

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

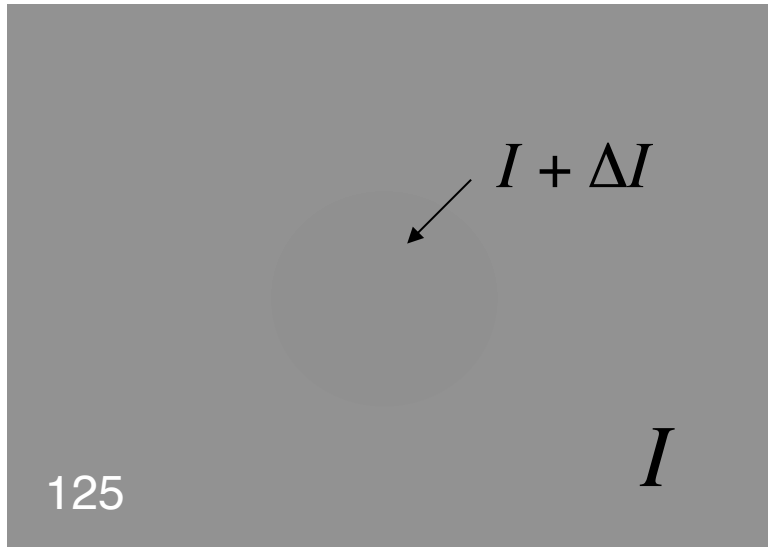


256 levels



- 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

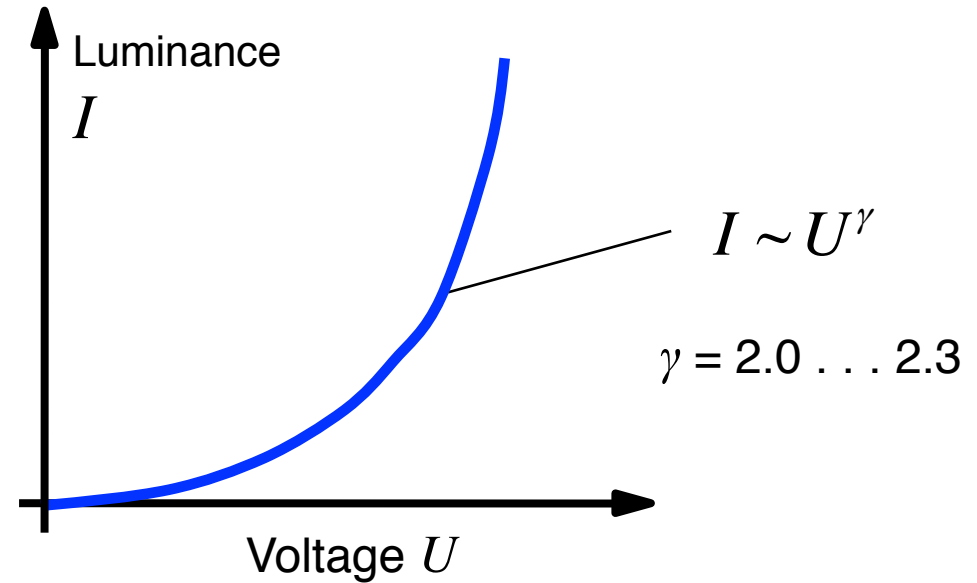
- Luminance ratio between two successive quantization levels at visibility threshold

