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?

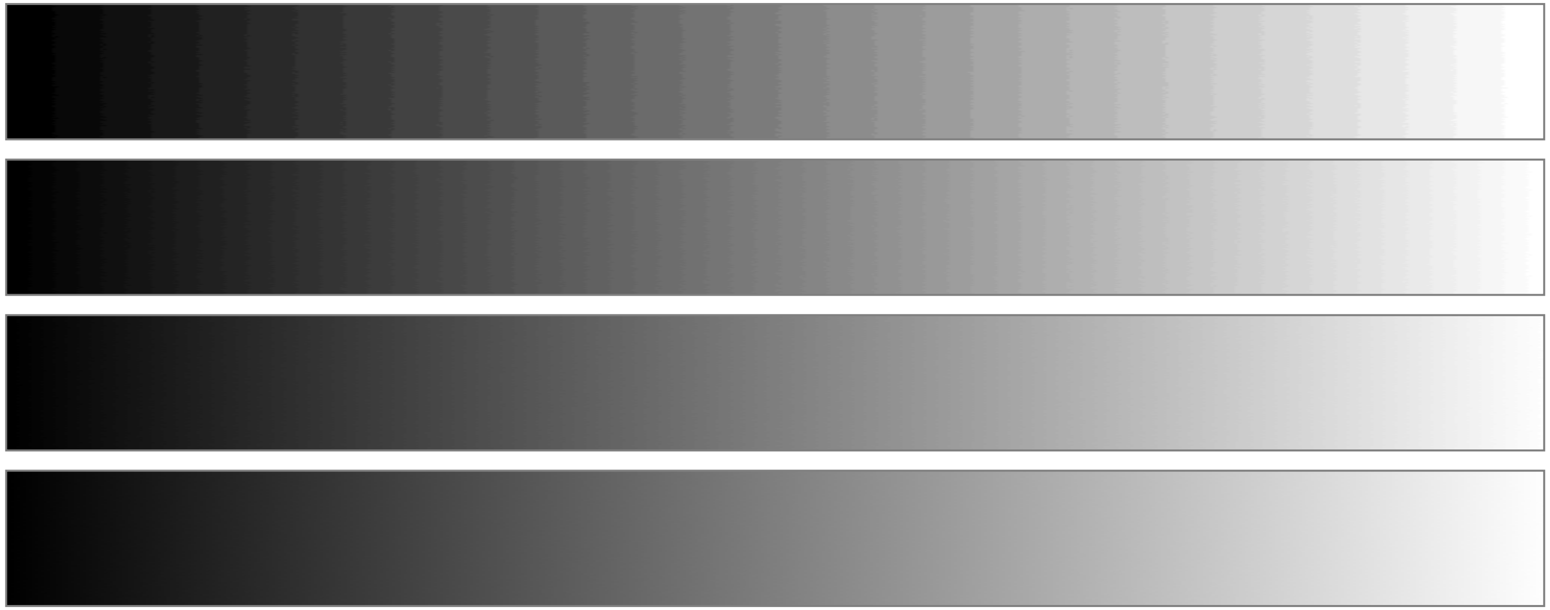
- Contouring is most visible for a ramp

32 levels

64 levels

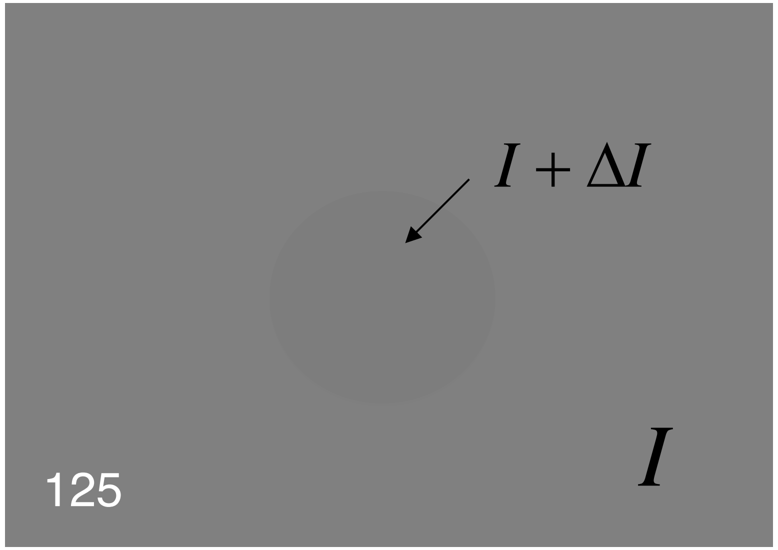
128 levels

256 levels



- Digital images typically are quantized to 256 gray levels.

Brightness discrimination experiment



Visibility threshold

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

