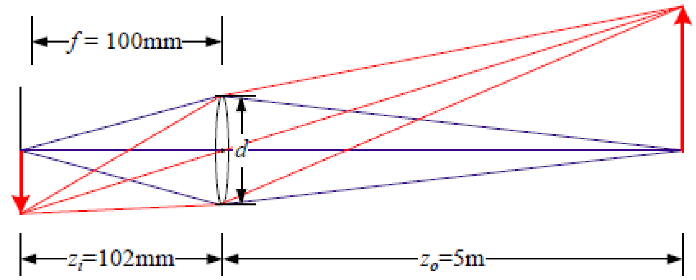
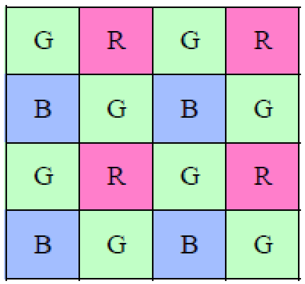




Digital Camera

Chao-Tsung Huang

National Tsing Hua University

Department of Electrical Engineering

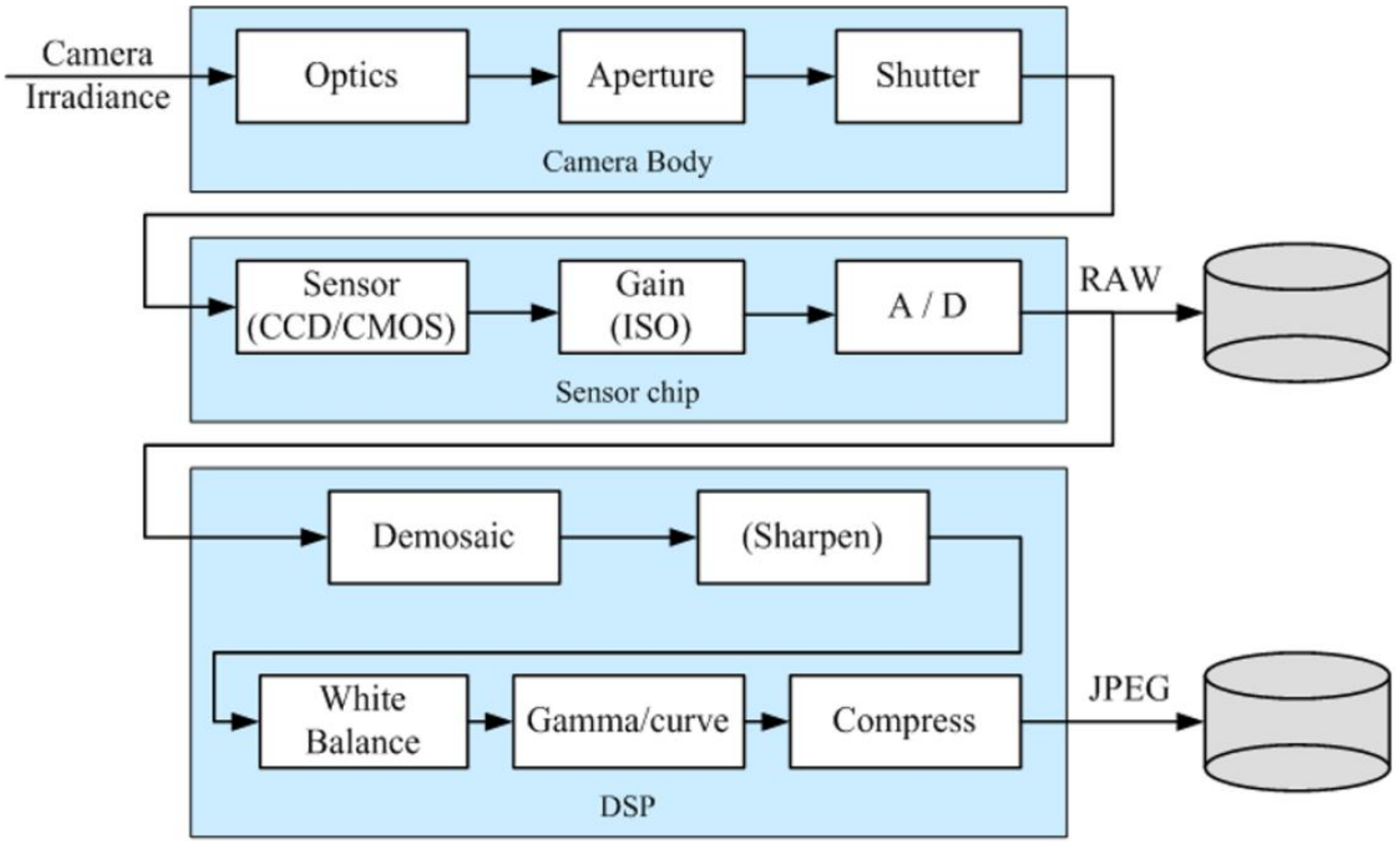
Digital Camera

- Complex scientific model in three parts

Light

Electron

Digital signal



Sensor

- Type
  - CCD: passive-pixel sensor, higher fill factor
  - CMOS: active-pixel sensor, lower fill factor
    - Could be changed using 3D IC technology
- Fill factor
  - Active sensing area over available area
  - Higher is preferable (more light and less aliasing)
- Analog gain
  - ISO setting: 100, 200, 400, … (confusing)
- Noise
  - Shot noise, amplifier noise, quantization noise (hard)
  - Fixed pattern noise, dark current noise (easy)

