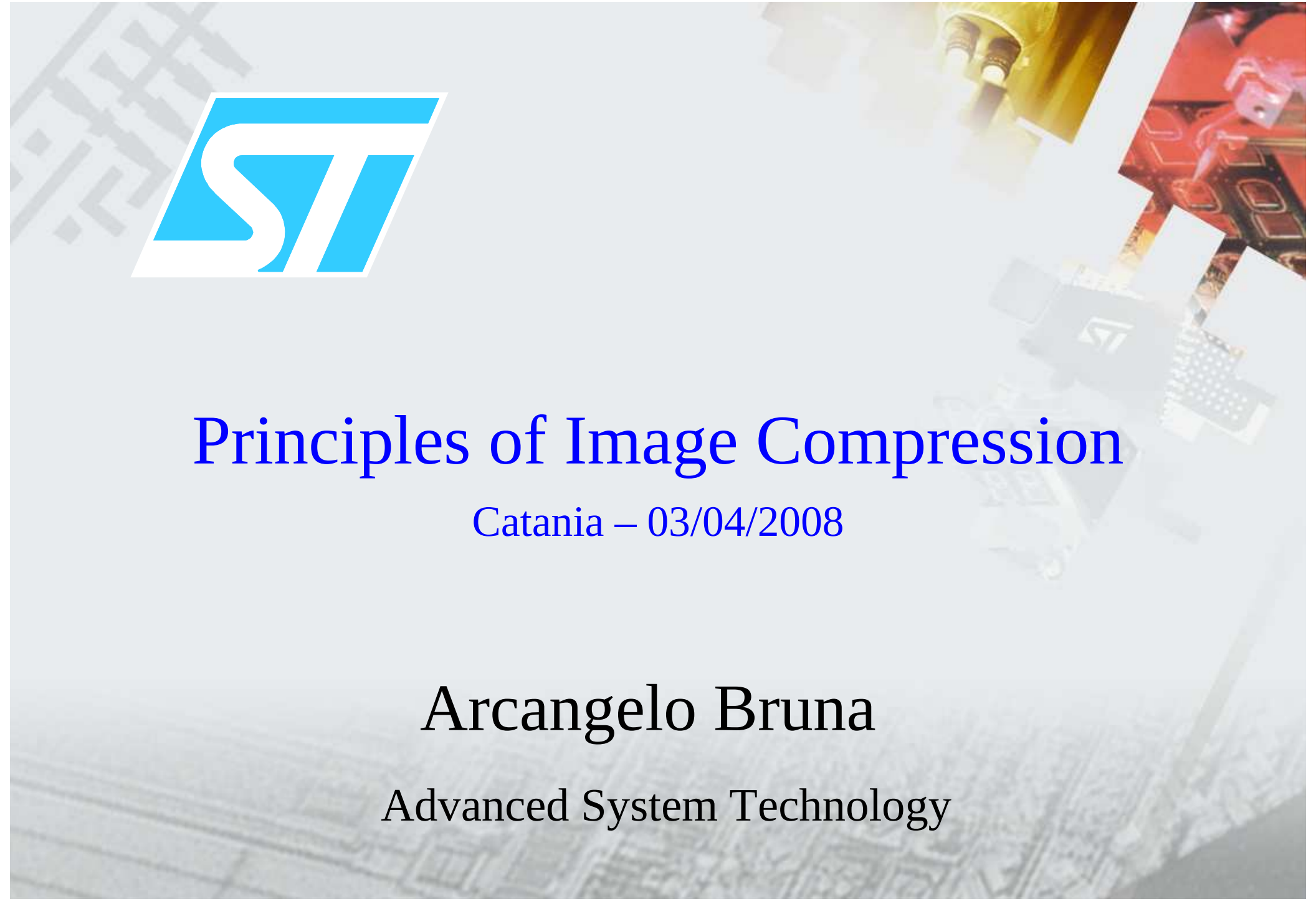


Principles of Image Compression

Catania – 03/04/2008

Arcangelo Bruna

Advanced System Technology

Overview

- Image Compression is the Image Data Elaboration branch dedicated to the image data representation

