A Comprehensive Framework for Modeling and Correcting Color Variations in Multi Projector Displays

Aditi Majumder

Historical Perspective

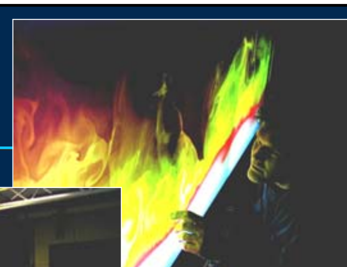
- A dream computer in 1980 (Bill Joy and others)
  - Megabytes of memory
  - Megahertz of speed
  - Mega pixels
- Today
  - Gigabytes of memory
  - Gigahertz of speed
  - And still Mega pixels !! (1000 x 1000 monitor)

Large Area Displays

	We have today in common use	*We would like to have*
Size	19 inch diagonal	15 feet x 10 feet
Resolution	60 pixels/inch	100 – 300 pixels/inch
Field of View	20 – 30 degrees	120 – 140 degrees
# of pixels	1 million	100 – 140 million

Applications

- Scientific Visualization
- Medical Visualization
- Telecollaboration
- Virtual Reality
- Training and Simulation



Flow Visualization of Fluids at Argonne National Laboratory (ANL)

Medical Visualization at Radiology Department of Stanford

Multi Projector Displays

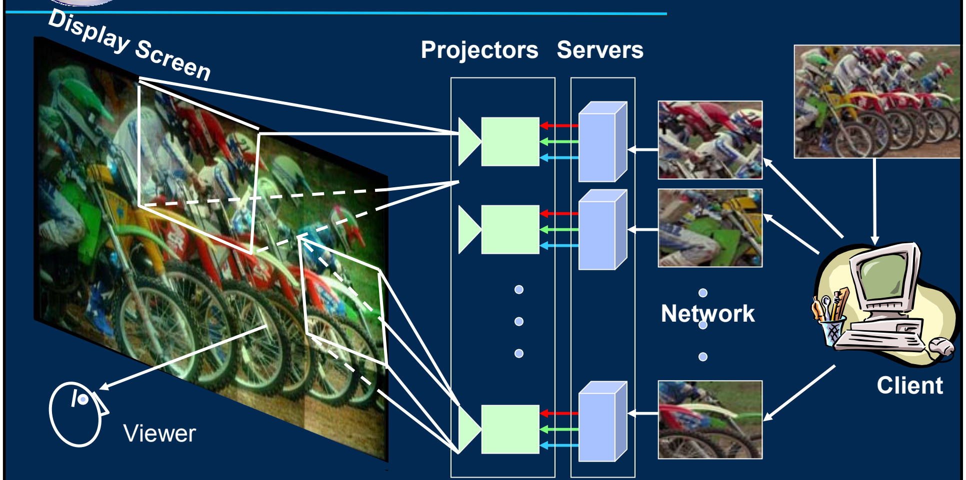
- Tile projectors

Multi Projector Displays

- Tile projectors
- 15 projectors
  - 3x5 array
  - 10 feet x 8 feet
  - 50 pixels/inch
  - 12 million pixels

At ANL

Building Multi Projector Displays

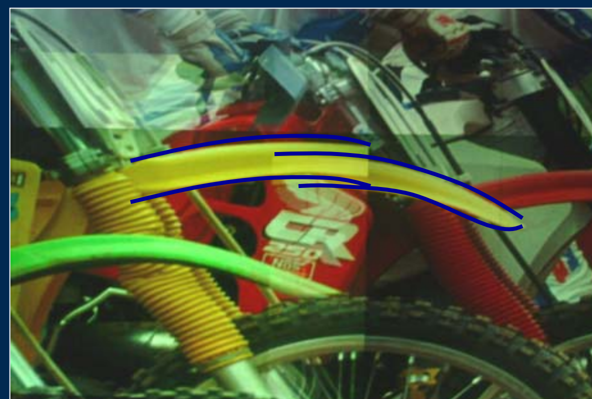


Making them seamless

- Geometric Alignment

Making them seamless

- Geometric Alignment

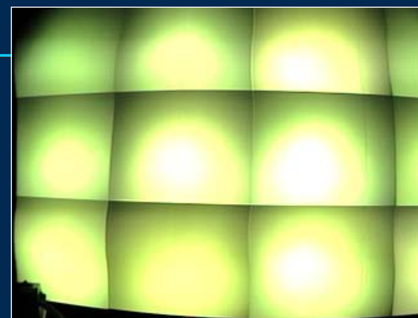


Making them seamless

- Geometric Alignment

Making them seamless

- Geometric Alignment
- Color Seamlessness



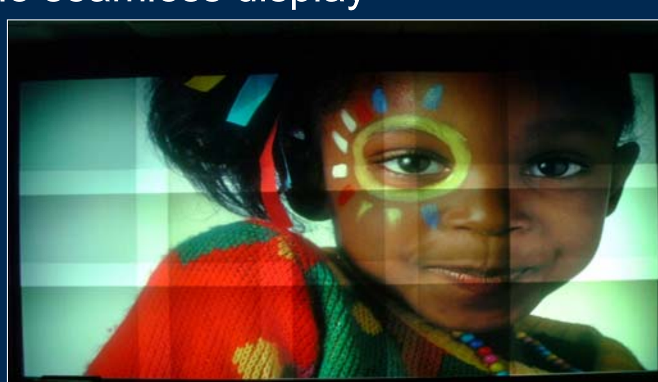
Overlapping

Abutting

Slide 11

The Problem

Even with perfect geometric alignment, color variation breaks the illusion of a single seamless display



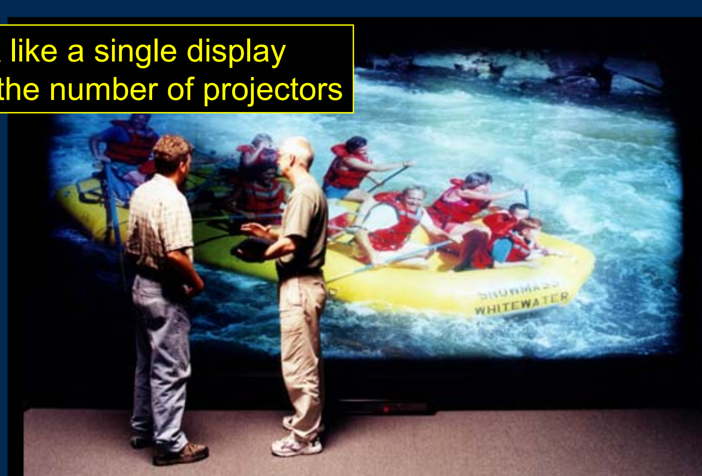
At ANL

Slide 12

The Goal of Color Seamlessness

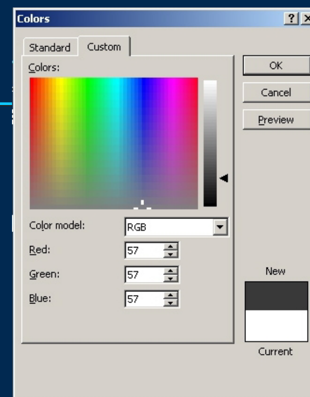
The Goal of Color Seamlessness

Should look like a single display
Cannot tell the number of projectors



Background: Color

- Perceptual Representation
  - Luminance (L) 
    - » Sense of Brightness
  - Chrominance (x , y)
    - » Sense of hue



- Representation Using Primaries
  - – Three channels (Red, Green, Blue)

Color Seamlessness

- Luminance Seamlessness (Brightness)
- Chrominance Seamlessness (Hue)

Why Is It Difficult?

