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Polytech'Nantes
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Représentation structurelle d'images par transformées locales orientées et codage

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Lossy image compression



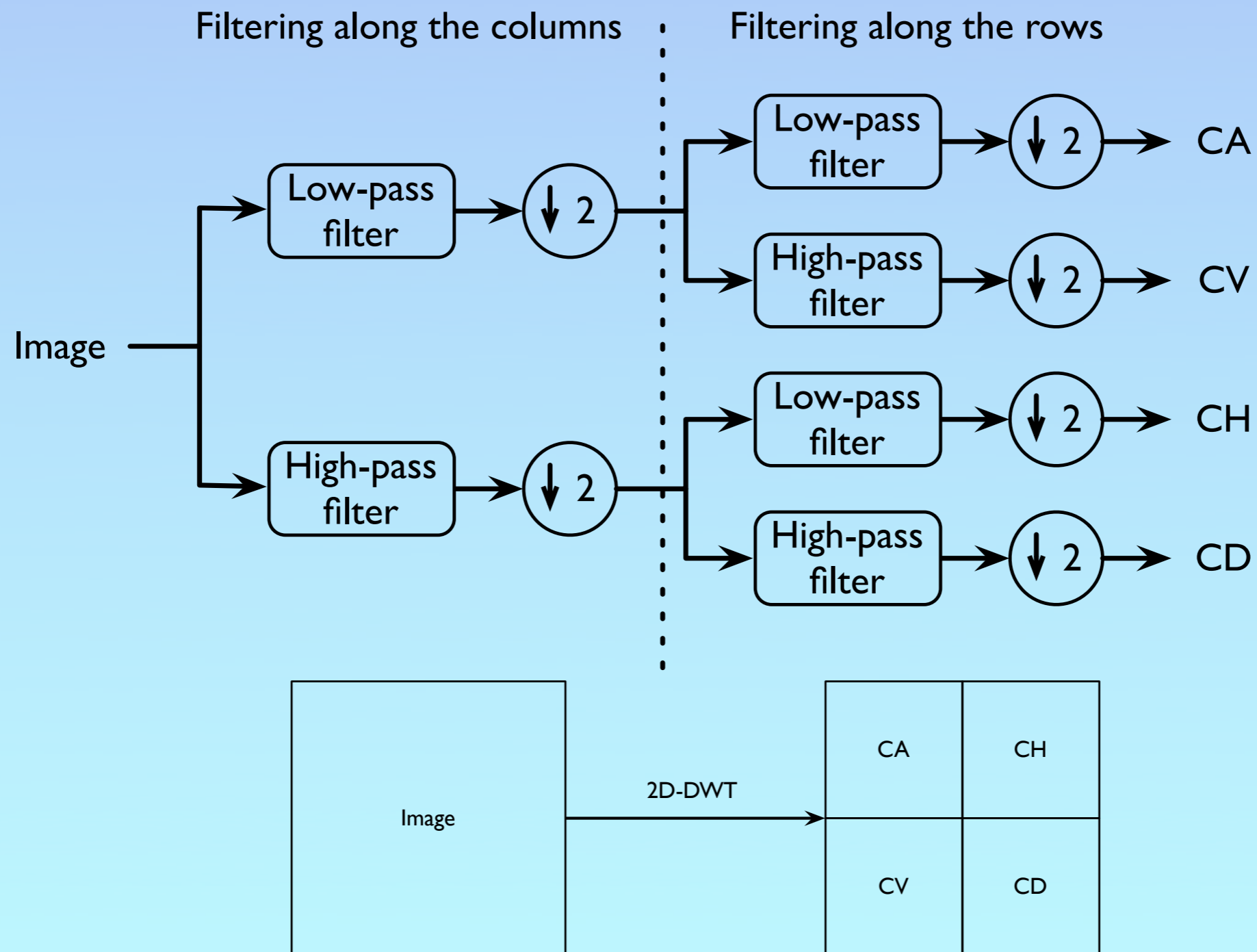
- Reduce redundancy
- Suppress not significant visual information
- Provide services
 - scalability (resolution, quality)
 - error resiliency
 - region of interest
 - ...

Still image coding

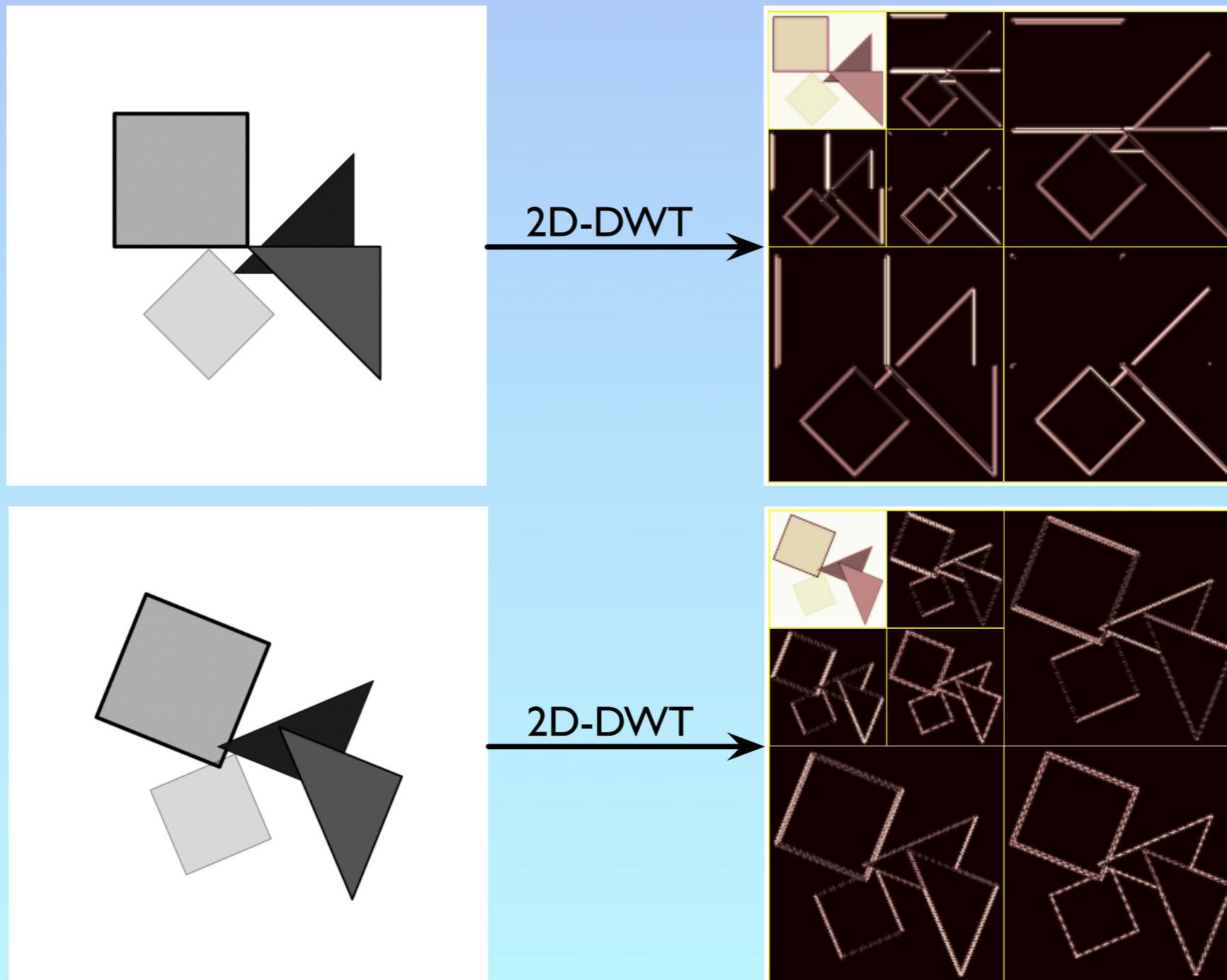


- Transform
 - Change the image representation
- Quantization
 - Approximate the magnitude of the transformed coefficients
- Coding
 - Represent this information into binary codes

2D Discrete Separable Wavelet Transform (2D-DWT)



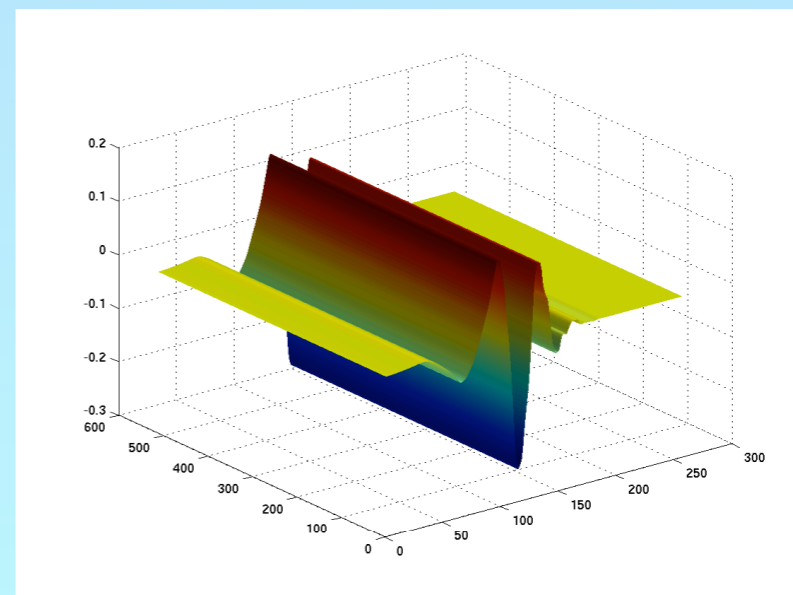
Limitations of the 2D-DWT



New representations (1/2)

Fixed representations taking into account more orientations

- Ridgelets: DWT applied on Radon projections [Candès 98]
- Curvelets: multiscale ridgelet transform [Candès Donoho 99]
- Contourlets: [Do Vetterli 05]