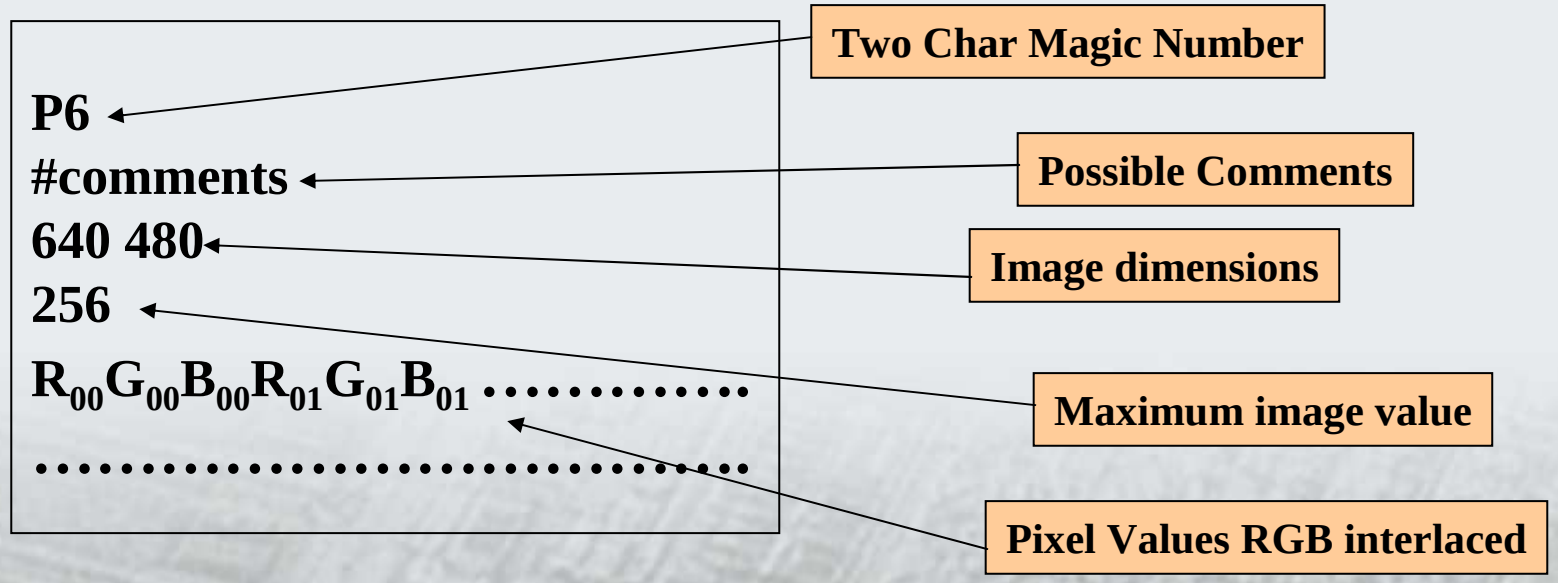
- It analyzes the techniques allowing to reduce the amount of data to describe the information content of the image

Why Image Compression (1)?

- Images are usually matrices.
- Colour images are composed by 3 matrices of values.
- In a 24 bit per pixel (bpp) representation each color (e.g. Red, Green, Blue) is represented with an unsigned byte in the range [0;255]
- The 3 Matrices can be filed separately or together.
- The bytes number to store an uncompressed image can be really huge!

