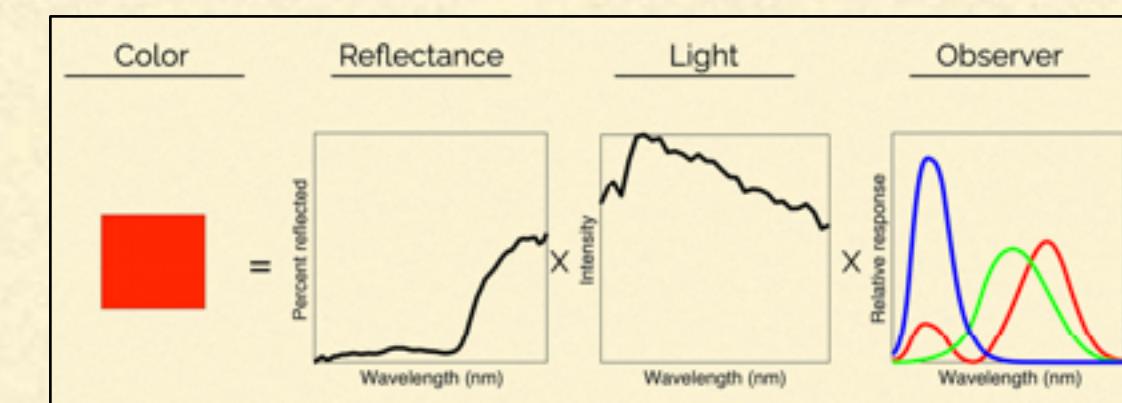


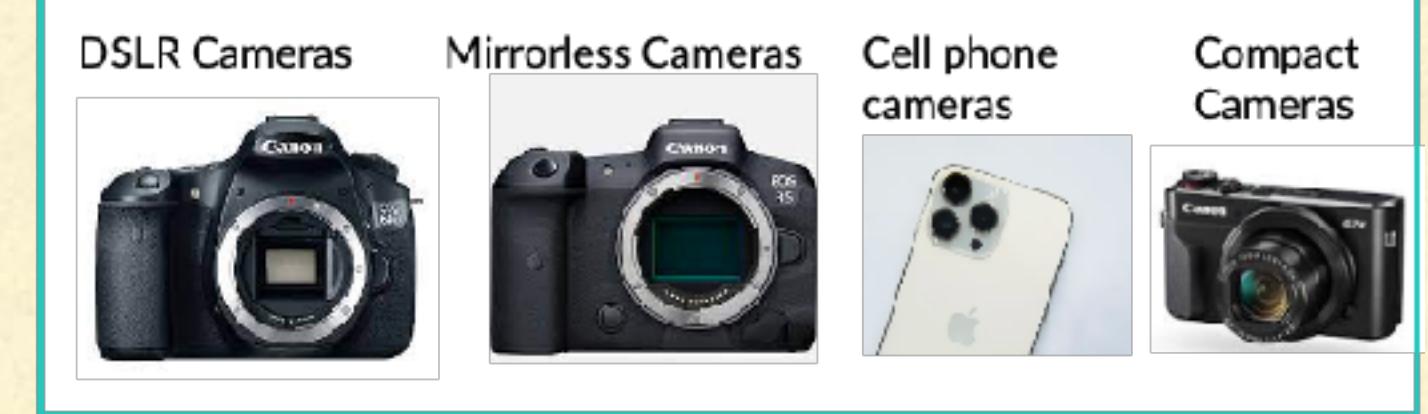
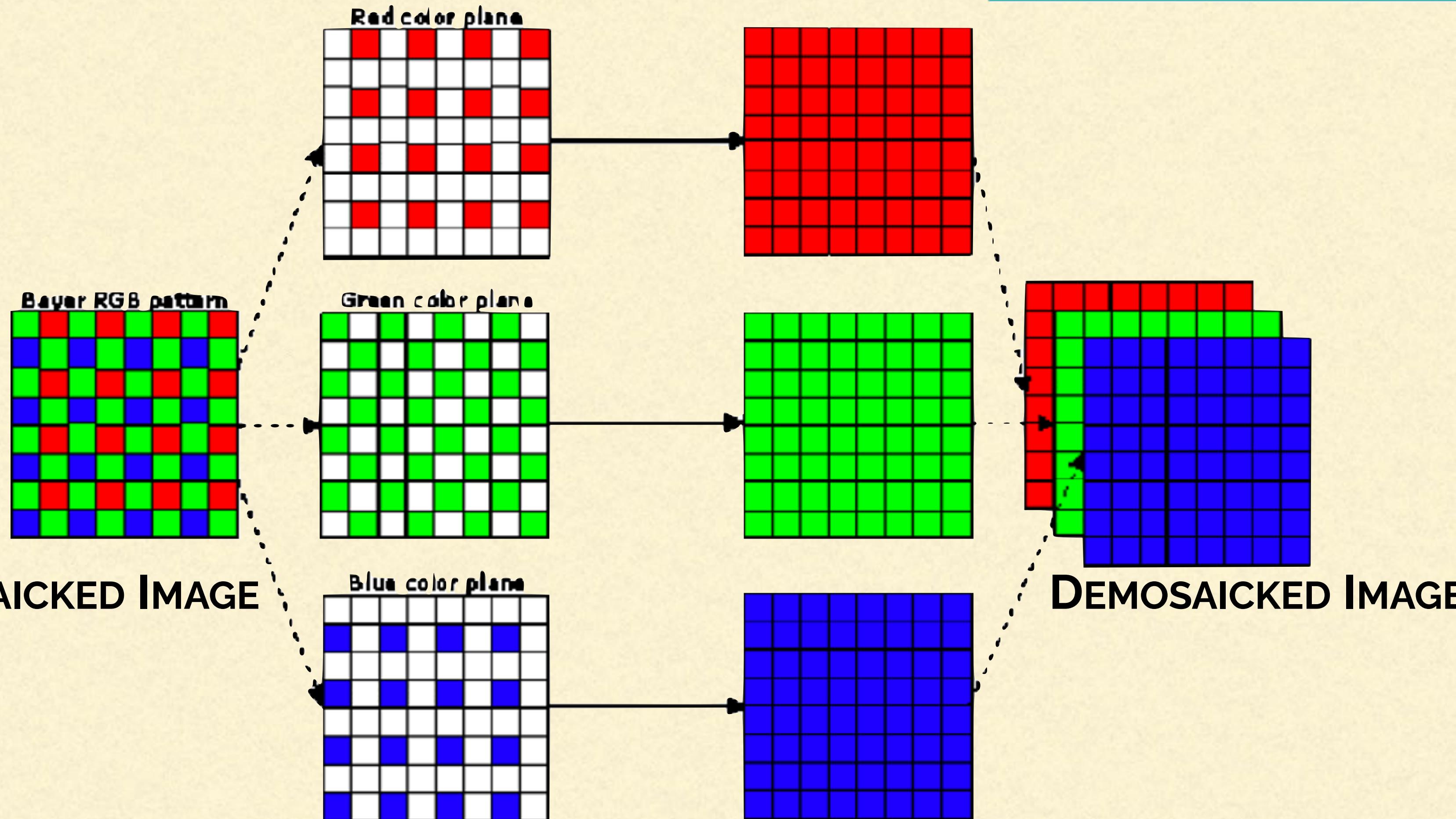
UNDERWATER COLORIMETRY



DIGITAL IMAGE FORMATION - III

Dr. Derya Akkaynak | dakkaynak@univ.haifa.ac.il

Demosaicking

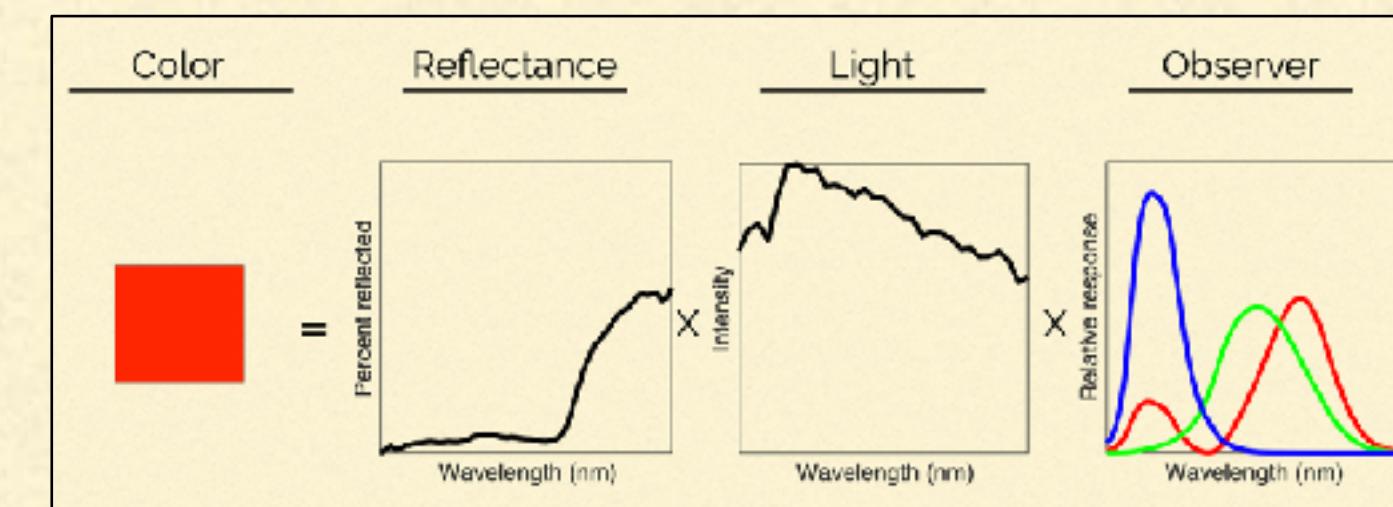


Demosaicking algorithms are an area of research on their own. Do you think demosaicking affects linearity?

PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
- Global Shutter vs Rolling Shutter
- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
- Spectral Response
- Low-Pass Filter (Anti-Aliasing Filter)
- Backside Illumination (BSI)
- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

Image Formation



$$\text{Color} = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

κ : exposure-related constant

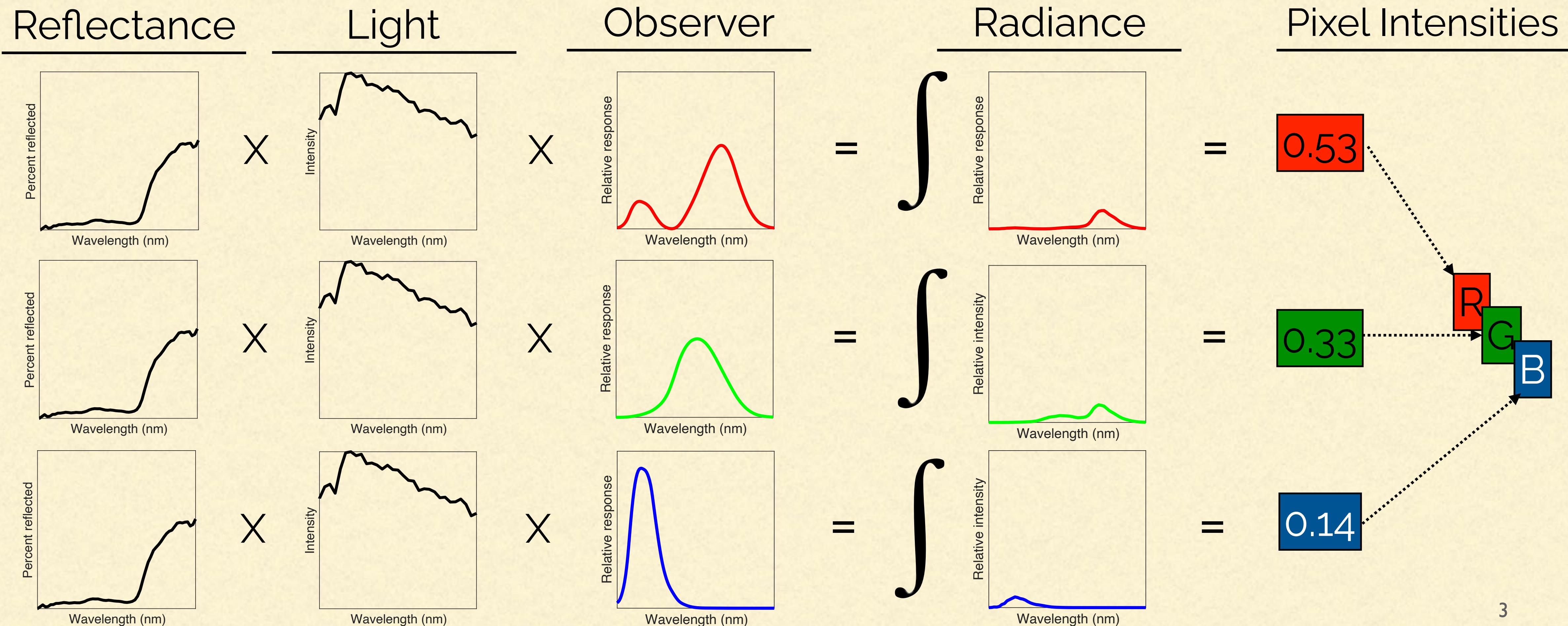
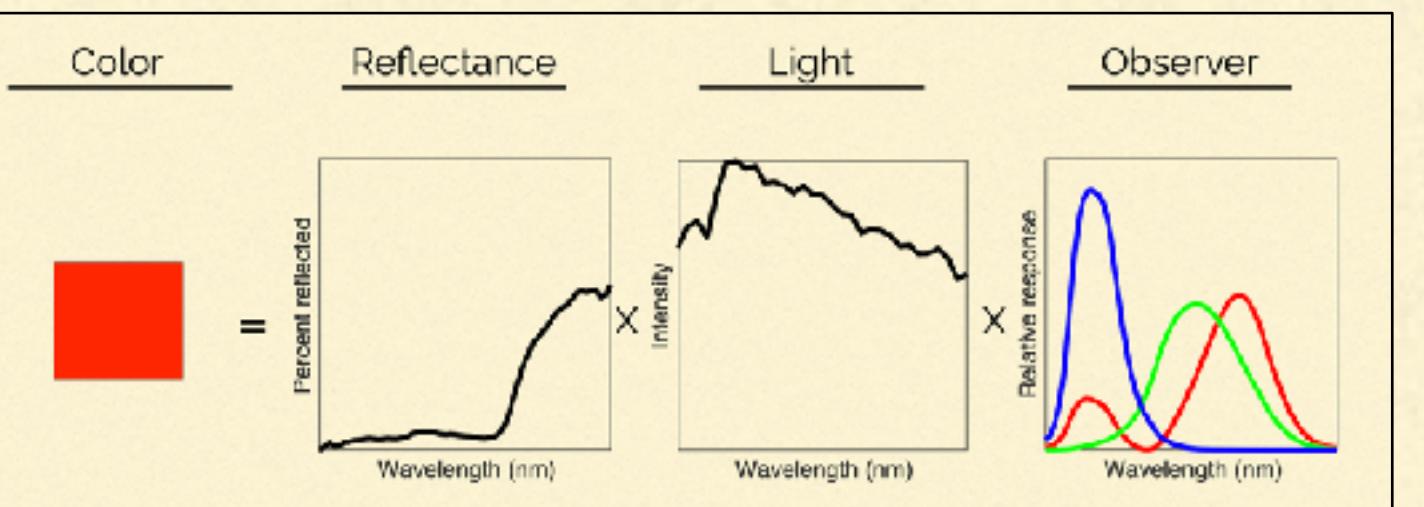


