THE UNIVERSITY OF BRITISH COLUMBIA

CPSC 425: Computer Vision

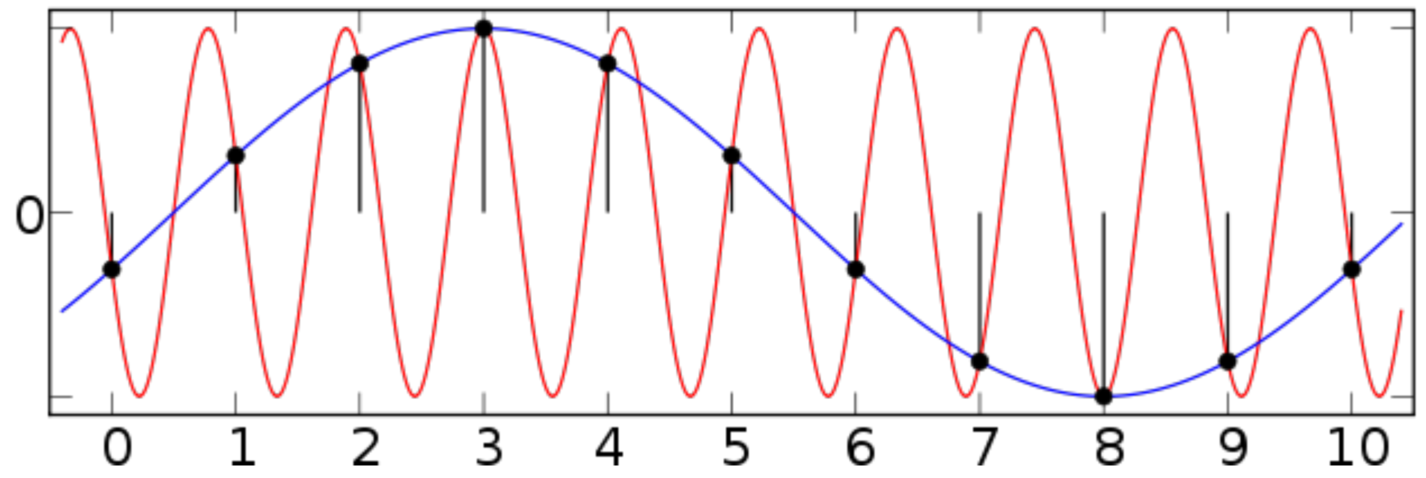


Image Credit: https://en.wikibooks.org/wiki/Analog_and_Digital_Conversion/Nyquist_Sampling_Rate

Lecture 8: Sampling (continued)

(unless otherwise stated slides are taken or adopted from **Bob Woodham, Jim Little** and **Fred Tung**)

Menu for Today (**September 25, 2020**)

Topics:

— Color Filter Arrays
— Bayer patterns
— Template matching
— Normalized Correlation

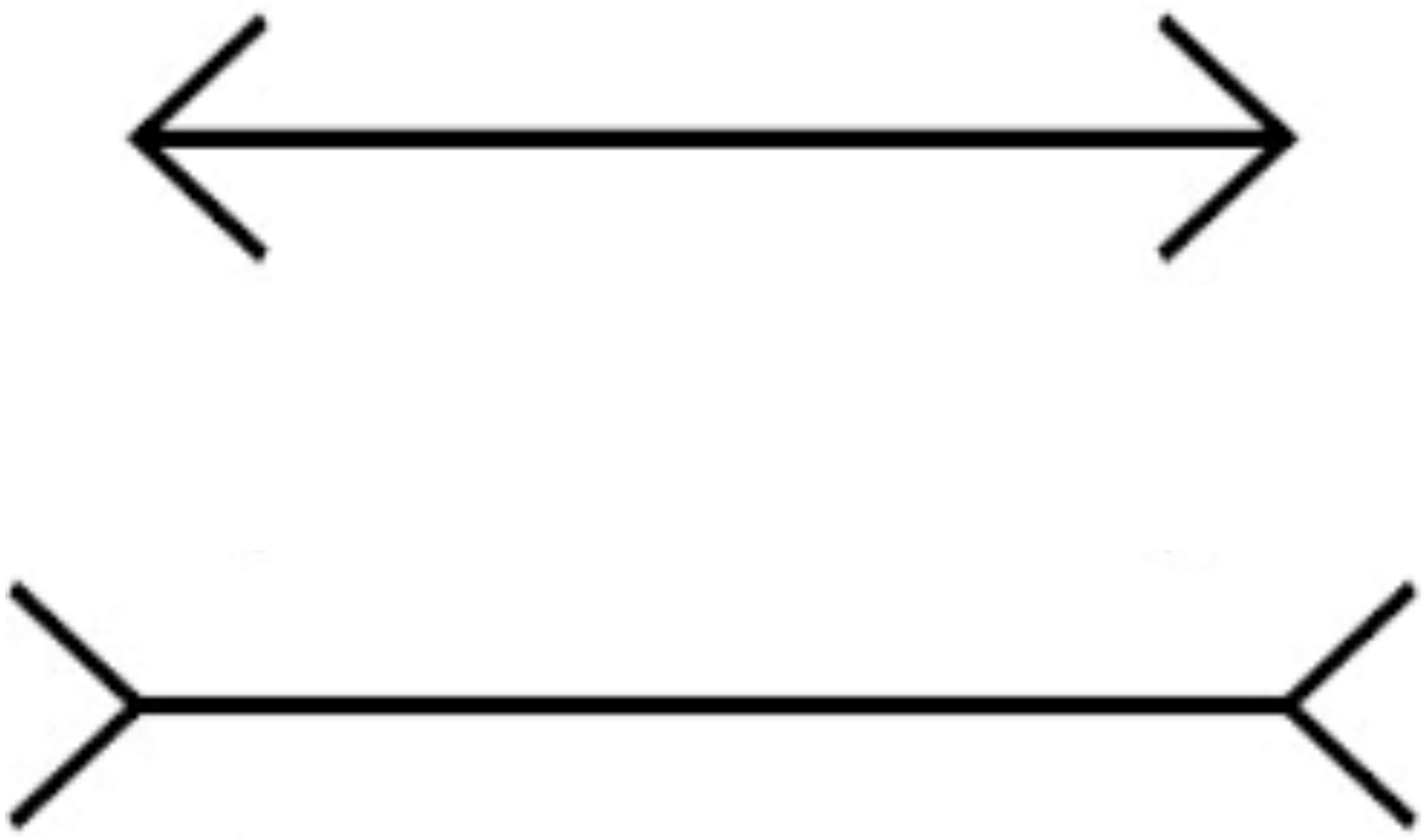
Redings:

— **Today's** Lecture: Forsyth & Ponce (2nd ed.) 4.5
— **Next** Lecture: Forsyth & Ponce (2nd ed.) 4.6, 4.7

Reminders:

— **Assignment 1:** Image Filtering and Hybrid Images due **September 30**th
— **Quiz 1** is out (due by midnight Friday) — chance performance 45%
— Lecture timing

Today's "**fun**" Example: Müller-Lyer Illusion



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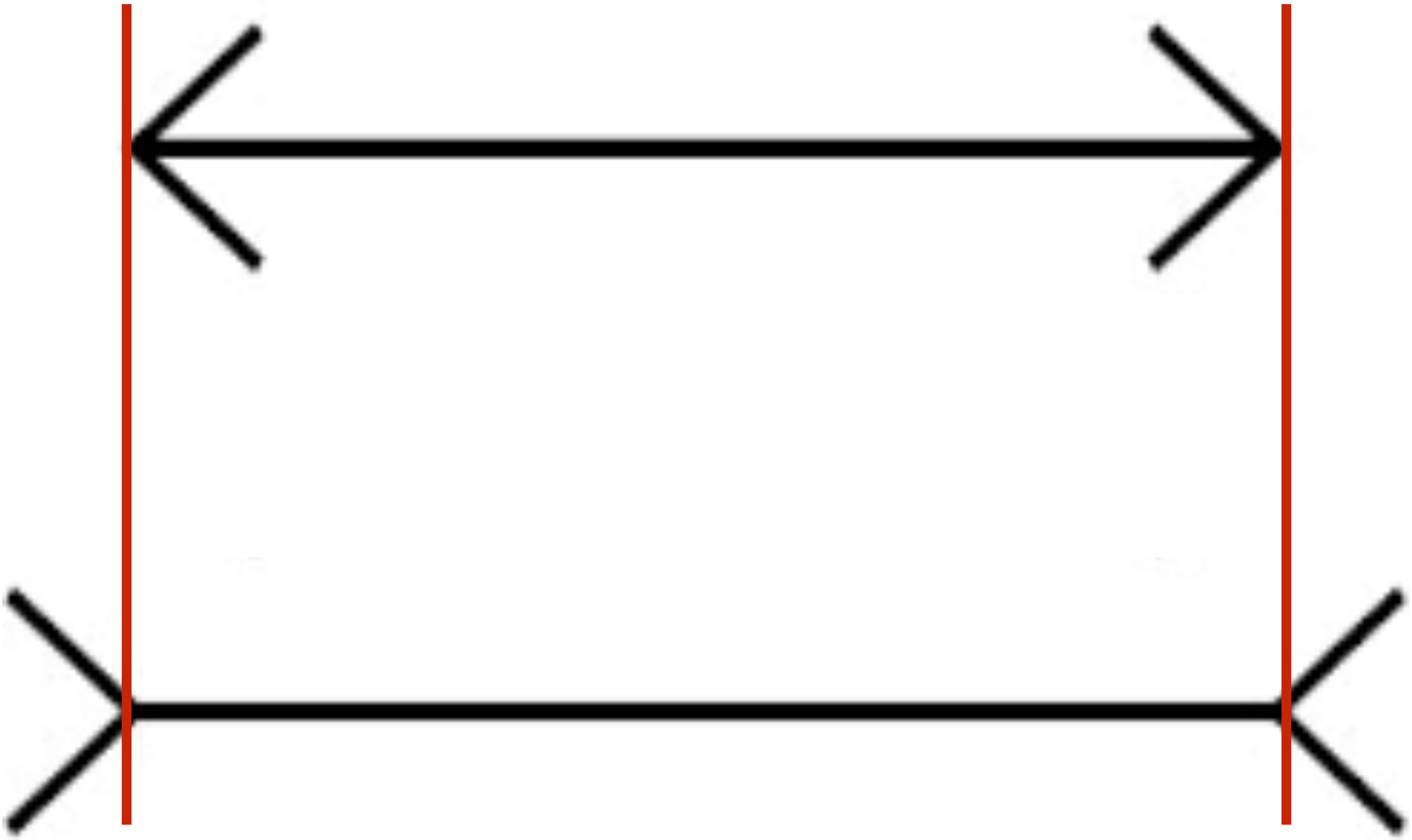

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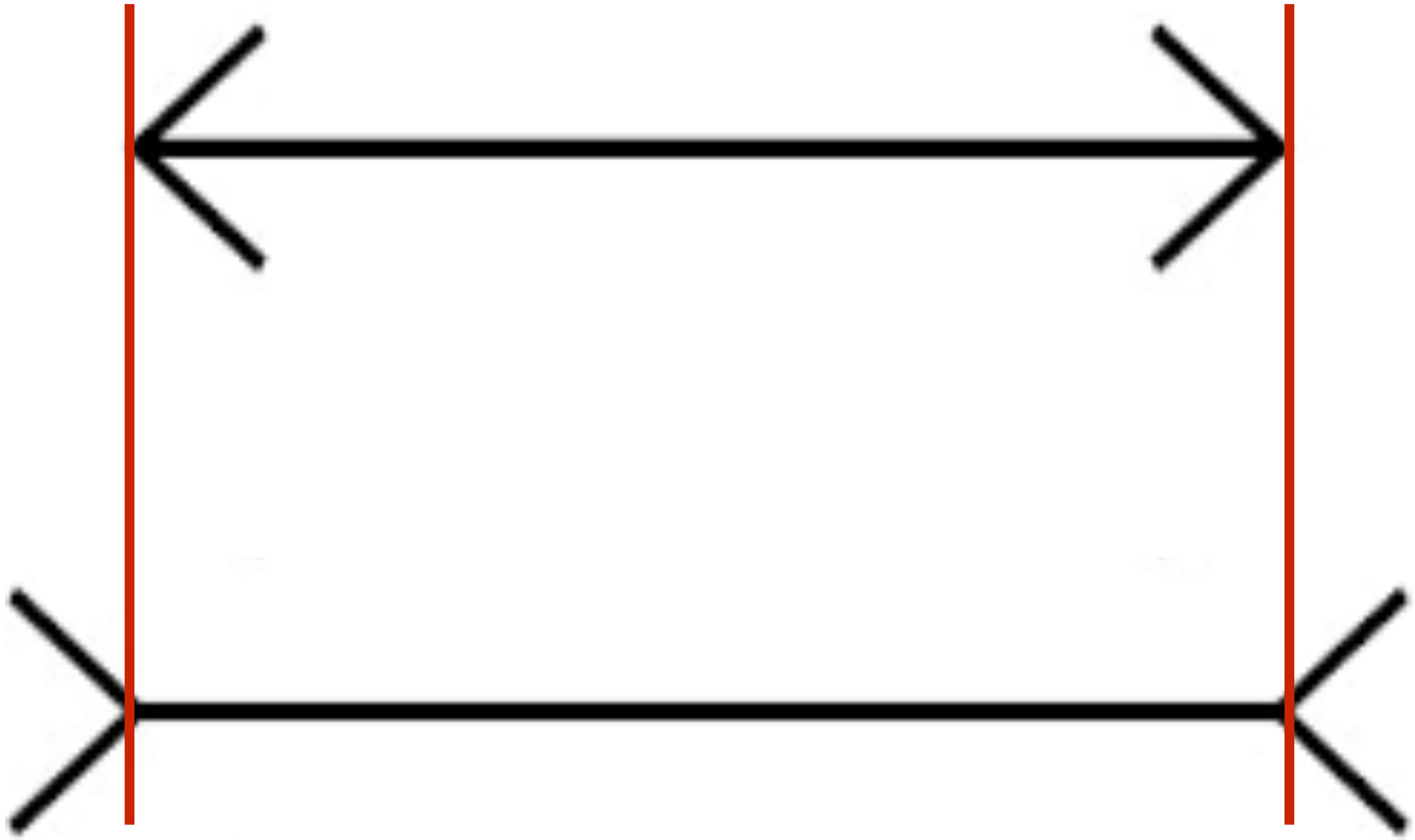