„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

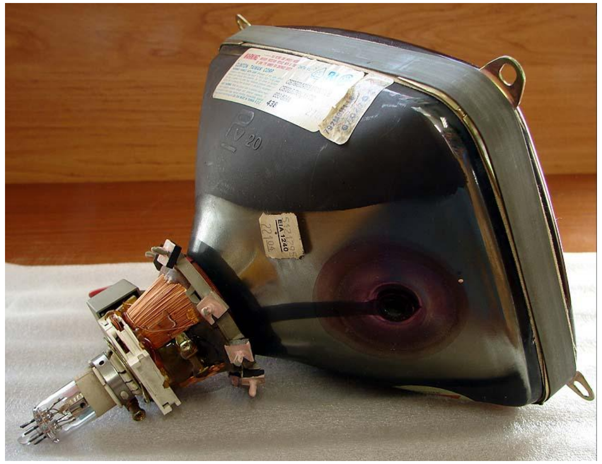
- Luminance ratio between two successive quantization levels at visibility threshold

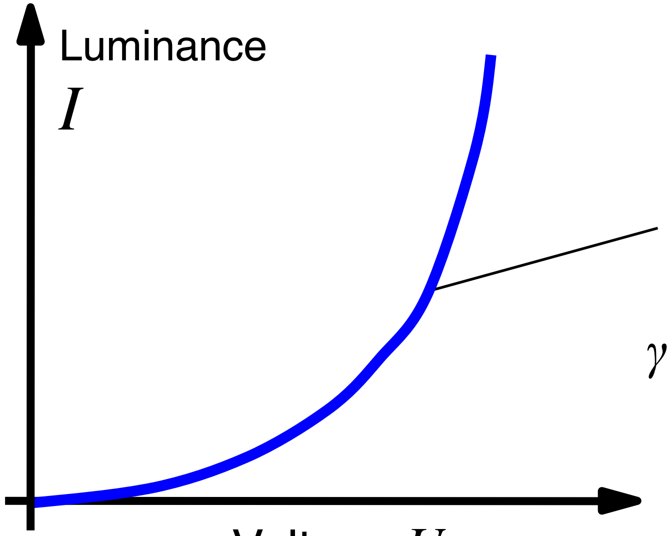
$$\frac{I_{\max}}{I_{\min}} = \left(1 + K_{Weber}\right)^{N-1}$$

- For $K_{Weber} = 0.01 \ldots 0.02 \quad N = 256 \quad \mathrm{I}_{\max} / \mathrm{I}_{\min} = 13 \ldots 156$
- 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

