Introduction to Image Processing

Jacqueline Le Moigne
NASA GSFC
What is “Image Processing”?

(Definition from Wikipedia) “Image Processing is any form of information processing for which the input is an image, such as photographs or frames of video; the output of image processing can be either an image or a set of characteristics or parameters related to the image. Most image-processing techniques involve treating the image as a two-dimensional signal and applying standard signal processing techniques to it.”
Applications of Image Processing

- Medical Applications (e.g., Cancer Detection, Remote and Assisted Surgery)
- Security Applications (e.g., Face and Fingerprints Recognition)
- Commercial Applications (e.g., Video and Photograph Enhancement)
- Industrial Applications (e.g., Assembly Line Manipulation, Visual Inspection)
- Military Applications (e.g., Missile Guidance)
- Space Applications (e.g., Remote Sensing, Space Robotics)
Multi-Disciplinary Field

Physics
- Optics
- Imaging Sensors

Computer Science
- Data (HP) Processing
- Storage, Archiving, Mining
- Artificial Intelligence

Mathematics
- Probabilities and Statistics
- Scientific Computing
- Geometry
- Algebra

Engineering
- Signal Processing
- Automatic Control
- Robotics

Neurobiology

Image Processing and Computer Vision

Psychology

Biological Vision
Sequence of Image Processing Tasks

3D Scene → Image Formation → 2D Image → Digitization → Gray Level Image → Enhancement → Compression → Mining

Storage

Gray Scale/ Histogram Modifications, Sharpening, Smoothing, etc.

Karhunen-Loeve Fourier, Hadamard, Cosine Transform Wavelets JPEG, JPEG 2 Rice, etc.

Compression

Least Squares Filtering, Deconvolution, Recursive Filtering, Maximum Entropy, etc.

Restoration/ Reconstruction

Intensity Correlation, FFT, Landmark/ Feature Matching Wavelet-Based, etc.

Registration

Feature Extraction

Image Interpretation

Segmentation

Histogram Thresholding, Edge Detection, Line/Corner Detection, Mathematical Morphology, Shape Measurement, etc.

Feature Extraction

Region Growing, Texture/[Cooccurrence, Fractal Dimension, Textons, …], Watershed, Color/Wavelength, etc.

Segmentation

Principal Component Analysis, Classification/Labeling, Object Recognition, Model/Knowledge Based, Scene Representation, etc.

Mining

Intensity Correlation, FFT, Landmark/ Feature Matching Wavelet-Based, etc.

Restoration/ Reconstruction

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Image Formation
Biological Vision

- Visual functions Integrated by Brain:
  - Field of View, Focusing Ability, Depth Perception, Motion Perception, Color Perception

- Different Kinds of Vision/ “See” and “Understand” in Different Ways
  - Human Vision
    - Image Formed on the Retina/ photoreceptors (or rods and cones), produce electrical transmitted to brain via optic nerve.
    - 3 kinds of color receptors - blue, greenish-yellow and red
    - Position of eyes determines degree of peripheral vision; Visual field of 200º; Stereo vision => depth
  - Animal Vision:
    - Dogs:
      - 2 kinds of color receptors - yellow and greenish-blue
      - Visual field of 240º but central binocular field of view ≈1/2 human’s
      - Optimal dilation of pupil (≈ camera’s aperture) + reflective layer under retina => Enhanced night vision
      - Lower details sensing (no fovea); Greater sensitivity to motion
    - Snakes:
      - Do not see color
      - Combination of light receptors: rods => low-light fuzzy vision & cones => clear images
      - Underground snakes: smaller eyes/light and dark; above ground: very clear vision and good depth perception. Some species (e.g., boas and pythons): pit organs similar to IR goggles.
    - Insects:
      - “Compound eyes: Bees’ eyes made up of 1000’s of lenses, dragon flies 30,000’s
      - Wide field of view, and better motion perception
Biological Vision

- Optical Illusions, Illumination, A-priori Knowledge, Domain-Dependent
Image Formation - Physics

- Vision uses Light Reflected from the Surrounding World to Form an Image

- Light Source
- Eye/Camera/Sensor

- Absorption
- Refraction
- Reflection
- Scattering

Diagram showing the interaction of light with different mediums and objects.
• **Pinhole Imaging Model**

If \( W = (X,Y,Z) \) and \( P = (x,y,f) \)

\[
\overrightarrow{OW} = \alpha \cdot \overrightarrow{OP}
\]

so

\[
\begin{align*}
X &= \alpha x \\
Y &= \alpha y \\
Z &= \alpha f
\end{align*}
\]

