Large Format Displays

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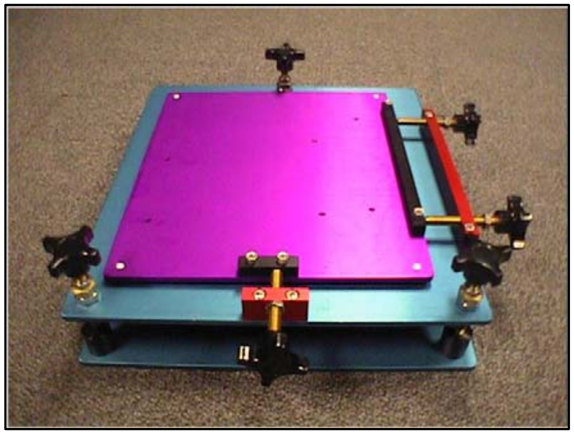
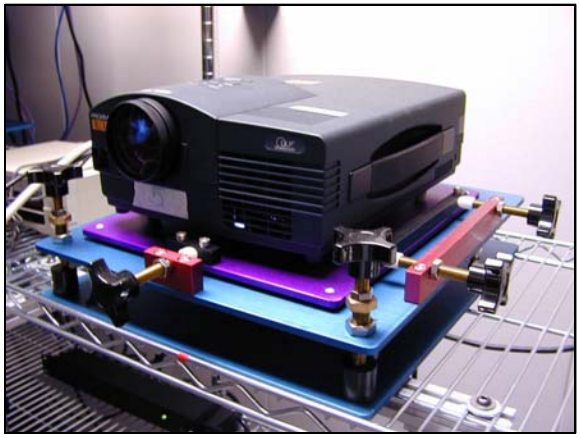
Multi-projector Displays

- Tile multiple projectors
  - Covers a much larger viewing area
- Logical abstraction of a single display
- Seamless imagery across projectors

First Generation Displays

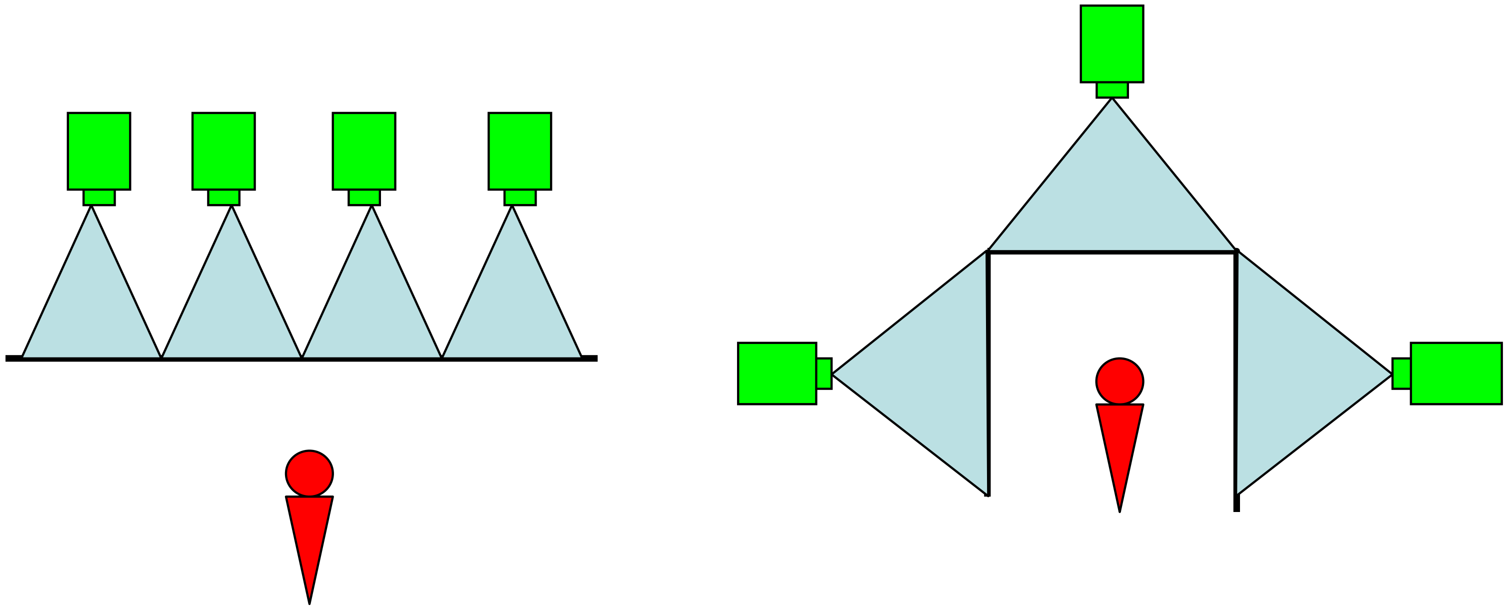
- Cost Prohibitive
  - Projectors ($75,000)
  - SGI Infinite Reality ($1,000,000)
- Manual Registration
  - Expensive 6 DOF mounts
  - Fresnel lens
  - Manual manipulation
    - Projector and mount controls





Courtesey: ANL

First Generation Displays



- Precise *abutting* construction
- Hardwired in rendering software

Problems

- Rigid permanent structures in dedicated rooms
- Not scalable
- Not easily deployable
- Not reconfigurable

Current Generation Displays

- Affordable
  - Portable projectors, PC Cluster Rendering
    - 10 projector wall < $50,000
- Casually aligned
- No expensive optics
- Allowing *overlaps* between projectors

Geometric & Photometric Mismatch

Registration for Seamless Display

Camera Based Registration

- Camera feedback detects misregistration
- Encoded in a mathematical function
  - Both geometric and photometric
- Change the projected image digitally
  - Apply the inverse function
  - In real-time via GPU

Overview

- Geometric Registration
- Photometric Registration
- PC Cluster Based Rendering
- Distributed Rendering

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Classification

- Based on nature of display surface
  – Parametric
    - Parameterized by two parameters
      – E.g. plane, cylinder, sphere
  – Non-parametric

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Basic Idea

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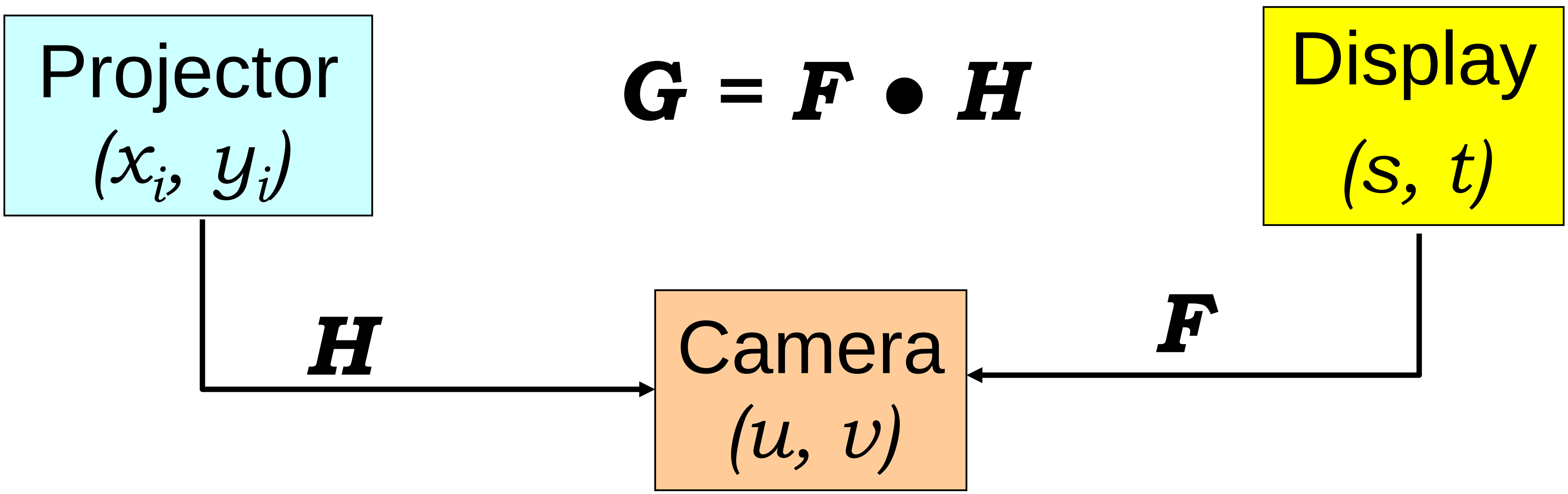


Image wallpapered seamlessly on *D*

Planar Displays

- Representation of G, H and F
  - Type of function
    - Linear, piecewise linear, non-linear
  - Number of cameras (usually single)
  - Geometric imperfections in projectors
  - Desired accuracy

Linear

- Assumptions
  - Perfect projectors (No radial distortion)
- H and F are both linear 3x3 matrices
  - Commonly called *homography*
- $G = F \times H$
  - Matrix multiplication
- G^{-1} applied to I to generate image for each P_i
  - Easy to find the inverse

R. Raskar, Immersive Planar Display using Roughly Aligned Projectors, IEEE VR, 2000.

Non-Linear Method for Planar Display

- Projectors can have non-linearities
- Use of lens on rear projectors
- H is non-linear
- Issues
  - Not easily invertible
  - Cannot be concatenated

Piecewise Linear Method

- H is a piecewise linear function
  - – Reduces local errors
  - – Requires dense sampling
  - – Triangulation

R. Yang, D. Gotz, J. Henseley, H. Towles, M. S. Brown, PixelFlex: A Reconfigurable Multi-Projector Display System, IEEE Visualization, 2001.

Non-Linear Method for Planar Display

- H is a cubic polynomial
  - Linear regression for polynomial fitting
- Issues
  - Not perspective projection invariant
  - Assumes near rectangular array

M. Hereld, I. Judson, R. Stevens, DottyToto: A Measurement Engine for Aligning Multi-Projector Display Systems, Argonne National Laboratory preprint ANL/MCS-P958-0502, 2002.

Non-Linear Method for Planar Display

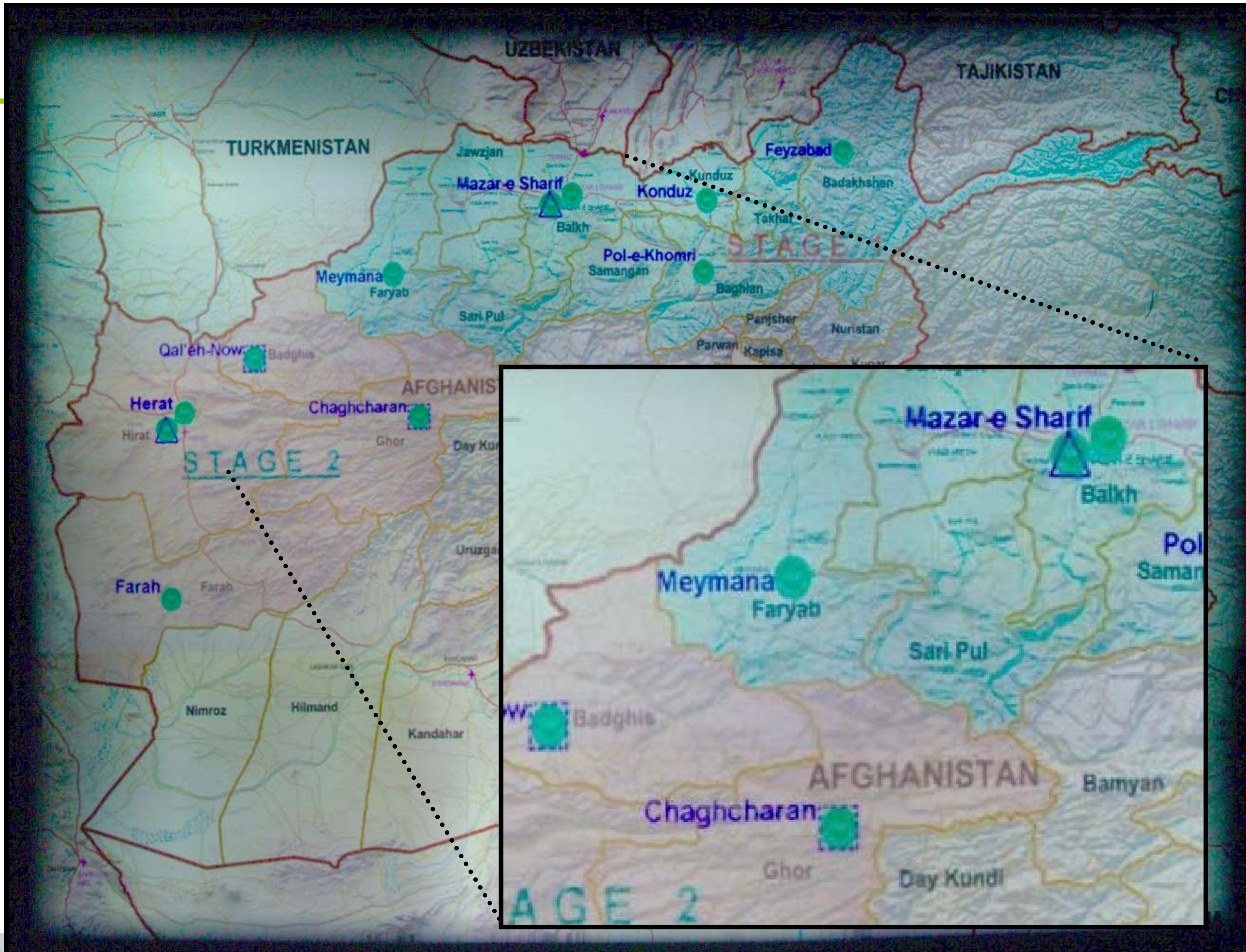
- H is a rational Bezier function
  - Perspective projection invariant
  - Can tolerate large non-linearities
  - Uses iterative procedure (Levenberg-Marquadt) for Bezier fitting
  - Assures global smoothness of lines
  - Requires sparse sampling (compact)

E. Bhasker, R. Juang, A. Majumder, Registration Techniques for Using Imperfect and Partially Calibrated Devices in Planar Multi-Projector Displays, IEEE Visualization, 2007.

Results


UZBEKISTAN
TAJIKISTAN
TURKMENISTAN
Konduz
Kunduz
Balkh
Pol-e-Khomri
Samangan
Baghlan
Meymana
Faryab
Herat
Hirat
STAGE 2
Chaghcharan
Farah
Nimroz
Bamyan

Results

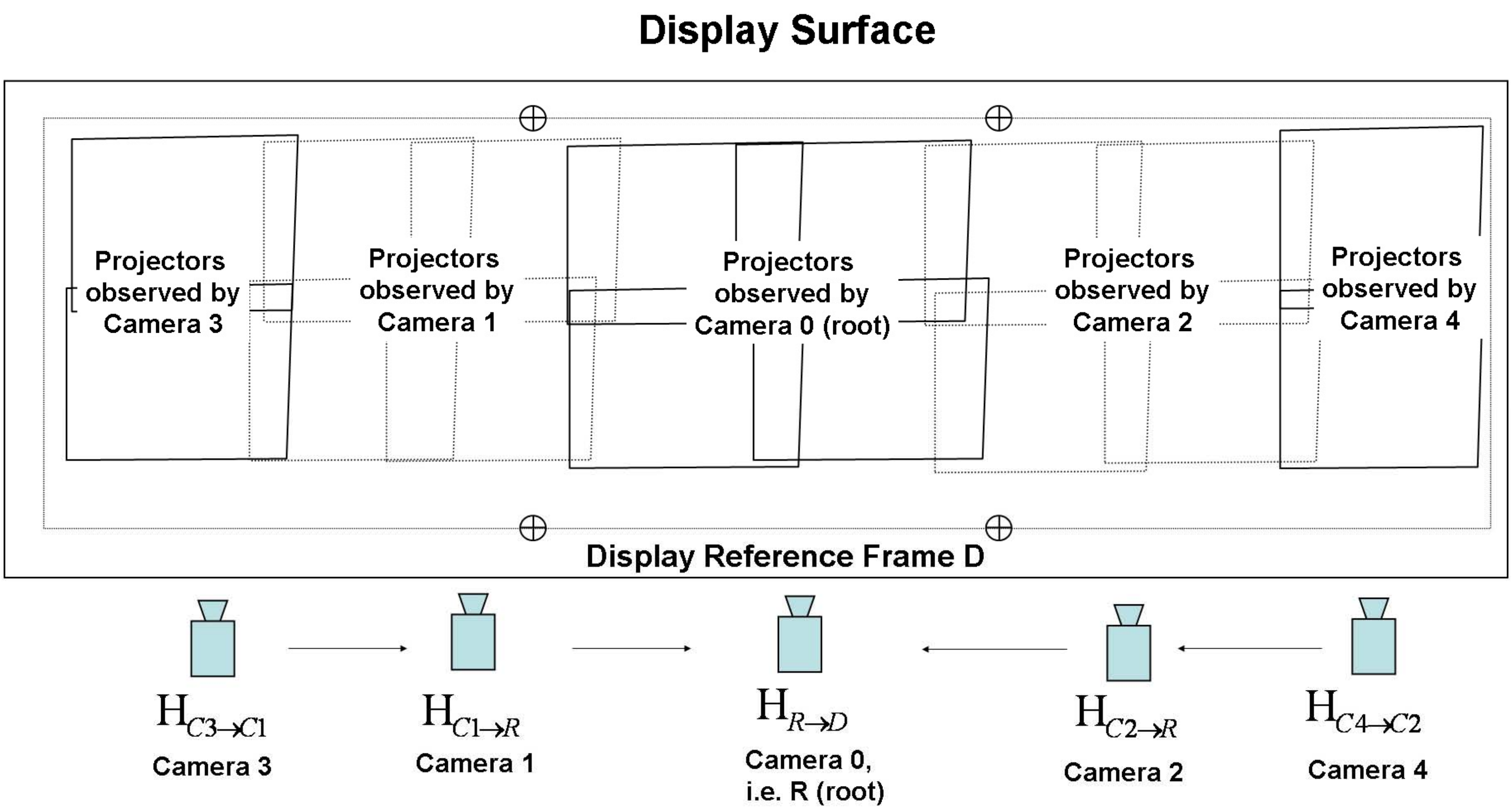


UZBEKISTAN
TAJIKISTAN
TURKMENISTAN
Jawzjan
Mazar-e Sharif
Balkh
Konduz
Kunduz
Feyzabad
Badakhshan
Takhar
STAGE 1
Pol-e-Khomri
Samangan
Baghlan
Meymana
Faryab
Sari Pul
Panjsher
Nuristan
Parwan
Kapisa
Qal'eh-Now
Badghis
AFGHANISTAN
Herat
Hirat
Chaghcharan
Ghor
STAGE 2
Farah
Nimroz
Hilmand
Kandahar
Bamyan
Day Kundi

Using Multiple Cameras

- Scalability not limited by camera resolution
- Linear method can be scaled
  - Homographies can be concatenated
- Cheaper cameras with smaller FOV

Set Up


Display Surface
Projectors observed by Camera 3
Projectors observed by Camera 1
Projectors observed by Camera 0 (root)
Projectors observed by Camera 2
Projectors observed by Camera 4
Display Reference Frame D
$H_{C3 \to C1}$
Camera 3
$H_{C1 \to R}$
Camera 1
$H_{R \to D}$
Camera 0, i.e. R (root)
$H_{C2 \to R}$
Camera 2
$H_{C4 \to C2}$
Camera 4

Method

- FOV of adjacent cameras C_j and C_k overlaps
- C_j and C_k are related by homography
  - $H_{C_j \to C_k}$
  - Observing projected points in overlapping FOV
- Choose a root camera R
- R is related to D by a homography
  - $H_{R \to D}$

Method

- C_j can be related to D by a concatenation of camera homographies
  - $H_{C_j \to D} = H_{R \to D}$ x $H_{C_k \to R}$ x ….. $H_{C_j \to C_k}$
- More than one path from C_j to R
  - Minimum spanning homography tree
  - Hence, unique path

Method

- Projector P_i can be related to C_j
  - $H_{P_i \rightarrow C_j}$
- Hence, P_i can be related to D by concatenation of homographies
  - $H_{P_i \rightarrow D} = H_{C_j \rightarrow D} \times H_{P_i \rightarrow C_j}$
- Errors can accumulate along a path of tree
  - Global error diffusion

H. Chen, R. Sukthankar, G. Wallace, Scalable Alignment of Large-Format Multi-Projector Displays Using Camera Homography Trees, IEEE Visualization, 2002.

Parametric Non-planar Display

- Cylindrical display
- Display parameterization
  - Equally placed physical markers
  - Top and bottom rim of the surface
- H and F are piece-wise linear functions
  - Sample densely

M. Harville, B. Culbertson, I. Sobel, D. Gelb, A. Futzhugh, D. Tanguay, Practical Methods for Geometric and Photometric Correction of Tiled Projector Displays on Curved Screens, IEEE PROCAMS, 2006.

Results

Classification

- Based on nature of display surface
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    - Parameterized by two parameters
      - E.g. plane, cylinder, sphere
  - Non-parametric

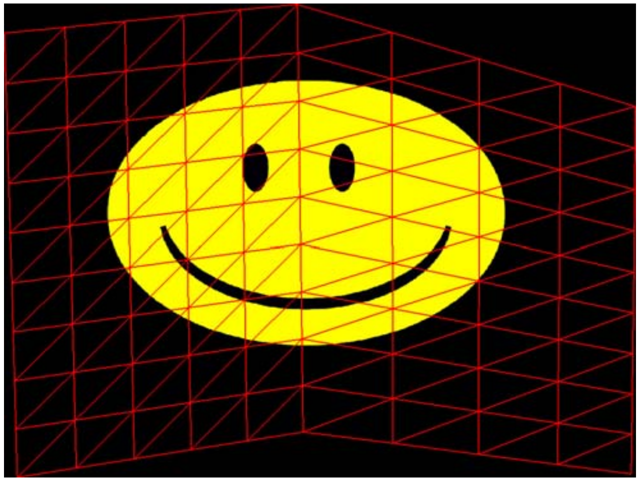
Main Question: What is correct?

