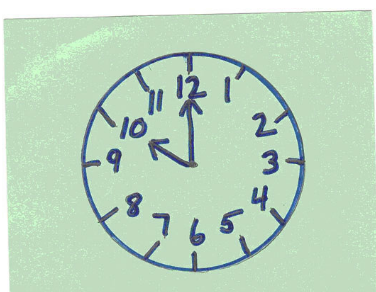
# FROM ANALOGUE TO DIGITAL: CONCEPTS AND TECHNIQUES





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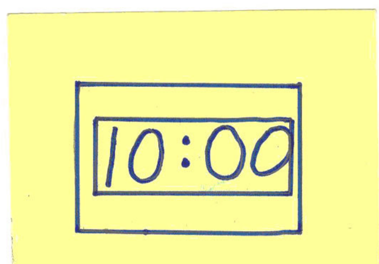
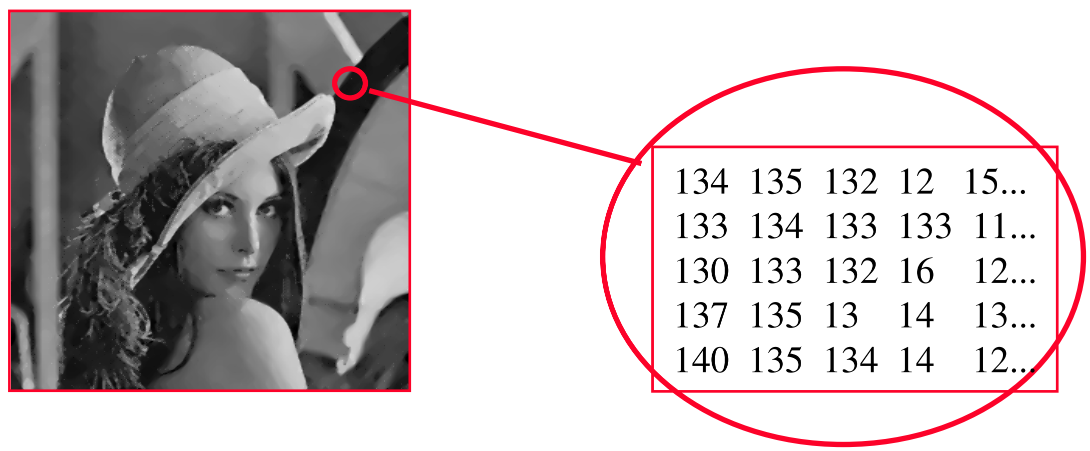


# Digitization

**Process of expressing analog data in digital form.**

**Analog data implies continuity while digital data is concerned with discrete states, e.g. digits.**

- **Vantages of digitization:**
- **Easier to process**
- **Easier to compress**
- **Easier to multiplex**
- **Easier to protect**
- **Lower powers**
- **...**

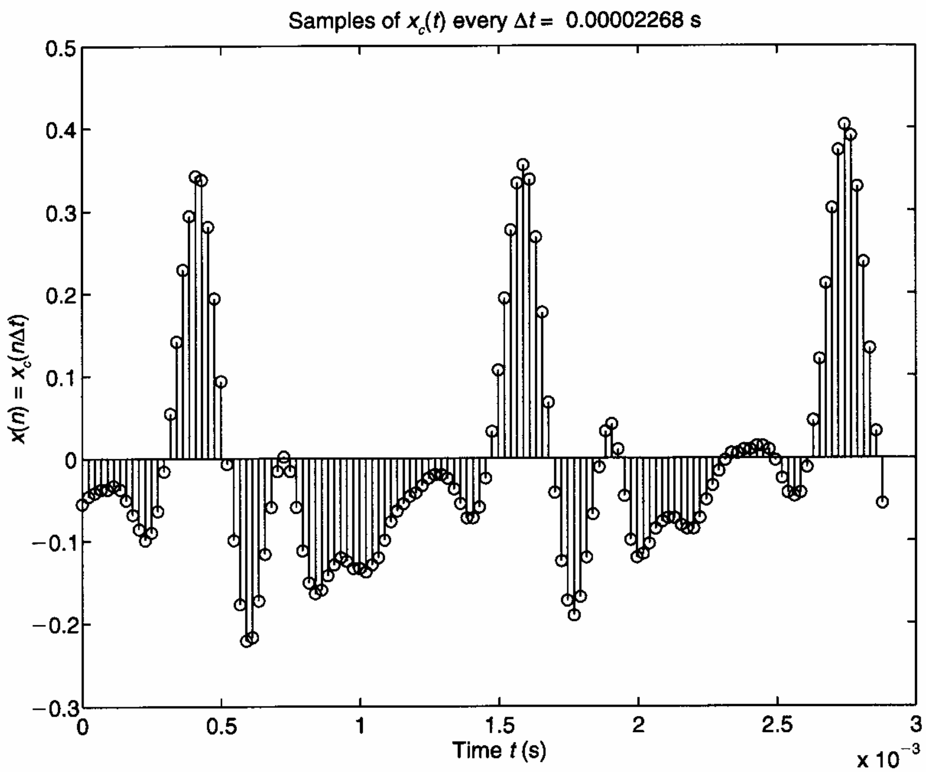


# Sampling or Time Discretization

**Process to obtain a periodic sequence of samples from a signal.**

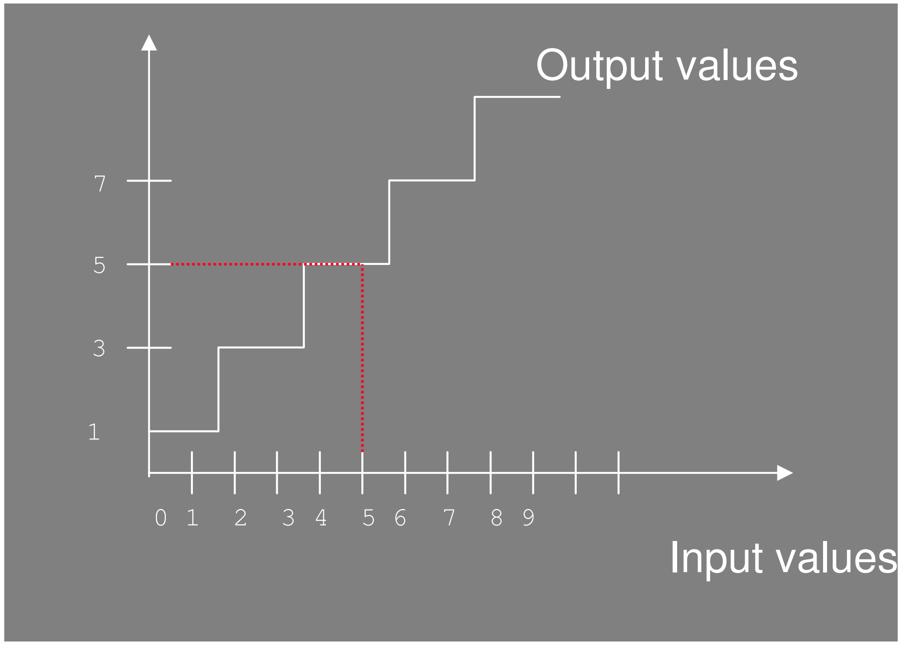
**Sampling is governed by the Sampling Theorem which states that:**

