Parameter Estimation for Photographic Tone Reproduction

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Abstract

Tone reproduction algorithms attempt to compress a large range of pixel values into a smaller range that is suitable for display on devices with limited dynamic range. A recently proposed tone reproduction operator achieved this goal by emulating photographic practice. Like in photography, the manual tuning of a small set of intuitive parameters was required. In this paper we extend this photographic tone reproduction algorithm with an automatic method for estimating these parameters. The estimation process is also based on photographic practice. The resulting operator produces good images and does not require manual parameter tuning. Sample source code is available online.

1 Introduction

The range of intensities that can be displayed on current display devices tends to be much smaller than the dynamic range of real scenes. Hence the need to compress real world data to fit the displayable range of such display devices. This compression is called tone mapping or tone reproduction and often requires visual appearance, contrast or brightness to be preserved. To compress a high dynamic range image, a number of different approaches may be taken, as is evident from a large quantity of previous work (e.g. [Tumblin and Rushmeier 1993; Ward et al. 1997; Pattanaik et al. 1998; Durand and Dorsey 2002; Fattal et al. 2002]).

Tone reproduction algorithms can be broadly classified into global and local operators. The former class compresses the luminance of each pixel using a fixed curve, which may contain an image dependent constant that computes the overall luminance level (a log average is often used). While the simplicity of these algorithms is attractive, for very high dynamic range images detail is frequently lost in light or dark areas.

Local operators on the other hand, scale each pixel according to the average luminance level of its local neighborhood. The key issue with this type of algorithm is to correctly determine the size of the local neighborhood for each pixel. If done incorrectly, ringing artifacts may occur. Local operators also tend to be computationally more expensive than global operators.

We previously developed a tone reproduction technique designed for a wide variety of images [Reinhard et al. 2002]. The method exists as both a very simple but effective global operator for medium to high dynamic range images, and as a somewhat more elaborate local operator for very high dynamic range images. This photographic tone reproduction technique is inspired by common photographic practices and borrows from Ansel Adams' Zone System [Adams 1981].

A *zone* is defined as a Roman numeral associated with an approximate luminance range in a scene as well as an approximate reflectance of a print. There are eleven print zones, ranging from pure black (zone 0) to pure white (zone X), each doubling in intensity, and a potentially much larger number of scene zones. *Dynamic range* is the ratio of the highest and lowest luminance regions where detail is visible, expressed as the difference between highest and lowest distinguishable scene zones. The *key* of a scene indicates whether it is subjectively light, normal, or dark. A white-painted room would be high-key, and a dim stable would be low-key.

Display devices typically span a range of 4 to 5 zones, which is also the range of values found in low dynamic range images. Medium dynamic range scenes span up to 11 zones and high dynamic range images have more than 11 zones. Our photographic tone mapping operator attempts to bring medium and high dynamic range images within displayable range using the following sequence of fairly simple steps [Reinhard et al. 2002]. First, luminance is computed from RGB triplets using $L_w(x,y) = 0.27R(x,y) + 0.67G(x,y) + 0.06B(x,y)$. Then the log average luminance L_{av} is computed with:

$$\bar{L}_w = \exp\left(\frac{1}{N}\sum_{x,y}\ln\left(\delta + L_w(x,y)\right)\right) \tag{1}$$

where δ is a small constant and $L(x,y)$ are the N input pixels. Then, each pixel is scaled such that the log average luminance is mapped to the key value α (hitherto a user specified parameter):

$$L(x,y) = \frac{\alpha}{\bar{L}_w} L_w(x,y) \tag{2}$$

Second, this method assumes that part of the scene is allowed to "burn out", or produce values outside the displayable range that are subsequently clamped to fit. The smallest value in the range of world luminances that is allowed to be clamped, is called the "white point", L_{white}, and is a second user parameter. Our simple, but effective global tone mapping operator for medium dynamic range images is given by:

$$L_d(x,y) = \frac{L(x,y)\left(1 + \frac{L(x,y)}{L^2_{\text{white}}}\right)}{1 + L(x,y)} \tag{3}$$

with L_{white} the smallest luminance that is mapped to pure white and $L_d(x,y)$ the displayable luminance values.

This algorithm can be transformed into a local tonemapping operator by replacing $L(x,y)$ in the denominator with $V(x,y)$, as shown in [Reinhard et al. 2002]. This effectively implements *dodging-and-burning*, which is a printing technique where some light is withheld from a portion of the print during development (dodging), or more light is added to that region (burning). Using V instead of L makes the algorithm suitable for the compression of very high dynamic range images, but does not lead to further user parameters that need to be specified on a per-image basis.

