CS780 Computational Colorimetry

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Color alteration in photographs

COLORIZATION

Acknowledgements: some of slides are courtesy of Anat Levin, Prof. Dani Lischinski (Hebrew Univ.), Prof. Gabriel Brostow, and Prof. Tim Weyrich (UCL)

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Scope

- Colorization using Optimization
  - Levin, Lischinski, Weiss, SIGGRAPH2004
- Color Transfer Between Images
  - Reinhard, Ashikhmin, Gooch, Shirley, CG&A 2001
- N-Dimensional Probability Density Function Transfer and its Application to Color Transfer
  - Pitie, Kokaram, Dahyot, ICCV 2005

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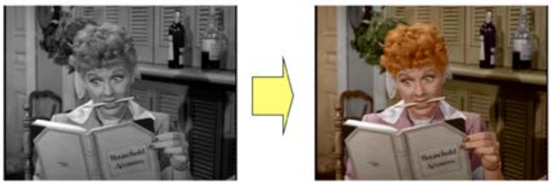
Colorization



Colorization: a computer-assisted process of adding color to a monochrome image or movie. (Invented by Wilson Markle, 1970)

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Motivation

- Colorizing black and white movies and TV shows

Earl Glick (Chairman, Hal Roach Studios), 1984:
"You couldn't make Wyatt Earp today for $1 million an episode. But for $50,000 a segment, you can turn it into color and have a brand new series with no residuals to pay"

Hugh O'Brien as Wyatt Earp, 1957

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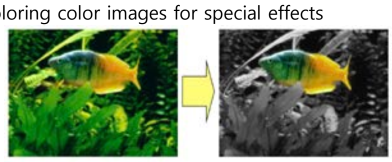
Motivation

- Colorizing black and white movies and TV shows

- Recoloring color images for special effects



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Typical Colorization Process

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Images from:
"Yet Another Colorization Tutorial"
http://www.worth1000.com/
tutorial.asp?sid=161018

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Typical Colorization Process

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- Delineate region boundary

Images from:
"Yet Another Colorization Tutorial"
http://www.worth1000.com/
tutorial.asp?sid=161018

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Typical Colorization Process

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- Delineate region boundary
- Choose region color from palette.

Images from:
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Typical Colorization Process

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Typical Colorization Process

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tutorial.asp?sid=161018

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Video Colorization Process

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

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Colorization Process Discussion

- Time consuming and labor intensive
  - Fine boundaries
  - Failures in tracking

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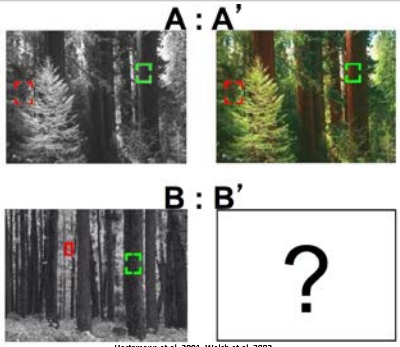
Colorization by Analogy



Hertzmann et al. 2001, Welsh et al. 2002

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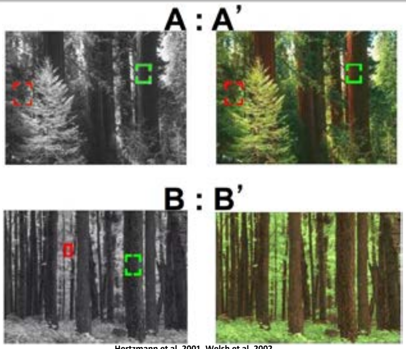
Colorization by Analogy



Hertzmann et al. 2001, Welsh et al. 2002

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Transferring Color To Grayscale Images

- Only indirect artistic control
- No spatial continuity constraint

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Levin's Colorization (SIG2004)

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Levin's Colorization (SIG2004)

- Artist scribbles desired colors inside regions

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Levin's Colorization (SIG2004) KAIST

- Colors are propagated to all pixels
- "Nearby pixels with similar intensities should have the same color"

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Propagation using Optimization KAIST

$$Y \Rightarrow U,V$$

Luminance Intensity channel

uv chromaticity channels

- Work in YUV color space
- Input: Y, Output: U,V
- "Neighboring pixels with similar intensities should have similar colors"

