Colorization Using Optimization

Anat Levin    Dani Lischinski    Yair Weiss

School of Computer Science and Engineering
The Hebrew University of Jerusalem, Israel
Colorization: a computer-assisted process of adding color to a monochrome image or movie. (Invented by Wilson Markle, 1970)
Motivation

- Colorizing black and white movies?
- Maybe not...
- But what about black and white TV shows?
Motivation

• Colorizing black and white movies / TV shows
• Recoloring color images for special effects
Image colorization tutorial - Sandesh
Image colorization tutorial. In this tutorial we are about to learn How to colorize a black and white image. The underlying features that we will explore in ...
in.geocities.com/skexz/tuts/colorization/index.htm - 20k - Cached - Similar pages

Worth1000.com | Photoshop Contests | Are you Worthy™ | tutorial
Variety is the spice of life, and with that in mind, I offer you yet another colorization tutorial. This one uses a different method than either of the ...
www.worth1000.com/tutorial.asp?id=161016 - 23k - 29 Apr 2007 - Cached - Similar pages

Photoshop Colorization Tutorial
Tutorial Summary: Photoshop Illustrator and Design Tutorials ! Get Addicted! or Welcome! We ve updated our tutorial section here at. ...
www.tutorio.com/tutorial/photoshop-colorization-tutorial - 5k - Cached - Similar pages

Colorization Tutorial
Tutorial Summary: Colorization in Photoshop ! Get Addicted! or All tutorials are property of PixelAddiction.com and their respective. ...
www.tutorio.com/tutorial/colorization-tutorial - 5k - Cached - Similar pages

Colorization - Colors Tutorial
Learn to colorize using CMYK adjustment layers in Photoshop.
www.photoshop101.com/tutorial/colors/1011/ - 17k - Cached - Similar pages

Artist Dreams :: View topic - Colorization Tutorial
I had wanted to get into the colorization technique, and started last night for that Zhang Zyi (sp?) colorization challenge from nowhere... but I think this ...
artistdreams.net/forum/viewtopic.php?t=291 - 42k - Cached - Similar pages

Colorization Tutorial
Get out your crayons folks, because Keb has written a fabulous colorization tutorial. Get your layers in a groove and check it out. Thanks Keb...you're the ...
www.freakingnews.com/stories/thread.asp?cid=58&eid=30362 - 33k - Cached - Similar pages
Color 101

• Typically represented by points in a three dimensional color space:
  • (Red, Green, Blue)
  • (Cyan, Magenta, Yellow)

• Some color spaces separate between the grayscale and the chromatic components of a color:

\[
\begin{bmatrix}
Y \\
U \\
V
\end{bmatrix} = \begin{bmatrix}
0.299 & 0.587 & 0.114 \\
-0.14713 & -0.28886 & 0.436 \\
0.615 & -0.51498 & -0.10001
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]
Typical Colorization Process

Images from: “Yet Another Colorization Tutorial”
Typical Colorization Process

- Delineate region boundary

Images from: “Yet Another Colorization Tutorial”
Typical Colorization Process

• Delineate region boundary
• Choose region color from palette
Typical Colorization Process

• Delineate region boundary
• Choose region color from palette
Typical Colorization Process

- Delineate region boundary
- Choose region color from palette
Video Colorization Process

- Delineate region boundary
- Choose region color from palette
- Track regions across video frames
Process Limitations

- Time consuming and labor intensive
- Difficult to delineate detailed or fuzzy boundaries
- Failures in tracking
Colorization by Analogy

A : A'

B : B'

Hertzmann et al. 2001, Welsh et al. 2002
Colorization by Analogy - Discussion

- Indirect artistic control
- No spatial continuity constraint
Our Approach
Our Approach

Artist scribbles desired colors inside regions
Our Approach

Colors are propagated to all pixels

“Nearby pixels with similar intensities should have the same color”
Propagation using Optimization

\[ Y \Rightarrow U, V \]

Intensity channel \hspace{1cm} Color channels

Assumption: Neighboring pixels with similar intensities should have similar colors
Propagating using Optimization

\[ Y \Rightarrow U, V \]

Intensity channel \hspace{1cm} Color channels

Minimize the sum of affinity-weighed squared distances between the colors of adjacent pixels:

\[ J(U) = \sum_{r,s} w_{rs} (U(r) - U(s))^2 \]
Affinity Functions

\[ W_{rs} \propto e^{-\frac{(Y(r) - Y(s))^2}{2\sigma_r^2}} \]

\( \sigma_r \) proportional to local variance
Space-time Affinity

\[ W_{rs} \propto e^{-\frac{(Y(r) - Y(s))^2}{2\sigma_r^2}} \]
Optimization

Minimize the cost function:

\[
J(U) = \sum_{r,s} w_{rs} (U(r) - U(s))^2
\]

Subject to labeling constraints  \( \{ U(r_k) = \tilde{U}_k \} \)

Since the cost function is quadratic, its minimum may be found by solving sparse system of linear equations.
Optimization

\[ U^* = \arg \min_U J(U) \]
\[ V^* = \arg \min_V J(V) \]

Minimize by solving the equations:

\[ \nabla J(U) = 0 \]
\[ \nabla J(V) = 0 \]
Derivation

\[ J(U) = \sum_{r,s} w_{rs} (U_r - U_s)^2 \]

\[ = \sum_{r,s} w_{rs} (U_r^2 - 2U_rU_s + U_s^2) \]

\[ = \sum_{r,s} w_{rs} U_r^2 - 2 \sum_{r,s} w_{rs} U_r U_s + \sum_{r,s} w_{rs} U_s^2 \]

\[ = \sum_r D_{rr} U_r^2 - 2 \sum_{r,s} w_{rs} U_r U_s + \sum_s D_{ss} U_s^2 \]

\[ = 2U^T (D - W) U \]
Derivation

\[ J(U) = 2U^T (D - W) U \]
\[ \nabla J(U) = 4 (D - W) U = 0 \]

Unconstrained system:
\[ (D - W) U = 0 \]

Note: has a trivial solution (any constant vector U).
Derivation

Add constraints:

\[ J(U) = U^T (D - W) U + \lambda \sum_k (U_k - \tilde{U}_k)^2 \]

\[ J(U) = U^T (D - W) U + \lambda (U - \tilde{U})^T C (U - \tilde{U}) \]

\[ \nabla J(U) = 2(D - W) U + 2\lambda C (U - \tilde{U}) = 0 \]

Constrained system:

\[ (D - W + \lambda C) U = \lambda C\tilde{U} \]
Color Interpolation
Colorizing Stills
Colorizing Stills

Original

Colorized
Colorizing Stills
Colorizing Stills
Challenging Case
Segmentation?

NCuts Segmentation (Shi & Malik 97)

Segmentation aided colorization

Our result
Recoloring

Affinity between pixels – based on intensity AND color similarities.
Recoloring
Recoloring
Colorizing Video

13 out of 92 frames
Colorizing Video

16 out of 101 frames
Matting

Red channel<->matte
Matting
Future Work

• Import image segmentation advantages: affinity functions, optimization techniques.

• Alternative color spaces, propagating hue and saturation differently.
Summary

★ Interface: User scribbles color on a small number of pixels

★ Colors propagate in space-time volume respecting intensity boundaries

★ Convincing colorization with a small amount of user effort

Code & examples available:
www.cs.huji.ac.i/~yweiss/Colorization/