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?

8 bits
3 bits

5 bits
2 bits

4 bits
1 bit

„Contouring“
How many gray levels are required?

- Contouring is most visible for a ramp
- 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 \( K_{\text{Weber}} = 0.01 \cdots 0.02 \) \( N = 256 \) \( I_{\text{max}} / I_{\text{min}} = 13 \cdots 156 \)

- Typical display contrast ratio
  - Modern flat panel display in dark room 1000:1
  - Cathode ray tube 100:1
  - Print on paper 10:1
What luminance level would appear (to a human) to be half-way between 1 cd/m² and 100 cd/m²?

(a) 10 cd/m² (b) 50.5 cd/m² (c) 70.7 cd/m²

For a flat panel display with a 1000:1 contrast ratio how many bits are needed to display images without contouring artifacts?

(a) 7 bits (b) 8 bits (c) 10 bits (d) 12 bits
Gamma characteristic

- Cathode ray tubes (CRTs) are nonlinear

- Cameras contain $\gamma$-predistortion circuit

\[ I \sim U^\gamma \]

\[ U \sim I^{1/\gamma} \]
log vs. $\gamma$-predistortion

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

$$U \sim \log(I)$$

$$U \sim I^{1/\gamma}$$

$$\frac{I_{\text{max}}}{I_{\text{min}}} = 100$$
Photographic film

Luminance

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

\( \gamma \) 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 small change in luminance leads to a particularly large increase in the output signal of a camera with a built-in gamma pre-distortion circuit when occurring in a part of the image that is

(a) dark  (b) mid-grey  (c) bright
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 $f[x,y]$  
$\gamma$ increased by 50% $a \cdot (f[x,y])^{\gamma}$  
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 $\gamma_0$
An image is taken by a camera with a gamma of 1/3.0 and displayed with a gamma of 2.0. What is the overall effect?

(a) Contrast is reduced  (b) No noticeable effect  (c) Contrast is enhanced