Cluster-Based Color Space Optimizations

Cheryl Lau[1] Wolfgang Heidrich[1] Rafał Mantiuk[2]

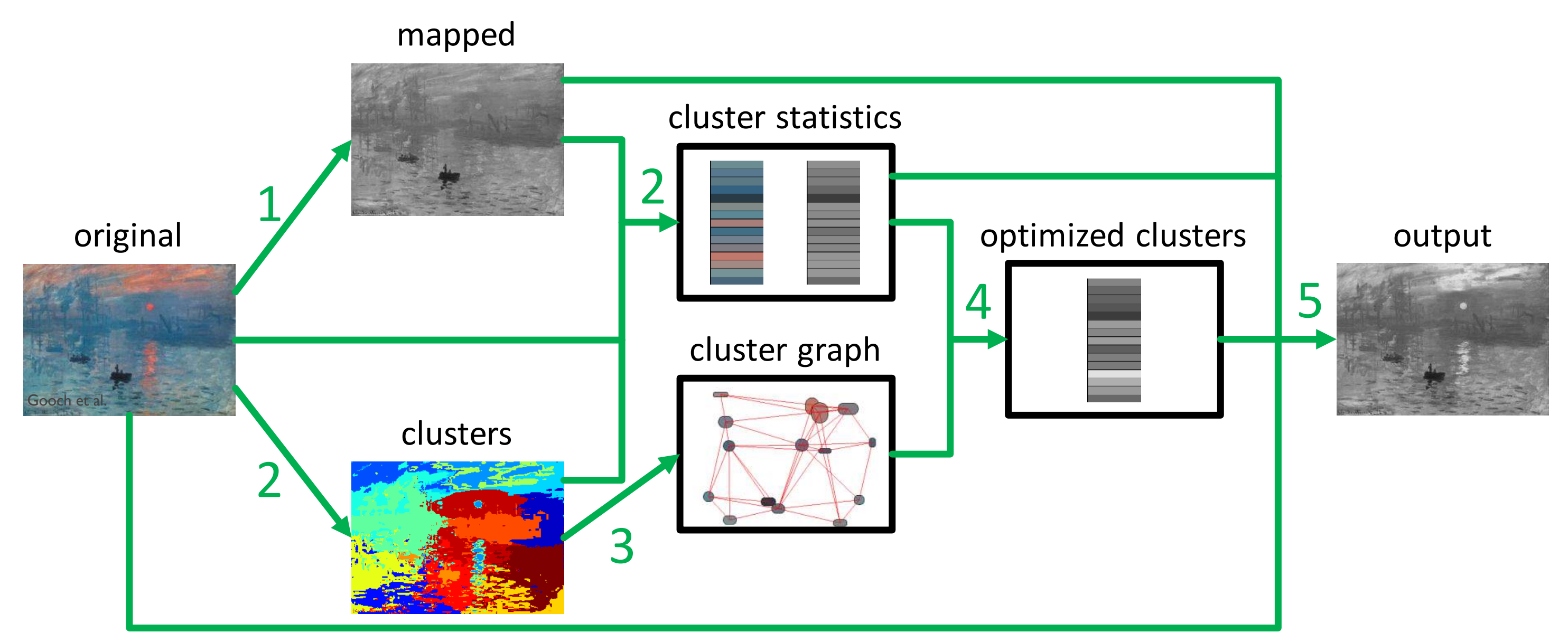
[1]University of British Columbia [2]Bangor University

ABSTRACT

Printing, displaying, and visualizing images are common tasks that may require a transformation of the input image from its source color space to a target color space. Such transformations include converting color images to grayscale for printing, mapping images to the gamuts of target display devices, and fusing multispectral data into a tristimulus image. Each of these transformations has a straightforward, standard mapping, often involving information loss. In the extreme case, contrast is completely lost when different colors in the source space map to the same color in the target space, an effect known as metamerism.

We present a framework for mapping an image from a source color space to a target color space in a way that preserves as much of the local contrast from the source image as possible while staying as faithful as possible to the standard mapping. Our unified framework is a cluster-based approach which we apply to a variety of color space transformations including color to gray conversion, color gamut mapping, image optimization for color deficient viewers, and multispectral image fusion.