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Propagation using Optimization KAIST

$$Y \Rightarrow U,V$$

Luminance Intensity channel

uv chromaticity channels

$$J(U) = \sum_{r} \left(U(\mathbf{r}) - \sum_{s \in N(\mathbf{r})} w_{\mathbf{rs}} U(\mathbf{s}) \right)^2$$

$\mathbf{r}, \mathbf{s}$ denote (x, y, t)

- *Y* (**r**) is the intensity of a particular pixel.
- Minimize difference *J(U), J(V)* between color at a pixel and an *affinity-weighted average* of the neighbors

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Propagation using Optimization KAIST

$$Y \Rightarrow U,V$$

Luminance Intensity channel

uv chromaticity channels

$$J(U) = \sum_{r} \left(U(\mathbf{r}) - \sum_{s \in N(\mathbf{r})} w_{\mathbf{rs}} U(\mathbf{s}) \right)^2$$

- The notation **r** ∈ *N*(**s**) denotes the fact that **r** and **s** are neighboring pixels.

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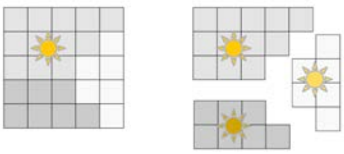
Propagation using Optimization KAIST

$$Y \Rightarrow U,V$$

Luminance Intensity channel

uv chromaticity channels

- Key idea: "Neighboring pixels with similar intensities should have similar colors"



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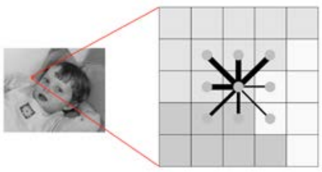
Affinity Functions KAIST

$$w_{\mathbf{rs}} \propto e^{-(Y(\mathbf{r}) - Y(\mathbf{s}))^2 / \sigma_{\mathbf{r}}^2}$$

$\sigma_{\mathbf{r}}$ is proportional to local variance

W_{rs} is large when *Y* (**r**) is similar to *Y* (**s**)



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Affinity Functions

- The correlation affinity can also be derived from assuming a local linear relation between color and intensity [Zomet and Peleg 2002; Torralba and Freeman 2003].
- Formally, it assumes that the color at a pixel $U(\mathbf{r})$ is a linear function of the intensity $Y(\mathbf{r})$: $U(\mathbf{r}) = a_i Y(\mathbf{r}) + b_i$ and the linear coefficients a_i, b_i are the same for all pixels in a small neighborhood around $\mathbf{r}$.

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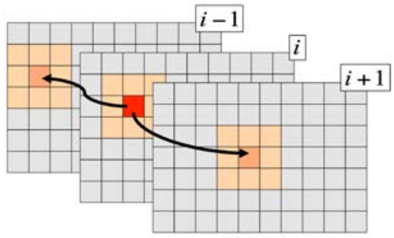
Affinity Functions in Space-Time

$$w_{\mathbf{rs}} \propto e^{-(Y(\mathbf{r})-Y(\mathbf{s}))^2/2\sigma_{\mathbf{r}}^2}$$



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Minimizing cost function

- Minimize:

$$J(U) = \sum_r \left(U(\mathbf{r}) - \sum_{s\in N(\mathbf{r})} w_{\mathbf{rs}} U(\mathbf{s}) \right)^2$$

- Subject to *labeling constraints*
- Since cost is quadratic, minimum can be found by solving sparse system of linear equations.
- Using Matlab's least-squares solver for sparse linear systems (see their code for detail):
- http://www.cs.huji.ac.il/~yweiss/Colorization/

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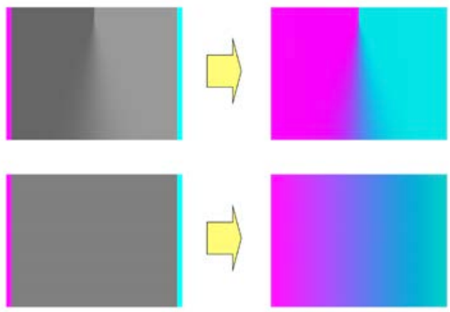
Color Interpolation



