Embedded Block Coding with Adaptive Scan Order for Image Compression

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Abstract

Embedded block coding with optimized truncation (EBCOT) has been adopted by JPEG2000. It is a two-tier algorithm: tier-1 is composed of bit-plane coding followed by entropy coding; tier-2 performs rate distortion optimization using the PCRD algorithm, which requires a large memory space for storing all the code streams of code blocks. However, some code blocks of less importance might not be used for the optimal decoded image at a given bit rate. To avoid waste of memory space and computational power, a simple context based rate distortion estimation (CBRDE) is proposed to arrange the scan order of code blocks in the adaptive manner. CBRDE is based on the MQ table of EBCOT, which is available at both encoder and decode. Thus, there is no need to store and transmit the contributions of code blocks. Experimental results show that the rate distortion curves are almost convex; this demonstrates the goal of the proposed embedded block coding with CBRDE.

Keywords: image compression, wavelet transform, JPEG2000, EBCOT, CBRDE.

I. Introduction

With the rapid growth of modern communications and computer technologies, image compression continues to be in great demand [1]-[2]. Wavelet transform, which has been adopted by JPEG2000 [3], provides numerous desirable properties, such as multiresolution representation, progressive transmission, and embedded coding [4]. Image coding with progressive transmission is desirable for Internet streaming and database browsing. In many cases, the embedded code stream of an image is organized in decreasing order of information importance for progressive transmission.

In wavelet domain, if a wavelet coefficient is insignificant with respect to a given threshold, all the spatially related wavelet coefficients in the higher frequency subbands of the same orientation are likely to be insignificant with respect to the same threshold; this property known as the self similarity of wavelet coefficients was first introduced by Shapiro in the famous embedded zerotree wavelet (EZW) algorithm [5]. The improved EZW known as the set partitioning in hierarchical trees (SPIHT) has become a benchmark [6]. Mukherjee and Mitra developed a vector extension of SPIHT called the VSPIHT algorithm [7].

There are some coders based on block coding in wavelet domain to exploit the energy clustering of wavelet coefficients [8]-[10]. The embedded block coding with optimized truncation (EBCOT) algorithm [11], for example, has been adopted by JPEG2000 [12]. For real-time applications, dedicated hardware is required to implement JPEG2000. EBCOT is a two-tier algorithm: tier-1 applies embedded block coding with arithmetic coding to each code block of transform coefficients; tier-2 takes charge of rate distortion control using the post compression rate distortion (PCRD) optimization algorithm. One of the crucial implementation issues of EBCOT is the design of PCRD, which requires a large amount of memory to store all the code streams of code blocks with their respective rate distortion information. In addition, all the code blocks of an image must be processed before the operation of PCRD. However, some code blocks may not be needed to reconstruct the optimal decoded image at a given bit rate; this surely leads to waste of computational power. In [13], Fang et al. proposed a precompression rate distortion optimization algorithm to avoid unnecessary computations and to reduce the memory space by ignoring the unused code streams. To arrange the scan order of code blocks so that the available coding bits can be allocated for the most significant code block, a context based rate distortion estimation (CBRDE) based on the MQ table of EBCOT is proposed in this paper. As the MQ table is available at both encoder and decoder, the scan order of code blocks can be also obtained at decoder; thus, the transmission of the contributions of each code block is unnecessary.

The remainder of this paper proceeds as follows. In Section II, EBCOT is briefly reviewed. Section III describes EBC with CBRDE. Experimental results are presented in Section IV, and conclusion is given in Section V.

