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

Google "ICCV 2007 gradient course"

Welcome

- Understanding Gradient Fields
  - Integrability, Curl, Divergence
- Manipulating Gradient Fields
  - Image editing, Stitching, HDR compression, Mosaics, Shadow Removal, Intrinsic Images
- Reconstruction Tools
  - Direct Solvers, Multigrid, Preconditioning, Hierarchical Basis
  - Feature Preserving Reconstructions
- Advanced Topics
  - Gradient camera, Video editing, Mesh editing, Large neighborhood differences

Goals

- Review of 20+ recent/classical papers

- Understanding gradient domain processing
  - Estimation & Manipulation of gradients
  - Reconstruction from gradients
    - Algorithmic & Numerical aspects
  - Learn vision and graphics techniques for image/video editing, computational photography

- What we will not cover
  - Traditional image processing/editing
  - Non-gradient domain methods for applications such as Shape from Shading/Photometric Stereo

Speaker: Amit Agrawal

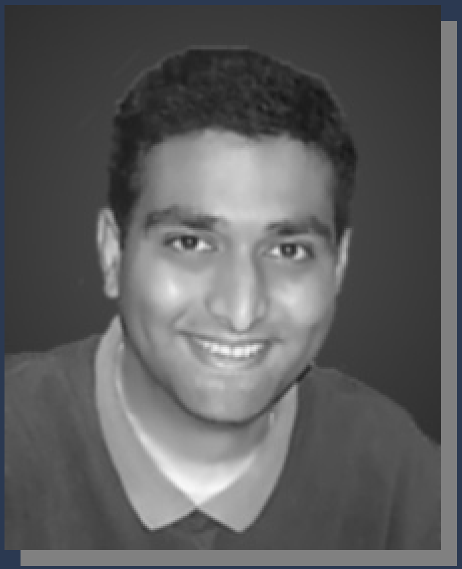
Amit Agrawal is a Visiting Research Scientist at MERL.

His research interests include computational photography, novel sensing and computer vision. During his doctoral studies at Univ. of Maryland, he investigated gradient domain methods for scene analysis. He has published several articles on imaging and photography including coded exposure & coded aperture photography and gradient-domain imaging. His papers have appeared in several vision and graphics conferences including SIGGRAPH, CVPR, ICCV and ECCV. He is a member of IEEE and ACM.

http://www.merl.com/people/agrawal/index.html

Speaker: Ramesh Raskar

Ramesh Raskar is a Senior Research Scientist at MERL.



His research interests include projector-based graphics, computational photography and non-photorealistic rendering. He has published several articles on imaging and photography including multi-flash photography for depth edge detection, image fusion, gradient-domain imaging and projector-camera systems. His papers have appeared in SIGGRAPH, EuroGraphics, IEEE Visualization, CVPR and many other graphics and vision conferences. He was a course organizer at Siggraph 2002, 2003 and 2004. He is a panel organizer at the Symposium on Computational Photography and Video in Cambridge, MA in May 2005. He is a member of the ACM and IEEE.

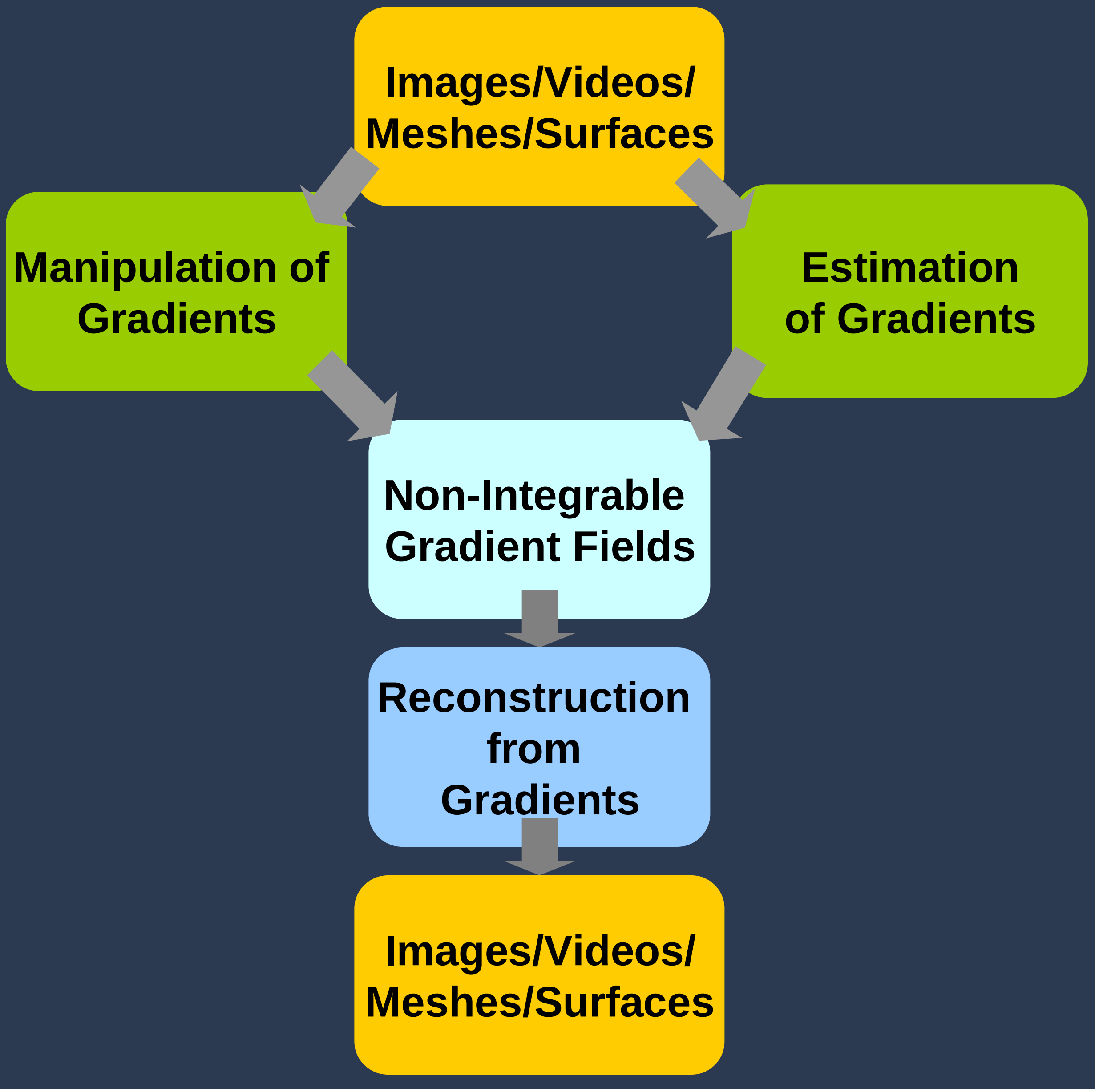
http://www.merl.com/people/raskar/raskar.html

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	

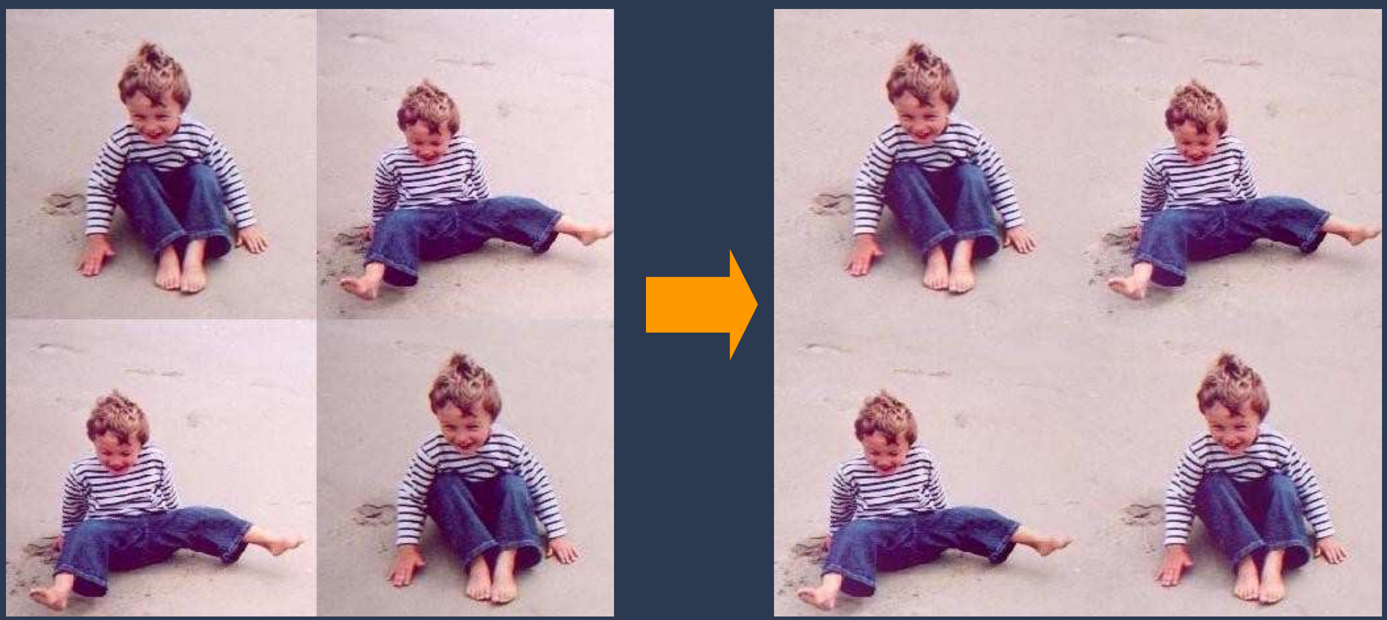
Course WebPage : Google "ICCV 2007 gradient course"