METHOD OVERVIEW



1) **Projection to target space.** project source image to target space

2) **Clustering.** cluster pixels in spatio-chromatic space

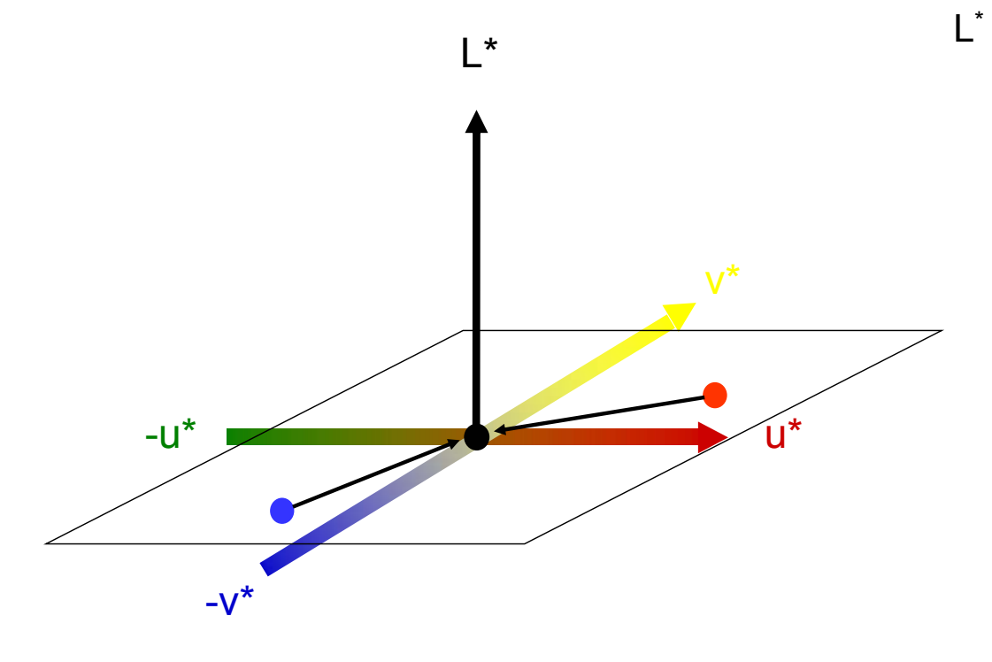
3) **Graph creation.** connect spatially close clusters

4) **Optimization.** solve for new cluster colors, preserve local contrasts

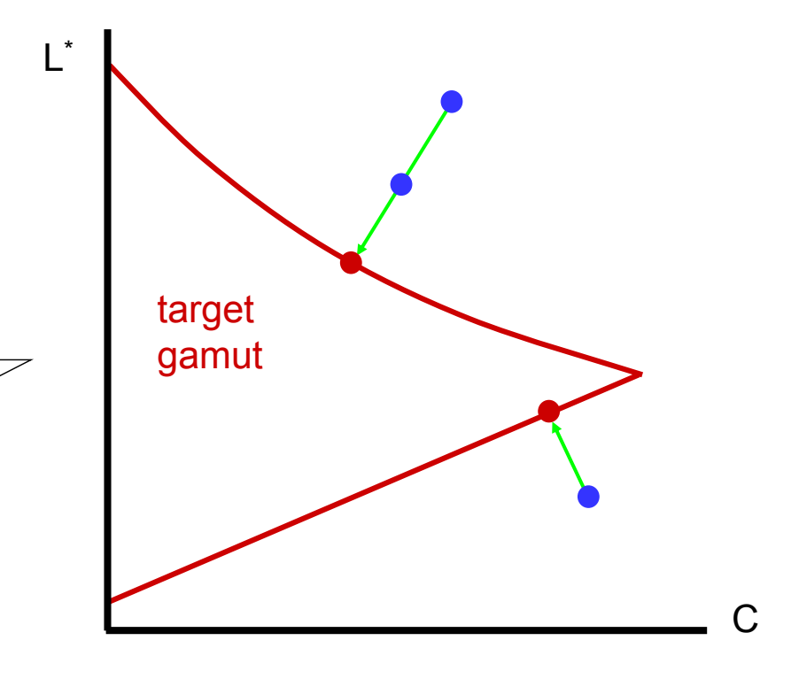
5) **Blending.** transfer results back to pixels