Therefore

\[
\begin{align*}
x &= f \cdot \frac{X}{Z} \\
y &= f \cdot \frac{Y}{Z}
\end{align*}
\]

(with \( f \) is the focal length of the camera)

• **Perspective Geometry**
Digital Images

• Mathematical Model: Representation of an Image as a Discrete (Intensity) Function of Spatial Samples
  – I: (x,y) ----> I(x,y) = Gray Level at Pixel (x,y)
  – Gray Levels = Discrete Values Taken by Intensity Function

• Pixel ("Picture Element") = Image Representation of a Basic Volume Element in the World
  – Tesselation: Pixel Organization

• Spatial Resolution = Represents Interval Sampling of 2D/3D Space

• Spectral Resolution = Represents Interval Sampling of Electromagnetic Spectrum

• Radiometric Resolution = Refers to the Number of Digital (Gray) Levels Used to Represent the Data
Remote Sensing Imaging

Electromagnetic Spectrum

Examples of Spectral Response Patterns for 4 Different Types of Features - Fir Tree, Clear Water, Barley, Granite - White Areas Show the Portions of the Spectrum Corresponding to the 7 Channels of Landsat-Thematic Mapper (TM)

Signal to Noise at Wavelength $\lambda$:

$\frac{S}{N}_{\lambda} = D_{\lambda} \, \beta^2 \, (H/V)^{1/2} \, \Delta_{\lambda} \, L_{\lambda}$

Where

- $D_{\lambda}$: detectivity (measures detector performance quality)
- $\beta$: instantaneous field of view
- $H$: flying height of the spacecraft
- $V$: velocity of the spacecraft
- $\Delta_{\lambda}$: spectral bandwidth of the channel (spectral resolution)
- $L_{\lambda}$: spectral radiance of ground feature

$=>$ Tradeoff between spatial and spectral resolutions, e.g.: To maintain the same SNR while improving spatial resolution by a factor of 4 (i.e., decreasing $\beta$ by a factor of 2), we must degrade the spectral resolution by a factor of 4 (i.e., increase $\Delta_{\lambda}$ by a factor of 4)
### Remote Sensing Imaging (2)

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<th>Instrument (Spat. Resol.)</th>
<th>Number of Channels</th>
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<td>Landsat7-Panchromatic</td>
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<td>(Ch1-4:18m;Ch5-8:24m)</td>
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<td>SPOT-HRV Panchromatic</td>
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<td>SPOT-HRV Multispectral</td>
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<td>MODIS</td>
<td>36 Channels (Ch1:2.500m;Ch2-7:500m;Ch8-36:1km)</td>
<td>3, 8-10</td>
<td>1-4</td>
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<td>Hyposion</td>
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<td>LAC</td>
<td>256 Channels (250m)</td>
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<td>IKONOS-Panchromatic</td>
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<td>IKONOS-MS</td>
<td>4 Channels (4m)</td>
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<td>ASTER</td>
<td>14 Channels (Ch1:1.5m;Ch2-9:30m;Ch10-14:90m)</td>
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<td>CZCS</td>
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<td>TOVS-HIRS2 (D)</td>
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<td>GOES</td>
<td>(1 km:1.4km;2.4km;5.8km:3)</td>
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<td>METEOSAT</td>
<td>(V/2.5km,WV&amp;IR:5km)</td>
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Introduction to Image Processing
Imaging Examples - Photographs
Imaging Examples - Medical

Blood Platelets

Brain MRI
Earth Science Imaging
ETM/IKONOS Mosaic of Coastal VA Data
Hubble Space Telescope Imaging

(Barred Spiral Galaxy NGC1672)
Planetary Imaging
Image Processing Steps
Sequence of Image Processing Tasks

- **3D Scene** to **Image Formation**
- **2D Image** to **Digitization**
- **Gray Level Image** to **Enhancement**
  - Karhunen-Loeve Fourier, Hadamard, Cosine Transform Wavelets JPEG, JPEG 2 Rice, etc.
  - Projections, Correction of Geometric Distortions (Domain-Based)
- **Compression**
- **Storage**
- **Mining**
  - Gray Scale/ Histogram Modifications, Sharpening, Smoothing, etc.
- **Least Squares Filtering, Deconvolution, Recursive Filtering, Maximum Entropy, etc.**
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- **Segmentation**
- **Image Interpretation**

**Introduction to Image Processing**

02/20/08
What is Image Processing?

