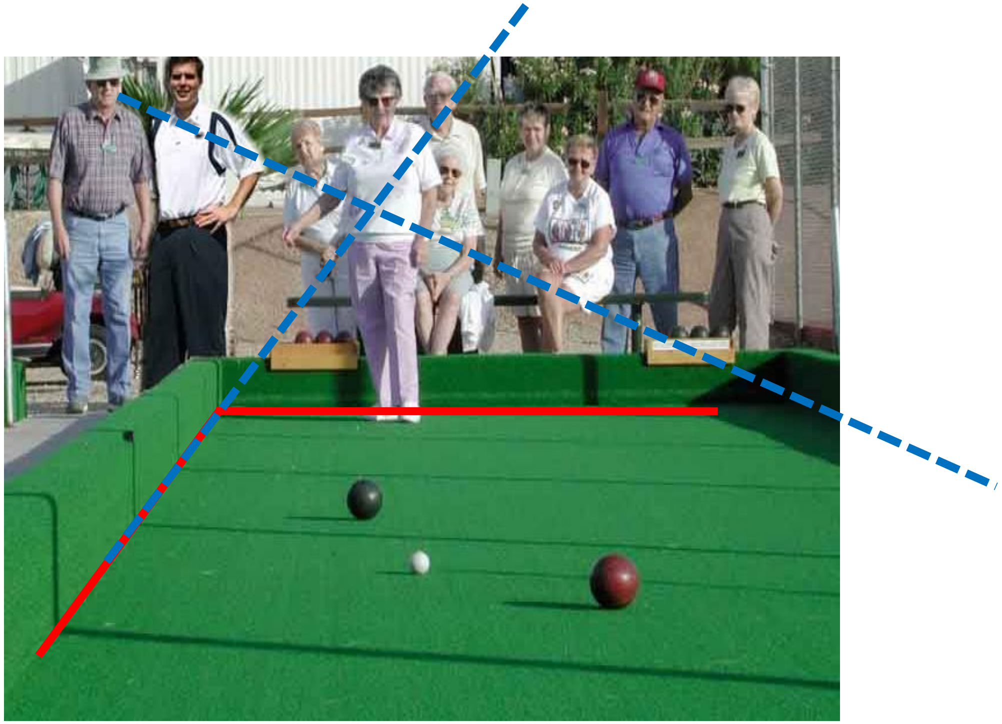
- Length
- Angles



Projective Geometry

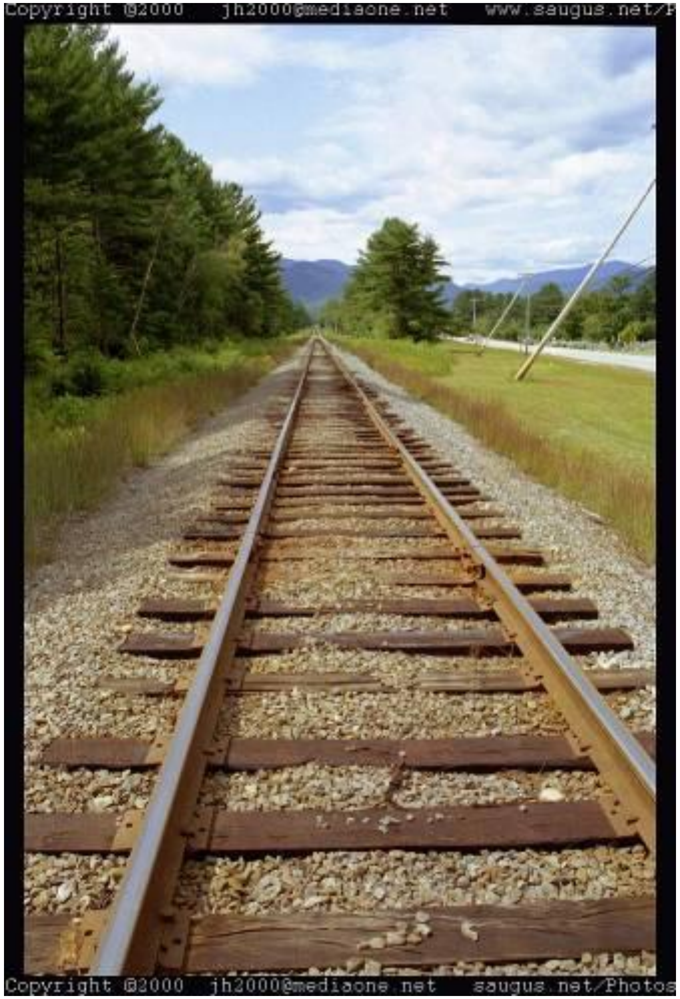
What is preserved?

