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ISO/IEC JTC1/SC29/WG1
(ITU-T SG8)

Coding of Still Pictures

JBIG	**JPEG**
Joint bi-level Image Experts Group	Joint Photographic Experts Group

TITLE: Interim Report on (Part 2) Core Experiment CodEff07, "7-tap/5-tap Filter Bank Option"

SOURCE : Chris Brislawn
Los Alamos National Lab, USNB

PROJECT : JPEG 2000

STATUS : Report

REQUESTED ACTION : To be presented at WG1 meeting in Arles July 2000

DISTRIBUTION: WG1 web pages

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Core Experiment Description/Results Summary on VM 7.2

Experiment Name: 7-tap/5-tap Filter Bank Option (Part 2)

Sub-Group: _Coding Efficiency__ Number: __CE7________

Description:

Core experiment **partners**	Los Alamos National Lab-USA, Motorola Australia
Core experiment **objective**	Design and characterize performance of proposed 7/5 filter bank as a Part 2 option.
JPEG 2000 **Requirement** Focus	Expand user options for complexity-vs.-performance tradeoffs.
What will **change** fro Verification Model 7.	Additional filter bank option.
Key **Benefit** of chang	Intermediate complexity and performance as compared to 9/7 and 5/3 filter banks in Part 1.
Related Experiments	
Expected Memory Decrease/increase	no anticipated changes
Expected Complexity Decrease/increase	Intermediate DWT complexity as compared to 9/7 and 5/3 filter bank in Part 1.
Other expected result	

Core experiment detai description	Produce a 7-tap/5-tap filter bank optimized for JPEG-2000 applications using recently developed numerical design techniques. Characterize complexity, coding gain, and rate-distortion performanc in comparison to the 9/7 and 5/3 filter banks in baseline (Part 1).

Results:

VM Mode used in experiment	VM 7.2, 5-octave (Mallat) decomposition, rates of 0.25 to 3.0 bpp. Results taken on 3 grayscale JPEG test images.

Was this experiment performed on the VM or in a testbed?	VM

Key **findings**	Rate-distortion characteristics were measured on 3 test images using the baseline 9/7 and 5/3 filter banks and a new 7/5 filter bank with rational taps and rational lifting parameters. The 7/5 filter bank consistently produces SNR results in-between the SNR's generated using the 5/3 and 9/7 filter banks.

1 Introduction

The intent of this report is to describe the quantitative performance of a new 7-tap/5-tap linear phase filter bank designed by numerical optimization methods. As such, this report represents partial results on Core Experiment CodEff_07. The motivation for this work is to produce an alternative to the 9/7 and 5/3 filter banks (the baseline filter banks in Part 1), with intermediate coding performance and intermediate complexity.

2 Experimental Setup

The new filter bank was generated by a numerical optimization procedure and tested for rate-distortion performance on VM 7.2 using JPEG test images. The exact test conditions were as follows.

2.1 Filter bank design

The 7/5 filter bank was designed using a group-theoretic cascade-form polyphase matrix factorization developed by the author and O. Treiber[1]. The factorization was constrained to ensure that both the analysis and synthesis wavelets have two vanishing moments. In the 7/5 category this leaves a single unused degree of freedom, α_3, which is then optimized for coding performance. For the filter bank described in this report, the remaining degree of freedom was used to optimize an analytic model of theoretical coding gain for highly correlated AR(1) processes (correlation coefficient = 0.95) with 5 levels of subband decomposition.

The coding gain and Hoelder regularity landscapes for the 7/5 category are plotted with respect to α_3 in Figure 1. We are using the long (7-tap) lowpass filter for analysis, for the filter bank defined by the parameter value $\alpha_3 = 0.05$. The value $\alpha_3 = 0$ corresponds to the natural embedding of the 5/3 LeGall-Tabatabai filter bank[2] (the 5/3 filter bank from Part 1) into the 7/5 category, so our 7/5 filter bank can be regarded as a perturbation of the 5/3 LeGall-Tabatabai filter bank in a higher-dimensional parameter space. See Figure 2 and Figure 3 for a comparison of these two filter banks. The AR(1, 0.95) coding gain for the 7/5 filter bank is 9.7, versus figures of 9.6 for the 5/3 filter bank and 9.9 for the 9/7 filter bank, which predicts an intermediate coding gain for the 7/5 filter bank that closes the gap between the 5/3 and 9/7 filter banks by about 33%.