Example: the PPM format

- **Acronym of Portable Pixel Map**
- **It is one of the simpler format of image representation**
- **The color data are inserted in RAW format.**
- **The 3 color matrices are filed together.**
- **It uses a header giving general information about the image.**



Memory requirements (still)

Sensor dim (pixel)	Size (uncompressed)
307200 (VGA)	900KB
1.3 Mpel	3.7MB
2.1 Mpel	6MB
5 Mpel	14.3MB
8 Mpel	22.8 MB

Memory requirements (video)

Sensor dim (pixel)	Size (bytes) (15 fps)
176x144 (QCIF)	1 MB/s
352x288 (CIF)	4.3 MB/s
640x480 (VGA)	13.2 MB/s
1280x720 (HDTV)	39.5 MB/s
1920x1080 (Full HDTV)	89 MB/s

Why Image Compression (2)?

- … storing in a physical device (perhaps no more a problem)
- … sending with GPRS (cost)
- … sending with MMS (upper bound limit)
- … shot to shot time latency (customer satisfactory)
- … video clip transmission (cost)
- … streaming - real time video conference (bandwidth, cost)
- …

How

- The image compression algorithms can be divided into two branches:
  - Lossless algorithms
    The information content is not modified
  - Lossy algorithms
    The information content is reduced and it is not recoverable

Entropy

Information Theory **(Shannon) was developed to provide a mathematical tool to better design data compression algorithms.**

The *entropy H* the source generating a data is in general impossible to measure in practice, due to the larger amount of interdependencies (of infinite order) and the non-stationarities.

Usually, a zero-order entropy measure is used to estimate the entropy of the source:

$$H_0 = -\sum p_i \log_2 (p_i) \qquad i \in S$$

It is impossible to compress data in a *lossless* way with a *bitrate* less than the *entropy* of the source that generated it.

Measure the quality

For *lossy* coding, the rate-distortion theory was developed. Its main goal is summarized the Rate-Distortion optimization criterion:

> **Find the lowest bitrate possible for a certain distortion, or the lowest distortion for a given bitrate.**

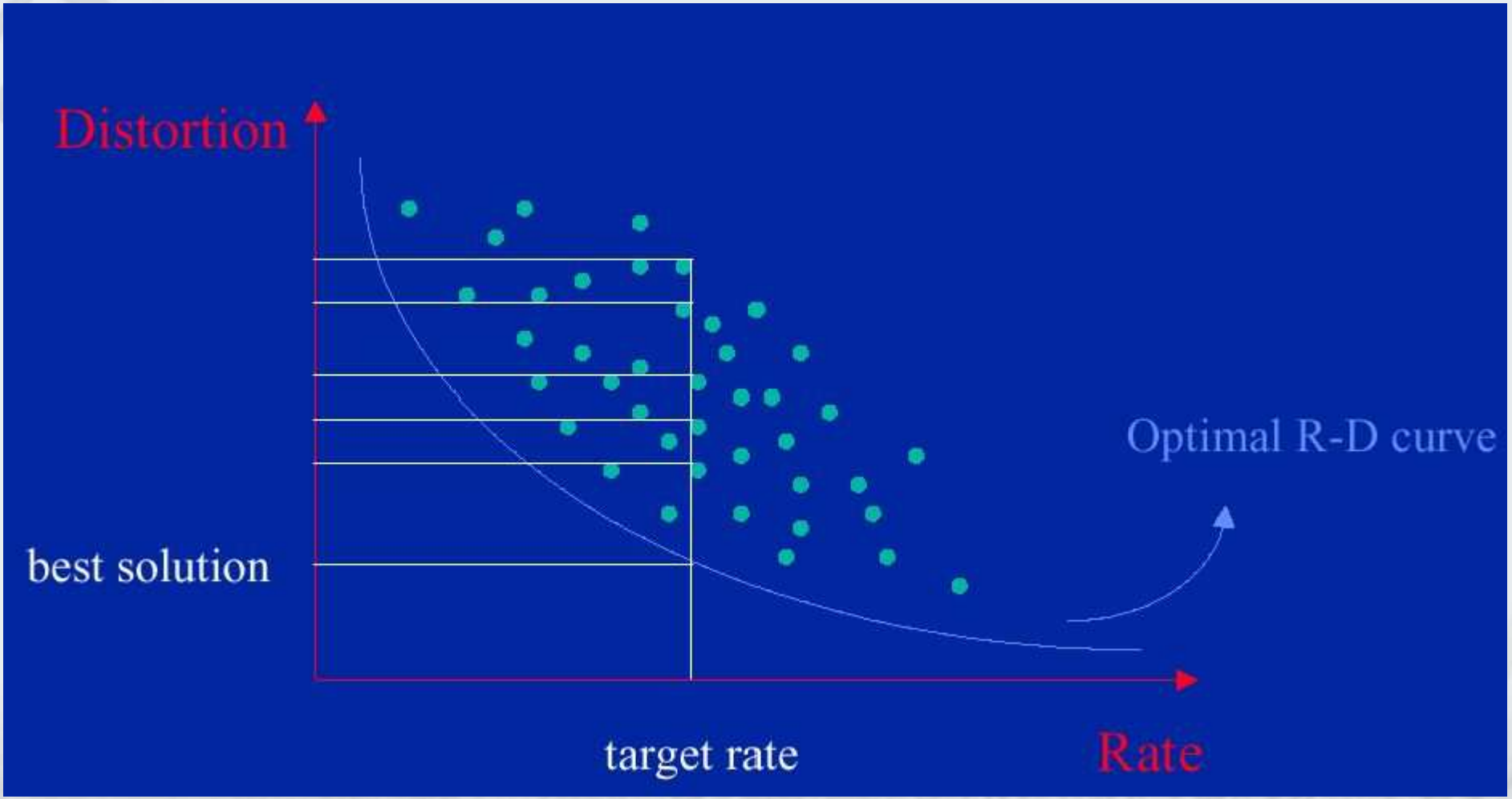
The most popular distortion measure is the mean square error (MSE):

