Gradient Domain Manipulation Techniques in Vision and Graphics

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Course WebPage :
http://www.cfar.umd.edu/~aagrawal/ICCV2007Course/

Course: Gradient Domain Techniques

Course Web Page

http://www.cfar.umd.edu/~aagrawal/ICCV2007Course/

Google: 'iccv 2007 gradient domain'

Course Evaluation

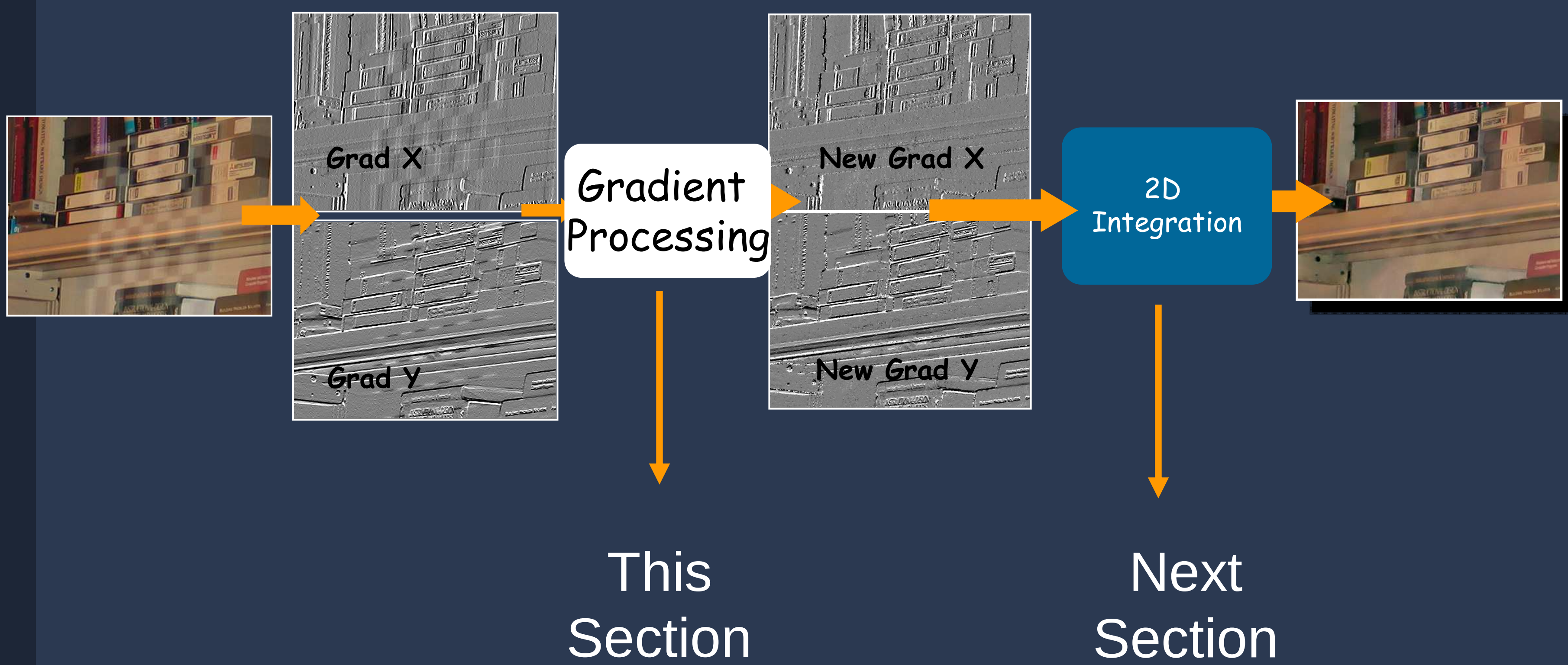
Schedule

Introduction	(30 min, Agrawal)
Gradient Domain Manipulations	(1 hr, Raskar)
Break	(30 min)
Reconstruction Techniques	(1 hr, Agrawal)
Advanced Topics	(30 min, Raskar)
Discussion	

Course WebPage : http://www.cfar.umd.edu/~aagrawal/ICCV2007Course

Intensity Gradient Manipulation

A Common Pipeline



Gradient Domain Manipulations: Overview

(A) Per pixel

(B) Corresponding gradients in two images

(C) Corresponding gradients in multiple images

(D) Combining gradients along seams

Gradient Domain Manipulations: Overview

(A) Per pixel

- Non-linear operations (HDR compression, local illumination change)
- Set to zero (shadow removal, intrinsic images, texture de-emphasis)
- Poisson Matting

(B) Corresponding gradients in two images

- Vector operations (gradient projection)
  - Combining flash/no-flash images, Reflection removal
- Projection Tensors
  - Reflection removal, Shadow removal
- Max operator
  - Day/Night fusion, Visible/IR fusion, Extending DoF
- Binary, choose from first or second, copying
  - Image editing, seamless cloning

Gradient Domain Manipulations

(C) Corresponding gradients in multiple images

- Median operator
  - Specularity reduction
  - Intrinsic images
- Max operation
  - Extended DOF

(D) Combining gradients along seams

- Weighted averaging
- Optimal seam using graph cut
  - Image stitching, Mosaics, Panoramas, Image fusion
  - A usual pipeline: Graph cut to find seams + gradient domain fusion

A. Per Pixel Manipulations

- Non-linear operations
  - HDR compression, local illumination change

- Set to zero
  - Shadow removal, intrinsic images, texture de-emphasis

- Poisson Matting

High Dynamic Range Imaging

- Cameras have limited dynamic range

Small Exposure image, dark inside

1/500 sec

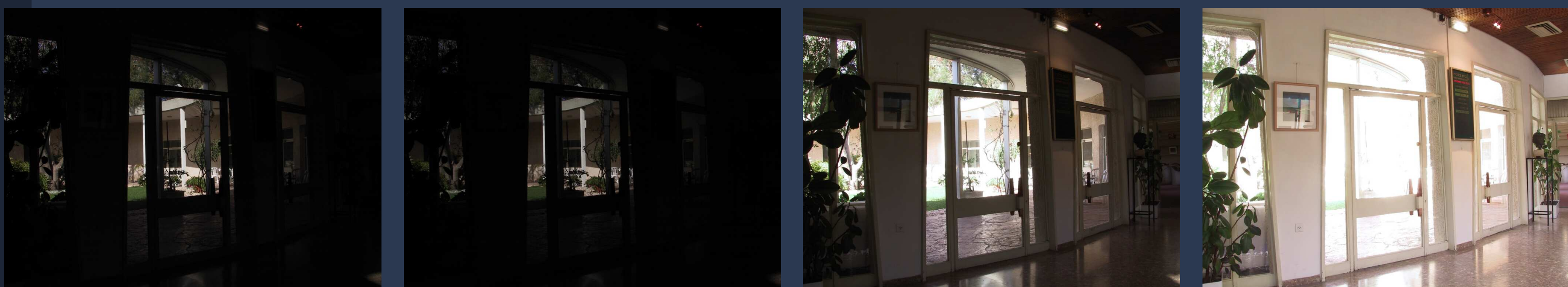
Large exposure image, saturated outside

¼ sec

Images from Raanan Fattal

High Dynamic Range Imaging

- Combine images at different exposures
- Exposure Bracketing
- [Mann and Picard 95, Debevec et al 96]

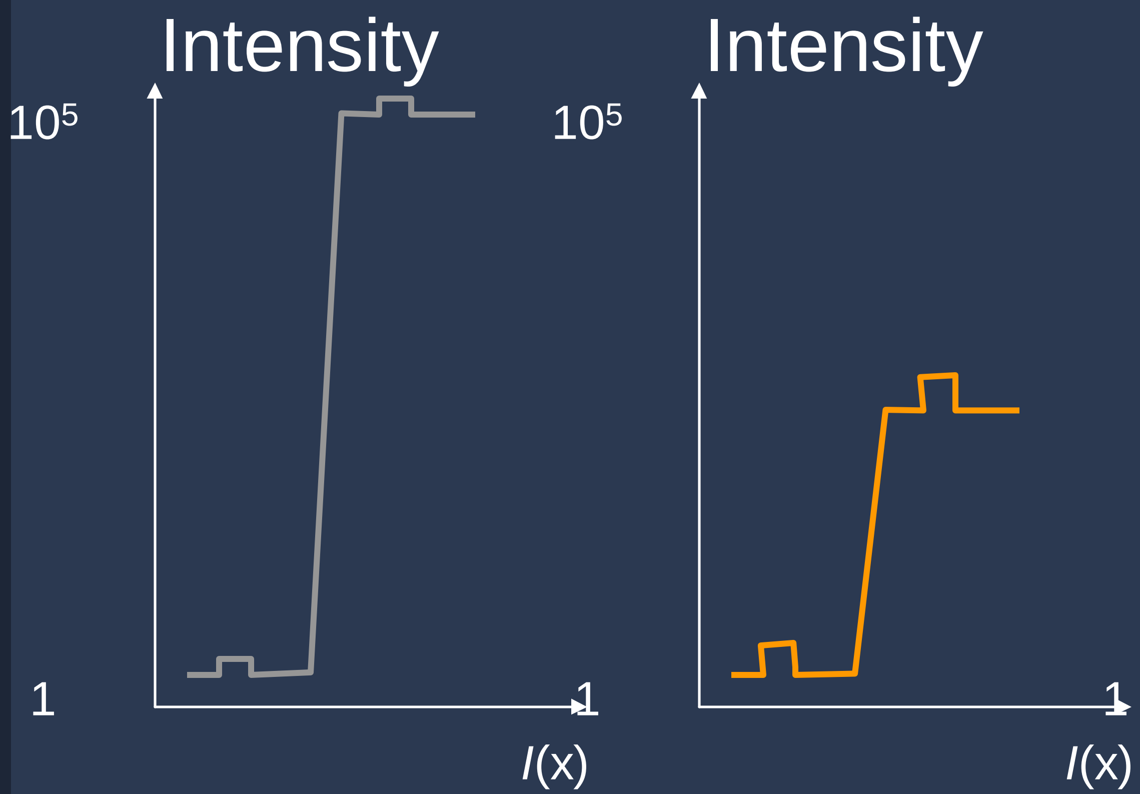


Images from Raanan Fattal

How could we put all this information into one image ?