- Single view point
  - Camera *(u, v)* = Display *(s, t)*
  - May not be correct from other viewpoints
  - Users can tolerate a large deviation from viewpoint

1) *M. S. Brown, W. B. Seales, A Practical and Flexible Tiled Display System, IEEE Pacific Graphics, 2002*
2) *R. Raskar, M.S. Brown, R. Yang, W. Chen, H. Towles, B. Seales, H. Fuchs, Multi Projector Displays Using Camera Based Registration, IEEE Visualization, 1999.*

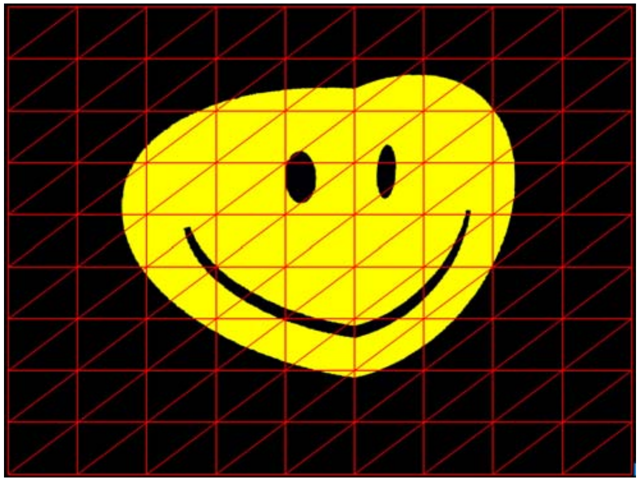
Corner : Single View

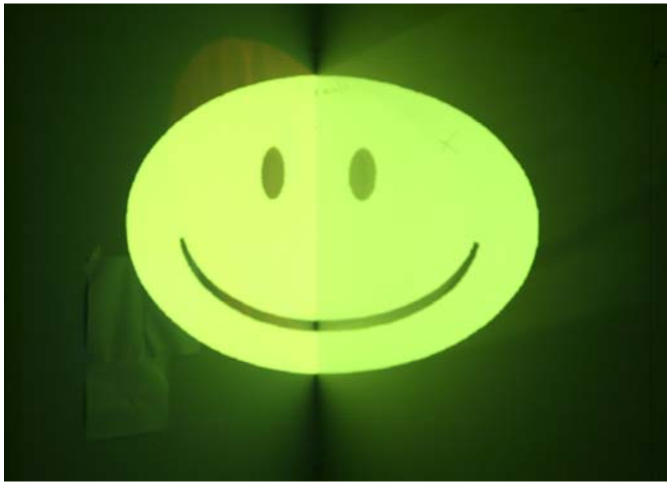
Original projector input



Projected image is distorted

Warped projector input





Projected image is undistorted from camera's viewpoint

Main Question: What is correct?

- Wall paper with local correctness
  - Globally incorrect from any one view point
  - Locally correct from normal at that point
  - Conformal mapping

1) *R. Raskar, J. van Baar, P. Beardsley, T. Willwacher, S. Rao, C. Forlines, iLamps: Geometrically Aware and Self-Configuring Projectors, SIGGRAPH 2003*
2) *R. Raskar, J. van Baar, T. Willwacher, S. Rao, Quadric Image Transfer for Immersive Curved Screen Displays, Eurographics 2004.*

Corner : Conformal Mapping

Before

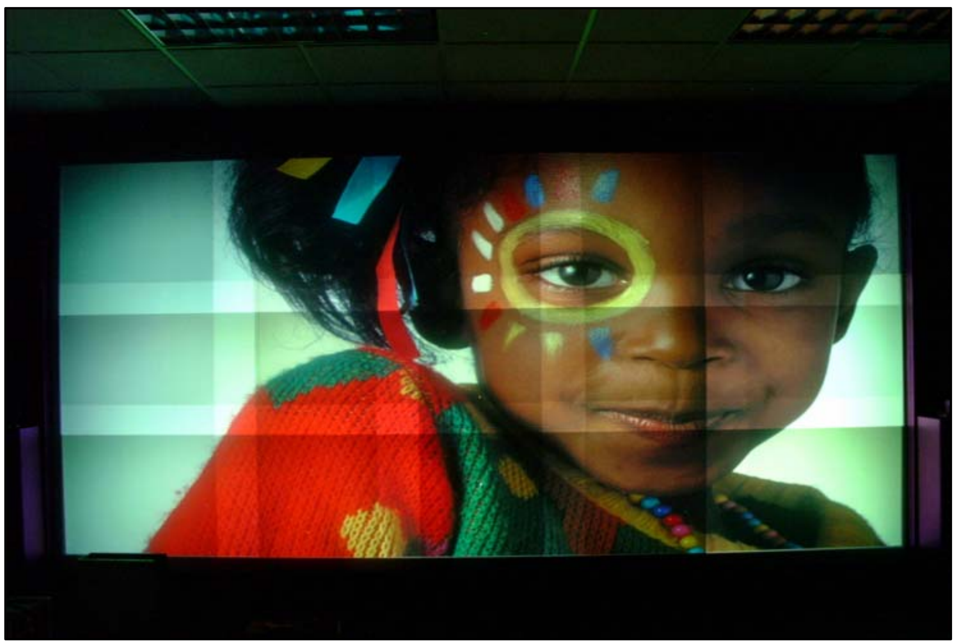
After

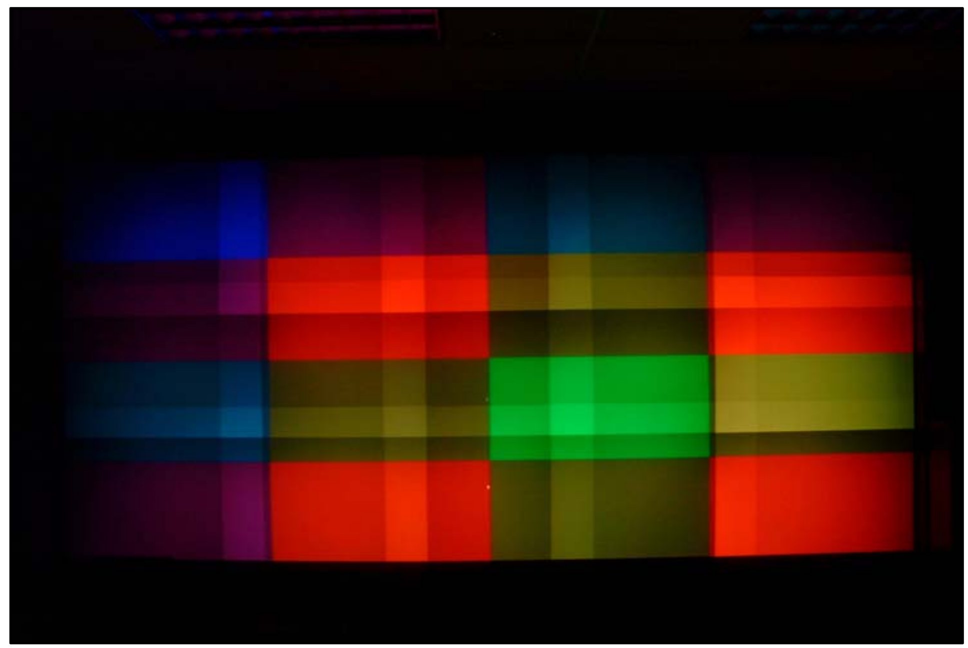
Overview

- Geometric Registration
- Photometric Registration
- PC Cluster Based Rendering
- Distributed Rendering

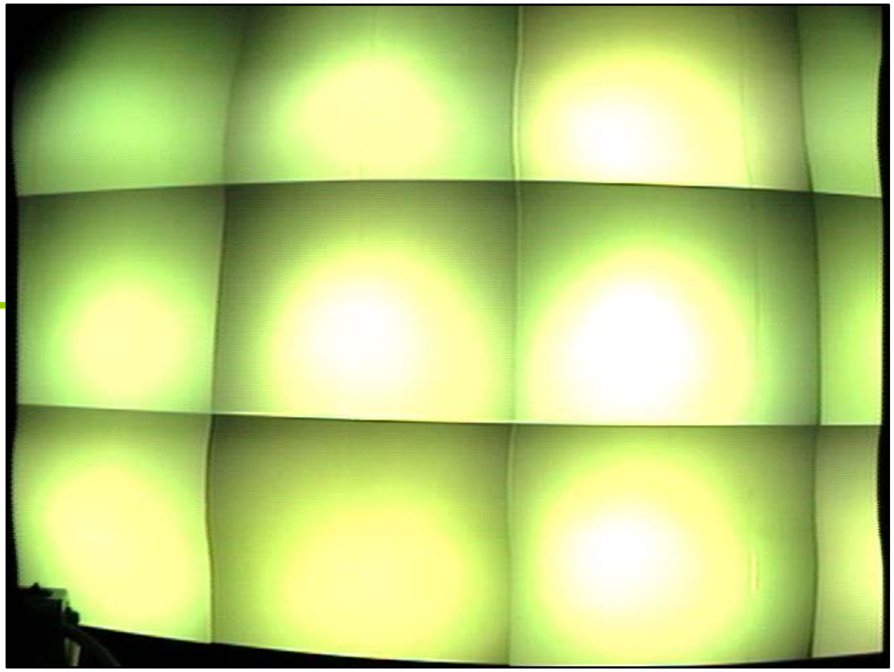
The Problem

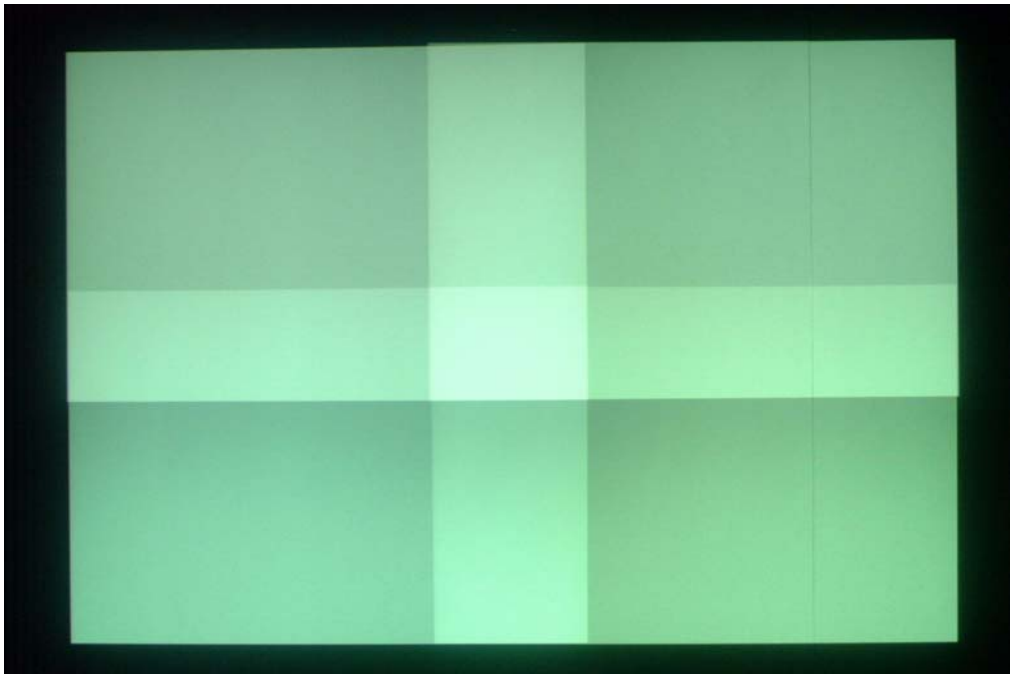
- Perfect geometric alignment
- Color variation problem not addressed
- Breaks the illusion of a single display



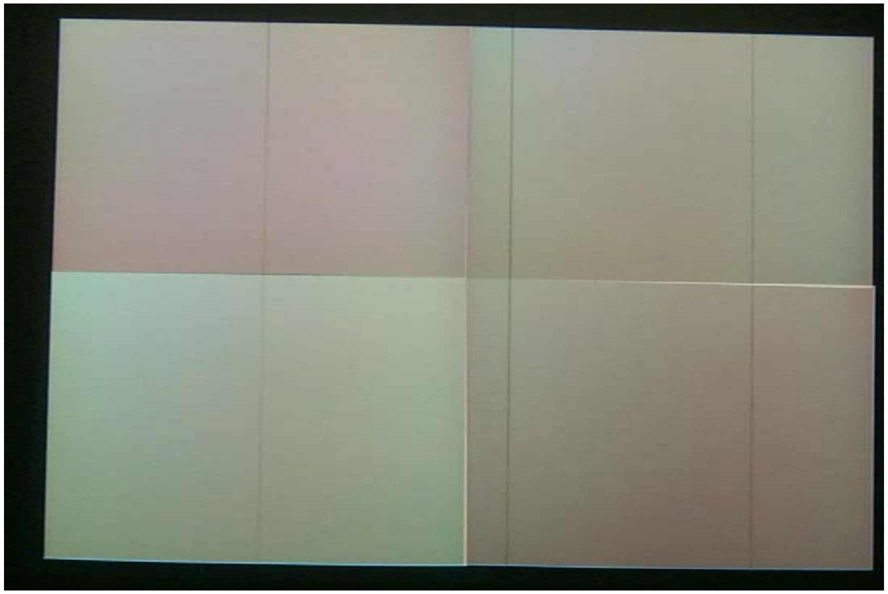


The Problem





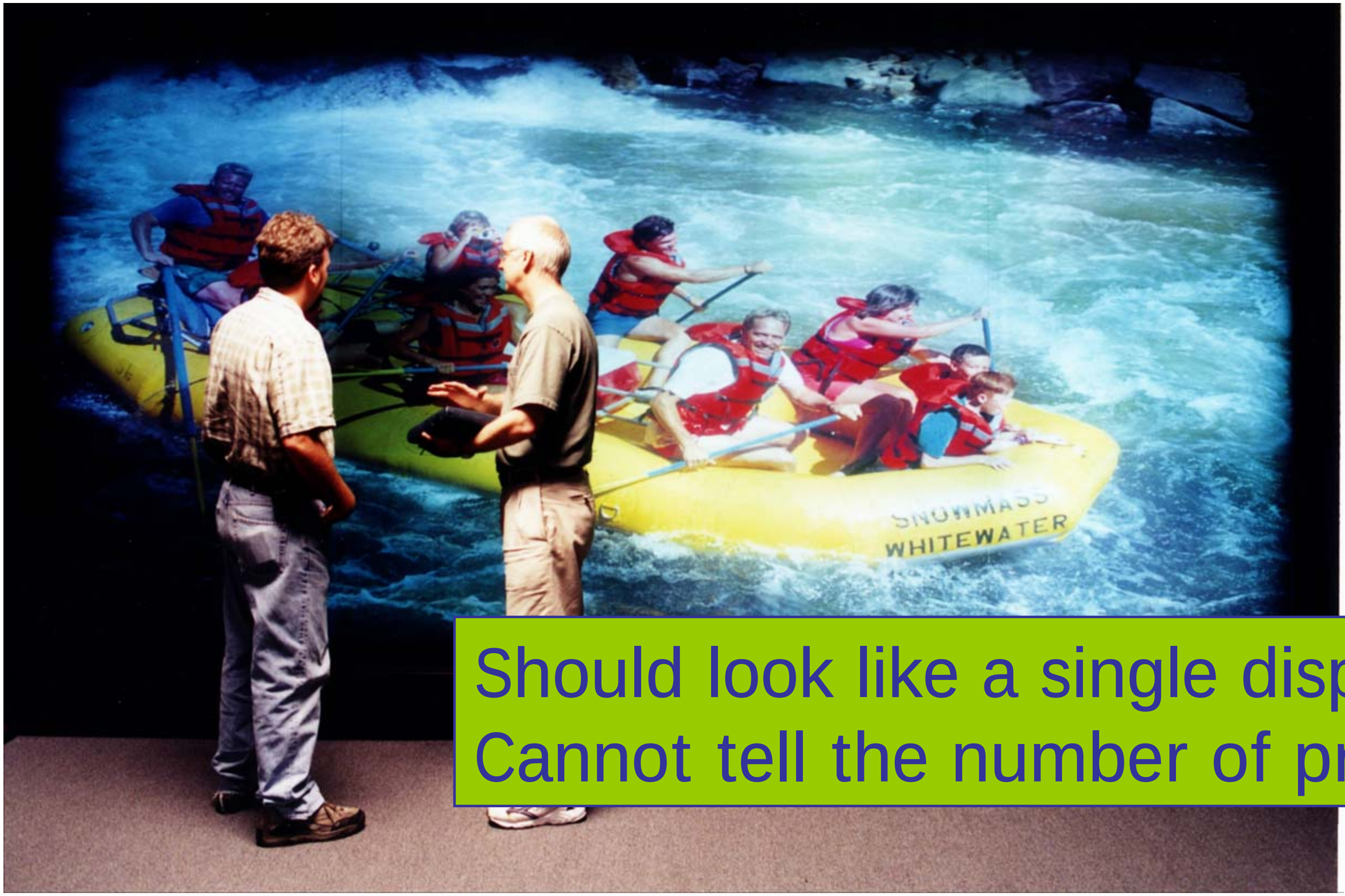
Overlapping



Abutting

The Goal

The Goal



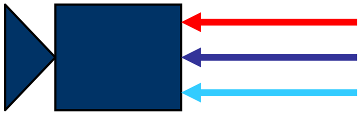
Should look like a single display
Cannot tell the number of projectors

Background: Color

- Perceptual Representation
  - Luminance $(\mathcal{L})$
    - Brightness

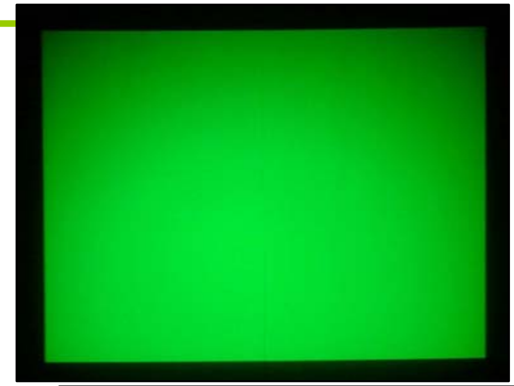
  - Chrominance (x , y)
    - Hue and Saturation

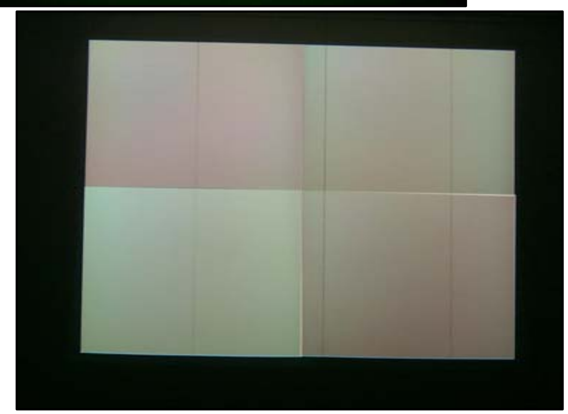
- Representation Using Primaries
  - Three channels (Red, Green, Blue)
- Color Gamut

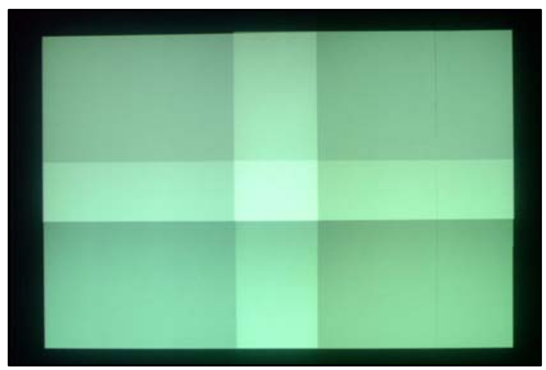


Properties of Color Variation

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







Luminance variation is more significant

1) *A. Majumder, Properties of Color Variation in Multi Projector Displays, SID Eurodisplay, 2002.*
2) *A. Majumder and R. Stevens, Color Non-Uniformity in Multi Projector Displays: Analysis and Solutions, IEEE Transactions on Visualization and Computer Graphics, Vol. 10, No. 2, 2003.*

Existing Methods

- Edge Blending
- Gamut Matching
- PRISM

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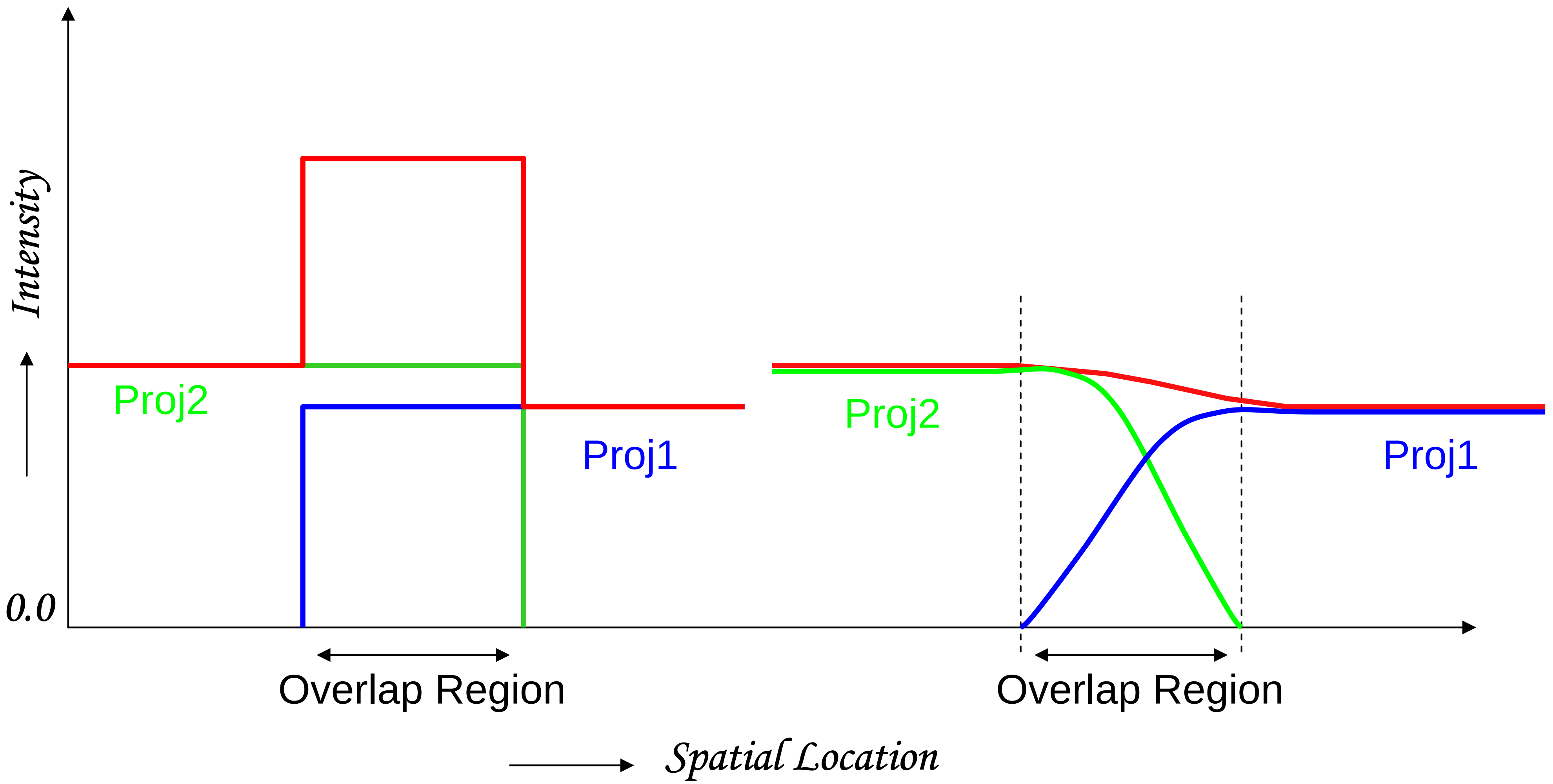
- PRISM