II. Brief Review of EBCOT

The embedded block coding with optimized truncation (EBCOT) algorithm has received a lot of attention to the image compression applications since its introduction. EBCOT is a two-tier algorithm: tier-1 performs bit-plane coding (BPC) followed by arithmetic coding; tier-2 performs the post compression rate distortion (PCRD) algorithm. In BPC, three coding passes, namely significance propagation pass, magnitude refinement pass and cleanup pass are involved with four primitive coding operations: significance coding operation, sign coding operation, magnitude refinement coding operation and cleanup coding operation. For a transform coefficient that is still insignificant in some bit-plane, if all the 8 neighbors are also not yet significant, this coefficient is then coded by using cleanup coding operation in cleanup pass; otherwise it is coded by using significance coding operation in significance propagation pass. If an insignificant coefficient becomes significant, its sign is then coded immediately by using sign coding operation. For every significant coefficient that has been already identified in previous coding passes, its magnitude is updated by using magnitude refinement coding operation in magnitude refinement pass. The output bitstream of each coding pass can be further coded by using a common arithmetic coding engine to improve the compression performance at the cost of increasing complexity. In JPEG2000, the context based adaptive arithmetic coder known as the MQ coder is defined, which utilizes 18 different context labels, based on the present status of the 8 neighbors of a coefficient, to define the probability models of primitive coding operations. Specifically, 10 context labels are used for significance coding operation and cleanup coding operation, 5 context labels for sign coding operation, and 3 context labels for magnitude refinement coding operation. Figure 1 shows block diagram of EBCOT.

III. Proposed EBC with CBRDE

In JPEG2000, a large image is first divided into rectangular sub-images called tiles; each tile is independently decomposed into subbands with orientation selectivity by wavelet transform; every subband is further partitioned into small blocks called code blocks, which are quantized to form bit-planes and then coded from the most significant bit-plane to the least significant bit-plane. For each bit-plane, all the code blocks of an image must be processed in the first tier of EBCOT before proceeding with the post compression rate distortion (PCRD) algorithm in the second tier. However, some code blocks that are less important may not be used for the optimal decoded image at a given bit rate and will be discarded. Thus, waste of computational power results. In addition, waste of memory space might take place as a large memory space needs to be allocated for storing all the code streams of code blocks with their respective contributions to the decoded image for rate distortion optimization. Thus, an efficient scheme to arrange the scan order of code blocks in the adaptive manner is proposed to reduce the aforesaid waste of computational power and memory space.

Recall that code blocks are independently coded bit-plane by bit-plane, from most to least significant, and the output bitstream can be truncated at an intermediate point between bit-planes; this raises the following interesting questions regarding the scan order of code blocks. For each bit-plane, is there an adaptive scan order such that the available coding bits can be allocated for the most significant code block? Is there a common piece of information available at both encoder and decoder, based on which the code blocks of an image can be arranged adaptively in decreasing order of significance? If so, there is no need to store all the code streams of code blocks and to transmit the scan order of code blocks from encoder to decoder. For computational simplicity, is there an easy way to solve the above-mentioned questions?

As one might expect, the first question can be solved effectively through the analysis of rate distortion curves of code blocks. The optimal scan strategy turns out to take the code block with the steepest rate distortion slope as the first to be coded. In other words, the available coding bits should be first allocated for the code block with the largest amount of distortion decrease per coding bit. Take the second question into consideration; the estimated rate distortion slopes are preferable to the true ones for arranging the scan order of code blocks. Since the MQ table of probabilities of more probable symbol (MPS) and less probable symbol (LPS) used for arithmetic coding is available at both encoder and decoder, an efficient, context based rate distortion estimation (CBRDE) is proposed to estimate the rate distortion slope of code blocks.

For each bit-plane, the code block with significant rate of distortion decrease per coding bit should be coded as early as possible. To avoid transmitting the scan order of code blocks from encoder to decoder, the estimated rate distortion slope of a code block is desirable, which is given by

$$S = \frac{E[\Delta D]}{E[\Delta R]} \tag{1}$$

where ΔD and ΔR denote the amount of distortion decrease and the number of coding bits, respectively, and $E[\cdot]$ is an expectation operator. Though most of the correlation between images pixels can be removed by wavelet transform, there may still be some residual correlation between neighboring coefficients; this motivates the development of context based rate distortion estimation (CBRDE). To incorporate with the framework of EBCOT, the proposed CBRDE for each code block is based on the MQ table, which is available at both encoder and decoder. Specifically, let the i^{th} code block (in wavelet domain) be denoted by B_i ; the j^{th} significant bit of a coefficient at position: (m,n) in B_i be denoted by $b_{ij}(m,n)$; and $B_{ij} = \bigcup_{m,n} \{b_{ij}(m,n)\}$. The proposed CBRDE of B_{ij} is as follows.