The value $\alpha_3 = 0.05$ is only an approximate maxima for AR(1, 0.95) coding gain; the parameter has been rounded to yield a filter bank with rational impulse response taps and rational lifting parameters, as indicated in Table 1, though the number of vanishing moments is preserved exactly in spite of rounding α_3. (Both lowpass filters tabulated here have DC gains of unity.) The rational lifting parameters are in Table 2, followed by

[1] C. Brislawn and O. Treiber, “Lattice Structures for Parametric Design of Odd-Length Linear Phase Filter Banks and Regular Wavelets,” in preparation.

[2] D. LeGall and A. Tabatabai, “Subband coding of digital images using symmetric short kernel filters and arithmetic coding techniques," Proc. IEEE ICASSP-88.

the text of the VM kernel file. Note that the VM syntax requires an initial lifting step of 0 for this filter length, and the software implementation requires that it be a length-2 transfer function!!

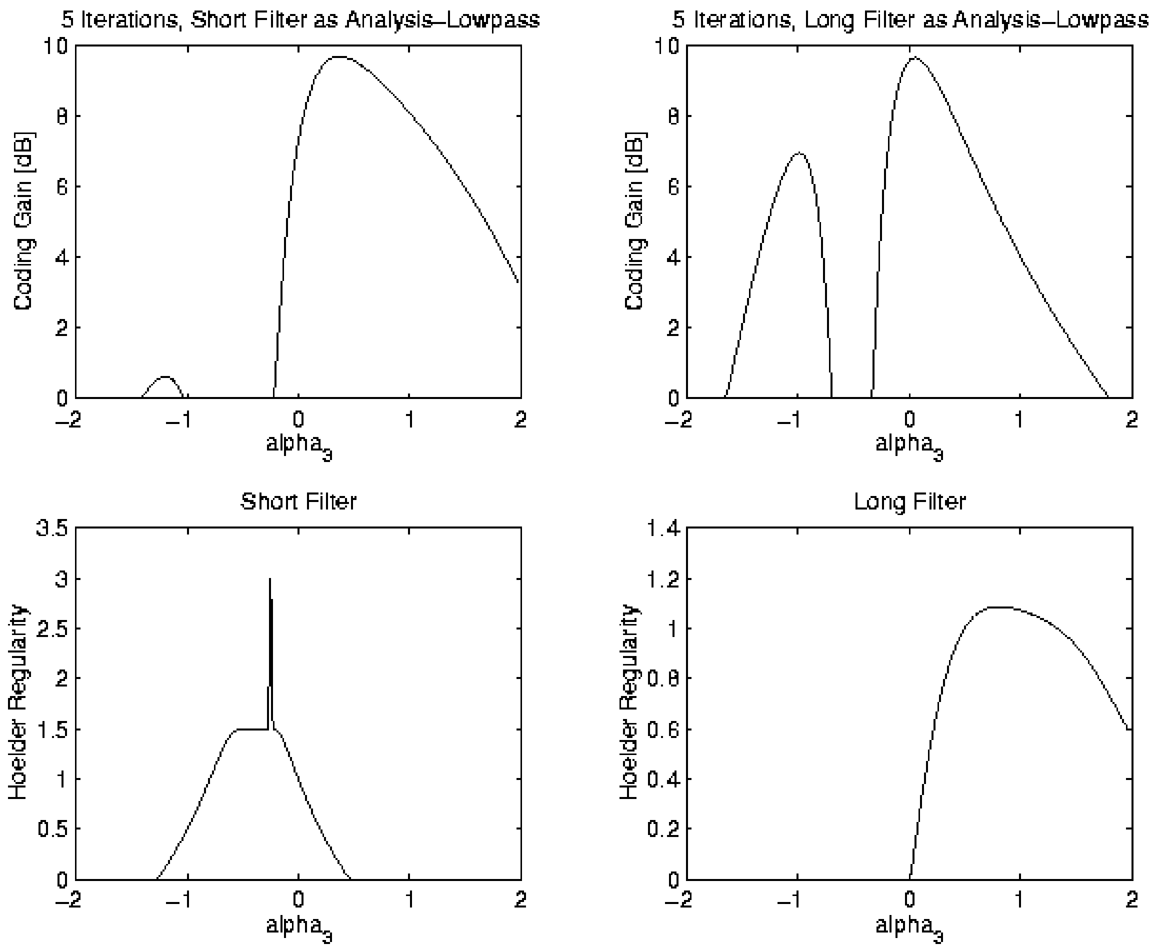

Figure 1. Coding gain and regularity landscapes for 7/5 filter banks.

