Cross Dissolve Without Cross Fade:

Improving Image Quality in Image Compositing

Mark Grundland ◆ Rahul Vohra ◆ Gareth P. Williams ◆ Neil A. Dodgson

Computer Laboratory, University of Cambridge, United Kingdom

University of Cambridge Computer Laboratory

Rainbow Research Group

University of Cambridge

Creating Better Tools for Compositing Artists

60%

+

40%

=

Interpolation

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Creating Better Tools for Compositing Artists

+

=

60% **40%** **Our Method**

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Tools for Visual Expression

- **Stylized image representation (2005)**
  - Non-photorealistic image compression and interpolation
- **Color to grayscale conversion (2005)**
  - Fast decolorization by rendering color contrasts in grayscale
- **Color transfer (2005)**
  - Color histogram specification by histogram warping
- **Color correction (2005)**
  - Image recoloring by finding and replacing color gradients
- **Contrast adjustment (TBA)**
  - Interactive contrast enhancement by contrast brushes
- **Image compositing (2006)**
  - Image blending by preserving of contrast, color and salience

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Linear Image Blending

20% Sunrise

40% Lake

40% Couple

Linear Image Blending

Quadratic Image Blending

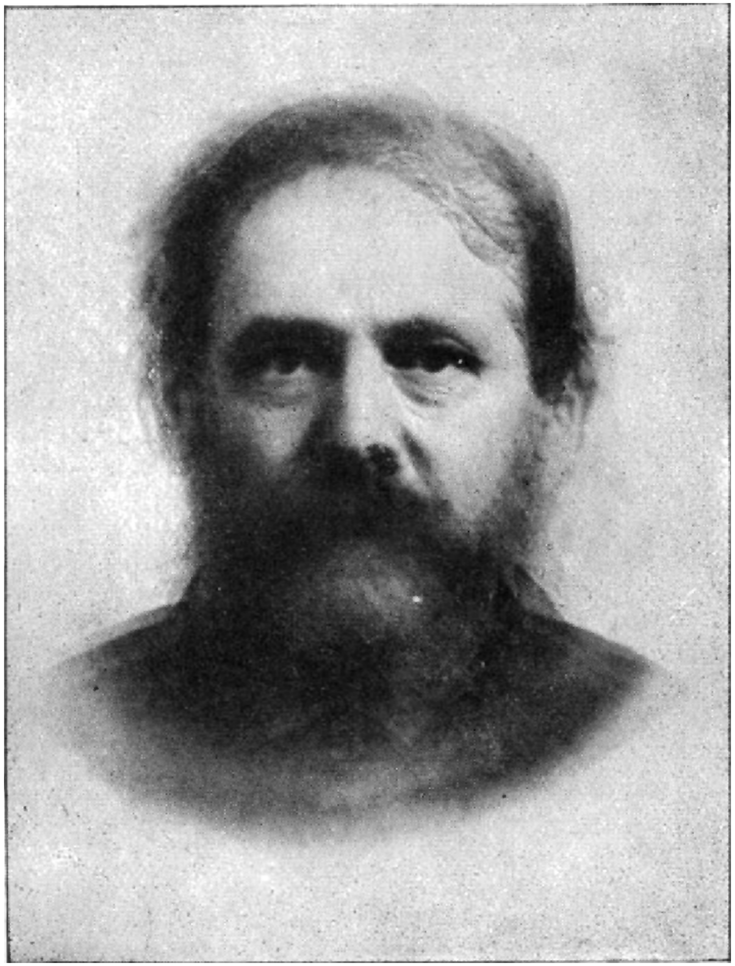
Quartic Image Blending

Selection Image Blending

Linear Image Blending **Contrast Preserving Image Blending**

Color Preserving Image Blending **Salience Preserving Image Blending**

Composite Photography:



31 Members of the Academy of Sciences

49 Students at Smith College

Composite portraits published in the journal *Science* in 1885-1886

Compositing Techniques:

- **Image Cloning (Cut-and-Paste)**
  - **Occluded opaque objects: images placed on top of each other**
  - **Example: Image stitching**
  - **Accurate image mattes**
  - **Simple image blending**
- **Image Mixing (Cut-and-Merge)**
  - **Superimposed translucent objects: images combined with each other**
  - **Example: Cross dissolve**
  - **Simple image mattes**
  - **Perceptual image blending**

Traditional Photomontage by Jerry Uelsmann

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Compositing Goals

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Enable the artist to control the aesthetic appearance of the composite without the need to individually manipulate its components or their opacities

- **Image compositing:** (see the paper)
  - Multiple independent images with variable opacities
- **Cross dissolve:** (see the presentation)
  - Two independent images with constant opacities
- **Image stitching:**
  - Two independent images with binary opacities
- **Image fusion:**
  - Multiple dependent images with unknown opacities

Compositing Representations

- Pixel values
  - Alpha channel (Smith & Catmull, 1977)
  - Blending modes (Porter & Duff, 1984)
  - Optimal image stitching (Milgram, 1977)
- Laplacian pyramids
  - Multiresolution splines (Burt & Adelson, 1983)
- Wavelet decompositions
  - Wavelet image stitching (Hsu & Wu, 1996)
  - Optimal wavelet image stitching (Su, Hwang, & Cheng, 2001)
- Gradient domain representations
  - Poisson image editing (Perez, Gangnet, & Blake, 2003)
  - Interactive digital photomontage (Agarwala et al., 2004)
  - Optimal gradient domain image stitching (Zomet et al., 2006)

Blending by Linear Interpolation

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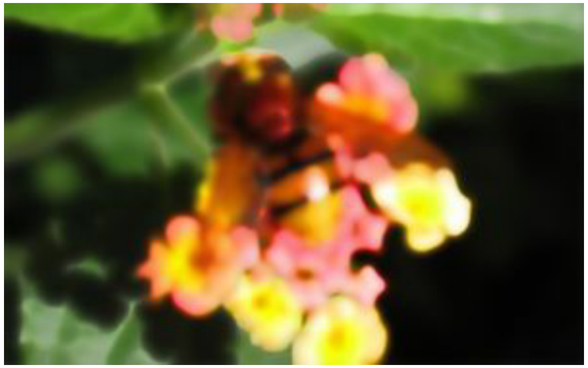
$$C = wA + (1 - w)B$$

- Linear cross dissolve of A and B, with constant opacity $0 \le w \le 1$
- Linear averaging reduces variation: $\sigma_C \le w\sigma_A + (1-w)\sigma_B$
  - A nondegenerate linear combination of bounded, identically distributed signals, with nonzero mean, can not simultaneously maintain both their expected intensity μ and variation σ
- Linear blending averages coinciding pixels of different images: variation loss in the dynamic range reduces image contrast
- Linear smoothing averages adjacent pixels of the same image: variation loss in the frequency domain reduces image sharpness

Standard Linear Gaussian Smoothing



Our Color Preserving Gaussian Smoothing

Compositing Operators

- Mathematical models:
  - Linear weighted mean
    - Results in undesirable contrast loss (emphasizes gray)
  - Signed weighted power mean
    - User controlled contrast enhancement (emphasizes details)
  - Maximal absolute magnitude selection
    - Results in undesirable contrast gain (emphasizes noise)
- Physical models:
  - Absorption of light
    - Results in undesirable darkening (emphasizes black)
  - Emission of light
    - Results in undesirable brightening (emphasizes white)
  - Mixture of pigments
    - Results undefined if pigment parameters are not available

Redefining Linear Interpolation

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$$C = wA + (1 - w)B$$

- **Change linearity:** A^{ρ}, B^{ρ}, and $C^{1/\rho}$
  - **Detail preserving image compositing**
    - Generalized means: enhances varied details over flat colors
- **Change result:** C'
  - **Contrast preserving image compositing**
    - Statistical analysis: recovers contrast lost due to averaging
- **Change operators:** $\oplus$ and $\otimes$
  - **Color preserving image compositing**
    - Vector algebra: emphasizes vivid colors over shades of gray
- **Change weights:** w'
  - **Salience preserving image compositing**
    - Information theory: keeps what is deemed most informative

Standard Linear Image Blending

Detail Preserving Image Blending

Detail Preserving Blending

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$$\mathbf{C} = \left\langle \mathbf{w} \langle \mathbf{A} \rangle^{\rho} + (1 - \mathbf{w}) \langle \mathbf{B} \rangle^{\rho} \right\rangle^{1/\rho} \quad \textbf{for} \quad \langle \mathbf{X} \rangle^{\rho} = \textbf{sign}(\mathbf{X}) \, |\mathbf{X}|^{\rho}$$

- **Problem:** Linear blending obliterates fine details
- **Model:** Combine image values using a signed weighted power mean
- **Solution:** Emphasize variation over uniformity when compositing a heterogeneous image region with a homogenous image region
- **Parameter ρ :** User control over the degree of detail enhancement
- **Advantage:** Simple, efficient and continuous compositing method balances the effects of linear averaging and coefficient selection
- **Disadvantage:** May exaggerate image colors in order to emphasize image details

