SECV – Tobias Weis

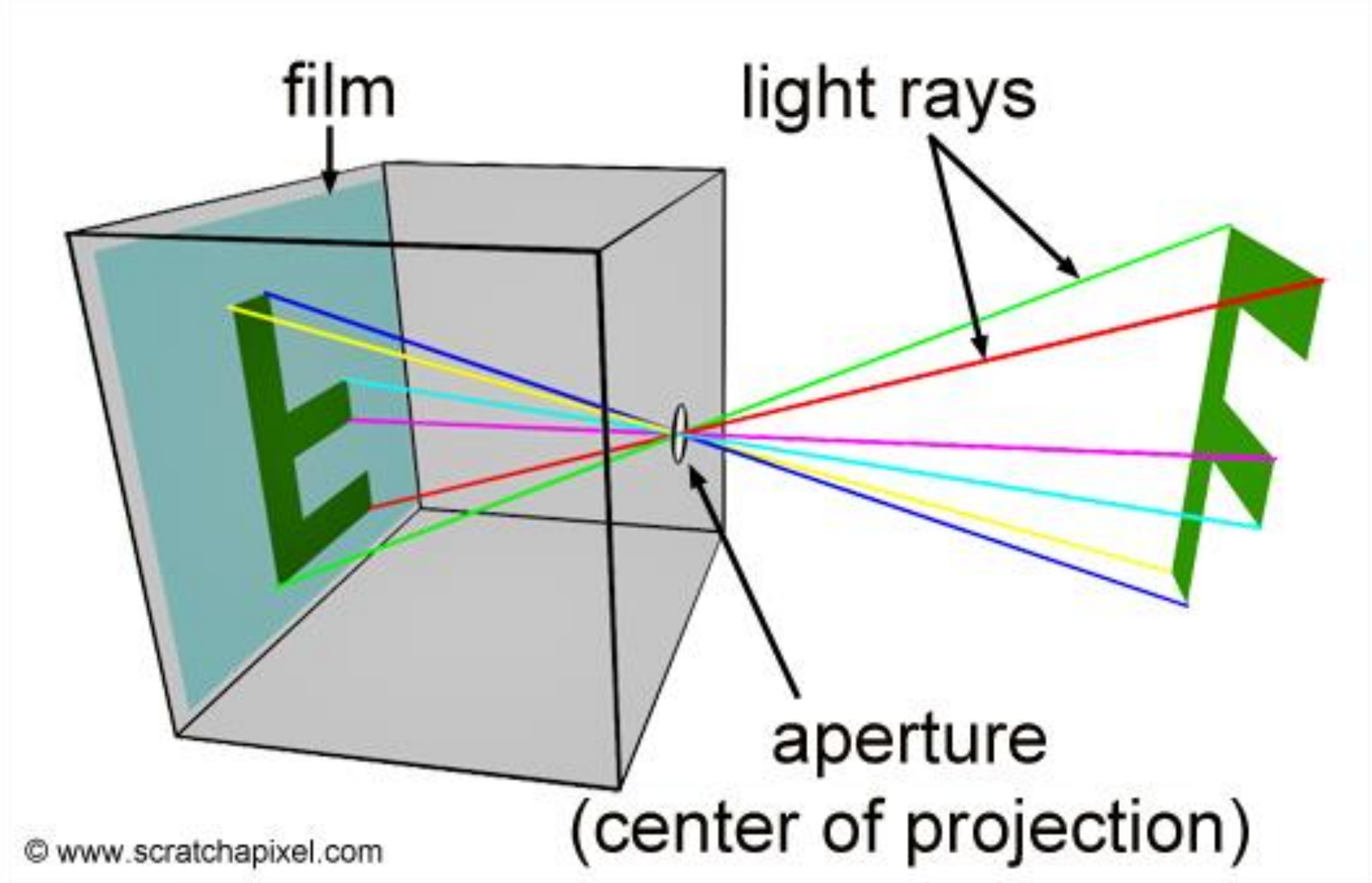
RoboCup – Camera stuff

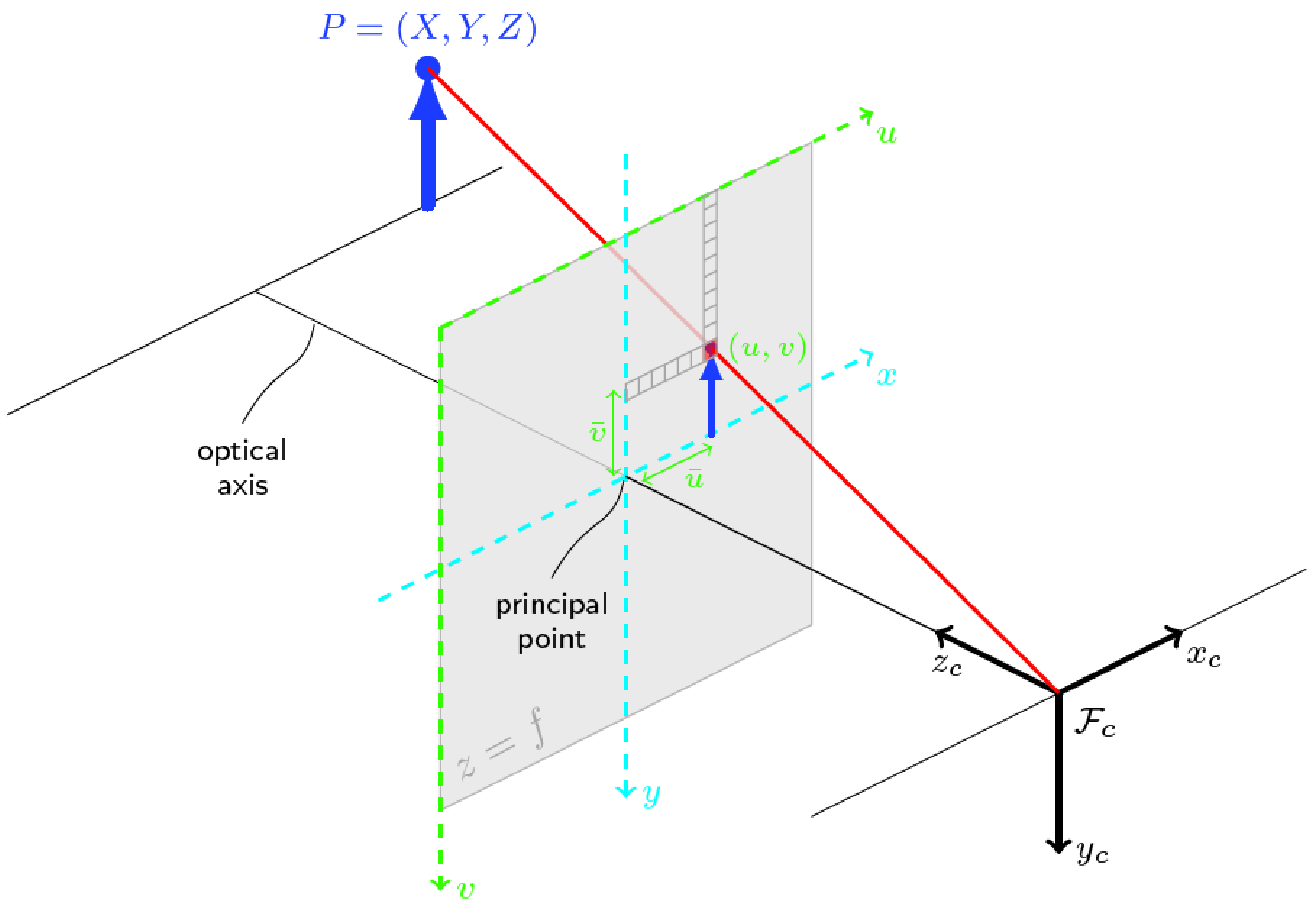
TOC

- Camera & sensor hardware
- Parameters

Camera parameters & effects

- Camera hardware





https://www.scratchapixel.com/lessons/3d-basic-rendering/3d-viewing-pinhole-camera

http://docs.opencv.org/2.4/modules/calib3d/doc/camera_calibration_and_3d_reconstruction.html

