JPEG 2000
Descrizione ed applicazioni

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Advanced System Technology

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 (Mobile), H264

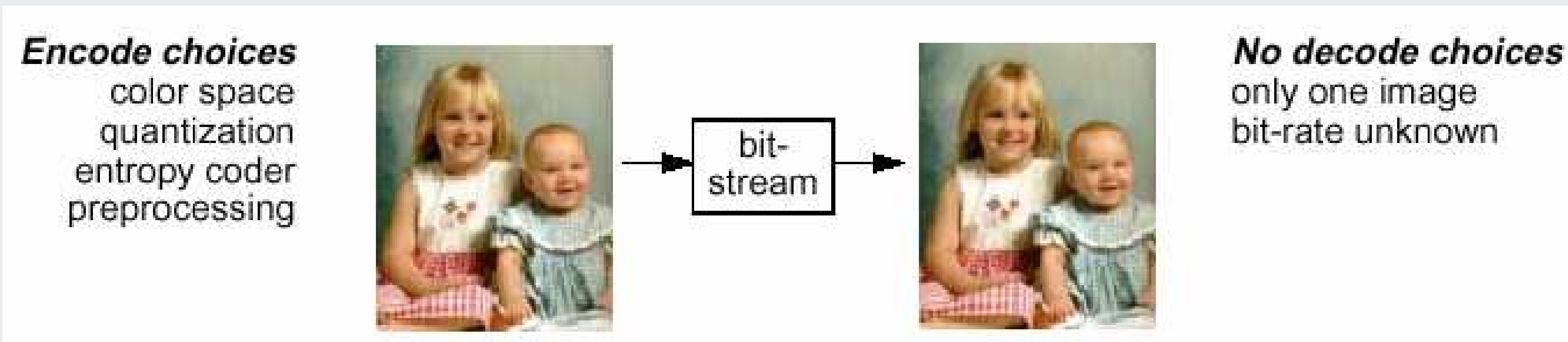
Current image compression standards

Compression method	Input image type	Compression ratio	Controllability
JBIG	Binary	½ - 10:1	Lossless
JPEG	8, 12 bit gray/color	5-25:1	Iterate on Q-tables
JPEG-LS	4-12 bit	2-10:1	Lossless/near lossless
JPEG2000	ANY	Lossless-200:1	A lots of methods

Current video compression standards

Video Compression	Market	Video Bitrate	Frame-accurate editing	Scalabilit y	Still Image Mode	Lossless Mode
MPEG-1	Video CD authoring	1.0-1.5 Mbits/s @ 352x240x29.97 fps	No	Low	No	No
MPEG-2	DVD authoring	3.0-100.0 Mbits/s @ 720x480x29.97 fps	No	Low	No	No
MPEG-4	Internet Streaming	0.3-1.0 Mbits/s @ 352x240x29.97 fps	No	High	Yes	No
MJPEG	Video Production	10.0-80.0 Mbits/s @ 720x480x29.97 fps	Yes	Low	Yes	No
DV	Professional Video Production Digital Video Cameras	25.0 Mbits/s @ 720x480x29.97 fps	Yes	Low	No	No
MJPEG2000	Professional Video Production Digital Video Cameras Video/image streaming	2.0-50.0 Mbits/s @ 720x480x29.97 fps	Yes	High	Yes	Yes

Conventional compression method (JPEG)



JPEG Pros and Cons

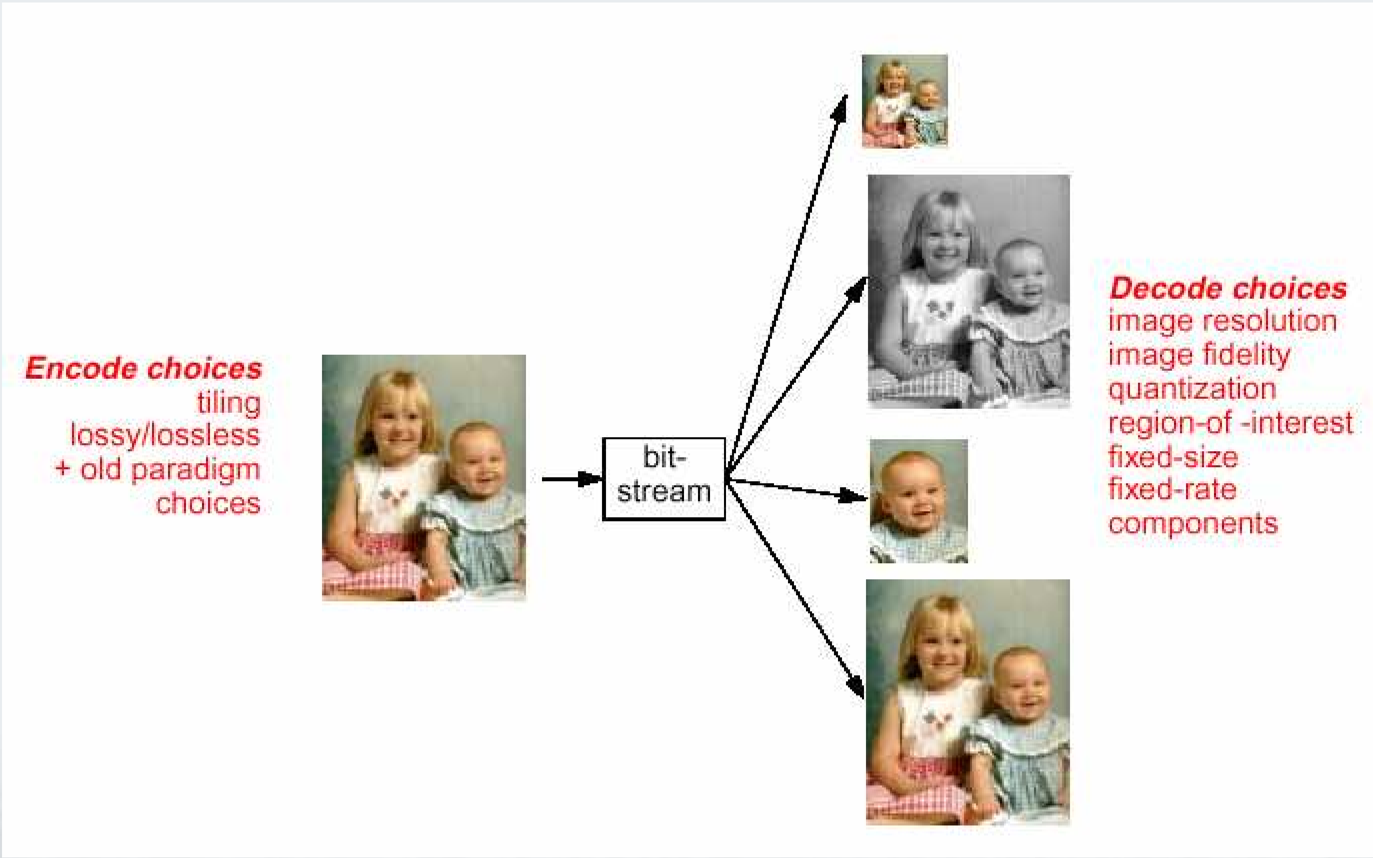
Advantages

- Memory efficient
- Low complexity
- Compression efficiency

Disavantages

- Single resolution
- Single quality
- Difficult to control the target bit rate
- No tiling
- No region of interest
- Blocking artifacts
- Poor error resilience

JPEG 2000 flexibility



Where to use JPEG 2000?

Medical imagery	Satellite imagery
Scanners	Printers
Network imagery (WWW)	Pre-press imagery
Image archival (CD-ROM)	Interframe video
Page description languages	Multi-function copiers
Digital cameras	Facsimile
Compound documents	Set Top Box
Graphic images	etc.

briefly...

everywhere!!!

JPEG 2000

The standard description

Who is it?

JPEG2000 *was standardized by ISO/IEC*:

- **Part 1:** the core, is now published as an **International Standard ISO/IEC 15444**

- **Parts 2-6:** Extensions *(adds more features and sophistication to the core)*, Motion JPEG 2000,Conformance,Reference software *(Java and C implementations)*, Compound image file format *(document imaging, for pre-press and fax-like applications, etc.)*

  complete / nearly complete

- **Part 7:** should have contained a Technical Report (TR) outlining guidelines for minimum support of Part 1 of the Standard

  abandoned

- **Parts 8-13:** JPSEC *(security aspects)*, JPIP *(interactive protocols and API)*, JP3D *(volumetric imaging)*, JPWL *(wireless applications)*, ISO Base Media File Format *(common with MPEG-4)*