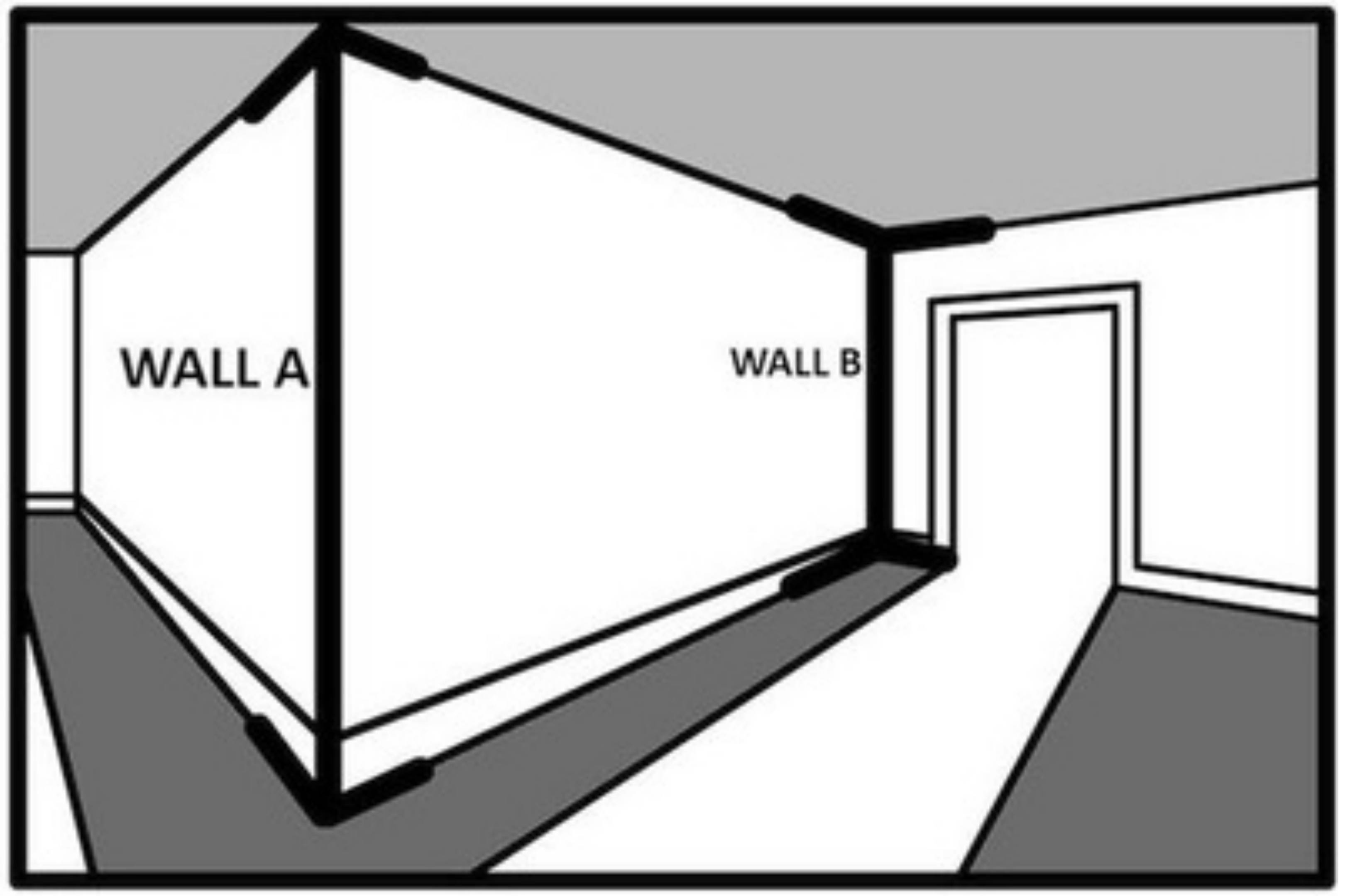

Lecture 7: Re-cap

In the **continuous** case, images are functions of two spatial variables, x and y.

The **discrete** case is obtained from the continuous case via sampling (i.e. spatial tessellation, grayscale quantization).

If a signal is **bandlimited** then it is possible to design a sampling strategy such that the sampled signal captures the underlying continuous signal exactly.

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If we know what we imaging (position and texture of objects, etc.) and how (distance of those object to the camera, lens parameters of the camera, etc.) then we can calculate whether resolution of the sensor is sufficient to produce artifact-free images

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If we know what we imaging (position and texture of objects, etc.) and how (distance of those object to the camera, lens parameters of the camera, etc.) then we can calculate what resolution sensor we may need to “trust” our imaging

Lecture 7: Re-cap

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If a signal is **bandlimited** then it is possible to design a sampling strategy such that the sampled signal captures the underlying continuous signal exactly.

Adequate sampling may not always be practical. In such cases there is a trade-off between “things missing” and “artifacts”.

— Different applications make the trade-off differently

Sampling Theory (informal)

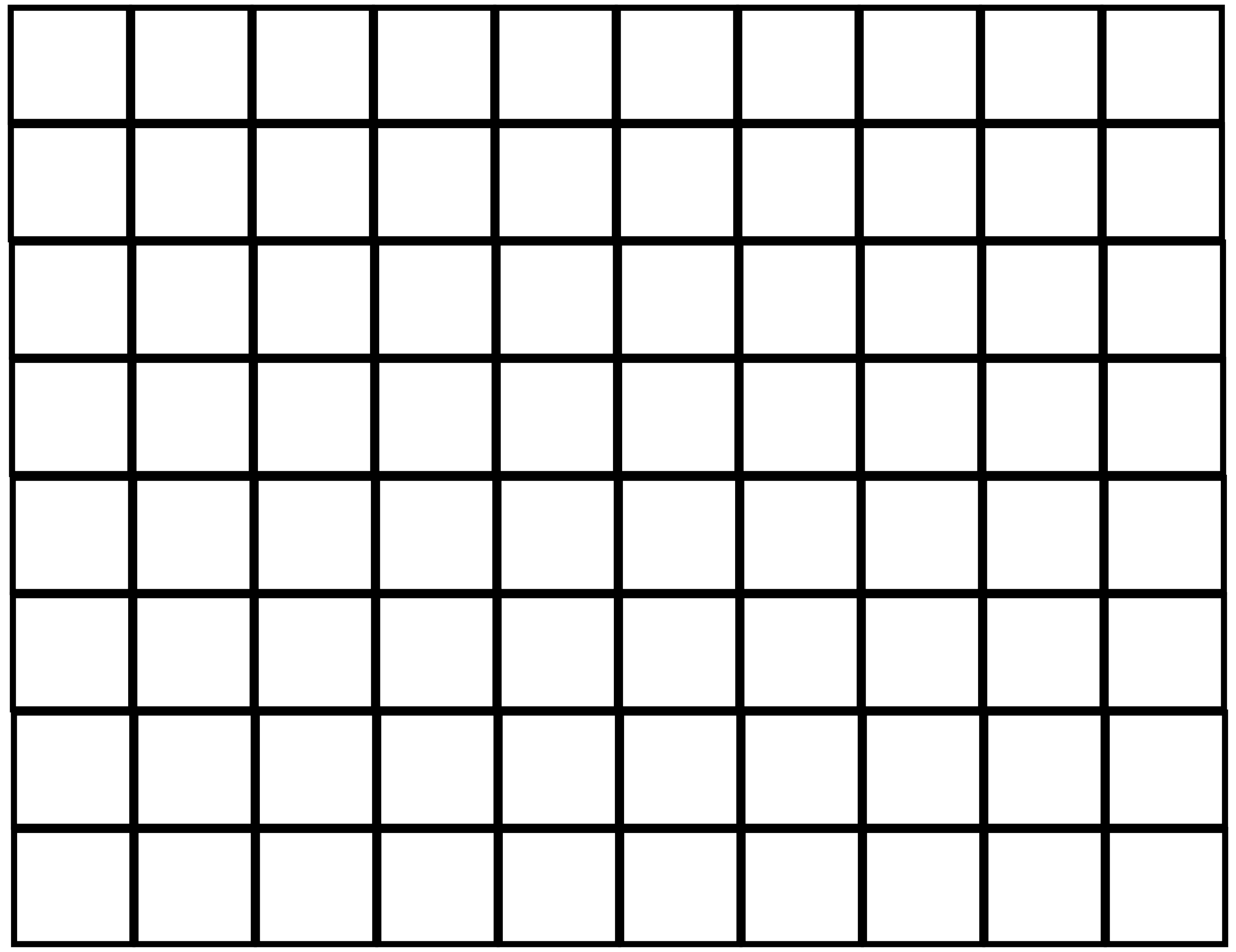
Sometimes **undersampling** is unavoidable, and there is a trade-off between “things missing” and “artifacts.”

— **Medical imaging**: usually try to maximize information content, tolerate some artifacts

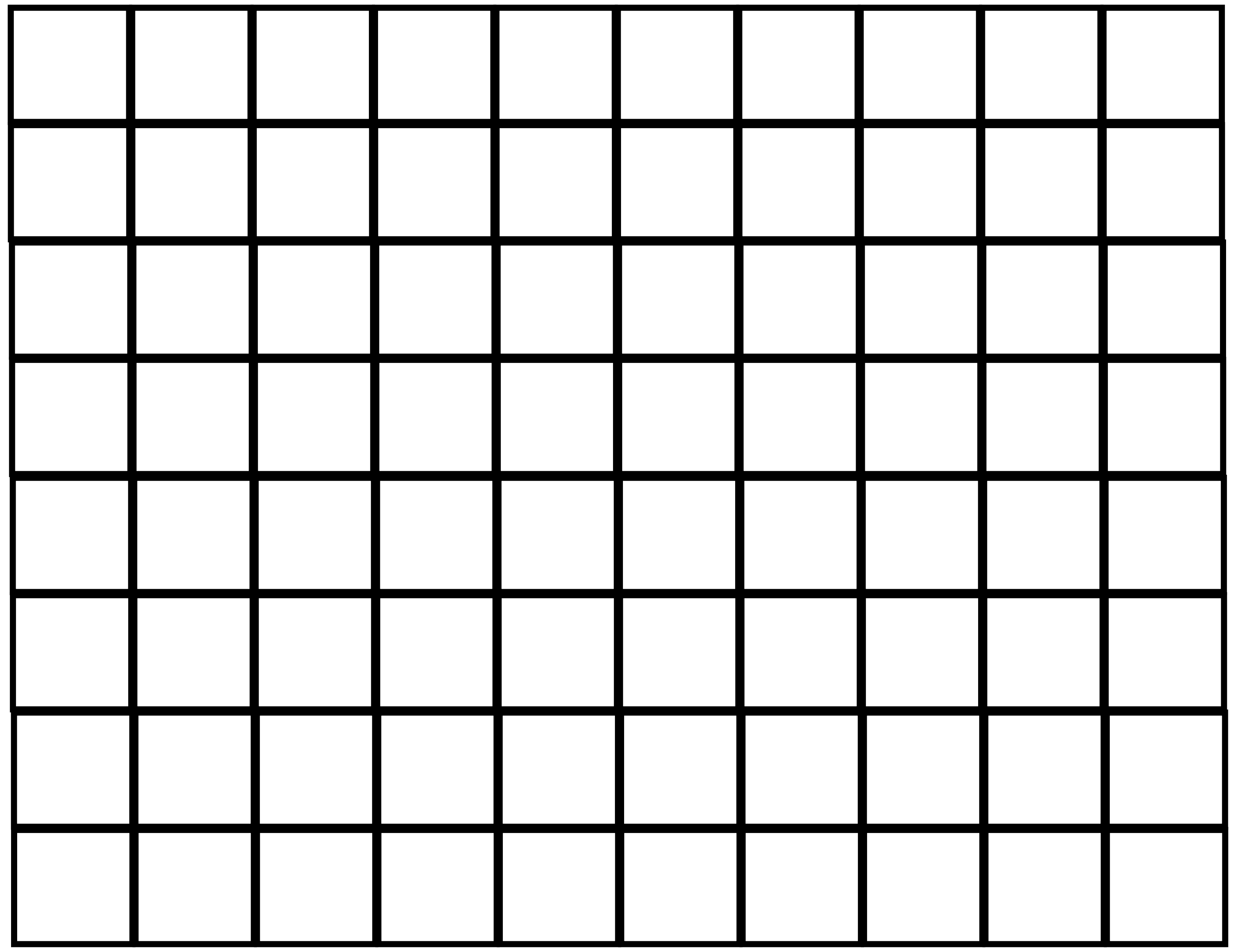
— **Computer graphics**: usually try to minimize artifacts, tolerate some information missing