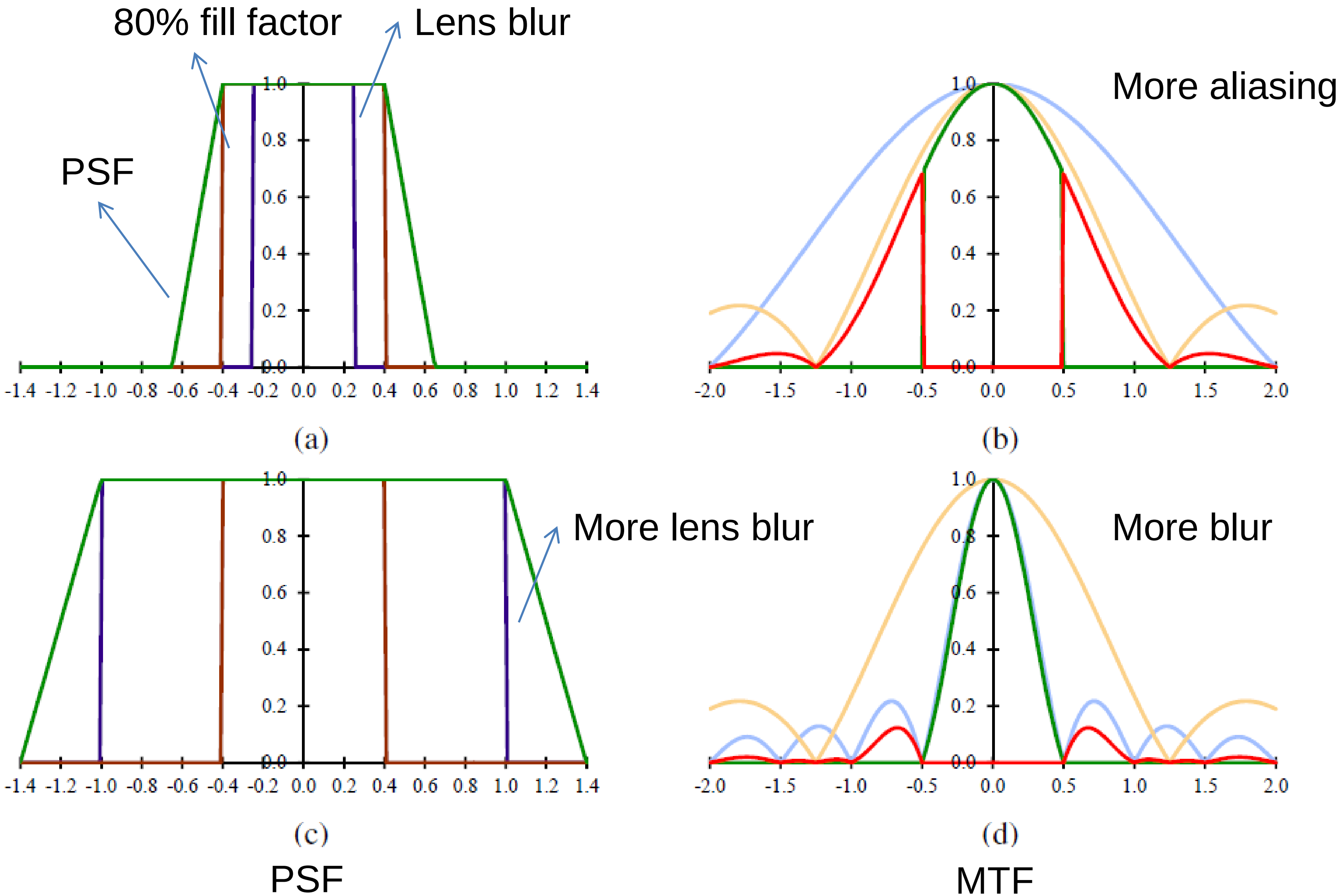
Sampling and Aliasing

- Point spread function (PSF)
  - Response of an ideal point source
  - Equivalent to convolution of the lens blur and the finite active pixel area
- Modulation transfer function (MTF)