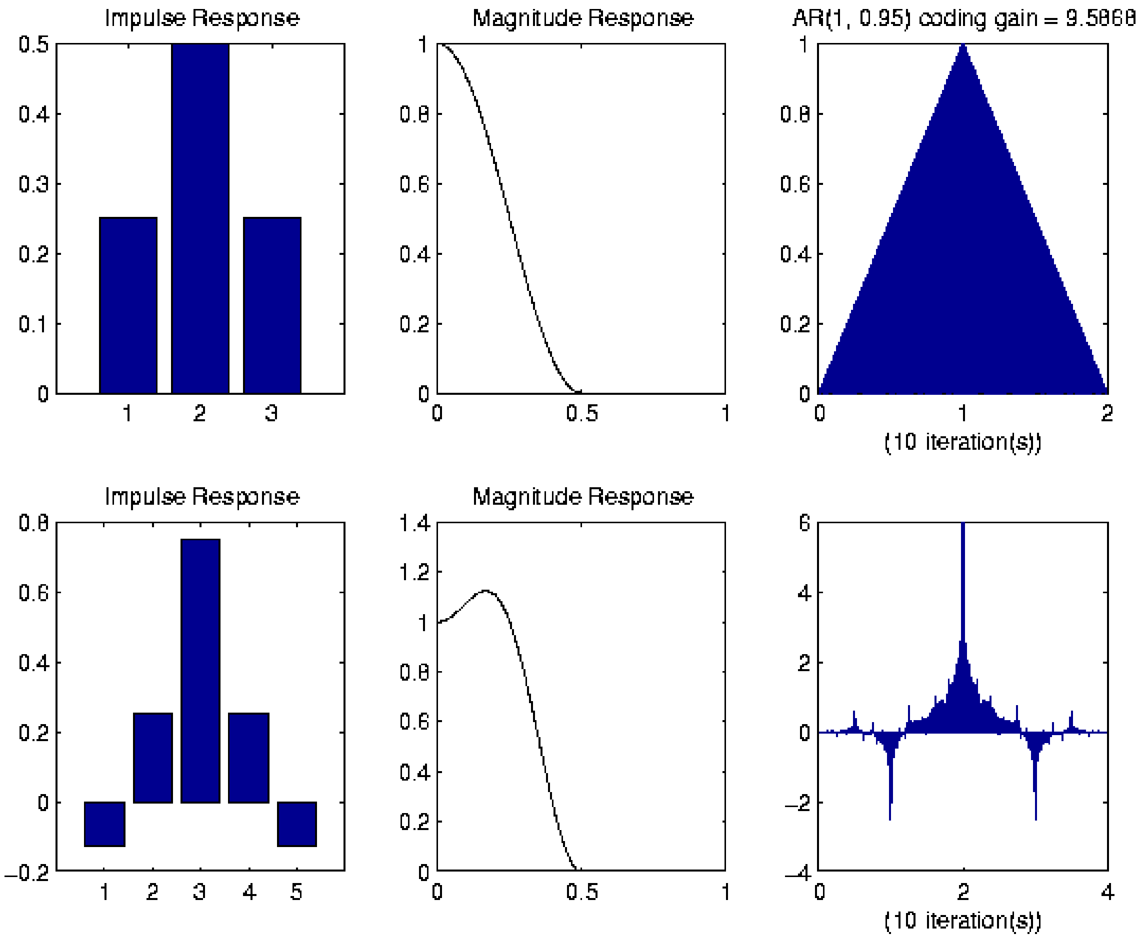

Figure 2. LeGall-Tabatabai 5/3 lowpass filters and corresponding scaling functions.