Signed Weighted Power Mean

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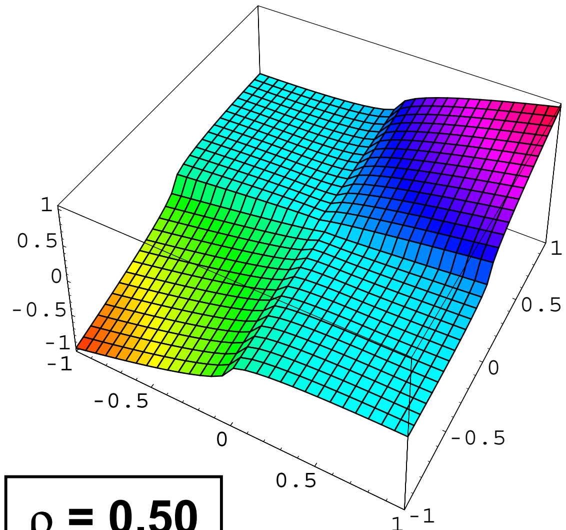
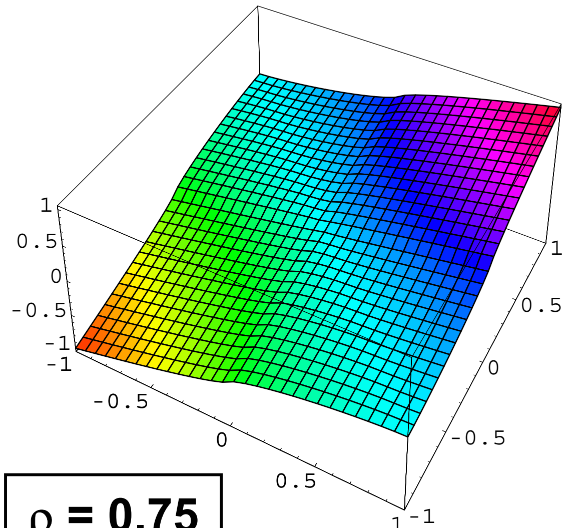
$$\mathbf{C} = \left\langle \mathbf{w}\langle \mathbf{A}\rangle^{\rho} + (1-\mathbf{w})\langle \mathbf{B}\rangle^{\rho} \right\rangle^{1/\rho} \quad \text{for} \quad \langle \mathbf{X}\rangle^{\rho} = \operatorname{sign}(\mathbf{X})\,|\mathbf{X}|^{\rho}$$

- **Intermediate Value: Bounded contrast**
  - For $0 \le \rho \le \infty$: $\min(\mathbf{A},\mathbf{B}) \le \mathbf{C} \le \max(\mathbf{A},\mathbf{B})$
- **Geometric Mean: Minimal contrast**
  - For $\rho \to 0$: $\mathbf{C} = \frac{1}{2}(\operatorname{sign}(\mathbf{A}) + \operatorname{sign}(\mathbf{B}))\,|\mathbf{A}|^{\mathbf{w}}\,|\mathbf{B}|^{1-\mathbf{w}}$
- **Linear Mean: Reduced contrast**
  - For $\rho = 1$: $\mathbf{C} = \mathbf{w}\mathbf{A} + (1-\mathbf{w})\mathbf{B}$
- **Power Mean: Enhanced contrast**
  - For $\rho \in \mathbb{N}$ odd: $\mathbf{C} = \sqrt[\rho]{\mathbf{w}\mathbf{A}^{\rho} + (1-\mathbf{w})\mathbf{B}^{\rho}}$
- **Coefficient Selection: Maximal contrast**
  - For $\rho \to \infty$: $\mathbf{C} = \mathbf{A}$ when $|\mathbf{A}| \ge |\mathbf{B}|$ or $\mathbf{C} = \mathbf{B}$ when $|\mathbf{B}| \ge |\mathbf{A}|$

