

# **Color Seamlessness in Multi-Projector Displays Using Constrained Gamut Morphing**

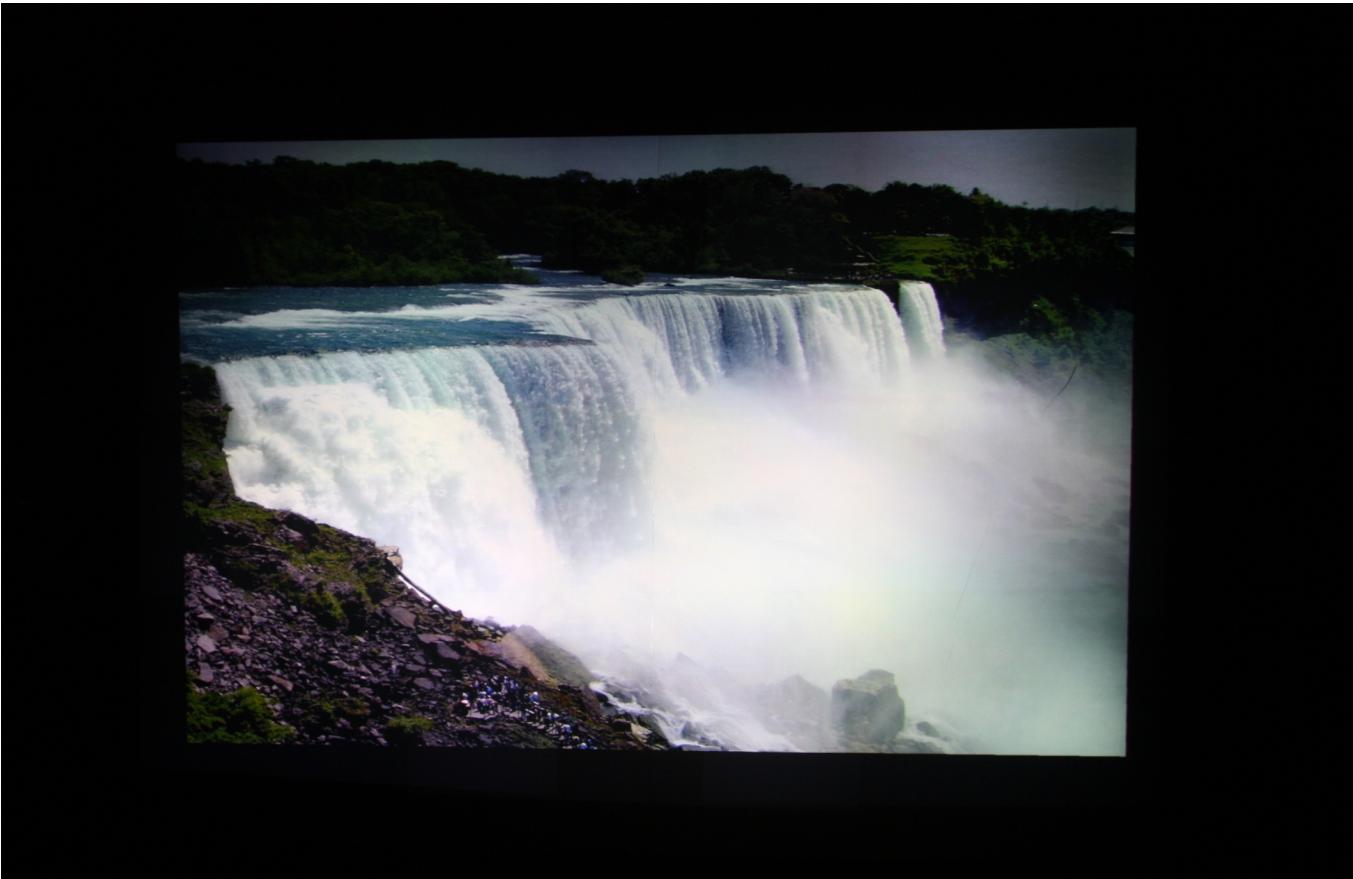
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IEEE Visualization, 2009

Behzad Sajadi  
Maxim Lazarov  
Aditi Majumder  
M. Gopi

# Registration Problem

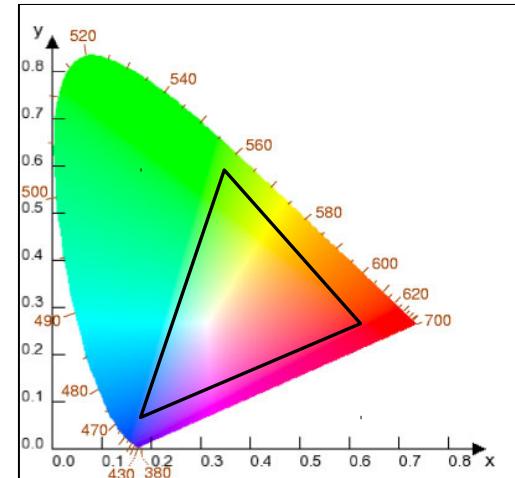
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# Color: Brightness & Chrominance

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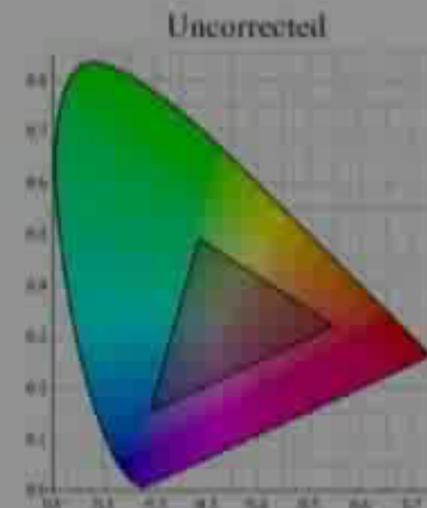
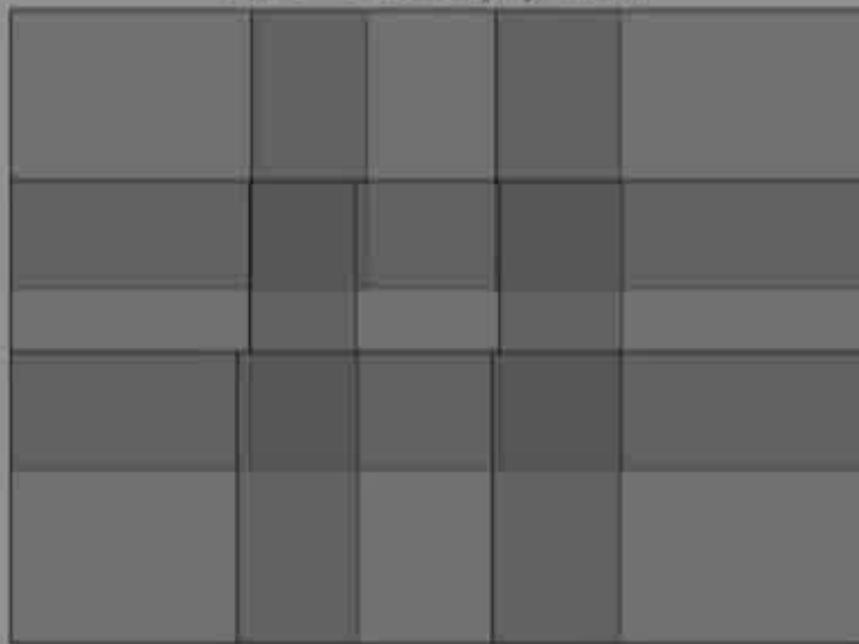
- Brightness: 1D
- Chrominance ( $x$ ,  $y$ ): 2D
- 3D color gamut



# Color Variation Visualization

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Our  $3 \times 3$  tiled display surface

