JPEG 2000 Progress Report: Part 2 Support for Optional Filter Banks

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Objective

- **Allow user-supplied filter banks other than the 9/7 and 5/3 from Part 1**
- **Facilitates various extensions:**
  - **Specific camera or computing hardware characteristics**
  - **Specialized image content**
  - **Multicomponent band-decorrelation filters**
  - **Data-dependent filters (e.g., "principal component filter banks")**
- **Decision to employ user-supplied filter bank is an *encoder* option; hard to anticipate in advance what encoders will want to do in the future, but syntax and algorithms for decoding need to be supplied in Part 2.**
- **Two primary categories of "Part 2" filters:**
  - **"Old favorites" that have been used in the past**
    - **Can codify specific implementations, including reversible methods**
  - **Arbitrary user-defined filter banks**
    - **Need generic algorithms for implementing and signaling filter banks**
    - **Demand for both odd- and even-length linear phase filter categories**

Key Technical Problems

- Implementation of generic odd-length filters is a straightforward generalization of current Part 1 algorithms:
  - Same symmetric extension methods used for the 9/7 filter bank will work for arbitrary odd-length filter banks, either convolutional or lifted.
  - Symmetric extension does not affect reversibility; i.e., symmetric extension techniques enable lossless coding with *any* reversible filter bank.
  - Lifting implementation necessary for reversible transforms and SSOWT.
- Signaling generic lifting implementations requires validating a generic lifting architecture:
  - VM currently accepts multiple, high-order lifting steps.
  - Part 2 Annex F (CD Pre-release) has been structured to formalize the VM's approach to signaled filter banks, using the same lifting step structure for both odd- and even-length linear phase filters.
- Implementation of generic even-length filters requires new transform algorithms to enable resolution scalability and geometric image manipulations within the compressed codestream.

Resolution Scalability

- **Resolution scalability: expressed by the convention of alternating lowpass & highpass samples, incl. across tile boundaries, regardless of tile sizes or number of levels of wavelet decomposition.**
  - **Equivalent to having DWT algorithms for both "lowpass-first" and "highpass-first" transforms on both even-length and odd-length tiles:**
    - **For even-length tiles (N=2K), need algorithms that produce K lowpass and K highpass outputs.**
    - **For odd-length tiles (N=2K+1), need algorithm that produces K+1 lowpass and K highpass outputs ("lowpass-first"), and another that produces K+1 highpass and K lowpass outputs ("highpass-first")**
  - **This is already enabled for arbitrary odd-length filter banks using symmetric extension algorithms in Part 2 Annex F.**
- **We have defined transform methods for even-length filter banks that satisfy these conditions, as well as enabling geometric image transformations via compressed codestream manipulation.**
- **Four transform cases: even-length input w/ lowpass-first (EL) or highpass-first (EH) offset; odd-length input w/ lowpass-first (OL) or highpass-first (OH) offset.**

