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>![Image with 8 bits]</td>
</tr>
<tr>
<td>5</td>
<td>![Image with 5 bits]</td>
</tr>
<tr>
<td>4</td>
<td>![Image with 4 bits]</td>
</tr>
<tr>
<td>3</td>
<td>![Image with 3 bits]</td>
</tr>
<tr>
<td>2</td>
<td>![Image with 2 bits]</td>
</tr>
<tr>
<td>1</td>
<td>![Image with 1 bit]</td>
</tr>
</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

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

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

- 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

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

\[ \gamma = 2.0 \ldots 2.3 \]
Weber’s Law suggests uniform perception in the $\log(I)$ domain.

Similar enough for most practical applications.
**Photographic film**

Luminance

\[
I = I_0 \cdot 10^{-d} \\
= I_0 \cdot 10^{(-\gamma \log E + d_0)} \\
= I_0 \cdot 10^{-d_0} \cdot E^\gamma
\]

- **Hurter & Driffield curve (H&D curve)** for photographic negative
- \( \gamma \) measures film contrast
  - General purpose films
    \( \gamma = -0.7 \ldots -1.0 \)
  - High-contrast films
    \( \gamma = -1.5 \ldots -10 \)
  - Lower speed films tend to have higher absolute \( \gamma \)
A perturbation of the gray values of a digital image 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
\[ \gamma = 2.0 \ldots 2.3 \]
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 $\gamma_0$

Scaled ramp $2 \gamma_0$

Scaled ramp $0.5 \gamma_0$

Scaling chosen to approximately preserve brightness of mid-gray
Contrast adjustment by changing $\gamma$

Interactive applet
https://graphics.stanford.edu/courses/cs178/applets/gamma.html