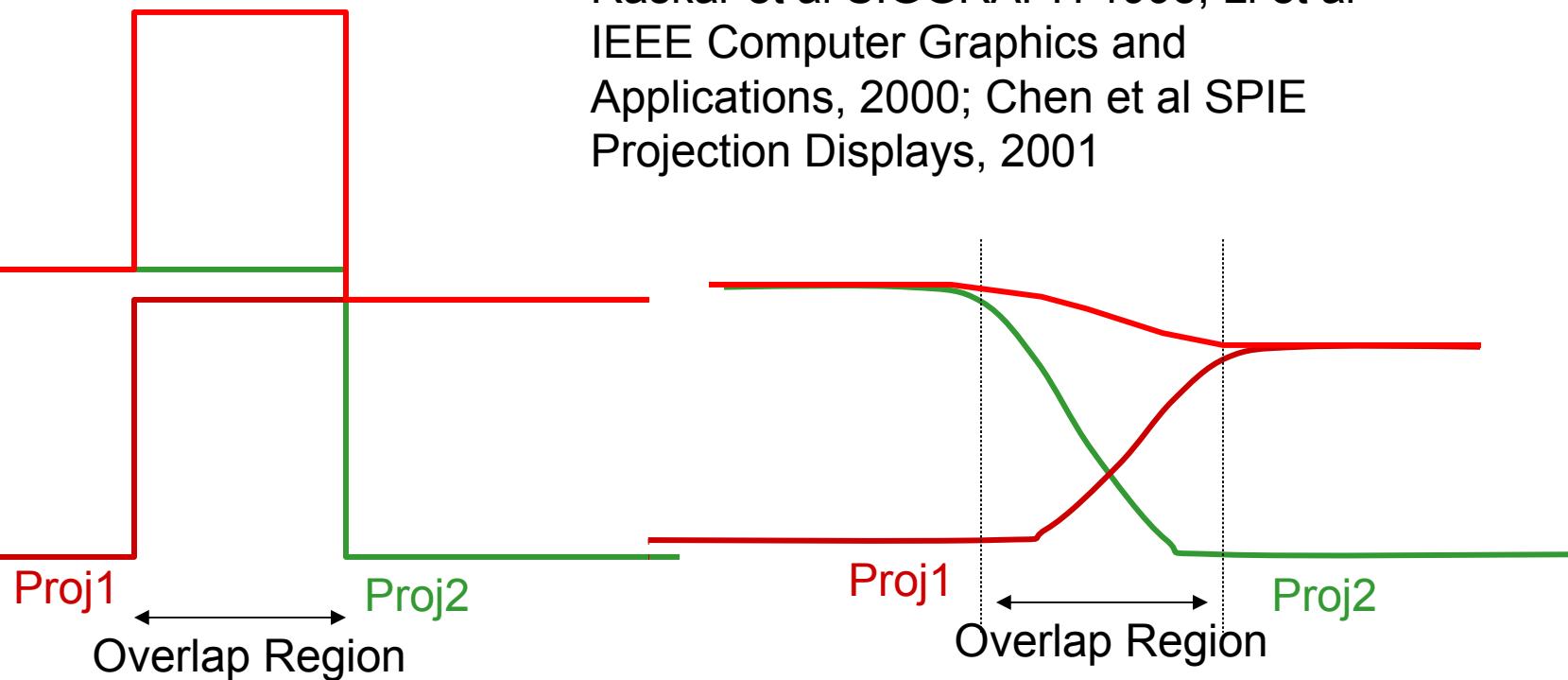


# Overview

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- Prior Art
- Motivation
- Algorithm
- Results

# Prior Art: Overlap Blending



# Prior Art: Overlap blending

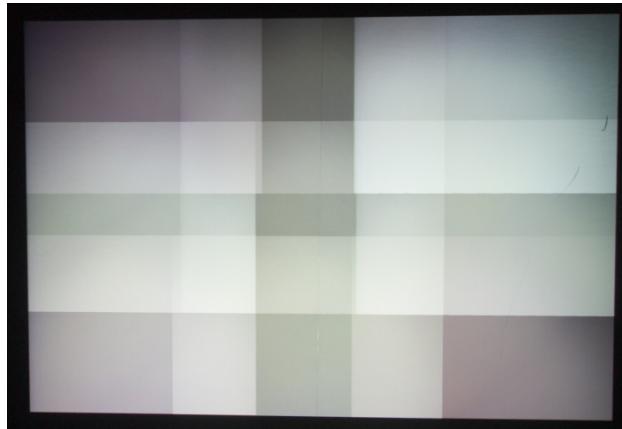
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- Assumes
    - Uniform brightness in each projector
    - All projectors have similar brightness
    - Projectors are linear devices
  - Addresses the overlaps only
  - No measurement or correction of intra or inter projector brightness variation
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# Prior Art: Overlap Blending

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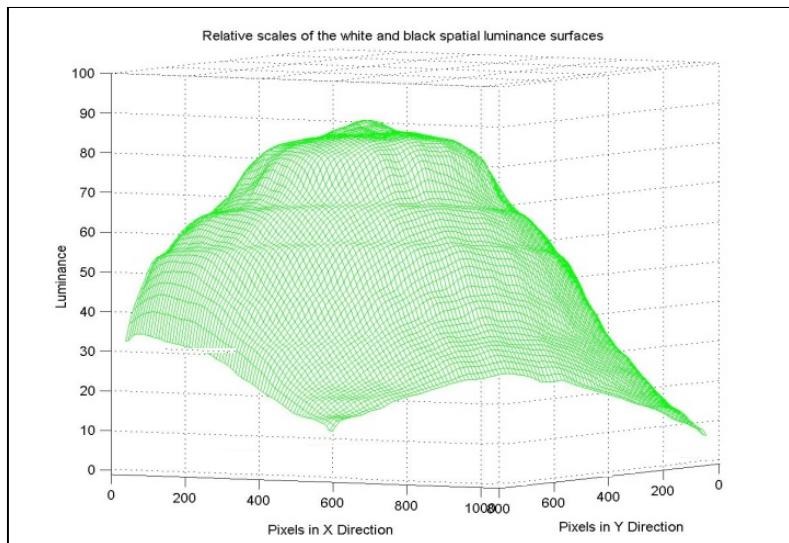
Before  
Correction