- No comprehensive model of color variation
- No formal definition of *color seamlessness*
- The problem is inherently five dimensional
  - Color (3D – 1D luminance and 2D chrominance)
  - Display surface (2D)
- Humans are more sensitive spatial variations than to temporal variations in color

Innovations

- Emineoptic function : Models the luminance and chrominance variation in multi projector displays
  - *'emineoptic'* signifies *'viewing projected light'*
- A definition for color seamlessness
  - Optimization Problem
- An algorithm to address luminance variation (photometric seamlessness)
  - Same model projectors differ significantly in luminance
  - Humans are more sensitive to luminance than chrominance

Thesis Statement

- *The color variation in multi-projector displays can be modeled by the emineoptic function.*
- *Achieving color seamlessness is an optimization problem that can be defined using the emineoptic function.*
- *Perceptually uniform high quality displays can be achieved by realizing a desired emineoptic function that differs minimally from the original function and has imperceptible color variation.*

Organization

- Previous Work
- The Emineoptic Function
- Definition of Color Seamlessness
- Achieving Photometric Seamlessness
- Results

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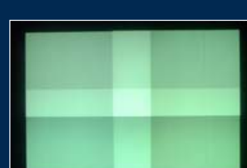
Classification of Color Variation

- Intra-projector
  - Within a single projector
- Inter-projector
  - Across different projectors
- Overlaps



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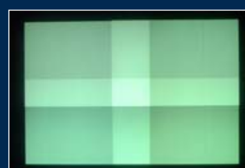
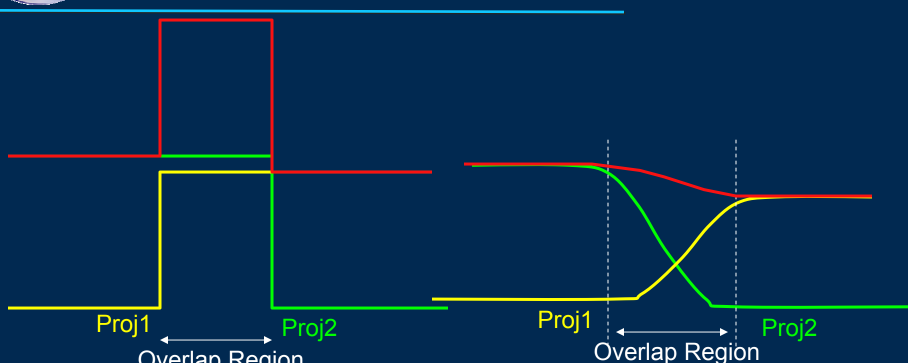


Edge Blending

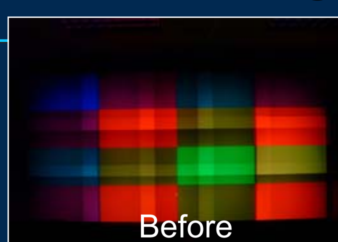


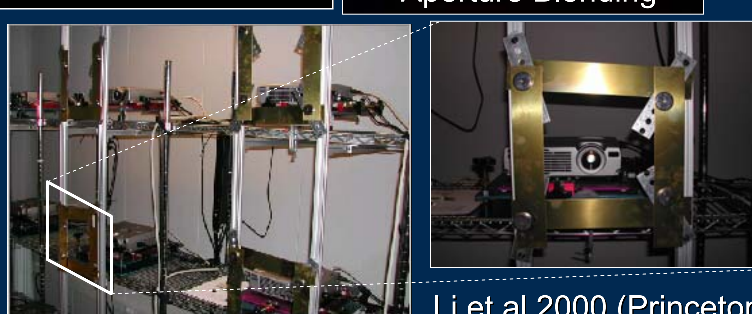
Software Edge Blending

Raskar et al 1998 (UNC)

Yang et al 2001 (UNC)

Aperture Edge Blending





Li et al 2000 (Princeton)

Classification of Color Variation

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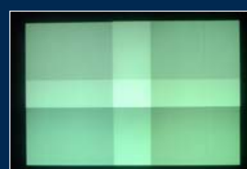

Previous Work

- Projector Controls
- Using the same bulb
  - –Pailthorpe et al 2001 (NSCA San Diego)
- Inter-projector response matching
  - –Stone et al 2000, 2001 (Stanford)
  - –Chen et al 2002 (Princeton)

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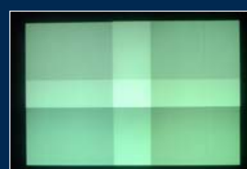
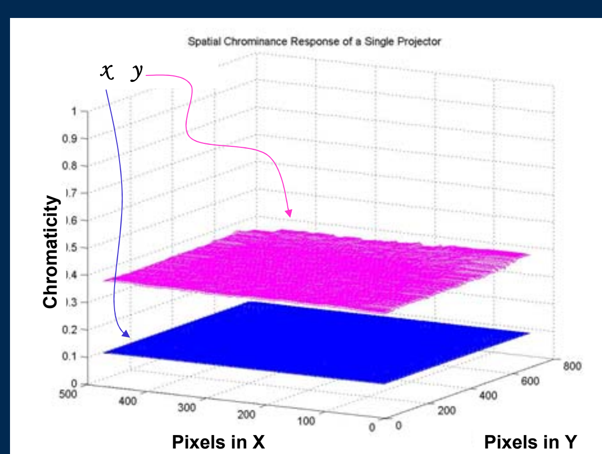


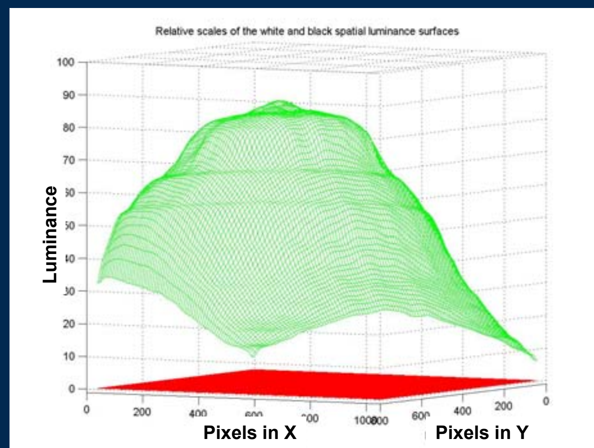
Intra-Projector Variations

- Chrominance response



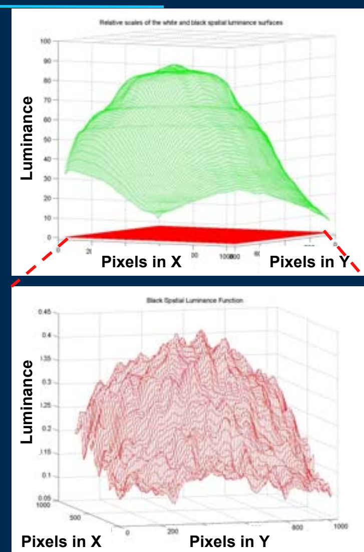
Intra-Projector Variations

- Luminance response



Intra-Projector Variations

- Luminance response
- Black offset
  - Always present



Limitations of Previous Methods

- No algorithm addresses intra projector variation
- No algorithm addresses more than one class of problems
- Each class of problems treated as a special case
- *Strict uniformity mindset*
  - *Identical color response at every display coordinate*

Desiderata

- Comprehensive and general framework
  - –Addresses intra, inter and overlap variations
  - –Design general solutions
    - » No special cases
    - » Automated
    - » Scalable
  - –Explain and compare existing methods

Organization

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Achieving Color Seamlessness

- To correct, first capture
- Complexity of capture
  - –Input color space : 24 bit color
  - –Need 2^{24} images
- Reduce complexity by modeling projector color variations

Emineoptic Function

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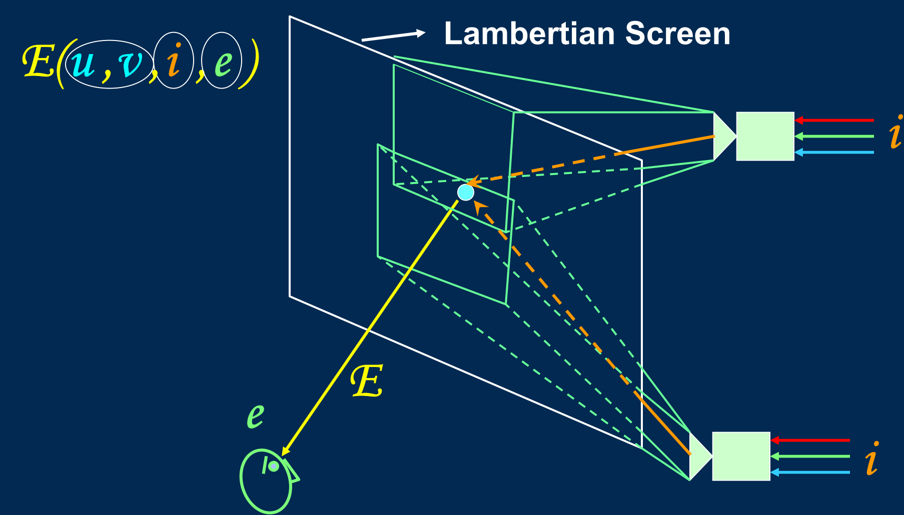
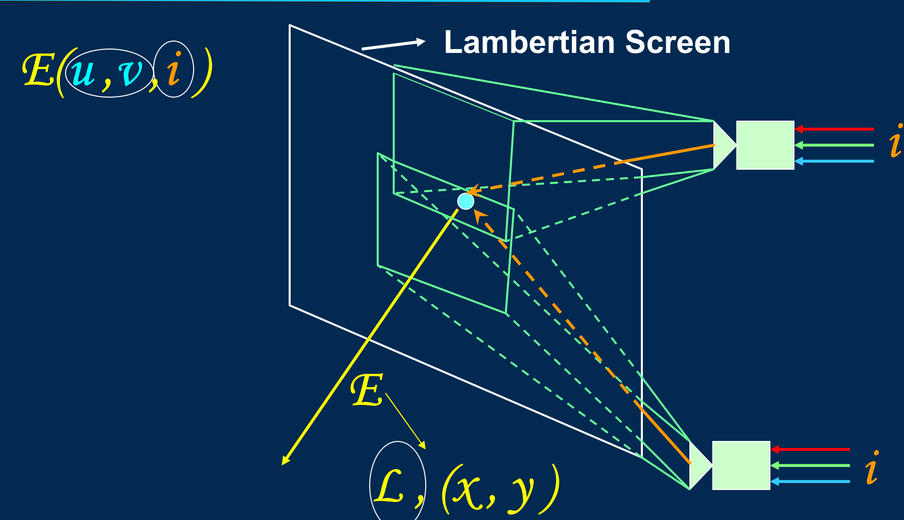
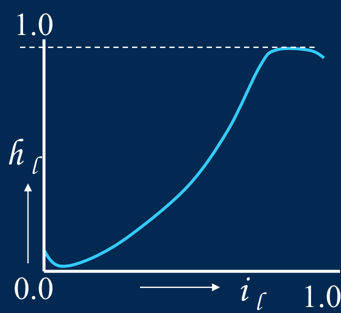
The Emineoptic Function