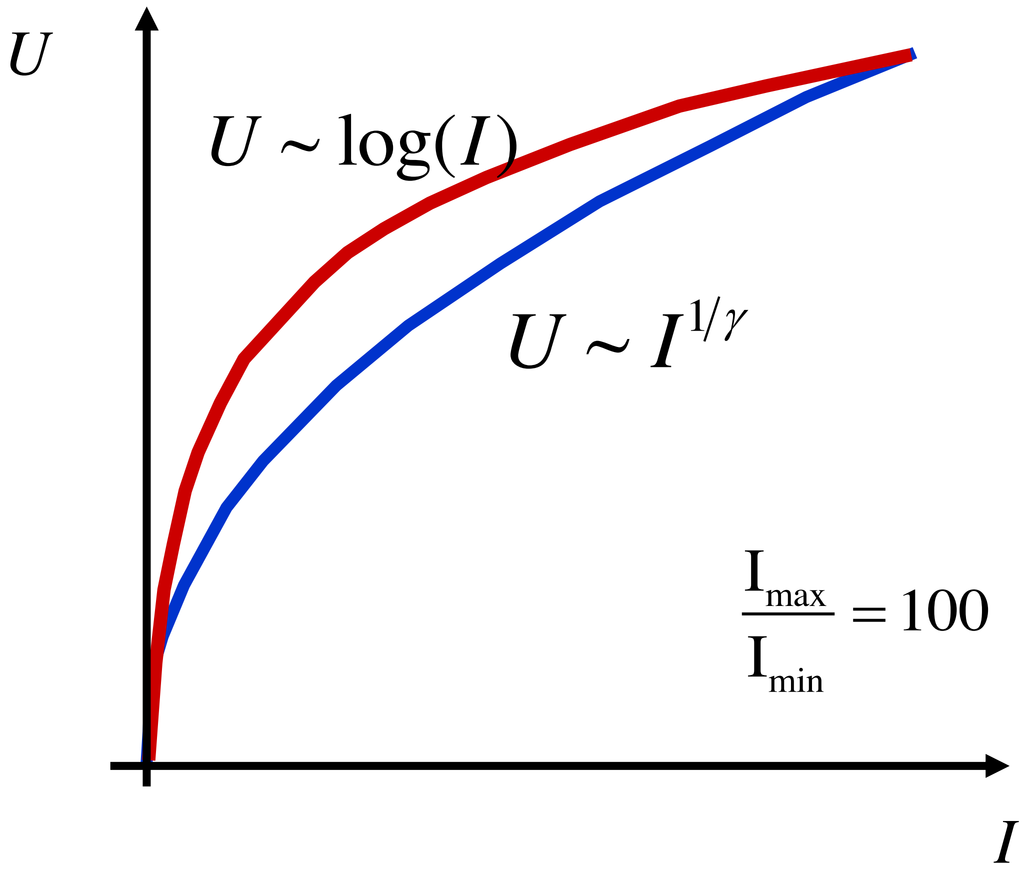




- Cameras contain γ-predistortion circuit

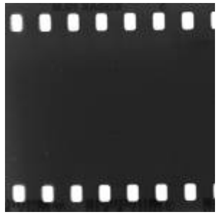
$$U \sim I^{1/\gamma}$$

log vs. γ-predistortion



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

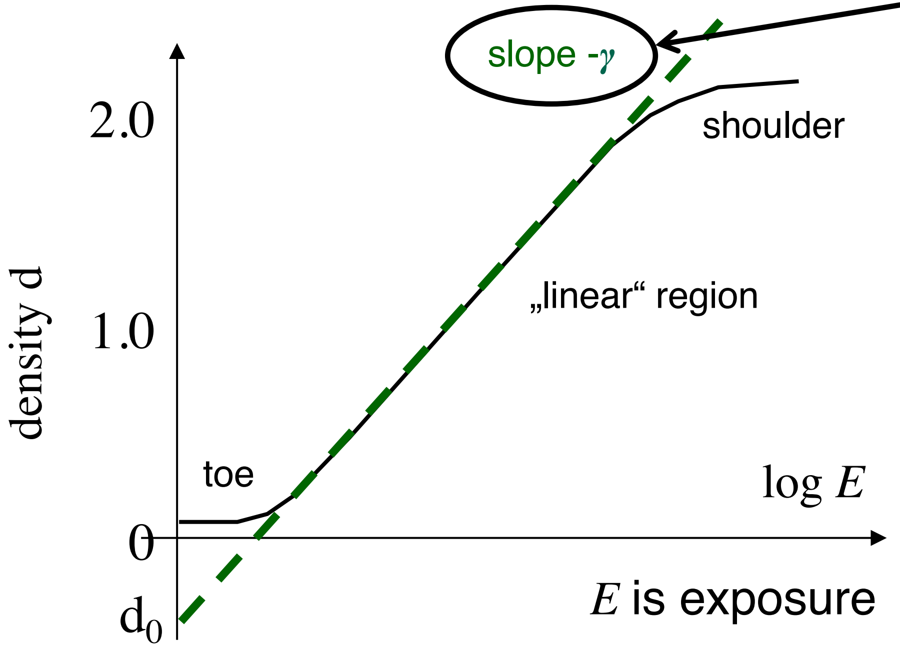
Photographic film



Luminance

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

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



γ measures film contrast