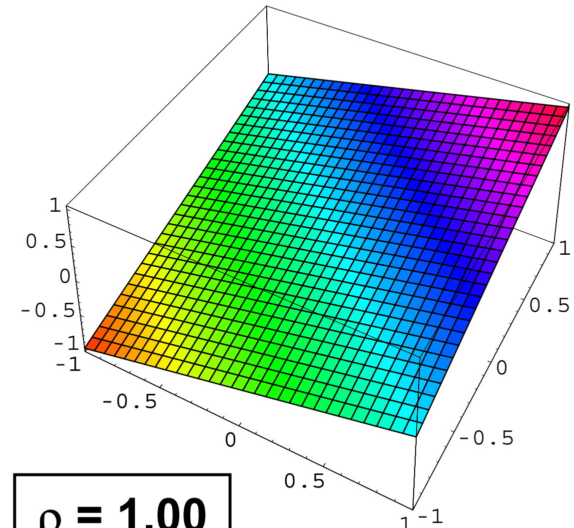
Signed Weighted Power Mean



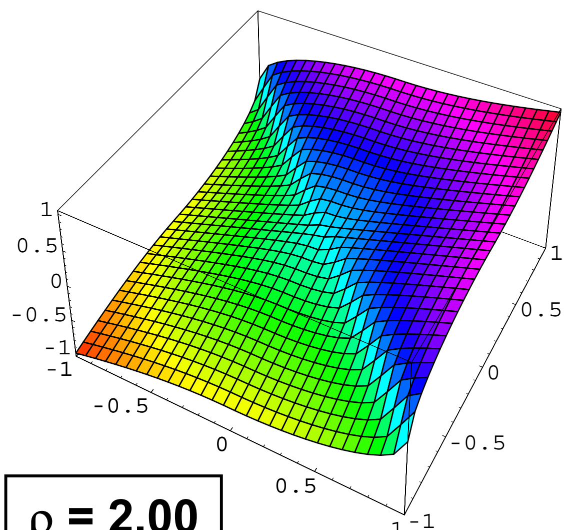
ρ = 0.50



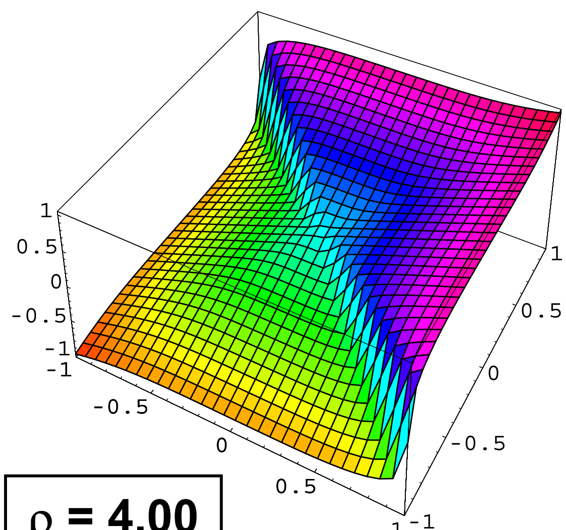
ρ = 0.75



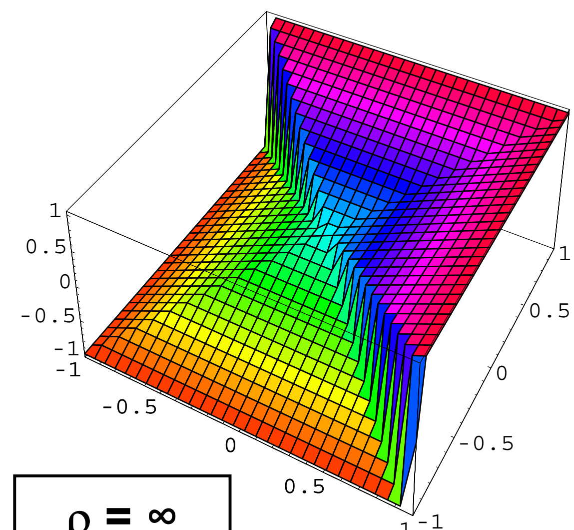
ρ = 1.00



ρ = 2.00



ρ = 4.00



ρ = ∞

ρ = 0.5

ρ = 1.0

ρ = 2.0

ρ = 4.0

ρ = ∞

Contrast Preserving

ρ = 0.5
Nonlinear
Cross Dissolve

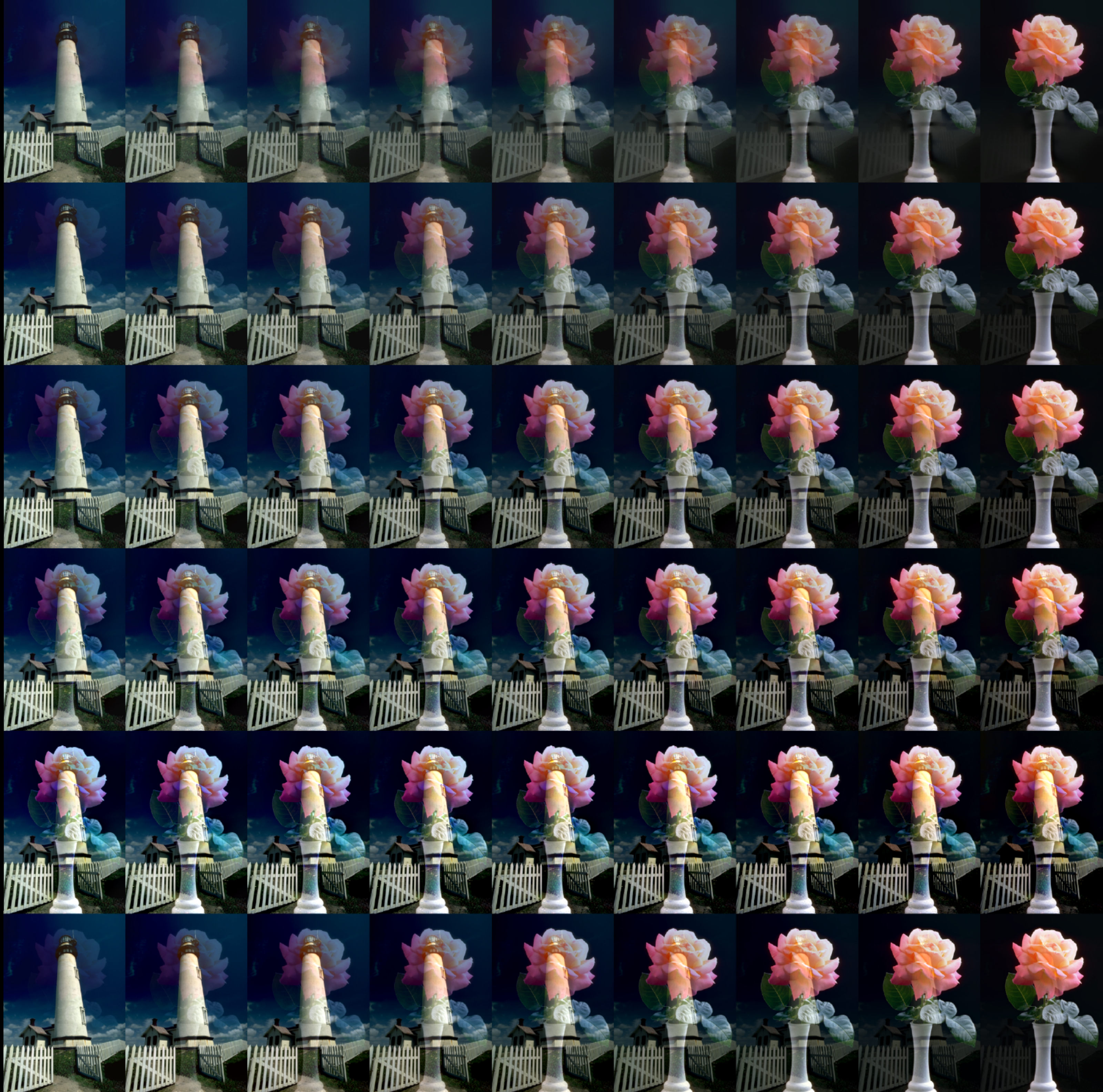
ρ = 1.0
Linear
Cross Dissolve

ρ = 2.0
Nonlinear
Cross Dissolve

ρ = 4.0
Nonlinear
Cross Dissolve

ρ = ∞
Selection
Cross Dissolve

Contrast
Preserving
Cross Dissolve



ρ = 0.5
Nonlinear
Cross Dissolve

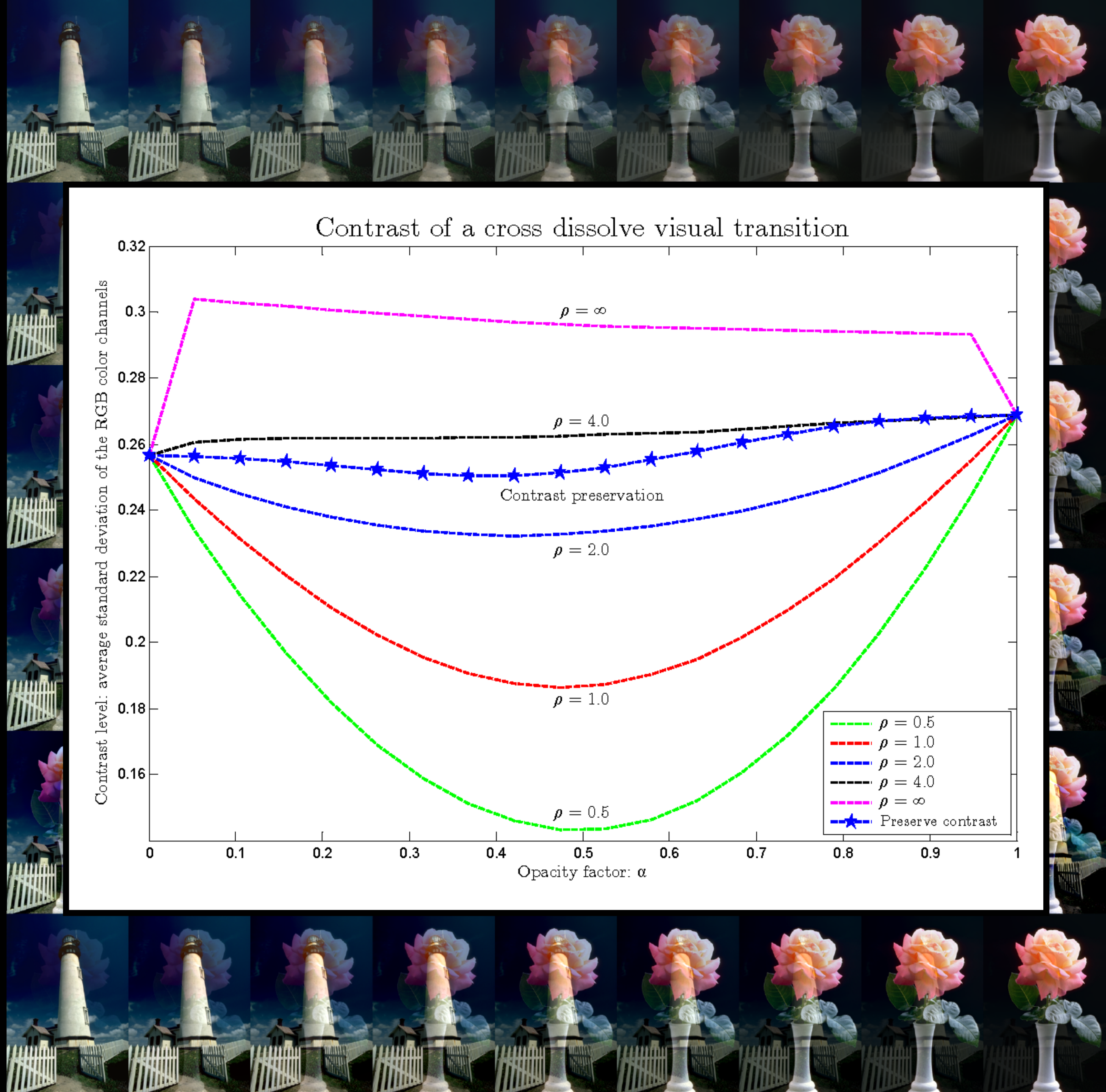
ρ = 1.0
Linear
Cross Dissolve

ρ = 2.0
Nonlinear
Cross Dissolve

ρ = 4.0
Nonlinear
Cross Dissolve

ρ = ∞
Selection
Cross Dissolve

Contrast
Preserving
Cross Dissolve



Standard Linear Image Blending

Contrast Preserving Image Blending

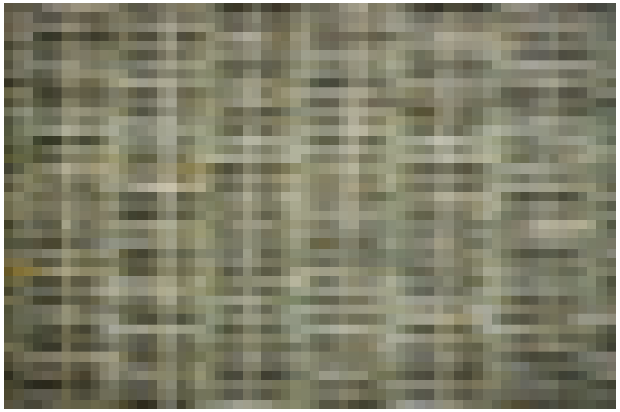
Contrast Preserving Blending

$$\mathbf{C}' = \tau \frac{\sigma'_{\mathbf{C}}}{\sigma_{\mathbf{C}}}(\mathbf{C} - \mu_{\mathbf{C}}) + \mu_{\mathbf{C}} \quad \textbf{for} \quad \sigma'_{\mathbf{C}} = \mathbf{w}\sigma_{\mathbf{A}} + (\mathbf{1} - \mathbf{w})\sigma_{\mathbf{B}}$$