Tone Map 20 bit image for 8 bit Display

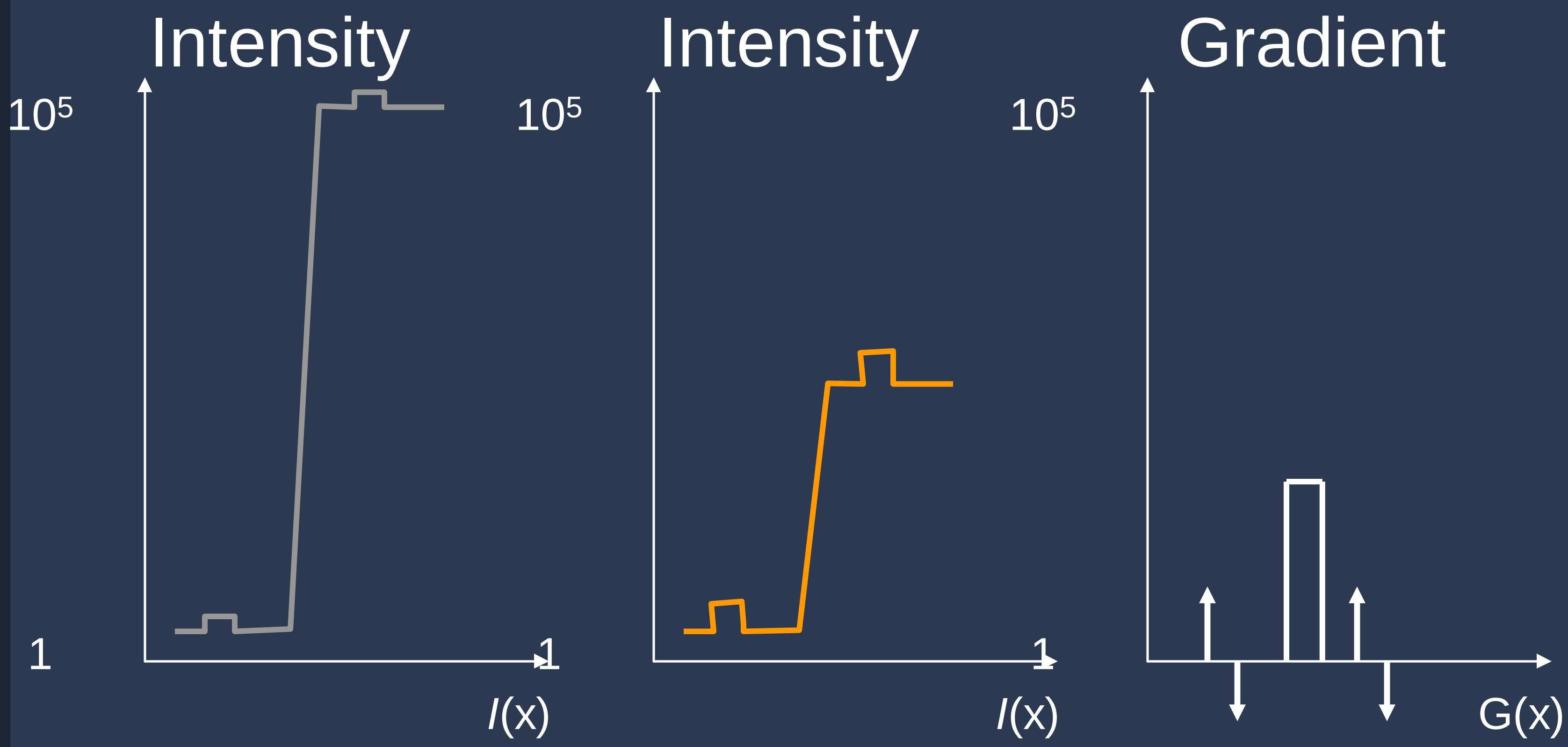
Attenuate High Gradients



Maintain local detail at the cost of global range

Fattal et al Siggraph 2002

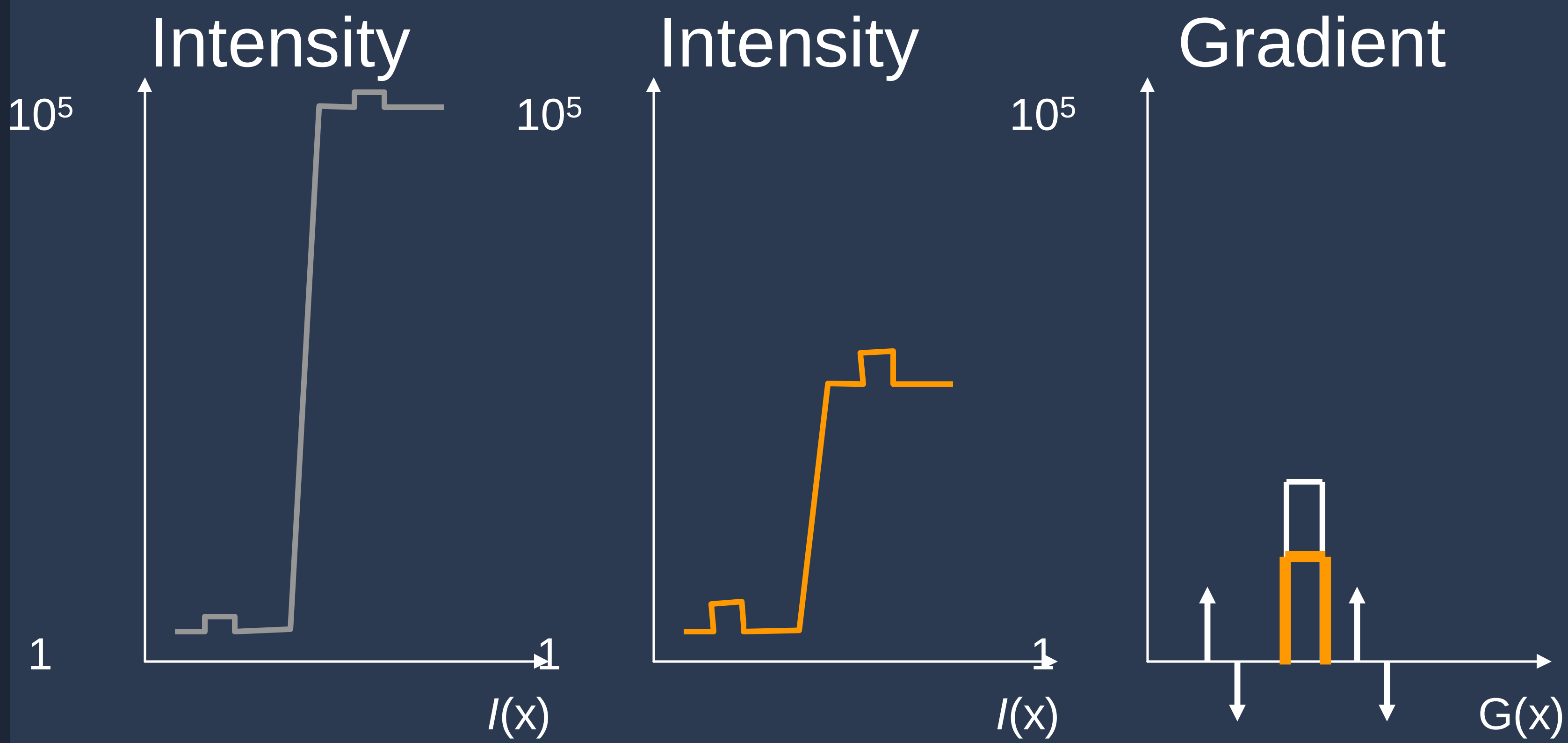
Attenuate High Gradients



Maintain local detail at the cost of global range

Fattal et al Siggraph 2002

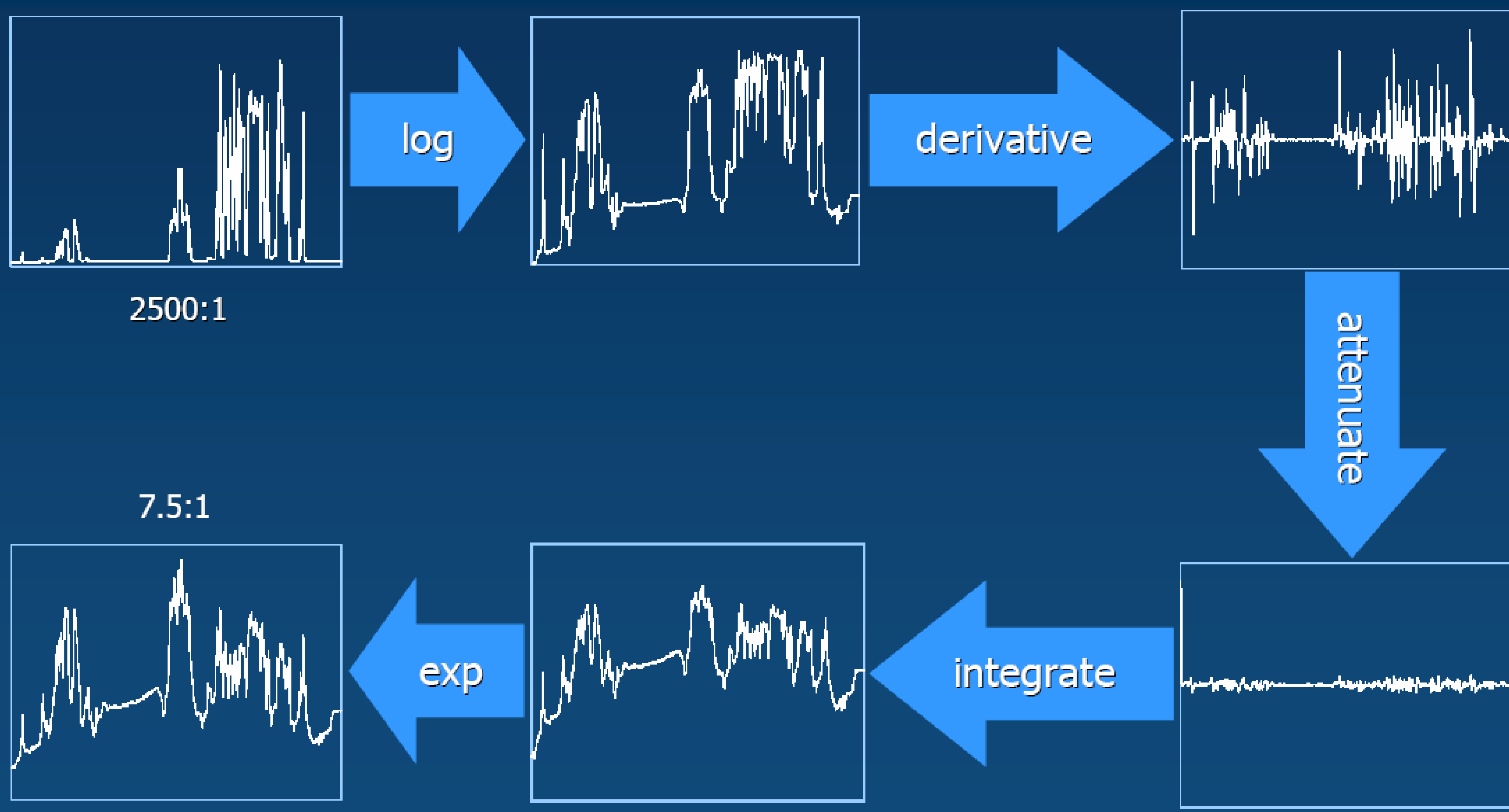
Attenuate High Gradients



Keep low gradients

Fattal et al Siggraph 2002

Gradient Compression in 1D



Gradient Domain Compression

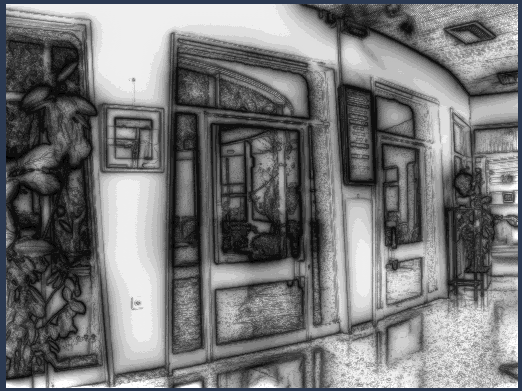
HDR
Image L

Log L

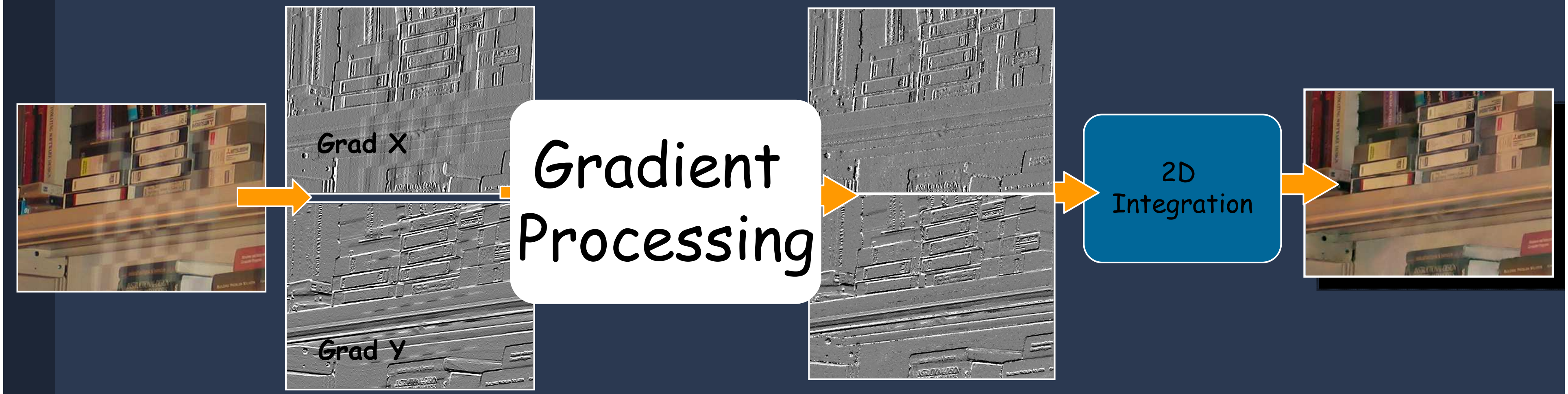
Gradients
L_x, L_y

Multiply

2D
Integration



Gradient Attenuation
Function G


Grad X
Grad Y
Gradient Processing
2D Integration

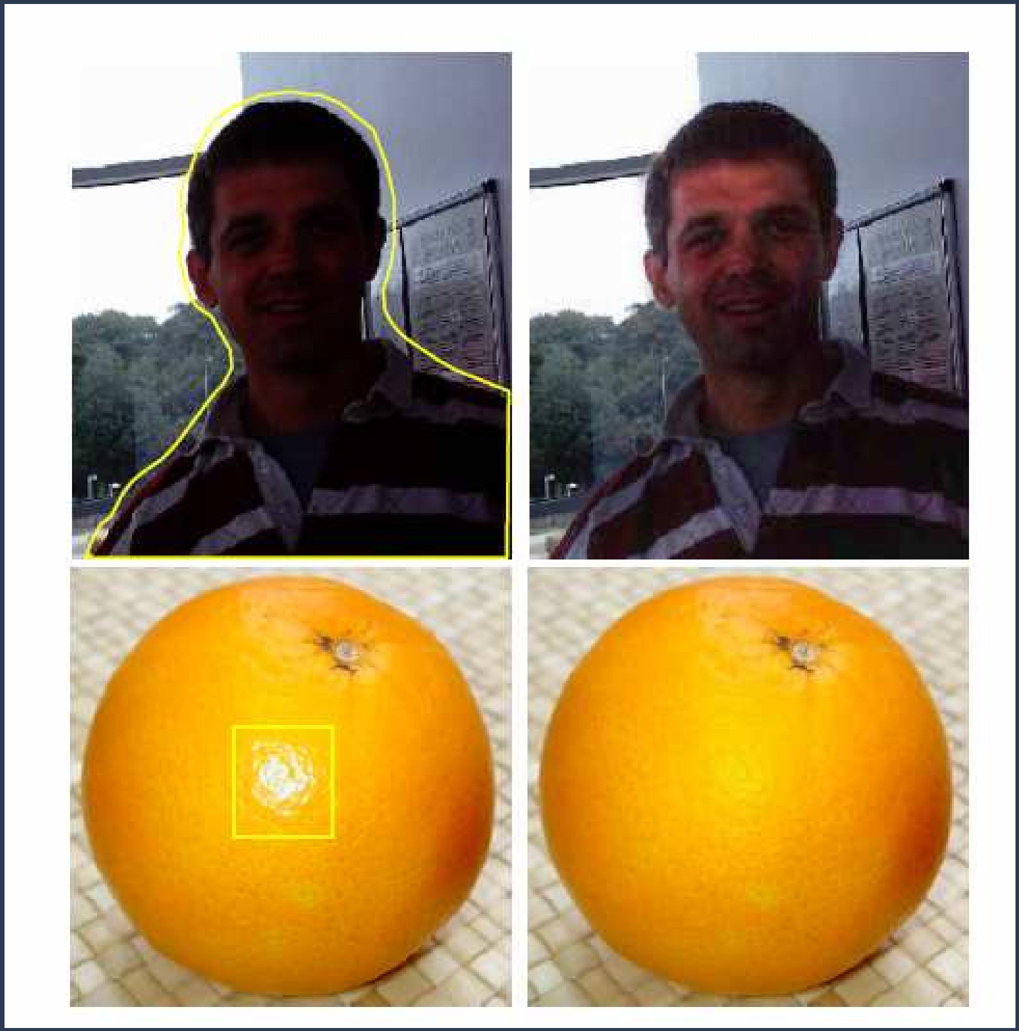
Local Illumination Change

Original Image: f

$$\mathbf{v} = \alpha^{\beta} |\nabla f^*|^{-\beta} \nabla f^*,$$

Original gradient field: ∇f^*

Modified gradient field: v



Perez et al. Poisson Image editing, SIGGRAPH 2003

Per Pixel Manipulations

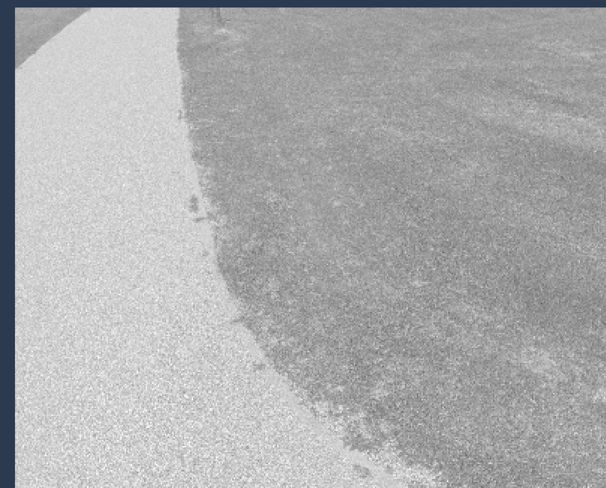
- Non-linear operations
  - HDR compression, local illumination change

- Set to zero
  - Shadow removal, intrinsic images, texture de-emphasis

- Poisson Matting

Illumination Invariant Image

Original Image



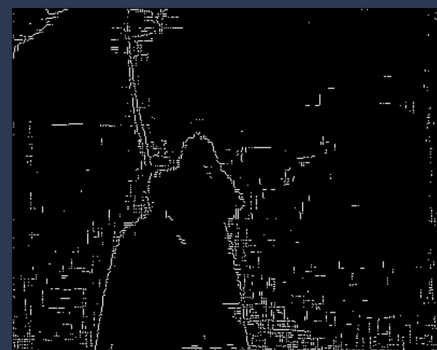
Illumination invariant image

- Assumptions
  - Sensor response = delta functions R, G, B in wavelength spectrum
  - Illumination restricted to Outdoor Illumination

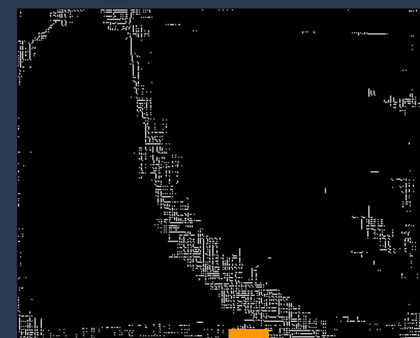
G. D. Finlayson, S.D. Hordley & M.S. Drew, Removing Shadows From Images, ECCV 2002

Shadow Removal Using Illumination Invariant Image

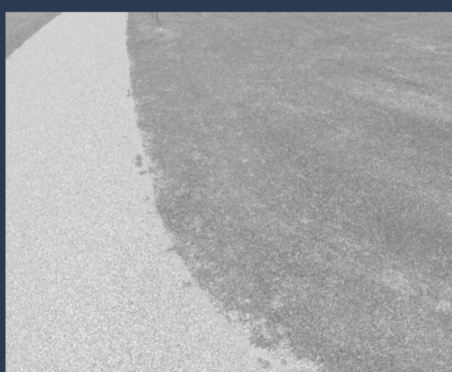
Original Image



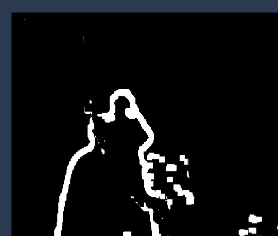
Edge Map



Integrate



Illumination invariant image



Shadow Edge Locations

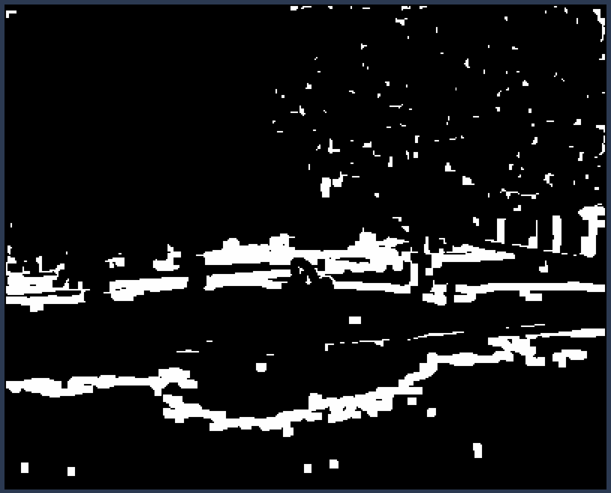
G. D. Finlayson, S.D. Hordley & M.S. Drew, Removing Shadows From Images, ECCV 2002

Illumination invariant image

Original Image

Invariant Image

Detected Shadow Edges



Shadow Removed

G. D. Finlayson, S.D. Hordley & M.S. Drew, Removing Shadows From Images, ECCV 2002

Intrinsic Image

- [Barrow & Tenenbaum]
- Photo = Illumination Image * Intrinsic Image
- Retinex [Land & McCann 1971, Horn 1974]
  - Illumination is smoothly varying
  - Reflectance, piece-wise constant, has strong edges
  - Keep strong image gradients
  - Integrate to obtain reflectance

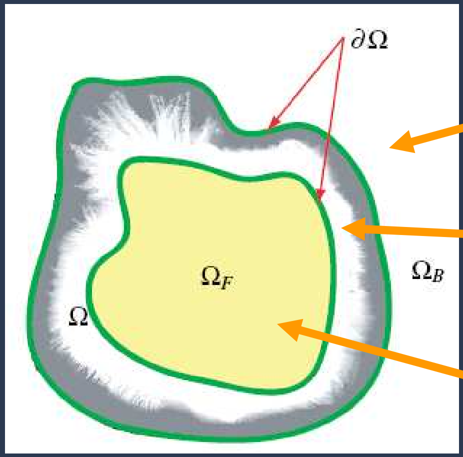
Per Pixel Manipulations

- Non-linear operations
  - HDR compression, local illumination change

- Set to zero
  - Shadow removal, intrinsic images, texture de-emphasis

- Poisson Matting

Poisson Matting



Background B

Alpha

Foreground F

Trimap: User specified

Jian Sun, Jiaya Jia, Chi-Keung Tang, Heung-Yeung Shum, Poisson Matting, SIGGRAPH 2004

Poisson Matting

$$I = \alpha F + (1 - \alpha) B$$

$$\nabla I = (F - B)\nabla\alpha + \alpha\nabla F + (1 - \alpha)\nabla B$$

Approximate: Assume F and B are smooth

$$\nabla I = (F - B)\nabla\alpha$$

$$\nabla\alpha \approx \frac{1}{F - B}\nabla I$$

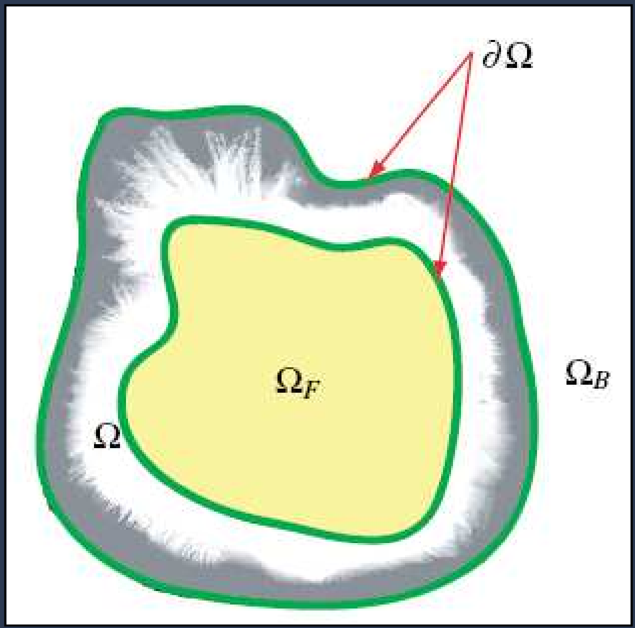
$$\Delta\alpha = div\left(\frac{\nabla I}{F - B}\right)$$

