On the efficiency of luminance-based palette reordering of color-quantized images

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Abstract. Luminance-based palette reordering is often considered less efficient than other more complex approaches, in what concerns improving the compression of color-indexed images. In this paper, we provide experimental evidence that, for color-quantized natural images, this may not be always the case. In fact, we show that, for dithered images with 128 colors or more, luminance-based reordering outperforms other more complex methods.

1 Introduction

Traditionally, most color-quantized images have been encoded according to the well-known and widely used Graphical Interchange Format[3] (GIF). As part of this format there is a coding engine based on the Lempel-Ziv-Welch (LZW) compression algorithm [1], a variant of one of the seminal algorithms developed by Ziv and Lempel [2], commonly known as LZ78. LZW is intrinsically a compression technique for one-dimensional sequences of symbols and, therefore, might not be particularly tailored for exploiting the two-dimensional dependencies that characterize image data.

Two-dimensional approaches specifically designed for coding color-indexed images have been proposed. Among them we find methods such as PWC [3], EIDAC [4], RAPP [5] or the method recently proposed by Chen *et al.* [6]. On the other hand, it is frequently convenient to address the problem of coding color-quantized images under the framework of general purpose coding techniques, such as JPEG-LS [7, 8] or lossless JPEG 2000 [9, 10].

Color-indexed images are represented by a matrix of indexes (the index image) and by a color-map or palette. The indexes in the matrix point to positions in the color-map and, therefore, establish the colors of the corresponding pixels. For a particular image, the mapping between index values and colors (typically, RGB triplets) is not unique — it can be arbitrarily permuted, as long as the corresponding index image is changed accordingly. However, for most continuous-tone image coding techniques these alternative representations are generally not equivalent, having sometimes a dramatic impact on the compression performance.

[3] `http://pds-geophys.wustl.edu/info/gif.txt`.

With the aim of minimizing this drawback several preprocessing techniques have been proposed. Basically, they rely on finding a suitable reordering of the color table in such a way that the corresponding image of indexes becomes more amenable to compression. These preprocessing techniques have the advantage of not requiring post-processing and of being cost-less in terms of side information. However, if the optimal configuration is sought, then the computational complexity involved can be high (for M colors, $M!$ configurations have to be tested). Clearly, exhaustive search is impractical for most of the interesting cases, which motivated several sub-optimal, lower complexity, proposals.

In this paper, we provide a comparison of three palette reordering methods in what concerns their ability to improve compression rates. Two standard image compression techniques are used to perform this evaluation: JPEG-LS and lossless JPEG 2000. Our study addresses a particular class of images (color-quantized natural images, with and without dithering), and intends to show that, for this class of color-indexed images, a simple luminance-based palette reordering approach can provide comparable or better results than other more complex approaches.

2 Palette reordering for improving compression

The problem of reordering a color map for better fitting the coding model of general purpose image coding techniques is not a trivial task, due to the combinatorial nature of the problem [11]. Several sub-optimal solutions have been proposed, based on approximated solutions to the traveling salesman problem [12, 13], on the maximization of the compression performance through a greedy index assignment [14], on greedy pairwise merging heuristics [11], or on color reordering by luminance [15].

In this paper, we compare the performance of three of these methods in what concerns their ability to improve compression: (1) the pairwise merging heuristic proposed by Memon *et al.*, (2) the greedy index assignment proposed by Zeng *et al.* and (3) luminance-based reordering.

The method proposed by Zeng *et al.* [14] starts by finding the symbol that is most frequently located adjacent to other symbols ($S_{\max}$), i.e., the symbol that most contributes to transitions. This symbol is put into a symbol pool and, right next to it, the symbol that is most frequently found adjacent to $S_{\max}$. New symbols are added to the symbol pool only from the left or right end position. A particular symbol S_i is chosen to integrate the pool if it is the one among the unassigned symbols that maximizes

$$D_i = \sum_{j=0}^{n-1} w_{n,j} C(S_i, L_j)$$

where $C(S_i, S_j)$ denotes the number of occurrences, measured on the initial index image, corresponding to pixels with symbol S_i spatially adjacent to pixels with symbol S_j, and where $w_{n,j}$ are some appropriate weights. The summation is performed over all symbols L_j already located in the symbol pool. Moreover, it is suggested in [14] that setting

$$w_{n,j} = \log_2(1 + 1/d_{n,j})$$

is usually a good choice, where $d_{n,j}$ corresponds to the physical distance between the current end position of the pool and the position of symbol L_j.