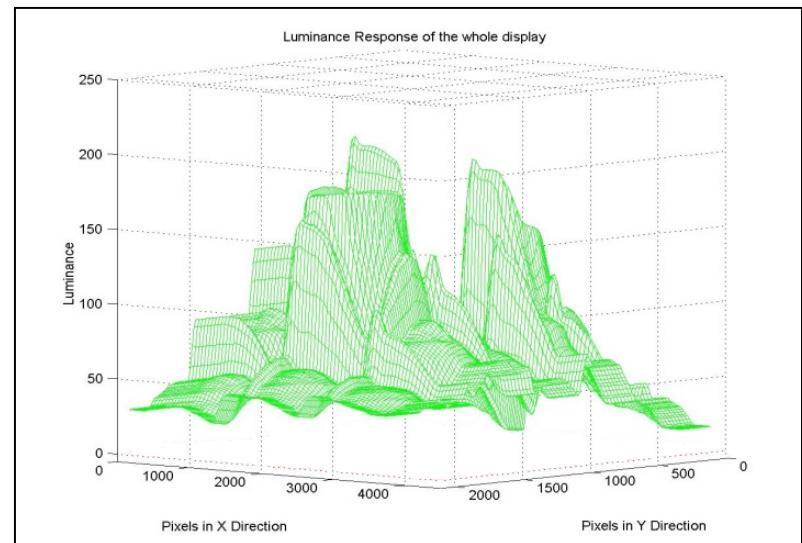
Overlap  
Blending



# Prior Art: Measurement with High Resolution Camera

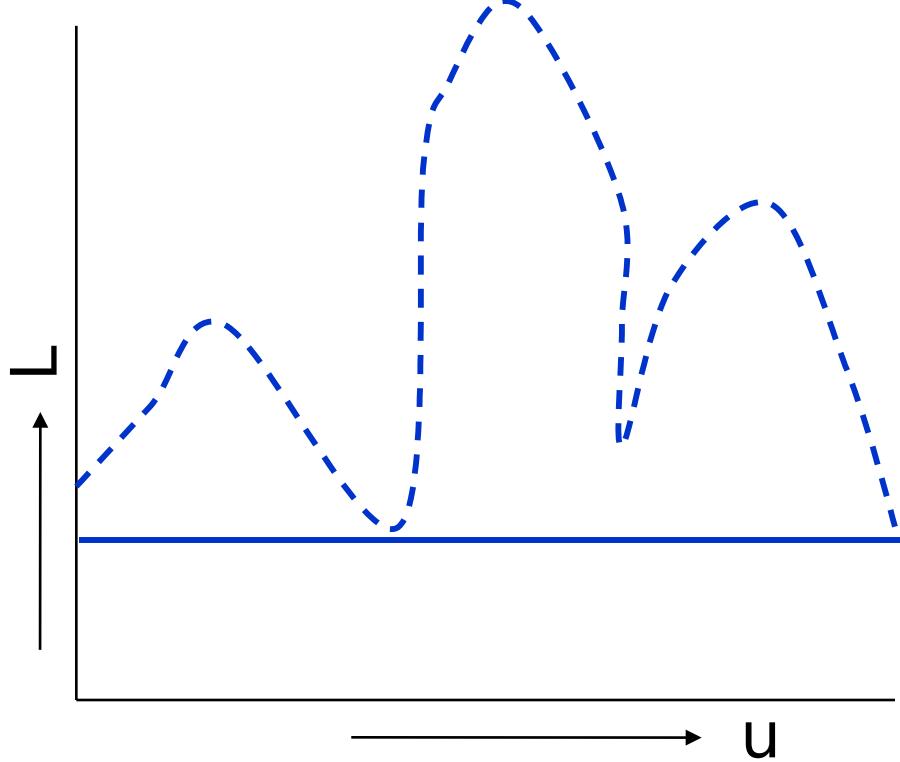


Single Projector  
Brightness Profile

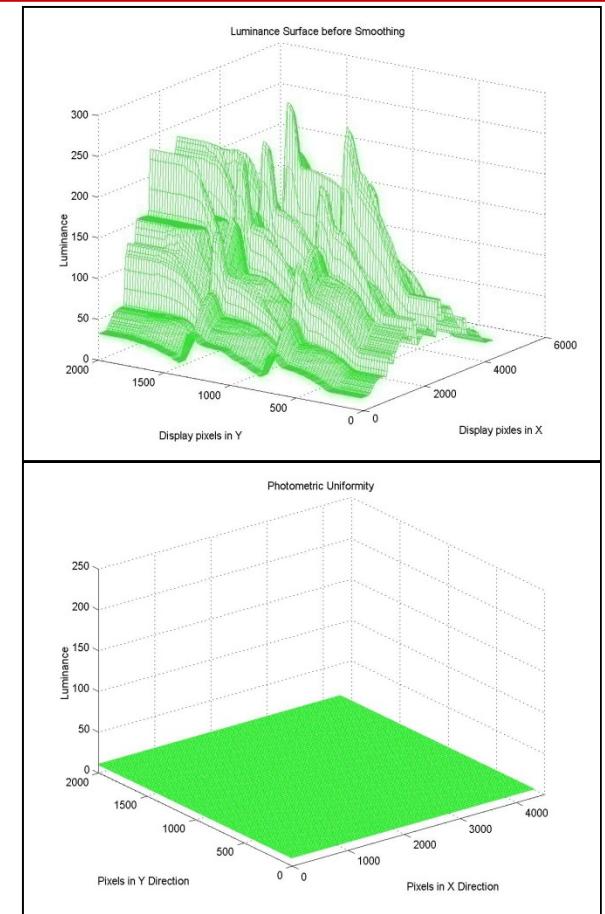


Multi Projector  
Brightness Profile

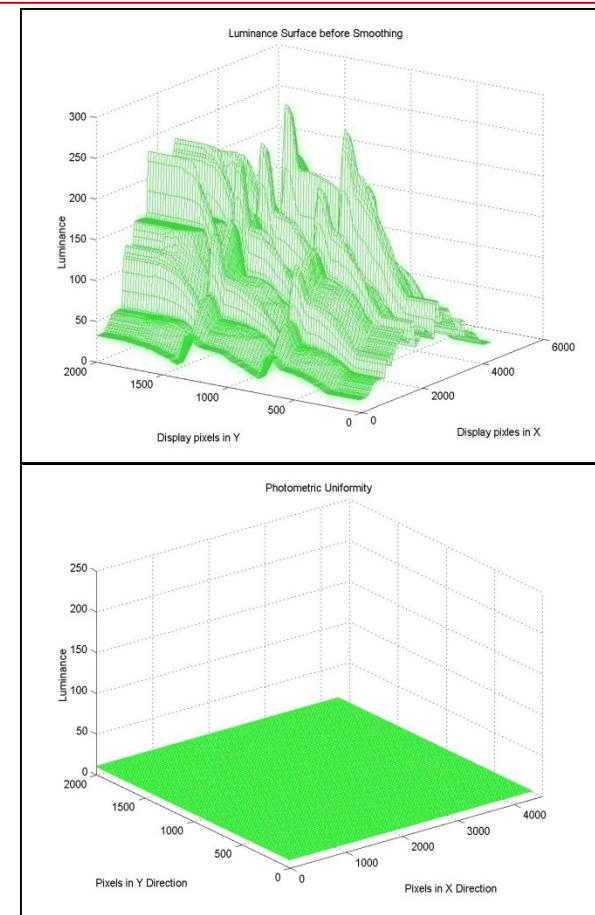
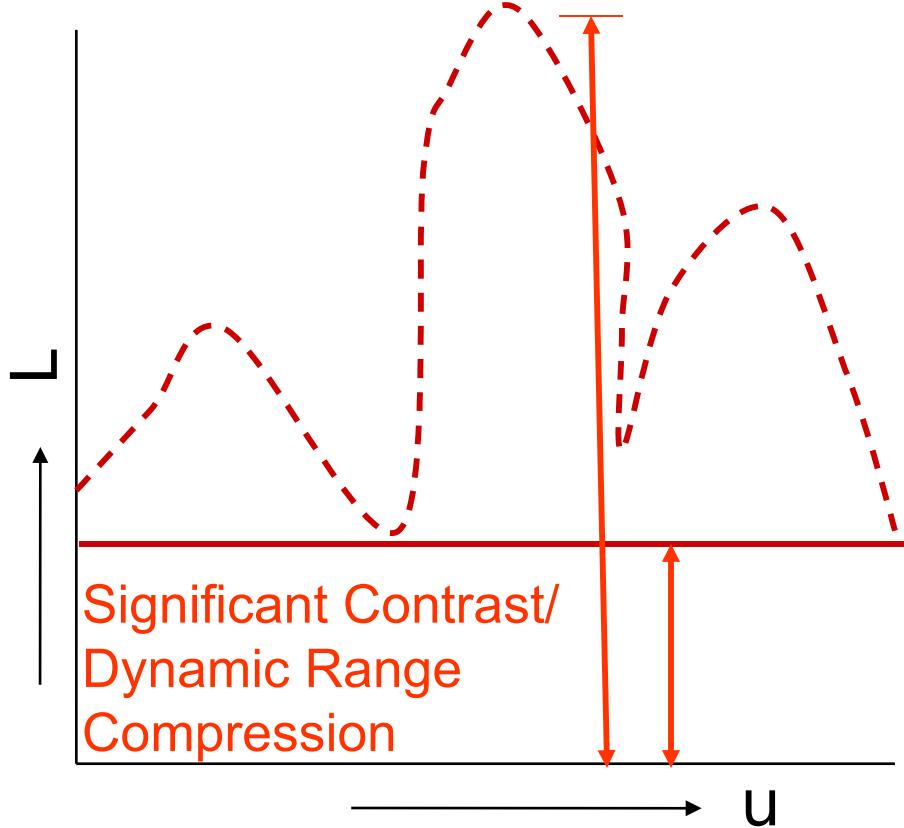
# Prior Art: Strict Brightness Uniformity



*IEEE TVCG 2003, PROCAMS 2003  
Majumder and Stevens*



# Prior Art: Strict Brightness Uniformity



# Prior Art: Strict Brightness Uniformity



Before



After Strict Brightness Uniformity

# Prior Art: Constrained Brightness Smoothing

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- Smoothing is sufficient for perceptual seamlessness
  - Non-linear filtering
  - Maximize dynamic range
  - Solved using dynamic programming

# Prior Art: Constrained Brightness Smoothing



Before

After Strict Brightness Uniformity



*IEEE TVCG 2003, PROCAMS 2003  
Majumder and Stevens*

# Prior Art: Constrained Brightness Smoothing



Before

After Constrained Brightness Smoothing



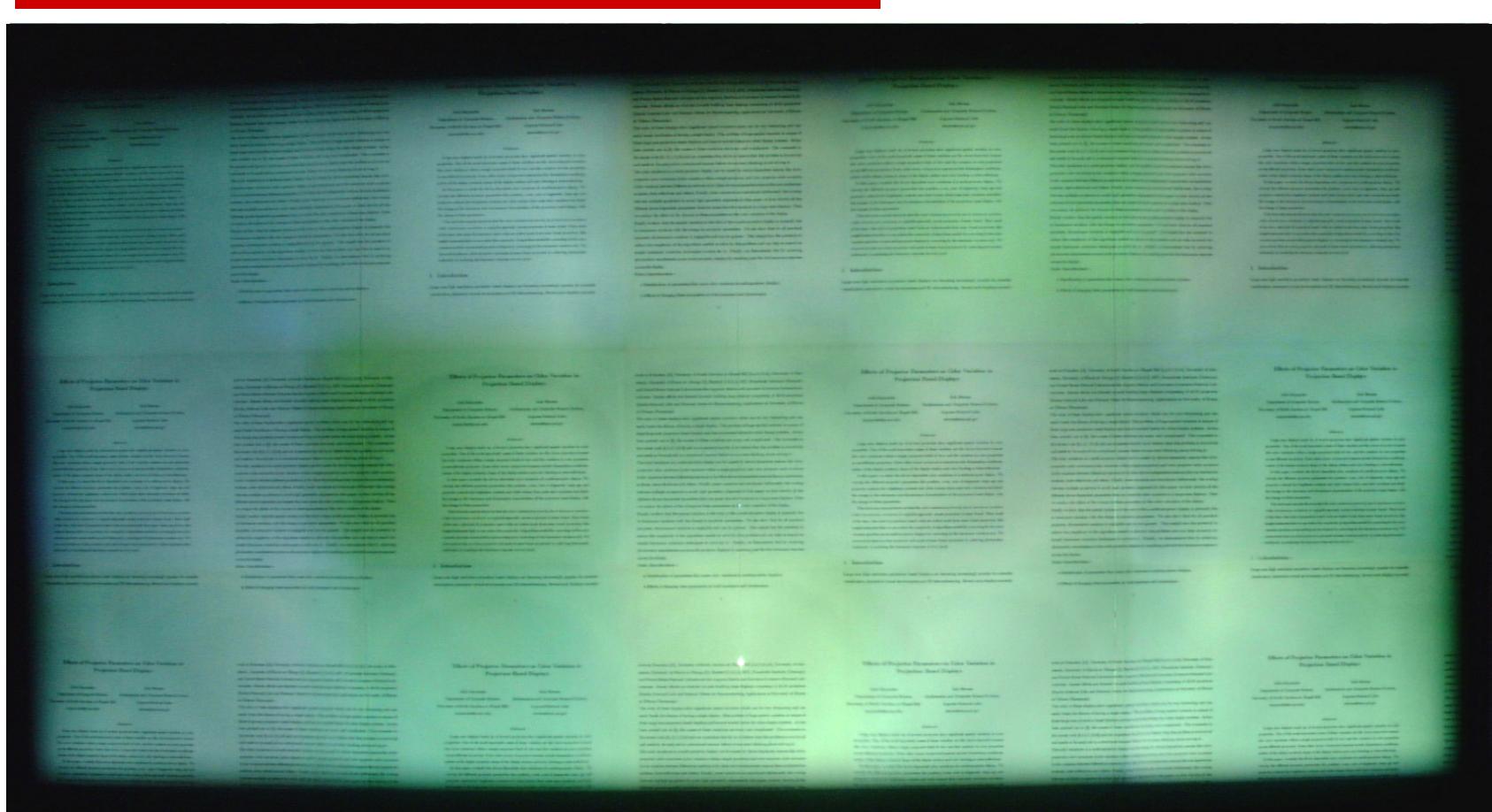
*ACM Transactions on Graphics 2005  
Majumder and Stevens*