Example

Sensor Resolution: 10 x 8



Sensor Resolution: 10 x 8



Example

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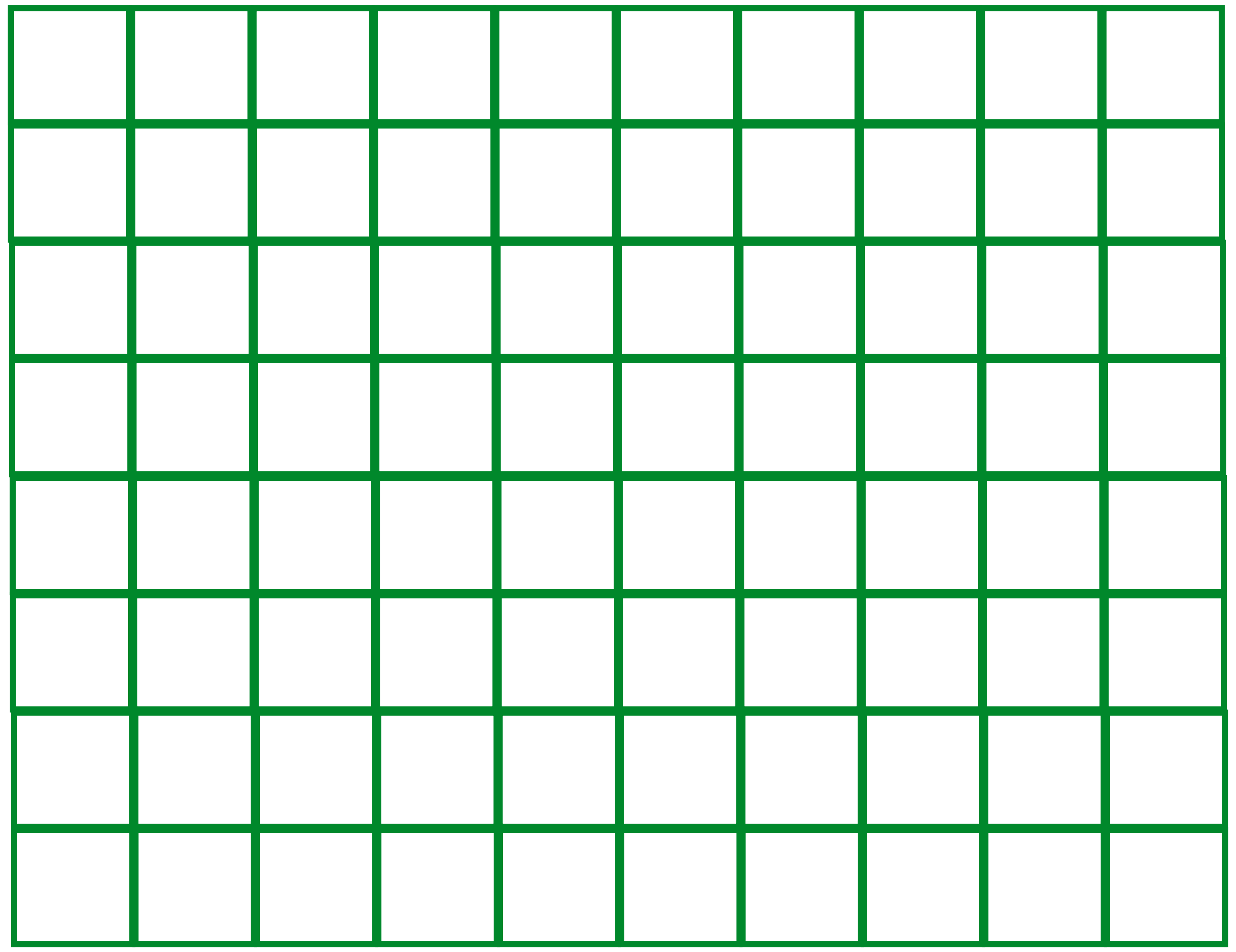


Image Resolution: 10 x 8

Sensor Resolution: 10 x 8

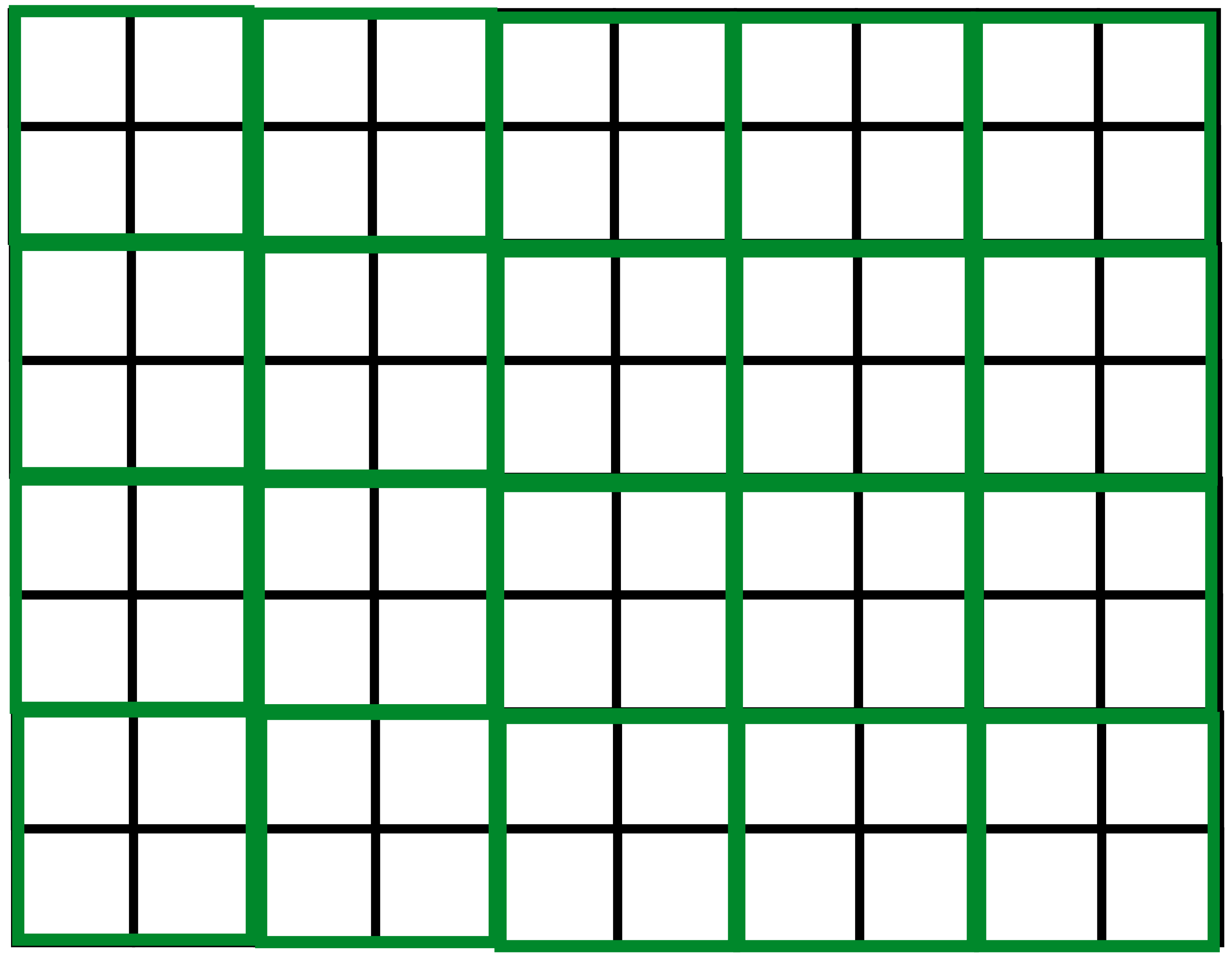


Image Resolution: 5 x 4

Review: Continuous Case

— Images also can be considered a function of time. Then, we write $i(x, y, t)$ where x and y are spatial variable and t is a **temporal variable**

— To make the dependence of brightness on wavelength explicit, we can instead write $i(x, y, t, \lambda)$ where x, y and t are as above and where λ is a **spectral variable**

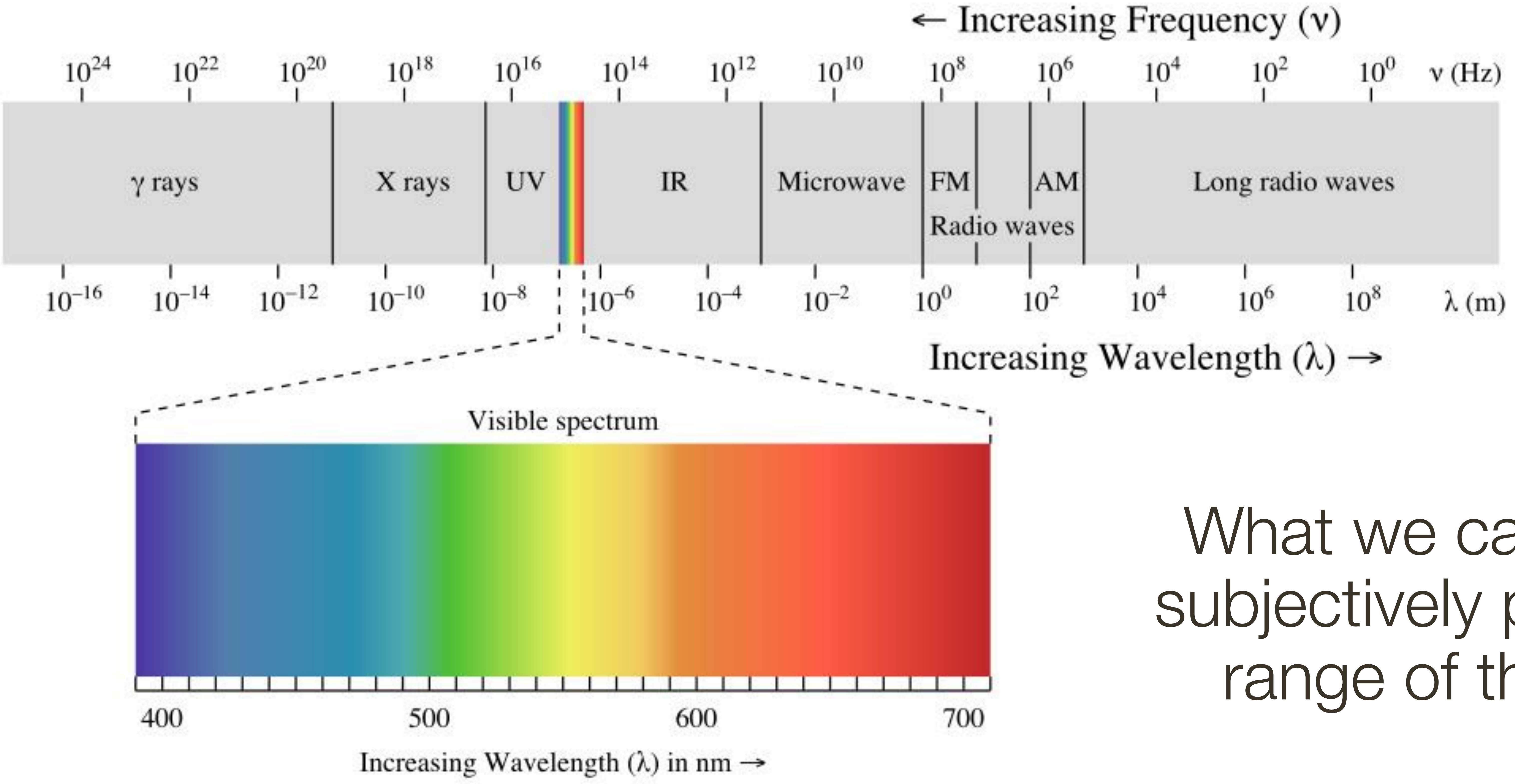
— More commonly, we think of “color” already as discrete and write

$$i_R(x, y)$$
$$i_G(x, y)$$
$$i_B(x, y)$$

for specific colour channels, R, G and B

Color is an Artifact of Human Perception

"Color" is **not** an objective physical property of light (electromagnetic radiation).
Instead, light is characterized by its wavelength.