Image Formation

$$Color = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

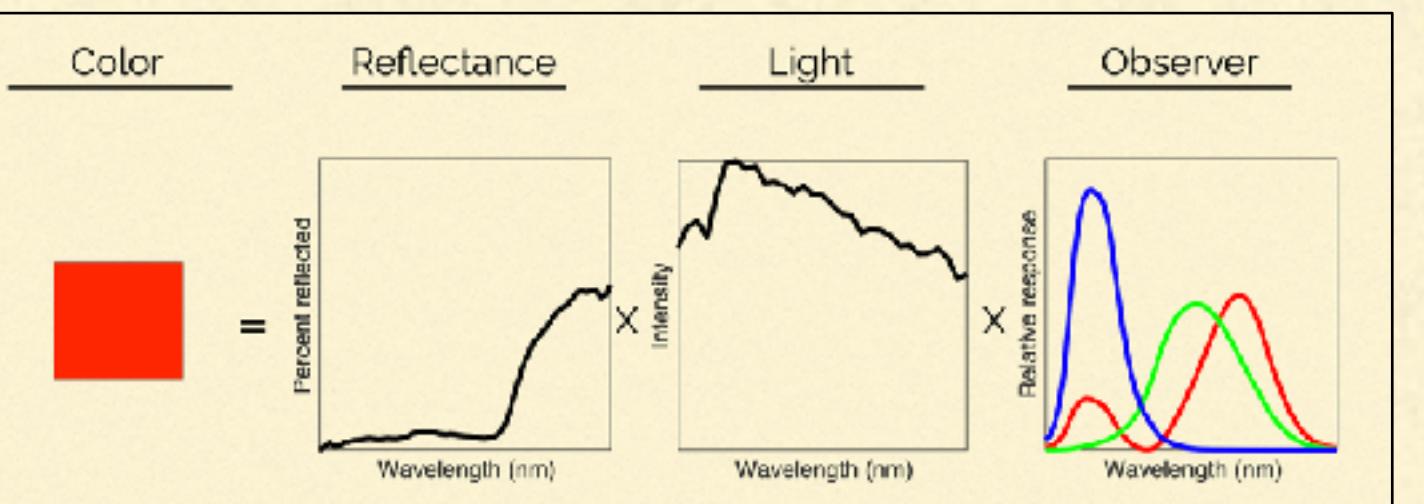


We went from **continuous** quantities in the physical world that were all a function of the wavelength of light, to **discrete** quantities in the camera world.

Image Formation

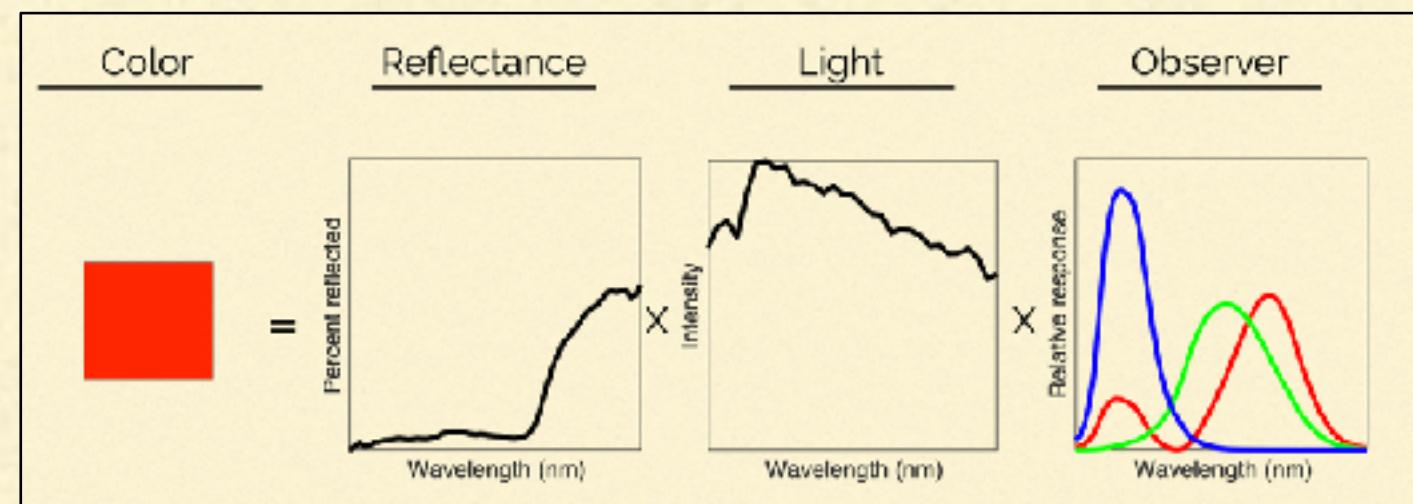
$$Color = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

$$\approx \sum_{i=1}^n \rho(\lambda_i) E(\lambda_i) S_c(\lambda_i) \Delta \lambda$$



We went from **continuous** quantities in the physical world that were all a function of the wavelength of light, to **discrete** quantities in the camera world.

Image Formation



$$Color = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

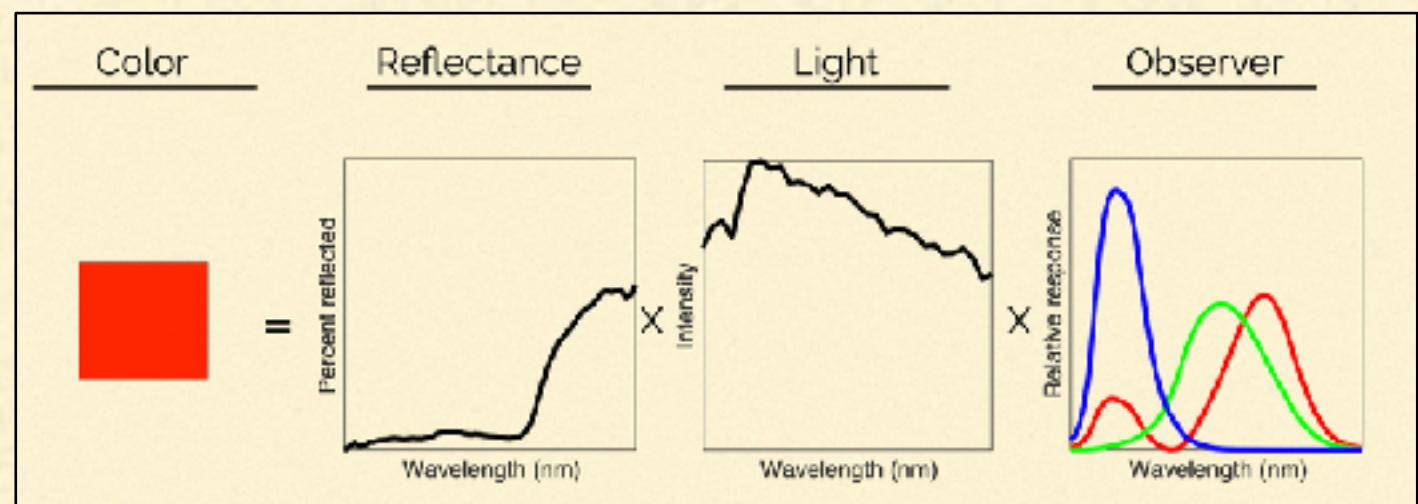
$$\approx \sum_{i=1}^n \rho(\lambda_i) E(\lambda_i) S_c(\lambda_i) \Delta \lambda$$

$$\Delta \lambda = \frac{700 - 400}{n - 1} \text{ nm} = \frac{300}{n - 1} \text{ nm} \quad \text{and}$$

$$\lambda_i = 400 \text{ nm} + (i - 1) \Delta \lambda \quad \text{for } i = 1, \dots, n .$$

We went from **continuous** quantities in the physical world that were all a function of the wavelength of light, to **discrete** quantities in the camera world.

Image Formation



$$Color = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

$$\approx \sum_{i=1}^n \rho(\lambda_i) E(\lambda_i) S_c(\lambda_i) \Delta\lambda \quad \rightarrow$$

$$I_c \approx \rho E S_c$$

c: color channel

$$\Delta\lambda = \frac{700 - 400}{n - 1} \text{nm} = \frac{300}{n - 1} \text{nm} \quad \text{and}$$

$$\lambda_i = 400 \text{nm} + (i - 1)\Delta\lambda \quad \text{for } i = 1, \dots, n .$$

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Image Formation

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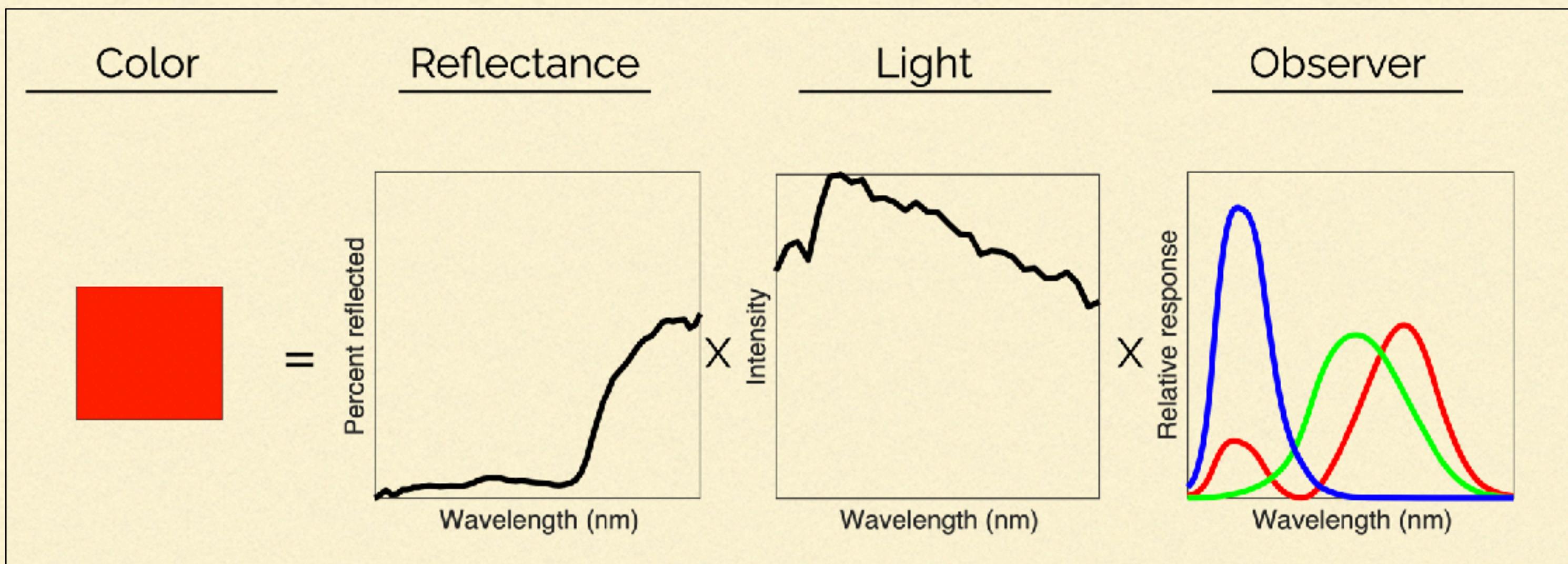


Image Formation

Integral form

$$\text{Color} = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

We went from **continuous** quantities in the physical world that were all a function of the wavelength of light, to **discrete** quantities in the camera world.