  - Magnitude of FT of PSF

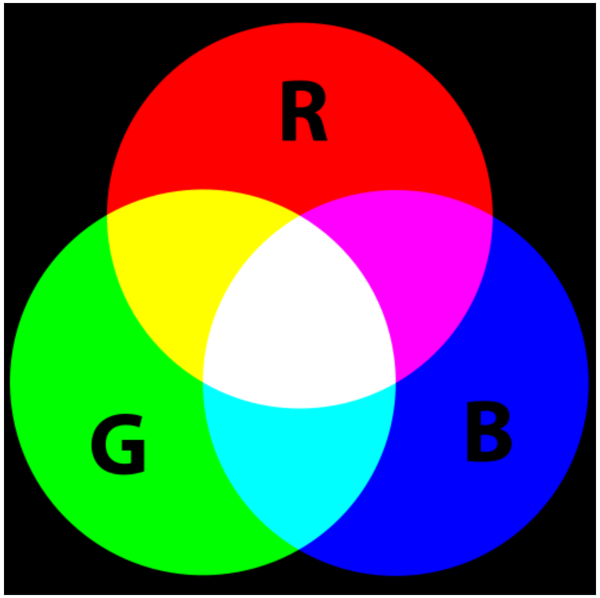
- Image pixels have aliasing inevitably due to fill factor <= 100% < 400%

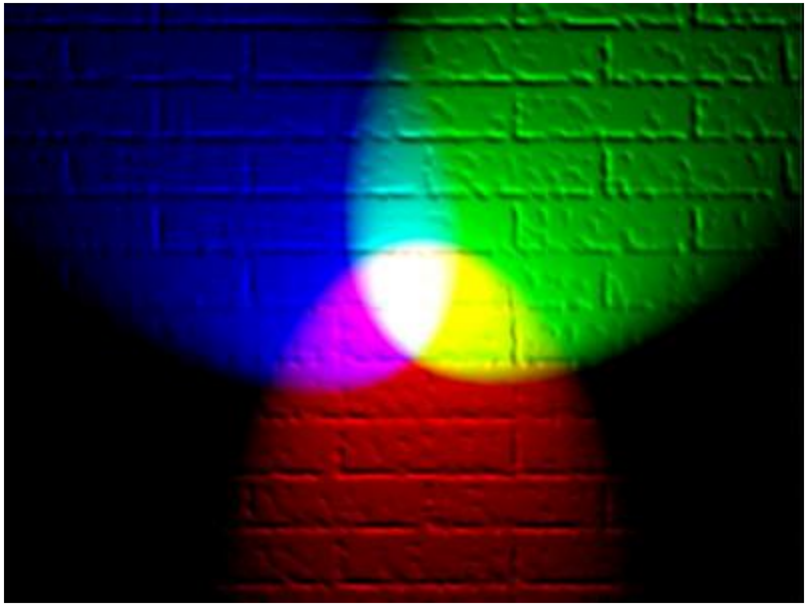
$$f_{\mathrm{s}} \geq 2 f_{\mathrm{max}}$$

