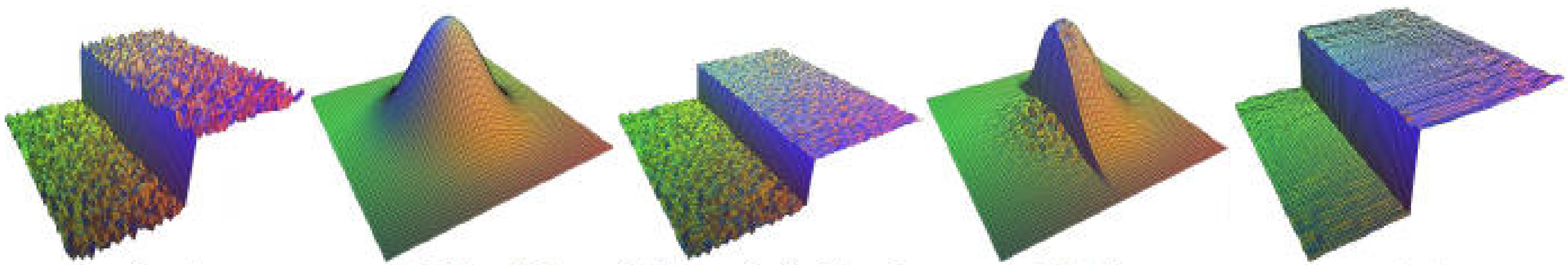
Capture and Displays

CS 211A

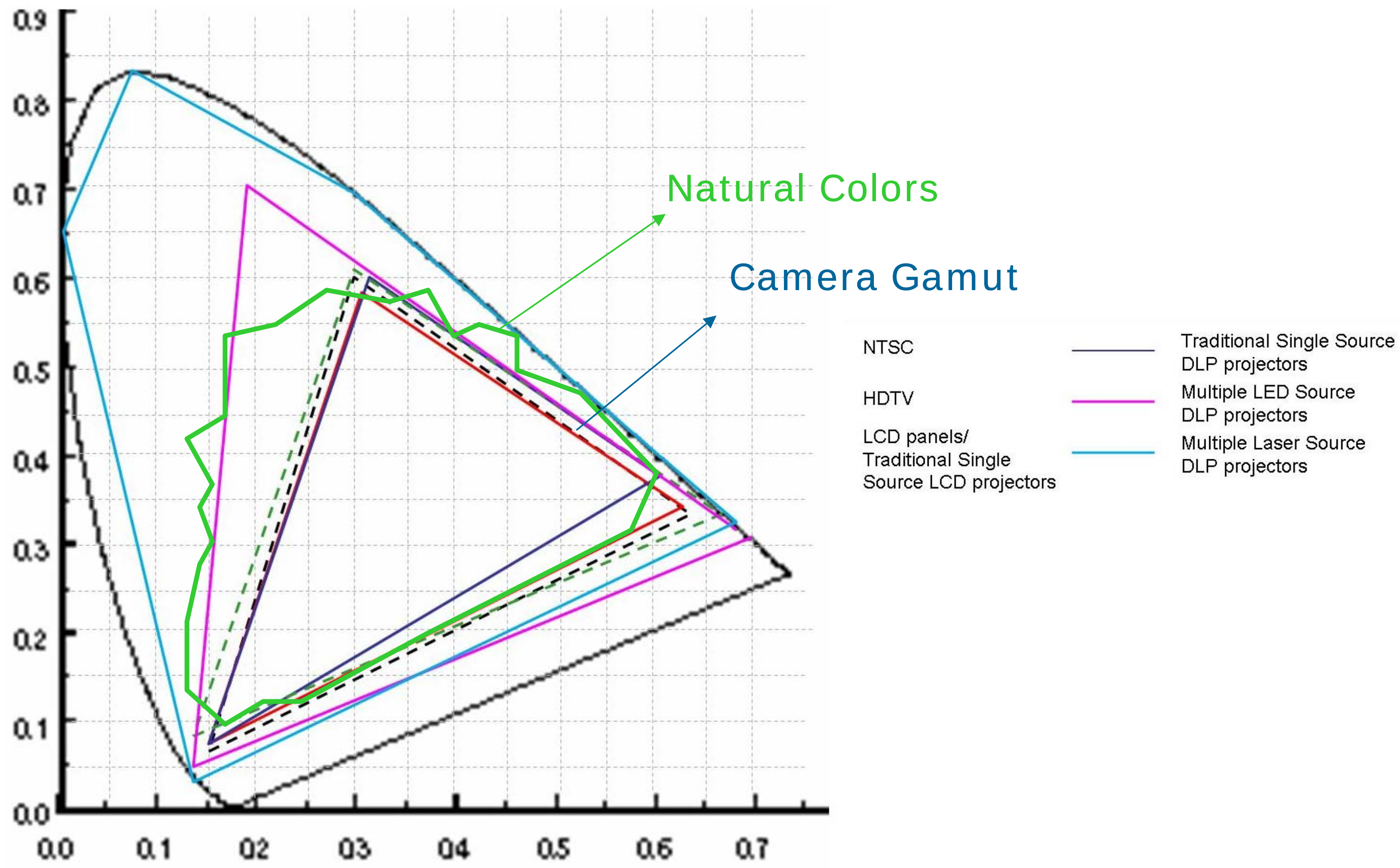
HDR Image

Bilateral Filter



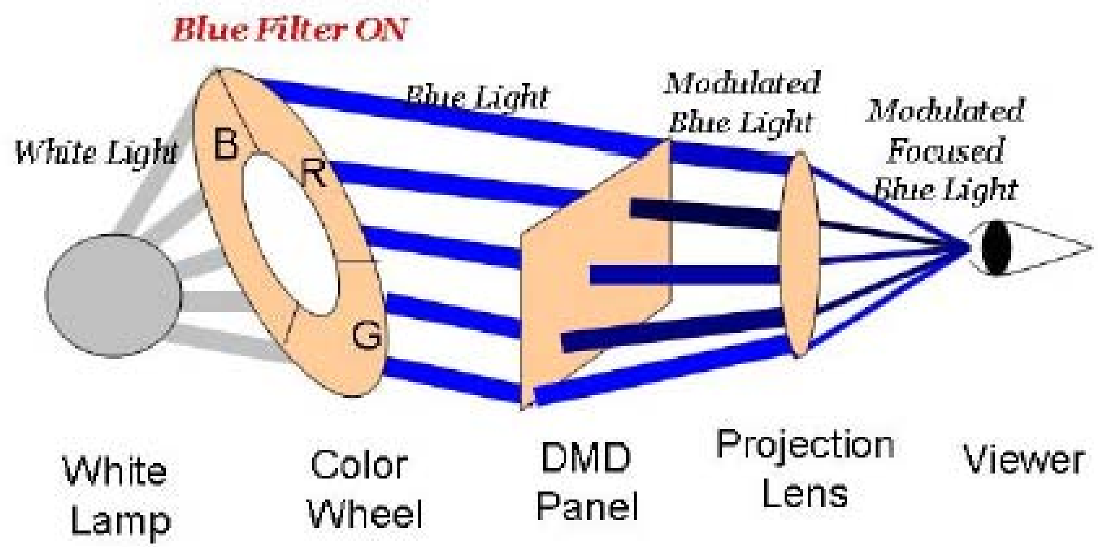
input | spatial kernel f | influence g in the intensity domain for the central pixel | weight $f \times g$ for the central pixel | output

Color Gamut


Natural Colors
Camera Gamut
NTSC
HDTV
LCD panels/
Traditional Single
Source LCD projectors
Traditional Single Source
DLP projectors
Multiple LED Source
DLP projectors
Multiple Laser Source
DLP projectors
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