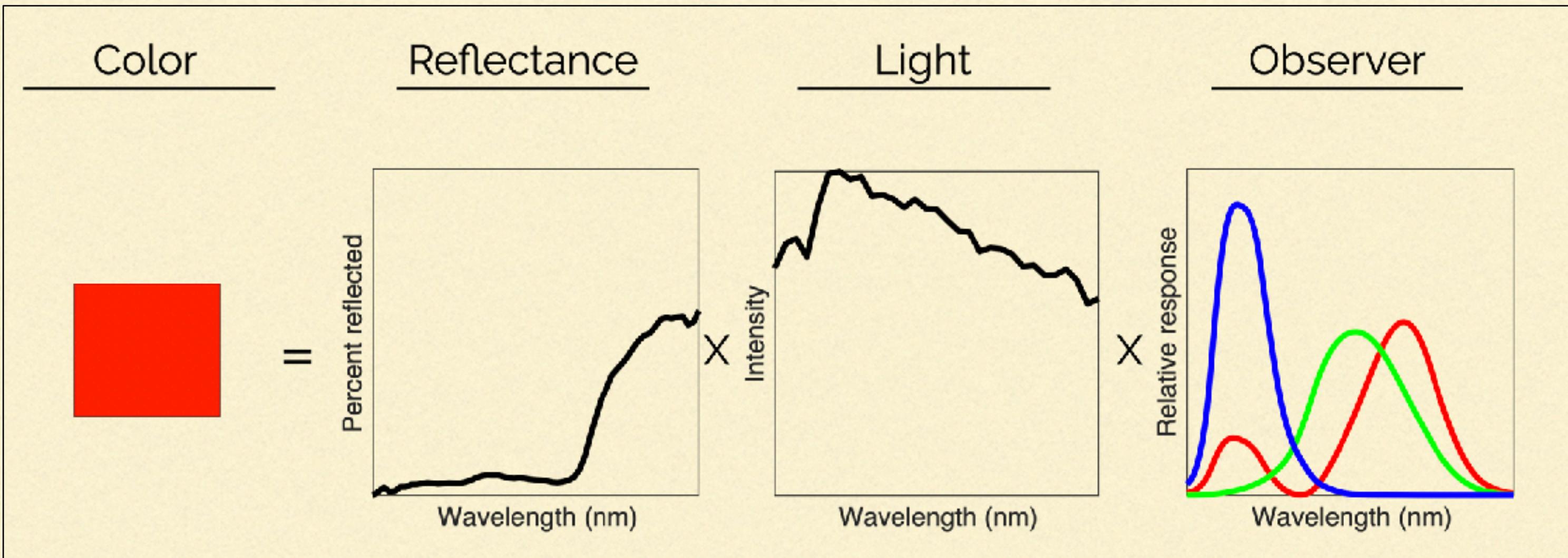
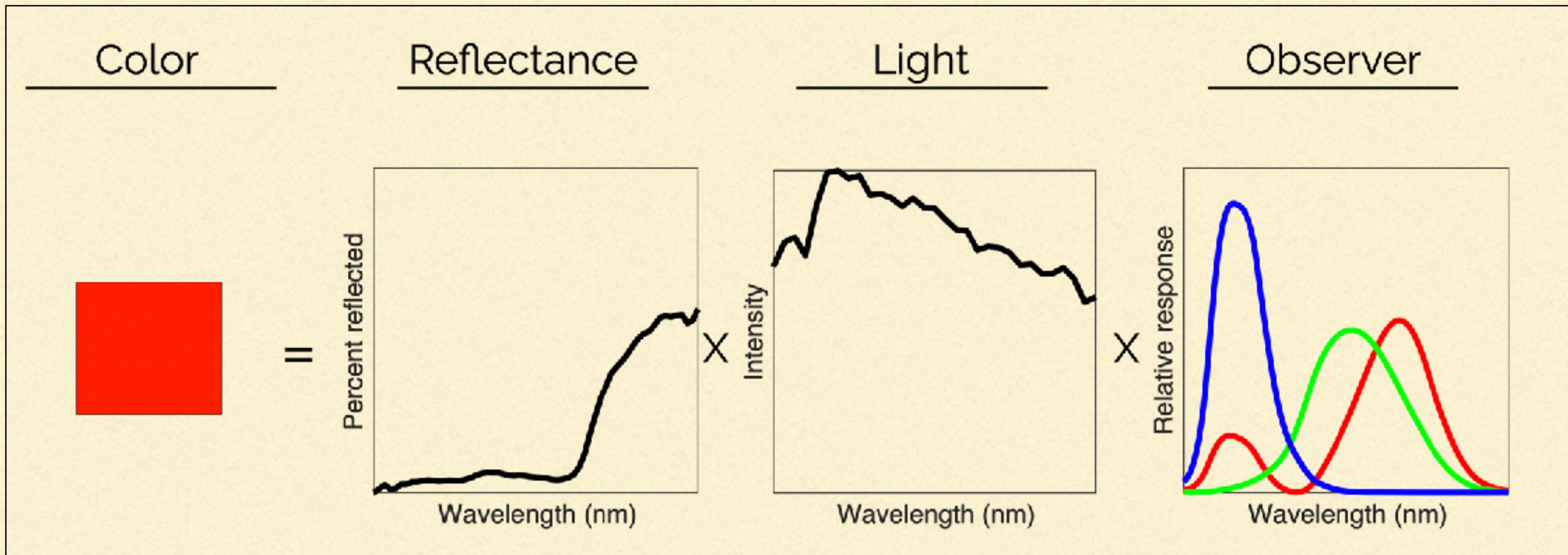


Image Formation

Integral form

$$\text{Color} = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

We went from **continuous** quantities in the physical world that were all a function of the wavelength of light, to **discrete** quantities in the camera world.



Discretized form

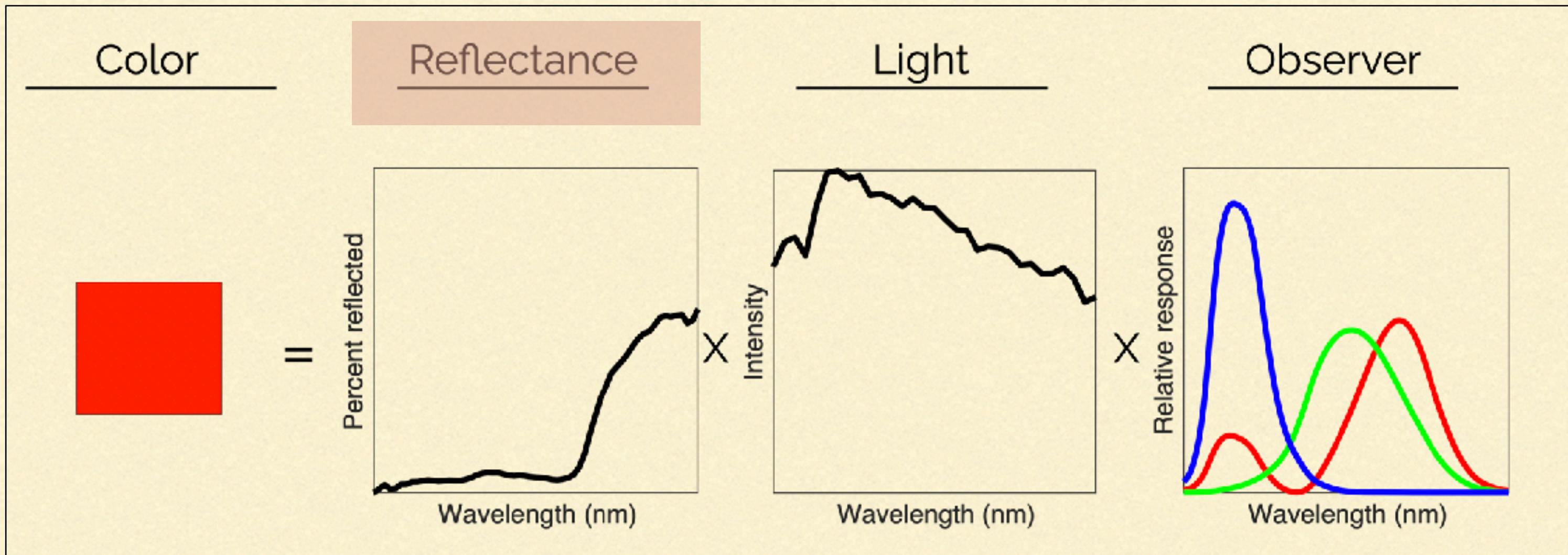
$$I_c \approx \rho E S_c$$

Image Formation

Integral form

$$\text{Color} = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

We went from **continuous** quantities in the physical world that were all a function of the wavelength of light, to **discrete** quantities in the camera world.



Discretized form

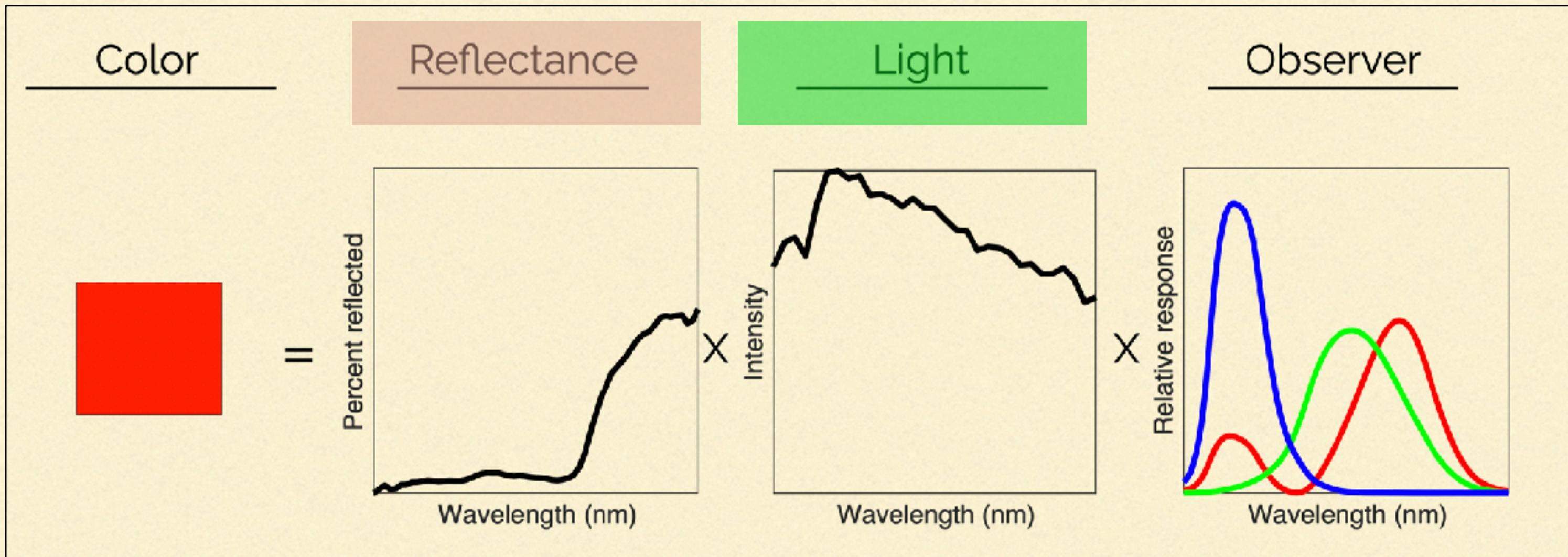
$$I_c \approx \rho E S_c$$

Image Formation

Integral form

$$\text{Color} = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

We went from **continuous** quantities in the physical world that were all a function of the wavelength of light, to **discrete** quantities in the camera world.



