Progressive Color Transfer for Images of Arbitrary Dynamic Range

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Abstract

◆ Proposed method
  – Novel histogram reshaping technique
    • Allowing significantly better control than previous methods
    • Transferring the color palette between images of arbitrary dynamic range
    • Manipulating histograms at different scales
      – Coarse and fine features
Introduction

◆ Color transfer technique
  – Using the color palette of a second image as a target
  – Achieving similar results
  – Matching the color distribution of one image to another
    • Transferring some characteristics between the two images
  – Limitation of existing color transfer techniques
    • Lack of control over how much the input image should be matched to the target
Proposed method

- Hypothesis
  - Manipulating histogram at different scales
  - Allowing different portions of the image to be affected without requiring manual selection or segmentation

- Proposed a color transfer technique
  - Reshaping the histogram of a given image
  - Relying on the novel idea of a scale-space manipulation of the histogram
  - Allowing colors to be transferred between images of varying dynamic ranges

![Fig. 1.](image-url) 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.
Related work

◆ Color transfer
  – Matching the mean and standard deviation from the target
  – Use of histogram matching
    • Transferring the distributions of images in a variety of color spaces
  – Using stroke based input to define target color
◆ Tone reproduction
  – Simple operator
    • Using a specific functional form
      – Logarithms
      – Histograms
      – Sigmoids

◆ Manipulating other image modalities
  – Bae et al.
    • Transferring the tonal balance and texture information between two image
Novel progressive histogram reshaping approach

- Goal of proposed algorithm
  - Transferring the color palette between two images
  - Allowing the user to control the amount of matching in a simple way

Fig. 2. Our algorithm transfers the color palette between two images by first computing their respective histograms in several scales, detecting minima in each histogram and reshaping the source histogram using the mean and standard deviation of the target for each region between the detected minima. Once the source is reshaped appropriately, the resulting image is produced by matching the source image to the cumulative reshaped histogram.
– Histogram

• Persistent maxima in the image histogram
  – Corresponding to important color clusters in the image

Fig. 3 The histogram shown is computed from the red–green opponent channel of the image that was first converted to the CIELab color space. At this particular scale, only two major maxima are visible. The first corresponds to the green portions in the image (bottom right) and the second to the red portions of the flowers (top right).
– Overview of proposed approach

```plaintext
function RESHAPEHISTOGRAM(Is, It, perc)

Convert Is, It to CIELab color space
Compute Smax

for each channel ic
    Compute histograms Hs, Ht from Is(ic), It(ic)
    for each level k in perc/Smax
        Hs,k ← Down- and up-sample Hs
        Ht,k ← Down- and up-sample Ht
        Rmin,t ← FINDPEAKS(Ht,k)
        for each min-bound region m in Rmin,t
            Hs,k'(Rmin,t(m):Rmin,t(m+1)) ← REGIONTRANSFER(Hs,k(Rmin,t(m):Rmin,t(m+1)),
            Ht,k(Rmin,t(m):Rmin,t(m+1)),
            k/Smax)
        end
    end
    Rmin,s ← FINDPEAKS(Hs,k')
    for each min bound region in Rmin,s
        Ho,k(Rmin,t(m):Rmin,t(m+1)) ← REGIONTRANSFER(Hs,k(Rmin,s(m):Rmin,s(m+1)),
            Ht,k(Rmin,s(m):Rmin,s(m+1)),
            k/Smax)
    end
    Io(ic) ← HISTMATCH(Is(ic), Ho)
end

Convert Io back to RGB for display
return Io
end

function FINDPEAKS(H)
    H(H >= 0) = 1
    H(H < 0) = -1
    H2 ← VH
    return Rmin ← find(H2 < 0)
end

function REGIONTRANSFER(Hs,Ht,wt)
    ws ← 1-wt
    Ho ← (Hs-ws·mean(Hs))(wt·std(Ht)/ws·std(Hs)) + wt·mean(Ht)
end
```

Fig. 8 Pseudocode describing the main steps of the core part of our algorithm.
\textbf{Background}

– Histograms

\[ H = \{(h(1), v(1)), \ldots, (h(B), v(B))\} \]  \hspace{1cm} (1)

\[ B = \left\lfloor \frac{\max(I) - \min(I)}{V} \right\rfloor \]  \hspace{1cm} (2)

\[ h(i) = \sum_{p=1}^{N} P(I(p), i), \quad i \in [1, B] \]  \hspace{1cm} (3)

\[ v(i) = \min(I) + (i-1)V \]  \hspace{1cm} (4)

\[ P(I(p), i) = \begin{cases} 1 & \quad i = \left\lfloor \frac{I(p) - \min(I)}{V} + 1 \right\rfloor \\ 0 & \quad \text{otherwise} \end{cases} \]  \hspace{1cm} (5)

where \( H \) is the set of all pairs \((h(i), v(i))\) for all \( i \in [1, B] \) corresponding to the number of elements and values of the \( i \) bin of the histogram, and \( I(p) \) is the value of the \( p \)th pixel of image \( I \) which contains to total of \( N \) pixels and \( P(I(p), i) \) represents the probability of a pixel \( I(p) \) belonging to a bin \( i \).
– Bilateral filtering
  