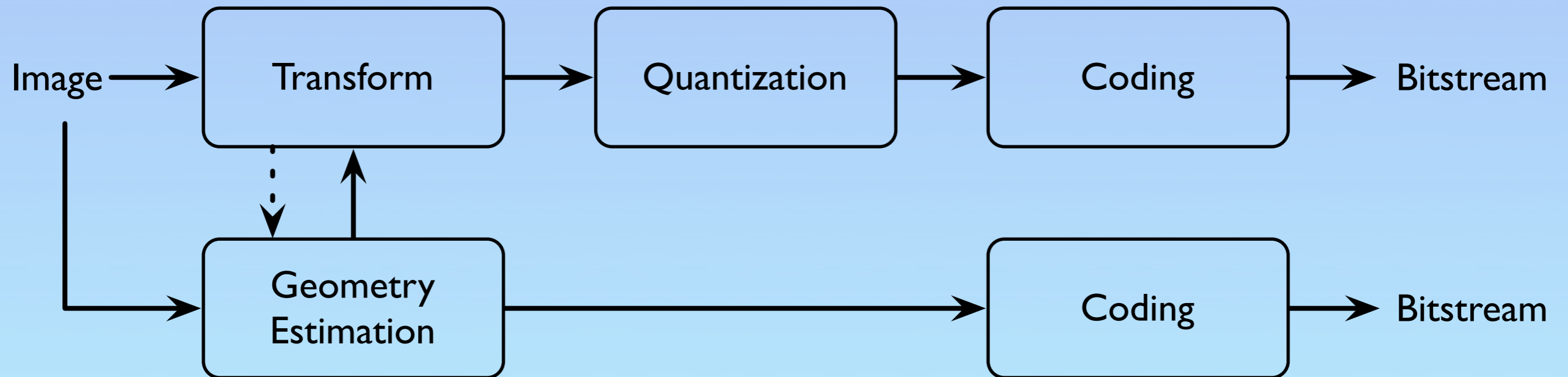


New representations (2/2)

Adaptive representations exploiting the regularity along a local orientation

- Representations adapting the image to the discrete separable wavelet transform [Le Guen 08]
- Representations adapting the wavelet transform to the image
Bandelets [Le Pennec 02] [Peyré 05], Curved Wavelets [Wang et al 04],
Directionlets [Velisavljević et al 06], [Chappelier 05] Adaptive Directional Lifting
[Ding et al 07], Direction-Adaptive Discrete Wavelet Transform [Chang Girod 07], ...

Outline



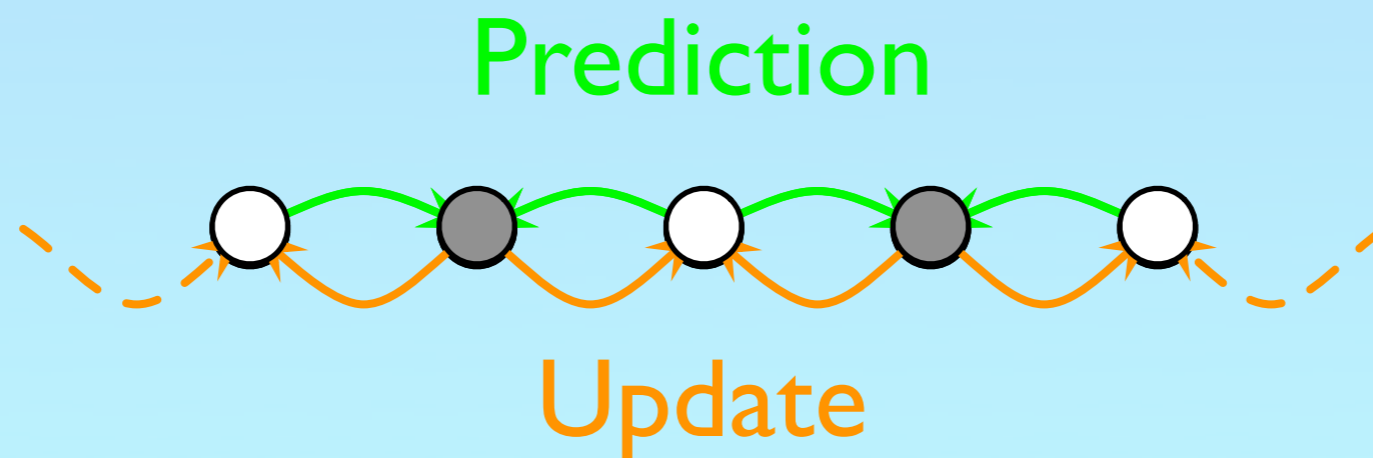
- I. Adaptive oriented wavelet transforms
- II. Geometry estimation and coding
- III. Quantization of oriented wavelet coefficients

Adaptive oriented wavelet transform

1. Presentation of existing oriented lifting schemes
 - 8-connected-(p,q)-lifting
 - (p,q)-connected-(p,q)-lifting
 - θ -lifting
2. Benchmark of oriented lifting schemes...
 - ...on synthetic images
 - ...on natural images

1D-DWT using lifting scheme

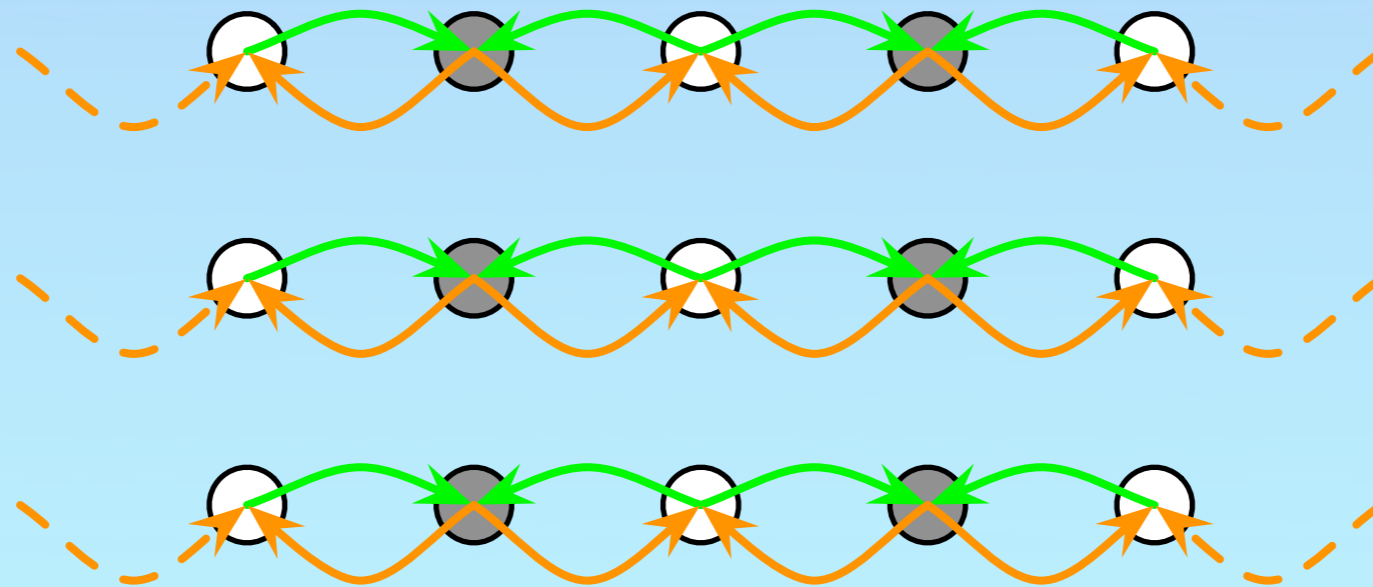
- Any wavelet transform can be implemented using lifting schemes instead of filter banks [Daubechies Sweldens 98]
 - + In-place transform
 - + Lower complexity