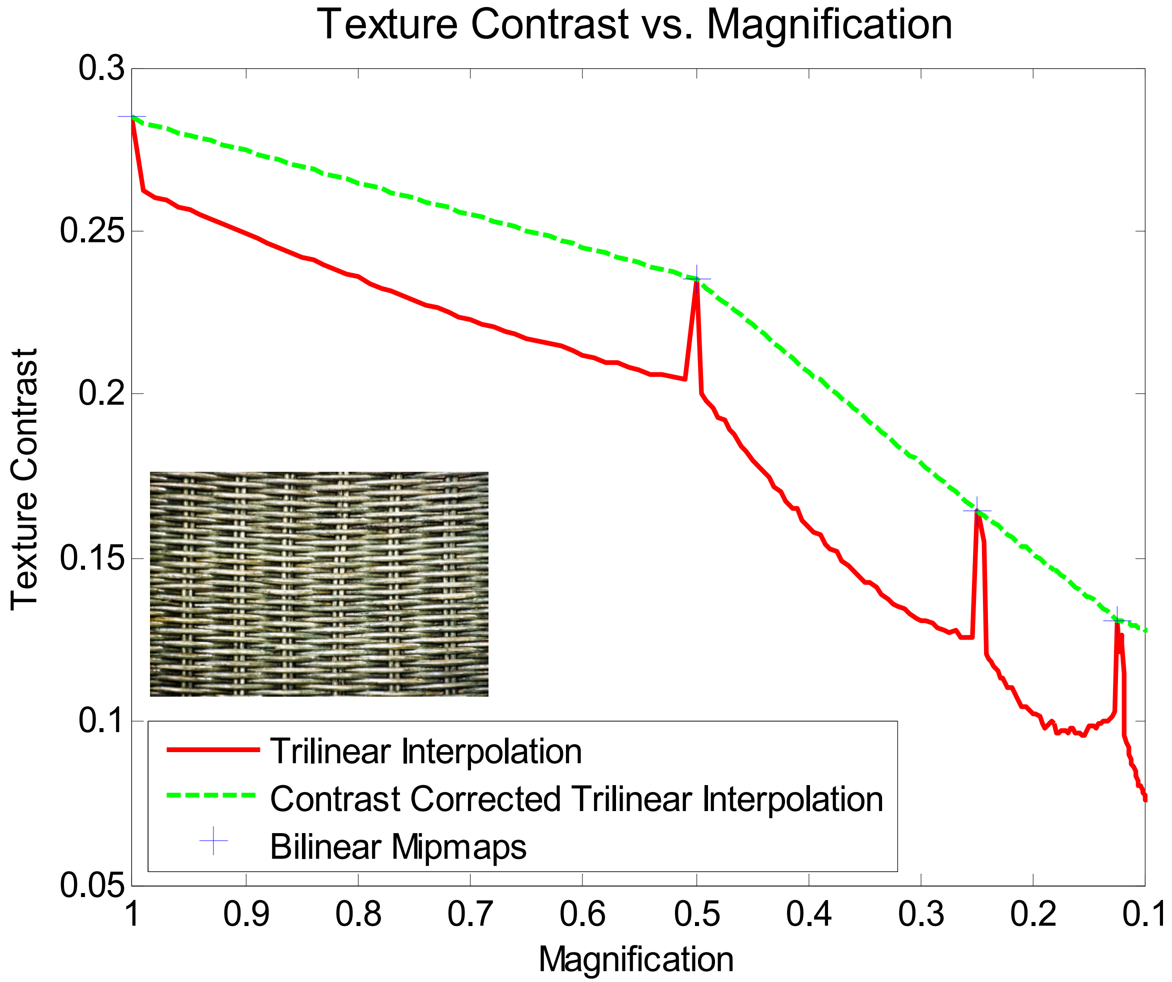
- **Problem:** Linear blending causes contrast to fade
- **Model:** Represent the average color by the mean μ and the average contrast by the standard deviation σ
- **Solution:** Stretch each color channel around its mean to enable the composite image to reproduce both the average color and contrast of its component images
- **Parameter τ :** User control over the contrast gain $\tau > 1$ or loss $\tau < 1$
- **Advantage:** Corrects contrast with minimal color distortion
- **Disadvantage:** May map a few colors out of gamut

Contrast and Interpolation

Preventing Contrast Loss in Linear Interpolation

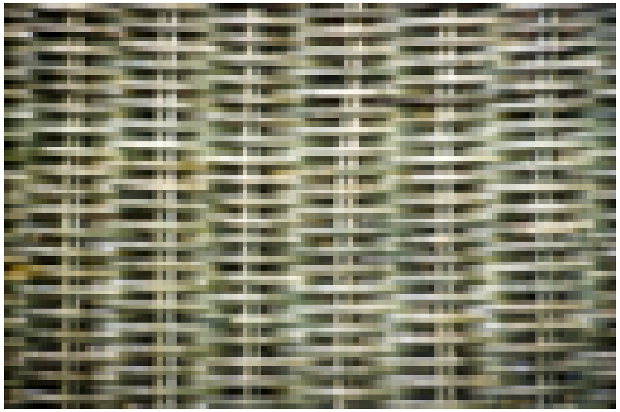


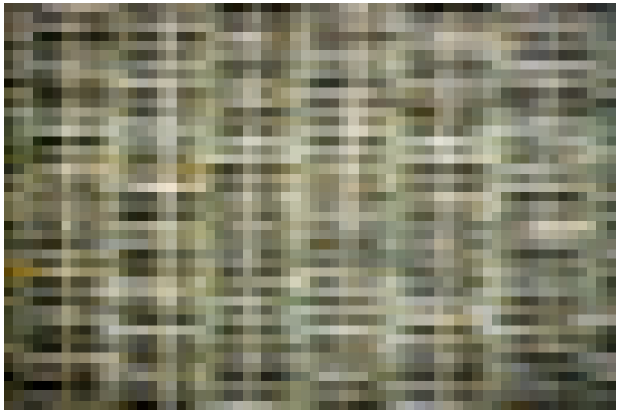
Normal Mipmapping
Trilinear Interpolation



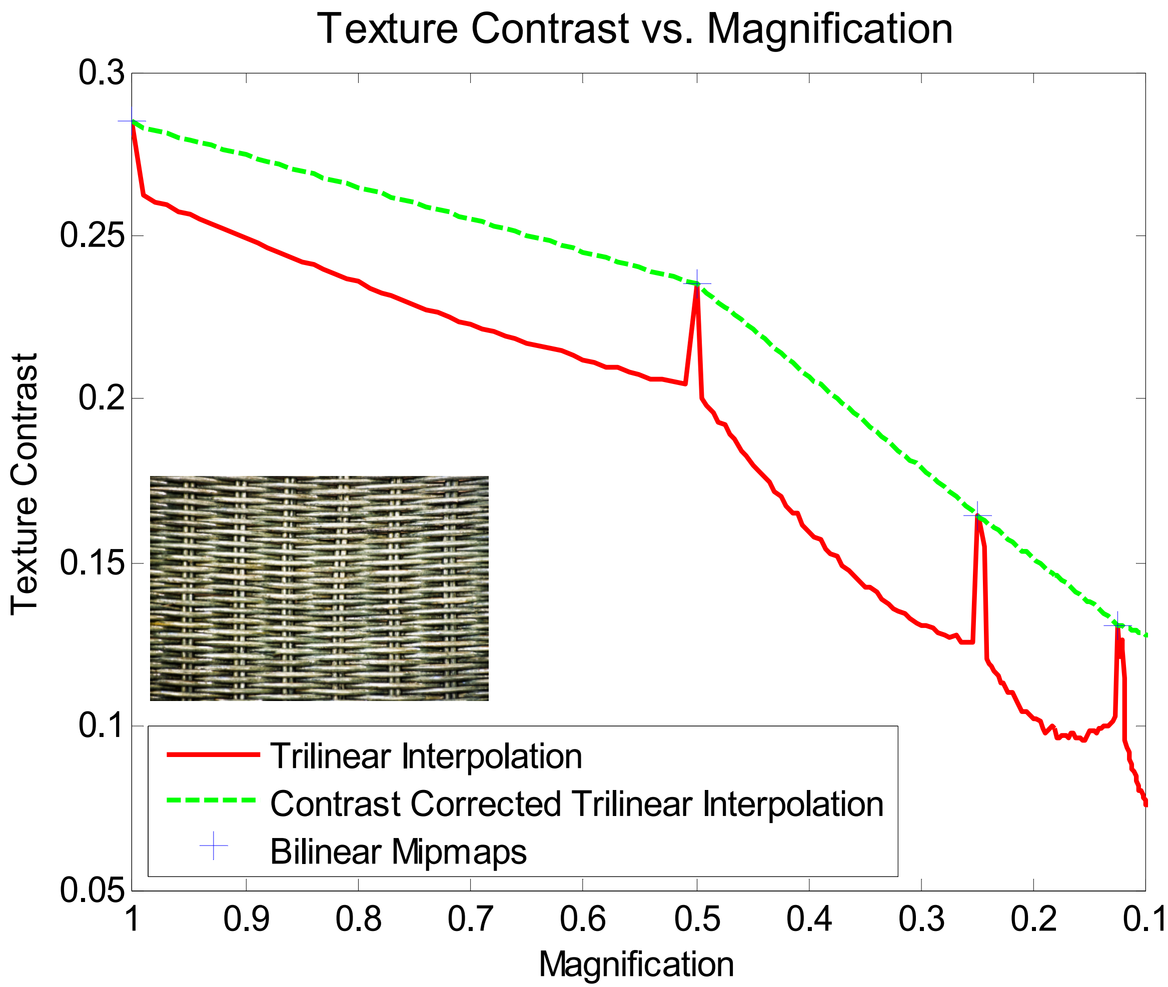
Contrast and Interpolation

Preventing Contrast Loss in Linear Interpolation



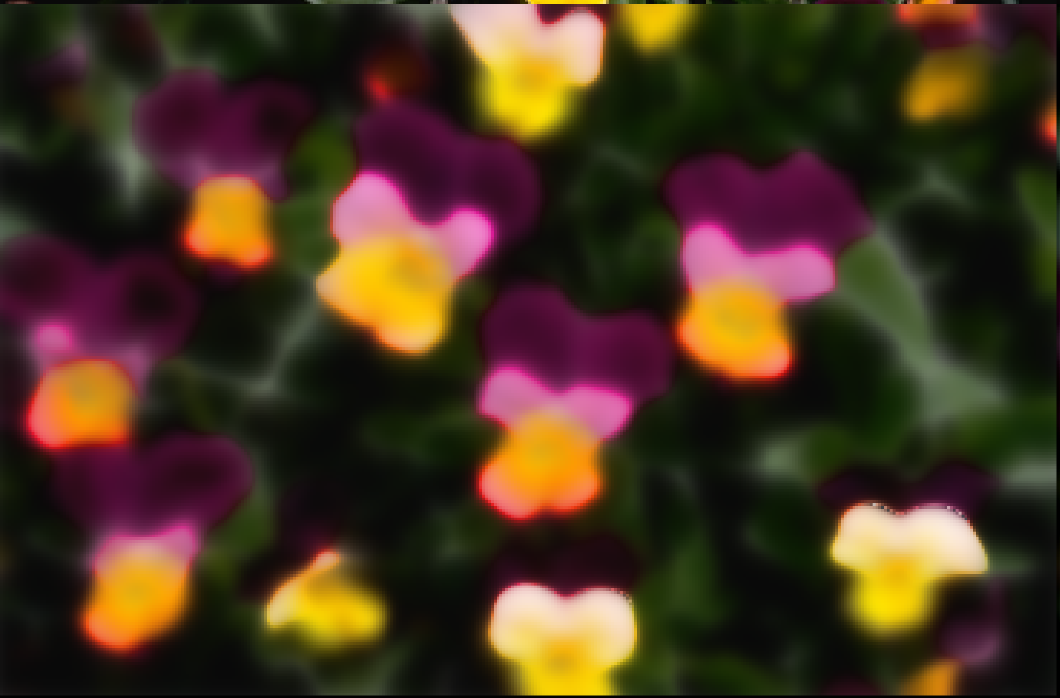


Contrast Preserving Trilinear Interpolation



Flowers

Linear Gaussian Filter



Color Preserving Gaussian Filter

Contrast Preserving Gaussian Filter

Standard Linear Image Blending

Color Preserving Image Blending

Color Preserving Blending

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Isomorphic Color Image Processing

