Lecture 5
Image Characterization
ch. 4 of Machine Vision by Wesley E. Snyder & Hairong Qi

Spring 2012
BioE 2630 (Pitt) : 16-725 (CMU RI)
18-791 (CMU ECE) : 42-735 (CMU BME)

Dr. John Galeotti

Digital Images

- How are they formed?
- How can they be represented?
Image Representation

- Hardware
  - Storage
  - Manipulation
- Human
  - Conceptual
  - Mathematical

Iconic Representation

- What you think of as an image, ...
  - Camera
  - X-Ray
  - CT
  - MRI
  - Ultrasound
  - 2D, 3D, ...
  - etc
Iconic Representation

- And what you might not

<table>
<thead>
<tr>
<th>Range Image</th>
<th>Corresponding Intensity Image</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Range Image" /></td>
<td><img src="image2.png" alt="Intensity Image" /></td>
</tr>
</tbody>
</table>

Images from CESAR lab at Oak Ridge National Laboratory, Sourced from the USF Range Image Database: http://marathon.csee.usf.edu/range/Database.html Acknowledgement thereof requested with redistribution.

Functional Representation

- An Equation
  - Typically continuous
- Fit to the image data
  - Sometimes the entire image
  - Usually just a small piece of it
- Examples:
  - Biquadratic \( z = ax^2 + by^2 + cxy + dx + ey + f \)
  - Quadric \( 0 = ax^2 + by^2 + cz^2 + dxy + exz + fyz + gx + hy + iz + j \)
Linear Representation

- Unwind the image
  - "Raster-scan" it
- Entire image is now a vector
  - Now we can do matrix operations on it!
  - Often used in research papers

Probabilistic & Relational Representations

- Probability & Graphs
- Discussed later (if at all)

Spatial Frequency Representation

- Think “Fourier Transform”
- Multiple Dimensions!
- Varies greatly across different image regions
- High Freq. = Sharpness

- Steven Lehar’s details: [http://sharp.bu.edu/~slehar/fourier/fourier.html](http://sharp.bu.edu/~slehar/fourier/fourier.html)
Image Formation

- Sampling an analog signal
- Resolution
  - # Samples per dimension, OR
  - Smallest clearly discernable physical object
- Dynamic Range
  - # bits / pixel (quantization accuracy), OR
  - Range of measurable intensities
    - Physical meaning of min & max pixel values
    - light, density, etc.

Dynamic Range Example

(A slice from a Renal Angio CT: 8 bits, 4 bits, 3 bits, 2 bits)
FYI: Python Code for the Dynamic Range Slide

```python
import SimpleITK as sitk

# a processed slice from http://pubimage.hcuge.ch:8080/DATA/CENOPIX.zip
img = sitk.ReadImage('UpperChestSliceRenalAngioCT-Cenovix.tif')
out4 = sitk.Image(512,512,sitk.sitkUInt8)
out3 = sitk.Image(512,512,sitk.sitkUInt8)
out2 = sitk.Image(512,512,sitk.sitkUInt8)

y=0
while y<512:
x=0
while x<512:
  #print "img ",x,y,"=",img[x,y]
  out4[x,y] = (img[x,y] >> 4) << 4
  out3[x,y] = (img[x,y] >> 5) << 5
  out2[x,y] = (img[x,y] >> 6) << 6
  x = x + 1
  y = y + 1
```

An Aside: The Correspondence Problem

- **My Definition:**
  - Given two different images of the same (or similar) objects,
    - for any point in one image
      - determine the exact corresponding point in the other image
  - **Similar (identical?)** to registration
  - **Quite possibly,** it is THE problem in computer vision
Image Formation: Corruption

- There is an ideal image
  - It is what we are physically measuring
- No measuring device is perfect
  - Measuring introduces noise
    - \( g(x,y) = D(f(x,y)) \), where \( D \) is the distortion function
- Often, noise is additive and independent of the ideal image

\[
g(x,y) = f(x,y) * h(x,y) + n(x,y)
\]
The image as a surface

- Intensity → height
  - In 2D case, but concepts extend to ND
  - \( z = f(x, y) \)
- Describes a surface in space
  - Because only one \( z \) value for each \( x, y \) pair
  - Assume surface is continuous (interpolate pixels)

Isophote

- “Uniform brightness”
  - \( C = f(x, y) \)
- A curve in space (2D) or surface (3D)
- Always perpendicular to image gradient
  - Why?
Isophotes & Gradient

- Isophotes are like contour lines on a topography (elevation) map.
- At any point, the gradient is always at a right angle to the isophote!

Ridges

- One definition:
  - Local maxima of the rate of change of gradient direction
  - Sound confusing?
  - Just think of ridge lines along a mountain
  - If you need it, look it up
    - Snyder references Maintz
Medial Axis

- Skeletal representation
- Defined for binary images
  - This includes segmented images!
- “Ridges in scale-space”
  - Details have to wait (ch. 9)

Neighborhoods

- Terminology
  - 4-connected vs. 8-connected
  - Side/Face-connected vs. vertex-connected
  - Maximally-connected vs. minimally-connected (ND)
- Connectivity paradox
  - Due to discretization
- Can define other neighborhoods
  - Adjacency not necessarily required

Is this pixel connected to the outside?
Is this shape closed?
Curvature

- Compute curvature at every point in a (range) image
  - (Or on a segmented 3D surface)
- Based on differential geometry
- Formulas are in your book
- 2 scalar measures of curvature that are invariant to viewpoint, derived from the 2 principal curvatures, $(K_1, K_2)$:
  - Mean curvature (arithmetic mean)
  - Gauss curvature (product)
    - $=0$ if either $K_1=0$ or $K_2=0$