$$MSE = 1/N \sum_i [x(i) - x^*(i)]^2 = 1 \qquad i=1,2,\ldots, N$$

The MSE (*Mean Squared Error*) does not always reflect the real distortion perceived by human visual system. For practical purposes the PSNR (Peak Signal to Noise Ratio) is used:

$$PSNR = 10 \log_{10} (255^2 / MSE)$$

Rate-Distortion curve

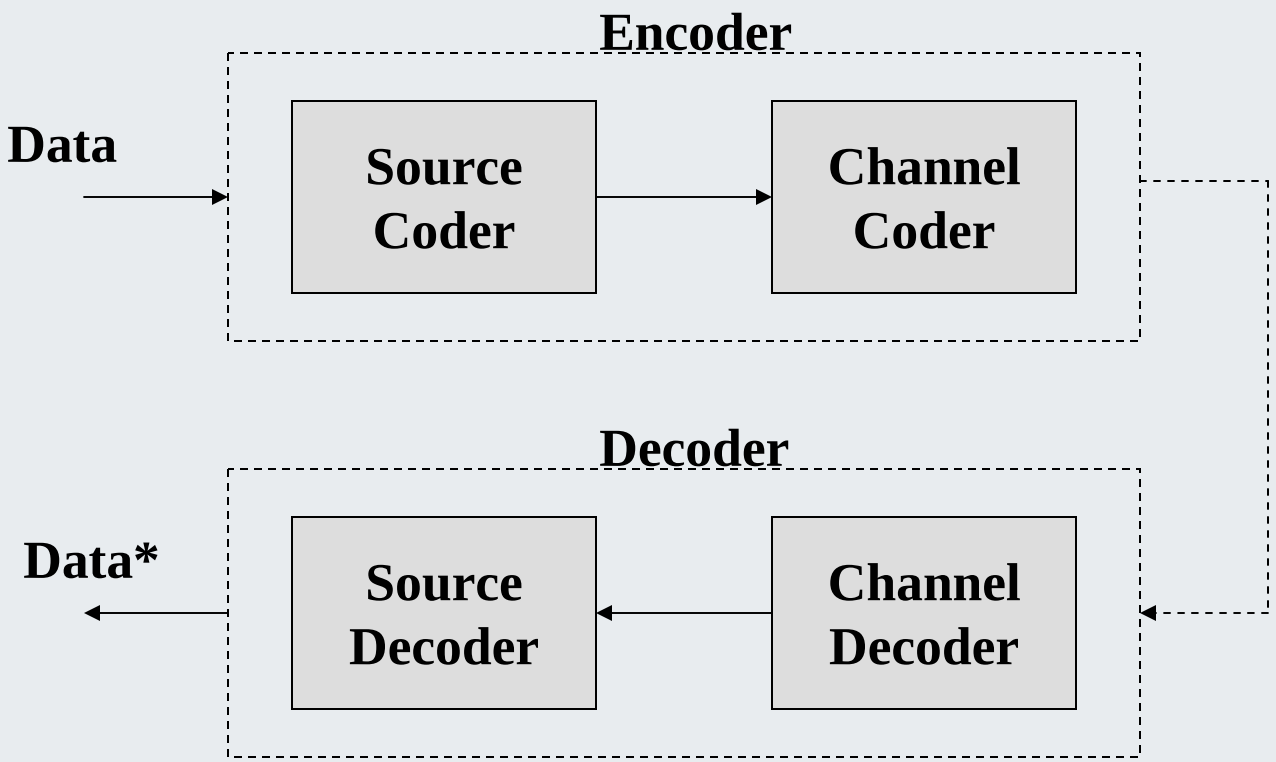


How to compare?

The performance of an image compression technique must be evaluated considering three different aspects:

- **Compression efficiency (Compression Ratio/Factor, bit per pixel *bpp* or bit rate);**
- **Image quality (Distortion Measure);**
- **Computational cost.**

Compression-Decompression process



Compression Methods

Lossy/Lossless data compression in Image Processing try to eliminate the spatial redundancies.

Example of coding techniques are the following:

- **Huffman coding;**
- **Arithmetic coding;**
- **Substitutional (Dictionary based) coding;**
- **Sample/based coding;**
- **Transform Domain coding;**

Huffman Coding

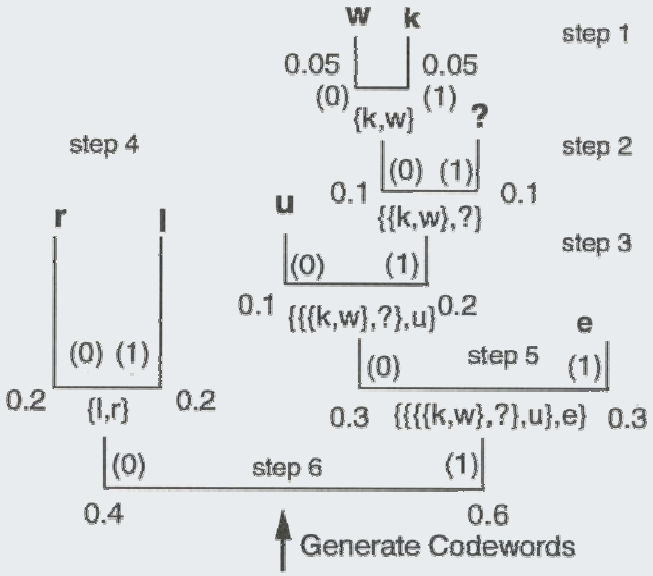
Probability model and symbol-to-codeword are combined
Input: sequence of symbols.

- **Order the symbols according to their probabilities.**
- **Apply a contraction to the two symbols with the smaller probabilities.**
- **Repeat the previous step until the final set has only one member.**

Construction of a binary tree:
The codeword for each symbol is obtained traversing the binary tree from its root to the leaf corresponding to the symbol.