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

- 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

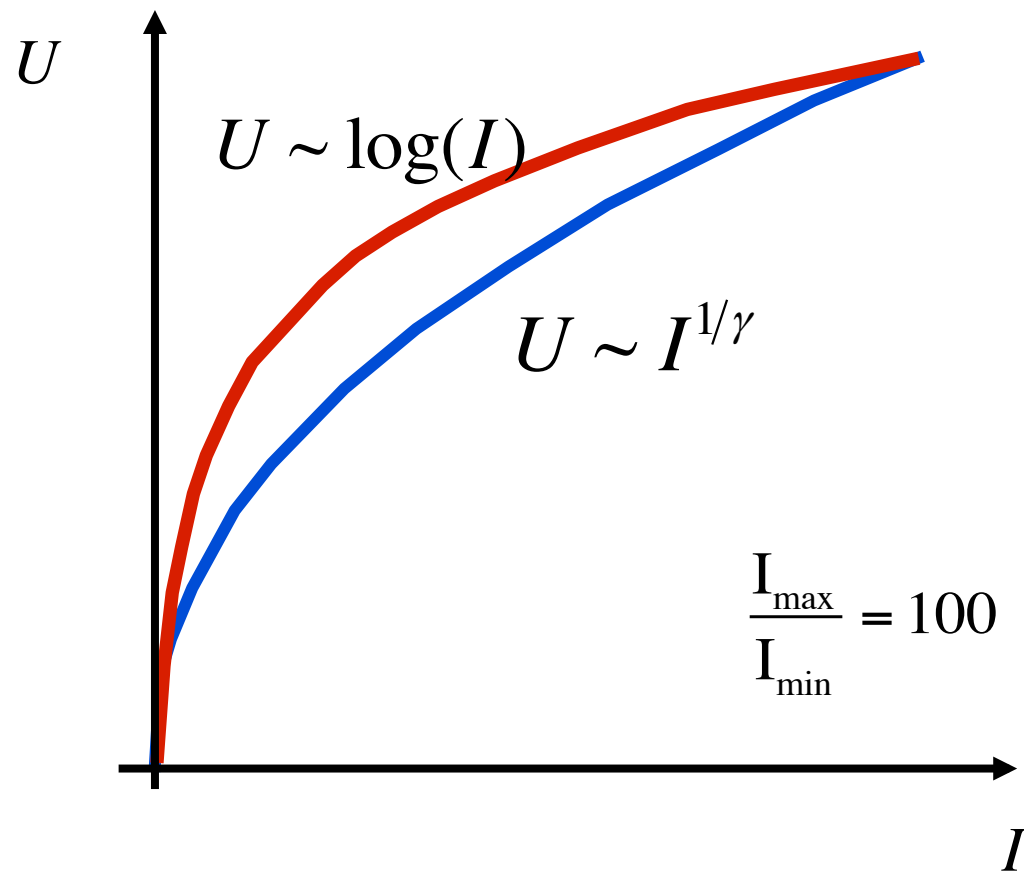
- Cathode ray tubes (CRTs) are nonlinear