The Emineoptic Function



Single Pixel, Single Channel Input



- Maximum channel luminance $(\mathcal{M}_l)$
- Variation in luminance with channel input
  - » Channel transfer function $(h_l(i_l))$

$$C_l(i_l) = h_l(i_l)\,\mathcal{M}_l$$

Single Pixel, Three Channel Input

At one pixel for one channel:

$$C_l(i_l) = h_l(i_l)\,\mathcal{M}_l$$

For any input $i = (i_r, i_g, i_b)$:

$$\mathcal{P}(i) = C_r(i_r) + C_g(i_g) + C_b(i_b)$$

With black Offset $\mathcal{B}$:

$$\mathcal{P}(i) = C_r(i_r) + C_g(i_g) + C_b(i_b) + \mathcal{B}$$

Single Projector Display

At one pixel for one channel:

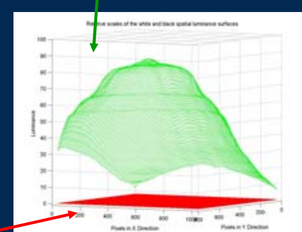
$C_\ell(i_\ell, u, v) = h_\ell(i_\ell, u, v)\ \mathcal{M}_\ell(u, v)$

For any input $i = (i_r, i_g, i_b)$:

$\mathcal{P}(i, u, v) = C_r(i_r, u, v) + C_g(i_g, u, v) + C_b(i_b, u, v)$

With black Offset $\mathcal{B}$:

$$\mathcal{P}(i, u, v) = C_r(i_r, u, v) + C_g(i_g, u, v) + C_b(i_b, u, v) + \mathcal{B}(u, v)$$



Single Projector Display

At one pixel for one channel:

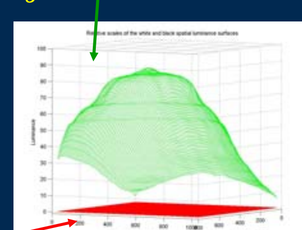
$C_\ell(i_\ell, u, v) = h_\ell(i_\ell)\ \mathcal{M}_\ell(u, v)$

For any input $i = (i_r, i_g, i_b)$:

$\mathcal{P}(i, u, v) = C_r(i_r, u, v) + C_g(i_g, u, v) + C_b(i_b, u, v)$

With black Offset $\mathcal{B}$:

$$\mathcal{P}(i, u, v) = C_r(i_r, u, v) + C_g(i_g, u, v) + C_b(i_b, u, v) + \mathcal{B}(u, v)$$



Single Projector Display

At one pixel for one channel:

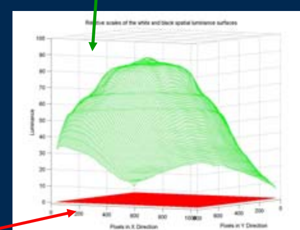
$$C_l(i_l, u, v) = h_l(i_l)\, M_l(u, v)$$

For any input $i = (i_r, i_g, i_b)$:

$$P(i, u, v) = C_r(i_r, u, v) + C_g(i_g, u, v) + C_b(i_b, u, v)$$

With black Offset B:

$$P(i, u, v) = h_r(i_r)M_r(u, v) + h_g(i_g)M_g(u, v) + h_b(i_b)M_b(u, v) + B(u, v)$$



Single Projector Display

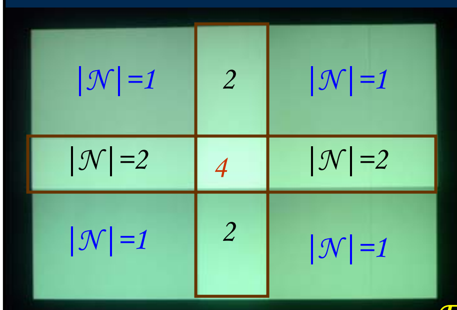
$$P(i, u, v) = h_r(i_r)\, M_r(u, v) + h_g(i_g)\, M_g(u, v) + h_b(i_b)\, M_b(u, v) + B(u, v)$$

Transfer Functions

Luminance Functions

Black Offset

Multi-Projector Display



$$\mathcal{E}(u, v, i) = \sum_{j \in \mathcal{N}(u,v)} \mathcal{P}_j(u, v, i)$$

$$\begin{aligned} \mathcal{E}(i, u, v) = & \sum h_r(i_r)\mathcal{M}_r(u, v) \\ & + \sum h_g(i_g)\mathcal{M}_g(u, v) \\ & + \sum h_b(i_b)\mathcal{M}_b(u, v) \\ & + \sum \mathcal{B}(u, v) \\ & j \in \mathcal{N}(u,v) \end{aligned}$$

Multi-Projector Display

- Intra projector luminance variation
  - $\mathcal{M}_l(u, v)$ and $\mathcal{B}(u, v)$ are not flat
- Inter projector luminance variation
  - $h_l(i_l)$ is different
  - $\mathcal{M}_l(u, v)$ and $\mathcal{B}(u, v)$ have different shapes
- Overlap luminance variation
  - $\mathcal{N}$ is different

$$\begin{aligned} \mathcal{E}(i, u, v) = & \sum h_r(i_r)\mathcal{M}_r(u, v) \\ & + \sum h_g(i_g)\mathcal{M}_g(u, v) \\ & + \sum h_b(i_b)\mathcal{M}_b(u, v) \\ & + \sum \mathcal{B}(u, v) \\ & j \in \mathcal{N}(u,v) \end{aligned}$$

Including Chrominance

$$\mathcal{E}(i,u,v) = \sum h_r(i_r)\mathcal{M}_r(u,v) + \sum h_g(i_g)\mathcal{M}_g(u,v) + \sum h_b(i_b)\mathcal{M}_b(u,v) + \sum \mathcal{B}(u,v)$$

$$j \in \mathcal{N}(u,v)$$

Including Chrominance

$$\mathcal{E}(i,u,v) = \sum h_r(i_r)(\mathcal{M}_r(u,v), c_r(u,v)) + \sum h_g(i_g)(\mathcal{M}_g(u,v), c_g(u,v)) + \sum h_b(i_b)(\mathcal{M}_b(u,v), c_b(u,v)) + \sum (\mathcal{B}(u,v), c_{\mathcal{B}}(u,v))$$

$$j \in \mathcal{N}(u,v)$$

Including Chrominance

$$
\begin{aligned}
\mathcal{E}(i,u,v) = & \sum h_r(i_r) \otimes (\mathcal{M}_r(u,v), c_r(u,v)) \\
& + \sum h_g(i_g) \otimes (\mathcal{M}_g(u,v), c_g(u,v)) \\
& + \sum h_b(i_b) \otimes (\mathcal{M}_b(u,v), c_b(u,v)) \\
& + \sum (\mathcal{B}(u,v), c_{\mathcal{B}}(u,v)) \\
& j \in \mathcal{N}(u,v)
\end{aligned}
$$

$$k \otimes (\mathcal{L}_1, c_1) = (k\mathcal{L}_1, c_1)$$

Luminance Scaling

Including Chrominance

$$
\begin{aligned}
\mathcal{E}(i,u,v) = & \oplus h_r(i_r) \otimes (\mathcal{M}_r(u,v), c_r(u,v)) \\
& \oplus \oplus h_g(i_g) \otimes (\mathcal{M}_g(u,v), c_g(u,v)) \\
& \oplus \oplus h_b(i_b) \otimes (\mathcal{M}_b(u,v), c_b(u,v)) \\
& \oplus \oplus (\mathcal{B}(u,v), c_{\mathcal{B}}(u,v)) \\
& j \in \mathcal{N}(u,v)
\end{aligned}
$$

$$k \otimes (\mathcal{L}_1, c_1) = (k\mathcal{L}_1, c_1)$$

Luminance Scaling

$$(\mathcal{L}_1, c_1) \oplus (\mathcal{L}_2, c_2) = \left(\mathcal{L}_1 + \mathcal{L}_2, \ \frac{c_1 \mathcal{L}_1}{\mathcal{L}_1 + \mathcal{L}_2} + \frac{c_2 \mathcal{L}_2}{\mathcal{L}_1 + \mathcal{L}_2} \right)$$