- **Problem:** Linear blending favors dull, neutral tones while viewers prefer vibrant, colorful images
- **Model:** Intuitive color mixing model based on a novel color algebra
- **Solution:** Define an isomorphism between colors and real numbers to allow mathematical operations to be applied to colors without losing their algebraic properties or mapping colors out of gamut
- **Parameter λ :** User control over the amount of color enhancement
- **Advantage:** Supports generalized linear combinations $w_A, w_B \in \mathbb{R}$ instead of just positive, convex linear combinations $w_A + w_B = 1$
- **Disadvantage:** Does not adapt operators to suit image content

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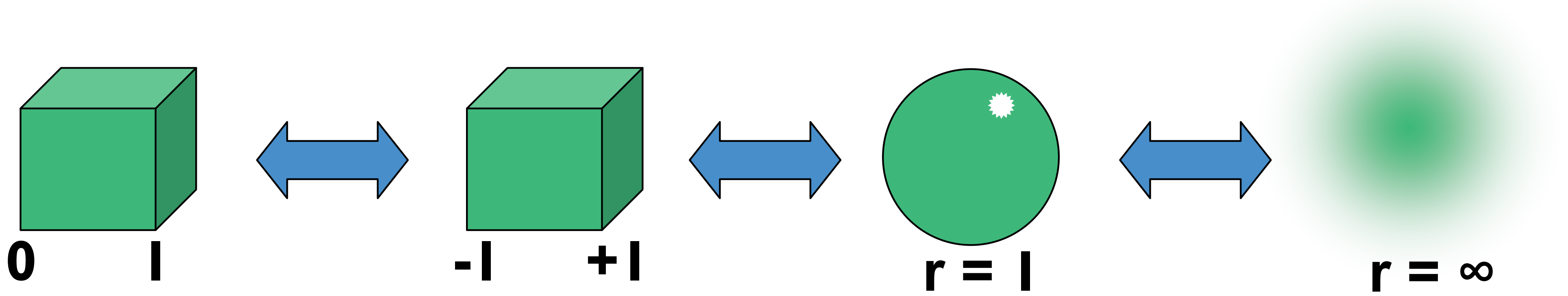
Isomorphic Compositing

Isomorphic Color Image Processing



Translate and rescale the color coordinates

Transform the color cube to a color sphere

Apply a nonlinear radial mapping

- Makes operations on colors as easy as operations on real numbers
- Supports both color interpolation and color extrapolation
- Looses geometric properties of linear displacement in color space
- Gains algebraic properties of linear algebra in a vector space

Isomorphic Compositing

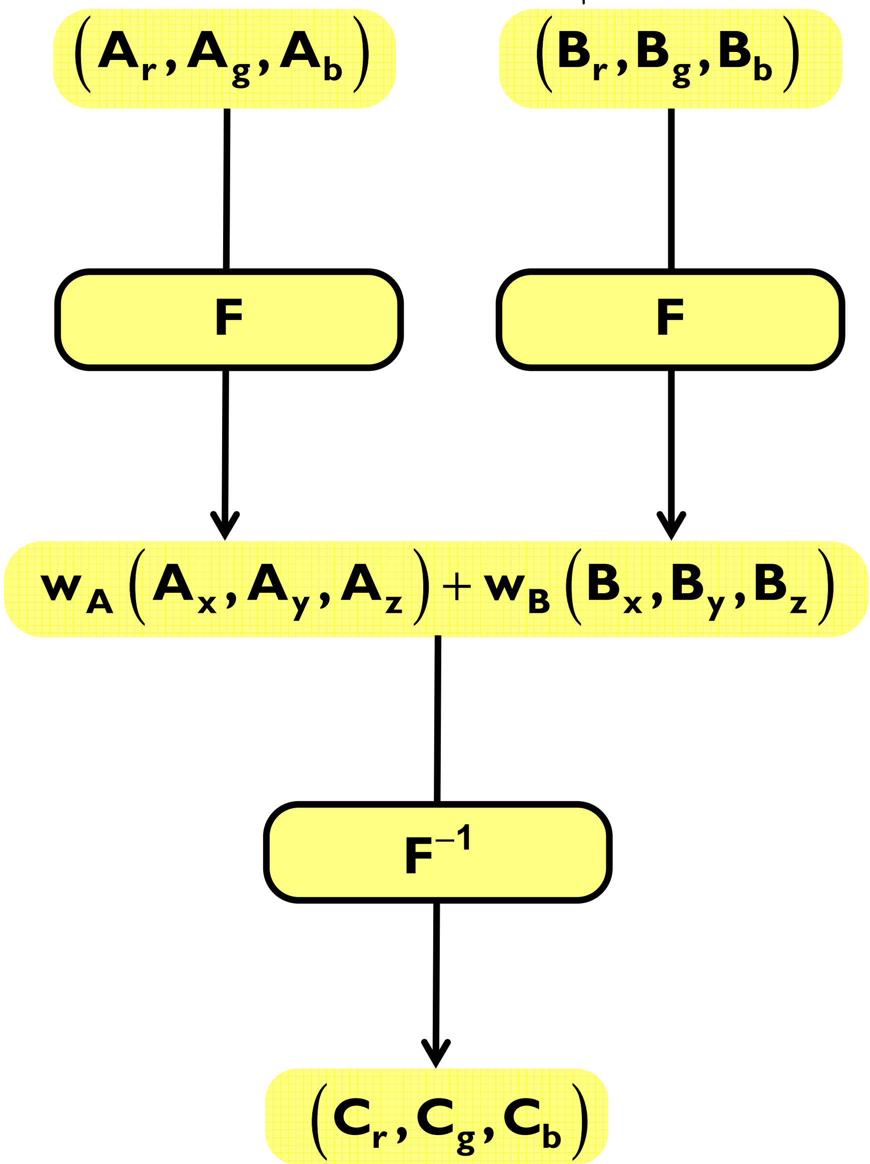
RGB Color Cube $(r,g,b) \in (0,1)^3$

Forward Isomorphism $F : (0,1)^3 \to \mathbb{R}^3$

Image Processing $C = (w_A \otimes A) \oplus (w_B \otimes B)$

Backward Isomorphism $F^{-1} : \mathbb{R}^3 \to (0,1)^3$

RGB Color Cube $(r,g,b) \in (0,1)^3$



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Isomorphic Compositing

RGB Color Cube $(r,g,b) \in (0,1)^3$

Color Sphere $(\rho,\theta,\phi) \in [0,1) \times (-\pi,\pi) \times (0,\pi)$

Forward Nonlinear Radial Map $f_\lambda : [0,1) \to \mathbb{R}$

Real Numbers $(x,y,z) \in \mathbb{R}^3$

Image Processing $C = (w_A \otimes A) \oplus (w_B \otimes B)$

Real Numbers $(x,y,z) \in \mathbb{R}^3$

Backward Nonlinear Radial Map $f_\lambda^{-1} : \mathbb{R} \to [0,1)$

Color Sphere $\rho \in [0,1),\ \theta \in (-\pi,\pi),\ \phi \in (0,\pi)$

RGB Color Cube $(r,g,b) \in (0,1)^3$

(A_r, A_g, A_b) (B_r, B_g, B_b)

$(A_\rho, A_\theta, A_\phi)$ $(B_\rho, B_\theta, B_\phi)$

$A_\rho^* = f_\lambda(A_\rho)$ $B_\rho^* = f_\lambda(B_\rho)$

(A_x, A_y, A_z) (B_x, B_y, B_z)

$w_A (A_x, A_y, A_z) + w_B (B_x, B_y, B_z)$

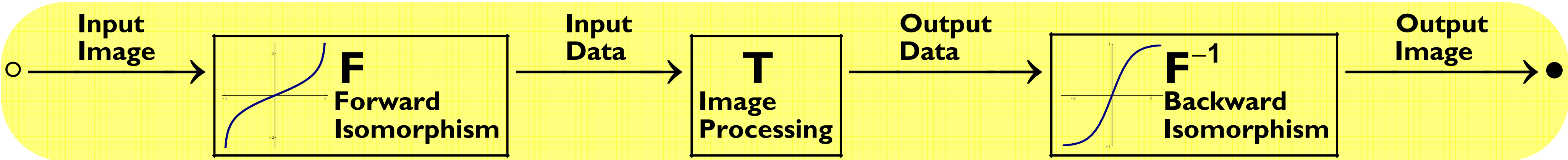
(C_x, C_y, C_z)

