

# Point Operations

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

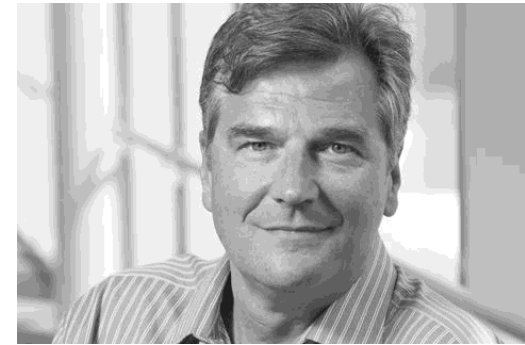
# Quantization: how many bits per pixel?



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

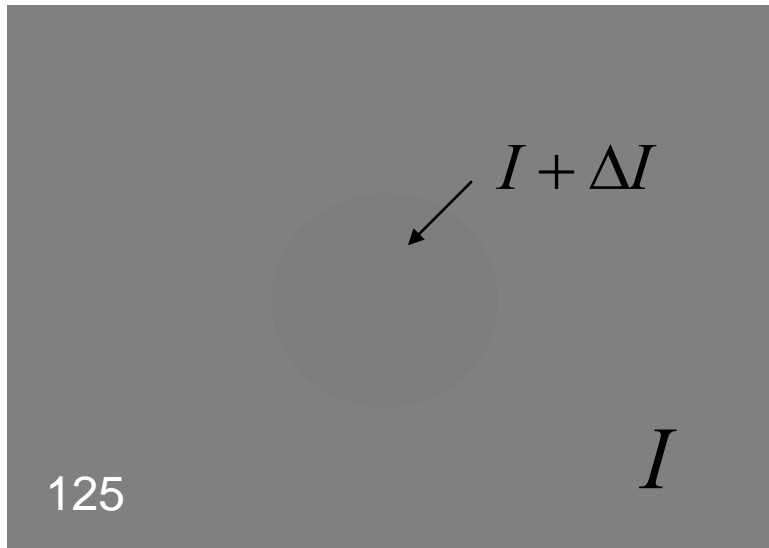


256 levels



- 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

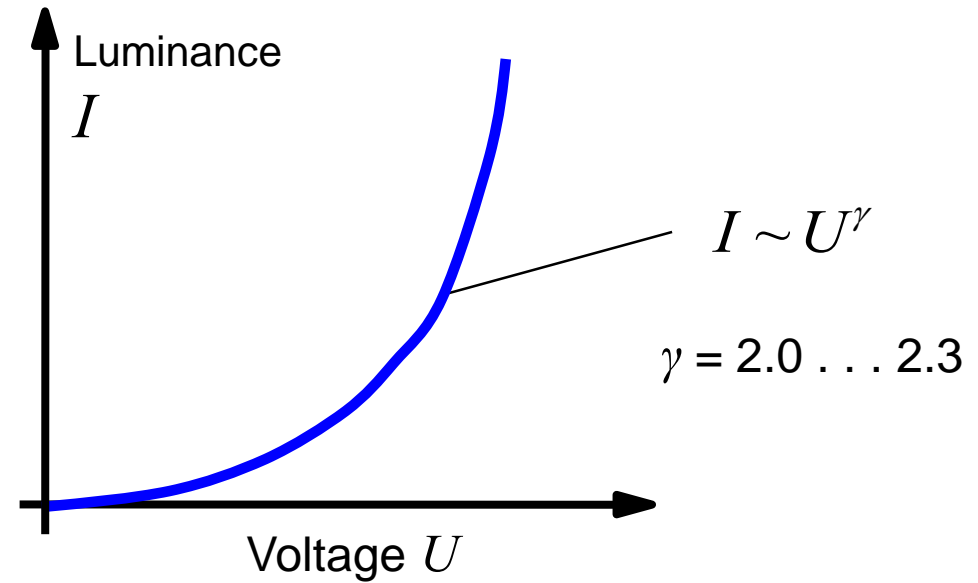
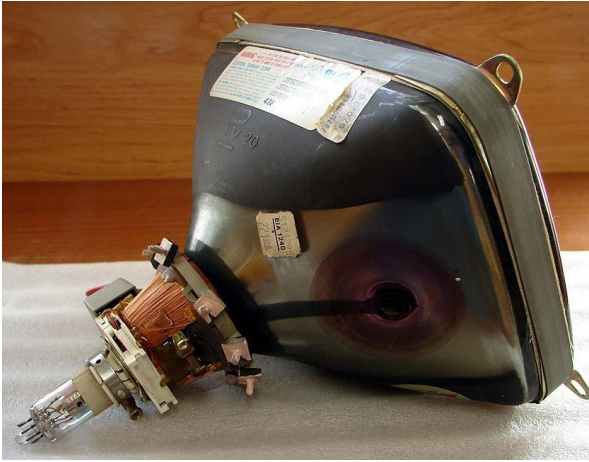
- Luminance ratio between two successive quantization levels at visibility threshold