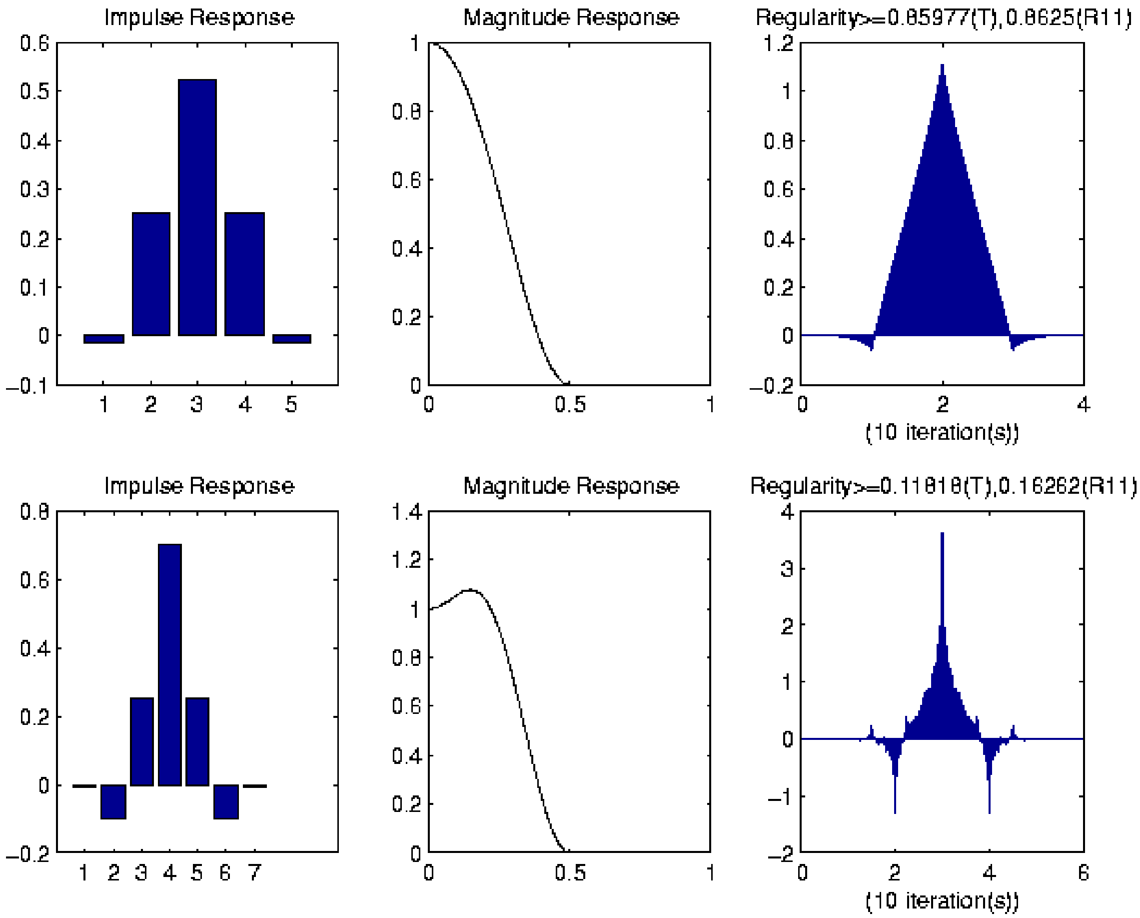

Figure 3. Brislawn-Treiber 7/5 filter bank, parameter $a_3 = 0.05$.

Table 1. Impulse responses of the 7/5 lowpass filters.

n	$h_0(n)$ *(analysis)*	$f_0(n)$ *(synthesis)*
0	31/44	21/40
±1	449/1760	1/4
±2	-9/88	-1/80
±3	-9/1760	

Table 2. Lifting parameters for the 7/5 filter bank.

parameter	*value*
α	1/20
β	-5/11
γ	99/400
K	10/11

Text of the VM kernel file for the 7/5 filter bank:

```
2 2 2 2    # This is the 7-5 filter bank with alpha_3 = 0.05
0              0  # it is necessary to start with a length-2 null lifting step in VM 7.2
0.05           0.05
-0.454545454545    -0.454545454545
0.2475         0.2475
```

2.2 Experimental results

So far, we have tested on just 3 panchromatic (8-bit grayscale) JPEG test images: bike, cafe, and gold. The rate-distortion performance of the 7/5 filter bank was evaluated and compared against the performance of the 9/7 and 5/3 filter banks in irreversible implementations with entropy-constrained optimal rate allocation. Note that this is not the reversible, quantization-free implementation mode for the 5/3 prescribed in Part 1. This choice of nonstandard 5/3 implementation was made in order to compare the performance of the filter banks under identical quantization strategies rather than to compare the performance of Part 1 coding methods. To achieve this, the lifting parameters for all 3 filter banks were supplied to VM 7.2 using the float_lifting syntax. We will, nonetheless, present one comparison (the cafe image) with both irreversible and reversible 5/3 implementations.