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Coloring Stills

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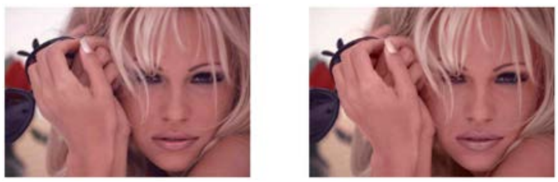
Coloring Stills



Original

Colorized

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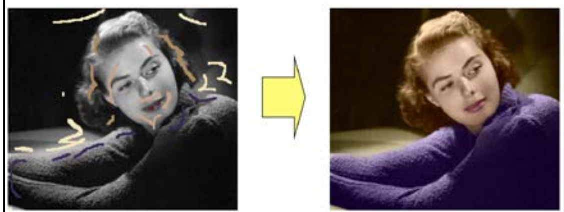
Progressive Colorization

Progressive Colorization

Progressive Colorization

Coloring Stills



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Coloring Stills

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Colorization Challenges

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Colorization Challenges

NCuts Segmentation
(Shi & Malik 97)

Segmentation aided
colorization

Our result

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Recoloring

- **Affinity between pixels – based on intensity AND color similarities.**

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Recoloring

- Affinity between pixels – based on intensity AND color similarities.

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Recoloring

- c.f. "Poisson image editing" Perez et al. SIGGRAPH 2003

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Colorizing Video

13 out of 92 frames

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Colorizing Video

16 out of 101 frames

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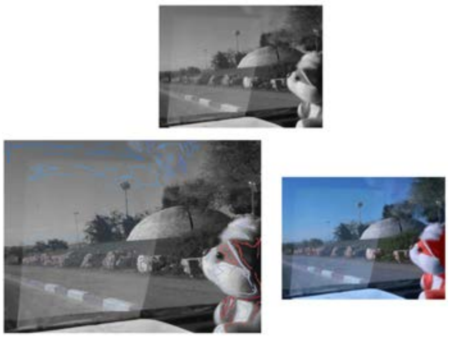
Colorizing Video



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Matting as Colorization

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Still Needed:

- Import image segmentation developments:
  - affinity functions, optimization techniques.
- Alternative color spaces, propagating hue and saturation differently

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Other Approaches?

- Color space was YUV
- Small amount of user effort needed
- For film/color *grading*, can this be automated?

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Color Transfer

- (R, G, B) is ambiguous: all channels are correlated
- (L*, a*, b*) is good
- Algorithm (per channel):
  - Align mean
  - Rescale standard deviation

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Color Transfer

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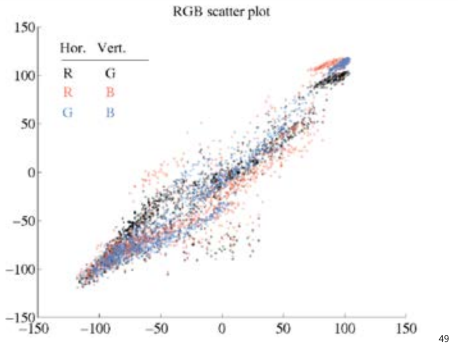

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Color Transfer

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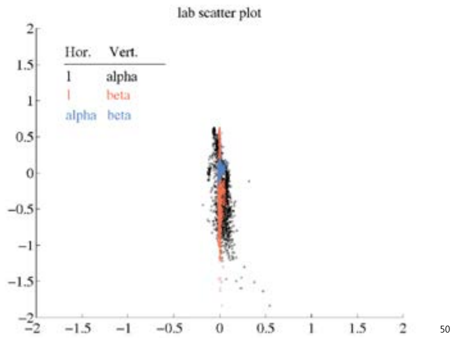

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Color Transfer

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- Subtract the mean from the data points
- Scale the data points comprising the synthetic image by factors determined by the respective standard deviations:

$$l^* = l - \langle l \rangle$$

$$\alpha^* = \alpha - \langle \alpha \rangle$$

$$\beta^* = \beta - \langle \beta \rangle$$

$$l' = \frac{\sigma_t^l}{\sigma_s^l} l^*$$

$$\alpha' = \frac{\sigma_t^\alpha}{\sigma_s^\alpha} \alpha^*$$

$$\beta' = \frac{\sigma_t^\beta}{\sigma_s^\beta} \beta^*$$

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Color Transfer

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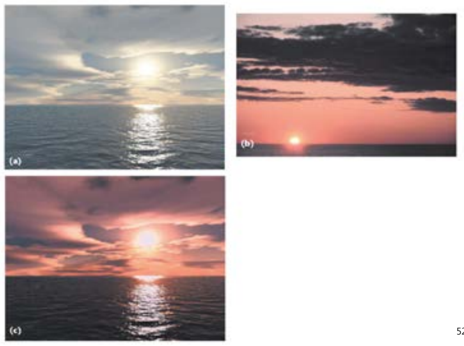