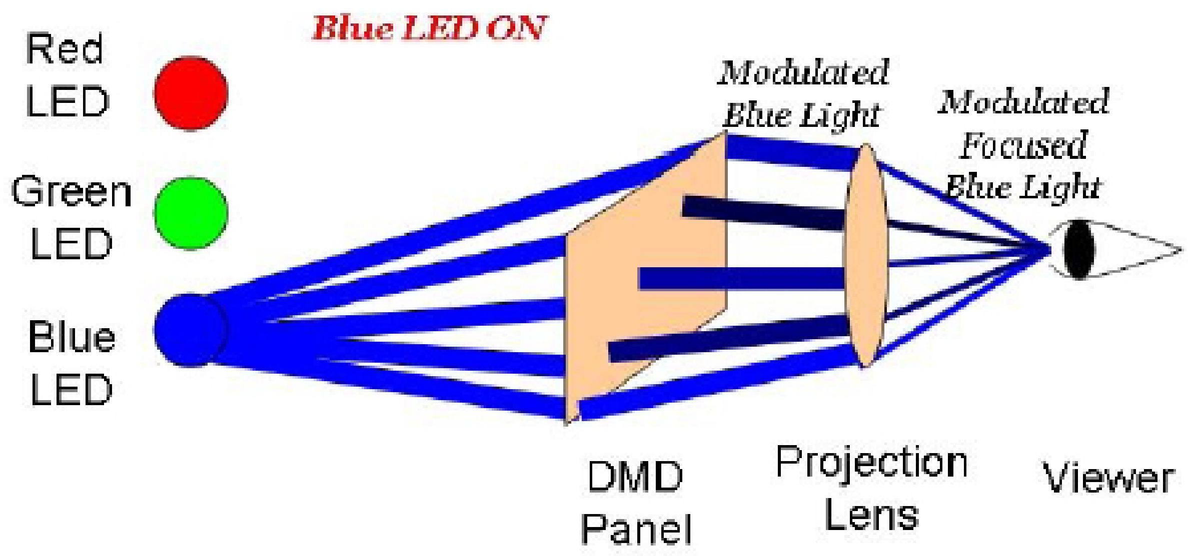
Traditional Displays

- LCD panels
  - The gamut is the result of the filters used
- In projectors



Recent high gamut displays

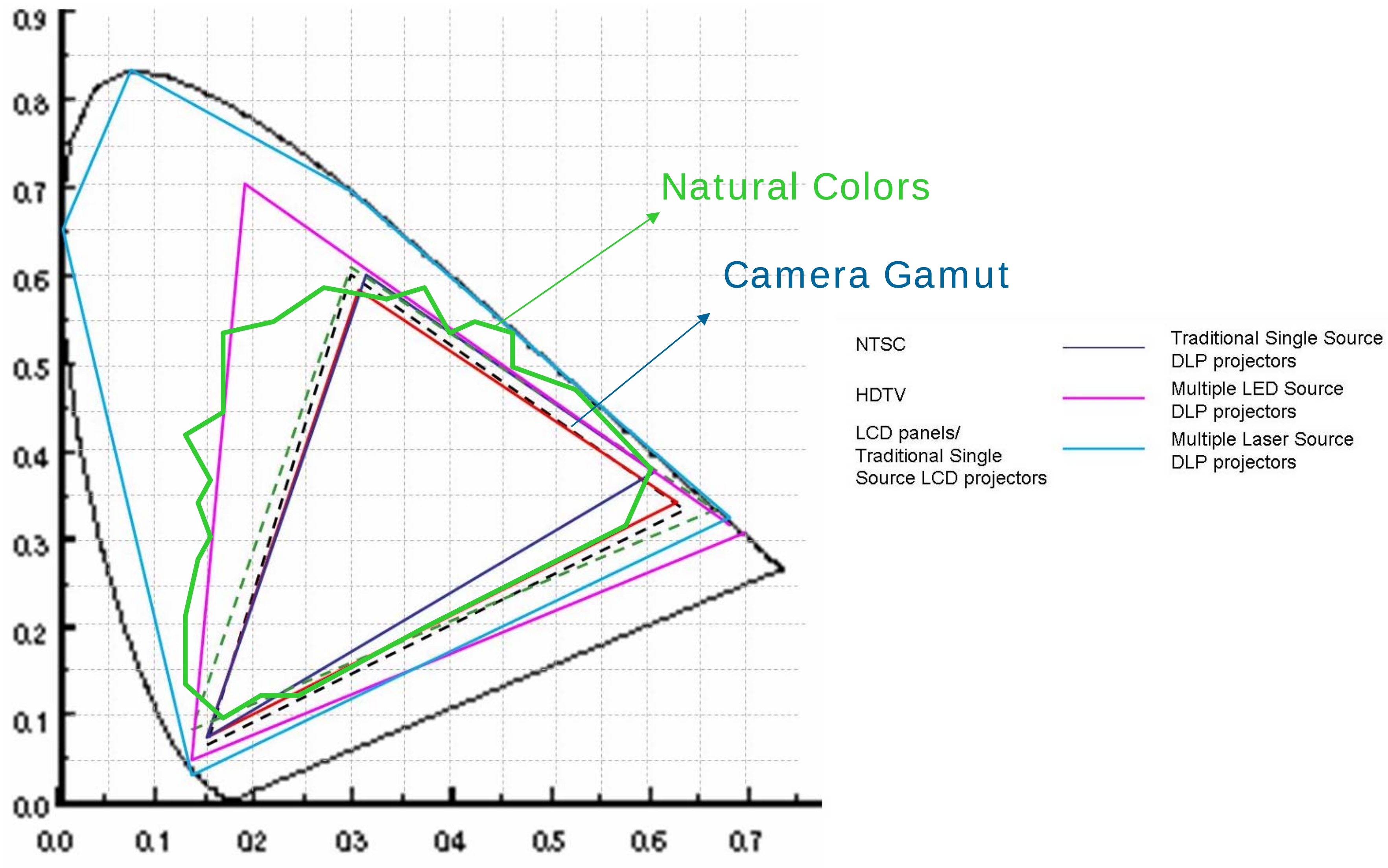
- Comes from use of LEDs
  - LEDs are much saturated primaries
  - 1.5 times HDTV gamut
- Projectors (MERL)



Recent high gamut displays

- Comes from use of LEDs
  - LEDs are much saturated primaries
  - 1.5 times HDTV gamut
- LCD panels (HP Dream Color)
  - Use LED backlighting
- Laser multi-primary ones are coming up

Color Gamut



Natural Colors
Camera Gamut
NTSC
HDTV
LCD panels/ Traditional Single Source LCD projectors
Traditional Single Source DLP projectors
Multiple LED Source DLP projectors
Multiple Laser Source DLP projectors
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

What about capture?

- No HG capture
  - Not in the required spatial and temporal resolution
- Closest is hyperspectral imagery
  - Captures multiple narrow spectral bands
  - Low spatial resolution (512x512)
  - Low temporal resolution (10 fps)
  - Cost is $50,000
  - Used for scientific application

Gap between Capture and Display

- Hollywood have defined a digital cinema standard gamut
  - What they want?
- Close to the current high gamut displays
- No capture device
- Sophisticated gamut extrapolation methods

High Resolution Imagery

- Capture
  - Panoramic Image generation
- Display
  - Tiled displays

Panoramic Image

Basic Algorithm

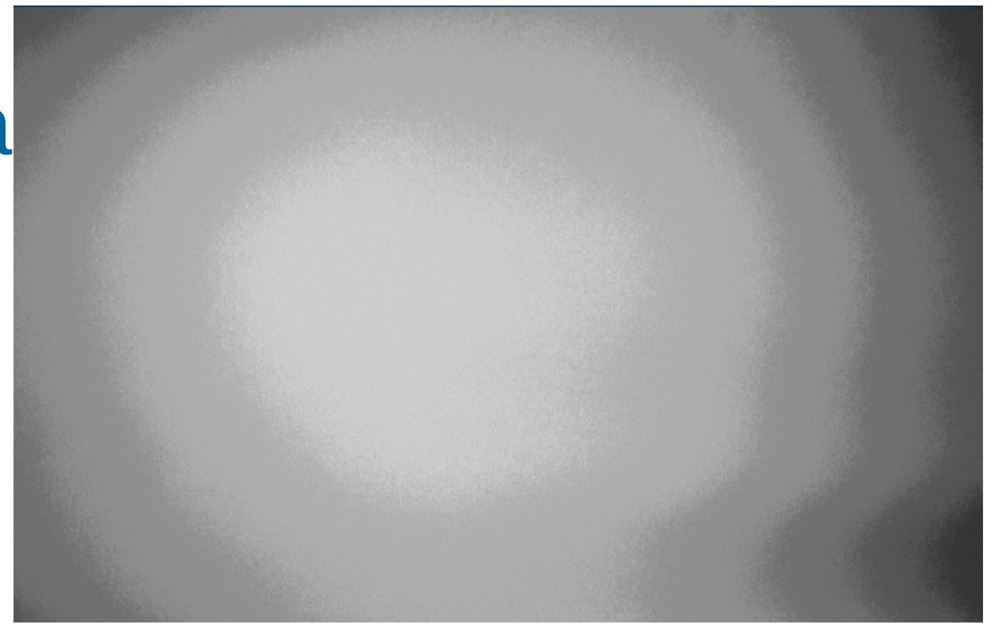
- Assume distant scene, locally planar
- Detect features across adjacent pics
- Relate two adjacent pictures by a homography
- Stitch them

Problems?

- What if circular?
  - Can have inconsistencies
- What is more than one row?
  - Same issue inconsistencies
- Use some global optimization techniques
  - Optimize across all images together
  - Bundle adjustment

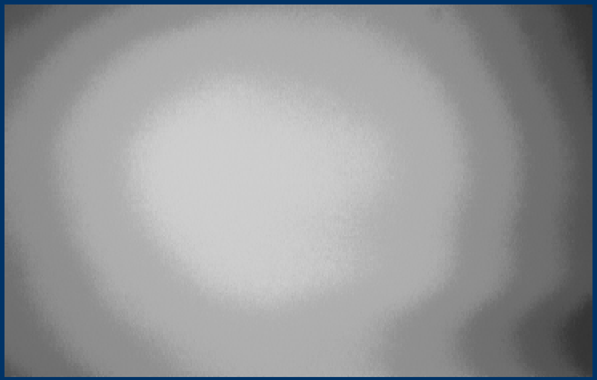
Another problem

- Spatial intensity fall off in camera
  - Primarily due to the lens
  - Vignetting
- Radial Fall off
- May not be centered



Modelling vignetting

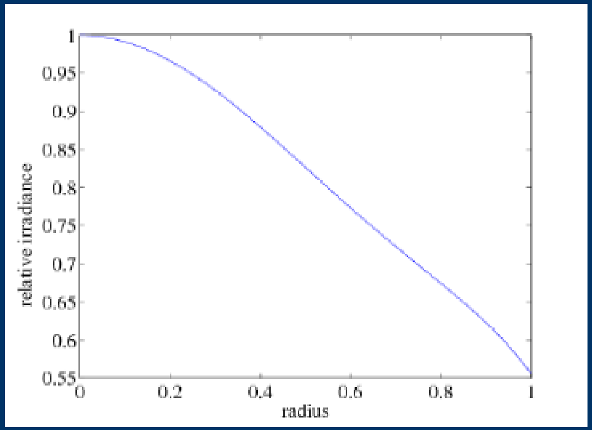
- Non-Parametric models
  - Flatfield image
    - accurate
    - acquisition cumbersome



- Parametric models
  - Radial polynomial model

$$M = \beta_1 r^6 + \beta_2 r^4 + \beta_3 r^2 + 1$$

  - Allow center shift c



Inaccurate feature detection

Radiometric Camera Calibration

- Finding transfer function and vignetting
- Debevec's method
  - Recovers transfer function
  - Assumes no vignetting effect
  - Assures by setting aperture of a narrow FOV camera to a very low value

How to calibrate the camera?