F and B in tri-map using nearest pixels

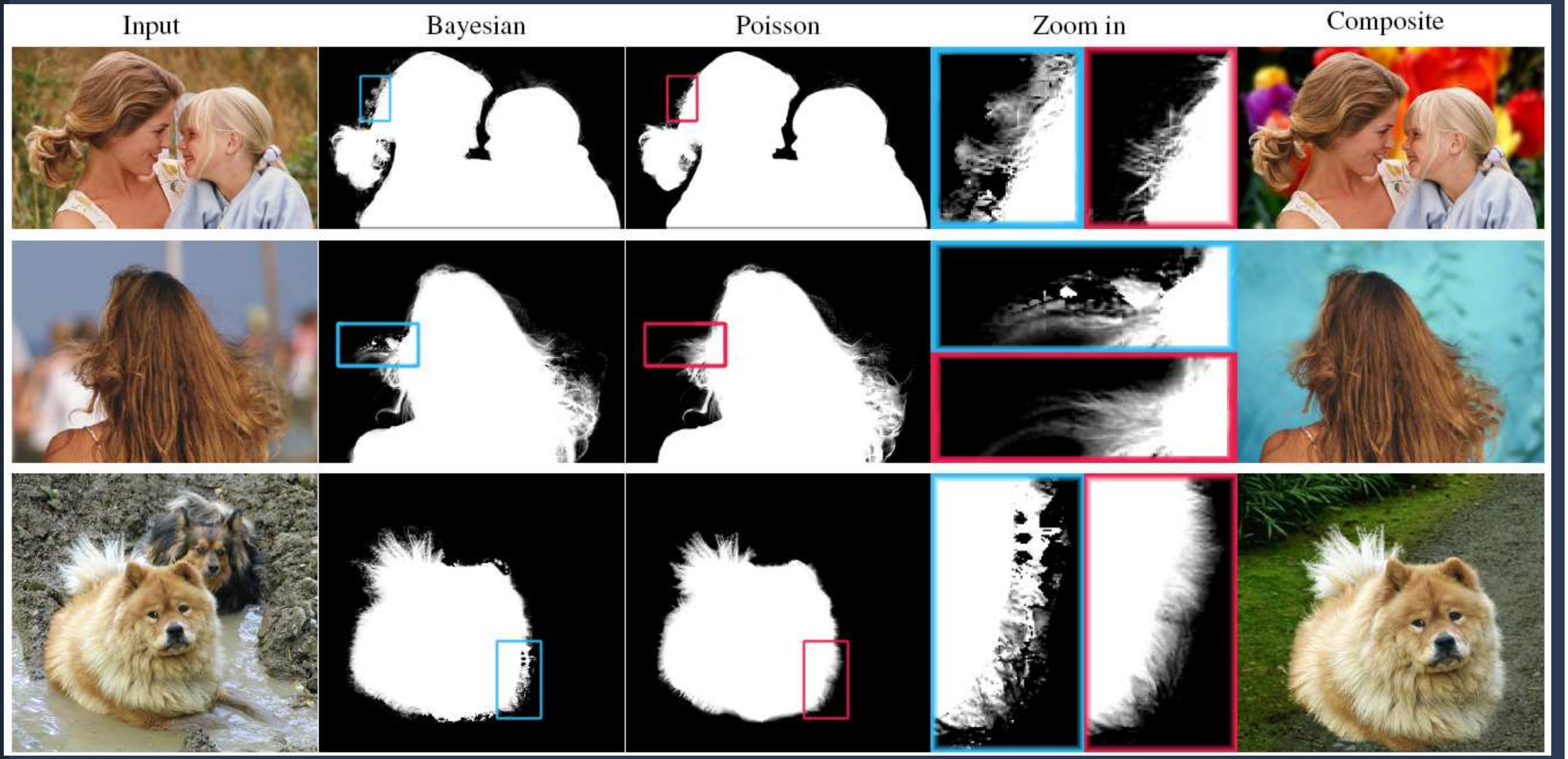
Poisson Equation

Poisson Matting

- Steps
  - Approximate F and B in trimap Ω
  - Solve for α , $\Delta\alpha = div(\frac{\nabla I}{F - B})$
  - Refine F and B using α
  - Iterate



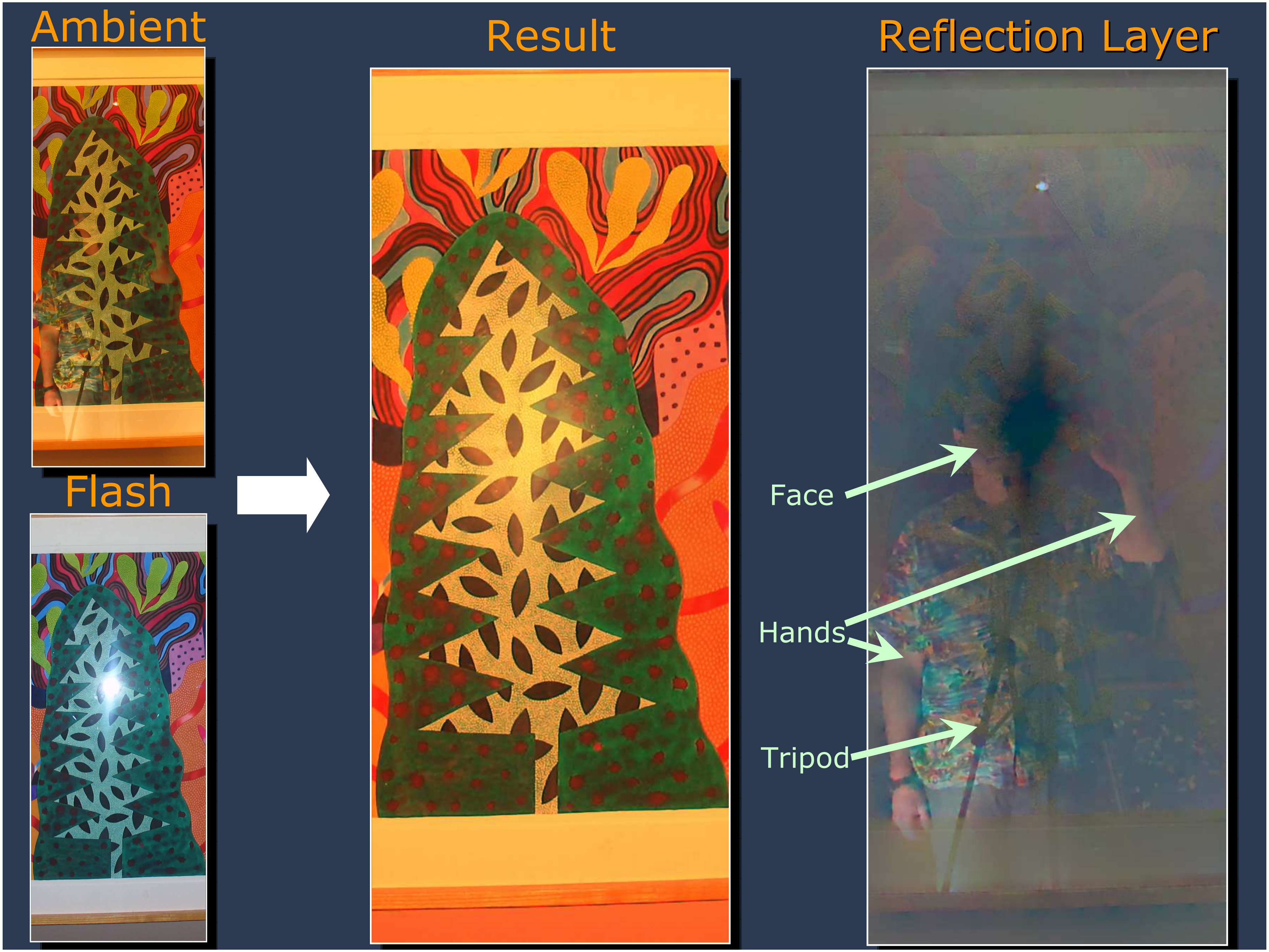
Results



Gradient Domain Manipulations: Overview

- Per pixel
  - Non-linear operations (HDR compression, local illumination change)
  - Set to zero (shadow removal, intrinsic images, texture de-emphasis)
  - Poisson Matting
- Corresponding gradients in two images
  - Vector operations (gradient projection)
    - Combining flash/no-flash images, Reflection removal
  - Projection Tensors
    - Reflection removal, Shadow removal
  - Max operator
    - Day/Night fusion, Visible/IR fusion, Extending DoF
  - Binary, choose from first or second, copying
    - Image editing, seamless cloning

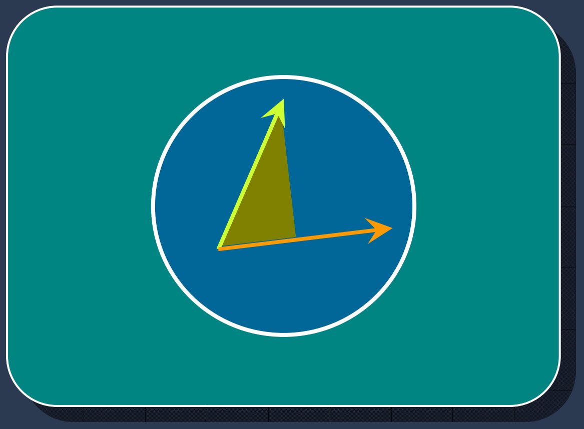
Self-Reflections and Flash Hotspot



Ambient
Flash
Result
Reflection Layer
Face
Hands
Tripod

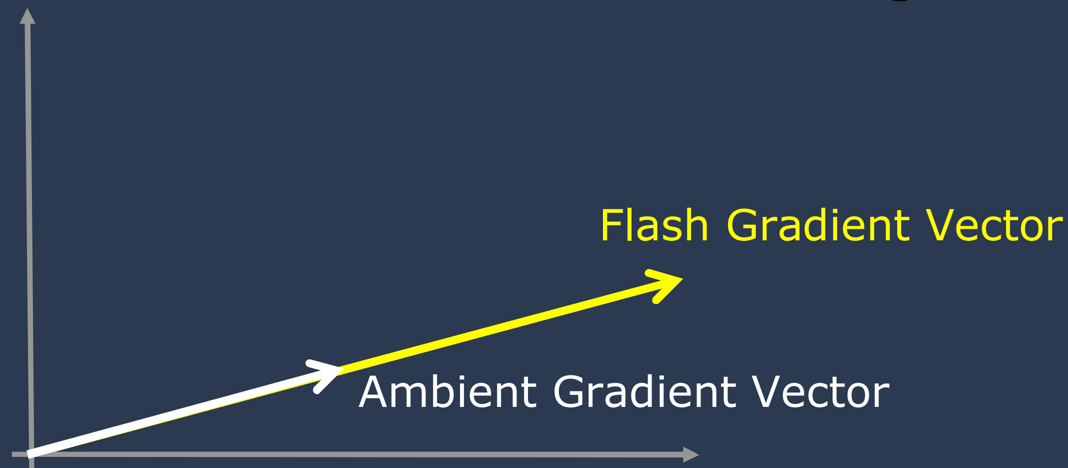
Intensity Gradient Vector <u>Projection</u>

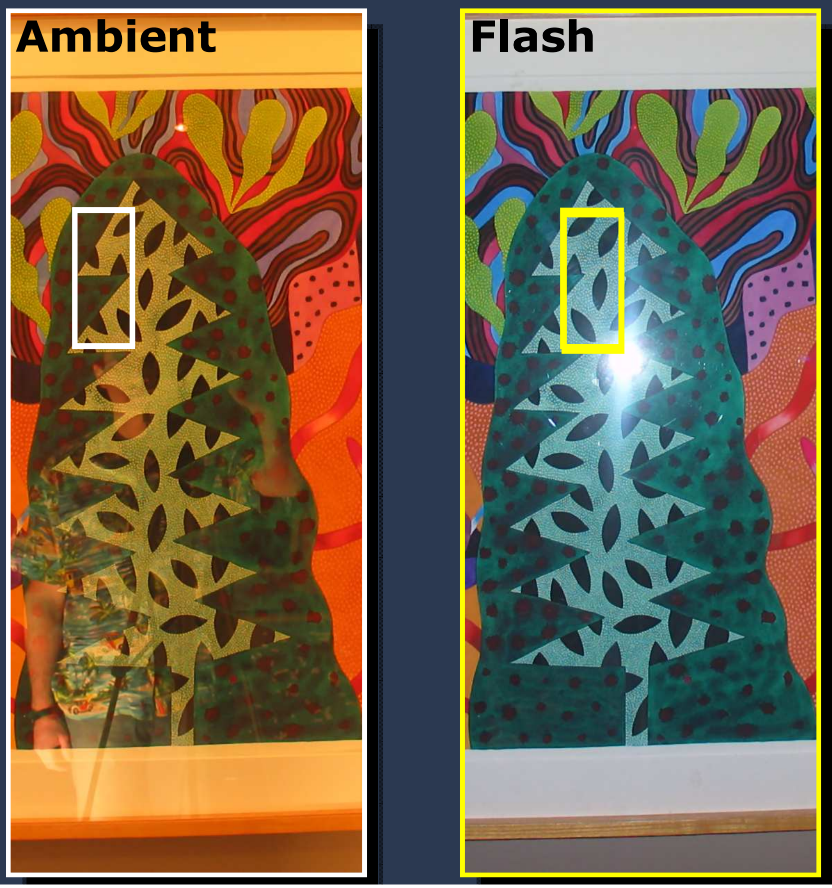
[Agrawal, Raskar, Nayar, Li SIGGRAPH 2005]