Edge Blending

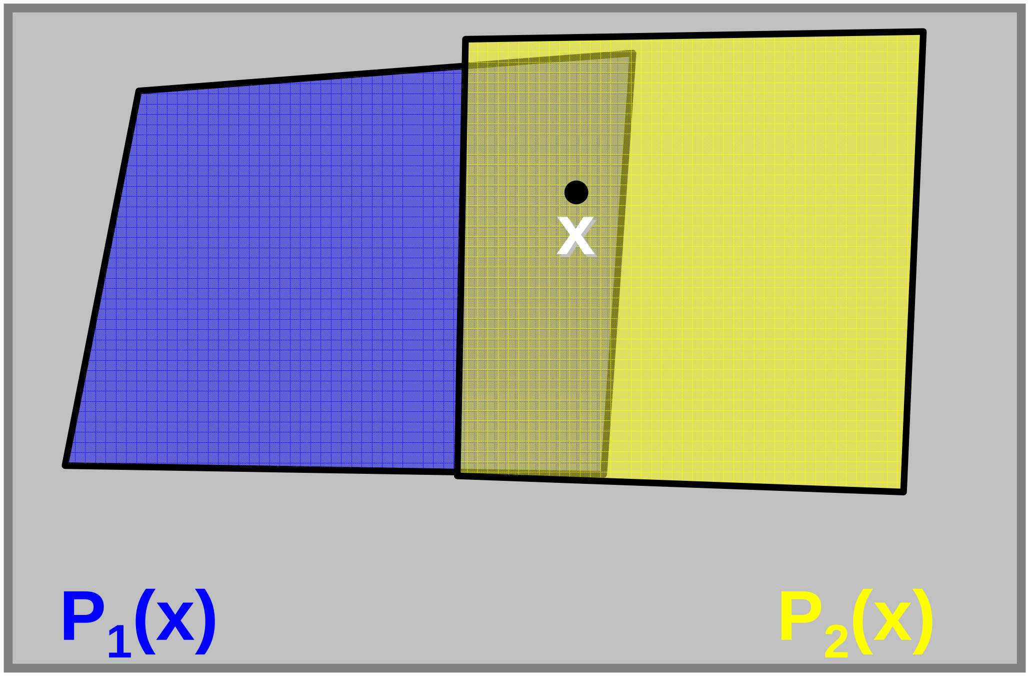


Edge Blending

- Software Edge Blending
- Aperture Edge Blending

Software Edge Blending

Camera image



x has contributions from $P_1(x)$ and $P_2(x)$

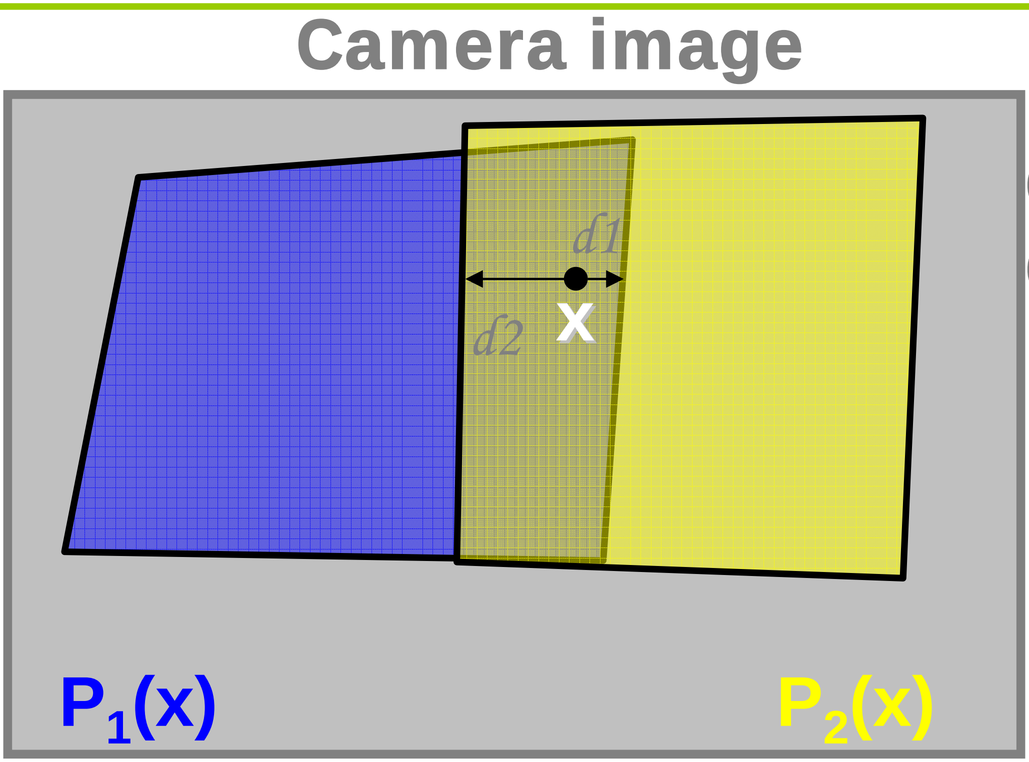
Intensity at x:
$\alpha_1(x)P_1(x) + \alpha_2(x)P_2(x)$

Find alpha such that:
$\alpha 1(x) + \alpha 2(x) = 1$

Algorithm

Assign intensity weights based on *x*'s distance from projector boundaries

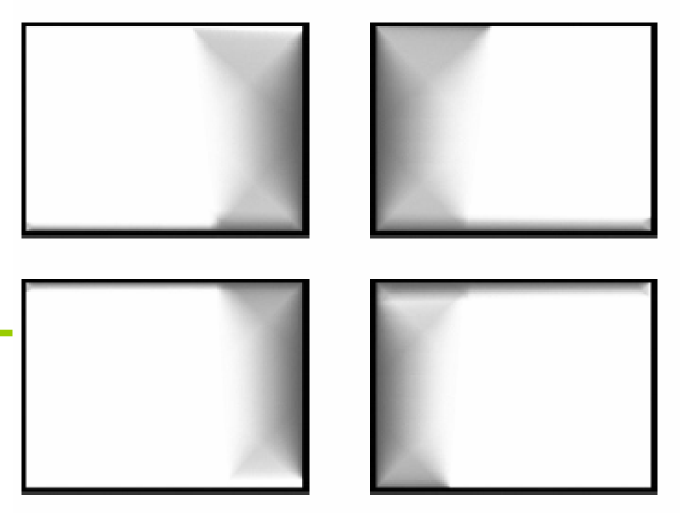
Assigning Intensity Weights



d1=x's distance to $\mathbf{P_1}$'s boundary
d2=x's distance to $\mathbf{P_2}$'s boundary

Results

Cannot attenuate the blacks



Computed Alpha Masks

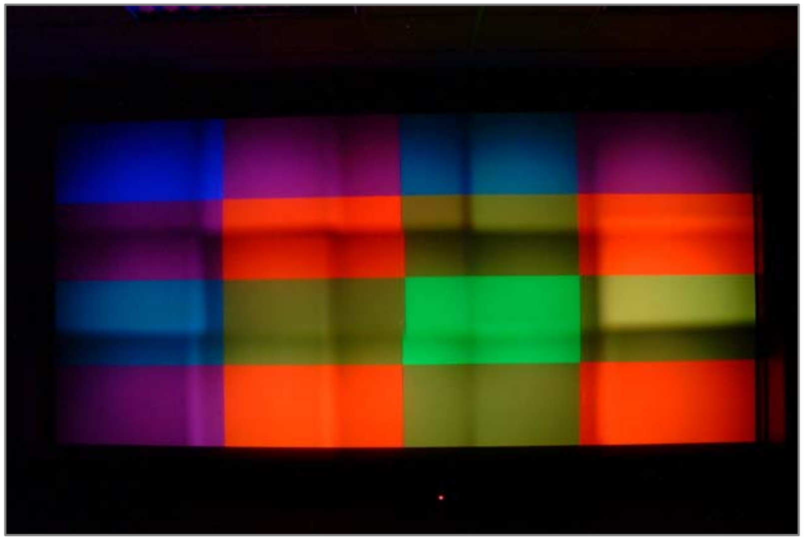
Before

Software Blending

1) Lyon Paul, *Edge-blending Multiple Projection Displays On A Dome Surface To Form Continuous Wide Angle Fields-of-View,* *Proceedings of 7th I/ITEC, 203-209, 1985.*
2) R. Raskar et al, *Seamless Camera-Registered Multi-Projector Displays Over Irregular Surfaces,* *Proceedings of IEEE Visualization, 161-168, 1999.*

Aperture Edge Blending

Before

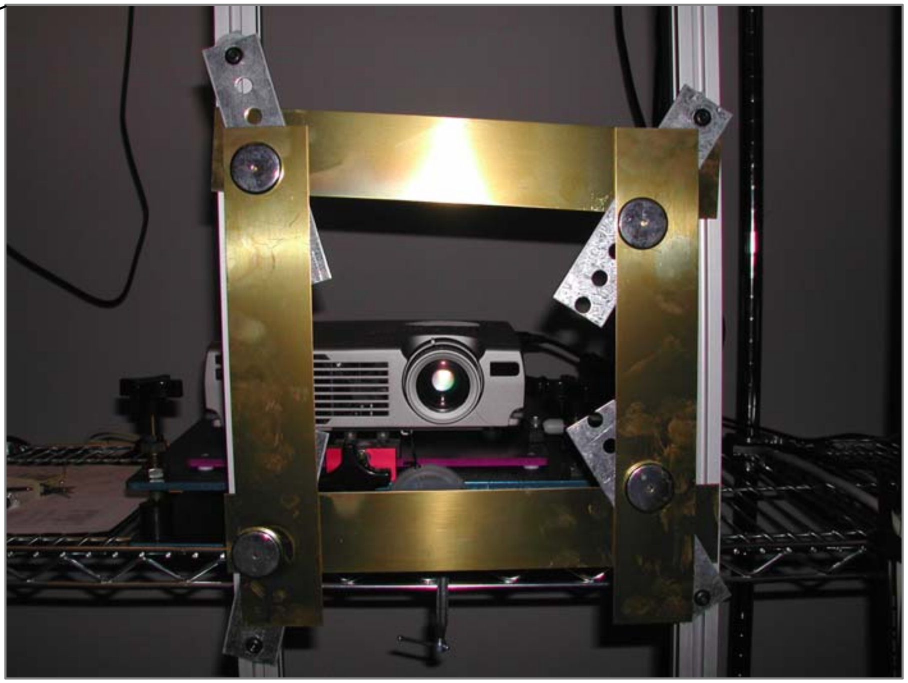


Aperture Blending

Aperture Edge Blending

Before

Aperture Blending



K. Li et.al, Early experiences and challenges in building and using a scalable display wall system, IEEE Computer Graphics and Applications 20(4), 671-680, 2000. [Aperture Edge Blending]

Edge Blending

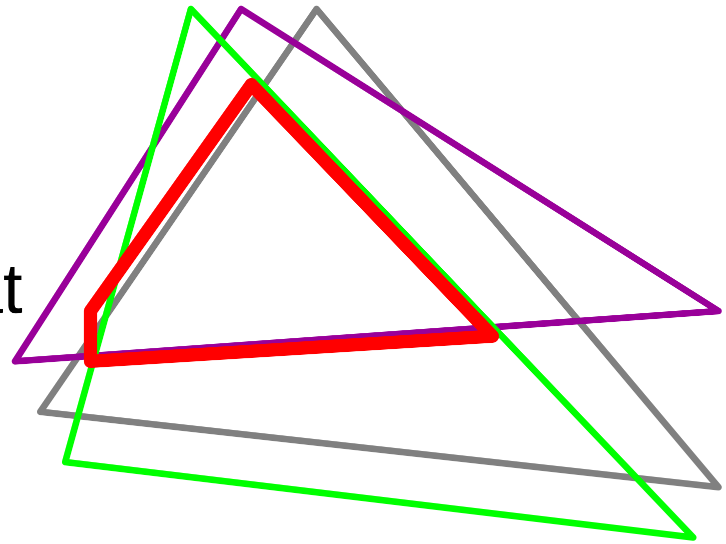
- Scalable
- Can be used in overlapping configuration only
  - Addresses only overlap variation
- Not enough control (Aperture)
- No black attenuation (Software)
- Assumes linearity of projector response
- Works if projectors are adjusted to be very similar

Existing Methods

- Blending
- Gamut Matching
- PRISM

Gamut Matching

- Use a photometer to capture the color gamut
  - One measurement per projector
- Find the common color gamut that all the projectors can reproduce
- Use linear transformations to achieve the matching



1) *G. Wallace, H. Chen, and K. Li, Color gamut matching for tiled display walls, Immersive Projection Technology Workshop, 2003.*
2) *M. Bern and D. Eppstein, Optimized color gamuts for tiled displays, 19th ACM Symposium on Computational Geometry, 2003.*

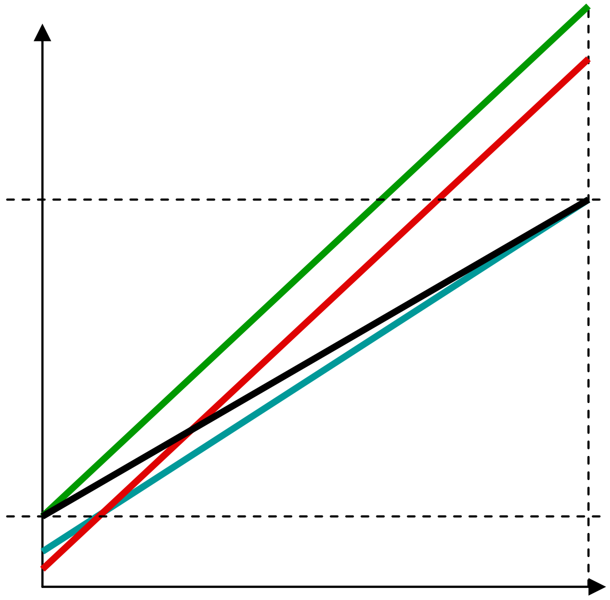
Gamut Matching

- Can be used in abutting configuration only
  - Addresses only inter projector variation
- Not scalable to 40-50 projectors
  - Due to algorithmic complexity

1) *M.C. Stone, Color balancing experimental projection displays, 9th IS&T/SID Color Imaging Conference, 2001.*
2) *M. C. Stone, Color and brightness appearance issues in tiled displays, IEEE Computer Graphics and Applications, 2001.*

Matching Transfer function

- Assume chrominance is spatially constant



A. Majumder, Z. He, H. Towles and G. Welch, Achieving Color Uniformity in Multi-Projector Displays, IEEE Visualization, 2000.

Existing Methods

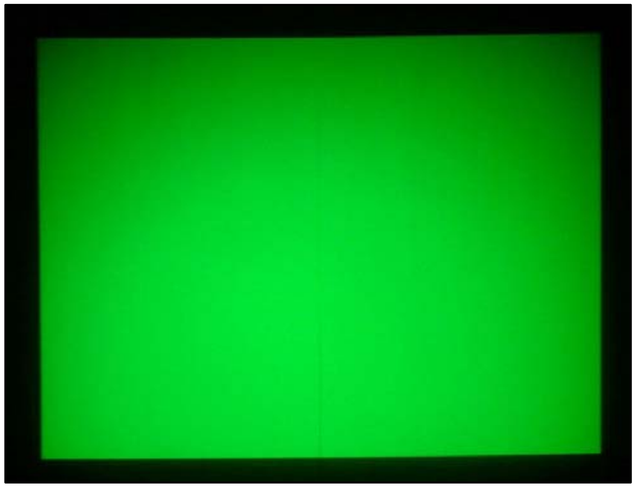
- Blending
- Gamut Matching
- PRISM: PeRceptual Seamlessness in Multi-Projector Displays

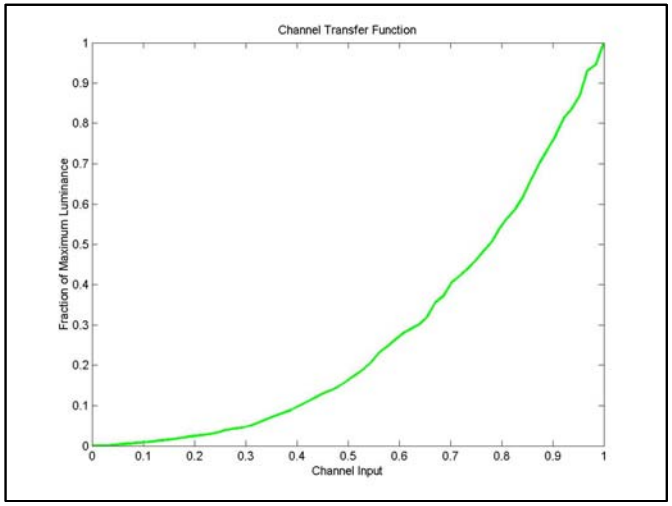
What we want?

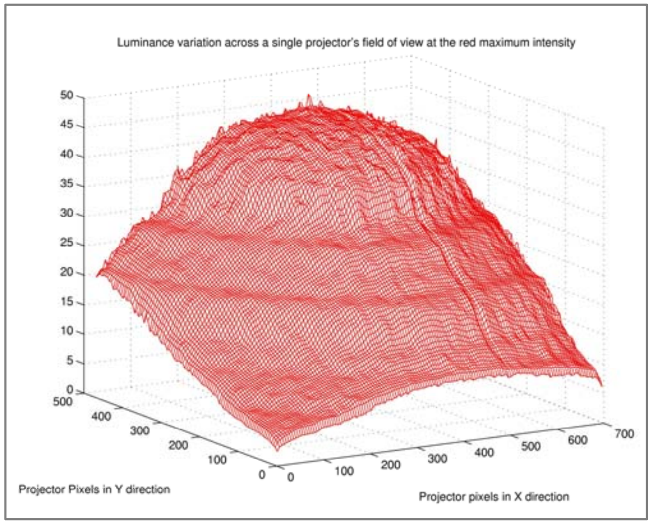
- Addresses parts of the problem only
  – Blending : Overlaps
  – Others: Inter Projector Variations
- Intra-projector variation not addressed
  – Spatial variation
- Desire an unified method
  – Takes care of inter, intra and overlap together

Intra-Projector Luminance Variation

- Spatial luminance variation
  - – Luminance function
- Constant transfer function

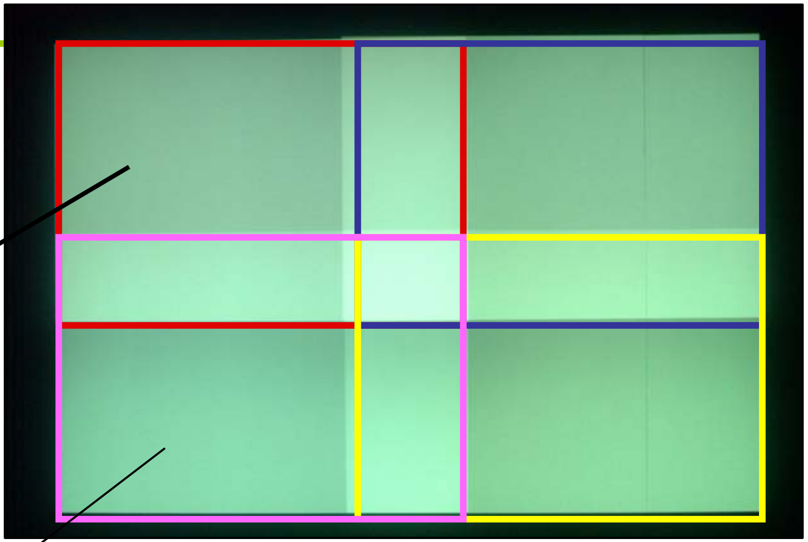


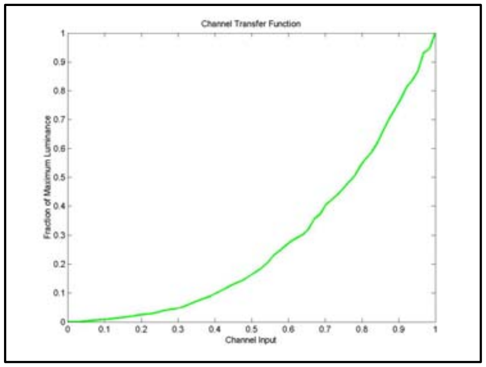


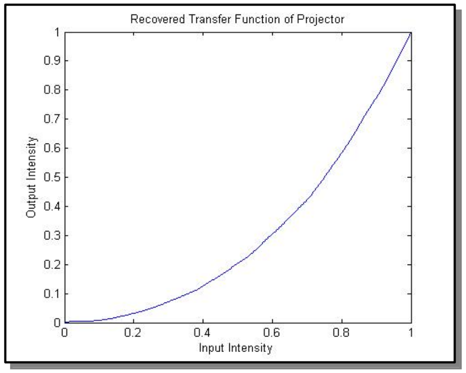


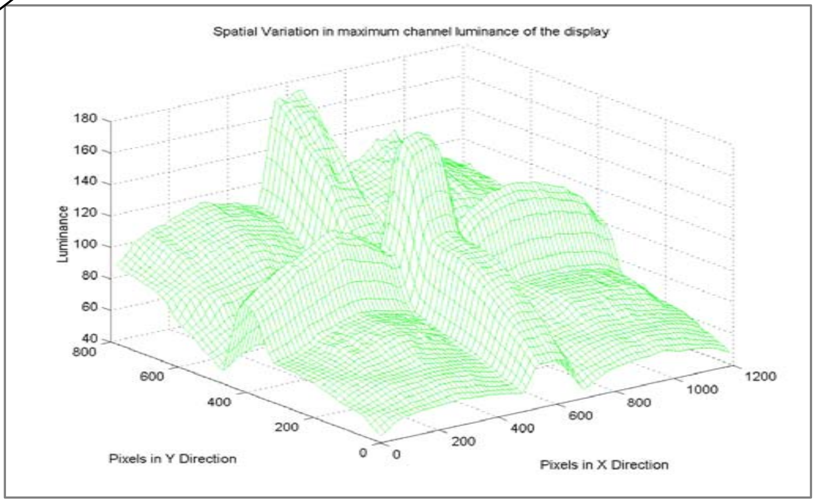
Display Luminance Variation

- Add luminance function of each projector









PRISM

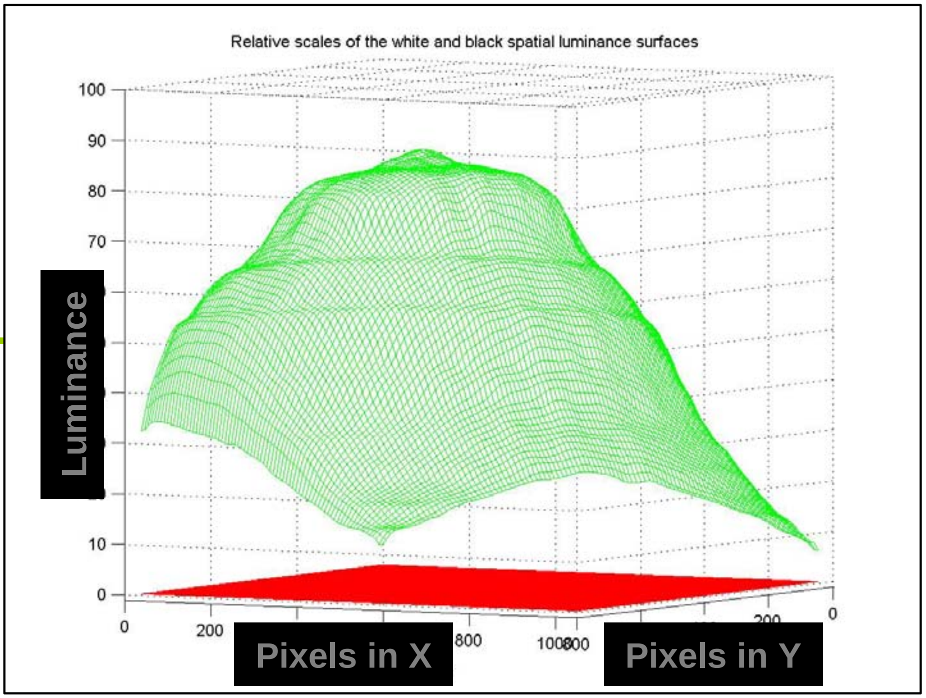
- Reconstruction
- Modification
- Reprojection

