Generalized Lifting for Lossy Image Coding

Julio Rolón, Philippe Salembier

Technical University of Catalonia (UPC)
Dept. of Signal Theory and Telecommunications

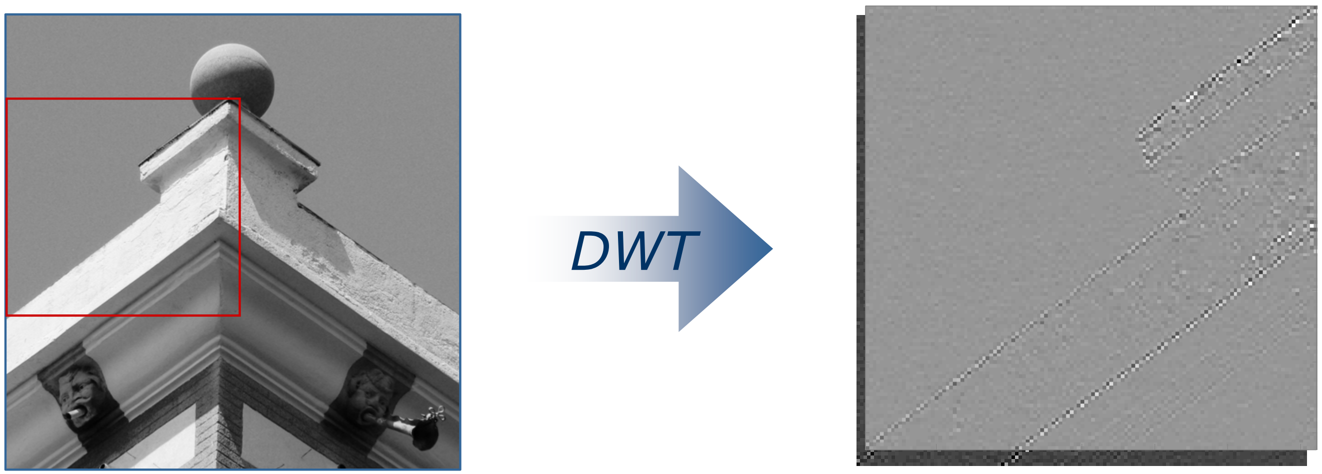
Outline

- ✓ Introduction
  - Motivation and previous work
- ✓ Generalized Lifting
  - Classical Lifting
  - Generalized Lifting
  - Mapping design
- ✓ Evaluation of the potential: The ideal case
- ✓ Image coding implementations
  - Case I: Modeling of contours (global pdf estimation)
  - Case II: Adaptive local pdf estimation
- ✓ Discussion
  - Entropy coding
- ✓ Conclusion

Motivation

✓ Limitations of wavelets in image representation

- Excellent for decorrelation of impulsional-like events
- Limitations on images because wavelets are not able to fully decorrelate edges



LH subband zoom

Need of additional decorrelation for coding applications

Previous work

Main approaches

- Go beyond wavelets trying to overcome their limitations
- Edges become 1-dimensional localizable singularities
- Increased sparsity of the coefficients

Frequency-domain methods

Curvelets
[Candès,Donoho 1999; Candès 2006]

Contourlets
[Do,Vetterli 2005]

Spatial-domain methods

Bandelets
[LePennec,Mallat 2005; Peyré,Mallat 2005]

Adaptive directional lifting
[Chappelier *et al* 2006; Ding *et al* 2007; Heijmans *et al* 2005; Mehrseresht,Taubman 2006; Piella *et al* 2002,2006; Wang *et al* 2006; Zhang *et al* 2005]

Generalized lifting
May be highly non-linear, preserving perfect reconstruction
[Solé,Salembier 2004,2007]

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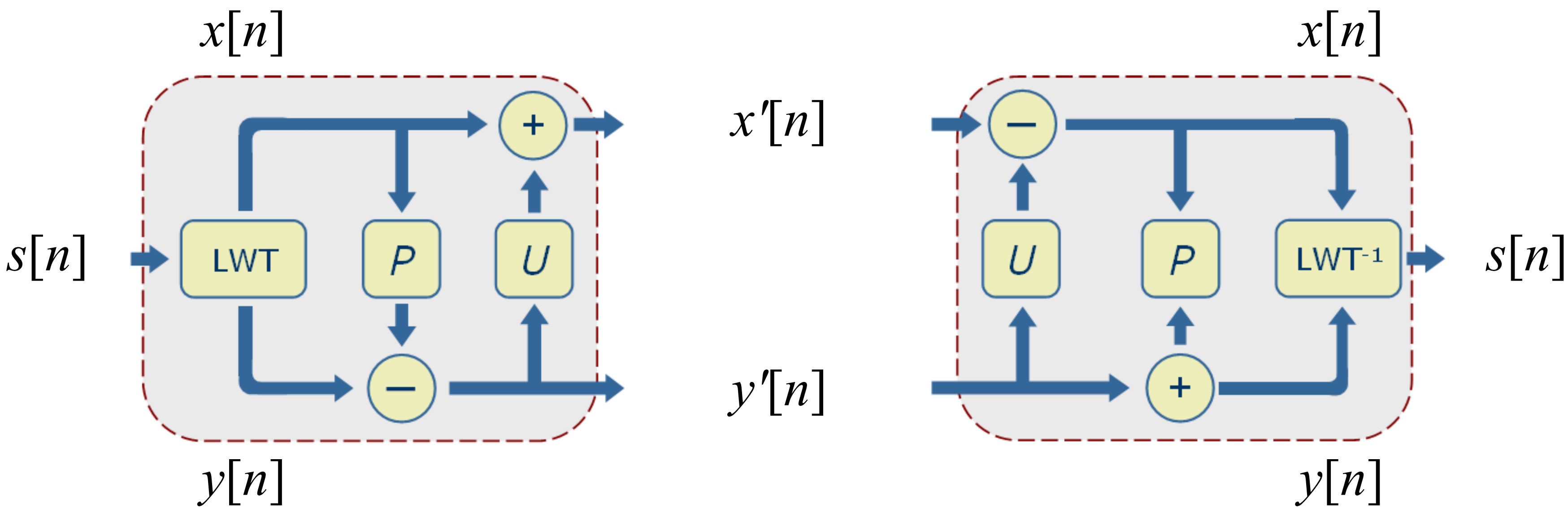
Classical Lifting