# Overview

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- Results

# Motivation: Does it solve the problem?



# Motivation: Our Contribution

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- Chrominance is constant within projector
  - Chrominance varies across projectors and in overlaps
  - Brightness smoothing does not guarantee chrominance smoothing
  - **3D Gamut Morphing**
  - **Constrained chrominance smoothing in addition to brightness smoothing**
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# Motivation: Key Insight

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- Smooth transition of chrominance across overlap region
    - Blending of the chromaticity coordinates
    - Only need to manipulate the brightness proportions of overlapping projectors
  - Manipulate brightness to address chrominance variation
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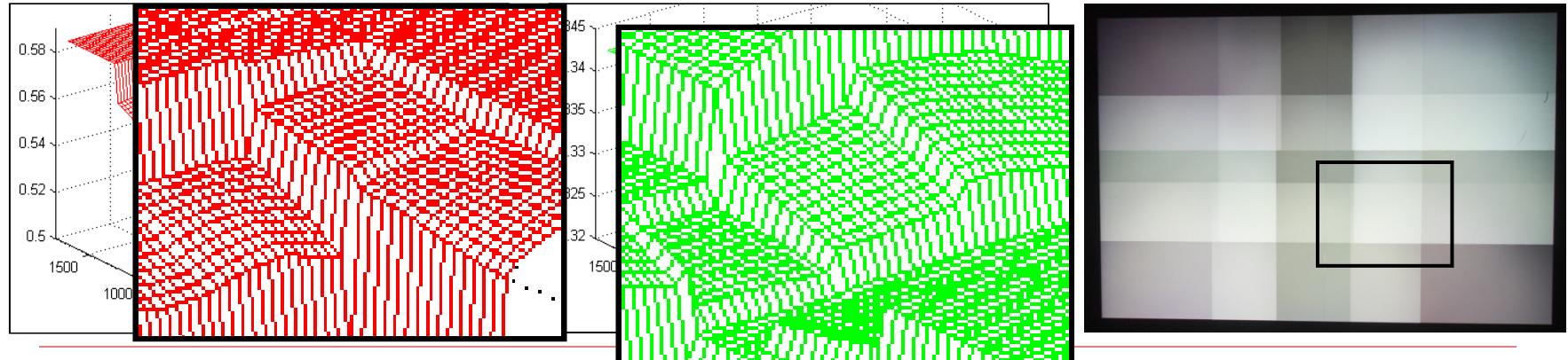
# Overview

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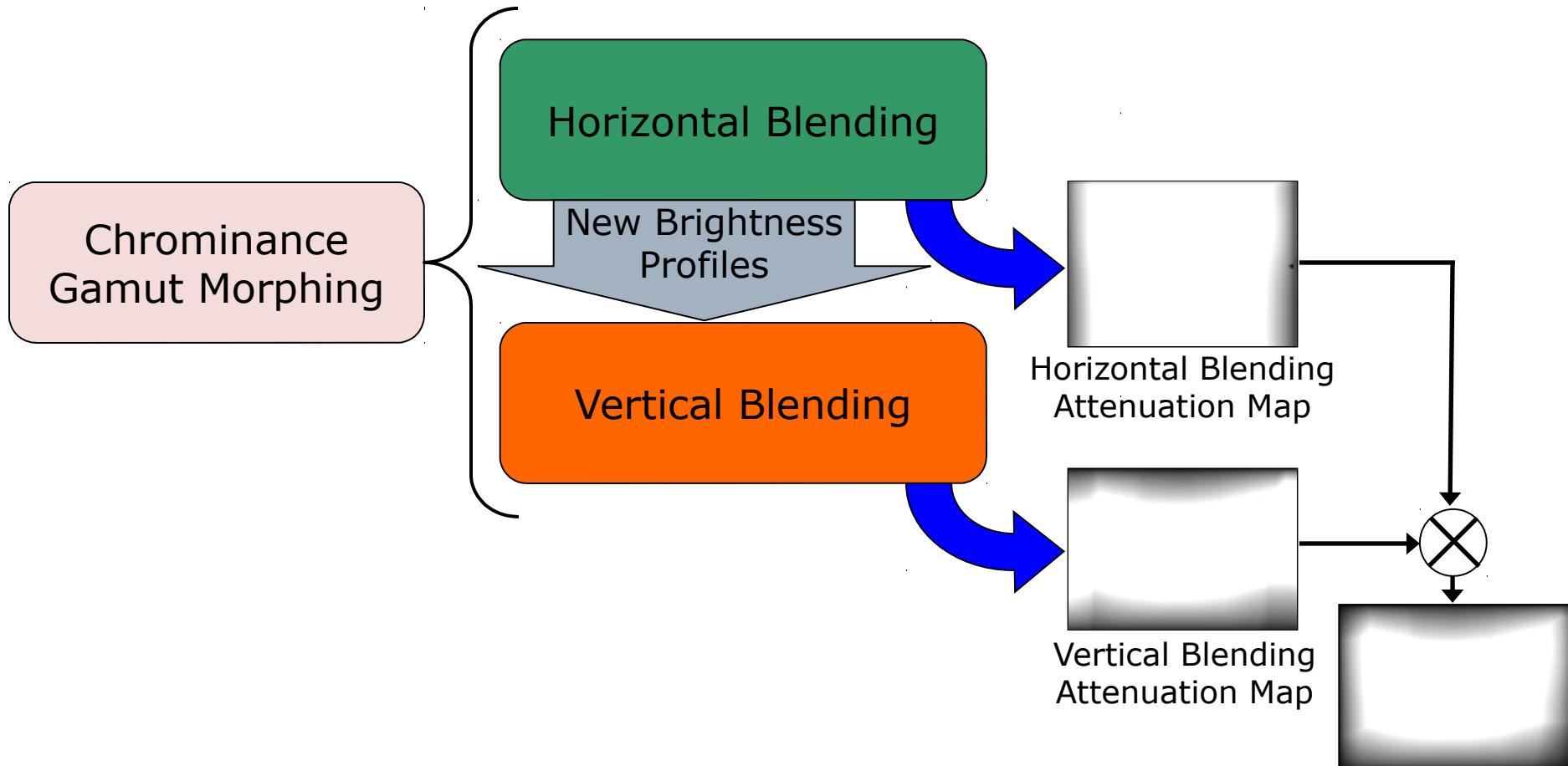
- Prior Art
  - Motivation
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-