Gradient Domain Manipulations



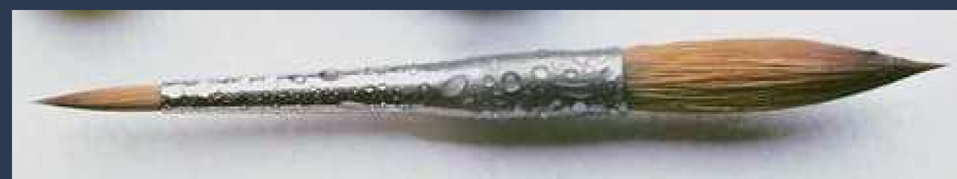
Example Applications Discussed

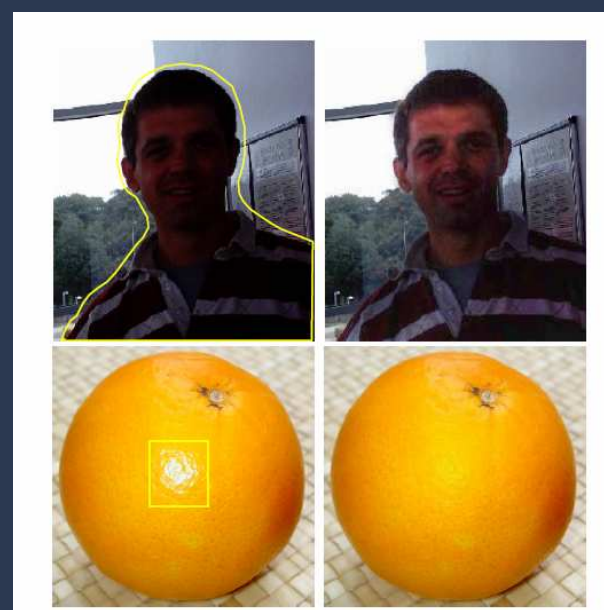
Removing Glass Reflections



Seamless Image Stitching

Image Editing



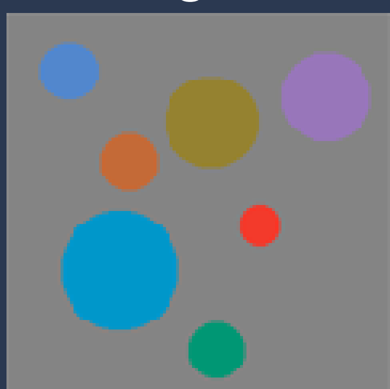


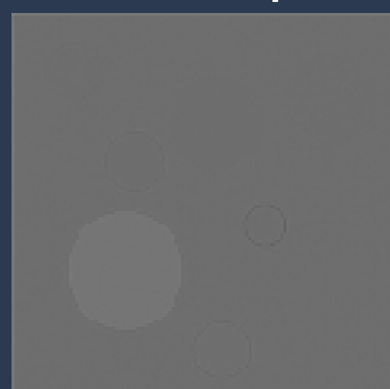
Changing Local Illumination

Original

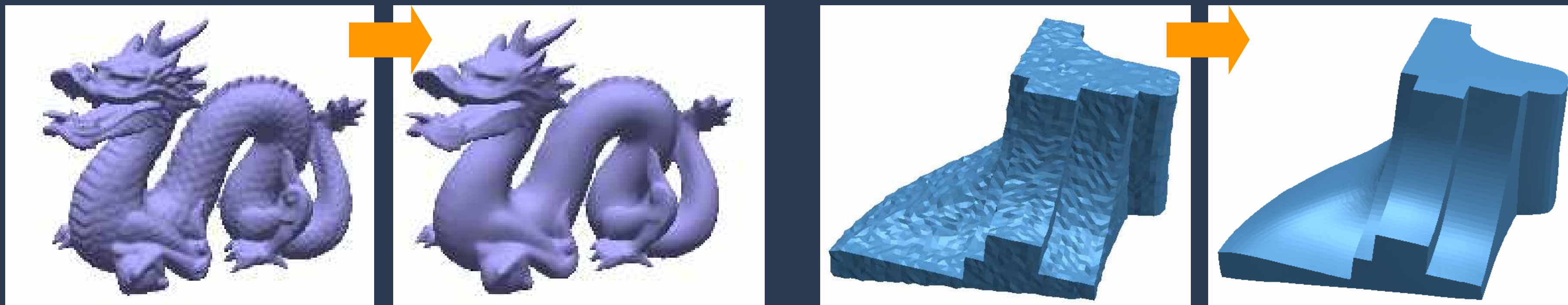
PhotoshopGrey

Color2Gray

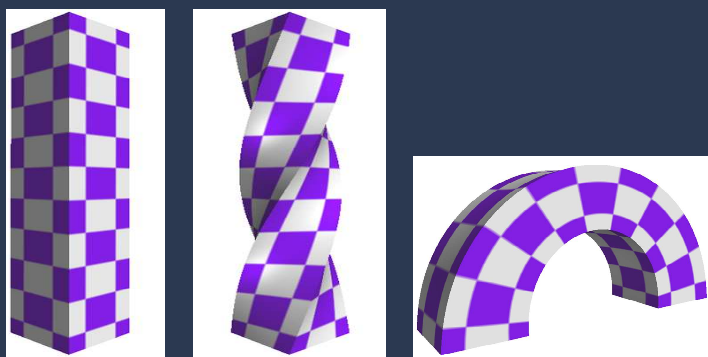




Color to Gray Conversion



Mesh Smoothing



(a) (b) (c)