Aliasing Examples (Trade-off)



Additive Color



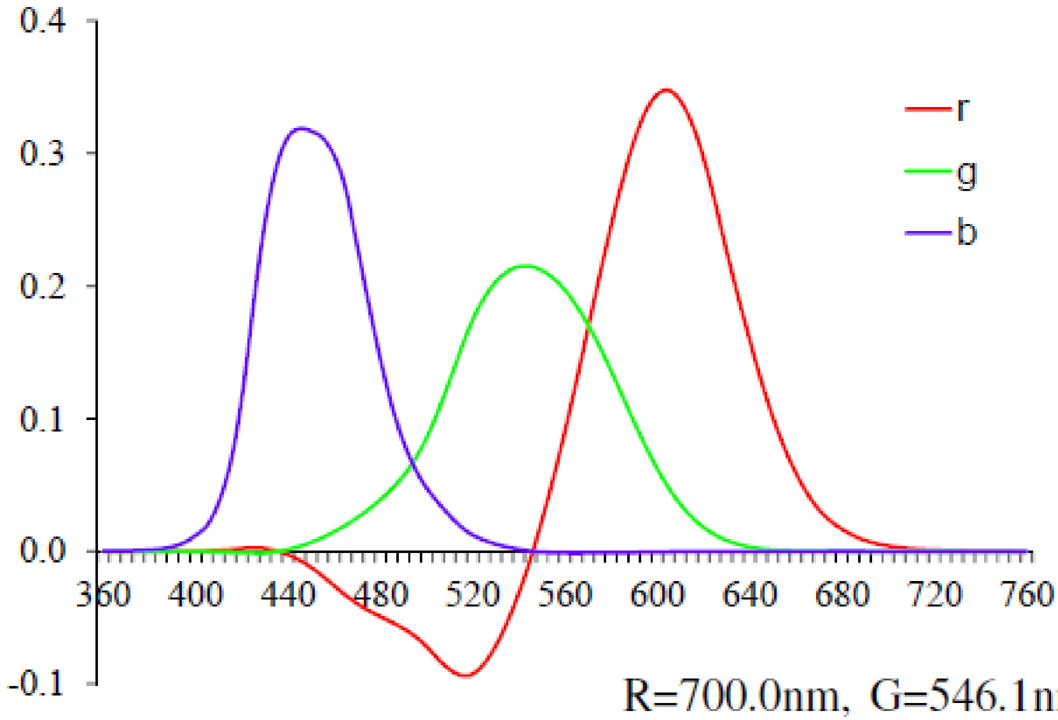


Additive color created by mixing light of colors, usually the three primary colors: red, green, and blue. (used in display devices)

Ref: *Wikipedia*

CIE RGB

- Color matching functions
  - – by experiments with a standard observer



R=700.0nm, G=546.1nm, and B=435.8nm

Grassman's Law

- Linearity of color matching for mixture of colors (enable linear transformation between color space)

$$R = \int I(\lambda)\bar{r}(\lambda)d\lambda$$

$$G = \int I(\lambda)\bar{g}(\lambda)d\lambda$$

$$B = \int I(\lambda)\bar{b}(\lambda)d\lambda$$

Linearity ⇨

$$I(\lambda) = I_1(\lambda) + I_2(\lambda)$$
$$\Rightarrow$$
$$(R, G, B) = (R_1, G_1, B_1) + (R_2, G_2, B_2)$$

Every color's SPD $I(\lambda)$ has its matched (R,G,B)