Camera parameters & effects

- Nao camera hardware - meaning

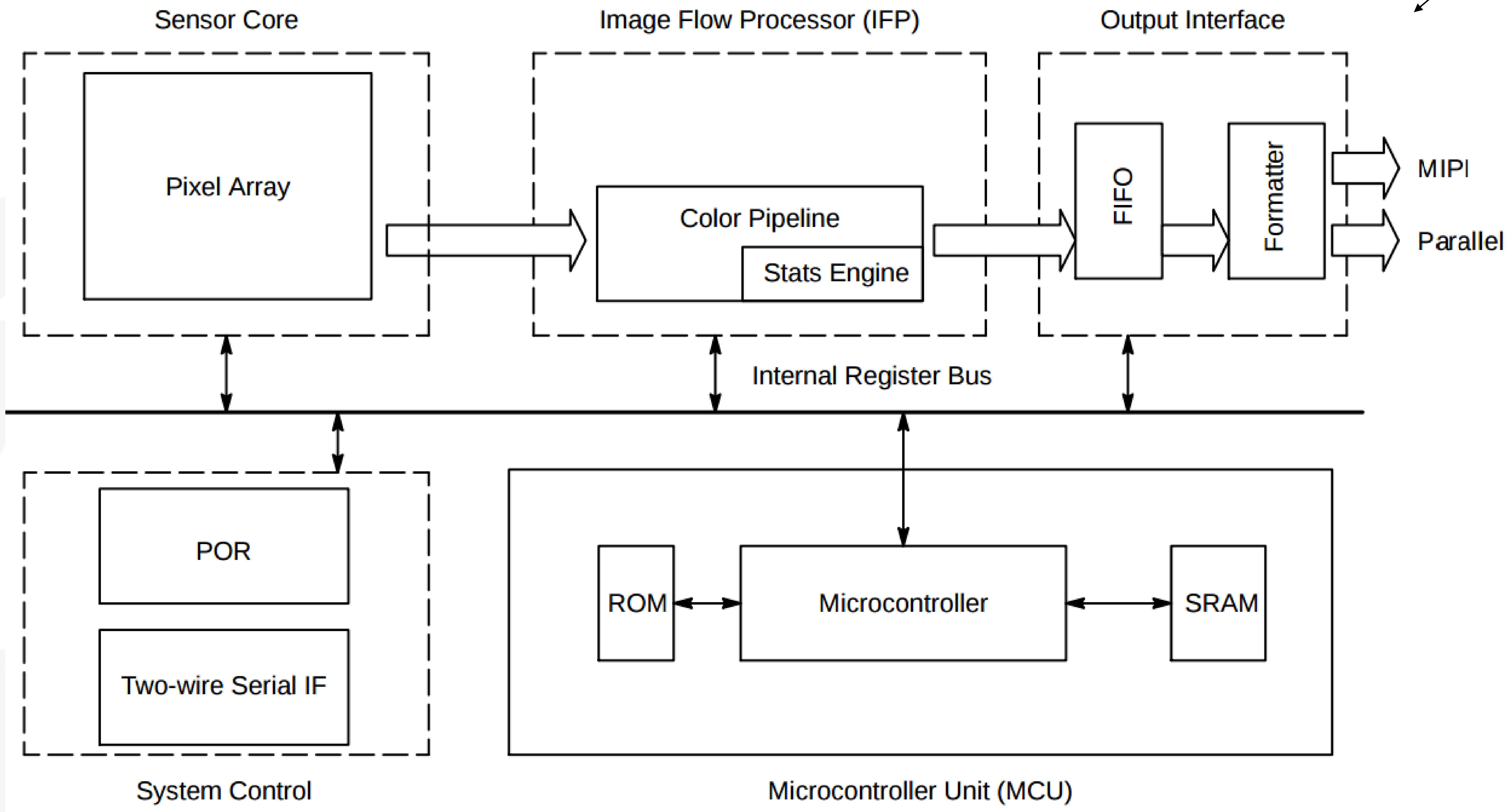


Figure 1. MT9M114 Block Diagram

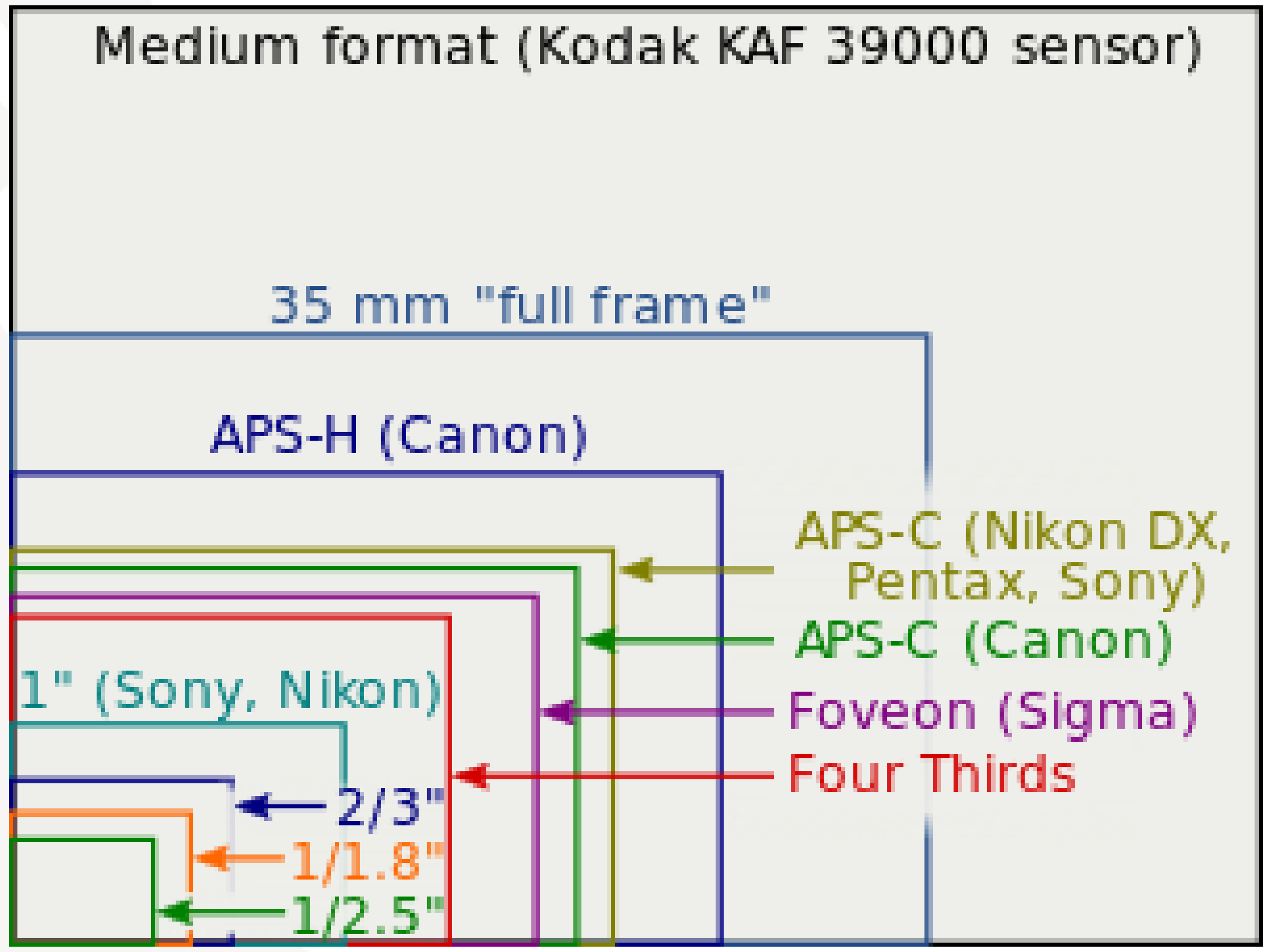
Camera	Model	MT9M114
	Type	**SOC Image Sensor**
Imaging Array	Resolution	1.22 Mp
	Optical format	1/6 inch
	Active Pixels (HxV)	1288x968
Sensitivity	Pixel size	1.9µm*1.9µm
	Dynamic range	70 dB
	Signal/Noise ratio (max)	37dB
	Responsivity	2.24V/Lux-sec (550 nm)
Output	Camera output	1280*960@30fps
	Data Format	(YUV422 color space)
	Shutter type	Electronic Rolling shutter
View	Field of view	72.6°DFOV
	Focus range	30cm ~ infinity
	Focus type	Fixed focus

http://www.onsemi.com/pub_link/Collateral/MT9M114-D.PDF

Camera parameters & effects

- Nao camera hardware - meaning

https://upload.wikimedia.org/wikipedia/commons/3/32/Resolution_test.jpg



https://en.wikipedia.org/wiki/Image_sensor_format

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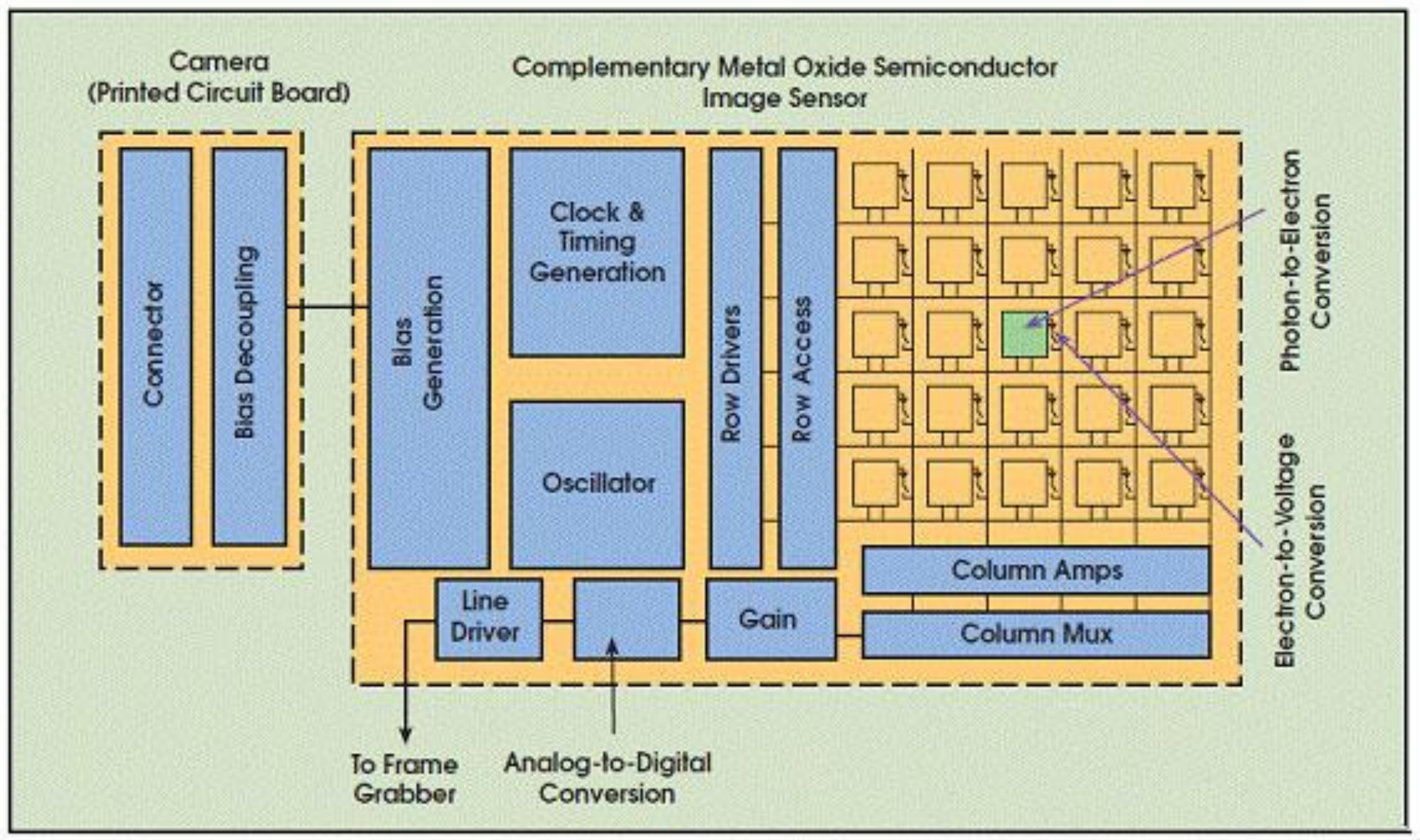
Camera parameters & effects

- Nao camera hardware – meaning
- CMOS technology:
- Electron-to-Voltage conversion IN PIXEL:
- Effective sensing area smaller (than CCD)
  - due to other needed electronics
  - Less blooming/bleeding than CCD



https://www.tedpella.com/cameras_html/ccd_cmos.htm

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Camera parameters & effects

- Nao camera hardware – meaning
- Pixels – Full-well capacity
- Blooming artifacts & oversaturation are a function
  - of pixel-size

http://www.leica-microsystems.com/science-lab/microscope-cameras/introduction-to-digital-camera-technology/

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Camera parameters & effects

- Nao camera hardware - meaning

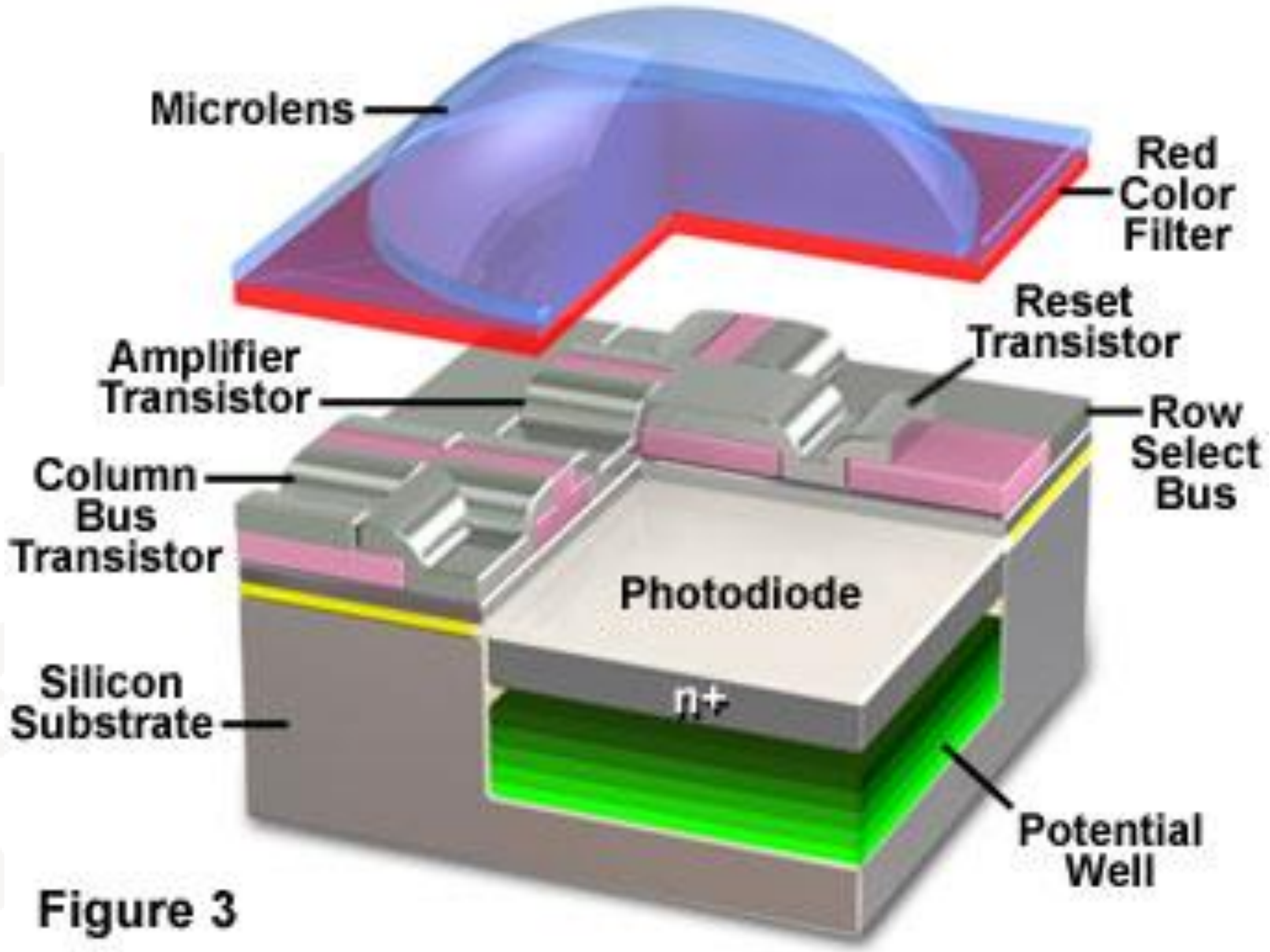

Figure 3

http://olympus.magnet.fsu.edu/primer/digitalimaging/cmosimagesensors.html

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Camera parameters & effects

- Nao camera hardware – meaning
  - Bayer-Filter:
  - Twice as many green (luminance-sensitive) as
    - red and blue (chrominance-sensitive)
    - Mimic physiology of human eye
    - De-Mosaicing for final image, e.g. interpolation
      - Can cause artifacts at fine details (e.g. Moiré)

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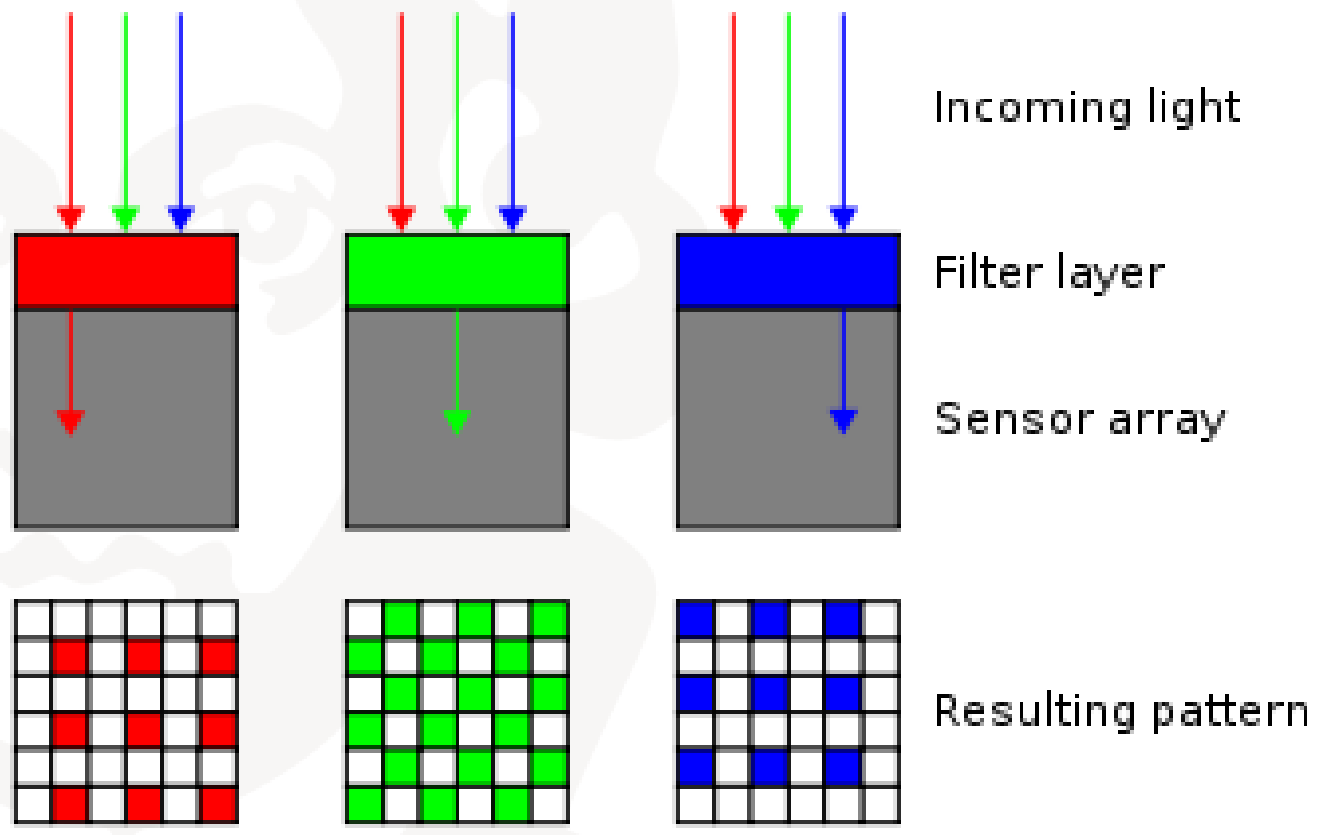