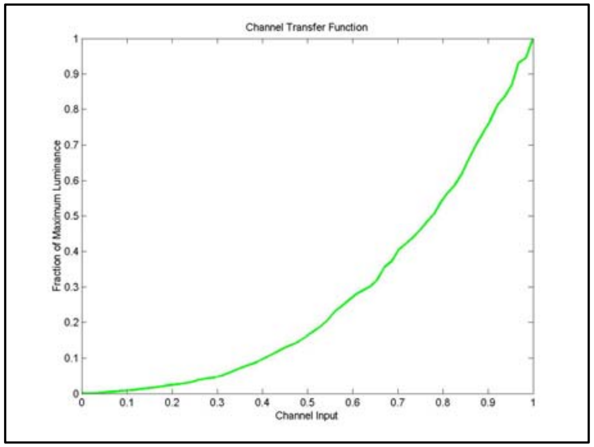
PRISM

- Reconstruction
- Modification
- Reprojection

Each projector

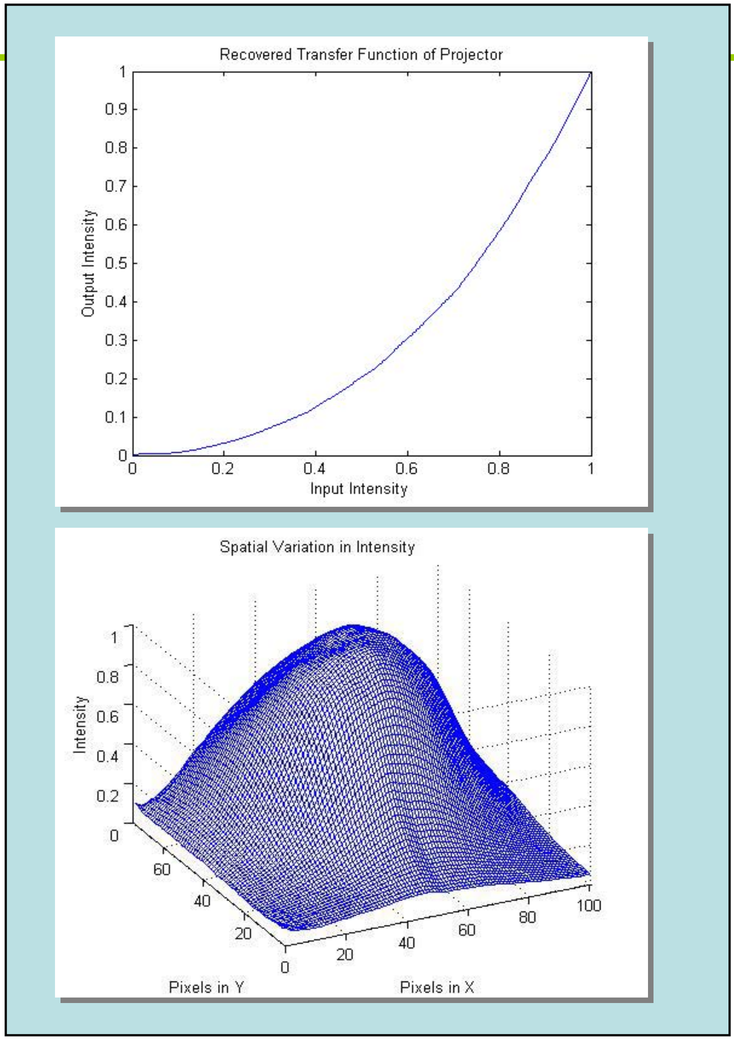
- Using a camera find
  - Luminance function
  - Black Offset
  - Transfer function
- How to calibrated camera?
  - HDR imaging



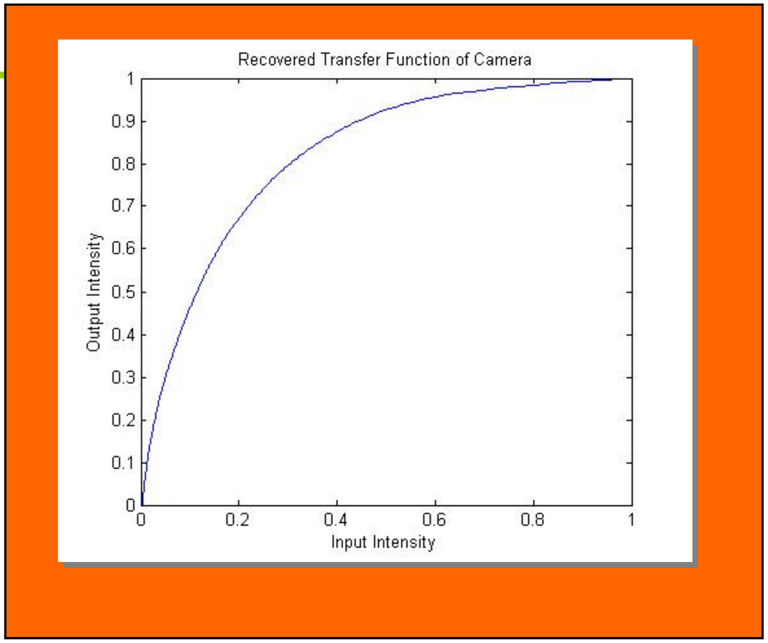


1) A. Majumder, R. Stevens, *LAM: Luminance Attenuation Map for Photometric Uniformity Across Projection Based Displays,* ACM Virtual Reality Software and Technology, 2002.
2) A. Raij, G. Gill, A. Majumder, H. Towles, H. Fuchs, *PixelFlex2: A Comprehensive, Automatic, Casually-Aligned Multi-Projector Display,* IEEE PROCAMS, 2003

Projector-camera self-calibration



Projector

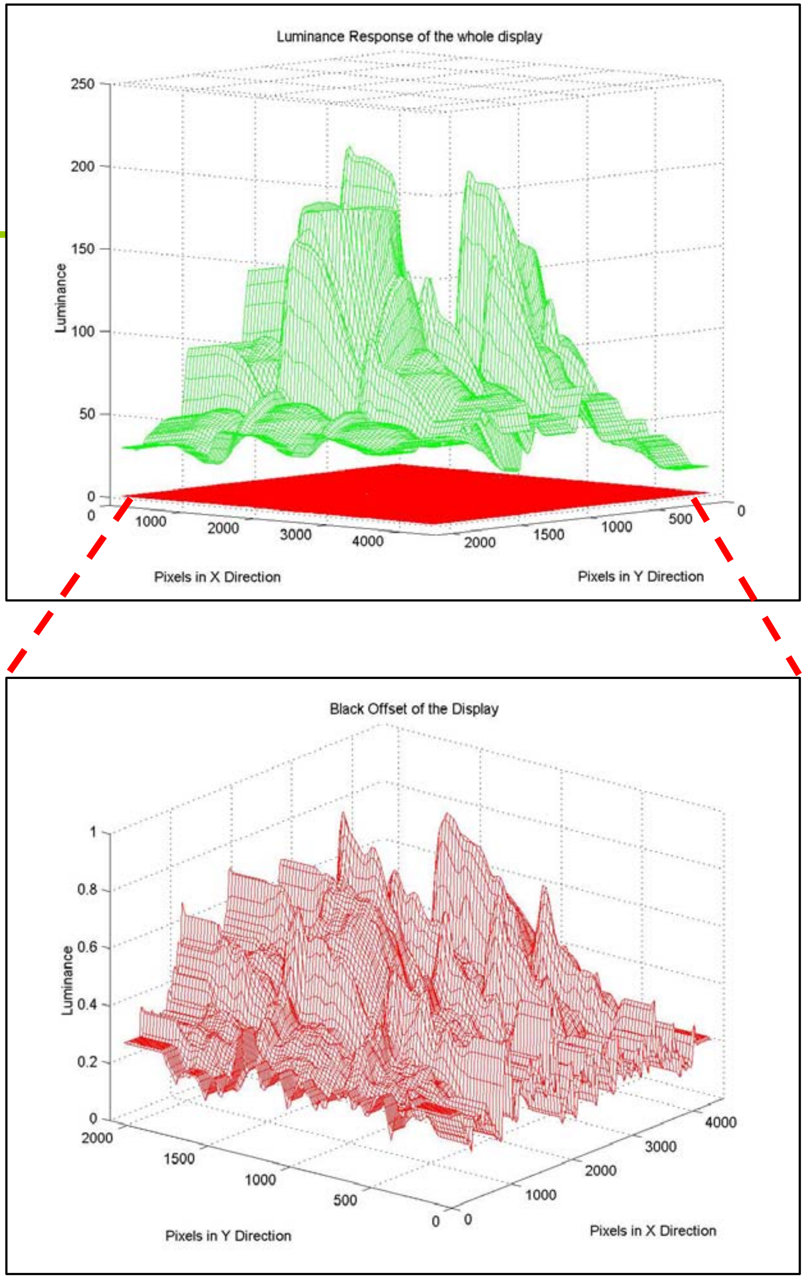


Camera

1) *R. Juang, E. Bhasker, A. Majumder, Registration Techniques for Using Imperfect and Partially Calibrated Devices in Planar Multi-Projector Displays, IEEE Visualization, 2007.*
2) *R. Juang, A. Majumder, Photometric Self-Calibration of Projector-Camera Systems, IEEE PROCAMS 2007.*

Display

- Add luminance functions of all projectors



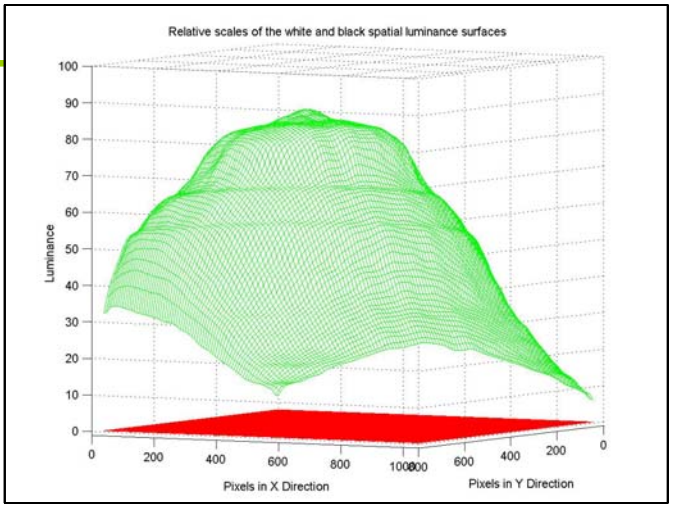
15 Projector Display

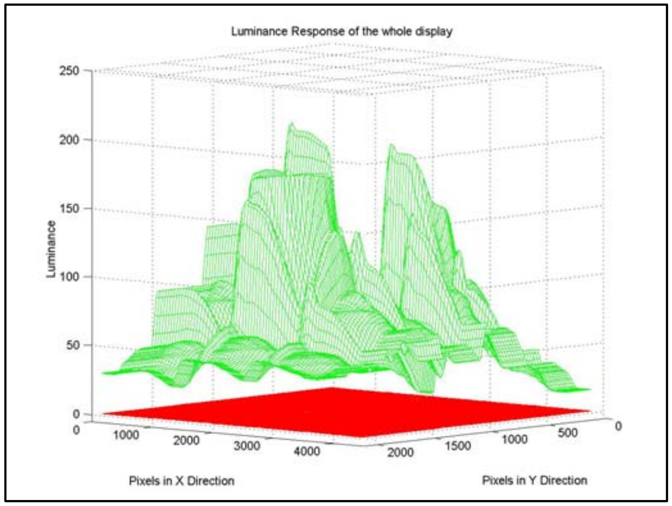
PRISM

- Reconstruction
- Modification
- Reprojection

Goal: Make it look like one projector

- Single projector
  - Constant transfer function
  - Luminance function does not have sharp changes
- Multi-projector
  - Varying transfer function
  - Luminance function shows sharp changes





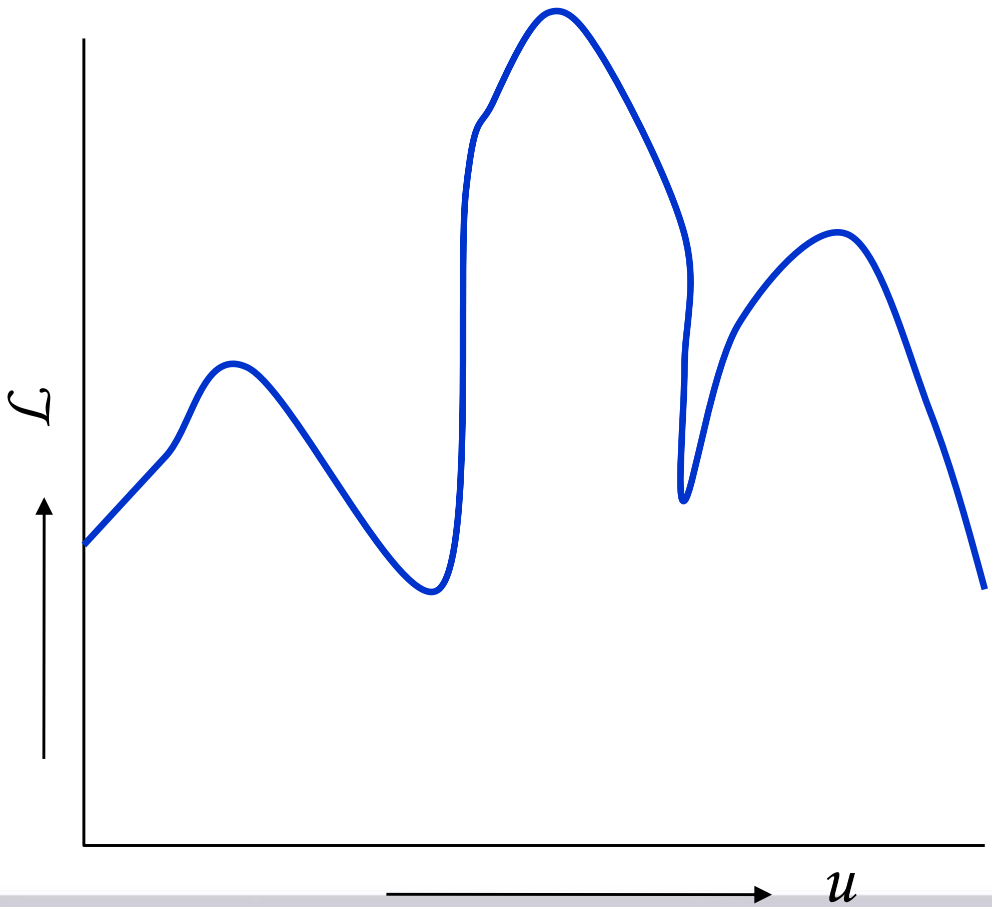
Modification

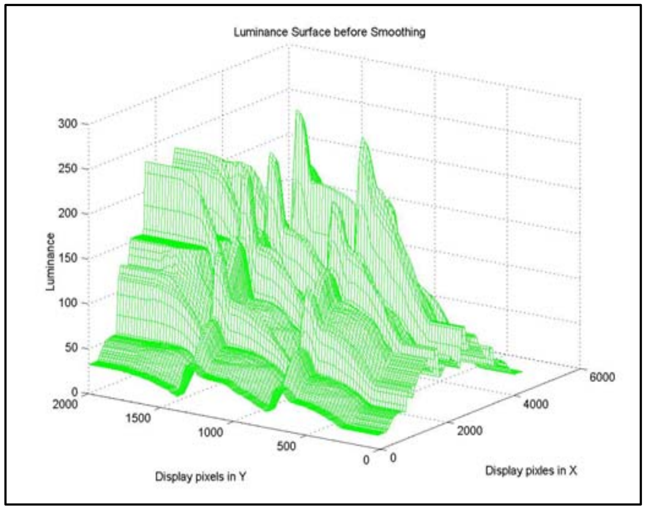
- Design a new luminance function that does not have sharp discontinuities
- Design a common transfer function for all projectors

Modification

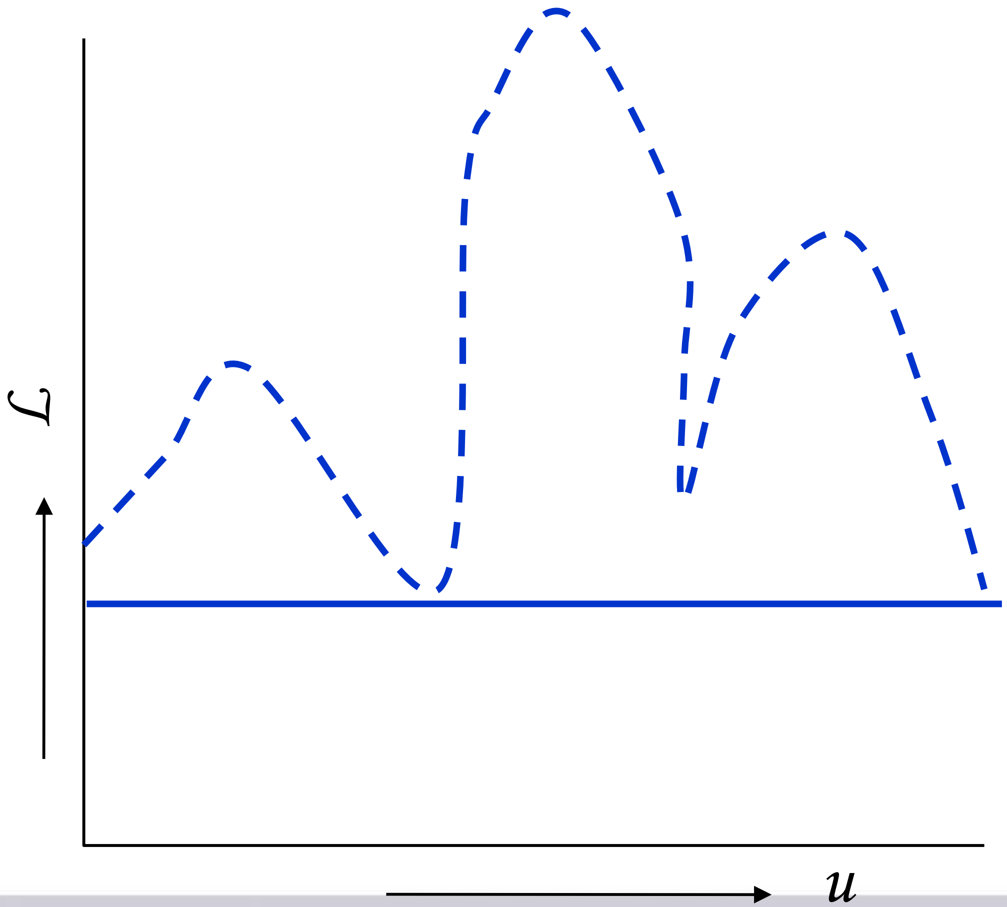
- Design a new luminance function that does not have sharp discontinuities
- Design a common transfer function for all projectors