Test Case:

- 10 by 10 pixels Image
- 256 gray levels
- Image = 10 x 10 Matrix Made up of Numbers in Range [0-255]
Image Processing Basics

Intensity Function:

Gray Level Histogram:

Gray Level Occurrence:

02/20/08 Introduction to Image Processing
Image Convolution

- Many Image Processing Operations are “Local”
  - Smoothing, Edge Detection, Slope Computation, Wavelet Transforms, etc.
  - Parallel Computations

- Pixel Neighborhood, N

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4 Neighbors

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8 Neighbors

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5 Neighbors

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<td>14</td>
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- Image Convolution
  - Convolution of Image I with Filter h at Pixel (x,y) is defined by:
    \[
    I * h(x,y) = \sum_{(u,v) \in N} I(u,v) \cdot h(x-u,y-v)
    \]
  - Theorem / Fourier Transforms (F):
    \[
    F(I_1 * I_2) = F(I_1) \cdot F(I_2)
    \]
Image Enhancement
Histogram Equalization
Image Smoothing

Original

Gaussian Blur

Median Filtering

(Edge-Preserving Smoothing)
Edge Detection
Edge Detection

- Find “Jumps in Intensity”, i.e. pixels where Gradient is Maximum

- Edge Detection Methods: Compute 1st and 2nd Derivatives
  - Find Maxima of First Derivative
  - Find Zeros of Second Derivative
Gradient Operator
(1st Derivative)

- Sobel Edge Detector (2 masks):
  \[ G_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix} \quad G_y = \begin{pmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{pmatrix} \]

- Convolution of Gradient Operators with Image:
  - \( \partial I/\partial x \ (x,y) = G_x * I \ (x,y) = \sum u \sum v \ [G_x(u,v) \cdot I(x-u,y-v)] \)
  - \( \partial I/\partial y \ (x,y) = G_y * I \ (x,y) = \sum u \sum v \ [G_y(u,v) \cdot I(x-u,y-v)] \)

- Gradient of image \( I \) at Pixel \((x,y)\):
  - Magnitude: \( G_I(x,y) = \sqrt{(G_x * I(x,y))^2 + (G_y * I(x,y))^2} \)
  - Direction: \( \arctg(DG_I(x,y)) = G_y * I \ (x,y) / G_x * I \ (x,y) \)

- Variants: Prewitt (1 instead of 2), Roberts (2x2 neighborhood)

- Operators non Isotropic
  - Isotropic Edge Detection with 1, 4 or 8 Masks, e.g., Laplacian:
    \[ L = \begin{pmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{pmatrix} \]
Example Gradient Computations

Gradient Magnitude:

\[
\begin{bmatrix}
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\times
\begin{bmatrix}
-1 & 0 & 1 \\
-2 & 0 & 2 \\
-1 & 0 & 1 \\
\end{bmatrix}
= 0
\]

\[
\begin{bmatrix}
0 & 0 & 127 \\
0 & 0 & 127 \\
0 & 0 & 127 \\
\end{bmatrix}
\times
\begin{bmatrix}
-1 & 0 & 1 \\
-2 & 0 & 2 \\
-1 & 0 & 1 \\
\end{bmatrix}
= 508
\]

Gradient Direction:

- \( G_x = 508 \); \( G_y = 0 \)
- \( \arctg(G_y/G_x) = \arctg(0) = 0 \)
  - Normal to Edge => Vertical Edge

- Edge Pixel = Pixel where Gradient Magnitude is Maximum
- Can be determined by Thresholding Gradient Magnitude
Some Other Edge Detection Methods

- **Hueckel**
  - Approximate Edges with an “Edge Template”
  - \[ S(x,y,c,s,r,b,d) = \begin{cases} b & \text{if } cx + sy \leq \rho \\ b+d & \text{else} \end{cases} \]

- **Marr & Hildreth**
  - Filter Image by Gaussian Filters of Various Variances (i.e., various frequencies)
  - For each variance \( \sigma \), find the zero crossings of the derivative of Image I filtered by \( G_{\sigma} \) or \( \Delta \). Convolve I with 2nd derivative of \( G_{\sigma} \) or Laplacian
  - Laplacian approximated by Difference of 2 Gaussian filters