Mesh defomations

High Dynamic Range Compression

Edge Suppression under Significant Illumination Variations

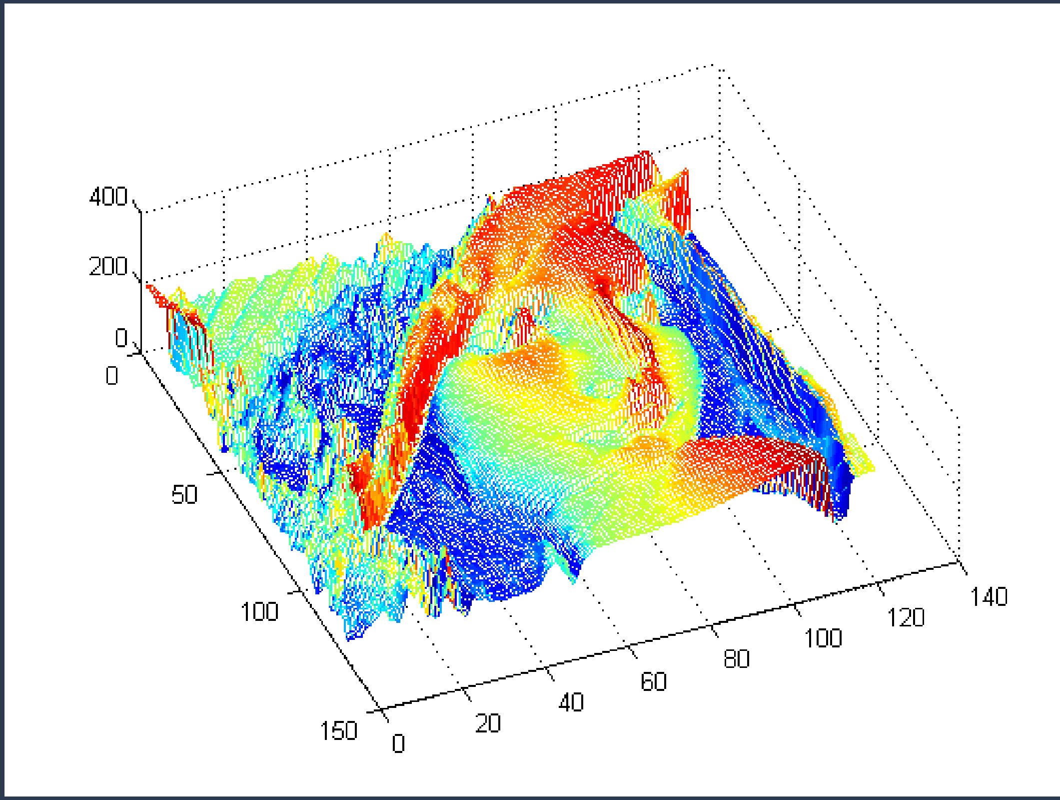
Fusion of day and night images

Overview

- Curl, Divergence
- Non-integrable gradient fields
- Reconstruction problem
- Motivating Applications

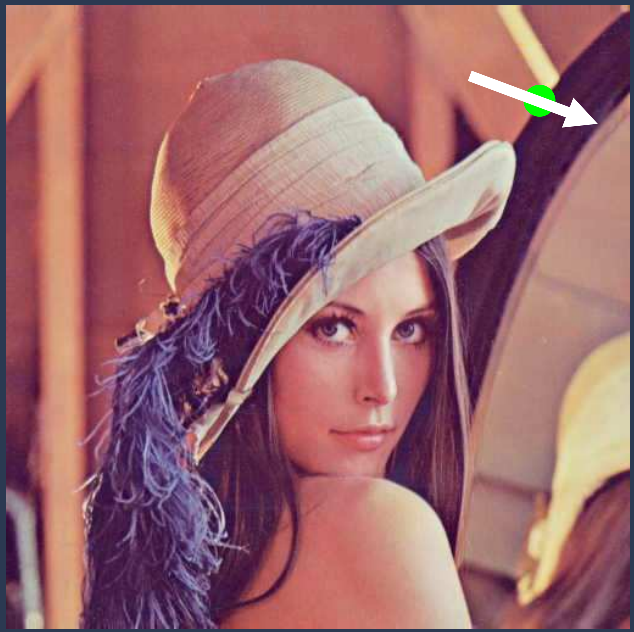
Basics

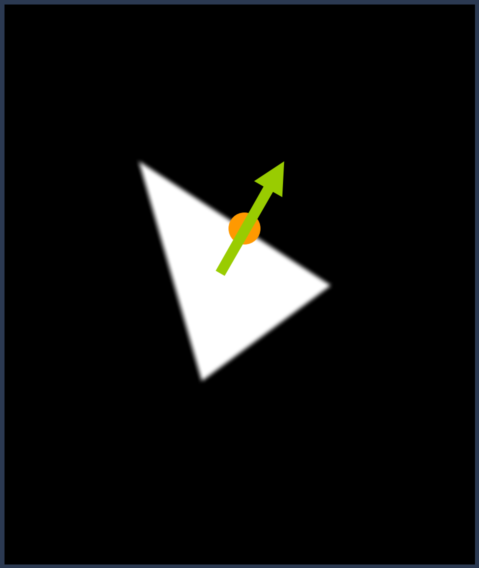
- Images as scalar fields
  - R^2 -> R



Gradients

- Vector field (gradient field)
  - Derivative of a scalar field
- Direction
  - Maximum rate of change of scalar field
- Magnitude
  - Rate of change





Gradient Field

- Components of gradient
  - Partial derivatives of scalar field

$$I(x, y)$$

$$\nabla I = \{\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}\}$$

$$I(x, y, t)$$

$$\nabla I = \{\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}, \frac{\partial I}{\partial t}\}$$

Example

Image
$I(x,y)$

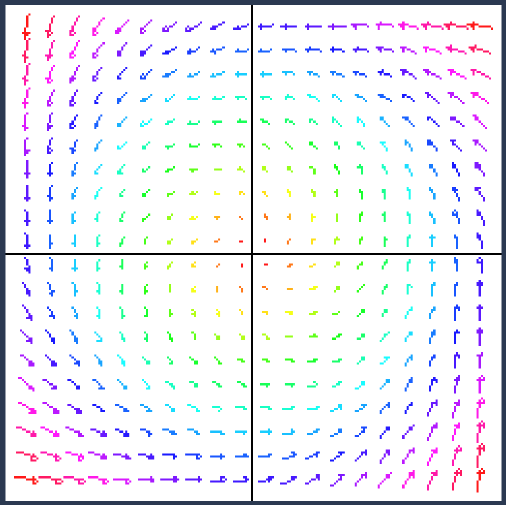
I_x

I_y

Finite Differences

Curl

- Vector operator
- Shows rate of rotation of a vector field
  - Circulation density
  - Direction of axis of rotation and magnitude of rotation



$$Curl(\nabla I) = \nabla \times \nabla I$$

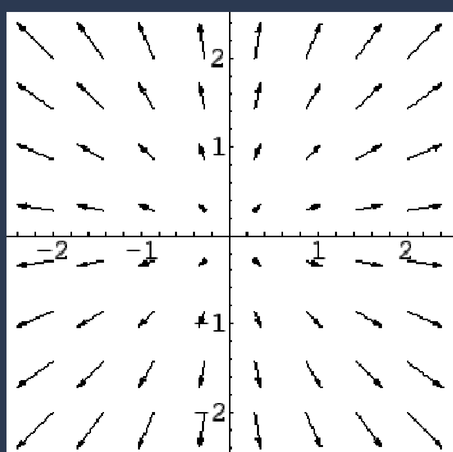
Curl

$$Curl(\nabla I) = \nabla \times \nabla I$$

$$\det \begin{vmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} \\ I_x & I_y \end{vmatrix} = \frac{\partial I_y}{\partial x} - \frac{\partial I_x}{\partial y} = I_{yx} - I_{xy}$$

Divergence

- Vector Operator
- Shows magnitude of source and sink
- e.g. Translation Optical flow in Z direction



Divergence

$$Div(\nabla I) = \nabla \bullet \nabla I$$

$$div(I_x, I_y) = \frac{\partial I_x}{\partial x} + \frac{\partial I_y}{\partial y} = I_{xx} + I_{yy}$$

