Computational Photography and Capture:

(Re)Coloring

Gabriel Brostow & Tim Weyrich

TAs: Clément Godard & Fabrizio Pece

Today's Lecture

- Colorization using Optimization
  - Levin, Lischinski, Weiss, **Siggraph 2004**
- Color Transfer Between Images
  - Reinhard, Ashikhmin, Gooch, Shirley, **CG&A 2001**
- N-Dimensional Probability Density Function Transfer and its Application to Colour Transfer
  - Pitié, Kokaram, Dahyot, **ICCV 2005**

(see also Interactive Local Adjustment of Tonal Values'06 ,

and NRDC: Non-Rigid Dense Correspondence with Applications for Image Enhancement,2011 – with code)

Note:
Using Anat Levin's slides for structure,
with the other papers appearing throughout

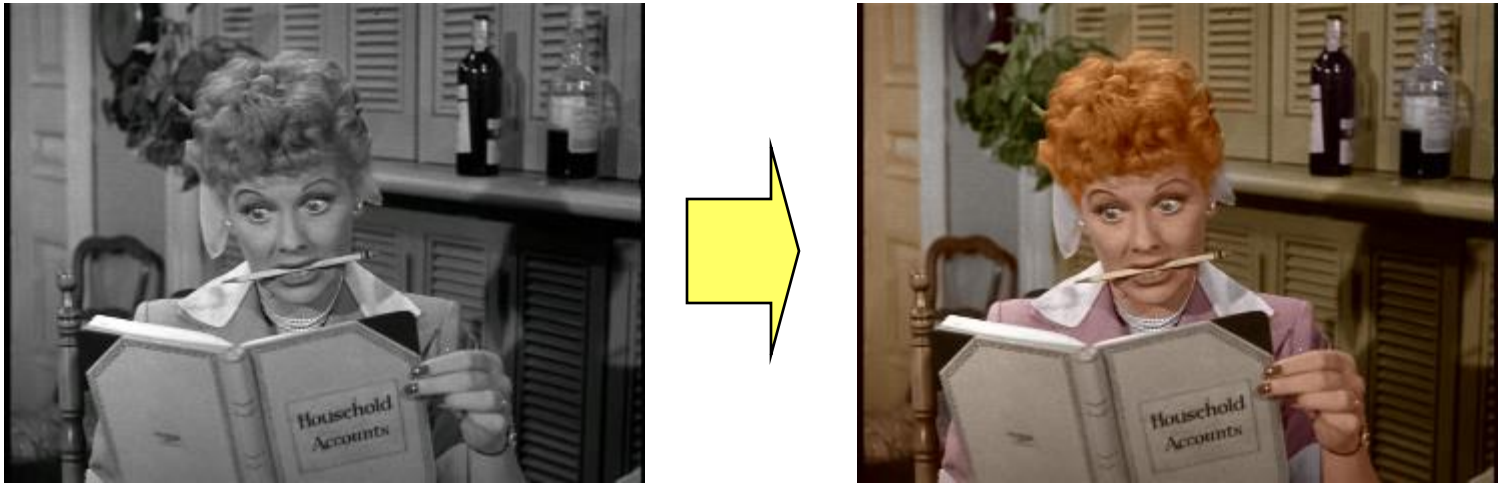
Colorization Using Optimization

Anat Levin Dani Lischinski Yair Weiss

SIGGRAPH 2004

Project web page with code

Colorization



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 and TV shows**

Earl Glick (Chairman, Hal Roach Studios), 1984:

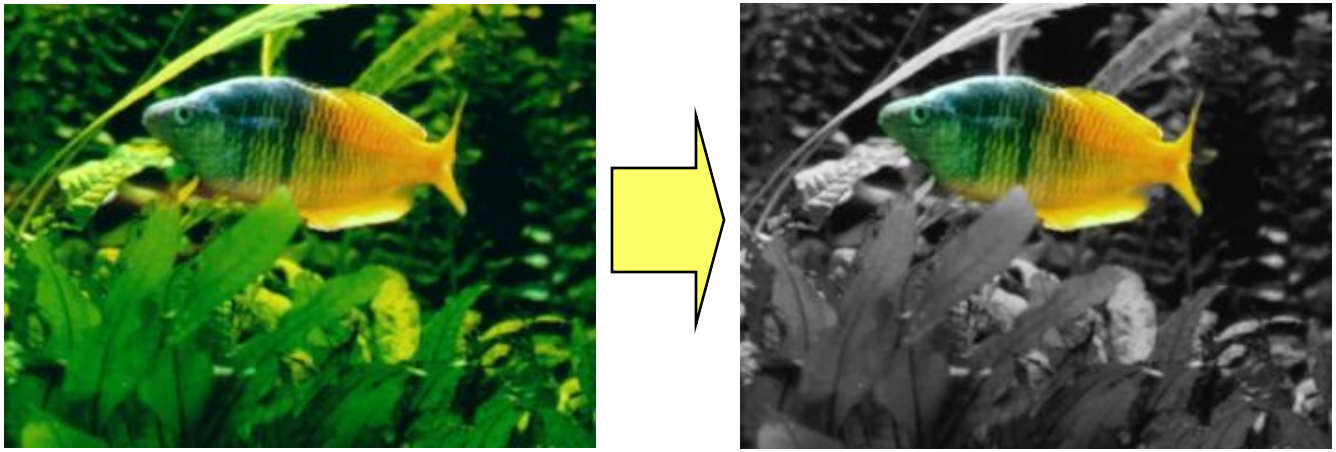
"You couldn't make Wyatt Earp today for $1 million an episode. But for $50,000 a segment, you can turn it into color and have a brand new series with no residuals to pay"