PROJECTION TO TARGET SPACE

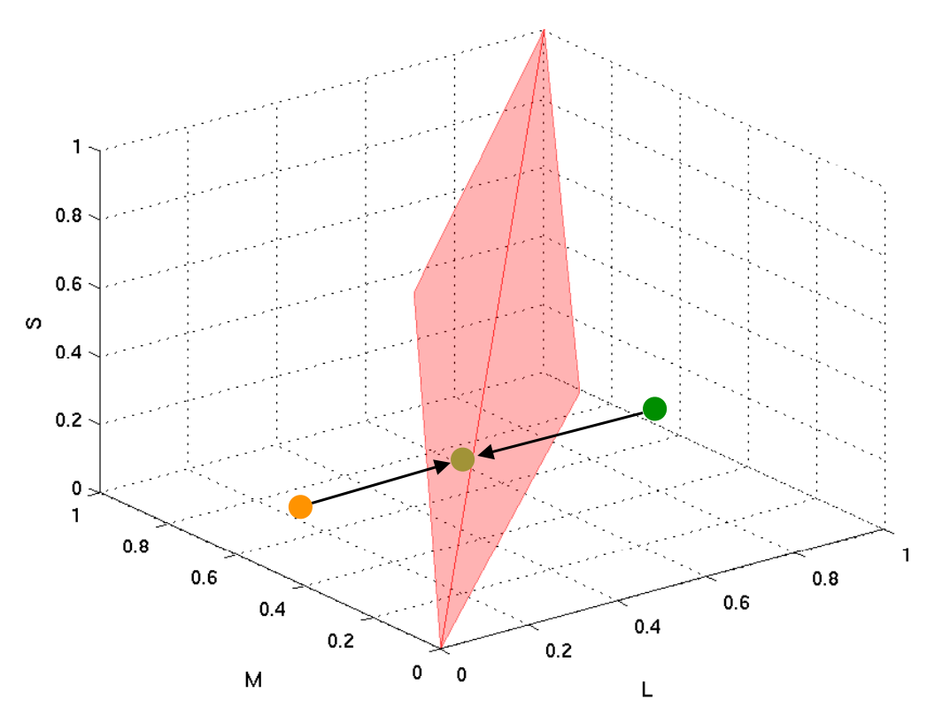
- project source image to target space using standard mapping
- get initial mapped image whose contrast we aim to enhance



gray axis



target gamut



protanopic surface

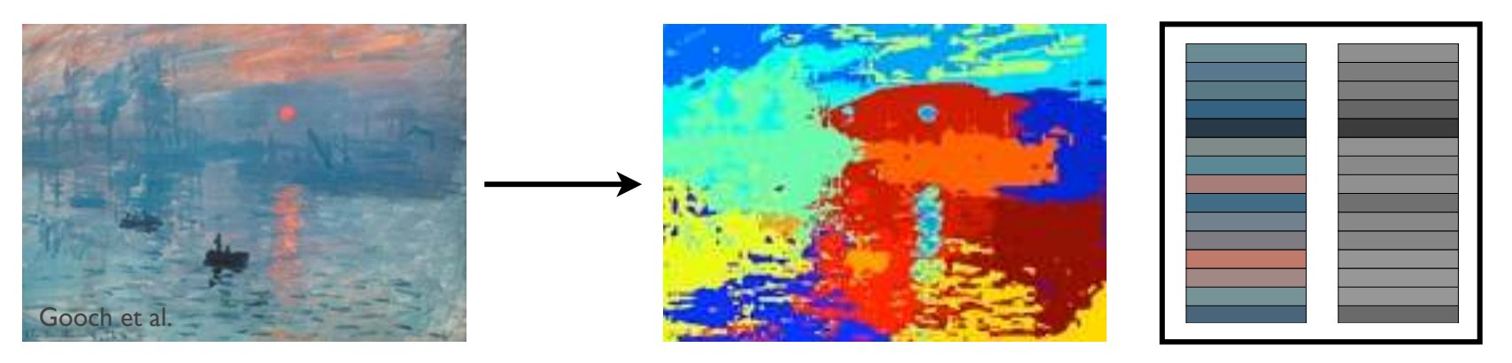
CLUSTERING

- cluster pixels in spatio-chromatic space $\mathcal{U}$ to get areas that may exhibit local contrast

$$\mathbf{u} \in \mathcal{U},\ \mathbf{u} = (\mathbf{s}, x', y'),\ \mathbf{s} = \text{pixel color},\ (x', y') = \text{weighted spatial dimensions}$$

spatial weight is parameter dependent on image size, viewing distance, monitor resolution, desired number of just-noticeable-difference units (JNDs) per 2° visual field