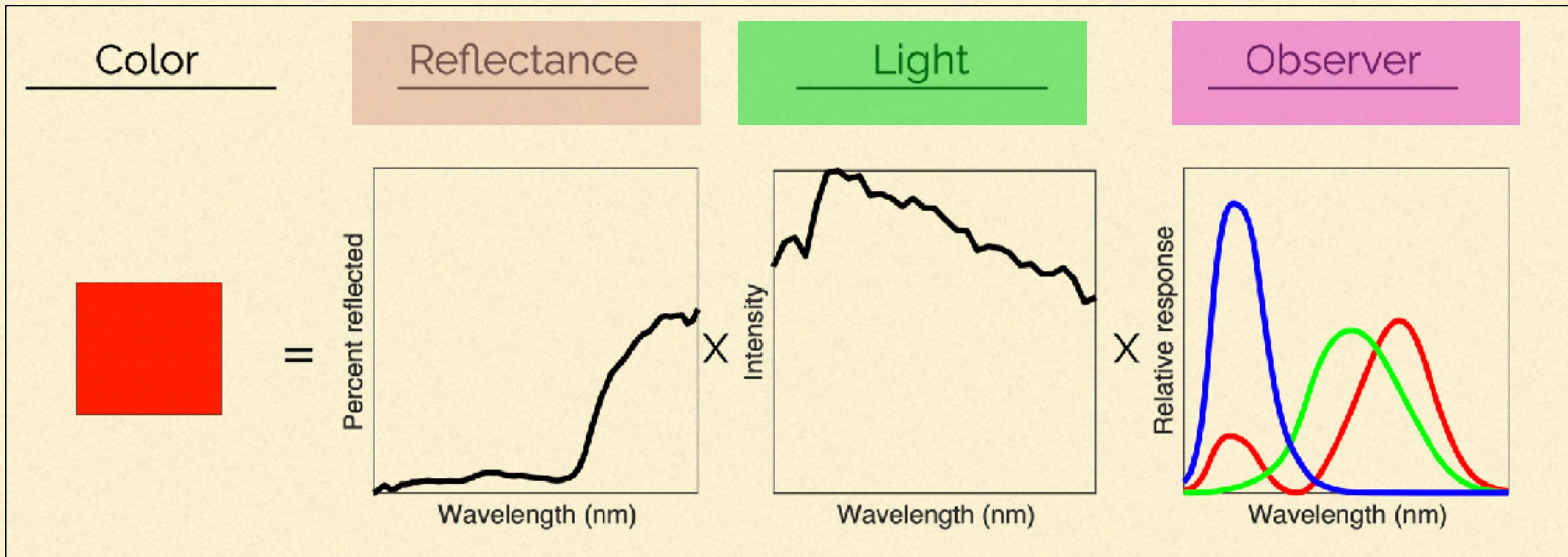
Discretized form

$$I_c \approx \rho E S_c$$

Image Formation

Integral form

$$\text{Color} = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$



Discretized form

$$I_c \approx \rho E S_c$$

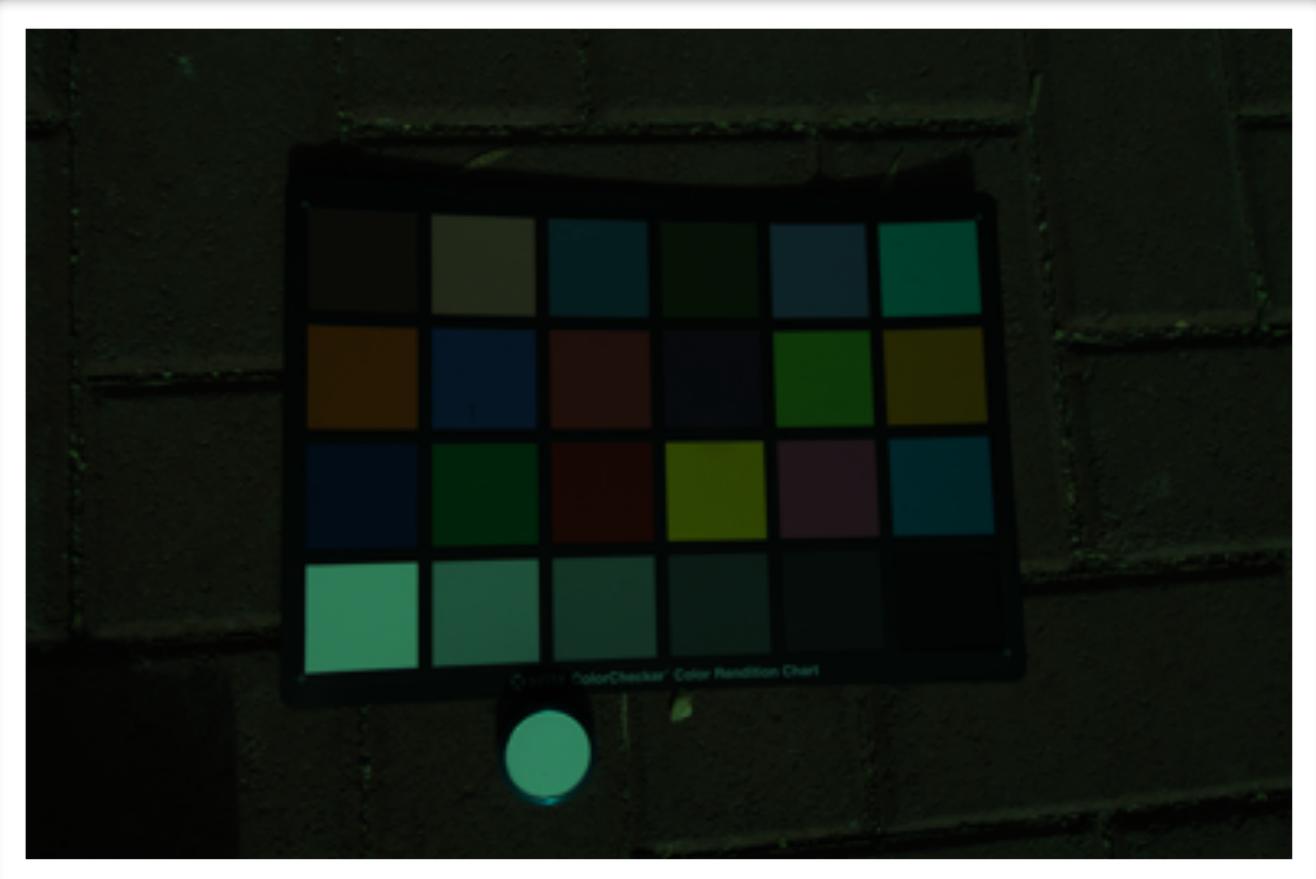
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In-Camera Processing

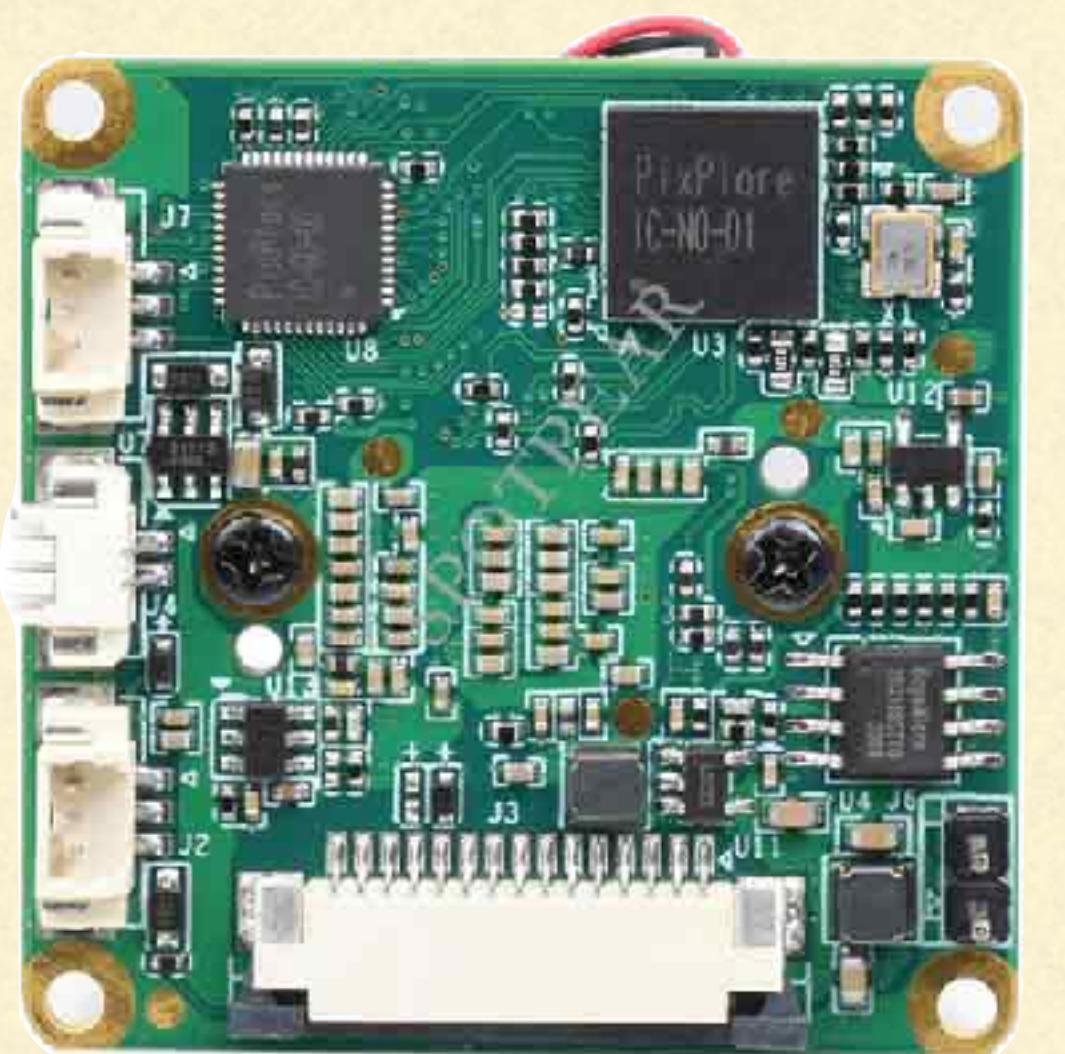
Consumer cameras are designed to create visually pleasing images!

Consumer cameras do a lot of in-camera processing the user does not know about.

RAW IMAGE



IN-CAMERA PROCESSING



JPG IMAGE



In-Camera Processing

START

RAW IMAGE



FINISH

JPG IMAGE



The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.



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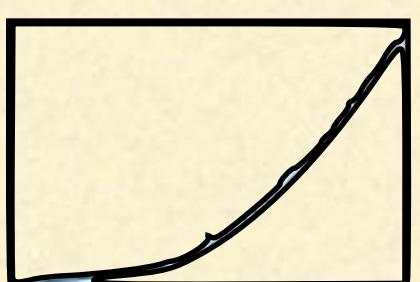
In-Camera Processing

START

RAW IMAGE



Black noise subtraction,
linearization



FINISH

JPG IMAGE

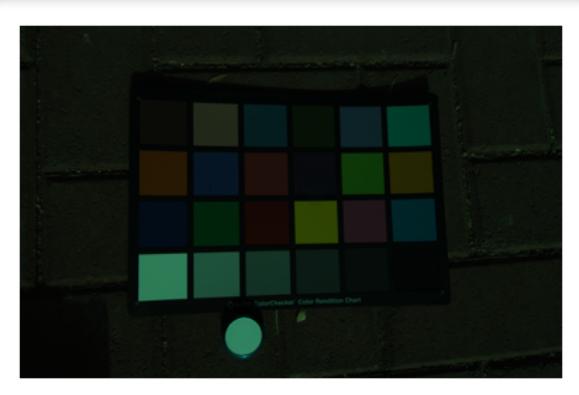


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

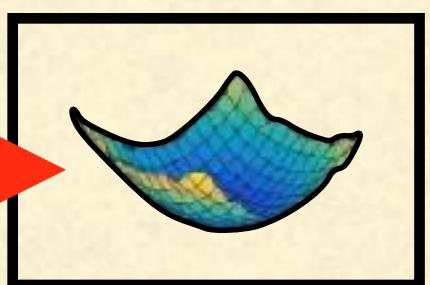
In-Camera Processing

START

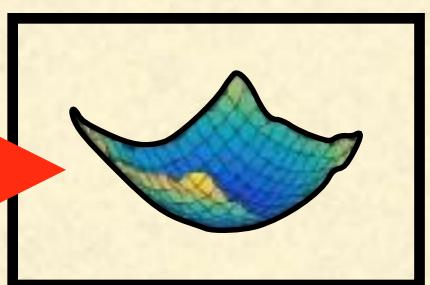
RAW IMAGE



Black noise subtraction,
linearization

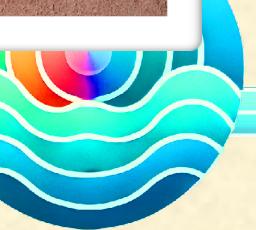
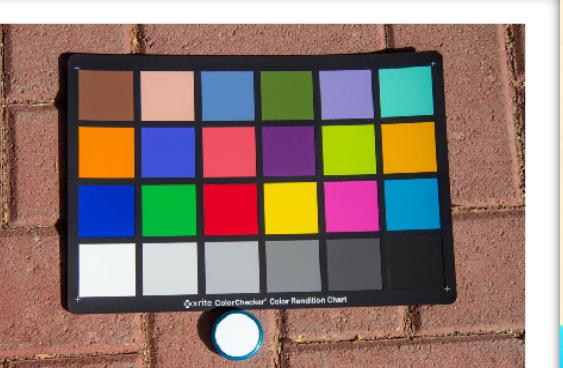