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Color Transfer

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Color Transfer

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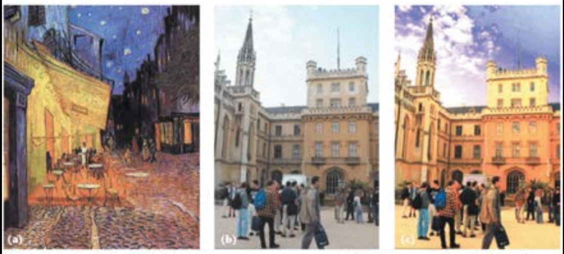
But needs some guidance



4 Using swatches. We applied (a) the atmosphere of Vincent van Gogh's *Cafe Terrace on the Place du Forum, Arles, at Night* (Arles, September 1888, oil on canvas; image from the Vincent van Gogh Gallery, http://www.vangoghgallery.com) to (b) a photograph of Lednice Castle near Brno in the Czech Republic. (c) We matched the blues of the sky in both images, the yellows of the cafe and the castle, and the browns of the tables at the cafe and the people at the castle separately.

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target image original image Reinhard

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Iterate 1D Solution at Different Rotations

- 1D solution uses cumulative probability density function (PDF): $$t(x) = C_Y^{-1}(C_X(x))$$
- where *t(x)* is a mapping function; *Cx* and *Cy* are the cumulative pdfs of X and Y images.
- N-D solution:
  - Pick a rotation matrix R, apply to both 3D distribs.
  - Project both distribs. onto each axis in turn – Apply 1D solution
  - Unproject, unrotate
  - <repeat> until convergence on all marginals for every possible rotation

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PDF Transfer Algorithm

Algorithm 1 pdf transfer algorithm

1: **Initialisation** of the data set source $\mathbf{x}$ and target $\mathbf{y}$. For example in colour transfer, $\mathbf{x}_j = (r_j, g_j, b_j)$ where r_j, g_j, b_j are the red, green and blue components of pixel number j.
$k \leftarrow 0$, $\mathbf{x}^{(0)} \leftarrow \mathbf{x}$
2: **repeat**
3: take a rotation matrix R and rotate the samples: $\mathbf{x}_r \leftarrow R\mathbf{x}^{(k)}$ and $\mathbf{y}_r \leftarrow R\mathbf{y}$
4: project the samples on all axis i to get the marginals f_i and g_i
5: for each axis i, find the 1D transformation t_i that matches the marginals f_i into g_i
6: remap the samples $\mathbf{x}_r$ according to the 1D transformations. For example, a sample $(x_1, \ldots, x_N)$ is remapped into $(t_1(x_1), \ldots, t_N(x_N))$, where N is the dimension of the samples.
7: rotate back the samples: $\mathbf{x}^{(k+1)} \leftarrow R^{-1}\mathbf{x}_r$
8: $k \leftarrow k + 1$
9: **until** convergence on all marginals for every possible rotation
10: The final one-to-one mapping t is given by: $\forall\, j\,, \mathbf{x}_j \mapsto t(\mathbf{x}_j) = \mathbf{x}_j^{(\infty)}$

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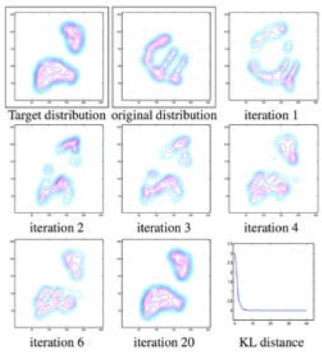
PDF Transfer Algorithm

- Example of 2D pdf transfer. Note the decrease of the measure of the Kullback-Leibler distance (see the paper for proof)



PDF Transfer Algorithm

(a) Original (b) Target Recolouring (a) using (b)

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PDF Transfer Algorithm

Original Frame 70's atmosphere pub atmosphere

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