- Straight lines are still straight



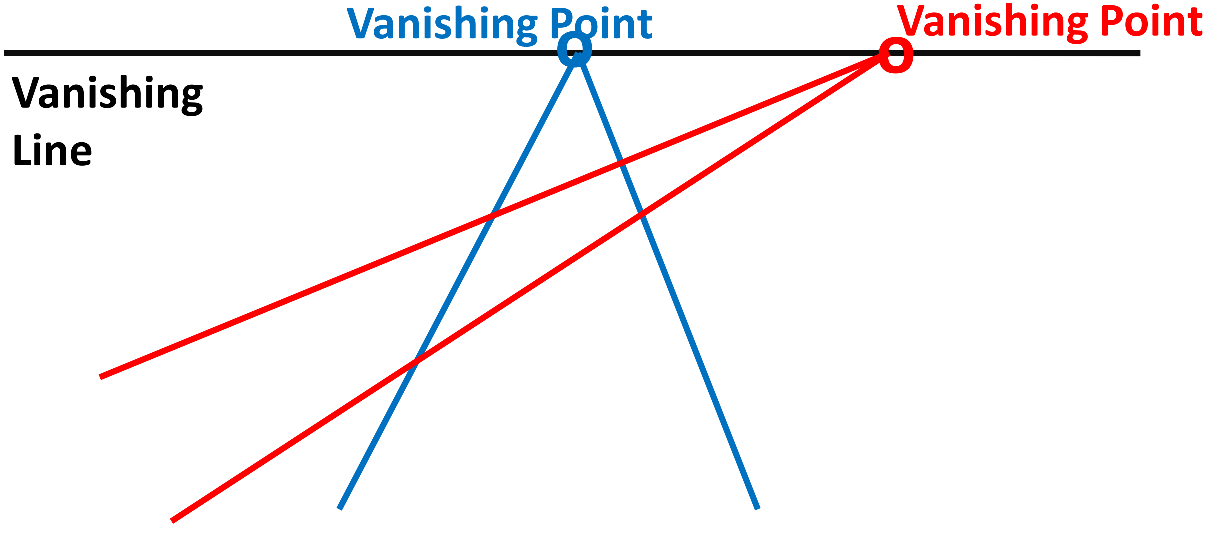
Vanishing points and lines

- Parallel lines in the world intersect in the image at a “vanishing point”