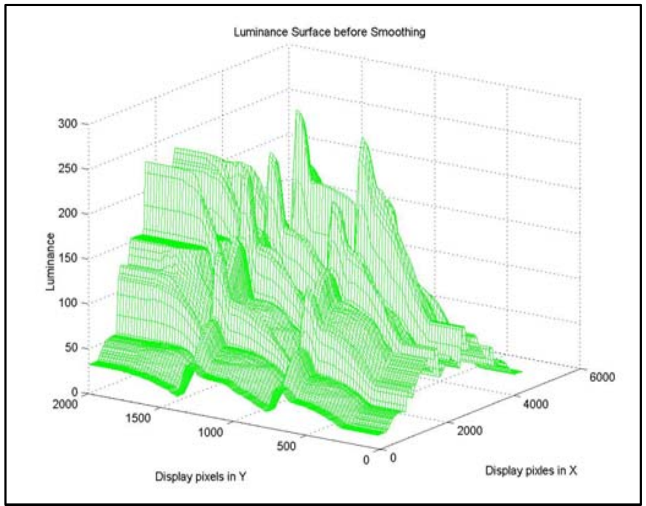
Strict Luminance Uniformity

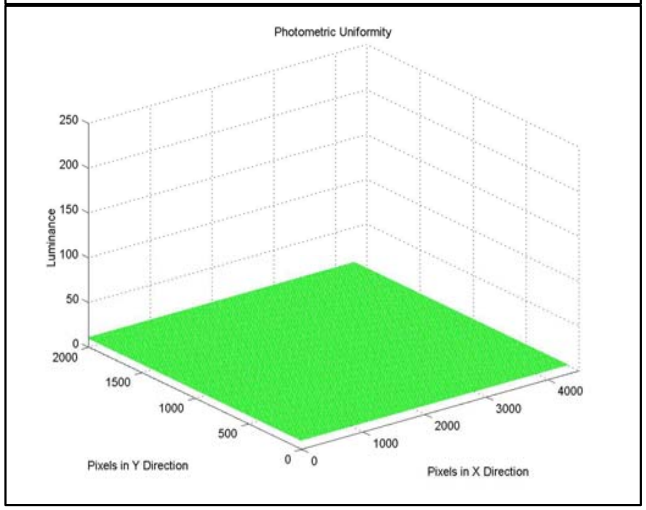




Strict Luminance Uniformity







Results

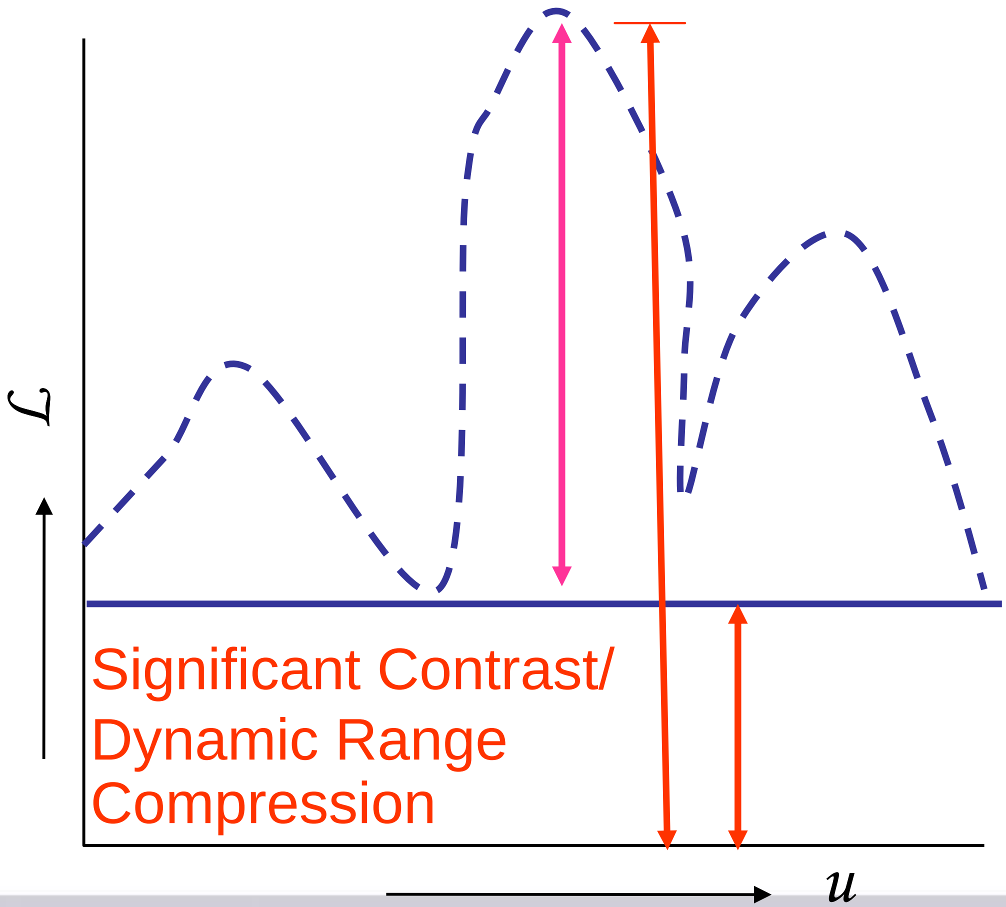
Before

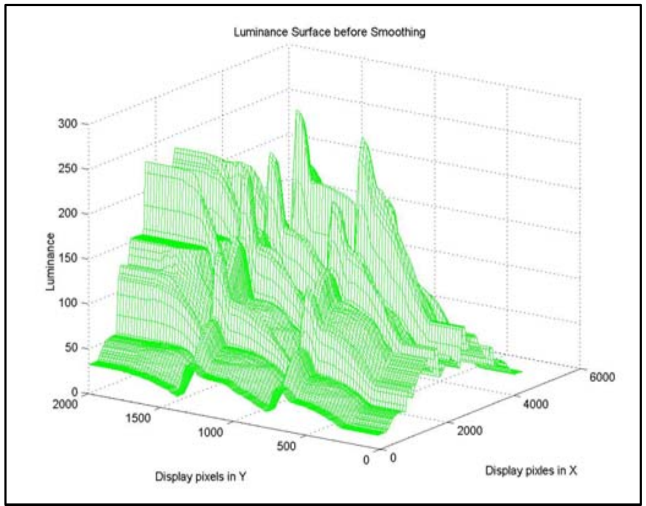
After Strict Luminance Uniformity

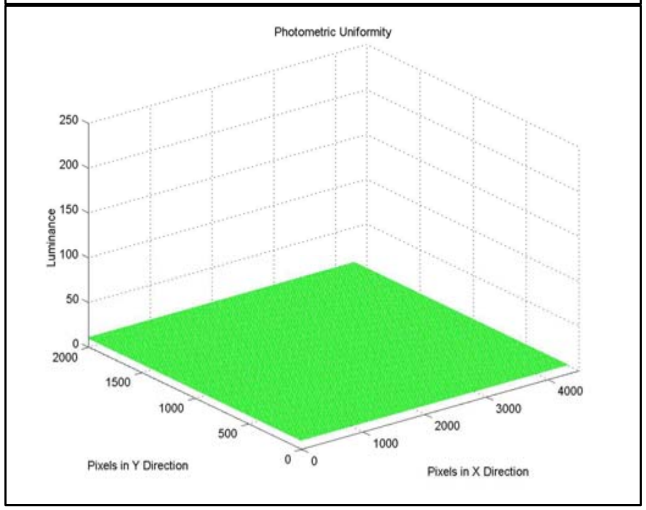
A. Majumder and R. Stevens, Color Non-Uniformity in Multi Projector Displays: Analysis and Solutions, IEEE Transactions on Visualization and Computer Graphics, Vol. 10, No. 2, 2003.

Strict Luminance Uniformity

Suboptimal use of system resources







Results

Before

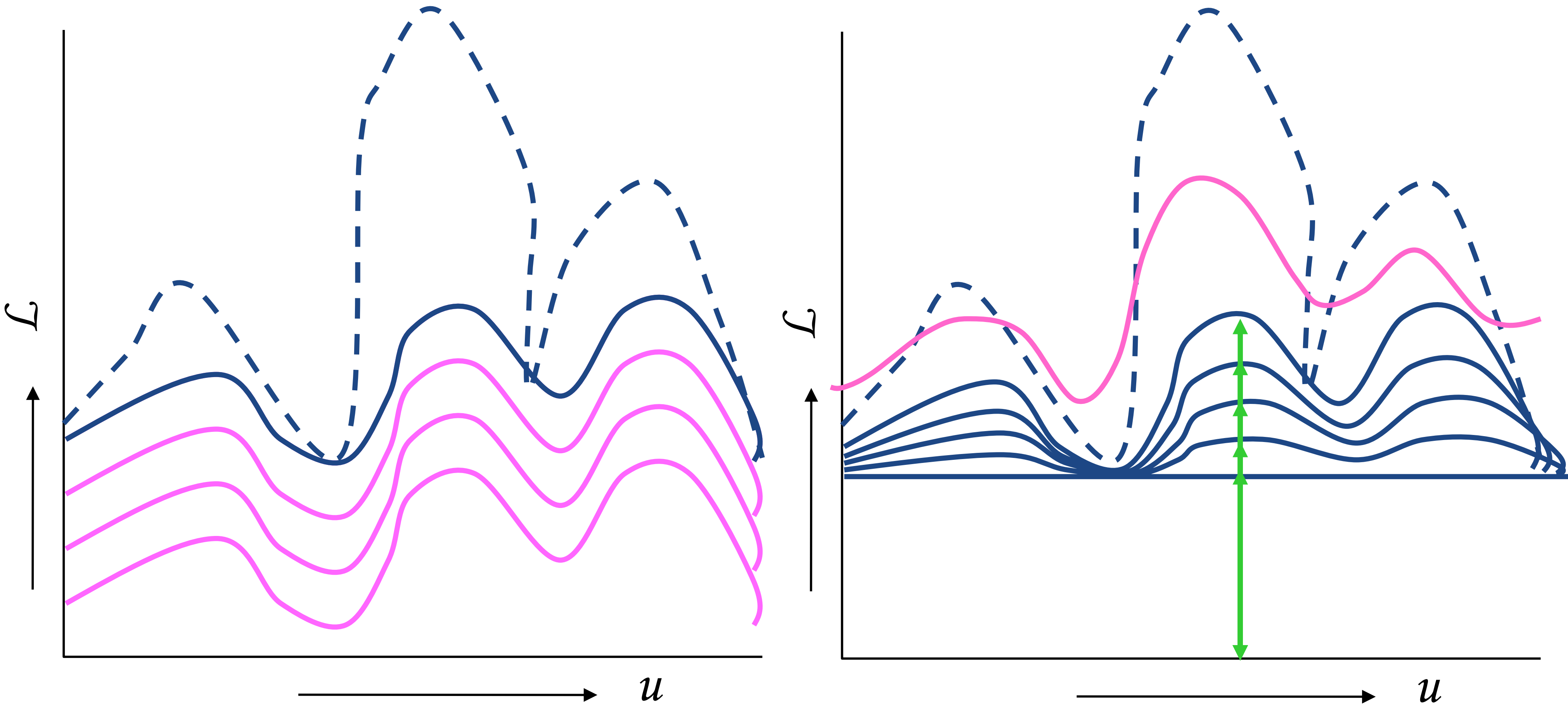
Which one is better?

After Strict Luminance Uniformity

Optimization Problem

- Smoothing $P(x,y)$ to generate $F(x,y)$
  - Maximize dynamic range $\sum F(x,y)$
  - Smoothing guided by perceptual parameters
    - $F'(x,y) \leq kF(x,y), 0.0 \leq k \leq 1.0$
    - Assures no *visible* seams
  - Smoothened profile within the original profile
    - $F(x,y) \leq P(x, y)$
    - Assures with display capability
  - Optimal solution using dynamic programming

Optimization Problem



Strict photometric uniformity is a special case.

Results

Before

After Strict Luminance Uniformity

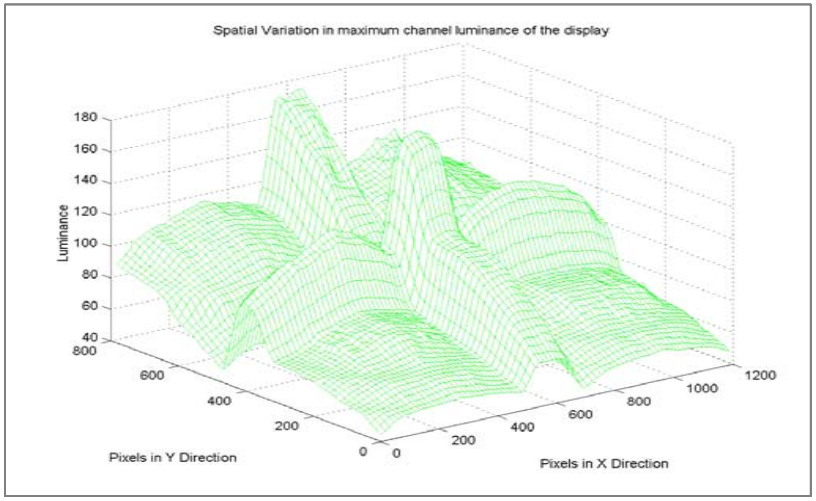
Results

Before

After Luminance Smoothing

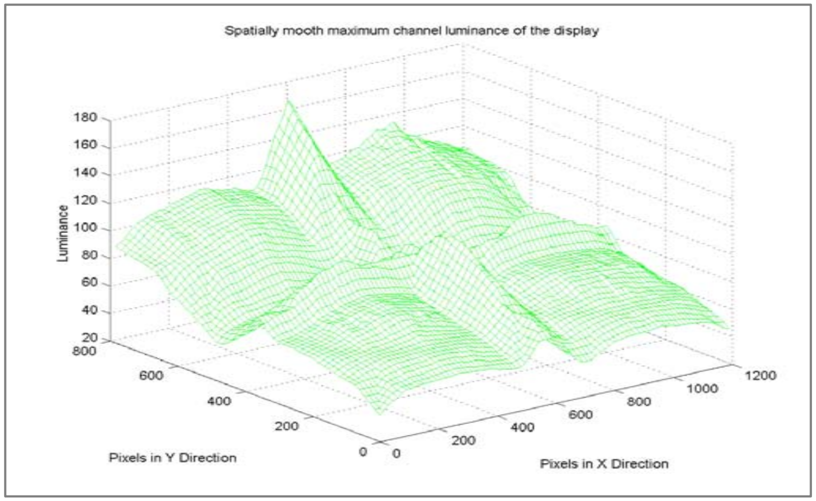
1) *A. Majumder, R. Stevens, Perceptual Photometric Seamlessness in Tiled Projection Based Displays, ACM Transactions on Graphics, Vol. 24, No. 1, 2005.*
2) *A. Majumder, Improving Contrast of Multi-Displays Using Human Contrast Sensitivity, IEEE CVPR 2005.*

Different Smoothing Parameter (2x2 array of four projectors)

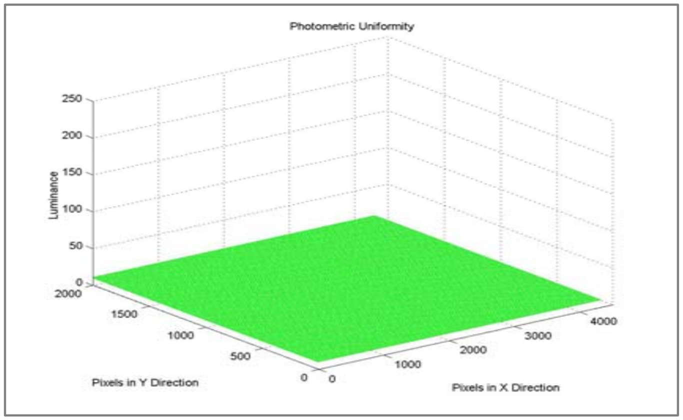


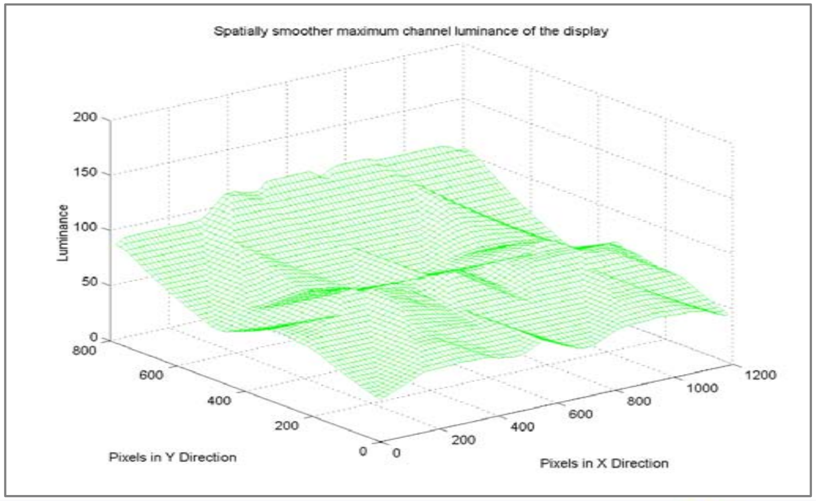
Original

Smooth



Flat





Different Smoothing Parameter (3x5 array of 15 projectors)

Smooth

Original

Smoother

Flat

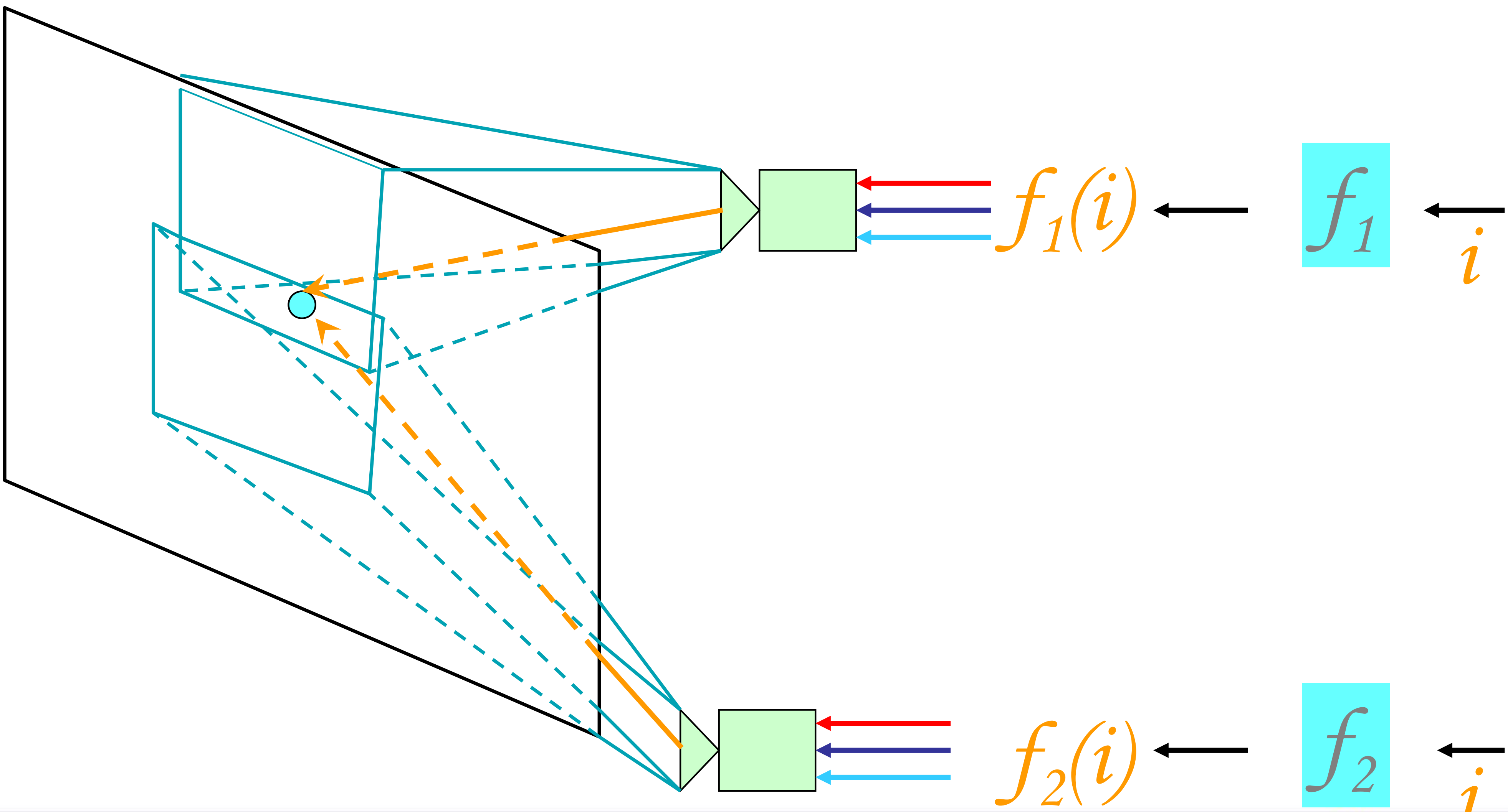
Modification

- Design a new luminance function that does not have sharp discontinuities
- Design a common transfer function for all projectors
  - Usually a quadratic function is good

PRISM

- Reconstruction
- Modification
- Reprojection

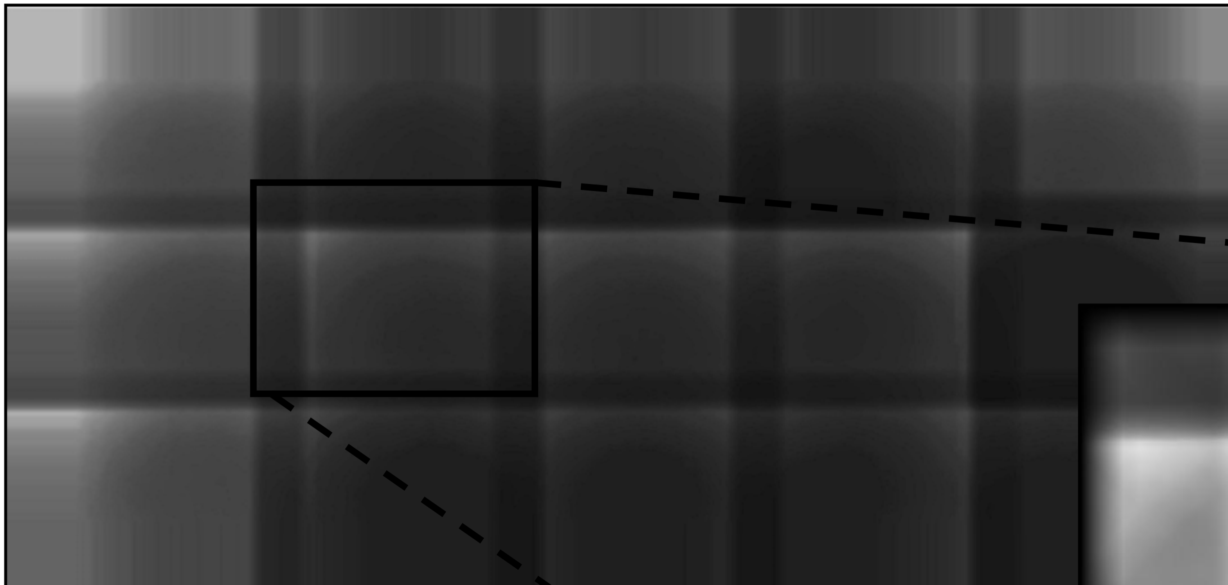
How to modify input?