# Algorithm: Chrominance profile before registration

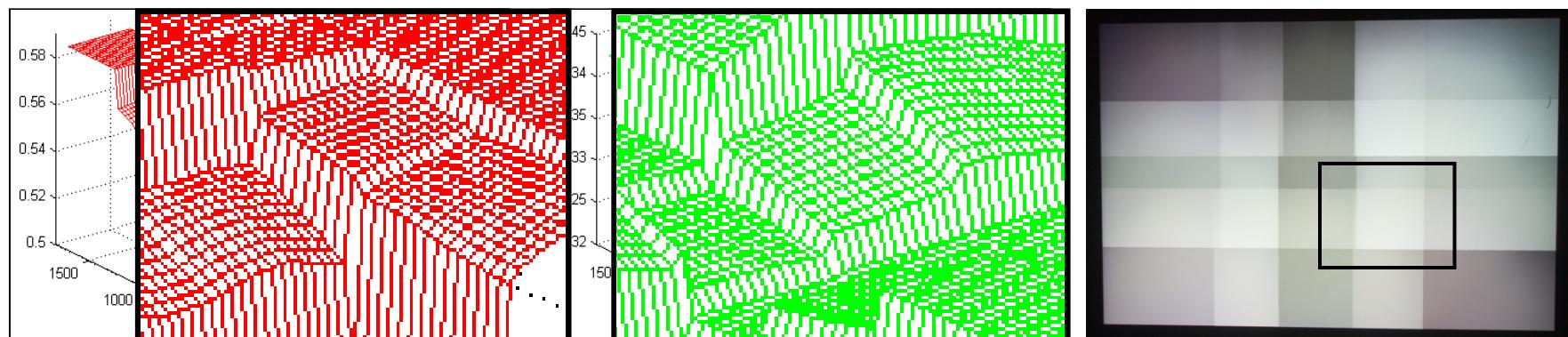
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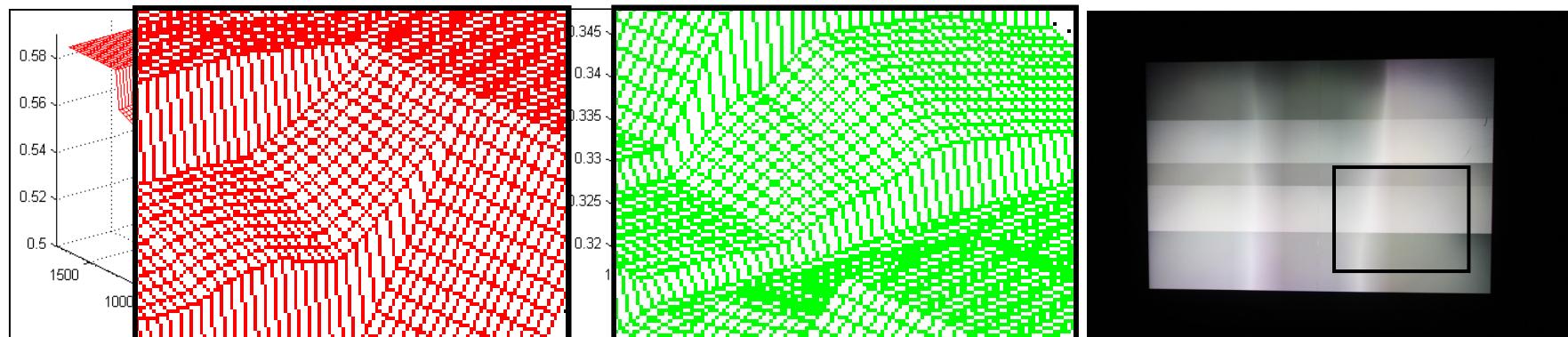
# Algorithm: Chrominance Gamut Morphing



# Algorithm: Horizontal Blending

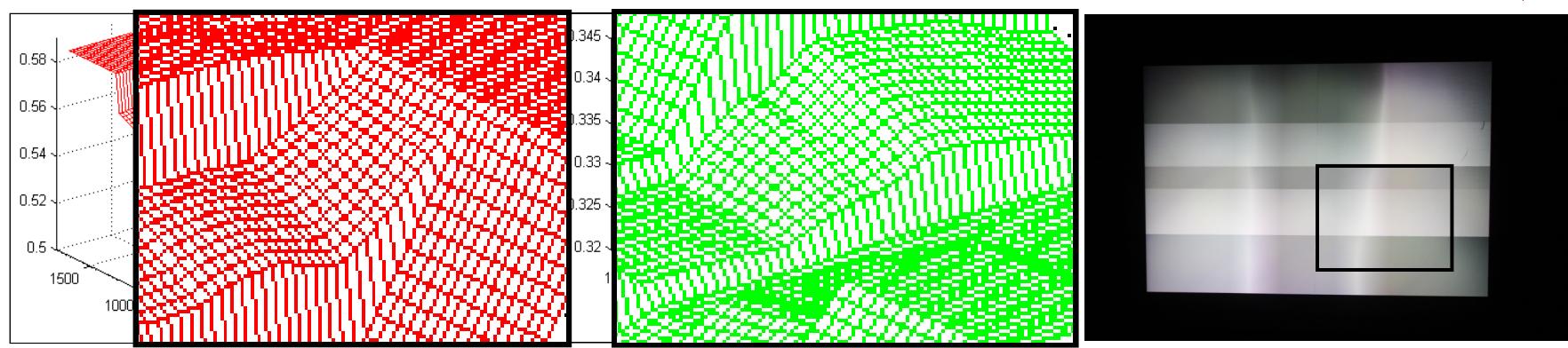


Before Chrominance Blending

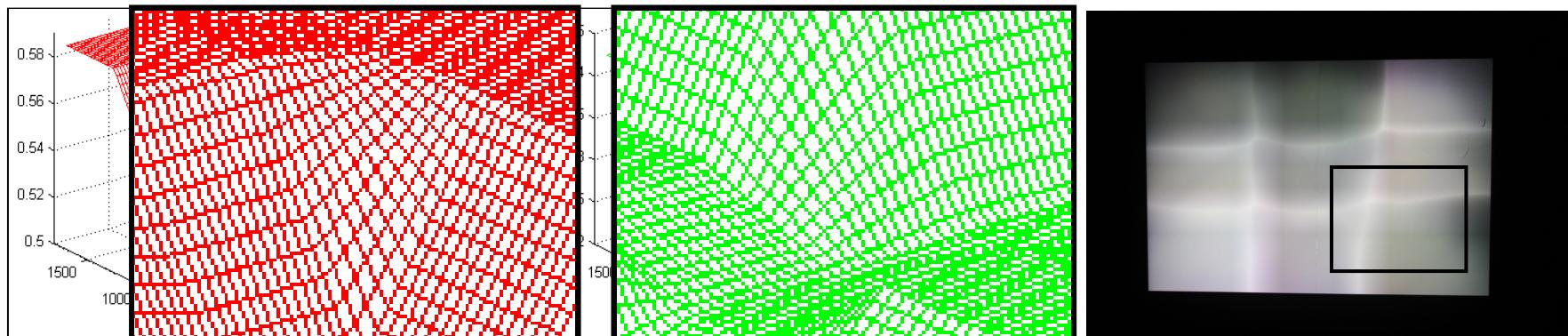


After Horizontal Blending

# Algorithm: Vertical Blending



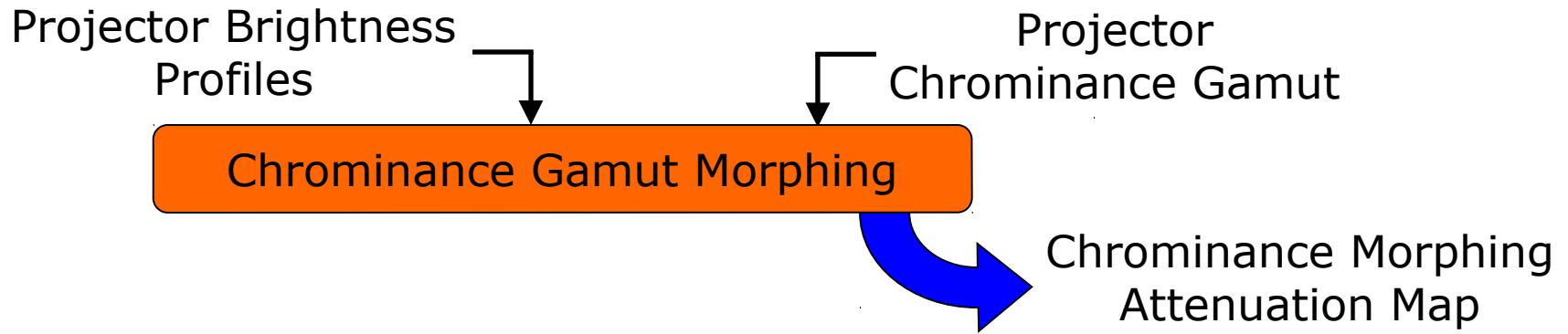
After Horizontal Blending



After Vertical Blending

# Algorithm: Pipeline

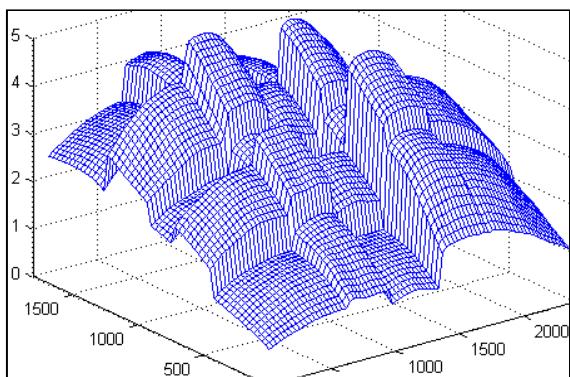
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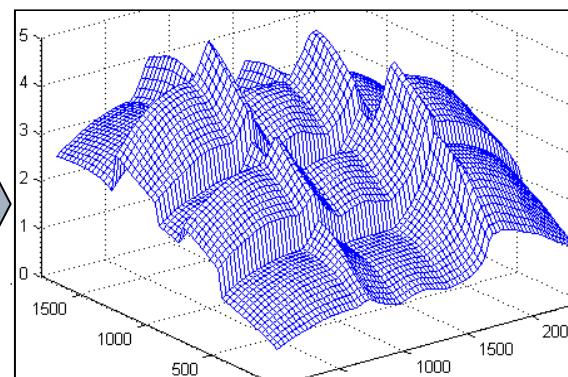
# Algorithm: Chrominance gamut morphing