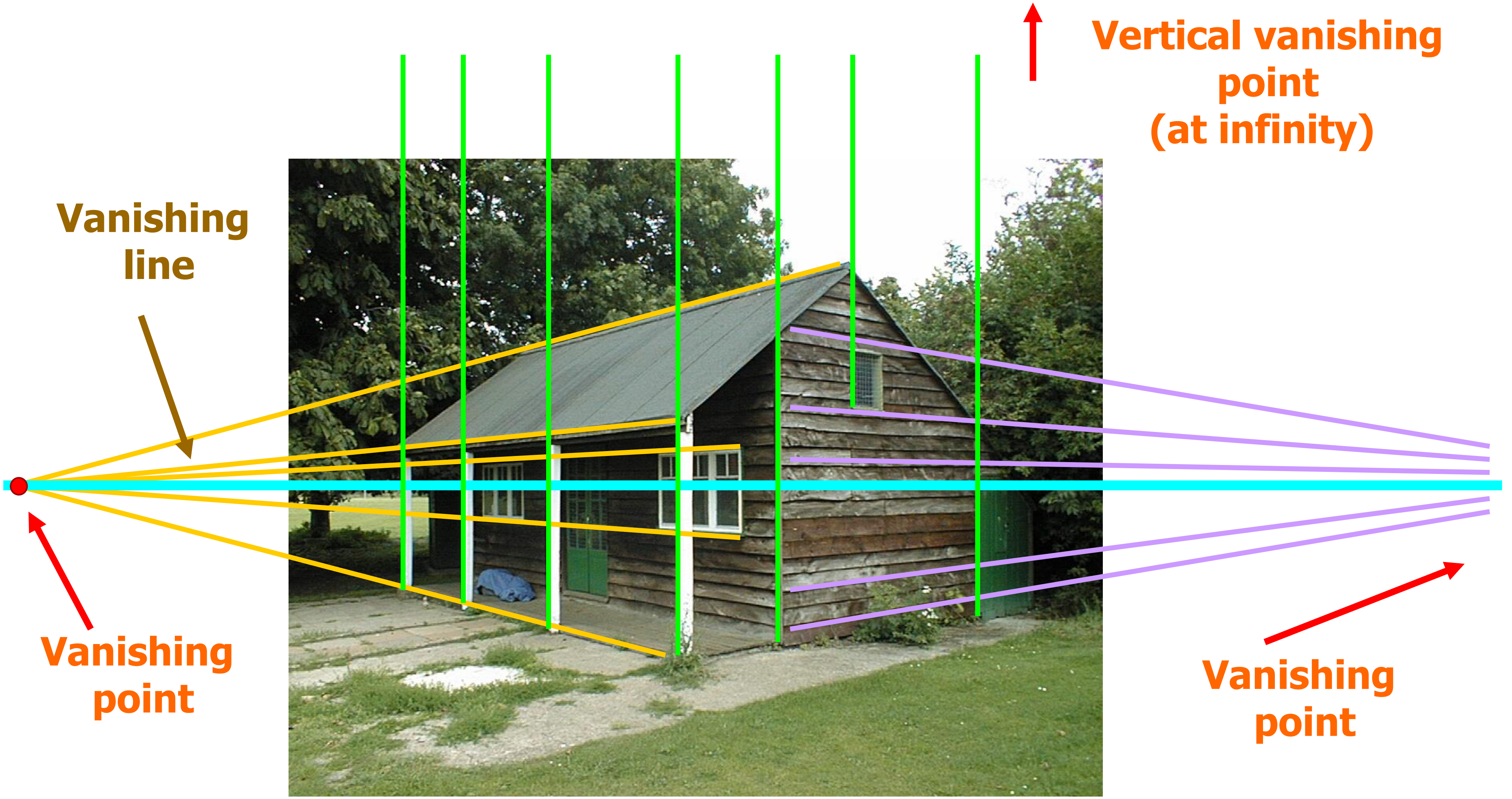


Vanishing points and lines

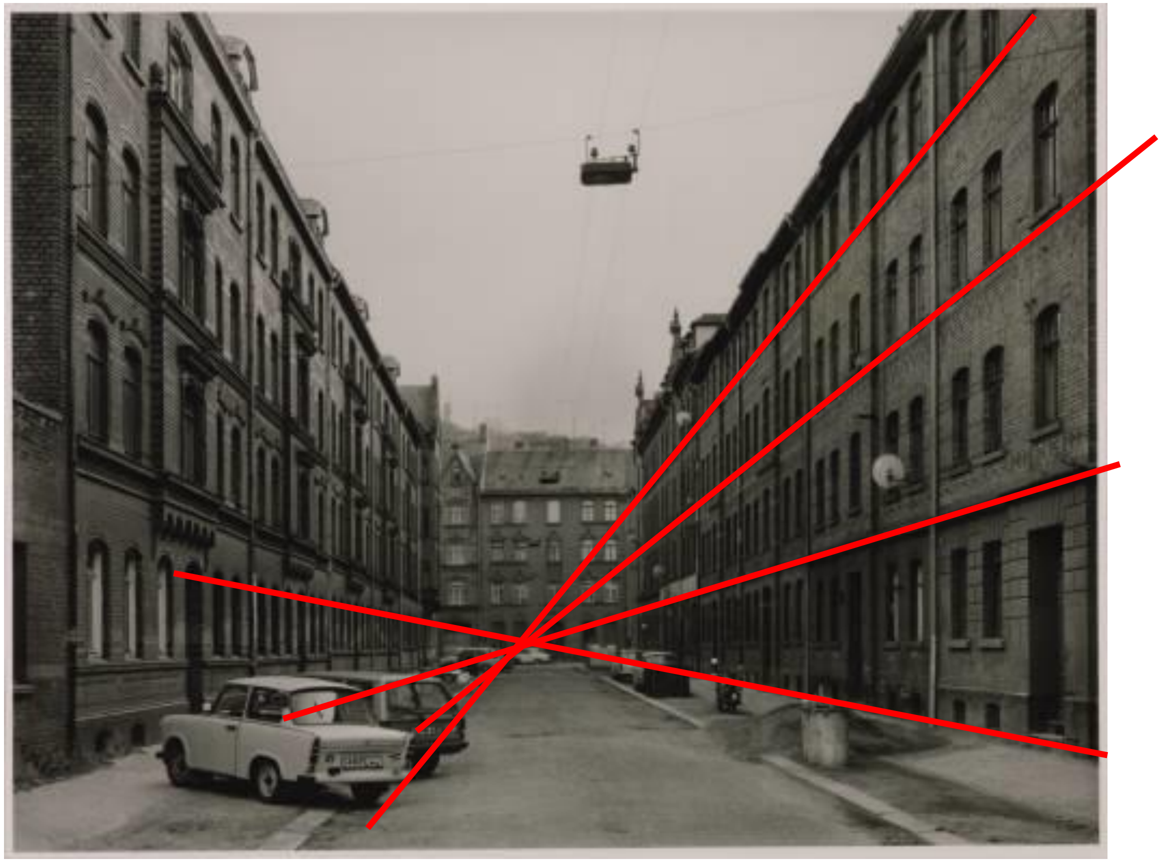
- Parallel lines intersect at a point
- Sets of parallel lines on the same plane form a vanishing line
- Not all lines that intersect are parallel