Huffman Process

Symbol	Probability	Codeword
k	0.05	10101
l	0.2	01
u	0.1	100
w	0.05	10100
e	0.3	11
r	0.2	00
?	0.1	1011



	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
k 1/20	e 0.3	e 0.3	e 0.3	e 0.3	{l,r} 0.4	{{{{k,w},?},u},e} 0.6
l 0.2	l 0.2	l 0.2	l 0.2	{{{k,w},?},u} 0.3	e 0.3	{l,r} 0.4
u 0.1	r 0.2	r 0.2	r 0.2	l 0.2	{{{k,w},?},u} 0.3	
w 1/20	u 0.1	u 0.1	{{k,w},?} 0.2	r 0.2		
e 0.3	? 0.1	? 0.1	u 0.1			
r 0.2	k 1/20	{k,w} 0.1				
? 0.1	w 1/20					

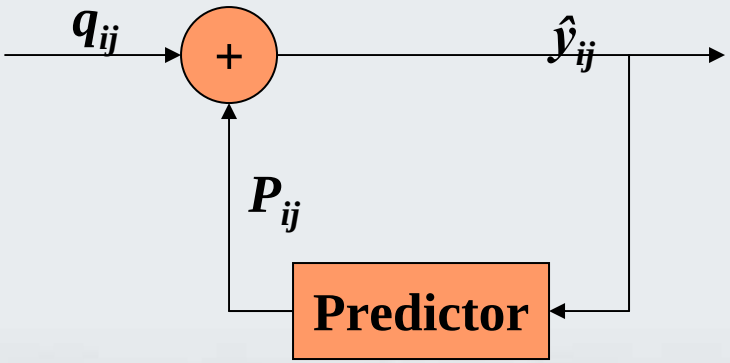
$$l_{avg} = \sum l_i p_i$$

$$H(S) \le l_{avg} \le H(S)+1$$

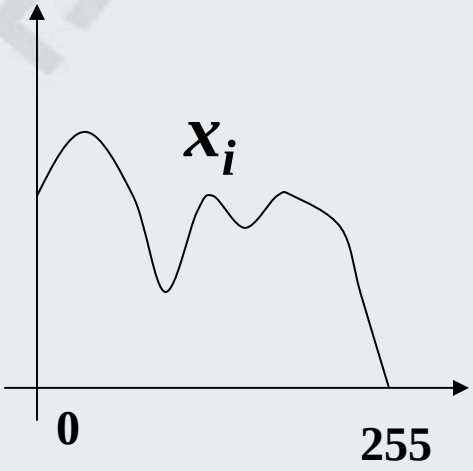
Predictive algorithms

These algorithms are based on a prediction of the values to be encoded.
A good prediction allows to:
- **Reduce the number of symbols**
- **Move the data range toward the zero value**

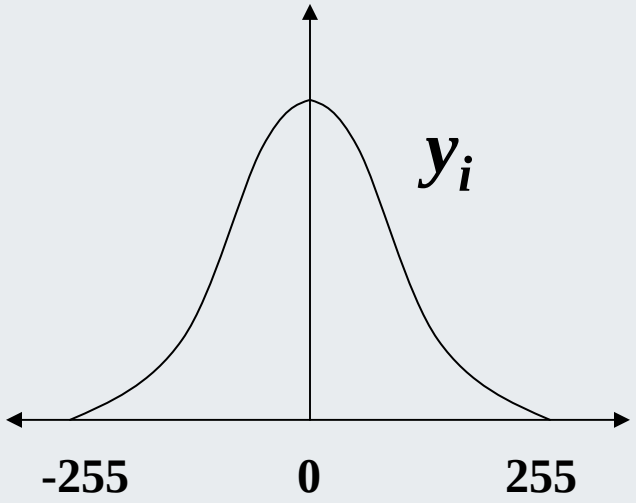
The prediction is usually based on the previous encoded values.