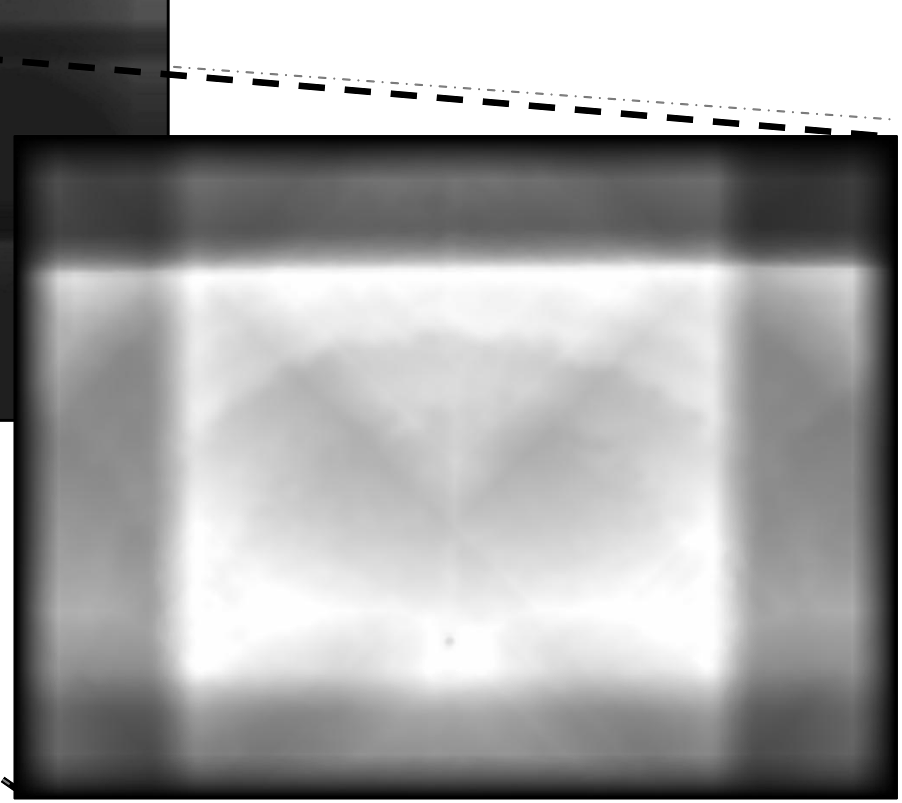
Smoothing Maps

- 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

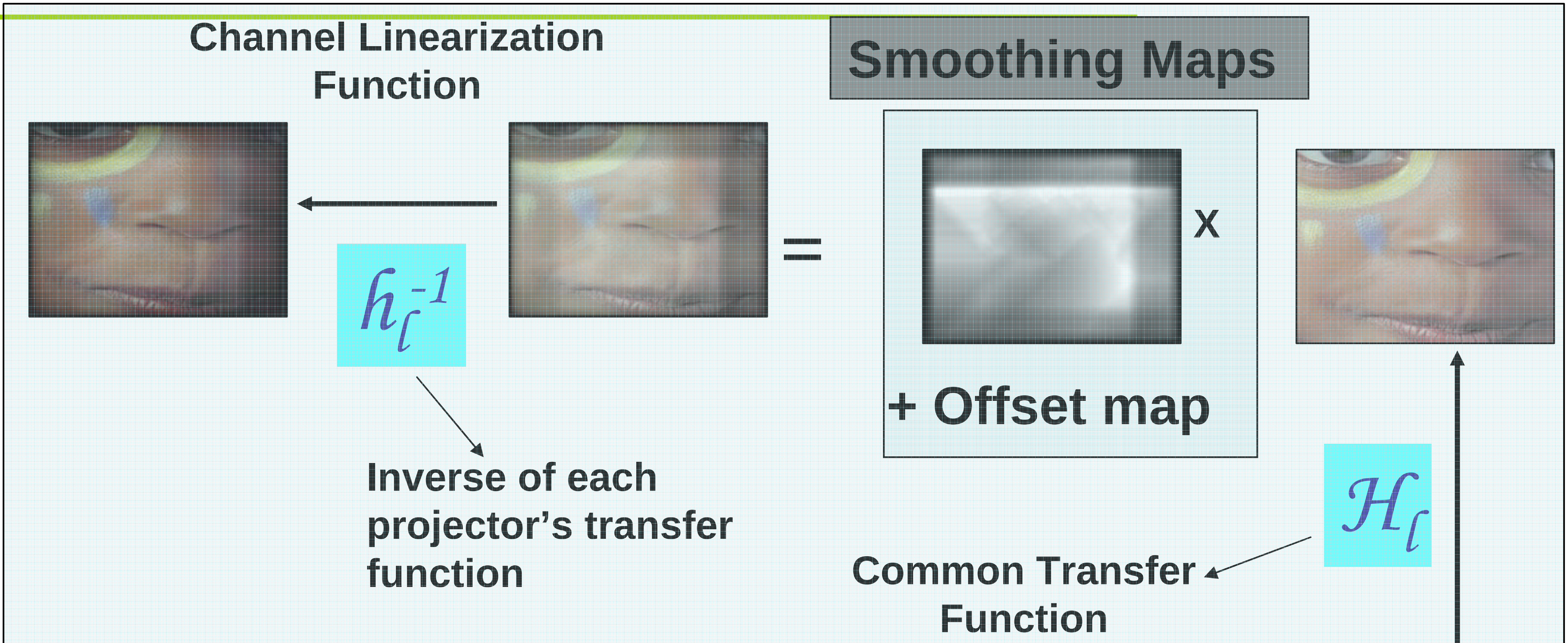


Display Attenuation Map
(15 projector display)



Projector Attenuation Map

Per Projector Image Correction

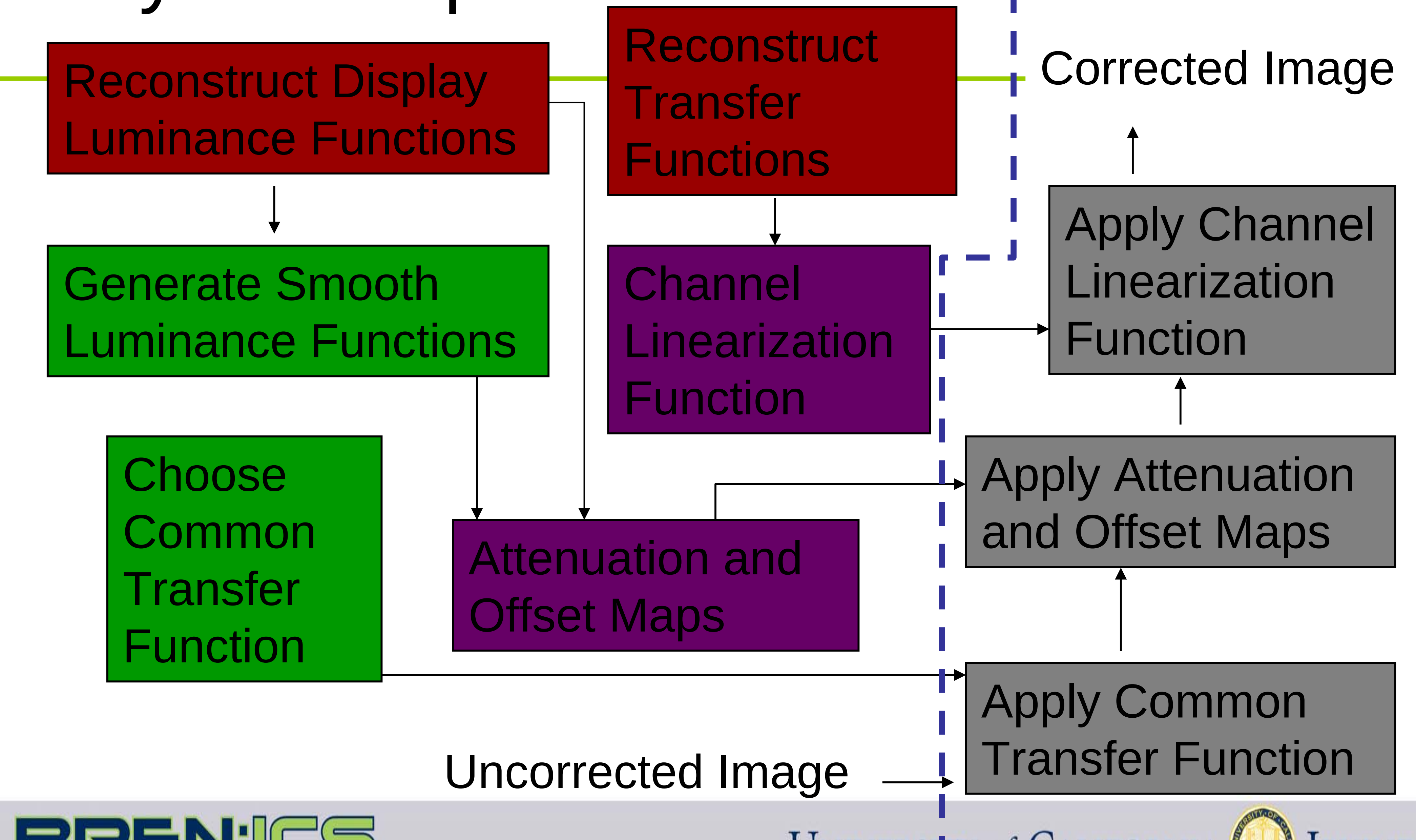


A. Majumder, R. Stevens, Perceptual Photometric Seamlessness in Tiled Projection Based Displays, ACM Transactions on Graphics, Vol. 24, No. 1, 2005.

System Pipeline

OFF-LINE CALIBRATION

ON-LINE IMAGE CORRECTION



Results (Before)

6 Projector Display

Results (After)

Results (Before)

15 Projector Display

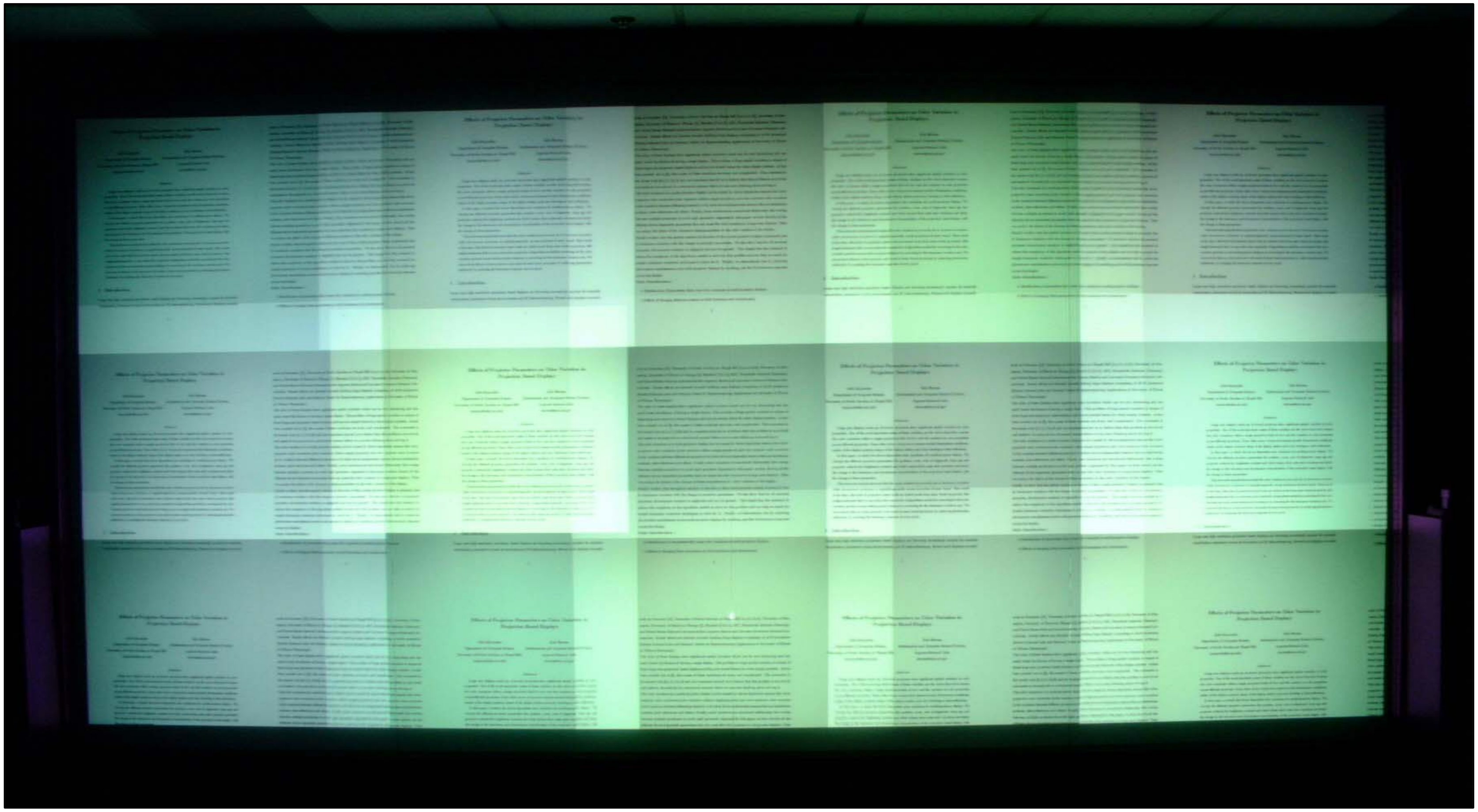
Results (After)

Summary

Method	Addresses..	
Edge Blending	Overlap	Luminance Only
Gamut matching	Inter	Luminance and Chrominance
PRISM	Intra + Inter + Overlap	Luminance Only

