# ADAPTIVE DILATION ANALYSIS FOR WAVELET CODING WITH EMDC

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**ABSTRACT**

The Embedded Morphological Dilation Coding (EMDC) algorithm, recently proposed by the author of this work, implements a direct coding of the wavelet coefficients significance map that is based on the action of a new kind of multiresolution binary (bit-plane) morphological operator. EMDC actually includes the most part of existing morphological wavelet codecs, it produces a fully progressive bit-stream with low complexity and has demonstrated competitive coding performances. A peculiar feature of EMDC is the adaptive and the extended connectivity nature of the morphological analysis of the subband coefficients. In this paper we give a detailed description of this feature and quantify the related performance improvements. We conclude that the considered pattern analysis and coding technique allow an increased reduction of the data redundancy and fills the gap between existing morphological dilation techniques and state-of-the-art wavelet coders.

## 1. THE MORPHOLOGICAL APPROACH TO WAVELET CODING

The structural and statistical properties of the wavelet transform coefficients has been increasingly recognized and exploited in various visual data processing applications.
Such properties play a key role both in the quantization and in the entropy coding stages of current wavelet coding techniques. In particular the insignificant coefficients predictability, in terms of subband zerotree or zeroblocks, is the common denominator of a family of techniques (e.g. SPIHT[1], EZBC[2]) which present state-of-the-art Rate-Distortion (R–D) coding performance. However zerotree based techniques only indirectly exploit a salient property of wavelet-transformed natural images: the clustering trend of most significant coefficients [3]. A possible approach to directly exploit this behavior has been introduced with the morphological conditioned dilation coding [3, 4, 5], where the significant coefficients (i.e. set to 1 in the significance-map) already detected are used as a basis for the search of new significant ones in a progressive bit-plane quantization framework. This approach is justified by observing that clusters tend to grow both in spatial and in frequency domain when crossing successive bit-planes. The work of Servetto *et al.* [3] first justifies the morphological approach to better represent significance maps, but use it in an intra-band mode only, letting the entropy coder exploit some inter-band statistical dependencies. Chai et al. [4] define a bit-saving inter-band linking mechanism among subband clusters. However, this codec architecture does not produce an embedded bit-stream, since good R–D performance are also due to a pre-processing stage which eliminates all isolated significant coefficients, whose positions are too expensive to code; moreover, in [4], the assessment accuracy of cluster boundaries is conceived as a static trade-off between structuring element extent and related bit cost. The extent of the structuring elements is also an issue related to the performance of the embedded approaches proposed by Zhong *et al.* in [5, 6, 7].
In [8] we presented a coding technique called Embedded Morphological Dilation Coding for 2D and 3D data that we refined in [9]. The main innovations introduced in EMDC with respect to the previous morphological approaches are the subdivision of a single morphological dilation in different layers ordered according to their expected R–D performance, and an original method for the analysis of the cluster boundaries by performing an adaptive search around each found cluster. The first aspect is representative of the action and interaction of the morphological dilation within the coding process. The second aspect is better analyzed in this work and represents an example of the benefits that the direct access to the significant coefficient patterns could give in terms of coding performance. EMDC goes beyond the simple duality with respect to the insignificant coefficients prediction; in fact, it introduces an additive pattern analysis which allows to save a portion of bit in the coded description.
The adaptive analysis of cluster boundaries is described in detail in Sec.3 while the related performance improvement is quantified in Sec.4. In the next section the ideas and the structure of the EMDC algorithm are briefly recalled. Algorithmic details can be found in [9].

## 2. EMDC: EMBEDDED MORPHOLOGICAL DILATION CODING

As in the popular zerotree coders, our progressive EMDC algorithm is composed of two iterative stages. The first one is the significant coefficient map description, which is progressively coded by means of a combination of subband scanning, bit-plane thresholding and binary morphological dilations based on predictive hypothesis. After each bit-plane scanning a refinement pass adds to the precision of the previously marked significant coefficients.
The dilation operator is conceived to work in a subband image structure. It is structured in different layers because of the different predictive hypothesis to which each layer corresponds. The layers of this “multiresolution morphological operator” are the following:

- layer (a): *intra-band morphological dilation*
- layer (b): *inter-band expansion*
- layer (c): *adaptive boundary dilation*

The layer (a) exploits the clustering trend of the wavelet coefficient, the layer (b) recognizes the morphological similarities among the different scales in the multiresolution subband domain and authorizes to establish a linking mechanism among different scale clusters based on some parent-child relations. The layer (a) and (b) allow to explore the already identified clusters. The layer (c) analyzes the coefficients on the cluster boundaries and is detailed in the following section. An additional layer (d) called *explicit position coding* works as a “seed layer” in order to start the dilation of unexplored significant clusters and also serves to locate isolated significant coefficients.
In this framework the cluster dilation is performed by a unique operator: this operator works during the coding processing, and it is activated by means of different coding layers in order to guarantee an R–D optimized progressive coded bit-stream. In previous works, the different coding steps correspond to separate pattern dilation or linking mechanisms. For example the algorithm described in [5] considers 3 steps which correspond to our layers (a), (b) and (d).
In EMDC, the layers have been ordered by decreasing expected frequencies of identification of significant coefficients, corresponding to decreasing expected R–D performance [9]. In addition, the four layers do not act in a strictly sequential order, but layer (a), which appears the most effective, is started each time a new significant coefficient is found. The combination of bit-plane quantization with such a prioritized multiresolution dilation, guarantees a good R–D embedding.
The so produced progressive bit-stream is entropy coded using an in-line context-based adaptive arithmetic coder. The probability tables are associated with the quantized bit-stream structure and with causal contexts based on parent-children neighborhoods. The entropy coding is performed also on refinement bits. Further details can be found in [9, 10].