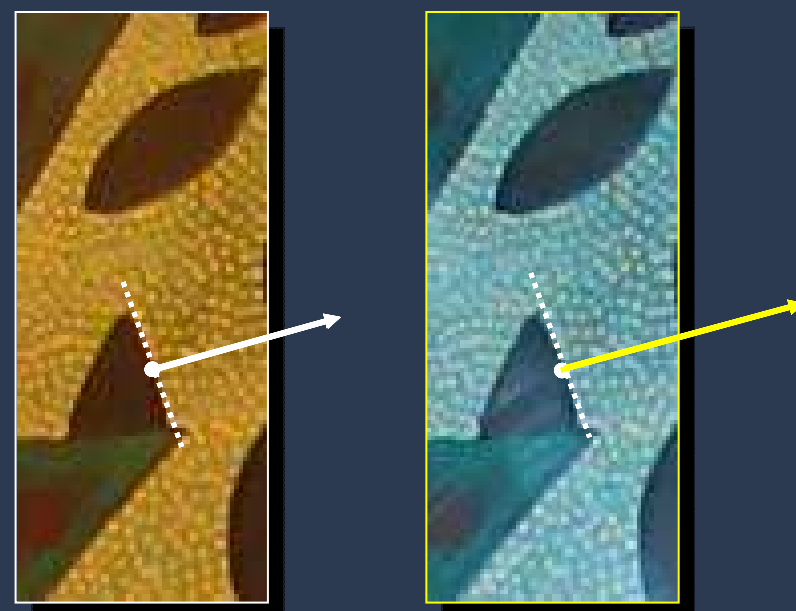


Intensity Gradient Vectors in Flash and Ambient Images

Same gradient vector direction

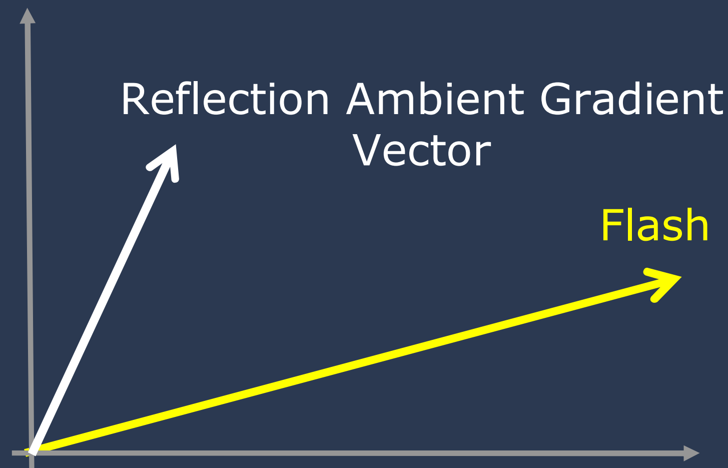


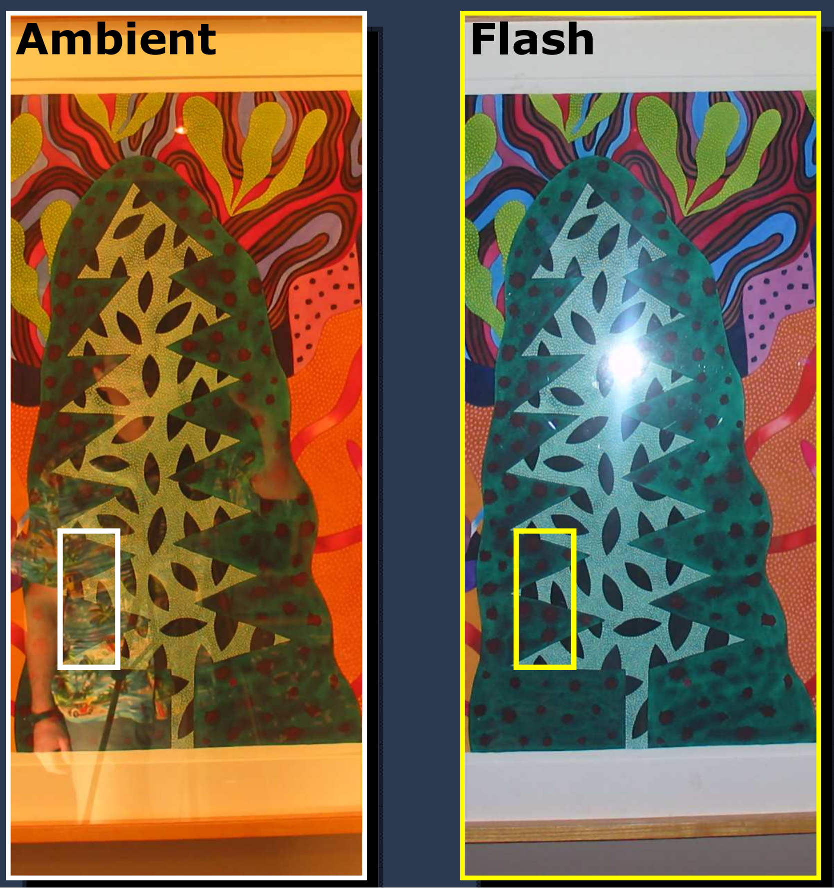


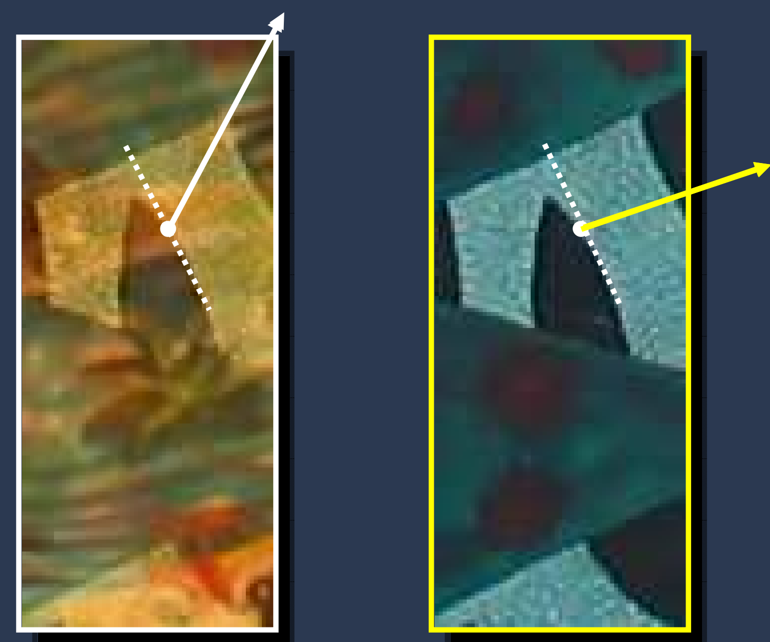


No reflections

Different gradient vector direction

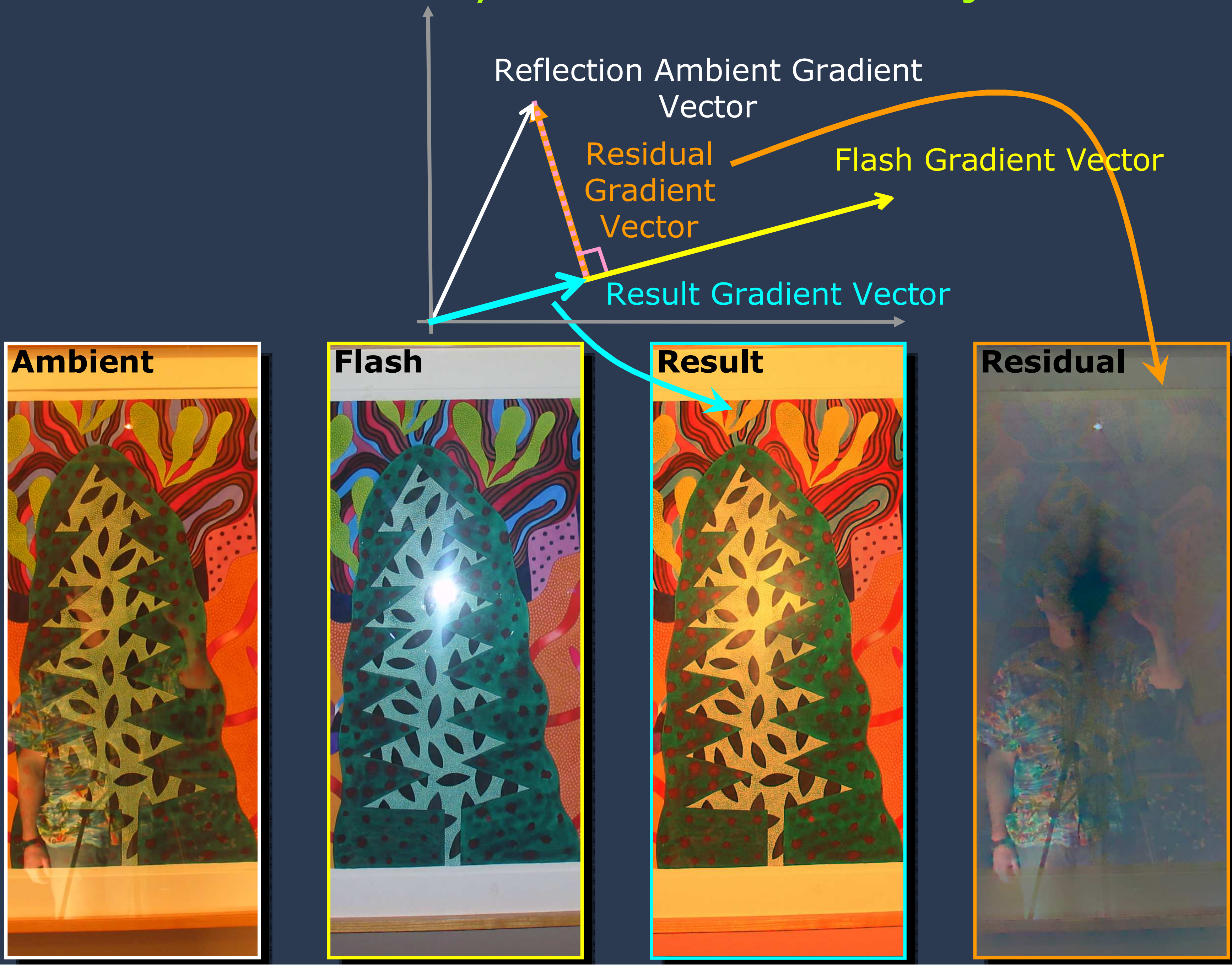


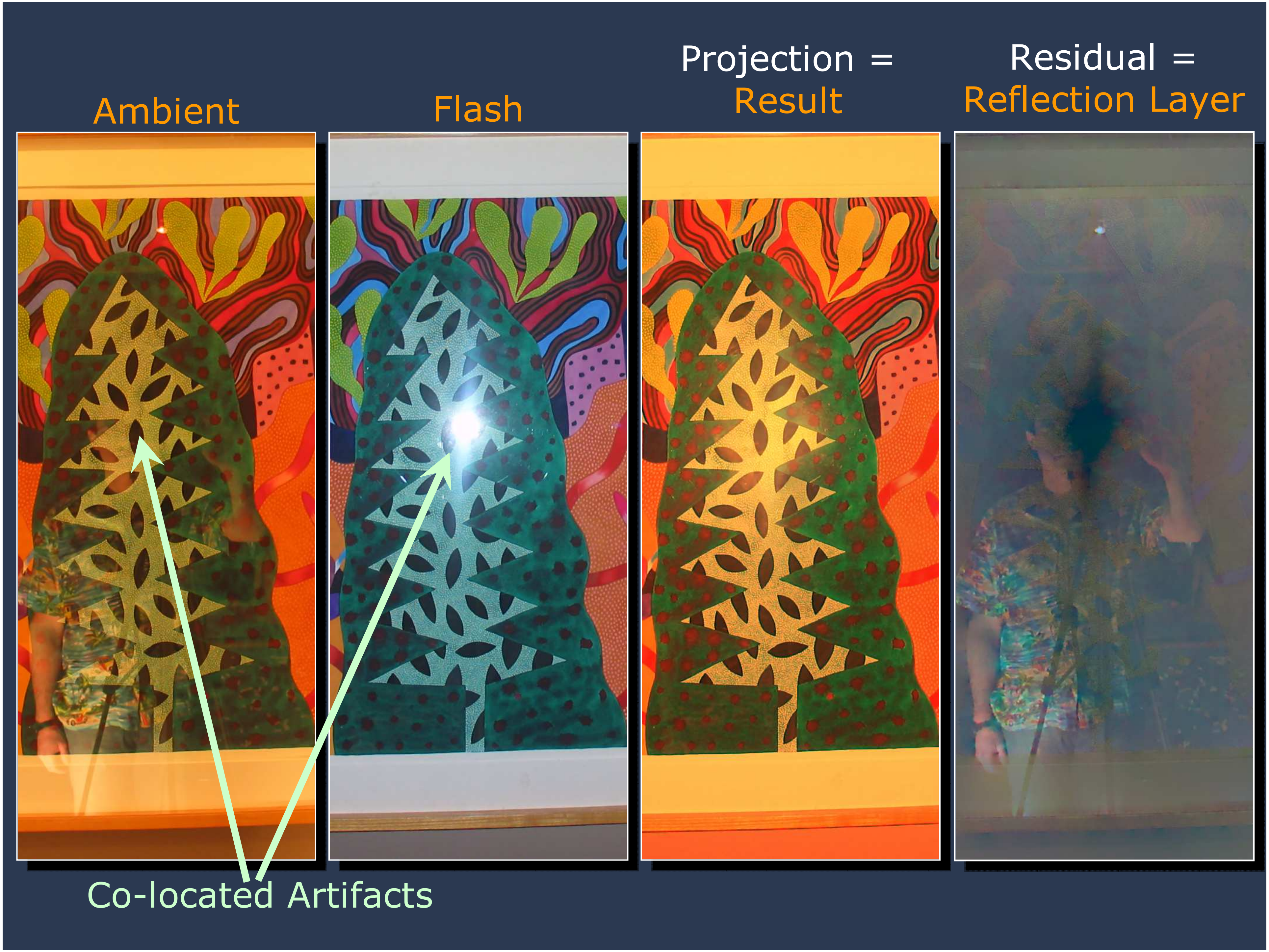




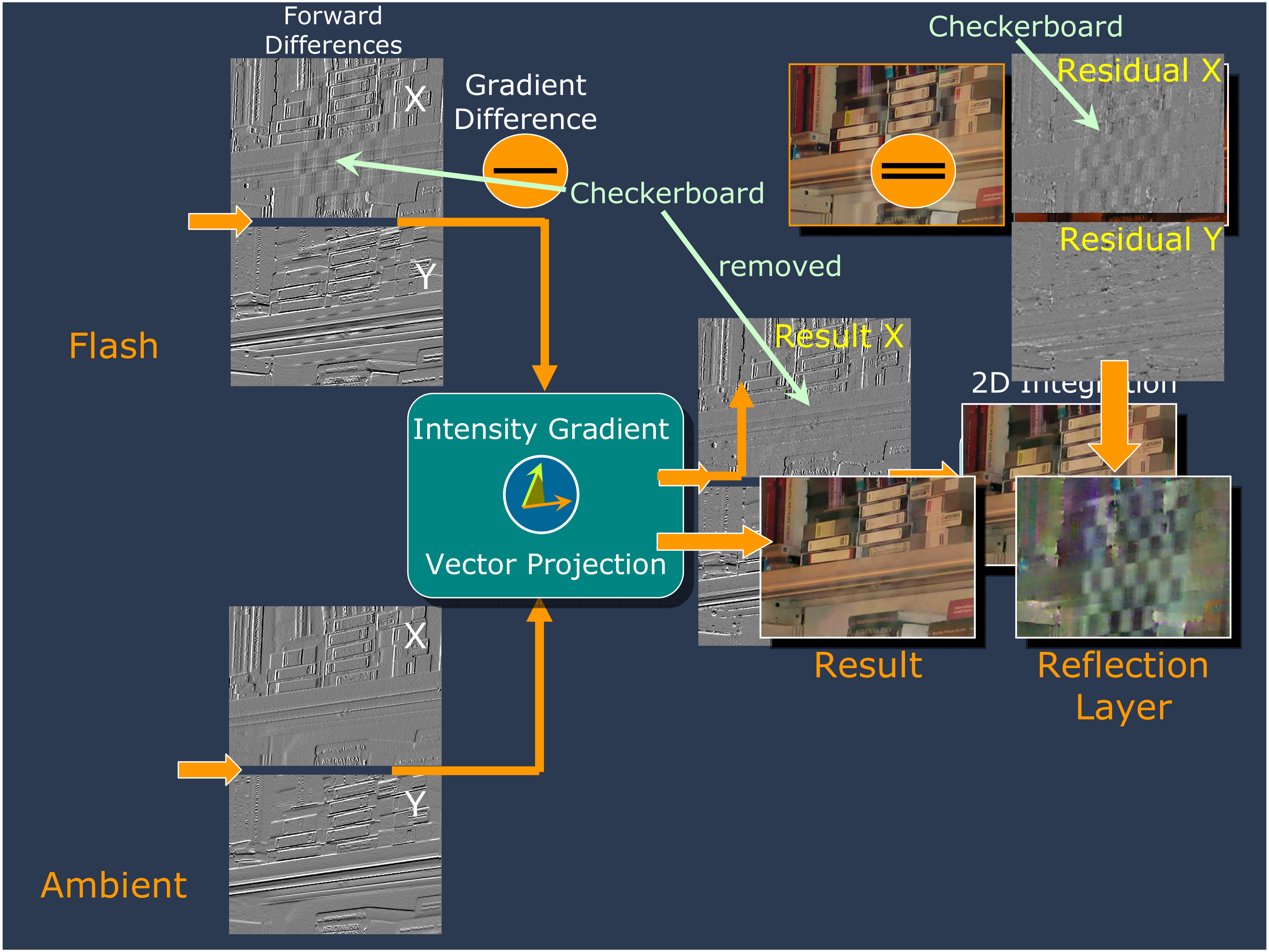
With reflections

Intensity Gradient Vector Projection



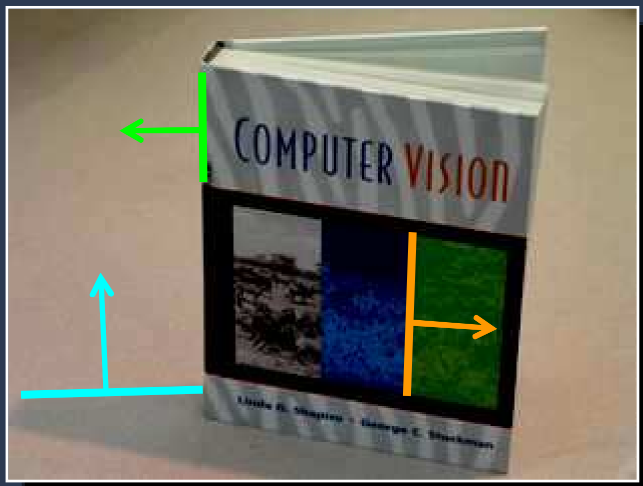

Ambient
Flash
Projection =
Result
Residual =
Reflection Layer
Co-located Artifacts

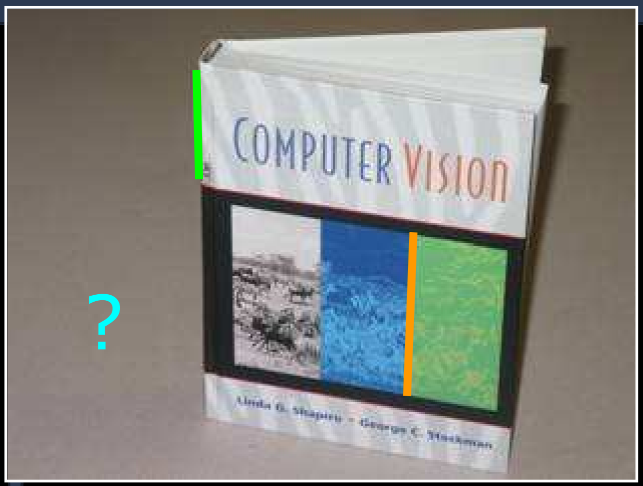

Flash
Ambient
Checkerboard
outside glass window
Reflections on
glass window



Forward Differences
X
Y
Gradient Difference
Checkerboard
Checkerboard
Residual X
Residual Y
removed
Flash
Result X
2D Integration
Intensity Gradient
Vector Projection
X
Y
Ambient
Result
Reflection Layer

Invariance of Gradient Vectors Orientation
(Gradient Orientation Coherency)





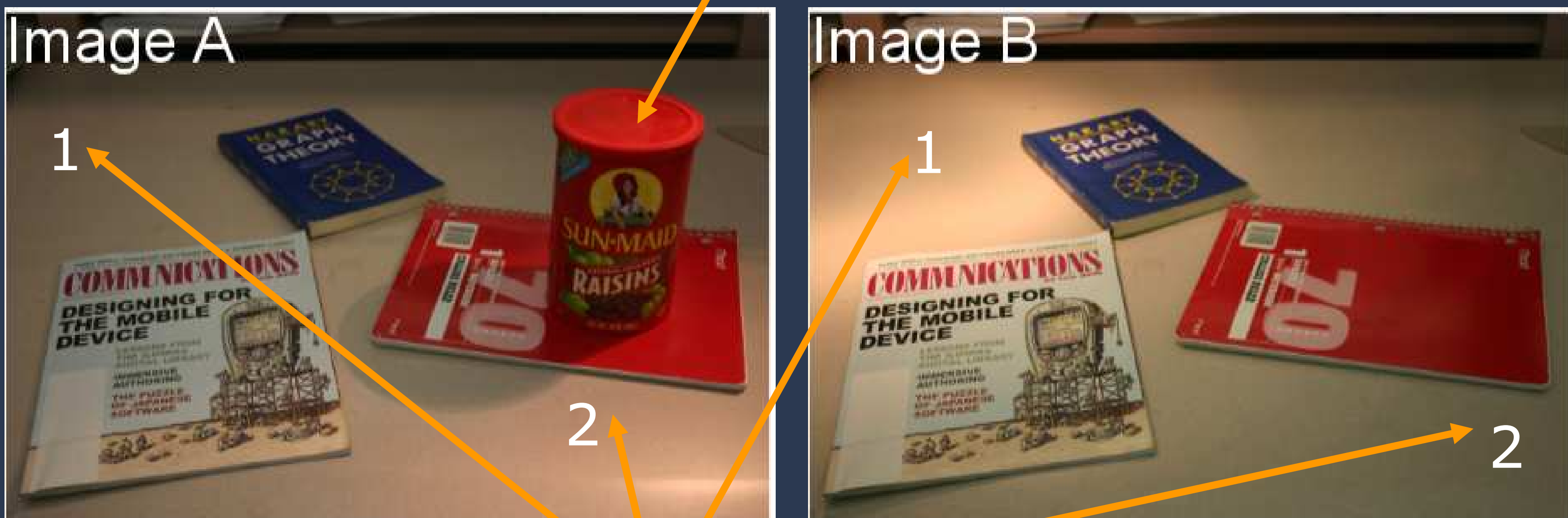
✓ Reflectance Edge

• ↑↓ Geometric Edge

✕ Illumination Edge

How to discount illumination variations?