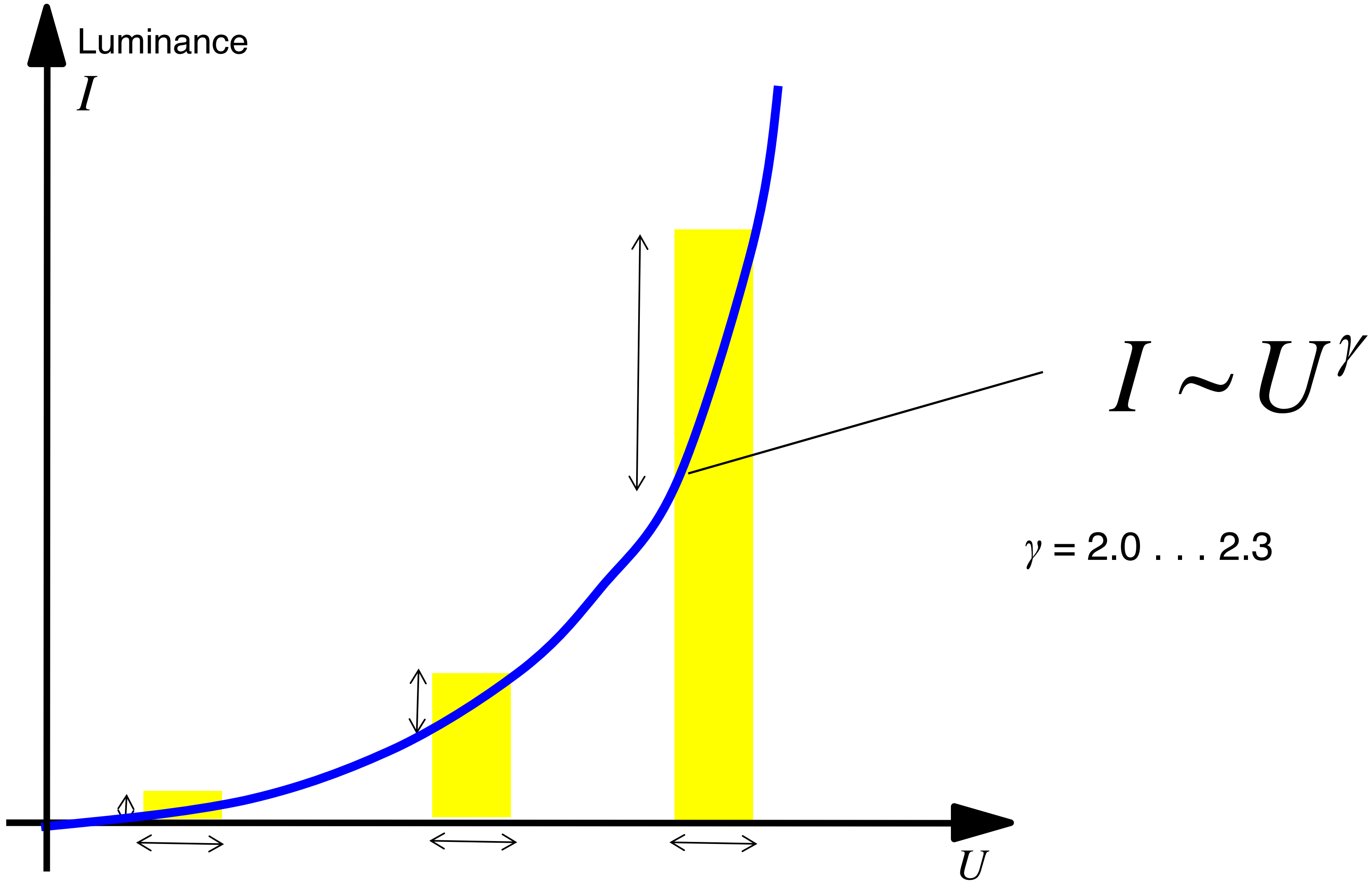
- General purpose films

  γ = -0.7 . . . -1.0

- High-contrast films

  γ = -1.5 . . . -10

- Lower speed films tend to have higher absolute γ


Luminance
I
$I \sim U^{\gamma}$
γ = 2.0 . . . 2.3
U

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

$$I \sim \left(a \cdot f[x,y]\right)^{\gamma} = a^{\gamma} \cdot \left(f[x,y]\right)^{\gamma}$$

. . . same effect as changing camera exposure time.