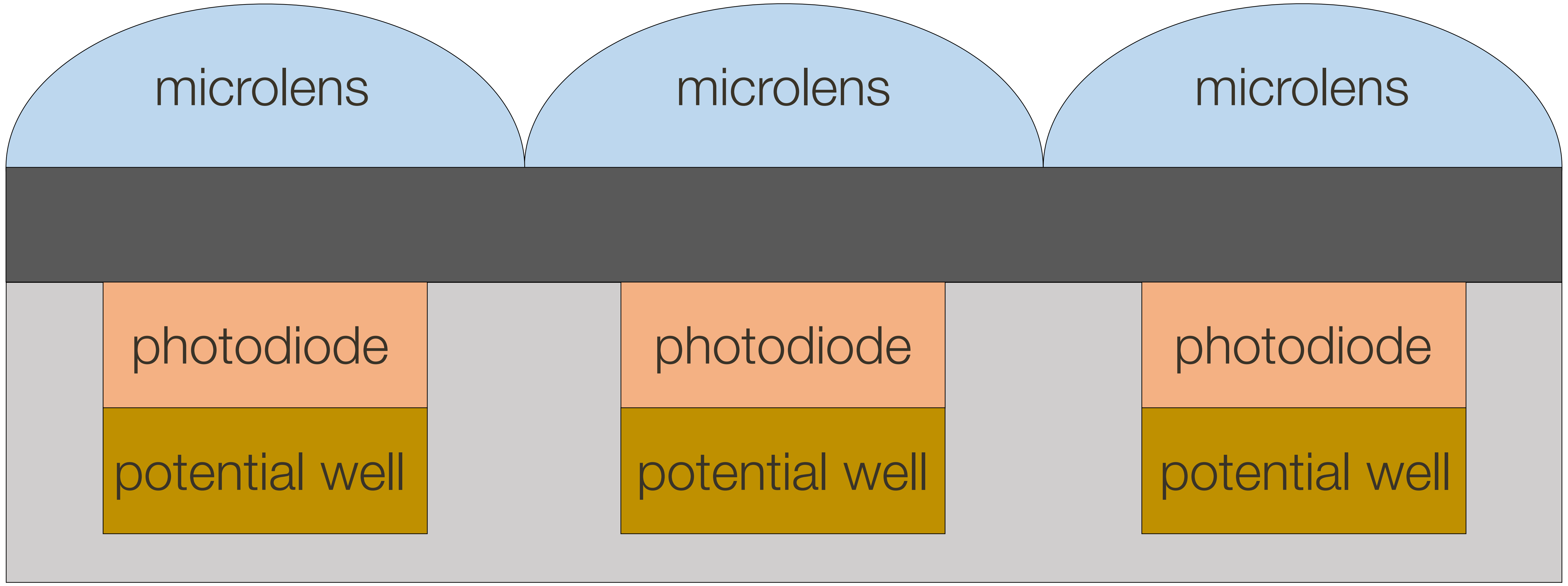


electromagnetic spectrum

What we call "color" is how we subjectively perceive a very small range of these wavelengths.

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

Color Filter Arrays (CFA)



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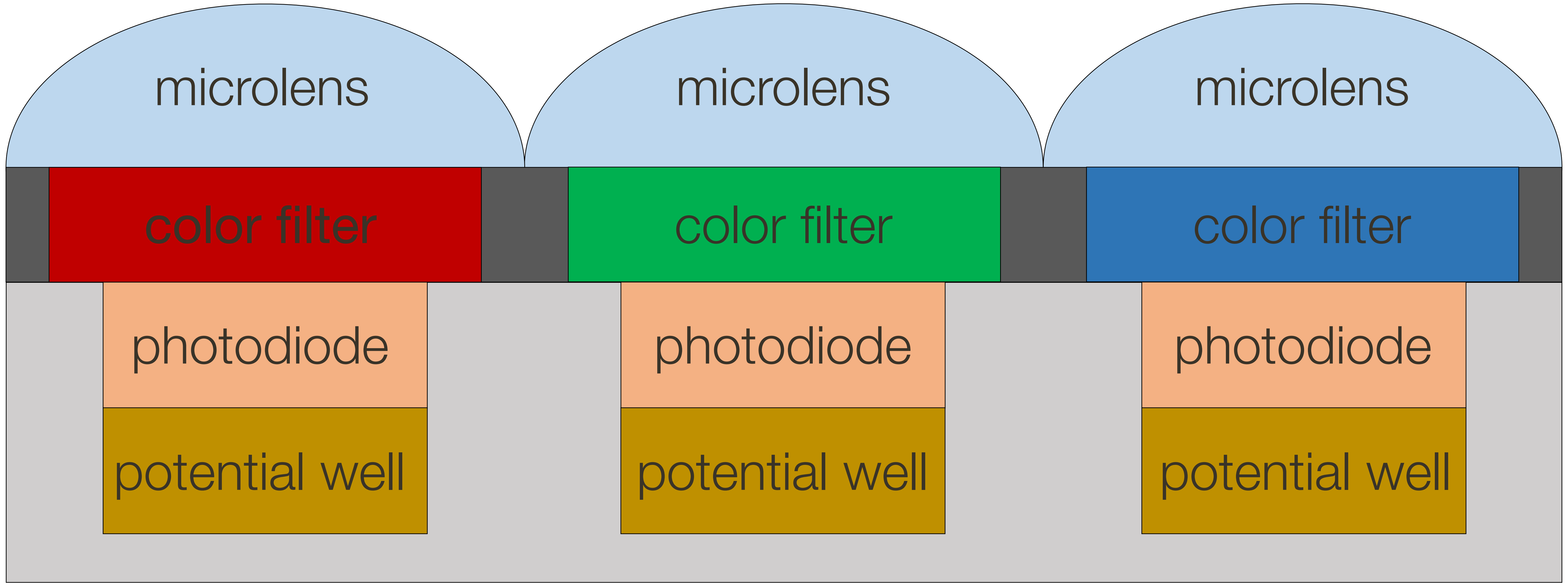

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

Color Filters

Two **design choices**:

— What spectral sensitivity functions $f(\lambda)$ to use for each color filter?

— How to spatially arrange ("**mosaic**") different color filters?

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

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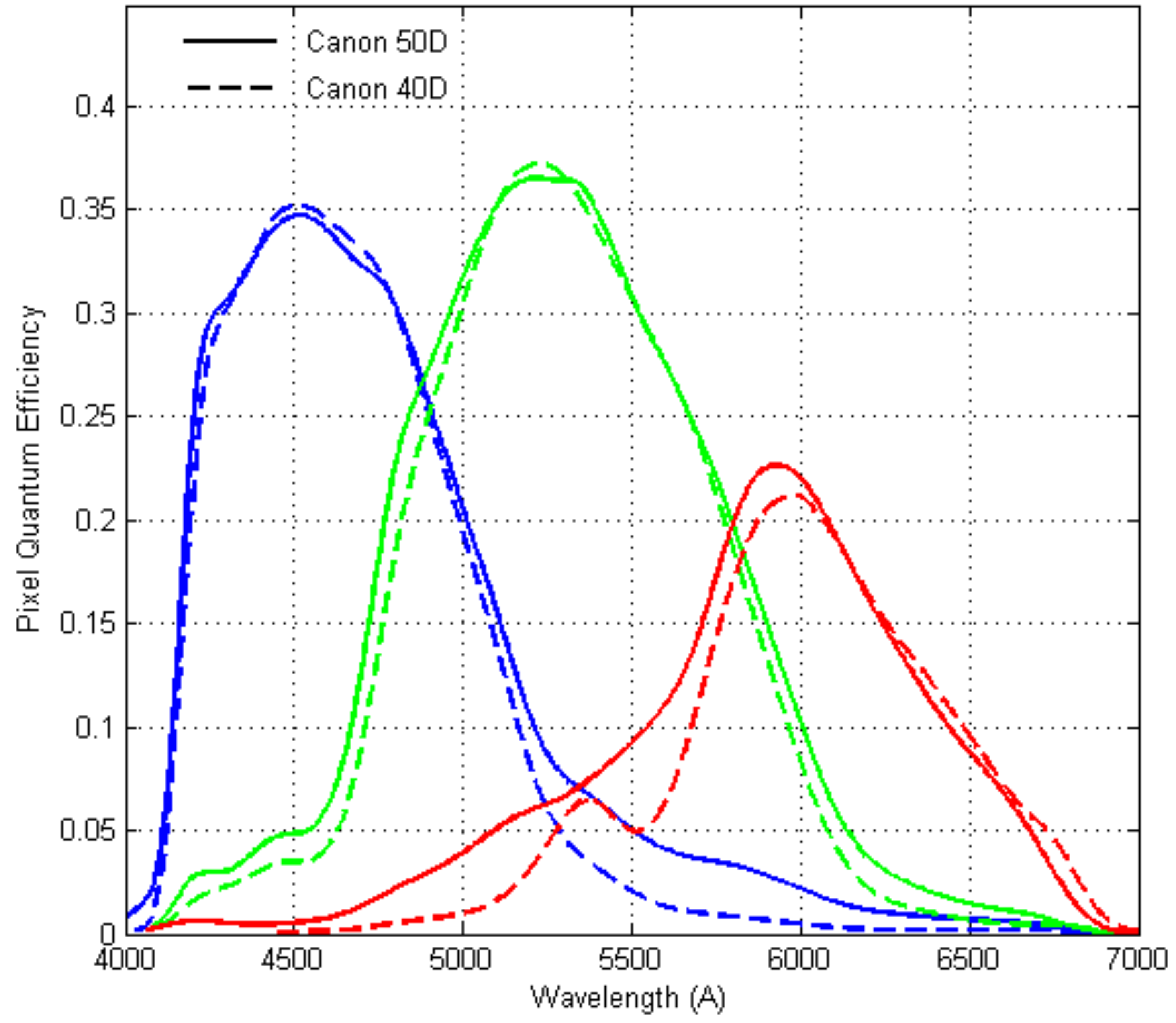
Canon 50D



