What is an image before we digitize it?

- Continuous range of wavelengths.
- 2-dimensional extent
- Continuous range of power at each point.
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 the plane.
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An image as a surface
How do we represent this continuous surface efficiently?
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.
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Projection through a pixel

Digitized 35mm Slide or Film

Central Projection Ray

Image irradiance is the average of the scene radiance over the area of the surface intersecting the solid angle!
Goal: determine a mapping from a continuous signal (e.g. analog video signal) to one of K discrete (digital) levels.

\[ I(x,y) = 0.1583 \text{ volts} \]

= ???? Digital value
- $I(x,y)$ = continuous signal: $0 \leq I \leq M$
- Want to quantize to $K$ values $0, 1, \ldots, K-1$
- $K$ 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.
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Choice of K

Original

Linear Ramp

K=2

K=4

K=16

K=32
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Choice of K

K=2 (each color)

K=4 (each color)
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:
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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Logarithmic Quantization

Original

Logarithmic Quantization

Quantization Curve
Given a 24-bit color image (8 bits each for R, G, B)
- Turn on 3 subpixels with power proportional to RGB values:

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

- Turn on 3 subpixels with power proportional to RGB values:

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“White” text on a color display

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See movie.
8 bit image: 256 different values.

- Simplest way to display: map each number to a gray value:
  - 0-> (0.0, 0.0, 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 image.
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Lookup tables

- `im (24 bits)`
  - "true color"

- `im8 (8 bits)`
  - gray color look up table

Mathematical code examples:

```
grayscale = im2gray(im);  
ans = 
    428    500     3
```

```
>> imshow(im);  
>> size(im)
ans =
    428    500
```
We can also use other mappings:

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

These are called look up tables.
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More look up tables.
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.
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Can we “enhance” an image after digitization?
Brightness Equalization

Two methods:
- Change the data (histogram equalization)
- Use a look up table (brightness or color remapping)
An unequalized image
An unequalized image

Corresponding histogram
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Histogram Equalization

An unequalized image

Corresponding histogram

Same image after histogram equalization

Corresponding histogram
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Brightness Equalization

Two methods:
- Change the data (histogram equalization).
- Use a look up table (brightness equalization).

![Corresponding histogram](image_with_arrows.png)
Map lowest value in image to black, highest value to white.

- 0 -> (0, 0, 0)
- 1 -> (0, 0, 0)
- 2 -> (0, 0, 0)
- 3 -> (0, 0, 0)
- ...
- 130 -> (0, 0, 0)
- 131 -> (.01, .01, .01)
- 132 -> (.02,.02,.02)
- ...
- 229 -> (1,1,1)
- 230 -> (1,1,1)
- ...
- 255 -> (1, 1, 1)
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Brightness Equalization

An unequalized image

An equalized image
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Mixed Pixel Problem
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Mixed Pixel Problem
Typical recognition problems:
- Recognize letters and words
- Recognize people
- Recognize classes of objects
- Recognize places
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Recognizing Text
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Recognizing People
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Classes of objects

- Labrador Retriever
- Cartoon dog
- Border Collie with a stick
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Recognizing places
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Recognizing Handwritten Digits
Supervised learning:
- Formalization of the idea of learning from examples.

2 elements:
- Training data
- Test data

Training data:
- Data in which the class has been identified.
  - Example: This is a “three”.

Test data:
- Data which the algorithm is supposed to identify.
- What is this?
Formally:

- n training data pairs:
  \[(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)\]
  
x’s are “observations”
y’s are the class labels

- m test data samples:
  \[(x_{n+1}, x_{n+2}, \ldots, x_{n+m})\]