

Point Operations

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

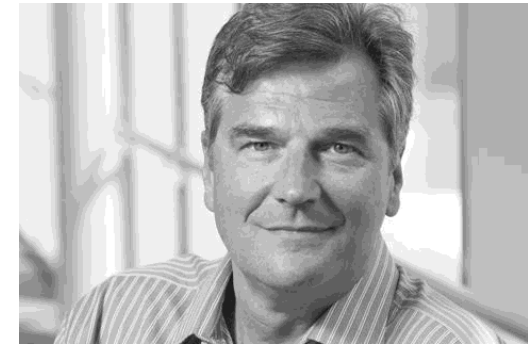
Quantization: how many bits per pixel?



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

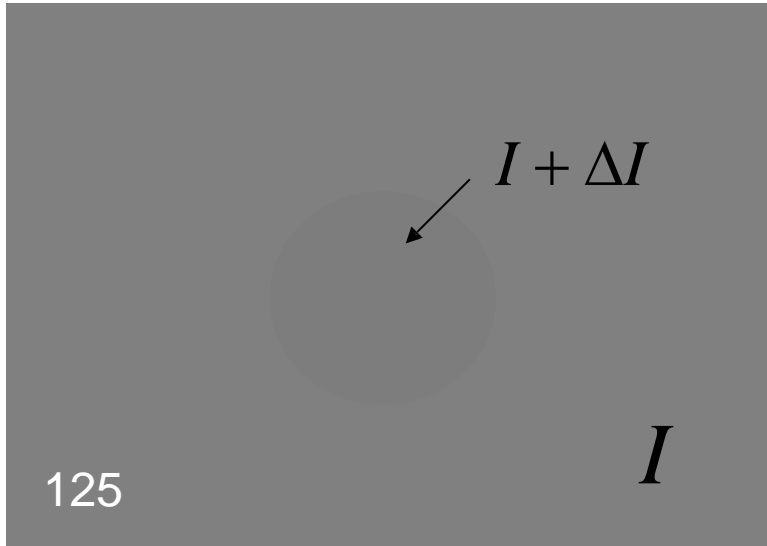


256 levels



- 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

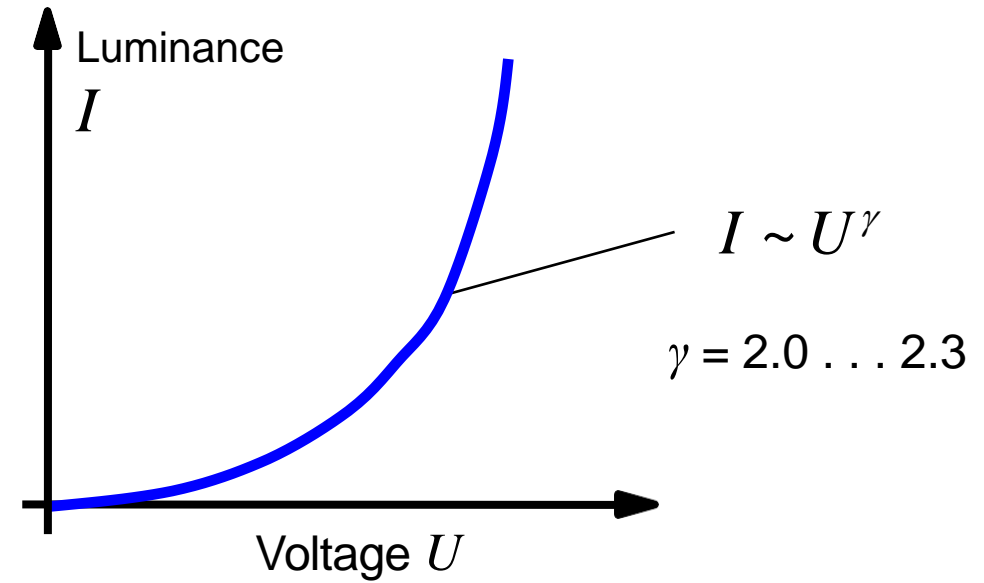
- Luminance ratio between two successive quantization levels at visibility threshold