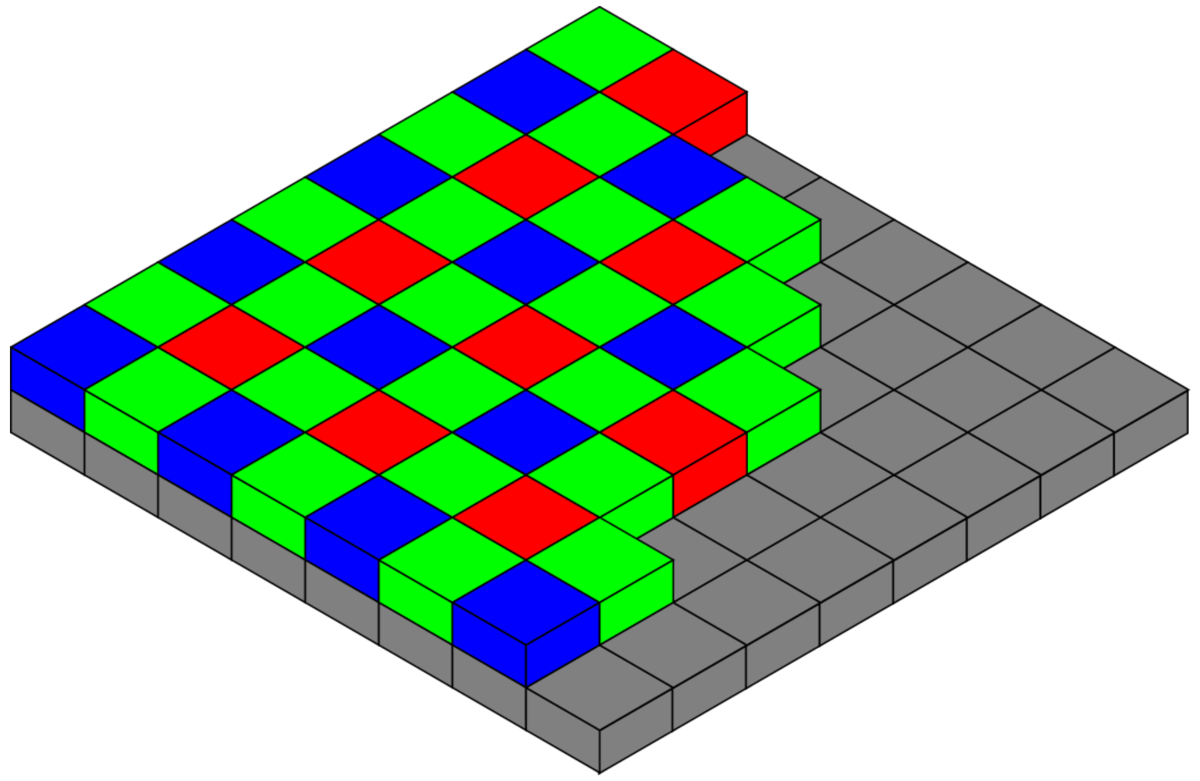

https://en.wikipedia.org/wiki/Bayer_filter

Camera parameters & effects

- Nao camera hardware – meaning
-

The sensor’s ability to simultaneously record low and high intensity signals

$$\text{Dynamic Range} = \frac{\text{FWC}}{\text{Camera Noise}}$$

$$\text{Dynamic Range} = 20 * \text{Log}\,\frac{\text{FWC (stated as number of electrons)}}{\text{Camera Noise (stated as number of electrons)}}$$

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Camera parameters & effects

- Nao camera hardware – meaning
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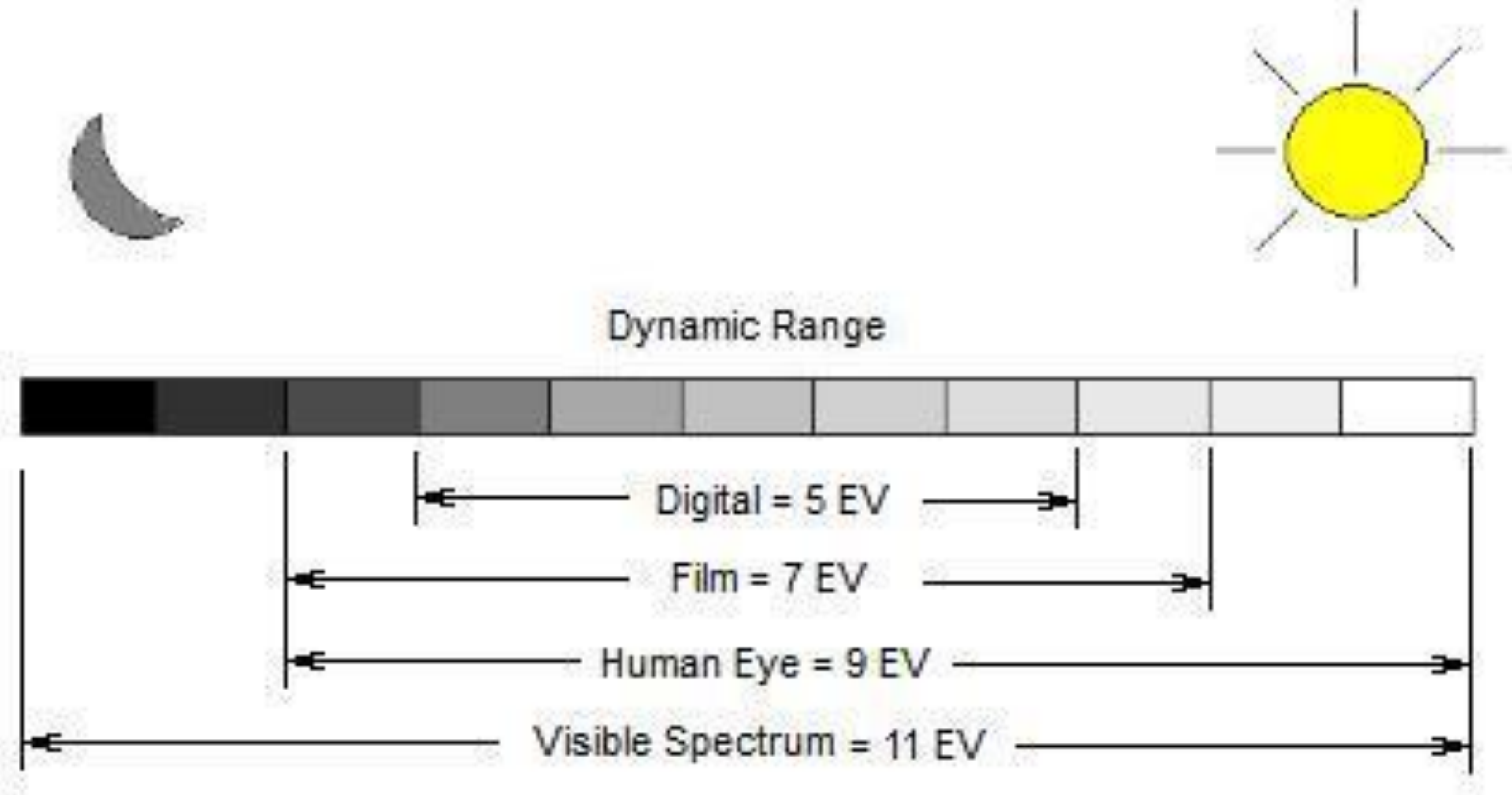

http://www.althephoto.com/concepts/spectrum.jpg

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Camera parameters & effects

- Nao camera hardware – meaning
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http://photographystepbystep.com/wp-content/uploads/2011/02/Dynamic-Range.jpg

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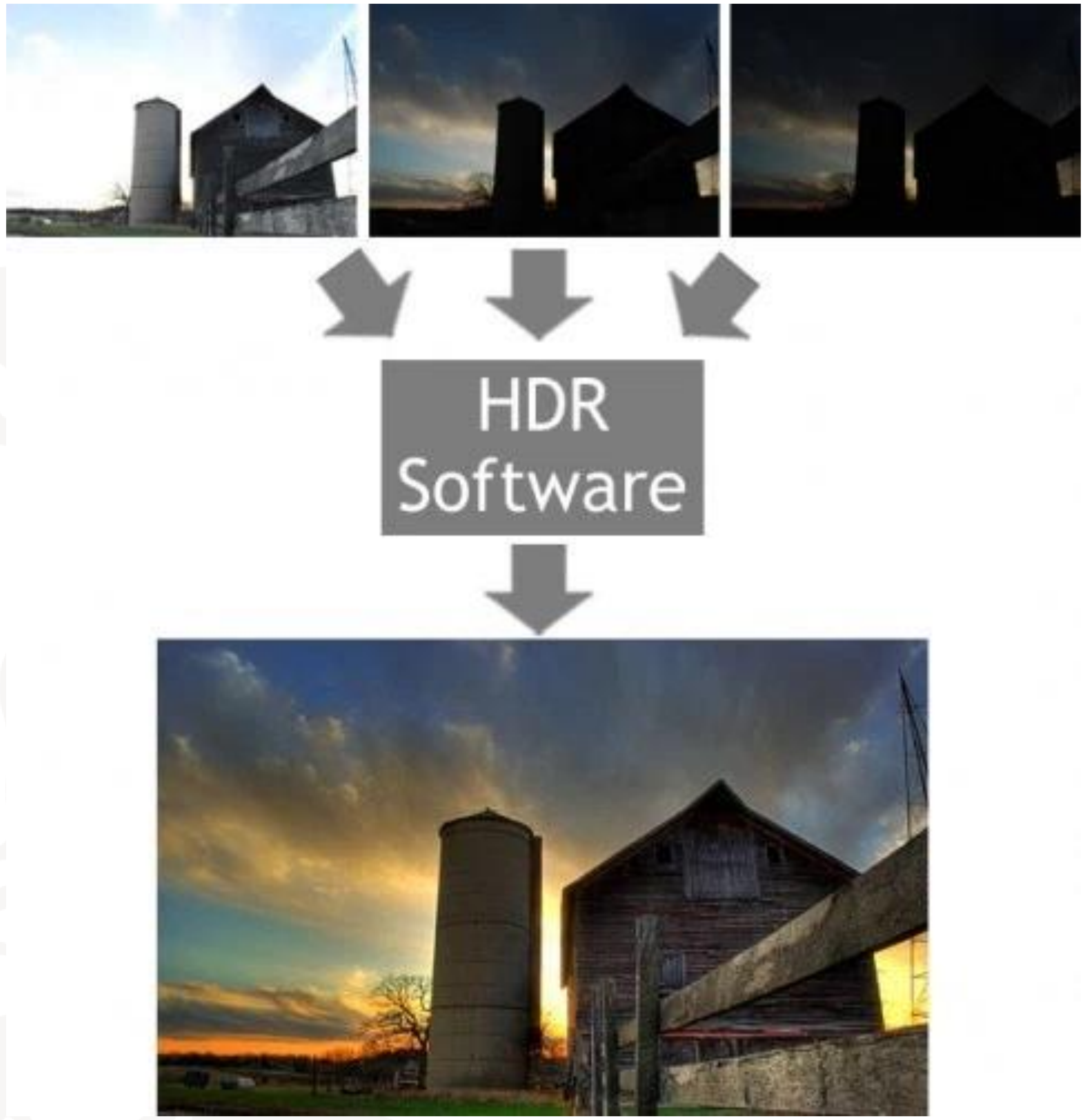
Camera parameters & effects

- Nao camera hardware – meaning



http://i0.wp.com/www.digicamhelp.com/site/wp-content/uploads/2009/06/hdr-demo.jpg