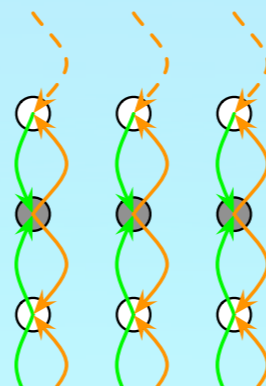
1D lifting on images

- 1D lifting scheme applied along the rows of an image

➔ column-based lifting

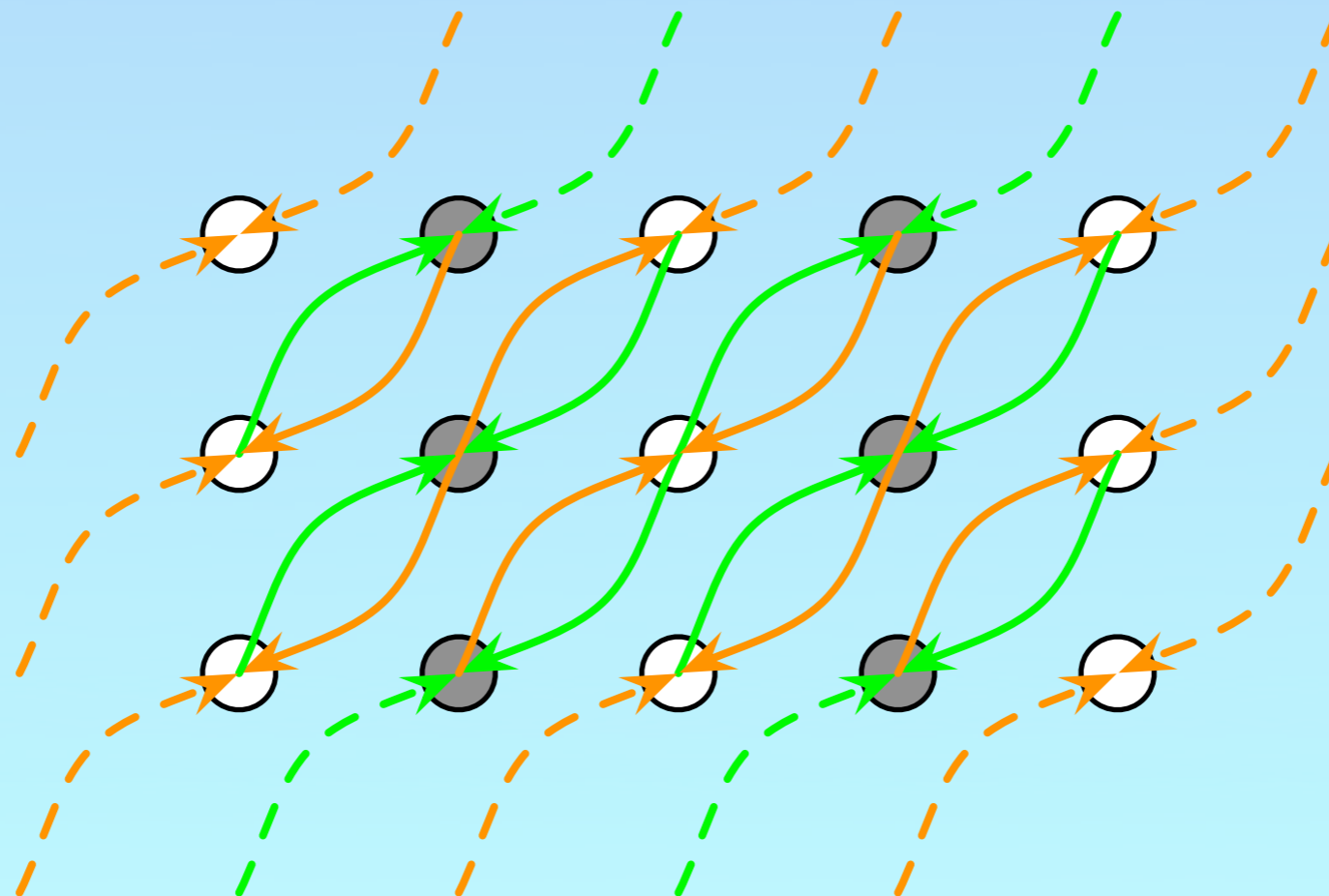


➔ row-based lifting



Oriented lifting scheme

- The flexibility of lifting schemes is used to define oriented lifting schemes
[Wang *et al* 06]



8-connected-(p,q)-lifting

[Jeannic *et al* 07] [Velisavljević *et al* 06]

- filtering orientation defined by a vector: (p, q)
- 8-connected discrete lines defined by:

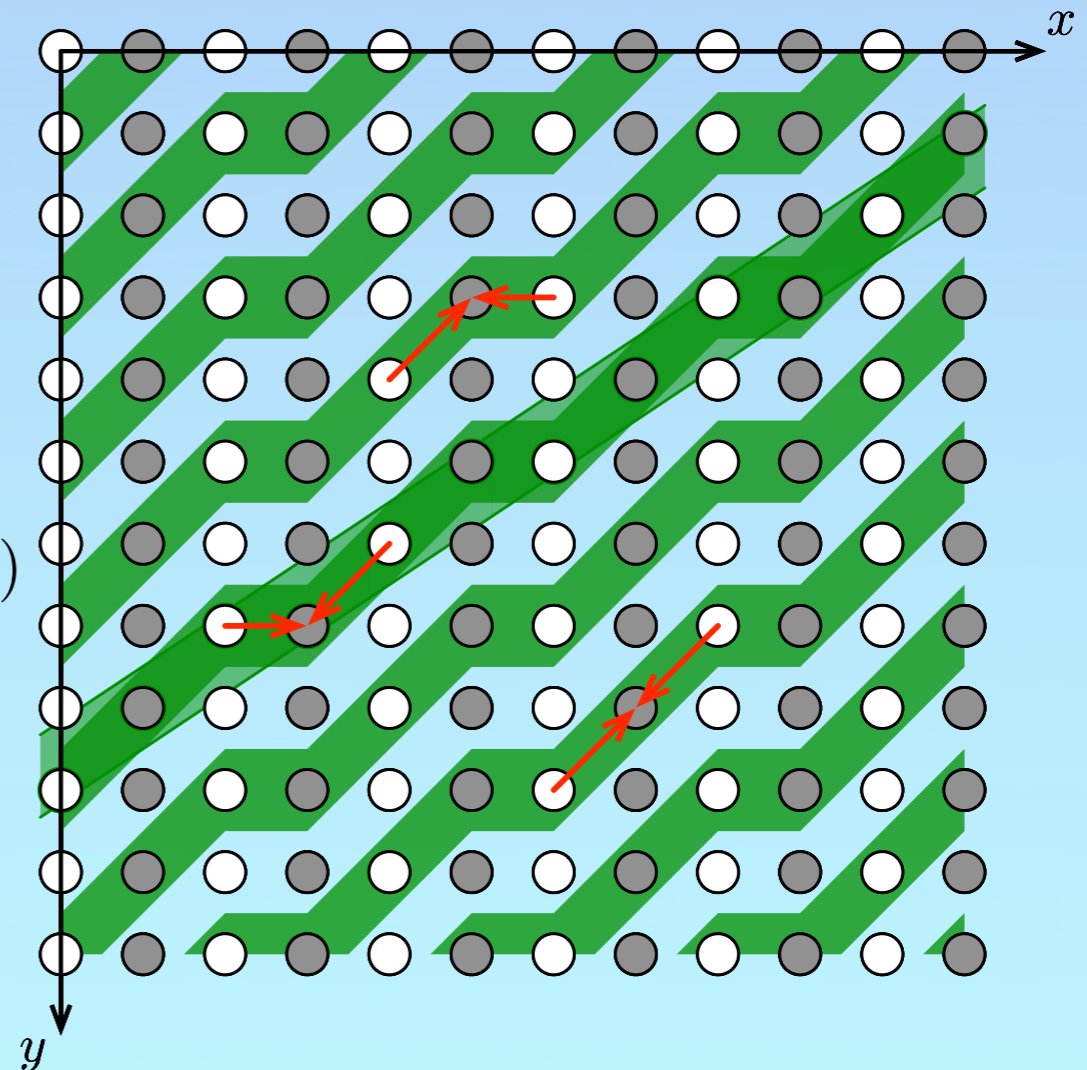
$$0 \leq -q \cdot (x - x_0) + p \cdot (y - y_0) < \max(|p|, |q|)$$

- example:

$$(p, q) = (3, -2)$$

$$(x_0, y_0) = (5, 5)$$

$$25 \leq 2x + 3y < 28$$

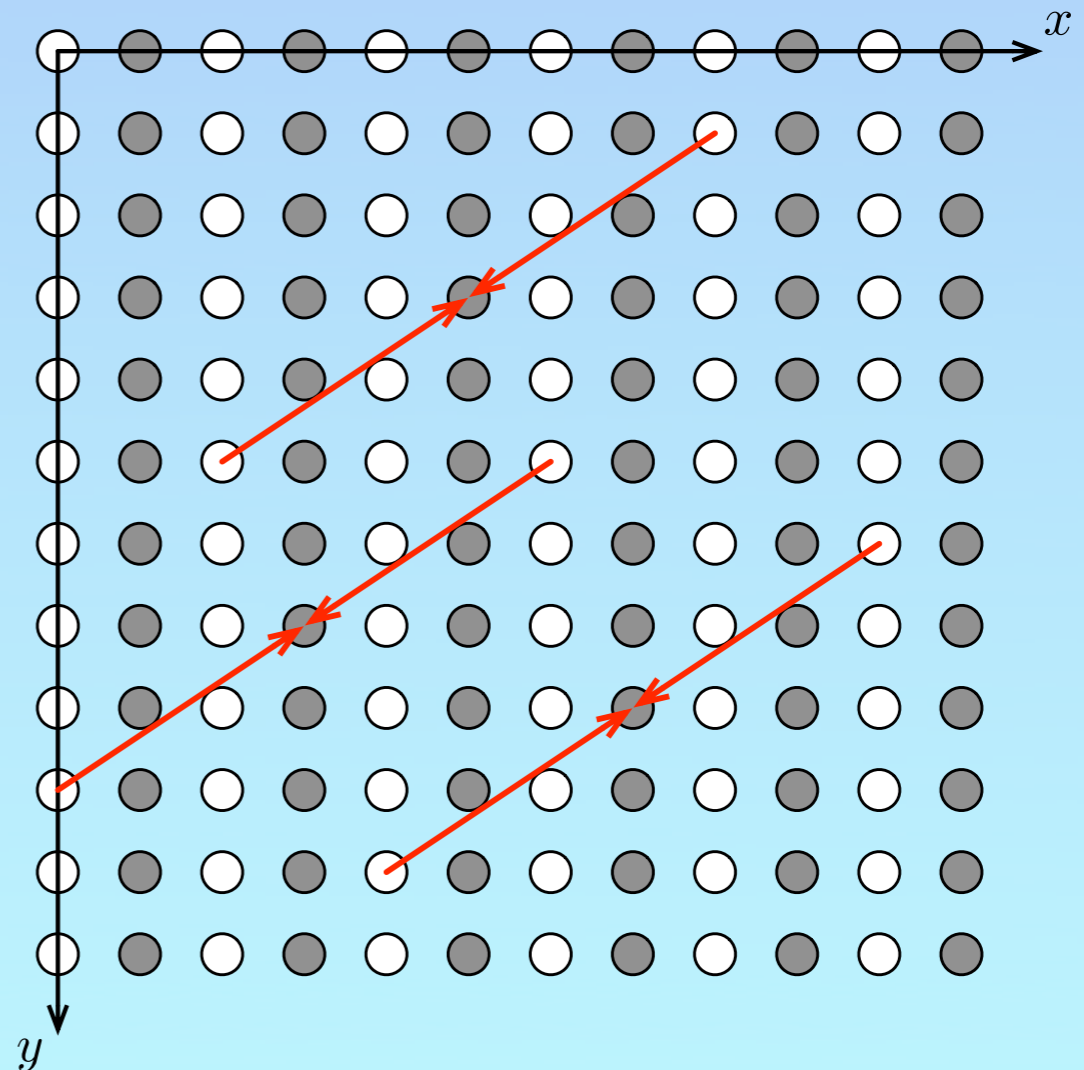


(p,q) -connected- (p,q) -lifting

[Velisavljević et al 06] [Chang Girod 07]