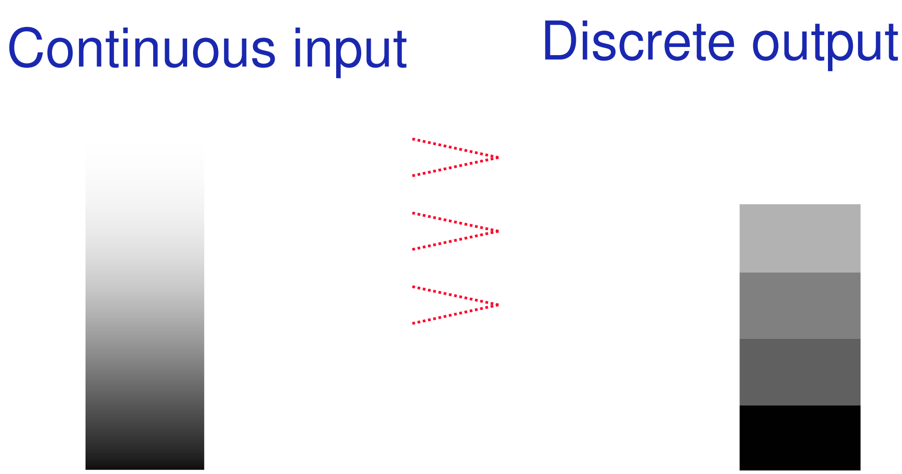
**An analog signal may be fully reconstructed from a periodic sequence of samples if the sampling frequency is, at least, twice the maximum frequency present in the signal.**



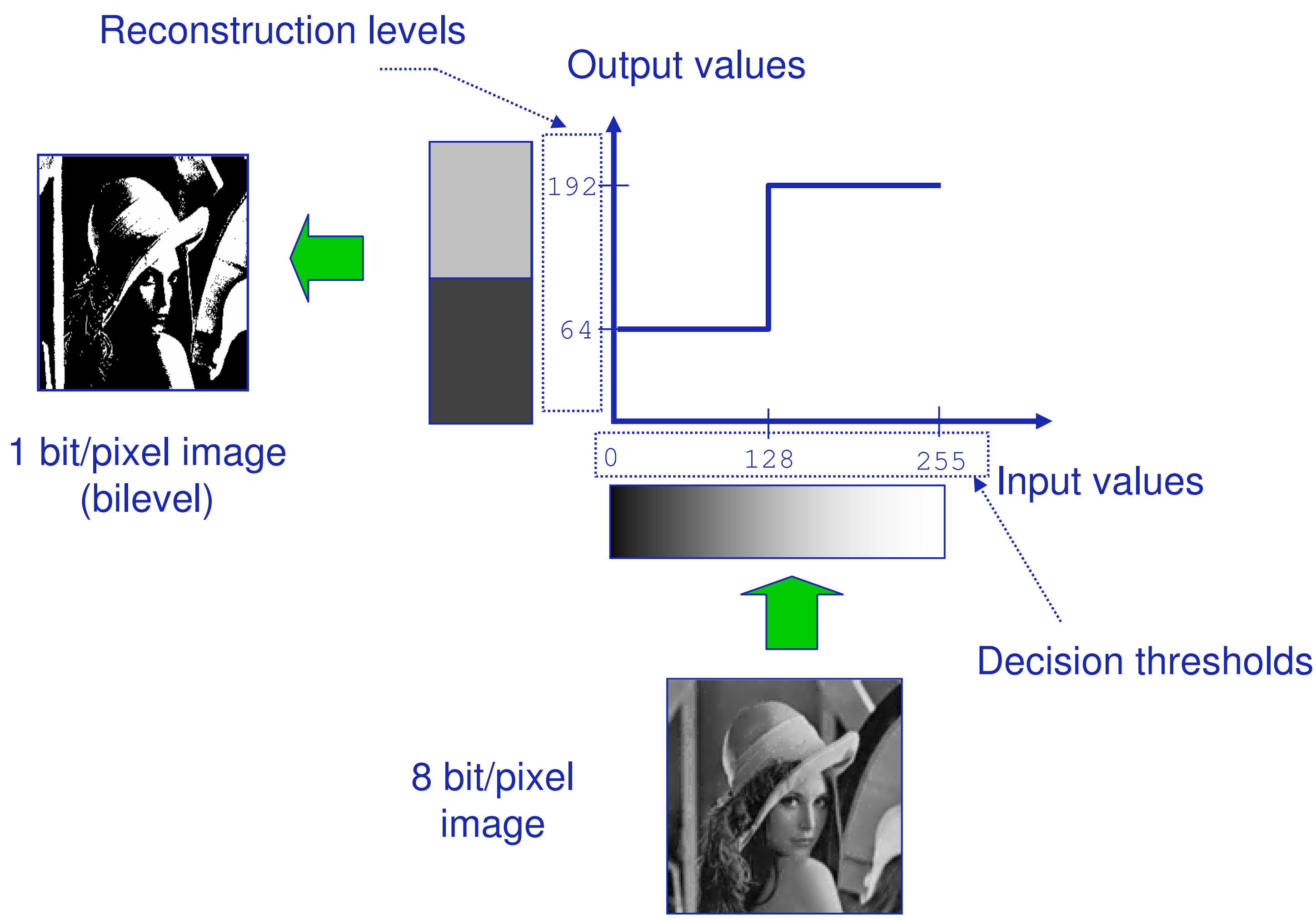
# Quantization or Amplitude Discretization

**Process in which the continuous range of values of an input signal is divided into nonoverlapping subranges, and to each subrange a discrete value of the output is uniquely assigned.**

