Image processing

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Pre-digitization image

What is an image before you digitize it?

- Continuous range of wavelengths
- 2-dimensional extent
- Continuous range of power at each point

Brightness images

To simplify, consider only a brightness image

- Two-dimensional (continuous range of locations)
- Continuous range of brightness values

This is equivalent to a two-dimensional function over a plane
**An image as a surface**

**Discretization**

**Sampling strategies**
- Spatial sampling
  - How many pixels?
  - What arrangement of pixels?
- Brightness sampling
  - How many brightness values?
  - Spacing of brightness values?
- For video, also the question of time sampling.

**Signal quantization**

Goal: determine a mapping from a continuous signal (e.g. analog video signal) to one of $K$ discrete (digital) levels.

**Quantization**

$I(x,y) =$ continuous signal: $0 \leq I \leq M$

Want to quantize to $K$ values $0, 1, ..., K-1$

$K$ usually chosen to be a power of 2:

<table>
<thead>
<tr>
<th>$K$</th>
<th>#Levels</th>
<th>#Bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>32</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>64</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>128</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>256</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

Mapping from input signal to output signal is to be determined.

Several types of mappings: uniform, logarithmic, etc.
**Choice of K**

Uniform sampling divides the signal range [0-M] into \( K \) equal-sized intervals. The integers 0,...,\( K-1 \) are assigned to these intervals. All signal values within an interval are represented by the associated integer value. Defines a mapping:

- **False contours problem**
  - "Dithering" adds random noise to reduce false contours
  - original image
  - 16 colors
  - with random noise

- **Choice of the function: uniform**
  - Uniform sampling divides the signal range [0-M] into \( K \) equal-sized intervals.
  - The integers 0,...,\( K-1 \) are assigned to these intervals.
  - All signal values within an interval are represented by the associated integer value.
  - Defines a mapping:

  ![Quantization Level vs. Signal Value](https://en.wikipedia.org/wiki/Dither)
Logarithmic quantization

Signal is: \( \log I(x,y) \)
Effect is:

Detail enhanced in the low signal values at expense of detail in high signal values.

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Color displays

Given a 24 bit color image (8 bits for R, G, B)

- Turn on 3 subpixels with power proportional to RGB values

A single pixel.

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“White” text on color display

A single pixel.
8 bit image: 256 different values.

Simplest way to display: map each number to a gray value:

- 0 → (0.0, 0.0, 0.0) or (0,0,0)
- 1 → (0.0039, 0.0039, 0.0039) or (1,1,1)
- 2 → (0.0078, 0.0078, 0.0078) or (2,2,2)
- ...
- 255 → (1.0, 1.0, 1.0) or (255,255,255)

This is called a grayscale mapping.

We can also use other mappings:

- 0 → (17, 25, 89)
- 1 → (45, 32, 200)
- ...
- 255 → (233,1,4)

These are called lookup tables.
Fun with Matlab

Contrast enhancement

Two methods:
- Normalize the data (contrast stretching)
- Transform the data (histogram equalization)

Contrast stretching

Enhancing images

What can we do to “enhance” an image after it has already been digitized?
- We can make the information that is there easier to visualize.
- We can guess at data that is not there, but we cannot be sure, in general.
### Contrast stretching

- **Basic idea:** scale the brightness range of the image to occupy the full range of values

  \[ I \leftarrow \text{floor} \left( \frac{I - \min(I)}{\max(I) - \min(I)} \times 255 \right) \]

- **Issues:**
  - What happens if there is one bright pixel?
  - What happens if there is one dark pixel?

### Matlab demo

- `imcontrast()` — contrast stretching

### Histogram equalization

- Make the distribution close to the uniform distribution

Let,

\[ p_n = \frac{\text{number of pixels with intensity } n}{\text{total number of pixels}} \quad n \in \{0, L - 1\} \]

If each intensity value \( k \) is mapped to \( T(k) \)

\[ T(k) = \text{floor} \left( \left( L - 1 \right) \sum_{n=0}^{k} p_n \right) \]

Then \( T(k) \) is roughly a uniform distribution (why?)

- [Wikipedia](https://en.wikipedia.org/wiki/Histogram_equalization)
Histogram equalization

source: http://www.math.uci.edu/icamp/courses/math77c/demos/hist_eq.pdf