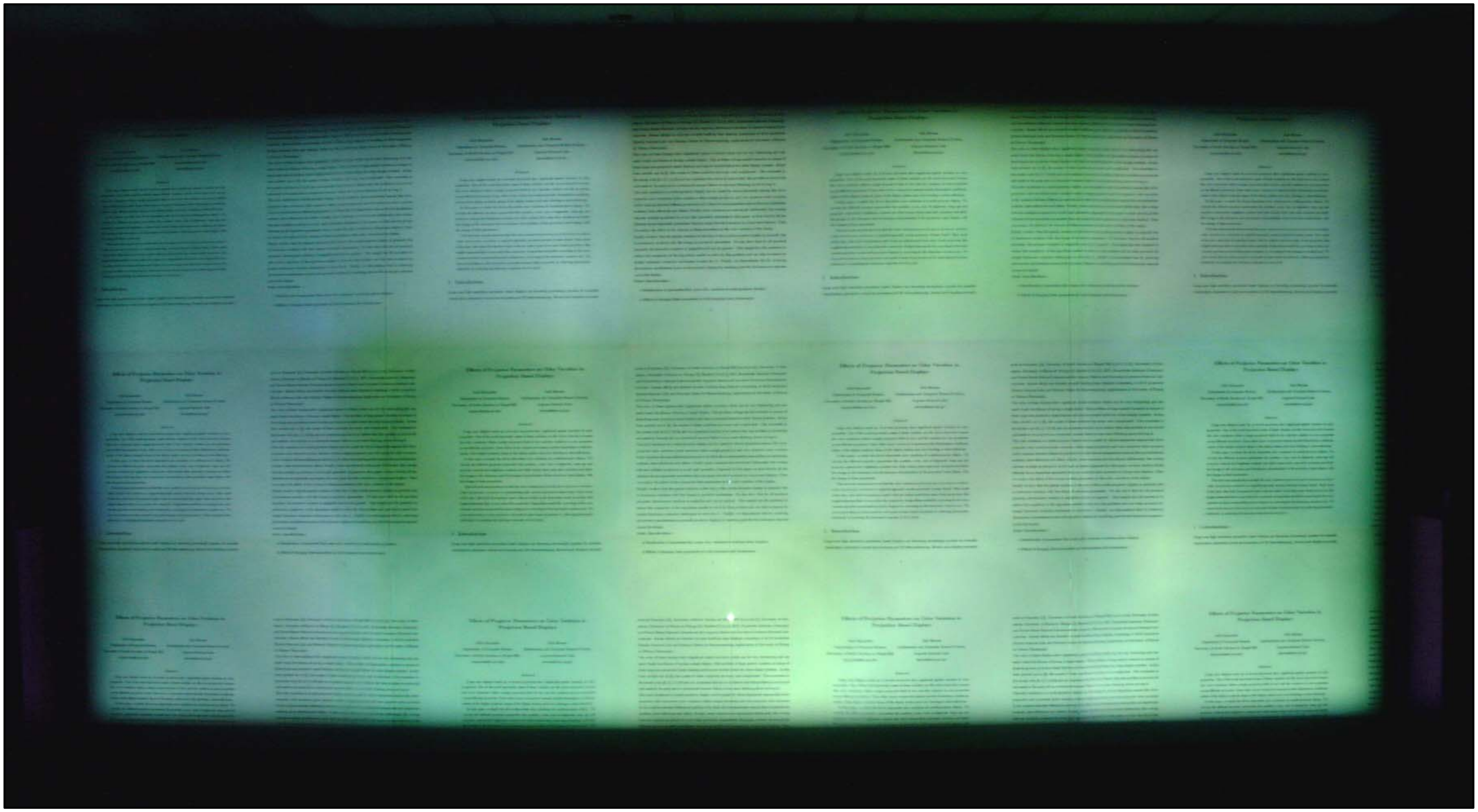
Handling Chrominance

Before

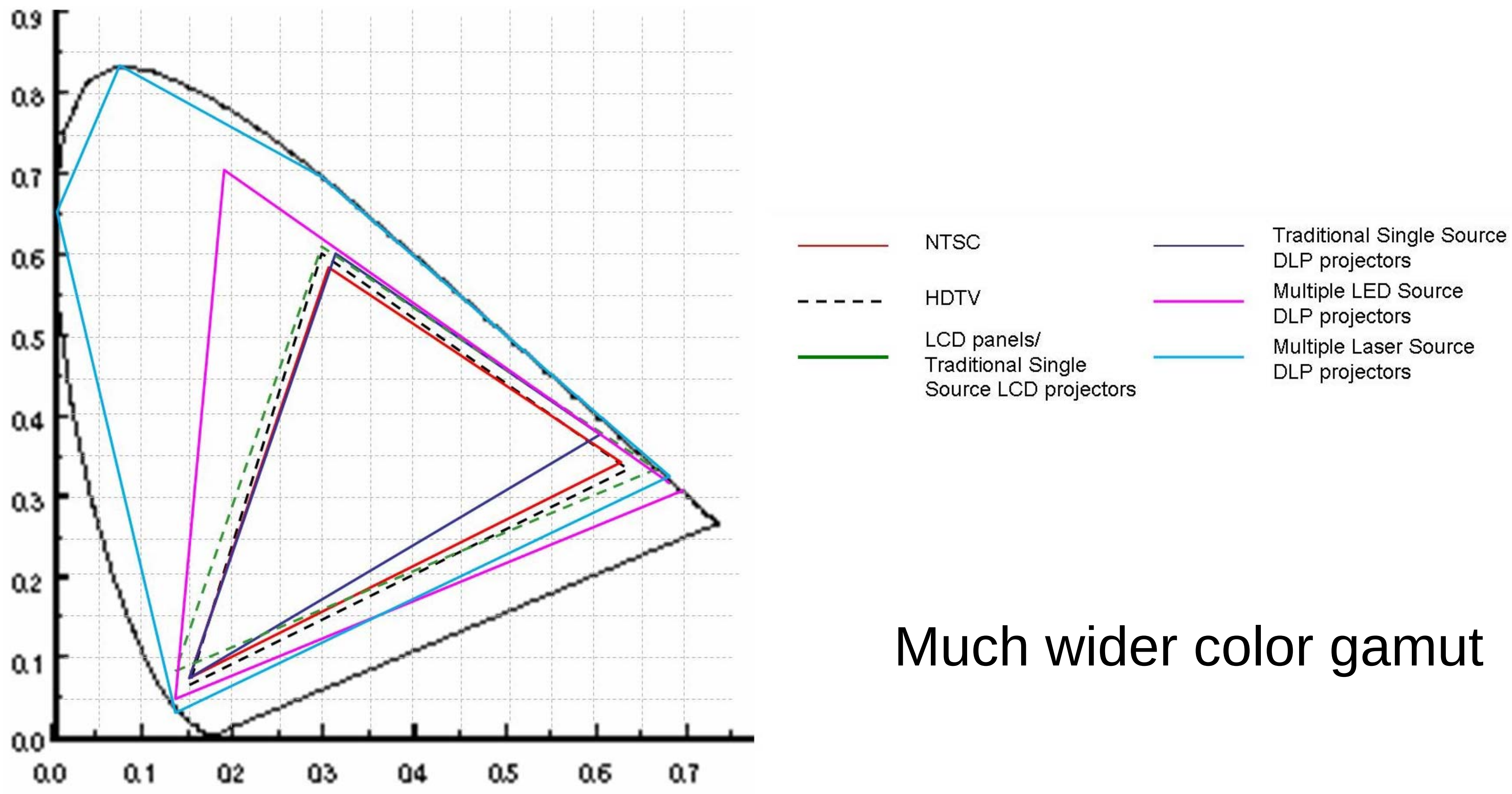


Handling Chrominance

After

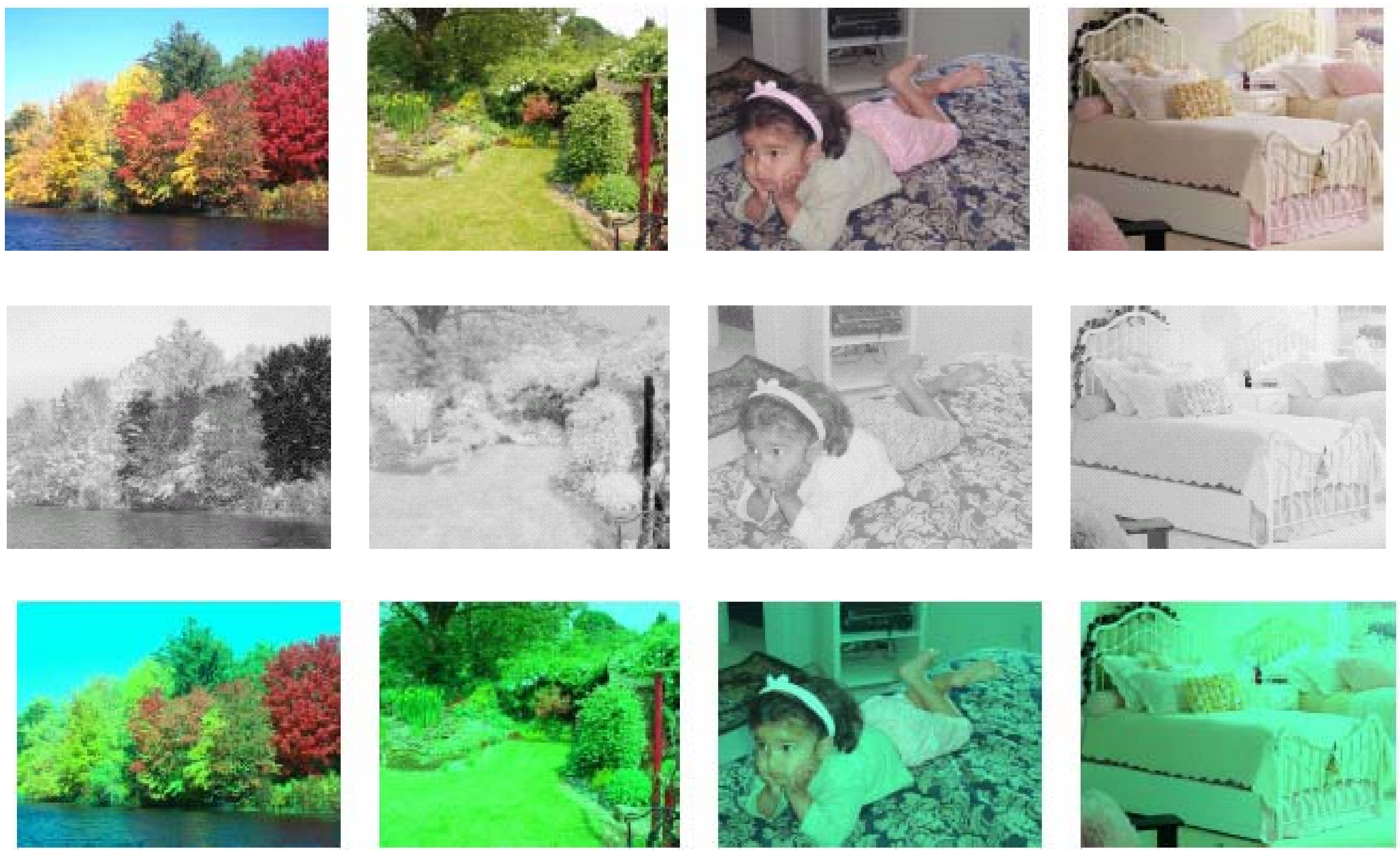


LED Based Projectors



Much wider color gamut

Results of Gamut Expansion

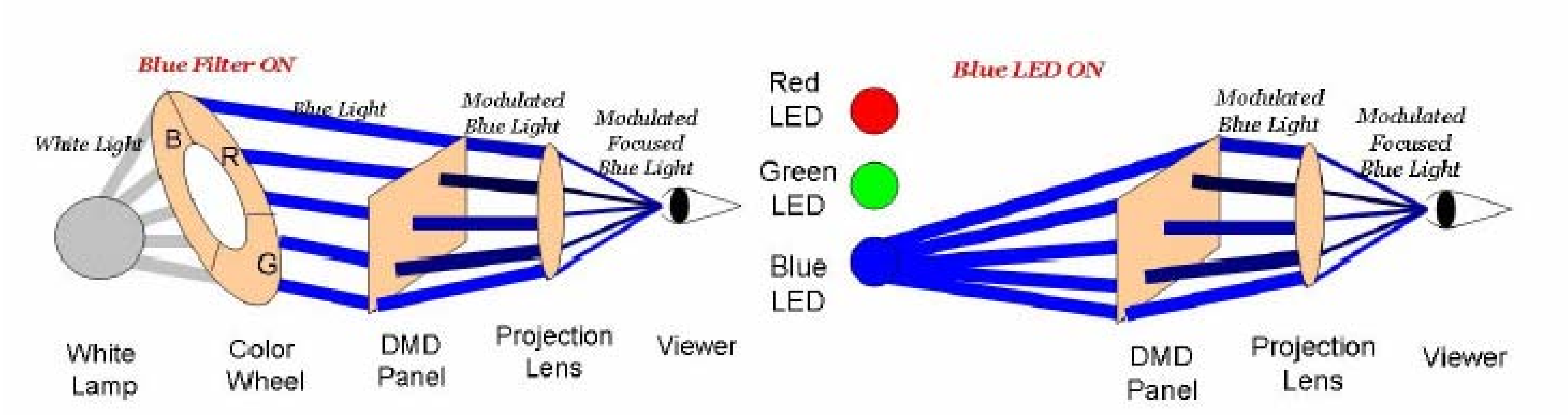


Original

JND (in grayscale) between original and the one displayed by LED (a difference of 3JND is visible)

The displayed image captured by a camera in a projector-camera application.

Difference in Architecture



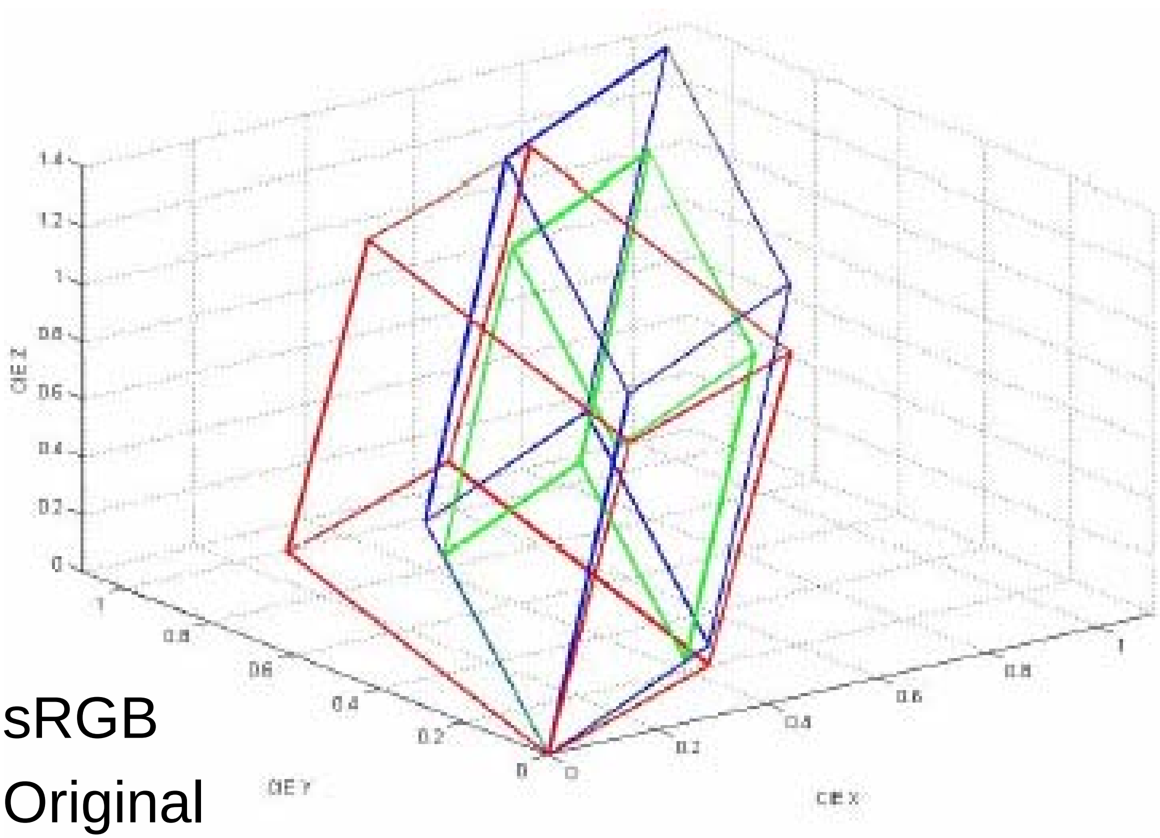
Traditional DLP Projectors

LED Projectors

Advantages

- Simultaneous ON-time for LEDs
- Hence, color of the primaries can be changed easily
- Gamut Reshaping
  - Color emulation for single projector
  - Color balancing for multiple projector
- Identify

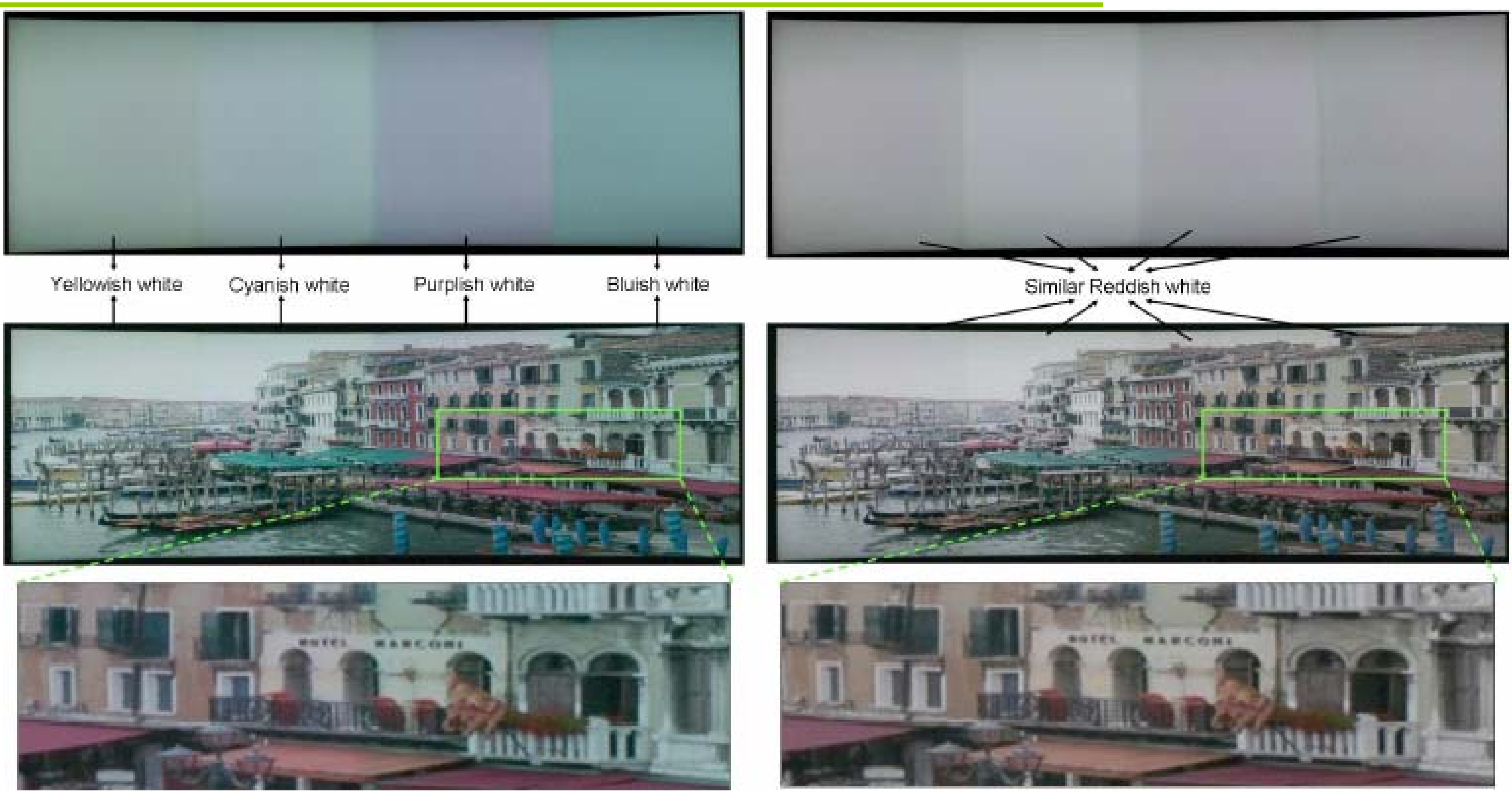
Gamut Reshaping



- sRGB
- Original
- Reshaped Gamut

- Finds optimal gamut
  - Emulates 2D *color gamut* and *white point*
  - Increases *dynamic range*
- Hence,
  - Color balances multiple projector with different color properties

Results (4 projector curved screen)



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INFORMATION AND COMPUTER SCIENCES

UNIVERSITY of CALIFORNIA IRVINE

Results (16 projector planar screen)

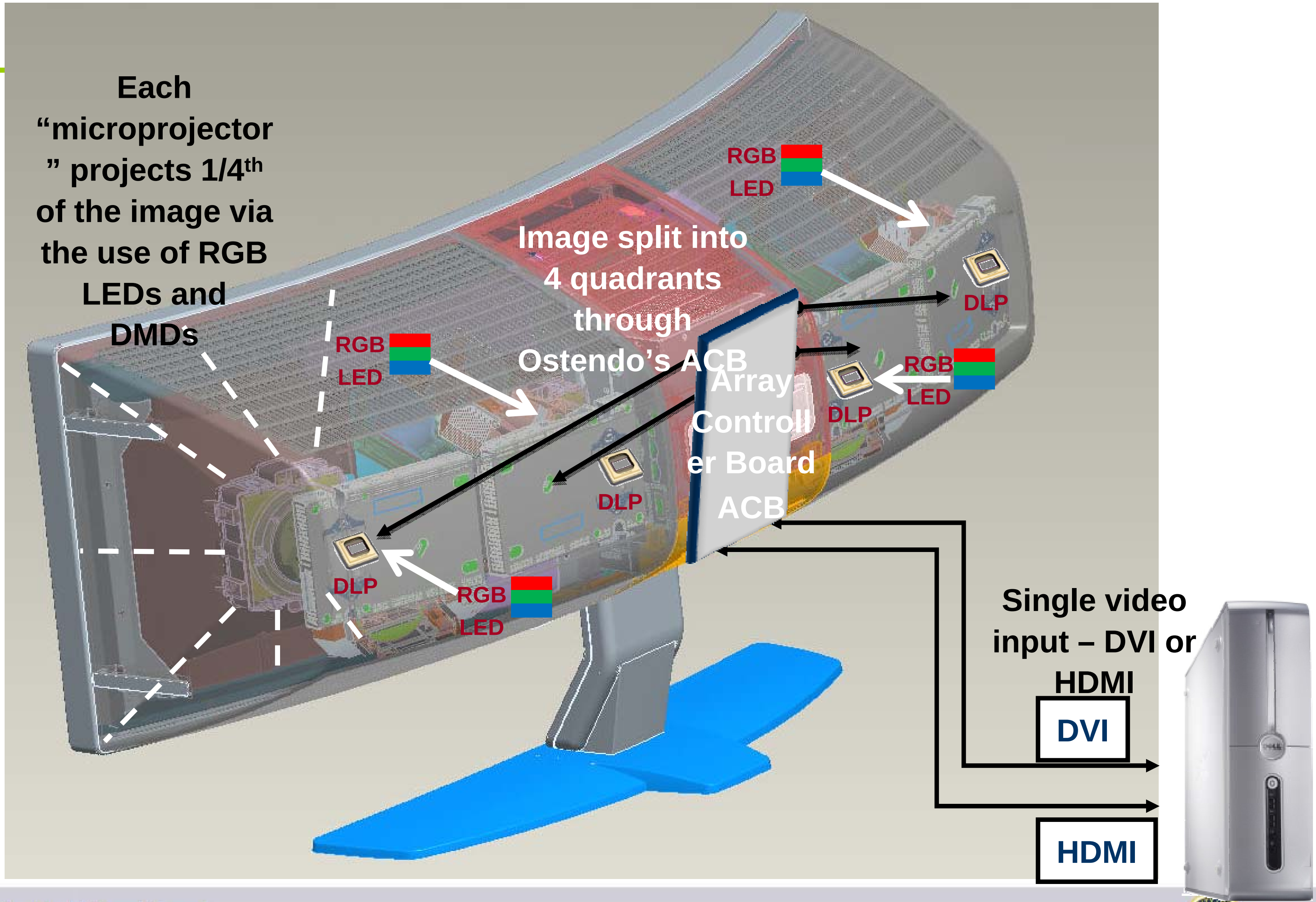
First multi-projector curved desktop

- Ostendo Technologies, Carlsbad
  - Demo in PROCAMS

R. Yang, A. Majumder, M. S. Brown, Camera-Based Calibration Techniques for Seamless Multi-Projector Displays, IEEE Transactions on Visualization and Computer Graphics 11(2), 2005

Model	*CRVD-42DWX+	
Diagonal	42.4”	
Native Resolution	2880 x 900 – Double WXGA+	
Curved Seamless Image	Yes	
Response Time	<0.02milliseconds	
Dynamic Range	12-bit - 4,096 levels	
Color Gamut	Coverage	Size
sRGB	100%	160%
Adobe RGB	99.3%	119%
Number of Colors	68.7 billion	
Contrast	>10,000:1	
Brightness	>300 nits	
Field of View	H90°@ 24” x V30° @ 24”	
Screen Dimensions (flat)	W: 40.4” x H: 12.6”	
Pixel Pitch	0.36mm, 71 DPI	
Aspect Ratio	3.2 : 1	
Monitor Weight (no stand)	25 lbs	
General Availability	Q4 2008	

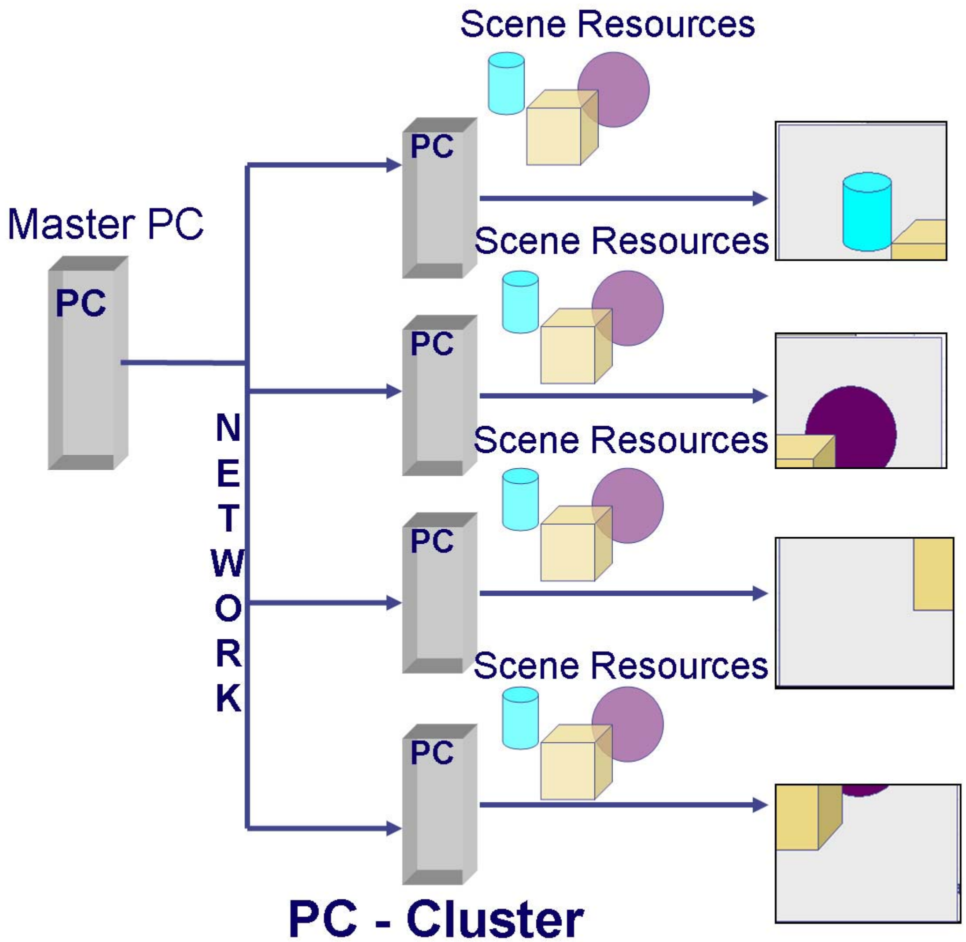
First multi-projector curved desktop



Overview

- Geometric Registration
- Photometric Registration
- PC Cluster Based Rendering
  - Figures: Courtesy Michael S. Brown
- Distributed Rendering

PC Cluster Rendering Framework



PC Cluster Rendering Solutions

- WireGL
- Chromium
- VR Jugglers
- All use PC cluster + network to render a large “logical” framebuffer
  - Rendering is synchronized via the network

Chromium

- Designed to support OpenGL API
  - No change to existing OpenGL applications
- Each PC renders a logical *tile*
- Tiles can overlap completely, partially or none
- Well suited for our application
  - Each PC drives a projector
  - Has partial overlap
- Use this to incorporate geometric/photometric corrections

PC Based Rendering

References:

- *G. Humphreys, P. Hanrahan, A Distributed Graphics System for Large Tiled Displays, IEEE Visualization, 1999.*