The color space for any given primaries is the corresponding linear space

Color Filter Arrays

G	R	G	R
B	G	B	G
G	R	G	R
B	G	B	G

Bayer Pattern
(RAW format)

rGb	Rgb	rGb	Rgb
rgB	rGb	rgB	rGb
rGb	Rgb	rGb	Rgb
rgB	rGb	rgB	rGb

Demosaiced RGB

Color Balance

- What color will you get when yellow light on white objects (e.g. book pages)?
  - But we humans perceive it as white, and demand the picture also look white
  - Usually achieved by per-component scaling

(not a scientific model)

Gamma

- Non-linear mapping before discretization
- Origin
  - CRT phosphors have non-linear response between input voltage and brightness

$$B = V^{\gamma}$$

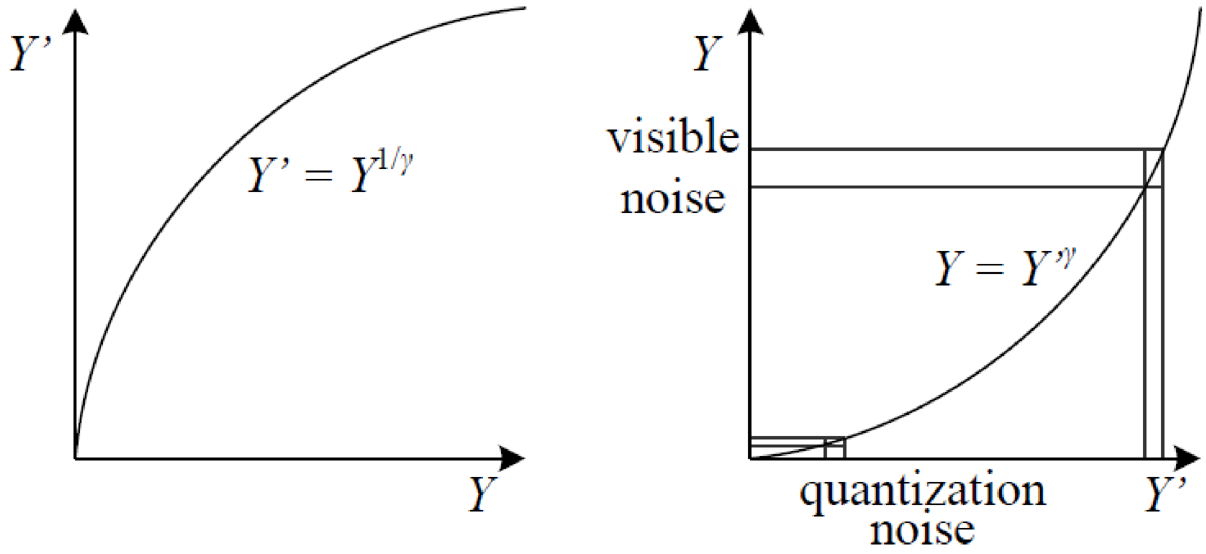
ϒ = 2.2~2.4

- So we would pre-map the luminance (gamma correction)