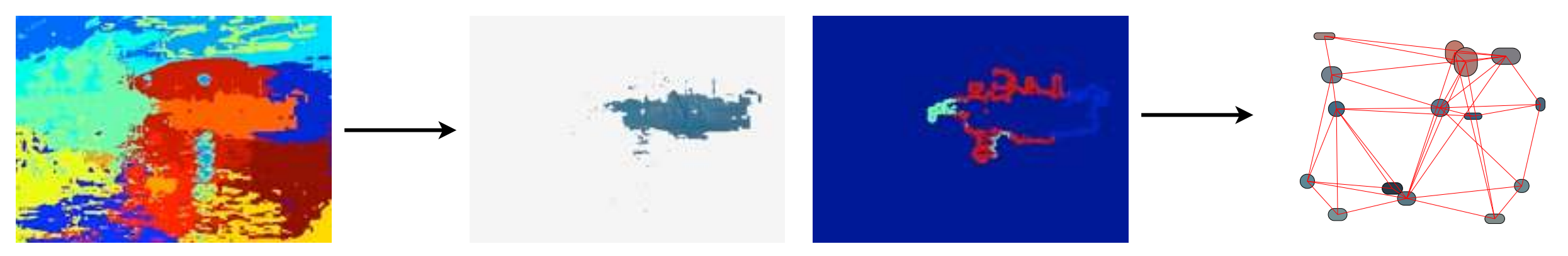
- kmeans clustering



original clusters cluster means

GRAPH CREATION

- vertices $\mathcal{V}$: clusters
- edges $\mathcal{E}$: connect spatially close clusters, represent local contrasts between neighboring clusters



clusters cluster dilated region cluster graph

find neighbors by dilating clusters

OPTIMIZATION

- solve for new cluster colors $\mathbf{x}$

$$\mathbf{x} = \arg\min_{\mathbf{x}} E_T + wE_M$$

- target term E_T: preserve local contrasts

$$E_T = \sum_{(i,j)\in\mathcal{E}} \tau_{ij}((\mathbf{x}_j - \mathbf{x}_i) - \mathbf{t}_{ij})^2$$

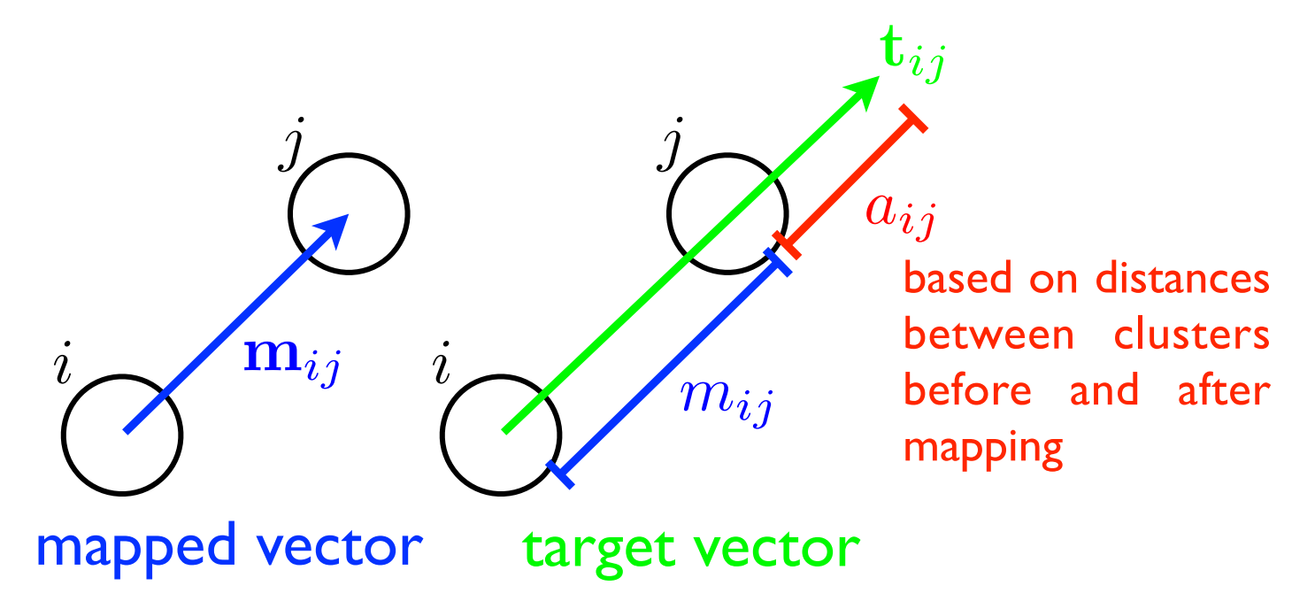
$$a_{ij} = k \cdot S(\psi_{ij}(o_{ij} - \underbrace{\left\|f(\mathbf{m}_j) - f(\mathbf{m}_i)\right\|}_{\text{distance between mapped clusters, } f() \text{ makes target space comparable to source space}}))$$

k: max magnitude increase, user parameter

$S()$ scales to range [0,1]

