Non-Causal Prediction for Lossless Coding of Images

Milton Simas Gonçalves Torres, Paulo Roberto Rosa Lopes Nunes
Instituto Militar de Engenharia – IME , Rio de Janeiro RJ, Brazil

Abstract - **In this work it is presented a lossless image coding method using a non-causal and non-linear prediction scheme. As in most lossless methods, each pixel is predicted from values of neighbors, and the differences between actual and predicted values are entropy coded. In the proposed method, prediction is not based only on pixels that have already been coded; pixels not coded yet can also be used. The nonlinear prediction scheme requires the storage of additional information. The amount of this side information however, is not significant. The method has been compared with state of the art lossless image coding schemes and good results were obtained.**

I. Introduction

The basis for the non-linear prediction scheme presented here was developed in [1]. In that work gray level pixels are scanned from left to right, top to bottom. For each pixel, one out of n (n=2,3,4) previously coded pixel is used as a prediction. Extra bits are used to indicate the relative position of this pixel. For n=2, one extra bit is needed. For n>2 more bits are necessary. Since even one extra bit per pixel represents a large amount of side information, acceptable results were obtained only when the choice of best direction of prediction was made for blocks of pixels, and not for individual ones. With blocks, the criterion for direction of prediction determination was minimum mean square error.

In [2], non-causality was introduced. Any pixel in the immediate neighborhood was a potential predictor. This scheme requires at least 2 extra bits to encode the direction of prediction (up, down, left, right). One more bit would be necessary to include diagonal directions. To ensure that the image can be reconstructed from the side information and the prediction differences, some rules must be followed when predictors are chosen, as will be seen below. As before, useful results are obtained only when pixels are processed in blocks.

Once a prediction is obtained, a difference is generated subtracting the predicted value from the actual one. In order to keep the same structure of the original image, module 2^n differences are computed, where n is the number of bits used to represent each original pixel. In this work we will assume gray level images with 256 levels (n=8).

Milton S. G. Torres (miltontorres@mailbr.com.br) is with CEFET-RJ, Rio de Janeiro, Brazil. Paulo Roberto R. L. Nunes (prnunes@ime.eb.br) is with the Department of Electrical Engineering, Instituto Militar de Engenharia -IME, Praça Gen. Tibúrcio 80, Praia Vermelha - 22290-270 - Rio de Janeiro RJ, Brazil. Phone: 55 21 2546-7133.

II. The Proposed Prediction Method

The prediction method proposed in this work is based in three main points: blocking, chaining of blocks and inside the block prediction schemes.

Blocking is required to keep low bit-per-pixel side information. Prediction in each block starts from an adjacent block defined by one out of four directions (up, down, left, right). To each block it is associated a pointer to the block used for prediction. This procedure creates chains of blocks, and we call it block chaining. In addition to this direction information, a internal-to-the-block prediction scheme has to be determine too. This scheme is chosen out of a number of possibilities that dependent of the block size. In practice, definition of chaining and internal prediction scheme is a single optimization process.

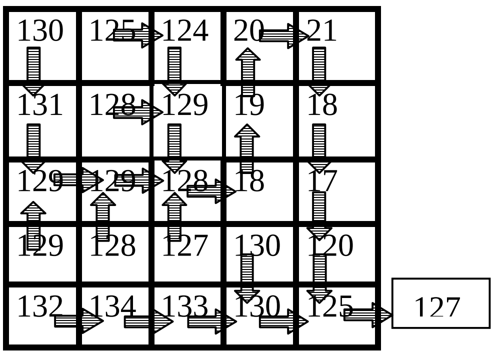
A. Chaining of blocks

The process for chaining blocks is similar to the process used for chaining individual pixels when blocking is not used. The difference consists in the metric used. When chaining single pixels, the best predictor is the adjacent pixel whose value is closer to the pixel being processed. When chaining blocks, the best prediction procedure is defined by a direction and a internal-to-the-block prediction scheme. In this work, minimum mean square prediction error is the criterion used to determine direction of prediction and inside-the-block prediction scheme. To assure that decoding is possible, some direction restrictions must be imposed , as will be seen soon.

Beginning with the first block in the left-upper corner, one out of n prediction scheme is chosen, using the mmse criterion. The selected scheme will define a pointer from the current block to a neighbor one, connecting then. The first block can be connected only to the one at right or to the one below. A generic block has four potential connection possibilities. Blocks are processed following a standard raster sequence. As the process goes on, sets of connected blocks, or chains, will begin to form. In order to guarantee decoding, closed chains, or loops, must be avoided. So, as the process goes on, some blocks adjacent to the current one will be labeled forbidden. Forbidden blocks cannot be pointed and will not be considered in the mse minimization process.

The described chaining process is guaranteed to reach the last (right-lower) block. This block cannot point to any other, but it is allowed to point to a fictitious single valued one (usually 127 for images with 256 gray levels) located at any position.

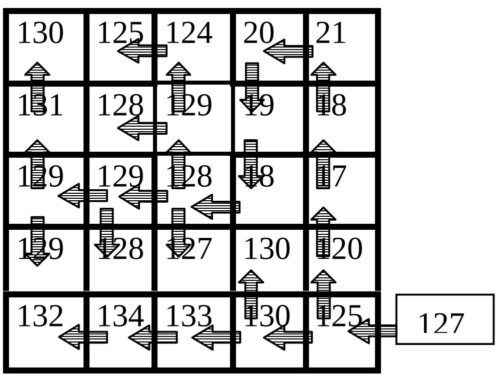
The decoding process starts from the last block and proceeds following chains in the inverse direction, until all blocks are recovered. Figure 1 illustrates coding and decoding. In this figure, in order to make it clear, single pixels (1x1 blocks) are assumed. In Figure 1a, the pointers are shown, in figure 1b, the image of the differences (or difference-image) is shown. To make the example clear, mod 256 arithmetic has not been used. In Figure 1c the inverse paths, used for reconstruction, are shown.