$C_\rho = f_\lambda^{-1}(C_\rho^*)$

$(C_\rho, C_\theta, C_\phi)$

(C_r, C_g, C_b)

Isomorphic Image Processing



- **Invertible mapping of images to real numbers**
- **Numerical data has a consistent visualization**
- **Visual data has consistent numerical operations**
- **Operations on images obey the same algebraic laws as operations on real numbers**
- **Operations on images always yield valid images**
- **Image compositing is associative and invertible**

Color Image Algebra

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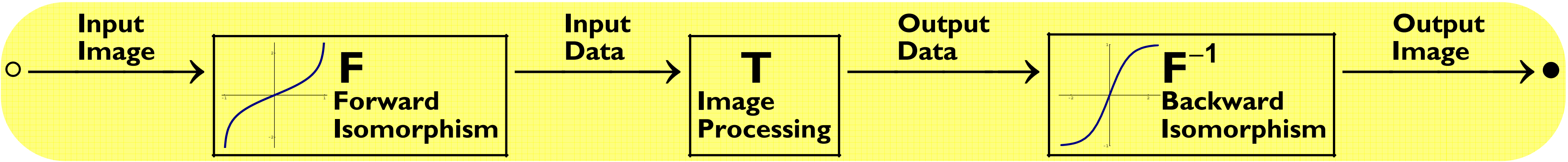

- **Grayscale algebra:** ordered field
- **Color algebra:** normed vector space
- **Nonlinear mapping f_λ:** parametric Frank operator
- **Vector addition:** color change $A \oplus B = F^{-1}(F(A) + F(B))$
- **Scalar multiplication:** contrast change $w \otimes A = F^{-1}(wF(A))$
- **Negative elements:** inverse colors RGB $\rightarrow$ CMY
- **Zero element:** neutral gray

RGB Color Operators

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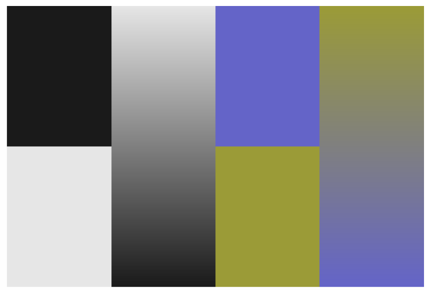
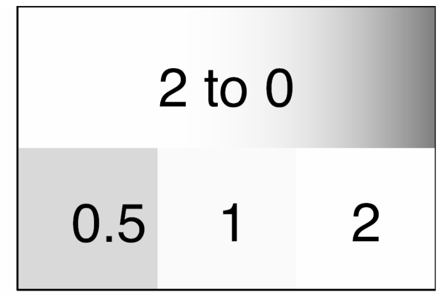
$[0,1]^3$ Linear Color Space

$\oplus$



$\otimes$



Our Color Operators

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$\mathbb{R}^3$ Nonlinear Color Space

Standard Linear Image Blending

Salience Preserving Image Blending

Salience Preserving Blending

Salience maps + Image mattes = Salience mattes

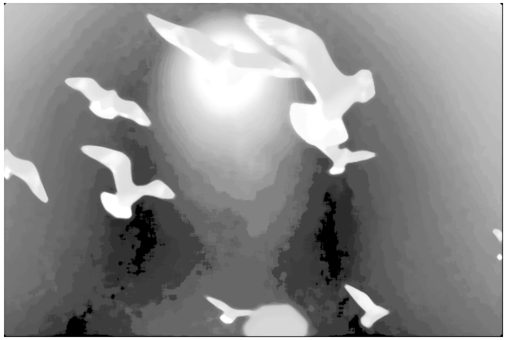
- **Problem:** Linear blending obliterates relevant image details
- **Model:** Opacity prescribes inter-image semantic importance, while saliency describes intra-image perceptual relevance
- **Solution:** Integrate opacity with saliency to make a composite that retains the most visually informative aspects of its components
- **Parameter γ :** User control over the sharpness of the image mattes
- **Advantage:** Gives effective results with very simple opacity maps
- **Disadvantage:** Limited by the quality of the available salience maps

Salience by Color Entropy

Uncommon ⇒ Informative ⇒ Salient

- Salience is a predictor of visual attention
- Salience is used to determine the degree to which an image can be obscured without becoming illegible
- High entropy colors are considered salient because unusual colors stand out and attract attention

A: 50% Birds



s_A: Color Entropy

s_B: Color Entropy

B: 50% Forest

Salience Matting

$$C = w'A + (1 - w')B$$

- **Salience maps and opacity factor:** $s_A \in \mathbb{R},\ s_B \in \mathbb{R},\ w \in [0,1]$
- **Salience ranks:** $r \in [0,1]$ for $r = \Phi_s(s)$ and $s = s_A - s_B$
- **Salience matte:** $w' = \dfrac{w^\gamma r^\gamma}{w^\gamma r^\gamma + (1-w)^\gamma (1-r)^\gamma}$

A: 50% Birds

w´: Salience Matte

1-w´: Salience Matte

B: 50% Forest

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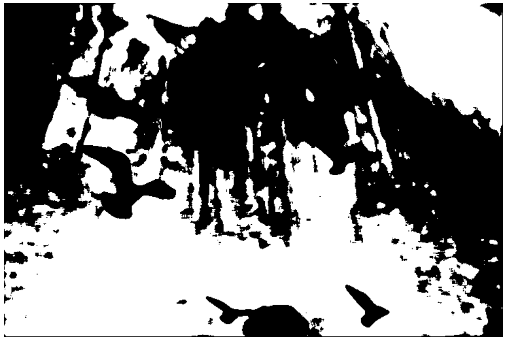
Dominance and Coverage

$$\mathbf{C} = \mathbf{w}'\mathbf{A} + (1 - \mathbf{w}')\mathbf{B}$$

- **Dominance:** $\mathbf{P}[\mathbf{w}' \geq 1 - \mathbf{w}'] = \mathbf{w}$
  - Proportion of a composite where the contribution of one component is greater than that of the other component
- **Coverage:** $\mathbf{E}[\mathbf{w}'] \to \mathbf{w}$ as $\gamma \to \infty$ and $\text{median}[\mathbf{w}'] = \mathbf{w}$ if $\gamma = 1$
  - Average contribution that a component makes to a composite