Approximation signal: $x'[n] = x[n] + \mathrm{U}(y'[n])$

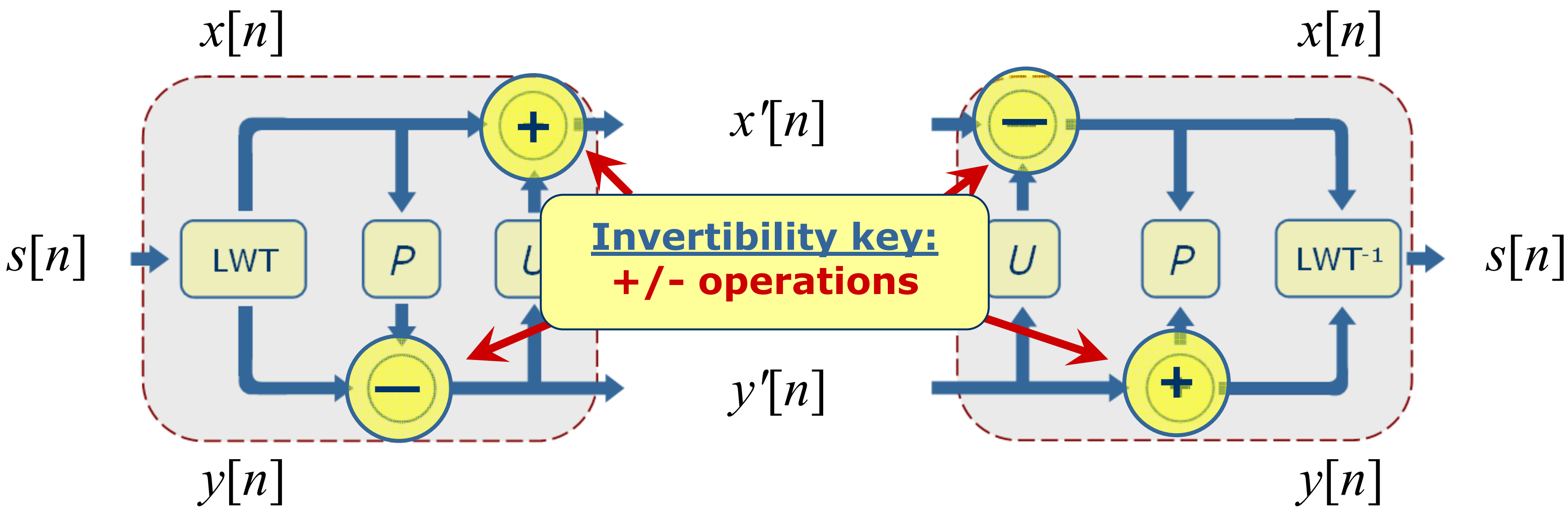


Detail signal: $y'[n] = y[n] - \mathrm{P}(x[n])$

[Sweldens 1996]

Classical Lifting

Approximation signal: $x'[n] = x[n] + \mathrm{U}(y'[n])$

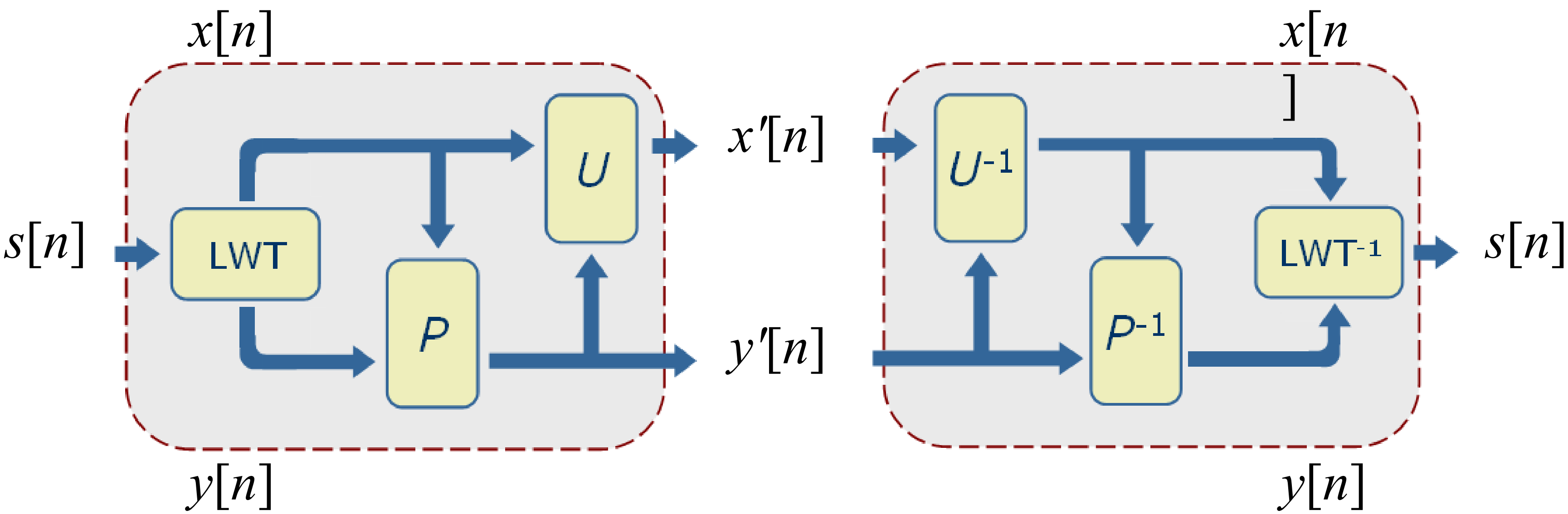


Detail signal: $y'[n] = y[n] - \mathrm{P}(x[n])$

[Sweldens 1996]