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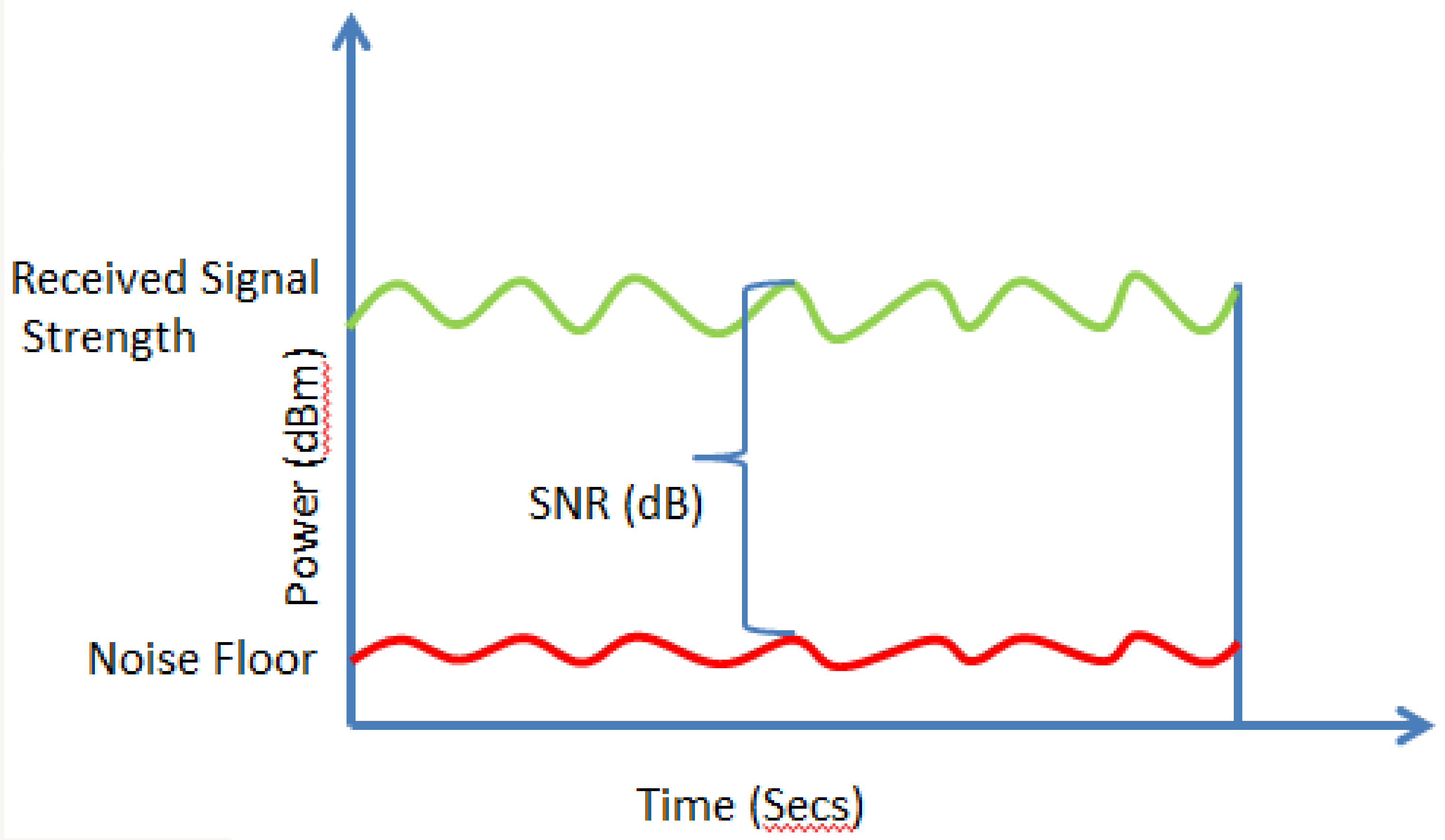
Camera parameters & effects

- Nao camera hardware – meaning
- Noise sources
- Dark noise (current): thermal energy
  - (electrons per pixel per second)
  - Read noise (Quantification noise in A2D)
  - Photon shot noise (uncertainty in counting photons
  - due to stochastic nature of photon impacts)
-
  -



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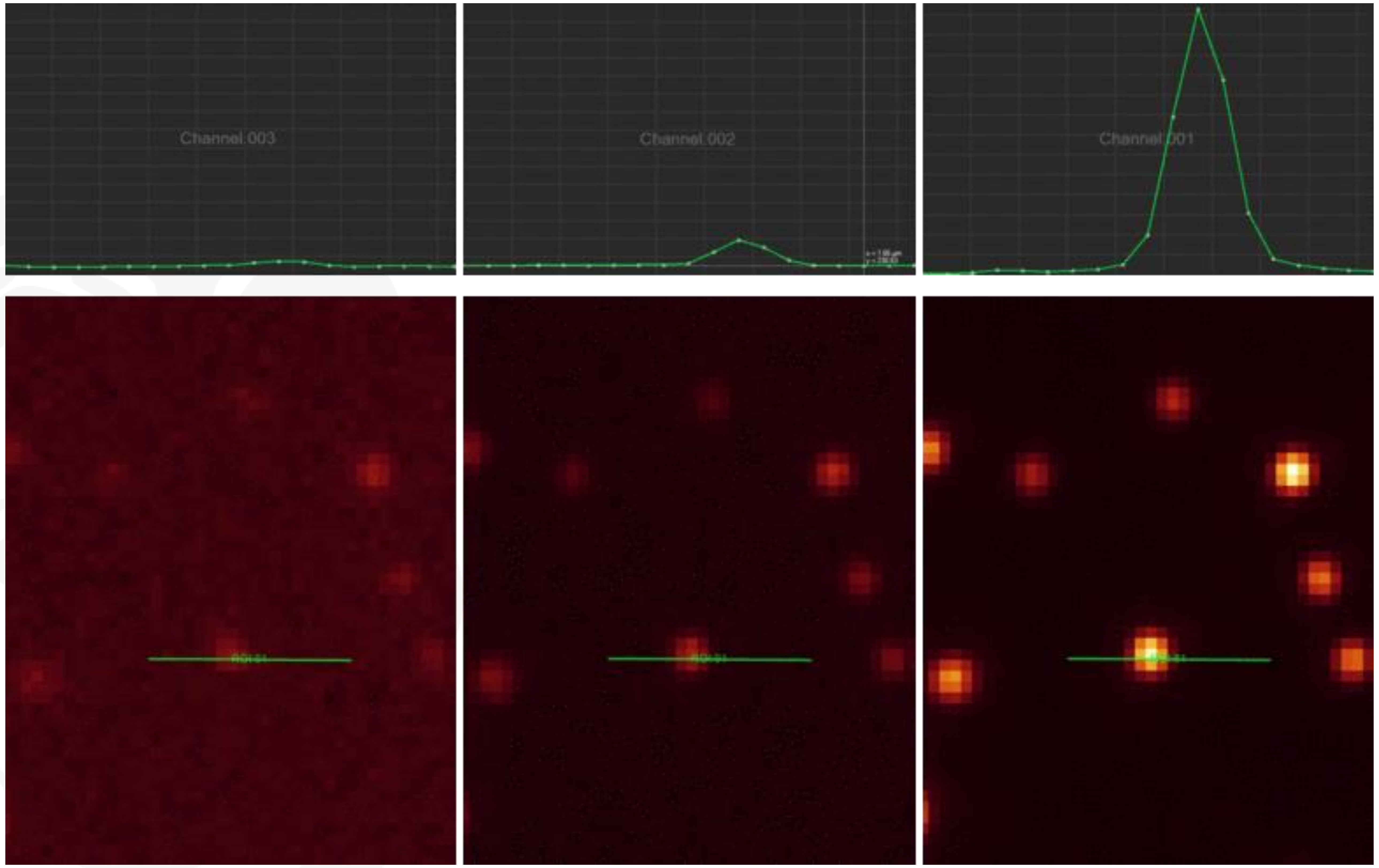
https://documentation.meraki.com/MR/WiFi_Basics_and_Best_Practices/Wireless_fundamentals%3A_Signal-to-Noise_Ratio_(SNR)__and_wireless_signal_strength

Camera parameters & effects

- Nao camera hardware – meaning
-



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Camera parameters & effects

- Nao camera hardware – meaning
- Responsivity:
  - input–output gain of a detector system:
  -
  - electrical output per optical input
-
-
  -

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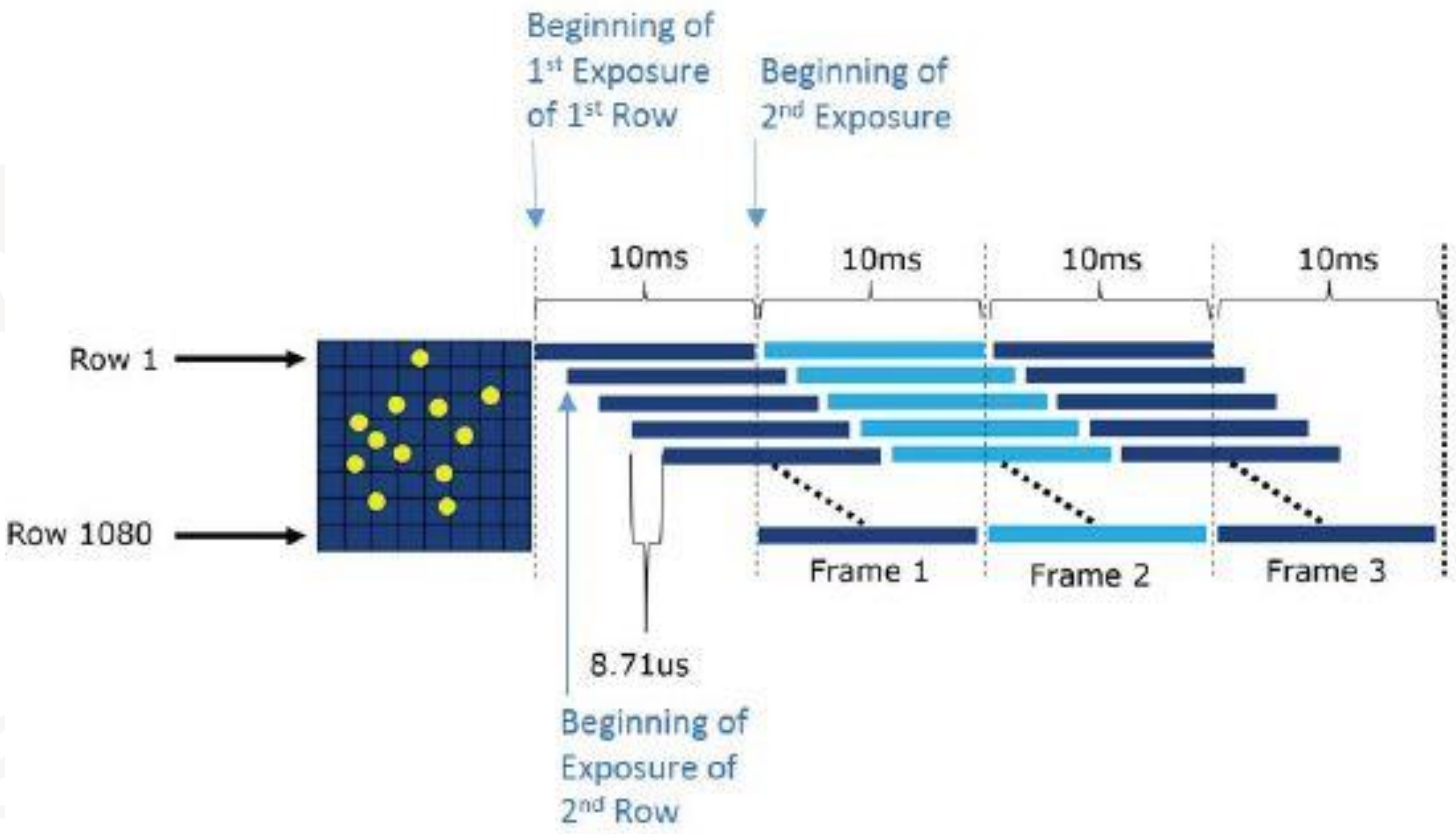
Camera parameters & effects

- Nao camera hardware – meaning
- Rolling shutter



http://www.azom.com/images/Article_Images/ImageForArticle_12006(3).jpg

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Camera parameters & effects

- Nao camera hardware – meaning
- Rolling shutter

a)

b)

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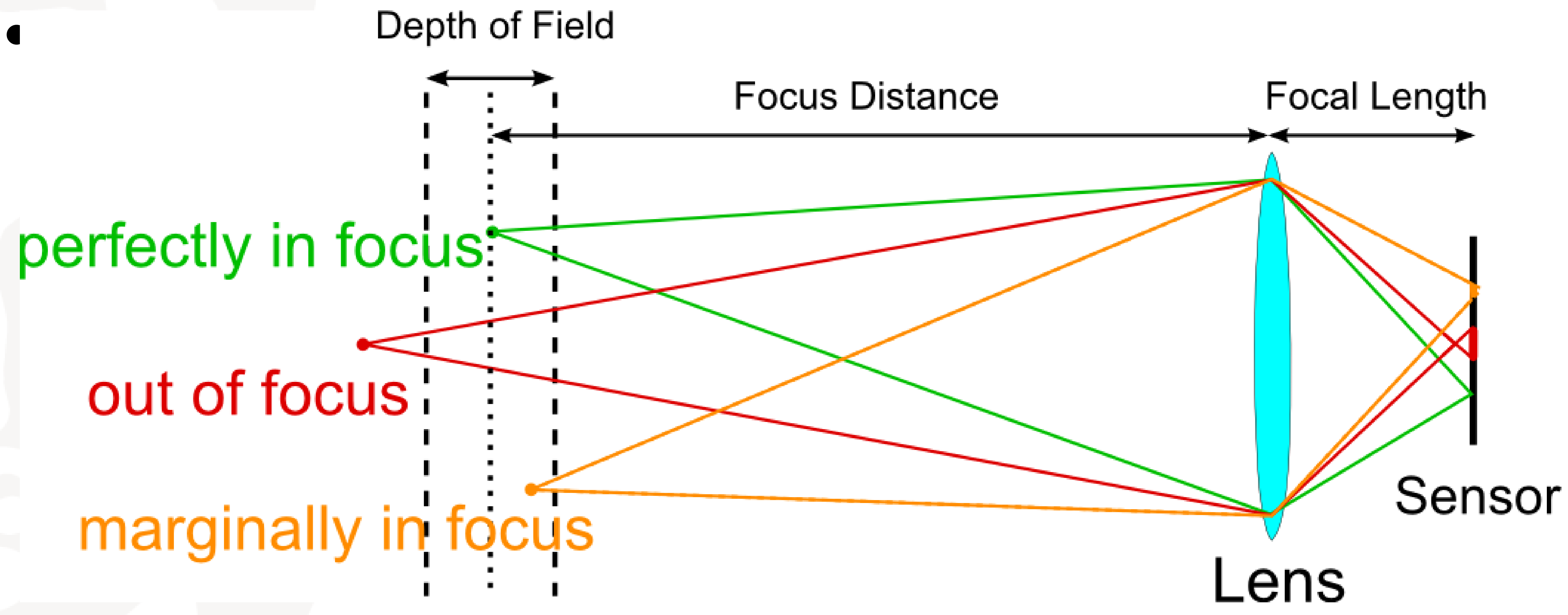
Camera parameters & effects