Contrast adjustment by changing γ

Original image

$$f[x,y]$$

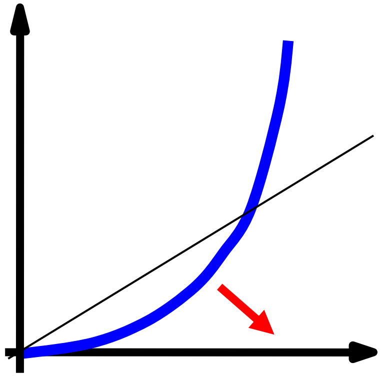
γ increased by 50%

$$a \cdot \left(f[x,y]\right)^{\gamma}$$

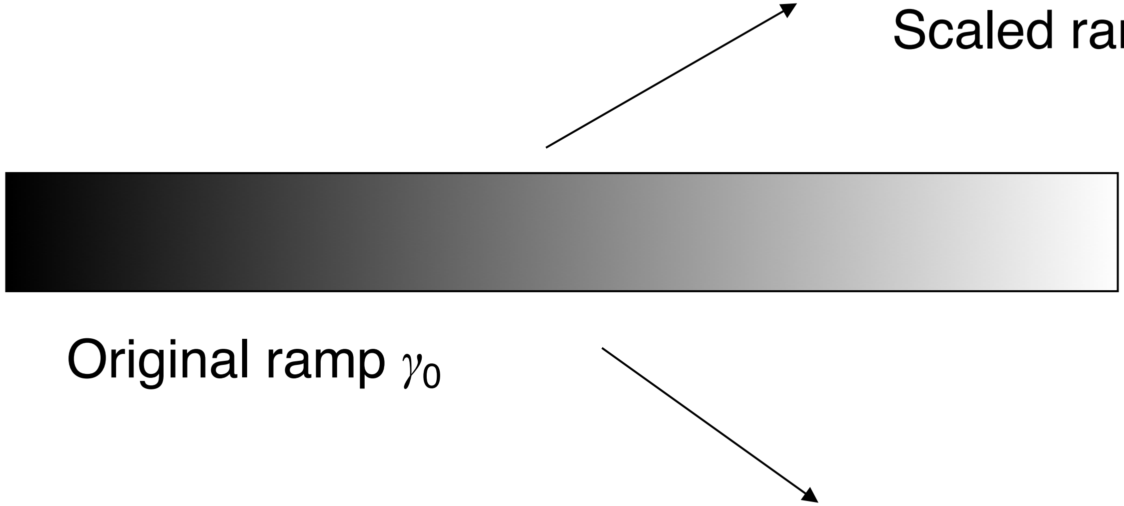
with $\gamma = 1.5$

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

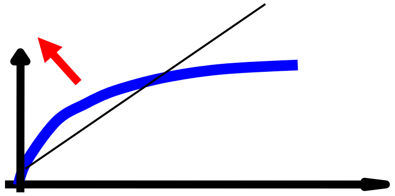
