Overview (1):
- Filtering in the Frequency Domain
  - Smoothing filters
  - Sharpening filters
- Discontinuity Detection
  - Introduction to image segmentation
  - Point detection
  - Line detection
  - Edge detection

Overview (2):
- Thresholding
  - Foundation
  - Introduction
Before We Begin

Administrative Details (1):
• Lab Eight Today
  • Final lab
  • No lab report required

Administrative Details (2):
• Exam Dec. 19 2005
  • Review next week during lab period
  • I will make some comments regarding the exam
  • Exam will be similar in format to mid-term
  • No surprises!
  • Focus on material after mid-term but you are still responsible for all material
  • Still need to know spatial filtering in the frequency domain
Some Questions to Consider (1):

- Why filter in the frequency domain?
- What are the steps to filtering an image in the frequency domain?
- Why do we shift the origin of the DFT output?
- Why do we scale (with an exponential function) the output of the Fourier output?
- From the origin, what can we say about the DFT frequency?
- What is a low/high pass frequency domain filter?
- What is a "notch" filter?

Smoothing Frequency Domain Filters

Introduction (1):

- What is a Smoothing Filter (Review)
  - Edges, noise, sharp transitions in intensity levels lead to the majority of high frequency components in the frequency domain (e.g., Fourier transform)
  - Smoothing in the frequency domain is therefore achieved by (ideally) removing a specified range of high frequency components in the transform
  - Remember → ideally these components are removed but in practice, they are attenuated
  - Gaussian is one type of smoothing filter
**Introduction (2):**

- Mathematically
- Recall
  - \( F[u,v] \rightarrow \) Fourier transform of image to be filtered
  - \( H[u,v] \rightarrow \) filter applied to image
  - \( G[u,v] \rightarrow \) filtered image (output image)

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**Introduction (3):**

- **Graphical Illustration of Low Pass Filtering**

  - Ideal low-pass filter
  - low pass filter displayed as an image
  - Filter radial cross-section where \( D_0 \) is radius of “circle” e.g., determines cut-off frequency

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**Introduction (2):**

- **Graphical Illustration of Low Pass Filtering**

  - Original image

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Sharpening Frequency Domain Filters

Introduction (1):

- What is a Sharpening Filter (Review)
  - Removes (ideally) low frequency components of an image's Fourier representation (e.g., keeps frequency components above some cut-off frequency)
  - Basically, the reverse of the low pass filter and given mathematically by
    \[ H_{hp}[u,v] = 1 - H_{lp}[u,v] \]
  - \( H_{hp}[u,v] \to \) high pass filter
  - \( H_{lp}[u,v] \to \) low pass filter

Introduction (1):

- Graphical Illustration of High Pass Filtering

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**Introduction (2):**

- **Graphical Illustration of High Pass Filtering**

- **Discontinuity Detection**

**Image Segmentation (1):**

- **What is Image Segmentation?**
  - Segmentation sub-divides an image into a number of regions or objects.
  - How far this sub-division is carried out depends on the task.
  - An extremely difficult yet important task.
  - Its accuracy determines the eventual success or failure of any automated analysis procedure which rely on its output.

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Image Segmentation (2):
- Image Segmentation Algorithms Generally Based on Two Basic Properties of Intensity
  - Discontinuity
    - Partition image based on abrupt changes in intensity (e.g., edges where there is a large change in intensity between adjacent pixels)
  - Similarity
    - Partition image into regions that are similar based on some pre-defined criteria (e.g., intensity of pixels within a certain range)

Introduction (1):
- Will Focus on Three Types of Discontinuities
  1. Points
  2. Lines
  3. Edges
- Regardless the type of discontinuity, most common approach to locating them is to "filter" the image with a 3 x 3 mask (e.g., convolution)
- Mask coefficients are chosen depending on the type of discontinuity being searched for

Introduction (2):
- Recall Spatial Domain Filtering with Mask
  - Sum of products of coefficients with the gray levels in image encompassed by the mask
  \[ R = w(-1,-1)f(x-1,y-1) + w(-1,0)f(x-1,y) + \ldots + w(0,0)f(x,y) + \ldots + w(1,1)f(x+1,y+1) \]
  - Example of a 3x3 template with its coefficients

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**Point Detection (1):**

- **In Principle, Straightforward**
  - Using the following mask, a point is detected at the location at which the mask is centered on if

\[ |R| \geq T \]

\( R \rightarrow \) output of filtering operation (e.g., sum of filter coefficients multiplied by corresponding image intensities)

\( T \rightarrow \) threshold (an intensity value, recall your labs)

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**Point Detection (2):**

- **Basic Idea**
  - Isolated point (a point whose gray level is much different from its background) will be different from its surroundings and will be detected by the mask used
  - Examine mask coefficients
    - Sum of coefficients equals 0 → mask response will be zero in areas of constant gray level

**Point Detection (1):**

- **Graphical Example**

- Original image → X-ray image of turbine blade with a porosity

- Result of running mask over entire image

- Result after thresholding → threshold set to 90% of highest pixel value in image

Detected point

Porosity with single black pixel embedded within it
Line Detection (1):