ψ_{ij}: sigmoidal weight, empirically determined parameters

o_{ij}: distance between original clusters



mapped vector target vector

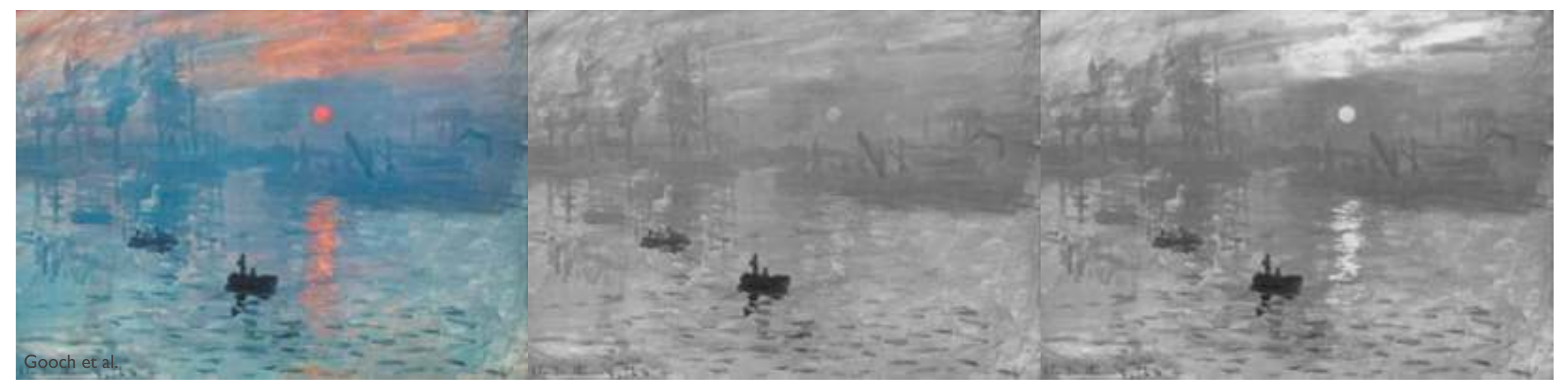
- regularization term E_M: stay close to standard mapping

$$E_M = \sum_{i\in\mathcal{V}} \tau_i(\mathbf{x}_i - \mathbf{m}_i)^2$$

- additional terms:
  - hue term: preserve hue by minimizing deviations from constant hue plane
  - achromaticity term: preserve neutrality of achromatic colors by minimizing deviations from gray axis
- constrained optimization for arbitrary-shaped target spaces: solve for colors, project to target space, iterate

BLENDING

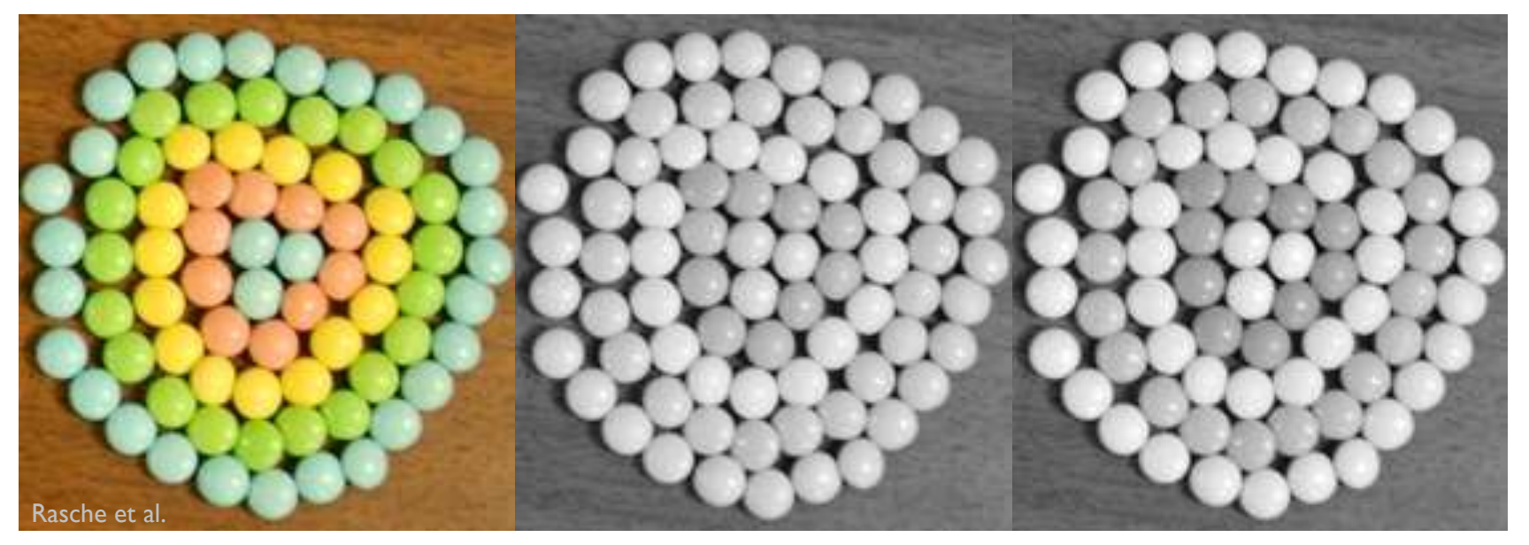
- calculate output pixels using weighted blend of cluster translations
- weights are inversely proportional to squared Mahalanobis distance