A: 50% Birds

w´ ≥ ½: Dominance



1-w´ ≥ ½: Dominance

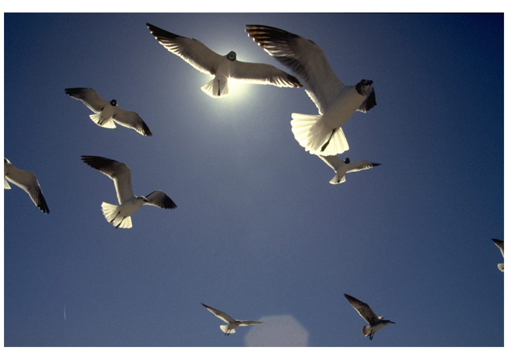
B: 50% Forest

Salience Compositing

$$C = w'A + (1 - w')B$$

Linear Composite

Salient Composite



A: 50% Birds

w´: Salience Matte

1-w´: Salience Matte

B: 50% Forest

Linear Image Blending

Salience Image Blending

Shell

Shore

Opacity Matte

Salience Matte

Shell Salience Map

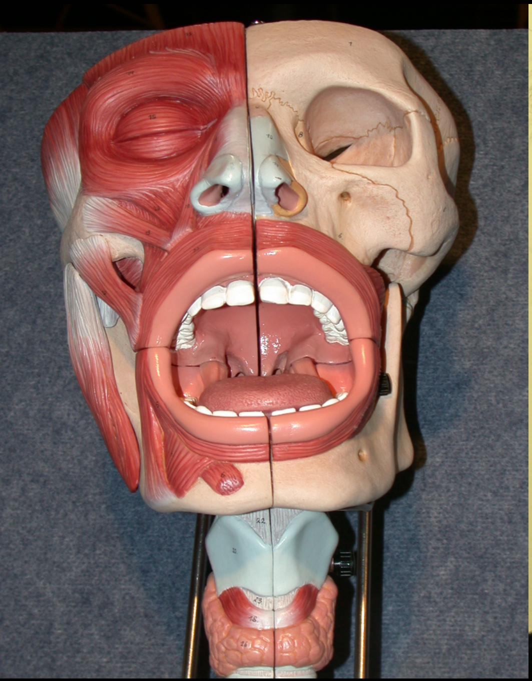
Shore Salience Map

Linear Image Blending

Salience Image Blending

Shell

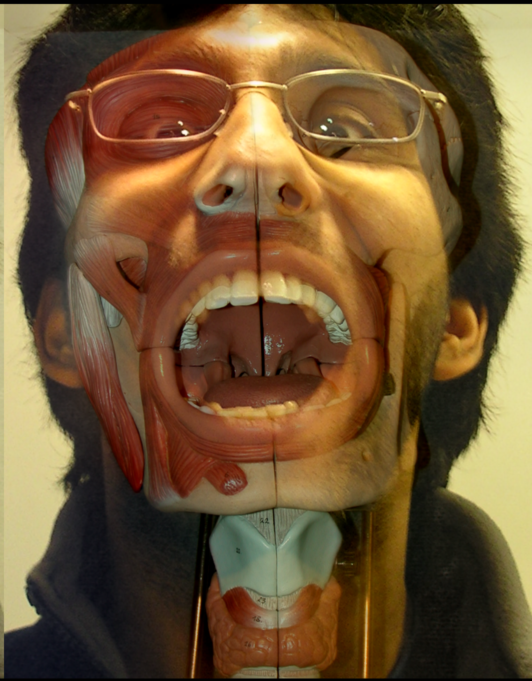
Shore



25% Inside

75% Outside

Linear Blending



Salience Blending

33% Coin

Linear Blending

Salience Preserving Blending

Linear Cross Dissolve

Contrast Preserving Cross Dissolve

Color Preserving Cross Dissolve

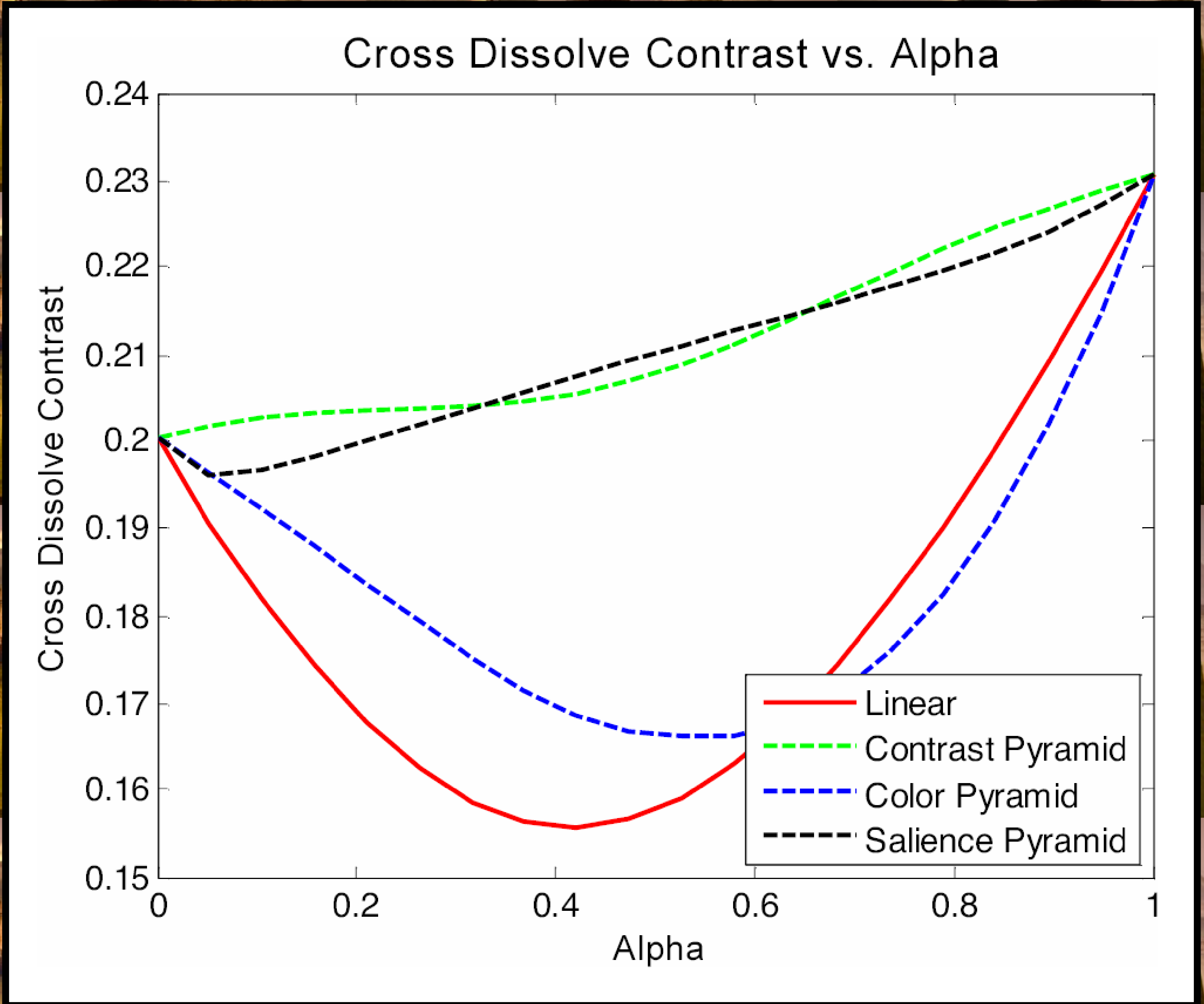
Salience Preserving Cross Dissolve

Linear Cross Dissolve

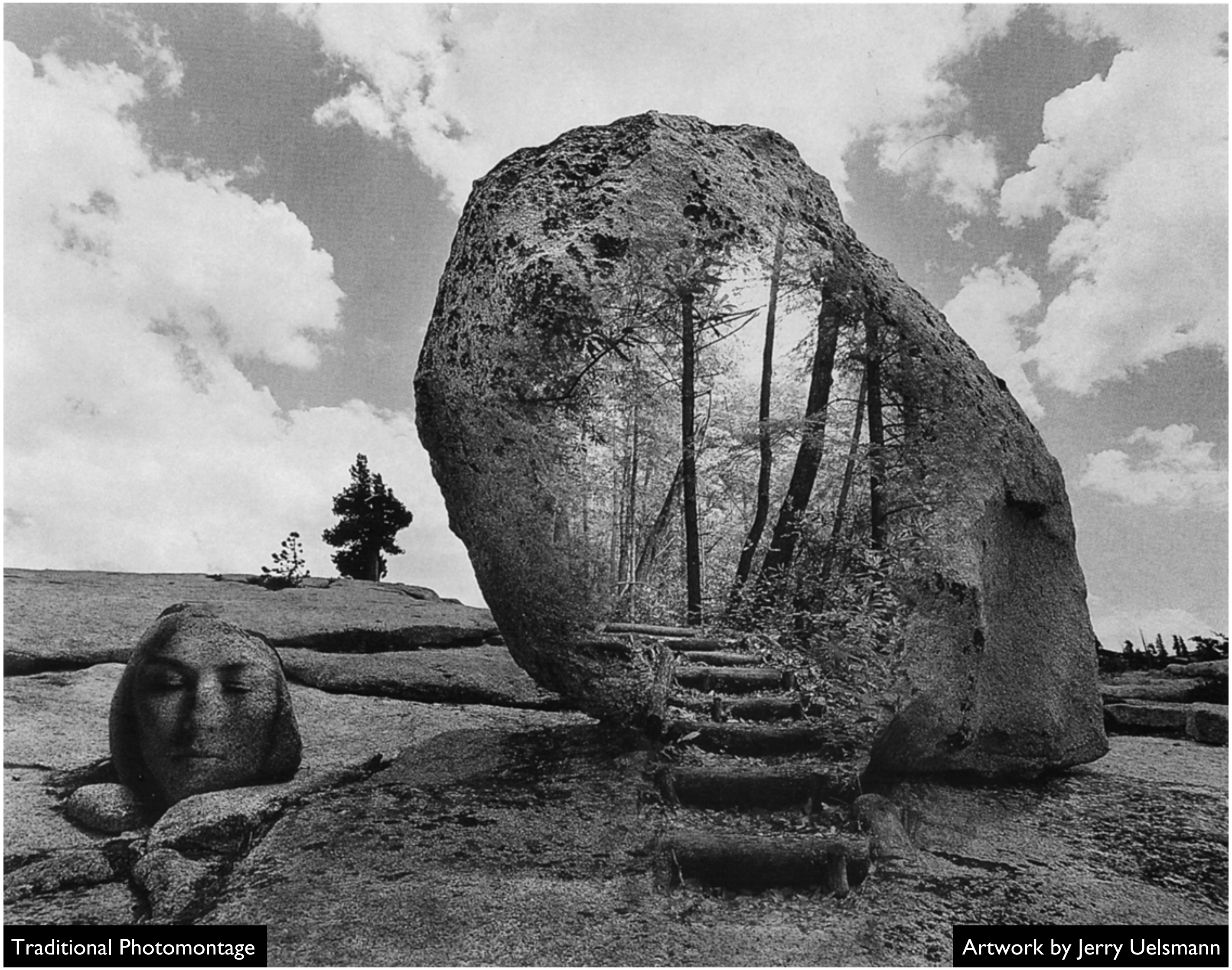
Contrast Preserving Cross Dissolve

Color Preserving Cross Dissolve

Salience Preserving Cross Dissolve



Questions?