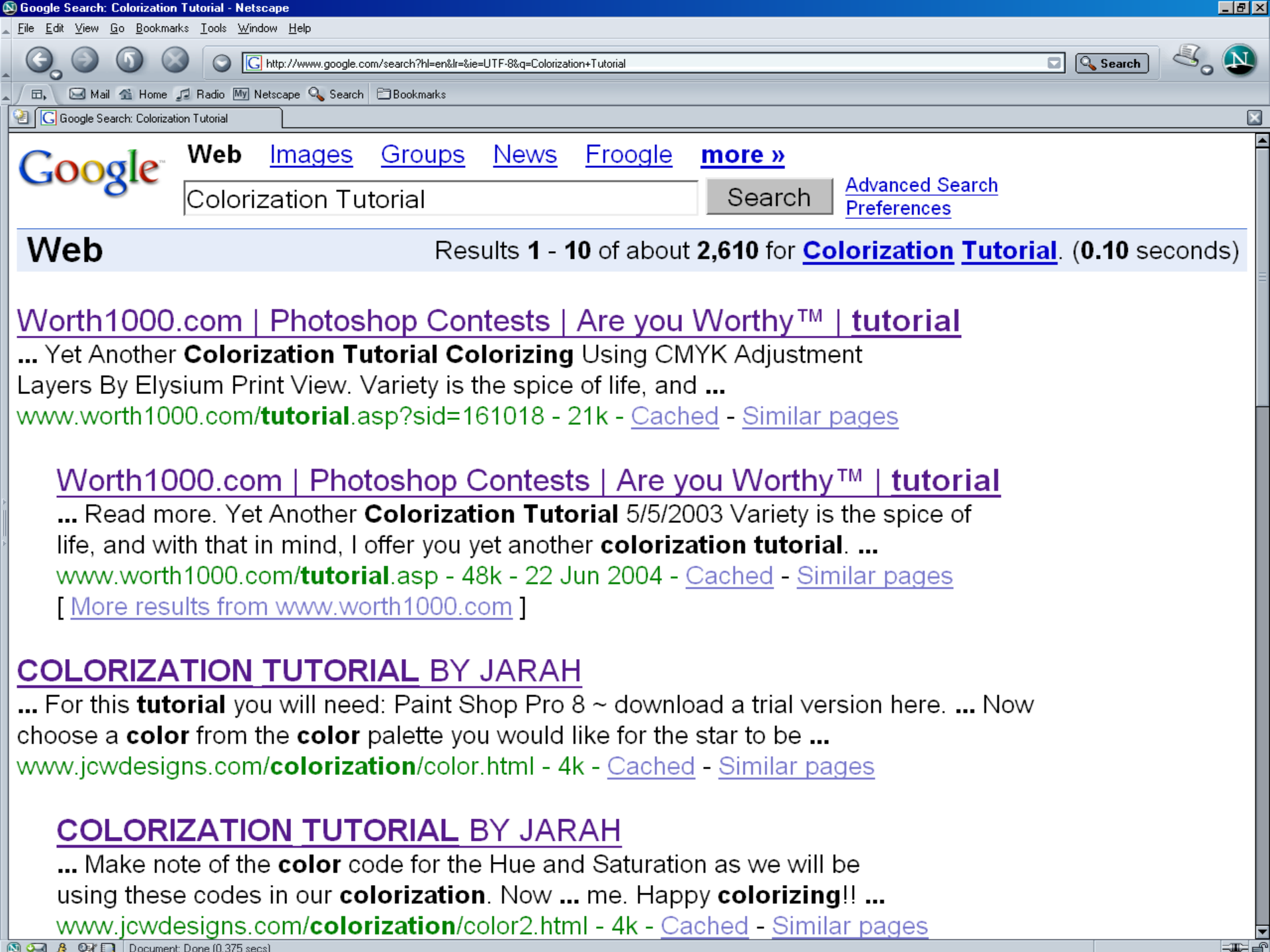
Hugh O'Brien as Wyatt Earp, 1957

Motivation

- **Colorizing black and white movies and TV shows**

- **Recoloring color images for special effects**

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... For this tutorial you will need: Paint Shop Pro 8 ~ download a trial version here. ... Now choose a color from the color palette you would like for the star to be ...
www.jcwdesigns.com/colorization/color.html - 4k - Cached - Similar pages
COLORIZATION TUTORIAL BY JARAH
... Make note of the color code for the Hue and Saturation as we will be using these codes in our colorization. Now ... me. Happy colorizing!! ...
www.jcwdesigns.com/colorization/color2.html - 4k - Cached - Similar pages
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Typical Colorization Process

Images from:
“Yet Another Colorization Tutorial”

http://www.worth1000.com/tutorial.asp?sid=161018

Typical Colorization Process

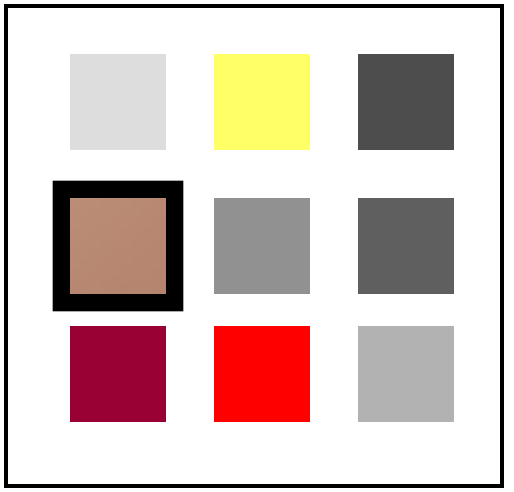
- **Delineate region boundary**

Images from:
“Yet Another Colorization Tutorial”

http://www.worth1000.com/tutorial.asp?sid=161018

Typical Colorization Process

- **Delineate region boundary**
- **Choose region color from palette.**



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- **Delineate region boundary**
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Typical Colorization Process

- **Delineate region boundary**
- **Choose region color from palette.**

Images from:
“Yet Another Colorization Tutorial”

http://www.worth1000.com/tutorial.asp?sid=161018

Video Colorization Process

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

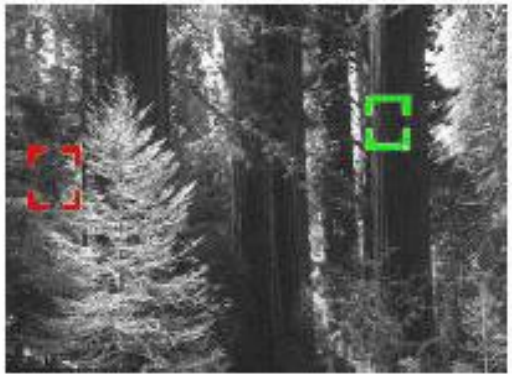
Colorization Process Discussion

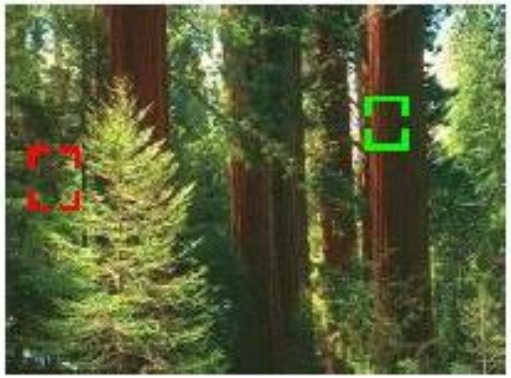
Time consuming and labor intensive

- **Fine boundaries.**
- **Failures in tracking.**

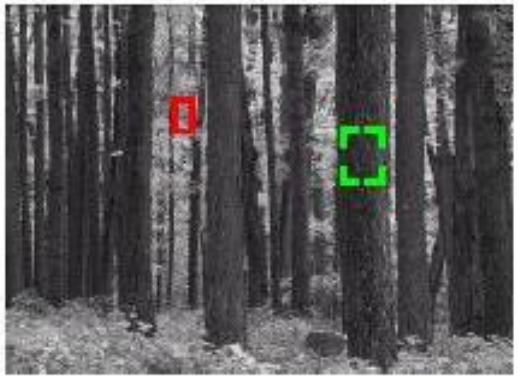
Colorization by Analogy

A : A’





B : B’

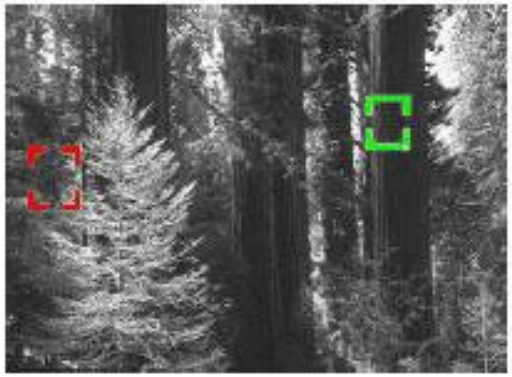


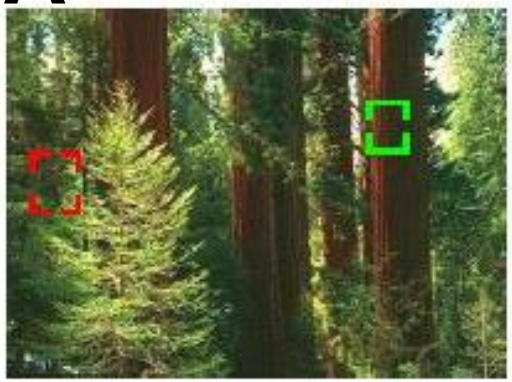
?