$$S_{ij} = \frac{\sum_{m,n} prob(b_{ij}(m,n)=1)}{\sum_{m,n} H(b_{ij}(m,n))} \quad (2)$$

where $H(b_{ij}(m,n))$ is the entropy of $b_{ij}(m,n)$. Note that the numerator of the above equation is proportional to the amount of distortion decrease, and the denominator is proportional to the number of coding bits. In addition, since the probability models of $b_{ij}(m,n)$ are based on the finite-entry MQ table, $H(b_{ij}(m,n))$ can be computed in advance and therefore the computational complexity is nothing but one lookup table operation. As a result, the proposed CBRDE is simple.

Take Lena image as an example. Figure 2 shows the true distortion decrease, ΔD, the true number of coding bits, ΔR, and their respective estimates $E[\Delta D]$ and $E[\Delta R]$ for the the 7^{th} and 8^{th} bit-planes. The appearance of nearly proportional relationship between the horizontal axis (true values) and vertical axis (estimated values) demonstrates the potential of the proposed CBRDE, which surely facilitates the image compression task.

Figure 3 depicts the proposed image encoder using embedded block coding (EBC) with adaptive block ordering (ABO). Where, the EBC algorithm is the same as the first tier of EBCOT; however, ABO with CBRDE replaces the second tier of EBCOT, i.e. PCRD. Through the adaptation of the MQ table, the code blocks of an image can be arranged according to their respective estimated rate distortion slopes and then coded in the adaptive manner. Figure 4 depicts the image decoder. Recall that rate distortion slopes of code blocks can be also estimated at decoder. Thus, the overhead of transmitting the scan order of code blocks from encoder to decoder is unnecessary; this is beneficial to the communication applications.

IV. Experimental Results

The test images, namely Barbara and Fingerprint are shown in Fig. 5. The biorthogonal Daubechies wavelet with 9/7-tap filter is used. The number of decomposition levels is 4. The size of code blocks is 32×32 except that the code blocks within the lowest frequency subbands of Fingerprint image are of size 16×16. The compression rate is measured in bits per pixel (bpp). The distortion is defined by mean squared error (MSE). The computed compression rates and MSE values are collected to generate the rate distortion curves. To avoid the overhead of identifying and transmitting the contributions of code blocks, the second tier of EBCOT, i.e. PCRD is replaced by the proposed CBRDE-based ABO (as shown in Fig. 3 and Fig.4). For comparison, as most of images' energies are concentrated in the low frequency subbands, the first tier of EBCOT with a fixed scan order starting from the lowest frequency subband is evaluated. In addition, for the most significant bit-plane, the initial scan order of the proposed image coder is the same as the above-mentioned order; however, for the successively less significant bit-planes, the scan order is adapted bit-plane by bit-plane.

For such an image with textures as Barbara, there are many significant wavelet coefficients in the middle and high frequency subbands. As shown in Fig. 6, the coding performance can be significantly improved at low bit rates (<0.35). The compression of fingerprints images is one of the most important issues, which demands the best solution. Figure 7 shows the simulation results of Fingerprint. It is noted that the rate distortion curve obtained by the proposed image coder is almost convex; this demonstrates the benefit of the proposed CBRDE when the embedded code stream of an image is truncated at an intermediate point between bit-planes.

V. Conclusion

Wavelet transform has been adopted by JPEG2000 as the underlying method to decompose an image into subbands with orientation selectivity. The energy clustering of wavelet coefficients of images builds the foundation of the EBCOT algorithm. In EBCOT, subbands of transform coefficients are divided into small blocks called code blocks and then coded bit-plane by bit-plane starting form the most significant bit-plane. A context based adaptive arithmetic coder known as the MQ coder can be used to improve the compression performance, however, at the cost of increasing complexity. All the code blocks of an image are coded to generate a set of code streams with their respective contributions to the decoded image, based on which the optimal code stream can be obtained by concatenating the suitably truncated code streams through the PCRD algorithm. As some code blocks, which are less important, are not needed for the optimal decoded image at a bit rate, waste of computational power and memory space may result. Furthermore, the implementation of PCRD is one of the crucial issues. To overcome the above-mentioned problems, an efficient context based rate distortion estimation (CBRDE) is proposed to arrange the scan order of code blocks in the adaptive manner. To avoid transmitting the side information regarding the scan order of code blocks from encoder to decoder, the proposed CBRDE is based on the MQ table, which is available at both encoder and decoder. The second tier of EBCOT, i.e. PCRD can be replaced by the CBRDE-based adaptive block ordering (ABO). Experimental results show that the rate distortion curves are almost convex