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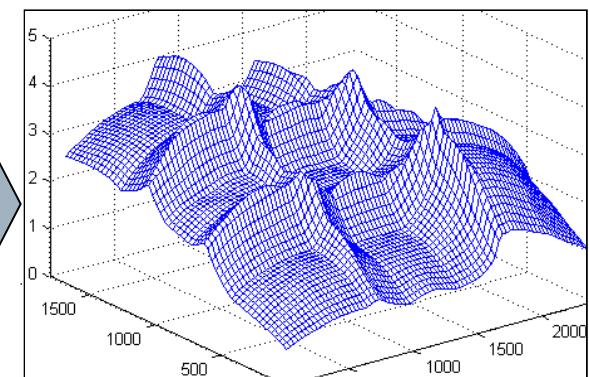
- Modifies brightness profiles
- Removes  $C_0$  brightness discontinuity



Before Correction



After Horizontal Blending

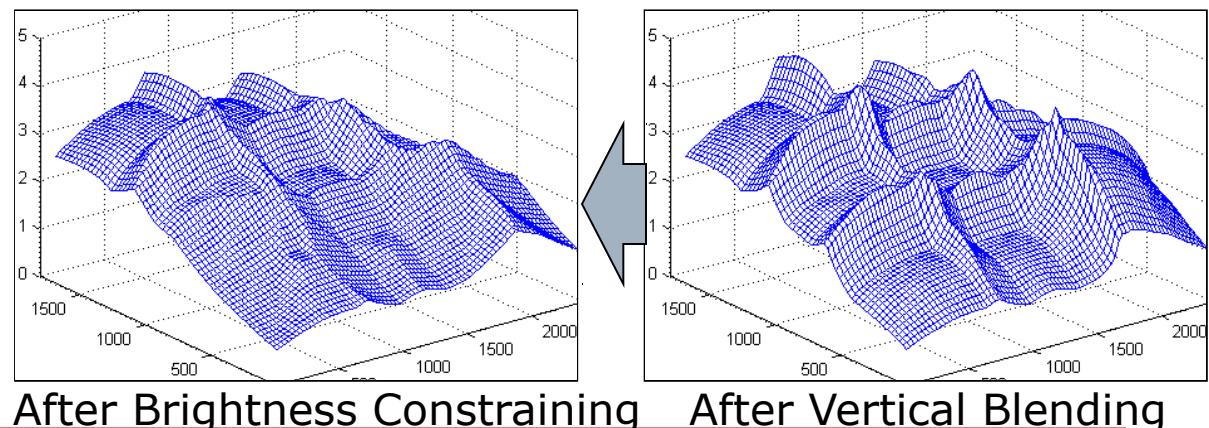


After Vertical Blending

# Algorithm: Perceptual Brightness Constraining

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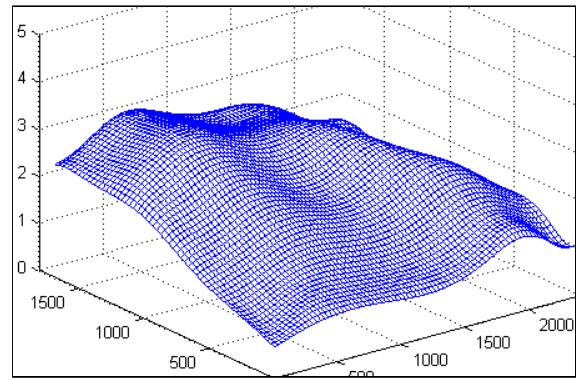
- Does not guarantee imperceptible brightness changes
- Apply Majumder et. al. 2005 to constrain the brightness variations
- Retains chrominance gamut morphing



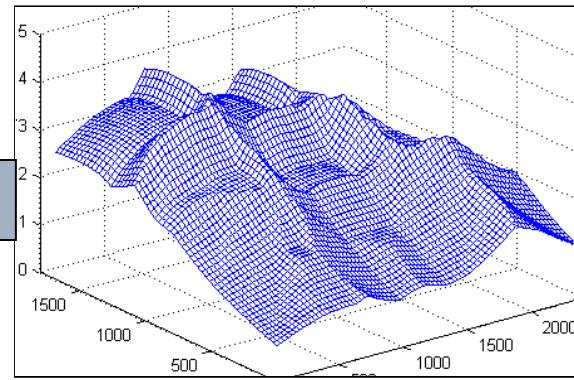
# Algorithm: Bezier-based Brightness Smoothing

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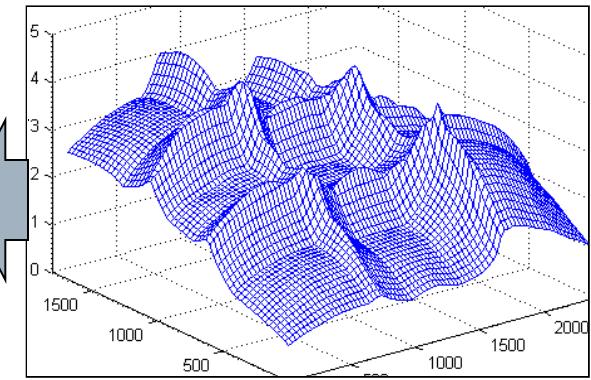
- Brightness profile is not derivative continuous after Majumder et. Al. 2005
- Assures  $C_n$  intensity continuity
- Retains chrominance gamut morphing