- Nao camera hardware – meaning
- No focus control, preset by designer,
- usually at a distance for which depth of field will
- reach infinity even at the greatest aperture
  - possible with the lens.
-



https://cdn.photographylife.com/wp-content/uploads/2014/06/lens_dof.png

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http://imgur.com/LI1kx5u

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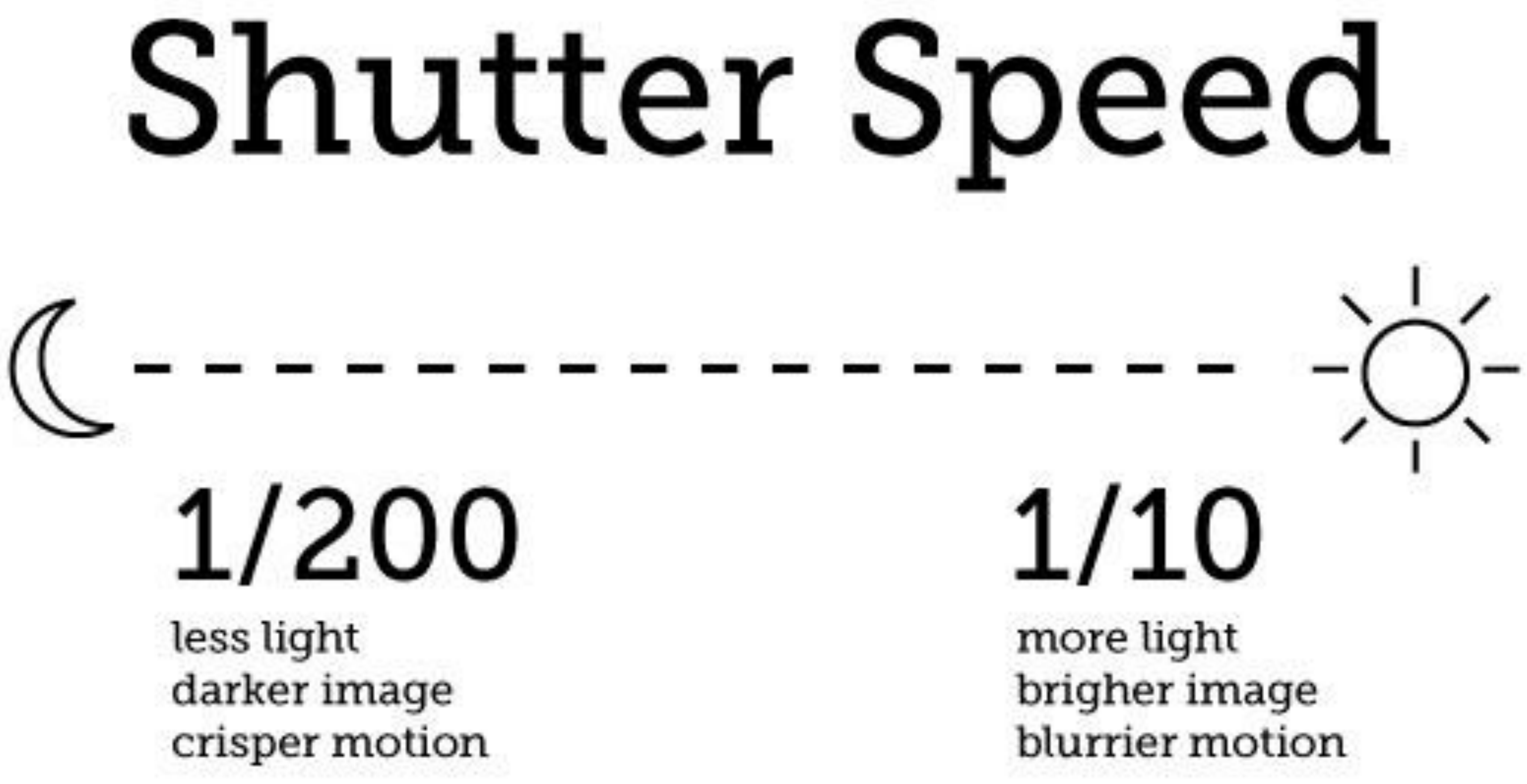
TOC

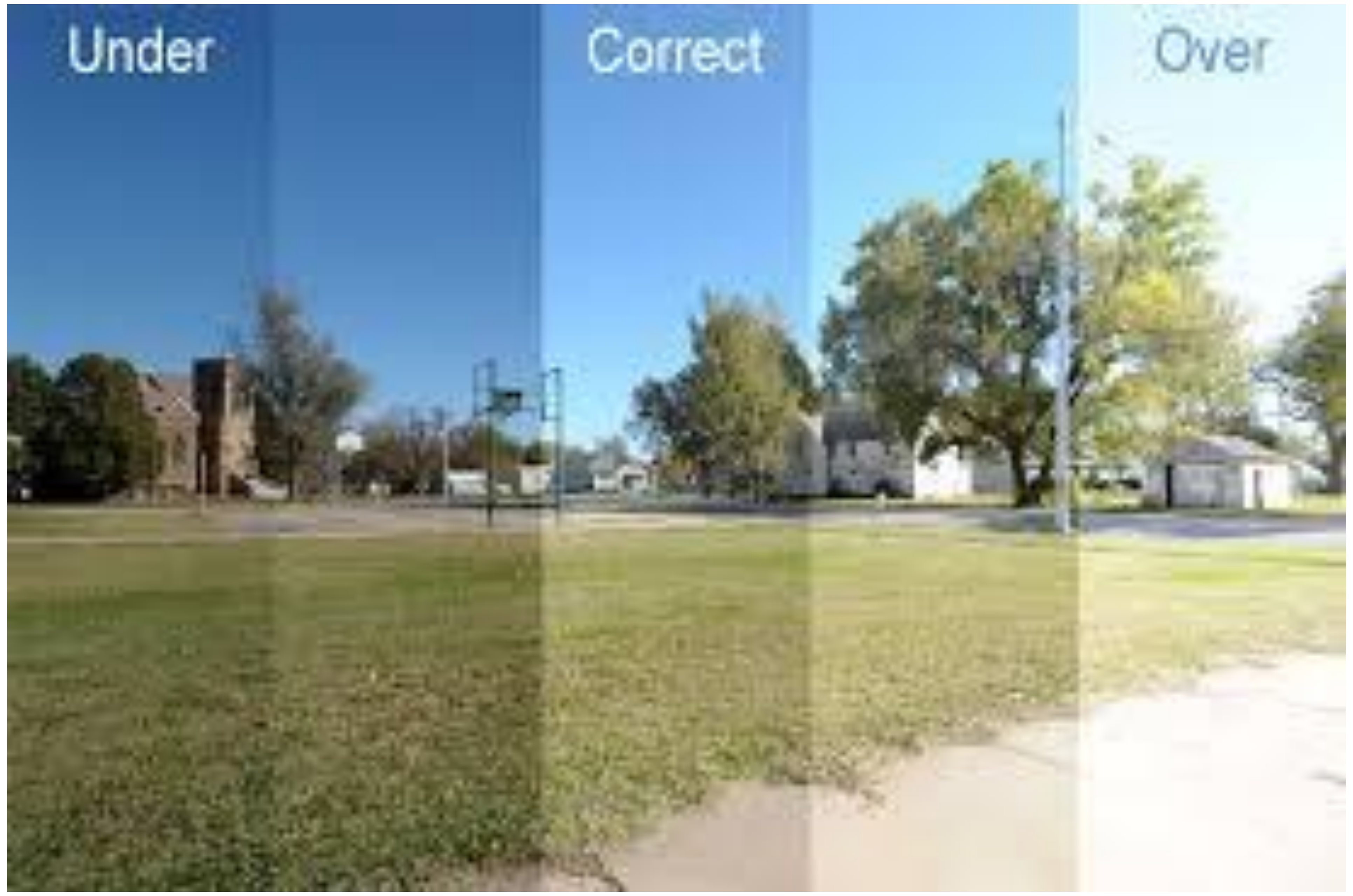
- Camera & sensor hardware
- Parameters

Parameters

- Parameters
  - Exposure
    - How long do we want to count photons?



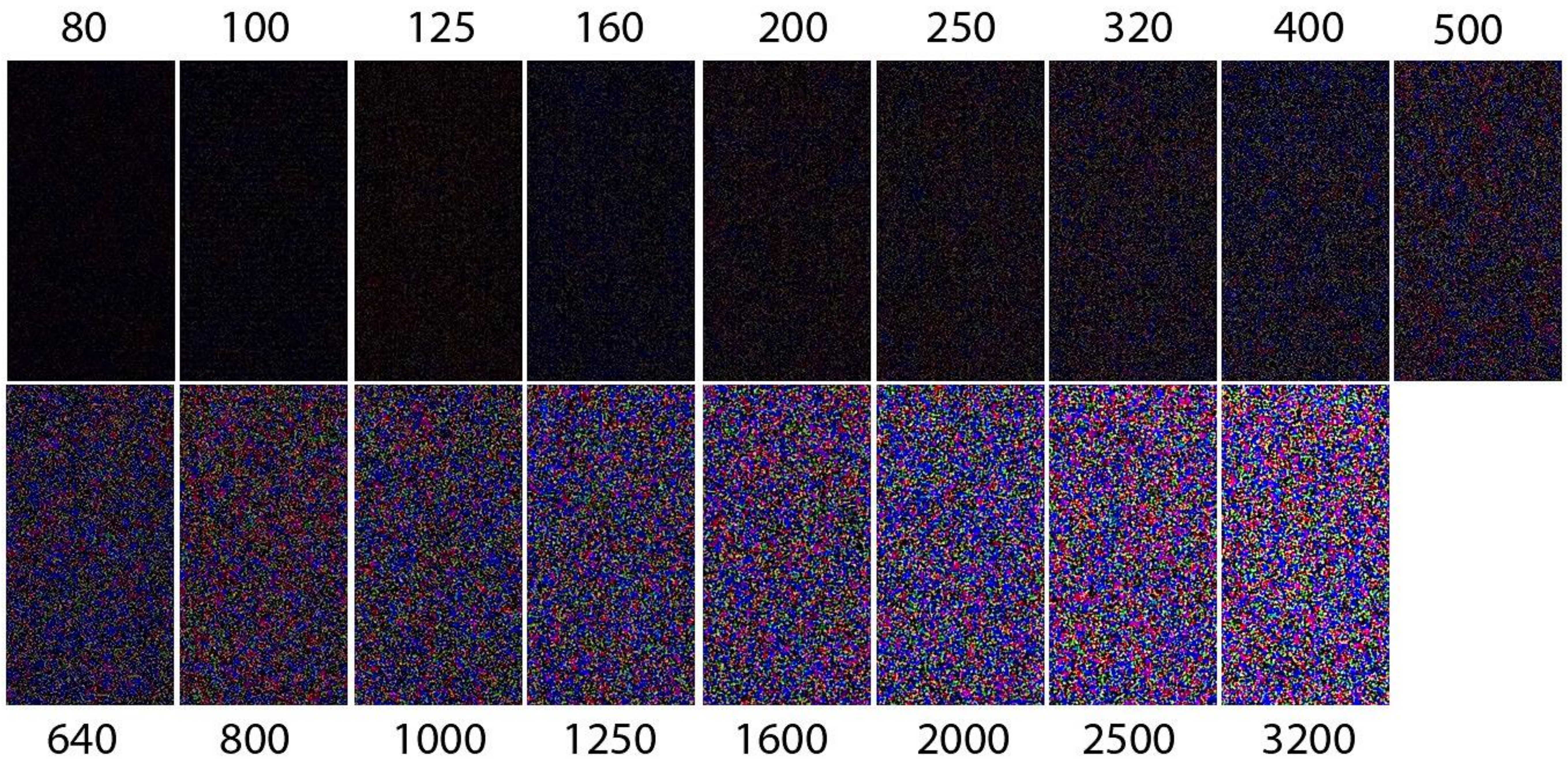
https://cdn.tutsplus.com/photo/uploads/legacy/287_meterviewfinder/PerfectExposure-1.jpg



http://www.myphotoshopsite.com/tutorials/level_3/images/exposure_sample.jpg

Parameters

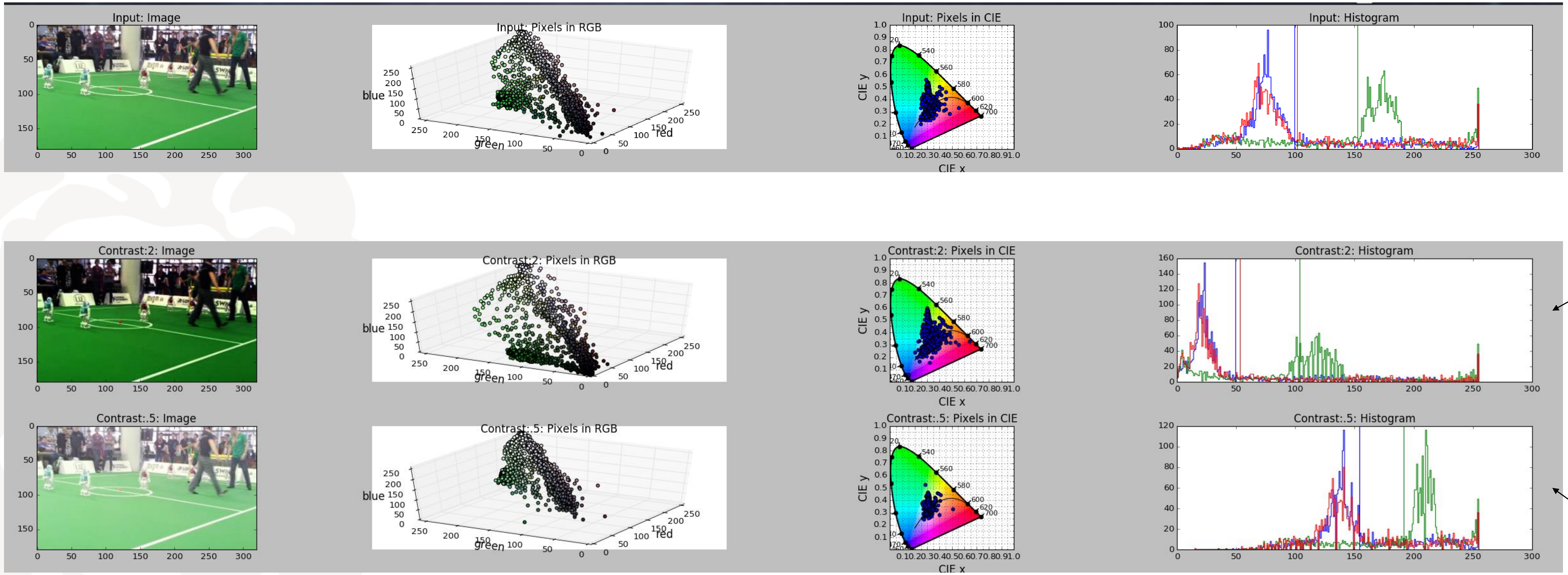
- Parameters
  - Gain (ISO in digital sensors)
    - Amount of amplification
    - Effect: More quantification & photon noise → Lower SNR!