Generalized Lifting

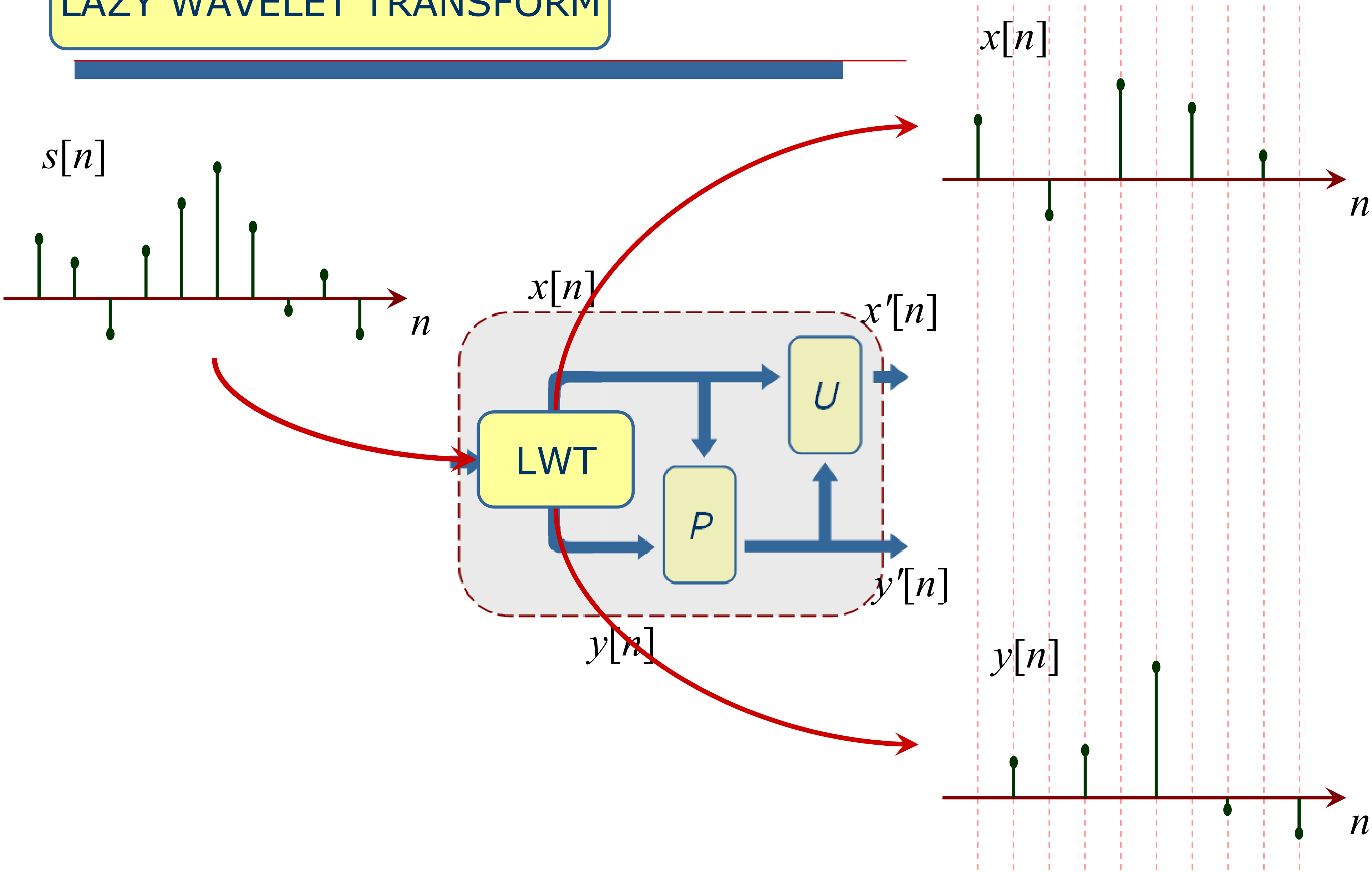
Approximation signal: $x'[n] = \mathrm{U}(x[n], y'[n])$



Detail signal: $y'[n] = \mathrm{P}(y[n], x[n-i])|_{i \in C}$

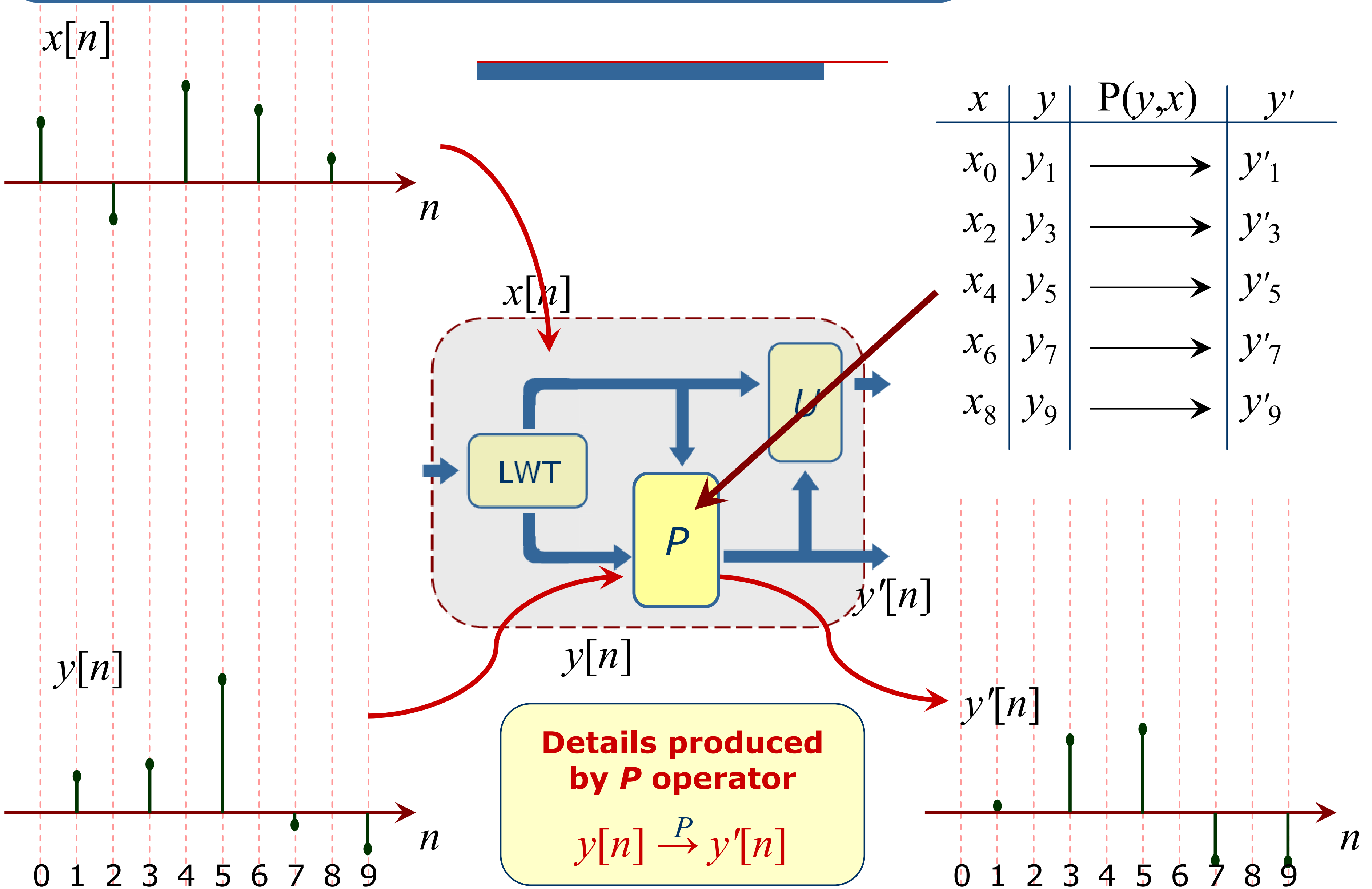
[Solé,Salembier 2004]

LAZY WAVELET TRANSFORM



Detail signal: $y'[n] = \mathrm{P}(y[n], x[n-i])|_{i \in C}$

x	y	$\mathrm{P}(y,x)$	y'
x_0	y_1	$\longrightarrow$	y'_1
x_2	y_3	$\longrightarrow$	y'_3
x_4	y_5	$\longrightarrow$	y'_5
x_6	y_7	$\longrightarrow$	y'_7
x_8	y_9	$\longrightarrow$	y'_9