  Under development

Overview

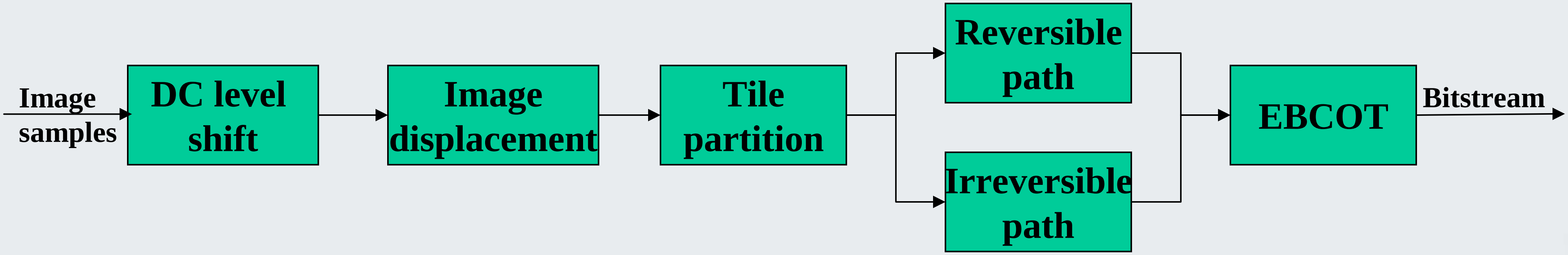
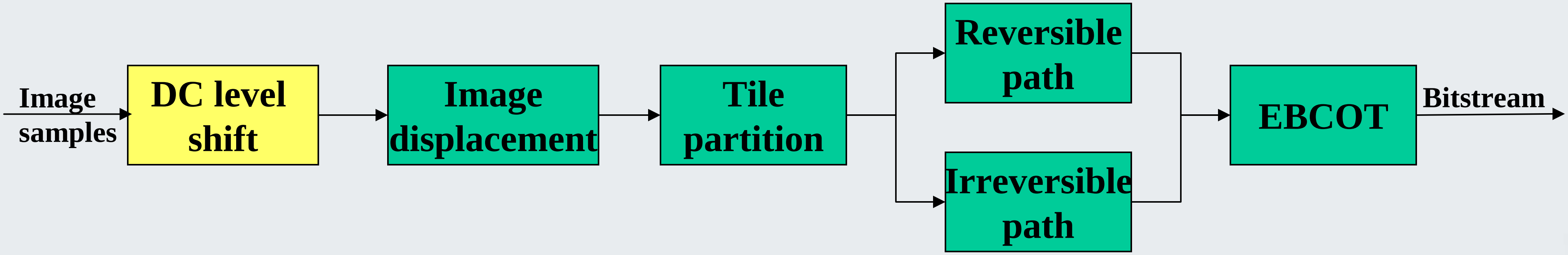


Image samples
DC level shift
Image displacement
Tile partition
Reversible path
Irreversible path
EBCOT
Bitstream

Overview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DC level shift

- The input image data can be level shifted (optional), in order to obtain the following data range:

$$-2^{B-1} \leq x[n] < 2^{B-1}$$

where B is the image bit depth

- It is useful to obtain a zero chain in the High Pass filters in the wavelet domain

Overview

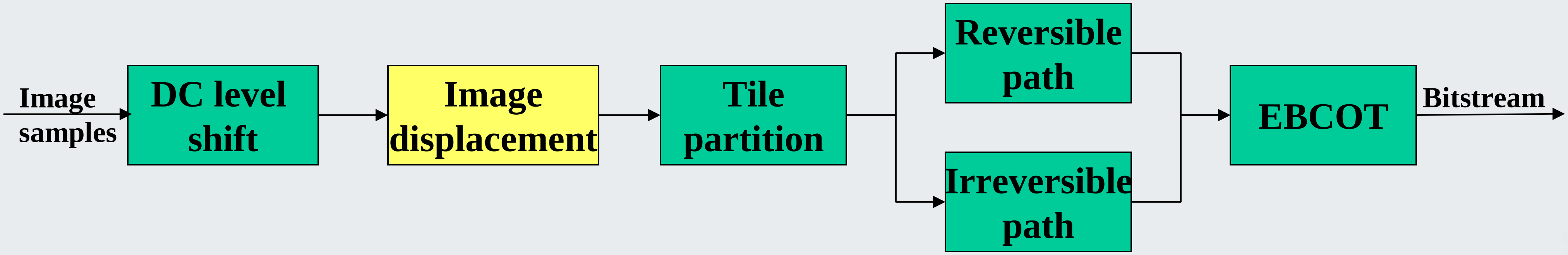

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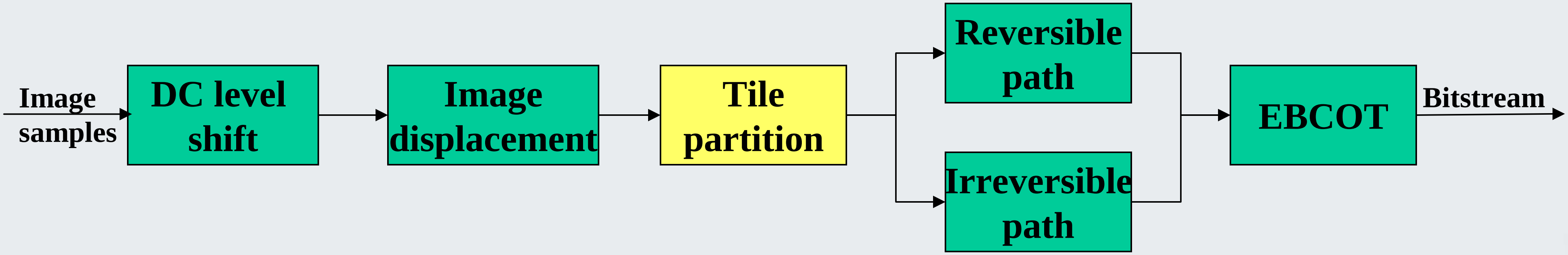
Image displacement

- The input image is mapped into a ***high resolution grid***
- All the color component are to be mapped into the Reference Grid
- It is useful, i.e., when the ROI tool is used (described later)

Overview



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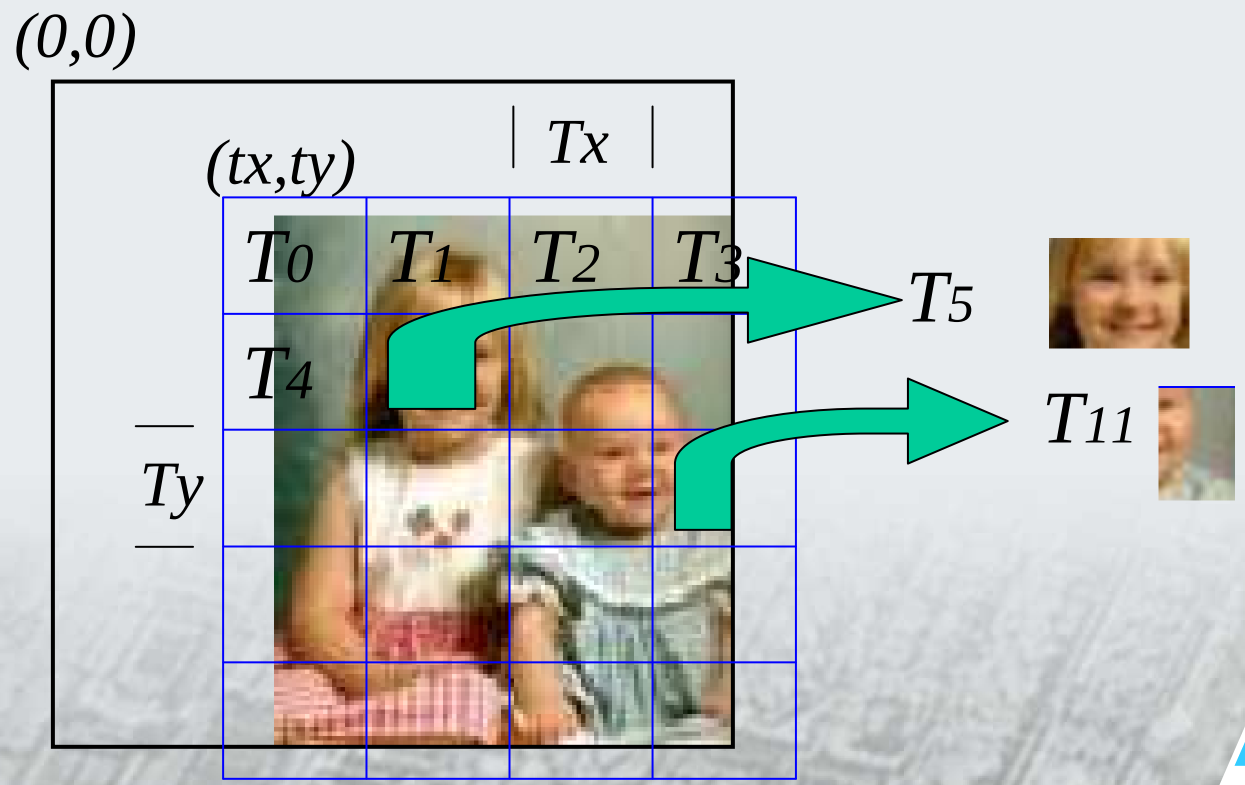
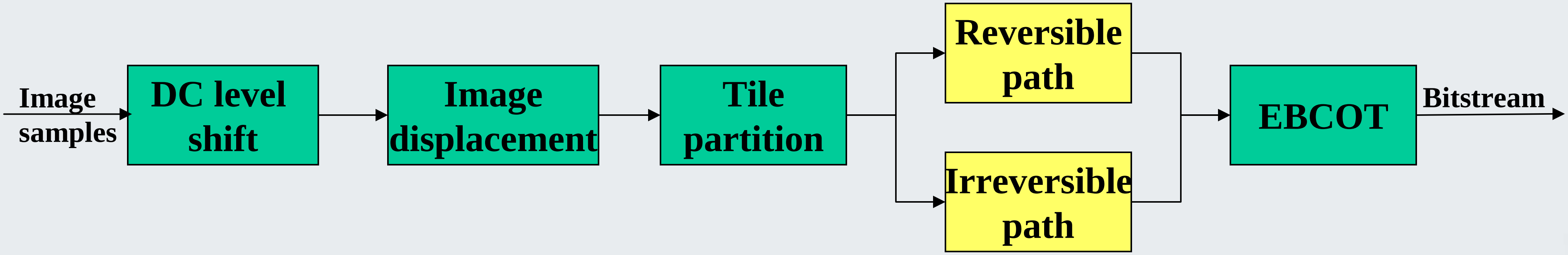
Tile partition

- The reference grid is partitioned into *TILES*
- Only the *tiles* comprising image's pixels are to be considered
- Each *tile* will be treated separately for further algorithms