- Goal: Recover foreground layer



Significant illumination variations

Illumination Variations

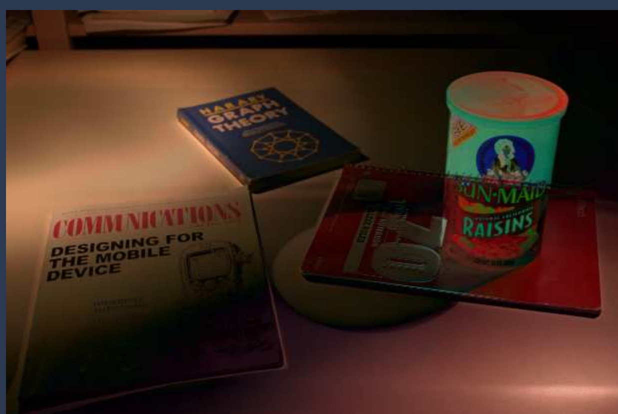
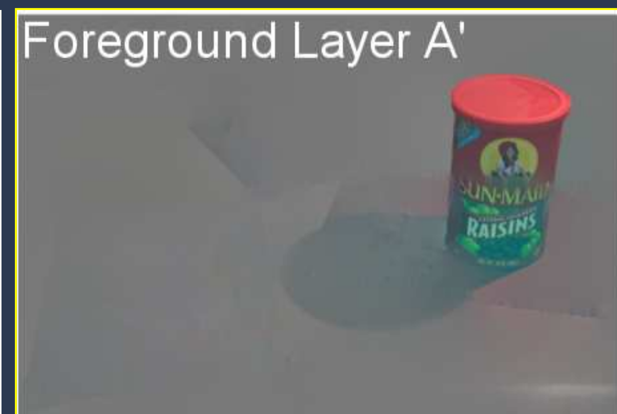


Image difference

Cross-Correlation



Edge Suppression

Edge Suppression in Gradient Domain

- How to suppress edges common to another image?
- Affine Gradient Transformation
  - Projection Tensors

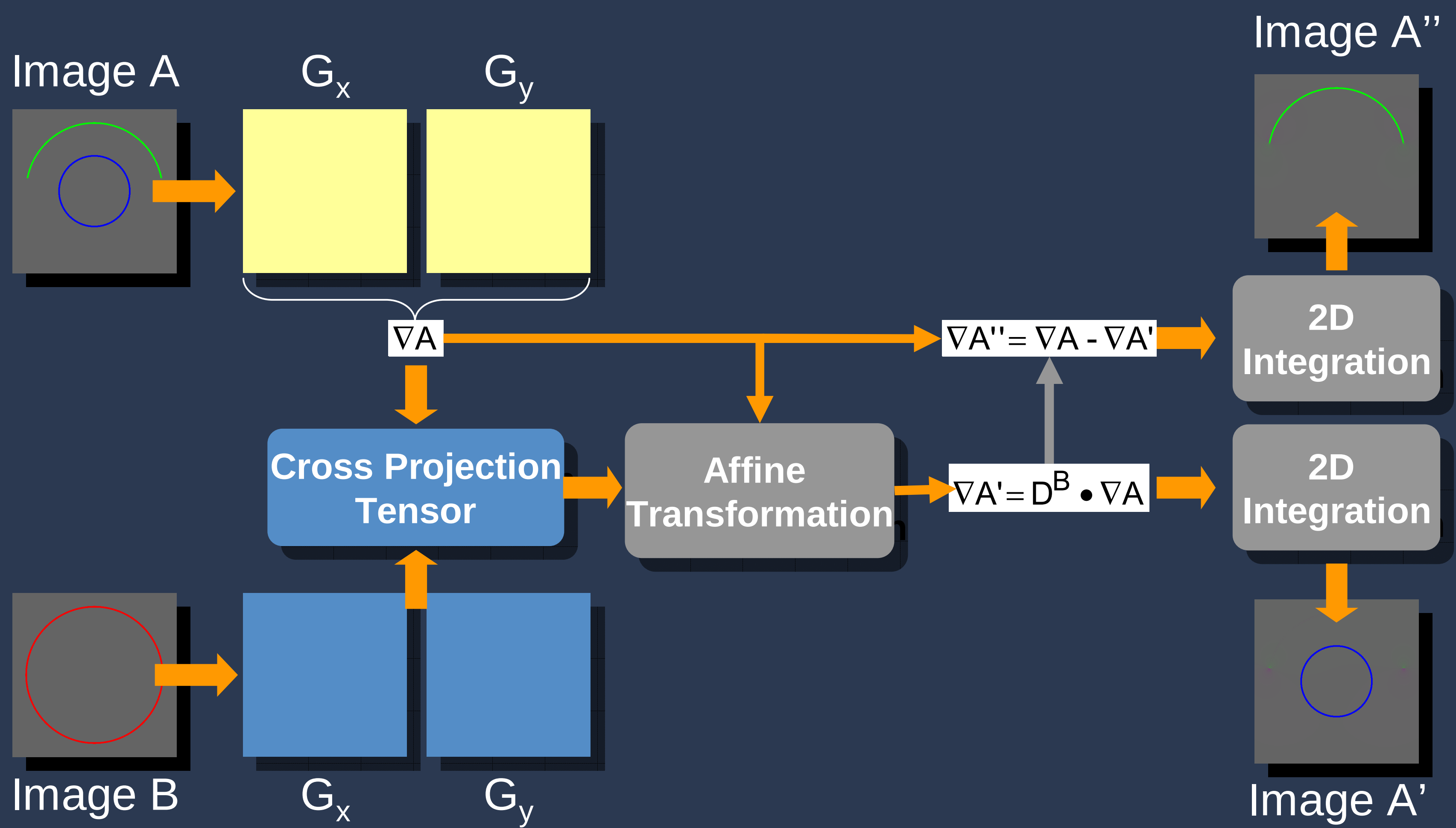
Amit Agrawal, Ramesh Raskar, Rama Chellappa, “Edge Suppression by Gradient Field Transformation using Cross-Projection Tensors”, CVPR 2006

Limitations of Comparing Gradients

- Color artifacts
  - Independent RGB processing
- Noisy gradient direction estimation
  - Need larger spatial support
- Homogeneous regions

- Improved approach: Affine Transformations of Gradients
  - Projection Tensors

Algorithm



A' : Common edges removed

A'': Common edges retained

Local Structure Tensors

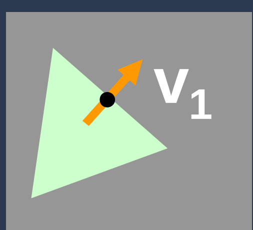
$$\nabla I = \begin{bmatrix} g_x \\ g_y \end{bmatrix}$$

Image gradient

$$\mathbf{G}_\sigma = (\nabla I \nabla I^T) * K_\sigma = \begin{bmatrix} g_x^2 & g_x g_y \\ g_x g_y & g_y^2 \end{bmatrix} * K_\sigma$$

Structure tensor: 2*2 matrix at each pixel

Gaussian Kernel



$$\mathbf{G}_\sigma = V \Sigma V^T = \begin{bmatrix} \mathbf{v}_1 & \mathbf{v}_2 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \begin{bmatrix} \mathbf{v}_1^T \\ \mathbf{v}_2^T \end{bmatrix}$$

Eigen vectors

Eigen values

Projection Tensor

- Basic idea: remove dominant edge

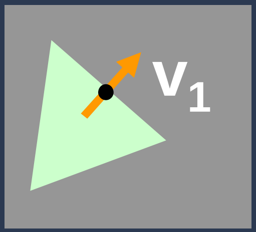
Set

$$\lambda_1 = 0, \quad \lambda_2 = 1$$

$$D^{self} = \begin{bmatrix} \mathbf{v}_1 & \mathbf{v}_2 \end{bmatrix} \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{v}_1^T \\ \mathbf{v}_2^T \end{bmatrix}$$

Then

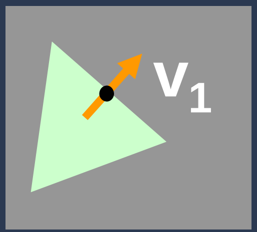
$$D^{self}\mathbf{v}_1 = 0$$



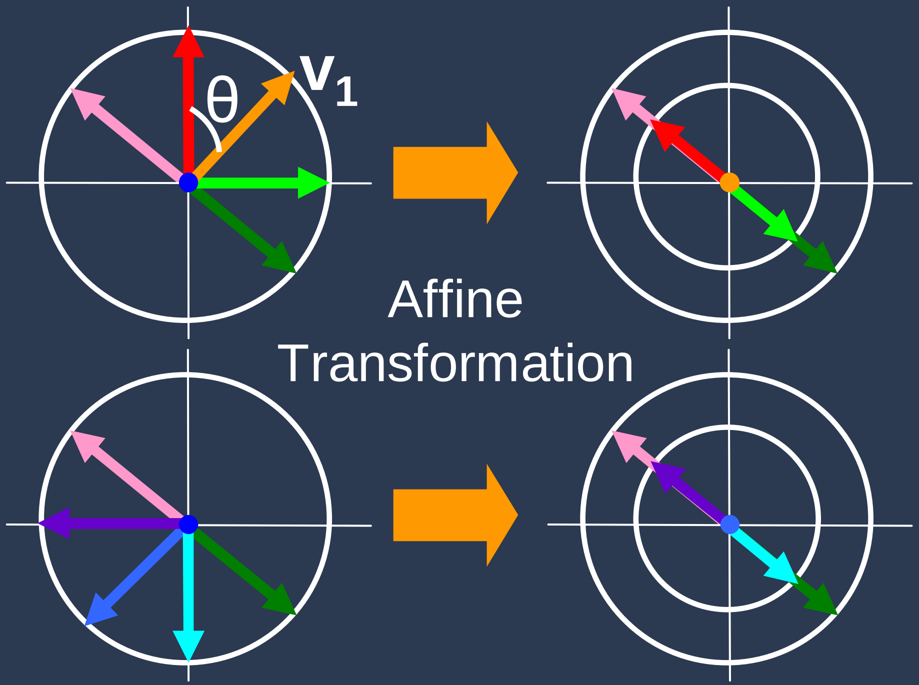
Transformation using D^{self}

- Transforming gradient vector by D^{self} is equivalent to projection on the direction orthogonal to v_1

$D^{self}\mathbf{v_1}=0$



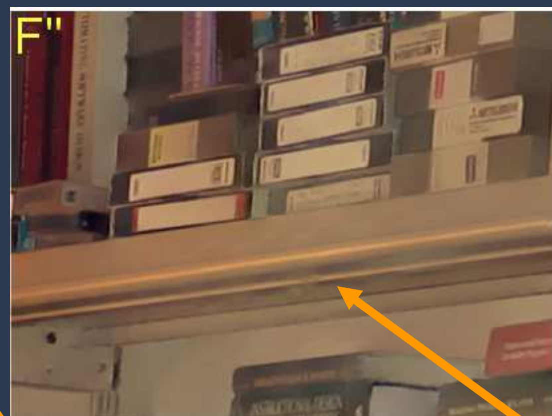
Image



Removing glass reflections

- Find tensor based on ambient image
- Transform the gradient field of flash image

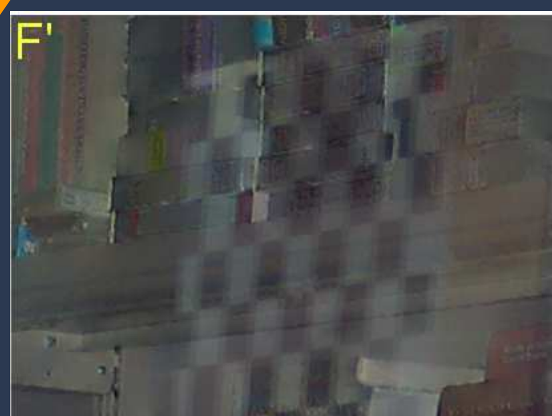
Flash Image



Reflection Removed

Gradient Projection

Ambient Image



Reflection layer

Reflections

Removing shadows

- Estimate tensor using flash image
- Transform gradient field of ambient image

Ambient Image

Shadows Removed

Gradient Projection

Flash Image

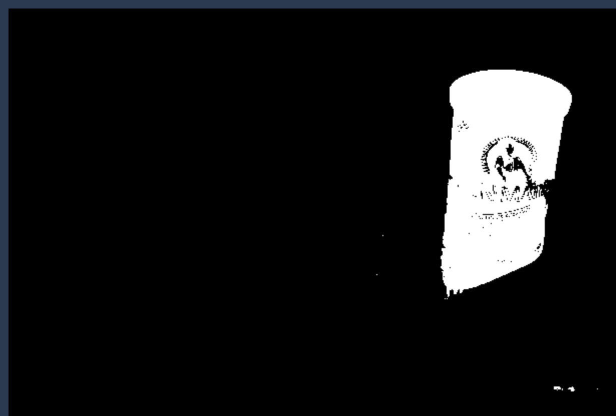
Illumination Map

A/F

Recovering foreground layer

- Find tensor based on background image
- Transform gradient field of foreground image

Image Difference



Foreground mask

Gradient Domain Manipulations

- Per pixel
  - Non-linear operations (HDR, local illumination change)
  - Set to zero (shadow removal, intrinsic images, NPR, texture de-emphasis)
  - Poisson Matting (matter gradient proportional to image gradient)
- Corresponding gradients in two images
  - Vector operations (gradient projection)
    - flash/no-flash, reflection removal
  - Projection Tensors
    - Reflection removal, shadow removal
  - Max operator: Day/Night fusion, Visible/IR fusion, extending DoF
  - Binary, choose from first or second, copying
    - Image editing, seamless cloning

Image Fusion for Context Enhancement and Video Surrealism

Ramesh Raskar

Mitsubishi Electric Research Labs, (MERL)