- 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

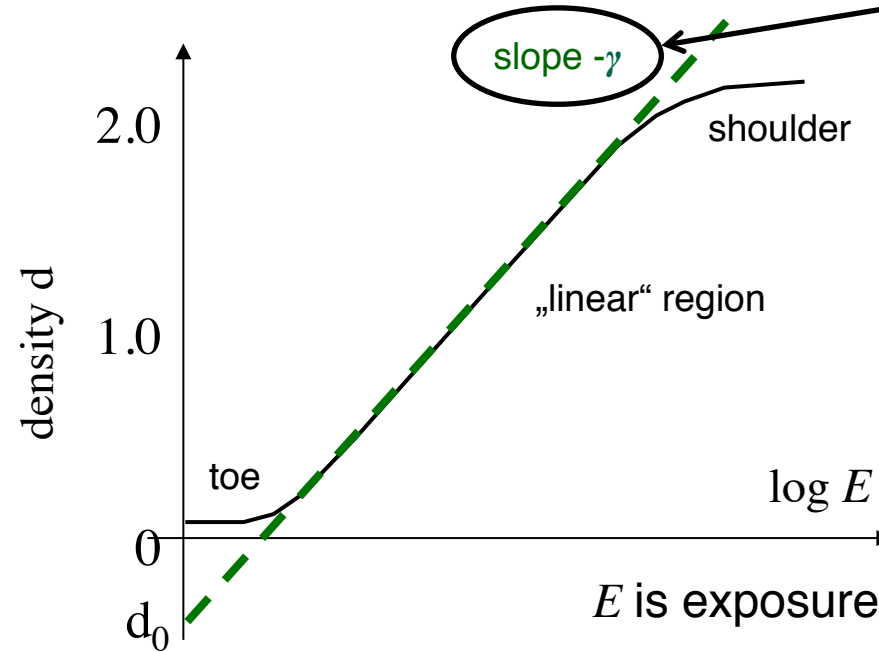
Photographic film



Luminance

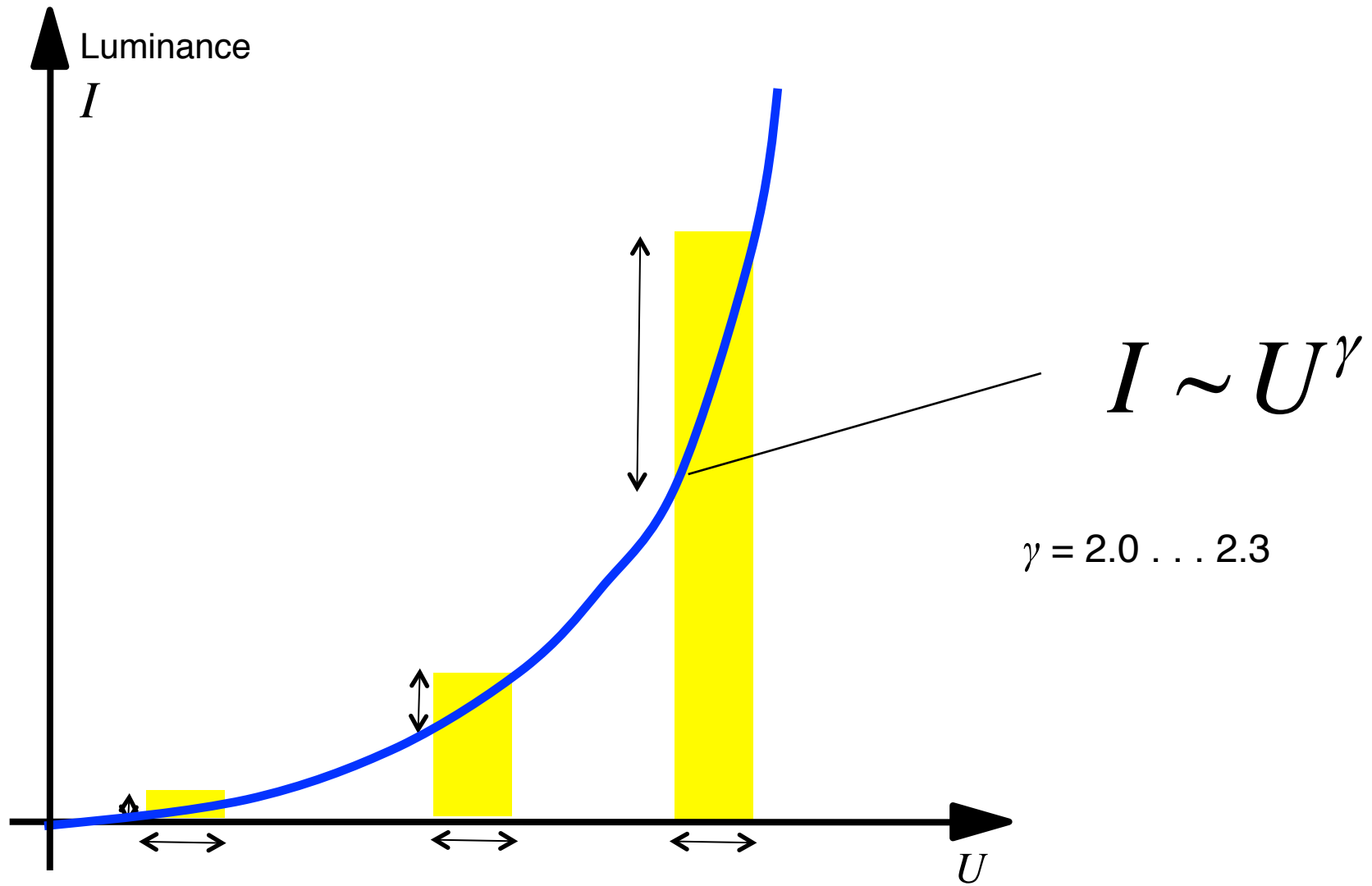
$$\begin{aligned} I &= I_0 \cdot 10^{-d} \\ &= I_0 \cdot 10^{-(-\gamma \log E + d_0)} \\ &= I_0 \cdot 10^{-d_0} \cdot E^\gamma \end{aligned}$$