In this paper, we are concerned with the automation of the two user parameters "key" and "white point". We believe that by making this photographic tone mapping operator free of user parameters, its use will be extended to include further applications where parameter tuning on a per-image basis is impractical. At the same time, the global operator remains very simple to implement, avoids excessive clamping of values, and does not introduce artifacts other than some contrast reduction in the light areas. Sample source code is available on the web site listed at the end of this paper.

2 Parameter Estimation

To estimate the key of an image, we first compute the minimum and maximum zone of the image ($\log_2 L_{\min}$ and $\log_2 L_{\max}$), which is computed from the minimum and maximum luminance value of the image. To improve stability, we exclude the brightest and dimmest 1% pixels. The log average luminance $\bar{L}_w$ falls into a zone somewhere in between the minimum and maximum. The determination of the key of the scene is based on the observation that for high key scenes, the number of zones below the log average luminance is larger than the number of zones above. For low key scenes, the situation would be reversed, as shown in the histograms of Figure 1. Hence, we can compute the key α of a scene as follows:

$$\alpha = 0.18 \times 4^{\left(\frac{2\log_2 \bar{L}_w - \log_2 L_{\min} - \log_2 L_{\max}}{\log_2 L_{\max} - \log_2 L_{\min}}\right)} \qquad (4)$$

The constant 4 was determined empirically.

The white point L_{white} can be determined by noting that for most high dynamic range images, any large number would be sufficient. Only for low and medium dynamic range images, this parameter should be chosen more carefully. For a low dynamic range image of 5 zones, a white point of $L_{\text{white}} = 1.5$ is a suitable choice that produces a reasonably enhanced display image. Hence, an appropriate formula for computing the white point is:

$$L_{\text{white}} = 1.5 \times 2^{(\log_2 L_{\max} - \log_2 L_{\min} - 5)} \qquad (5)$$

Finally, a criterion is needed to determine if the global tone reproduction operator of Equation 3 is suitable, or if the more elaborate dodging-and-burning (local) technique is more appropriate. As mentioned above, high dynamic range images tend to consist of more than 11 zones. For these images, the dodging-and-burning technique would have advantages over our simple operator. As such, our criterion to select dodging and burning is based simply on the dynamic range of the image:

$$\log_2 L_{\max} - \log_2 L_{\min} > 11 \qquad (6)$$

3 Results and Discussion

To demonstrate that the automatic setting of the key value according to Equation 4 produces satisfactory results for a variety of different dynamic ranges, we show a number of compressed images in Figure 2. For low dynamic range images, in addition to the automatic determination of the key value, the white point parameter is important. Results for low dynamic range images using automatic key and white point settings, are given in Figure 3. We would like to encourage the reader to compare the results in these figures with those obtained by manual tuning of key and white point parameters — images with these parameters specified manually are presented in [Reinhard et al. 2002]. We believe that these results are similar enough to conclude that automatic parameter selection for our photographic tone reproduction operator is feasible.

The global operator that is automated in this paper, uses a compression curve that has an asymptote of 1 and a derivative of 1 at 0 if the white point is chosen to be large (Equation 3). This simultaneously guarantees that dark areas do not lose detail and that light areas do not suffer from burn-out. Contrast is reduced only in the light areas, so that a potential disadvantage of the global operator is that some detail may be lost in those areas. The local operator suffers less from this phenomenon, but is computationally much more intensive.

Finally, by reducing the white point, some desirable burn-out may be introduced, which is a level of control that is not offered by other tone reproduction operators. In addition, the automation presented in this paper produces a reasonable amount of burn-out that is neither too much nor too little and closely approximates the values that one would choose by hand. The automated parameter selection technique presented in this paper is intended to cover most applications where dynamic range reduction is required. Certain images may still benefit from manual parameter selection to suit particular tastes and viewing conditions.

Figure 3: *Low dynamic range images (left) enhanced using automatic parameter selection (right).*

Web Information

Sample C source code as well as the images in this paper are available online at http://www.acm.org/jgt/papers/Reinhard02

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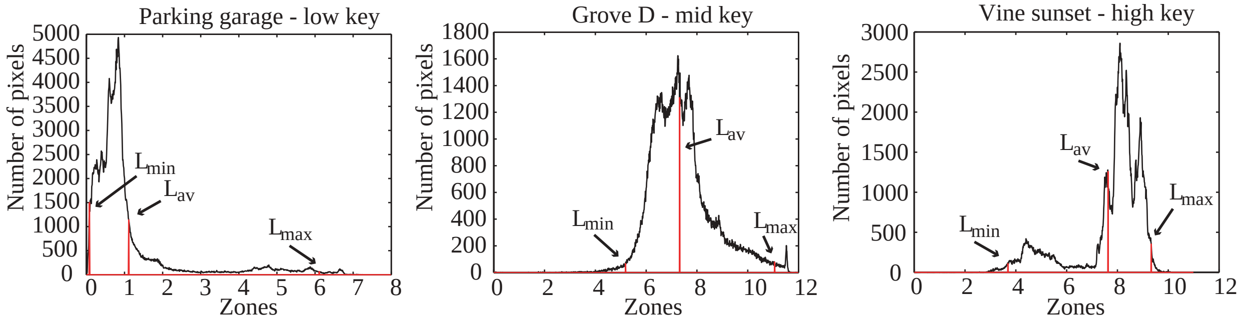