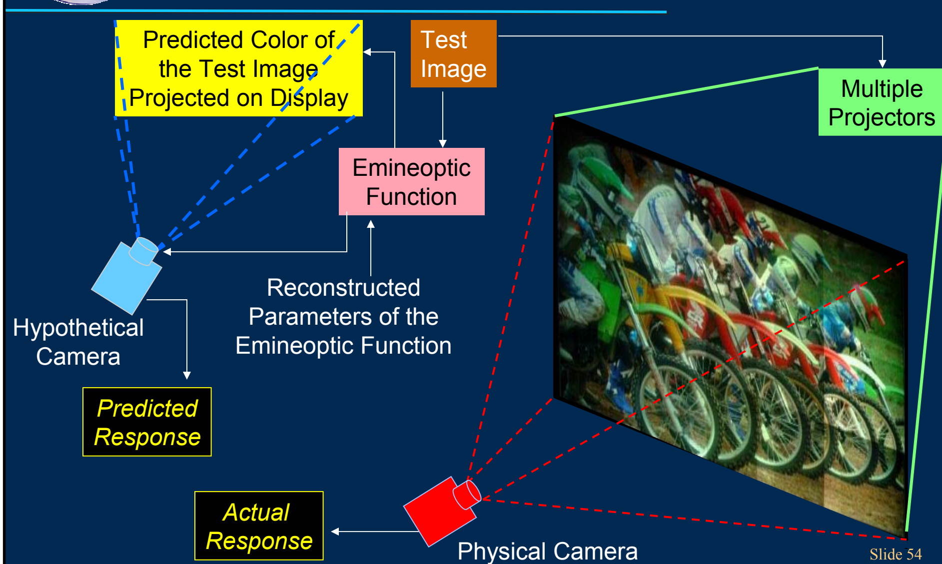
Optical Superposition

Including Chrominance

$$\mathcal{E}(i,u,v) = \bigoplus h_r(i_r) \otimes (\mathcal{M}_r(u,v), c_r(u,v))$$
$$\oplus \bigoplus h_g(i_g) \otimes (\mathcal{M}_g(u,v), c_g(u,v))$$
$$\oplus \bigoplus h_b(i_b) \otimes (\mathcal{M}_b(u,v), c_b(u,v))$$
$$\oplus \bigoplus (\mathcal{B}(u,v), c_{\mathcal{B}}(u,v))$$
$$j \in \mathcal{N}(u,v)$$

- Intra projector chrominance variation
  - $c_l(u,v)$ and $c_{\mathcal{B}}(u,v)$ are not flat
  - $\mathcal{M}_r$, $\mathcal{M}_g$, and $\mathcal{M}_b$ differ in shape
- Inter projector and overlap chrominance variation
  - c_l and $c_{\mathcal{B}}$ differ
  - The relative proportions of $max(\mathcal{M}_l(u,v))$ across channels

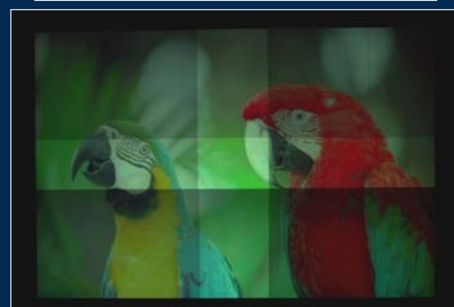
Model Verification



Modeled vs Actual (Both luminance and chrominance)

Test Image

Predicted Response



Actual Response

Organization

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Properties of Color Variation

Based on extensive empirical analysis of real projectors

- Intra-projector
  - Within a single projector
- Inter-projector
  - Across different projectors
- Overlaps

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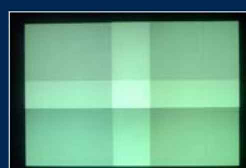
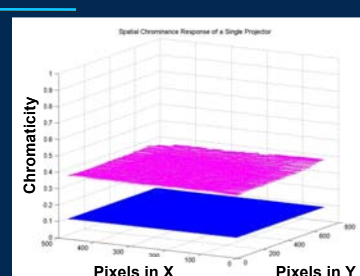
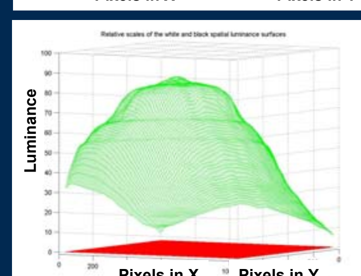


Intra-Projector Variations

- Chrominance is almost constant
- Luminance is not

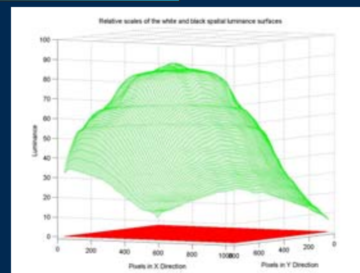




Luminance variation is more significant than chrominance variation

Intra-Projector Variations

- Chrominance is constant
- Luminance is not



$$E(i,u,v) = \bigoplus_{j \in \mathcal{N}(u,v)} h_r(i_r) \otimes (\mathcal{M}_r(u,v), c_r(u,v)) \oplus h_g(i_g) \otimes (\mathcal{M}_g(u,v), c_g(u,v)) \oplus h_b(i_b) \otimes (\mathcal{M}_b(u,v), c_b(u,v)) \oplus (\mathcal{B}(u,v), c_{\mathcal{B}}(u,v))$$

Properties of Color Variation

Based on extensive empirical analysis of real projectors

- Intra-projector
  - Within a single projector
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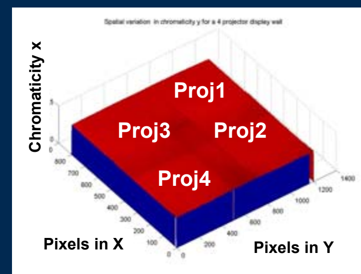
  - Across different projectors
- Overlaps

Inter-Projector Variations

- Projectors of same model
  - Chrominance variation is negligible
  - Luminance variation is significant
- Projectors of different models
  - Chrominance variation is relatively very small
  - Luminance variation is significant



Chrominance (x) of a four projector display

Luminance variation is more significant than chrominance variation

Inter-Projector Variations

$$\mathcal{E}(i,u,v) = \bigoplus_{j \in \mathcal{N}(u,v)} h_r(i_r) \otimes (\mathcal{M}_r(u,v), c_r(u,v)) \oplus h_g(i_g) \otimes (\mathcal{M}_g(u,v), c_g(u,v)) \oplus h_b(i_b) \otimes (\mathcal{M}_b(u,v), c_b(u,v)) \oplus (\mathcal{B}(u,v), c_{\mathcal{B}}(u,v))$$

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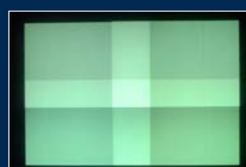
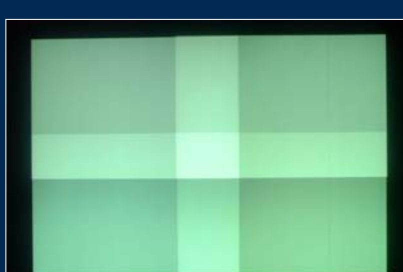
- Overlaps



Overlaps

- For displays made of same model projectors, at overlap regions
  - Chrominance remains almost constant
  - Luminance almost gets multiplied by the number of overlapping projectors



Luminance variation is more significant than chrominance variation

Addresses only Luminance

- Most display walls made of same model projectors
  - Spatial variation in chrominance is insignificant compared to luminance
- Humans are more sensitive to spatial luminance variation than to spatial chrominance variation

Achieving Photometric Seamlessness

- Reconstruction
  - Reconstruct $\mathcal{E}$
- Modification
  - Modify $\mathcal{E}$ to $\mathcal{E}'$
- Reprojection
  - Reproject $\mathcal{E}'$