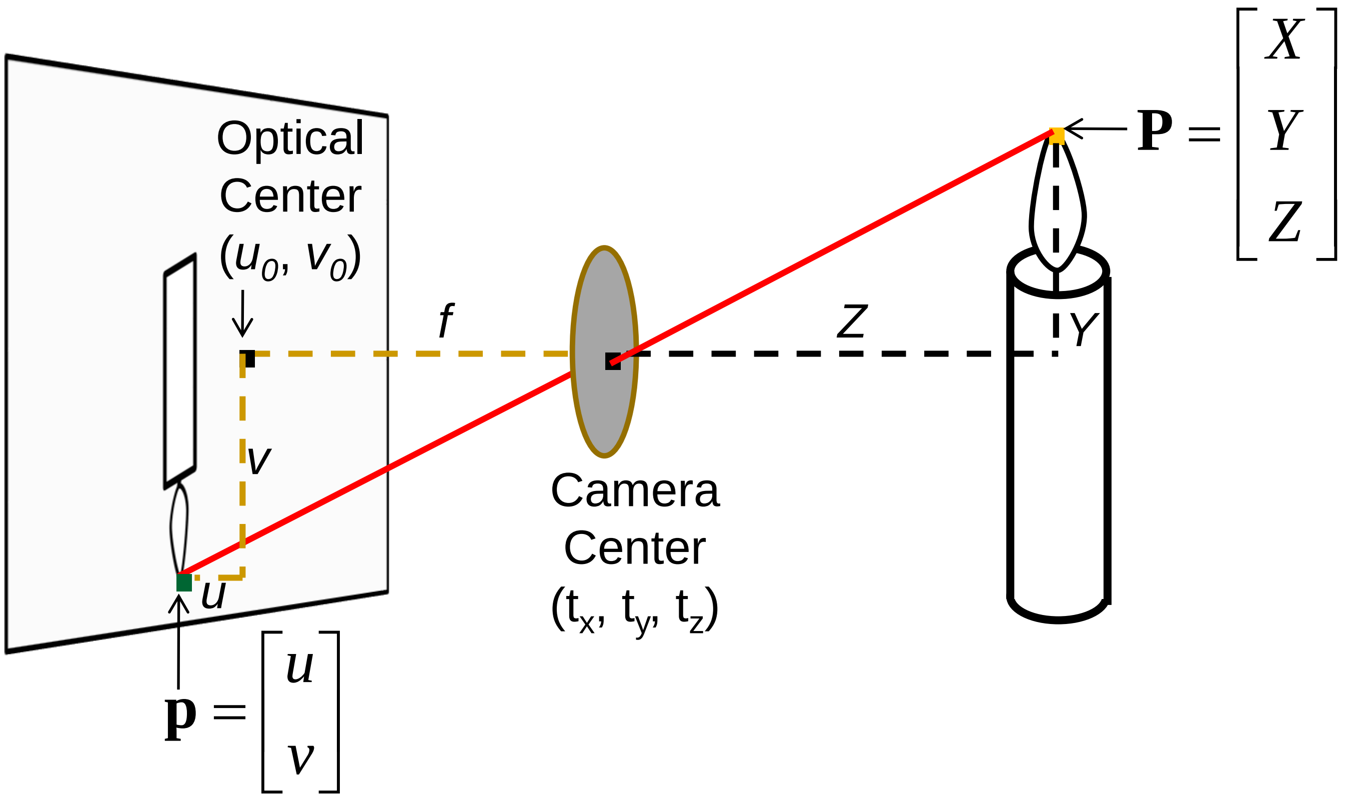
Vanishing points and lines



Vanishing points and lines



Projection: world coordinates→image coordinates



- Recovering information lost by perspective projection is only one, mainly geometric, problem of computer vision

- The second problem is how to understand image brightness.
- The only information available in an intensity image is brightness of the appropriate pixel, which is dependent on a number of independent factors such as

- object surface reflectance properties (given by the surface material, microstructure and marking),
- illumination properties,
- and object surface orientation with respect to a viewer and light source.