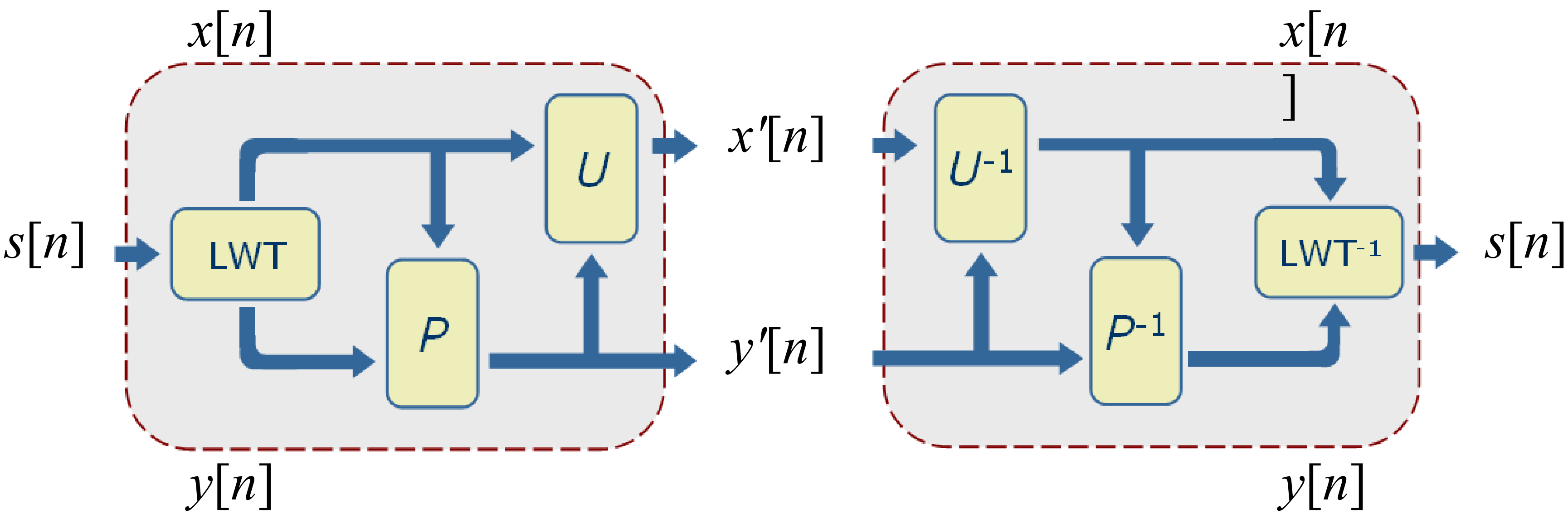


Details produced by *P* operator

$y[n] \xrightarrow{P} y'[n]$

Generalized Lifting

Approximation signal: $x'[n] = \mathrm{U}(x[n], \mathrm{y}'[n])$

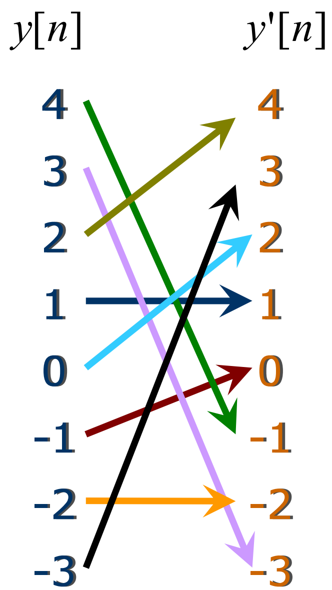


BIJECTIVITY OF *P*, *U* IS MANDATORY TO ACHIEVE PERFECT RECONSTRUCTION

[Solé,Salembier 2004]