- filtering orientation defined by a vector: (p,q)
- samples are (p,q) -connected
- example:

$$(p, q) = (3, -2)$$

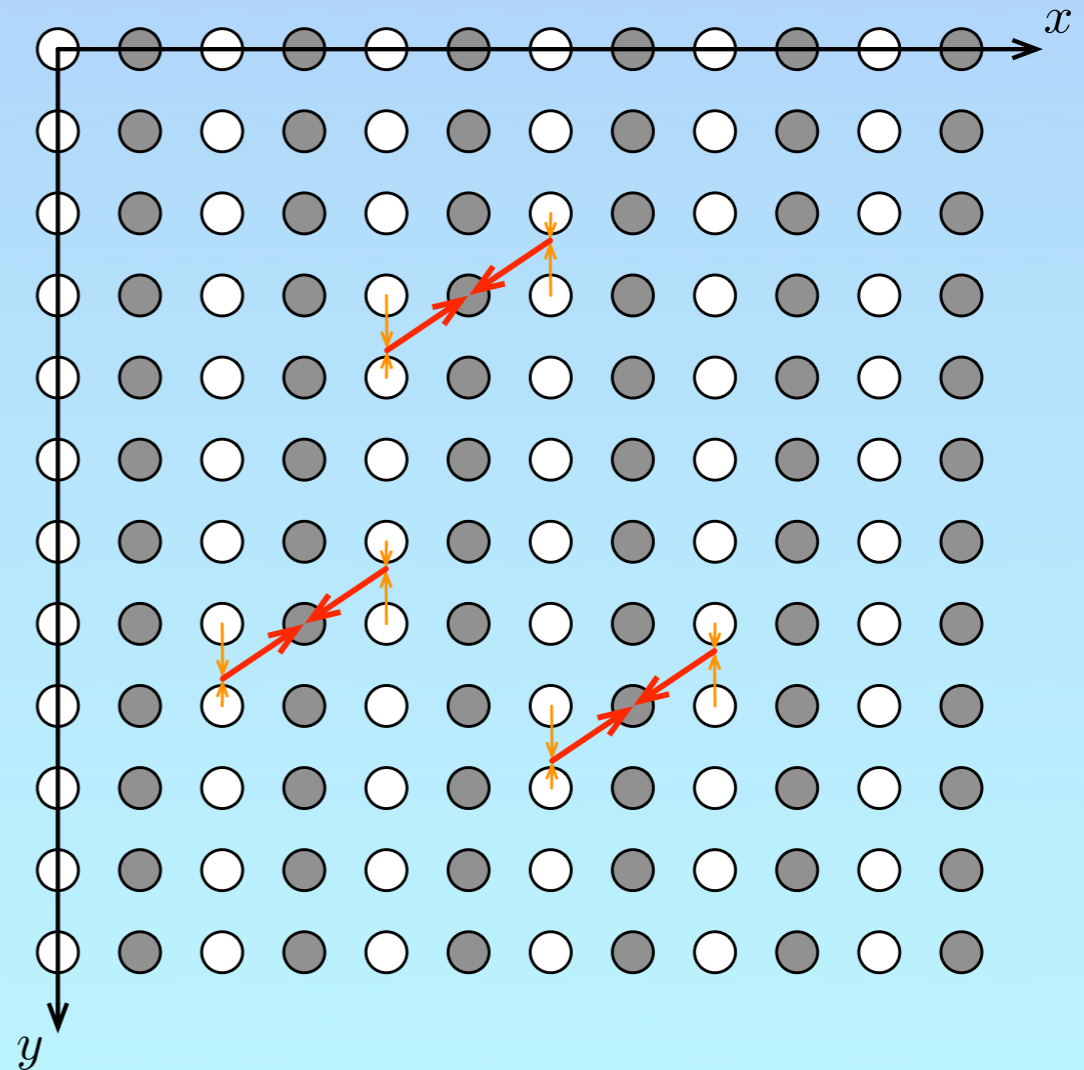


θ -lifting

[Jeannic *et al* 07] [Ding *et al* 07]

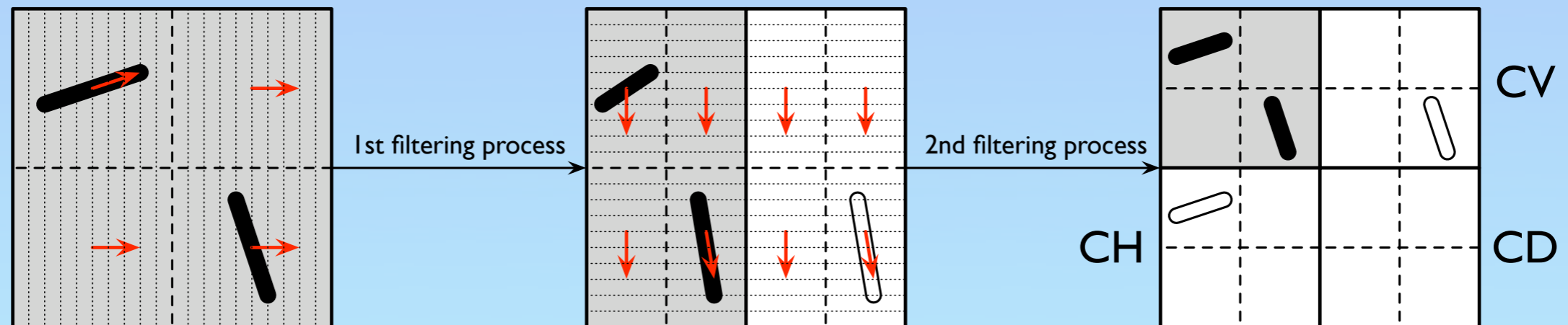
- filtering orientation defined by an angle: $\underline{\theta}$
- samples values are interpolated
- example:

$$\theta \approx 36,87^\circ$$

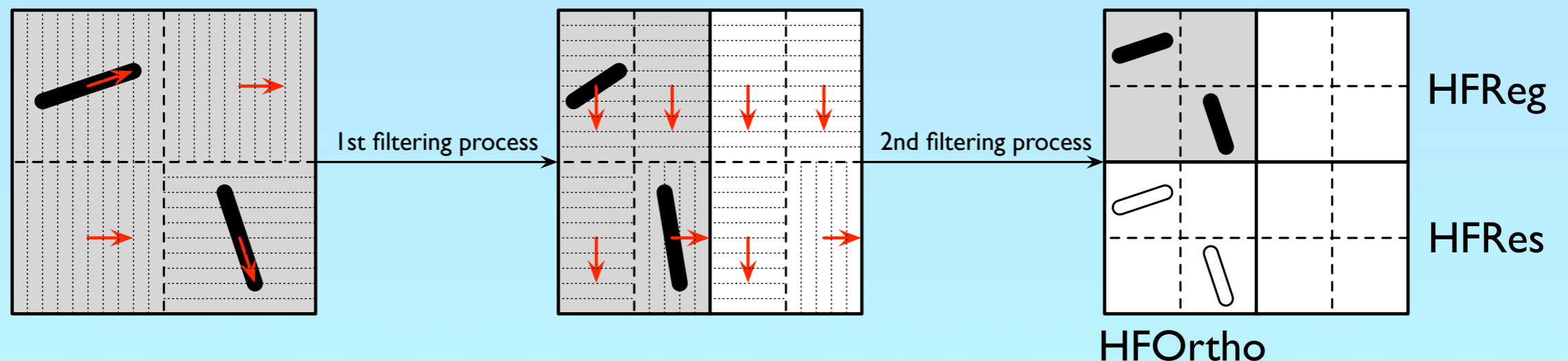


Filtering along the regularity orientation

- Usually, polyphase decomposition fixed for the whole image, then block-based oriented filtering (filtering orientations set depends on polyphase decomposition)



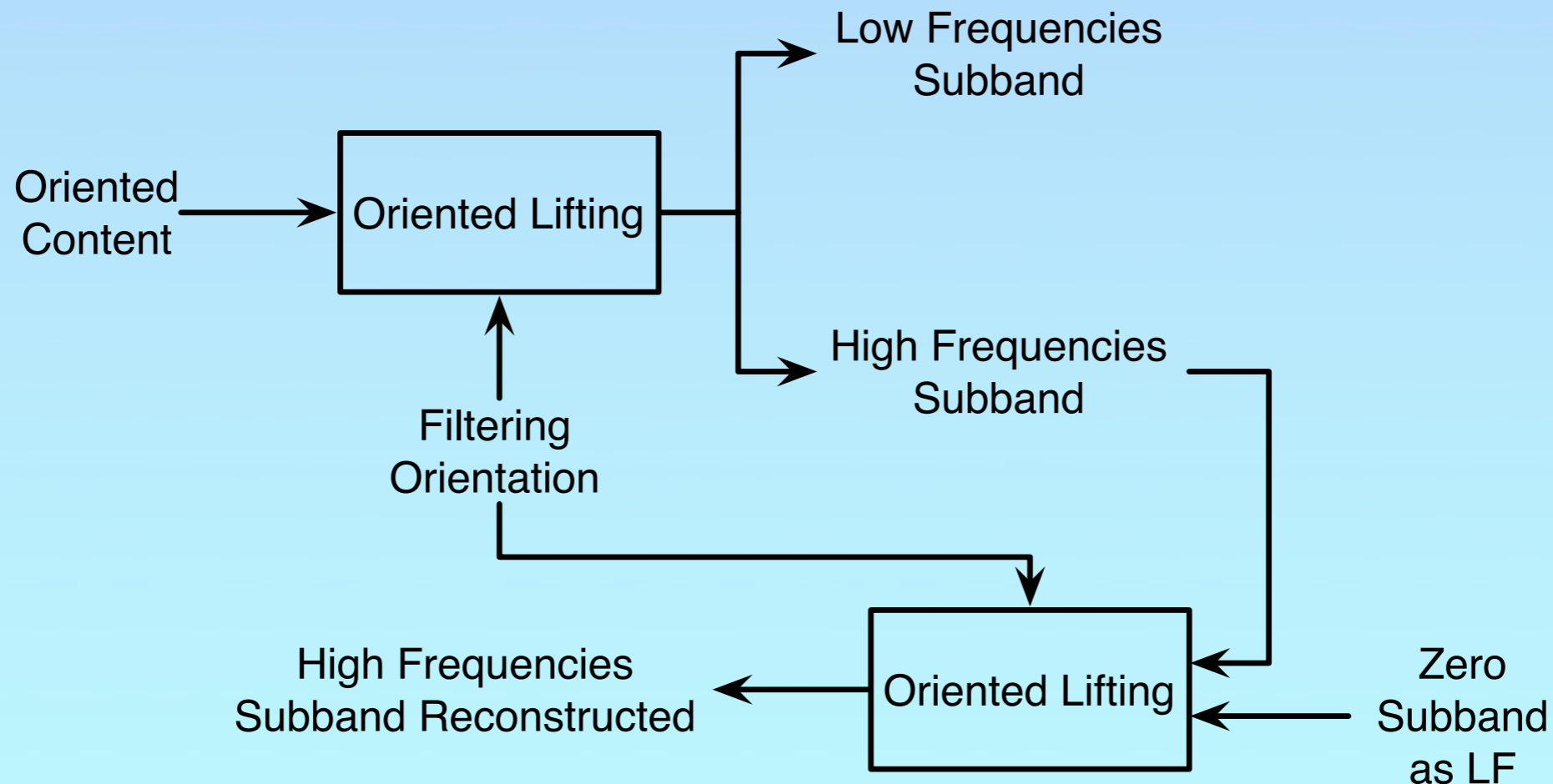
- Our approach: block based polyphase decomposition determined by filtering orientation