The command lines used for irreversible coding with all 3 filter banks were:

```
% vm_compress -i $image_root.pgm -o $image_root.jp2 -rate $rates[$j] -iter 15 -Cno_trunc -Fdir $local_path -Fkernels $kernels[$i]

% vm_expand -i $image_root.jp2 -o $image_root.recon.pgm
```

Rate-distortion curves for the goldhill and bike images are displayed in Figure 4 and Figure 5. In general, the performance of the 7/5 filter bank consistently falls between the performance of the 9/7 and 5/3 filter banks. The gaps in quantitative performance are consistently greater at higher bit rates. For instance, in the goldhill image the SNR for reconstruction at 3.0 bpp using the 9/7, 7/5, and 5/3 filter banks are, respectively, 35.1 dB, 34.9 dB, and 34.7 dB. The performance of the 7/5 filter bank appears to converge to the performance of the 5/3 filter bank at low bit rates (0.25 bpp here).

In Figure 6 we present the rate-distortion characteristics for the cafe image with both irreversible and reversible 5/3 implementations. The reversible coding was done using the following command line:

```
% vm_compress -i $image_root.pgm -o $image_root.rev.jp2 -Frev -Clayers 0.25 0.5 1.0 2.0 3.0

% vm_expand -i $image_root.rev.jp2 -o $image_root.rev.pgm -trunc $rates[$j]
```

Although the 7/5 and irreversible 5/3 implementations have very similar rate-distortion performance across the tested range of rates on this particular image, the reversible 5/3 implementation with optimized entropy-coding layers for the tested rates and entropy-constrained decoding has measurably poorer performance, particularly at higher rates.