- Some scientific and technical disciplines work with 2D images directly; for example,
  - an image of the flat specimen viewed by a microscope with transparent illumination,
  - a character drawn on a sheet of paper,
  - the image of a fingerprint, etc.

- Many basic and useful methods used in digital image analysis do not depend on whether the object was originally 2D or 3D

- Image processing often deals with static images, in which time t is constant.
- A monochromatic （單色）static image is represented by a continuous image function f(x,y) whose arguments are two co-ordinates in the plane

- Computerized image processing uses digital image functions which are usually represented by matrices, so co-ordinates are integer numbers.
- The range of image function values is also limited; by convention, in monochromatic images the lowest value corresponds to black and the highest to white.
- Brightness values bounded by these limits are ***gray levels***.

Image digitization

- ***Sampling*** means measuring the value of an image at a finite number of points.
- ***Quantization*** is the representation of the measured value at the sampled point by an integer.

- An image captured by a sensor is expressed as a continuous function f(x,y) of two co-ordinates in the plane.
- Image digitization means that the function f(x,y) is ***sampled*** into a matrix with M rows and N columns.

- The image ***quantization*** assigns to each continuous sample an integer value.
- The continuous range of the image function $f(x,y)$ is split into K intervals.

- The finer the sampling (i.e., the larger M and N) and quantitation (the larger K) the better the approximation of the continuous image function f(x,y).