Overview



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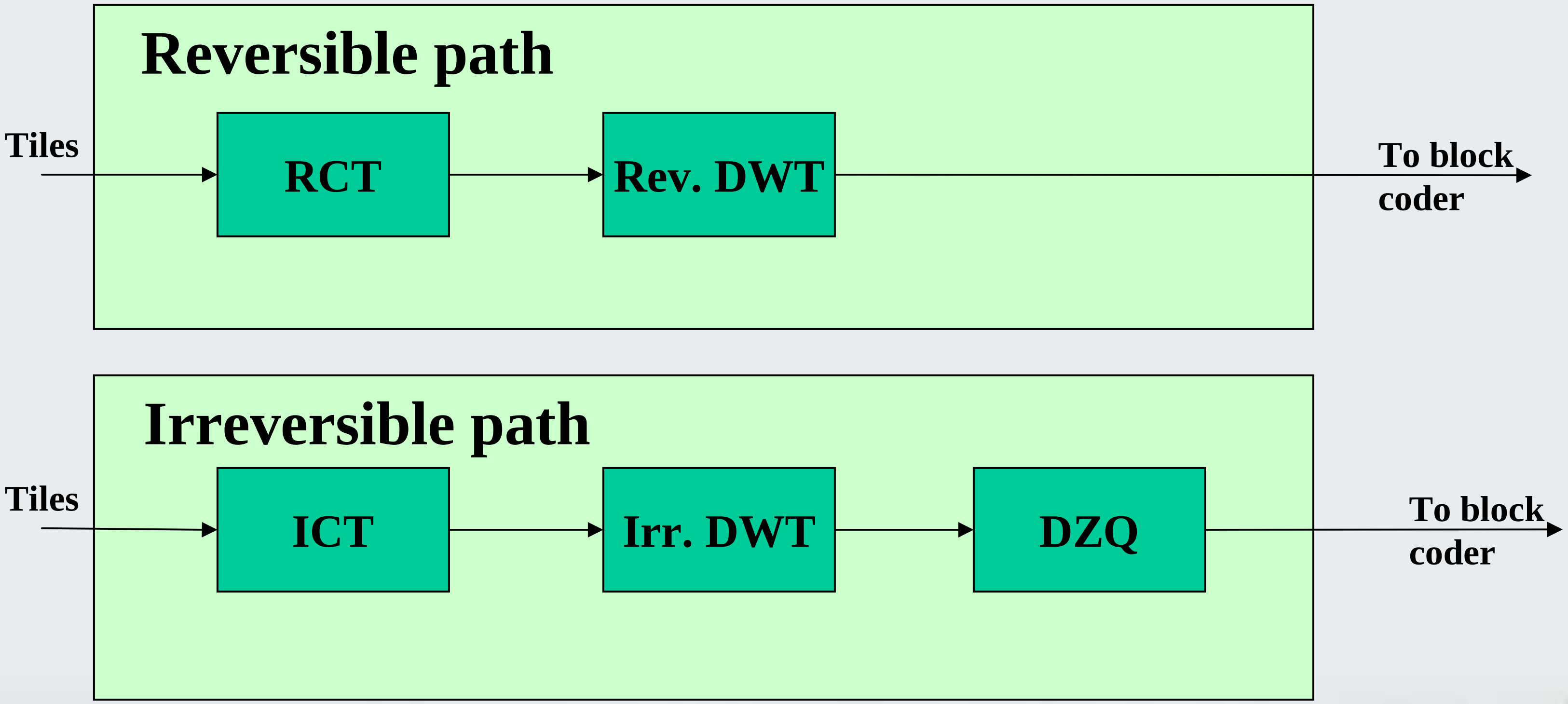
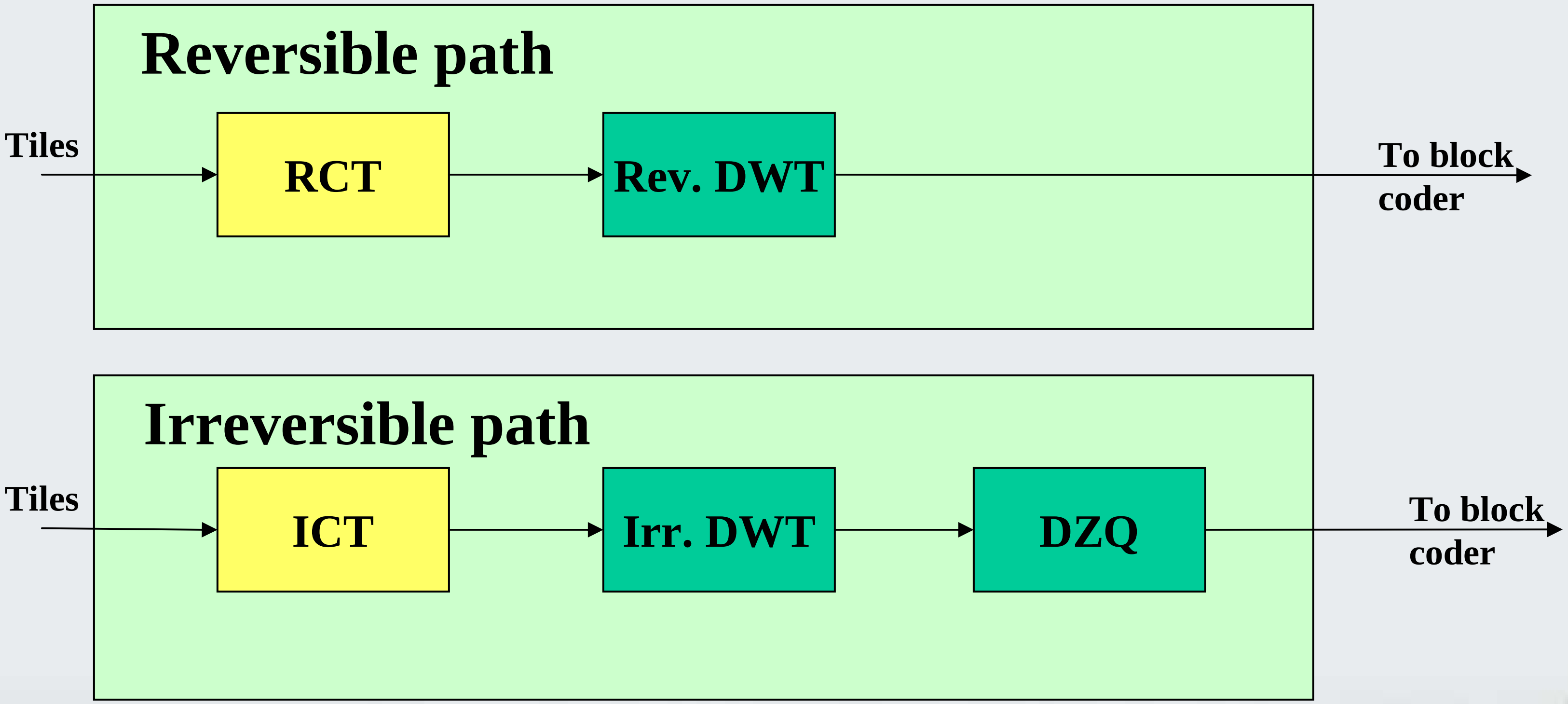
Reversible and Irreversible paths



Reversible and Irreversible paths



Component transform

- The color components are decorrelated
- The *YCrCb* color representation is used
- Two versions:
  - Reversible Color Transform (RCT)
    To be used for the lossless branch (integer)
  - Irreversible Color Transform (ICT)
    To be used for the lossy branch (floating point)
- More versions are available in the Part II