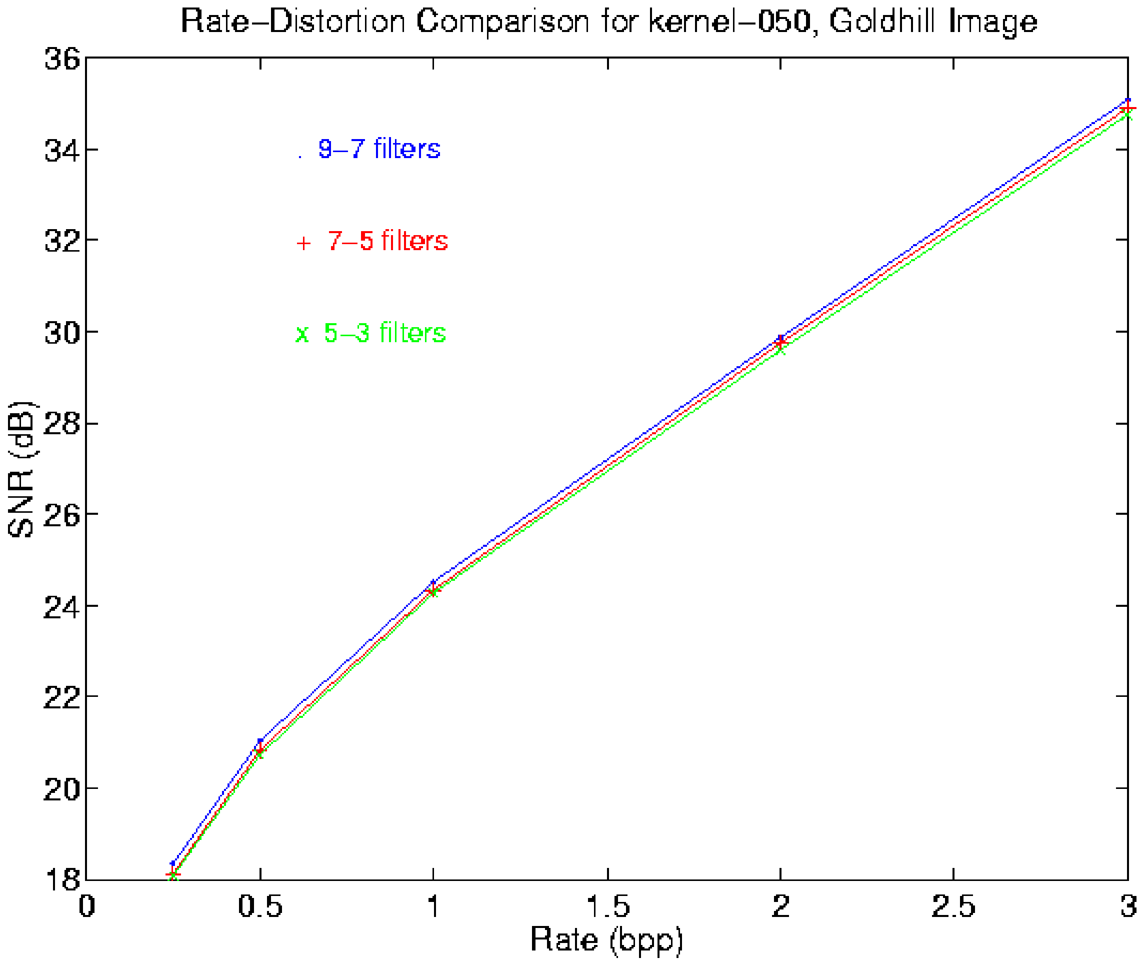

Figure 4. Goldhill rate-distortion characteristic.

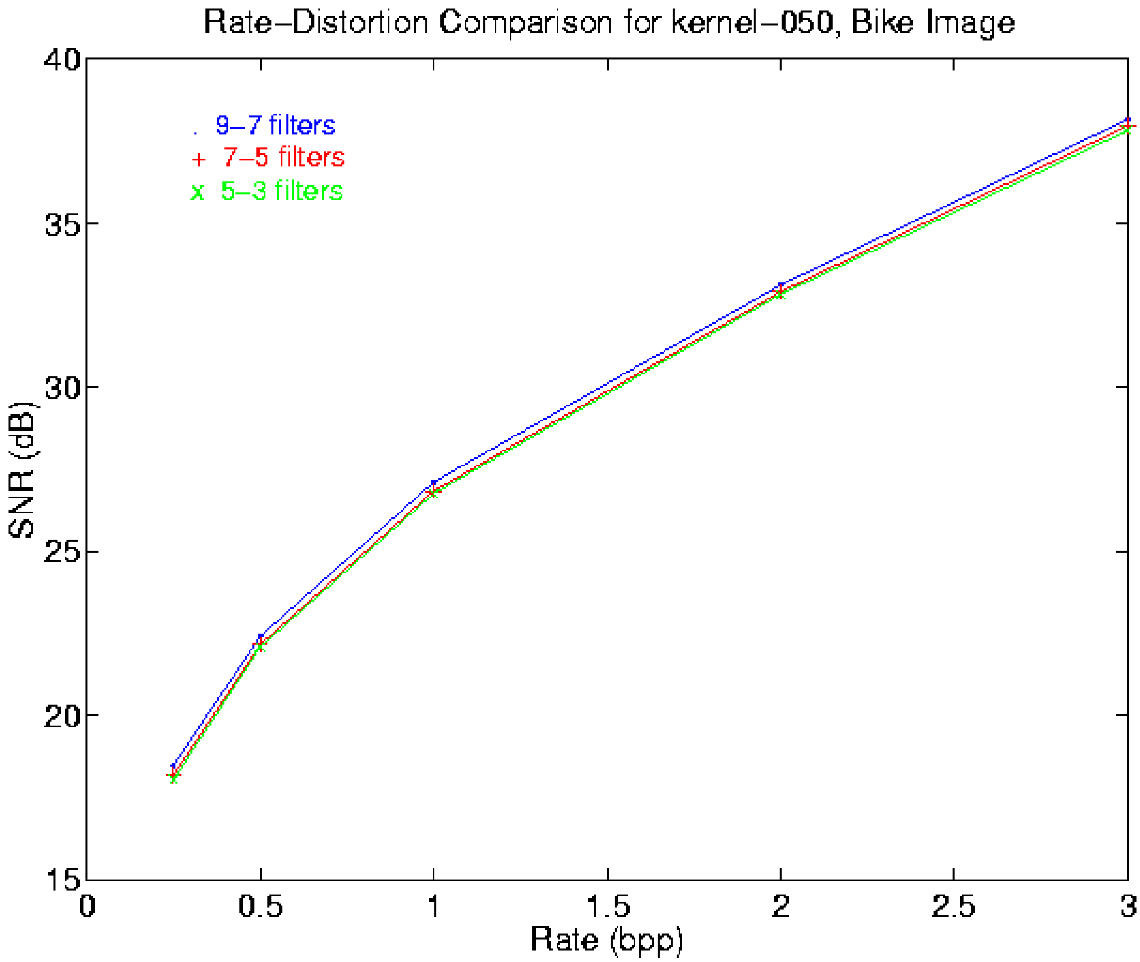

Figure 5. Bike rate-distortion characteristic.