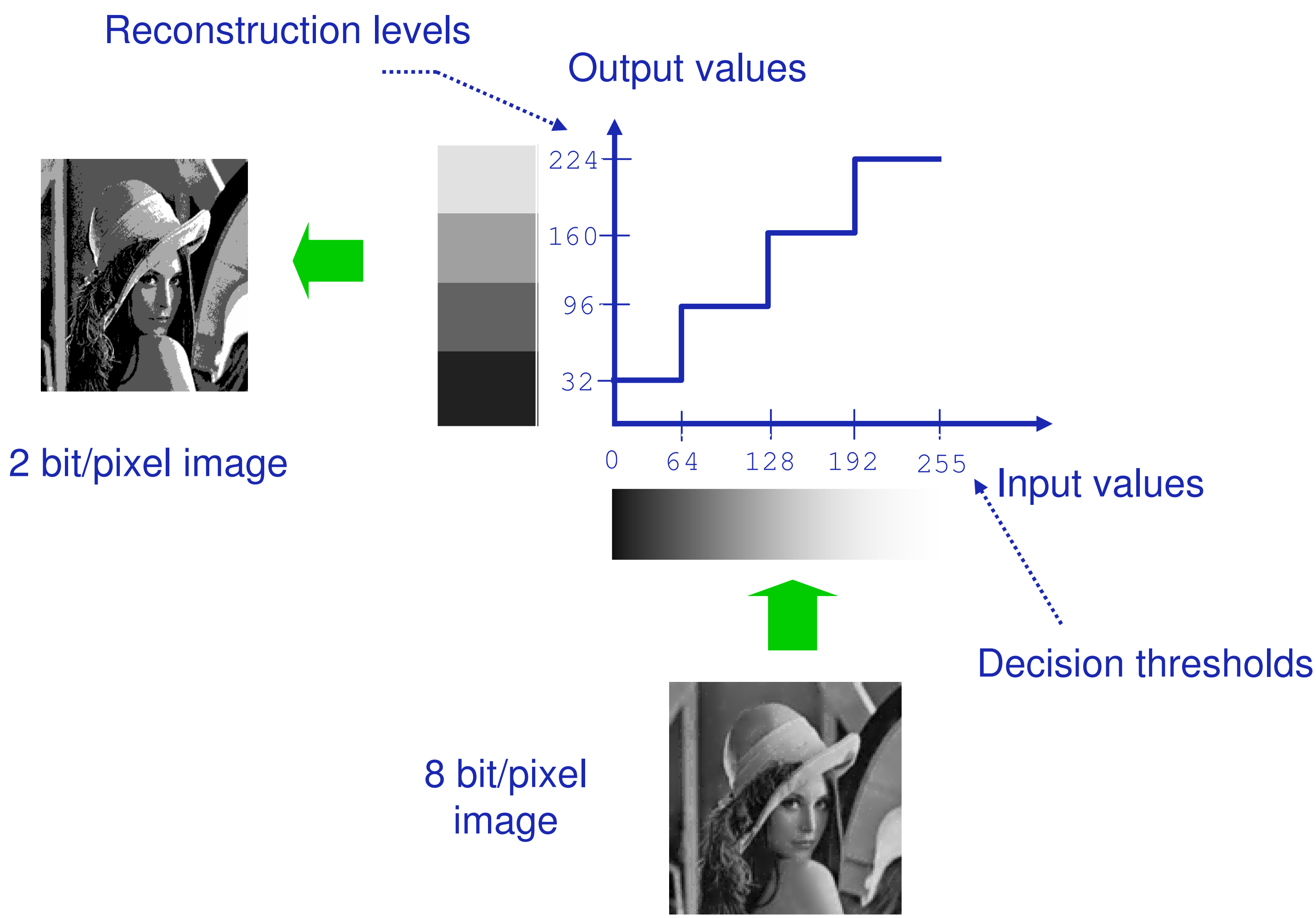


# 2 Levels Quantization



# 4 Levels Quantization



# Uniform Quantization

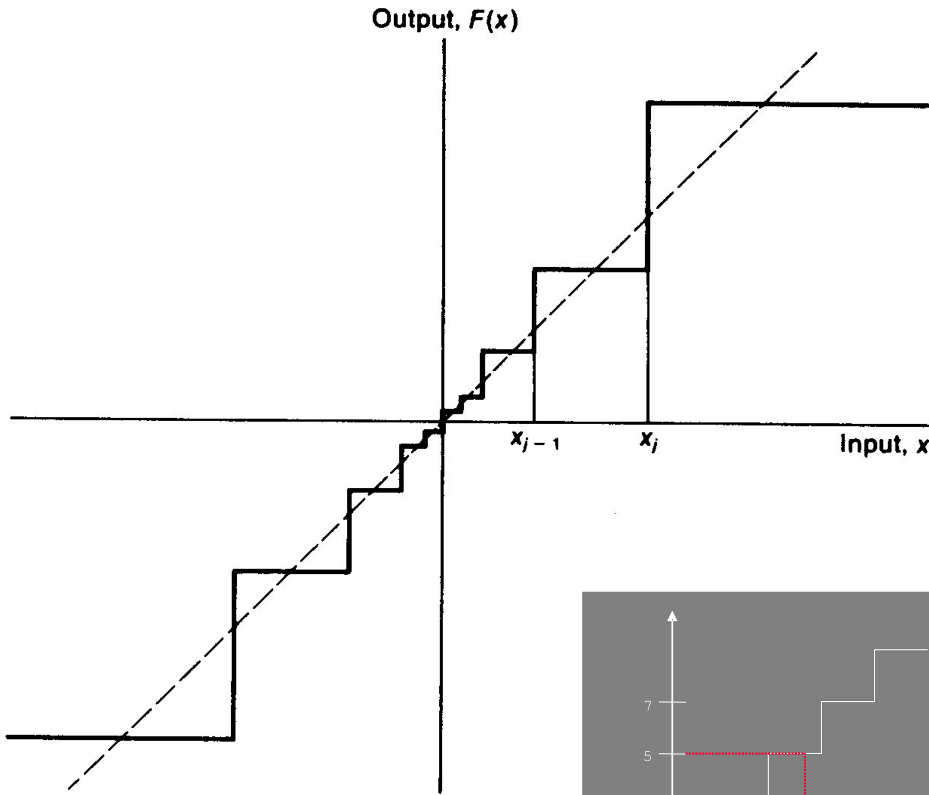
4 bits

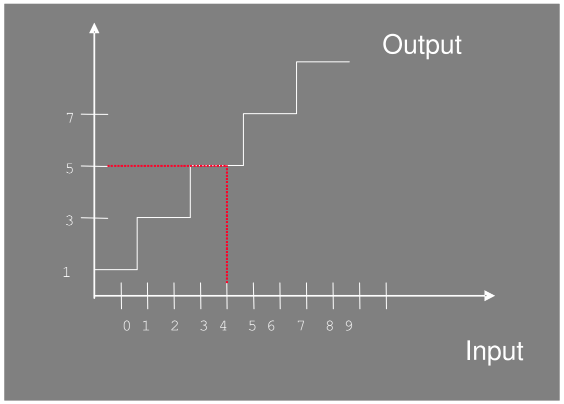
2 bits

3 bits

1 bit

# Non-Uniform Quantization

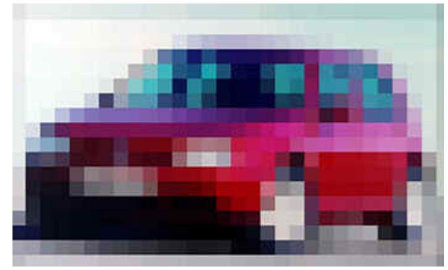



For many signals, e.g. Speech, uniform or linear quantization is not a good solution in terms of minimizing the mean square error (and thus SQR) due to the non unifomr statistics of the signal.