- Debevec
  - Need a few pixels to recover transfer function
  - Can be the center 10x10 of a camera where negligible vignetting
  - Find g

Goldman et al (2005)

- Assumes known transfer function
- Takes panoramic images with very large overlaps
- Same irradiance imaged at different pixels
  - Have different intensity due to different vignetting or exposure
- Basic idea
  - For corresponding feature f in image *i* and *j*
    - g(Zi) = ln(E) + ln (Vi) + ln(ti)
    - g(Zj) = ln(E) +ln(Vj) +ln(tj)
- Recover both vignetting and exposure

Results

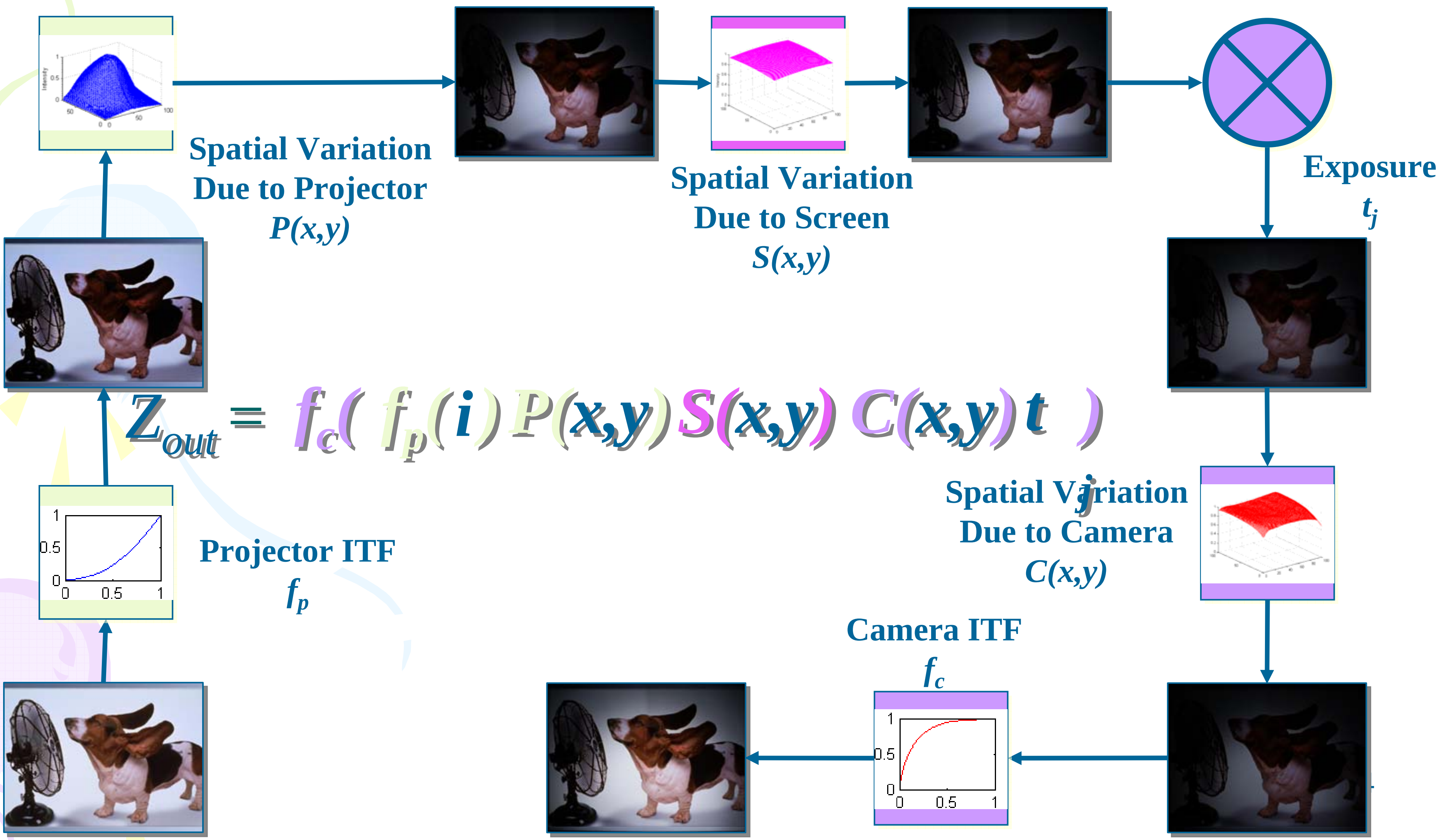
Radiometric camera calibration

- Underconstrained problem
- Cannot get both transfer function and vignetting effect
  - Transfer function upto an exponential ambiguity
- Both upto scale factor
  - If transfer function is known

Juang and Majumder 2007

- Use a projector in the loop
- Constrain the problem by using known inputs to the projector

Model



$$Z_{out} = f_c(\, f_p(i)\, P(x,y)\, S(x,y)\, C(x,y)\, t_j\,)$$

Calibration Algorithm

$$Z_{out} = f_c\left(f_p(i)\, \boxed{P(x,y)\, S(x,y)\, C(x,y)}\, t \right)_j$$

Calibration Algorithm

- Since $f_c(\ )$ is monotonic, inverse exists.

$$Z_{out} = f_c(\, f_p(i)\, L(x,y)\, t_j\ )$$

Calibration Algorithm

- Take the log of both sides

$$f_c^{-1}(Z_{out}) = f_p(i)\, L(x,y)\, t_j$$

$$\ln f_c^{-1}(Z_{out}) = \ln f_p(i) + \ln L(x,y) + \ln(t_j)$$

Calibration Algorithm

- Images of multiple projector inputs at multiple camera exposures
- Setup system of equations and solve using least-squares

$$\ln f_c^{-1}(Z_{out}) = \ln f_p(i) + \ln L(x,y) + \ln(t_j)$$

Separating Parameters

- Recall model

$$Z_{out} = f_c\left(f_p(i)\, L(x,y)\, t_j \right)$$

$$L(x,y) \rightarrow \underbrace{P(x,y)\, S(x,y)}_{\text{Projector vignetting}}\; \underbrace{C(x,y)}_{\text{Camera vignetting}}$$

Separating Parameters

- Recall model

$$Z_{out} = f_c\left(f_p(i)\, L(x,y)\, t_j \right)$$

$$\underbrace{P(x,y)\, S(x,y)}_{\text{Projector vignetting}}\ \underbrace{C(x,y)}_{\text{Camera vignetting}}$$

- Different camera aperture => different L

Separating Parameters

- At narrow camera apertures, camera vignetting is negligible, almost constant

$$L_{f/32}(x,y) = P(x,y)\,S(x,y)\,C_{f/32}(x,y)$$

Separating Parameters

- At wider apertures

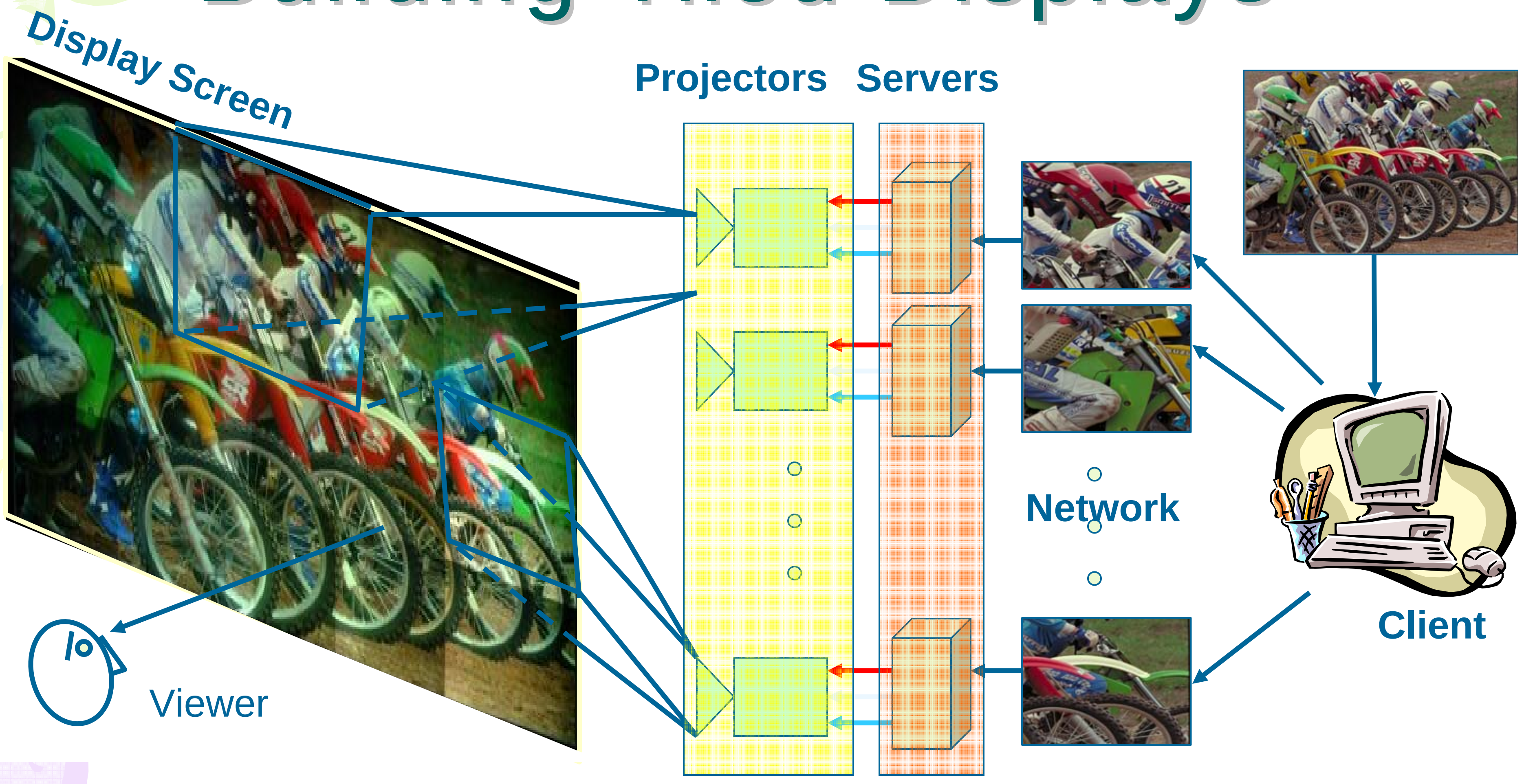
$$\frac{L_a(x,y)}{L_{f/32}(x,y)} = \frac{P(x,y)\,S(x,y)\,C_a(x,y)}{P(x,y)\,S(x,y)\,k} = \frac{C_a(x,y)}{k}$$