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

- 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

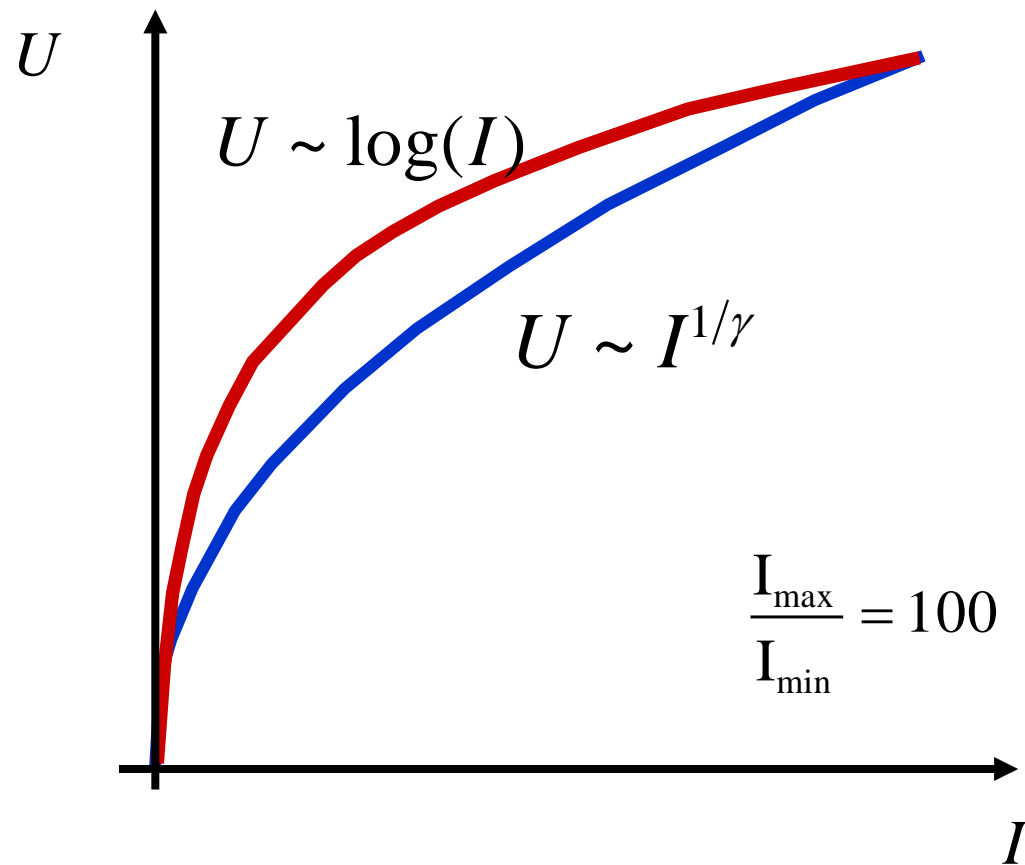
- Cathode ray tubes (CRTs) are nonlinear



