Point Operations

- How do gray values relate to brightness?
- Quantization
- Weber’s Law
- Gamma characteristic
- Adjusting brightness and contrast
Quantization: how many bits per pixel?

<table>
<thead>
<tr>
<th>Bits</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td><img src="image1.png" alt="8 bits image" /></td>
</tr>
<tr>
<td>5</td>
<td><img src="image2.png" alt="5 bits image" /></td>
</tr>
<tr>
<td>4</td>
<td><img src="image3.png" alt="4 bits image" /></td>
</tr>
<tr>
<td>3</td>
<td><img src="image4.png" alt="3 bits image" /></td>
</tr>
<tr>
<td>2</td>
<td><img src="image5.png" alt="2 bits image" /></td>
</tr>
<tr>
<td>1</td>
<td><img src="image6.png" alt="1 bit image" /></td>
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</tbody>
</table>

"Contouring"
How many gray levels are required?

- Contouring is most visible for a ramp
  - 32 levels
  - 64 levels
  - 128 levels
  - 256 levels

- Digital images typically are quantized to 256 gray levels.
Brightness discrimination experiment

Visibility threshold

\[
\frac{\Delta I}{I} \approx 1\ldots2\%
\]

„Weber fraction“
„Weber’s Law“

Note: \( I \) is luminance, measured in \( cd/m^2 \)

Can you see the circle?

Human brightness perception is uniform in the \( \log(I) \) domain („Fechner’s Law“)
Contrast ratio without contouring

- Luminance ratio between two successive quantization levels at visibility threshold

\[
\frac{I_{\text{max}}}{I_{\text{min}}} = \left(1 + K_{\text{Weber}}\right)^{N-1}
\]

- For \( K_{\text{Weber}} = 0.01 \ldots 0.02 \)  
  \( N = 256 \)  
  \( I_{\text{max}} / I_{\text{min}} = 13 \ldots 156 \)

- Typical display contrast ratio
  - Modern flat panel display in dark room 1000:1
  - Cathode ray tube 100:1
  - Print on paper 10:1
Gamma characteristic

- Cathode ray tubes (CRTs) are nonlinear

- Cameras contain $\gamma$-predistortion circuit

\[ U \sim I^{1/\gamma} \]

\[ I \sim U^\gamma \]

$\gamma = 2.0 \ldots 2.3$
log vs. $\gamma$-predistortion

- Weber’s Law suggests uniform perception in the $\log(I)$ domain
- Similar enough for most practical applications

\[ U \sim \log(I) \]
\[ U \sim I^{1/\gamma} \]

\[ \frac{I_{\text{max}}}{I_{\text{min}}} = 100 \]
A perturbation of the gray values of a digital image (think $U$) leads to a particularly large perturbation of the displayed luminance when occurring in a part of the image that is

(a) dark                               (b) mid-grey                   (c) bright

$\gamma = 2.0 \ldots 2.3$

$I \sim U^\gamma$
Brightness adjustment by intensity scaling

Scaling in the $\gamma$-domain is equivalent to scaling in the linear luminance domain

$$I \sim (a \cdot f[x,y])^\gamma = a^\gamma \cdot (f[x,y])^\gamma$$

... same effect as changing camera exposure time.
Contrast adjustment by changing $\gamma$

Original image

$\gamma$ increased by 50%

$f[x,y]$

$a \cdot (f[x,y])^{\gamma}$

with $\gamma = 1.5$

. . . same effect as using a different photographic film . . .
Contrast adjustment by changing $\gamma$

Original ramp $\gamma_0$

Scaling chosen to approximately preserve brightness of mid-gray

Scaled ramp 0.5 $\gamma_0$

Scaled ramp 2 $\gamma_0$