Hertzmann et al. 2001, Welsh et al. 2002

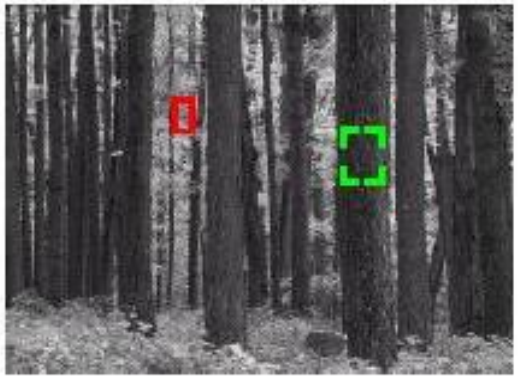
Colorization by Analogy

A : A’





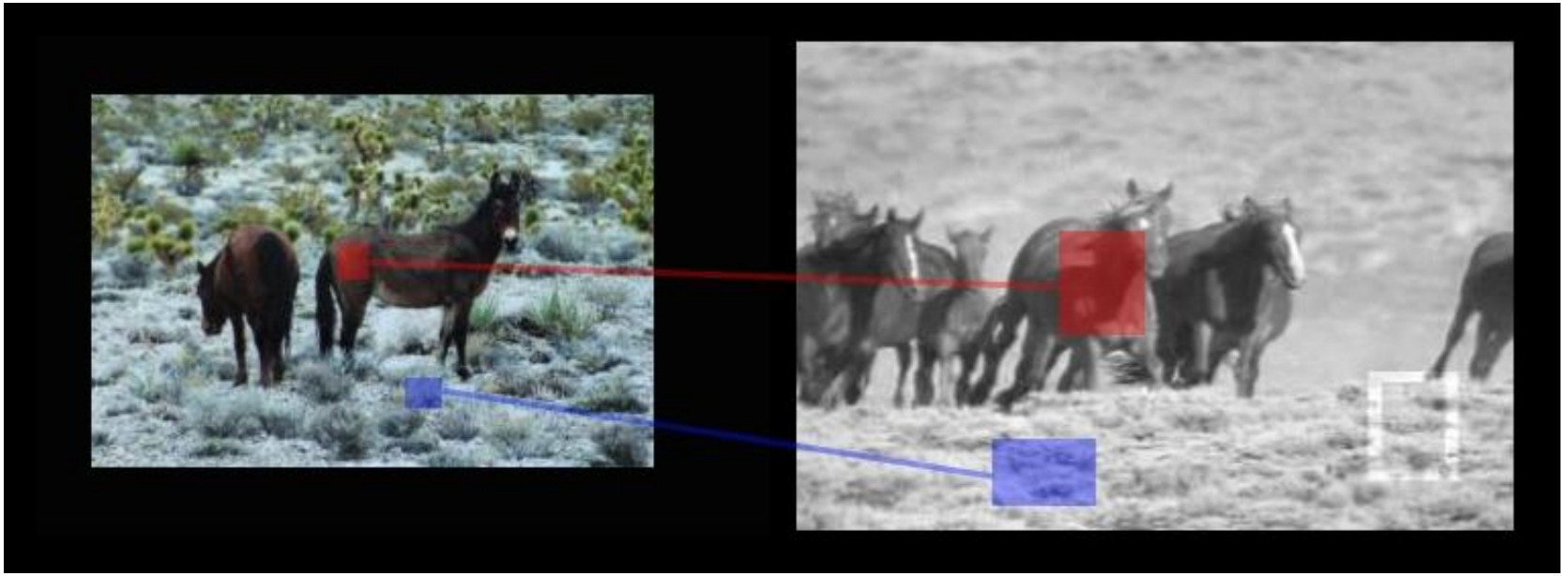
B : B’



Hertzmann et al. 2001, Welsh et al. 2002

Transferring Color To Greyscale Images

Welsh et al. 2002



Colorization by Analogy - Discussion

- **Only indirect artistic control**
- **No spatial continuity constraint**

Levin et al. Approach

Levin et al. Approach

Artist scribbles desired colors inside regions

Levin et al. 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

Color channels

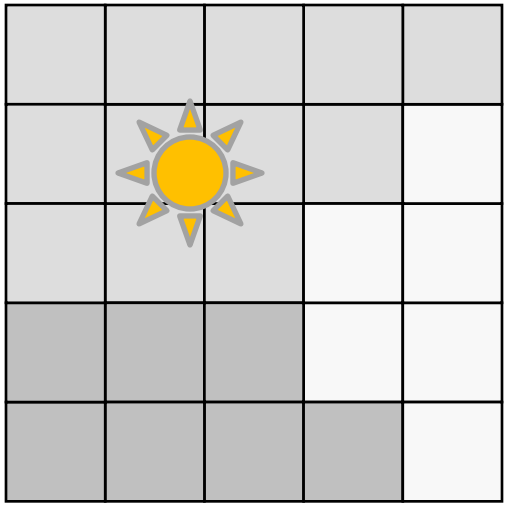
“Neighboring pixels with similar intensities should have similar colors”

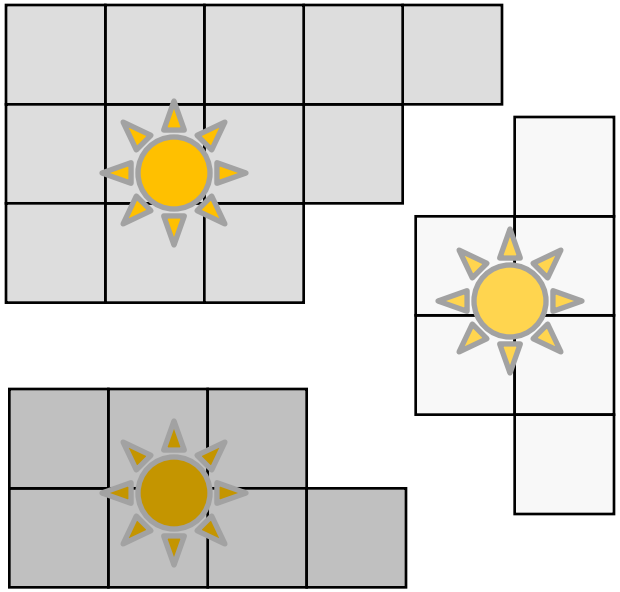
$$Y \Rightarrow U, V$$

Intensity channel

Color channels

“Neighboring pixels with similar intensities should have similar colors”