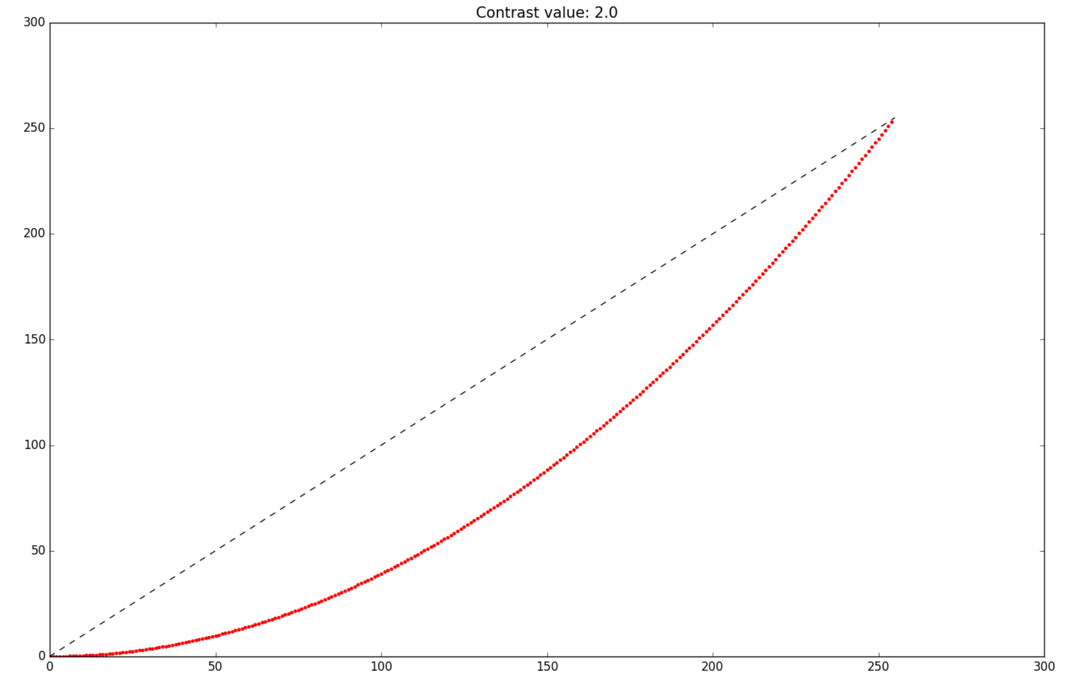


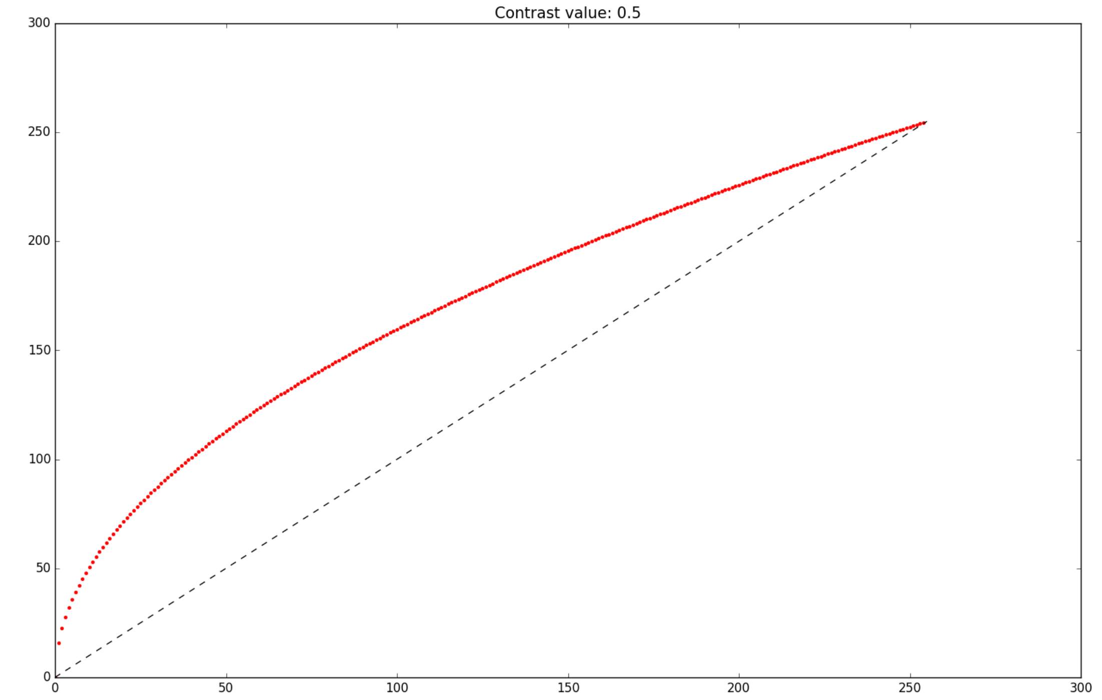
https://blog.carlchapman.com/wp-content/uploads/2011/07/canon-g12-noise-shots-4EV.jpg

Parameters

- Parameters
  - Contrast (nao: slope of curve at the end, could not find details about mapping function)