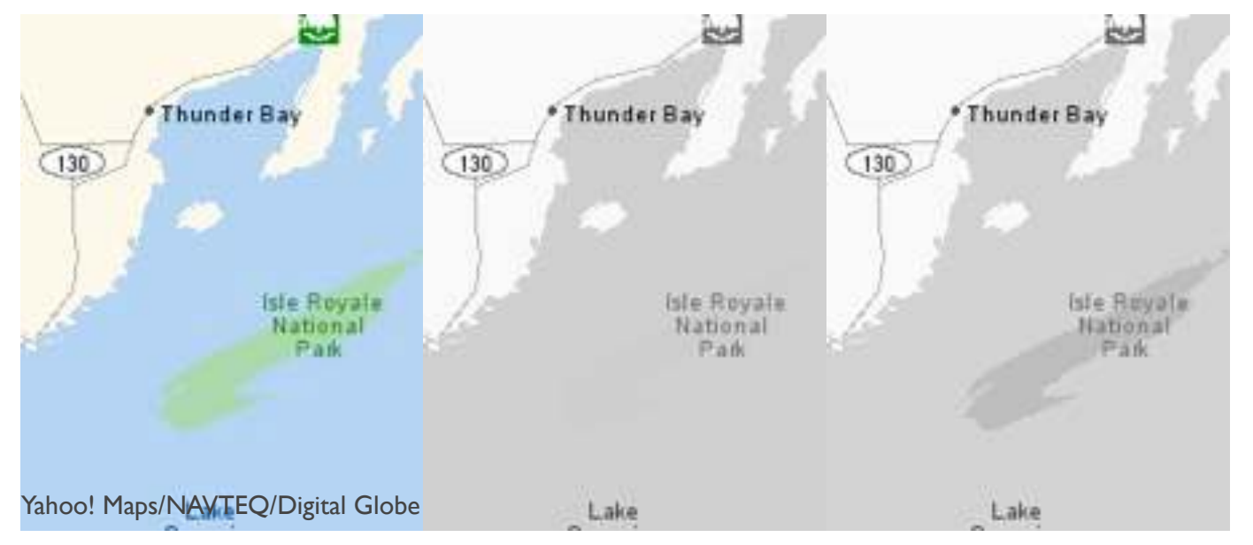


original CIE L* our output

COLOR TO GRAY CONVERSION

preserves chromatic contrast

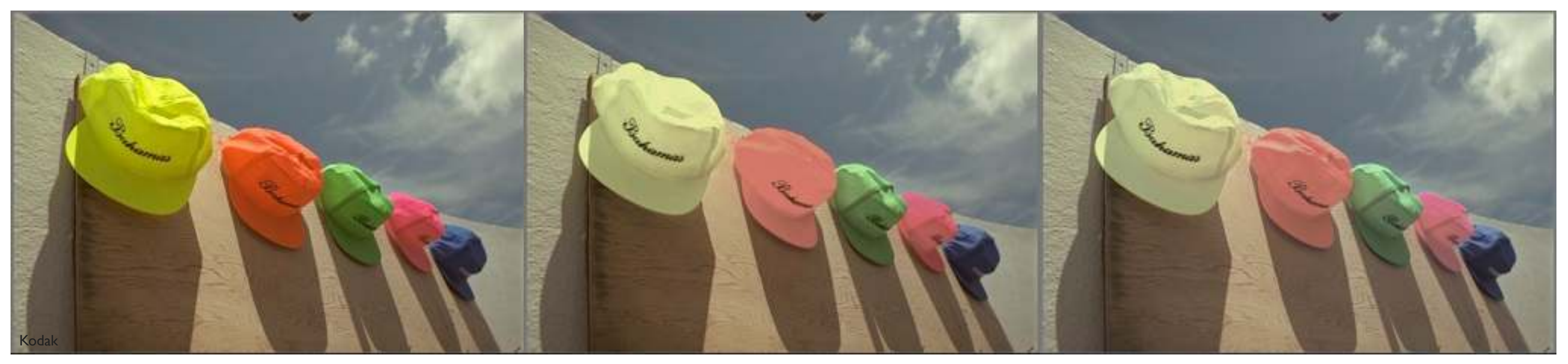




original luma our output original luma our output

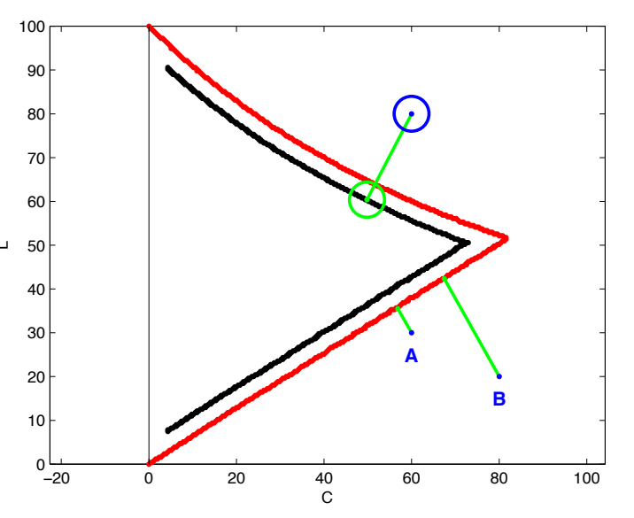
GAMUT MAPPING

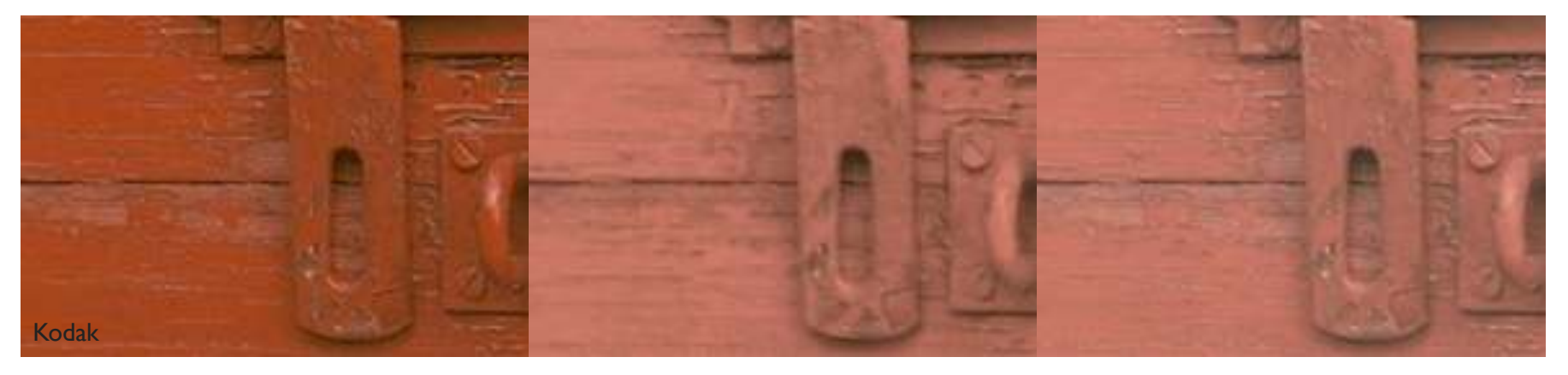