Also to get a certain SQR, lower quantization steps have to be used for lower signal amplitudes and vice-versa.

# *Pulse Code Modulation* (PCM)



**Simplest form of source coding where each sample is <u>independently</u> represented with the same number of bits.**

- **Example 1: Image with 200×100 samples at 8 bit/sample takes 200 × 100 × 8 = 160000 bits with PCM coding**
- **Example 2: 11kHz bandwidth audio at 8 bit/sample takes 11000 × 2 × 8 = 176 kbit/s kbit/s with PCM coding**

**Being the simplest form of coding as well as the less efficient, PCM s typically taken as the reference coding to evaluate the performance of more powerful source coding algorithms.**

# Digital TV: an Example

- ITU-R 601 Recommendation: 25 images/s with 720×576 luminance samples and 360×576 samples for each chrominance with 8 bit/sample

  $$[(720\times576) + 2 \times (360 \times 576)] \times 8 \times 25 = 166 \text{ Mbit/s}$$

- Acceptable rate, p.e. using MPEG-2 Video:  2-4 Mbit/s

**=> Compression Factor: 166/2-4 ≈ 40-80**

**The difference between the resources requested by compressed and non-compressed formats may lead to the emergence or not of new industries, e.g. DVD, digital TV.**

# Why Compressing ?


- For example, images are created and consumed as a set of M×N luminance and chrominance samples with a certain number of bit per sample (L)

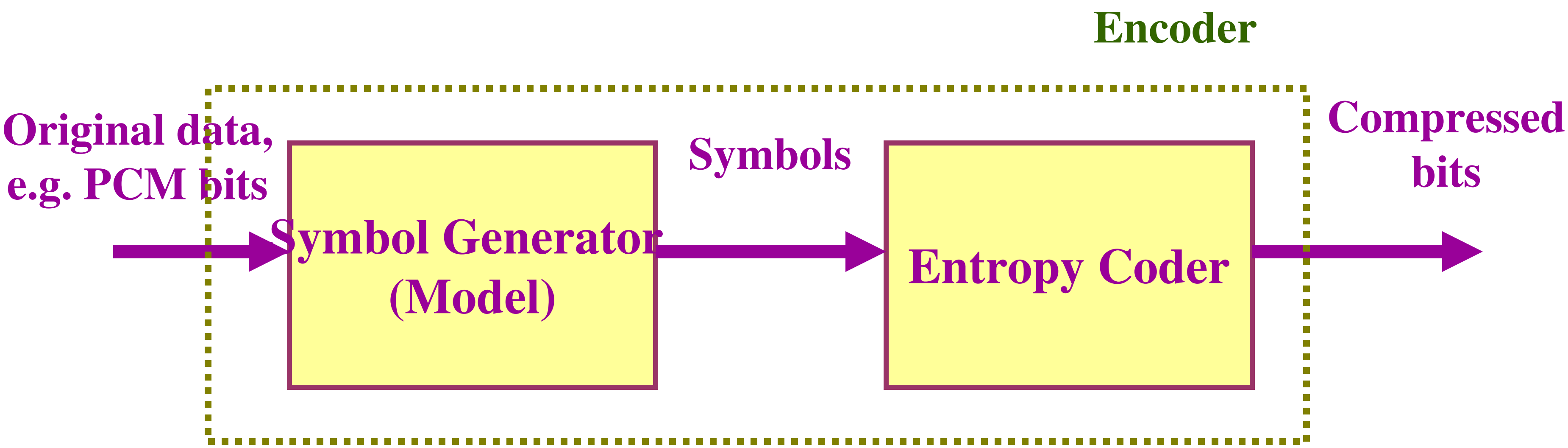
- The number of bits and thus the memory and rate necessary to represent a digital image is HUGE !!!

# Digital Source Coding/Compression

Process through which a source, e.g. Images, audio, video, is digitally represented considering relevant requirements such as compression efficiency, error resilience, random access, complexity, etc.

- Example 1: Maximizing the quality for the available rate
- Example 2: Minimizing the rate for a target quality

