CS443: Digital Imaging and Multimedia
Histograms of Digital Images

Spring 2008
Ahmed Elgammal
Dept. of Computer Science
Rutgers University

Outlines

- Digitizing images
- Image histograms and its applications

Sources:
- Burger and Burge “Digital Image Processing” Ch. 4
Digitizing images

- What is projected on the image plan is a distribution of light energy that is:
  - Two-dimensional
  - Time-dependent
  - Continuous
- To go digital:
  - Spatial sampling
  - Temporal sampling
  - Quantization of pixel values

Digital image: two-dimensional, ordered matrix of integers, i.e., a two-dimensional function of integer coordinates $N \times N$ that maps a range of image values $P$.

$$I(u, v) \in \mathbb{P} \quad \text{and} \quad u, v \in \mathbb{N}.$$
- Image resolution: number of image elements per measurement.
- Image coordinate system

<table>
<thead>
<tr>
<th>Grayscale (Intensity Images):</th>
<th>Class</th>
<th>Bits/Pix.</th>
<th>Range</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0..1</td>
<td>Binary image: document, illustration, fax</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>0..256</td>
<td>Universal: photo, scan, print</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>0..4096</td>
<td>High quality: photo, scan, print</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>0..16383</td>
<td>Professional: photo, scan, print</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>18</td>
<td>0..65536</td>
<td>Highest quality: medicine, astronomy</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Color Images:</th>
<th>Class</th>
<th>Bits/Pix.</th>
<th>Range</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>24</td>
<td>[0..255]^3</td>
<td>RGB, universal: photo, scan, print</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>[0..4096]^3</td>
<td>RGB, high quality: photo, scan, print</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>[0..16383]^3</td>
<td>RGB, professional: photo, scan, print</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>[0..255]^4</td>
<td>CMYK, digital prepress</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Special Images:</th>
<th>Class</th>
<th>Bits/Pix.</th>
<th>Range</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>2.27956..2.37167</td>
<td>Whole numbers pos./neg., increased range</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>32</td>
<td>±3.4 x 10^30</td>
<td>Floating point: medicine, astronomy</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>64</td>
<td>±1.6 x 10^31</td>
<td>Floating point: internal processing</td>
<td></td>
</tr>
</tbody>
</table>
Image Histograms

- Histograms are used to depict image statistics in an easily interpreted visual format
- Useful during image capturing: now already in digital cameras
- Used to improve the visual appearance of an image
- Can also be used to determine what type of processing has been applied to an image.

- Image histogram: describes the frequency of the intensity values that occur in an image
Histograms don’t encode information about the spatial arrangement of pixels in the image.

We cannot reconstruct an image given only its histogram.

- Histograms don’t encode information about the spatial arrangement of pixels in the image.
- We cannot reconstruct an image given only its histogram.
Interpreting Histograms

- Histograms depict problems that originate during image acquisition
  - Exposure, contrast, dynamic range
- Histograms can be used to detect a wide range of image defects: saturation, spikes and gaps, impact of image compression

![Histograms and Exposure](image)

Histograms and Exposure

(a) (b) (c)
Histogram and Contrast

Dynamic Range

Dynamic Range: the number of distinct pixel value in an image
Detecting Image Defects

- There is no ideal or optimal histogram shape. It depends on the image and on the application.
- Image Defects:
  - Saturation: the illumination values lying outside of the sensor’s range are mapped to its maximum or minimum values: spike at the tails.
  - Spikes and Gaps in manipulated images. Why?
  - Impact of image compression.

- Histograms show the impacts of image compression.
- Ex: in GIF compression, the dynamic range is reduced to only few intensities (quantization).
- Ex: JPEG compression on a line graphics.
Computing Histograms

public class Compute_Histogram implements PlugInFilter {
    public int setup(String arg, ImagePlus imp) {
        return DOES_8G + NO_CHANGES;
    }
    public void run(ImageProcessor ip) {
        int[] X = new int[256]; // histogram array
        int w = ip.getWidth();
        int h = ip.getHeight();
        for (int y = 0; y < h; y++) {
            for (int x = 0; x < w; x++) {
                int i = ip.getPixel(x, y);
                X[i] = X[i] + 1;
            }
        }
        // Histogram X[] can now be used
    }
} // end of class Compute_Histogram

- Histograms of images with more than 8 bits:
  - Binning

\[ h(j) = \text{card}\{\{u, v\} | a_j \leq I(u, v) < a_{j+1}\} \quad \text{for } 0 \leq j < B \]

\[ a_j = j \cdot \frac{K}{B} = j \cdot k_B \]

- Ex: B=256 for 14 bit image
  - K=16384, bin width = 64
For color images, two kinds of histograms:
- Intensity histogram
- Individual Color Channel Histograms

Both provide useful information about lighting, contrast, dynamic range and saturation effects for individual color components.

They provide no information about the actual color distribution!
Cumulative Histograms

\[ H(i) = \sum_{j=0}^{i} h(j) \quad \text{for} \quad 0 \leq i < K \]

\[ H(i) = \begin{cases} h(0) & \text{for} \quad i = 0 \\ H(i-1) + h(i) & \text{for} \quad 0 < i < K \end{cases} \]

\[ H(K - 1) = \sum_{j=0}^{K-1} h(j) = M \cdot N \]