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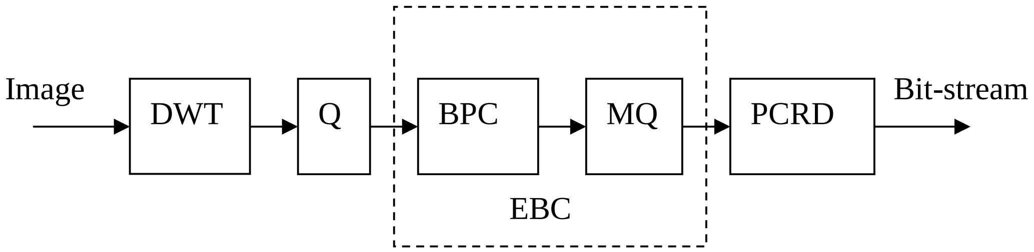
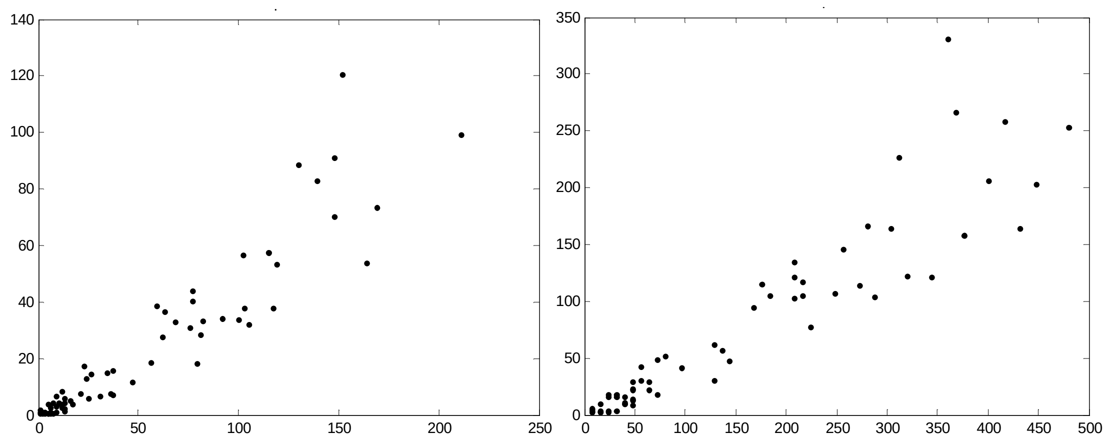
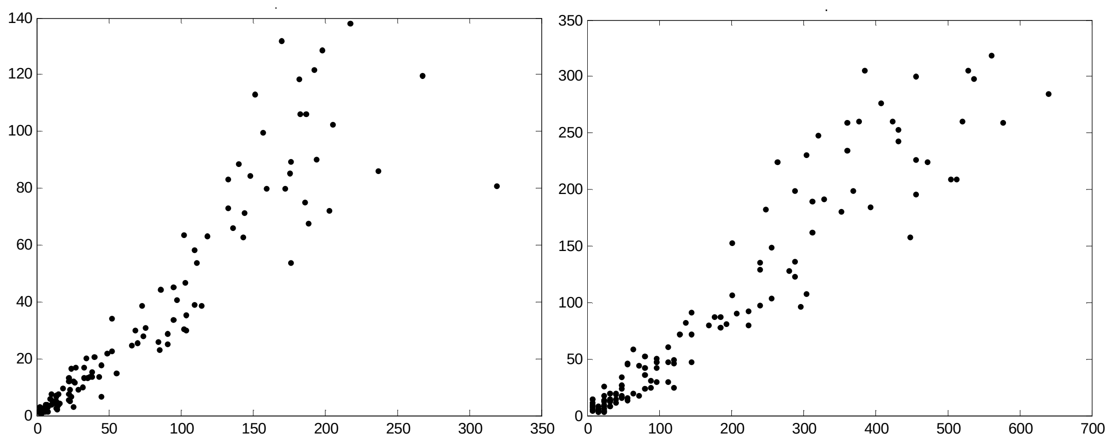


Fig. 1 Block diagram of EBCOT.