- Normalized vignetting effect

High Resolution Displays

- Tile Projectors or LCD panels
- Seamless or with seams

Building Tiled Displays

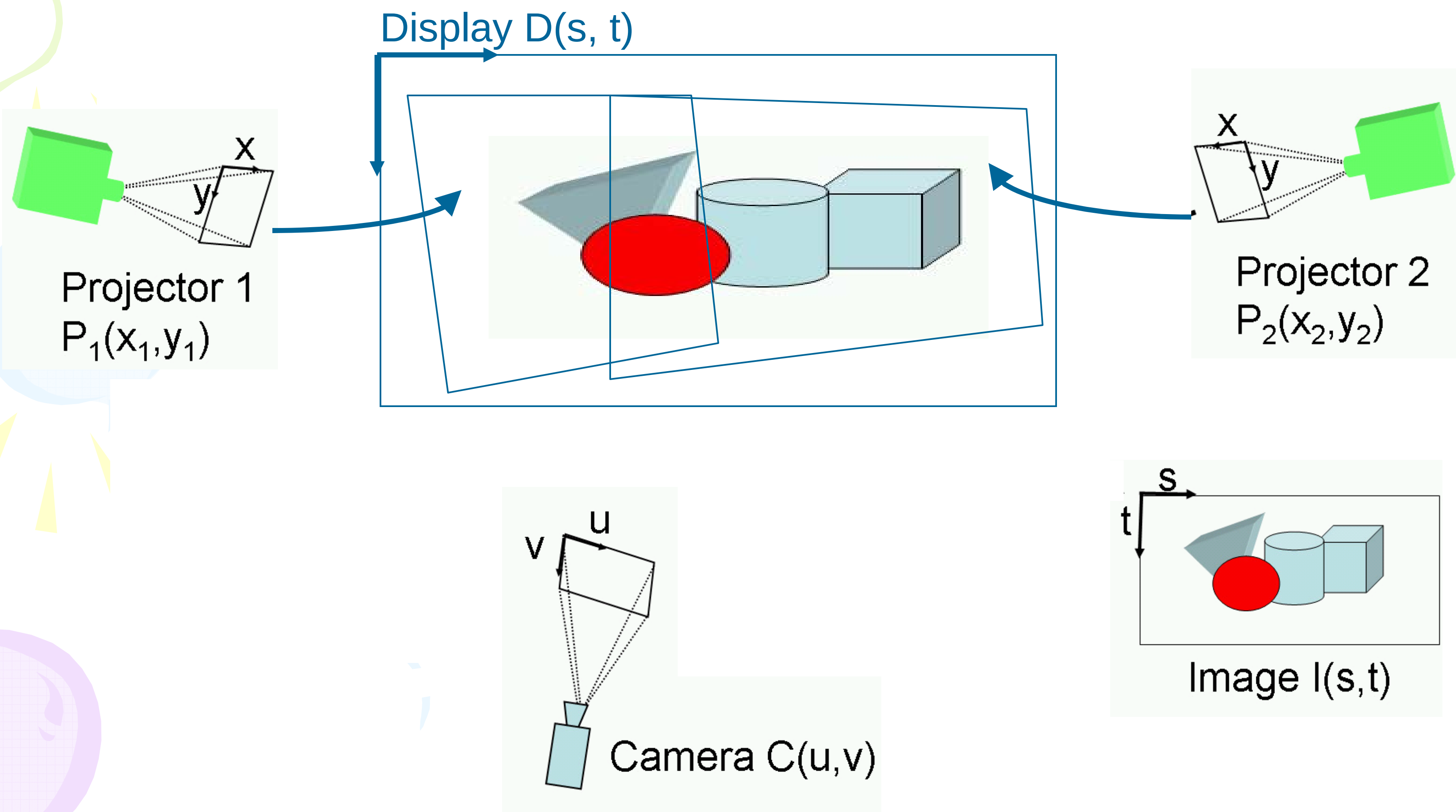


Geometric/Photometric Mismatch

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

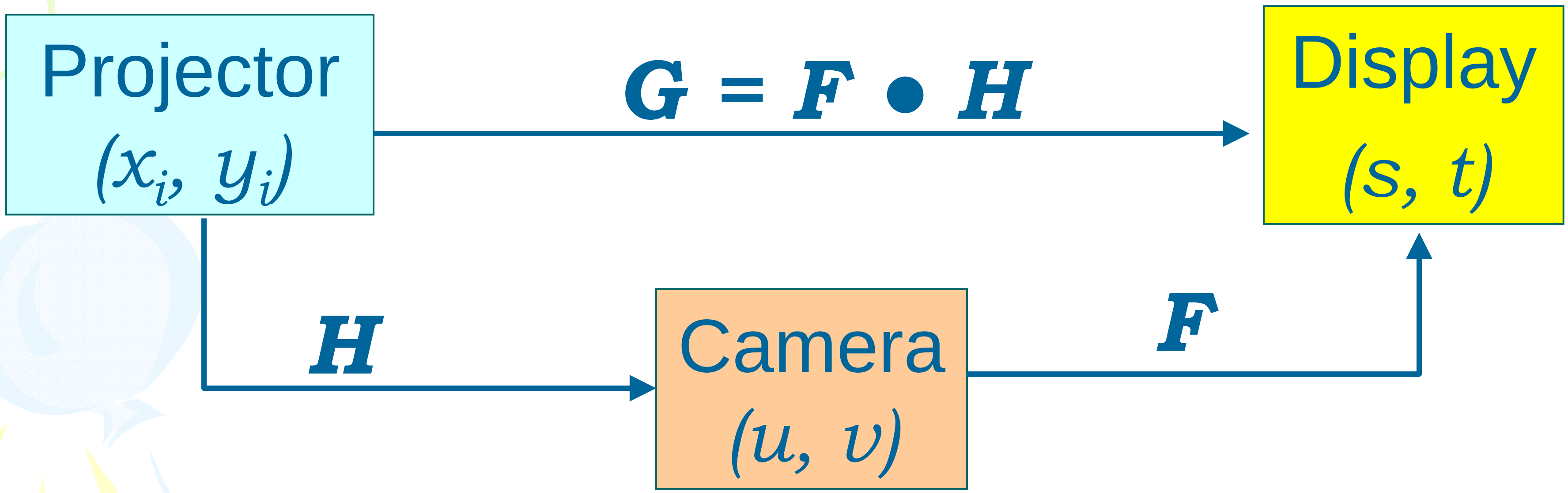
Different spaces



Simple Geometric Alignment

Projector (x_i, y_i) $\xrightarrow{\boldsymbol{G}}$ Display (s, t)

Simple Geometric Alignment

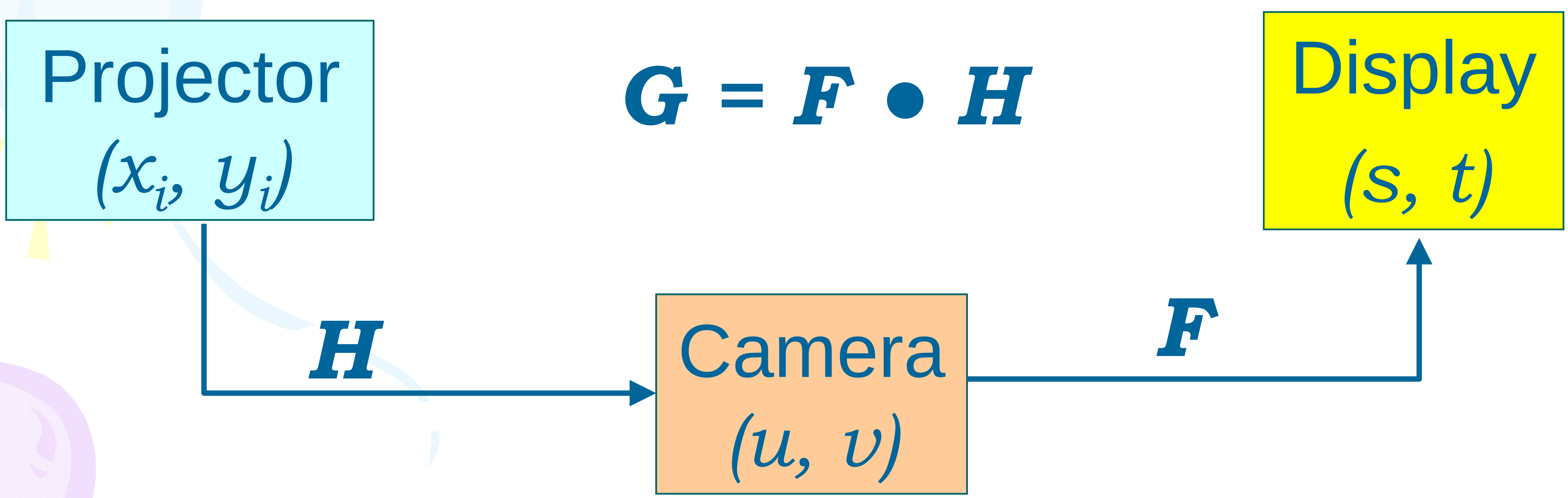


Apply G^{-1} for registration

Planar Display

- Calibrated camera (no radial distortion)
- $\boldsymbol{F}$ is linear (3x3 matrix called *homography*)

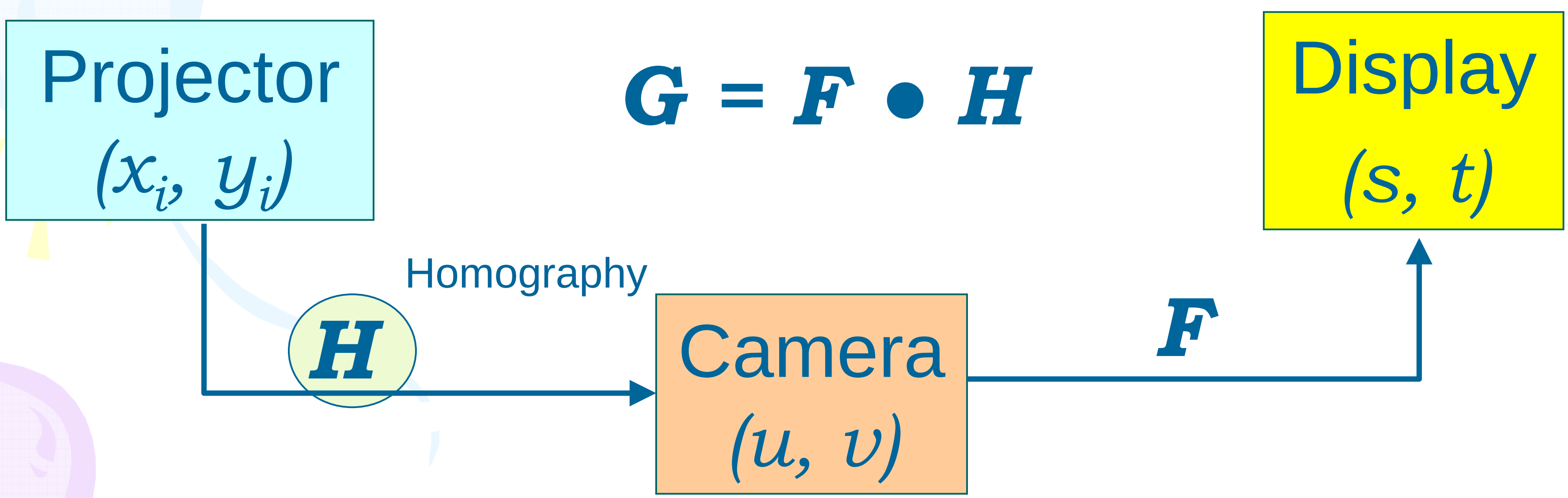
$$\boldsymbol{G} = \boldsymbol{F} \bullet \boldsymbol{H}$$