Comparison criteria

- Rate-distortion approach implies quantization laws, coder, distortion metric
- Concentrate the information in the LF subband
- For normalization purpose, energy of the reconstructed HF subband

$$D + \lambda \cdot h$$



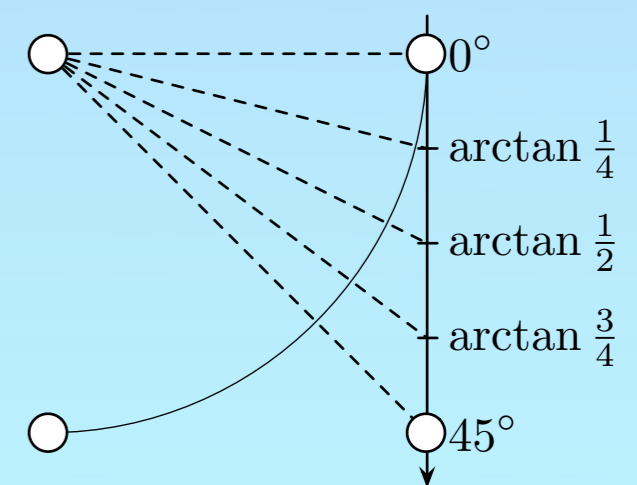
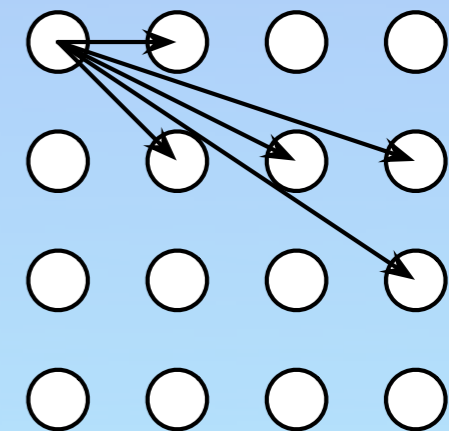
Filtering orientations

- Farey series of order 3 used to define the set of (p,q) filtering orientations

➔ $(1,0)$ $(3,1)$ $(2,1)$ $(3,2)$ $(1,1)$
 $(0^\circ, 18.43^\circ, 26.57^\circ, 33.69^\circ, 45^\circ)$

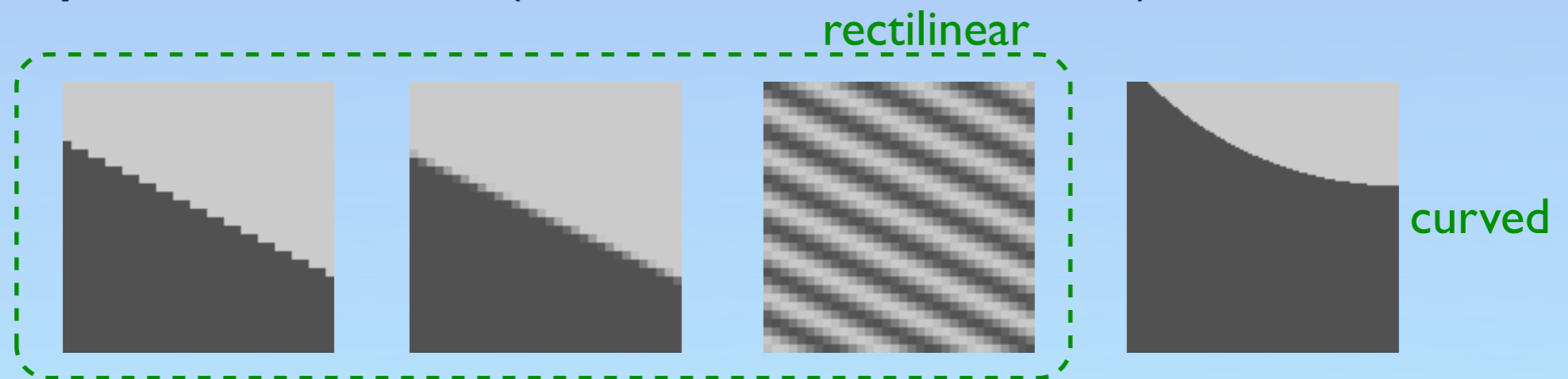
- Set of θ filtering orientations defined by quarter-pixel interpolation

➔ $0^\circ, 14.04^\circ, 26.57^\circ, 36.87^\circ, 45^\circ$



Benchmark of oriented lifting schemes

- Synthetic content (oriented from 0° to 45°)



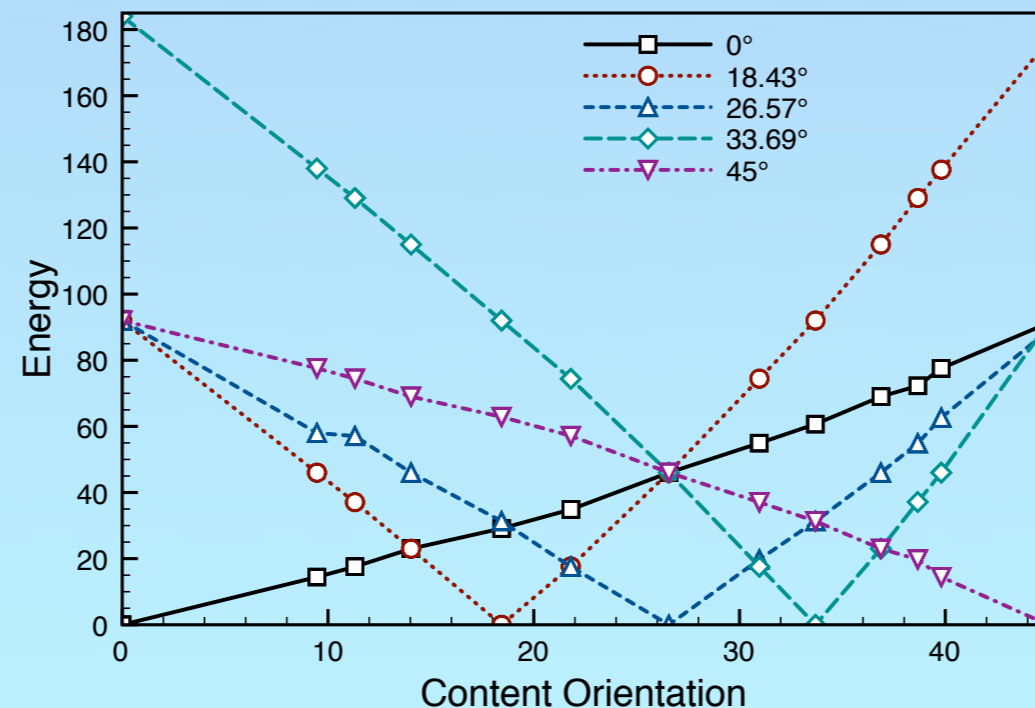
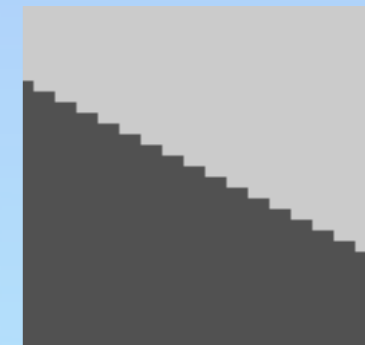
- Natural content



Synthetic contents – rectilinear

- Ideally, the best filtering orientation is the closest to the orientation content

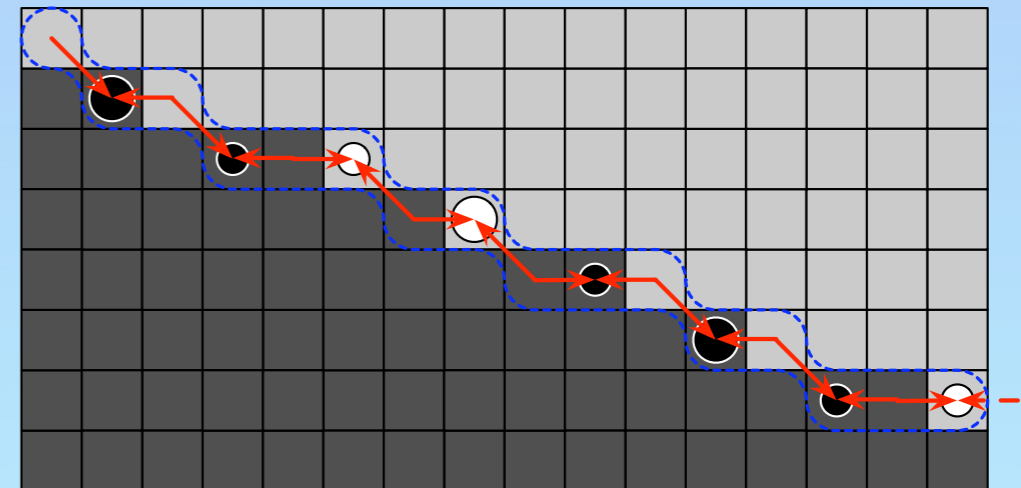
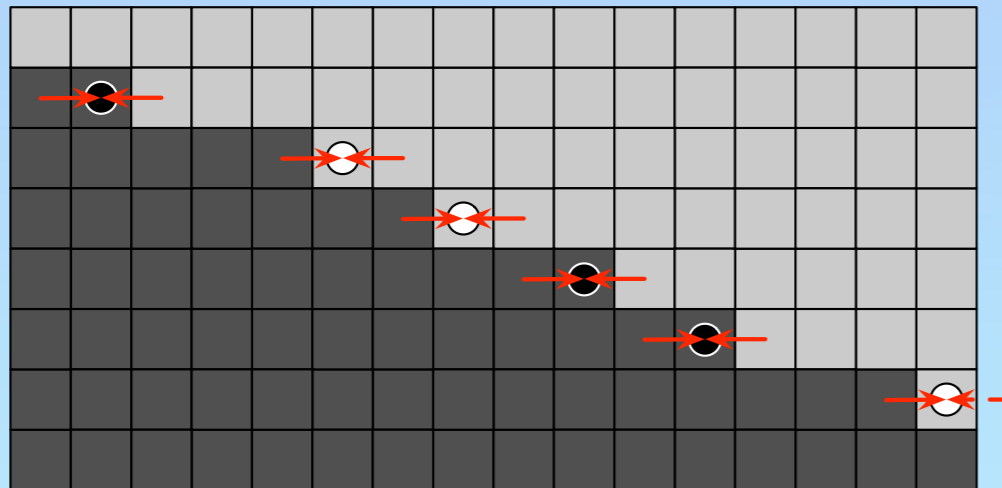
➔ ex: it works with (p,q) -connected- (p,q) -lifting on