- Cameras contain 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

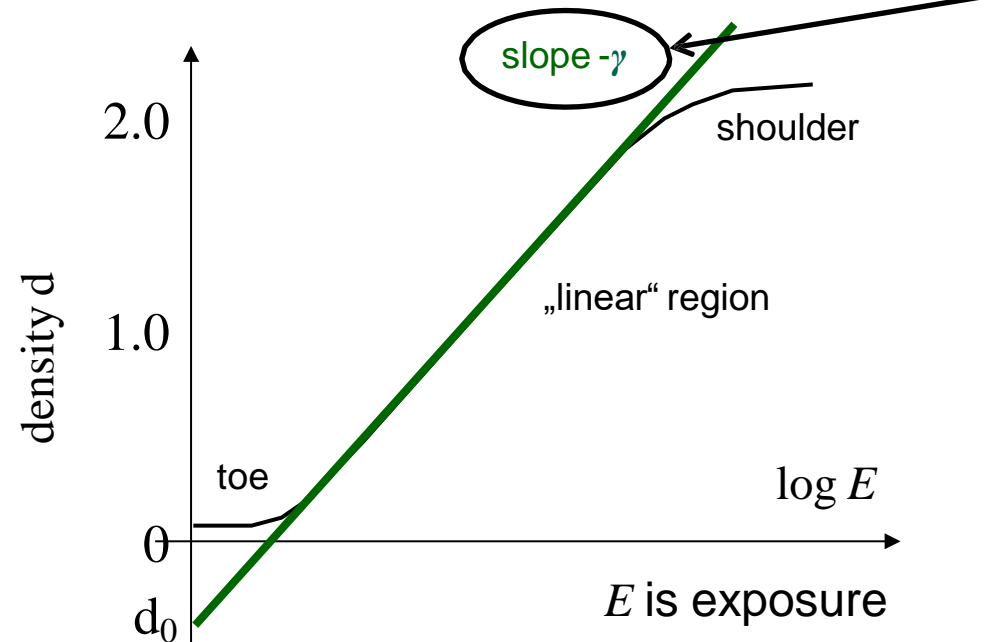
Photographic film



Luminance

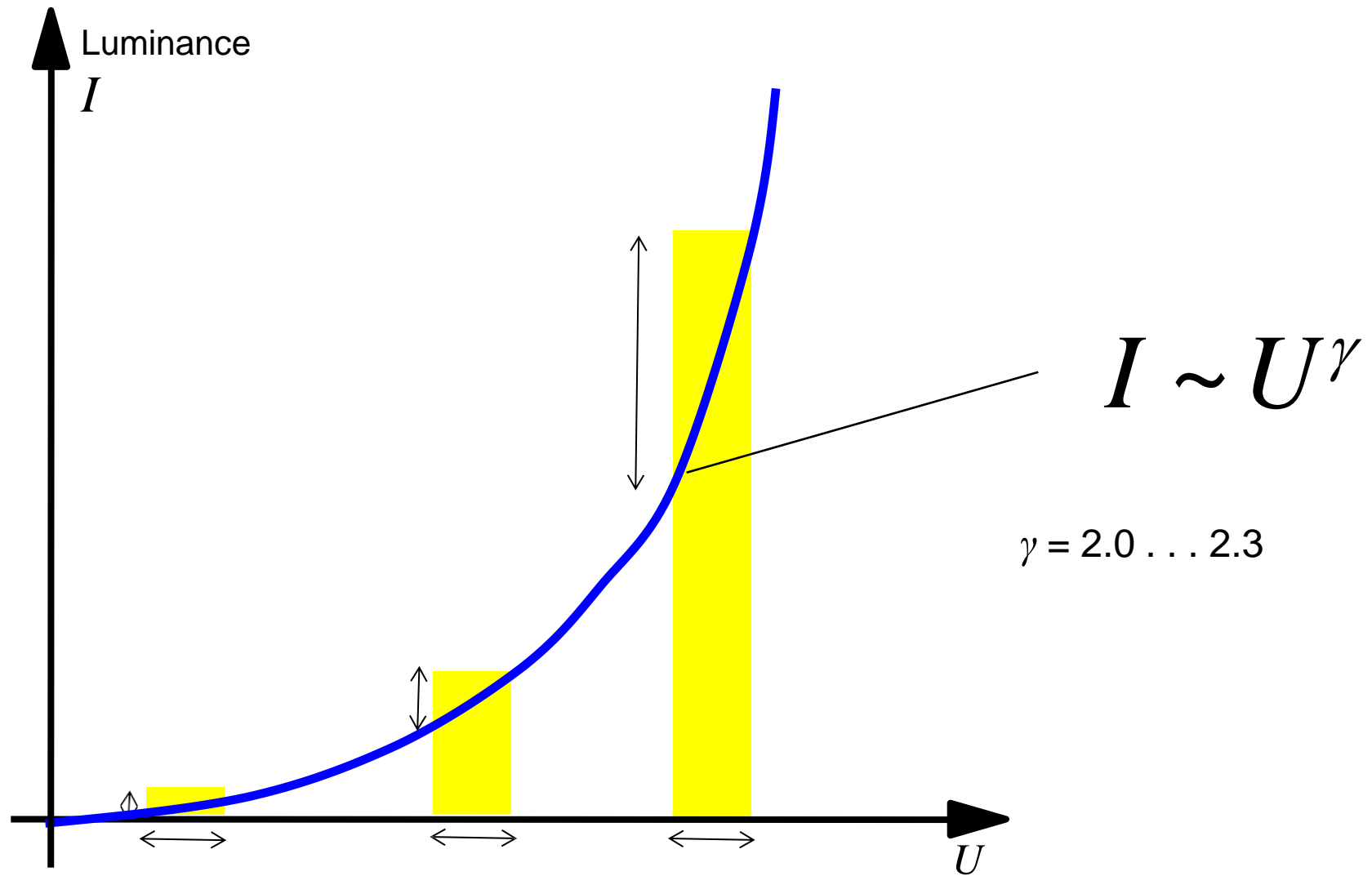
$$\begin{aligned} I &= I_0 \cdot 10^{-d} \\ &= I_0 \cdot 10^{-(\gamma \log E + d_0)} \\ &= I_0 \cdot 10^{-d_0} \cdot E^{-\gamma} \end{aligned}$$