After Bezier-based Smoothing

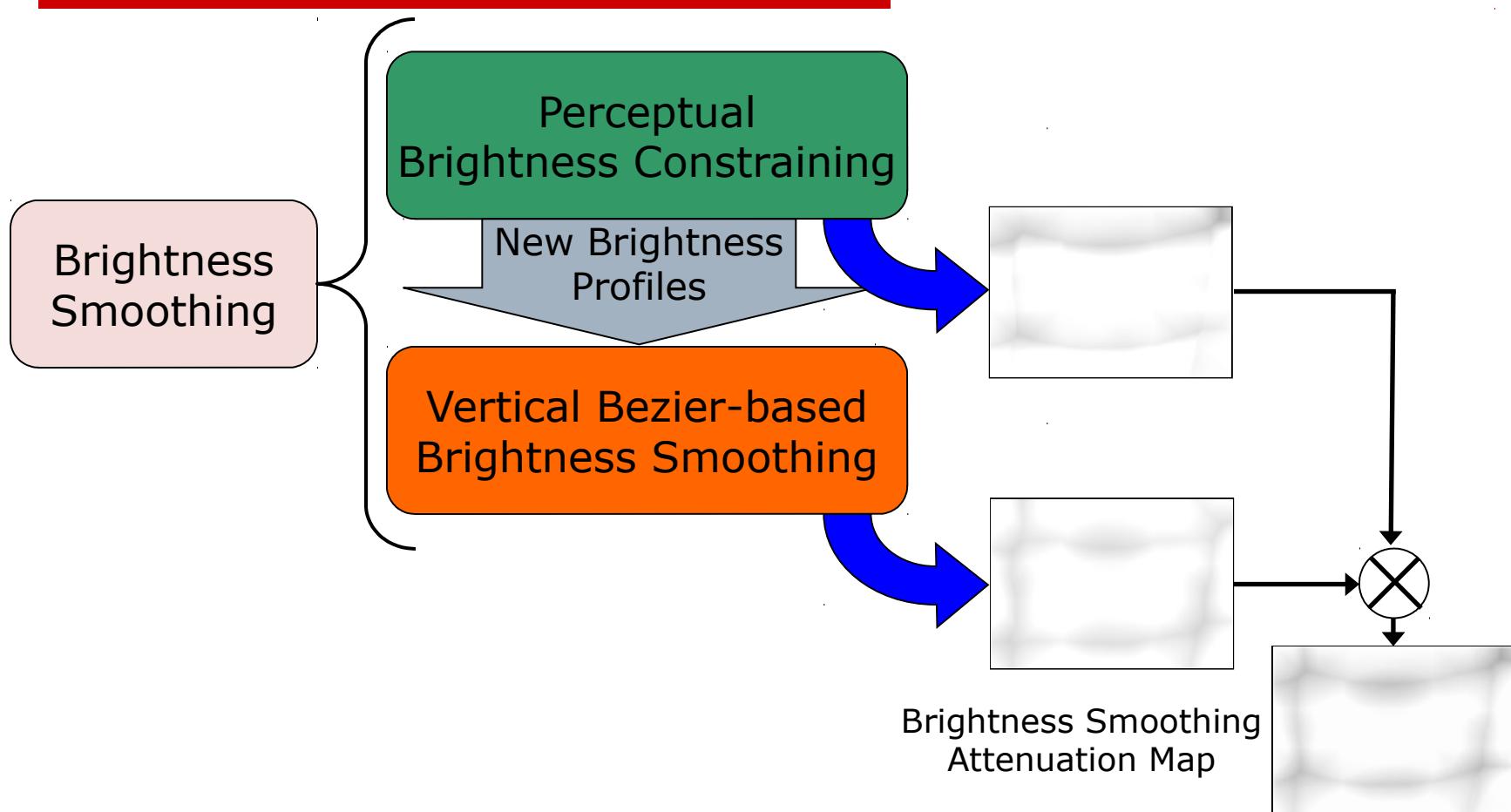


After Brightness Constraining



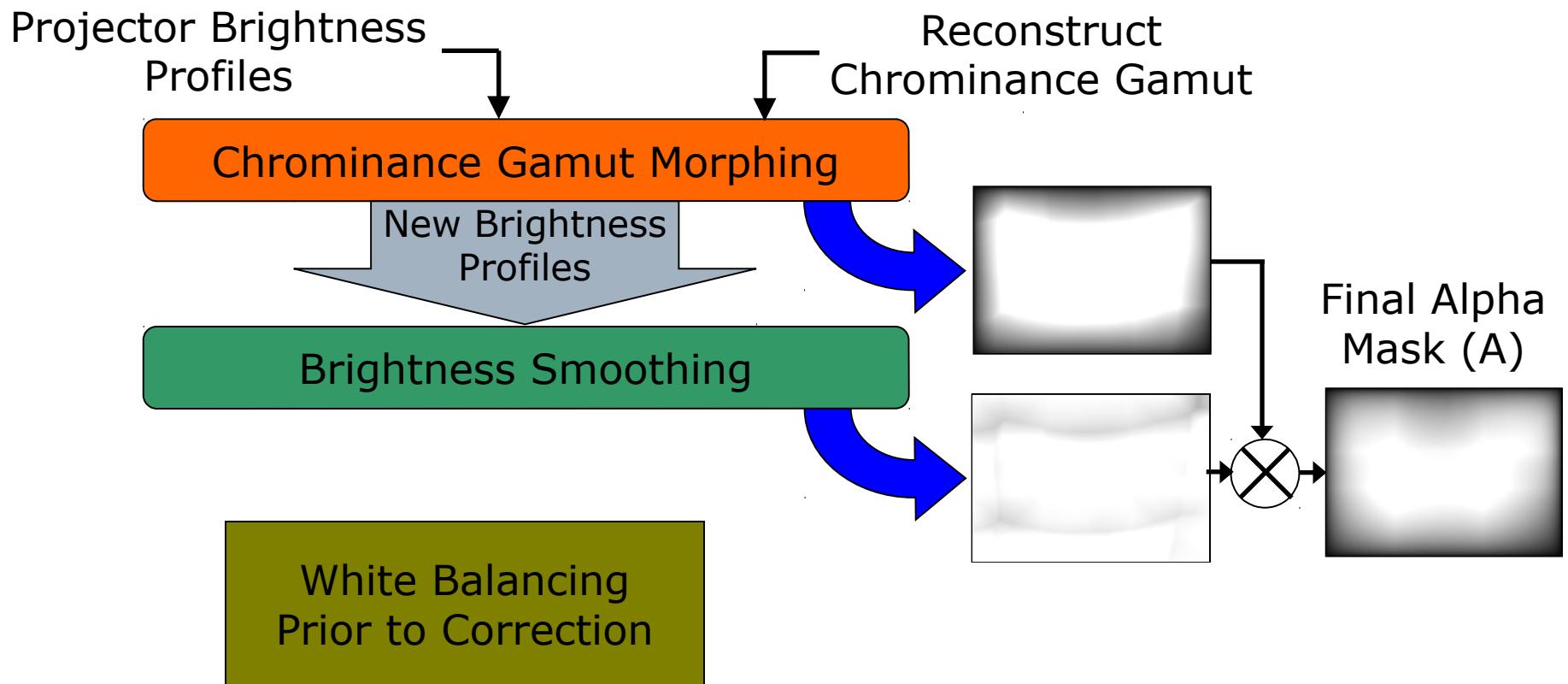
After Vertical Blending

# Algorithm: Brightness Smoothing



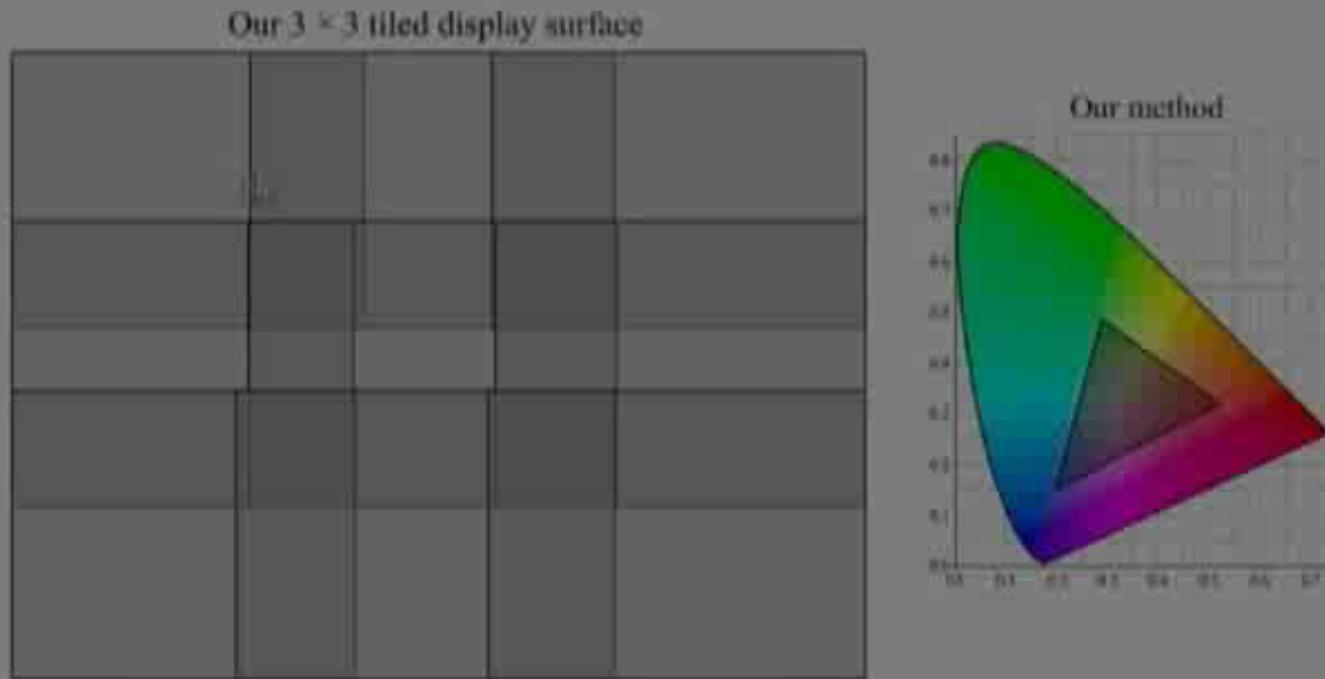
# Algorithm: Offline Correction Pipeline