Propagation using Optimization

$$Y \Rightarrow U, V$$

Intensity channel

Color channels

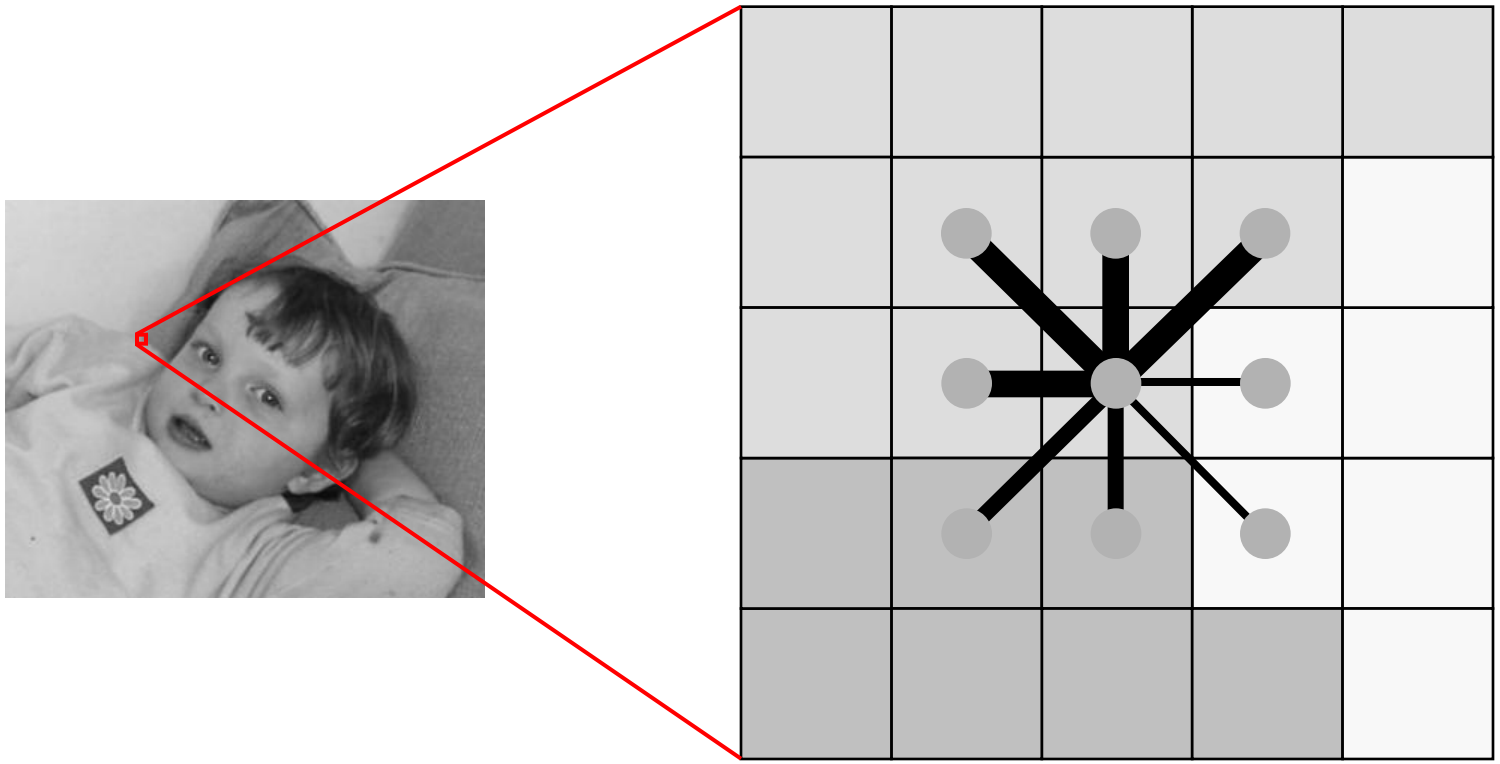
$$J(U) = \sum_r \left(U(r) - \sum_{s \in N(r)} w_{rs} U(s) \right)^2$$

- **Minimize difference between color at a pixel and an *affinity-weighted average* of the neighbors**

Affinity Functions

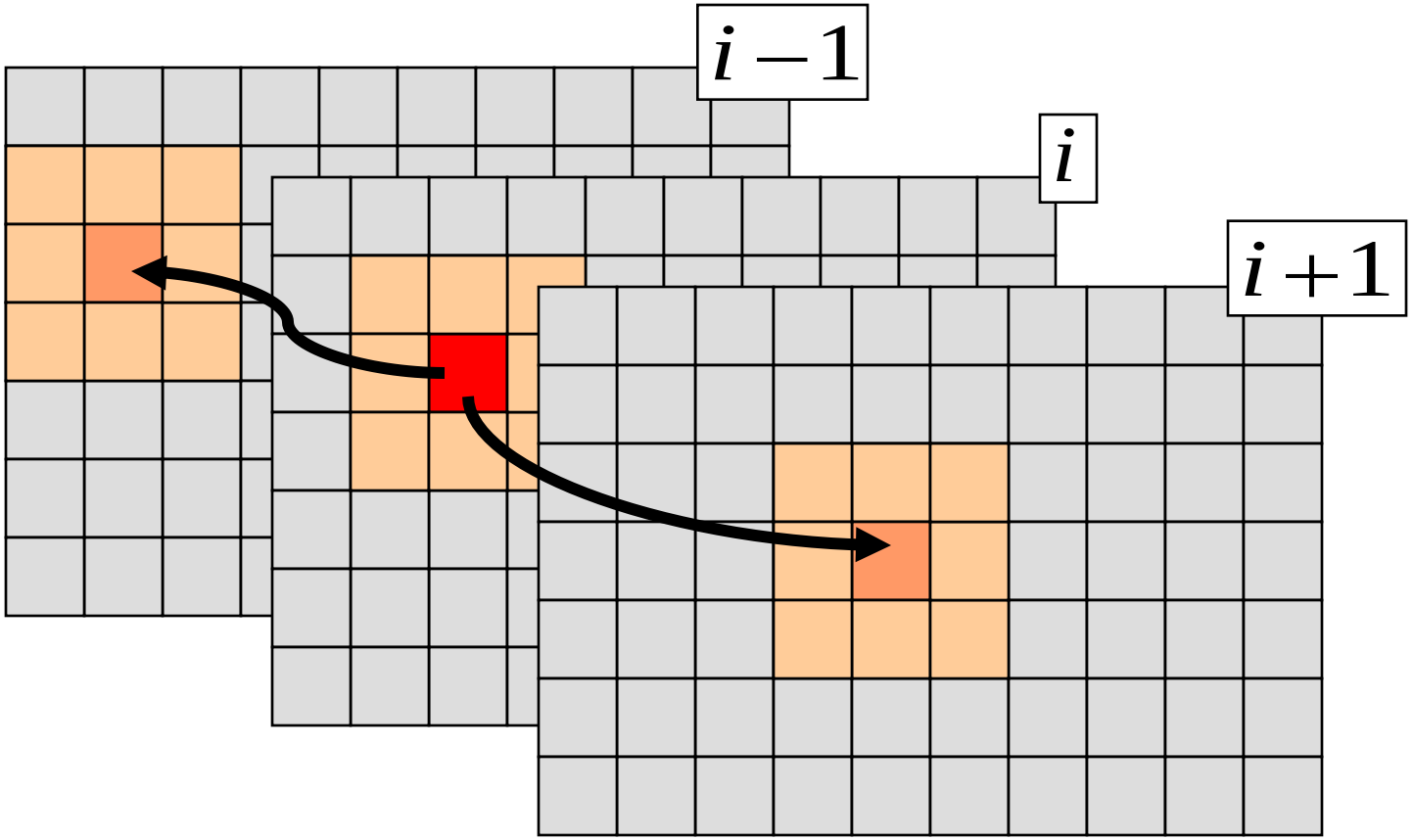
$$w_{rs} \propto e^{-(Y(r)-Y(s))^2/\sigma_r^2}$$

σ_r proportional to local variance



Affinity Functions in Space-Time

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



Minimizing cost function

Minimize:

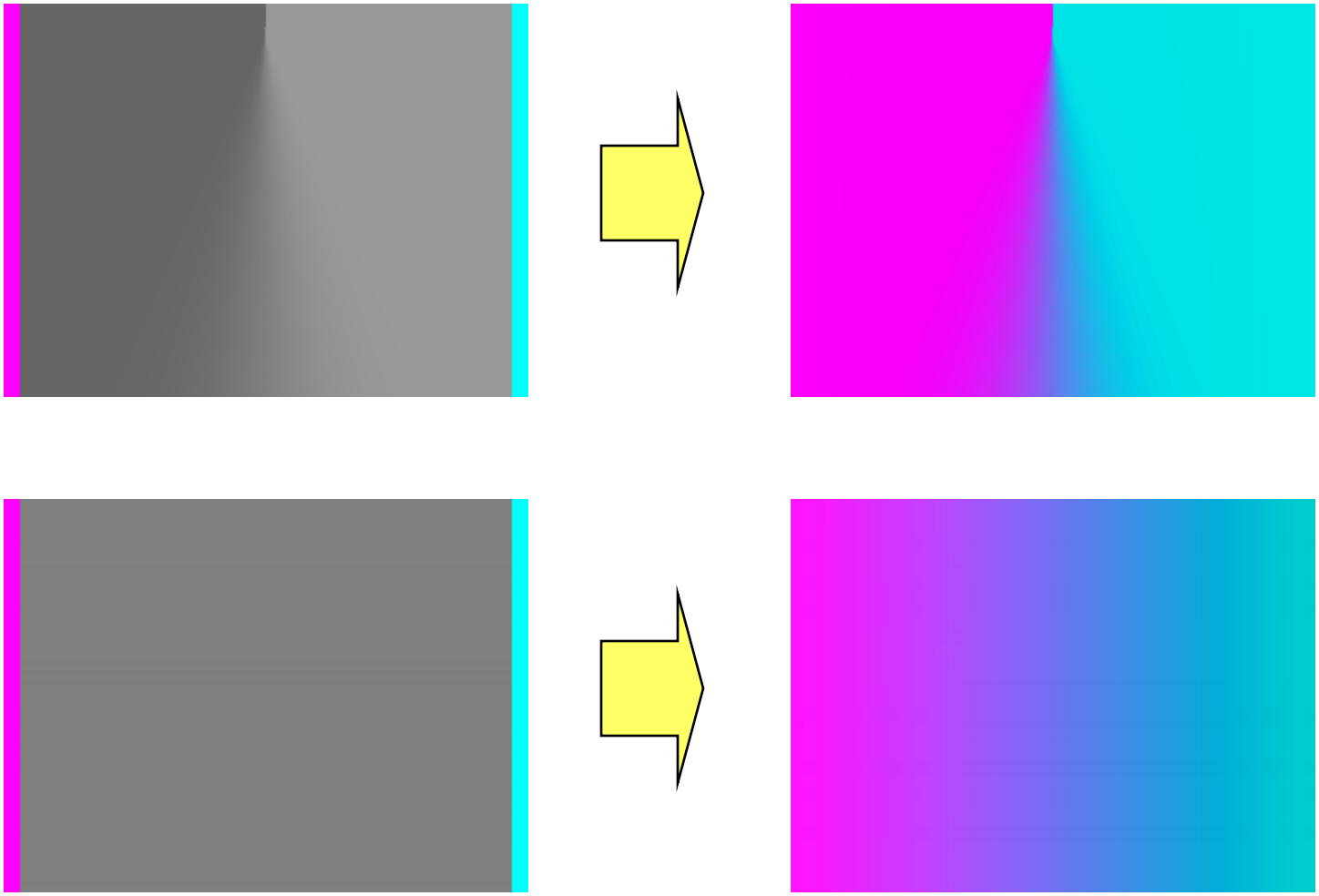
$$J(U) = \sum_r \left(U(r) - \sum_{s \in N(r)} w_{rs} U(s) \right)^2$$

Subject to *labeling constraints*

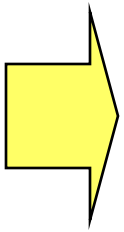
Since cost is quadratic, minimum can be found by solving sparse system of linear equations.

Using Matlab's least-squares solver for sparse linear systems (code online)

Color Interpolation



Coloring Stills



Coloring Stills

Original

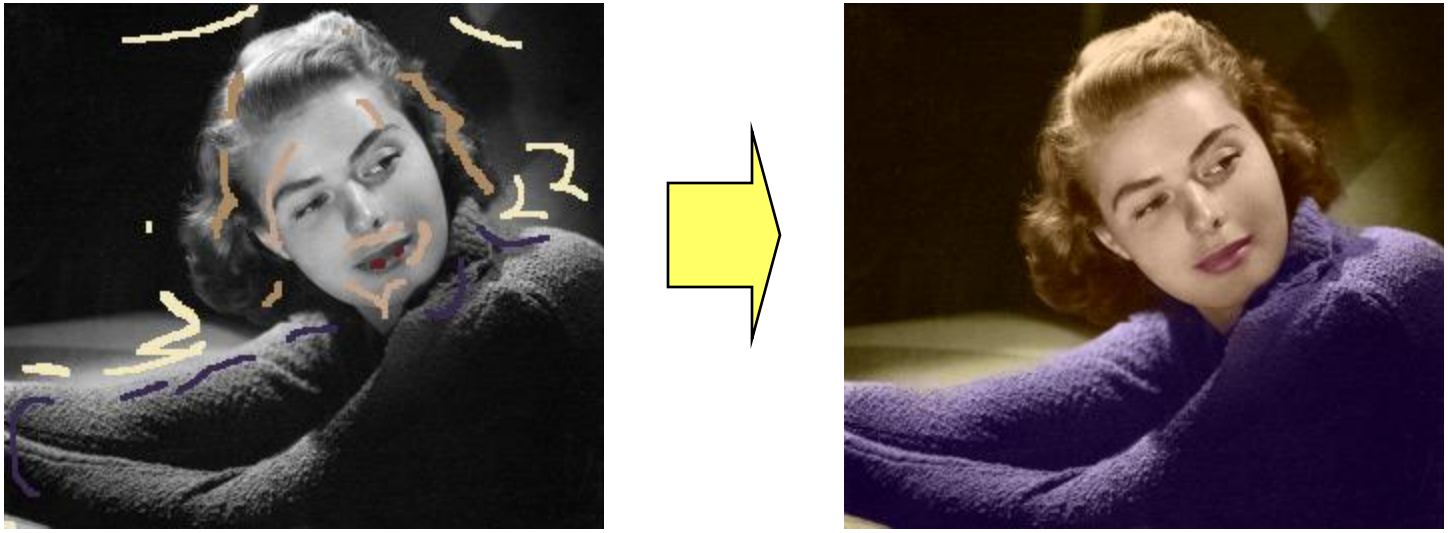
Colorized

Progressive Colorization

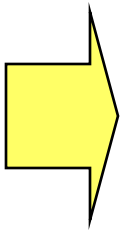
Progressive Colorization

Progressive Colorization

Coloring Stills



Coloring Stills



Colorization Challenges

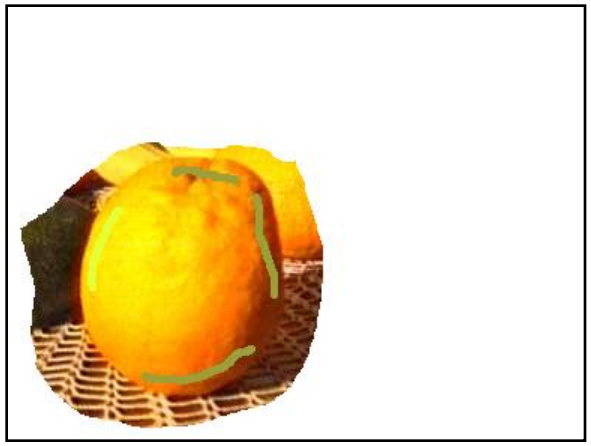
Segmentation?

NCuts Segmentation
(Shi & Malik 97)

Segmentation aided
colorization

Our result

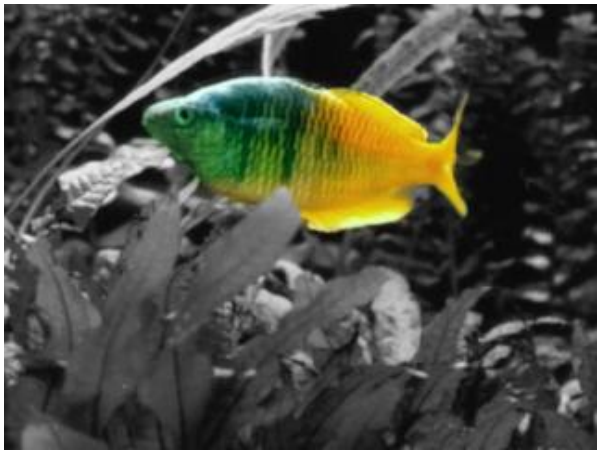
Recoloring



Affinity between pixels – based on intensity AND color similarities.

Recoloring





Recoloring



c.f. “Poisson image editing” Perez et al. SIGGRAPH 2003

Colorizing Video

13 out of 92 frames

Colorizing Video

16 out of 101 frames

Matting as Colorization

Red channel<->matte

Page of example results

Still Needed:

- Image segmentation developments:
  - affinity functions, optimization techniques.

- Alternative color spaces*, propagating hue and saturation differently

Other Approaches?