Reversible Color Trasform

- It is an integer-to-integer color transform
- Used for lossless coding

Forward RCT

$$Y = \left\lfloor \frac{1}{4}\left(R + 2G + B\right) \right\rfloor$$

$$C_b = B - G$$

$$C_r = R - G$$

Inverse RCT

$$G = Y - \left\lfloor \frac{1}{4}\left(C_r + C_b\right) \right\rfloor$$

$$R = C_r + G$$

$$B = C_b + G$$

Irreversible Color Trasform

- It is an integer-to-floating point color transform
- Used for lossy coding

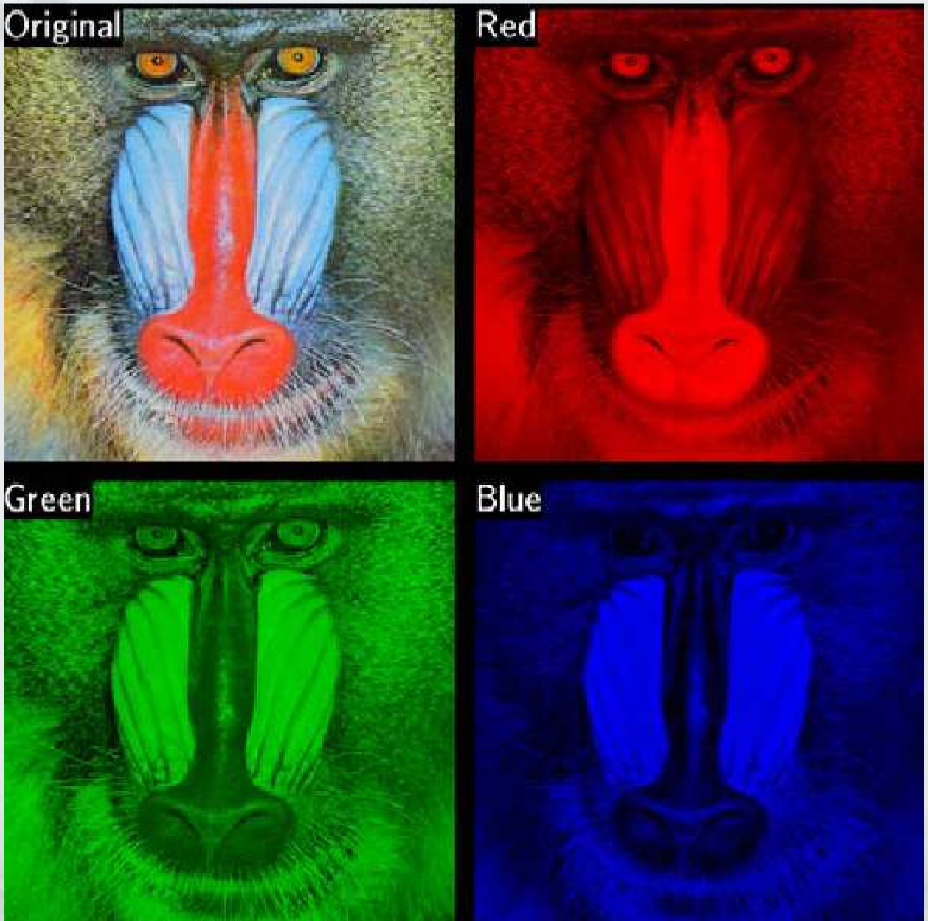
Forward ICT

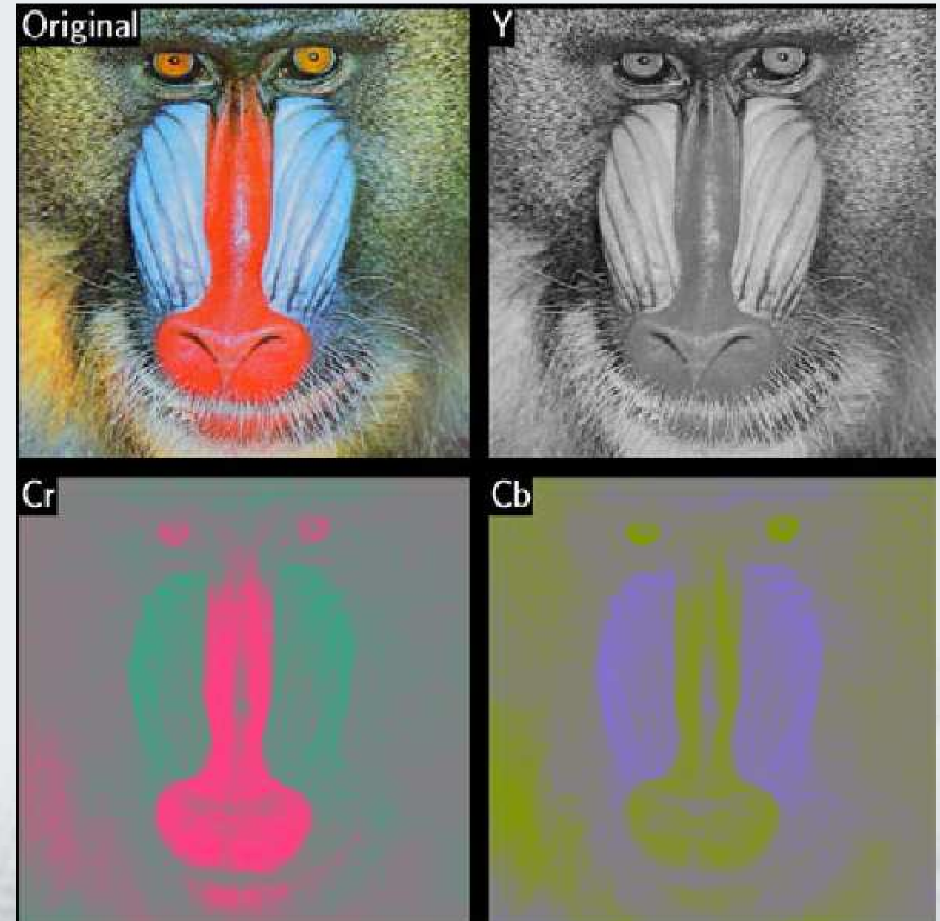
$$\begin{bmatrix} Y \\ C_r \\ C_b \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.5 \\ 0.5 & -0.419 & -0.081 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Inverse ICT

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.4021 \\ 1 & -0.3441 & -0.7142 \\ 1 & 1.7717 & 0 \end{bmatrix} \begin{bmatrix} Y \\ C_r \\ C_b \end{bmatrix}$$

RGB vs YCC





Subsampling

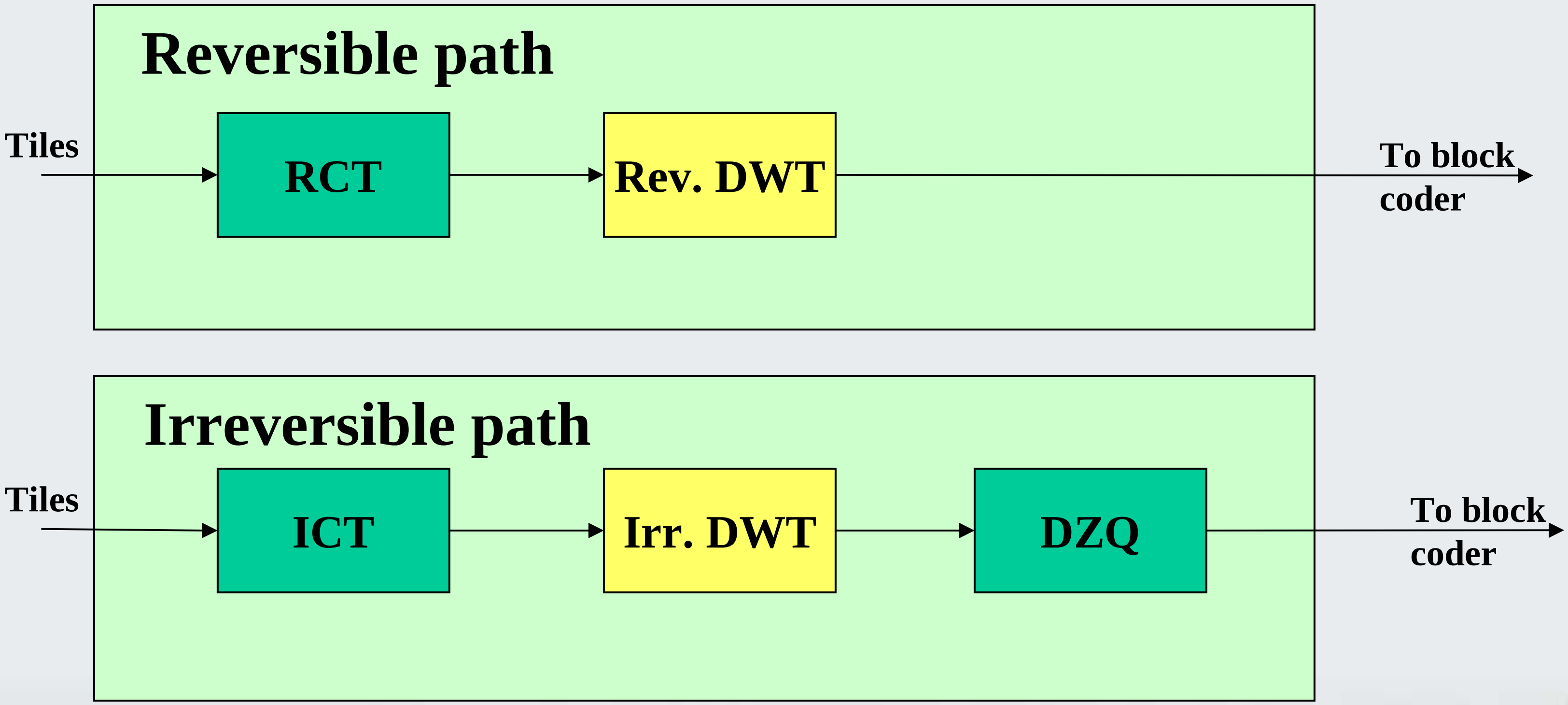
- Subsampling is allowed in all the components (Y,Cr,Cb)
- Only the chroma subsampling is usually used!!!

