

Overview (1):

Before We Begin

- Administrative details
- $\ensuremath{\,\,^{\scriptscriptstyle \ensuremath{\mathbb{R}}}}$ Review \rightarrow some questions to consider

Image Edges

- Introduction
- Importance of edge detection
- Modeling an edge

Overview (2):

Introduction to Sharpening Filters

- Foundation (quick review from last week)
- First order derivatives the gradient
- Second order derivative

Before We Begin

Administrative Details (1):

No Lab Today

- Review during the lab period
 - In this room if there is no other class after us otherwise, in the lab
 - \bullet Optional \rightarrow although it is recommended to attend, you do not have to attend
- $\ensuremath{\,^\circ}$ Lab 5 report due the day of the test

Administrative Details (2):

Mid-Term Exam

- November 7 2005
- 6:05pm ??? (won't be the entire period but you will have enough time) → be here on time!

Some Questions to Consider (1):

- What is spatial filtering ?
- What is a smoothing spatial filter ?
- What is an averaging filter ?
- What is a weighted averaging filter ?
- What is a sharpening filter ?
- What is a digital first derivate (define it)?
- What criteria must be satisfied by a first order derivative ?
- What is a digital second derivate (define it)?
- What criteria must be satisfied by a second order derivative ?

Image Edges

Introduction (1):

What is an Edge ?

- Intuitively → a border between two regions, where each region has (approximately) uniform brightness (gray level)
- In an image edges typically arise from
 - 1. Occluding contours in an image
 - Two image regions correspond to two different surfaces
 - 2. Abrupt changes in surface orientation
 - 3. Discontinuities in surface reflectance











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Modeling an Edge (2):

In Practice, Ideal Edges Don't Exist!

- Sampling and the fact that sampling acquisition equipment etc. is far from perfect leads to edges that are blurred
- Changing illumination (lighting conditions) will cause changes to edges & all parts of an image in general
 - Changing lighting conditions are actually a HUGE problem for vision/image processing tasks → many algorithms will not generalize across different lighting conditions
 - Color constancy \rightarrow a big field in computer vision but still an un-solved problem!



- Reality \rightarrow Edges Have a "Ramp-Like" Profile
 - The slope of the ramp is inversely proportional to the degree of blurring in the edge
 - Updated definition \rightarrow region of image in which the gray-level changes significantly over short distance



Modeling an Edge (4):

- In Practice, Ideal Edges Dont Exist! (cont.)
 - Edge is no longer a one-pixel thick path
 - An edge point is now any point contained in the ramp and an edge would be a set of such points which are connected
 - Thickness of edge depends on length of ramp which is determined by its slope which itself is determined by the amount of blurring
 - Blurred edges are typically thicker e.g., the greater the blurring \rightarrow the thicker the edge

Sharpening Filters (Review)

Foundation (5):

- First Order Derivative in Greater Detail
 - Basic definition of a first order 1D function f(x) is the difference

 $\frac{\partial f}{\partial x} = f(x+1) - f(x)$ $\frac{\partial f}{\partial y} = f(y+1) - f(y)$

 Remember → above definition is of one variable (x) only since images are a function of two variables x,y e.g., f(x,y) we will be dealing with derivatives along both spatial axis "separately" hence the use of "partial derivative"

Foundation (6):

- Second Order Derivative in Greater Detail
 - Basic definition of a first order 1D function f(x) is the difference

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x)$$
$$\frac{\partial^2 f}{\partial y^2} = f(y+1) + f(y-1) - 2f(y)$$

 Once again, remember, above definition is for one variable only whereas in digital images we are dealing with two variables, x,y





Foundation (8):

- Graphical Illustration Explained
 - Traversing profile from left to right
 - First order derivative is non-zero along entire ramp but second order derivative is non-zero only at onset and end of ramp
 - Since edges in image have similar profile, we can conclude first order derivative produces "thick" edges while second order derivatives produces "finer" edges
 - A second order derivative enhances much more finer detail than first order derivative (but also enhances noise as well!)

Foundation (9):

- Graphical Illustration Explained (cont...)
 - To summarize
 - 1. First order derivatives generate thicker edges in an image
 - Second order derivatives have stronger response to fine detail e.g., thin lines and isolated points (noise as well)
 - 3. First order derivatives have stronger response to gray level step
 - 4. Second order derivatives produce double response at step changes in gray level

Foundation (10):

- Graphical Illustration Explained (cont...)
 - To summarize (cont...)
 - Generally, second order derivatives are better for image enhancement as opposed to first order derivatives since they are able to enhance such fine detail

First Order Derivatives The Gradient

Introduction (1):

Gradient Defined

- Gradient is a measure of change in a function
- An image can be considered to be an "array" of samples of some continuous function of intensity
 - Significant changes in gray levels in image can thus be detected using discrete approximation of gradient
 - Edge detection \rightarrow detecting significant local changes in an image
- Two-dimensional equivalent of the first derivative

Introduction (2):

- Gradient Defined (cont...)
 - For function f(x,y) gradient of f at coordinates
 (x,y) is defined as a two-dimensional column vector

$$G[f(x,y)] = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

Gradient Properties (1):

• Two Important Properties of Gradient

- Vector G[f(x,y)] points in direction of maximum increase of function f(x,y)
- Magnitude of gradient equals maximum rate of increase of f(x,y) per unit distance in direction G. Magnitude given as

$$mag(G[f(x,y)]) = \sqrt{G_x^2 + G_y^2}$$
$$= \sqrt{\left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2\right]} \qquad \theta = \tan^{-1}(y/x)$$

Gradient Properties (2):

- Properties of the Gradient
 - Components of gradient vector are linear
 - Magnitude of gradient vector is not linear given squaring and square root operations
 - Partial derivates of gradient vector are not isotropic (e.g., not rotation invariant)
 - Magnitude of gradient is isotropic
 - Often, although incorrect, we refer to the magnitude of the gradient as the gradient itself

Gradient Properties (3):

Properties of the Gradient (cont...)

- Implementing the gradient magnitude equation for an entire image is very computationally expensive and certainly not a trivial matter!
 - Approximate gradient mag. using absolute values

 $mag(G[f(x,y)]) = |G_x| + |G_y|$

- Above equation is easier to compute and preserves relative changes in gray levels
- Isotropic property generally lost → as with Laplacian preserved for limited number of rotational increments, depending on mask



Approximating the Gradient (2):

Digital Approximation to Gradient (cont...)

• Simplest approximation to first order derivative satisfying previously stated conditions is

 $G_x = (z_8 - z_5)$ and $G_y = (z_6 - z_5)$

 Other definitions available including one proposed by Roberts in 1965, uses "cross differences" and known as the Roberts cross gradient operators

 $G_x = (z_9 - z_5)$ and $G_y = (z_8 - z_6)$

Gradient Approximations (1):

Roberts Cross Gradient Operator

Implemented with the following masks



- Difficult to implement given its "awkward" size
 - Minimum mask we are interested in is 3x3!
 - Approximation using a 3x3 mask can be given

$$\begin{split} & G[f\{x,y)] = |(z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)| \\ & + |(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)| \end{split}$$



 Difference between third and first columns approximates derivative in y direction

Gradient Applications (1):

Many Applications and Uses

- Industrial applications
 - Aid humans in detecting defects \rightarrow enhances defects and eliminates slowly changing background features
 - Pre-processing step in automated inspection
- Edge detection
- Highlight small specs not visible in gray scale image
- Enhance small discontinuities in flat gray field



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