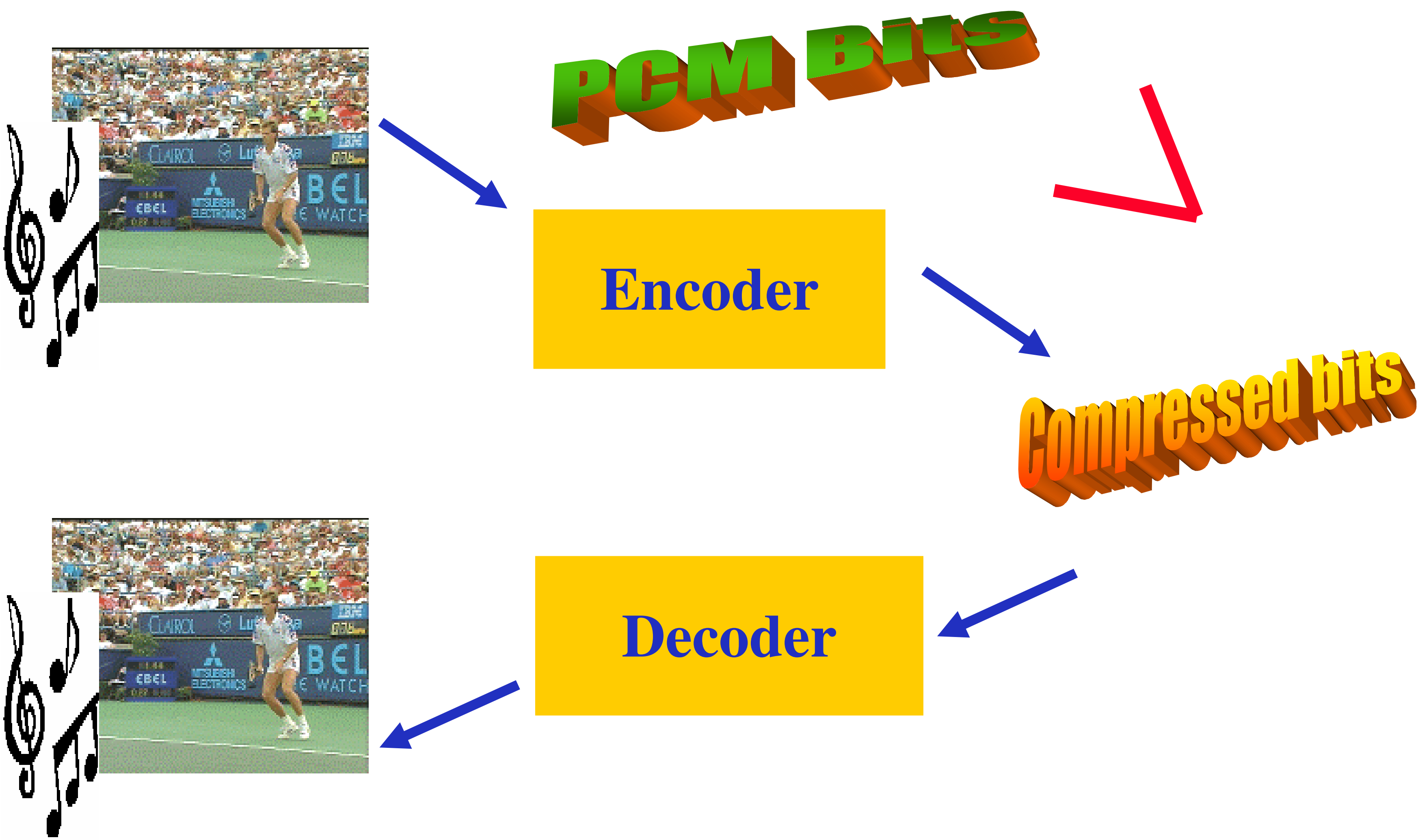
# Source Coding: Original Data, Symbols and Bits



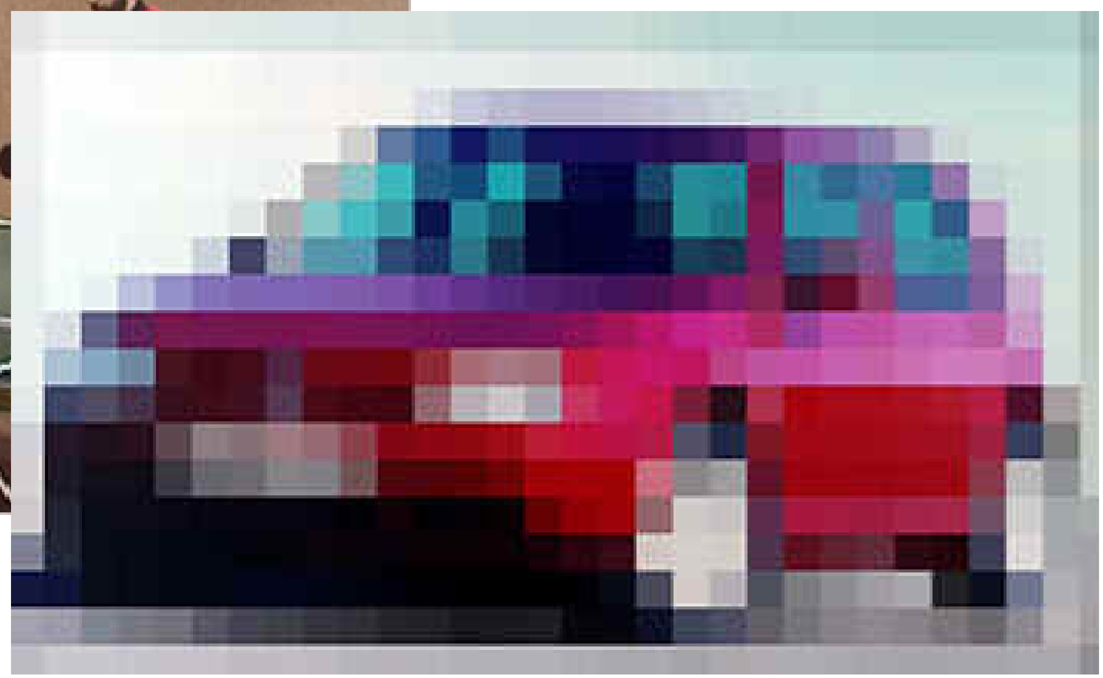

**The encoder represents the original (PCM) data as a sequence of symbols and later bits using in the best way the set of available coding tools to satisfy the relevant requirements.**

**The encoder extracts from original data ‘its best’ ...**

# Coding … and Decoding ...



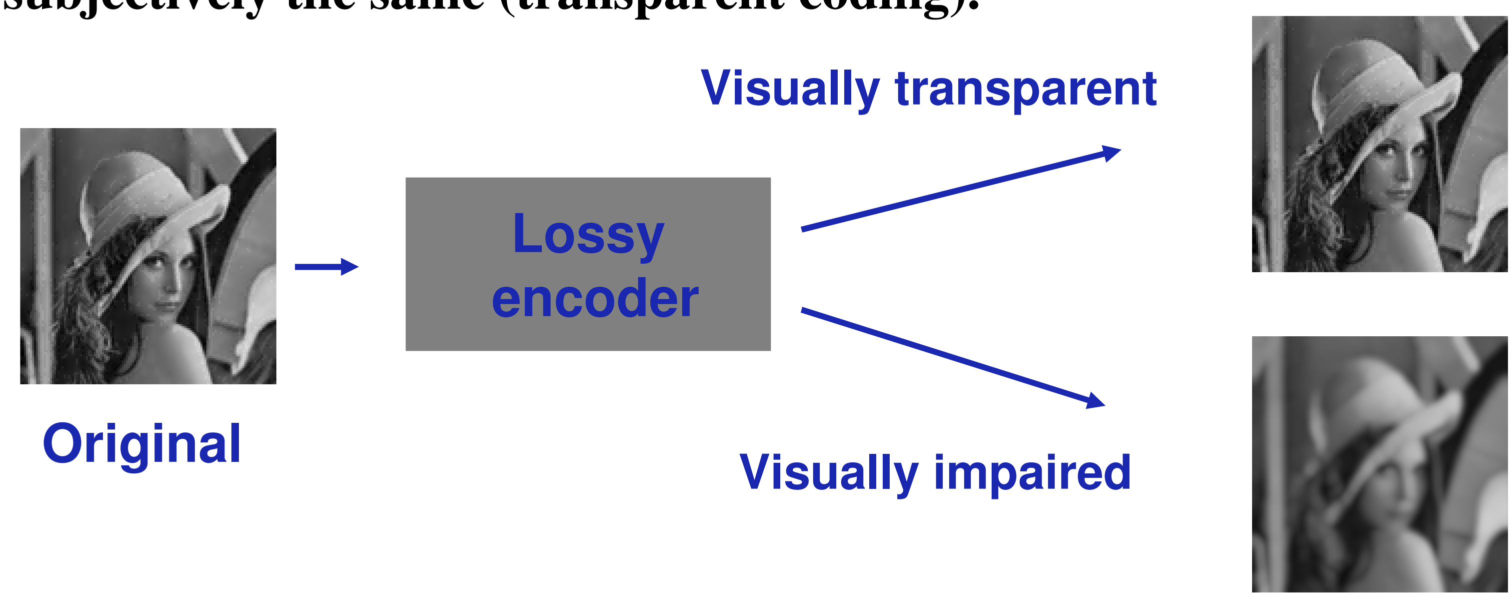
# Efficient Digitization: Sampling + Quantization + Source Coding