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

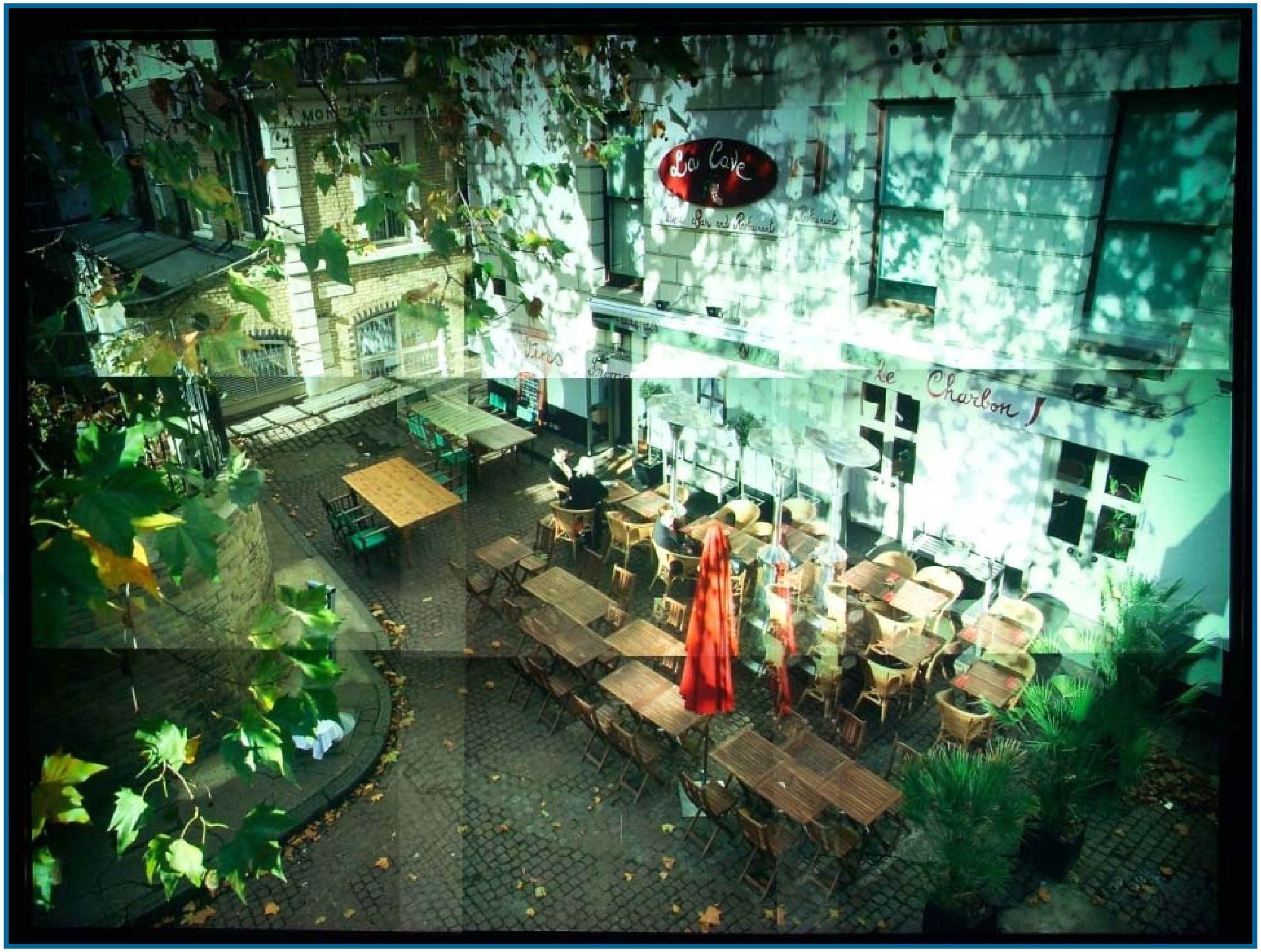
Perfect Projectors

- $G = F \times H$
- G^{-1} is just a matrix inversion

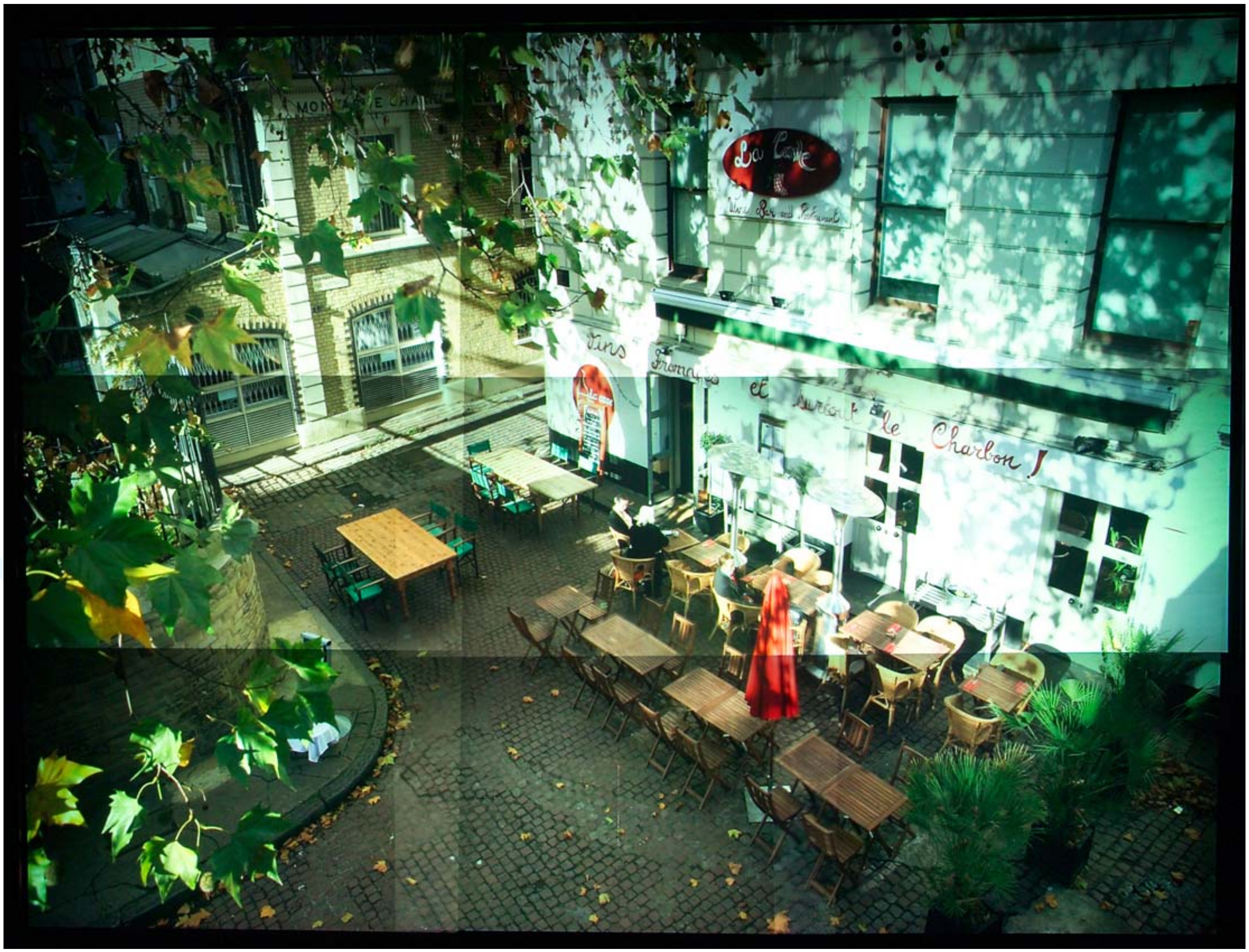


R. Raskar, *Immersive Planar Display using Roughly Aligned Projectors*, IEEE VR, 2000.

Linear *G*

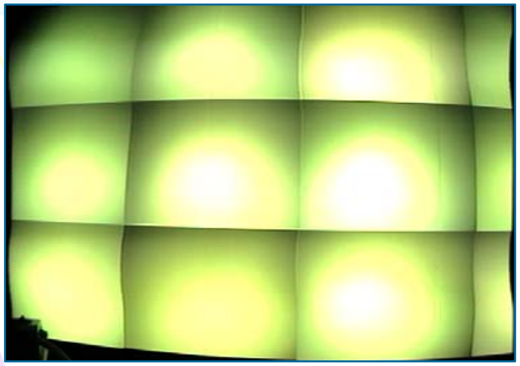


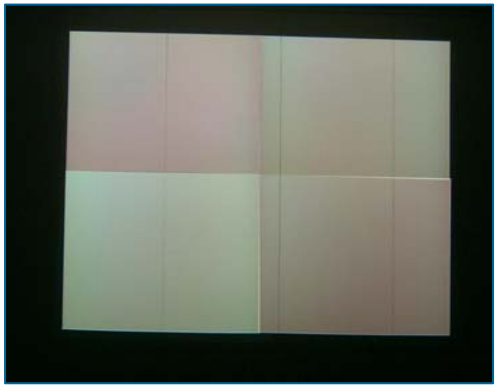
Corrected using G^{-1}

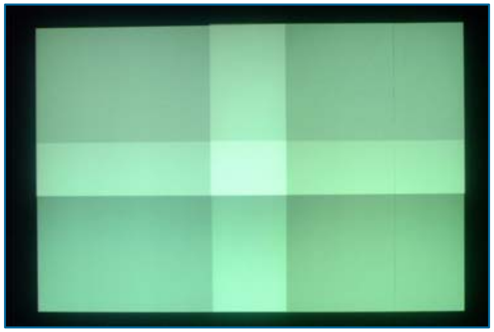


Intensity Variation

- If the projectors are good and similar
  - No vignetting
    - Take care of overlaps
- If not, measure accurately