- Color space was YUV
- Small amount of user effort needed

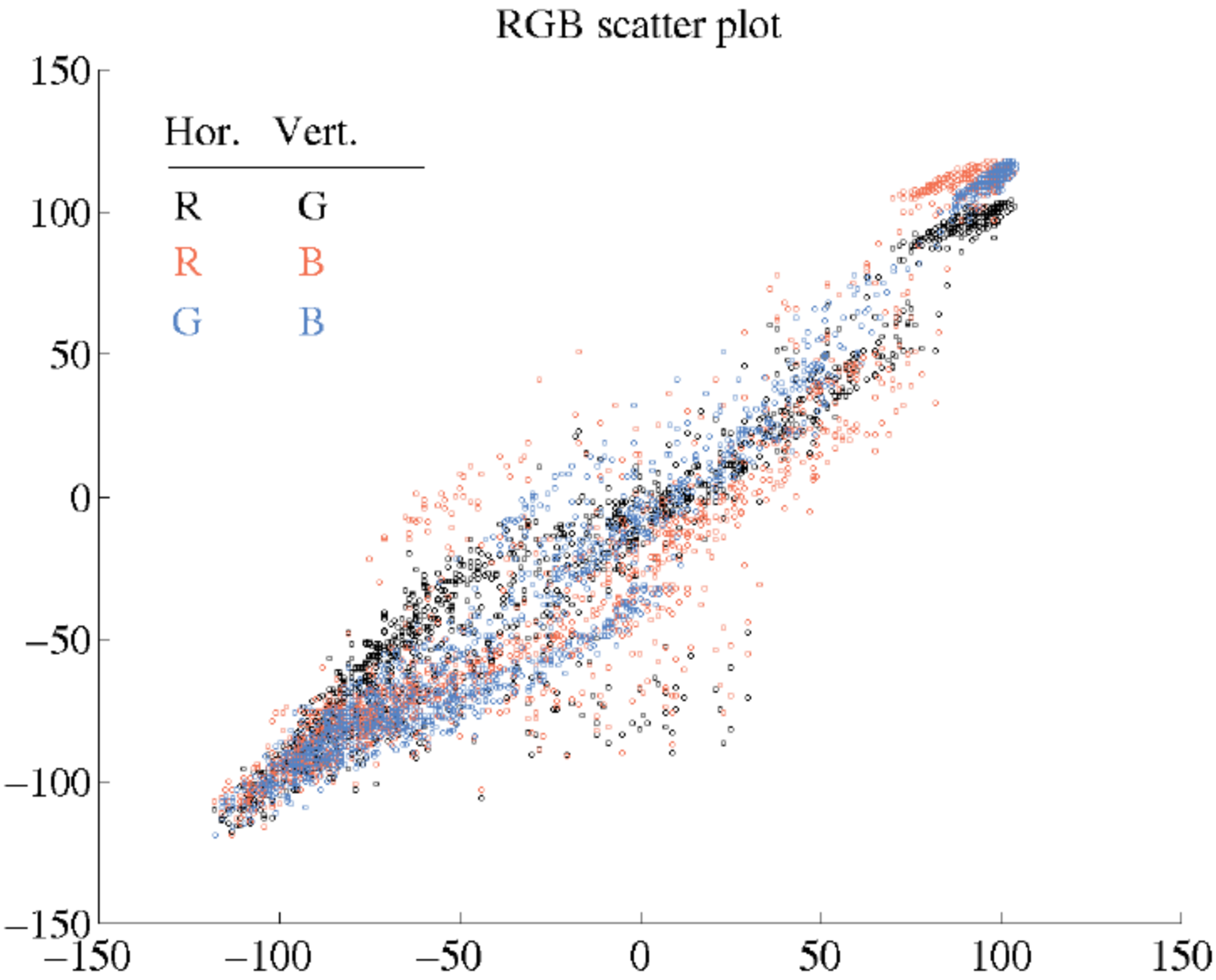
- For film/color *grading*, can this be automated?

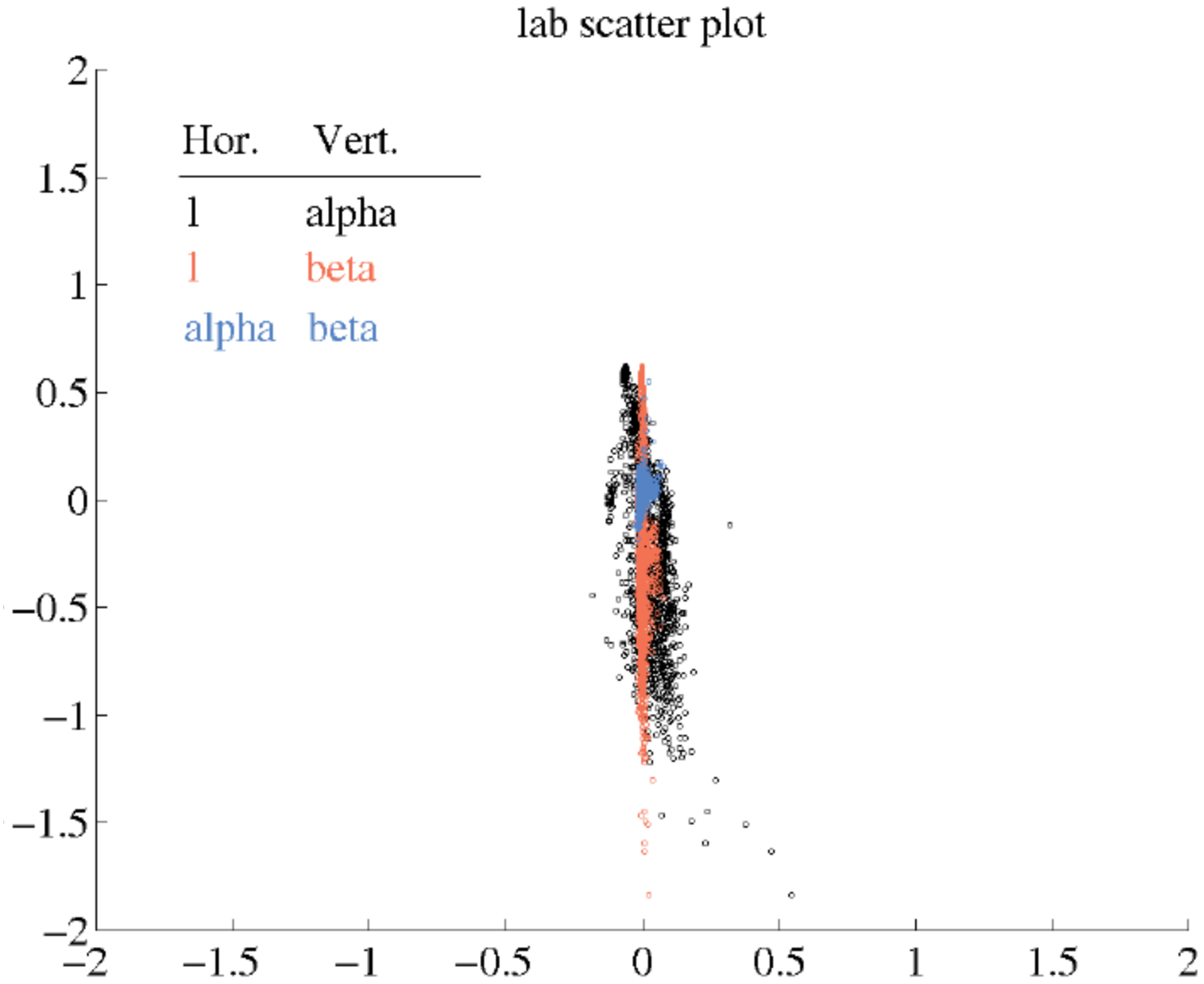
Linear Alignment

Reinhard, Ashikhmin, Gooch, Shirley, **CG&A 2001**

- (R, G, B) is rubbish: all channels are correlated
- (L*, a*, b*) is good

- Algorithm (per channel):
  - Align mean
  - Rescale standard deviation


RGB scatter plot
Hor. Vert.
R G
R B
G B
150
100
50
0
−50
−100
−150
−150
−100
−50
0
50
100
150


lab scatter plot
Hor. Vert.
l alpha
l beta
alpha beta
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2

