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Progressive color transfer for images of arbitrary dynamic range

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ABSTRACT

Image manipulation takes many forms. A powerful approach involves image adjustment by example. To make color edits more intuitive, the intelligent transfer of a user-specified target image's color palette can achieve a multitude of creative effects, provided the user is supplied with a small set of straightforward parameters. We present a novel histogram reshaping technique which allows significantly better control than previous methods and transfers the color palette between images of arbitrary dynamic range. We achieve this by manipulating histograms at different scales, which allows coarse and fine features to be considered separately. We compare our approach to a number of existing color transfer and tonemapping techniques and demonstrate its performance for a wide range of images.

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1. Introduction

Images can convey information not only through the depicted objects but also through the particular mood, color scheme and composition of the scene. Artists can manipulate the color palette manually to change the appearance of an image and achieve specific effects but that can be a time-consuming process, requiring advanced image manipulation skills. To that end, several color transfer techniques have been proposed that uses the color palette of a second image as a target and achieve similar results with minimal user input and skill necessary. Matching the color distribution of one image to another is typically achieved by transferring some characteristics between the two images ranging from simple statistical properties to more complex distribution transfers, generally focusing on preserving certain visual qualities of the image.

A limitation of existing color transfer techniques is the lack of control over how much the input image should be matched to the target. As color transfer is particularly useful for artistic purposes, intuitive and simple control over the result is a desirable feature. This would also make the selection of the target image less critical to achieve a plausible result. As a consequence, a wider range of target images could be used, opening up the possibility of using the selection of target images as a part of the creative process.

Histograms are used extensively in imaging applications as they provide a compact space in which images can be manipulated. Images of typical scenes (natural or otherwise) contain a lot of redundant information as most pixels are similar in color to their neighbors. These similarly colored image portions tend to

correspond to persistent peaks in the histogram of the image, while smaller within-region variations create the higher frequency details. We therefore hypothesize that histograms can be manipulated at different scales, allowing different portions of the image to be affected without requiring manual selection or segmentation.

With this motivation, we propose a color transfer technique that can progressively reshape the histogram of a given image to match it to the histogram of another. Our approach relies on the novel idea of a scale-space manipulation of the histograms, which allows us to match features at coarser or finer scales. This is the key for achieving a range of appearances: we allow the user to select how well the color palette of the input image should be matched to that of the target. At a minimum, the result will maintain the original appearance of the source image, while at a maximum the histogram of the input will fully match that of the target. With our scale-space approach a partial match can be achieved by only reshaping the histogram according to features in coarse scales, while a full match considers finer scales too, allowing more detail to be captured (see Fig. 1).

Additionally, our approach allows colors to be transferred between images of varying dynamic ranges. When a high dynamic range (HDR) source and a low dynamic range (LDR) target are used, the input HDR image is matched to the target LDR both in color and in dynamic range. As such, the proposed technique is suitable for creatively tonemapping HDR images using a target to specify the desired appearance of the result.

We review the relevant literature in Section 2 and present our algorithm in Section 3, while Section 4 proposes two region selection mechanisms that can be used with our technique. Section 5 discusses tone reproduction with a reference using the proposed method. Lastly, a wide range of examples is shown and compared with a representative set of existing techniques in Section 6. The paper ends with a brief summary in Section 7.

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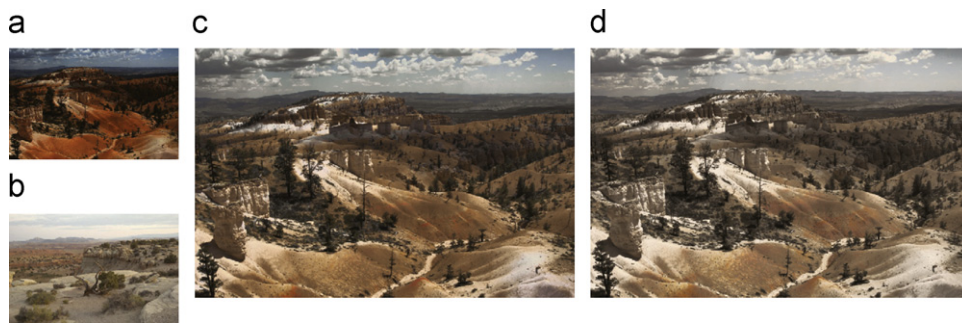


Fig. 1. An example of a progressive color transfer result produced by our algorithm. (a) Source, (b) target (c) our result, partial match, (d) our result full match.