Differential Coding



$$y_i = (x_i - x_{i-1})$$



-Based on Interpixel correlation

-y_i are prediction residual

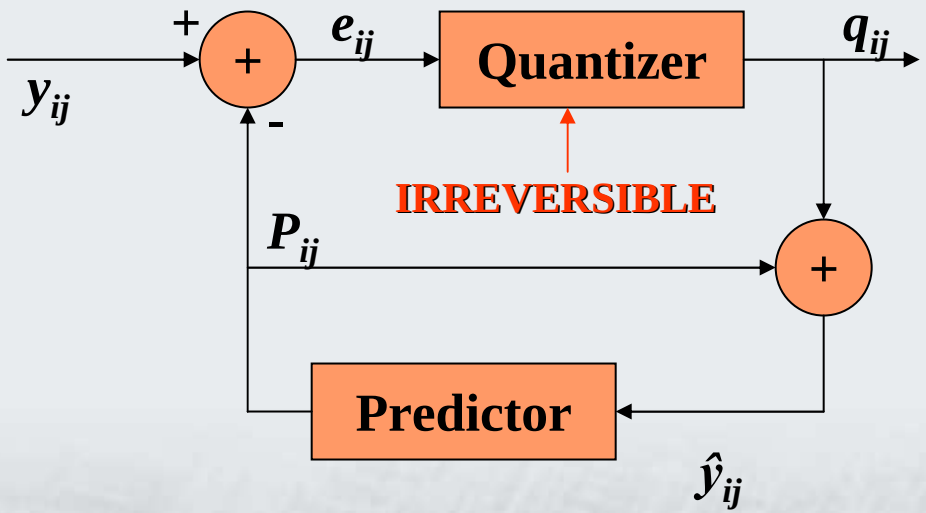
-Note: the differential coding is not able, alone, to compress the image, rather the data range is bigger!

Lossy compression

A quantization step reduces allows to:

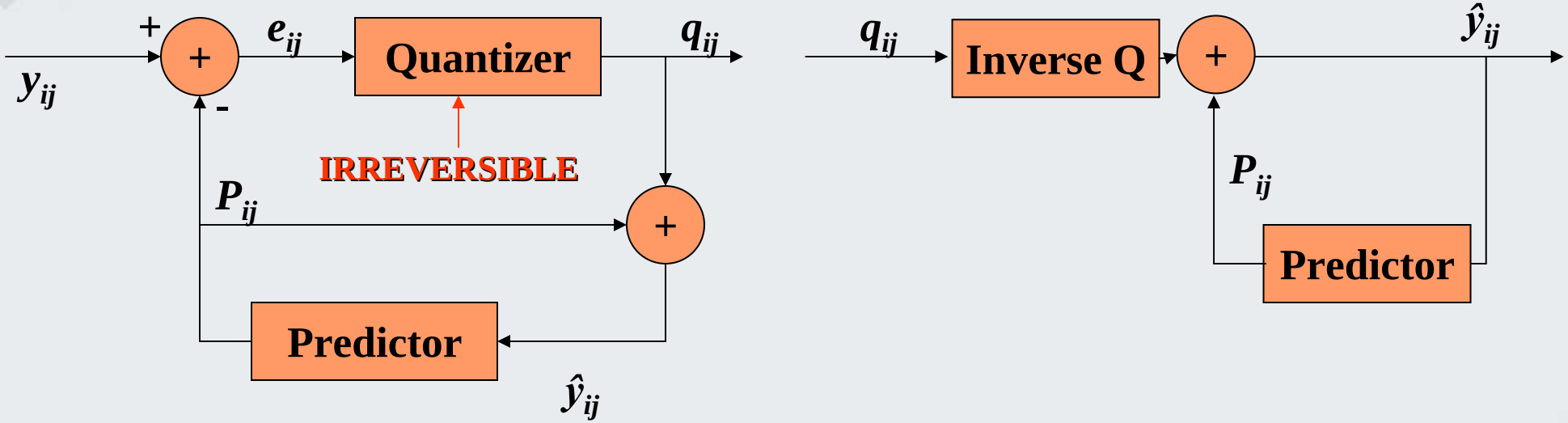
- **Reduce the non-zero elements;**
- **Reduce the allowed values**

A lossy algorithm is obtained



Lossy compression (SBC)

Sample-Based Coding (spatial or frequency domain).