(a)



(b)

Fig. 2 Performance of the proposed CBRDE applied to Lena image; Horizontal axis: the true ΔD (left column) and ΔR (right column); Vertical axis: $E[\Delta D]$ (left column) and $E[\Delta R]$ (right column); (a) the 7th bit-plane; (b) the 8th bit-plane.

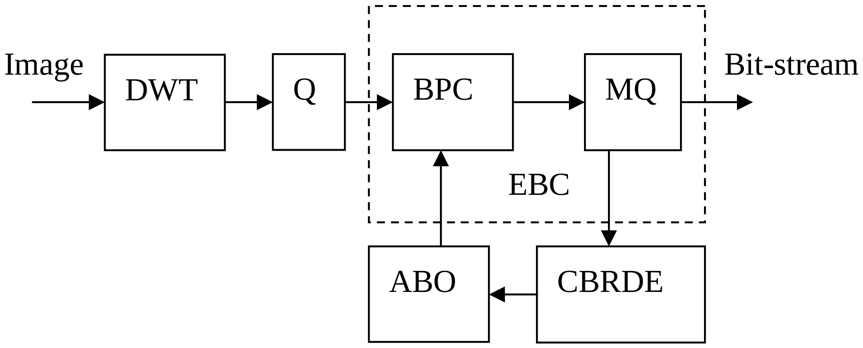


Fig. 3 Block diagram of the proposed encoder using EBC with ABO.

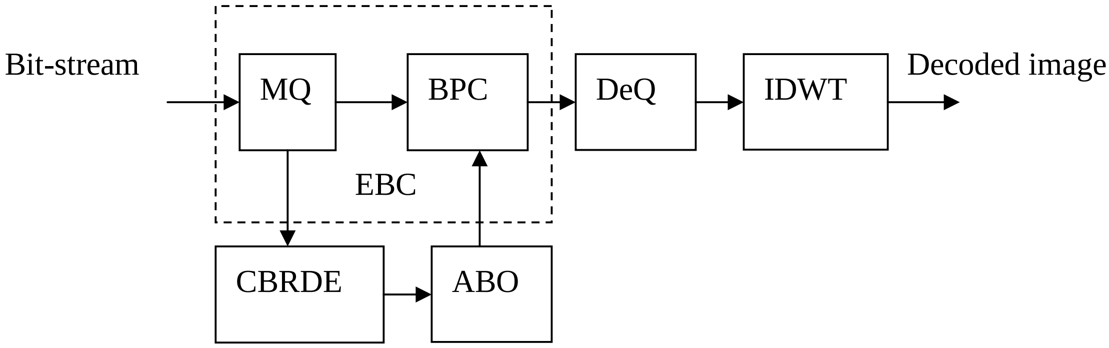


Fig. 4 Block diagram of the proposed decoder using EBC with ABO.

(a) (b)

Fig. 5 Test images; (a) Barbara; (b) Fingerprint.