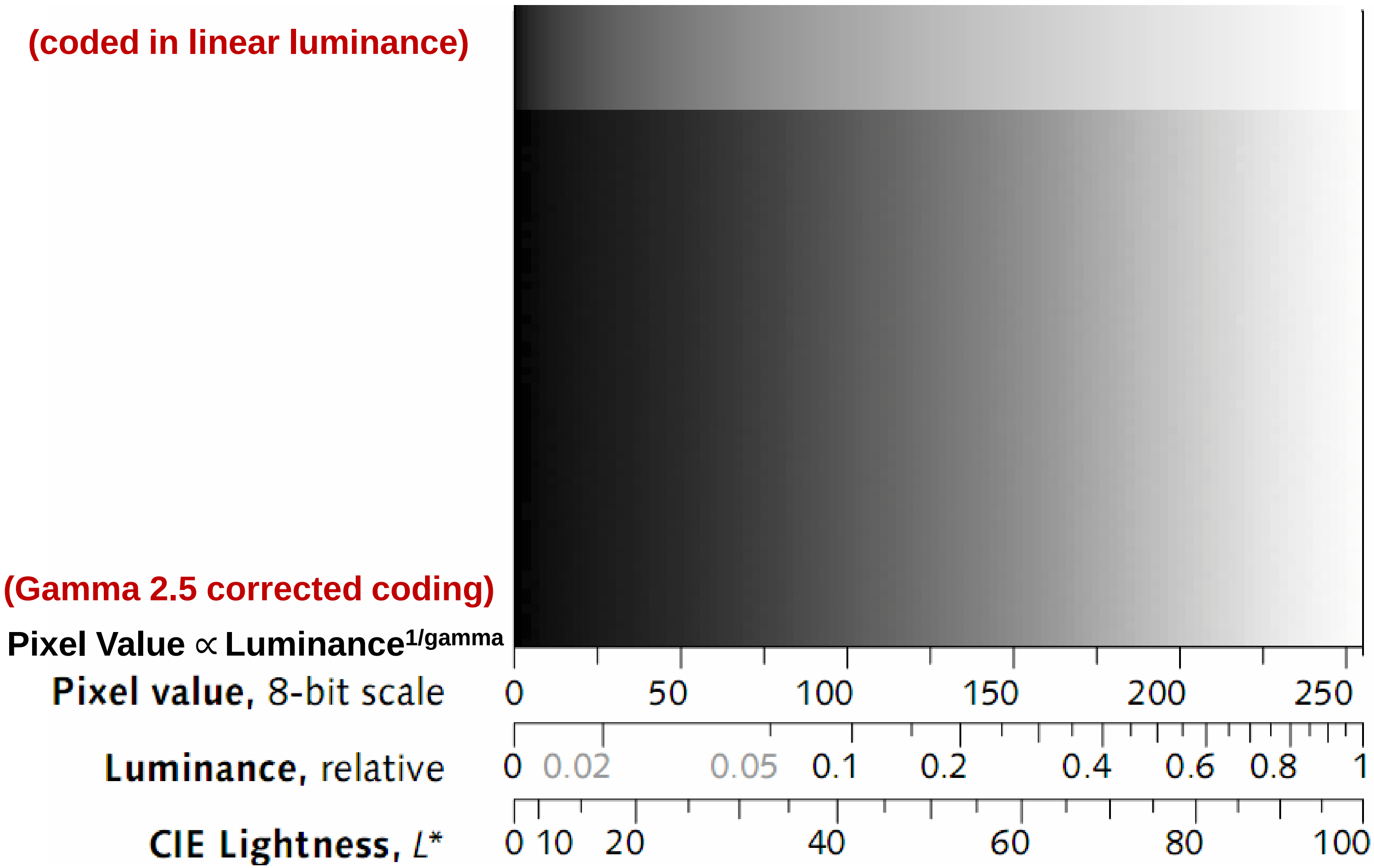
$$Y' = Y^{\frac{1}{\gamma}}$$

Gamma

- Why we still use gamma correction now?
- Its map suitable for human perception sensitivity



Linear vs. Non-linear Coding



Ref: *Digital Video and HDTV*

Y'CbCr color space

- Widely used in image/video storage
- Rec. 601 luma/chroma matrix

$$\begin{bmatrix} Y' \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.168736 & -0.331264 & 0.5 \\ 0.5 & -0.418688 & -0.081312 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} + \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix}$$

↑

RGB after
gamma correction
(the prime ' indicates non-linearity)

Compression

- Lossless
  - Camera RAW, PNG, BMP
- Lossy
  - Usually in Y'CbCr and use block-based coding
  - Image: JPEG
  - Video: MPEG-1/2/4, H.264, WMV, H.265

Digital camera 3A

- AE: automatic exposure
  - F-number, shutter speed, ISO
  - Aperture-priority vs. shutter-priority
- AF: autofocus
  - Phase detection vs. contrast detection
- AWB: automatic white balance
  - How to identify which pixels are white?