Linear Alignment

Reinhard, Ashikhmin, Gooch, Shirley, **CG&A 2001**

- RGB is rubbish: all channels are correlated
- L* a* b* is good

- Algorithm (per channel):
  - Align mean
  - Rescale standard deviation


(a)


(b)

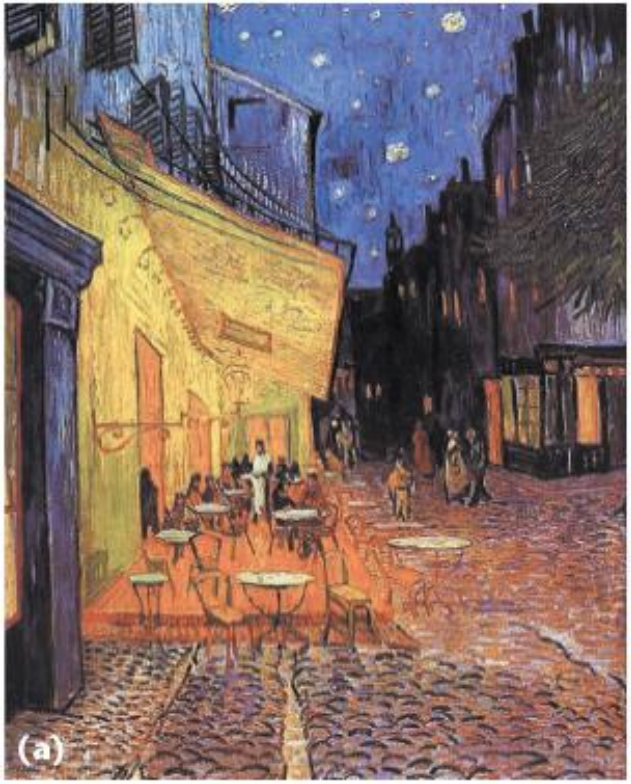

(c)


(a)


(b)


(c)

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.

Non-Linear Alignment

Pitié, Kokaram, Dahyot, **ICCV 2005**

target image

original image

Reinhard

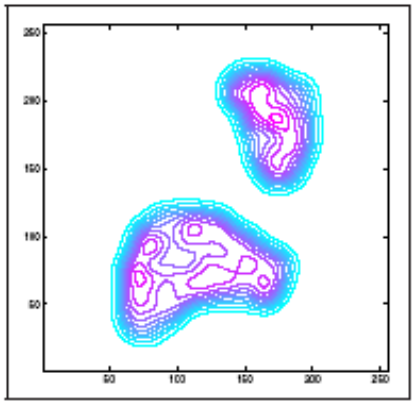
See here for code + paper

Iterate 1D Solution at Different Rotations

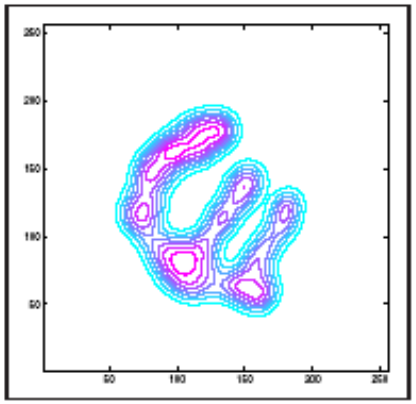
- 1D solution uses cumulative PDFs:

$$t(x) = C_Y^{-1}\left(C_X\left(x\right)\right)$$

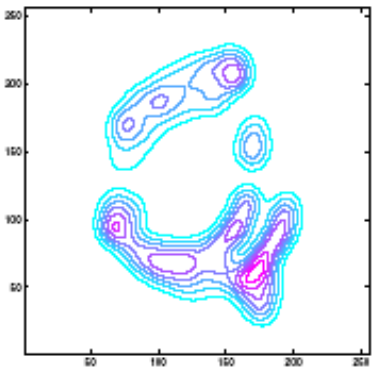
- ND solution:
  - Pick a rotation matrix R, apply to both 3D distribs.
  - Project both distribs. onto each axis in turn
  - Apply 1D solution
  - Unproject, unrotate
  - <repeat>