preserves out-of-gamut details



original HPMINDE clipped our output

fixes lightness inversions

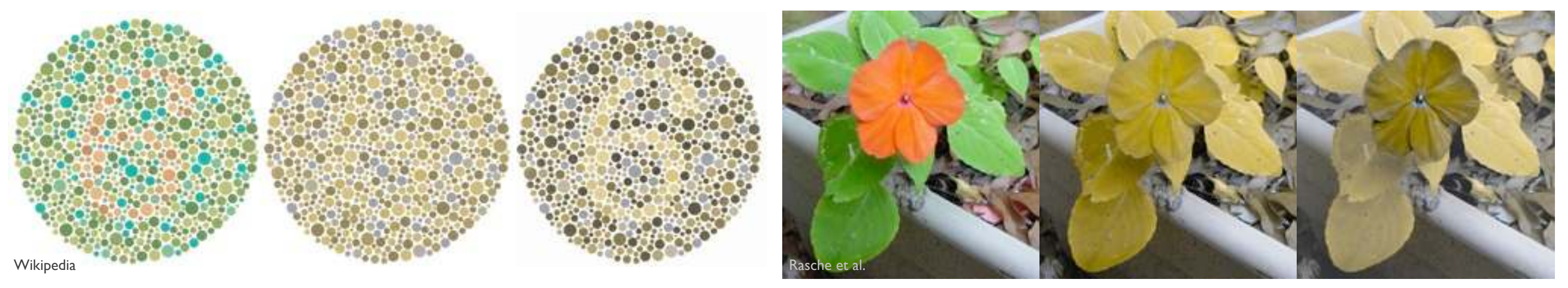




original HPMINDE clipped our output

IMAGE OPTIMIZATION FOR COLOR DEFICIENT VIEWERS

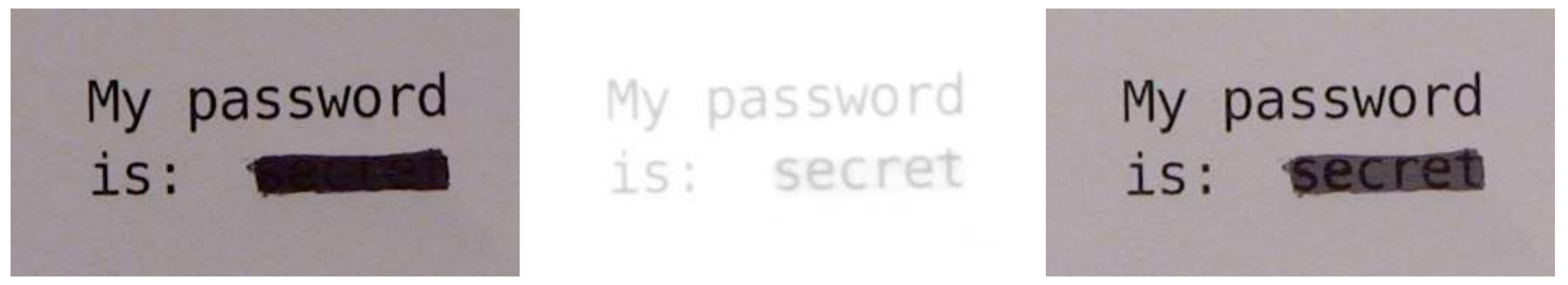