Lens distortion correction



FINISH

JPG IMAGE



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In-Camera Processing

START

RAW IMAGE

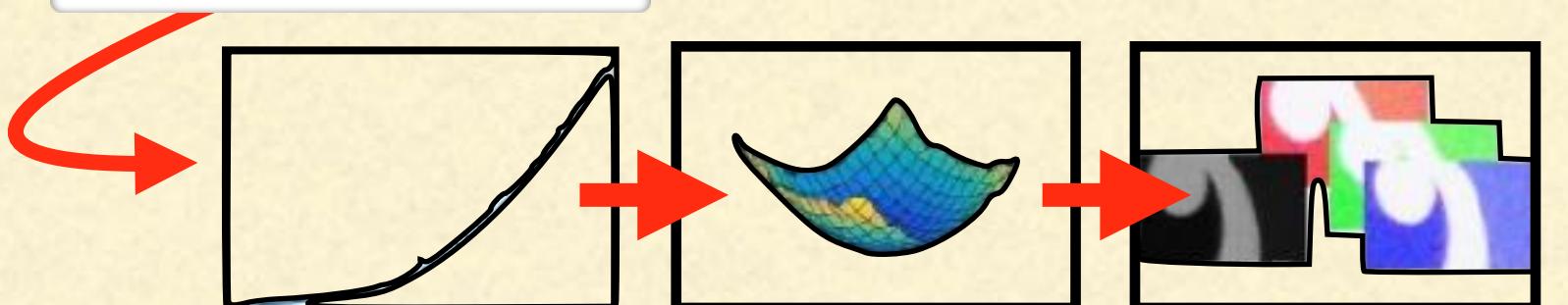


Black noise subtraction,
linearization

Black noise subtraction, linearization

Lens distortion correction

Demosaicking



FINISH

JPG IMAGE

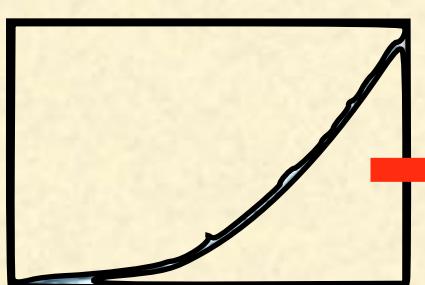


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

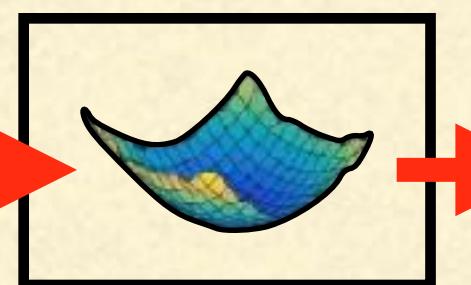
In-Camera Processing

START

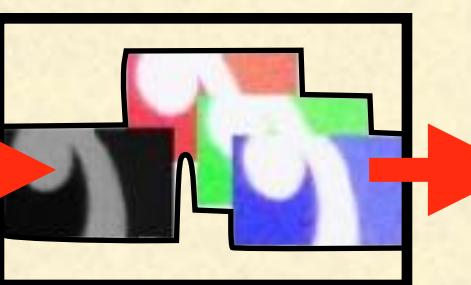
RAW IMAGE



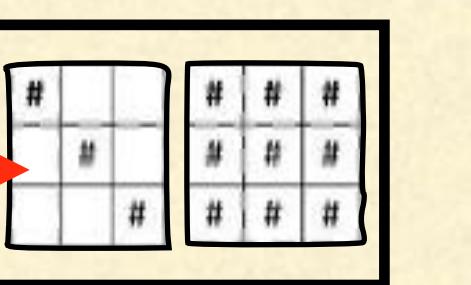
Black noise subtraction,
linearization



Lens distortion
correction



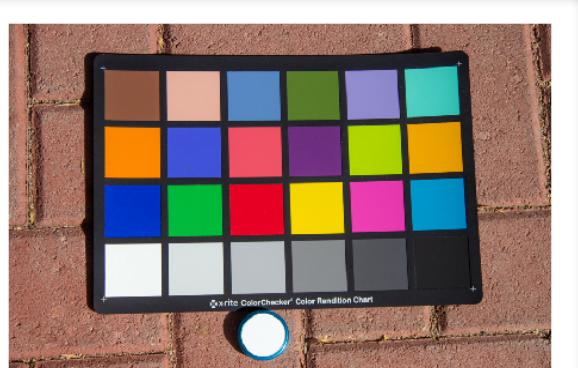
Demosaicking



White balancing
& color space
conversion

FINISH

JPG IMAGE

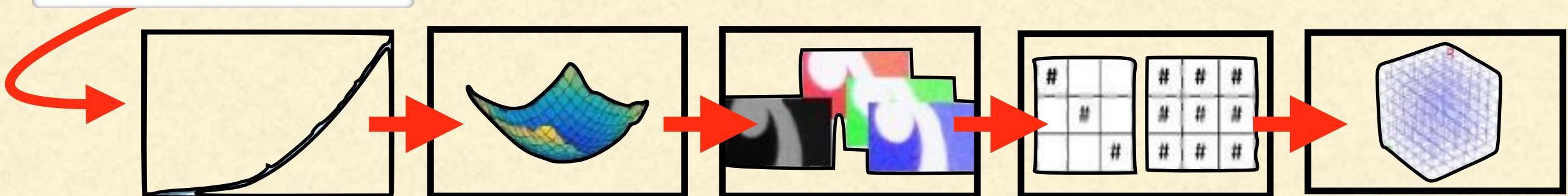


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

In-Camera Processing

START

RAW IMAGE



Black noise
subtraction,
linearization

Lens distortion
correction

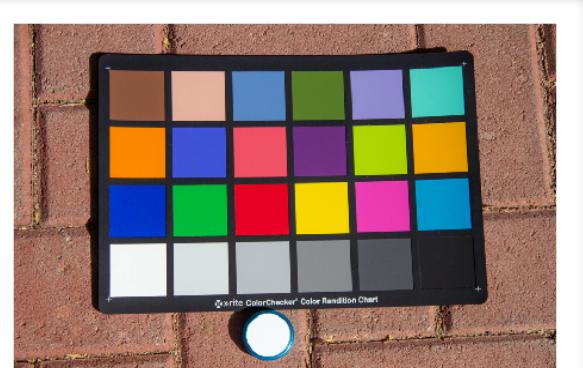
Demosaicking

White balancing
& color space
conversion

Hue & Sat
mapping

FINISH

JPG IMAGE



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In-Camera Processing

START

RAW IMAGE



Black noise
subtraction,
linearization

Lens distortion
correction

Demosaicking

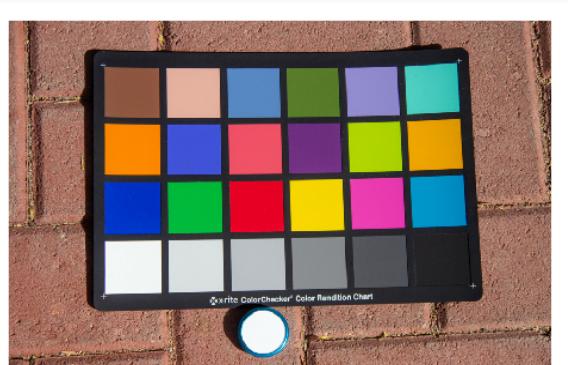
White balancing
& color space
conversion