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



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 $2 \gamma_0$

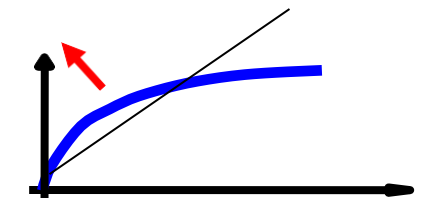
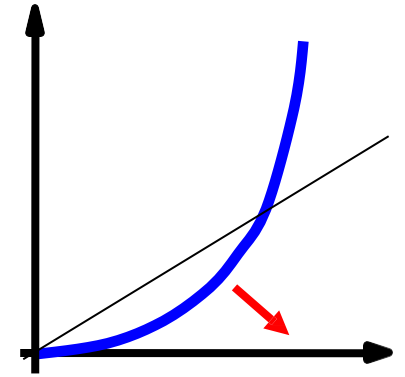


Original ramp γ_0

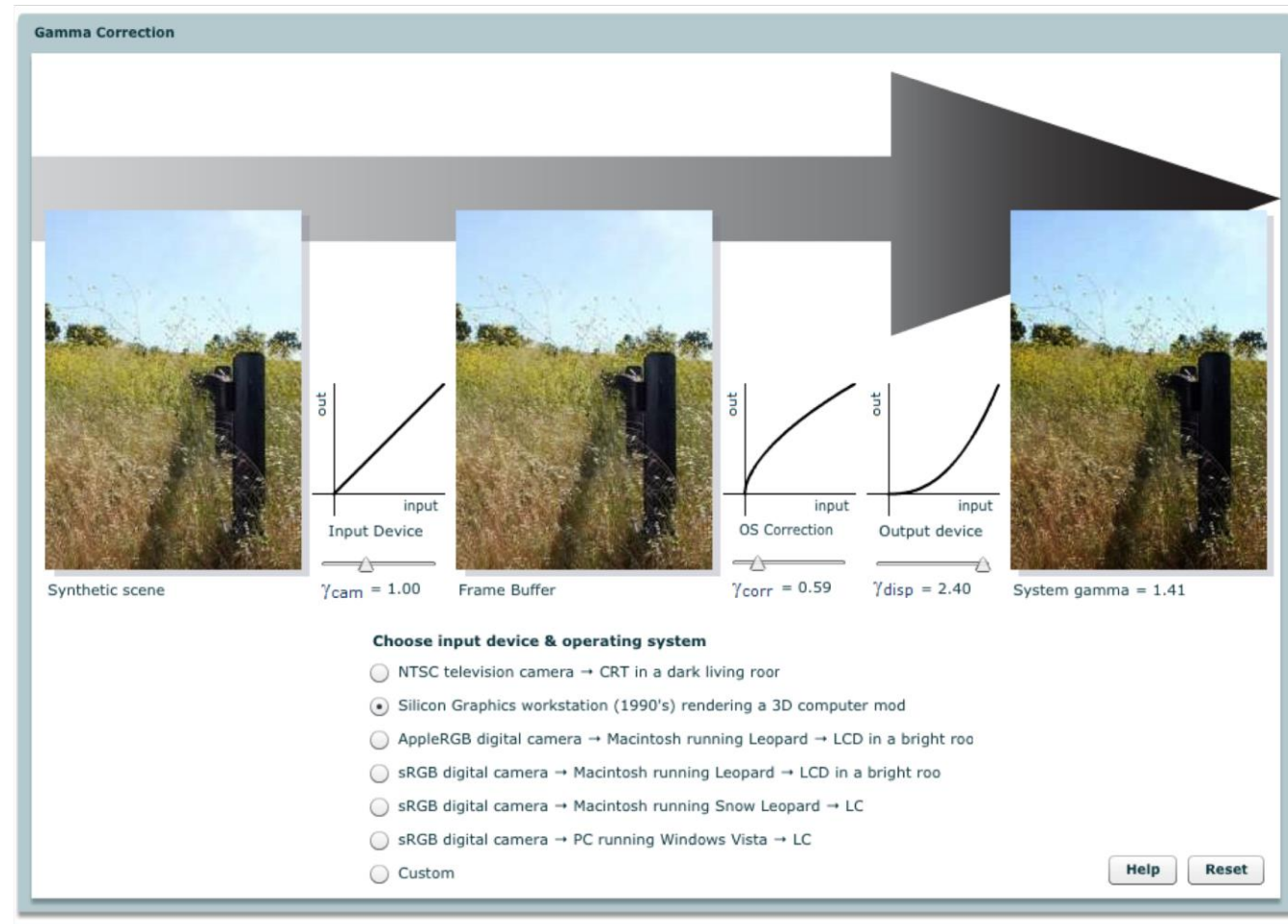


Scaled ramp $0.5 \gamma_0$

Scaling chosen to
approximately preserve
brightness of mid-gray



Contrast adjustment by changing γ



Interactive applet