Original

Luma Subsampled 8x

Chroma Subsampled 8x

Reversible and Irreversible paths

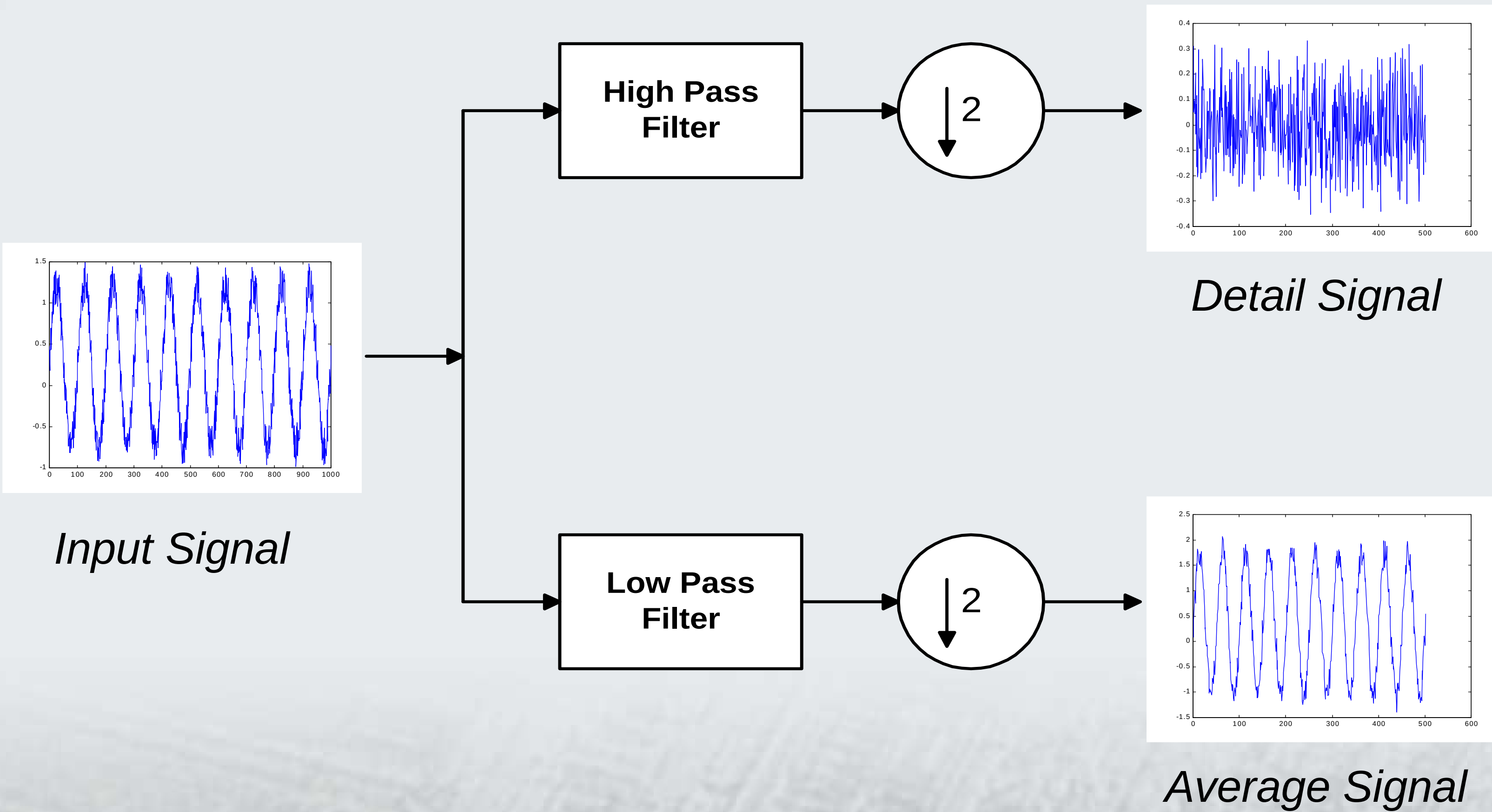


Discrete Wavelet Transform (DWT)

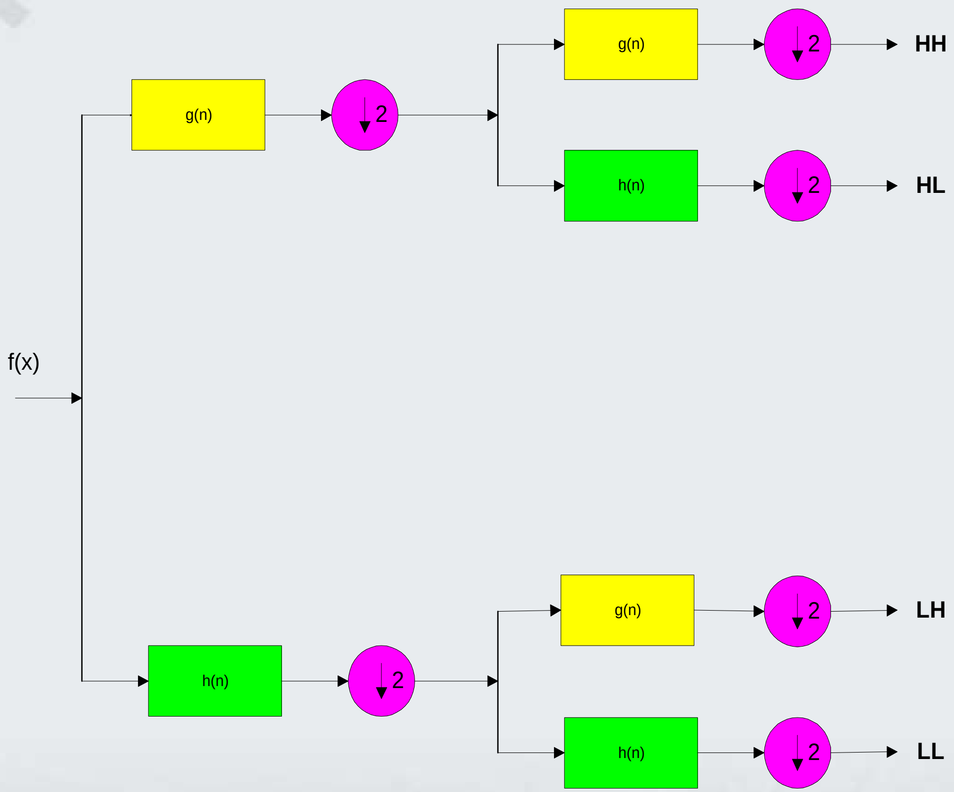
- Two versions
  - Reversible wavelet (integer 5/3)
  - Irreversible wavelet (Daubechies 9/7)