Achieving Photometric Seamlessness

- Reconstruction
  - Reconstruct $\mathcal{E}$
- Modification
  - Modify $\mathcal{E}$ to $\mathcal{E}'$
- Reprojection
  - Reproject $\mathcal{E}'$

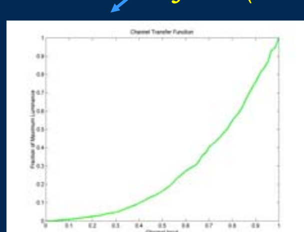
Reconstruction

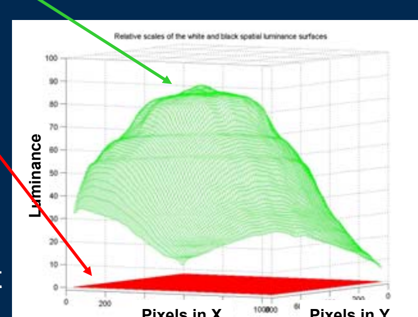
$$\mathcal{E}(i,u,v) = \sum_{j \in \mathcal{N}(u,v)} h_r(i_r)\,\mathcal{M}_r(u,v) + \sum h_g(i_g)\,\mathcal{M}_g(u,v) + \sum h_b(i_b)\,\mathcal{M}_b(u,v) + \sum \mathcal{B}(u,v)$$

Transfer Function

Luminance Function

Black Offset



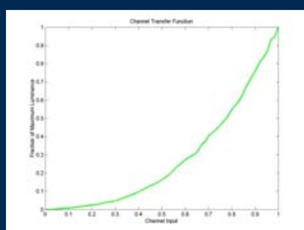


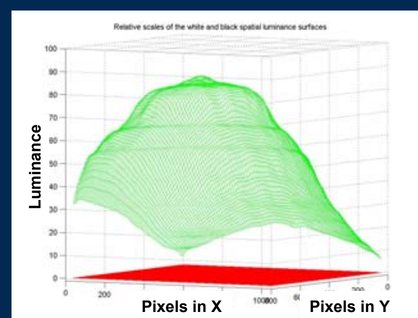
Reconstruction

$$\mathcal{E}(i,u,v) = \sum_{j\in\mathcal{N}(u,v)} h_r(i_r)\,\mathcal{M}_r(u,v) + \sum h_g(i_g)\,\mathcal{M}_g(u,v) + \sum h_b(i_b)\,\mathcal{M}_b(u,v) + \sum \mathcal{B}(u,v)$$

Photometer

Camera





Achieving Photometric Seamlessness

- Reconstruction
  - Reconstruct $\mathcal{E}$
- Modification
  - Modify $\mathcal{E}$ to $\mathcal{E}'$
- Reprojection
  - Reproject $\mathcal{E}'$

Modification 1

$$\mathcal{P}(i,u,v) = h_r(i_r)\,\mathcal{M}_r(u,v) + h_g(i_g)\,\mathcal{M}_g(u,v) + h_b(i_b)\,\mathcal{M}_b(u,v) + \mathcal{B}(u,v)$$

Single Projector

$$\mathcal{E}(i,u,v) = \sum h_r(i_r)\mathcal{M}_r(u,v) + \sum h_g(i_g)\mathcal{M}_g(u,v) + \sum h_b(i_b)\mathcal{M}_b(u,v) + \sum_{j \in \mathcal{N}(u,v)} \mathcal{B}(u,v)$$

Multi Projector

- Match $h_\lambda(i_\lambda)$ of projectors

Modification 1

$$\mathcal{P}(i,u,v) = h_r(i_r)\,\mathcal{M}_r(u,v) + h_g(i_g)\,\mathcal{M}_g(u,v) + h_b(i_b)\,\mathcal{M}_b(u,v) + \mathcal{B}(u,v)$$

Single Projector

$$\mathcal{E}(i,u,v) = \sum \mathcal{H}_r(i_r)\mathcal{M}_r(u,v) + \sum \mathcal{H}_g(i_g)\mathcal{M}_g(u,v) + \sum \mathcal{H}_b(i_b)\mathcal{M}_b(u,v) + \sum_{j \in \mathcal{N}(u,v)} \mathcal{B}(u,v)$$

Multi Projector

- Match $h_\lambda(i_\lambda)$ of projectors

Modification 1

$$\mathcal{P}(i,u,v) = h_r(i_r)\,\mathcal{M}_r(u,v) + h_g(i_g)\,\mathcal{M}_g(u,v) + h_b(i_b)\,\mathcal{M}_b(u,v) + \mathcal{B}(u,v)$$

Single Projector

$$\mathcal{E}(i,u,v) = \mathcal{H}_r(i_r)\sum \mathcal{M}_r(u,v) + \mathcal{H}_g(i_g)\sum \mathcal{M}_g(u,v) + \mathcal{H}_b(i_b)\sum \mathcal{M}_b(u,v) + \sum \mathcal{B}(u,v)$$

$j \in \mathcal{N}(u,v)$

Multi Projector

- Match $h_l(i_l)$ of projectors

Modification 1

$$\mathcal{P}(i,u,v) = h_r(i_r)\,\mathcal{M}_r(u,v) + h_g(i_g)\,\mathcal{M}_g(u,v) + h_b(i_b)\,\mathcal{M}_b(u,v) + \mathcal{B}(u,v)$$

Transfer Function of one Projector

Luminance Functions of one Projector

Black Offset of one Projector

$$\mathcal{E}(i,u,v) = \mathcal{H}_r(i_r)\sum \mathcal{M}_r(u,v) + \mathcal{H}_g(i_g)\sum \mathcal{M}_g(u,v) + \mathcal{H}_b(i_b)\sum \mathcal{M}_b(u,v) + \sum \mathcal{B}(u,v)$$

$j \in \mathcal{N}(u,v)$

Common Transfer Function

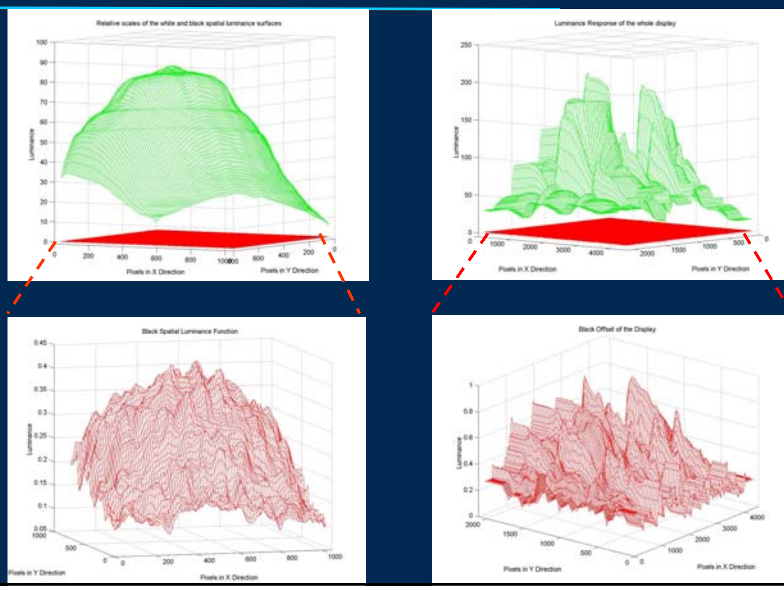
Luminance Functions of the whole Display