  • Smoothing regions in the image while respecting strong edges

\[
I_{\text{bilat}}(p) = \frac{\sum_{q \in N} f(q - p) g(I(q) - I(p)) I(q)}{\sum_{q \in N} f(q - p) g(I(q) - I(p))}
\]  

(6)

where \( I_{\text{bilat}}(p) \) is the output of the bilateral filter for the \( p \)th pixel of image \( I \), and \( f, g \) are Gaussians operating on pixel distances and intensities respectively.
Progressive histogram reshaping

- Computing each scale for the target histogram
  - Removing high frequency details of the histogram
  - Preserving prominent feature
  - Use of downsampling and upsampling the original histogram
  - Maximum number of scales

$$S_{\text{max}} = \left\lfloor \log_2 \left( \frac{B}{B_{\text{min}}} \right) \right\rfloor$$  \hspace{1cm} (7)

where $B$ is the number of bins, and $B_{\text{min}}$ is the minimum allowed histogram size.
– Detecting features in each scale of the histogram
  • Appropriate way
    – Locating zero-crossings in the first-order derivatives of the histogram
      \[
      \nabla h_{t,k} = h_{t,k}(i) - h_{t,k}(i + 1), \quad i \in [1, B_{k-1}]
      \]
      (8)
    – Classifying zero-crossings as minima or maxima
      » Use of the corresponding values of the second-order derivative
    – Dividing the target histogram into a set of regions
      » Using the detected minima
      \[
      R_{\text{min},k} = \left\{ i \mid \nabla h_{t,k}(i) < 0 \land \nabla^2 h_{t,k}(i) > 0 \right\}
      \]
      (9)
    where \( R_{\text{min},k} \) is the set of minima for a scale \( k \).
– Reshaping each corresponding region of the source histogram

• Bounds \([a, b]\) of a region \(j\)

\[
a = R_{\min,k} \left( j \right) \\
b = R_{\min,k} \left( j + 1 \right) - 1
\]

• Mean and standard deviations of each region

\[
\mu_{s,k} \left( j \right) = \frac{\sum_{i=a}^{b} h_{s,k} \left( i \right)}{b - a} \tag{10}
\]

\[
\sigma_{s,k} \left( j \right) = \sqrt{\sum_{i=a}^{b} \frac{\left( h_{s,k} \left( i \right) - \mu_{s,k} \left( j \right) \right)^2}{b - a}} \tag{11}
\]

where \(\mu_{s,k} \left( j \right)\) and \(\sigma_{s,k} \left( j \right)\) are the mean and standard deviation of the \(j\)th region of \(H_{s,k}\), respectively.
Reshaping the bins of corresponding regions

\[ h_{o,k}(i) = \left( h_{s,k}(i) - w_{s,k} \mu_{s,k}(j) \right) \frac{w_{t,k} \sigma_{t,k}(j)}{w_{s,k} \sigma_{s,k}(j)} + w_{t,k} \mu_{t,k}(j) \]  \hspace{1cm} (12)

where \( h_{o,k} \) is the set of output histogram bin counts for a given scale \( k \), and \( w_{s,k} \) is a weight dependent on \( k \), with \( w_{t,k} = 1 - w_{s,k} \).

**Fig. 5.** A color to grayscale example. The palette of this distinctive Ansel Adams image is transferred to the source image with various options for the level of matching (s) and the transfer weights (wt). As can be seen, the resulting images gradually take on the appearance of the target.
– Applying an additional match of means and standard deviations
  • First transfer between histograms
    – Taking into account the features of the target
  • Second transfer
    – Considering features of the source
– Resulting histograms of the matching process at each scale

Fig. 4. Histograms for a series of consecutive scales are shown. Scale 1 is the coarsest while scale 5 is the finest. Each iteration brings the source histogram closer to the target, allowing for partial matching.
– Creating output image through full histogram matching
  
  • Use of the source image and the reshaped histogram
  • Cumulative histograms

\[
C_s(j) = \sum_{i=1}^{j} h_s(i), \quad j = 1, \ldots, B \tag{13}
\]

\[
C_o(j) = \sum_{i=1}^{j} h_o(i), \quad j = 1, \ldots, B \tag{14}
\]

\[
I_o(p) = v_0 \left( C_o^{-1} \left( C_s \left( \frac{I(p) - \min(I) + 1}{V} \right) \right) \right) \tag{15}
\]

where a cumulative histogram \( C \) is defined as a function mapping a bin index to a cumulative count, and the inverse function \( C^{-1} \) acts as a reverse lookup on the histogram, returning the bin index corresponding to a given count.
– Example of partial matches between two HDR images