Geometric Image Manipulation

- **Transforms intertwined by an image manipulation on the canvas**

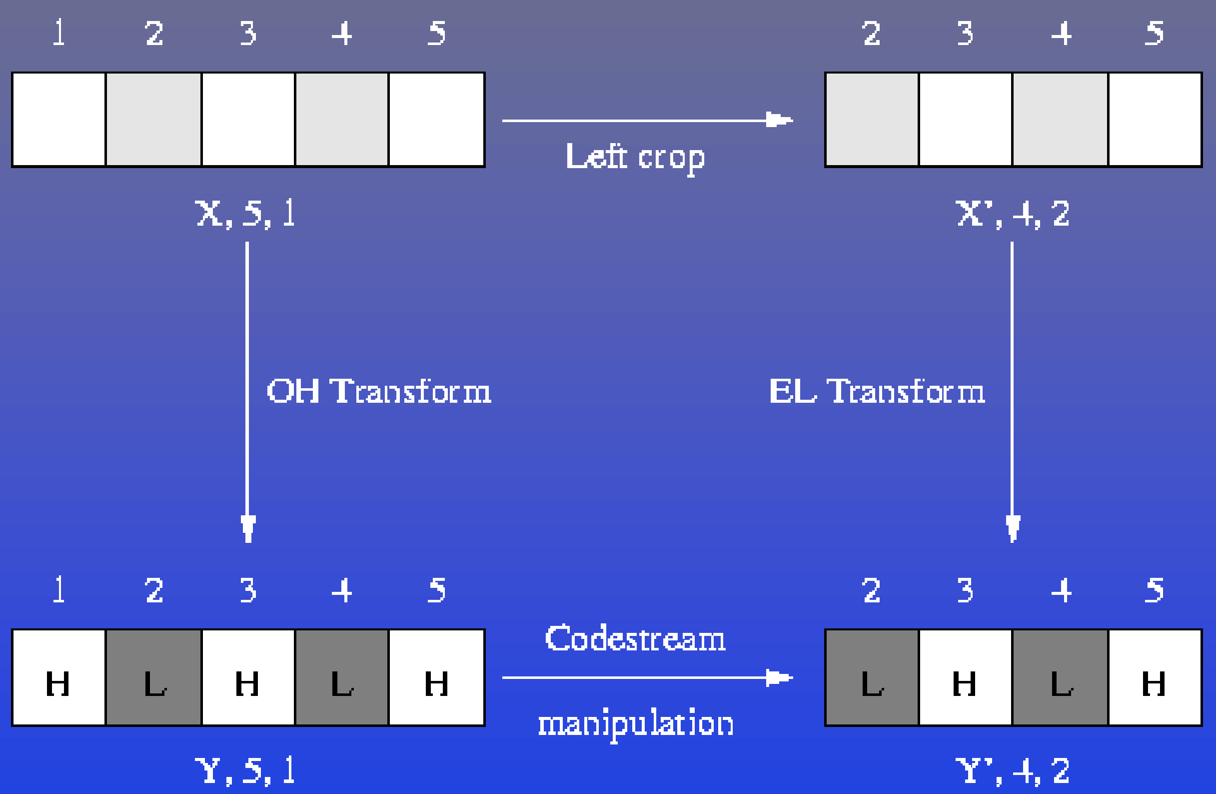
$$
\begin{tikzcd}
X, N_0, I_0 \arrow[r, "\text{Image manip}"] \arrow[d, "T"'] & X', N'_0, I'_0 \arrow[d, "T'"] \\
Y, N_0, I_0 \arrow[r, "\text{Codestream manip}"] & Y', N'_0, I'_0
\end{tikzcd}
$$

•Transforms T' intertwined with T: these intertwinings *must* be satisfied by any proposed transform def's so as to abide by the odd/even offset conventions of the canvas (necessary cond's)

T	**flip**	**shift & flip**	**crop 1 left**	**crop 1 right**
EL	EH	EL	OH	OL
EH	EL	EH	OL	OH
OL	OL	OH	EH	EL
OH	OH	OL	EL	EH

Intertwining Example: Left Cropping

- **OH and EL transforms need to be chosen so that the codestream manipulation only needs to crop a highpass coef. and recompute the next couple of samples of Y'.**



Transform Definitions for Odd-Length Filter Banks

- **All input vectors extended by (1,1)-symmetric extension.**
- **One analysis filter has impulse response center at 0, the other analysis filter has impulse response center at -1.**
- **The transforms for odd-length filter banks are defined as follows:**

Transform	Lowpass, Highpass Centers
EL	0, -1
EH	-1, 0
OL	0, -1
OH	-1, 0

- **These choices satisfy resolution scalability.**
- **Codestream manipulations exist for flip, crop transformations.**