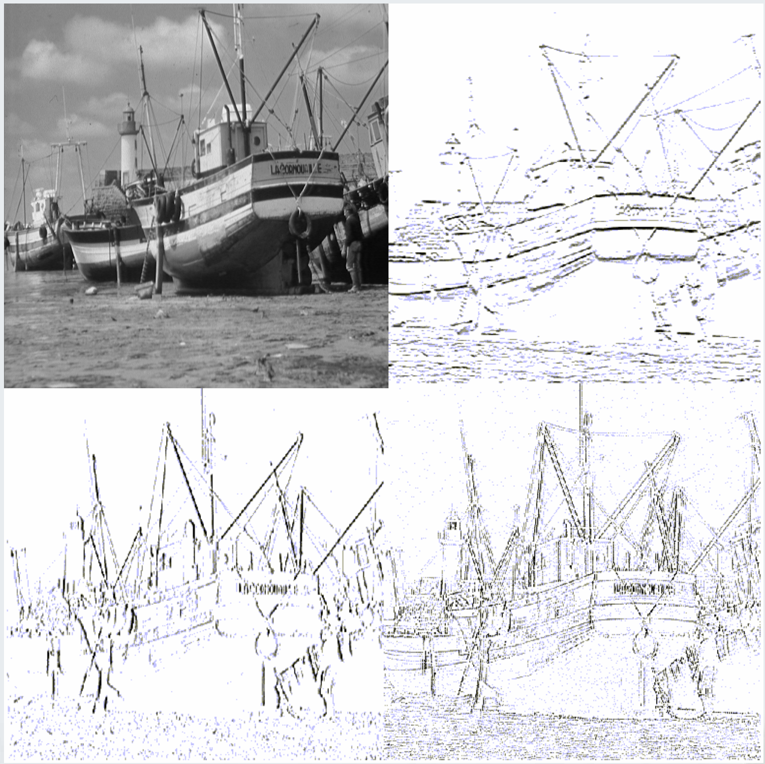
- Mallat schema is used

1-D Discrete Wavelet Transform



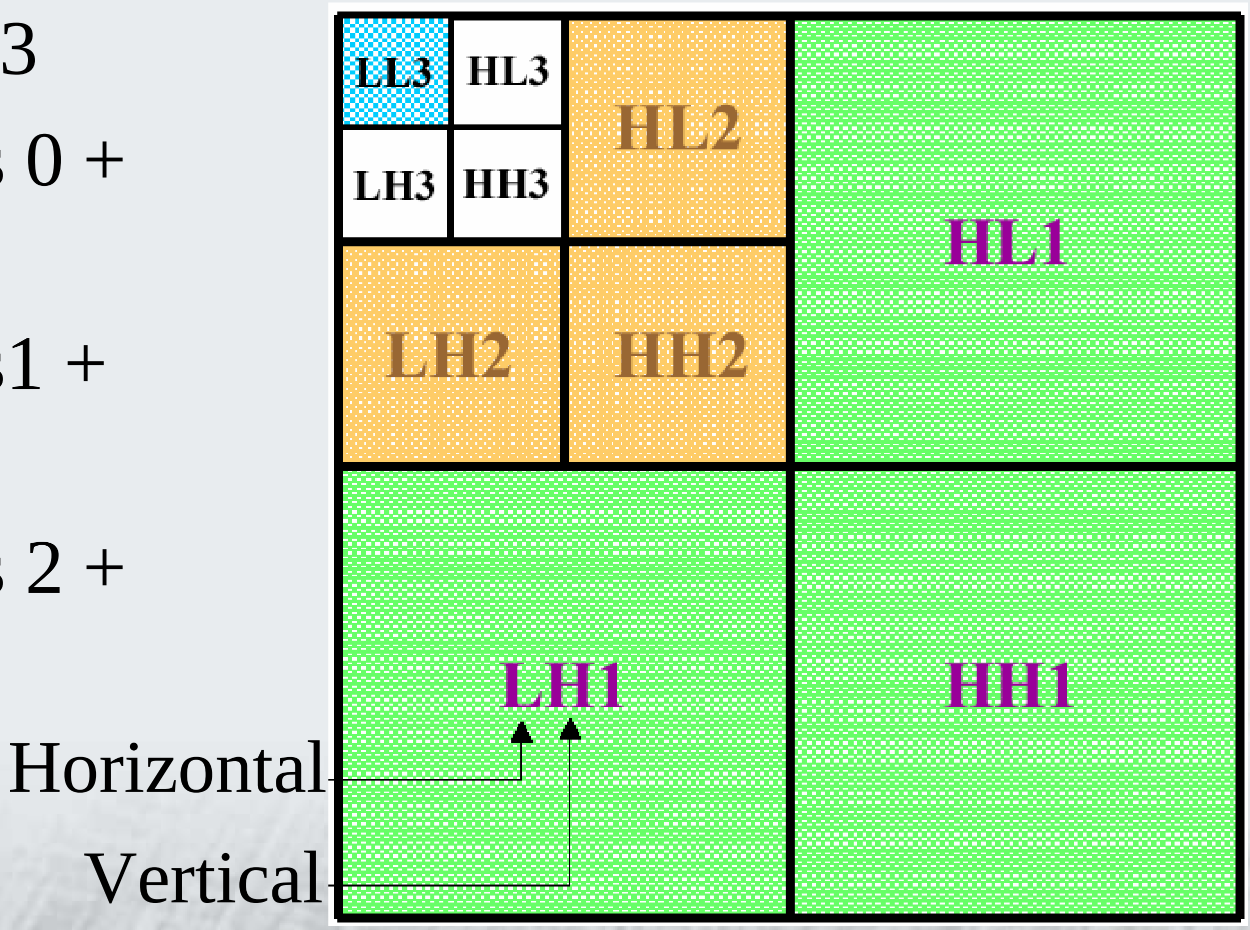
2-D Discrete Wavelet Transform



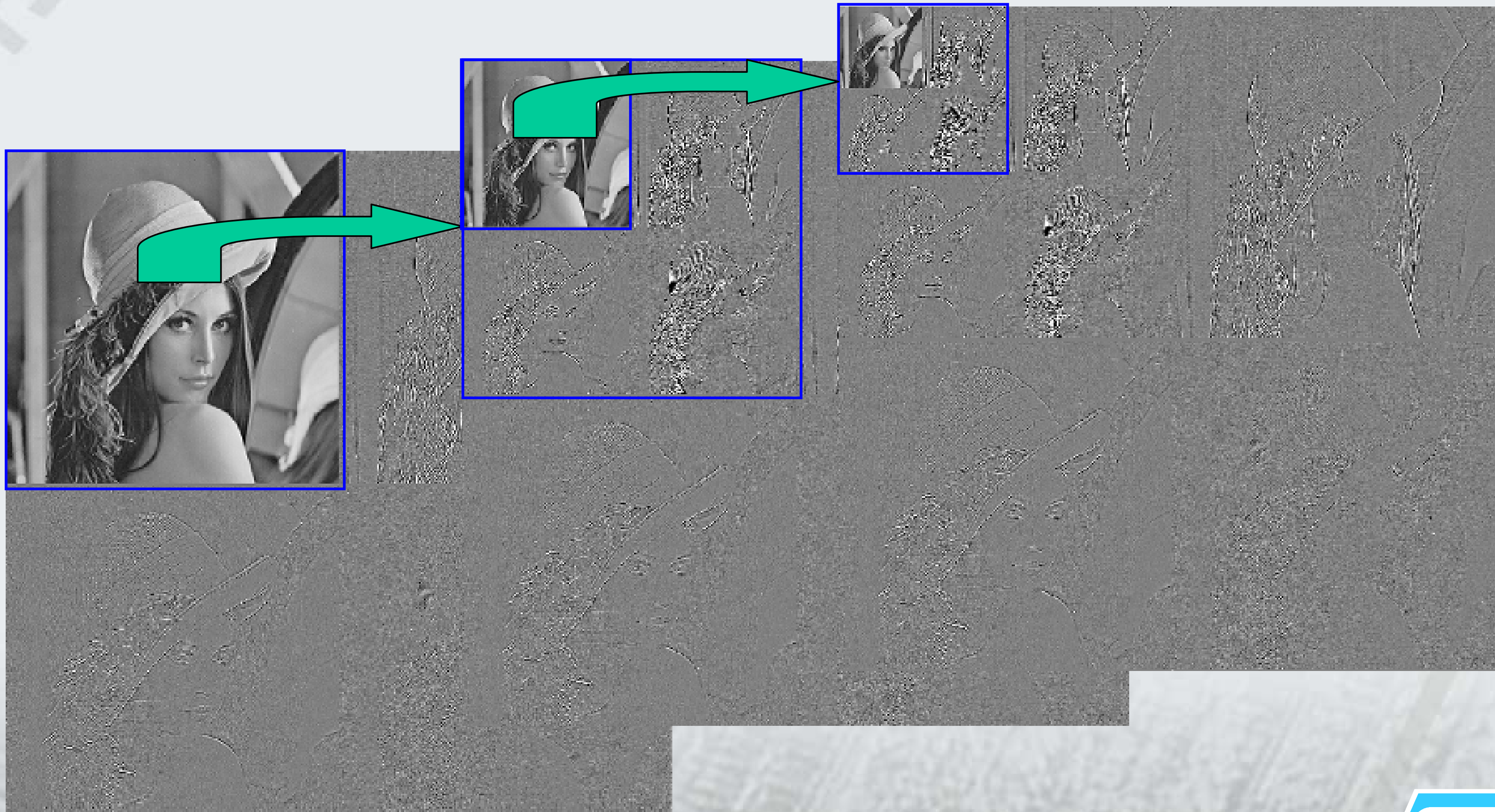


2-D Mallat schema

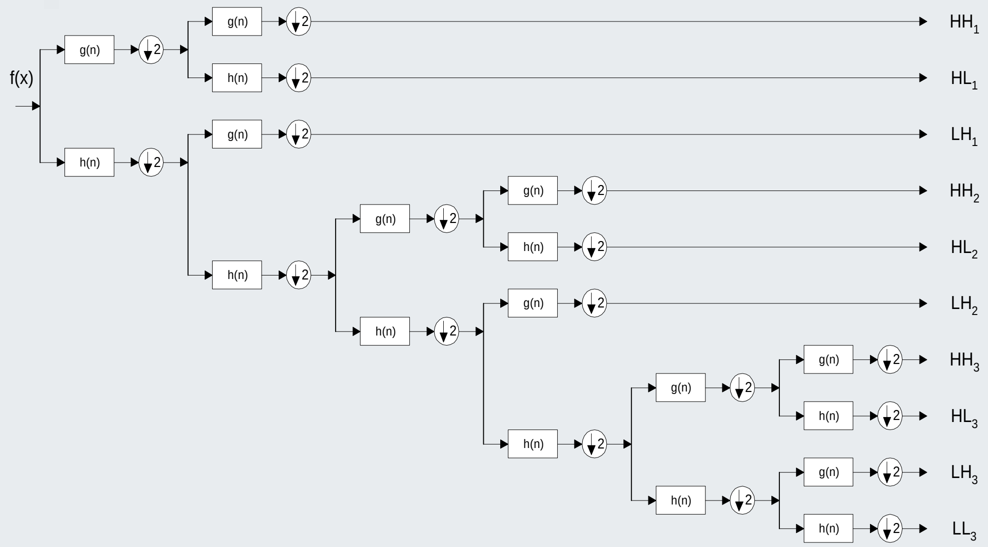
- Resolution 0: LL3
- Res 1 (LL2): Res 0 + LH3+HL3+HH3
- Res 2 (LL1): Res1 + LH2+HL2+HH2
- Res 3 (LL0): Res 2 + LH1+HL1+HH1