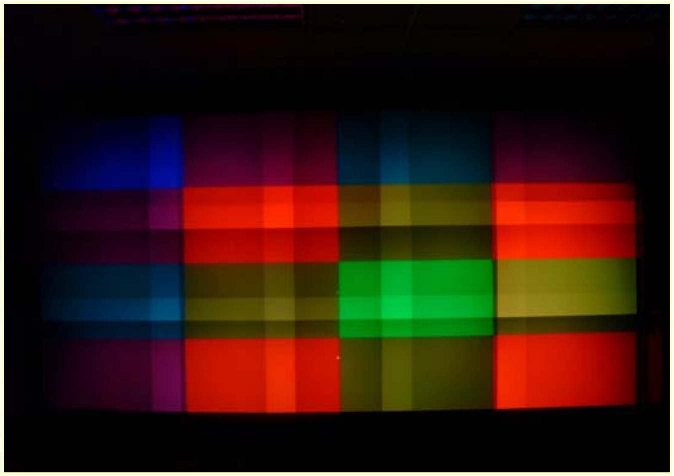




1) *A. Majumder, Properties of Color Variation in Multi Projector Displays, SID Eurodisplay, 2002.*
2) *A. Majumder and R. Stevens, Color Non-Uniformity in Multi Projector Displays: Analysis and Solutions, IEEE Transactions on Visualization and Computer Graphics, Vol. 10, No. 2, 2003.*

Use some edge blending

Before

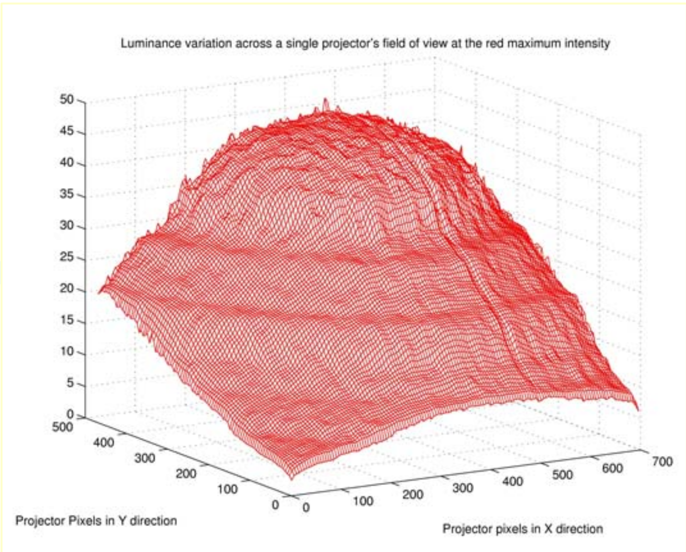


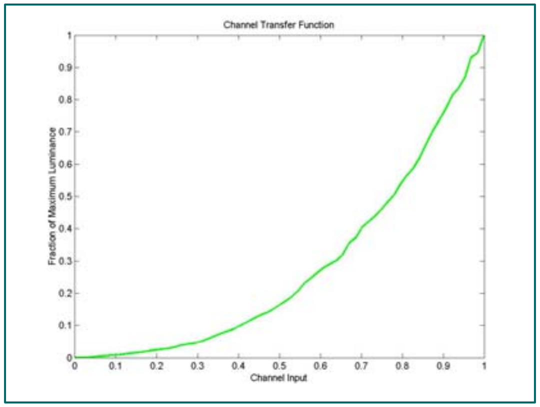
Software Blending

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.
3) 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.

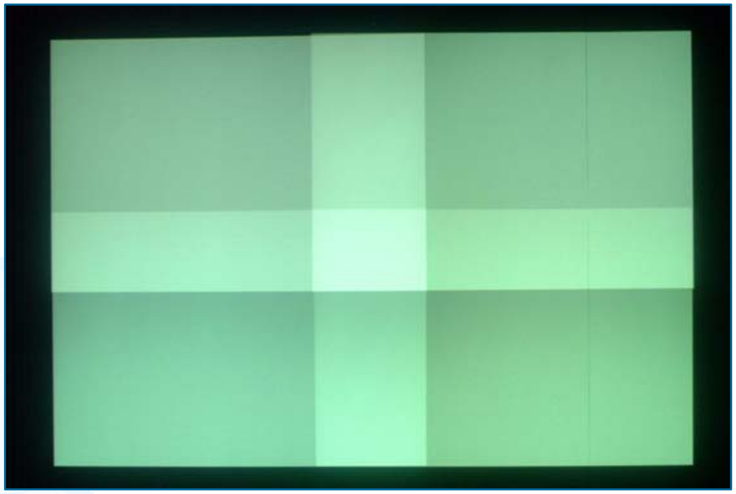
Handle all variations

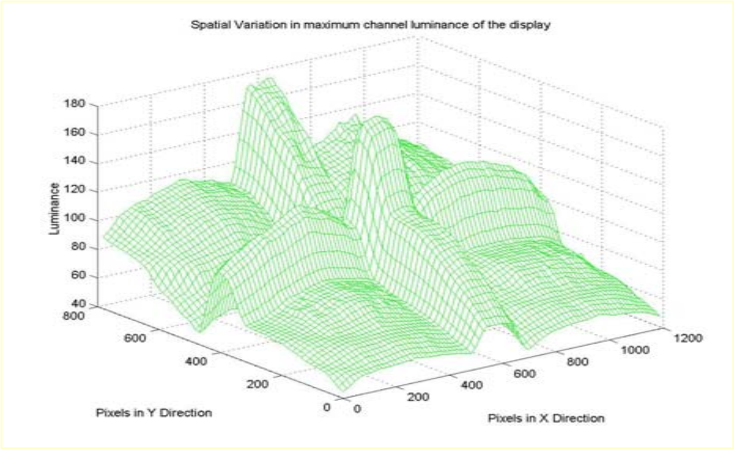
- Measure each projector's vignetting
- Measure each projector's transfer function



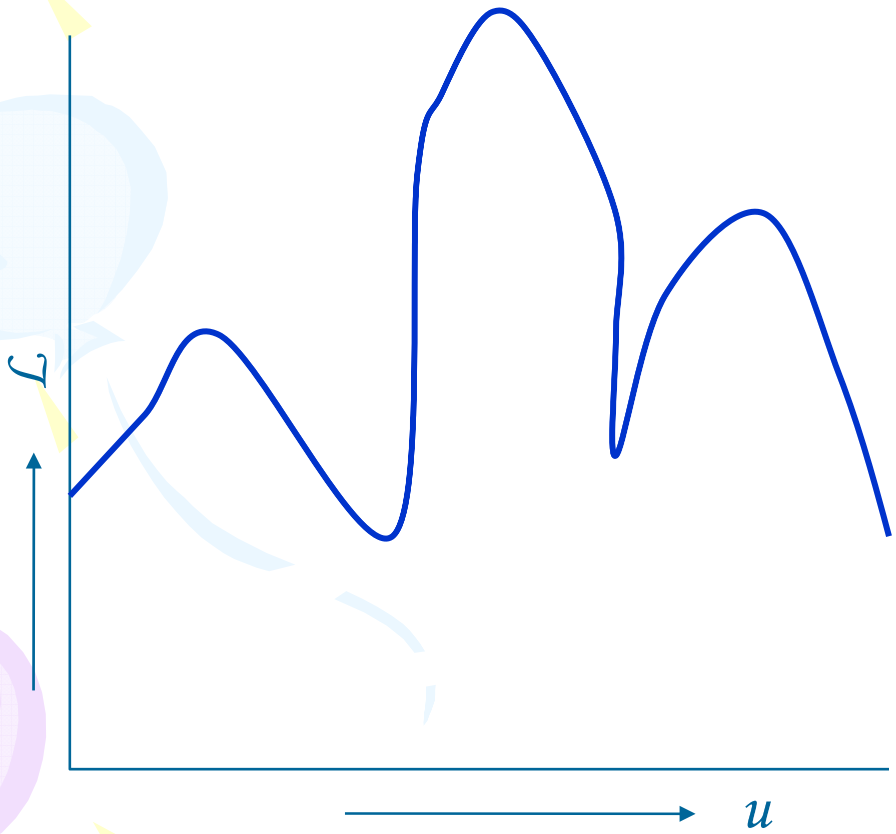


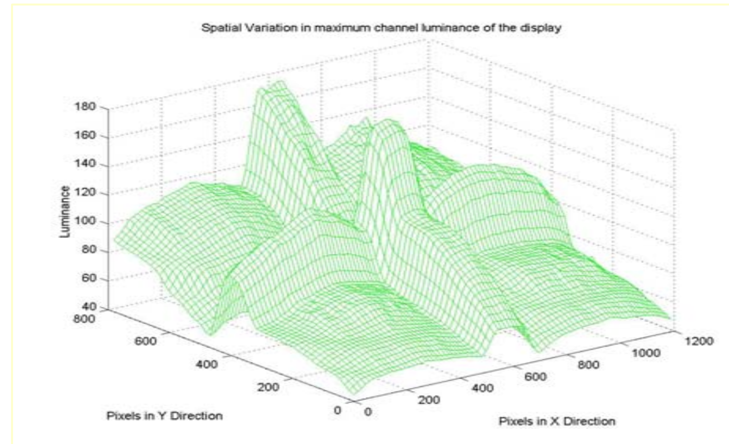
Add them up



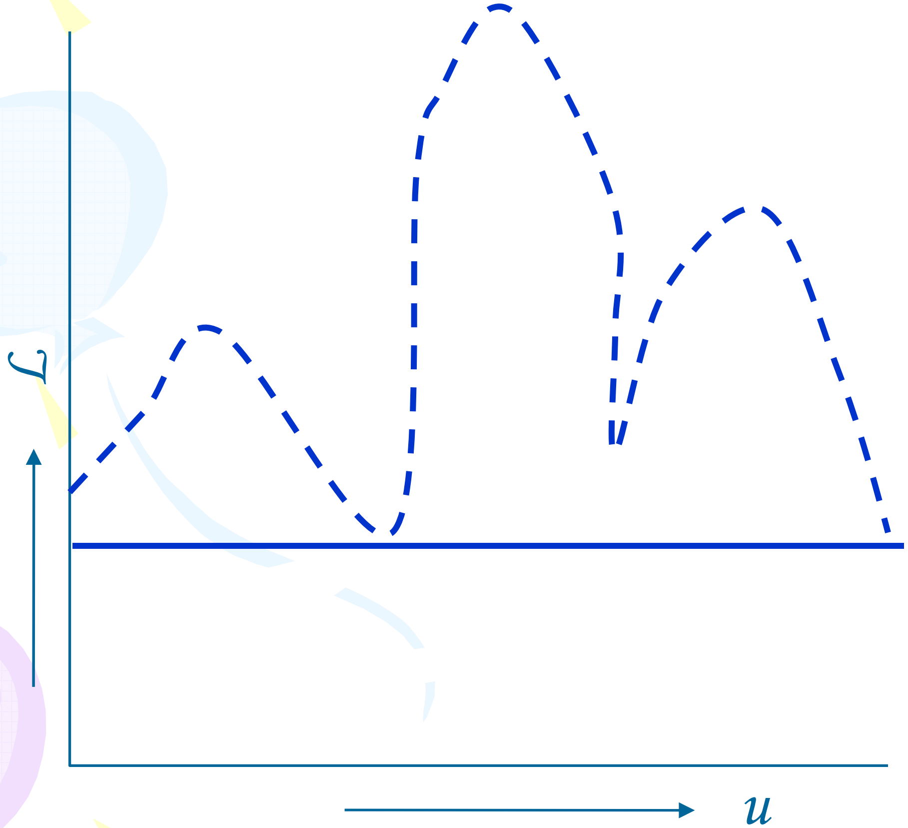

Spatial Variation in maximum channel luminance of the display
Luminance
180
160
140
120
100
80
60
40
800
600
400
200
0
0
200
400
600
800
1000
1200
Pixels in Y Direction
Pixels in X Direction