Transform Definitions for Even-Length Filter Banks

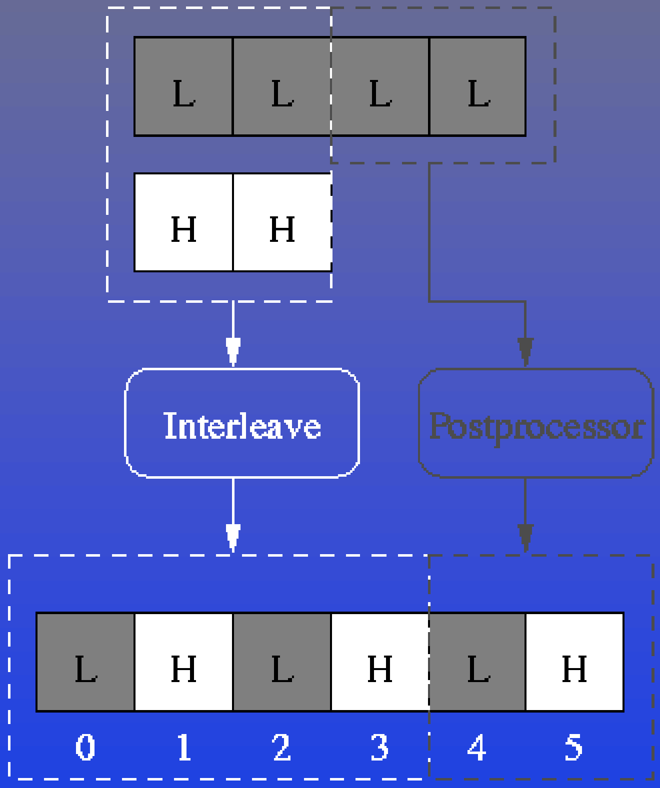
- **All input vectors extended by (2,2)-symmetric extension.**
- **Analysis filters have both impulse response centers at -1/2 or +1/2.**
- **The transforms for even-length filter banks are defined as follows:**

Transform	Lowpass, Highpass Centers	Postprocessing at right boundary
EL	+1/2, +1/2	(L,L) -> (L,H)
EH	-1/2, -1/2	
OL	+1/2, +1/2	
OH	-1/2, -1/2	(L,L) -> (L,H)

- **These choices satisfy resolution scalability.**
- **Codestream manipulations exist for shift & flip, crop transformations.**
- **Previous proposal involving (2,2)-antisymmetric extension:**
  - **Did not support all transform-domain geometric manipulations**
  - **Exhibited undesirable sensitivity to tiling parameters**