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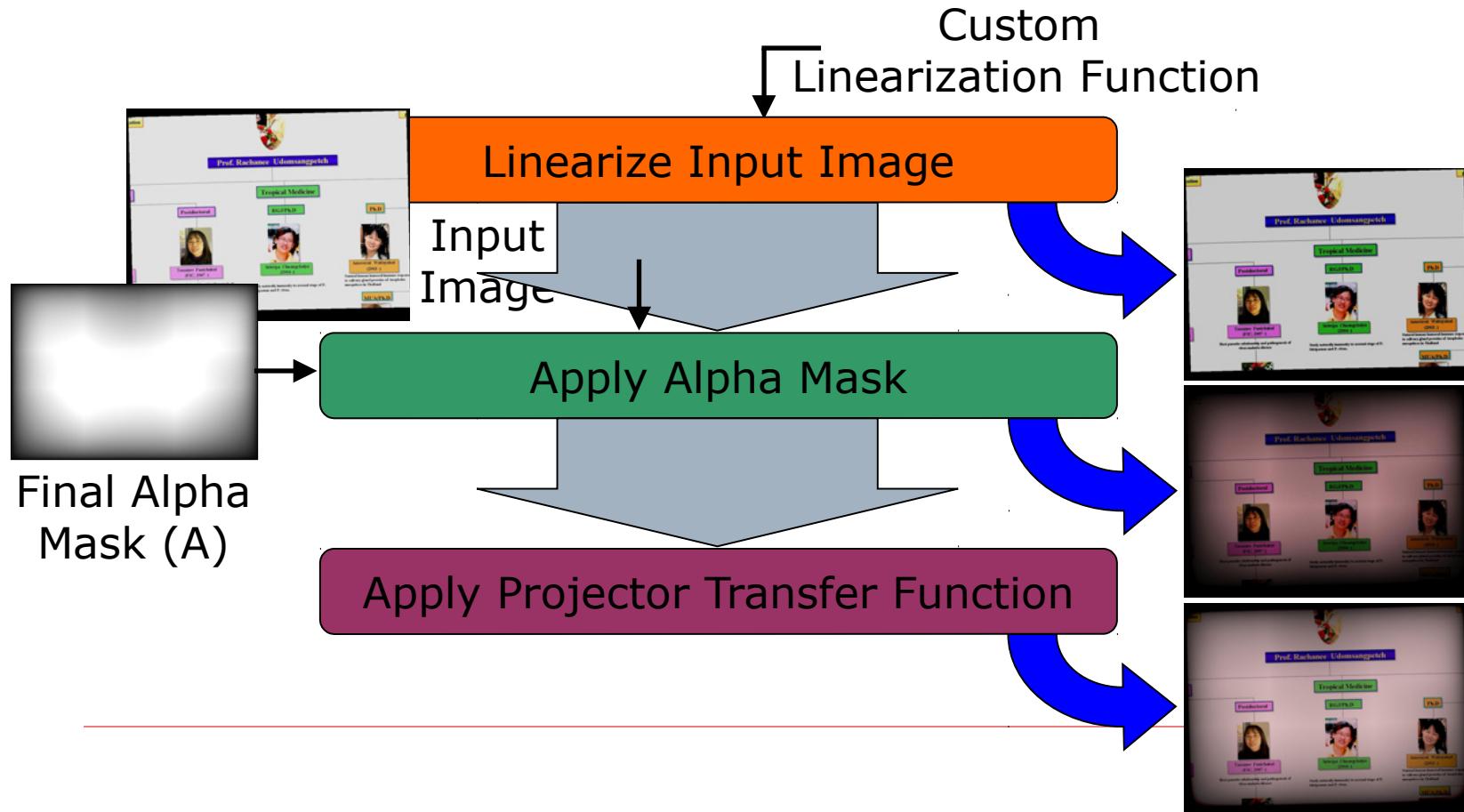


# Color Variation Visualization

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# Algorithm: Online Image Correction



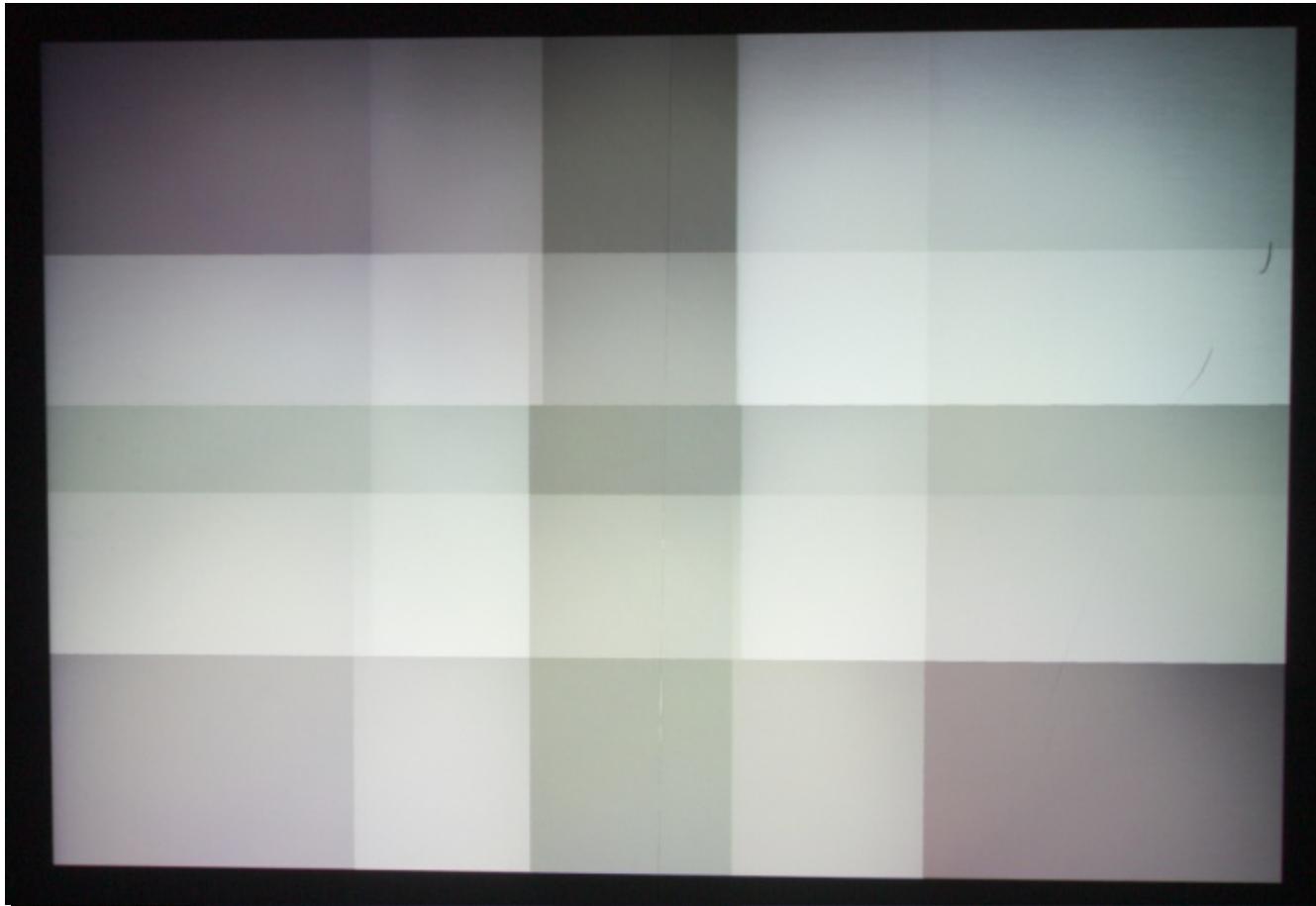
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# Results: More General Pictures

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# Results: Extends to any Geometry

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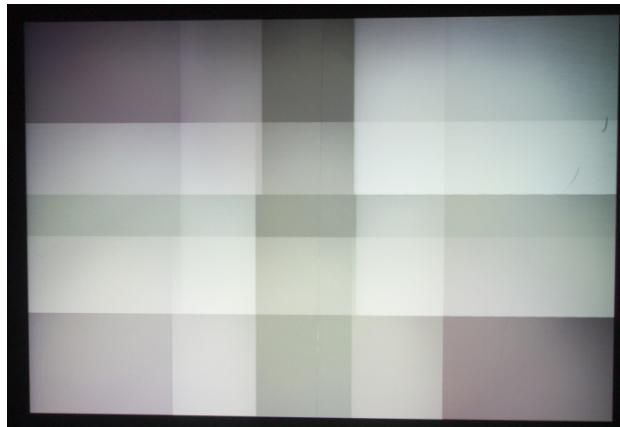


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# Results: Comparison

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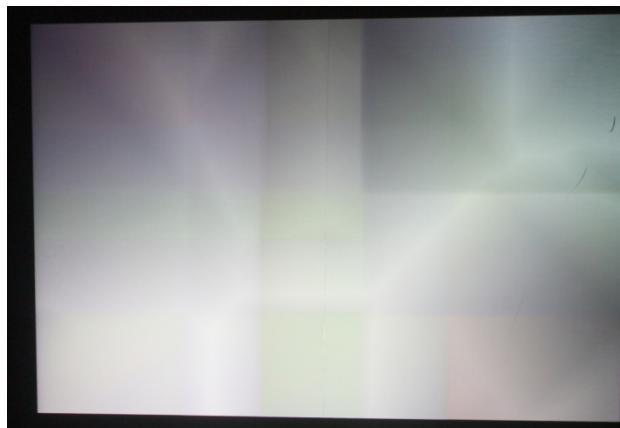
Before  
Correction



Overlap  
Blending



Majumder  
and Stevens  
2005



Final  
Result



# Conclusion

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- First method that
    - Complete 3D color registration
    - Addresses spatial variations in both chrominance and brightness
    - High quality display with commodity projectors
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# Future Work

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- Extend to non-developable surfaces
  - Address intra-projector color variations
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# Questions?

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# Prior Art: Color Seamlessness

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- Brightness
- Chrominance