Sampling

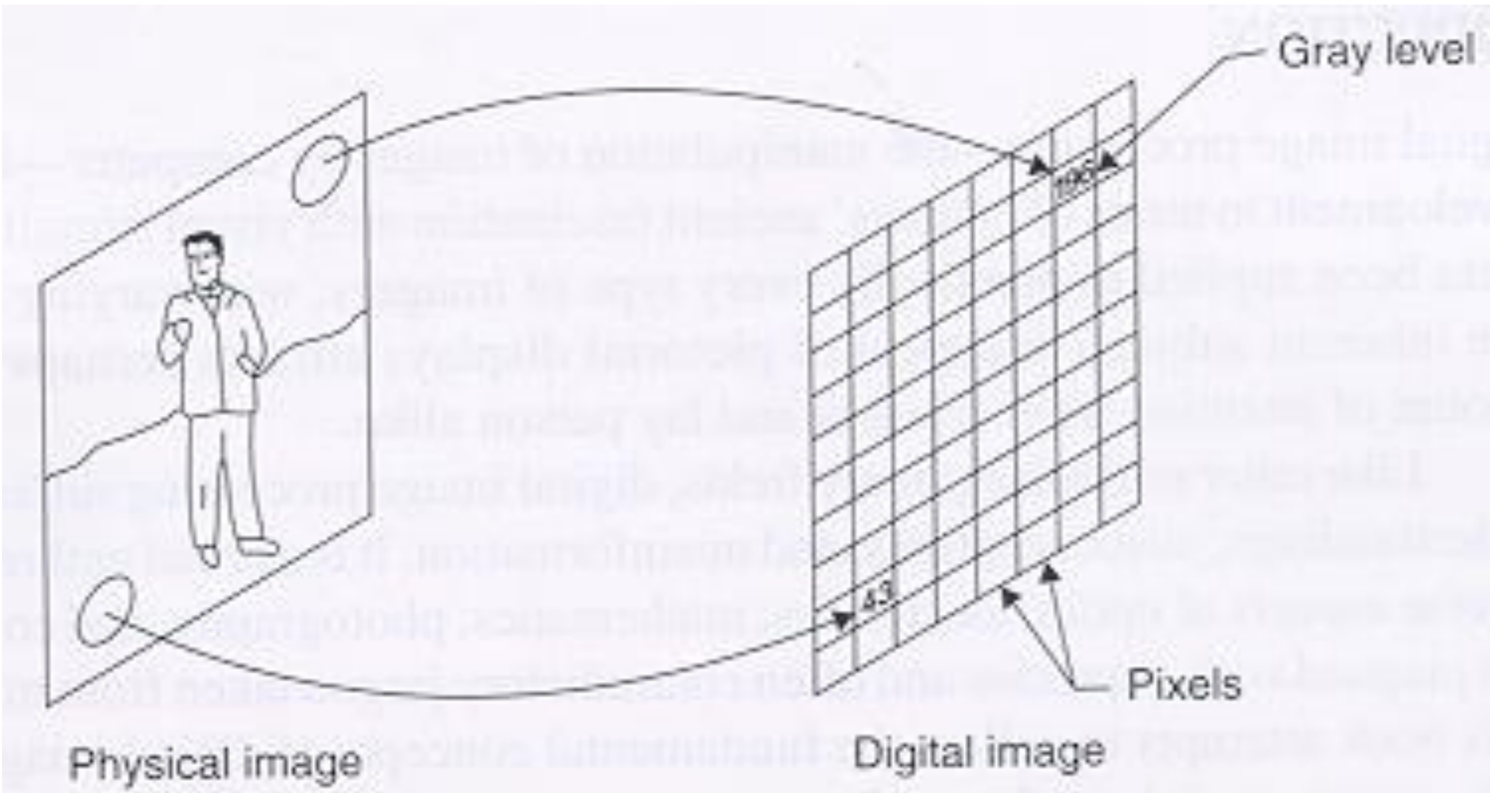


Image digitization (cont'd)

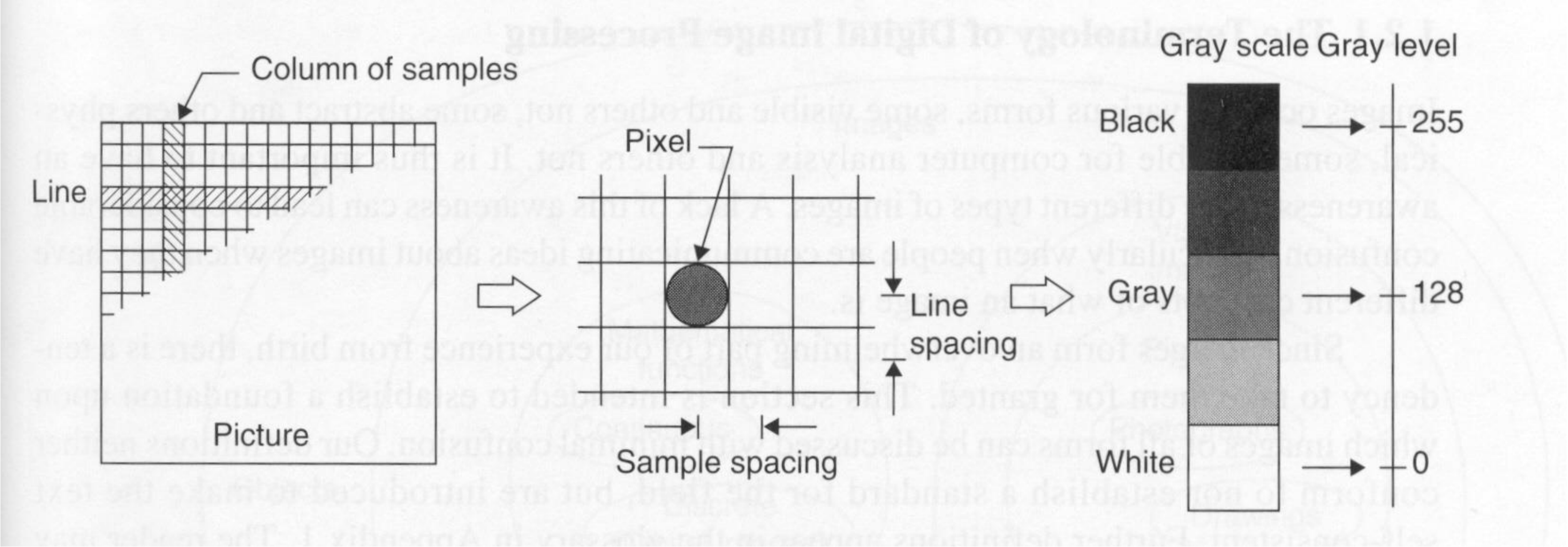


Image quantization (example)

256 gray levels (8bits/pixel)

32 gray levels (5bits/pixel)

16 gray levels (4bits/pixel)

8 gray levels (3bits/pixel)

4 gray levels (2bits/pixel)