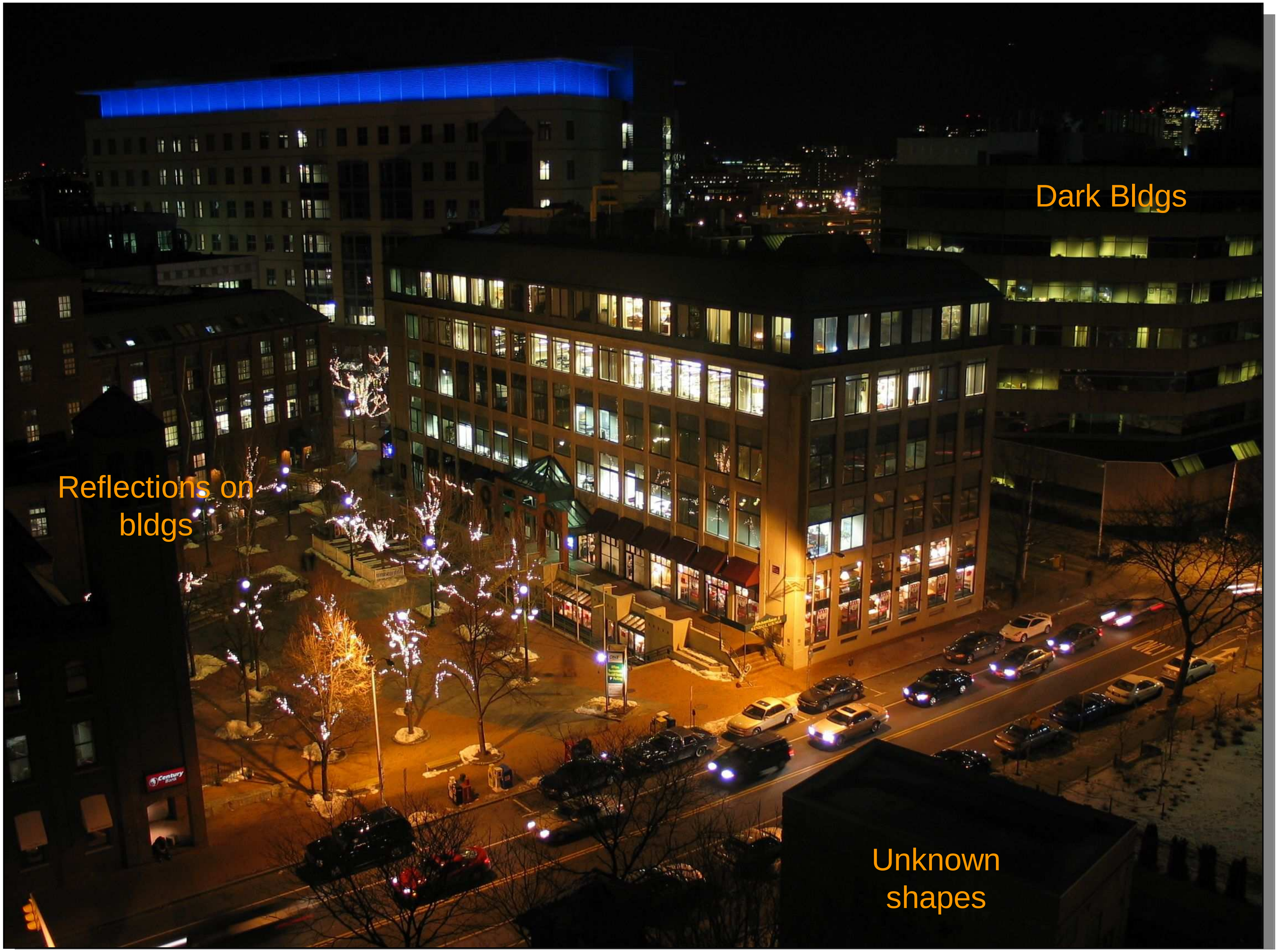
Adrian Ilie

UNC Chapel Hill

Jingyi Yu

MIT


Century
Bank


Dark Bldgs
Reflections on bldgs
Unknown shapes

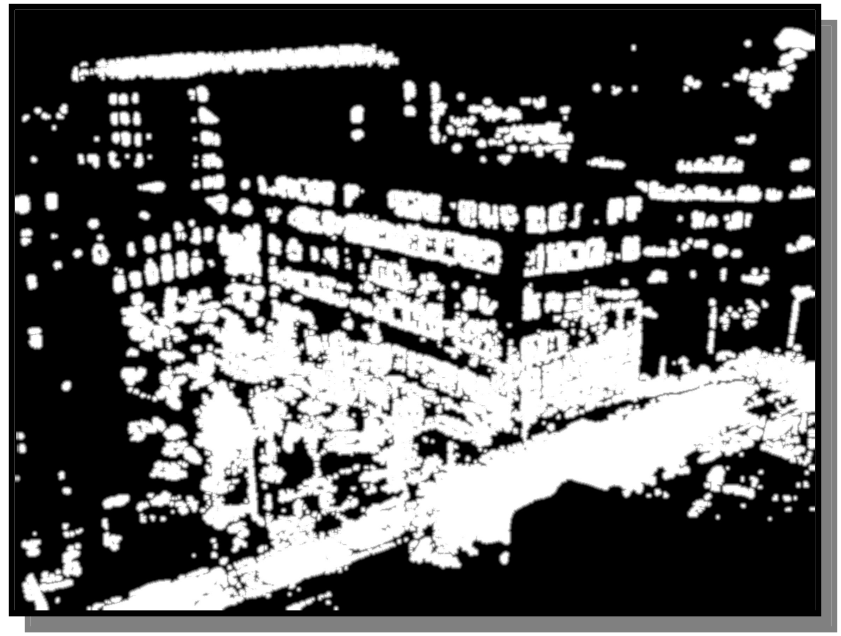

'Well-lit' Bldgs
Reflections in bldgs windows
Tree, Street shapes

Night Image

Day Image

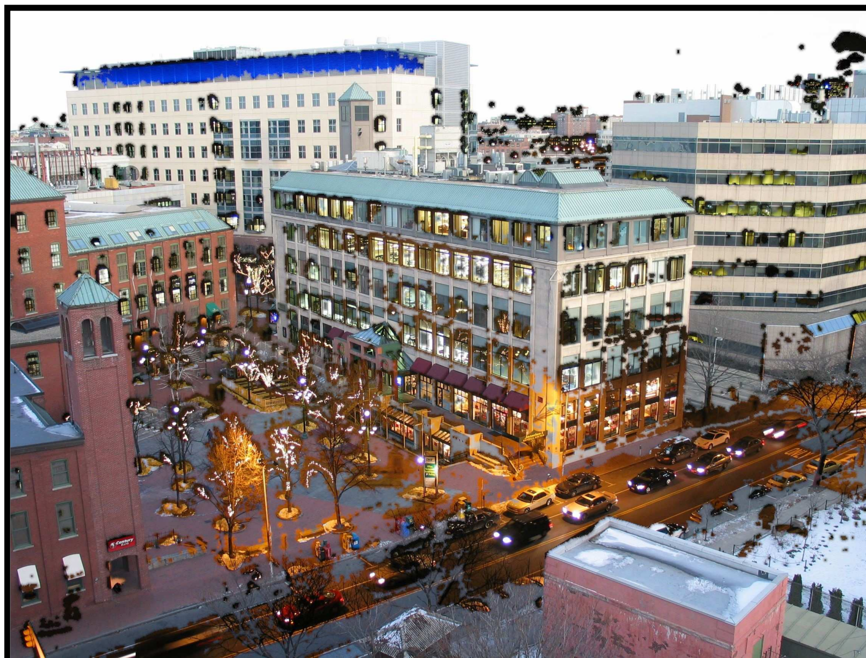
Background is captured from day-time scene using the same fixed camera

Context Enhanced Image



Mask is automatically computed from scene contrast

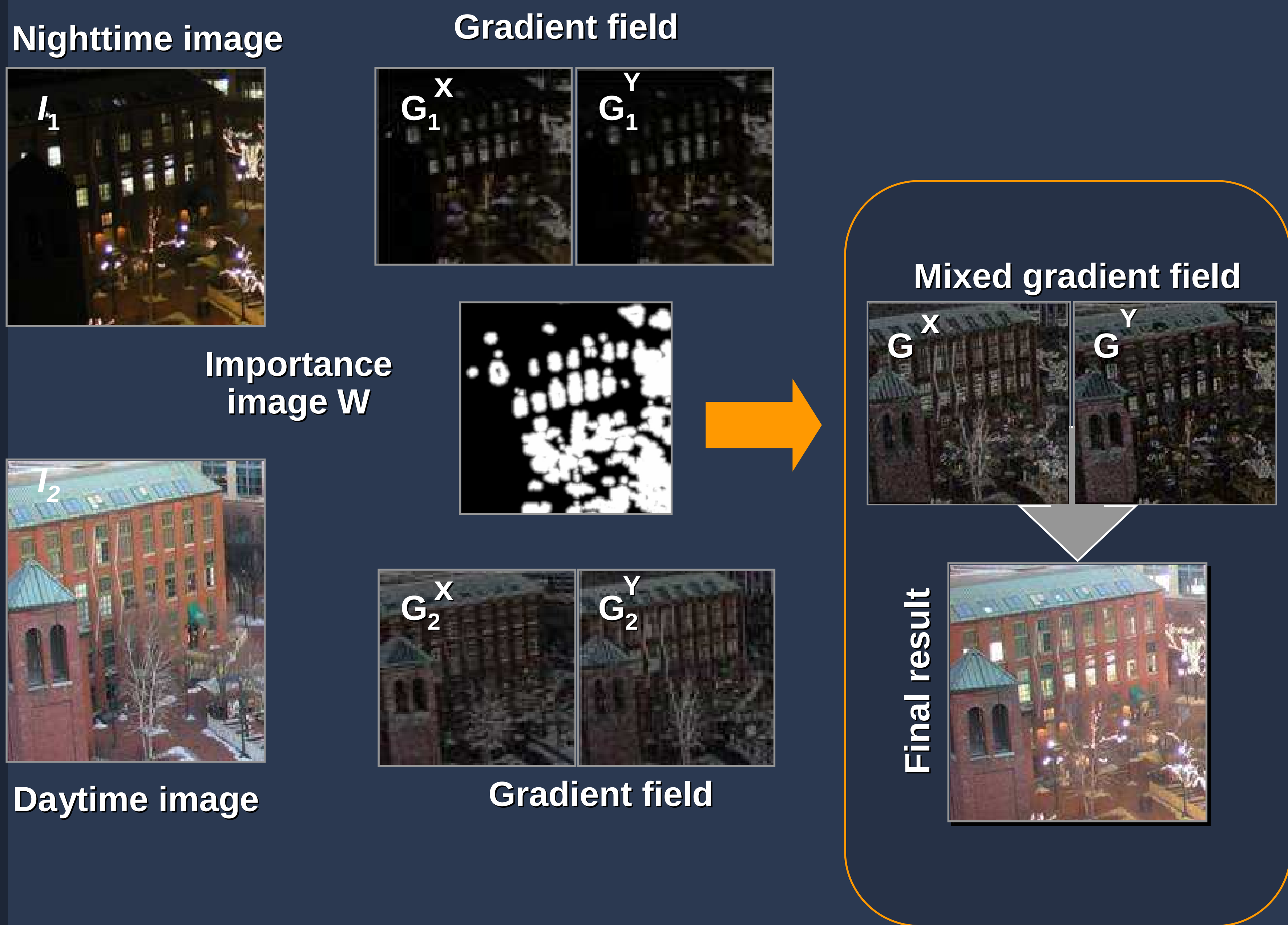
But, Simple Pixel Blending Creates Ugly Artifacts



Pixel Blending

Pixel Blending

Our Method:
Integration of
blended Gradients


Nighttime image
I_1
Gradient field
G_1^X
G_1^Y
Importance image W
Mixed gradient field
G^X
G^Y
Final result
I_2
Daytime image
G_2^X
G_2^Y
Gradient field

Reconstruction from Gradient Field

- Problem: minimize error $|\nabla I' - G|$
- Estimate I' so that

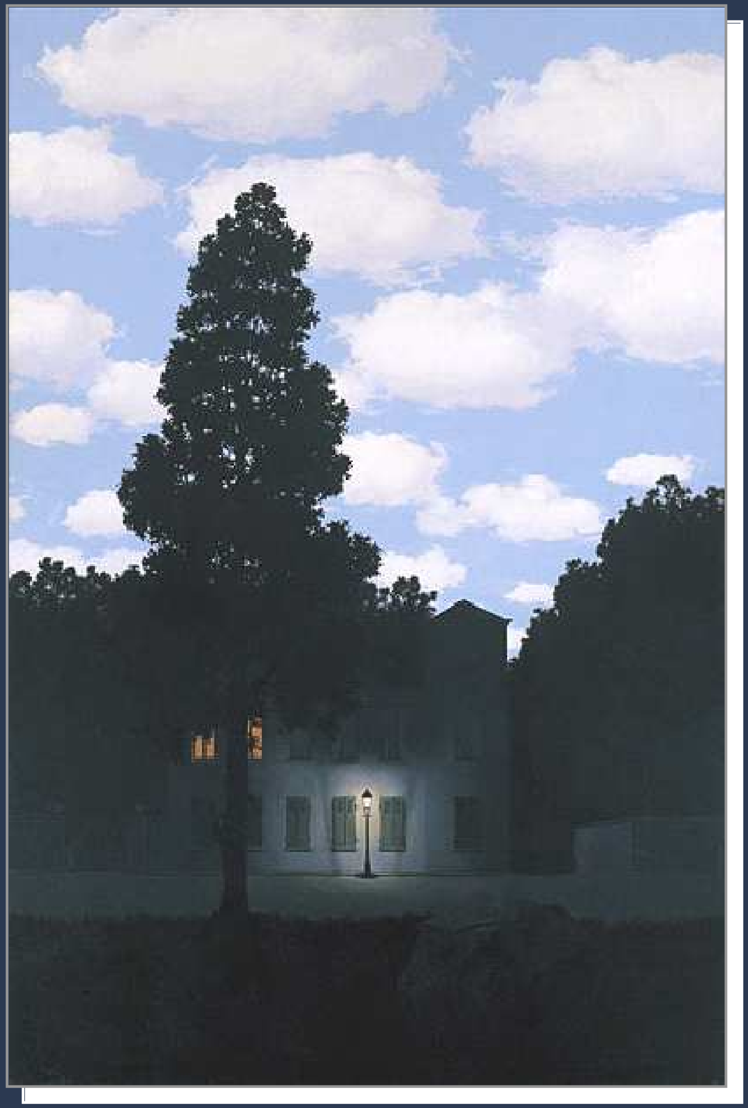
$$G = \nabla I'$$

- Poisson equation

$$\nabla^2 I' = div\ G$$

- Full multigrid solver

Surrealism



Rene Magritte, 'Empire of the Light'

Poisson Image Editing: Inserting Objects

- Precise selection: tedious and unsatisfactory
- Alpha-Matting: powerful but involved
- Seamless cloning: loose selection but no seams?

Smooth Correction: Copying Gradients

$$\Leftrightarrow f = \arg\min_f \int_\Omega |\nabla f - \nabla g|^2 \text{ s.t. } f|_{\partial\Omega} = f^*|_{\partial\Omega}$$

Conceal

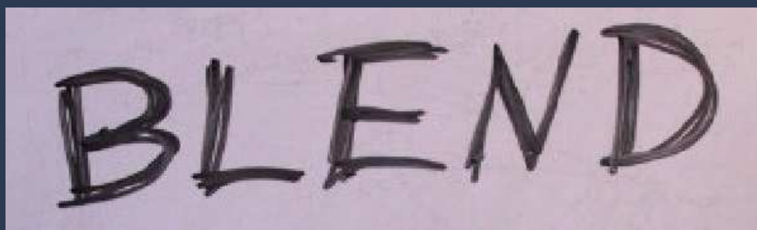
Copy Background gradients (user strokes)

Compose: Copy gradients from Source Images to Target Image

Source Images

Target Image

Transparent Cloning



$$\mathbf{v} = \frac{\nabla f^* + \nabla g}{2}$$

Largest variation from source and destination at each point

$$\mathbf{v}_{\max} = \begin{cases} \nabla f^*(\mathbf{x}) & \text{if } |\nabla f^*(\mathbf{x})| > |\nabla g(\mathbf{x})| \\ \nabla g(\mathbf{x}) & \text{otherwise} \end{cases}$$

Compose (transparent)

Gradient Domain Manipulations: Overview

(A) Per pixel

(B) Corresponding gradients in two images

(C) Corresponding gradients in multiple images

(D) Combining gradients along seams

Gradient Domain Manipulations

(C) Corresponding gradients in multiple images

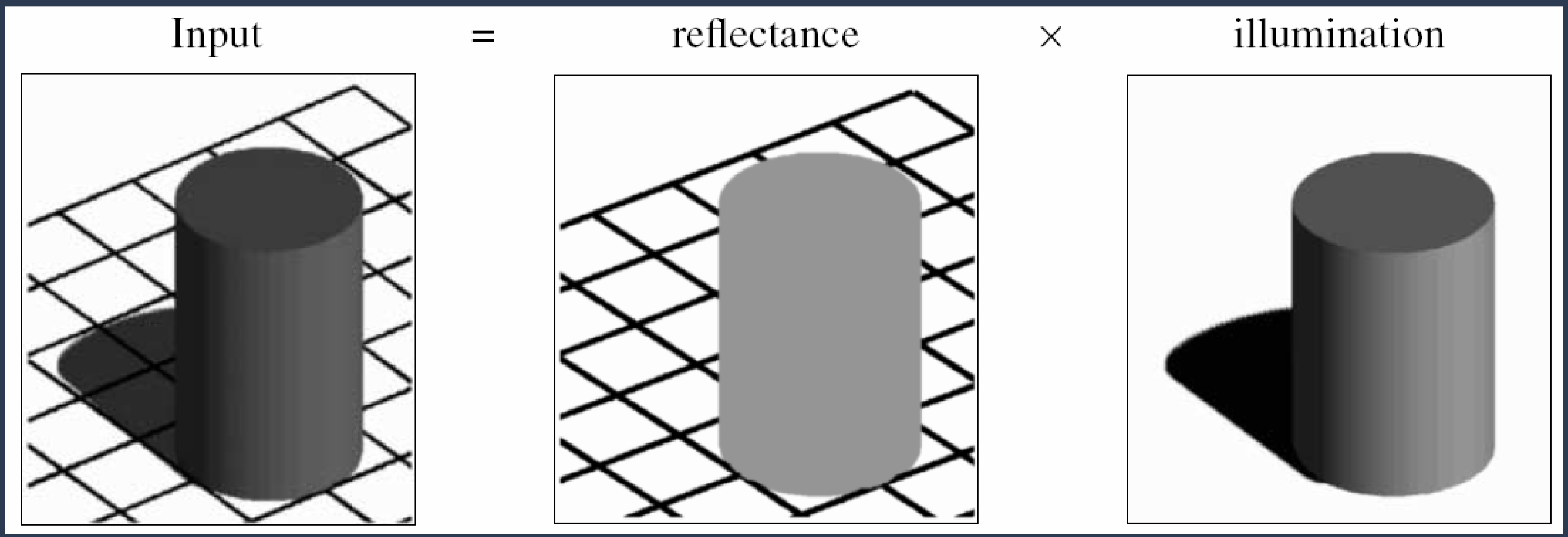
- Median operator
  - Intrinsic images
  - Specularity reduction

(D) Combining gradients along seams

- Weighted averaging
- Optimal seam using graph cut
  - Image stitching, Mosaics, Panoramas, Image fusion
  - A usual pipeline: Graph cut to find seams + gradient domain fusion