- **Canny Edge Detector**
  - Designed as an “Optimal Edge Detector” for following 3 criteria:
    - Good Detection
    - Good Localization (more smoothing improves detection but hurts localization)
    - Single Response per Edge
  - Steps:
    1. Gaussian Smoothing (Assumes Gaussian Noise)
    2. 2D First Derivative Gradient (e.g., Roberts or Sobel)
    3. Non-Maximal Suppression, i.e. keep Local Maxima in the Direction of the Gradient
    4. Hysteresis via 2 Thresholds, \( T_h \) and \( T_l \); if \( I < T_l \Rightarrow \) no-edge; if \( I > T_h \Rightarrow \) edge; if \( T_l \leq I \leq T_h \Rightarrow \) kept as an edge only if there is a path to an edge point
Edge Detection - Test Image
Gradient Thresholding

Test Image
Gradient Directions

Test Image
Other Edge Detectors

Test Image
Edge Detection Results

Boats
Fourier and Wavelet Analysis
Fourier Analysis

• Fourier Transform:
  o Decomposition of an Image in a Weighted Sum of Sinusoid Functions of Different Frequencies
  o  \[ F(I)(x,y) = \iint I(u,v) e^{-2\pi \Pi (ux+vy)} \, du \, dv = \text{Weights} \]
  \[ = \iint I(u,v) \cos(2 \pi (ux+vy)) \, du \, dv + i \iint I(u,v) \sin(2 \pi (ux+vy)) \, du \, dv \]
  \[ = \text{Real}(F(I))(x,y) + i \text{Complex}(F(I))(x,y) \]
  \[ \{ \text{Amplitude} = (\text{Real})^2 + (\text{Complex})^2 \text{ and} \]
  \[ \text{Phase} = \text{Arctg}(\text{Complex}/\text{Real}) \]
  o Property: Fourier Transform of a Gaussian is a Gaussian
  o No Localization

• Windowed Fourier Transform:
  – WF(I)(x,y,p,q) = \[ \iint I(u,v).G(u-p,v-q) e^{-2\pi \Pi (ux+vy)} \, du \, dv \]
  – Gabor Transform when G is a Gaussian function centered at every image point
  – Localization but G = Same Envelop for All Frequencies
Wavelet Analysis

- Wavelet Transform:
  - \( \text{Wav}(I)(a,b) = \frac{1}{\sqrt{|a|}} \iint I(u,v) \cdot W(u-b_1,v-b_2) \, du \, dv \)
  - \( W \) is the “Mother Wavelet”
  - Localization (similar to Gabor)
  - Better Division of Space(Time)-Frequency Plane: Good for Short-Lived HF Components Superposed on Longer-Lived LF parts

Windowed Fourier Transform

Wavelet Transform
Discrete Wavelets

- Orthonormal Basis and Frames
  - Daubechies Wavelets
  - Mallat: Definition of Wavelets from a Scaling Function

\[ L \xrightarrow{\downarrow 2} L(k-1) \]
\[ H \xrightarrow{\downarrow 2} H(k-1) \]

\[ F \] Represents the convolution of Image with Filter F
\[ \downarrow 2 \] Represents the Decimation of Image by 2
Daubechies Least Asymmetric Wavelets

![Wavelet Plots](image.png)
Example of 2D Wavelet Decomposition
Example of 2D Wavelet Reconstruction
Example: Wavelets Transform
Applications Of Wavelets

• Image Compression
  – Provide a More Compact Representation of an Image
    • Lossy Compression (some visual quality is lost)
    • Lossless Compression
  – JPEG (Joint Photographic Experts Group) and JPEG-2000: Lossy Compression
    • JPEG: Compression based on Discrete Cosine Transform (DCT)
    • JPEG 2000: Compression based on Wavelets

• Image Registration
• Image Segmentation
• Image Fusion
Image Registration
Image Registration

• If $I_1(x,y)$ and $I_2(x,y)$: images or image/map
  
  Registration = Find the Mapping $(f,g)$ which Transforms $I_1$ into $I_2$:  
  $$I_2(x,y) = g(I_1(fx(x,y),fy(x,y)))$$
  
  » $f$: spatial mapping
  » $g$: radiometric mapping

• Remote Sensing:
  
  – *Navigation* or Model-Based Systematic Correction
    • Orbital, Attitude, Platform/Sensor Geometric Relationship, Sensor Characteristics, Earth Model, ...