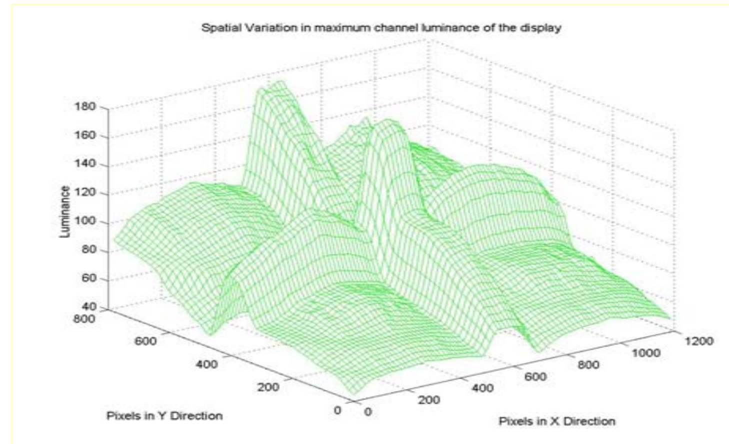
Strict Luminance Uniformity

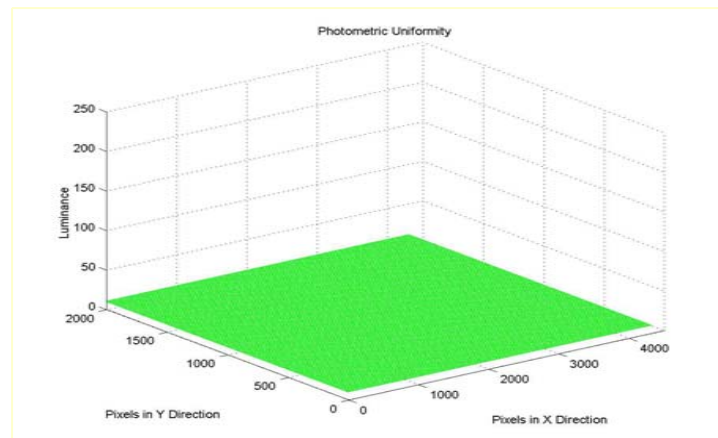




Strict Luminance Uniformity







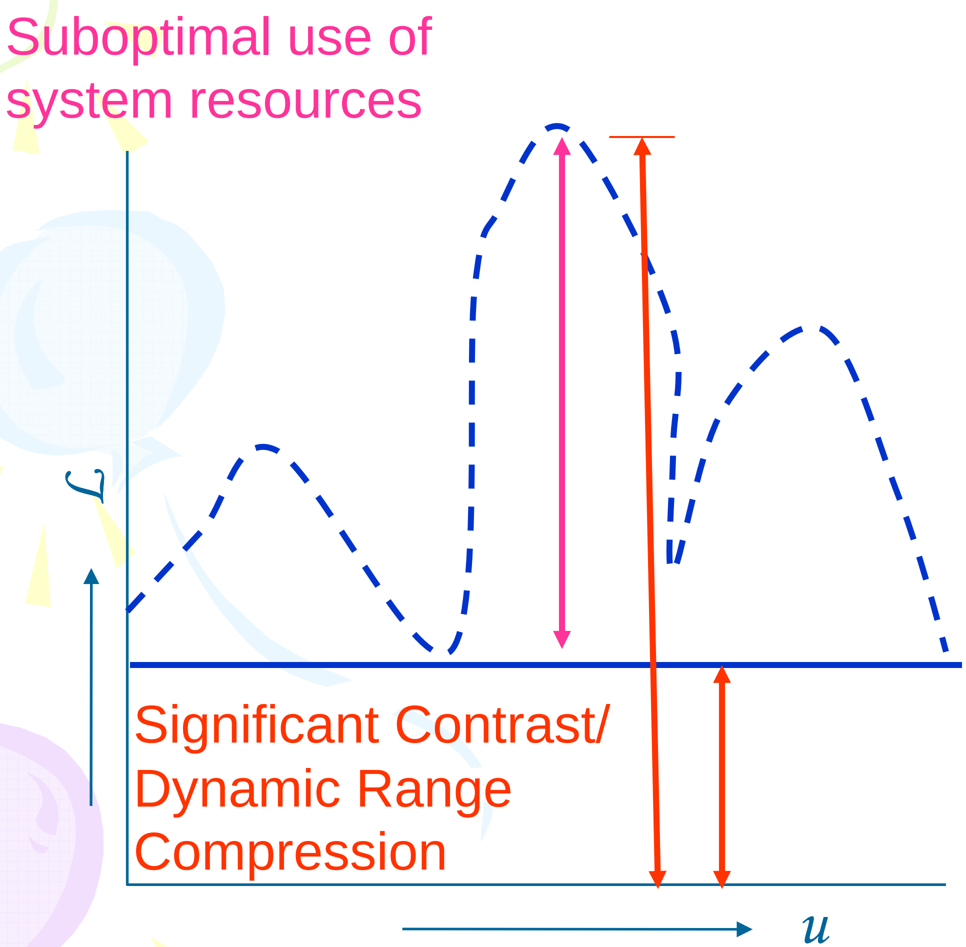
Results

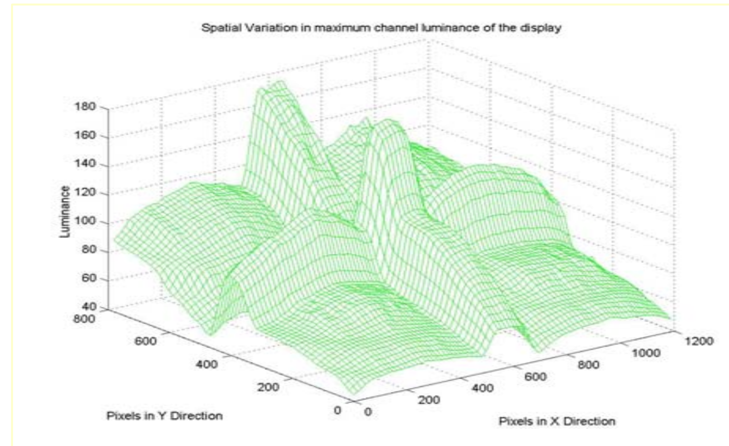
Before

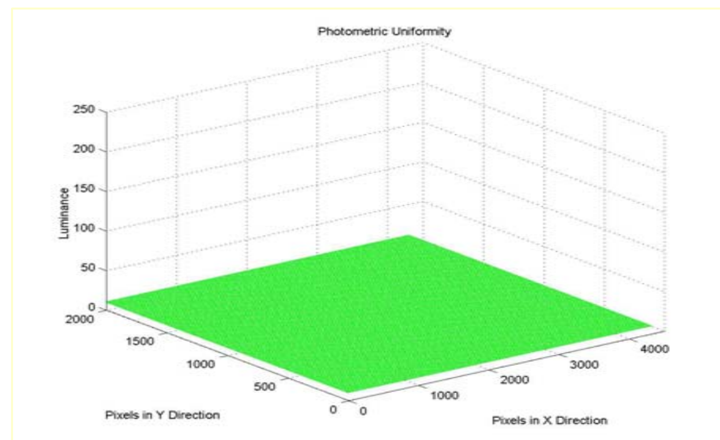
After Strict Luminance Uniformity

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.