- More Difficult Than Point Detection
  - Lines can be oriented in any manner (e.g., horizontally, vertically, ±/45°, etc.)
  - Different mask to detect each line orientation

```
  -1  -2  -1
   2   2   2
  -1   -2  -1
```

Horizontal

```
  -1  -1  -1
   5   5   5
  -1  -1  -1
```

+45°

```
  -1  2  -1
   2  -1  -1
  -1  2  -1
```

Vertical

```
  -1   2   -1
   2   -1   -1
  -1   2   -1
```

−45°

Line Detection (2):

- Notes Regarding the Line Detection Masks
  - Typically these masks detect lines 1 pixel thick
  - Preferred direction of each mask is weighted with a larger coefficient than the other possible directions (e.g., 2 instead of -1)
  - Coefficients sum to zero
    - Response will be equal to zero in areas of constant gray level

Line Detection (3):

- Line Detection Graphical Example

- Original image
- Processing image with -45° line detector mask
- Result of thresholding the image after applying filter
**Edge Detection (1):**

- **Basic Formulation**
  - What is an edge (review) → set of connected pixels that lie on a boundary between two regions
  - Different from a boundary → boundary is more of a “global” concept whereas edge is a more of a “local” concept
  - Modeling of an ideal edge
    - A set of connected pixels, each of which is located at an orthogonal step transition in gray level

**Edge Detection (2):**

- **Basic Formulation (cont...)**
  - Modeling of ideal edge – graphical illustration

**Edge Detection (3):**

- **In Practice, Ideal Edges Do Not 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
    - Changes in lighting is actually a HUGE problem for vision/image processing tasks → many algorithms will not generalize across different lighting conditions
    - Color constancy → a big field in computer vision but still an un-solved problem!
**Edge Detection (4):**

- In Practice, Ideal Edges Don’t Exist! (cont. . .)
  - In reality, edges have a more “ramp-like” profile
    - The slope of the ramp is inversely proportional to the degree of blurring in the edge

**Model of ramp digital edge**

- Gray-level profile of horizontal line through image

**Edge Detection (5):**

- In Practice, Ideal Edges Don’t 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 is given length of ramp which is determined by the slope which itself is determined by the amount of blurring
    - Blurred edges are typically thicker e.g., the greater the blurring → the thicker the edge

**Edge Detection (6):**

- Detecting Edges
  - Recall → edges are detected using first and second order digital derivatives (gradients)
**Edge Detection (7):**

- **Detecting Edges (cont...)**
  - Remember
    - First derivative $\rightarrow$ positive at points of transition into and out of ramp (moving from left to right) & zero in constant gray-level areas
    - Second derivative $\rightarrow$ positive at transition associated with the "dark" side of edge, negative at light side of edge and zero along ramp & in areas of constant gray level

**Edge Detection (8):**

- **Detecting Edges (cont...)**
  - Some conclusions regarding derivatives & edges
    - Magnitude of first order derivative can be used to detect presence of edge at point
    - Sign of second order derivative can be used to determine whether edge pixel itself lies on dark or bright side of edge
    - Second order derivative produces two values for every edge & therefore zero-crossing
    - Zero-crossing $\rightarrow$ imaginary straight line drawn from positive to negative value would cross zero near midpoint of the edge

**Edge Detection (9):**

- **Edge Detection Example**
  - Entire transition from left to right is single edge
  
  ![Image](image.png)

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**Edge Detection (10):**

**Edge Detection Example**

- Conclusions we can draw from previous examples
  - To be classified as edge point, gray-level transition must be significantly stronger than background
  - Threshold used to determine whether it is different from background → e.g., will be classified as edge only if derivative is greater than some but thresholds have their own problems!
  - The set of all these points greater than the threshold and connected comprise the edge

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**Thresholding**

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**Introduction (1):**

- **Central to Image Processing/Computer Vision**
  - Essentially, thresholding basically involves performing a check at each pixel location
  - This should be familiar from your labs!

  For each pixel (x,y) in image
  1. Obtain pixel intensity $p_i$
  2. Compare $p_i$ with pre-defined threshold value $T$
     - if $p_i \geq T$ then $p_i = 1$ (p is an object point)
     - if $p_i < T$ then $p_i = 0$ (p is background point)
**Introduction (2):**
- **Graphical Example**
  - Histogram of image with light object and dark background
  - After performing thresholding of image with threshold $T$, pixels corresponding to object will be highlighted (e.g., set to 1) while background pixels will be set to zero.

**Introduction (3):**
- **Multi-Level Thresholding**
  - Can be used to locate (detect) multiple objects where each object is within some range of intensities
  - Multiple thresholds and therefore multiple checks per pixel
  - For example, two objects, two threshold $T_1$, $T_2$
  - Pixel belongs to one object if $T_1 < f(x,y) \leq T_2$
  - Pixel belongs to other object if $f(x,y) > T_2$
  - Pixel belongs to background if $f(x,y) \leq T_1$

**Introduction (4):**
- **Graphical Example**
  - Multi-level thresholding
  - Multi-level thresholding
  - Object 1
  - Object 2
  - Background
  - Threshold 1
  - Threshold 2