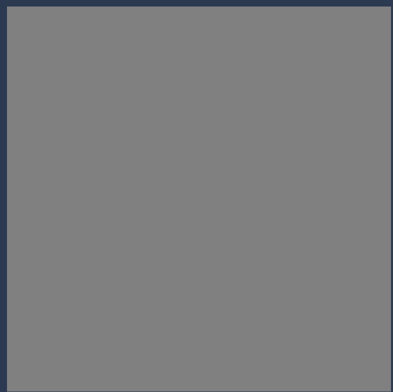
Example

Image

I_x

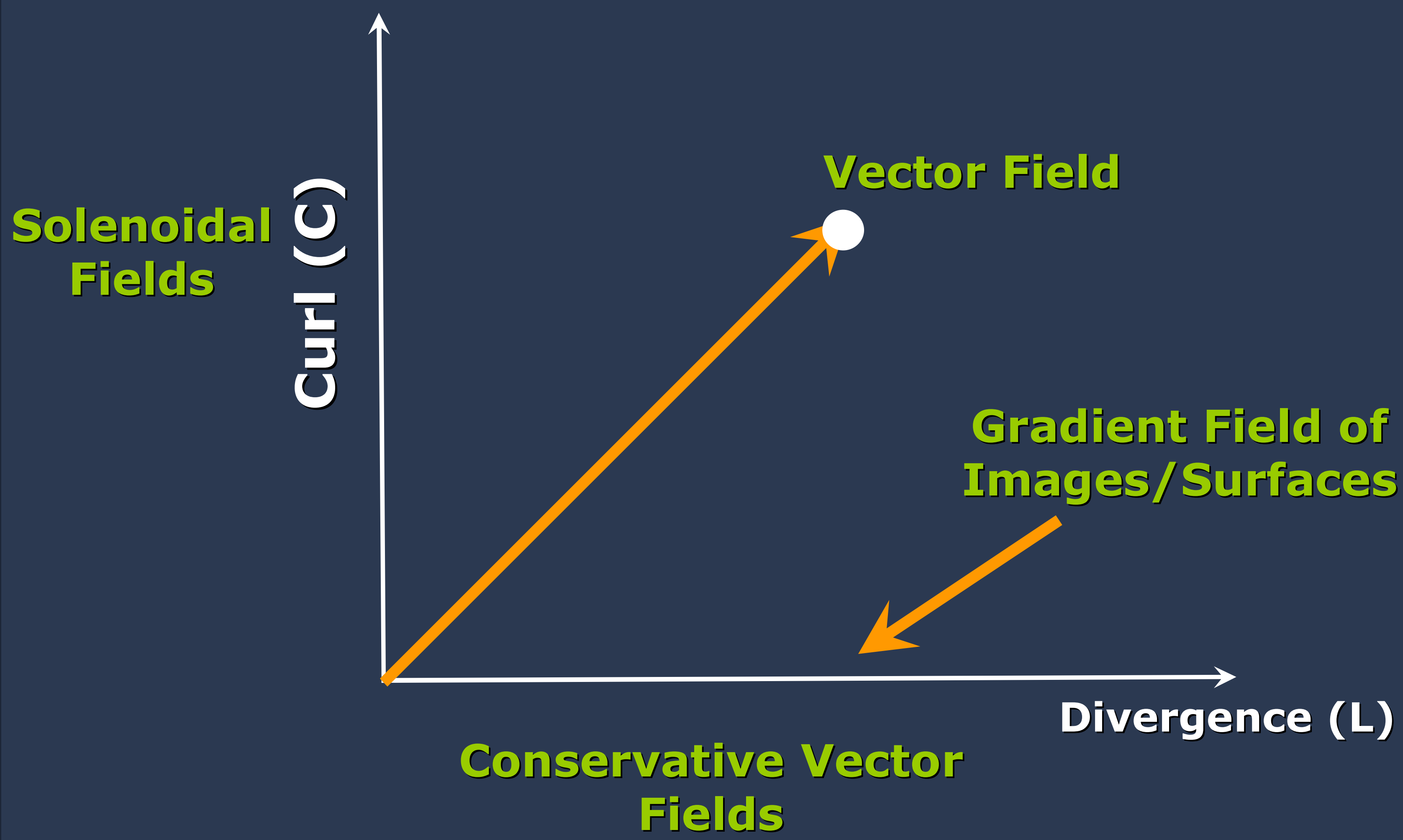
I_y

$Div(I_x, I_y)$



$Curl(I_x, I_y)$

Understanding Curl-Divergence



Integrability: Conservative vector field

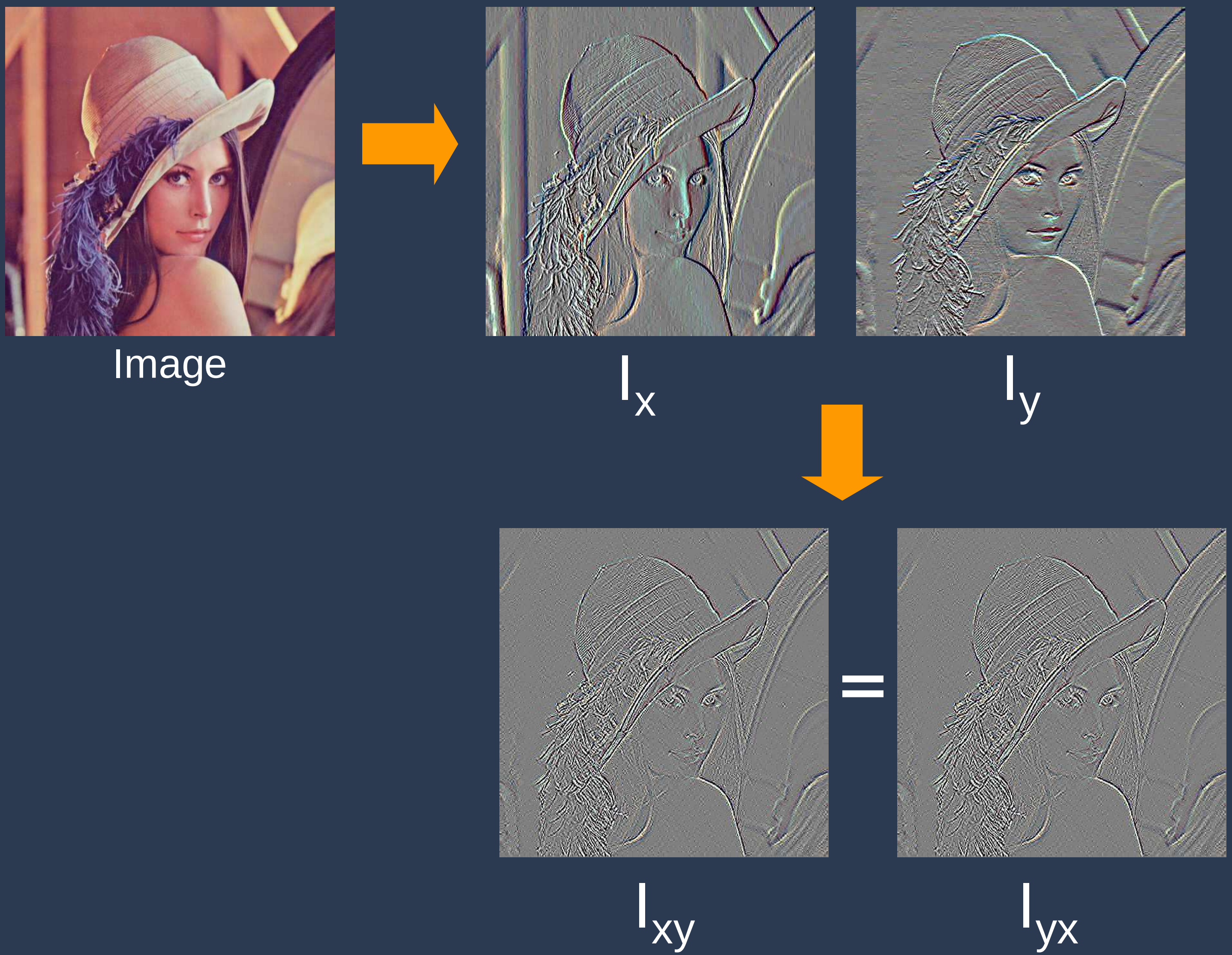
- For a scalar field I(x,y) $\boxed{\nabla \times \nabla I = 0}$
  - Curl of the gradient field should be zero

$$\boxed{Curl(\nabla I) = I_{yx} - I_{xy} = 0}$$

$$\boxed{I_{yx} = I_{xy}}$$

  - Same result independent of differentiation order

Example



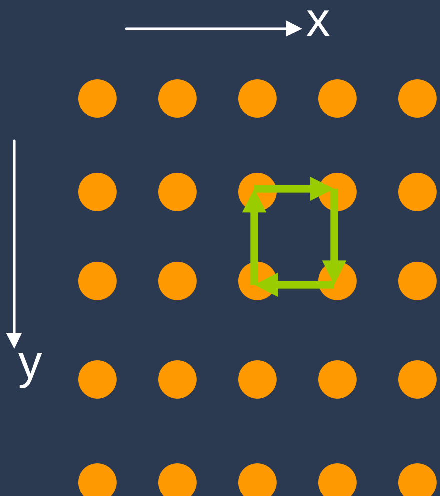
Integrability

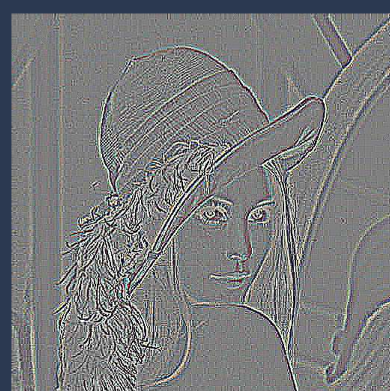
Image

I_x

I_y

$$Curl(x,y) = I_x(x,y) + I_y(x+1,y) - I_x(x,y+1) - I_y(x,y) = 0$$



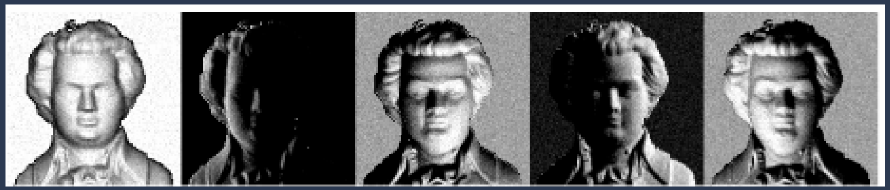


$Div(I_x, I_y)$

$Curl(I_x, I_y)$

Non-integrable gradient fields

- Several vision/graphics applications
- Two main causes
  - Estimation of gradients
    - E.g. Shape from Shading, Photometric Stereo
    - Surface gradients
    - Noise, outliers in estimation



Input Images

Surface Normals/Gradients

Not Integrable!!