preserves contrast within viewer's space of distinguishable colors



original deuteranope our output original protanope our output

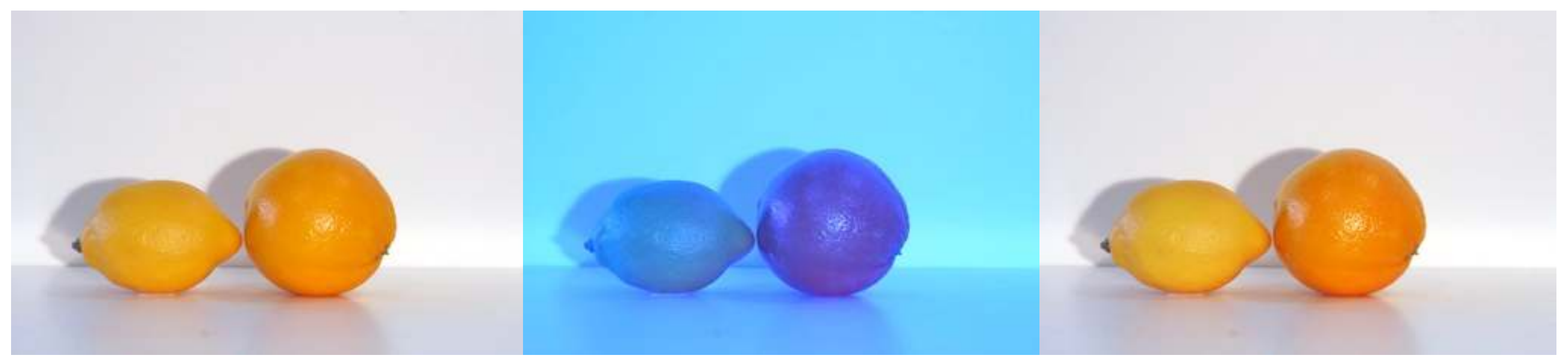
MULTISPECTRAL IMAGE FUSION

visible + near-infrared fusion



visible RGB near-infrared our output

multiprimary image fusion



no filter blue filter our output