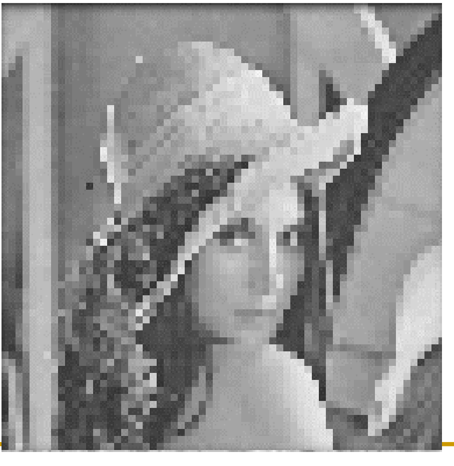
2 gray levels (1bits/pixel)

Image sampling (example)

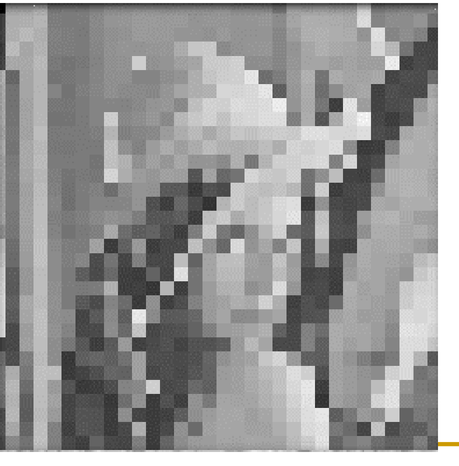
original image

sampled by a factor of 2

sampled by a factor of 4



sampled by a factor of 8



- N: # of rows, M: # of columns, Q: # of gray levels
  - N = 2^n, M = 2^m, Q = 2^q (q is the # of bits/pixel)
  - Storage requirements: N*M*Q (e.g., N=M=1024, q=8, 1MB)

$$
\begin{array}{cccc}
f(0,0) & f(0,1) & \ldots & f(0,M-1) \\
f(1,0) & f(1,1) & \ldots & f(1,M-1) \\
\ldots & \ldots & \ldots & \ldots \\
f(N-1,0) & f(N-1,1) & \ldots & f(N-1,M-1)
\end{array}
$$