Non-integrable gradient fields

Manipulation of integrable gradients

- Synthesis of new gradient field

Image

I_x

I_y

Gradient Manipulations

New Gradients

New Image???

Not Integrable!!!!

Example Gradient Manipulation

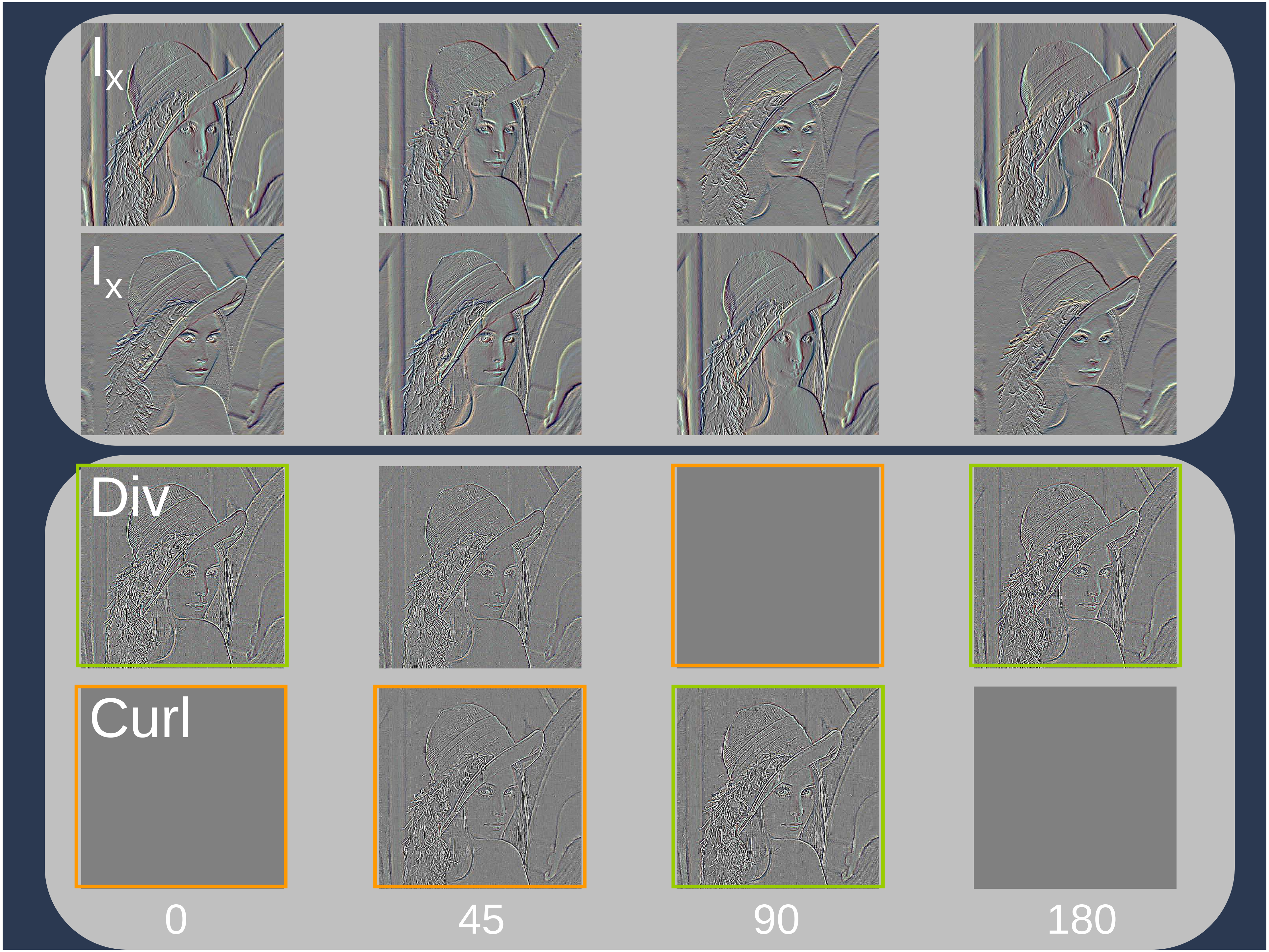
- Rotate gradient at every pixel by same angle
- How does Curl and Divergence change?

Gradient Rotation

$$I_{x'} = I_x \cos(\theta) - I_y \sin(\theta)$$
$$I_{y'} = I_x \sin(\theta) + I_y \cos(\theta)$$

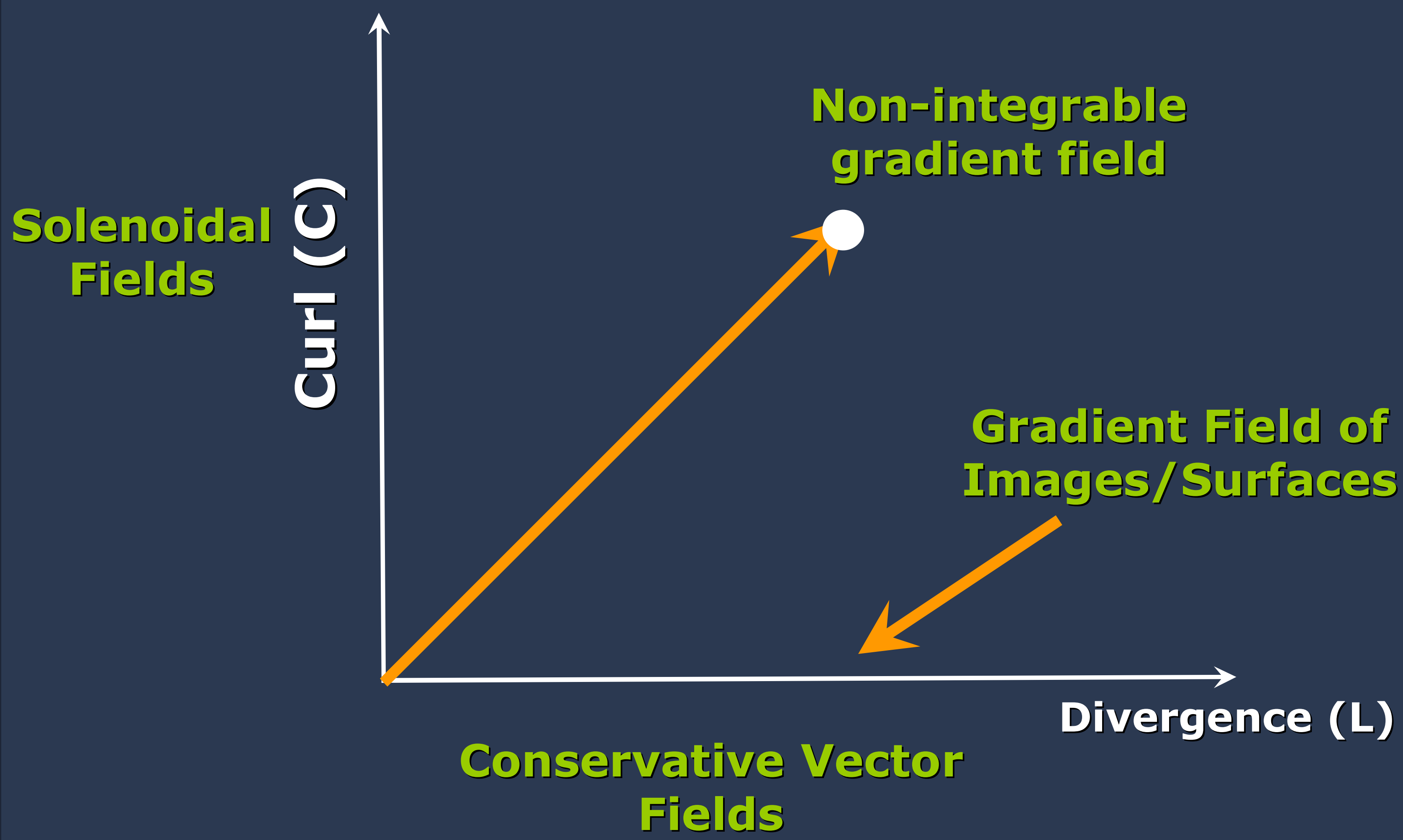
$$Div(I_{x'}, I_{y'}) = Div(I_x, I_y) * \cos(\theta)$$