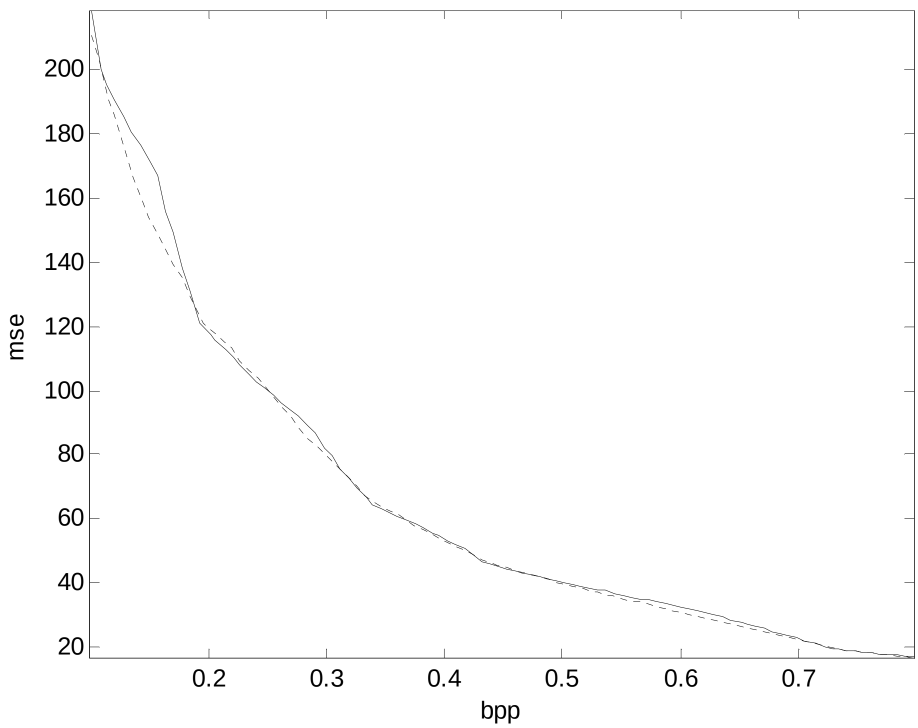


Fig. 6 Rate distortion curves of Barbara image by EBC with the CBRDE-based scan coder (dashed line) and EBC with a fixed scan order (solid line); Vertical axis: mean square error (MSE); Horizontal axis: bit rate (bpp).

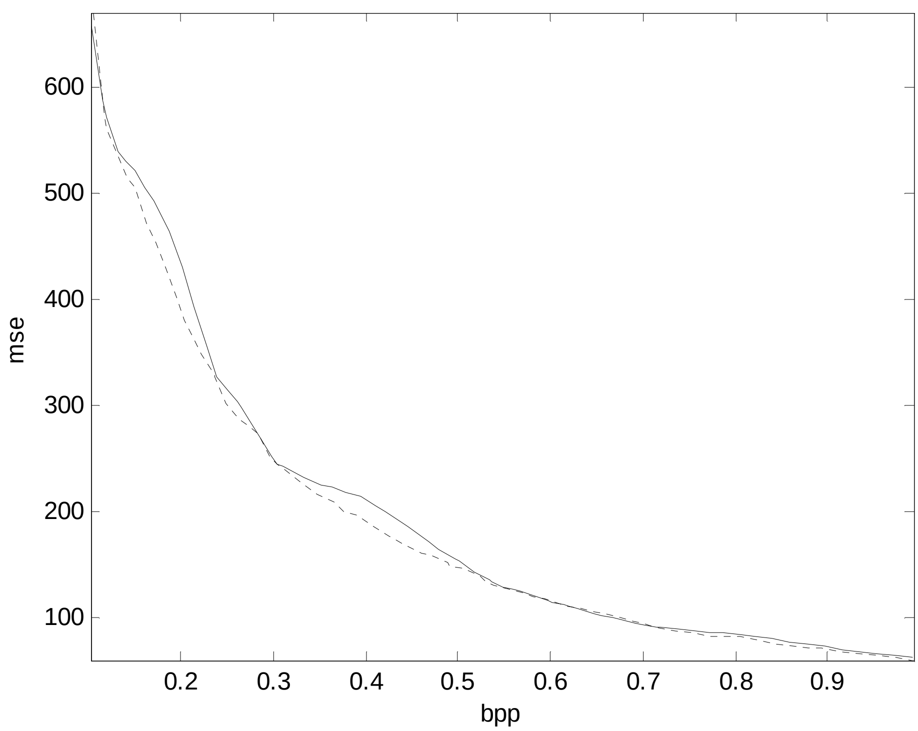


Fig. 7 Rate distortion curves of Fingerprint image by EBC with the CBRDE-based scan coder (dashed line) and EBC with a fixed scan order (solid line); Vertical axis: mean square error (MSE); Horizontal axis: bit rate (bpp).