Image coordinate system

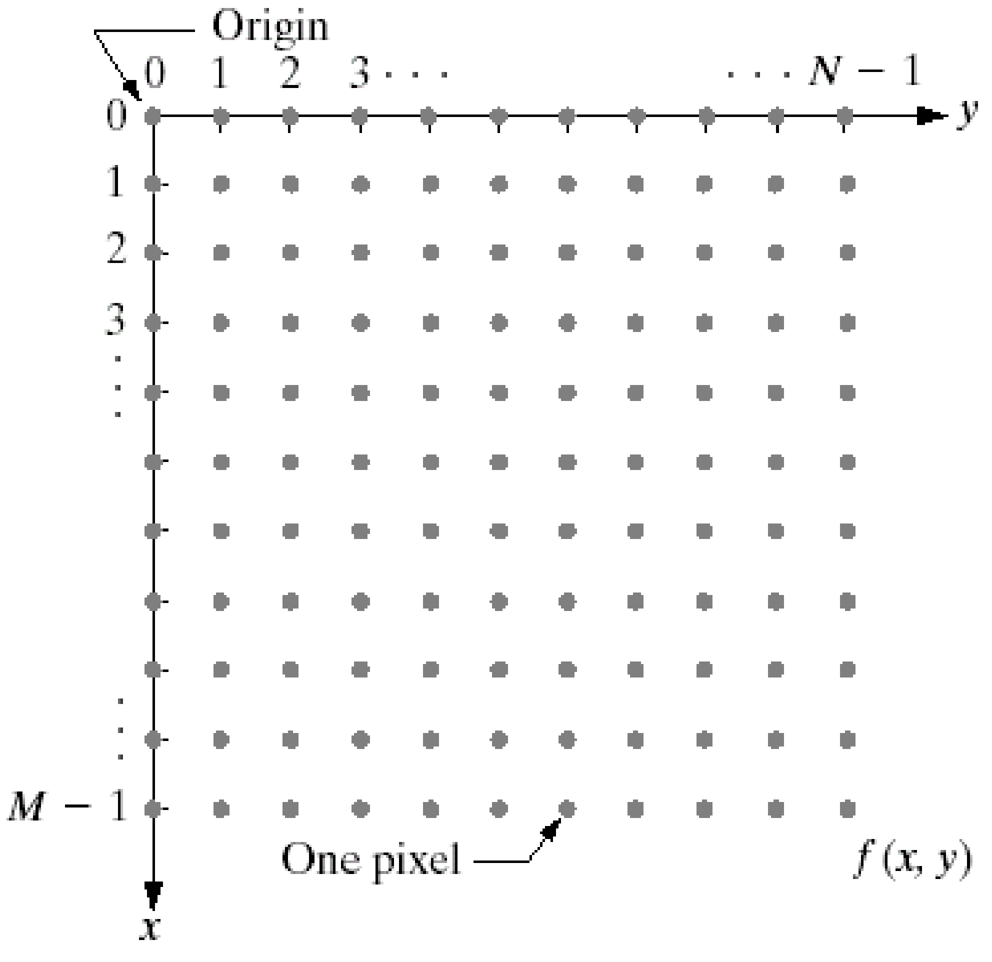
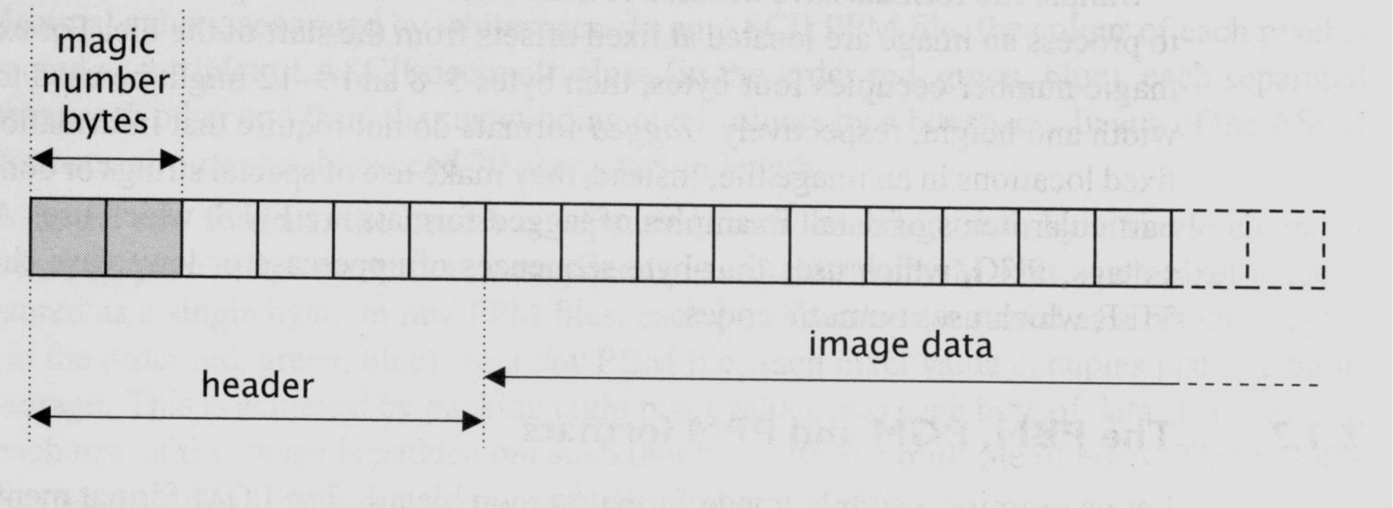


Image file formats

- Many image formats adhere to the simple model shown below (line by line, no breaks between lines).
- The header contains at least the width and height of the image.
- Most headers begin with a ***signature*** or “magic number” - a short sequence of bytes for identifying the file format.


magic
number
bytes
image data
header

Common image file formats

- **GIF** (Graphic Interchange Format): has been used to encode a huge number of images in the internet and databases.
  - Relatively easy to work with
  - Cannot be used for high-precision（高精度）color, since only 8-bits are used to encode color
    - Normally 256 color values available
    - 16-color is another option
  - Non-lossy compression is available

- **TIFF** (Tagged Image File Format): it is used on all popular platforms and is often the format used by scanners.
  - Supports multiple images with 1 to 24 bits of color per pixel.
  - Options are available for either lossy or lossless compression

- **JPEG** (Joint Photographic Experts Group): is a more recent standard from the ***Joint Photographic Experts Group***, the major purpose was to provide for practical compression of high-quality color still images.
  - Allows for real-time hardware for coding and decoding
  - High compression: a flexible but complex lossy coding scheme is used which often can compression a high quality image 20:1 without noticeable degradation.
  - The compression works well when the image has large regions of nearly constant color.
  - Is not designed for video.

- **MPEG** (Motion Picture Experts Group): a stream-oriented encoding scheme for video, audio, text, and graphics.
  - MPEG-1: suitable for multimedia for popular personal computers, but are too low for high-quality TV.
  - MPEG-2: handle high definition TV rates.