Memon *et al.* formulated the problem of palette reordering under the framework of linear predictive coding [11]. In that context, the objective is to minimize the zero-order entropy of the prediction residuals, a goal that can be very difficult to achieve. However, they noticed that, for image data, the prediction residuals are usually well modeled by a Laplacian distribution and that, in this case, minimizing the absolute sum of the of the prediction residuals leads to the minimization of the zero-order entropy. For the case of a first-order prediction scheme, the absolute sum of the prediction residuals reduces to

$$E = \sum_{i=0}^{M-1} \sum_{j=0}^{M-1} N(i,j)|i-j|$$

where $N(i,j)$ denotes the number of times index i is used as the predicted value for a pixel whose color is indexed by j (note that, according to this definition, generally we have $N(i,j) \neq N(j,i)$), and M denotes the number of colors of the image. The problem of finding the bijection that minimizes E can be formulated as the optimization version of the optimal linear ordering problem, which is known to be NP-complete [11].

One of the heuristics proposed by Memon *et al.* for finding good solutions to the above stated problem is the so-called pairwise merge heuristic. Essentially, it is based on repeatedly merging ordered sets of colors until obtaining a single (reordered) set. Initially, each color is assigned to a different set. Then, the two sets, S_a and S_b, maximizing

$$\sum_{i \in S_a} \sum_{j \in S_b} \big(N(i,j) + N(j,i)\big)|i-j|$$

are merged together. This procedure should be repeated until having a single set. To alleviate the computational burden involved in selecting the best way of merging the two sets, only a limited number of possibilities are generally tested [11].

Palette reordering based on luminance [15] is the simplest of the three methods addressed in this paper, since it only requires sorting the colors according to its luminance. Luminance is usually computed according to

$$Y = 0.299R + 0.587G + 0.114B,$$

where Y denotes the luminance, and R, G and B the intensities of the red, green and blue components, respectively.

3 Experimental results

In this section, we present experimental results based on the set of the 23 "kodak" color images[4]. These are 768×512 true color images from which we generated additional sets with resolutions 384×256 and 192×128. Color quantization was then applied, both with and without Floyd-Steinberg color dithering, creating images with 256, 128 and 64 colors. Image manipulations have been performed using version 1.2.3 of the "*Gimp*" program.[5]

Table 1. Each row of this table shows average JPEG 2000 lossless compression results, in bits per pixel, concerning a particular instance of the "kodak" image set. Compression results obtained directly from the unsorted index images and obtained using the GIF format are also given for reference. The best values are shown in **boldface**.

JPEG 2000

Image size	Colors	Dither	GIF	Unsorted	Zeng	Memon	Luminance
192 × 128	64	No	3.965	4.826	**3.819**	3.896	4.002
	128		5.100	6.032	**4.864**	4.905	4.993
	256		6.402	7.280	6.138	6.089	**6.086**
	64	Yes	4.371	5.306	**4.242**	4.311	4.316
	128		5.565	6.445	5.314	5.416	**5.254**
	256		6.880	7.609	6.491	6.488	**6.282**
384 × 256	64	No	3.498	4.476	**3.389**	3.457	3.674
	128		4.528	5.657	**4.422**	4.457	4.608
	256		5.695	6.824	5.574	**5.540**	5.611
	64	Yes	**3.924**	5.016	3.934	4.001	4.034
	128		4.994	6.129	4.955	4.966	**4.902**
	256		6.194	7.212	6.021	5.917	**5.833**
768 × 512	64	No	3.270	4.208	**3.147**	3.203	3.400
	128		4.277	5.359	4.203	**4.144**	4.309
	256		5.386	6.575	5.281	**5.229**	5.275
	64	Yes	**3.730**	4.845	3.808	3.892	3.816
	128		4.746	5.902	4.755	4.770	**4.650**
	256		5.941	7.035	5.835	5.709	**5.538**