  – *Image Registration* or Feature-Based Precision Correction
    • Navigation within a Few Pixels Accuracy
    • Image Registration Using Selected Features (or Control Points) to Refine Geo-Location Accuracy
Image to Image Registration

Correlation of Edge Features

Incoming Data → Image Characteristics (Features) Extraction → Feature Matching → Compute Transform

- Multi-Temporal Image Correlation
- Landmarking
- Coregistration
Image to Map Registration

Correlation of Edge Features

Input Data

Map

Masking and Feature Extraction

Feature Matching

Compute Transform
Application of Wavelets to Image Registration

Reference Image → Wavelet Decomposition → Successive Transformations of Wavelet Images → Maxima Extraction

Input Image → Wavelet Decomposition → Maxima Extraction

Correlation of Transformed Reference Maxima and Input Maxima → Choice of Best Transformation

At Each Level of Decomposition
## Multi-Resolution Wavelet Registration

### Level of Decomp.
- **4**
- **3**
- **2**
- **1**

### Reference Wavelet Coefficients
- **32x32**
- **64x64**
- **128x128**
- **256x256**

### Rotations of Ref. Wav. Coeffs
- **(inct=10)**
- **(inct=5)**
- **(inct=2)**

### Input Wavelet Coefficients

### Best Match
- **R₃**
- **R₂**
- **R₁**

### Diagram

![Diagram of Multi-Resolution Wavelet Registration](image.png)
Mathematical Morphology
Mathematical Morphology Concept

Mathematical Morphology (MM) Concept:

• Nonlinear spatial-based technique that provides a framework.
• Relies on a partial ordering relation between image pixels.
• In greyscale imagery, such relation is given by the digital value of image pixels

Greyscale MM Basic Operations:

Original image

3x3 structuring element defines neighborhood around pixel P

Max

Min

Dilation

Erosion

Original image

Structuring element
(4-pixel radius Disk SE)

Erosion

Dilation
Binary Erosion

Structuring element

Structuring element

Structuring element
Binary Dilation

Structuring element
Combined Operations, e.g.
Erosion + Dilation = Opening
Image Segmentation
Image Segmentation

- **Image or Region Segmentation** is the process that generates a spatial description of the image as a set of specific parts, regions or objects.

- Image divided into groups of pixels that are homogenous for a given criterion
  - Contrast with surroundings: *edge-based segmentation*
    - Examples: Edge following, line or curve fitting, etc.
  - Similar properties, gray level, color, etc. measured by some local statistics such as means, variance, etc.: *region-based segmentation*
    - Examples: Region Growing, Region Splitting, Split and Merge, Relaxation, Watershed, etc.
  - Remark: Image Classification = Pixel-Based Method (e.g., Neural Networks)

- Segmented Output => Higher-Level Image Interpretation Process, part of Computer Vision or Image Understanding.
Edge Following

- Prior Processing: Edge Detection and Thresholding => Choose Starting Point above Threshold

- Various Methods for Edge Following, e.g.:
  - Line by Line Edge Following: Label all Contours
  - Contour Following
    1. Starting Point P₀ with Gradient Magnitude above Threshold
    2. In Neighborhood (4 or 8 pixels) Centered around P₀, Search in Circular Pattern => 1st point above Threshold and Gradient Direction Compatible with P₀
  - Graph Traversal
    • All Pixels whose Magnitude is above Threshold represent the Nodes of a Graph
    • Define a Cost Function Based on Gradient Magnitudes and Orientations
    • Contour Extraction Performed by Finding Path of Optimum Cost
Blood Platelets Extraction

Algorithm:
1. Histogram Equalization
2. Sobel Edge Detection
3. Dilation
4. Circular Edge Following
Line and Shape Detection

- Build upon Edge Detection results
  - Let us call \((G,D)\) the edge magnitude and direction images of an image \(I\)

- **Hough Transform for Line Detection**
  - Every line can be represented as: \(xcos\Theta + ysin\Theta = \rho\)
  - Create an Accumulator:
    - For each \((x,y)\) for which \(G > \) threshold, compute \(\rho = xcosD + ysinD\)
    - Increment the counter of \((\rho,D)\) in the accumulator
    - The pair \((\rho,\Theta)\) corresponding to the maximum counter represents the strongest line in the image

- Idea: **Strong Lines in \((x,y)\) space correspond to Maxima (or Peaks) in \((\rho,\Theta)\) space**
- Can be Used to extract other shapes, e.g. ellipses
Bootstrap Algorithm:
1. Sobel Edge Detection
2. Segment Orientation Histogram
3. Create Magnitudes Images for each “Orientation Region”
4. For each “Orientation Image”, Compute Hough Transform => Strongest Line
5. Label All Lines According to World Model
Line Detection for Road Following
(Autonomous Land Vehicle, ALV)

Feedforward Algorithm:
Strongest Orientation
Known from Bootstrap Step

1. Sobel Edge Detection
2. Segment Orientation
   Histogram
3. Create Magnitudes Images
   for Strongest “Orientation Region” from Bootstrap
4. For Strongest “Orientation Image”, Compute Hough
   Transform => Strongest Line
Region-Based Segmentation

- Methods
  - Region Growing
  - Region Splitting
  - Split and Merge
  - Relaxation
  - Watershed Method
  - Means Cut
  - etc.