Black Offset of the whole Display

Display is like a single large projector

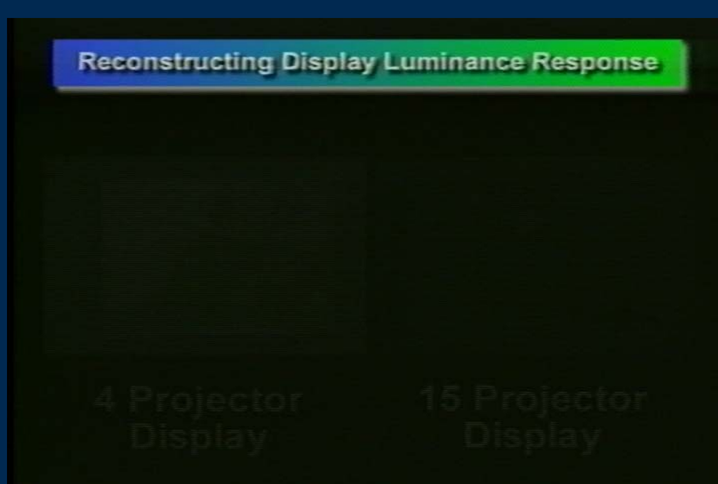
Display Luminance Functions

One Projector Display



15 Projector Display

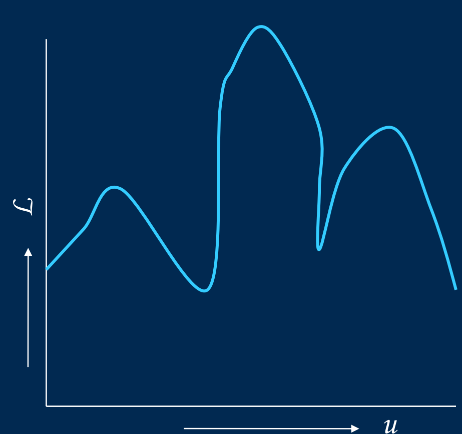
Display Luminance Functions

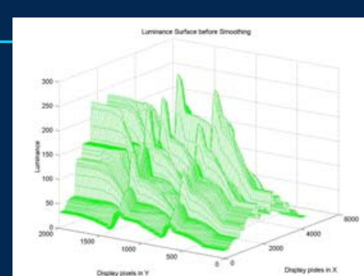


Modification 2

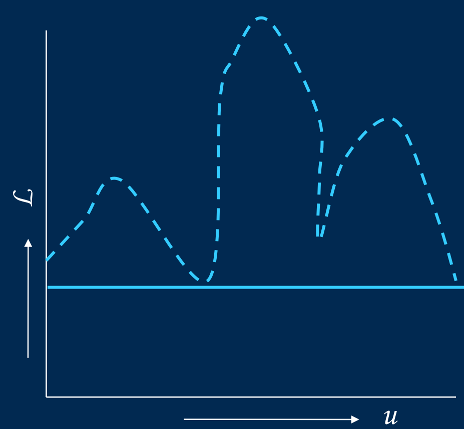
- Sharp discontinuities are the cause of photometric seams
- Remove the sharp discontinuities

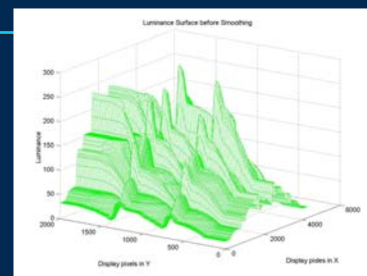
The Problem

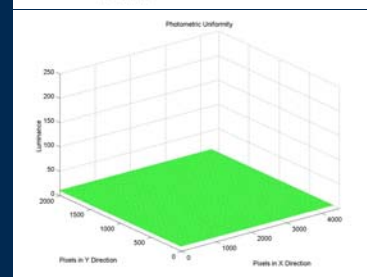




Strict Photometric Uniformity







Strict Photometric Uniformity

$$|\,lum\,(E'(u_1, v_1, i, e)) - lum\,(E'(u_2, v_2, i, e))\,| = 0$$

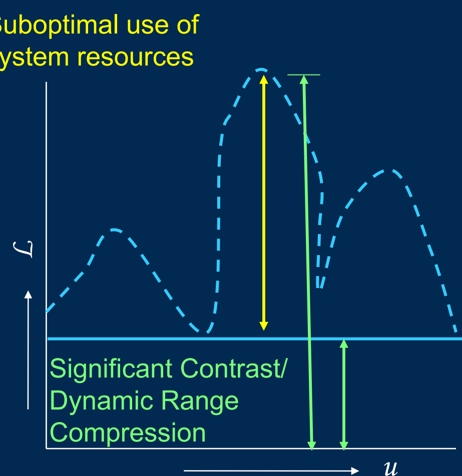
The luminance of the light reaching the viewer from any two coordinates is identical

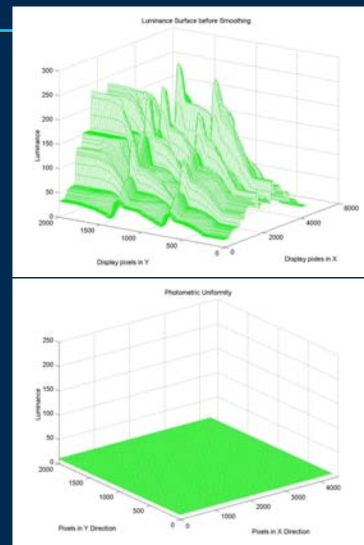
Strict Color Uniformity

$$|\,E'(u_1, v_1, i, e) - E'(u_2, v_2, i, e)\,| = 0$$

The color of the light reaching the viewer from any two coordinates is identical

Strict Photometric Uniformity



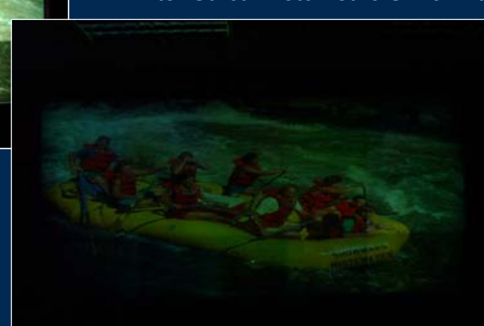


Display Quality

Before

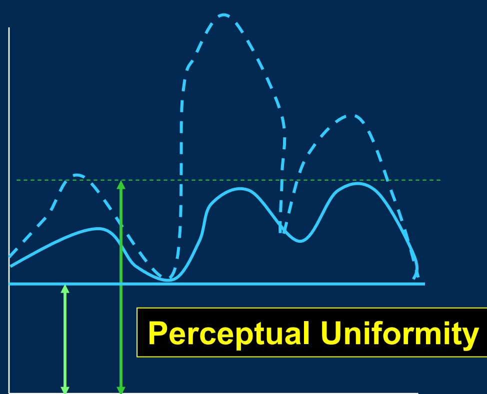
Which one is better?

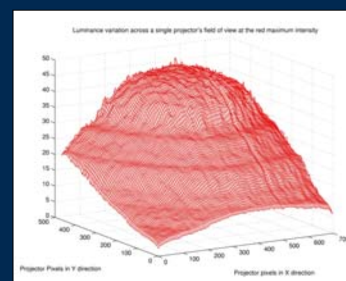
After Strict Photometric Uniformity



Is Strict Photometric Uniformity Required?

Humans cannot detect smooth luminance variations

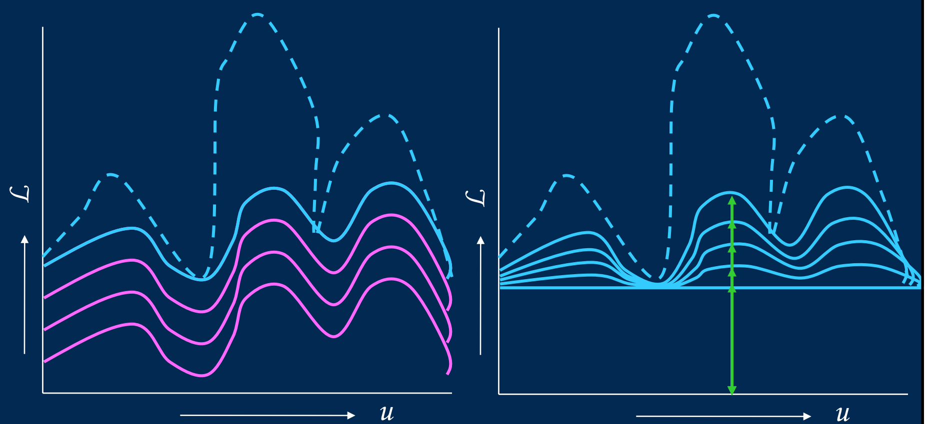




Achieving Photometric Seamlessness

- Optimization Problem
  - –Perceptual Uniformity
    - » Creates the *perception* of uniformity
  - –Display Quality
    - » Maintains *high* display quality

Optimization Problem



Strict photometric uniformity is a special case of perceptual uniformity

Photometric Seamlessness

- Perceptual Uniformity

  $$| \, lum(E'(u_1, v_1, i, e)) - lum(E'(u_2, v_2, i, e)) \, | \leq \Delta$$

- Display Quality

  Minimize

  $$Distance\big(lum(E(u, v, i, e)), lum(E'(u, v, i, e))\big)$$

Color Seamlessness

- Perceptual Uniformity

$$| E'(u_1, v_1, i, e) - E'(u_2, v_2, i, e) | \leq \Delta$$

- Display Quality

Minimize

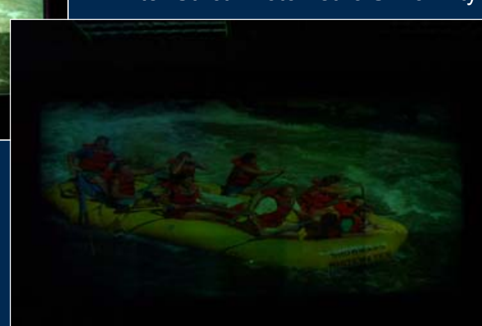
$$Distance\,(E(u, v, i, e), E'(u, v, i, e))$$

Perceptually uniform high quality displays can be achieved by realizing a desired emineoptic function that differs minimally from the original function and has imperceptible color variation.