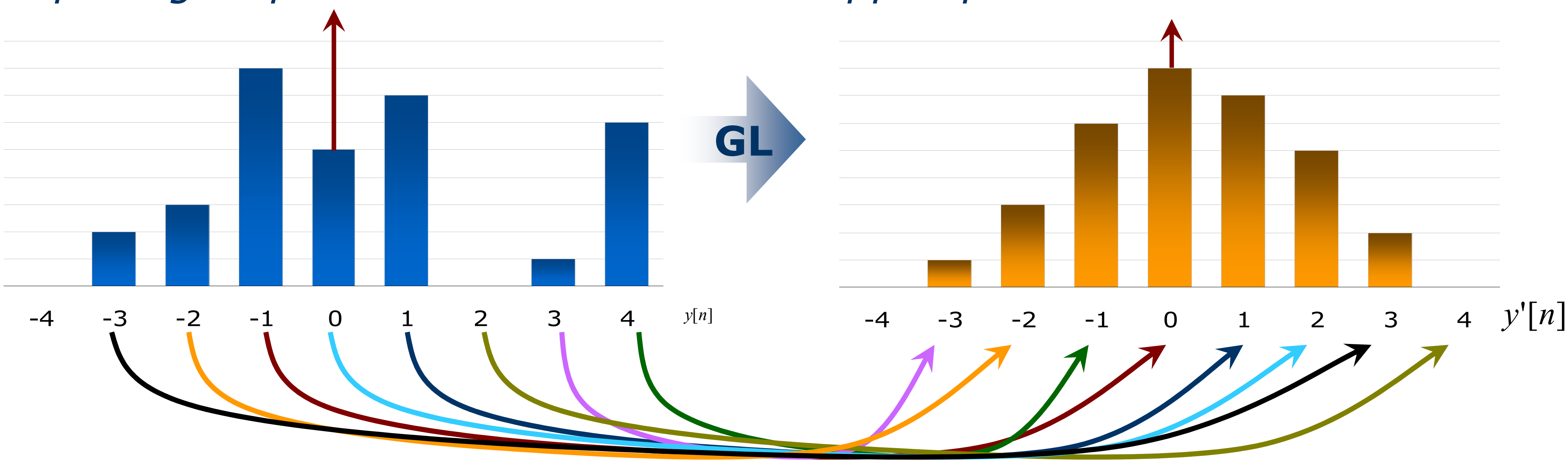
Mapping design

Criterion: Energy minimization of the mapped details



Input signal pdf

mapped pdf



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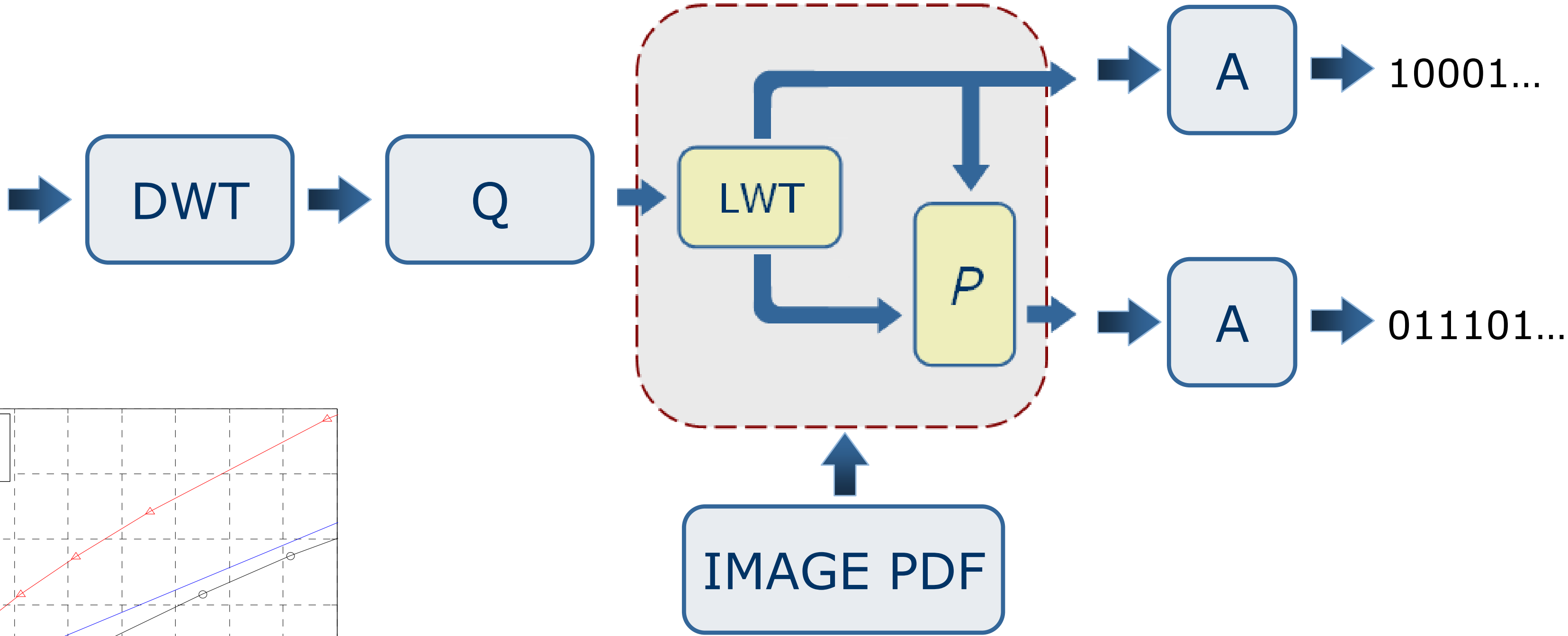
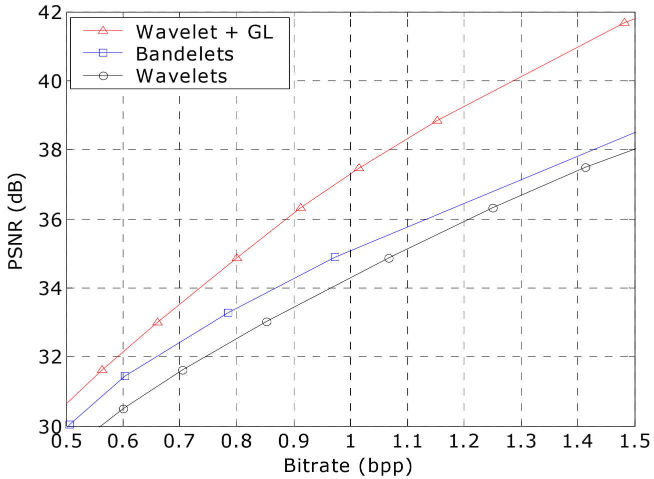
Evaluation of the potential: The ideal case

ASSUMPTION: THE DECODER KNOWS COMPLETELY THE PDF OF THE IMAGE

ORIGINAL





LARGE POTENTIAL CODING GAIN

Rolón, J.C., Salembier, P., Generalized Lifting for Sparse Image Representation and Coding, *PCS 2007*, Lisbon, Portugal

Evaluation of the potential: The ideal case

IDEAL CASE

POTENTIAL FOR THE METHOD IDENTIFIED

UNREALISTIC TO TRANSMIT THE IMAGE PDF

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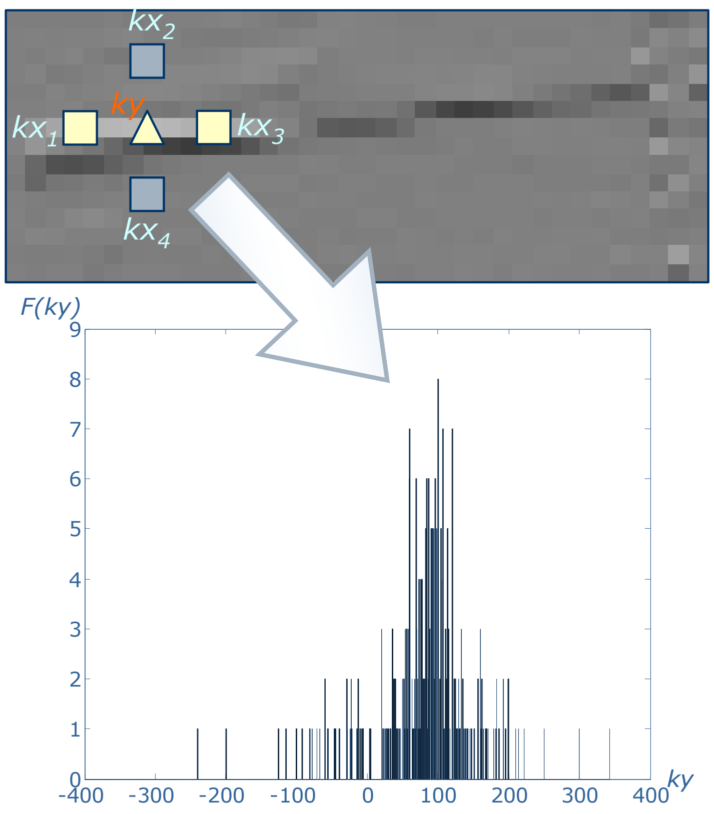
Case I. Modeling of contours

- ✓ The idea is to cluster contexts according to their structure in a contrast invariant way
- ✓ We group contexts into classes which produce largest reduction in energy
- ✓ We create a set of models with similar behavior
- ✓ The structures of these models properly describe contours in wavelet domain, where most of the energy is concentrated



Rolón, J.C., Ortega, A., Salembier, P., Modeling of Contours in Wavelet Domain for Generalized Lifting Image Compression, *Accepted in ICASSP 2009*, Taipei, Taiwan