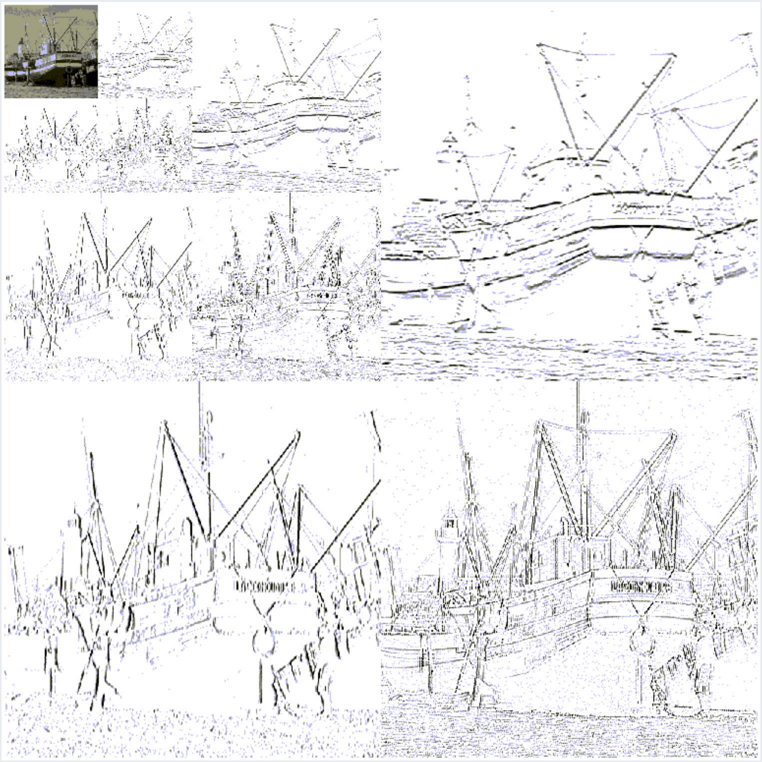


DWT example



Multilevel Wavelet Decomposition



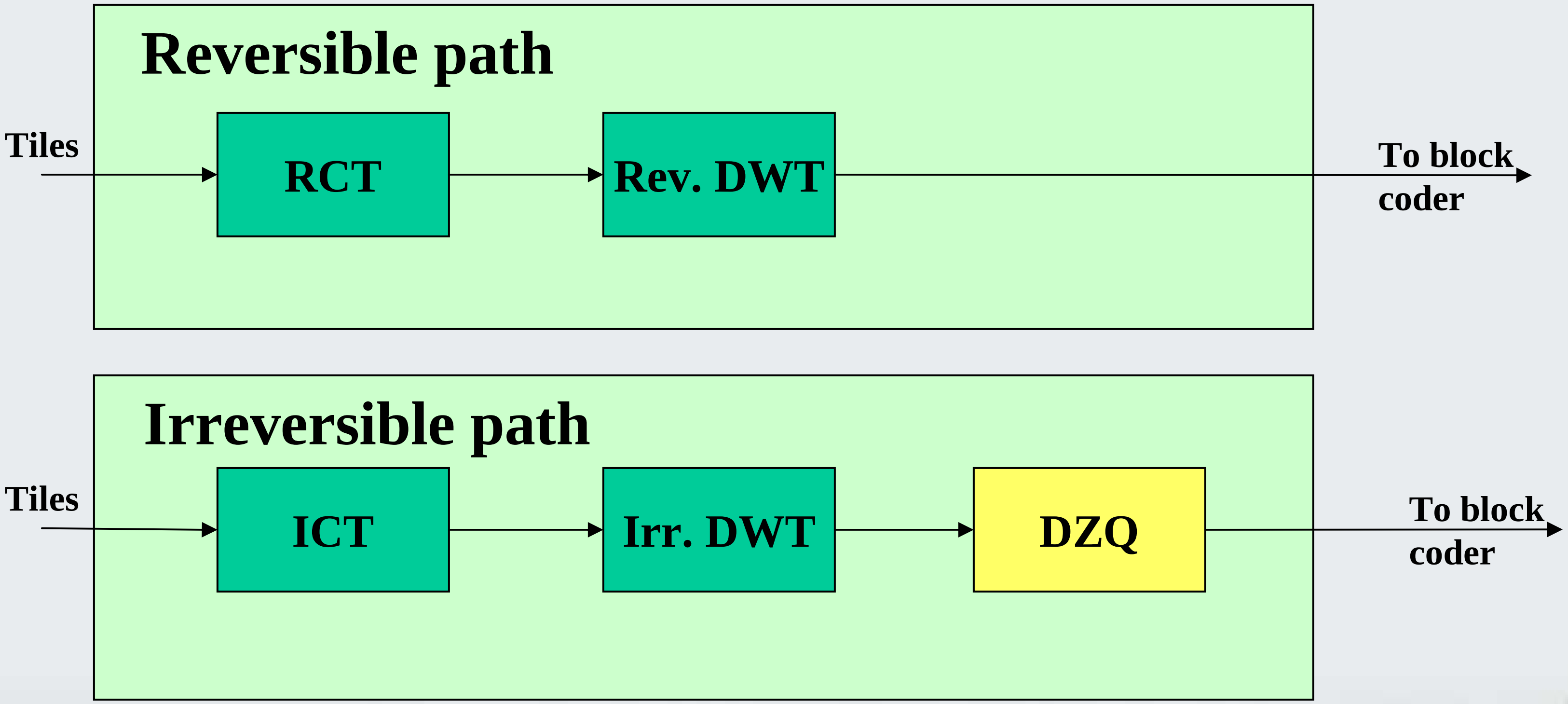


Two dimensional – three levels wavelet decomposition

DWT 9/7convolution coeff

Taps	Analysis Filter Bank		Synthesis Filter Bank	
	Low pass $H_0(z)$	High pass $H_1(z)$	Low pass $F_0(z)$	High pass $F_1(z)$
0	**0.6029490183263579**	**1.115087052456994**	**1.115087052456994**	**0.6029490183263579**
±1	**0.2668641184428723**	**-0.591271763114247**	**0.591271763114247**	**-0.2668641184428723**
±2	**-0.0782232665289878**	**-0.057543526228499**	**-0.057543526228499**	**-0.0782232665289878**
±3	**-0.0168664118442874**	**0.091271763114249**	**-0.091271763114249**	**0.0168664118442874**
±4	**0.0267487574108097**	**-**	**-**	**0.0267487574108097**

Reversible and Irreversible paths



Dead Zone Quantization (DZQ)

- Scalar quantization with deadzone

$$q_i[n] = sign(x_i[n]) \cdot \left\lfloor \frac{x_i[n]}{\Delta_b} \right\rfloor$$

where Δ_b is the quantization factor

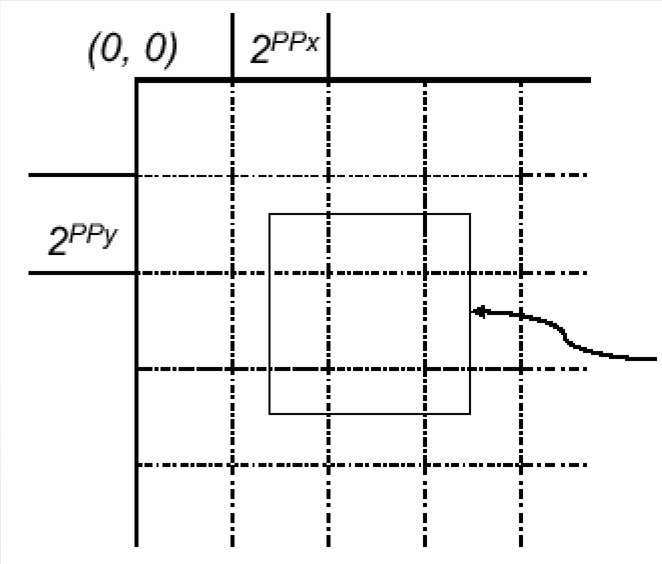
- Different stepsize for each subband
nLL, nLH, nHL, nHH, (n-1)LH, (n-1)HL, (n-1)HH, … 1LH, 1HL, 1HH

- Trellis method is allowed in part II

Precints

- Each tile is partitioned into *Precints*

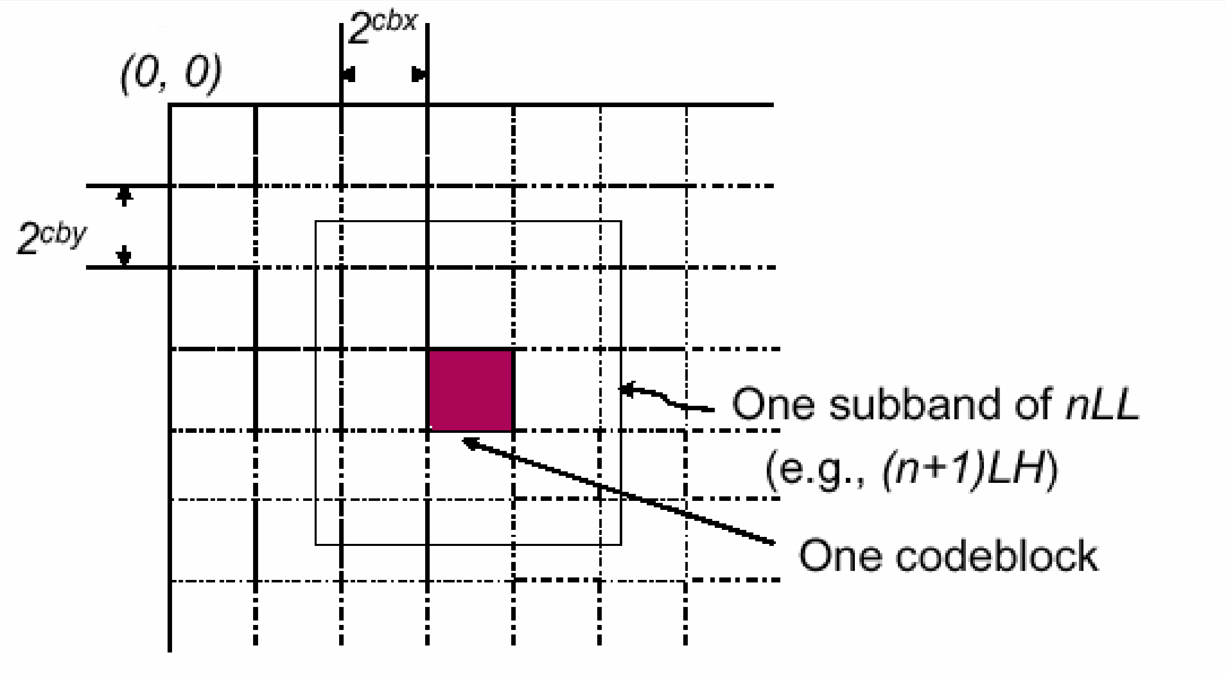
- The partitioning is similar to the *Tiles* partitioning



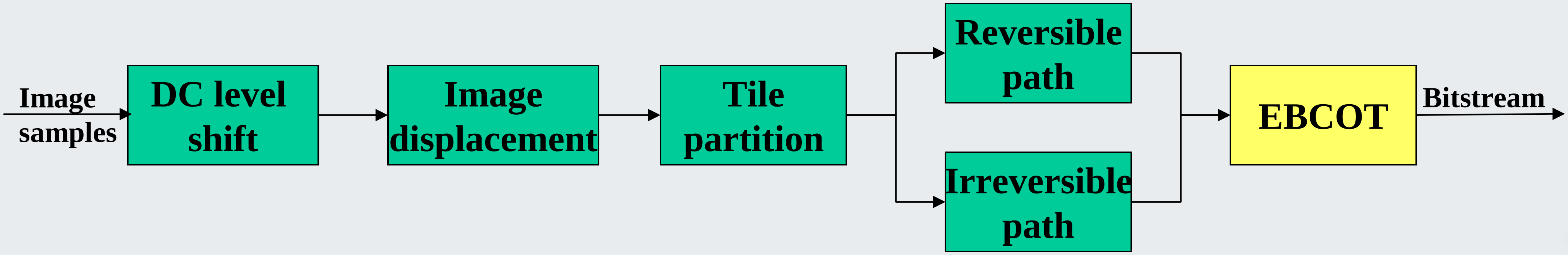
One component of the tile nLL

Codeblocks

- Each subband of each precint is partitioned into ***Codeblocks***
- Each **bitplane** of the codeblock is coded indipendently
- Every bitplane is compressed using the **EBCOT** algorithm