Hue & Sat
mapping

Exposure
correction

FINISH

JPG IMAGE

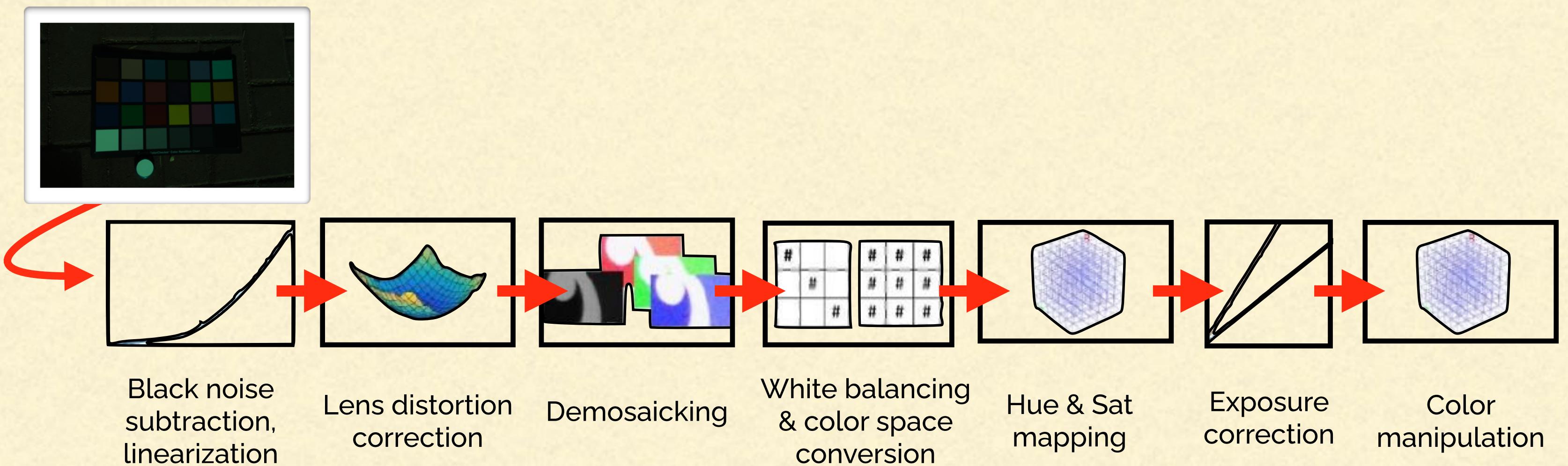


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

In-Camera Processing

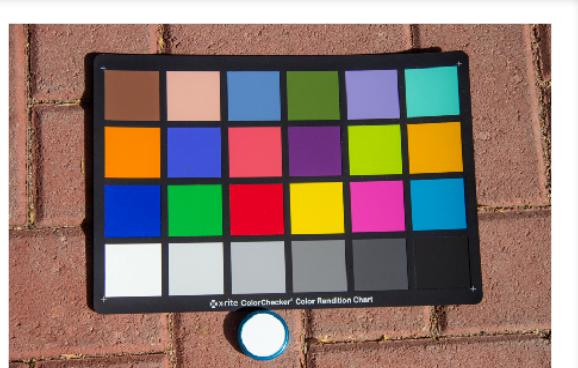
START

RAW IMAGE



FINISH

JPG IMAGE

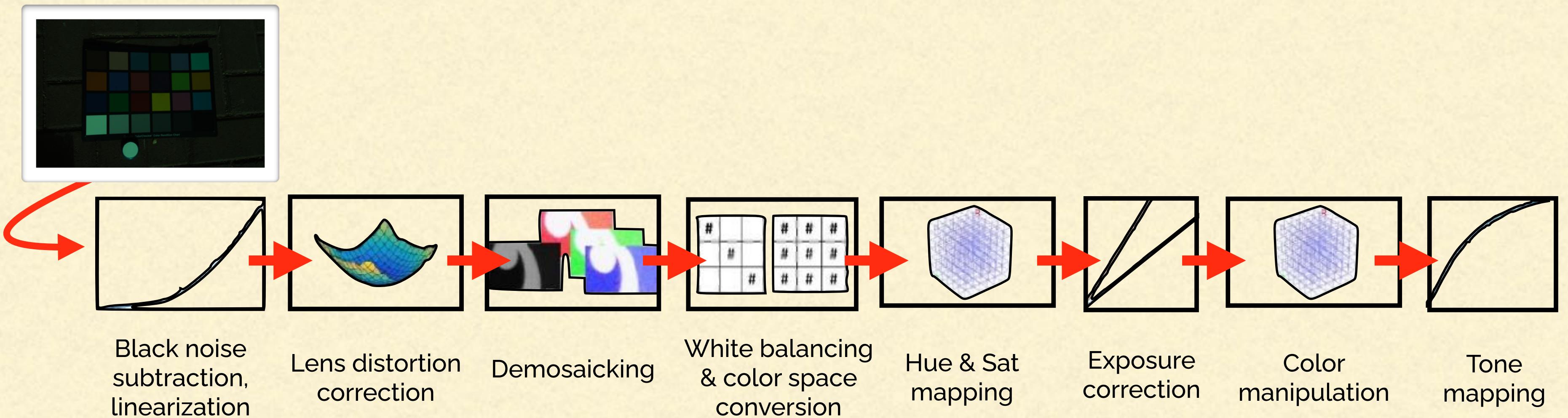


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

In-Camera Processing

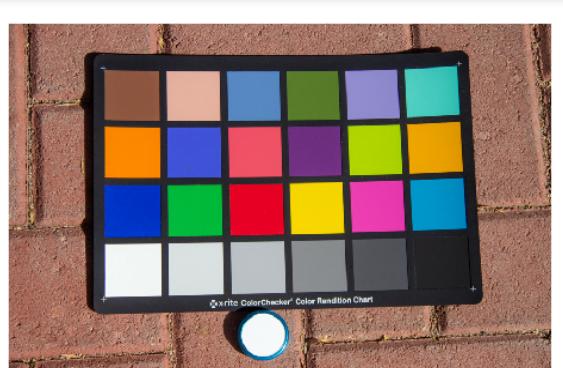
START

RAW IMAGE



FINISH

JPG IMAGE

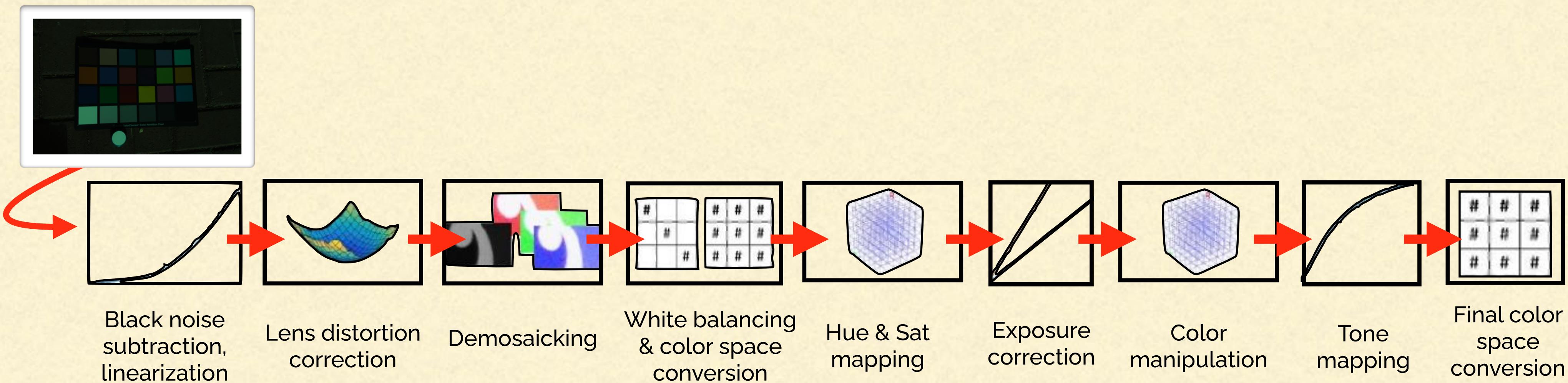


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

In-Camera Processing

START

RAW IMAGE



FINISH

JPG IMAGE

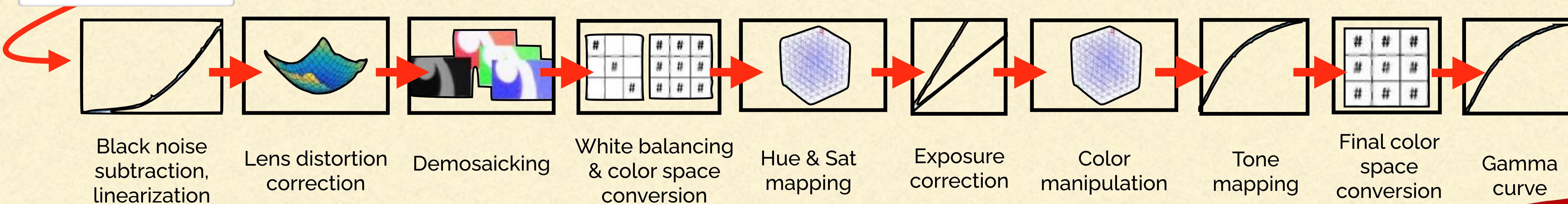


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

In-Camera Processing

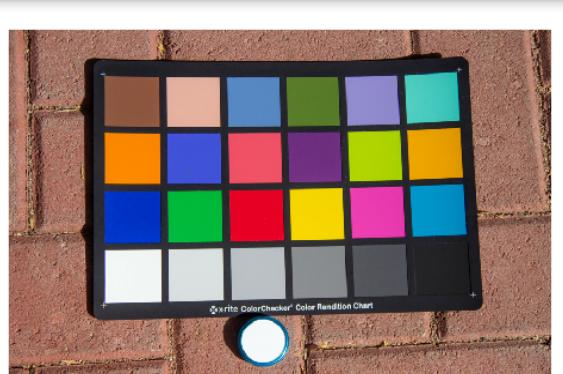
START

RAW IMAGE



FINISH

JPG IMAGE

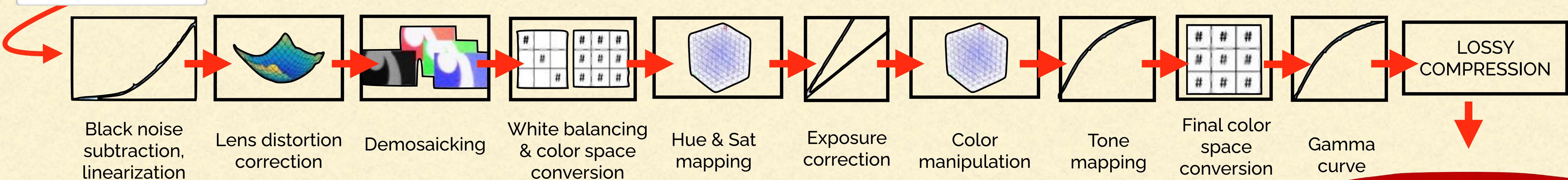


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In-Camera Processing

START

RAW IMAGE



FINISH

JPG IMAGE

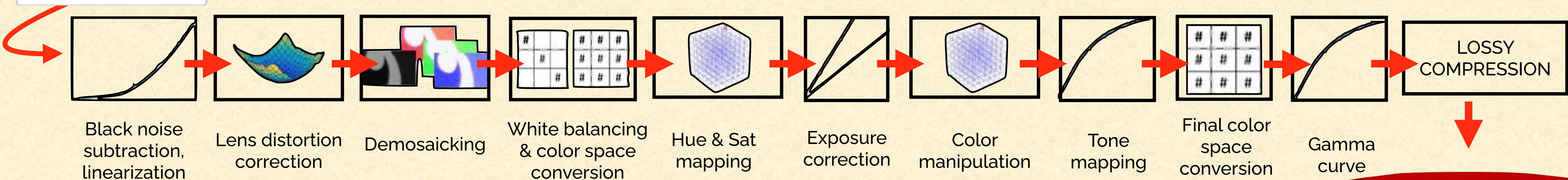


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In-Camera Processing

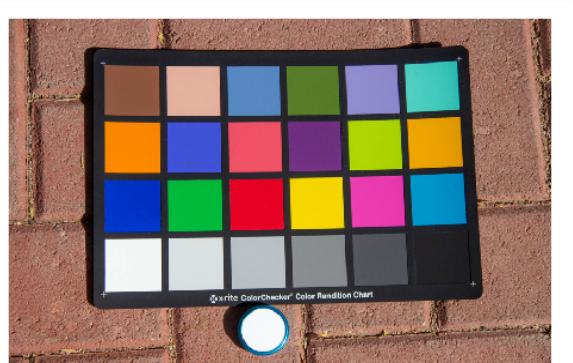
START

RAW IMAGE



FINISH

JPG IMAGE

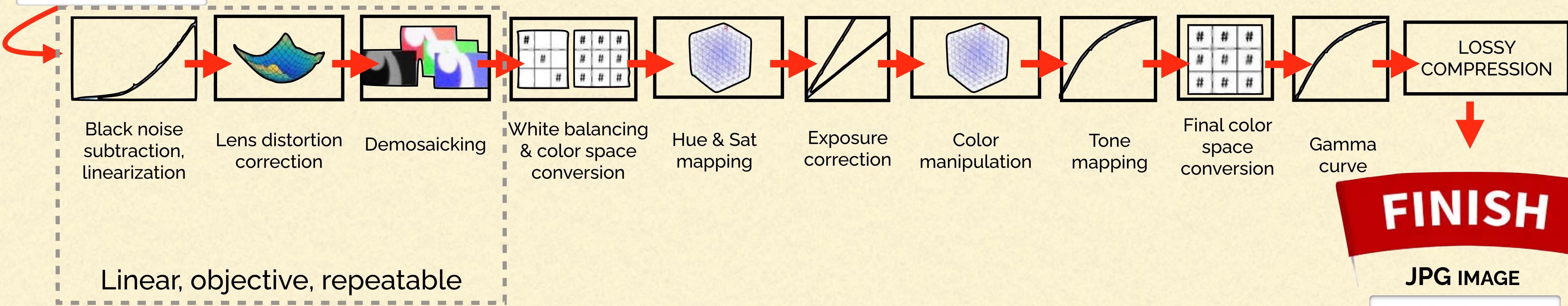


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

In-Camera Processing

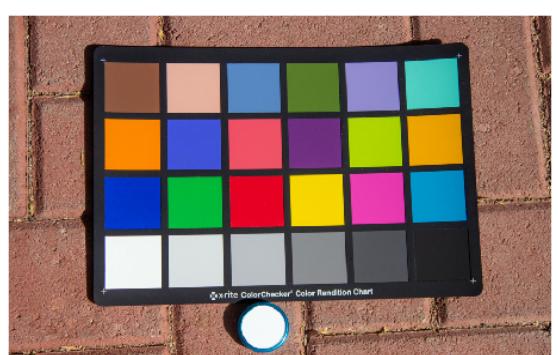
START

RAW IMAGE



FINISH

JPG IMAGE

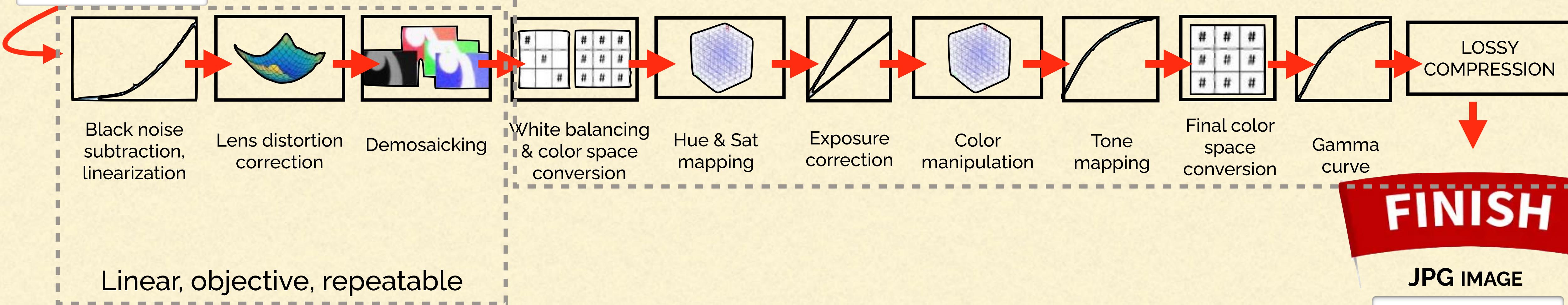


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In-Camera Processing

START

RAW IMAGE



RAW Image Manipulation Workflow

1

RAW image in
proprietary format
(e.g., .CR2)

Convert using
Adobe DNG converter



Image in .DNG
format

2

Image in .DNG
format

Convert using
Matlab or python



Image in .tiff
format
(uncompressed)

(Optional: If you don't have enough compute power)

3

Image in .tiff
format
(uncompressed)

Resize using
Matlab or python



Image in .png
format (losslessly
compressed)

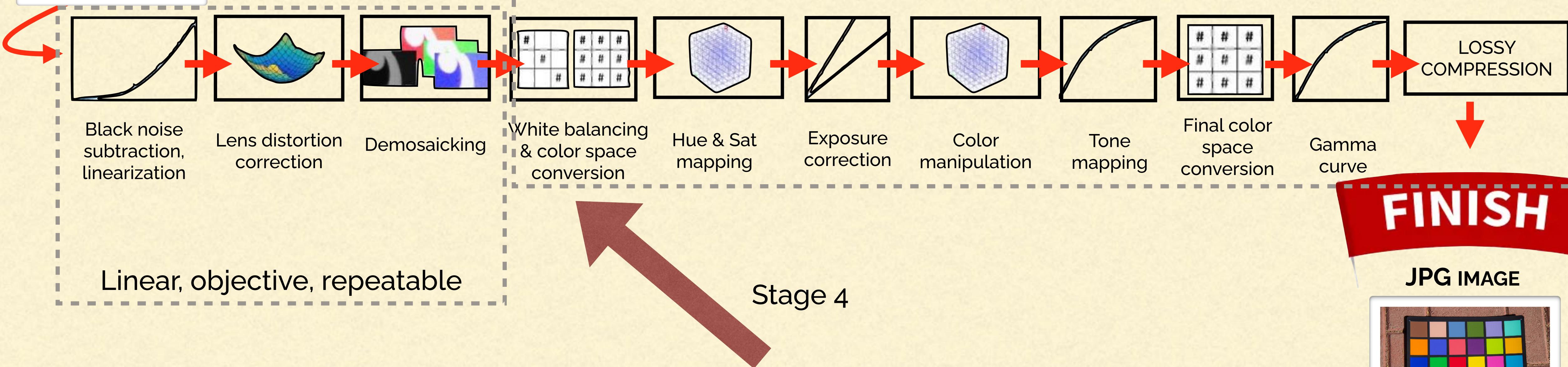


The in-camera processing pipelines are unique to a camera's make & model, but generally have modules similar to these.