# Digital Image Coding: Main Types

- **LOSSLESS (exact) CODING – The image is coded preserving all the information present in the digital image; this means the original and decoded images are mathematically the same.**

- **LOSSY CODING – The image is coded without preserving all the information present in the digital image; this means the original and decoder images are mathematically different although they may still be subjectively the same (transparent coding).**



# Where does Compression come from ?

- **REDUNDANCY – Regards the similarities, correlation and predictability of samples and symbols corresponding to the image/audio/video data.**

**-> redundancy reduction does not involve any information loss this means it is a reversible process –> *lossless coding***

- **IRRELEVANCY – Regards the part of the information which is imperceptible for the visual or audotory human systems.**

**-> irrelevancy reduction is an irreversible process -> *lossy coding***

**Source coding exploits these two concepts: for that, it is necessary to know the source statistics and the human visual/auditory systems characteristics.**

# Information Theory: Entropy

Information Theory states that there is a lower limit for the average number of bits per symbol when coding m symbols from a source of information, which one with probability $p_i$. This limit is given by the source entropy obtained by:

$$H = \Sigma\, p_i \log_2 (1/p_i) \quad \text{bit/symbol}$$

- **The source entropy:**
  - **Measures the average amount of information carried by each symbol output by the source**
  - **Is a convex function of the probabilities $p_i$**
  - **Takes its maximum value when all symbols are the same probability (all $p_i$ are the same)**
  - **Takes a maximum value of $\log_2 m$ bit/symbol**

Information Theory does not indicate how to obtain a code with this coding efficiency but there are methods which allow to obtain codes with an efficiency as close as desired to the entropy efficiency.

# Statistical Redundancy

**Statistical Redundancy of a source, R(X), is defined as the difference between the maximum possible entropy of a source with the same number of symbols and the actual source entropy**

$$R(X) = \log_2 m - H(X)$$

**R(X) > 0 implies predictability of the symbols created by the source manifests in two ways:**

- **Statistical dependency (memory) between the sucessice symbols of the signal**
- **Unequal probability distribution of the source symbols**

**Exploiting these factors leads to a reduction of the data associated to the representation of an image, video, audio, etc.**

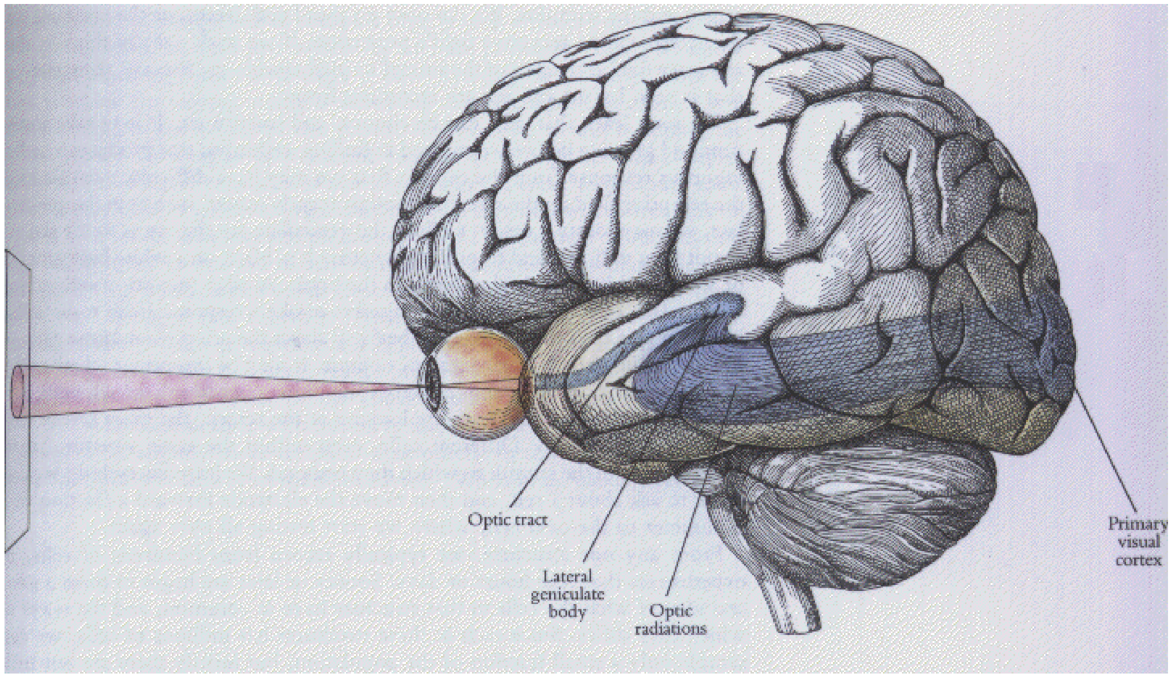
# Compression Metrics

$$\text{Compression Factor} = \frac{\text{Number of bits for the original image (PCM)}}{\text{Number of bits for the coded image}}$$

$$\text{Bit/pixel} = \frac{\text{Number of bits for the coded image}}{\text{Number of pixels in the image (typica. Y)}}$$

**The number of pixels of an image corresponds to the number of samples of its component with the highest resolution, typically the luminance.**