- but doesn't work for other lifting schemes

Oriented lifting issues

- Samples from one side of the edge are predicted using samples from the other side of this edge



- θ -lifting introduces interpolation errors

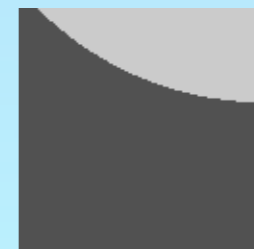
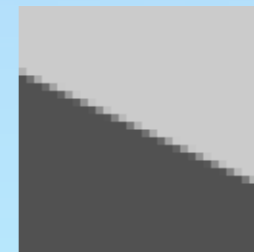
Conclusion on synthetic contents

➔ Only (p,q) -connected- (p,q) -lifting efficient on tested synthetic contents

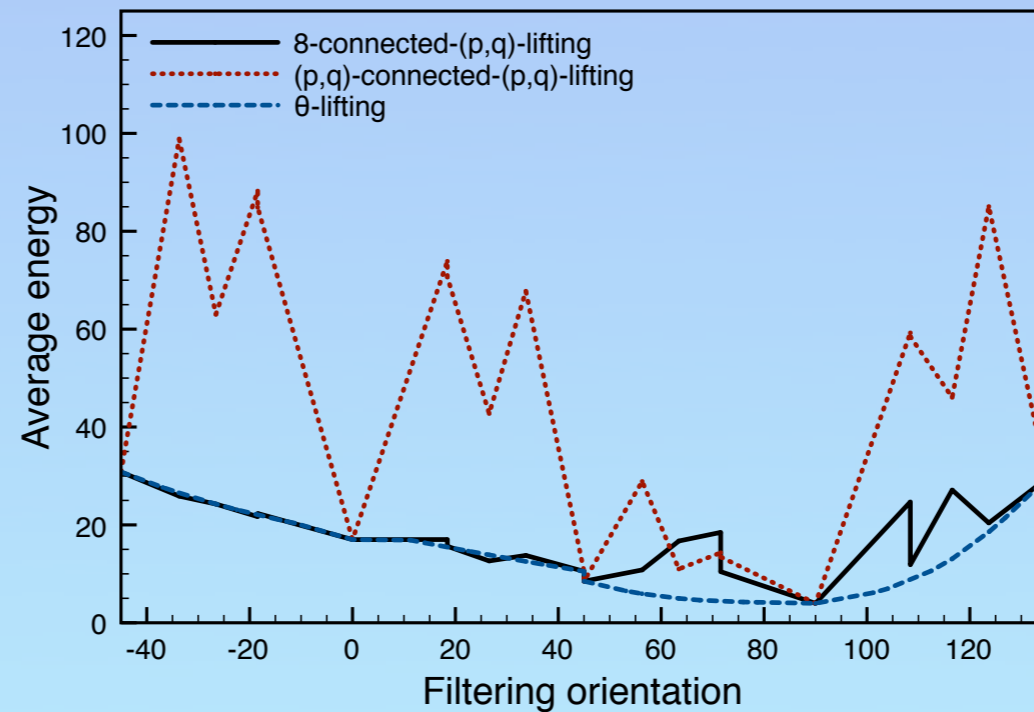
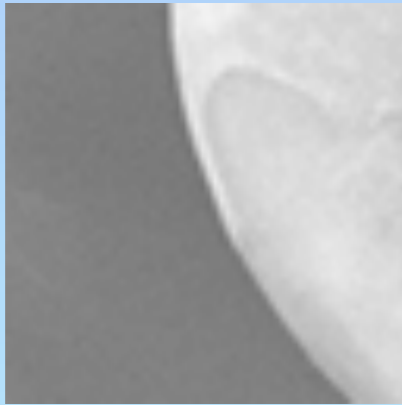
● however:

- edge smoothness ↗ ⇒ efficiency ↘

- edge curvature ↗ ⇒ efficiency ↘



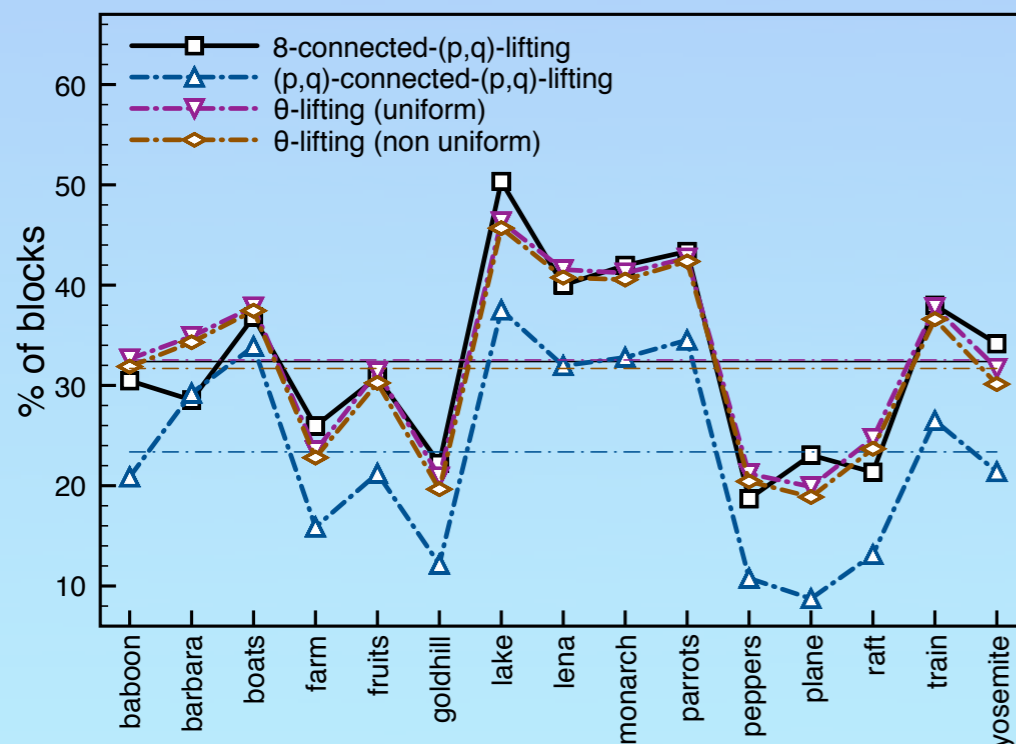
Natural contents



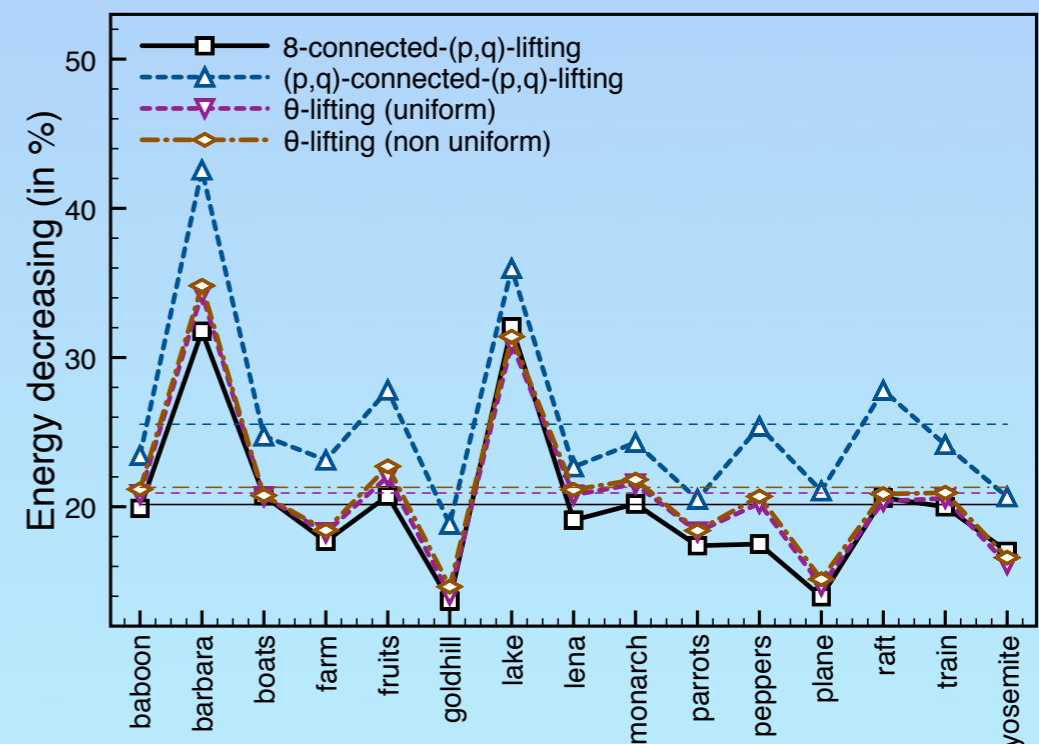
- (p,q)-connected-(p,q)-lifting
 - ➔ spatial coherency => worse results and instability
- + θ -lifting
 - ➔ interpolation => noise reduction