(a)

-1	1	-5	-1	3
2	-1	1	-1	1
0	1	110	-1	-103
0	-1	-1	0	-5
-2	1	3	5	-2

(b)



(c)

Fig. 1 – Example of coding and decoding .
(a)-chaining, (b) prediction error, (c) decoding paths

B. Inside-the-block prediction

The simplest way to perform prediction inside a block is to extend the between-blocks direction to pixels inside the block. This procedure reduces a lot the number of bits used to convey side information (if 4x4 blocks are used, only 1/8 of a bit per pixel will be used to indicate direction), but increases the entropy of the difference-image. The solution proposed in this work is to define arrays of prediction directions, to be used inside the blocks, like the ones shown in Figure 2.

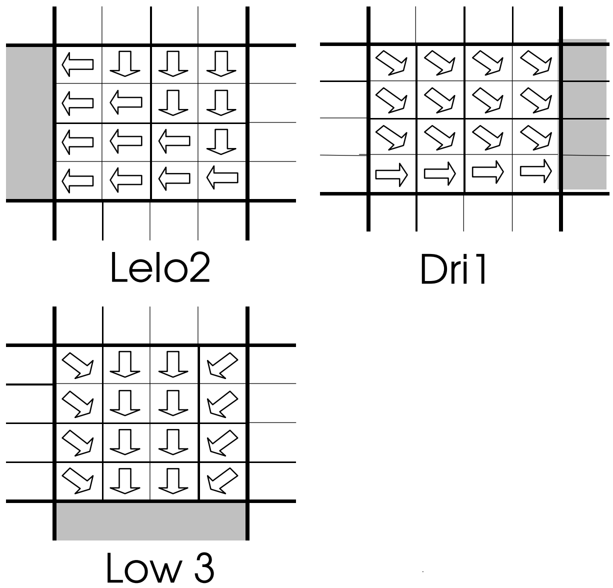


Fig. 2 – Examples of inside-the-block prediction schemes

The actual arrays used to obtain the results in section 3 were determined experimentally, and probably are not the best ones. The use of inside-the-block prediction does not need to follow the pointing scheme used for block chaining, provided decoding can be performed starting from the pointed block. A significant improvement in performance was obtained when a non-linear predictor called MAP (Median Adaptive Prediction), proposed by Martucci, in [3], was included among the inside-the-block prediction possibilities. The MAP predictor, in its usual form, uses three neighborhood pixels: the one at left (X_A), the one on top (X_C) and the top-left one (X_B). The predicted value is given by:

$$Y_N = MED\,(X_A, X_C, Z)$$

Where MED is the median operation and $Z=X_A+X_B-X_C$. Prediction schemes based on MAP are illustrated in Figure 3. Actual relative locations of X_A, X_B and X_C depend on the direction of prediction inside the block.

III. Exprimental Results

In order to evaluate the performance of the proposed method it was applied to the luminance components of nine images from the JPEG test set (ibarb, iboard, iboats, izelda, jbaloon, jbarb2, jgirl, jgold and jhotel). The number of bits necessary to code the differences were estimated by the first order entropy of the difference-images. No coding was used on side information data; it has been verified that it is of little or no value. Average results over all images are summarized in Table 1. Best performances were obtained when the MAP predictor was included among the inside-the-block available schemes. In order to compare performances, this best coder was implement using Huffman coding on the difference-image. The overall result can be seen in Table 2, where figures obtained from state of the art coders are also shown.

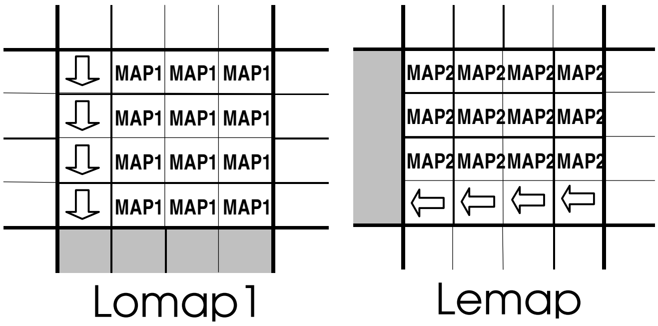


Figure 3. –MAP based prediction schemes.

TABLE 1
ESTIMATED COMPRESSION (BITS/PIXEL)

Block dimen-sions	**Number of Pred. schemes**	**side inform. (bits/block)**	**Measured diff. entropy+side inform./pixel**
1x1	4	2	5.30
1x1	8	3	5.62
2x2	4	2	4.57
3x3	4	2	4.48
4x4	4	2	4.46
6x6	4	2	4.45
8x8	4	2	4.47
4x4	20	4.25	4.45
8x8	20	4.25	4.42
4x4	64	6	4.48
8x8	64	6	4.39
8x8	64 w/ MAP (*)	6	4.32

TABLE 2
COMPARISON WITH STATE OF THE ART CODERS

Method	Bits/pixel
Proposed (*), Huffman Coded	4.38
FELICS [4]	4.44
LOCO [6]	4.04
CALIC [5]	3,92

IV. Conclusions

A non causal method for lossless image coding has been presented and compared with three state of the art schemes. The proposed method presented a performance slightly better than one of the reference methods and 0.46 bits per pixel worst than the most efficient scheme.

Better choice of inside-the-block prediction schemes would probably improve the method. Use of more sophisticated entropy coding methods, like arithmetic coding [7], are expected to provide better results.

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