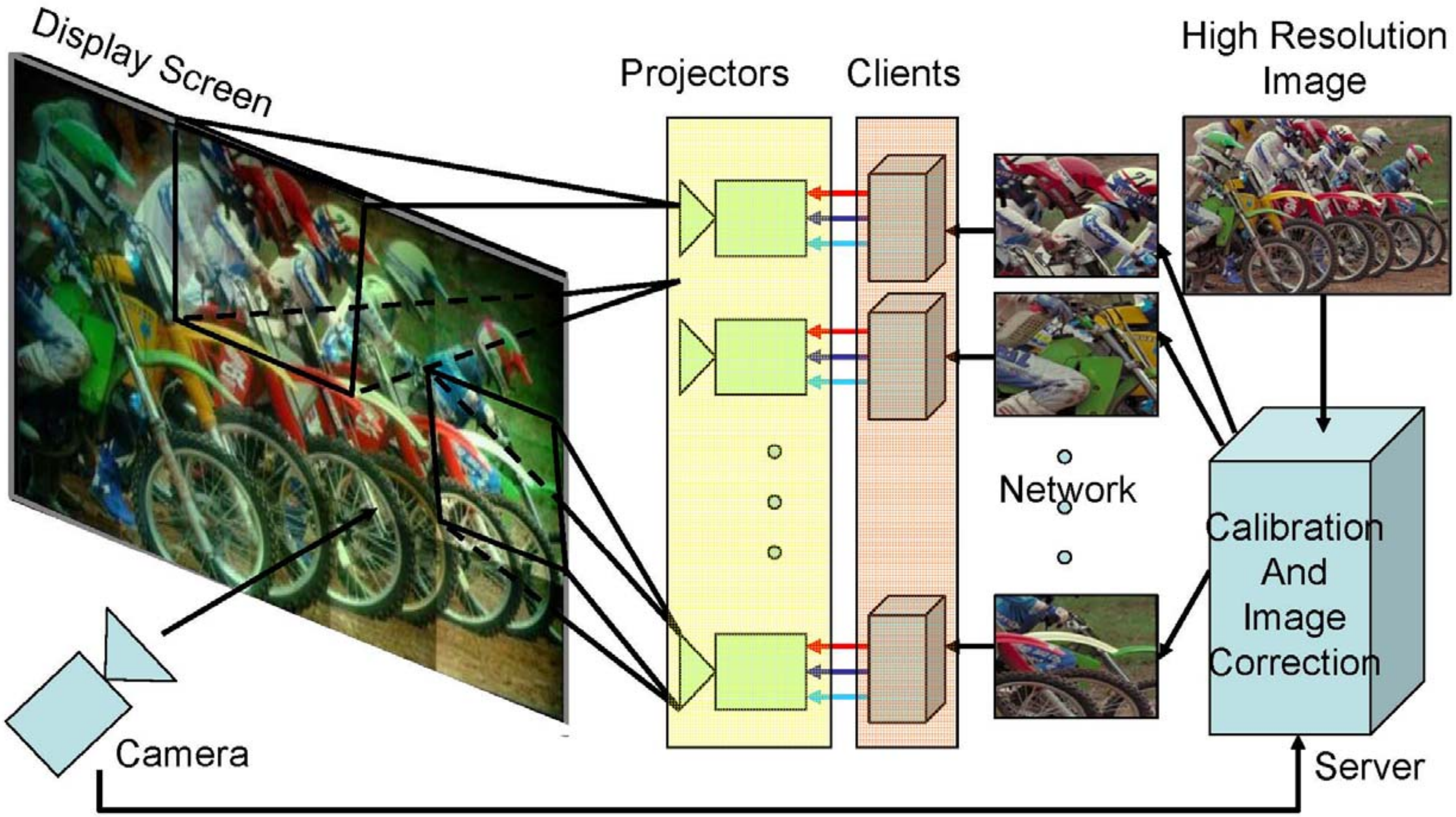
- *G. Humphreys, M. Eldridge, I. Buck, G. Stoll, M. Everett, P. Hanrahan, WireGL: A Scalable Graphics Systems for Clusters, SIGGRAPH 2001.*

- *G. Humphreys, M. Houston, R. Ng, R. Frank, S. Ahem, P. Kirchner, J. Klosowski, Chromium: A Stream Processing Framework for Interactive Rendering on Clusters, ACM Transactions on Graphics, 2002.*

Overview

- Geometric Registration
- Photometric Registration
- PC Cluster Based Rendering
- Distributed Rendering

Centralized Architecture



Centralized Server must use synchronized push

Limitations of Centralized Approach

- Educated User
  - Difficult to deploy
- Not easy to add/remove projectors
  - Not scalable (Limited by camera resolution)
- Not easy to rearrange projectors
  - Not reconfigurable
- Not easy to tolerate faults

Imagine…

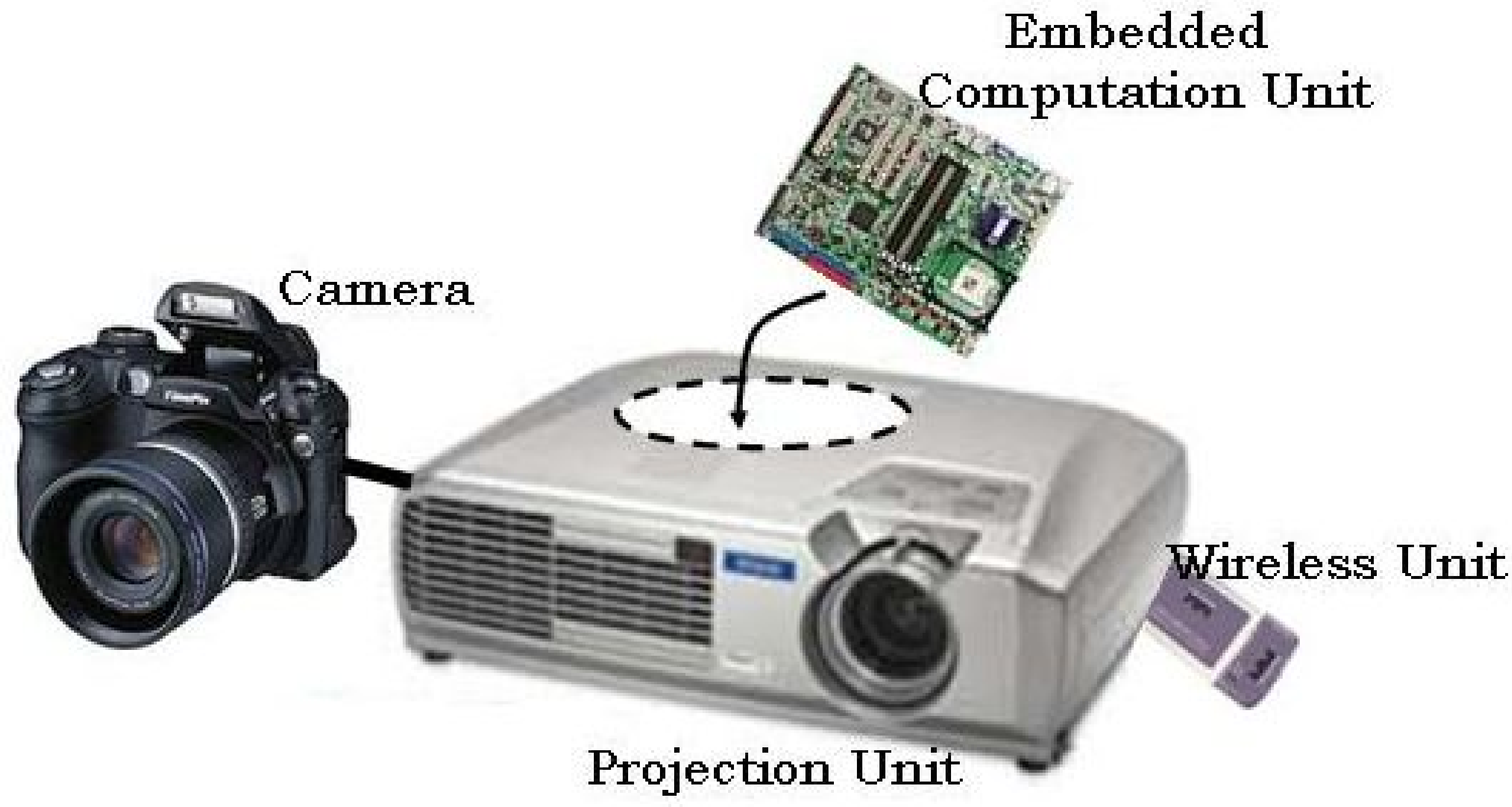
- A display that can calibrate itself with no user intervention
- Can detect addition/removal and recalibrate itself
- Can detect faults and function at a limited capability

Distributed Approach

- Plug-and-Play Projector (PPP)
- Distributed Architecture
- Asynchronous Distributed Calibration

E. Bhasker, P. Sinha, A. Majumder, Asynchronous Distributed Calibration for Scalable and Reconfigurable Multi-Projector Displays, IEEE Visualization, 2006.

Plug-and-Play Projectors (PPP)

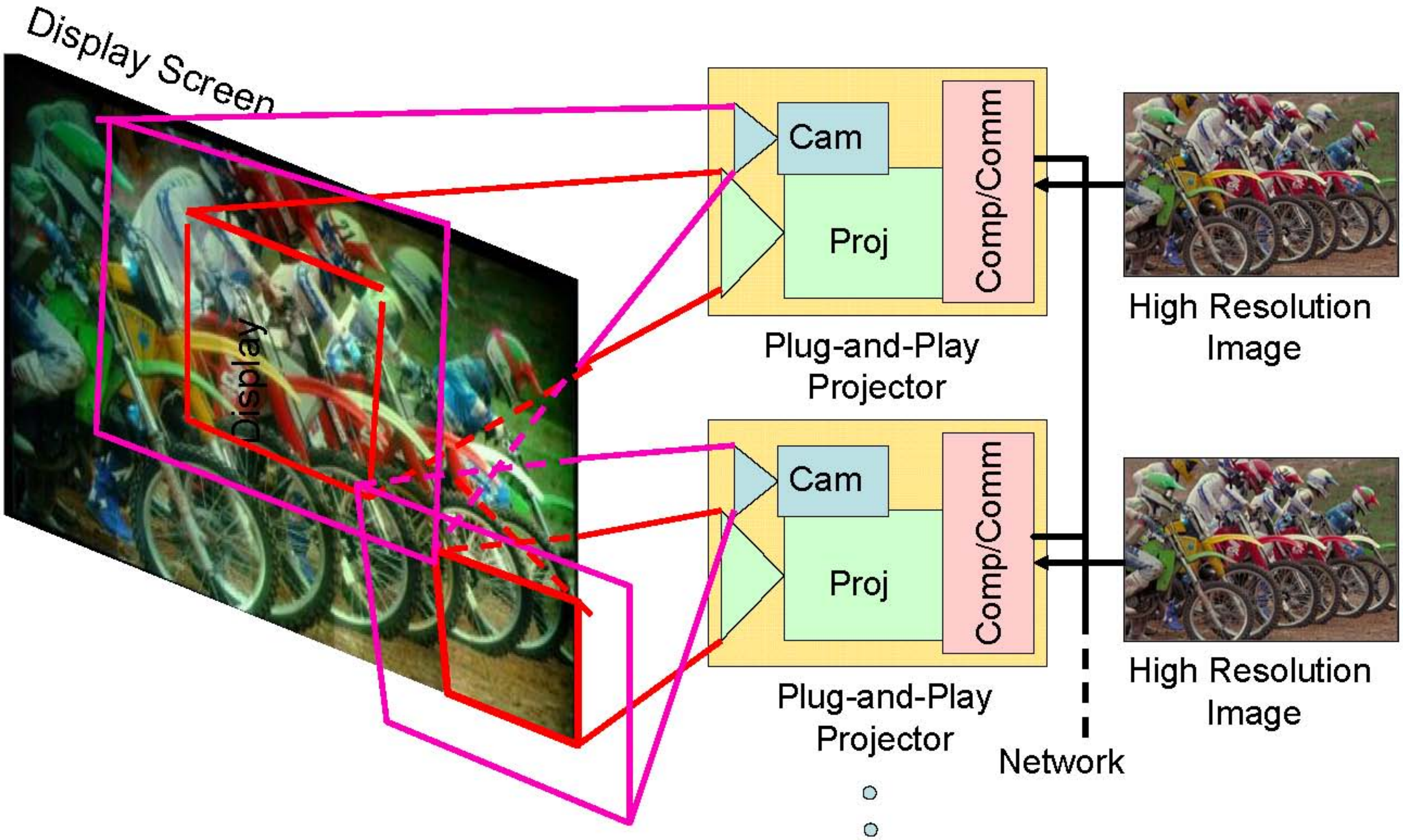


Projector, Camera, Wireless Unit, Embedded Computation Unit
(Inspired by Rasker ‘03)

Plug-and-Play Projectors (PPP)

Our Prototype

Distributed Architecture



Distributed Architecture

- Data is pulled by each PPP
- Data server does not know that these are displays
  - Acts like any other data client
- Each PPP manages its own pixels

Asynchronous Distributed Calibration

- Each PPP runs asynchronous SPMD algorithm
  - Each PPP discovers its neighbors
  - PPPs discovers the array configuration
    - Using camera-based-communication
  - Self-calibrates accordingly
    - Scalable
    - Reconfigurable
    - Fault-Tolerant

Initially…

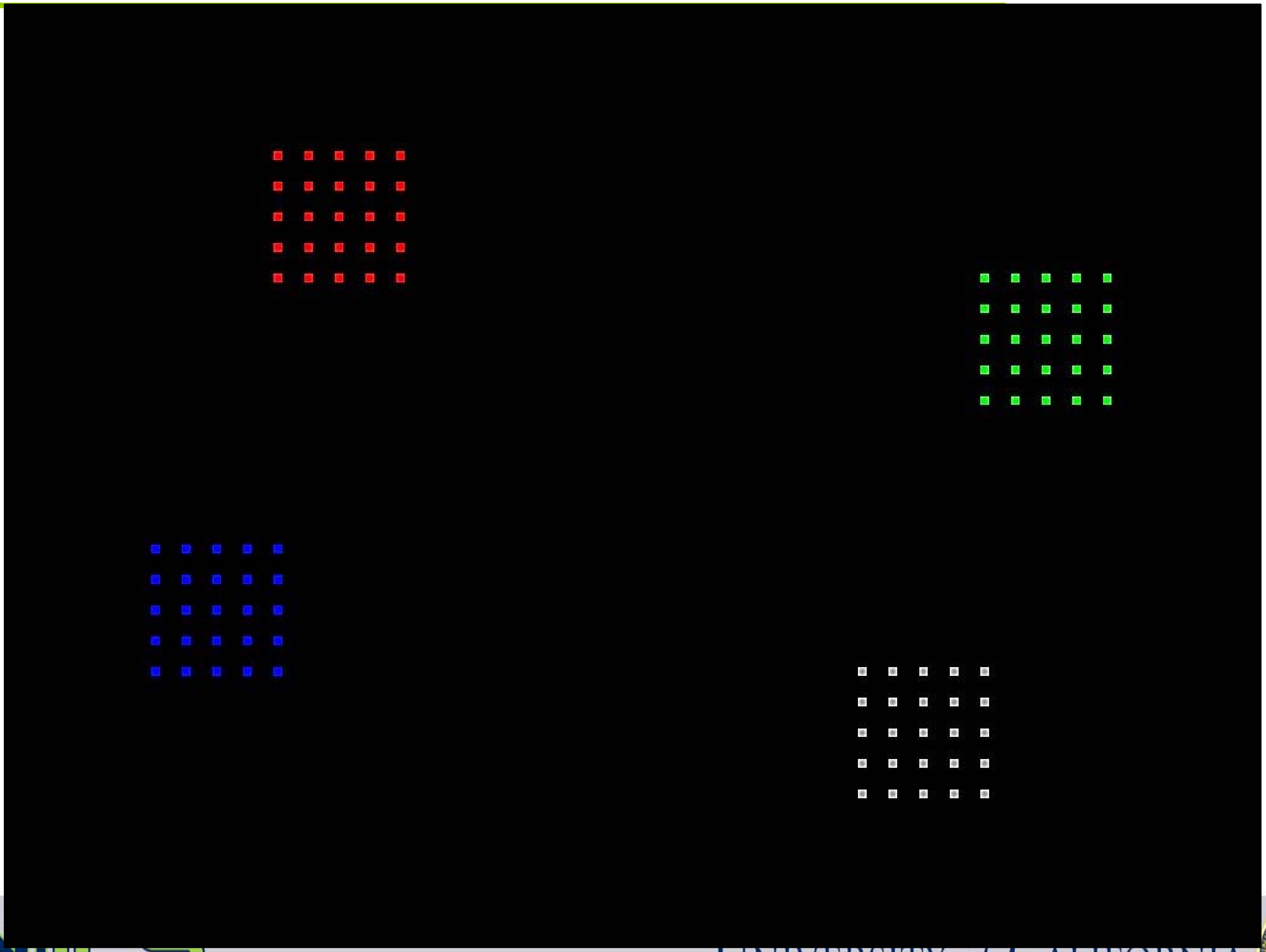
SPMD Algorithm

- Neighbor Discovery
- Configuration Identification
- Alignment

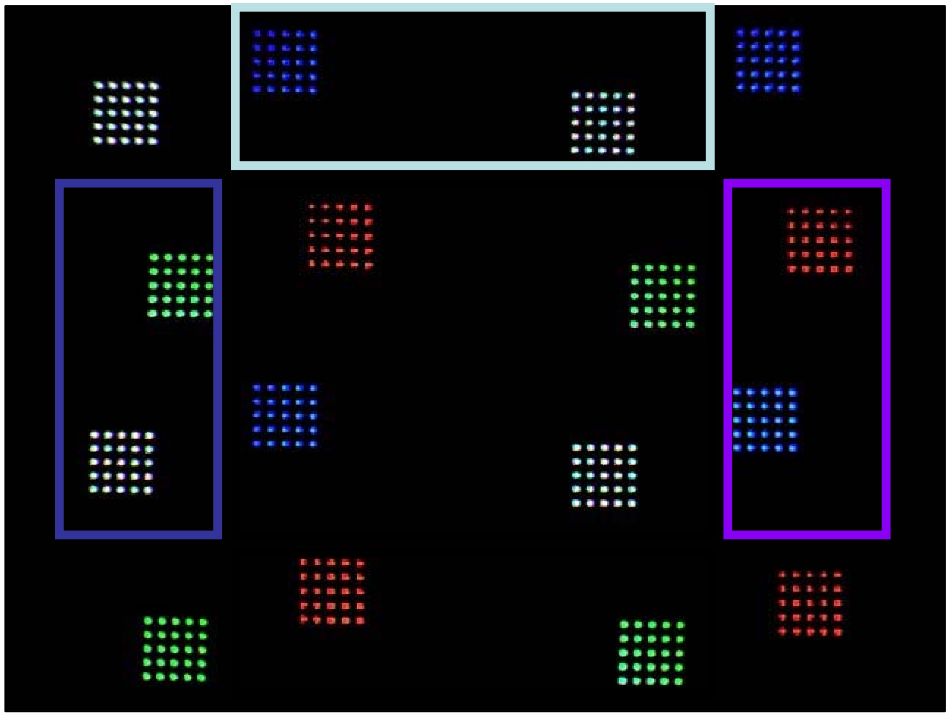
SPMD Algorithm

- Neighbor Discovery
- Configuration Identification
- Alignment

Projected Pattern

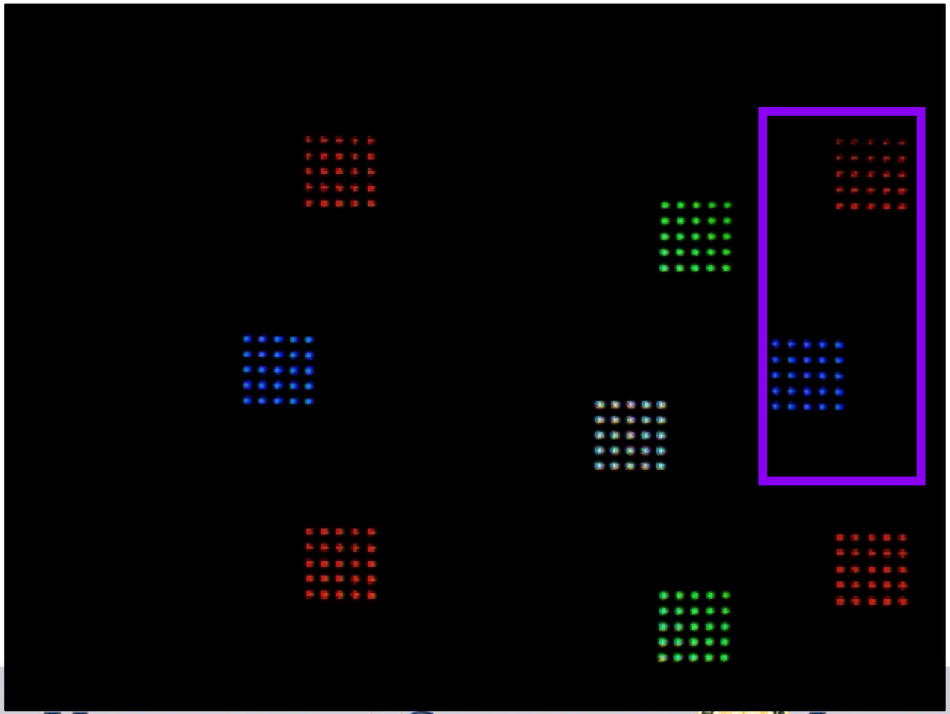


Pattern seen by Cameras



From a camera of a PPP with all four neighbors

From a camera of a PPP at the top-left corner of the display



After Neighbor Discovery

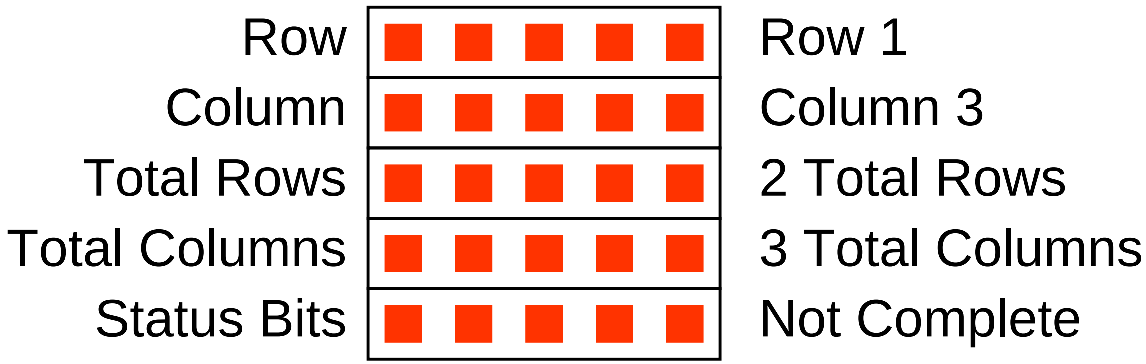
- Each PPP knows
  - The number of neighbors it has
  - Their location relative to self (top, bottom, etc.)
- But does not know
  - Total number of projectors
  - Projection array configuration
  - Its own coordinates in the array

SPMD Algorithm

- Neighbor Discovery
- Configuration Identification
- Alignment

Communication Pattern

- Binary-encoded cluster of blobs



  - Neighbors update beliefs by detecting patterns
- Several rounds of such local updates
  - Parameters diffuse to all PPPs
  - Asynchronously converge to correct global values

Enabling Low Bandwidth Network Communication

- Only camera-based communication till now
- PPPs need to know the IP addresses of its neighbors
- Each PPP broadcasts its IP address and coordinates

After Configuration Identification

- Each PPP knows
  - Total size of display
  - The part of the display it is responsible for
  - IP address of neighbors
- But does not know
  - The relative orientation of its neighbor to warp the image to make a seamless display

After Configuration Identification

SPMD Algorithm

- Neighbor Discovery
- Configuration Identification
- Alignment
  - Distributed Homography Tree
  - Iterative refinement

Geometric Alignment and Blending

Primary Reference

- Most common issues
- Many Examples
- Sample code for PC cluster rendering