Results on natural images — Conclusion

- Brute force on 8x8 blocks, 15 images



θ -lifting more frequently efficient

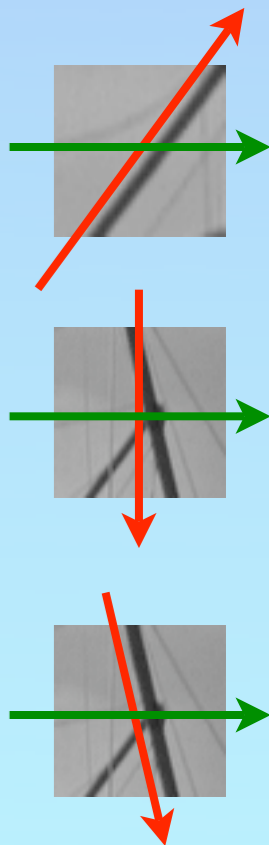
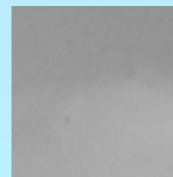


(p,q)-connected-(p,q)-lifting locally more efficient

- On average, θ -lifting more efficient and stable

Geometry estimation and coding (1/2)

- Brute force filtering orientation estimation
 - ➔ For **mono-oriented** region, orientation of the content close to the orientation minimizing the energy
 - ➔ For **multi-oriented** region, no relation
- Need to estimate the primary structure orientation so that HFRreg contains the less information about this structure
- For isotropic content, a DWT is applied
 - Uniform
 - Isotropic texture



Geometry estimation and coding (2/2)

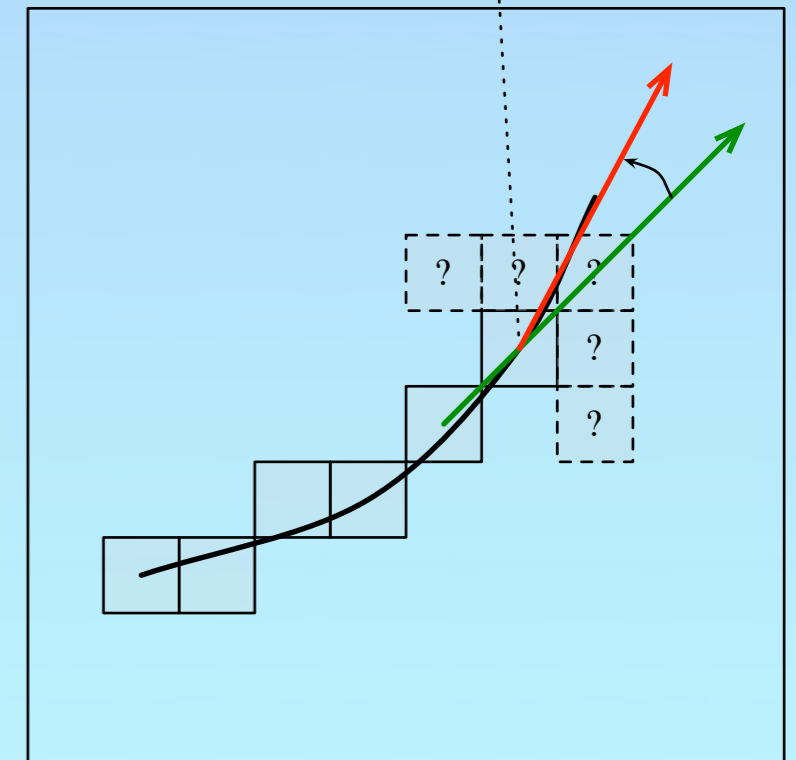
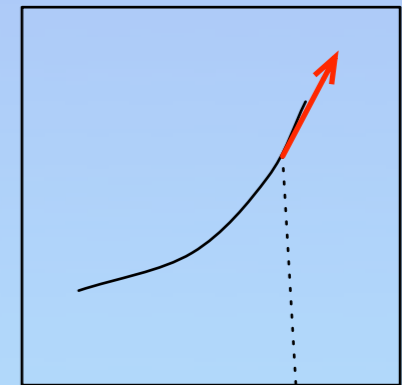
- 2 methods to estimate the orientation of the primary structure of a region, and to classify the region:
 - Explicit edge extraction and chain coding
 - Implicit geometry estimation and quadtree coding

Explicit geometry estimation and coding

- Local extrema of the gradient extraction => **pixels chains**
 - ➡ Estimation of edge elements orientations
 - ➡ Quadtree segmentation based on edgels orientations quantization
 - Filtering orientation quadtree
 - Structural classification quadtree
- Coding: **chain** coding or **quadtree** coding
- Issue: texture detection

Chain coding

- State of the art: differential Freeman codes using adaptive arithmetic coding
- Contribution: add **multiresolution** context to only local spatial context
- Chain pixel position predicted using previous chain pixels and/or **gradient orientation at the previous resolution**
- On average on 10 test images, 3% bitrate decrease up to 8% with only gradient information



Implicit geometry estimation

- Block based segmentation based on a cost function optimization

- Measure of the local gradient orientation θ_I

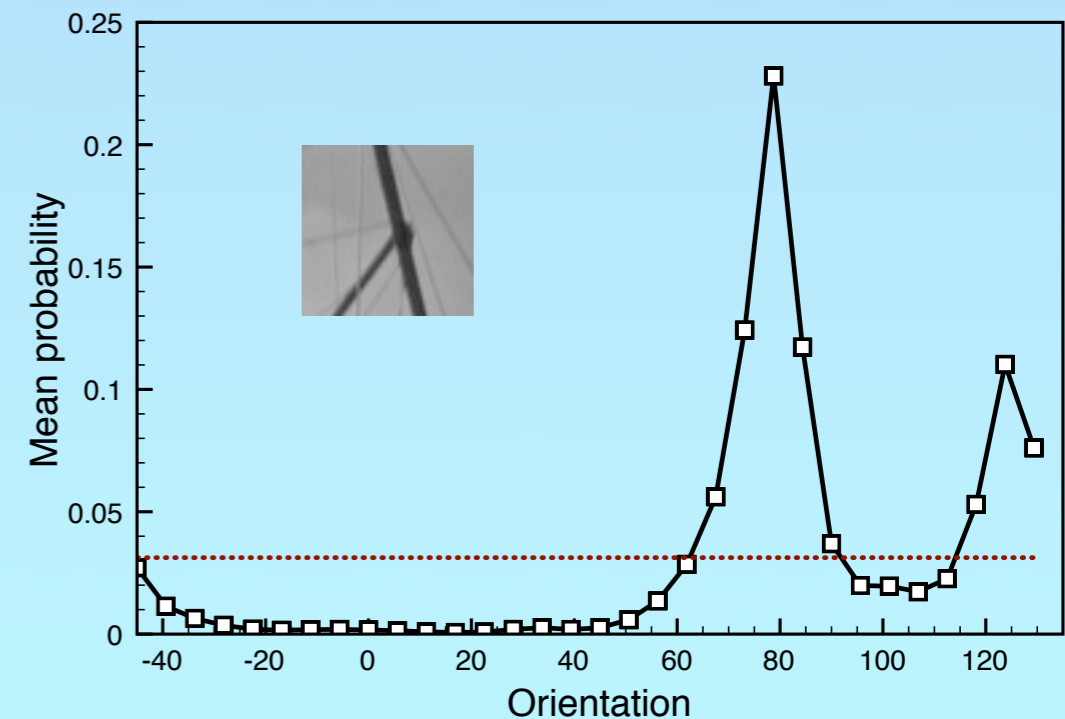
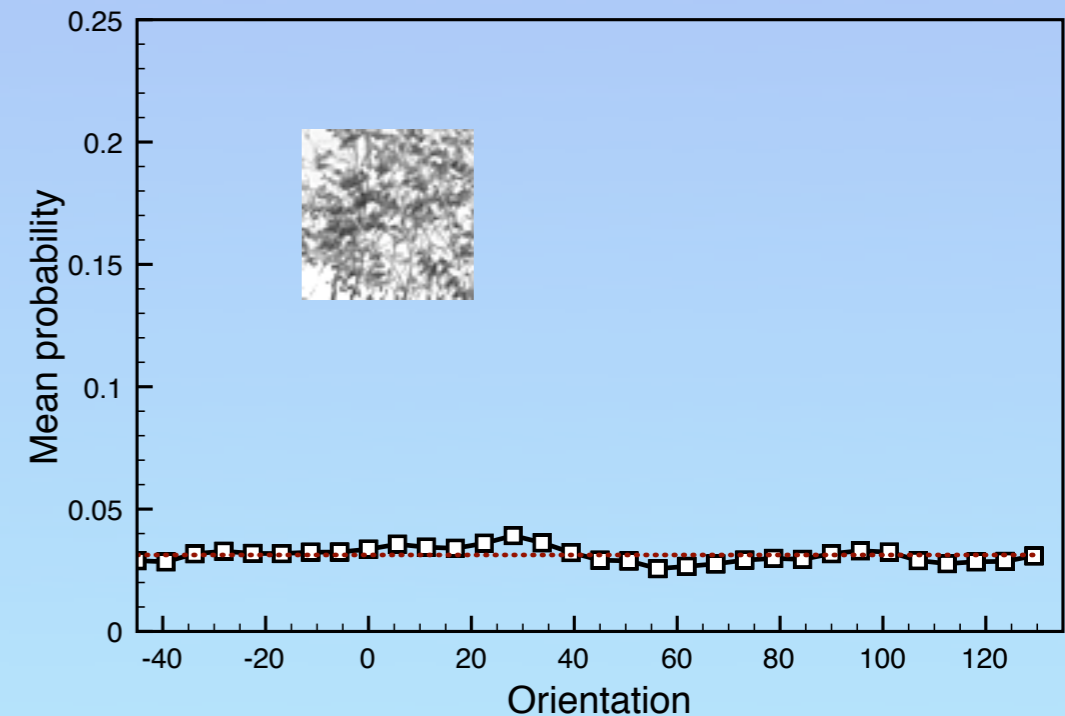
- Gaussian model of measure uncertainty

$$\mathcal{N} \left(\theta_I + \frac{\pi}{2}, \frac{\sigma}{\|\nabla I(x, y)\|} \right)$$