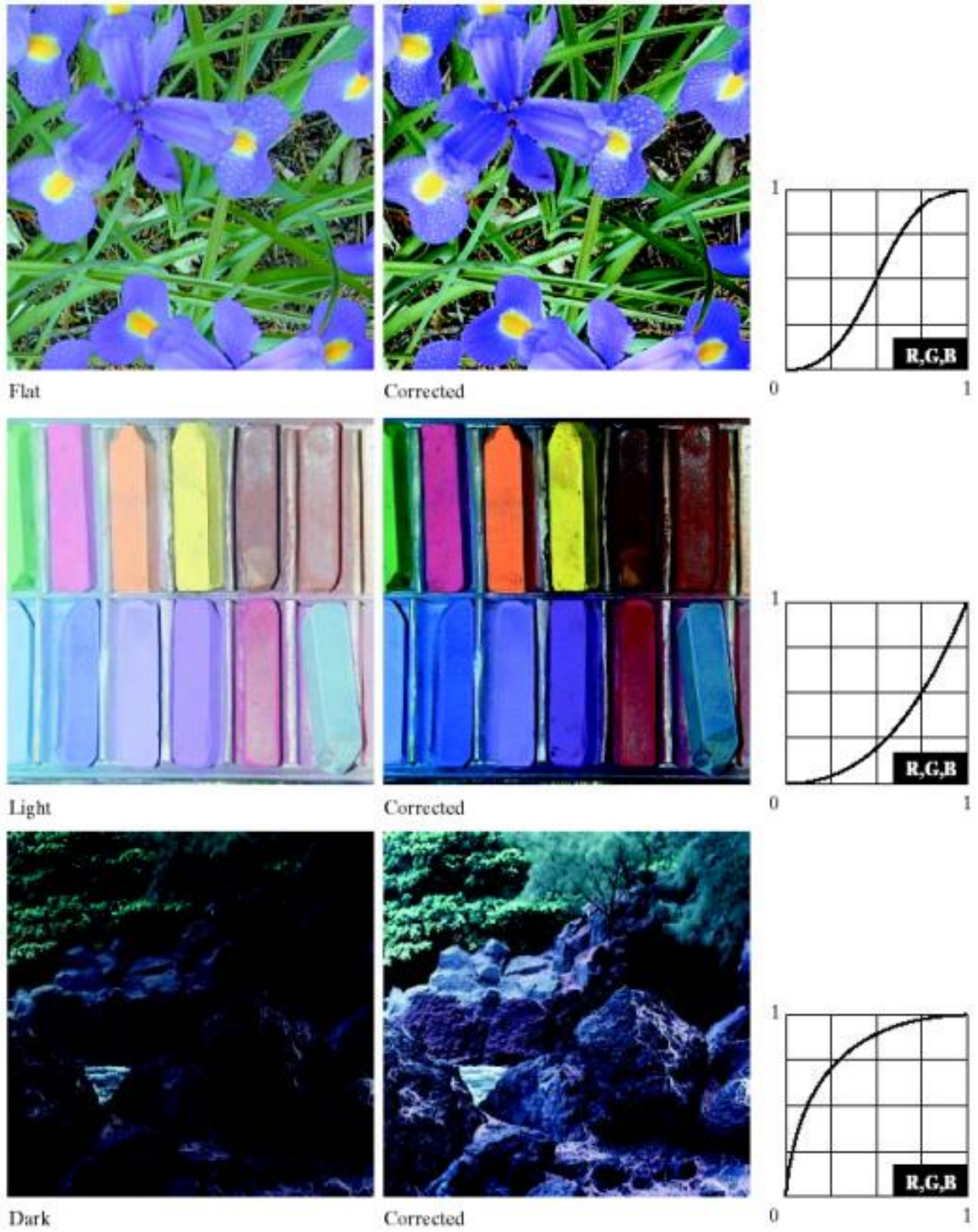






Parameters

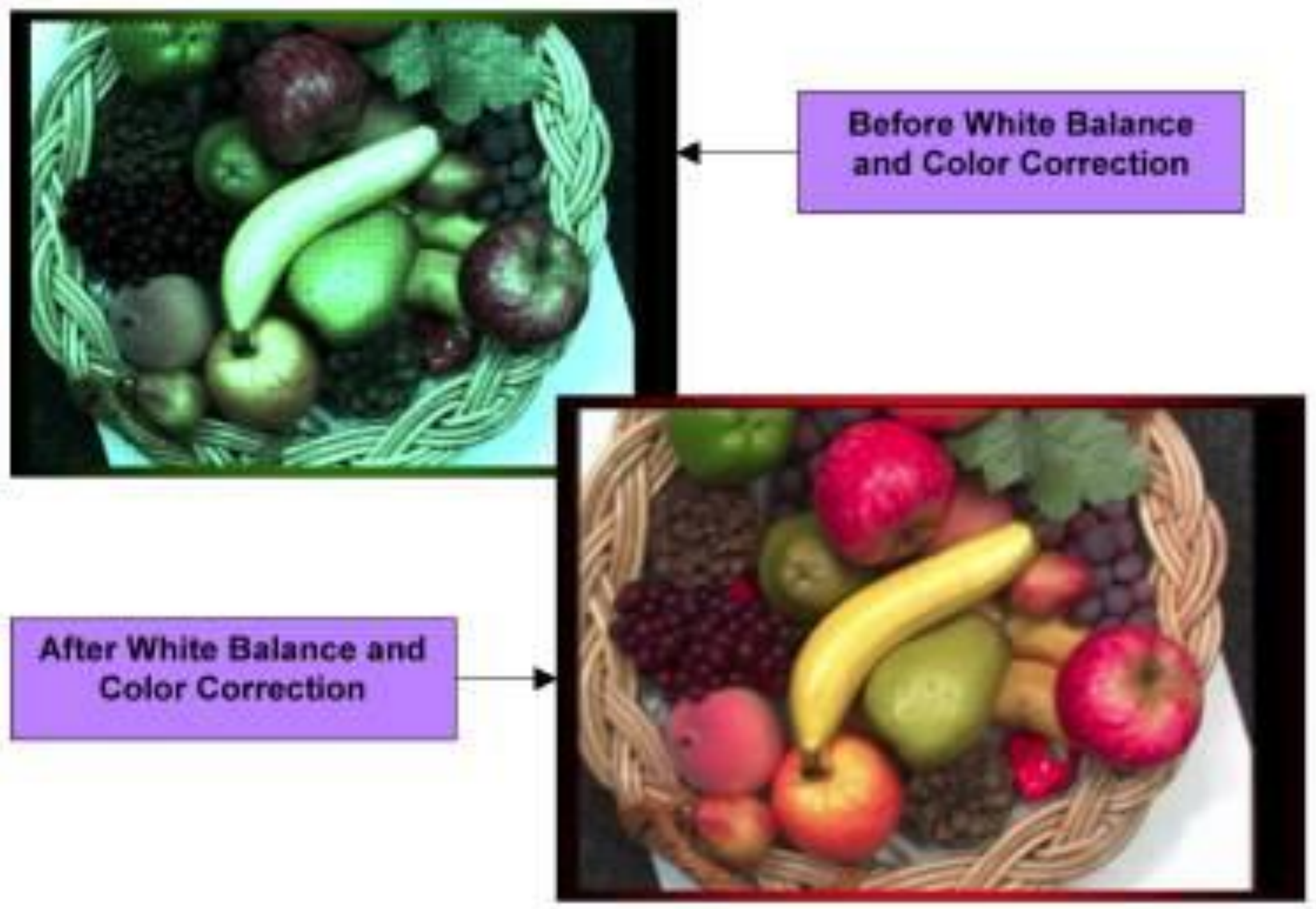
- Parameters
  - Contrast



http://eeweb.poly.edu/~yao/EL5123/lecture3_contrast_enhancement.pdf

Parameters – White balance

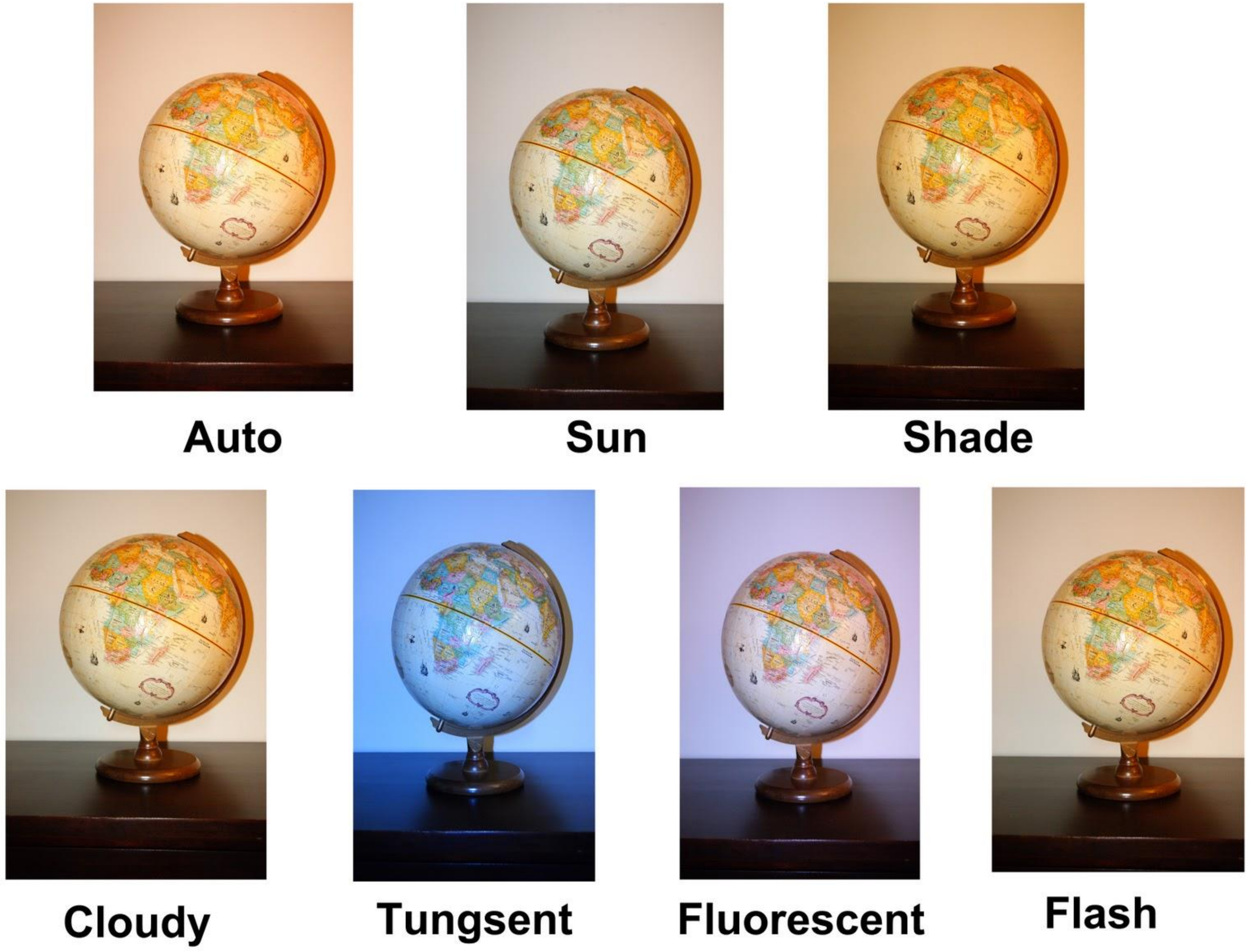
- Parameters - White balance
  - Why?
    - Remember: Bayer-Pattern to approximate the color response of the human visual system, which peaks in sensitivity in the green spectral region (approximately 550 nanometer wavelength). This approximation has to be translated back when displaying images → White balance (compute initial wavelength (color) that produced measurements)



http://www.siliconimaging.com/RGB%20Bayer.htm

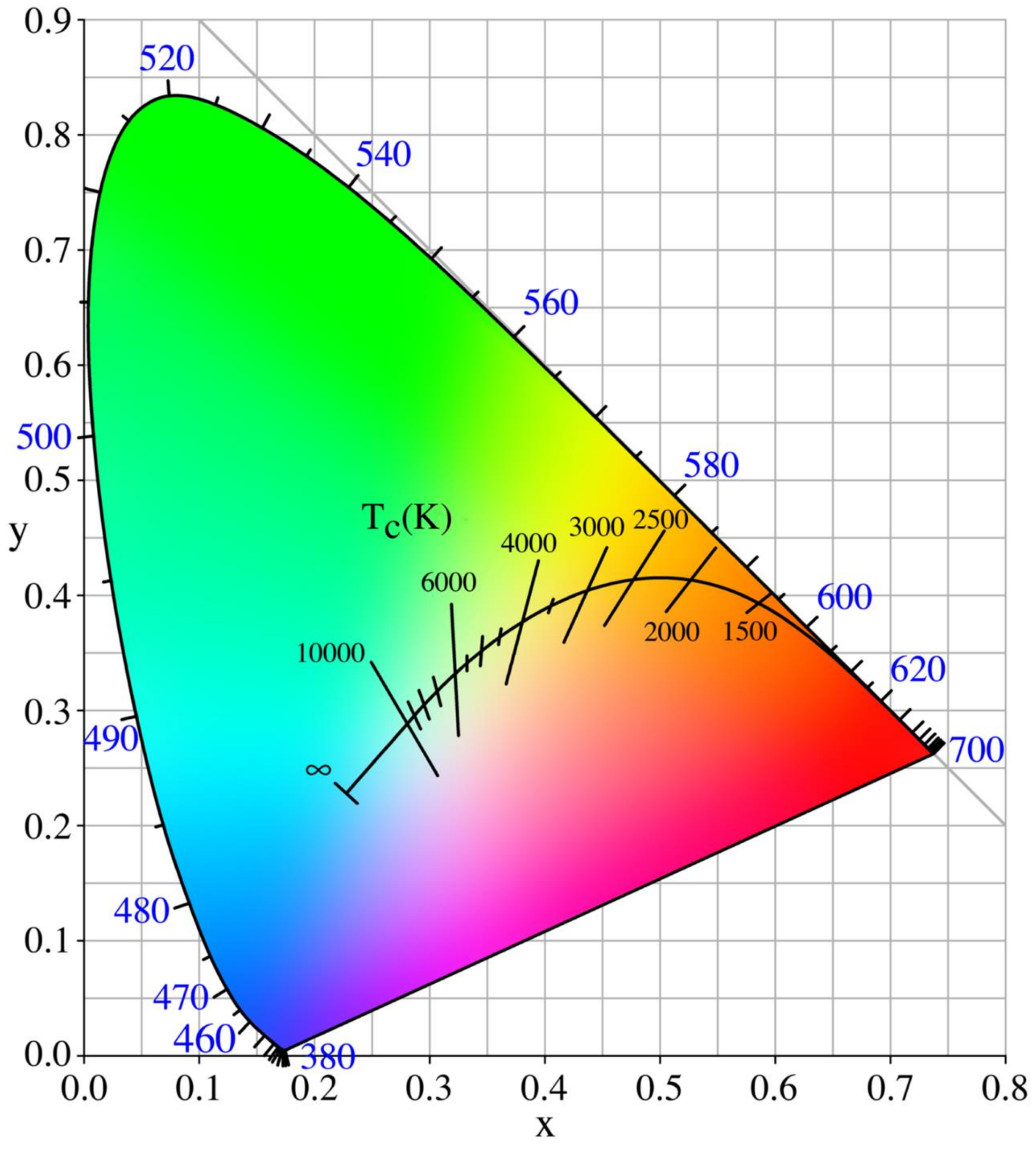
Parameters – White balance

- Parameters - White balance
  -



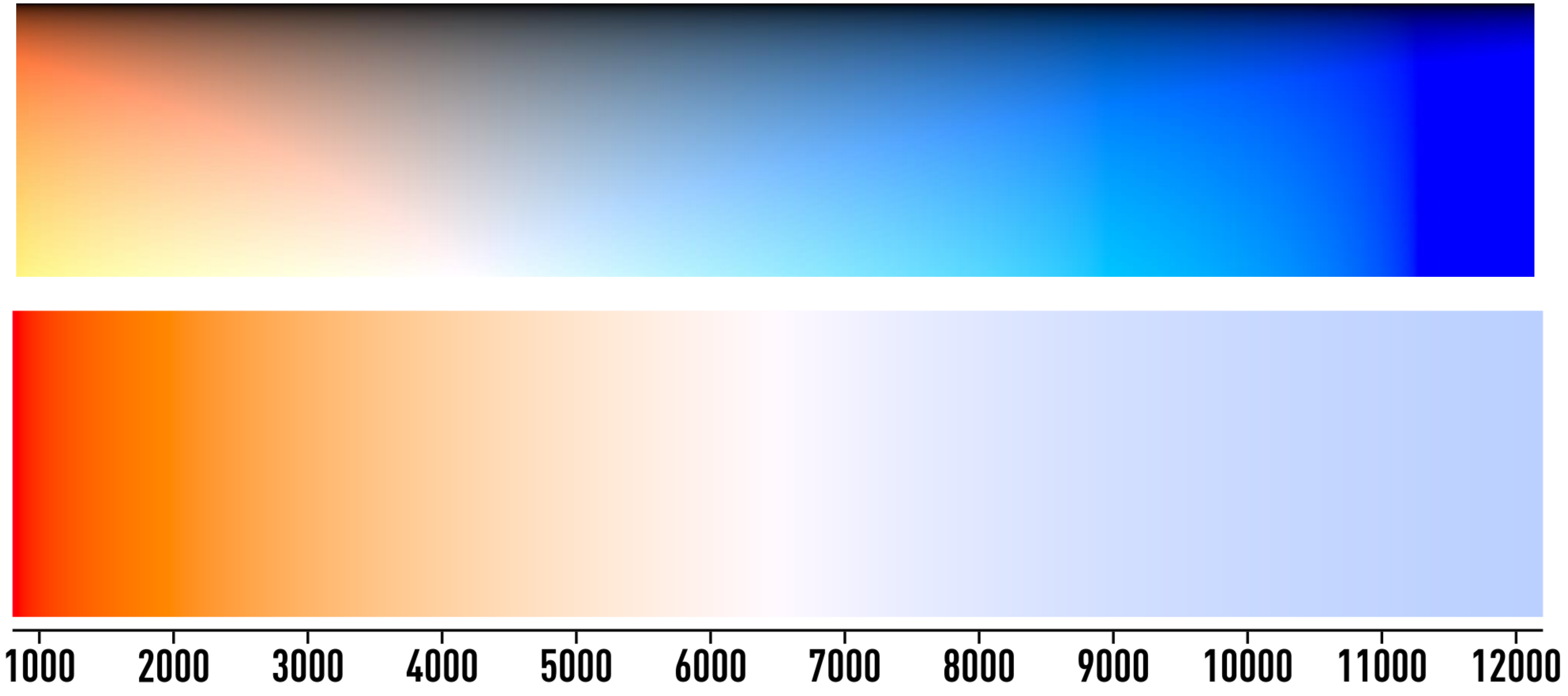
http://www.jrstjeanphotography.com/2011/01/end-of-white-balance.html

- Parameters - White balance
  - Why is white balance specified with Temperature in Kelvin?!
  - → planckian blackbody radiators (good approximation to natural + artificial light sources)
-



https://en.wikipedia.org/wiki/Black-body_radiation

Source: Tobi



https://en.wikipedia.org/wiki/Black-body_radiation

Parameters – White balance

- Parameters - White balance
  - Approaches (image color correction or illuminant estimation + correction)
  - Scale R,G,B (or XYZ, or LMS, von Kries hypothesis, image color correction):
    - Assumed “white/neutral” pixel: [R’, G’, B’], scale each color channel individually
  -

- Take a picture of a neutral object (white or gray)
- Deduce the weight of each channel
  - If the object is recoded as r_w, g_w, b_w use weights $1/r_w$, $1/g_w$, $1/b_w$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 255/R'_w & 0 & 0 \\ 0 & 255/G'_w & 0 \\ 0 & 0 & 255/B'_w \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

Parameters – White balance

- Common selection of white/neutral → scale factors:
- **Grey world assumption** (average reflectance of a scene is achromatic)
-
  - *"[…] we can adjust a gain factor to two of the channels so that both their means are now equal to the reference channel, which is often taken to be green."*

$$R_{\text{avg}} = \frac{1}{n^2}\sum_{x=1}^{n}\sum_{y=1}^{n} R_{\text{sensor}}(x,y)$$

$$G_{\text{avg}} = \frac{1}{n^2}\sum_{x=1}^{n}\sum_{y=1}^{n} G_{\text{sensor}}(x,y). \longrightarrow \hat{\alpha} = \frac{G_{\text{avg}}}{R_{\text{avg}}} \quad \text{and} \quad \hat{\beta} = \frac{G_{\text{avg}}}{B_{\text{avg}}}. \longrightarrow$$

$$B_{\text{avg}} = \frac{1}{n^2}\sum_{x=1}^{n}\sum_{y=1}^{n} B_{\text{sensor}}(x,y)$$

$$\hat{R}_{\text{sensor}}(x,y) = \hat{\alpha} R_{\text{sensor}}(x,y)$$
$$\hat{G}_{\text{sensor}}(x,y) = G_{\text{sensor}}(x,y).$$
$$\hat{B}_{\text{sensor}}(x,y) = \hat{\beta} B_{\text{sensor}}(x,y)$$

-
  - ***"This gray world method is quite effective in practice, except in situations where***
  - ***a certain color may dominate, […]"***

Very good general report on white balance and algorithms: https://courses.cs.washington.edu/courses/cse467/08au/labs/l5/whiteBalance.pdf

Parameters – White balance

- Common selection of white/neutral → scale factors:
  - **Retinex Theory (white patch)**
    - perceived white is associated with the maximum cone signals (white world assumption)
    - brightest point in an image is often due to reflectance of a glossy surface,
    - which tends to reflect the actual color of the light source
    - attempts to equalize the maximum value of the three channels to produce a white patch

$$R_{\max} = \max_{x,y} R_{\text{sensor}}(x,y)$$
$$G_{\max} = \max_{x,y} G_{\text{sensor}}(x,y).$$
$$B_{\max} = \max_{x,y} B_{\text{sensor}}(x,y)$$

$$\longrightarrow \quad \tilde{\alpha} = \frac{G_{\max}}{R_{\max}} \quad \text{and} \quad \tilde{\beta} = \frac{G_{\max}}{B_{\max}}. \quad \longrightarrow$$

$$\tilde{R}_{\text{sensor}}(x,y) = \tilde{\alpha} R_{\text{sensor}}(x,y)$$
$$\tilde{G}_{\text{sensor}}(x,y) = G_{\text{sensor}}(x,y).$$
$$\tilde{B}_{\text{sensor}}(x,y) = \tilde{\beta} B_{\text{sensor}}(x,y)$$

Very good general report on white balance and algorithms:
https://courses.cs.washington.edu/courses/cse467/08au/labs/l5/whiteBalance.pdf

Parameters – White balance

- Common selection of white/neutral → scale factors:
  - **Iterative white-balancing**
  - **Problems of grey-world: heavily biased towards color-cast if scene is dominated by color**
  - **Problems of white-world: a few bright pixels might dominate calculations**
  - Idea: transform image to YUV space, find pixels that satisfy a grey-condition (subset!)
  - $$\frac{|U|+|V|}{Y} < \eta,$$
  - Average the U,V values of these pixels, then:

$$\phi_j = \max(|\hat{U}_{\text{avg}}|, |\hat{V}_{\text{avg}}|). \tag{10.36}$$

If this equals to $\hat{U}_{\text{avg}}$, implying that the color is biased towards blue, we adjust the gain of the blue channel. Otherwise, the color is biased towards red, and the gain of the red channel is adjusted. The amount of adjustment used in Reference [24] is empirical and determined by trial and error. This changes $\hat{U}_{\text{avg}}$ and $\hat{V}_{\text{avg}}$ for the next iteration, and Equation 10.36 is computed again until satisfactory results are obtained.