$\hat{y}_{i-1\,j-1}$	$\hat{y}_{i-1\,j}$
$\hat{y}_{i\,j-1}$	$\hat{y}_{i\,j}$

$$P_{ij} = w1\,\hat{y}_{i-1\,j-1} + w2\,\hat{y}_{i-1\,j} + w3\,\hat{y}_{i\,j-1}$$

$$w1+w2+w3 = 1$$

Run-Length coding

(pixel, value)

(0,4) (255,11) (128,5)

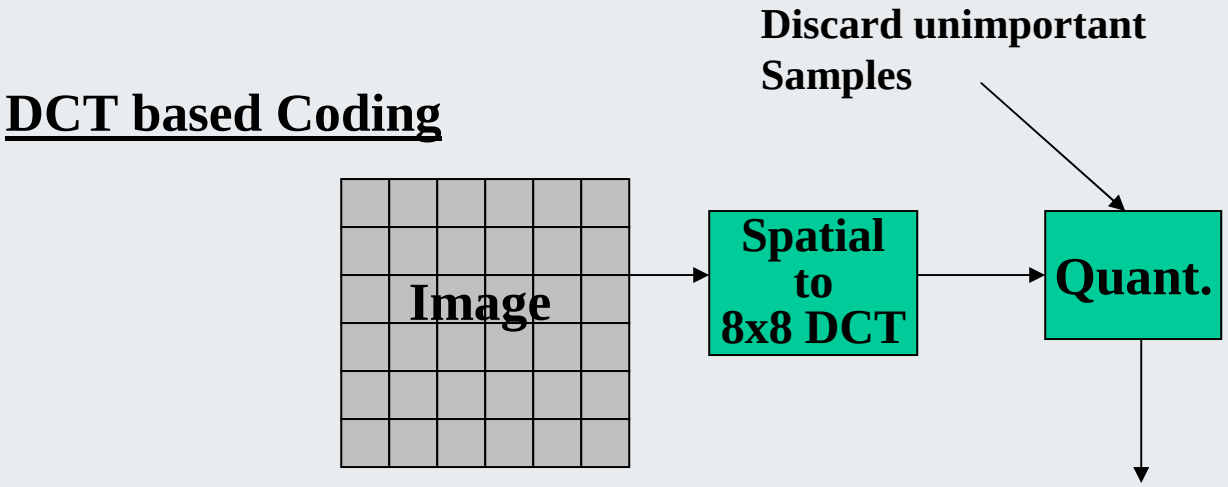
The combination of a run-length coding scheme followed by a Huffman coder forms the basis of image compression standards.

These compression standards yield good compression (20:1 to 50:1)

Lossy compression (BBC)

Block-based coding

Spatial and transform domain



Block size = 8x8

Orthogonal:

$$Y=T\ X\ T^t \rightarrow X= T^t\ Y\ T$$

Separable:

$$Z=T\ X^t \rightarrow Y = T\ Z^t = T\ X\ T^t$$

Standard algorithms in Digital Cameras

- Still
  - Uncompressed
    bmp, tiff, raw, ppm, ...
  - Compressed
    JPEG, JPEG 2000, GIF, ...

- Video
  - Uncompressed
    avi, raw, ...
  - Compressed
    MPEG (1, 2, 4), H263, ...

Why standardization is important?

Standardization allows to obtain

a multi-environment file.

All the standard compliant decoder will handle correctly such images.

Market's requirements for still compression standard

- Application's dependent
  - Digital Still Cameras (High / mid / low bit rate)
  - Mobile multimedia (Low / very low bit rate)

- Features requirements
  - Simple editing
  - Spatial scalability
  - Quality scalability

- JPEG – JPEG2000

Market's requirements for video compression standard

- Application's dependent
  - Video Cameras (High / mid / low bit rate)
  - Mobile multimedia (Low / very low bit rate)

- Features requirements
  - Simple editing
  - Spatial scalability
  - Quality scalability

- MPEG 2 (Video Cameras), MPEG4/H263/H264 (Mobile)