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%



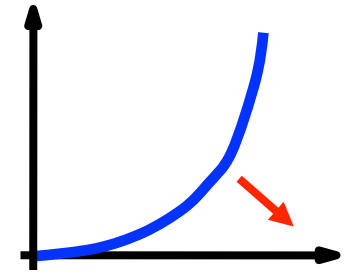
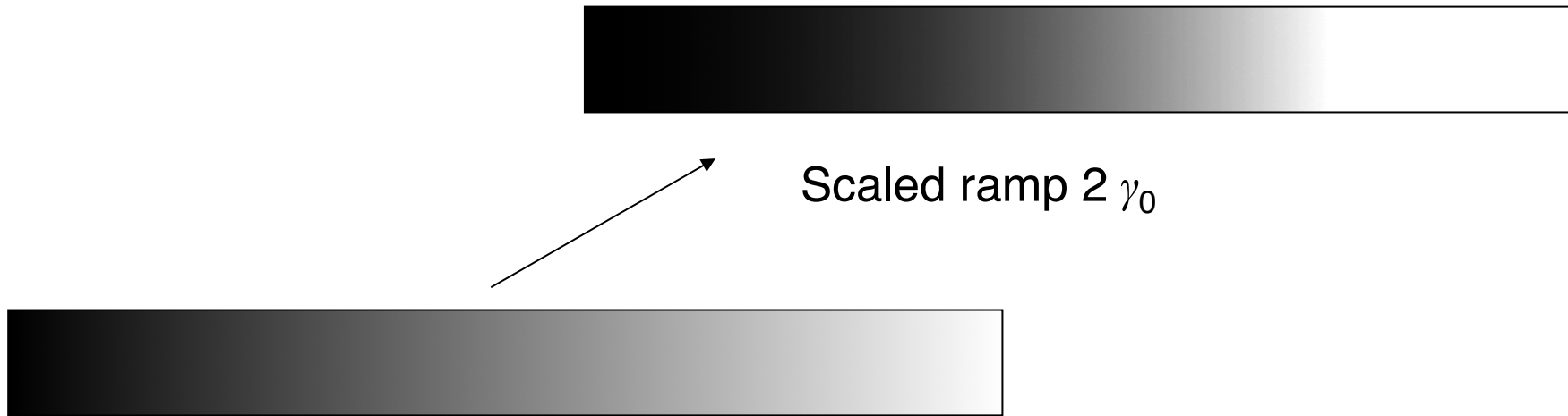
$$a \cdot (f[x,y])^\gamma$$

with $\gamma = 1.5$

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



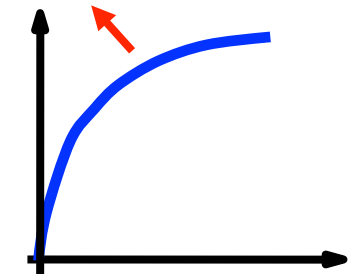
Contrast adjustment by changing γ



Original ramp γ_0

Scaling chosen to approximately preserve brightness of mid-gray

Scaled ramp $0.5 \gamma_0$



Contrast adjustment by changing γ

The applet, titled "Gamma Correction", illustrates the gamma correction process. It shows a sequence of five images: "Synthetic scene", "Frame Buffer", and "System gamma". Between the synthetic scene and frame buffer, there is a graph of a linear transfer function with $\gamma_{cam} = 1.00$ and a slider. Between the frame buffer and system gamma, there are two graphs: one for "OS Correction" with $\gamma_{corr} = 0.59$ and one for "Output device" with $\gamma_{disp} = 2.40$, both with sliders. A large grey arrow points from the frame buffer to the system gamma image. Below the images is a section titled "Choose input device & operating system" with radio button options: NTSC television camera → CRT in a dark living room; Silicon Graphics workstation (1990's) rendering a 3D computer mod (selected); AppleRGB digital camera → Macintosh running Leopard → LCD in a bright room; sRGB digital camera → Macintosh running Leopard → LCD in a bright room; sRGB digital camera → Macintosh running Snow Leopard → LC; sRGB digital camera → PC running Windows Vista → LC; and Custom. "Help" and "Reset" buttons are in the bottom right.

Interactive applet

<https://graphics.stanford.edu/courses/cs178/applets/gamma.html>