$f(\lambda)$

Generally do not match human sensitivity

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

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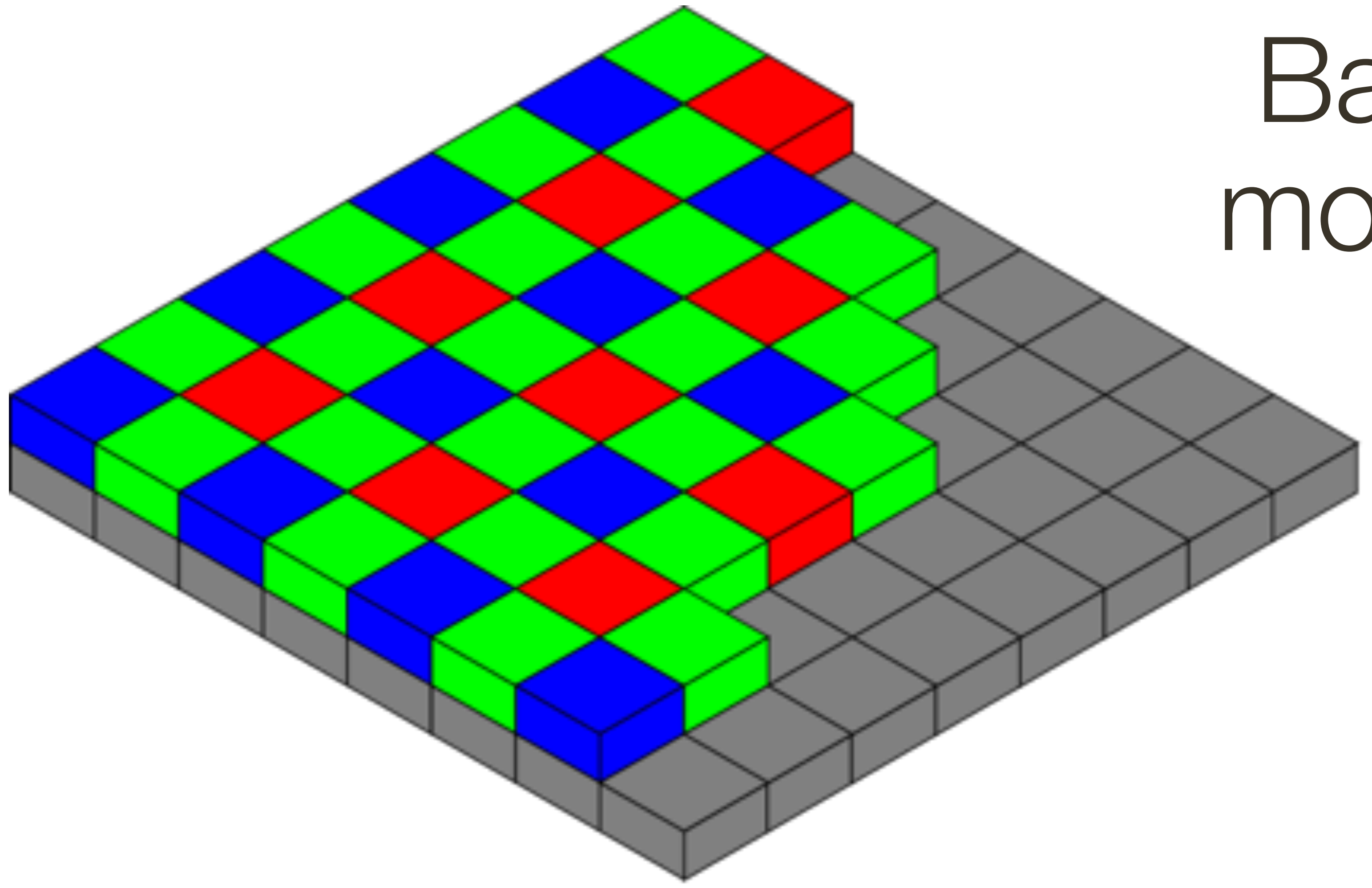
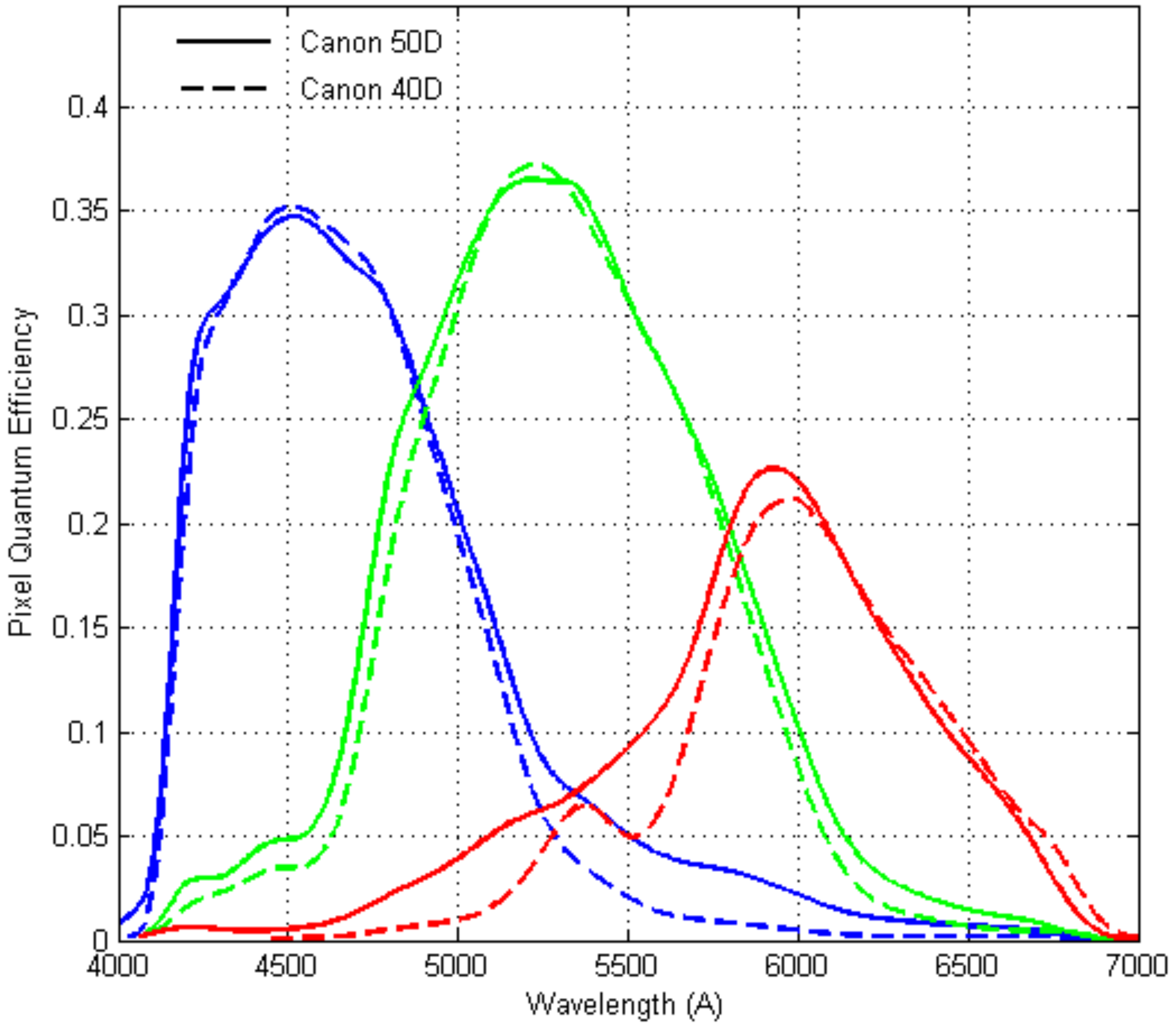


Bayer mosaic

Generally do not match human sensitivity

Canon 50D



$f(\lambda)$

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

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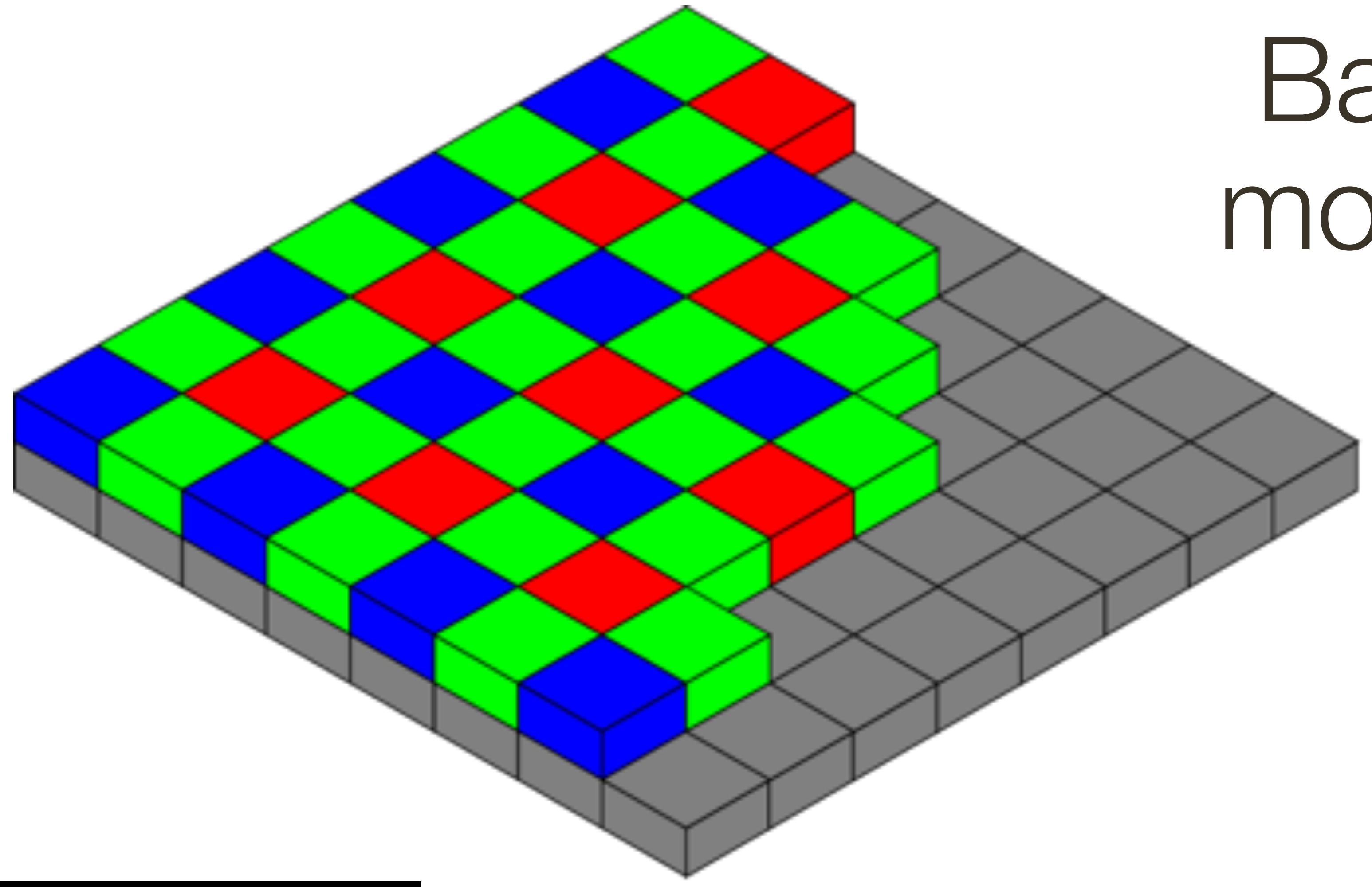
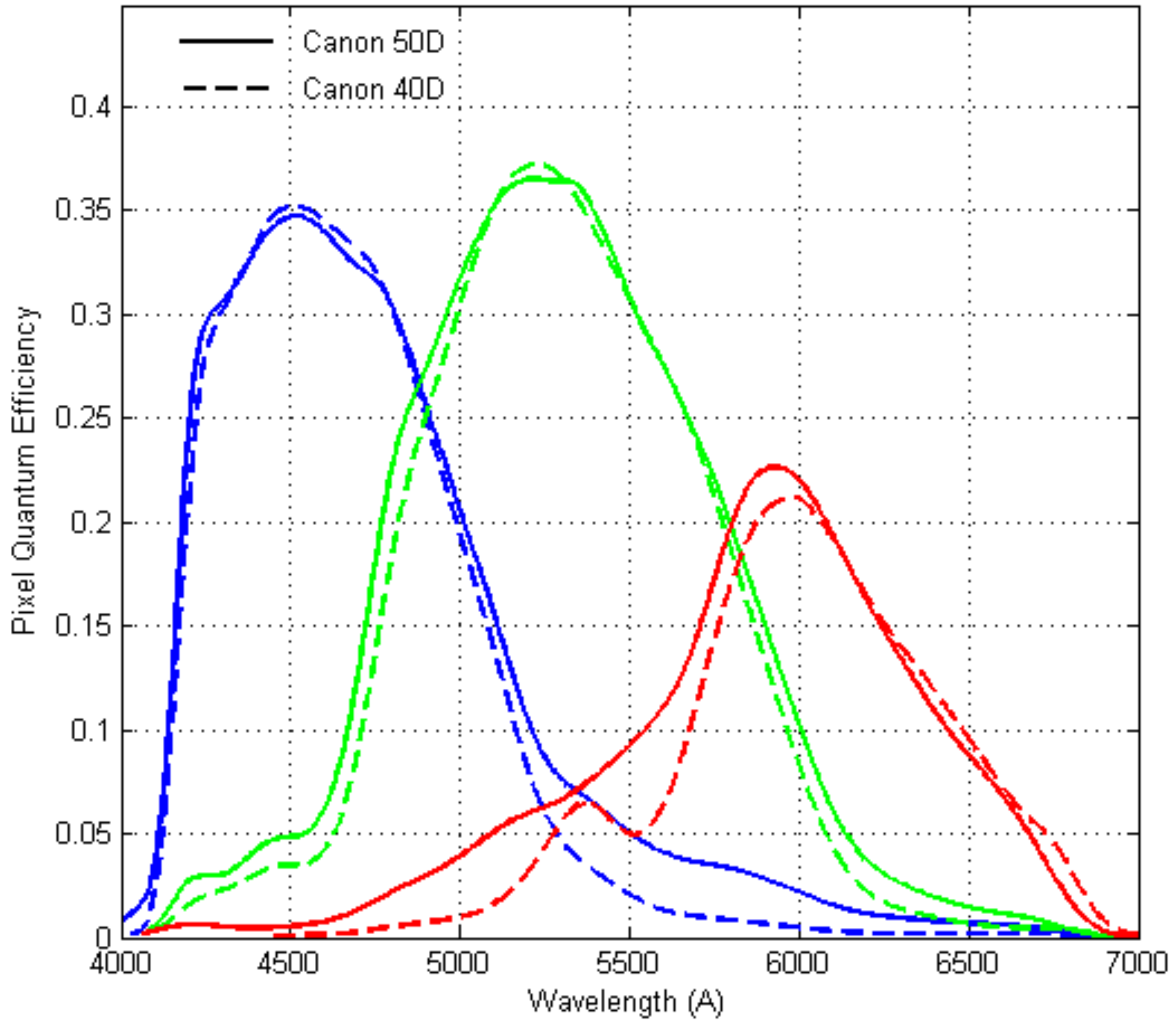