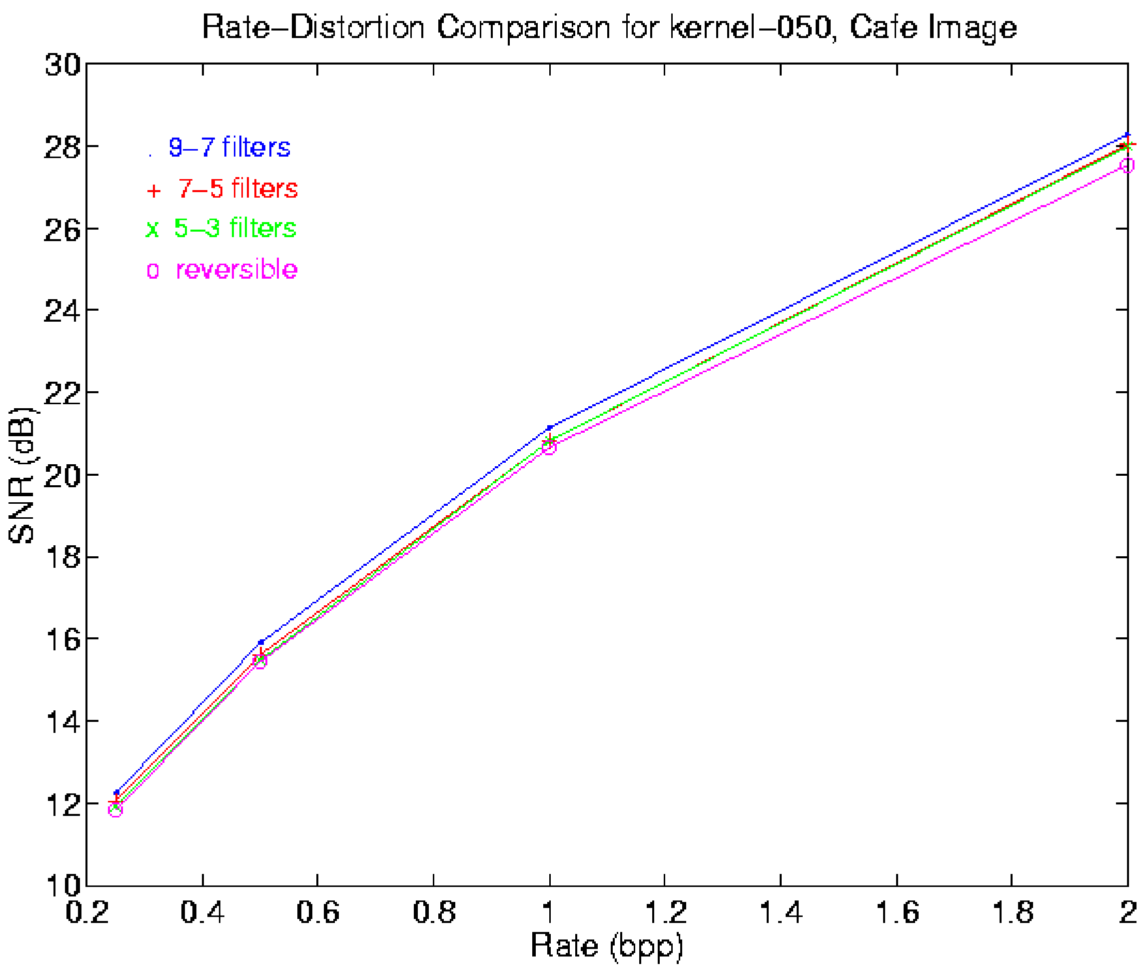

Figure 6. Cafe rate-distortion characteristic.

3 Remaining Core Experiment Activities

- More thorough quantitative optimization for low rates.
- Subjective evaluation of image quality in comparison to the 9/7 and 5/3 filter bank results.