Overview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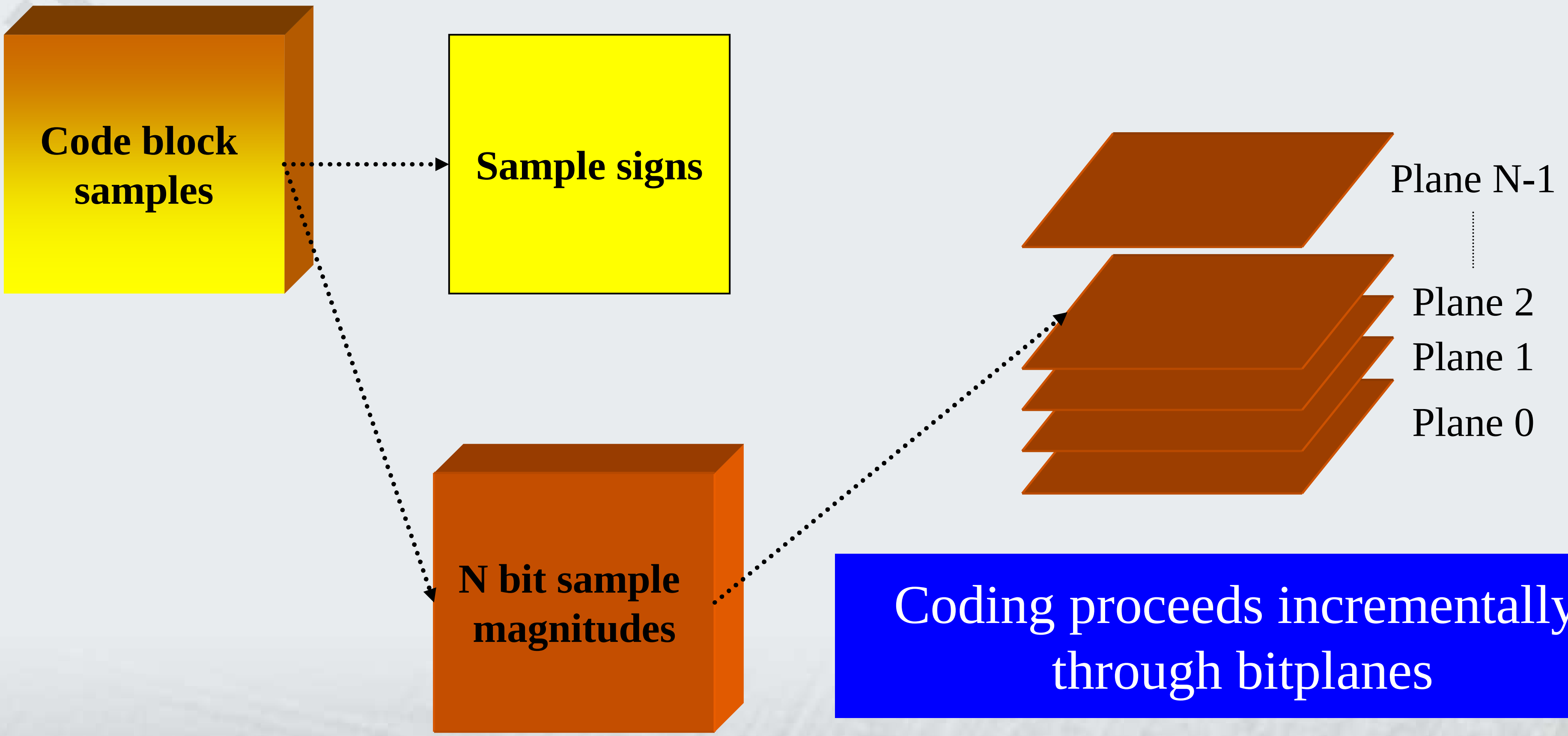
EBCOT

- Embedded Block Coding with Optimal Truncation

- It defines the methodology for the data arranging in the bitstream allowing the rate control with optimum quality

- It is composed by two *tier*
  - *Tier 1:* it generates the collection of encoded bits for each codeblock. Bitplane coding is used (Layers)
  - *Tier 2*: reorganize such data in order to obtain the better quality as possible given the compression ratio

Bitplane coding



Coding proceeds incrementally through bitplanes

Packets

- Each atomic data information is inserted in an individual bitstream portion called *Packet*
- A packet contains the data information related to each:
  - Tile, Precint (spatial)
  - Component (Y, Cr, Cb) (color)
  - Resolution level (LL, ...) (resolution)
  - Layer (quality)

Progression order

- Indicates how the packet's information are inserted in the bitstream
- Packets can be indexed by layer, resolution, precint, component
- 5 different progression order are defined
- The encoder choose the progression order based, e.g., on the application

Progression order

- The 5 progression orders are:
  1) layer - resolution level - component - position
  2) resolution level - layer - component - position
  3) component - position - resolution level - layer
  4) resolution level - position - component - layer
  5) position - component - resolution level - layer

e.g. the 1st progression order can be useful for low quality-full resolution decoding, while the 4th for a low resolution-high quality decoding.

Additional features

- Region of interest (ROI)

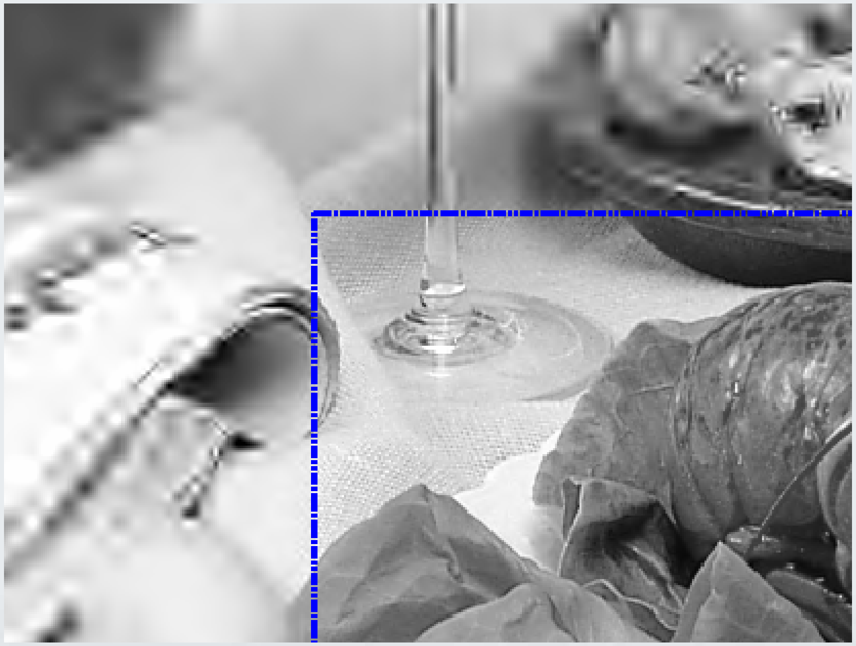
- Error resilient tools

ROI

- Allows obtaining finest quality for the most interesting image regions

- No algorithm is define to individuate the region of interest (i.e. proprietary algorithms must be used)

ROI example



The lower right
is the most
significative part

Errors handling

- Noise prone environments (transmission channel) can modify some bit in the bitstream
- Compressed data usually use variable length coding
- Corrupted bitstream cause the decoder to fail. All the following data are lost.
- Robust decoder must handle errors in order to be suitable for wireless multimedia applications.

Errors handling

- Two main phases for errors handling:
  - Error detection
    - It depends on both the encoder and the decoder
    - The encoder can use some tools to allow the error identification/resynchronization
    - The decoder uses such tools to identify the error and to jump to the next resynchronization point
  - Error concealment
    - It depends on the decoder

Errors handling

- JPEG is too poor in error handling
  - Resync marker is the only tool
  - When an error occurs at least all the line is lost (usually all the bitstream is discarded)

- JPEG 2000 has different tools for error handling
  - Part 13 in the standard (just started) is analyzing the wireless multimedia applications in order to provide specifications for robust transmission.

Error resilient tools

- The following tools are defined to increase the error detection and resynchronization
  - Resync marker
  - Segment marker
  - Precincts
  - Frequent arithmetic coder termination

- They provide robustness to the bitstream
- Error concealment algorithms are not defined in the standard. It is a research activity.

Error resilience example

Error rate:10-5

Original image

JPEG2000
Without
error
resilience

JPEG 2000
With
error
resilience

JPEG
Without
error
resilience

Error Concealment in MPEG-4

MPEG-4 example

Note the blocking artifacts

Quality comparison

- Visual tests looked for equivalent quality between JPEG 2000 and JPEG
- The results (Gormish & Marcellin) show better performances for JPEG 2000 in lower bitrate.

JPEG 2000 bitrate	Eq. JPEG bitrate	%larger for JPEG
0.25	0.73	112%
0.50	0.78	56%
0.75	0.92	23%
1.00	1.13	13%

Visual quality

0.125 bpp

Visual quality

0.250 bpp

Visual quality

0.5 bpp

Visual quality

1 bpp

Visual quality (ROI)

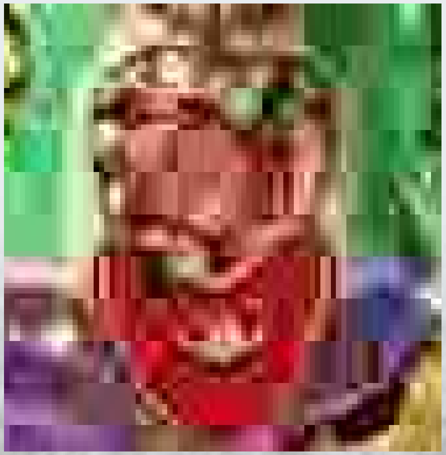
0.25 bpp overall (without and with ROI at 0.75 bpp)

Visual quality
JPEG vs JPEG2000

Compression factor 1:60

Original
24 bpp

JPEG 2000
0.4 bpp



JPEG
0.4 bpp

Original 24 bpp

JPEG 0.4 bpp

JPEG 2000 0.4 bpp

JPEG 2000 bibliography

- www.jpeg.org - official site
- ISO-IEC 15444 docs – standard pubblications
- JPEG 2000 Image compression fundamentals, standards and practice - Taubman, Marcellin - KAP (ISBN:0-7923-7519-X)

- A lots of scientific papers (IEEE, SPIE, CG, ...)