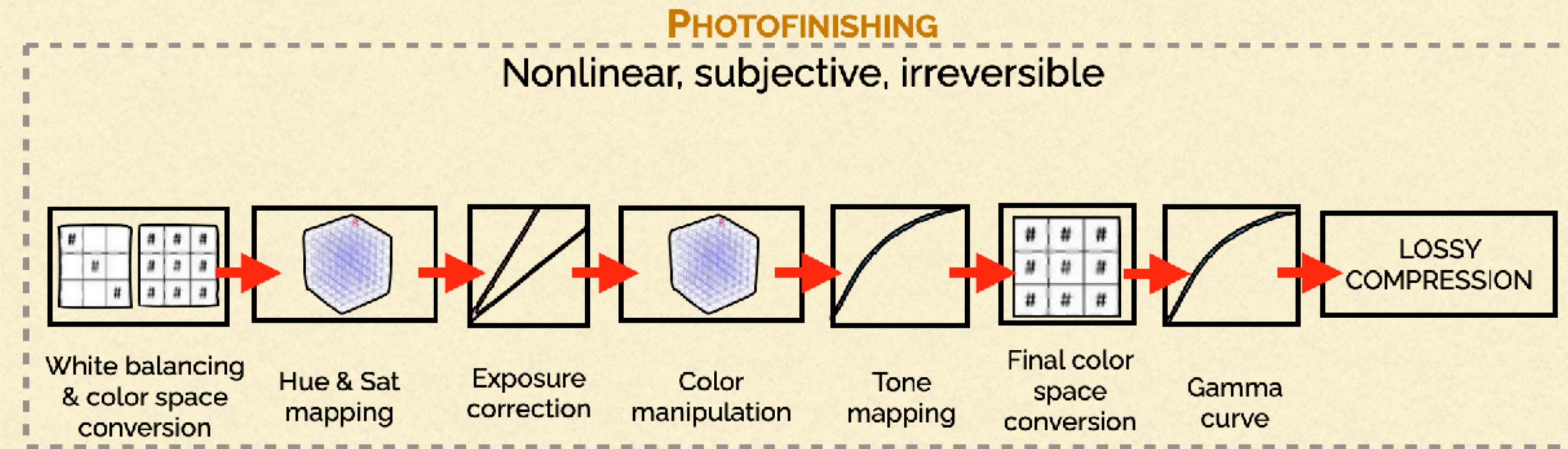
In-Camera Processing

START

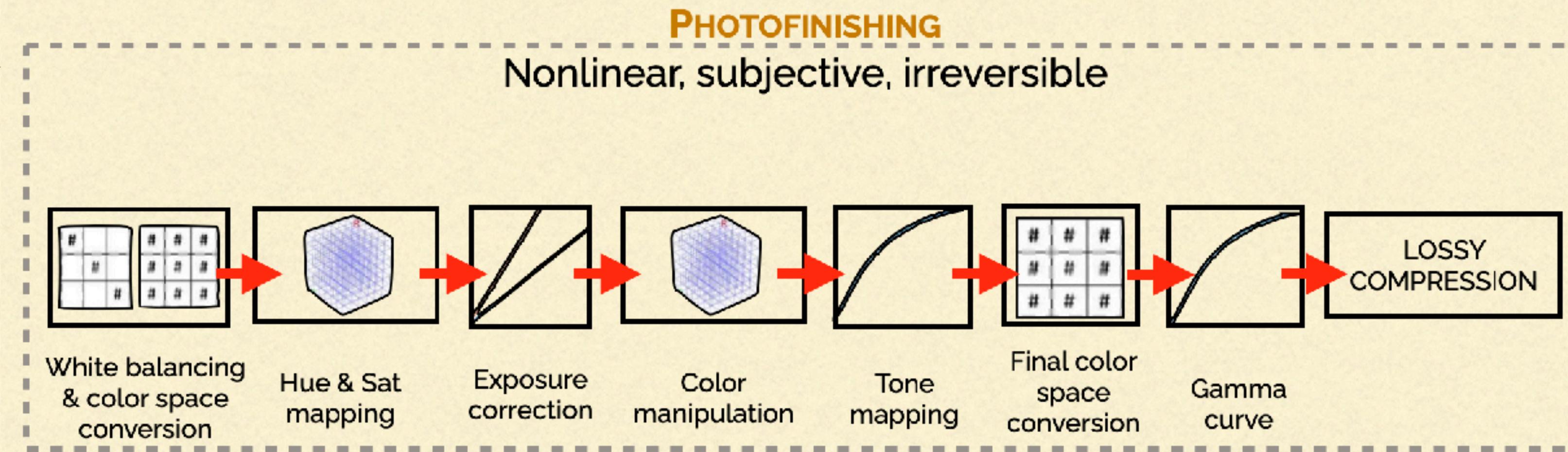
RAW IMAGE



Photofinishing



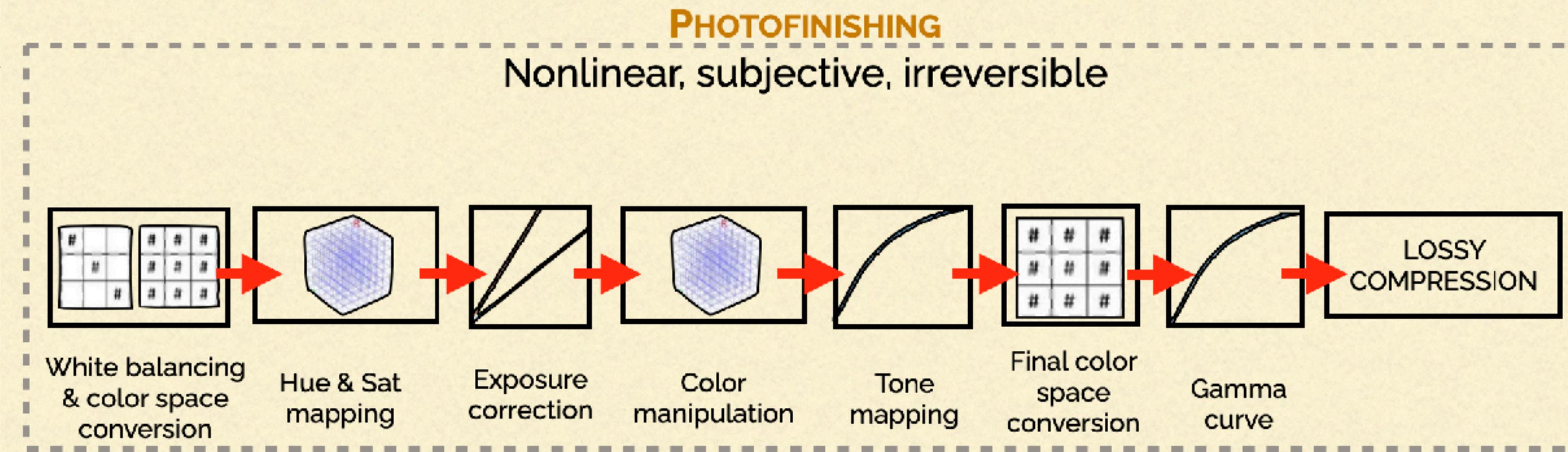
Photofinishing



- ▶ Photofinishing is a subjective sequence of operations characterizing the user's style.



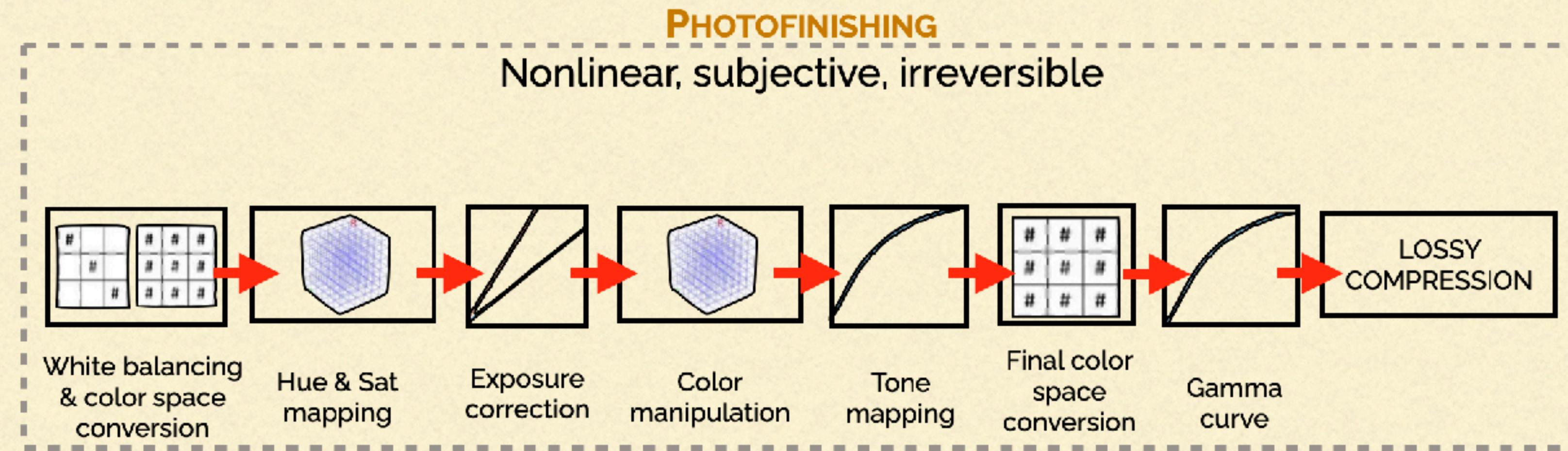
Photofinishing



- ▶ Photofinishing is a subjective sequence of operations characterizing the user's style.
- ▶ Photofinishing is generally done on a linear image resulting in a non-linear image.



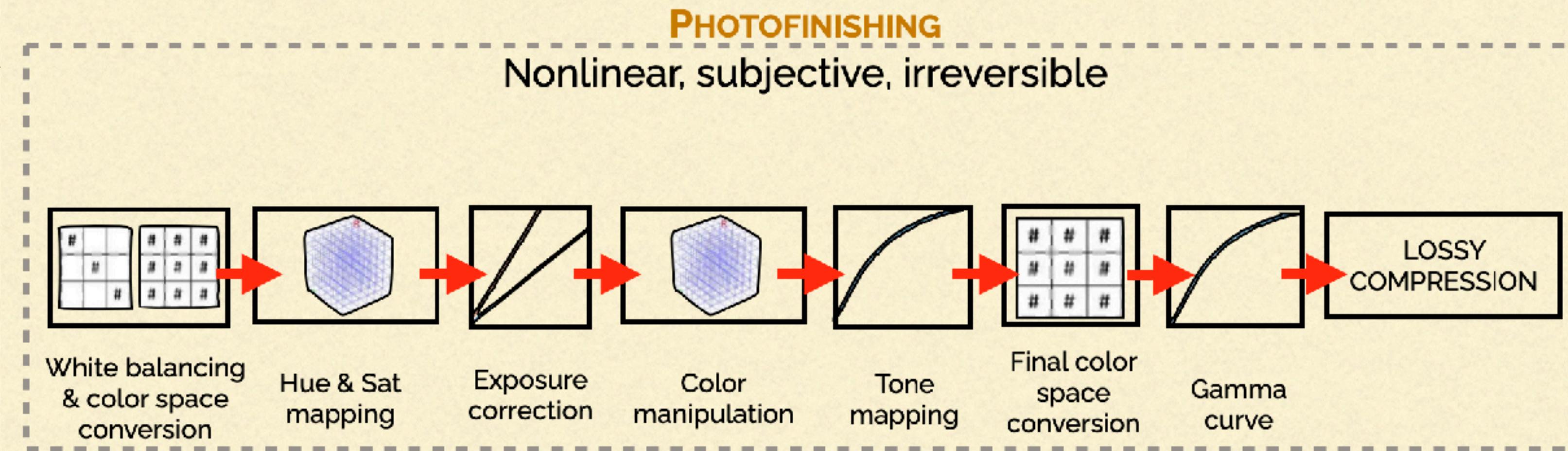
Photofinishing



- ▶ Photofinishing is a subjective sequence of operations characterizing the user's style.
- ▶ Photofinishing is generally done on a linear image resulting in a non-linear image.
- ▶ A JPG is a photofinished image, AND it is also compressed with loss.



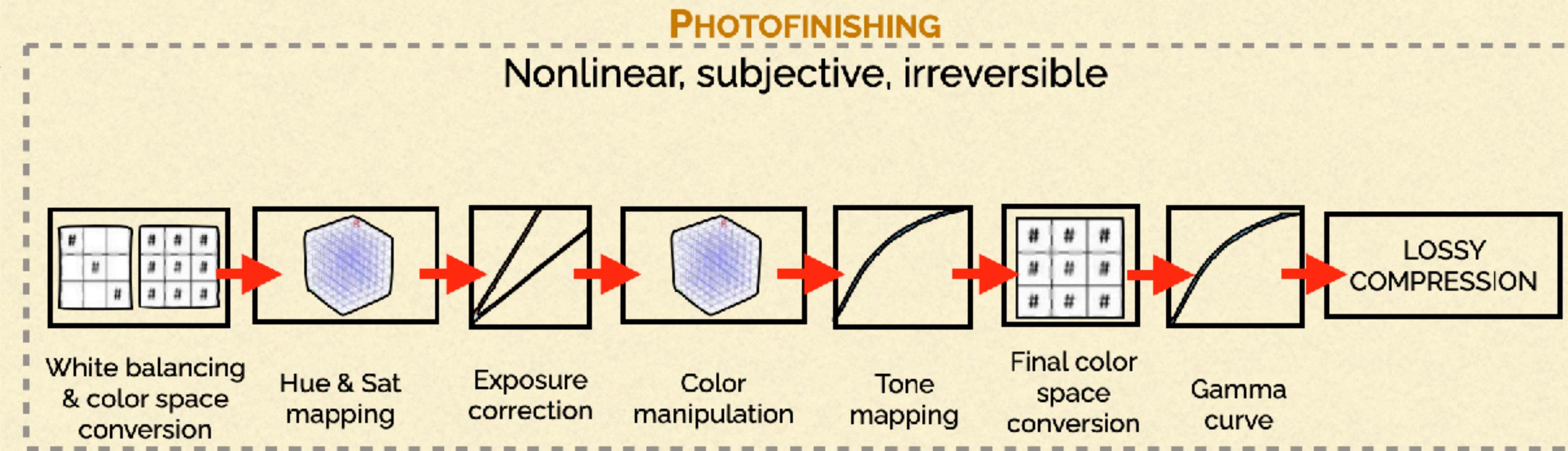
Photofinishing



- ▶ Photofinishing is a subjective sequence of operations characterizing the user's style.
- ▶ Photofinishing is generally done on a linear image resulting in a non-linear image.
- ▶ A JPG is a photofinished image, AND it is also compressed with loss.
- ▶ There is no lossless way to go back from a JPG image to a RAW image.