Table 1 shows JPEG 2000 lossless compression[6] results of the reordered index images, using Zeng's method[7], Memon's method[8] and the luminance-based

[4] These images can be obtained from `http://www.cipr.rpi.edu/resource/stills/kodak.html`.
[5] `http://www.gimp.org`.
[6] Compression was obtained using the JasPer 1.700.2 JPEG 2000 codec (`http://www.ece.uvic.ca/~mdadams/jasper`).
[7] The implementation of this algorithm was provided by the authors.
[8] We used an implementation of this technique included in a software package developed by Battiato *et al.*

Table 2. Each row of this table shows average JPEG-LS lossless compression results, in bits per pixel, concerning a particular instance of the "kodak" image set. Compression results obtained directly from the unsorted index images and obtained using the GIF format are also given for reference. The best values are shown in **boldface**.

JPEG-LS

Image size	Colors	Dither	GIF	Unsorted	Zeng	Memon	Luminance
192 × 128	64	No	3.965	4.219	**3.346**	3.363	3.496
	128		5.100	5.488	4.421	**4.371**	4.509
	256		6.402	6.769	5.672	**5.526**	5.599
	64	Yes	4.371	4.899	**3.901**	3.943	3.945
	128		5.565	6.104	5.013	5.037	**4.902**
	256		6.880	7.330	6.177	6.045	**5.919**
384 × 256	64	No	3.498	3.899	**2.997**	3.009	3.229
	128		4.528	5.090	4.000	**3.983**	4.160
	256		5.695	6.286	5.138	**5.015**	5.161
	64	Yes	3.924	4.666	**3.655**	3.677	3.731
	128		4.994	5.805	4.682	4.646	**4.602**
	256		6.194	6.906	5.724	5.548	**5.520**
768 × 512	64	No	3.270	3.661	**2.804**	2.812	3.002
	128		4.277	4.839	3.844	**3.722**	3.926
	256		5.386	6.078	4.908	**4.765**	4.898
	64	Yes	3.730	4.532	3.591	3.624	**3.556**
	128		4.746	5.621	4.537	4.501	**4.399**
	256		5.941	6.765	5.596	5.389	**5.289**

approach. Table 2 displays the corresponding results when a JPEG-LS codec is used[9]

Each row of the tables shows average compression results, in bits per pixel, concerning a particular instance of the "kodak" image set. Besides the size of the encoded index image, the (uncompressed) size of the color table is also accounted in the results shown. For reference, we also include compression results using directly the (unsorted) index images and also the GIF file format.

Observing Tables 1 and 2 it can be seen that, for images with dithering and 128 or more colors, the luminance-based palette reordering technique provides the best results, being the second best in a number of other situations. It can also be observed that Memon's method generally provides better results in images with 128 colors or more, whereas Zeng's method seems to work better for images with 128 colors or less.

[9] Compression was obtained using the SPMG / JPEG-LS V.2.2 codec (`ftp://spmg.ece.ubc.ca/pub/jpeg-ls/ver-2.2/`).

4 Conclusions

Palette reordering is a very effective approach for improving the compression performance of general purpose image coding techniques, such as lossless JPEG 2000 or JPEG-LS, on color-indexed images. In this paper, we provided experimental results showing the compression improvements provided by three palette reordering approaches — Zeng's method, Memon's method and the luminance-based method — under the context of color-quantized natural images with and without dithering.

Luminance-based palette reordering is often considered inefficient, when compared to other more complex approaches. However, we provided experimental evidence showing that this may not be always the case. In fact, for dithered images with 128 or more colors it outperforms the other more complex methods, being very competitive in a number of other cases, specially if we take into account its simplicity. The remaining cases are divided almost evenly among Zeng's and Memon's methods, with a tendency for a better performance of Zeng's method in images having 128 colors or less, and for Memon's method in images with 128 colors or more.

5 Acknowledgement

The authors would like to thank Dr. W. Zeng and Dr. S. Battiato for providing software which was a great help for performing the experimental part of this work.

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