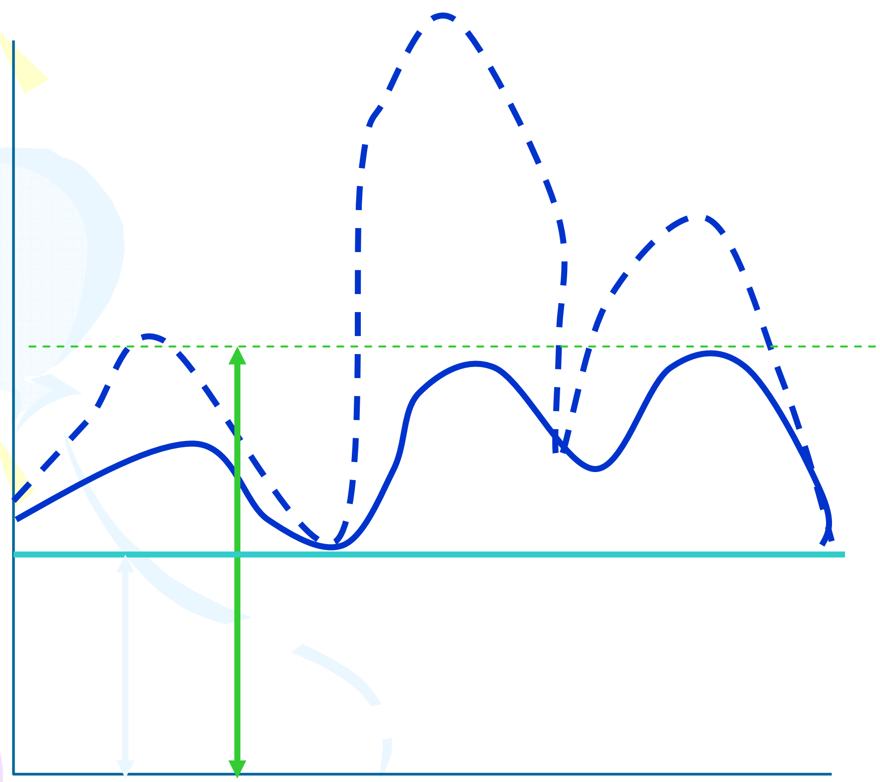
Strict Luminance Uniformity

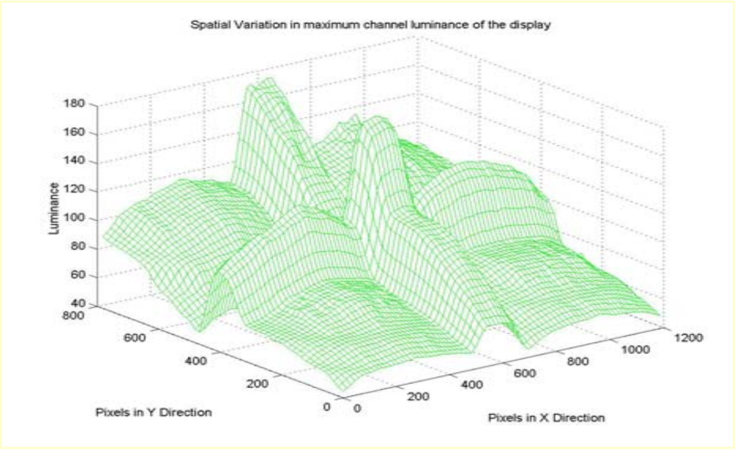


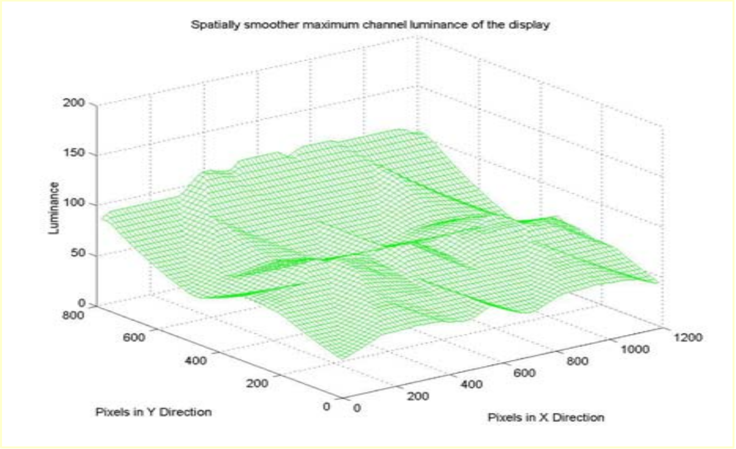




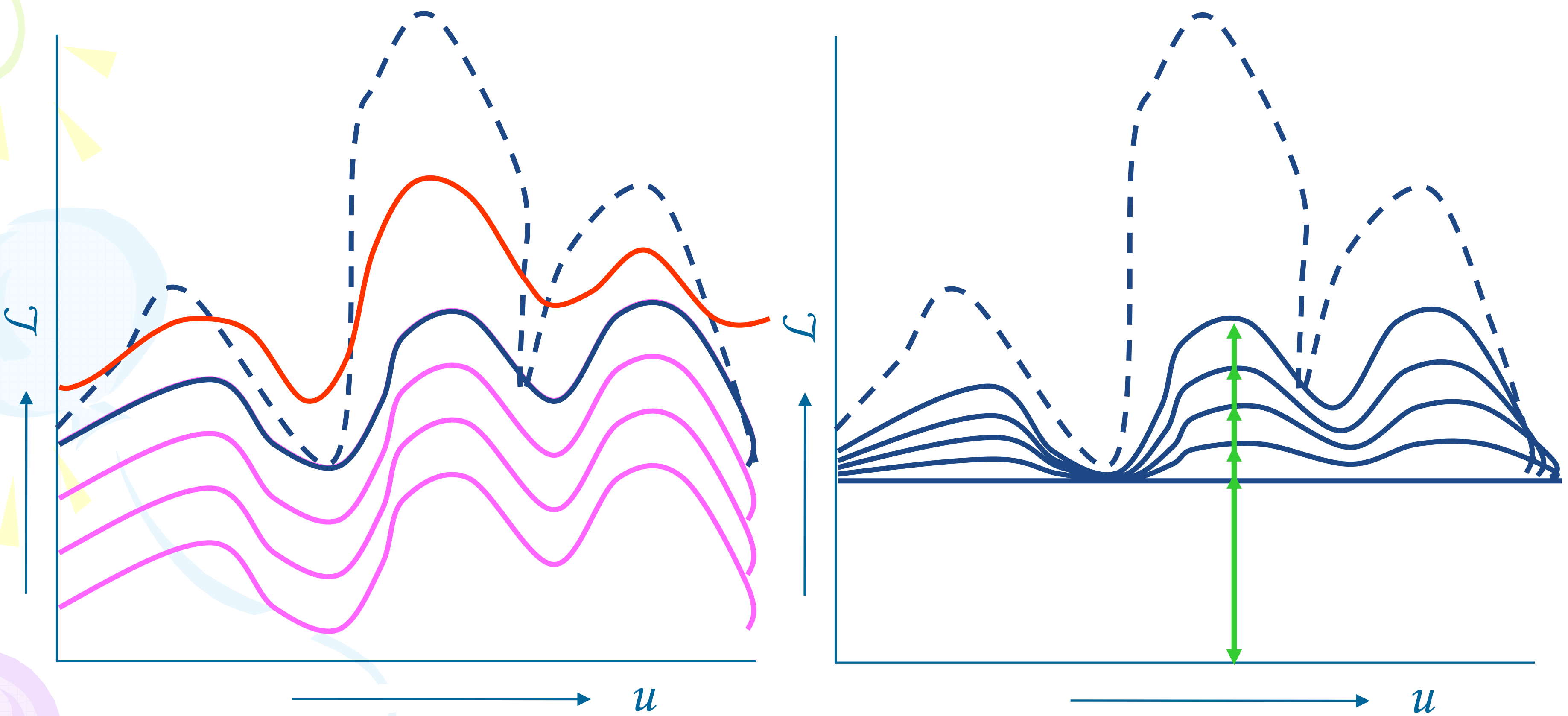
Smooth the Luminance function







Optimization Problem



Strict luminance uniformity is a special case.

Results

Before

After Strict Luminance Uniformity

Results

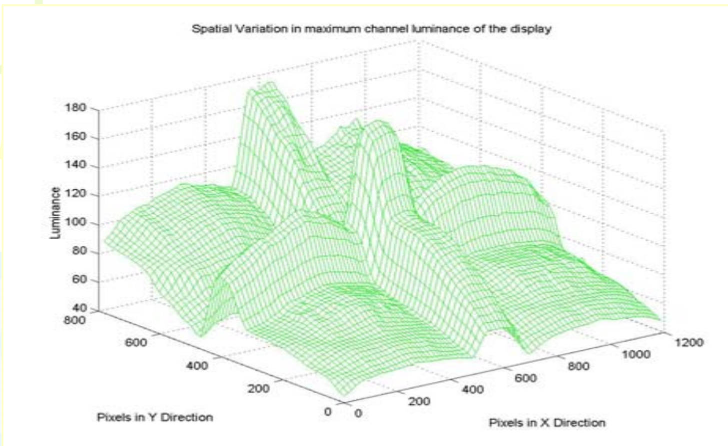
Before

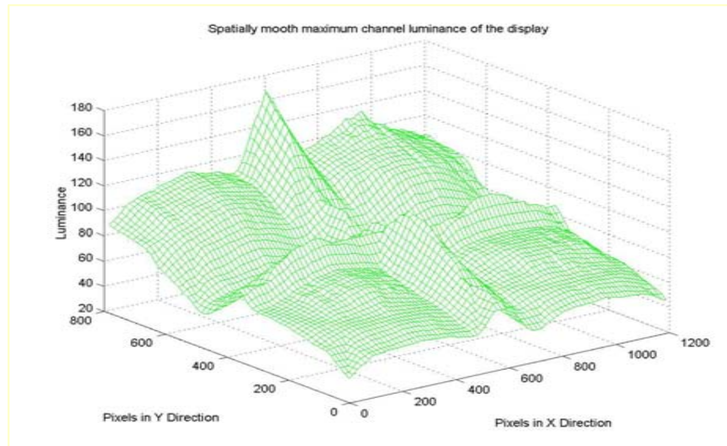
1) *A. Majumder, R. Stevens, Perceptual Photometric Seamlessness in Tiled Projection Based Displays, ACM Transactions on Graphics, Vol. 24, No. 1, 2005.*
2) *A. Majumder, Improving Contrast of Multi-Displays Using Human Contrast Sensitivity, IEEE CVPR 2005.*

After Luminance Smoothing

Different smoothing parameters (2x2 array of four projectors)

Smooth

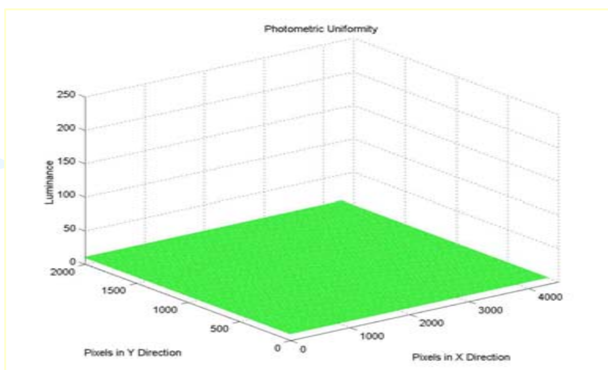


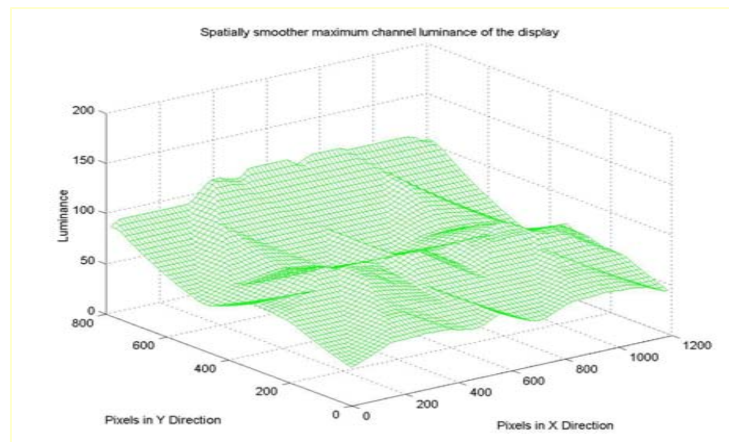


Original

Smoother

Flat





Different smoothing parameters (3x5 array of fifteen projectors)

Original

Smooth

Flat

Smoother