Bayer mosaic

Canon 50D



$f(\lambda)$

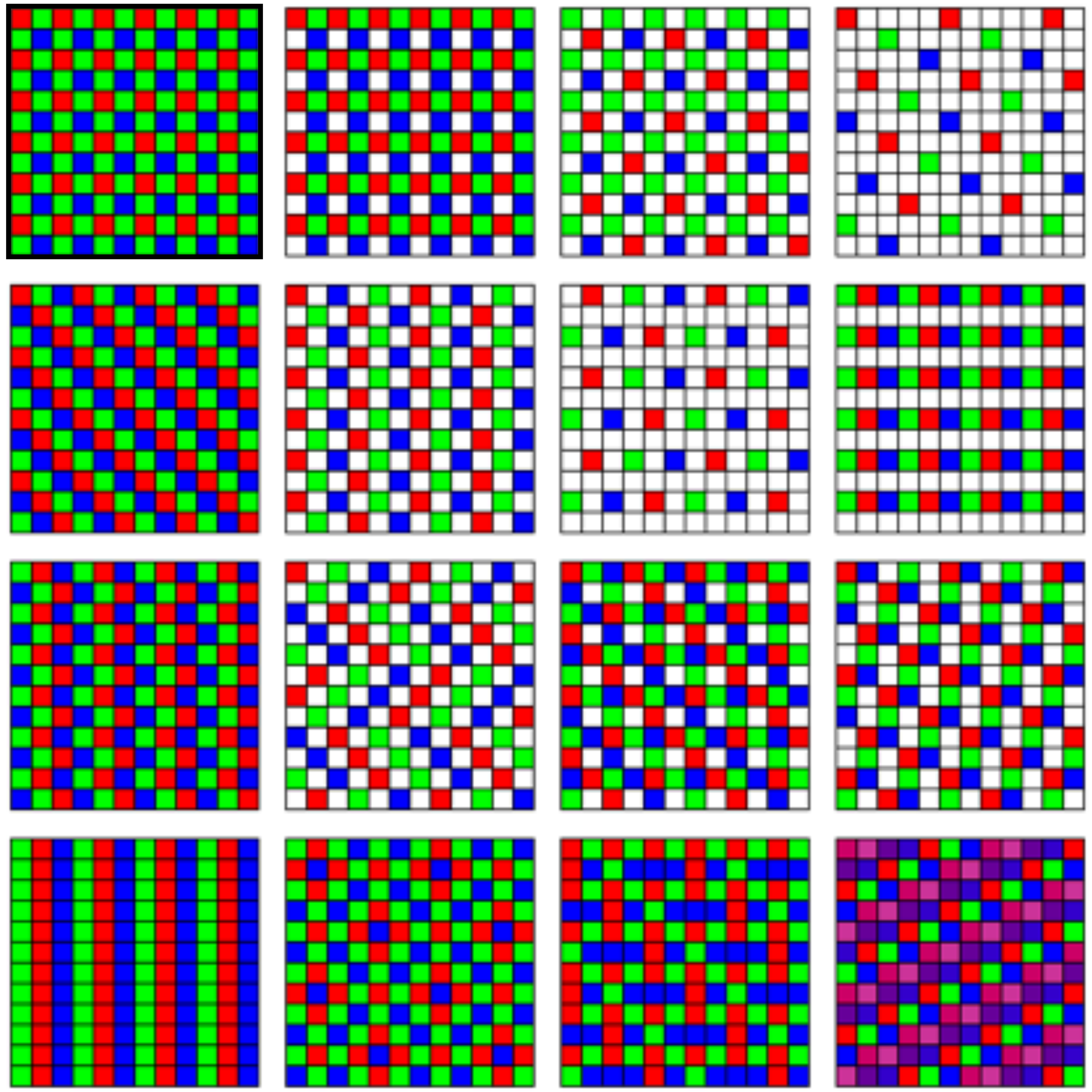
Generally do not match human sensitivity

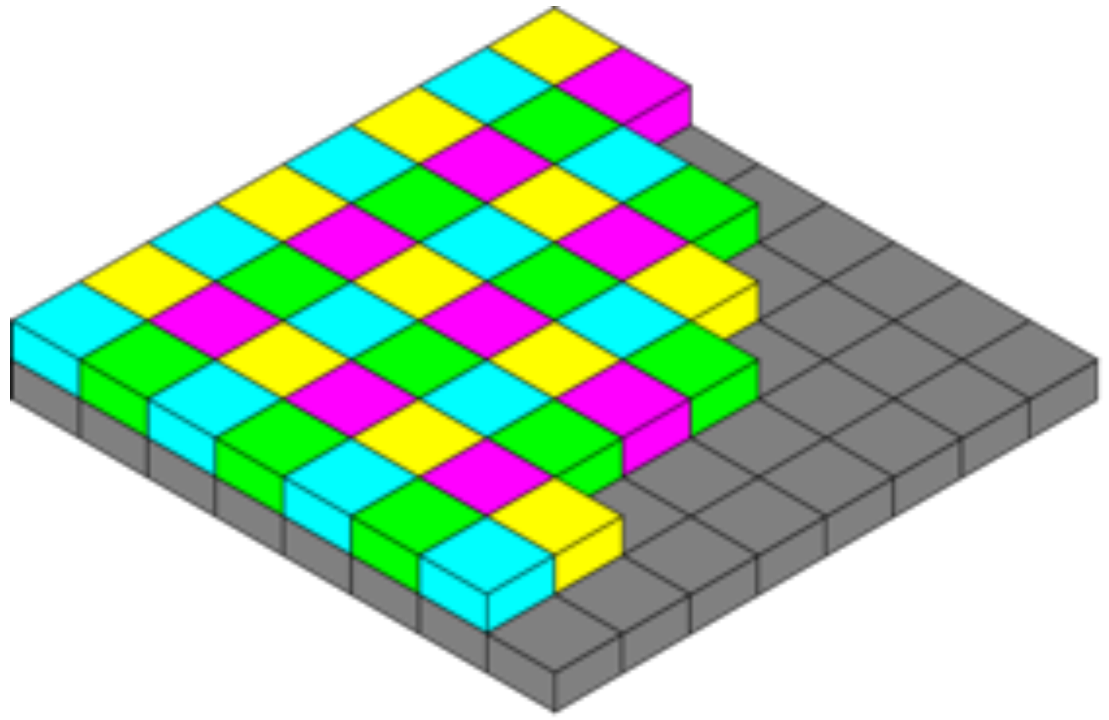
Why more green pixels?

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

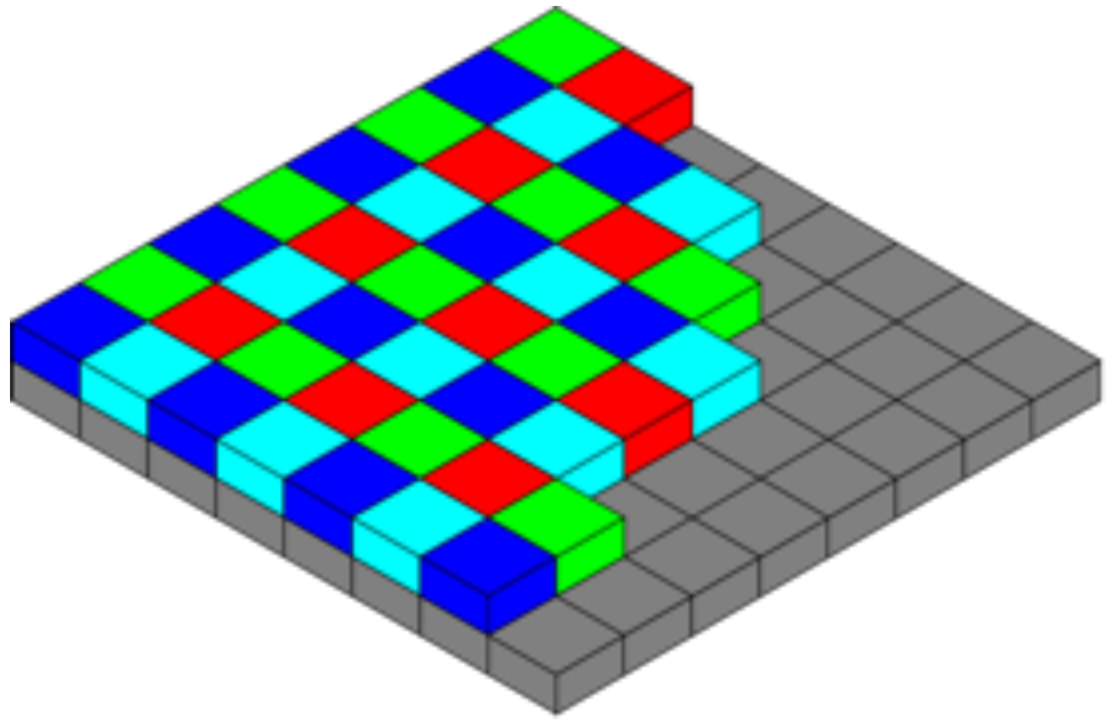
Different Color Filter Arrays (CFAs)

Finding the "**best**" CFA mosaic is an active research area.





CYGM
Canon IXUS, Powershot



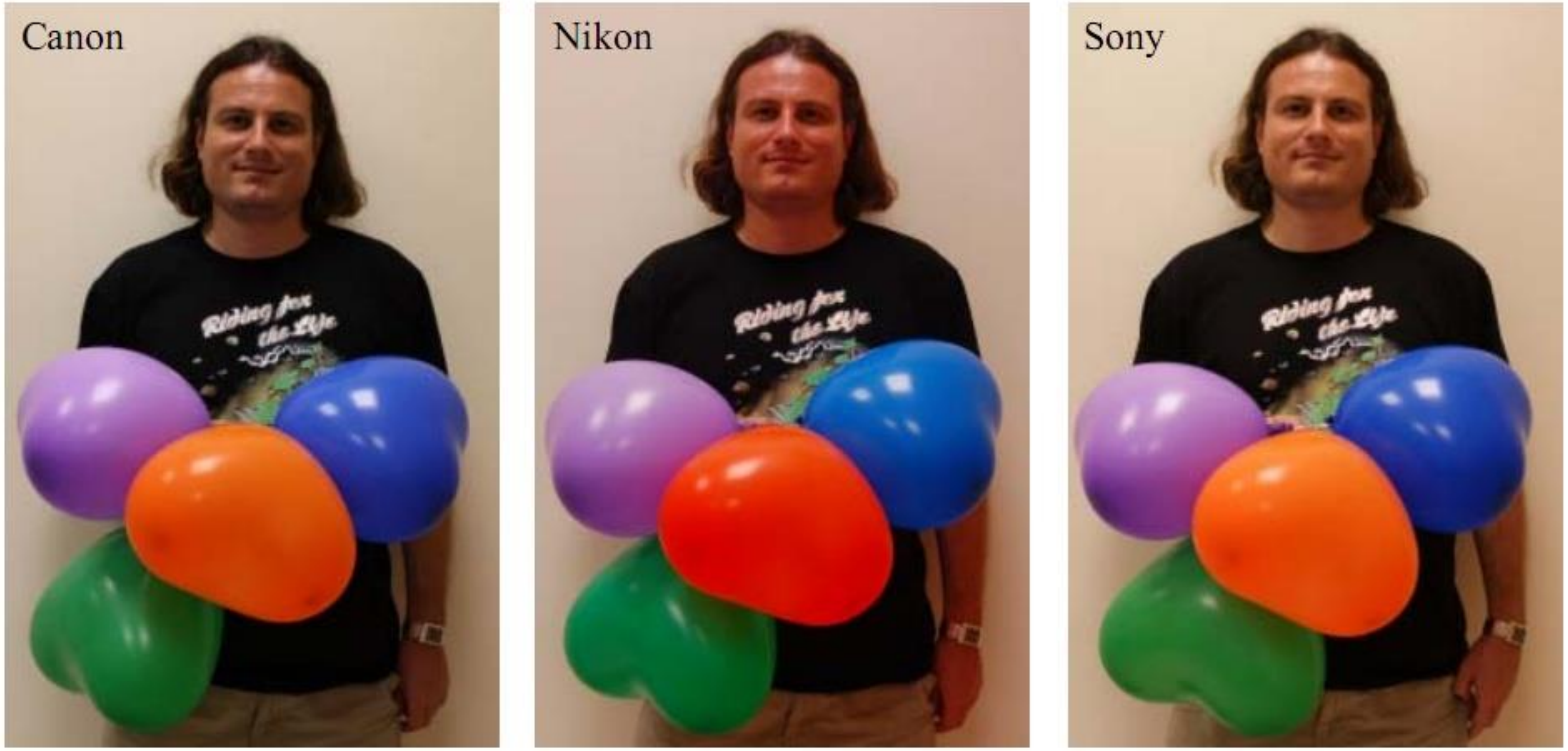
RGBE
Sony Cyber-shot

How would you go about designing your own CFA? What criteria would you consider?