Intrinsic images: Median of Gradient operator

- I = L * R
- L = illumination image
- R = reflectance image

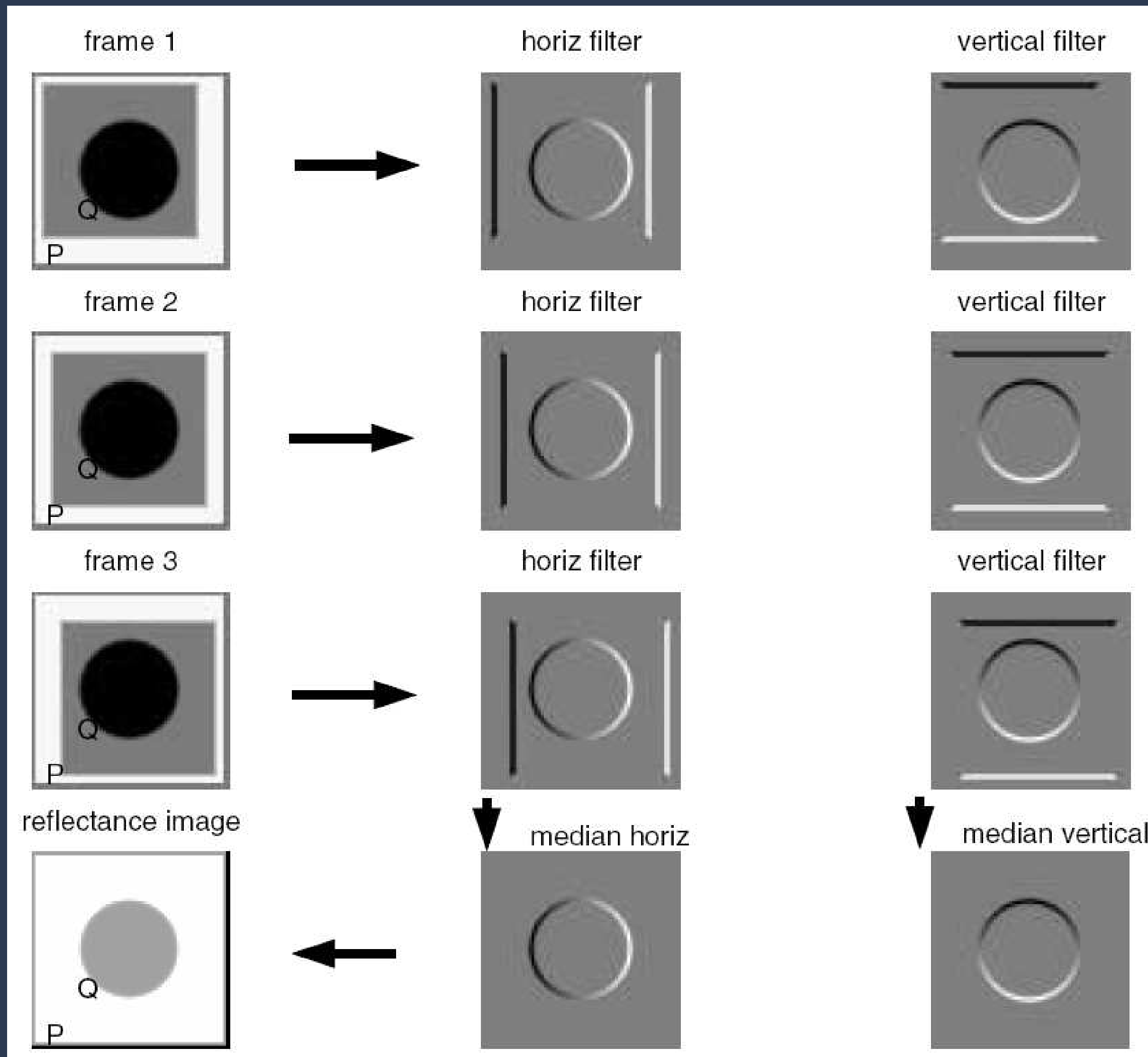


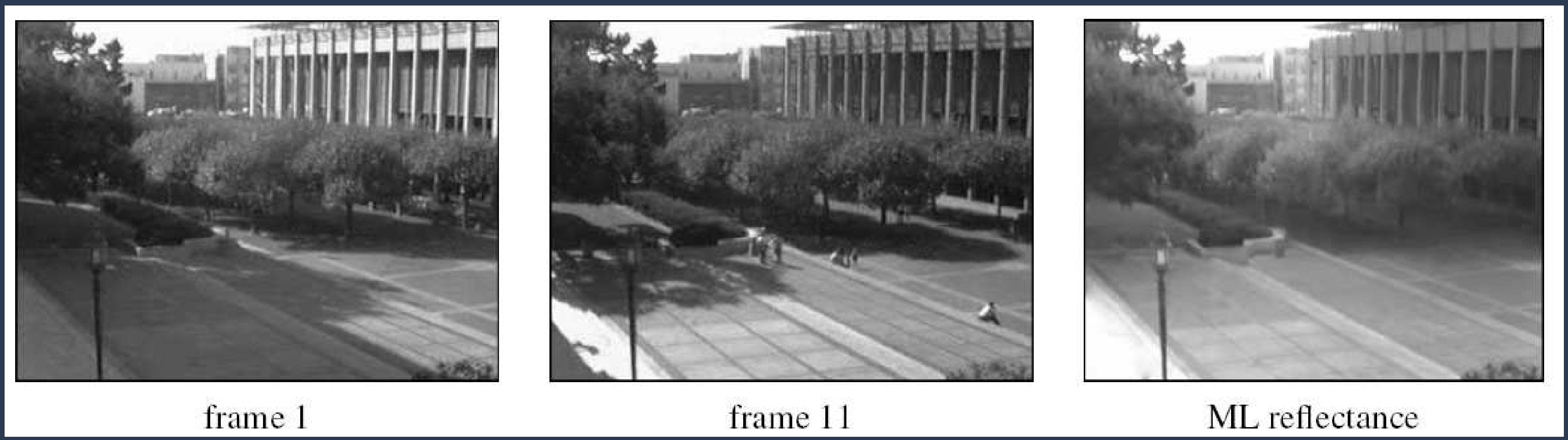
Intrinsic images

- Use multiple images under different illumination
- Assumption
  - Illumination image gradients = Laplacian PDF
  - Under Laplacian PDF, Median = ML estimator

- At each pixel, take Median of gradients across images
- Integrate to remove shadows

Yair Weiss, “Deriving intrinsic images from image sequences”, ICCV 2001

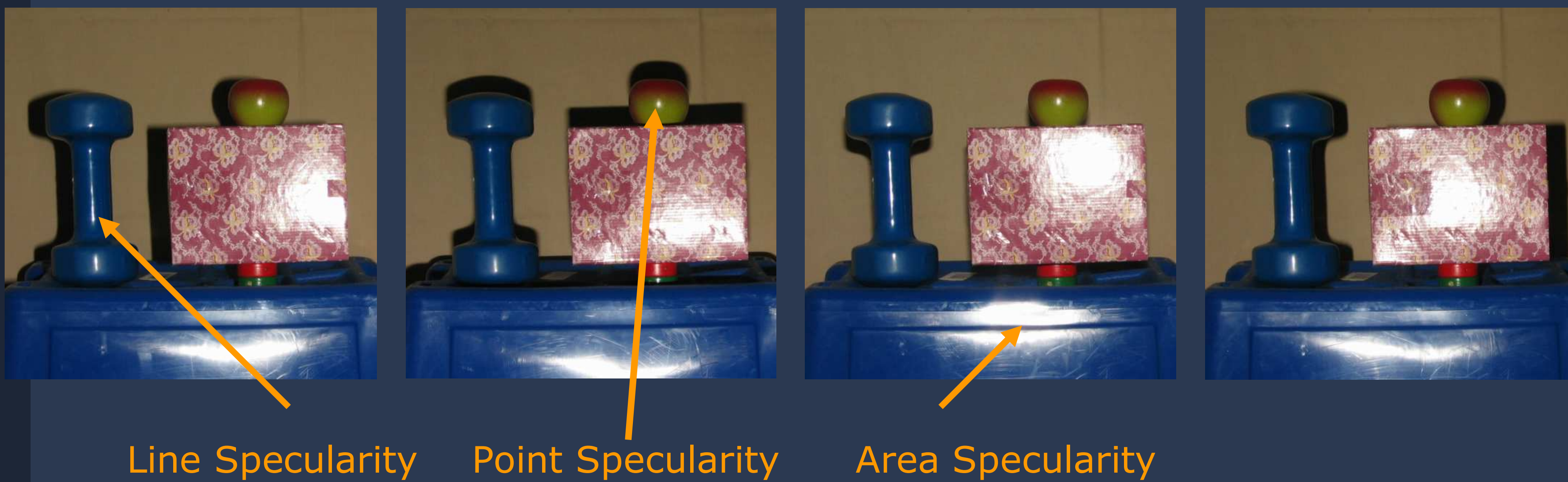

frame 1
horiz filter
vertical filter
Q
P
frame 2
horiz filter
vertical filter
Q
P
frame 3
horiz filter
vertical filter
Q
P
reflectance image
median horiz
median vertical
Q
P



Shadow free
Intrinsic Image

Result = Illumination Image * (Label in Intrinsic Image)

Specularity Reduction in Active Illumination



Multiple images with same viewpoint, varying illumination

How do we remove highlights?

Specularity Reduced
Image

Gradient Domain Manipulations: Overview

(A) Per pixel

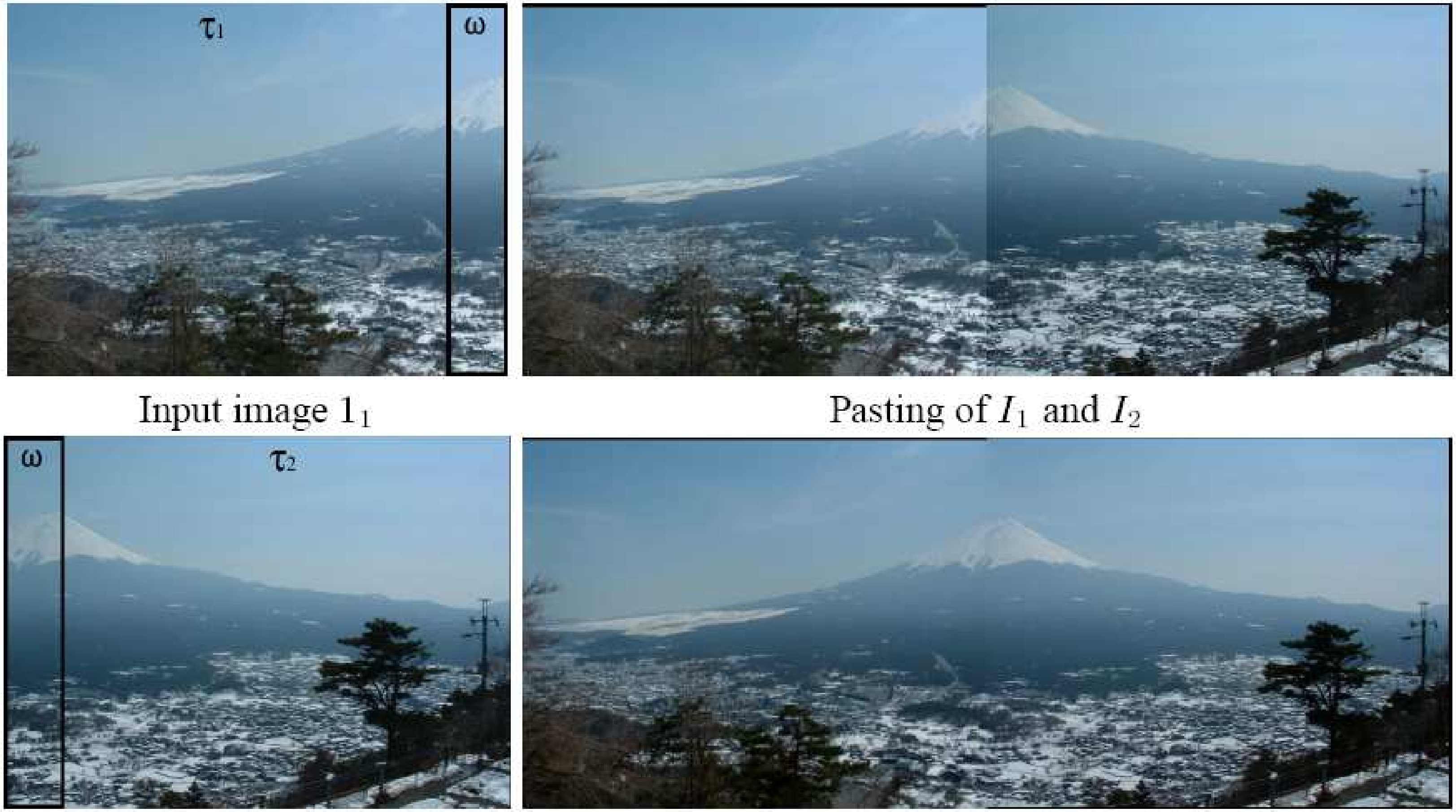
(B) Corresponding gradients in two images

(C) Corresponding gradients in multiple images

(D) Combining gradients along seams

- Image Stitching, Mosaics, Panoramas
- A general (popular) pipeline
- Graph cut to find seams + Gradient Domain fusion

Seamless Image Stitching



Input image 1₁ Pasting of I_1 and I_2

Input image I_2 Stitching result

Anat Levin, Assaf Zomet, Shmuel Peleg and Yair Weiss, “Seamless Image Stitching in the Gradient Domain”, ECCV 2004

Image Stitching

- Issues
  - Photometric and geometric inconsistencies
    - Camera gain, scene illumination
  - Visible edges in seam

- Popular Approaches
  - Optimal Seam
  - Feathering, alpha blending
    - Linear weighting
  - Pyramid blending
    - Blending over various scales

Optimal Seam

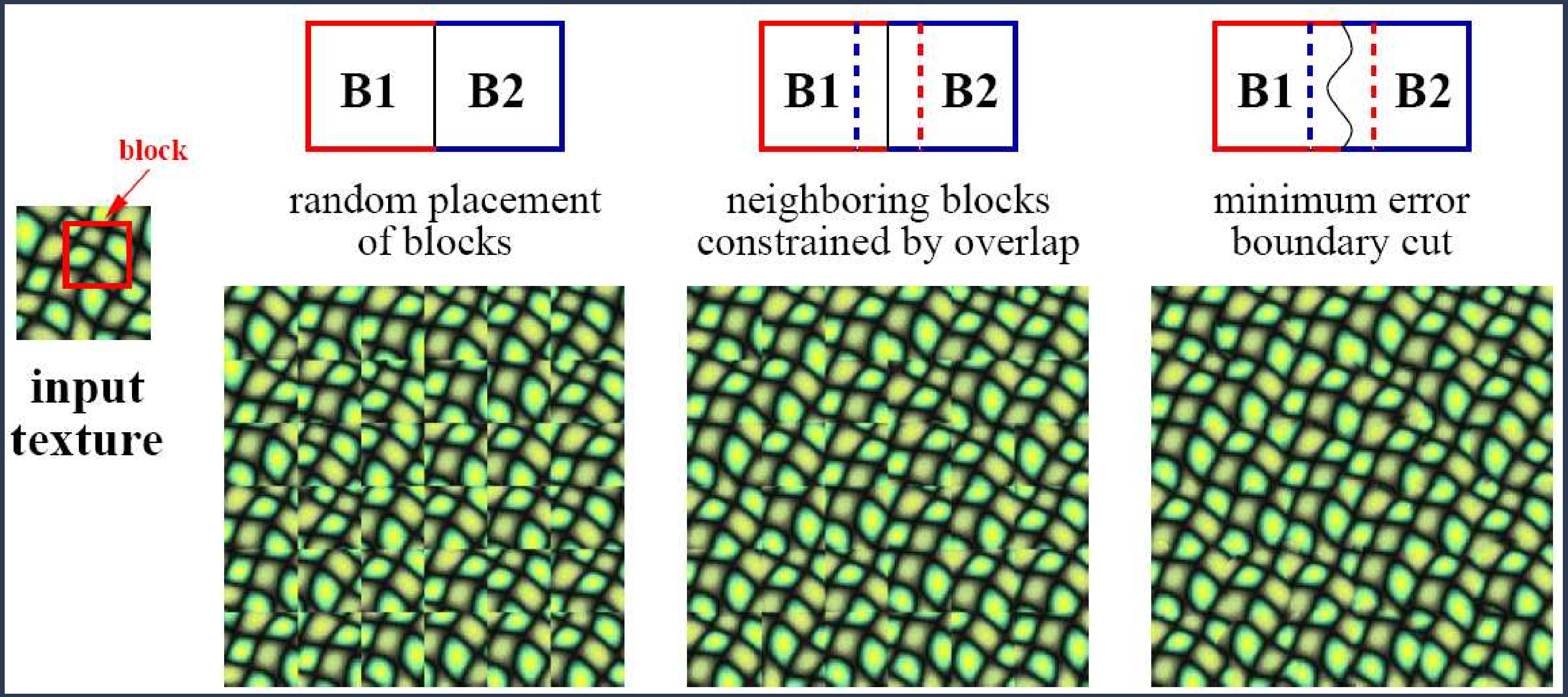


Image Quilting

Dynamic Programming

Alexei Efros and William T. Freeman, "Image Quilting for Texture Synthesis and Transfer", SIGGRAPH 2001

Gradient Domain Image Stitching (GIST)

- Minimize dissimilarity between gradients in overlap region
- As opposed to dissimilarity between intensities
- Advantages
  - Better in presence of photometric inconsistencies
  - Reduce seam artifacts and edge duplications

Anat Levin, Assaf Zomet, Shmuel Peleg and Yair Weiss, “Seamless Image Stitching in the Gradient Domain”, ECCV 2004