Strict Photometric Uniformity

Before

After Strict Photometric Uniformity



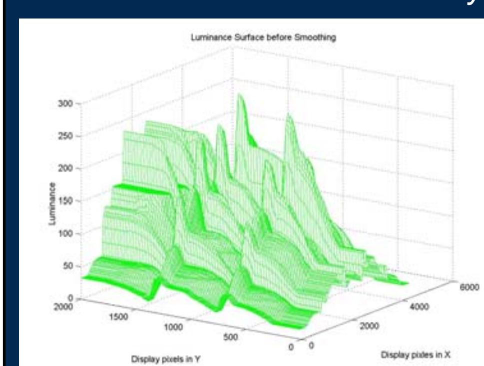
Photometric Seamlessness

Before

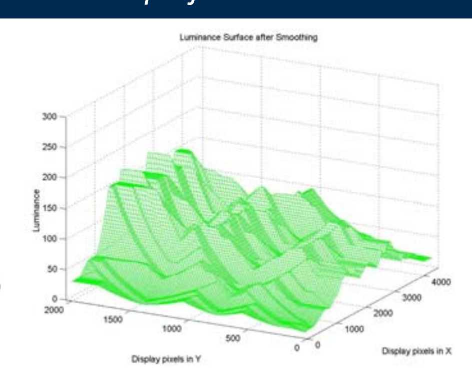
After Photometric Seamlessness

Smooth Luminance Functions

5 x 3 array of fifteen projectors



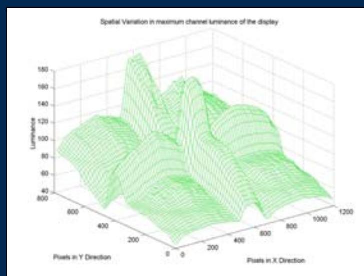
Before smoothing

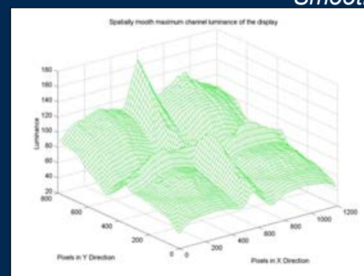


After smoothing

Different Smoothing Parameter (2x2 array of four projectors)

Smooth

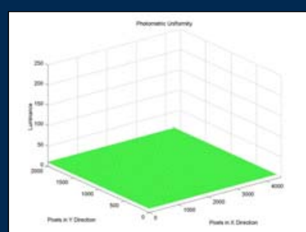


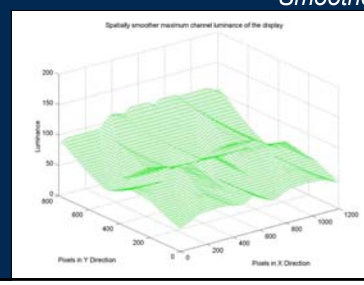


Original

Smoother

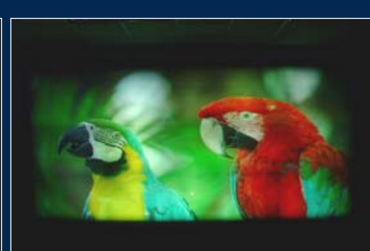
Flat





Using different smoothing parameters (3x5 array of 15 projectors)

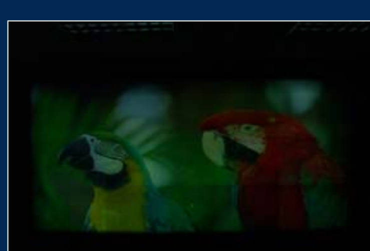
Smooth

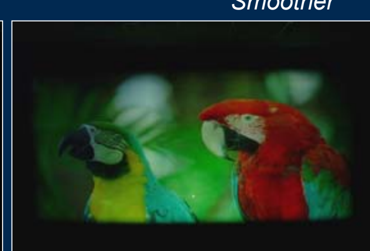


Original

Smoother

Flat

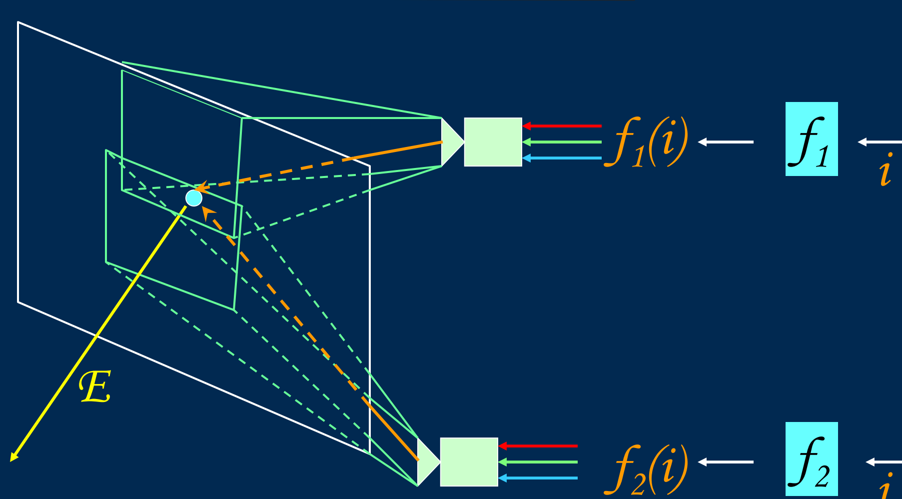




Achieving Photometric Seamlessness

- Reconstruction
  - Reconstruct $\mathcal{E}$
- Modification
  - Modify $\mathcal{E}$ to $\mathcal{E}'$
- Reprojection
  - Reproject $\mathcal{E}'$

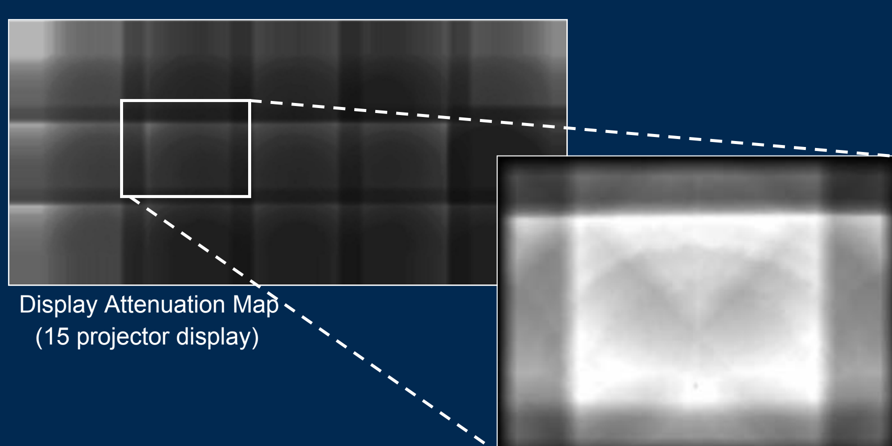
Reprojection



Smoothing Maps

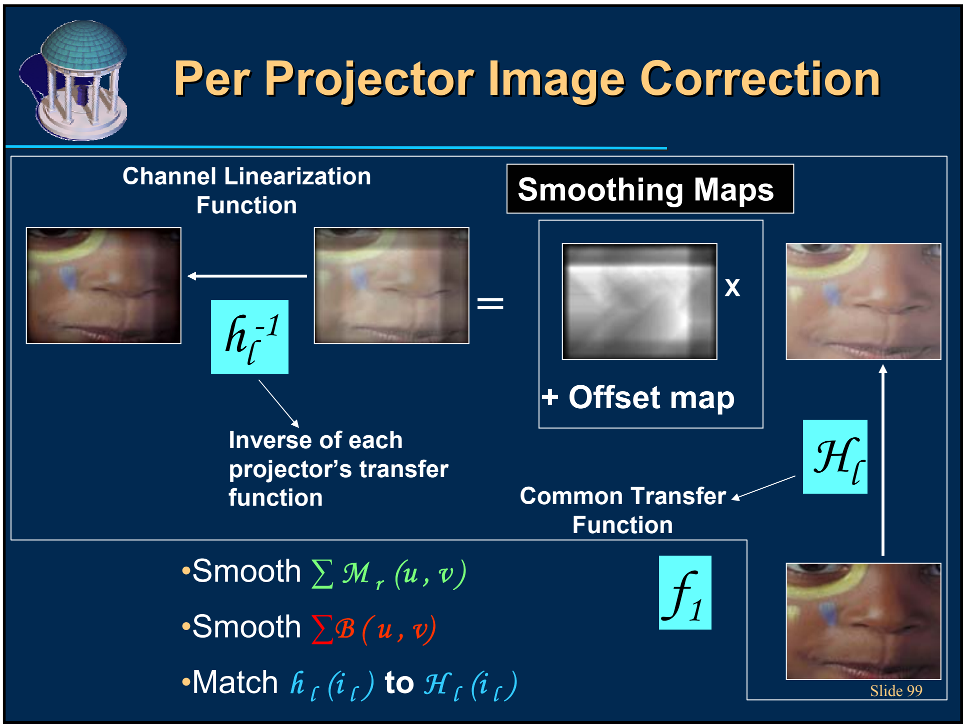
- Attenuation Map
  - Per pixel luminance attenuation to achieve the desired luminance function
- Offset Map
  - Per pixel luminance offset to achieve the desired black offset