Very good general report on white balance and algorithms:
https://courses.cs.washington.edu/courses/cse467/08au/labs/l5/whiteBalance.pdf

Parameters – White balance

- Other methods:
  - Illuminant voting
  - Color by correlation
  - Gamut mapping
  - Bayesian formulation, Neural nets, combined strategies
  -
  - Question: which method is used by Nao?

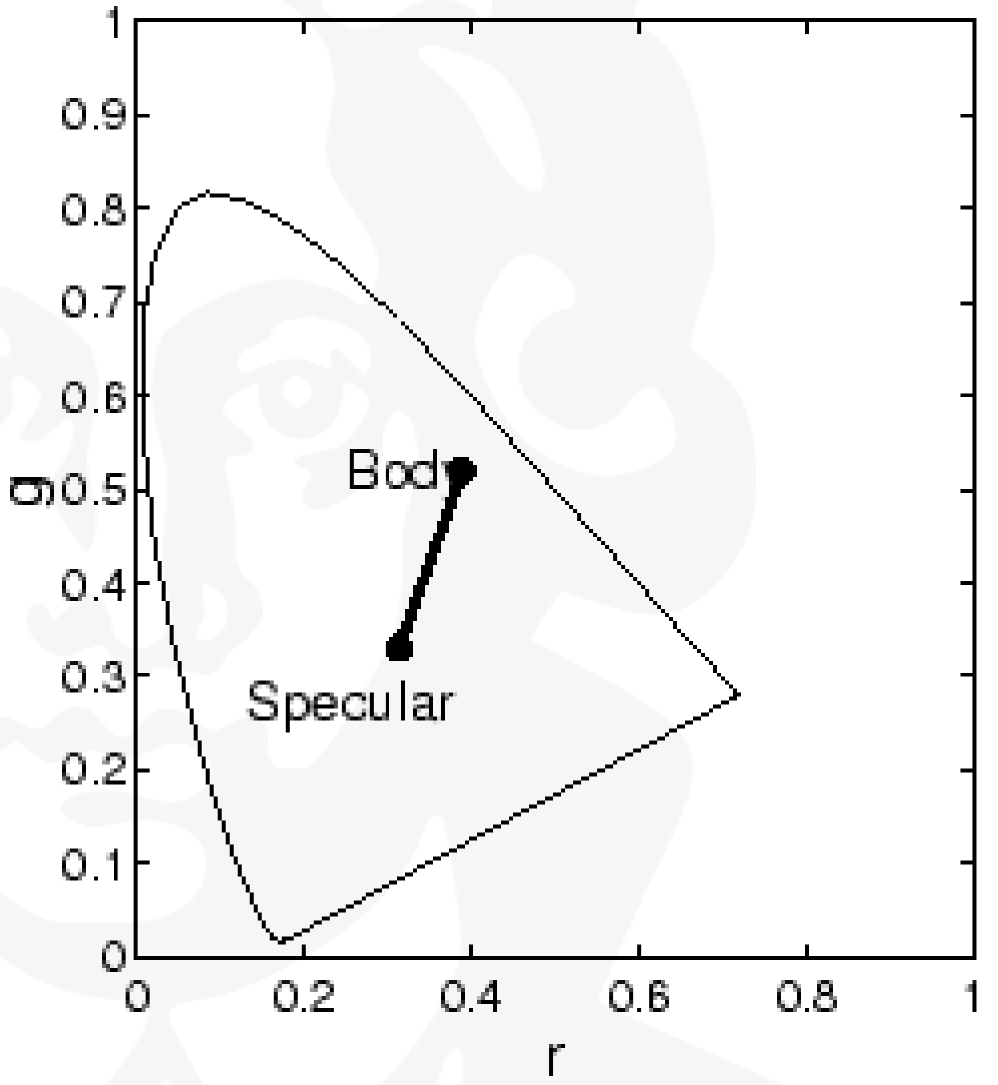
$$\begin{bmatrix} R_{\text{sensor}} \\ G_{\text{sensor}} \\ B_{\text{sensor}} \end{bmatrix} = \begin{bmatrix} \int_{400}^{700} r(\lambda) \sum_{j=1}^{m} \sum_{k=1}^{n} \alpha_j \beta_k I_j(\lambda) R_k(\lambda)\, \mathrm{d}\lambda \\ \int_{400}^{700} g(\lambda) \sum_{j=1}^{m} \sum_{k=1}^{n} \alpha_j \beta_k I_j(\lambda) R_k(\lambda)\, \mathrm{d}\lambda \\ \int_{400}^{700} b(\lambda) \sum_{j=1}^{m} \sum_{k=1}^{n} \alpha_j \beta_k I_j(\lambda) R_k(\lambda)\, \mathrm{d}\lambda \end{bmatrix}$$
$$= \left(\sum_{k=1}^{n} \beta_k M_k \right) \boldsymbol{\alpha},$$

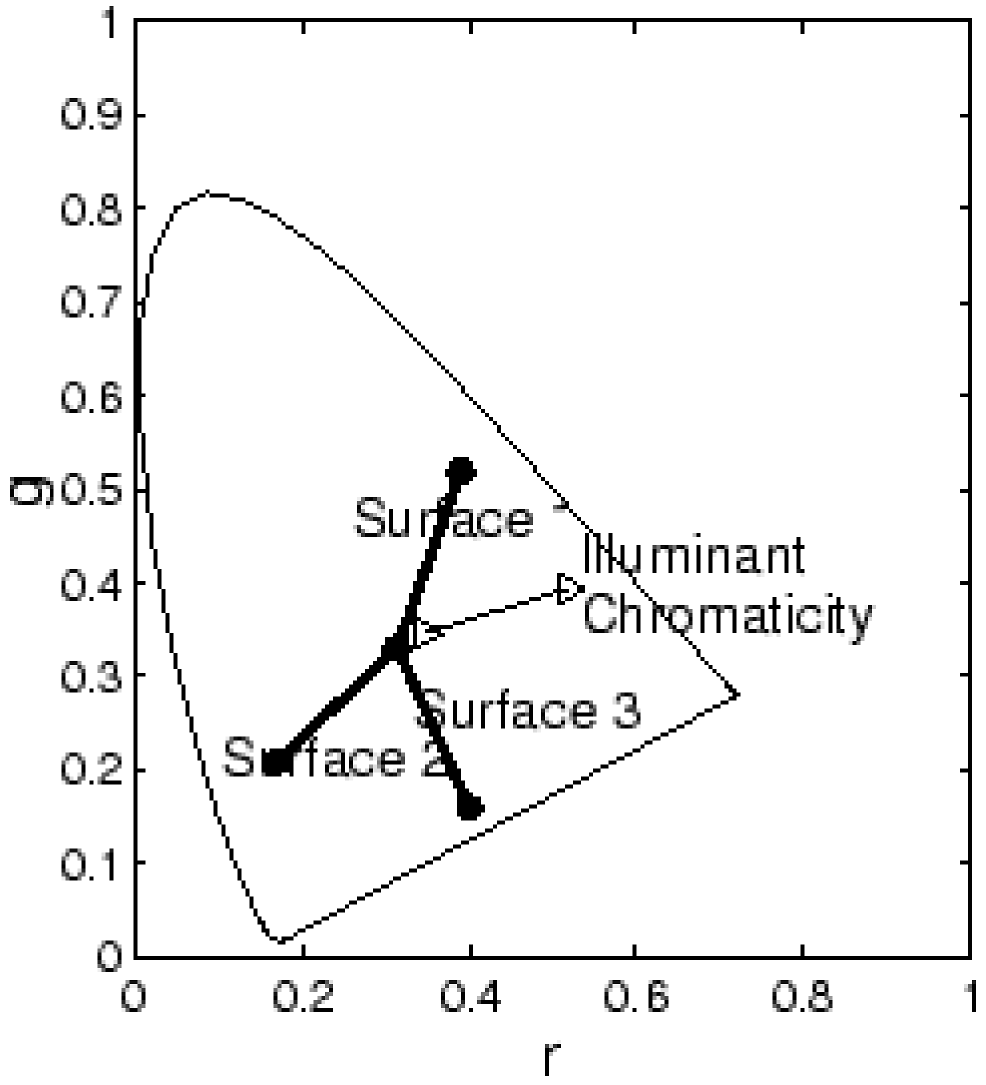
Very good general report on white balance and algorithms:
https://courses.cs.washington.edu/courses/cse467/08au/labs/l5/whiteBalance.pdf

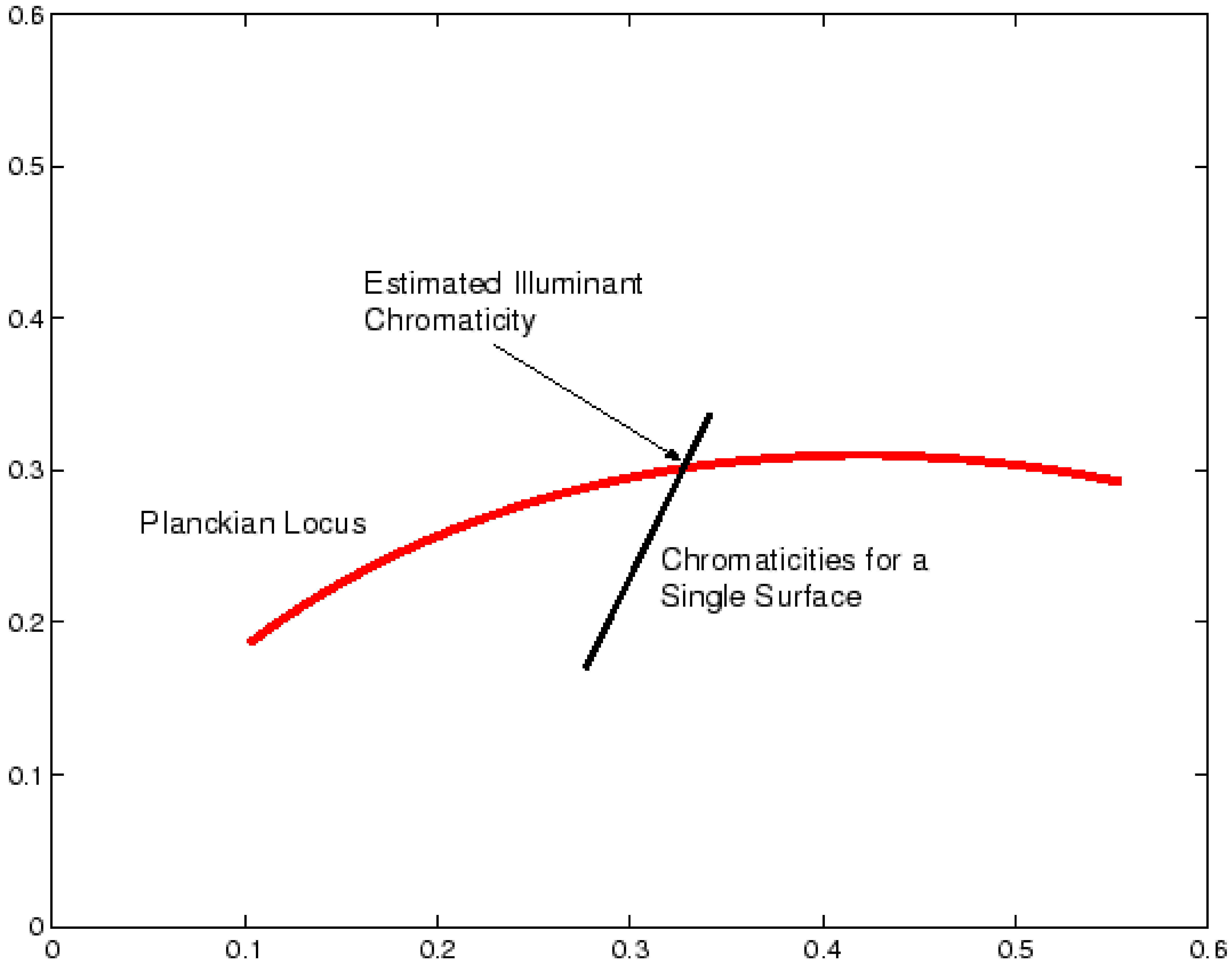
Parameters – Illuminant estimation

- Illumination estimation (constrained)
  - Lee et. al:
  -

Hsien-Che Lee. Method for computing scene-illuminant chromaticity from specular highlights. In Glenn E. Healey and Steven A. Shafer and Lawrence B. Wolff, editor, Color, pages 340-347. Jones and Bartlett, Boston, 1992.







http://www2.cmp.uea.ac.uk/Research/compvis/CGmainPhysicsBased.htm

Parameters – Illuminant estimation

- Illumination estimation
  -
  -