

Point Operations

- How do gray values relate to brightness?
- Quantization
- Weber's Law
- Gamma characteristic
- Adjusting brightness and contrast

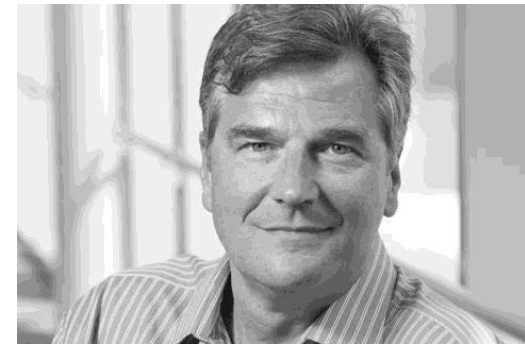
Quantization: how many bits per pixel?



8 bits



5 bits



4 bits



3 bits



2 bits



1 bit

„Contouring“



How many gray levels are required?

- Contouring is most visible for a ramp

32 levels



64 levels



128 levels

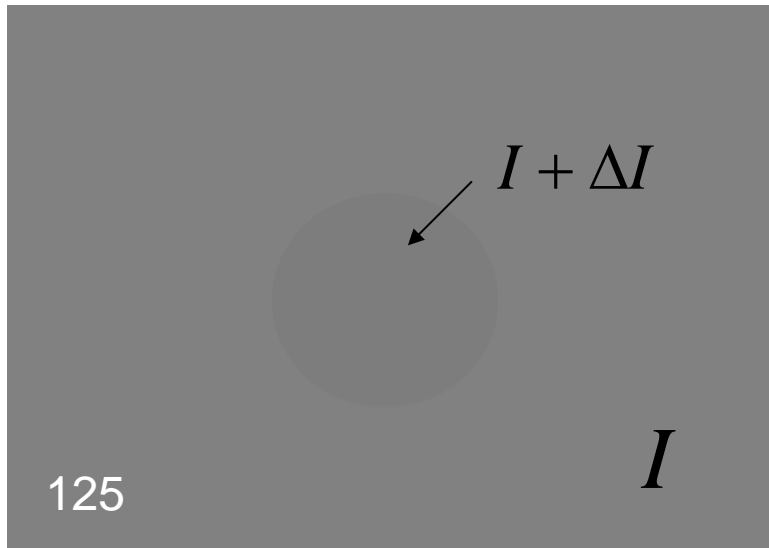


256 levels



- Digital images typically are quantized to 256 gray levels.

Brightness discrimination experiment



Visibility threshold

$$\Delta I / I \approx 1 \dots 2\%$$

„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

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

- For $K_{Weber} = 0.01 \dots 0.02$ $N = 256$ $I_{\max} / I_{\min} = 13 \dots 156$
- 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