Intensity vs Gradient Domain stitching


Optimal seam


Optimal seam on the gradients


Pyramid blending


Pyramid blending on the gradients


Feathering


GIST1

Interactive Digital Photomontage

- Combining multiple photos
- Find seams using graph cuts
- Combine gradients and integrate

Aseem Agarwala, Mira Dontcheva, Maneesh Agrawala, Steven Drucker, Alex Colburn, Brian Curless, David Salesin, Michael Cohen, “Interactive Digital Photomontage”, SIGGRAPH 2004

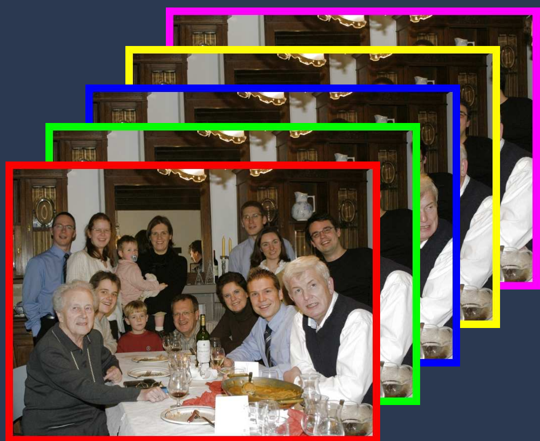
set of originals

actual

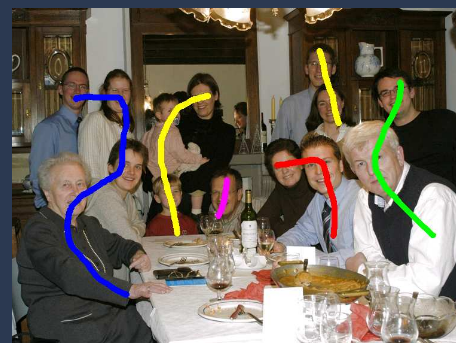
photomontage

perceived

Source images



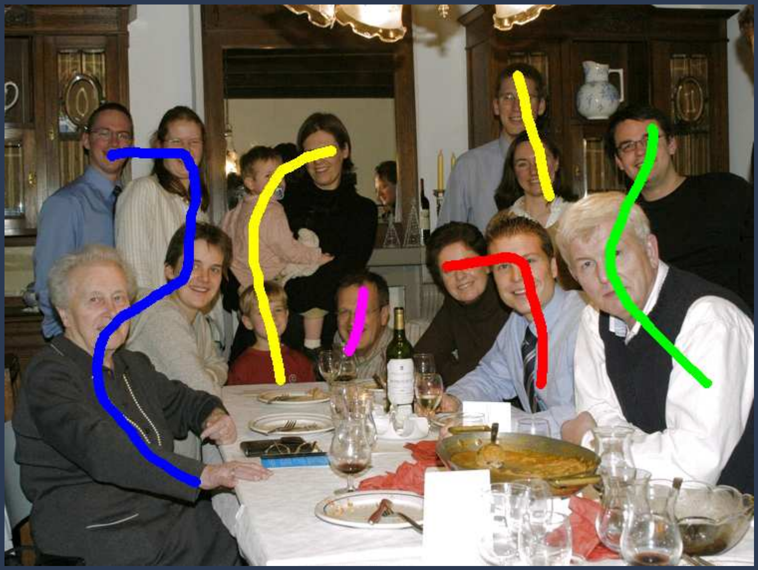
Brush strokes



Computed labeling

Composite

Brush strokes



Computed labeling

Summary

- Gradient domain manipulations
  - Better than directly combining image intensities
  - More user control, ease of use
  - Visually pleasing results
  - Enables non-linear operations and vector operations
- Interesting applications
  - HDR compression (Tone mapping)
  - Shadow removal
  - Image editing, cloning
  - Image stitching and mosaics
  - Reflection removal

Acknowledgements

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  - Rick Szeliski, Microsoft
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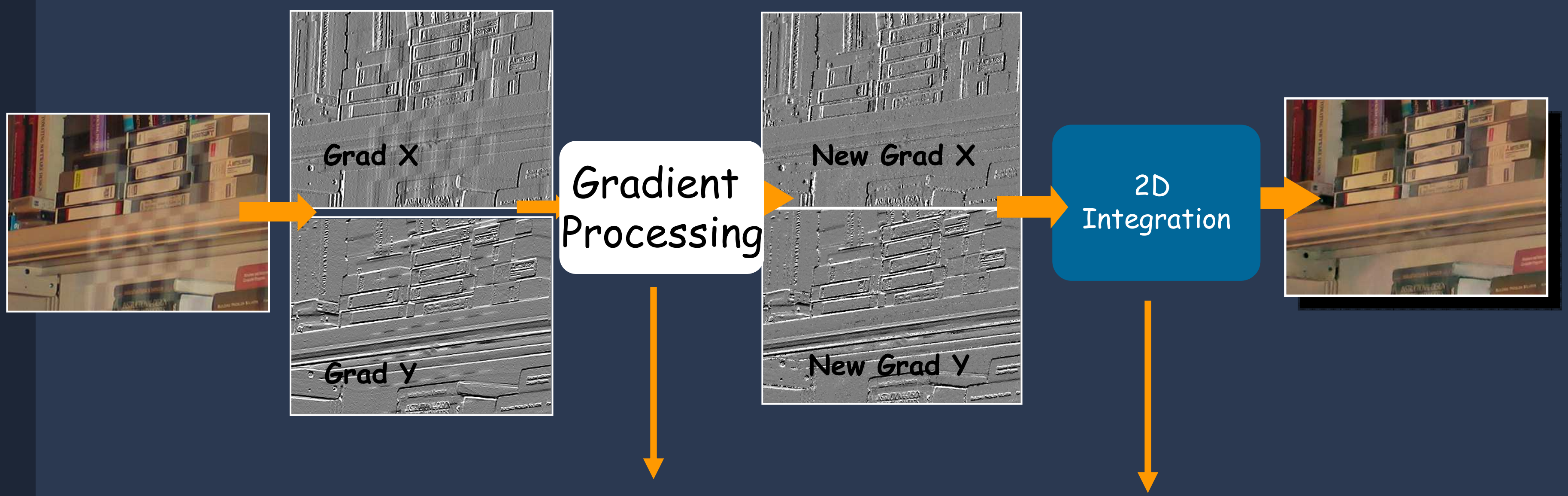
- Image Credits
  - Rannan Fattal
  - G. D. Finlayson
  - Jian Sun
  - And many more

Intensity Gradient Manipulation

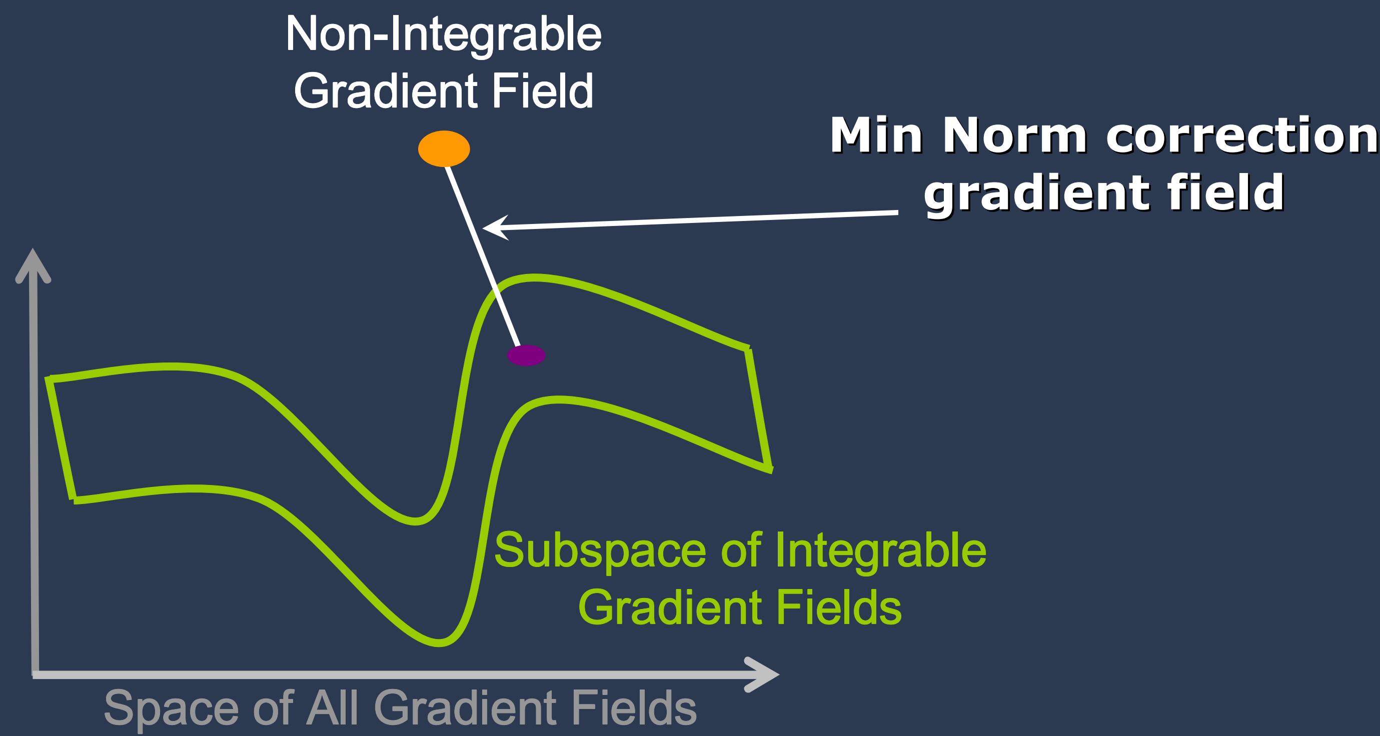
A Common Pipeline

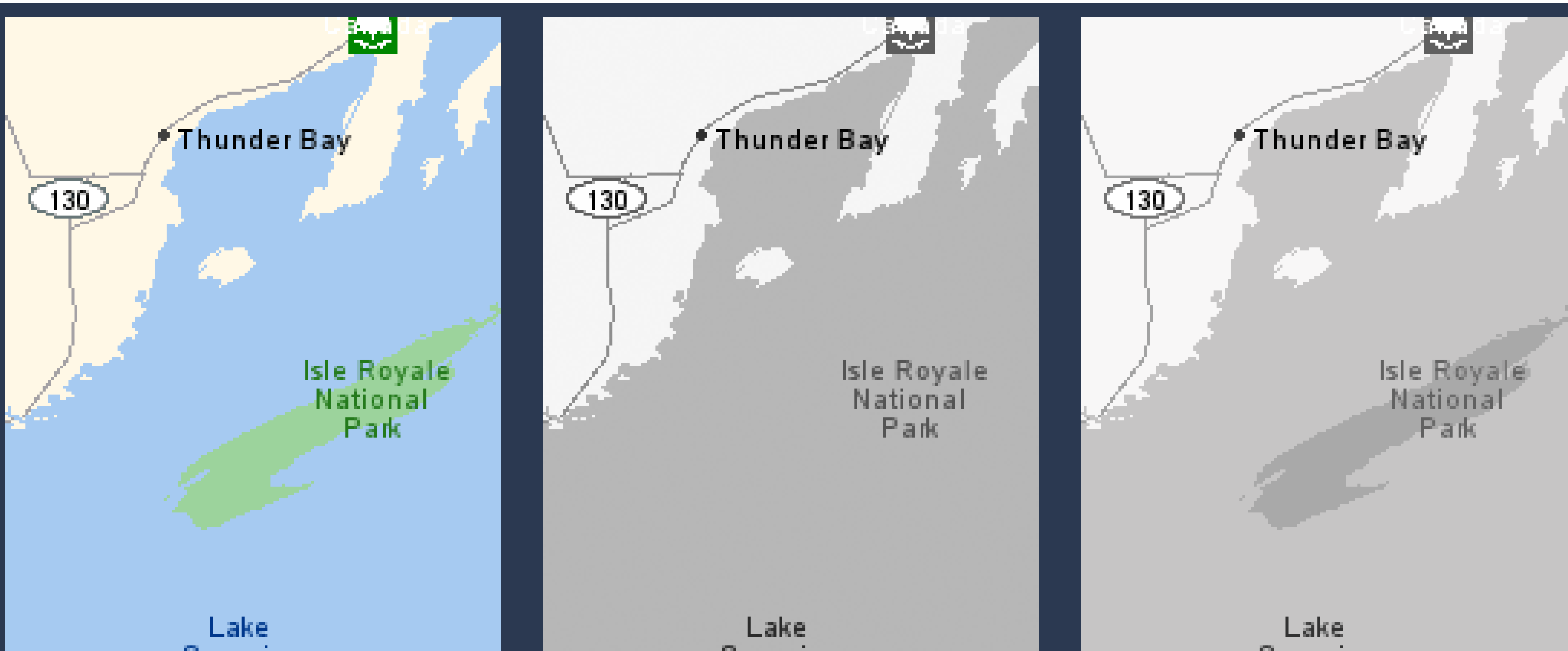


This Section

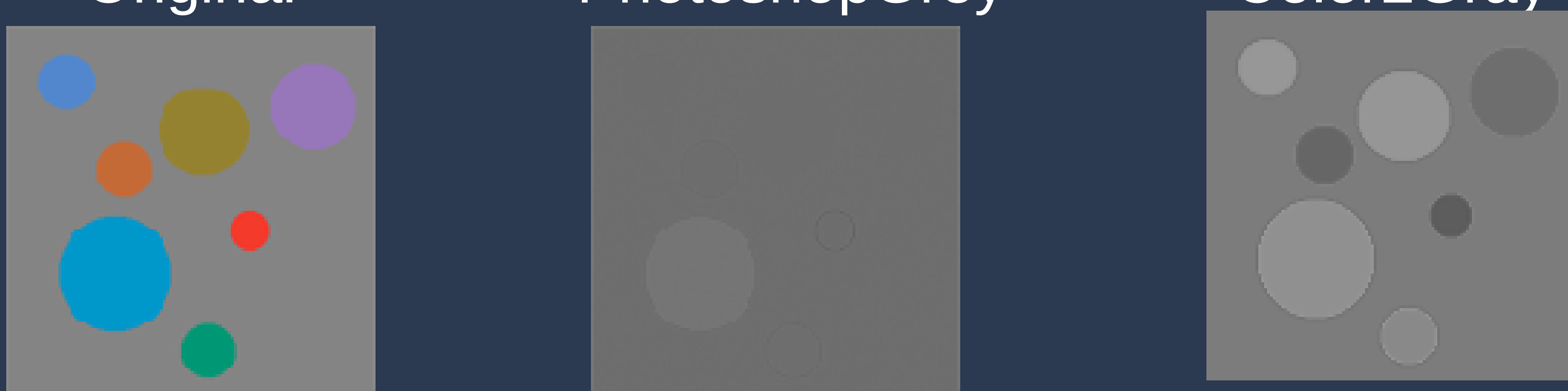
Next Section

Poisson Solver

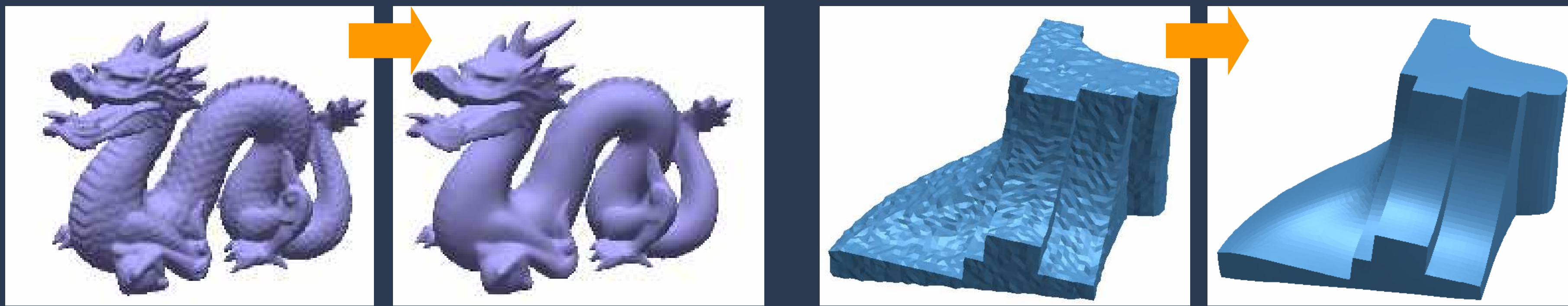




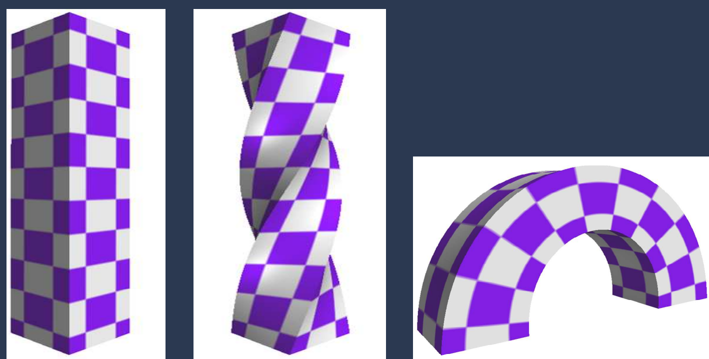
Original PhotoshopGrey Color2Gray



Color to Gray Conversion



Mesh Smoothing



(a) (b) (c)

Mesh defomations

High Dynamic Range Compression

Summary

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Schedule

Introduction	(30 min, Agrawal)
Gradient Domain Manipulations	(1 hr, Raskar)
Break	(15 min)
Reconstruction Techniques	(1 hr, Agrawal)
Advanced Topics	(30 min, Raskar)
Discussion	

Course WebPage : Google “ICCV 2007 gradient course”