$$Curl(I_{x'}, I_{y'}) = -Div(I_x, I_y) * \sin(\theta)$$

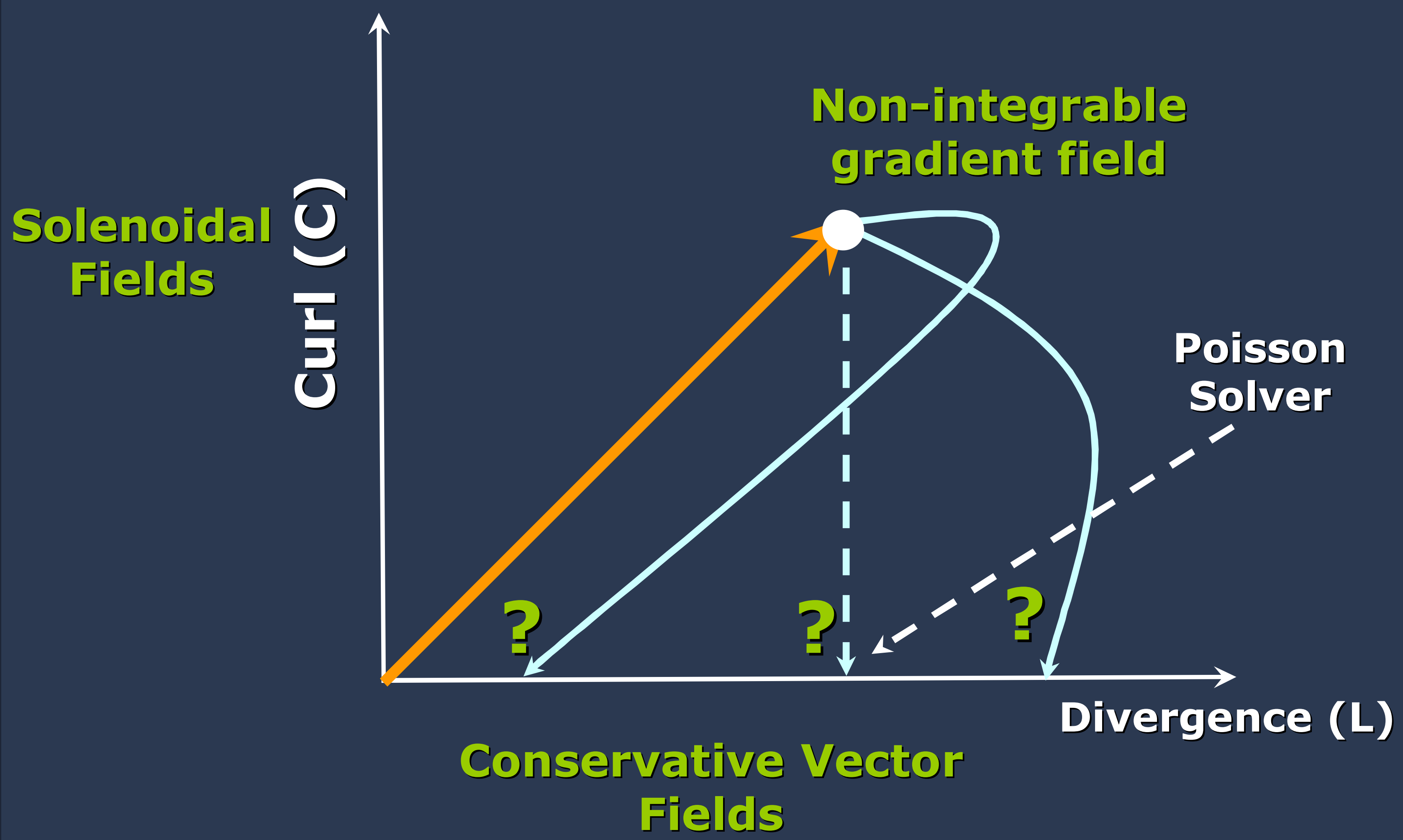


Ix
Ix
Div
Curl
0
45
90
180

Understanding Curl-Divergence



The Reconstruction Problem



Overview

- Curl, Divergence
- Non-integrable gradient fields
- Reconstruction problem
- Motivating Applications

Problems involving Integrability

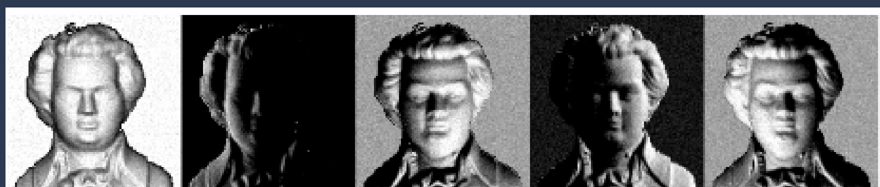
- Reconstructing height field from gradients (Next)
  - Applications: Shape from Shading, Photometric Stereo
- Manipulating image gradients (Section 2)
  - Applications: HDR compression, Image editing, matting, Fusion, Mosaics
- Manipulation of 3D gradients (Section 4)
  - Applications: Mesh editing, Video operations

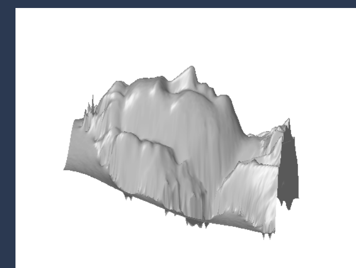
Reconstruction from non-integrable fields

- Algorithms
  - Poisson solver. Based on least squares fitting
  - Other approaches?
    - Projection on basis, Robust reconstruction, gradient transformations
- Numerical Methods
  - Direct solutions, Multigrid, Preconditioned congujate gradients, Hierarchical basis
  - Tradeoffs
- More in Section 3

Example Applications

- Analysis
  - Shape from Shading, Photometric Stereo





Height Field

- Synthesis
  - High Dynamic Range (HDR) Compression

Photometric Stereo (Gradient Estimation)

- Shape from multiple images
  - Fixed viewpoint, varying illumination
- Common Assumptions
  - Lambertian surfaces, Point light source
- We focus on recovering height fields by first estimating gradients

Photometric Stereo

- Lambertian reflectance model
  - Relates image intensities to surface normals n = [n_x,n_y,n_z]

$$I(x,y) = \rho(x,y)\mathbf{n}(x,y) \cdot \mathbf{s}$$

albedo

Light source direction

- Multiple images

$$I_i(x,y) = \rho(x,y)\mathbf{n}(x,y) \cdot \mathbf{s}_i \quad i = 1 \ldots n.$$

Estimating Gradient Field

$$I_i(x,y) = \rho(x,y)\mathbf{n}(x,y) \cdot \mathbf{s}_i \quad i = 1 \ldots n.$$

$$\mathbf{a}(x,y) = \rho(x,y)\mathbf{n}(x,y)$$

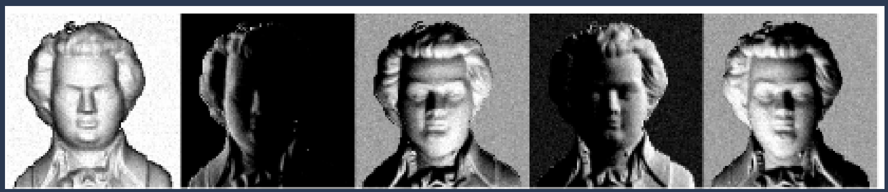
Scaled normal

$$\begin{bmatrix} \mathbf{s}_1^T \\ \mathbf{s}_2^T \\ \vdots \\ \mathbf{s}_n^T \end{bmatrix} \mathbf{a}(x,y) = \begin{bmatrix} I_1(x,y) \\ I_2(x,y) \\ \vdots \\ I_n(x,y) \end{bmatrix}$$

$p = -n_x/n_z$, $q = -n_y/n_z$ Estimated surface gradients

Photometric Stereo

- Multiple images, varying illumination
- Obtain surface gradient field from images
  - Lambertian reflectance model