- Parameters
  - Mean and Variance
  - Edge Magnitudes
  - Texture
    - Cooccurrence Matrix
    - Textural Edgeness
    - Filter Banks
    - Local Spatial Frequency Analysis, Gabor Filters and Wavelets
    - Mathematical Morphology
  - etc.
What is Texture?

- (Rosenfeld and Kak) “Visual Textures are complex visual patterns composed of entities, or subpatterns (textons), that have characteristic brightnesses, color, slopes, sizes, etc. Thus a texture can be regarded as a similarity grouping.”

- (Duraiswami) “Texture is something that repeats with variation”.

- Some Texture Measures:
  - Co-occurrence Matrix: Statistics Computed from Distribution of Gray Levels across the Image at Different Orientations
  - “Filter Banks”: Filtering Image with Various Linear Filters Corresponding to Multiple Patterns at Various Scales, e.g. Weighted of Gaussians at Different Scales
  - Gabor or Wavelets Filters, Steerable Pyramid (Simoncelli): Provide Local Spatial Frequency Analysis

http://www.ux.uis.no/~tranden/brodatz.html
Region-Based Segmentation

• Iterative Region Growing
  o First Iteration: Each pixel represents an individual region
  o Next Iteration: Regions are merged if the criterion for merging is satisfied (e.g., the variance of the pixel intensities in the merged region is below a given threshold)
    – Merged regions can be adjacent or not
    – One or several merges can happen at each iteration
  o Iterate until no more possible merging or until stopping criterion is satisfied, e.g., a minimum number of regions has been reached.
  o Successive Iterations can be represented by a tree structure where
    {Root: Complete Image; Leaves: Individual Pixels; Branches: Relations between Regions and Subregions}

• Remarks:
  o Iterative Region Splitting
    – Reverse process starting with entire image as one region
  o Split and Merge
    – Iterative Succession of splitting and growing regions based on separate criteria for splitting and merging
Region-Based Segmentation

Road Following Results
Region-Based Segmentation

Landsat Thematic Mapper Segmentation
(James Tilton/NASA GSFC)
Combining Regions and Edges

Landsat Thematic Mapper Segmentation

MasPar Application

- New Edge Image
- Extract Iteration Contours
- Compute Distance
- Find Best Iteration
- Exit

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Original Image | Canny Edges | Extracted Contours

02/20/08 Introduction to Image Processing
Image Modeling and Understanding
Understanding Images

• A-Priori Knowledge
  – Domain Knowledge
    o Medical
      – Radiology or Cytology, … If Cytology: Blood Cells, Cancer Cells, …
    o Remote Sensing
      – Space Science or Earth Science. If Earth Science: Agriculture, Change Detection (e.g., forest monitoring), Invasive Species, …
  – World Model or “Ground Truth”

• Based on “Low-Level and Intermediate-Level Processing”
  o Pixel Classification, Image Features, Grouping of Image Features, …

• “High-Level Processing”: Image Understanding or Computer Vision/Artificial Intelligence Techniques
    o Object Recognition (e.g., Crater, Boulder, Rock Detection, …)
    o Region Labeling (e.g., Trees, Water, Road, Buildings, …)
    o 3D World Modeling (e.g., Pose Estimation for AR&D, …)
Blood Platelets Classification

- A-Priori Knowledge
  - Blood Platelets Recognition after Freezing
  - Functional level related to Morphology and Texture

- Image Understanding

- Measurements:
  - Perimeter
  - Surface
  - Minimal Distance from Gravity Center to Contour
  - Maximal Distance from Gravity Center to Contour
  - Circularity Measure
  - Elongation Measures

- Classification by Decision Tree and Rule-Based System
Road Following

- A-Priori Knowledge
  - Road Networks
  - “Pencil of Lines” converging to a Vanishing Point

- Image Understanding
  - Classification of Lines into
    - “Left Road”
    - “Left Shoulder”
    - “Right Road”
    - “Right Shoulder”
    - “Center Road”
    - “Discarded”
Additional Reading

BOOKS:

ON LINE:
- http://www.dai.ed.ac.uk/CVonline/