Figure 1: *Histograms for low, mid and high key scenes. The images of these are depicted in Figure 2.*

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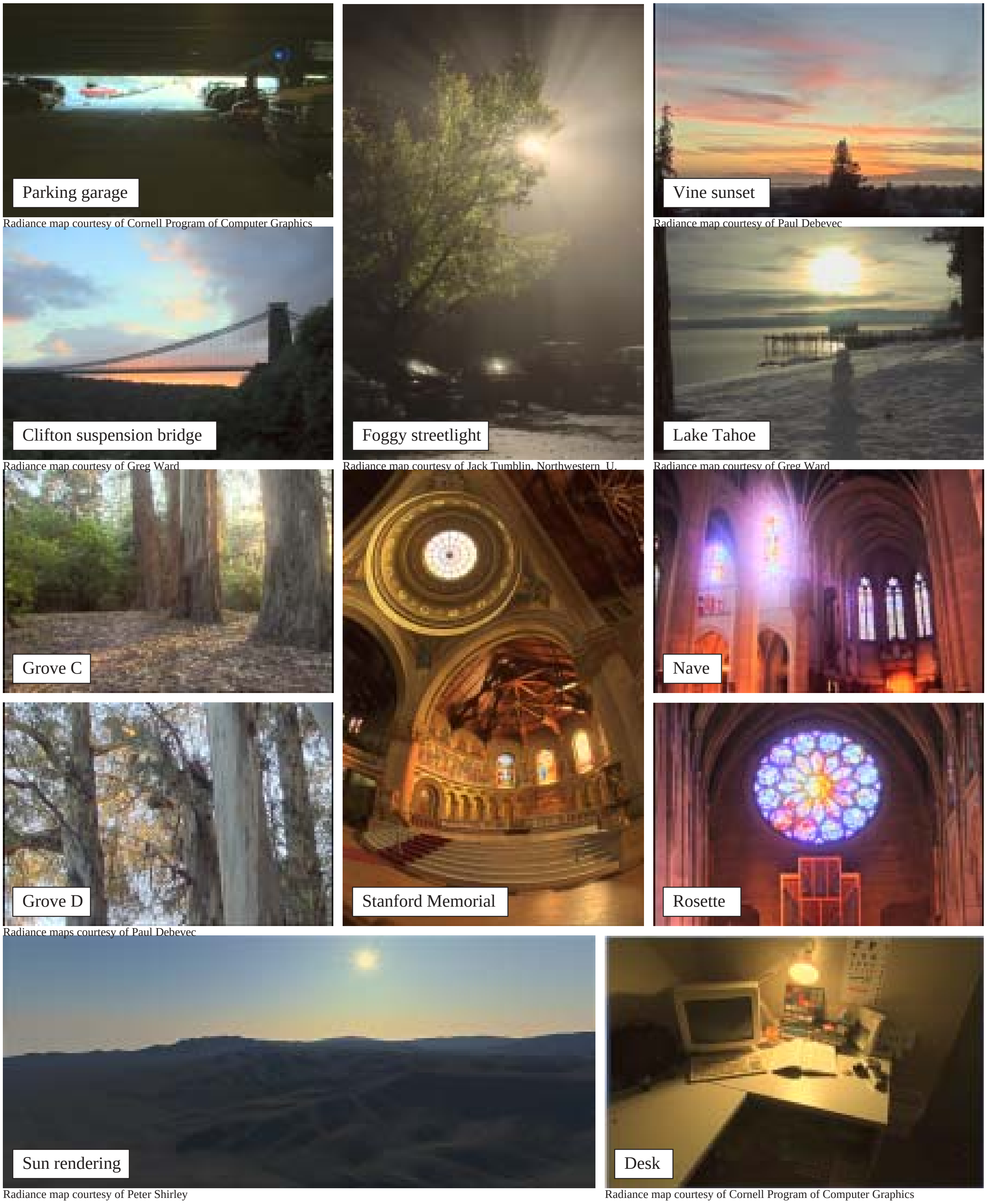

Figure 2: *A selection of high dynamic range images compressed using automatic parameter selection.*