Linear Image Blending

Church

Forest

Opacity

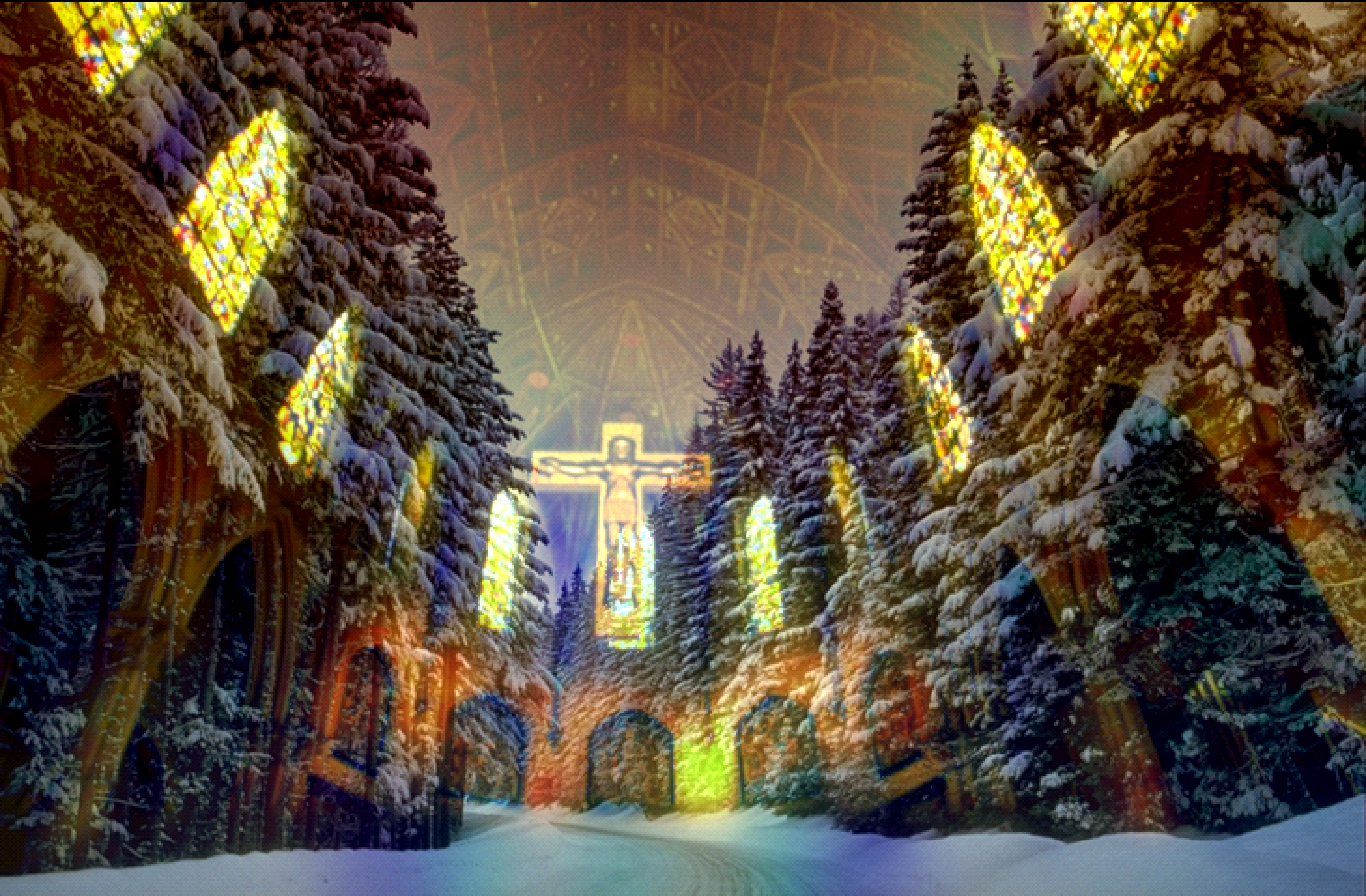
Square Root Image Blending: $\rho = 0.5$

Linear Image Blending: $\rho = 1.0$

Quadratic Image Blending: $\rho = 2.0$

Quartic Image Blending: $\rho = 4.0$

Selection Image Blending: $\rho = \infty$



Color Preserving Image Blending

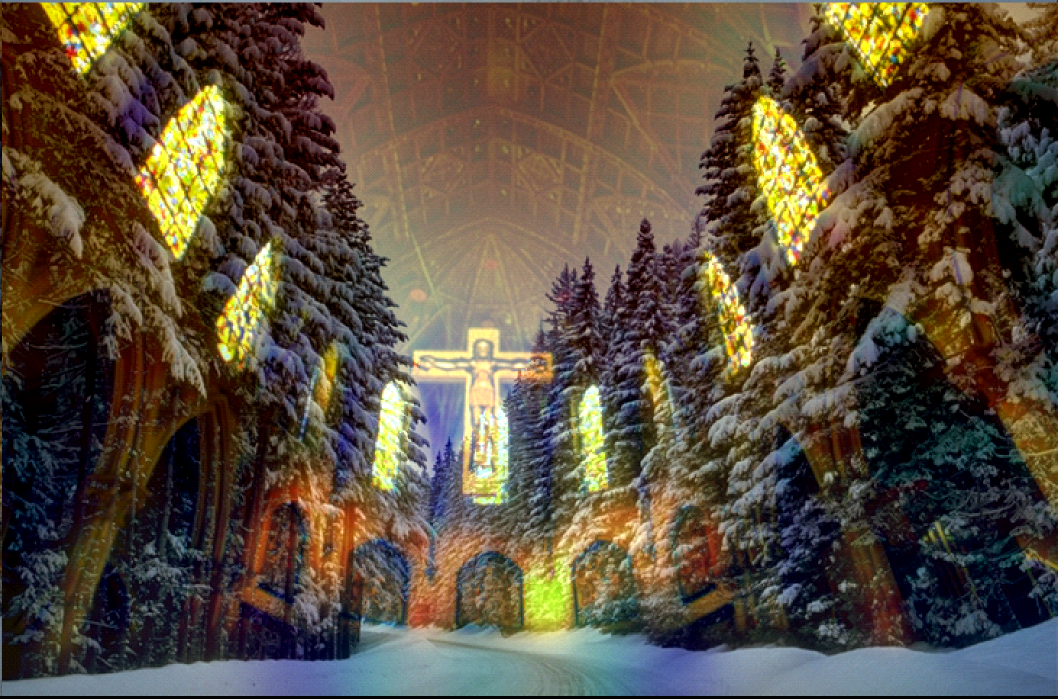
Contrast Preserving Image Blending

Salience Preserving Image Blending

Linear Image Blending

Quadratic Image Blending

Quartic Image Blending



Selection Image Blending

Linear Image Blending

Contrast Preserving Image Blending

Color Preserving Image Blending

Salience Preserving Image Blending

Linear Image Blending

Church

Forest

Opacity

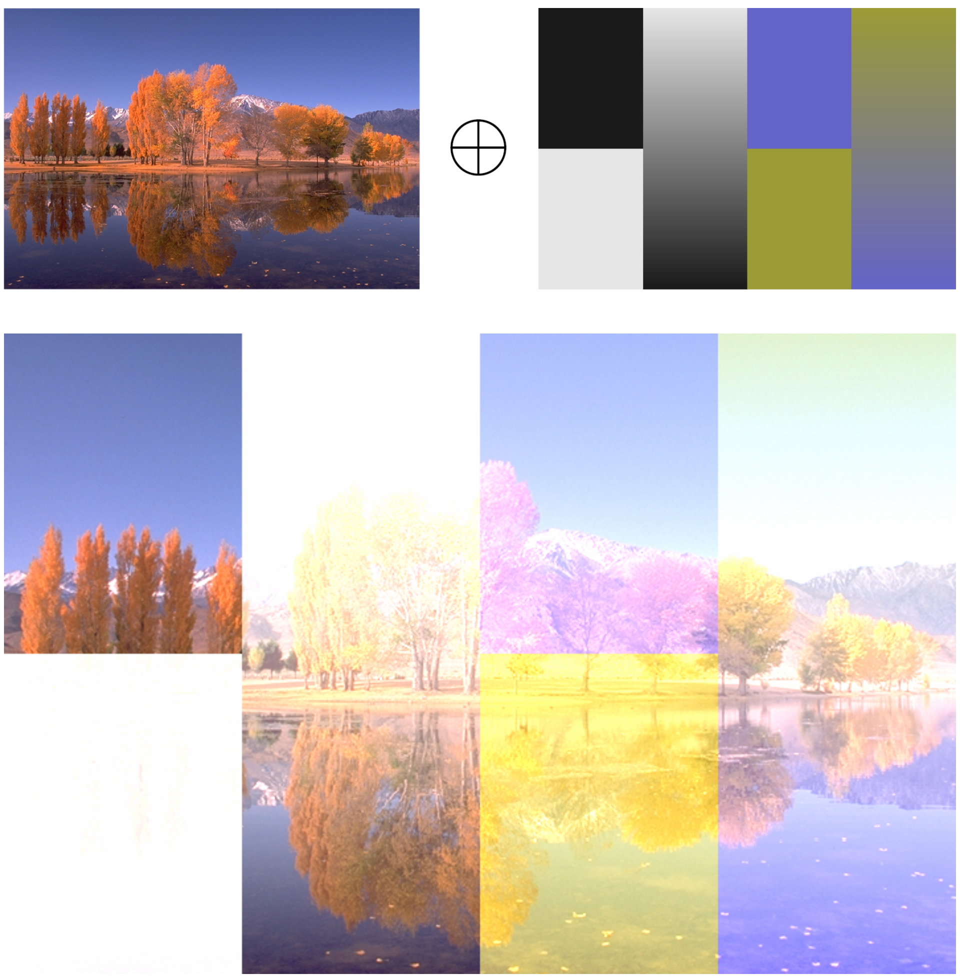
Linear Image Blending

All Preserving Image Blending

UNIVERSITY OF CAMBRIDGE
COMPUTER LABORATORY
RAINBOW RESEARCH GROUP

RGB Color Operators

$[0,1]^3$ Linear Color Space



R’G’B’ Color Operators

$[-1,1]^3$ Linear Color Space

Our Color Operators

$\mathbb{R}^3$ Nonlinear Color Space