Case I. Modeling of contours

✓ **Mapping design**

- Context models:
  1. {A,0,A,0} → A
  2. {A,-A,A,-A}→ A
  3. {A,0,A,A} → A
  4. {A,A,A,0} → A
- Contrast invariant:

  $\{kx_1, kx_2, kx_3, kx_4\} \rightarrow ky$

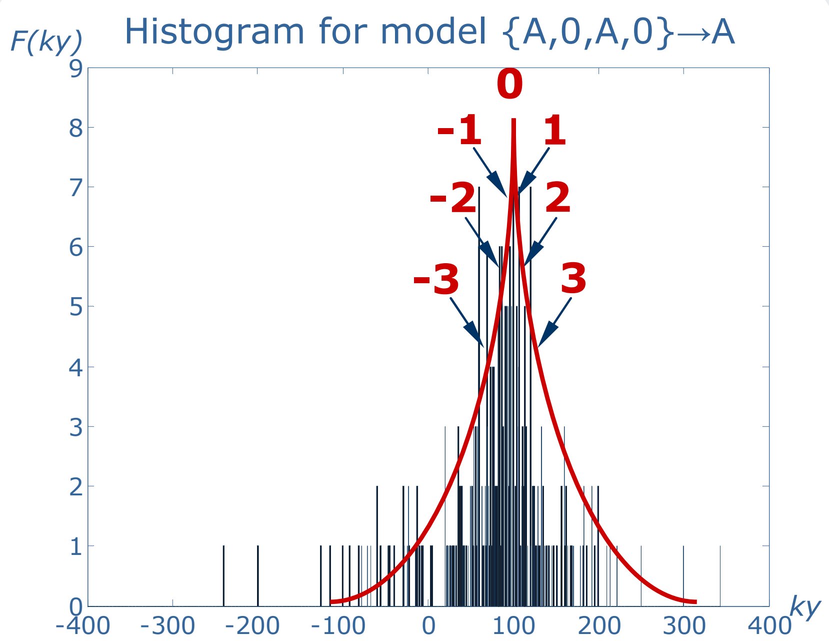
✓ **Decision for classification**

- Distance measure:

  $$mse = (kx_1 - A)^2 + (kx_2 - A)^2 + (kx_3 - A)^2 + (kx_4 - A)^2$$

✓ **Overhead (per model)**

$A,\ T_{mse}$



Mapping is: $y' = y - A/k$

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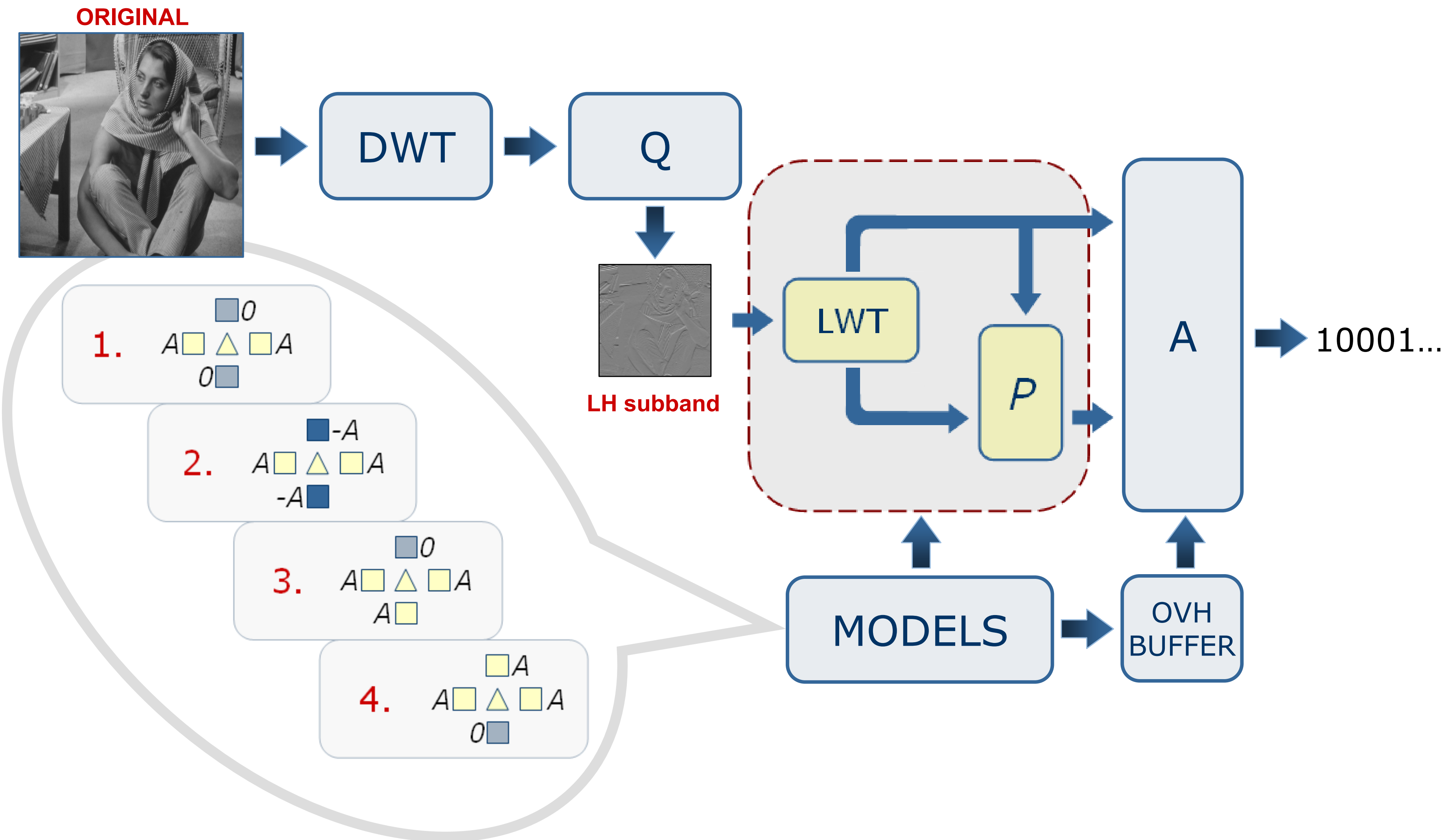
Case I. Modeling of contours



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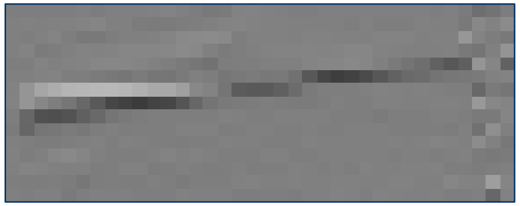
Case I. Modeling of contours