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

Many **Different Spectral Sensitivity** Functions

Each camera has its more or less unique, and most of the time secret, SSF

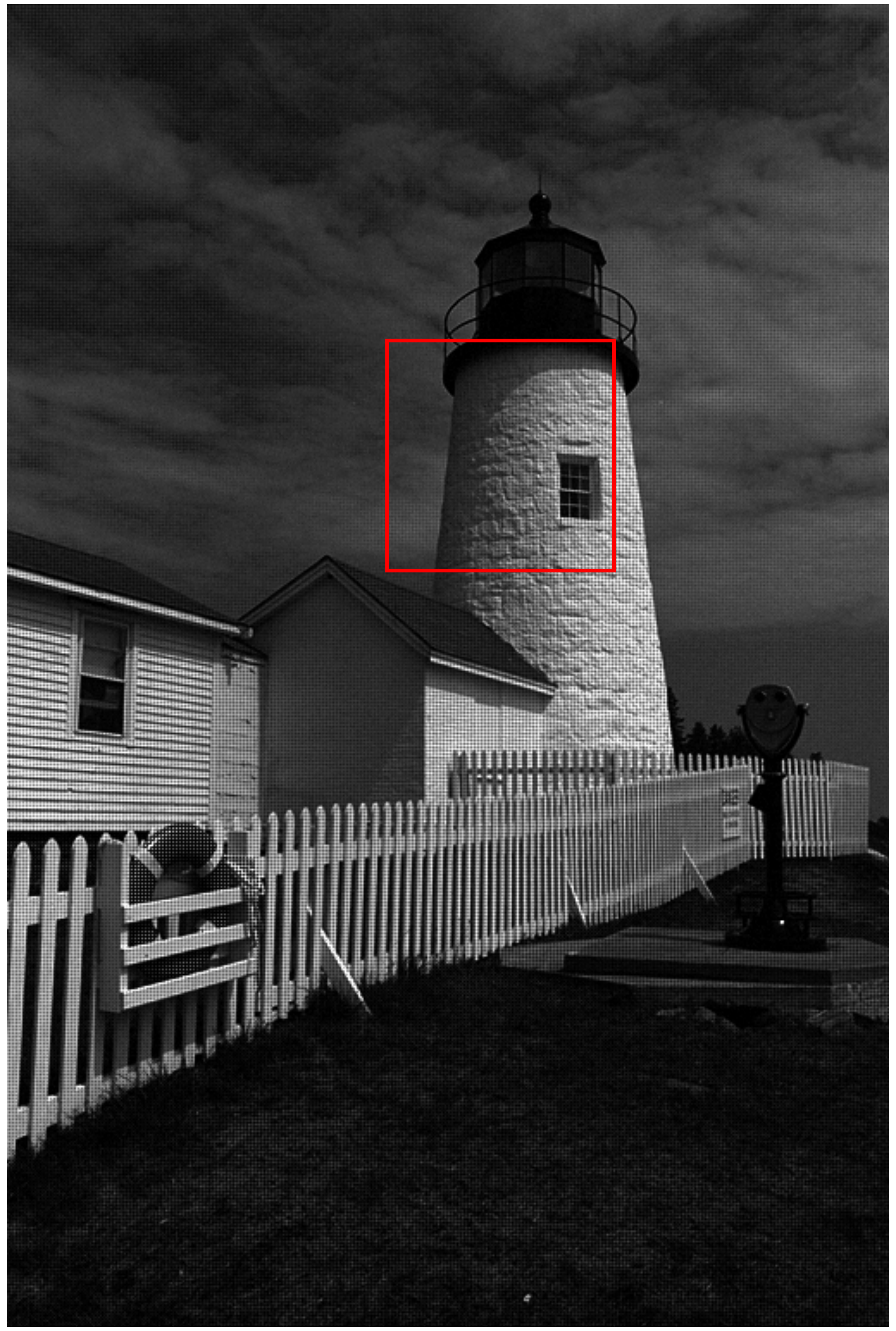


Same scene captured using 3 different cameras with identical settings

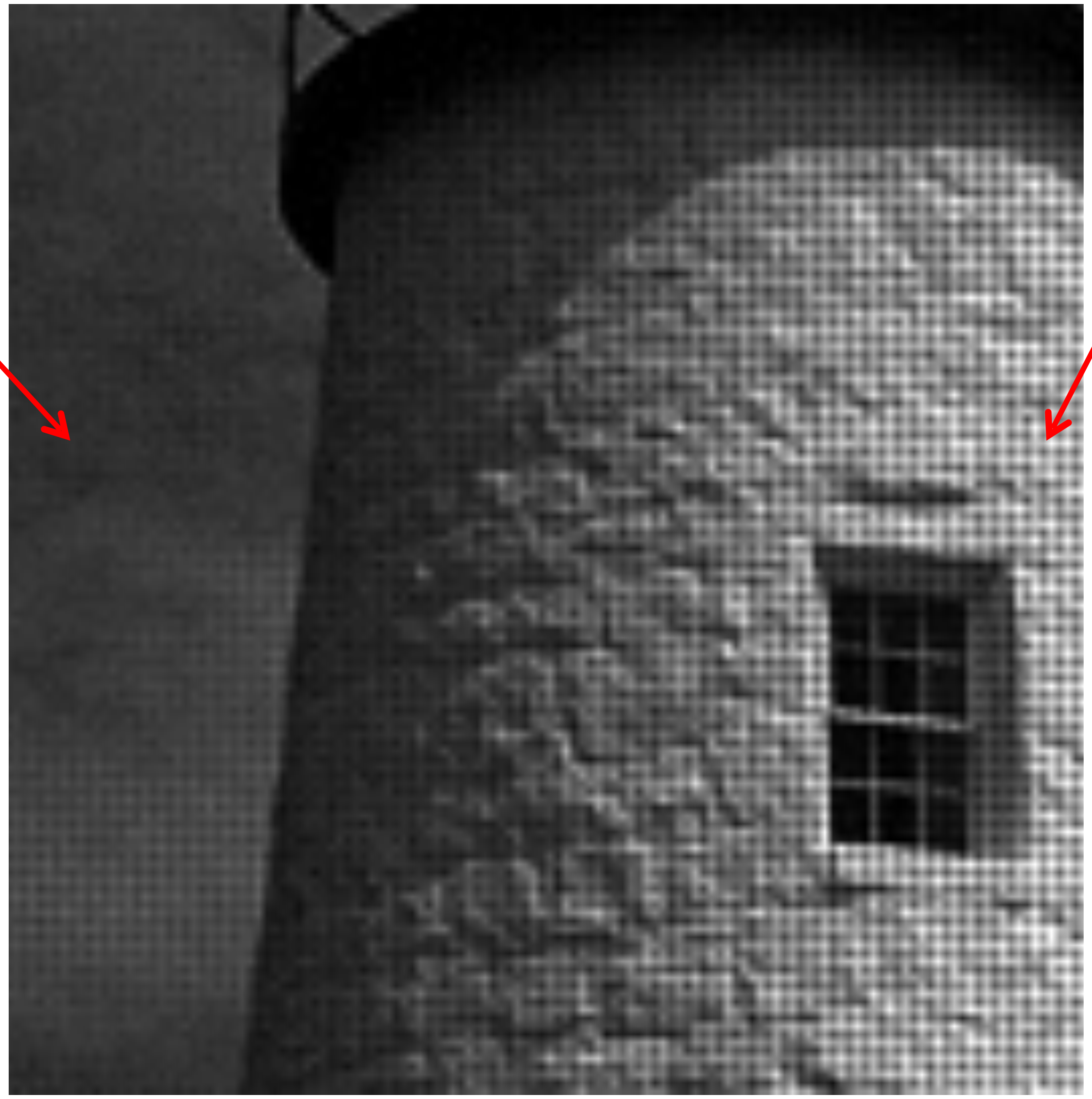
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

RAW Bayer Image

After all of this, what does an image look like?



lots of noise



mosaicking artifacts

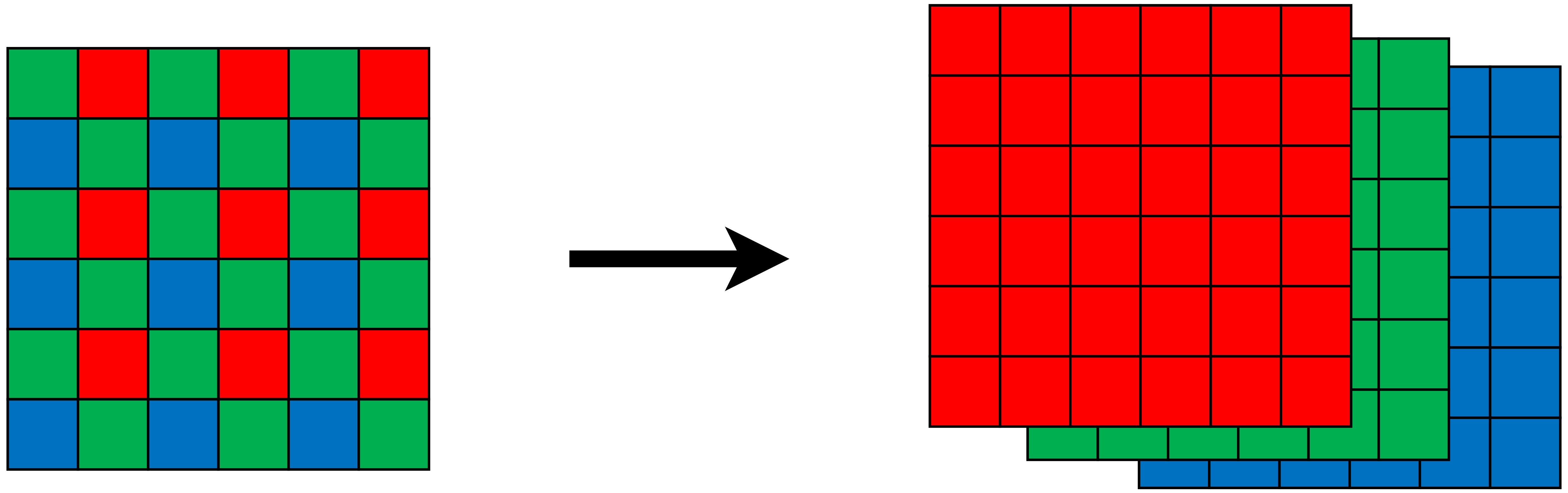
— Kind of disappointing

— We call this the RAW image

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

CFA **Demosicing**

Produce full RGB image from mosaiced sensor output



Any ideas on how to do this?

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

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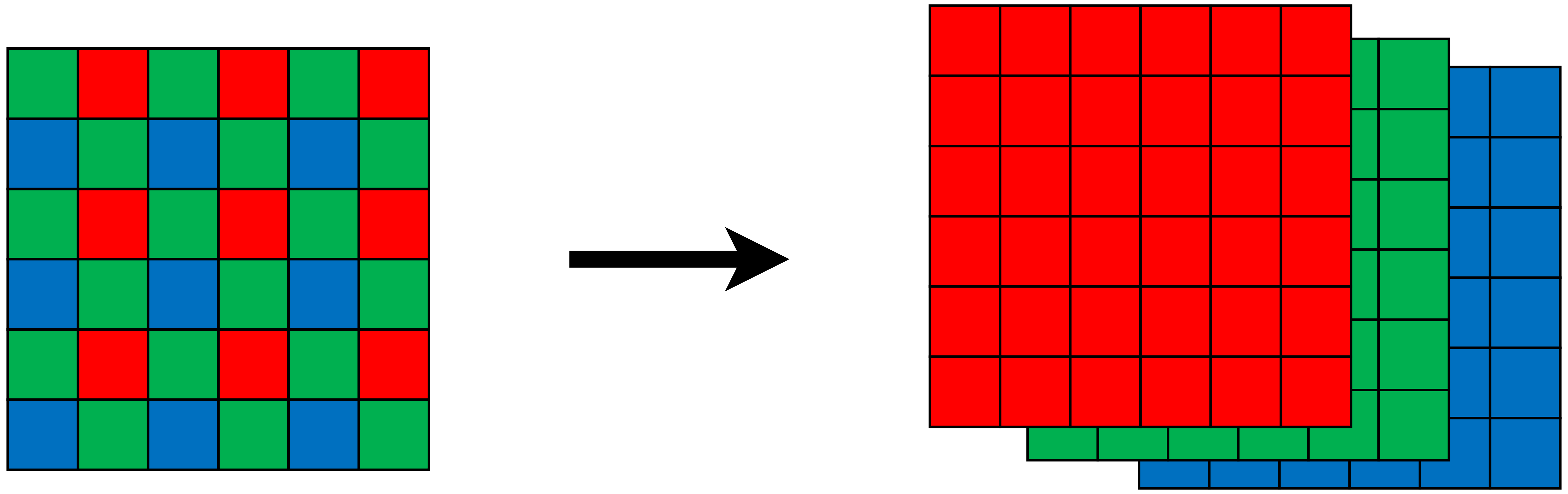


Interpolate from neighbors:

— Bilinear interpolation (needs 4 neighbors)

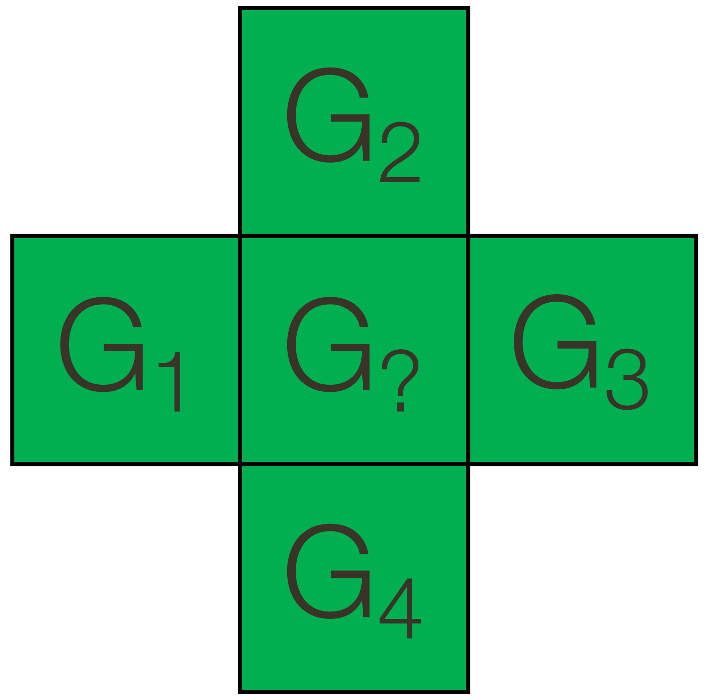
— Bicubic interpolation (needs more neighbors, may overblur)