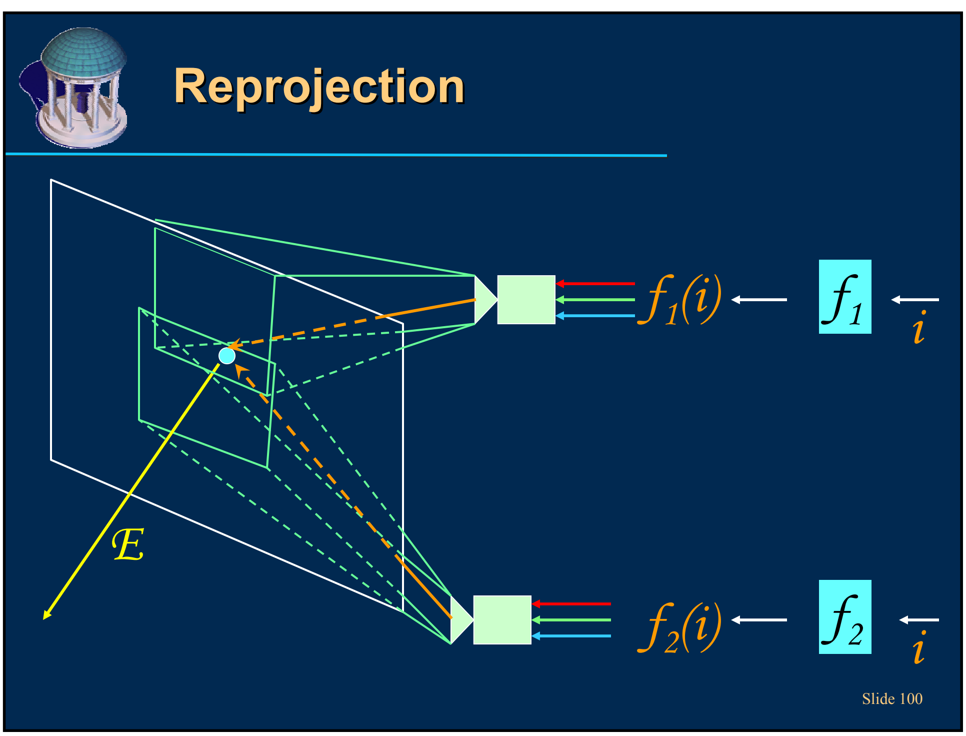
Attenuation Map



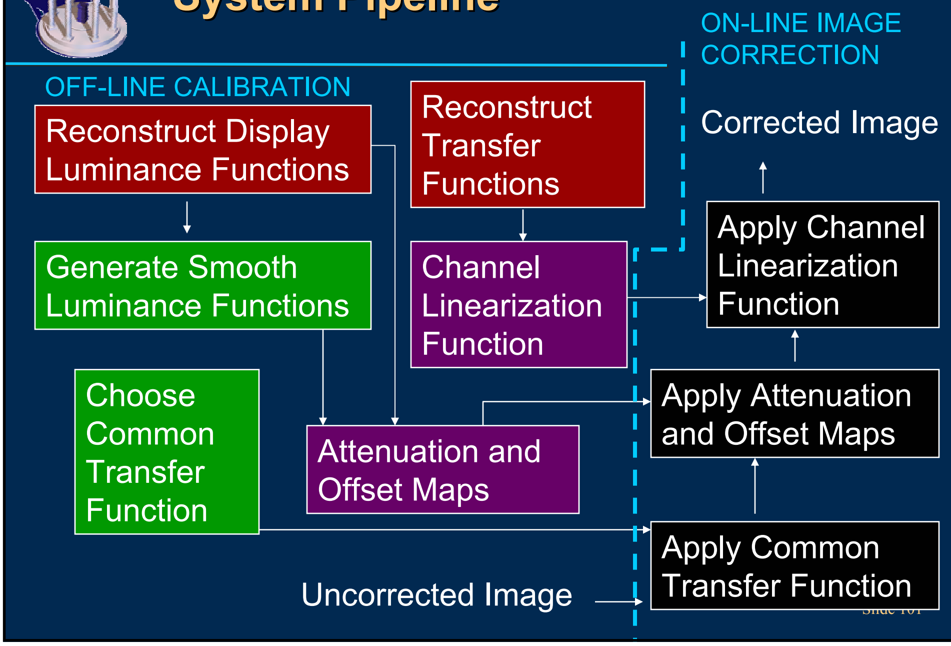
Display Attenuation Map
(15 projector display)

Projector Attenuation Map


Per Projector Image Correction
Channel Linearization Function
Smoothing Maps
=
x
+ Offset map
h_ℓ^{-1}
Inverse of each projector's transfer function
$\mathcal{H}_\ell$
Common Transfer Function
f_1
•Smooth $\sum \mathcal{M}_r(u, v)$
•Smooth $\sum \mathcal{B}(u, v)$
•Match $h_\ell(i_\ell)$ to $\mathcal{H}_\ell(i_\ell)$
Slide 99


Reprojection
$f_1(i)$
f_1
i
$\mathcal{E}$
$f_2(i)$
f_2
i
Slide 100

System Pipeline



Issues

- Camera
  - Linearity
  - Dynamic Range
  - Sampling Frequency
- Scalability

Organization

- Previous Work
- The Emineoptic Function
- Definition of Color Seamlessness
- Achieving Photometric Seamlessness
- Results

Results (After)

Results (Before)

6 Projector Display

Results (After)

Results (Before)

15 Projector Display

Chrominance

- Chrominance and luminance are not independent parameters
- 5D nonlinear optimization problem
- No definite perceptual objective metric
- Insights from emineoptic function
  - Luminance variations can be perceived as chrominance variations
- How far can we go with just luminance?

The Comprehensive Framework

- Validity of the Emineoptic Function
  - Model verification
- Generality
  - Can be used to model color variations of other devices
  - Also a camera
- Unifying Parametric Space
  - Explain and compare different algorithms
    - » Parameters addressed
    - » Formal color correction goal they strive to achieve
    - » Success they can achieve
  - Design new algorithms

Evaluation Metric

- Comparing the quality of display
  - Brightness
  - Contrast
  - Seamlessness

Summary

- Modeling color variation comprehensively
- Color Seamlessness
  - Optimization Problem
- Achieving Photometric Seamlessness

Future Work (Handling Chrominance)

Before

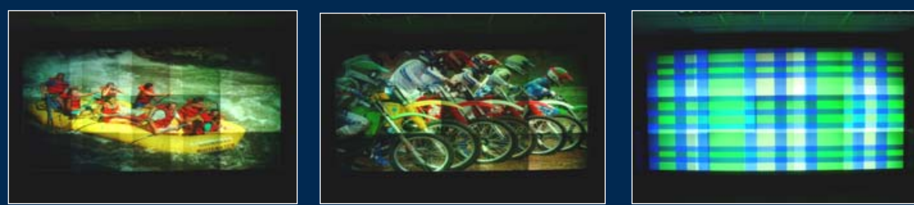
Future Work (Handling Chrominance)

After

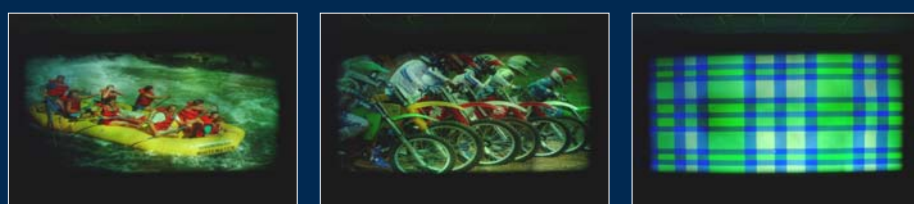
Future Work

- Real time Calibration
- Different kinds of sensors
- Perceptual Image Quality Metric

THE END



Before



After Smoothing