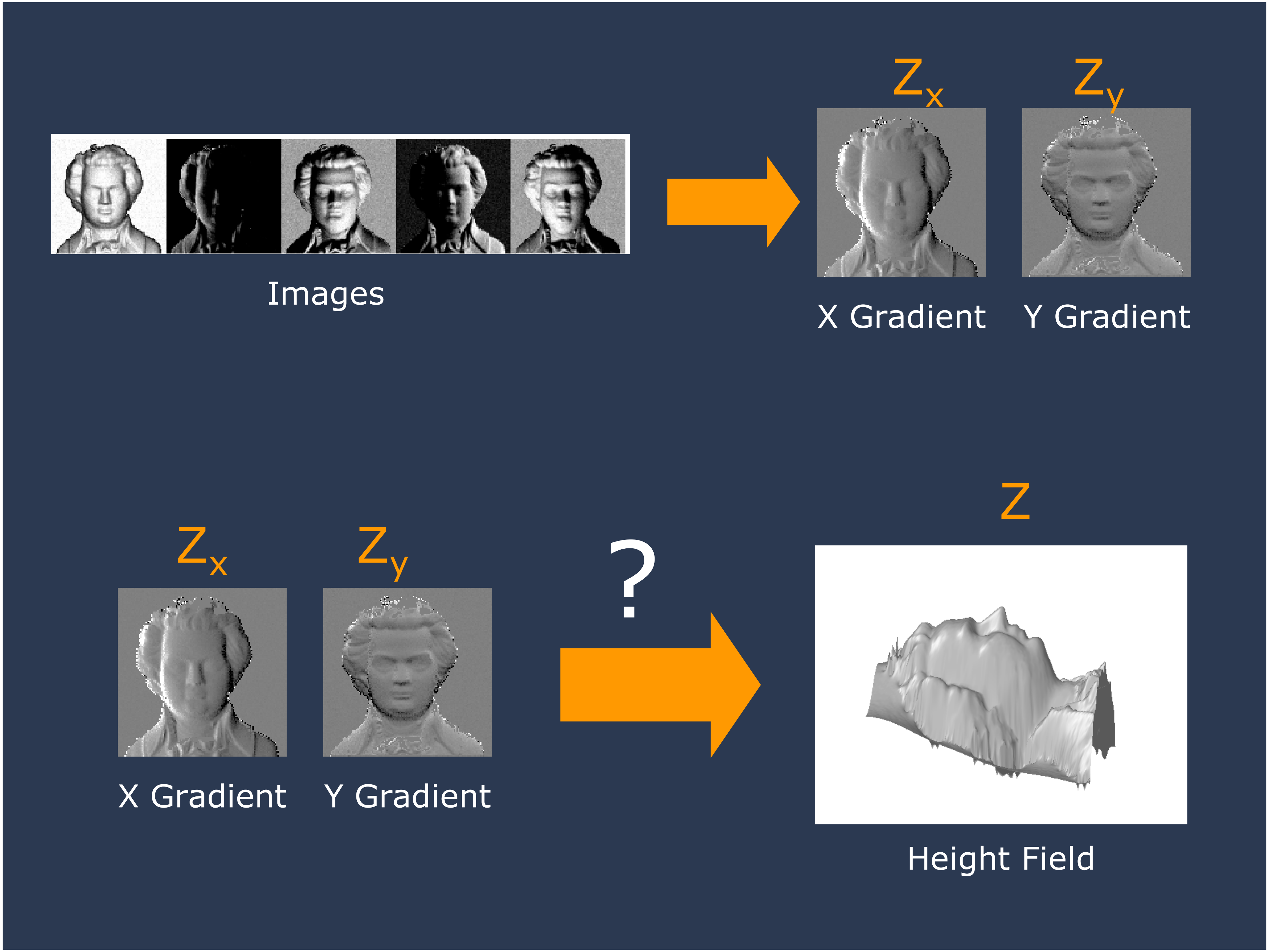
Images

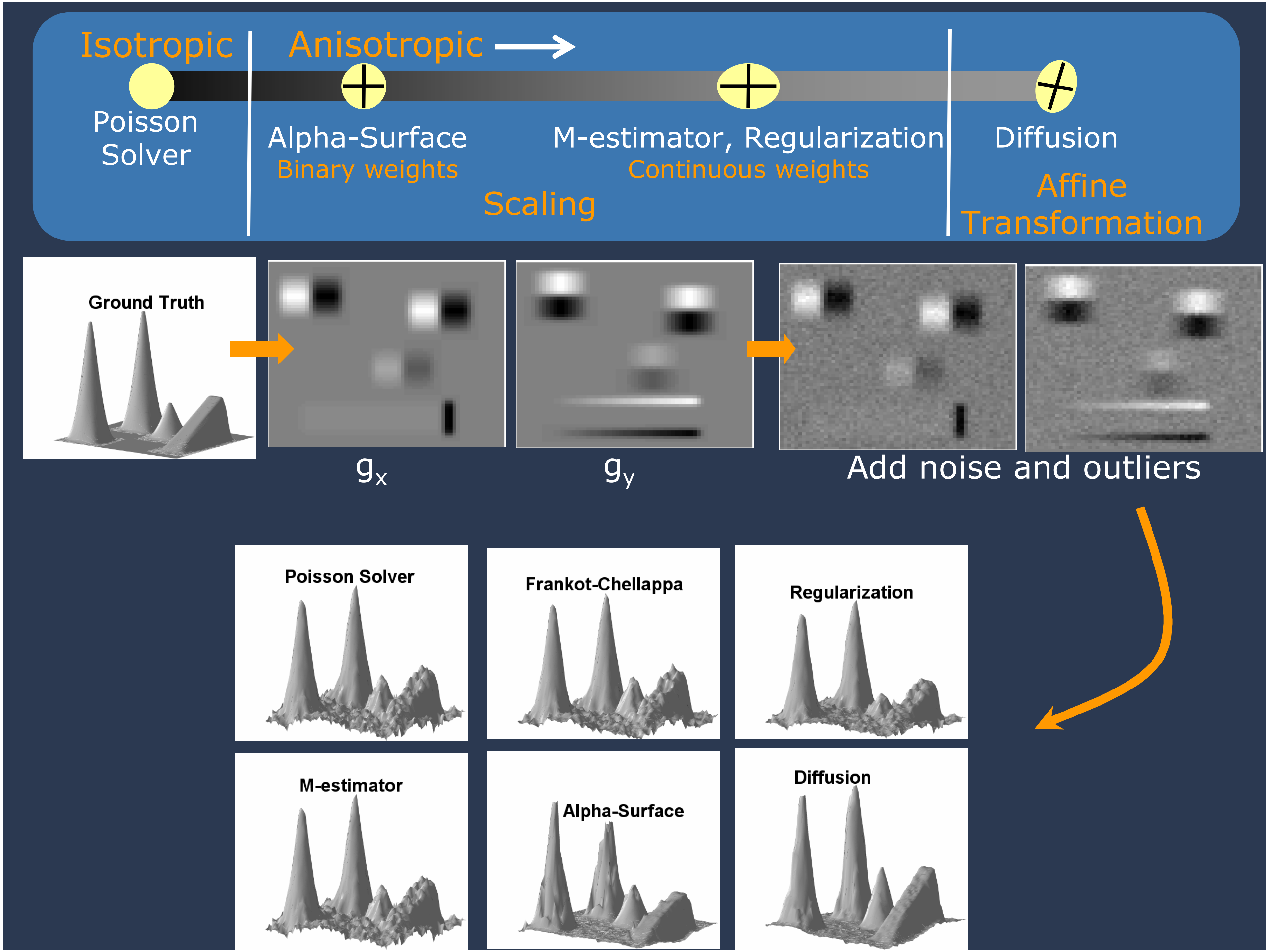
p

X Gradient

q

Y Gradient


Images
Z_x
Z_y
X Gradient
Y Gradient
Z_x
Z_y
?
Z
X Gradient
Y Gradient
Height Field



Isotropic
Anisotropic
Poisson Solver
Alpha-Surface
Binary weights
M-estimator, Regularization
Continuous weights
Scaling
Diffusion
Affine Transformation
Ground Truth
g_x
g_y
Add noise and outliers
Poisson Solver
Frankot-Chellappa
Regularization
M-estimator
Alpha-Surface
Diffusion