- Average of relevant contribution (gradient norm thresholding)

Implicit geometry estimation

- Not enough relevant contributions
➔ **Uniform** region
- Variance below threshold
➔ **Isotropic textured** region
- # of local maxima
➔ **Mono-oriented** or **multi-oriented** region
➔ global maximum => filtering orientation



Quadtree coding

- For both methods, 2 quadtrees to encode:
 - Filtering orientation quadtree
 - Structural classification quadtree
- Arithmetic contextual quadtree coding using causal neighbourhood
- For 8x8 blocks, edge coding cost on average 3 times lower than edge coding cost

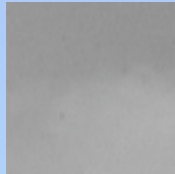
Conclusion

- 2 methods to estimate the primary structure orientation and structural classification of a region
- Contributions:
 - chain coding using multiresolution context
 - orientations detection and estimation using a gaussian model of the local gradient measure uncertainty
- However quadtree coding costs are lower than chain coding costs

Quantization of oriented wavelet coefficients

- Use the a priori of our representation to adapt the quantization of the oriented wavelet coefficients
 - Structural classification
 - ➔ Different quantization strategies for each class taking into account the spatial frequency content
 - For anisotropic regions, oriented filtering
 - ➔ Exploit the difference between HFReg and HFOrtho

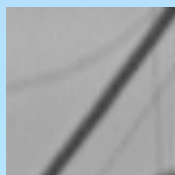
Quantization strategy



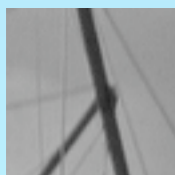
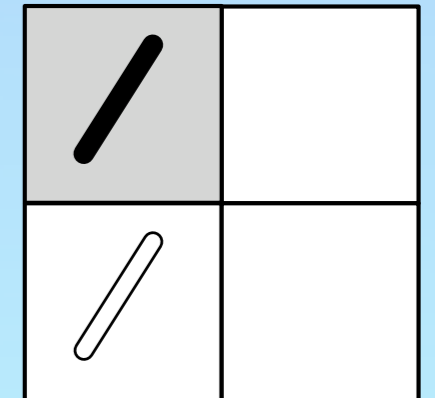
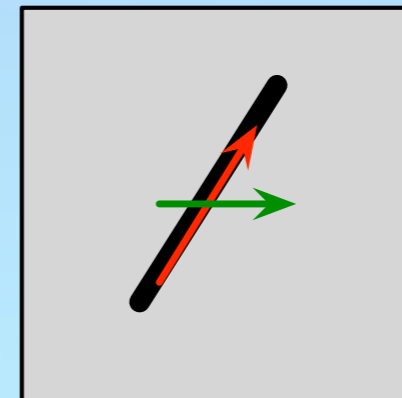
- Uniform:
 - CH, CV, CD => finer quantization



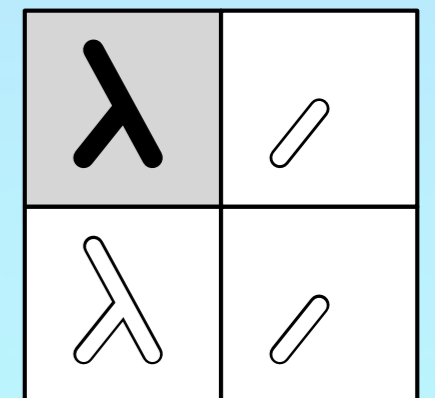
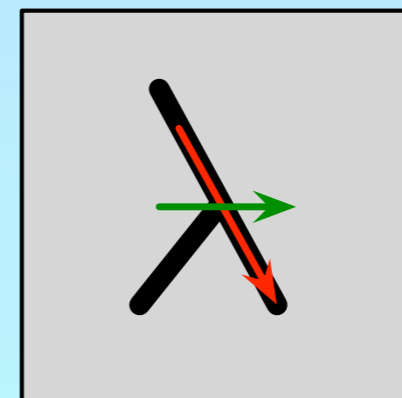
- Isotropic textured:
 - CH, CV, CD => coarser quantization



- Mono-oriented:
 - HFReg+HFRes => coarser quantization
 - HFOrtho => coarser quantization

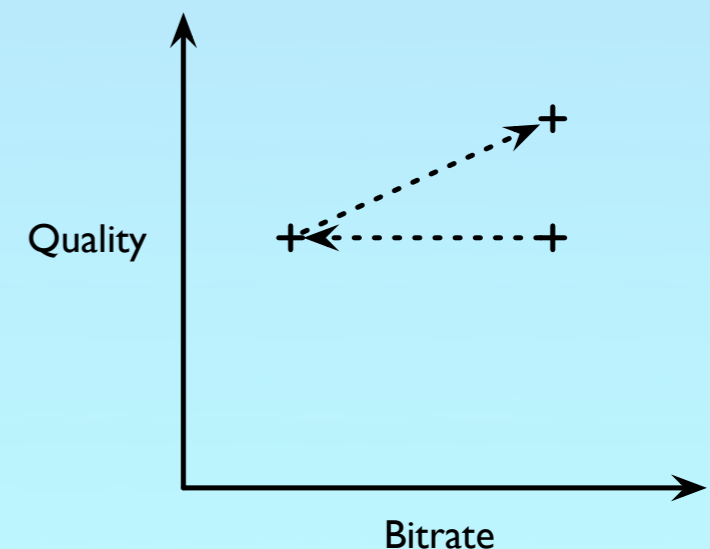


- Multi-oriented:
 - HFReg+HFRes => coarser quantization
 - HFOrtho => coarser quantization



Experimentations

- Setup
 - 5 levels transform, oriented wavelet on the 3 first ones (9/7)
 - 3 levels x 4 structural classes => 12 quantization step weights
 - SPIHT
- Automatic optimization requires efficient distortion metric
- Experimentations with only slightly annoying distortions
- Quantization steps tuning
 1. Increase quantization steps without introducing visible distortion
 2. Decrease quantization steps in uniform region



Objective quality results

	entropy		bitrate		PSNR		SSIM		C4	
	DWT	DOWT	DWT	DOWT	DWT	DOWT	DWT	DOWT	DWT	DOWT
baboon	0,506	0,456	0,524 \approx 0,528		25,32	25,91	0,758	0,780	0,842	0,852
barbara	0,594	0,547	0,538 \approx 0,533		31,94	31,59	0,906	0,899	0,884	0,875
boats	0,498	0,451	0,482 \approx 0,486		35,59	34,69	0,935	0,926	0,902	0,906
farm	0,505	0,457	0,516 \approx 0,520		31,82	30,97	0,849	0,821	0,899	0,890
monarch	0,289	0,246	0,277 \approx 0,275		30,82	30,84	0,920	0,919	0,880	0,881
train	0,873	0,840	0,887 \approx 0,881		25,47	26,99	0,828	0,865	0,893	0,893



-9%

Improvements and new distortions

- + edges or textures oriented along 45° or 135°
- + uniform regions
- + denoising along oriented structures



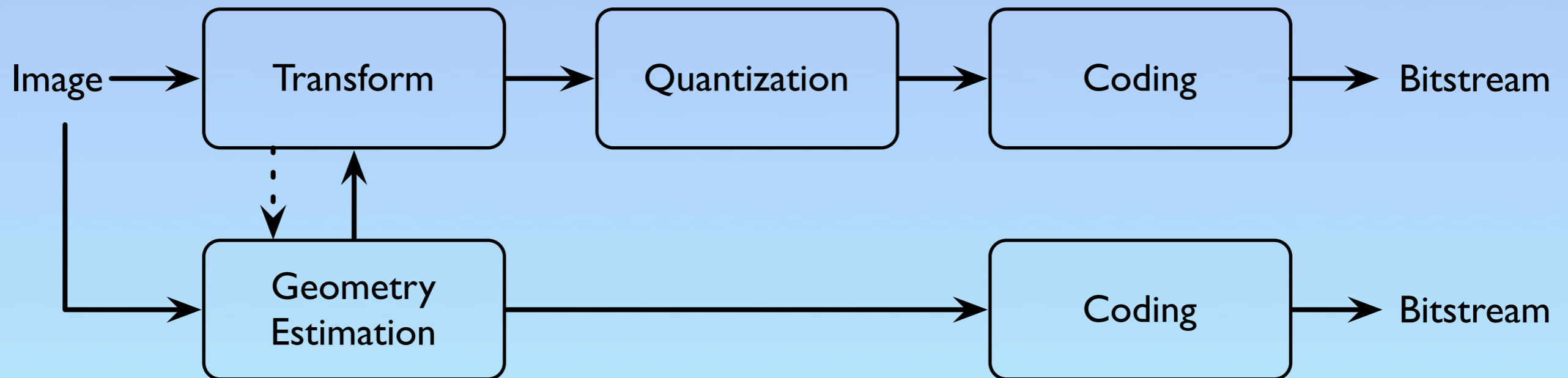
- staircase noise along edges
- structure loss because of classification
- oriented blurring



Conclusion

- Quantization laws adaptation using a priori from the structural classification
- Limitation: experimental approach at a very good quality range because at the time of the work, no very precise objective quality metric was available
- Quality improvements:
 - oriented transform $\Rightarrow 45^\circ$ and 135°
 - structural classification \Rightarrow on uniform region via bitrate re-allocation
- Apparition of new distortions
- SPIHT coder not adapted to 2D-DOWT

Global Conclusion



- Transform: θ -lifting scheme chosen among three lifting schemes
- Geometry estimation: implicit cost function maximization
- Geometry coding: contextual quadtree coding outperforms chain coding
- Quantization strategy: improves the true visual quality

Future works

- Segmentation optimization with variable block size
- Classification decision criteria taking into account the coding costs
- Design of quantization laws through psycho-physics tests
- Vector quantization to take into account the oriented structure of the wavelet coefficients
- Analytic formulation of distortion for optimizing bitrate/perceptual distortion
- Integrate other features in the representation (visual saliency)



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Thanks for your
attention