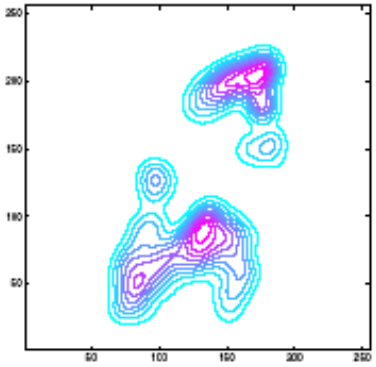
Target distribution



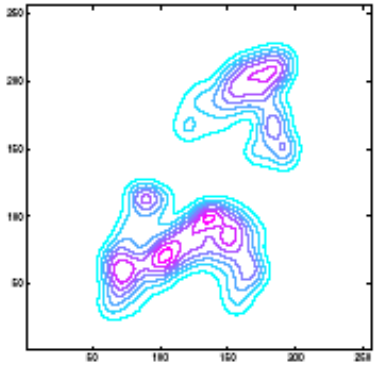
original distribution



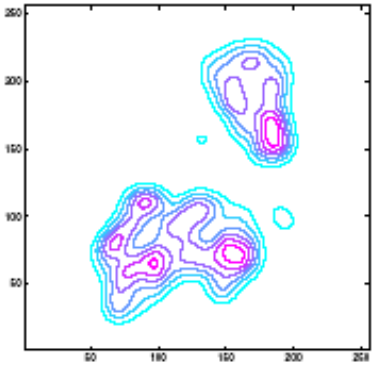
iteration 1



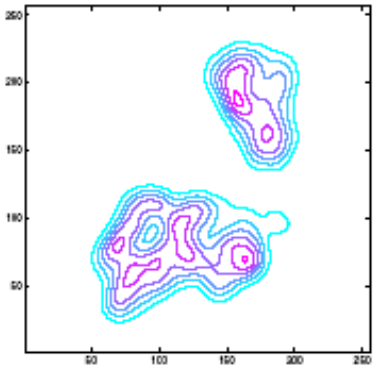
iteration 2



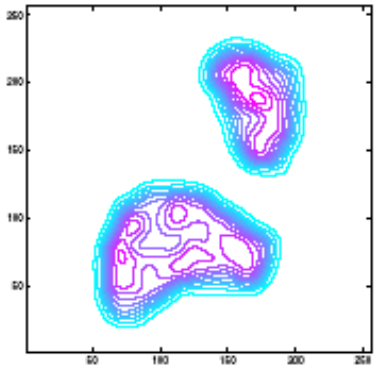
iteration 3



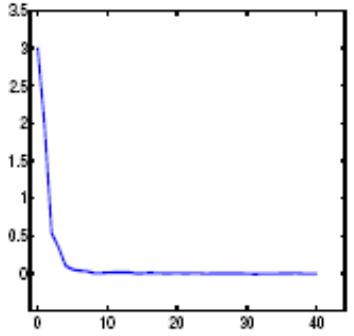
iteration 4



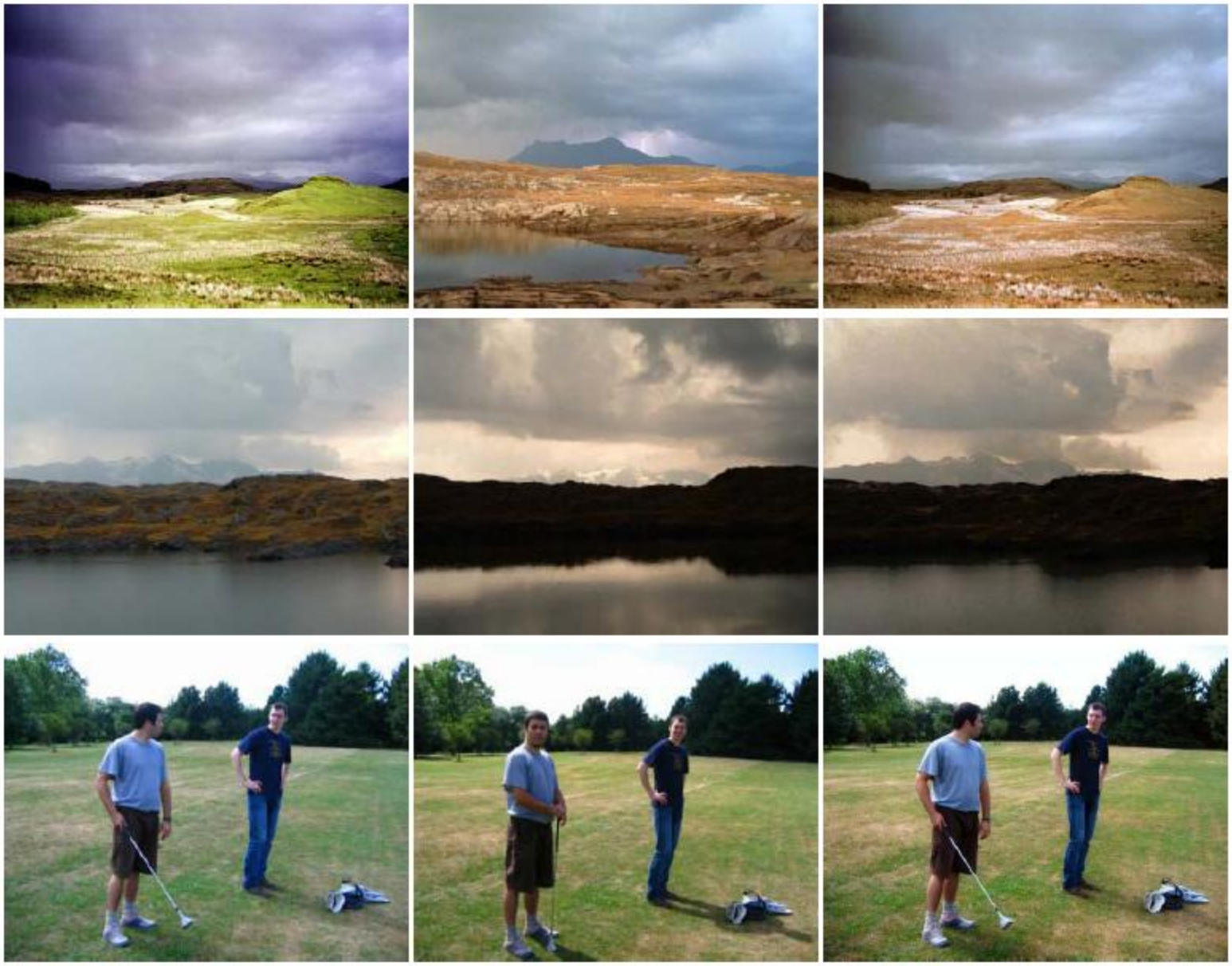
iteration 6



iteration 20



KL distance



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

Original Frame

70's atmosphere

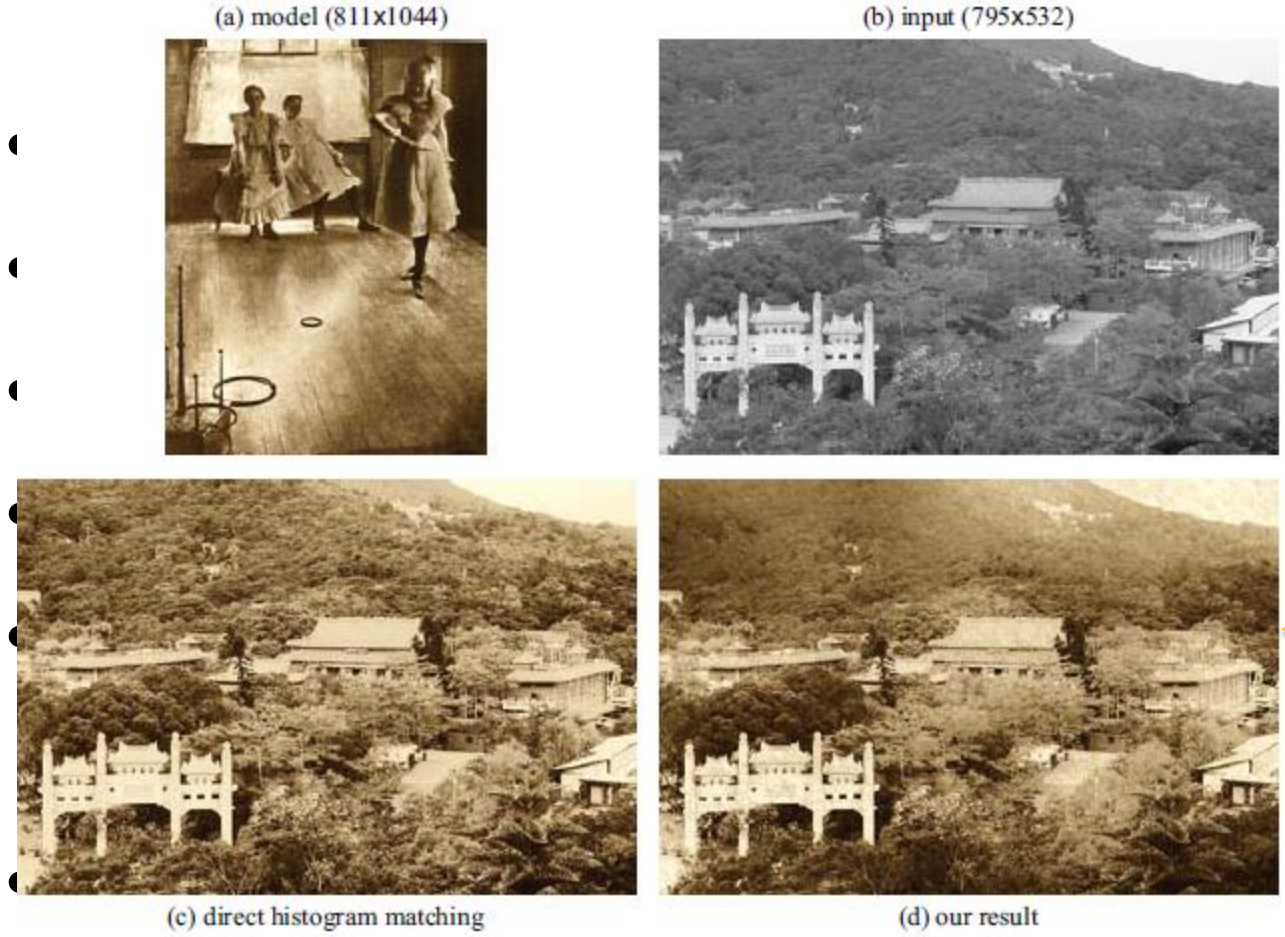
pub atmosphere

Don’t Forget Other Problems

- (Really) automatic colorization
- Flicker removal
- Dirt removal
- Noise removal
- Supersampling…

- Texture (aren’t histograms enough?)
  - Two-scale Tone Management for Photographic Look, by Bae, Paris, Durand, Siggraph 2006

Don’t Forget Other Problems



- Two-scale Tone Management for Photographic Look, by Bae, Paris, Durand, Siggraph 2006