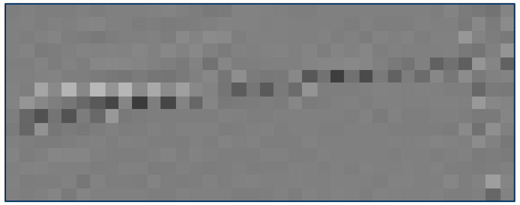
EXPERIMENTAL RESULTS

Model	*barbara*		*boat*	
	Cont (%)	E_{gain} (%)	*Cont* (%)	E_{gain} (%)
1. {A,0,A,0} → A	7.89	**-69.96**	7.07	**-83.69**
2. {A,-A,A,-A}→ A	16.43	-51.23	21.42	-35.71
3. {A,0,A,A} → A	13.48	-23.37	10.95	7.70
4. {A,A,A,0} → A	10.43	-14.99	9.29	-5.71
Z. {0,0,0,0} → 0	1.7	–	0.93	–
All other contexts	50.09	–	50.34	–

DWT



GL-1



GL-2

Image	Bitrate (bpp)		*Coding gain* (%)	E_{gain} (%)
	DWT	GL		
barbara	4.7755	4.6859	1.91	-36.34
boat	5.2432	5.2224	0.40	-37.50

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Case I. Modeling of contours

GENERIC IMAGE CASE I

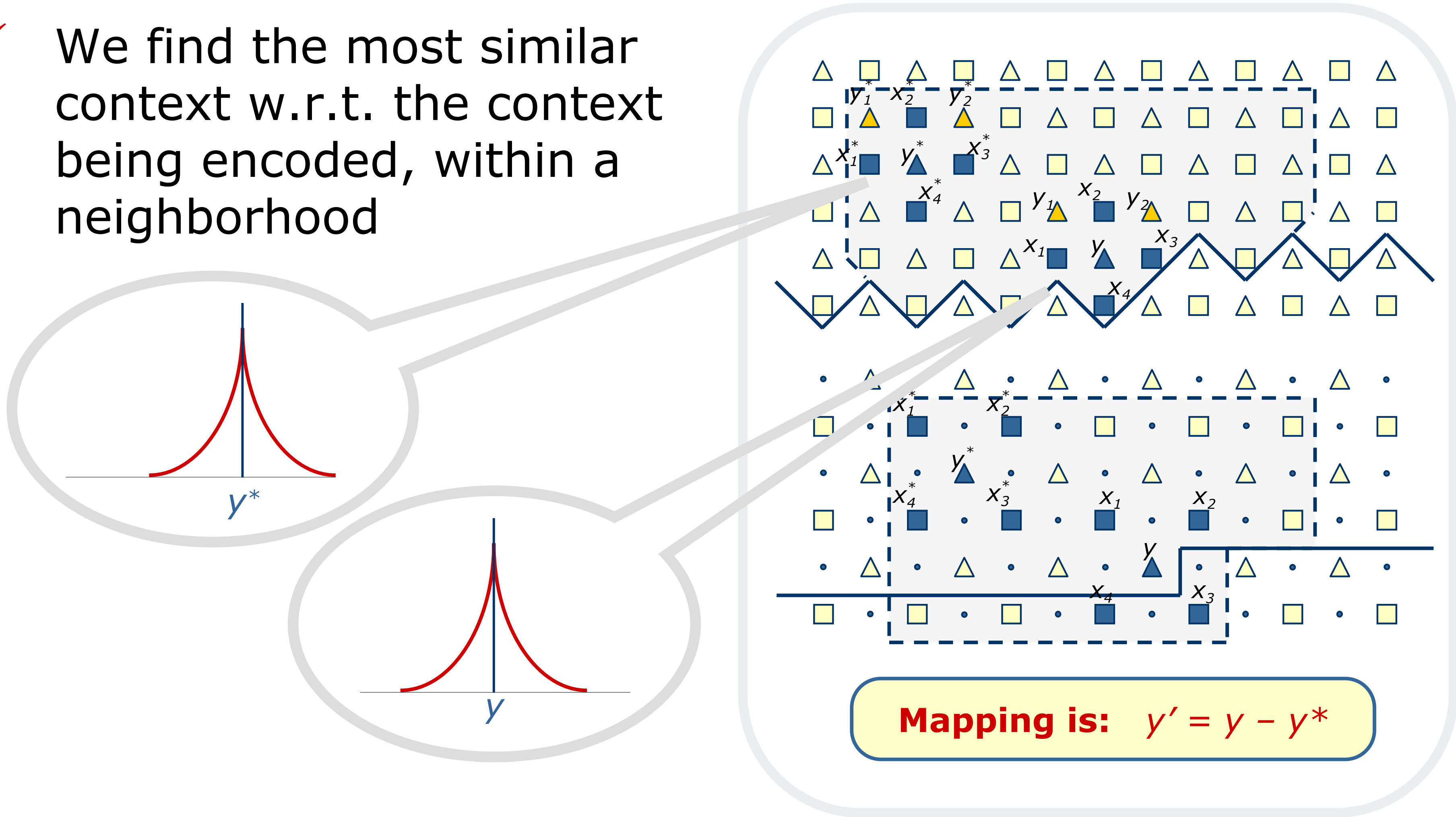
GLOBAL PDF ESTIMATED FOR THE MODELS

INTERESTING POTENTIAL OF THE METHOD IN GENERIC CASE I

Rolón, J.C., Ortega, A., Salembier, P., Modeling of Contours in Wavelet Domain for Generalized Lifting Image Compression, *Accepted in ICASSP 2009*, Taipei, Taiwan

Case II. Adaptive local pdf estimation

- ✓ We find the most similar context w.r.t. the context being encoded, within a neighborhood



Rolón, J.C., Mendonça, E., Salembier, P., Generalized Lifting with adaptive Local pdf Estimation for Image Coding, *Submitted to PCS 2009*, Chicago, USA