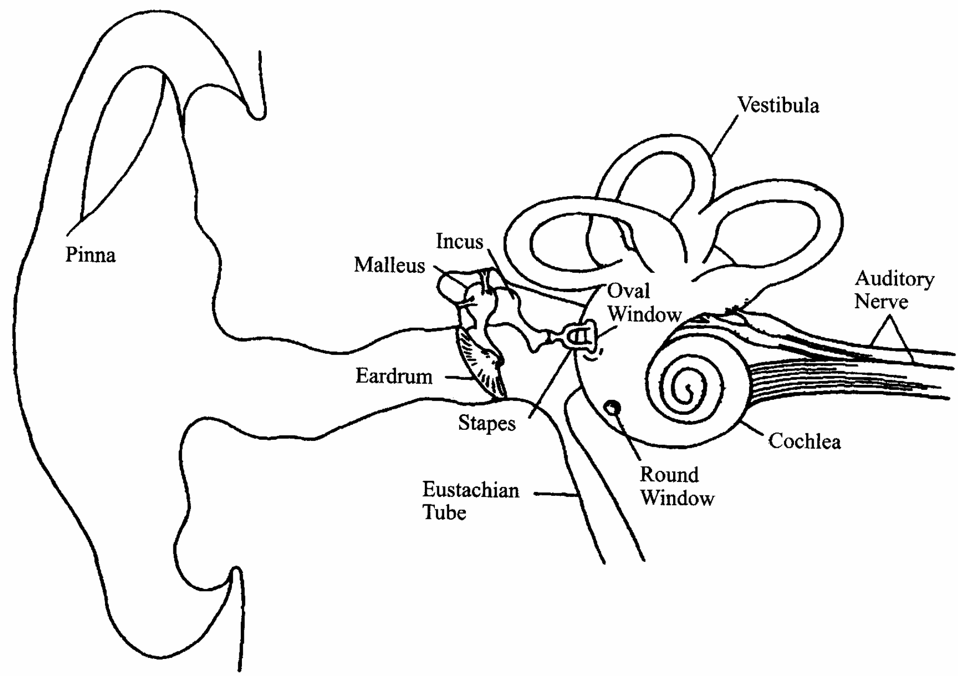
# Human Visual System




**It is essential to keep in mind that visual information is to be consumed by the Human Visual System !**

**The Human Visual System is the client that must be satisfied in terms of visual quality!**

# Human Auditory System




**It is essential to keep in mind that audio/speech information is to be consumed by the Human Auditory System !**

**The Human Auditory System is the client that must be satisfied in terms of audio/speech quality!**

# Quality Metrics

X(m,n)

Compression

Y(m,n)

Subjective evaluation ⇒ e.g., scores in a 5 levels scale

$$\mathrm{PSNR(dB)} = 10\log_{10}\frac{255^2}{\mathrm{MSE}}$$

Objective evaluation ⇒

$$\mathrm{MSE} = \frac{1}{\mathrm{MN}}\sum_{i=1}^{M}\sum_{j=1}^{N}(y_{ij} - x_{ij})^2$$

# Channel Coding

**Process applied to the bits produced by the source encoder to increase its robustness against channel or storage errors,**

- **At the sender, redundancy is added to the source compressed signal in order to allow the channel decoder to detect and correct channel errors.**
- **The introduction of redundancy results in an increase of data to transmit. The selection of the channel coding solution mus consider the type of channel, and thus error characteristics, and the modulation.**


**Block Codes**

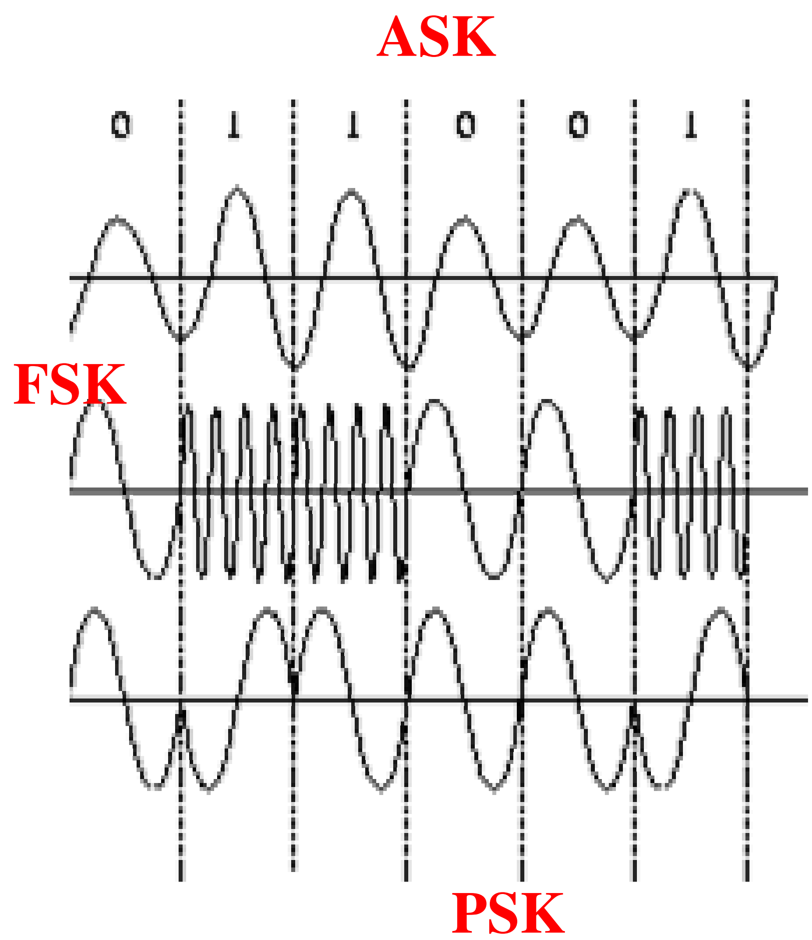
$$R = m/n = 1 - k/n$$

# Digital Modulation

Process through which one or more charateristics of a carrier (amplitude, frequency or phase) vary as a function of the modulating signal (the signal to be transmitted).