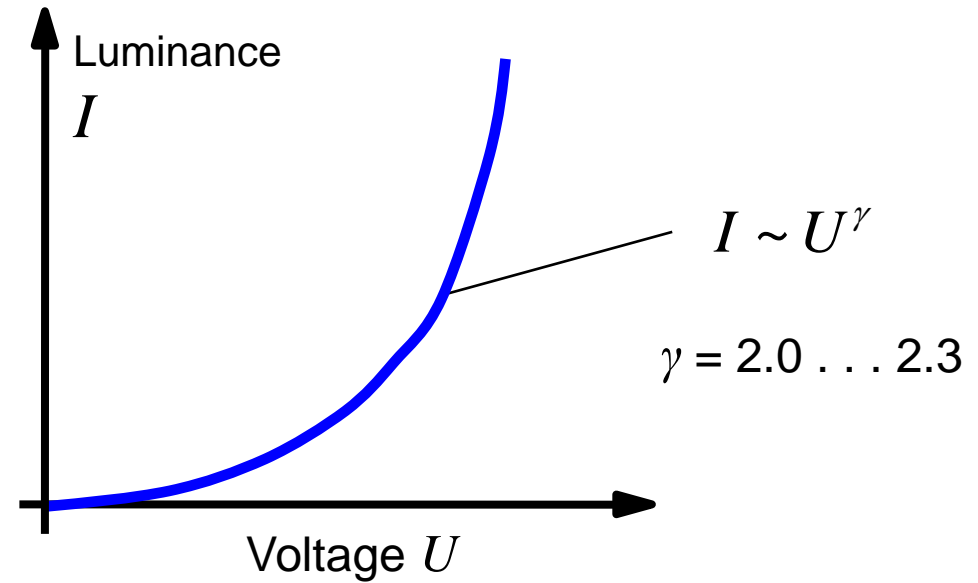
(b) 8 bits

(c) 10 bits

(d) 12 bits

Gamma characteristic

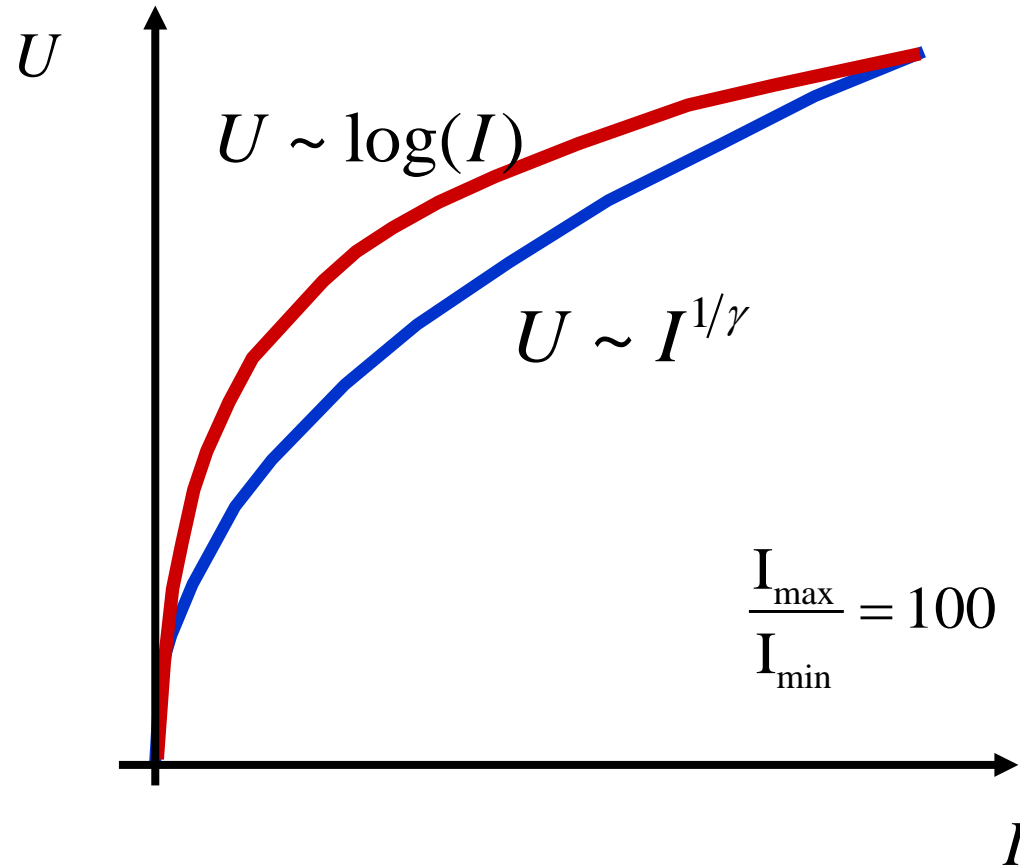
- Cathode ray tubes (CRTs) are nonlinear



- Cameras contain γ -predistortion circuit

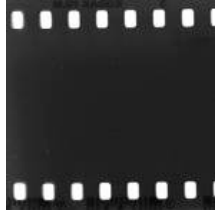
$$U \sim I^{1/\gamma}$$

log vs. γ -predistortion



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

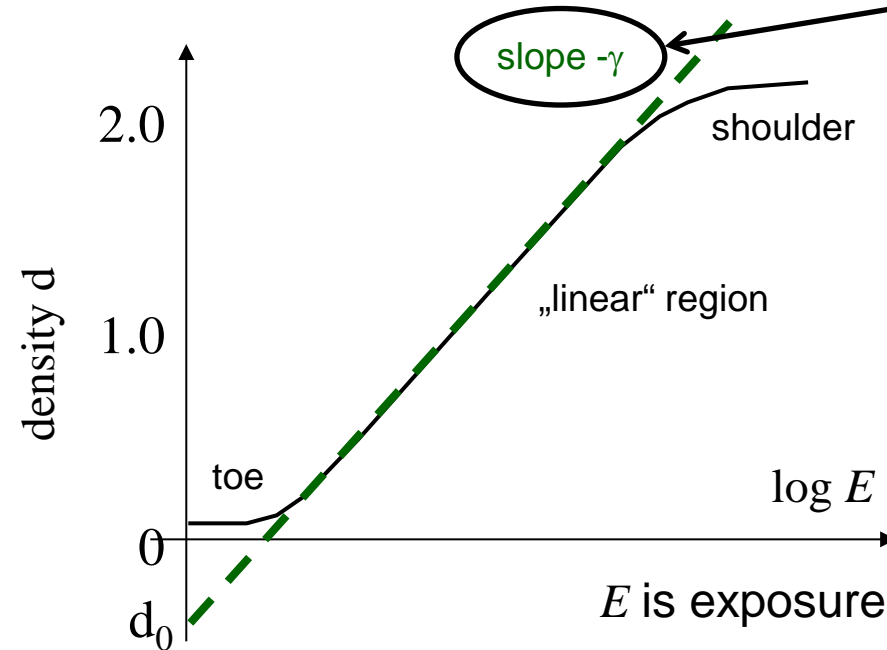
Photographic film



Luminance

$$\begin{aligned} I &= I_0 \cdot 10^{-d} \\ &= I_0 \cdot 10^{-(-\gamma \log E + d_0)} \\ &= I_0 \cdot 10^{-d_0} \cdot E^\gamma \end{aligned}$$

Hurter & Driffeld curve (H&D curve)
for photographic negative



γ measures film contrast

- General purpose films
 $\gamma = -0.7 \dots -1.0$
- High-contrast films
 $\gamma = -1.5 \dots -10$
- Lower speed films tend to have higher absolute γ

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

Original image



$f[x, y]$

Scaled image



$a \cdot f[x, y]$

Scaling in the γ -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 γ

Original image



$$f[x, y]$$

γ increased by 50%



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

with $\gamma = 1.5$

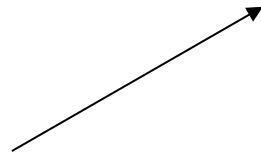
... same effect as using a different photographic film ...



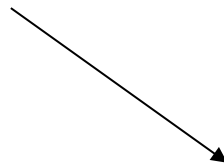
Contrast adjustment by changing γ



Scaled ramp $2 \gamma_0$



Original ramp γ_0



Scaling chosen to
approximately preserve
brightness of mid-gray



Scaled ramp $0.5 \gamma_0$

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