## 3. ADAPTIVE AND EXTENDED CONNECTIVITY PATTERN ANALYSIS

The EMDC dilation strategy is able to detect multiresolution clusters and to work on an extended connectivity basis in order to go beyond false cluster boundaries. This mechanism is implemented through the iterative dilation of the cluster boundaries (insignificant-marked coefficients which encircle a significant cluster) corresponding to the layer (c). Subband clusters presents irregular boundaries because of the complex nature of images and the oscillating response of wavelet filters. In fact, on the boundary of connected clusters, there are typically a relatively few scattered significant coefficients, but it is difficult to forecast the dimension of the area interested to this phenomenon. Such coefficients in the vicinity of a cluster are here considered connected to the cluster itself, like the rocks and stacks which could scatter an island or an archipelago. Therefore, the extent of the searching area around a cluster should be reasonably limited but may not be fixed a-priori.

The Fig.1 shows the way the algorithm searches around the clusters of significant coefficients at increasing distance as long as new significant coefficients are found: the width of the scanned area is adaptively selected on the basis of the occurrence of newly significant coefficients. In EMDC the searching by boundary dilation of scattered clusters is repeated until two successive scans do not lead to new significant coefficients, this can be justified by considering the nature of the analysis filter responses, while experimentally corresponds to the best trade-off between the ability to capture significant coefficient and the related description cost.
The gray line of Fig.1(a) is the boundary of a completely explored cluster, a first additional dilation (Fig.1(b)) allows the detection of the small connected components 1 and 2. The second dilation (c) doesn’t find any new significant coefficients, thus it represents the new cluster boundary. With another additional dilation (d) the components 3 are found and with (e) the component 4. Finally, the two additional dilations which follow do not detect new components, thus the gray-white interface in Fig.1(f) is the final extended cluster boundary; components 5 and 6 are considered too much far from the “coast”, and will be coded as connected to another archipelago or as isolated clusters. We observe that the use of a minimal 3x3 structuring element for cluster growing combined with the “adaptive extended connectivity” boundary detection, actually entails an adaptive morphological analysis, and allows to overcome the static trade-off, mentioned in Sec.1, which limits others morphological dilation

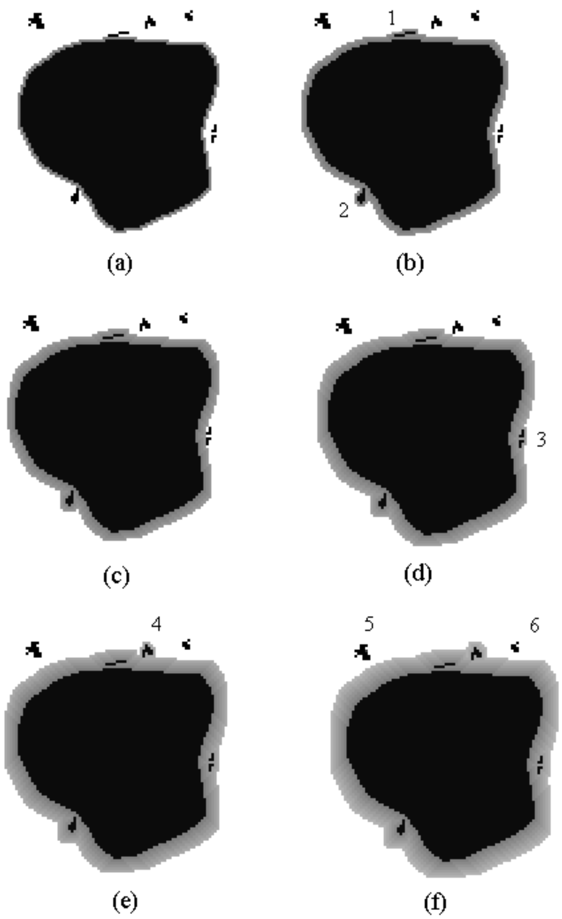


**Fig. 1**. Adaptive boundary analysis

coding approaches.
In the next section we evaluate the validity of our source model, based on the definition of the above multiresolution morphological operator. In particular we quantify the additional dilation layer (c) contribution in terms of coding performance improvement.