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

- 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

# Gamma characteristic

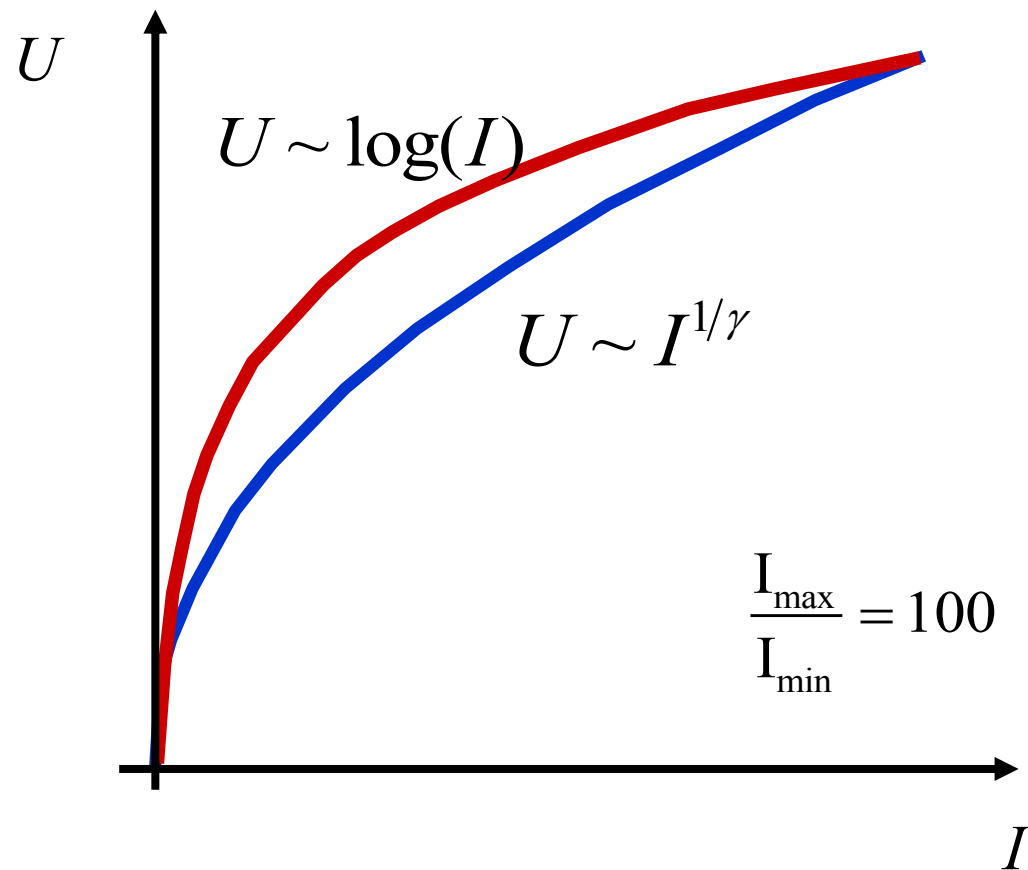
- Cathode ray tubes (CRTs) are nonlinear



- Cameras contain  $\gamma$ -predistortion circuit

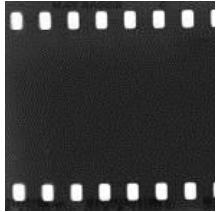
$$U \sim I^{1/\gamma}$$

# log vs. $\gamma$ -predistortion



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

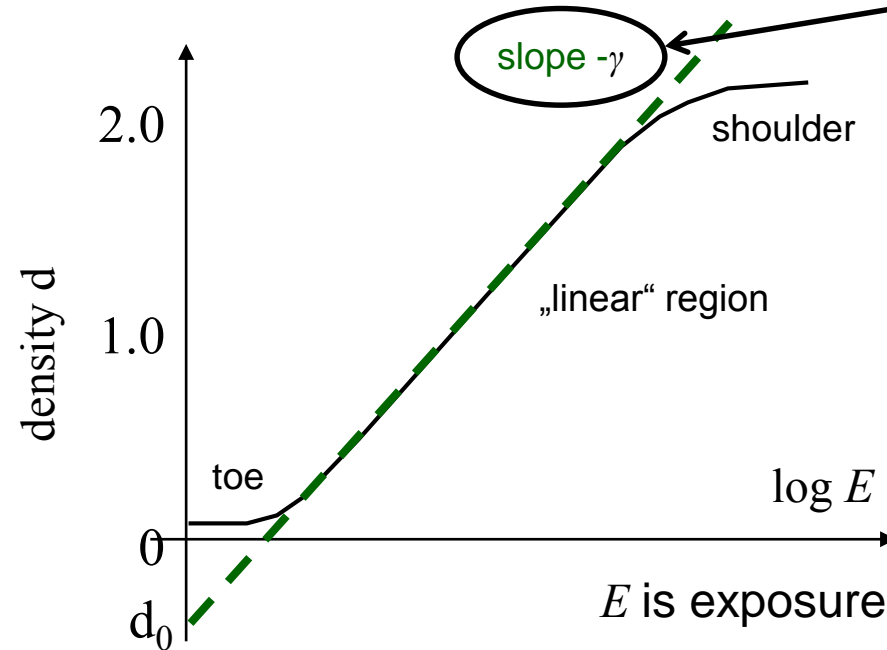
# Photographic film



## 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



$\gamma$  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  $\gamma$

# Brightness adjustment by intensity scaling

Original image



$f[x,y]$

Scaled image



$a \cdot f[x,y]$

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

$$I \sim (a \times f[x,y])^g = a^g \times (f[x,y])^g$$

. . . same effect as changing camera exposure time.



# Contrast adjustment by changing $\gamma$

Original image



$$f[x, y]$$

$\gamma$  increased by 50%



$$a \times (f[x, y])^g$$

with  $g = 1.5$

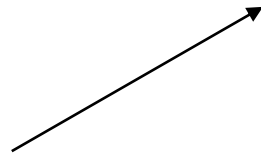
. . . same effect as using a different photographic film . . .



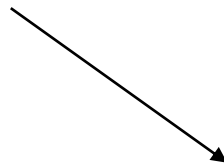
# Contrast adjustment by changing $\gamma$



Scaled ramp  $2 \gamma_0$



Original ramp  $\gamma_0$



Scaling chosen to  
approximately preserve  
brightness of mid-gray



Scaled ramp  $0.5 \gamma_0$