— Edge-aware interpolation

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

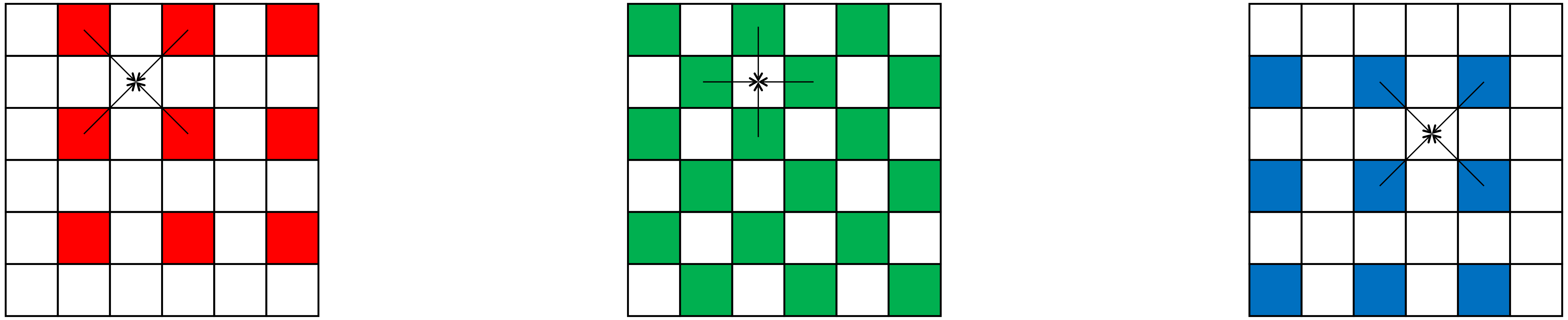
Demosaicing by Bilinear Interpolation

Bilinear interpolation: Simply average your 4 neighbors.



$$G_? = \frac{G_1 + G_2 + G_3 + G_4}{4}$$

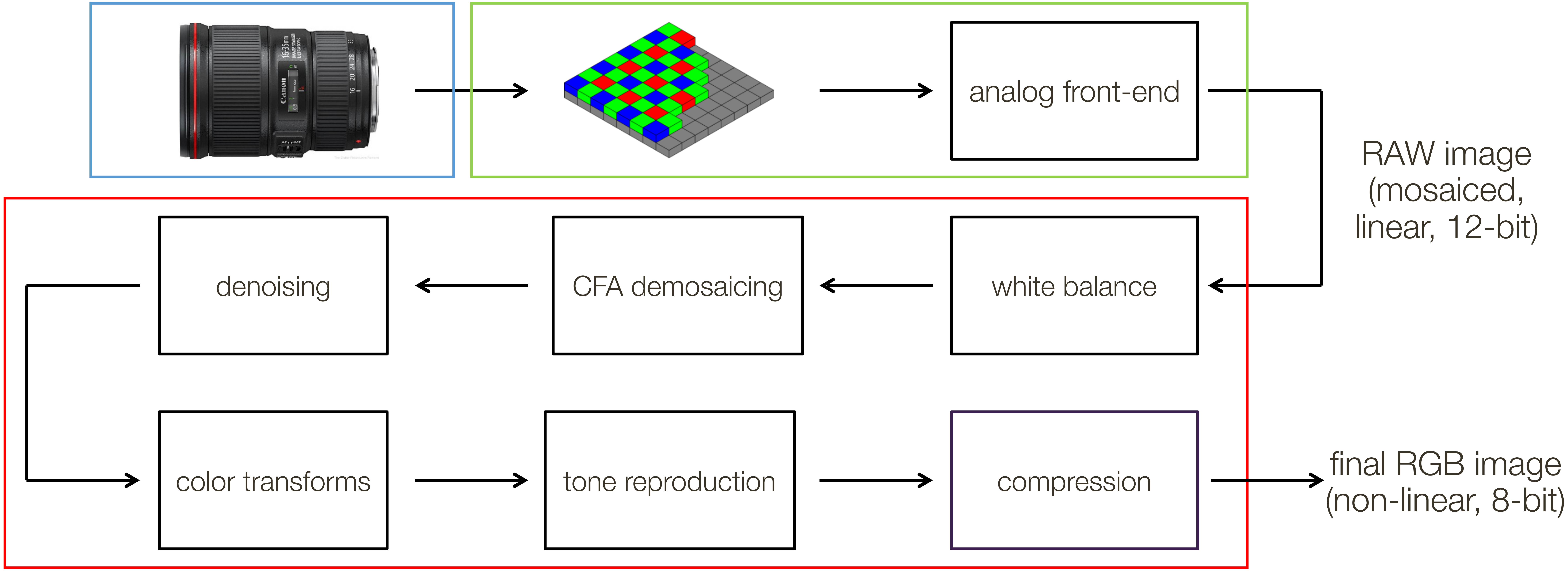
Neighborhood changes for different channels:



Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

(in camera) **Image** Processing Pipeline

The sequence of image processing operations applied by the camera's image signal processor (ISP) to convert a RAW image into a "conventional" image.

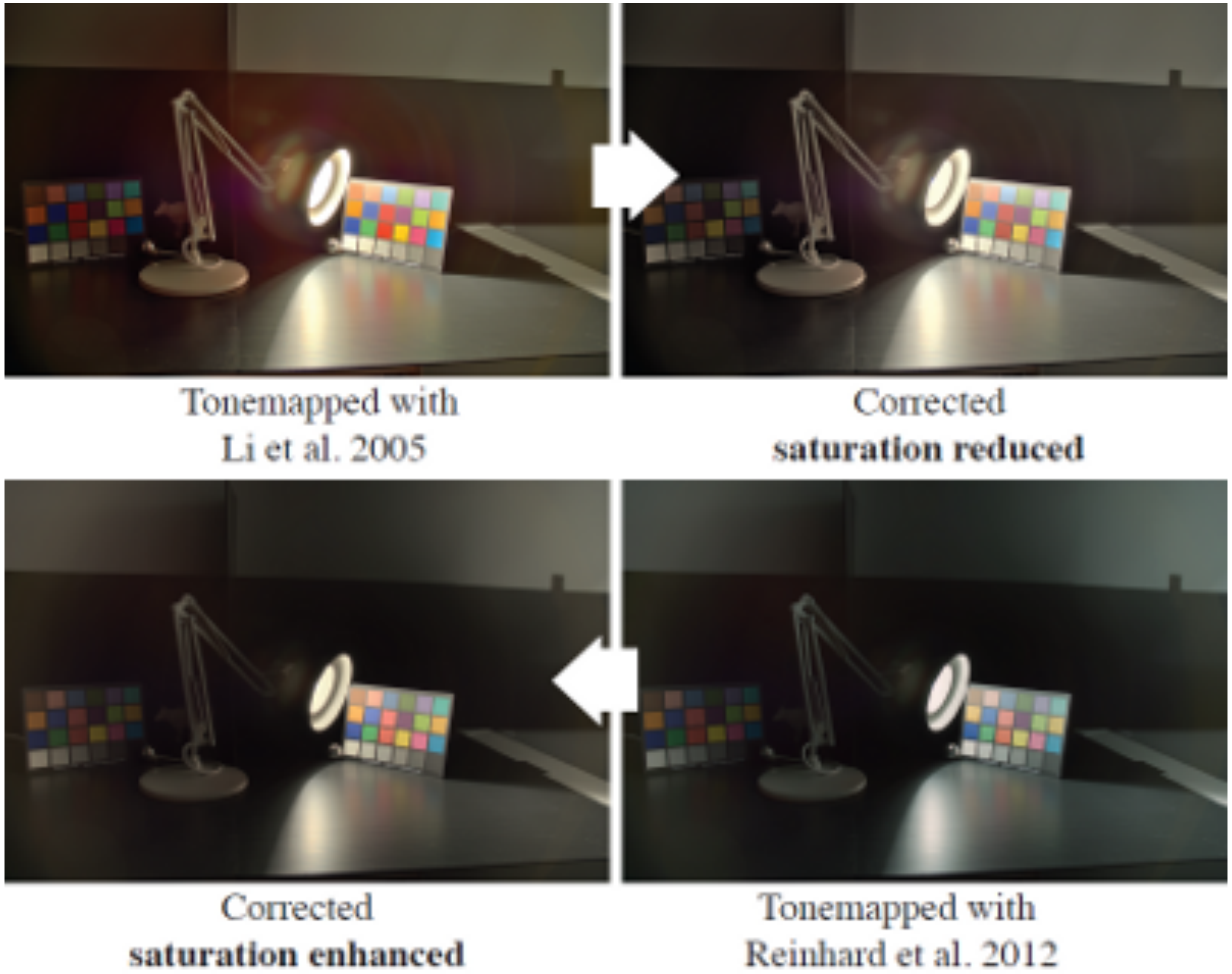


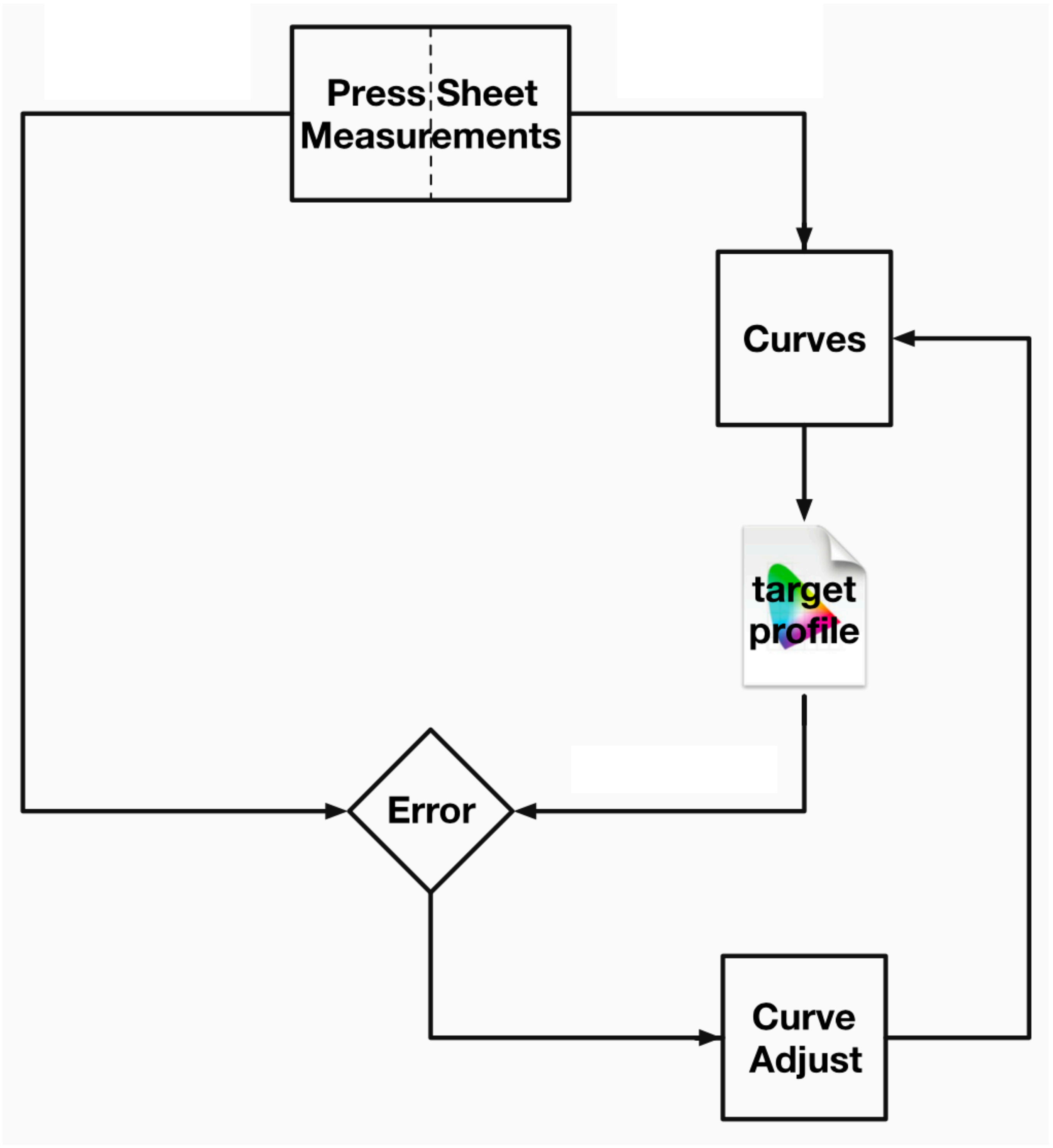
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

(in camera) **White** balance

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

(in camera) **Tone** reproduction





Summary

“Color” is **not** an objective physical property of light (electromagnetic radiation). Instead, light is characterized by its wavelength.

Color Filter Arrays (CFAs) allow capturing of mosaiced color information; the layout of the mosaic is called **Bayer** pattern.

Demosaicing is the process of taking the RAW image and interpolating missing color pixels per channel