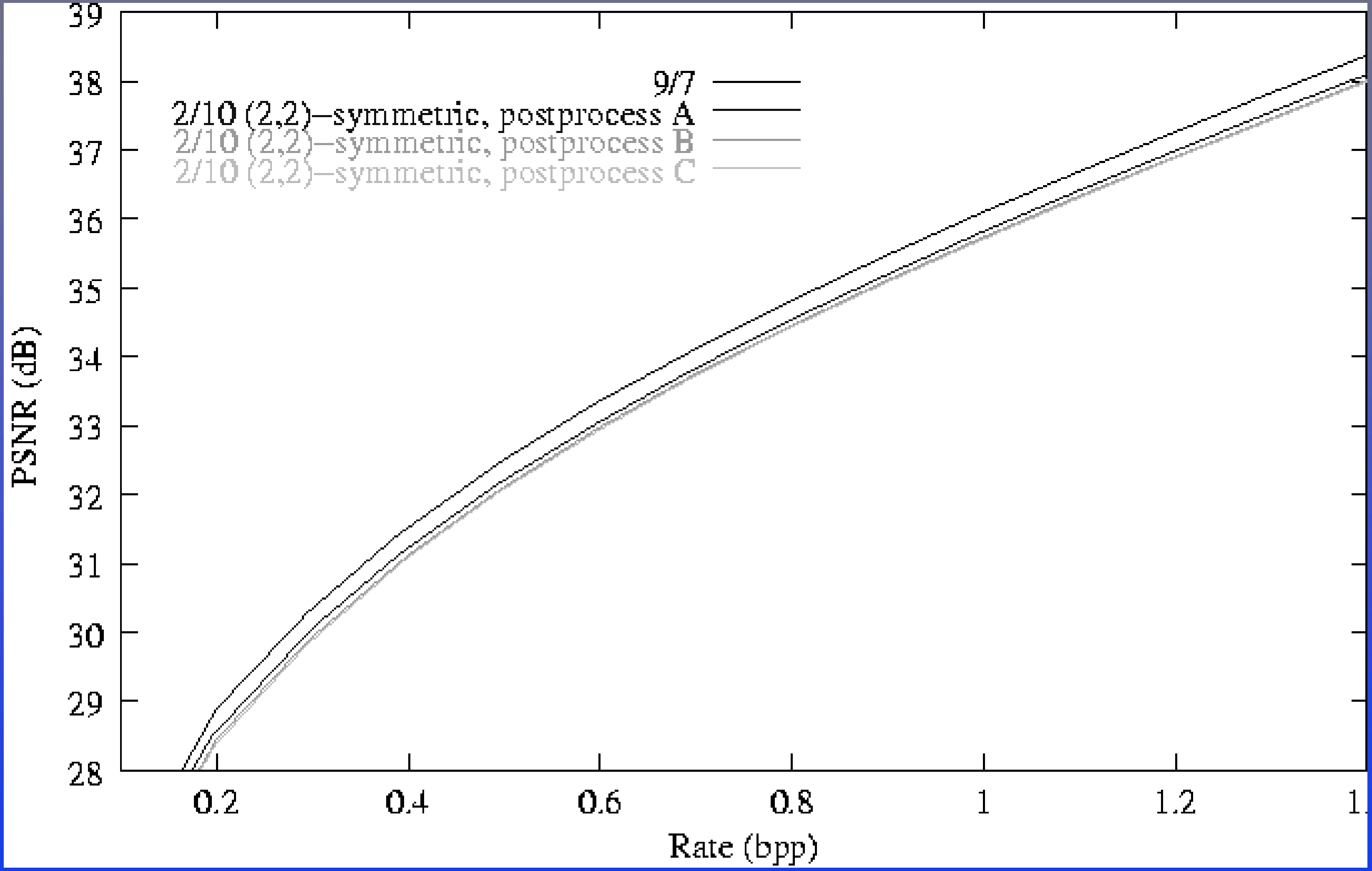
Postprocessing Concept

- **Example of postprocessing at right end of the EL transform.**
- **E.g., 2-point Haar: {L, L'} -> {(L+L')/2, (L-L')/2}**
- **Other options exist**



Quantitative Results

- **Rate-distortion comparisons for "goldhill" image with 128 x 128 tiles, 5 levels of decomposition (extreme case exaggerating boundary effects)**



Summary

- LANL has implemented the convolutional algorithms for even-length linear phase filter banks in VM 7.2.
  - Allows decomposition using even-length filter banks on arbitrary-size images with arbitrary tilings, subband decompositions, or reference grid offsets.
  - Handles all cases successfully based on testing done to date (testing has been limited to even-length filter banks with 2-tap lowpass analysis filters).
  - Shown to be compatible with transform domain geometric manipulations.
  - Fine-tuning details of postprocessing at right boundary to be resolved.

Recommendations

- Include even-length algorithms in Part 2 Annex F using the generic lifting framework already defined there.
- Add examples of even-length filter banks to Part 2 Annex F.
- Add LANL convolutional software to VM.
- Continue the core experiment for New Orleans:
  - Fine-tune choice of 2-point postprocessing transform, incl. subjective analysis of distortion & tiling artifacts.
  - Develop software lifting implementation of generic transforms for both even- and odd-length optional filter banks.
  - Work with Part 2 Annex G and H authors to verify compatibility of generic filter bank specifications and software with the SSOWT methods in Annex G and the generalized subband decompositions in Annex H.