Contrast adjustment by changing γ



Scaled ramp 2 γ_0



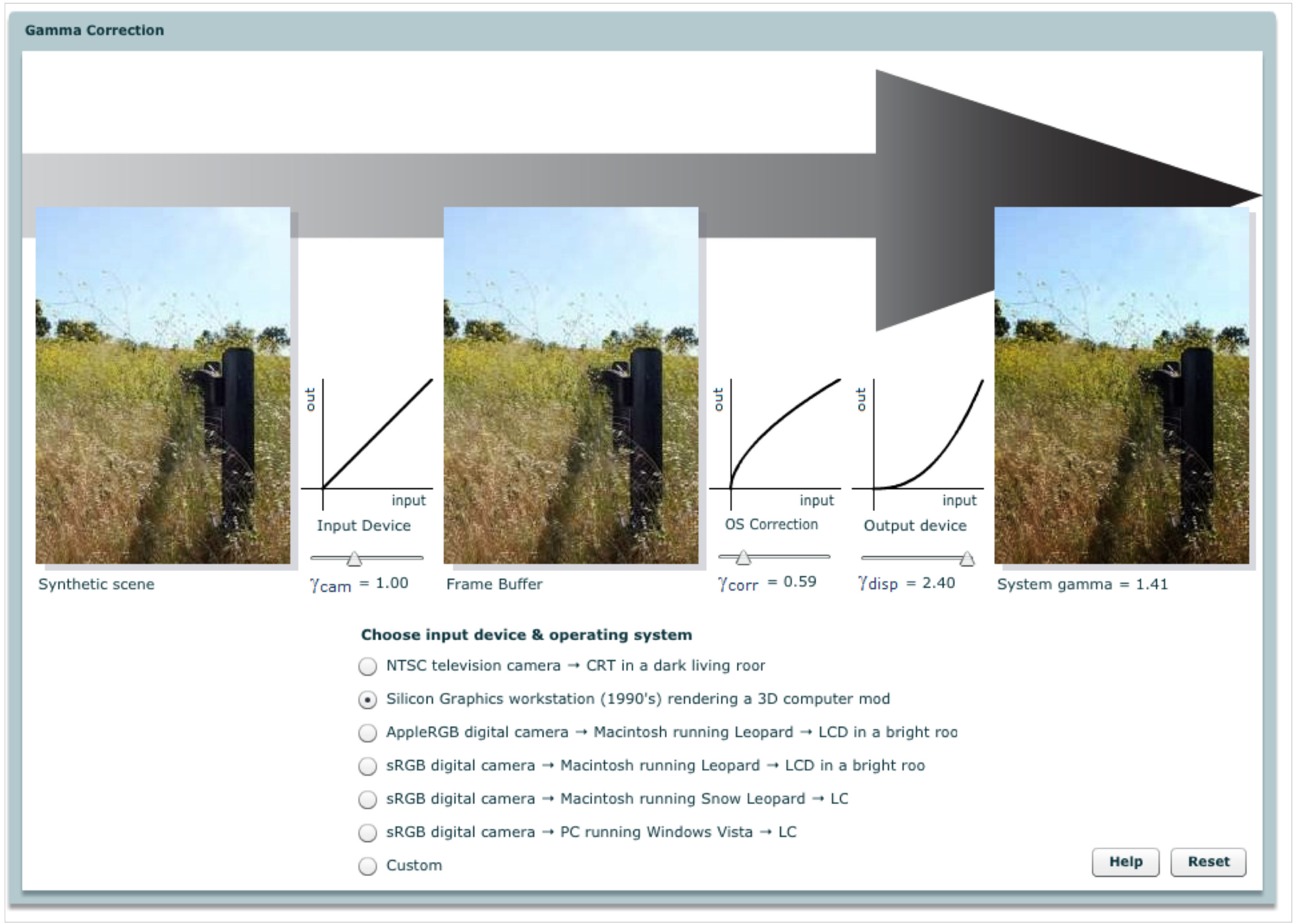
Original ramp γ_0



Scaled ramp 0.5 γ_0

Scaling chosen to approximately preserve brightness of mid-gray

Contrast adjustment by changing γ



Interactive applet

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