Case II. Adaptive local pdf estimation

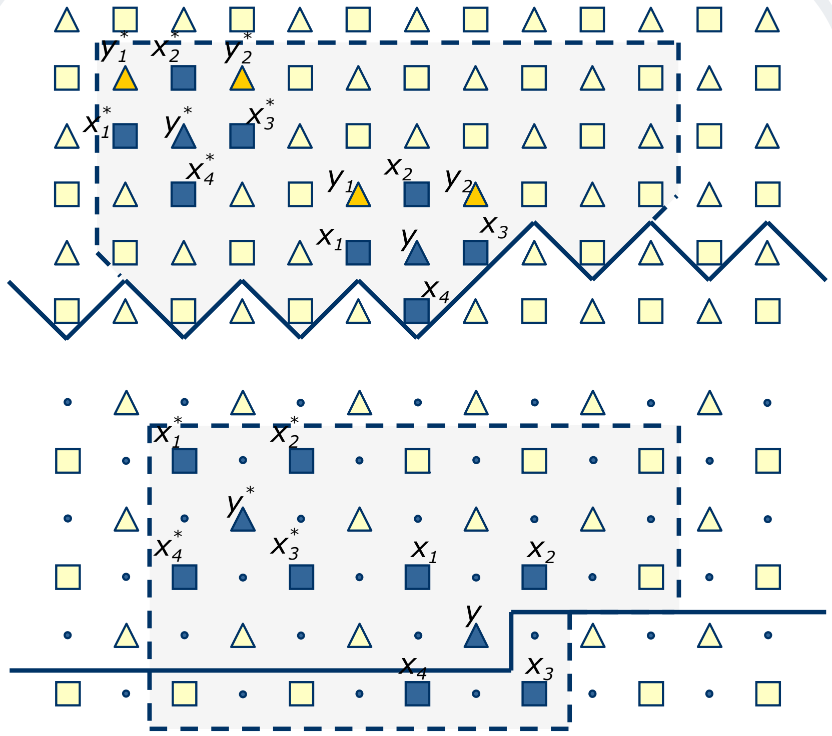
- ✓ We find the most similar context w.r.t. the context being encoded, within a neighborhood

- ✓ Distance measure

$$D = \frac{\sum_{i=1}^{4}(x_i - x_i^*)^2 + \alpha \sum_{i=1}^{2}(y_i - y_i^*)^2}{\sum_{i=1}^{4} x_i^2 + \alpha \sum_{i=1}^{2} y_i^2}$$

- ✓ Overhead

  window size, T_D , α



Mapping is: $y' = y - y^*$

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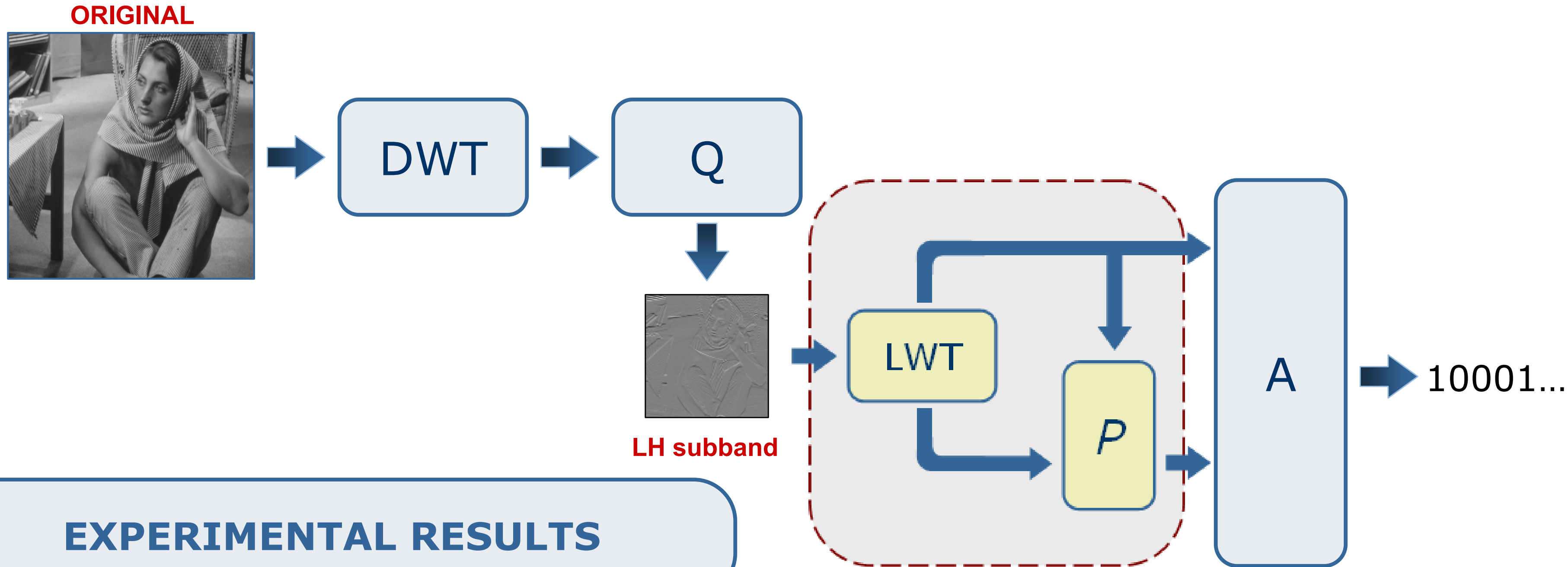
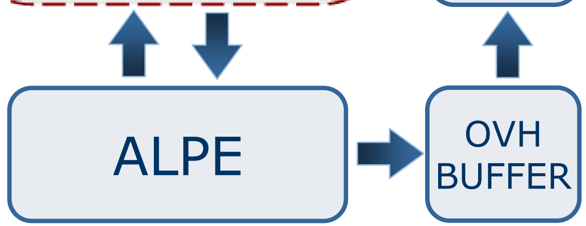
Case II. Adaptive local pdf estimation





EXPERIMENTAL RESULTS

Image	E_{gain} (%)		*Coding gain* (%)	
	Haar	CDF 9/7	Haar	CDF 9/7
barbara	-18.19	-16.63	-1.02	2.42
boat	-11.42	-5.12	-0.30	-0.12
bike	**-29.25**	**-28.96**	-3.27	-4.57

(ALPE: Adaptive Local Pdf Estimation)

Rolón, J.C., Mendonça, E., Salembier, P., Generalized Lifting with adaptive Local pdf Estimation for Image Coding, *Submitted to PCS 2009*, Chicago, USA

Case II. Adaptive local pdf estimation

GENERIC IMAGE CASE II

LOCAL PDF ESTIMATED ADAPTIVELY

INTERESTING POTENTIAL OF THE METHOD IN GENERIC CASE II

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Discussion: Entropy coding

- Energy minimization GL mapping increases the decorrelation of DWT coefficients
- This increased decorrelation prevents arithmetic encoder from increasing coding gain significantly

- The adverse effect of decorrelation is observed in conventional arithmetic encoders, hierarchical coders like SPIHT or SPECK, and in block coders like EBCOT
- Current work is focused on solving the entropy coding stage

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Conclusions

- ✓ The potential of GL method for lossy image coding has been demonstrated in the ideal and the generic cases

- ✓ The energy reduction achieved in the generic cases is considerable, but translates to a moderate reduction in bitrate. At this moment, it does not reflect the expected coding gain

- ✓ Our efforts are now concentrated on the entropy coder:

  <u>your ideas are welcome!</u>

Generalized Lifting for Lossy Image Coding

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Xavier Alameda,

Antonio Ortega,

and

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Julio Rolón, Philippe Salembier

Technical University of Catalonia (UPC)
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Generalized Lifting for Lossy Image Coding

Thank you !!!

Julio Rolón, Philippe Salembier

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