2. Related work

2.1. Color transfer

In its simplest form, the method proposed by Reinhard et al. [1] shifts and scales the pixel values of the source image to match the mean and standard deviation from the target. This is done in the $l\alpha\beta$ opponent color space, which is on average decorrelated [2]. This allows the transfer to take place independently in each channel, turning a potentially complex 3D problem into three much simpler 1D problems. Although this technique can be successful for a large range of images, the quality of the results largely depend on the composition of the source and target images.

Other global approaches transfer higher level statistical properties. Histogram matching can be used to transfer the distributions of images in a variety of color spaces. Neumann and Neumann [3] use 3D histogram matching in the HSL color space to achieve an exact match of the gamut of the target image. Histogram matching in the $l\alpha\beta$ color space is used by Xiao and Ma [4] with the addition of a post-processing step that uses optimization to preserve the gradients of the source image. To deal with larger differences in image composition, Pitié et al. [5] propose a method to transfer an N -dimensional probability distribution function to another. They use an iterative, non-linear technique that estimates the solution using 1D marginal distributions. This technique is very successful in terms of matching the color palette as it takes into account the correlations between channels, but tends to produce significant spatial artifacts. These can be removed by a somewhat involved post-process, which matches the gradient field of the output image to the input image [6].

Most color transfer techniques transfer properties in an appropriate color space that de-correlates the image data. Although color spaces such as $l\alpha\beta$ can achieve that for most images, counter-examples exist where a different set of axes would be more appropriate, i.e. better decorrelated. Using principal component analysis (PCA) Abadpour and Kasaei [7,8] compute a decorrelated color space suitable for the particular input images. They also propose a unified framework for colorizing grayscale images from colored ones. Using independent component analysis (ICA), Grundland and Dodgson [9] compute a decorrelated and independent color space that is based on the perceptually uniform CIE Lab color space and use an approximate histogram matching to transfer the colors between images. Similarly, in the work by Xiao and Ma [10], the image data of the source and target is decomposed into its principal components and the source pixels are transformed appropriately to match the target.

A potential source of problems with color transfer approaches in general is that if the contents of the target image are vastly different to the source, the results can look unnatural. If for instance the colors of a seascape are successfully transferred to a forest landscape, blue foliage will inevitably appear. To alleviate this effect, Chang et al. [11] propose a perception-based scheme whereby colors are classified into categories derived through a

psychophysical color-naming study. The color transfer then adheres to this classification by restricting resulting colors within their original categories in order to create a natural-looking image.

Color transfer has also found applications in image and video colorization. Using luminance and texture information, Welsh et al. [12] transfer the palette of a color image to a grayscale one. Texture information is also used in Ji et al. [13] to aid in the colorization of grayscale images. Infrared video colorization has been demonstrated in Yan et al. [14] where a reference color image is used to color a monochromatic frame sequence.

Colorization or recolorization of images can also be achieved using stroke based input to define the target colors. Levin et al. [15] color grayscale images by applying simple strokes in regions of the image. The color of the strokes is then propagated to the remainder of the region using optimization-based techniques. The approach by Wen et al. [16] on the other hand, uses strokes in both the source and target image to define corresponding regions in the images rather than directly specify a color palette. Partial recolorization can also be achieved by defining a region to be altered using a simple rectangular selection that is then propagated through a color influence map [17]. More recently, An and Pellacini proposed a stroke based approach that uses pairs of strokes to define region correspondences between images [18]. Colors are transferred for each stroke pair using a nonlinear constrained parametric model that achieves a high degree of matching while minimizing artifacts. Our technique optionally employs a simpler region selection mechanism using masks to define which regions should be used in the transfer, discussed in Section 4.

A technique relatively close to ours is the one proposed by Senanayake and Alexander [19] which aims to eliminate color variations in images of similar scenes that may be due to varying illumination or viewpoint. The source and target histograms are aligned based on corresponding features that are detected as persistent peaks through scale space using a polynomial mapping. Although their technique works well when the source and target images are similar, it is not appropriate for cases where the histograms are significantly different as no corresponding features exist. In contrast, our proposed algorithm aims to transfer properties between potentially very different images. By expanding on the notion of histograms in a scale space, we are able to reshape the source histogram in order to create peaks that match the target.

2.2. Tone reproduction

High dynamic range imaging and related topics have garnered much interest in recent years, with the film and games industries counted as early adopters. Tone reproduction takes a central place in this field, given the need to reduce the dynamic range of images for display on specific devices [20]. Dynamic range reduction is often inspired by aspects of human vision, aiming to reproduce visual attributes such as contrast, brightness, or more generally appearance.

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