A new quantization scheme for HDR two-layer encoding schemes

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Two-layer encoding schemes for High dynamic range (HDR) images (and video) not only provide backward compatibility with the existing displays, but also preserve additional details in the second layer which can be important for certain applications. The first layer is for visualization and should be encoded at the best quality, however the residual data can be processed before encoding in the second layer, to maximize the amount of details that can be preserved. Most of the existing schemes use JPEG encoding for the second layer as well. However, JPEG is a lossy scheme designed to give more importance to visually important features. Therefore, it is not the best choice for encoding of the second layer, which does not necessarily have the same spectrum as that of the original image. Instead, a lossless scheme such as PNG would be a better choice. This would reduce the encoding problem to a better packaging of floating point data to integers of fixed bit depth. In other words, we need to devise a non-linear quantization scheme to minimize the loss, since the encoding after quantization would be lossless.

Let's assume we use a bit depth of a byte for the second layer. In this case, each floating point value of the residual data will get an integer label in 0-255 range, or in other words, each pixel will be assigned to one of 256 regions, or bins, covering the whole range. A simple scaling followed by rounding would result in very uneven distribution of pixels, and hence accumulated errors across the bins will also be distributed unevenly. A typical case is shown by the red curve in Fig. 1. An alternate approach of having same number of pixels in each bin can result in some very wide bins, and therefore high individual pixel and accumulated bin errors (blue curve in Fig. 1). We propose to distribute the quantization error more uniformly over all bins, which can reduce the total amount of error significantly. A typical result of accumulated bin errors using our algorithm is shown by green curve in the figure.

A sophisticated clustering algorithm (such as k-means) can be used to segment the whole range into desired number of bins, but it cannot guarantee even distribution of error across bins due to uneven distribution of pixels. Moreover, clustering algorithms are generally very slow. We propose an efficient algorithm to reduce and spread the error over bins almost uniformly:

1. Sort all pixel values in ascending order, and place them in a single bin with edges at minimum and maximum values.
2. Divide the bin into two by placing an additional edge at the bin-center, which we define as mean of the pixel values inside the bin.
3. Calculate errors for each new bin. We define bin error as sum of Euclidean distance of each pixel in the bin from the bin-center. For a typical image, on average, the total error of two new bins is almost 50.5% of the error in the parent bin.

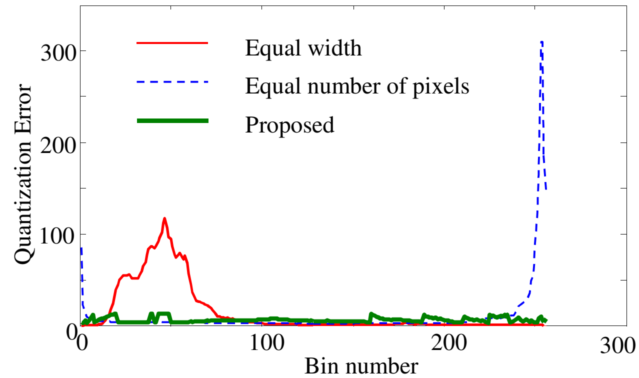

Fig. 1: Accumulated quantization errors in each bin.

4. Find the bin with the largest error among the existing bins. Apply the above split process (steps 2-3) on it, and repeat until 256 bins are obtained.

We perform an additional refinement step. Pixels lying near the boundaries of the bins are moved to a neighboring bin if doing so reduces the overall error. This is repeated until a local minima is achieved. and no significant further reduction in error is obtained. Note that this local minimization does not distort much the state of nearly uniform spread obtained by the algorithm given above. In the table below, we show improvements in some existing methods when our quantization method was incorporated in them. For all methods, the second layer is implemented in lossless PNG format, to observe the effect of proposed quantization only.

	Average improvement when proposed quantization was used with the methods of		
Metric	Ward et al.	Mantiuk et al.	Khan
MSE (RGB)	45%	82%	77%
MSE (Lab)	39.6%	83%	79%
HDR-VDP	19%	7%	8%
Size	-19%	-53%	-47%

Improvement in the visual metric HDR-VDP is relatively less because the tone-mapping process is generally designed to preserve the visual features in the first layer. MSE describes the overall deviation from the original image and shows more significant improvement. The last row shows increase in overall size of the encoded image, which is due to more tightly packed and hence relatively less compressible data, compared to the existing schemes.

References

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