Fig. 9. This is an example of partial matches between high dynamic range images. Only matches up to 50% are shown here as in this particular example, further scales did not produce significantly different results.
– Comparison with color transfer between pairs of HDR images

**Fig. 10.** Both source and target images have a high dynamic range. Our algorithm seamlessly handles pairs of arbitrary dynamic ranges. Existing algorithms however can lead to unexpected results as shown here.
◆ Detail control

– Manipulating local contrast in the resulting image
  • Use of the bilateral filter
  • Manipulating the residual after subtracting the filtered image

\[ I_{\text{res}} = I - I_{\text{bilat}} \]  \hspace{1cm} (16)

• Contrast-modified version of the output image

\[ I'_o = I_o + w_c \left( I_{\text{res,s}} - I_{\text{res,o}} \right) \] \hspace{1cm} (17)

**Fig. 11.** The result (b) was produced by simply matching the source HDR image to the shown LDR target (both shown in (a)). In this case, no contrast enhancement or detail modification was applied to the image.
Region selection

- Use of alpha matte created using the Soft Scissors approach

Fig. 6 The input images (source—left, target—right) are used with their corresponding mattes to produce the result shown at the bottom.
Achromatic parts of the source image

– Anchoring achromatic regions of the histogram

• Use of a simple mask $M$

$$M(p) = \begin{cases} 
1 & |I(p)| > w_a \left( \max(I) - \min(I) \right) \\
0 & \text{otherwise}
\end{cases}$$

(18)

where $w_a$ is a constant defining the percentage of the range of each channel that should be considered.

Fig. 7 The lower left image (c) is created without histogram anchoring. The tiger has acquired an unnatural red tint. The lower right image (d) demonstrates the effectiveness of histogram anchoring. Here the leaves have been correctly matched to the target but the tiger has remained white.
Creative tone reproduction

- Histogram reshaping technique
  - Transferring the color palette between two images
  - Reducing the dynamic range of the source image

Fig. 14. Tone reproduction examples created using our technique. Here the same source image was mapped to various different targets to get different appearances. The resulting tone curves are shown for each channel.
**Fig. 15.** The source and target images used for the results in Fig. 16.

**Fig. 16.** A series of partial results was created using the images shown in Fig. 15. The following values were used for the matching parameter (going from left to right): 15%, 25%, 35%, 50%, 65%, 80% and 100%.
Results

◆ Color transfer
  – Compare results with three representative color transfer algorithms
**Fig. 21.** Comparisons with existing methods
Suitable for partial or complete desaturation

Fig. 18. Results of the same source and target images as Fig. 5 using other color transfer techniques.

Fig. 19. The coarsest and finest scale histograms for the source, target and fully matched result from Fig. 5(a), (b) and (f). The source histogram is successfully reshaped to match the target for both of the chromatic channels, rendering the image to grayscale.
– Less extreme scenario

Fig. 17. Here, the effect achieved on the resulting image approaches selective desaturation as the target is largely achromatic.
Tone reproduction

- Results of the tone reproduction capabilities of proposed algorithm

Fig. 12. Another example of an HDR to LDR match. Here both the dynamic range and the colors of the target are very different to the source. The result has successfully matched both. (a) Source, (b) target, (c) Reinhard et al. [1], (d) our result.
Fig. 20. The target chosen here has a similar color palette to the source image but much lower dynamic range. The result has matched the dynamic range of the target, producing comparable results to existing tonemapping techniques. For display purposes, we show the linearly scaled source (b) and a tonemapped version (c) using [23]. Images (e)–(h) were created using other color transfer techniques.
Fig. 13. Here, a partial and a full match are shown for an HDR source and an LDR target. The result of a luminance only transfer is also shown and compared with corresponding results using several tonemapping algorithms.
– Time performance of proposed technique

**Table 1.** Relative timings between the tested algorithms, computed over the image pairs shown in Fig. 21. The performance of our algorithm for a full match over 400 bins has been taken as the baseline for these comparisons. Lower numbers indicate better performance and vice versa.

<table>
<thead>
<tr>
<th>Method</th>
<th>Relative performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ours (100%—400 bins)</td>
<td>1.000</td>
</tr>
<tr>
<td>Ours (50%—400 bins)</td>
<td>1.084</td>
</tr>
<tr>
<td>Ours (100%—255 bins)</td>
<td>0.687</td>
</tr>
<tr>
<td>Reinhard et al.</td>
<td>0.026</td>
</tr>
<tr>
<td>Pitié et al.</td>
<td>1.626</td>
</tr>
<tr>
<td>Xiao and Ma</td>
<td>2.538</td>
</tr>
</tbody>
</table>

◆ Limitations
– Decorrelating the three color channels for the given input
Summary

Proposed method

- Novel color transfer method
  - Allowing significantly better control than previous methods
  - Transferring the color palette between images of arbitrary dynamic range
  - Manipulating histograms at different scales
    - Coarse and fine features