High Dynamic Range Imaging

- Cameras have limited dynamic range

Small Exposure image, dark inside

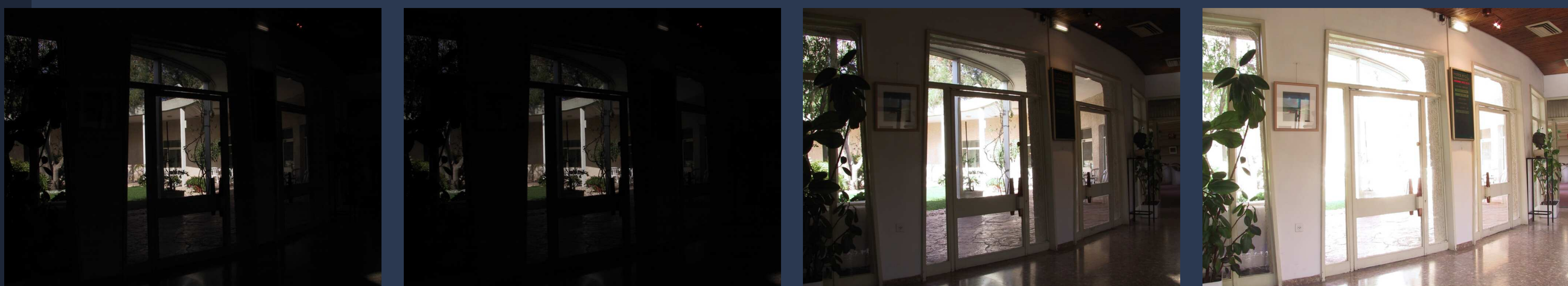
1/500 sec

Large exposure image, saturated outside

¼ sec

High Dynamic Range Imaging

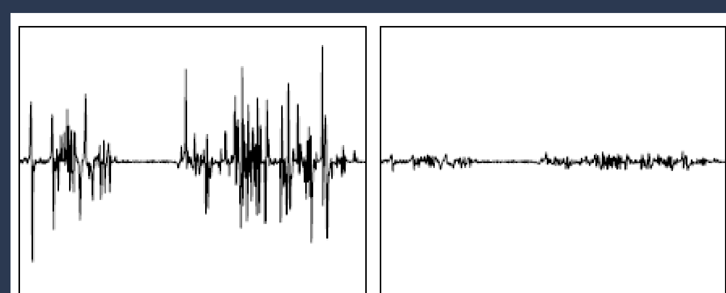
- Combine images at different exposures
- [Mann and Picard 95, Debevec et al 96]



High Dynamic Range Compression (Gradient Manipulation)

- Synthesize new gradient field
- Key Idea: Suppress large gradients, keep small gradients
- Integrate to obtain Low Dynamic Range (LDR) Image

High Dynamic Range Image



Gradients Modified

Low Dynamic Range Image

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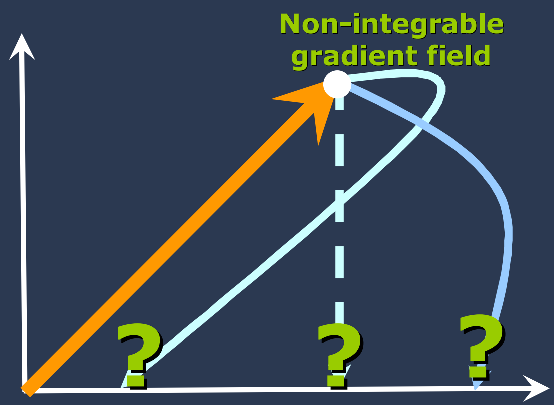
Summary

- Basics
  - Curl, Divergence, Intgerability
- Non-integrable gradient fields in vision/graphics
  - Estimation & Manipulation of gradients
- Reconstruction from gradients
- Motivating applications
  - HDR compression, Photometric Stereo



Next Section

- Gradient Domain Manipulation of images

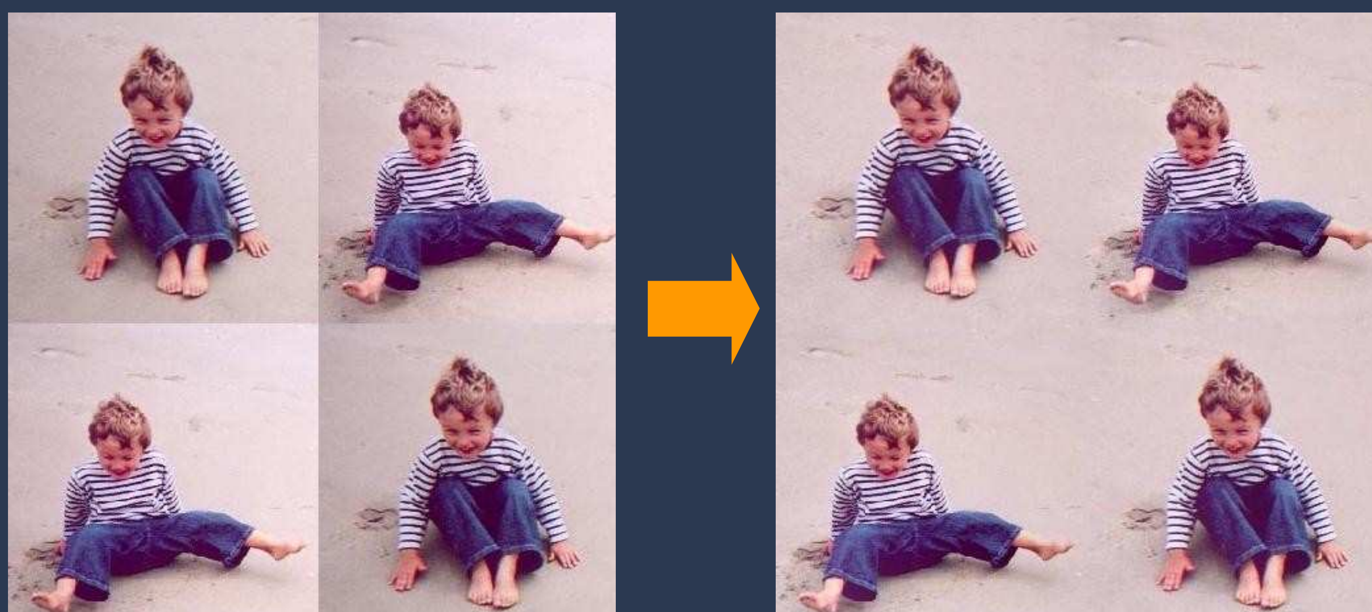
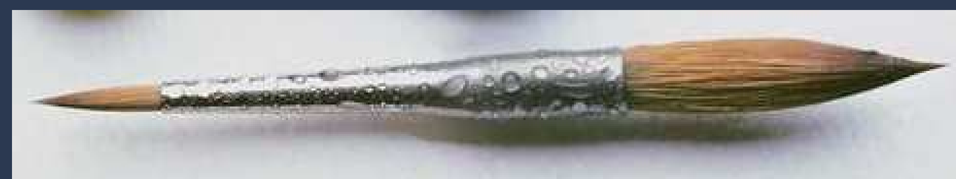
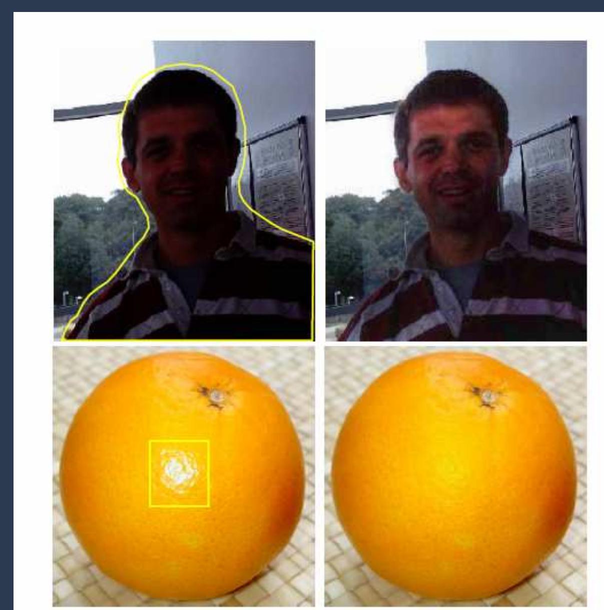


Image Editing





Changing Local Illumination

Edge Suppression under Significant Illumination Variations

Fusion of day and night images

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	

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