## 4. PERFORMANCE ANALYSIS

Quantitative coding performance results are here presented for the Lena, Barbara and Goldhill test images. The wavelet transform is implemented on a five-level decomposition with the popular 9/7-tap filters. To highlight the ovarall good performance of EMDC, PSNR coding results has been compared with respect to the progressive SPIHT [1] algorithm (the original software available on the SPIHT web site[1] has been used). As shown in Fig.2 the EMDC algorithm reaches for all bit-rates the best PSNR performance for the considered images.
In order to quantify the contribution of the adaptive boundary dilation to the above performance, Fig.2 shows the R–D curves obtained by the implementation of EMDC without the layer (c). A coding gain of about 0.15dB at 0.5bpp and 0.3dB at 1bpp due to the adaptive boundary dilation layer demonstrates that the adopted solution is effective.

## 5. CONCLUSIONS

This work dealt with the adaptive analysis of the boundary of significant coefficient clusters, in order to improve the wavelet subband description in a more synthetic significance-map coding. Such morphological analysis has been implemented as a layer of EMDC, a recently proposed coding technique, and the actual contribution of this layer with respect to the overall EMDC performance has been quantified here. The experimental results actually show an overall R–D performance improvement due to the cluster boundary analysis. We conclude that thanks to its particular morphological analysis, EMDC goes beyond a mere duality with respect zerotree based techniques, in addition, the additional boundary dialtion is a simple but effective analysis step in terms of significance-map description. For these reasons, this kind of significance-map coding approach seems to be an interesting field for further investigations: more advanced morphological subband analyses could be designed to capture other coefficient features and to be embedded in the coding algorithm causing a bit-saving description of the significance-map. Moreover, investigations should be directed not only towards objective quality improvements, but also by considering perceptual quality criteria.

## 6. REFERENCES

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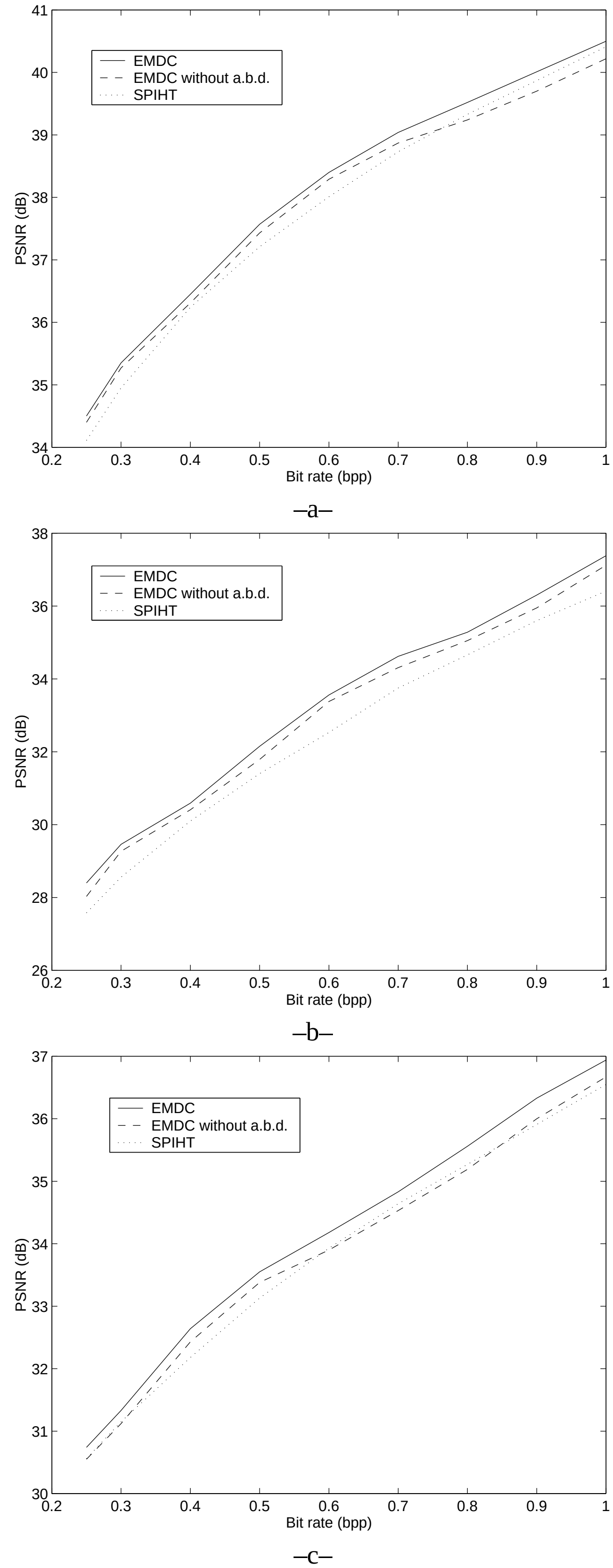


**Fig. 2**. PSNR curves for EMDC, EMDC without the additional boundary dilation (layer (c)), and SPIHT[1] on three 512x512 test images: -a- Lena, -b- Barbara and -c- Goldhill.