**The selection of an adequate modulation is esssential for the efficient usage of the bandwidth of any channel.**

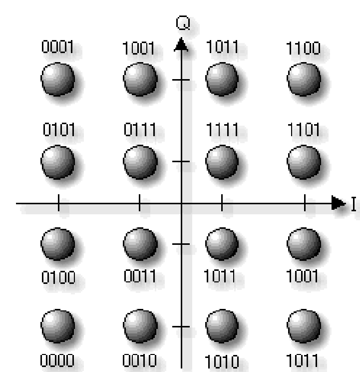
**Together, coding and modulation determine the bnadwidth necessary for the transmission of a certain signal.**



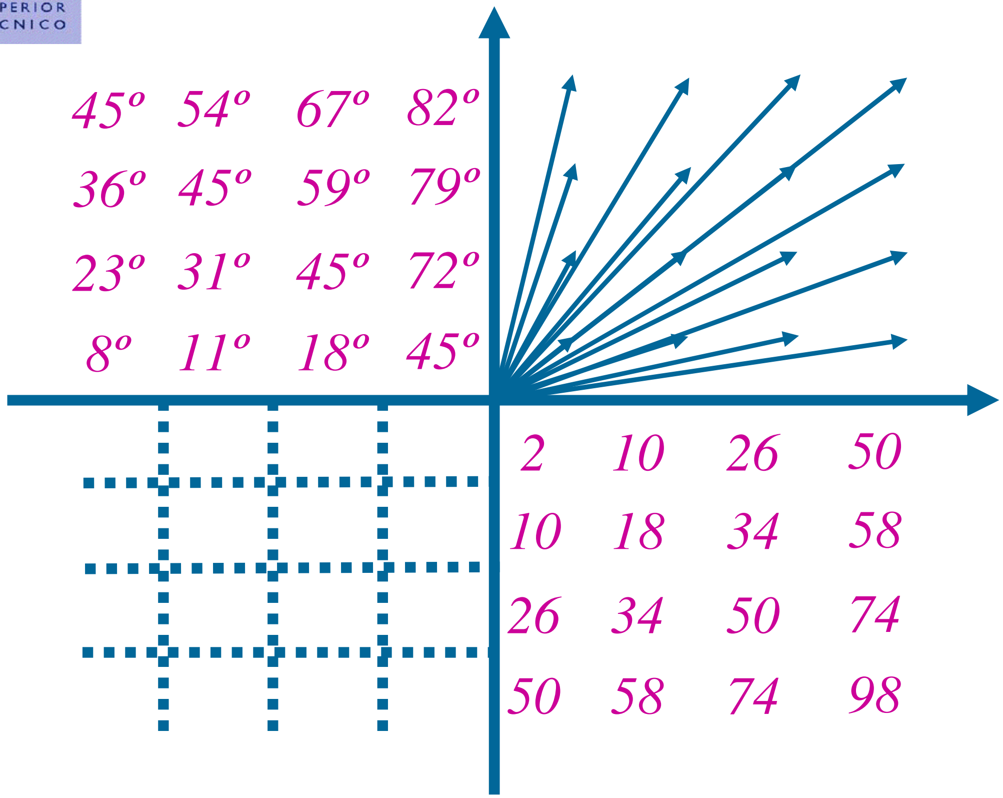
# Selecting a Modulation ...

- **Factors to consider in selecting a modulation:**
  - Channel characteristics
  - Spectrum efficiency
  - Resilience to channel distortions
  - Resilience to transmitter and receiver imperfections
  - Minimization of protection requirements against interferences

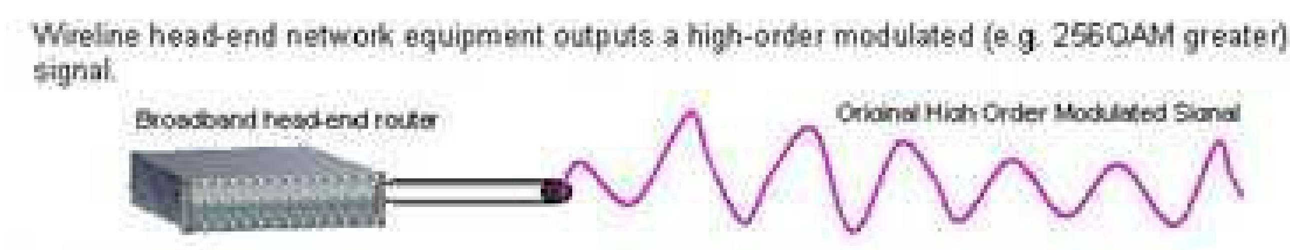
- **Basic digital modulation techniques:**
  - Amplitude modulation (ASK)
  - Frequency modulation (FSK)
  - Phase modulation (PSK)
  - Mix of phase and amplitude modulation (Q



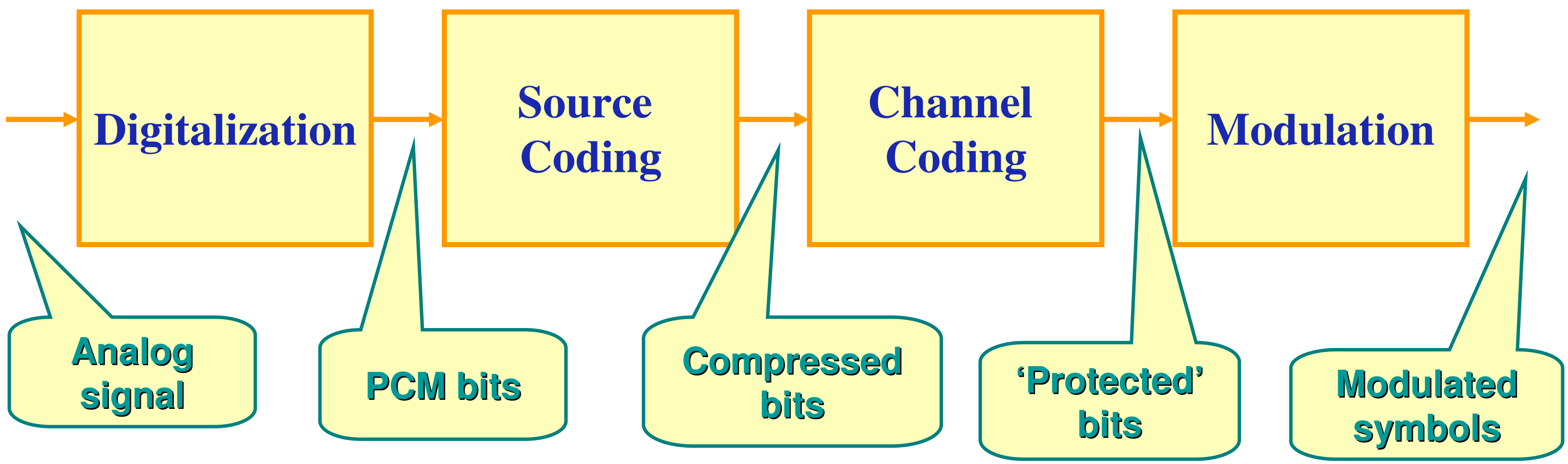
# 64-QAM Modulation Constelation




**Only 64 modulated symbols are possible !**



# Typical Digital Transmission Chain ...



# Bibliography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- Digital Video Processing, A. Murat Tekalp, Prentice Hall, 1995