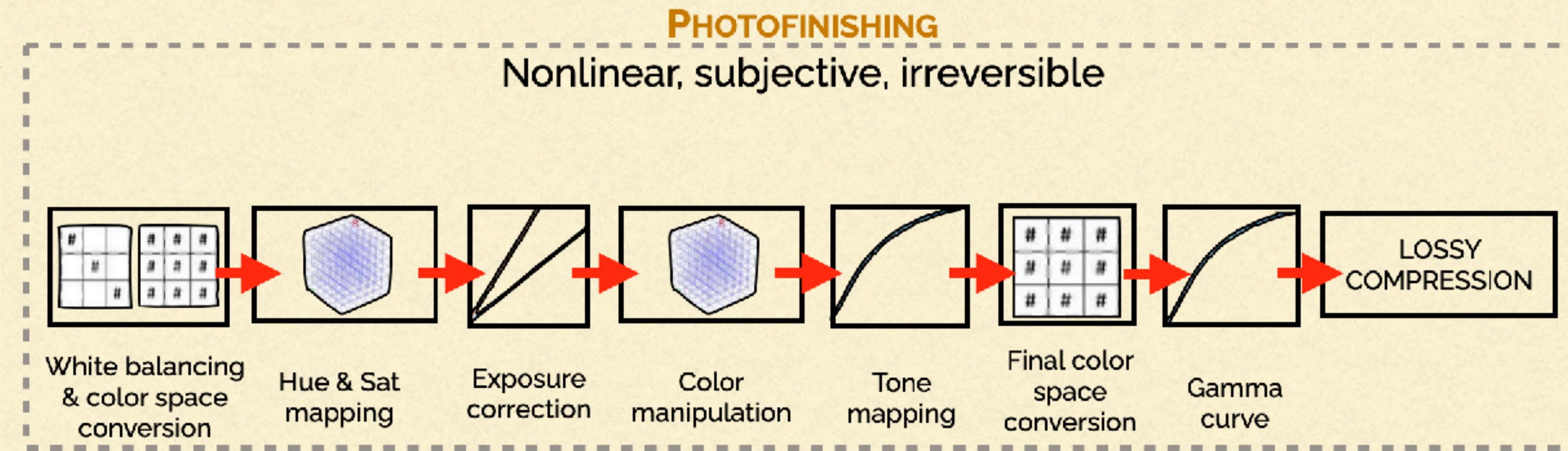
Photofinishing



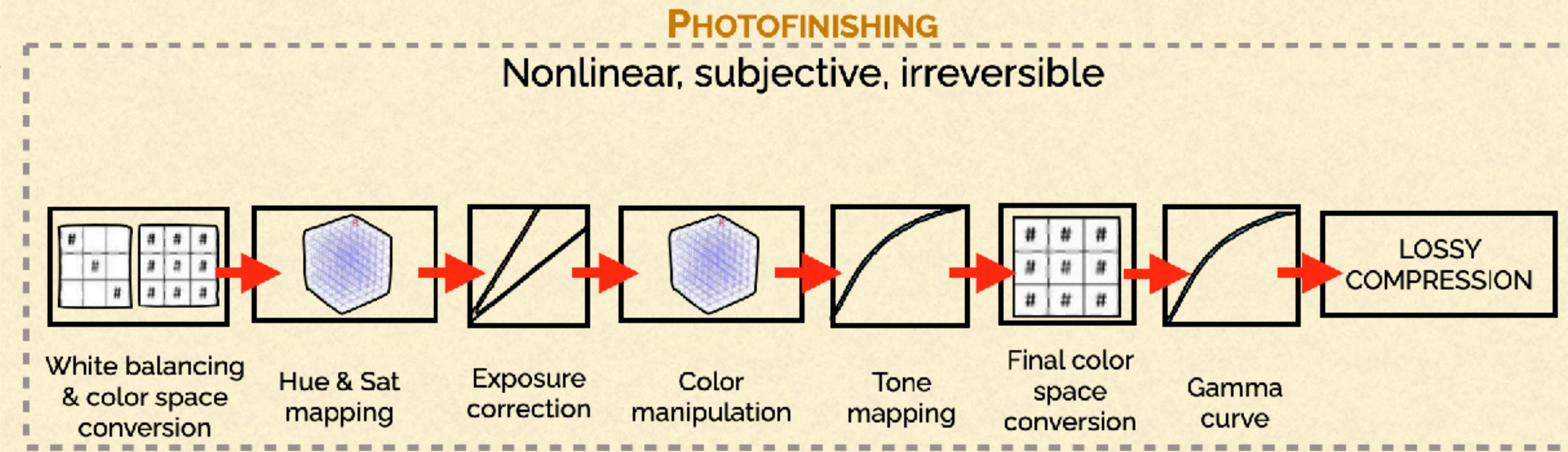
- ▶ Photofinishing is a subjective sequence of operations characterizing the user's style.
- ▶ Photofinishing is generally done on a linear image resulting in a non-linear image.
- ▶ A JPG is a photofinished image, AND it is also compressed with loss.
- ▶ There is no lossless way to go back from a JPG image to a RAW image.
- ▶ JPG images cannot be used for color-sensitive science.



Photofinishing



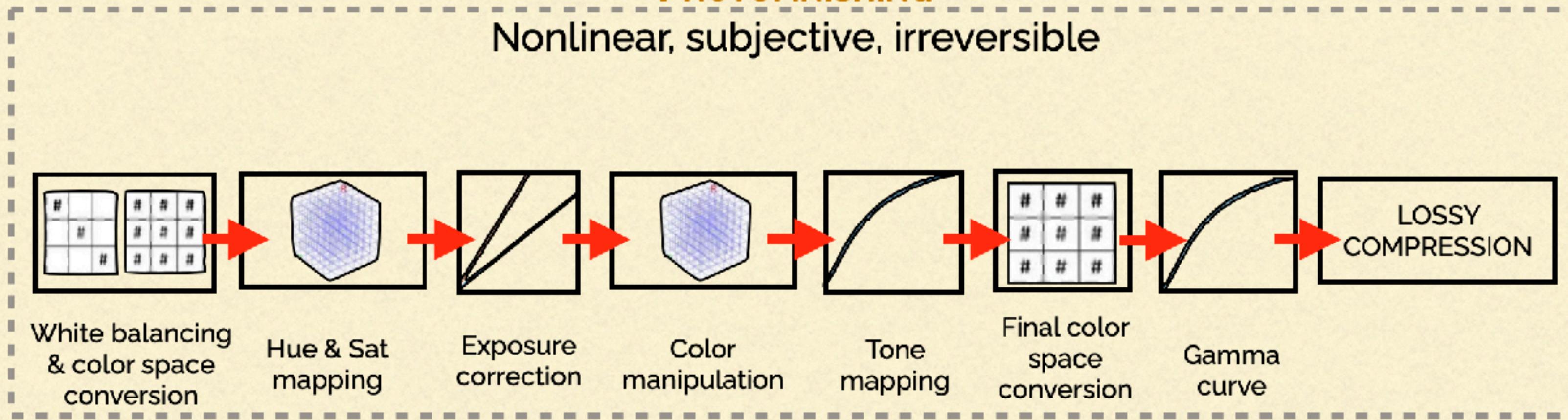
Photofinishing



Photofinishing

PHOTOFINISHING

Nonlinear, subjective, irreversible



Consumer Cameras



Consumer Cameras



- ▶ Every camera records colors differently.

Consumer Cameras



- ▶ Every camera records colors differently.
- ▶ Manufacturers do not provide the spectral sensitivities of a camera.

Consumer Cameras



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Consumer Cameras



- ▶ Every camera records colors differently.
- ▶ Manufacturers do not provide the spectral sensitivities of a camera.
- ▶ Cameras perform **black-box** processing to beautify images.
- ▶ The standard outputs of a consumer camera are non-linear.

*Consumer cameras are
not scientific instruments!*



JPGs are like hot dogs.

*If you knew how they were made,
you would never take one.*

— D. Akkaynak

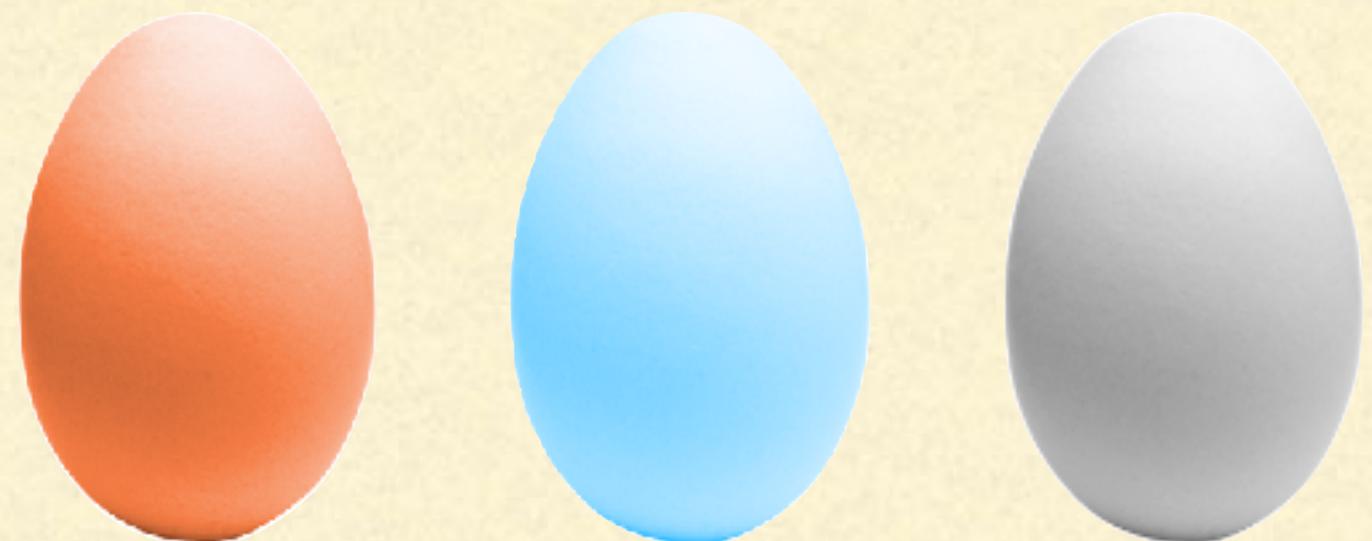
How Are Hot Dogs Made?



How Are Hot Dogs Made?



White Balancing

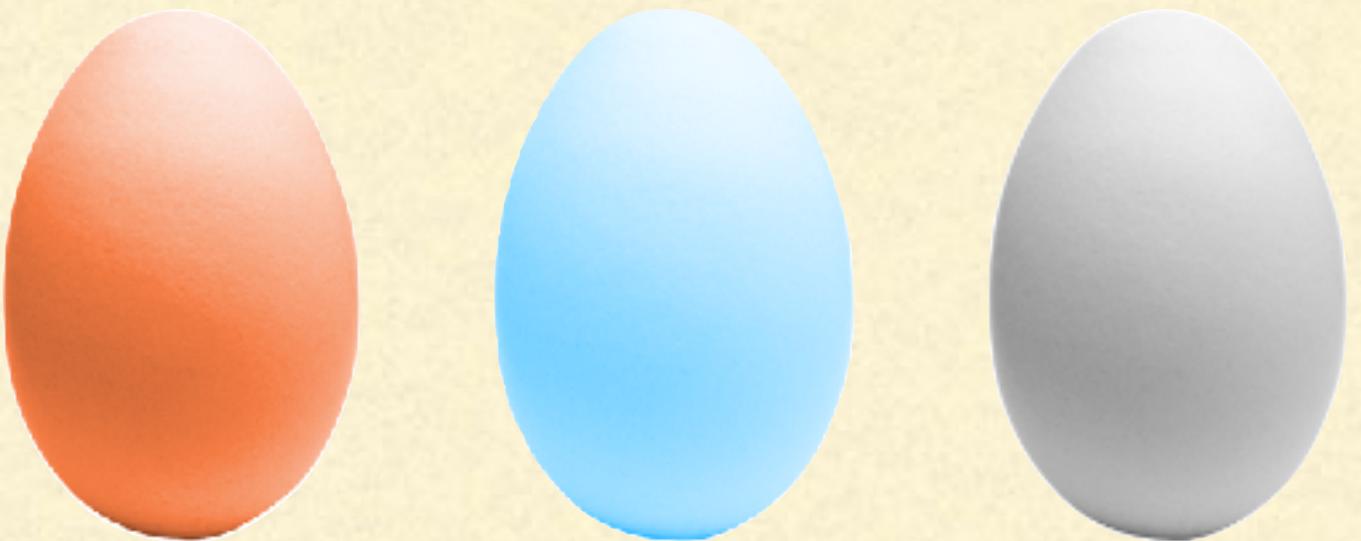


Color constancy and white balancing are related concepts, but not the same.

The same scene, under different lights, will have different colors.

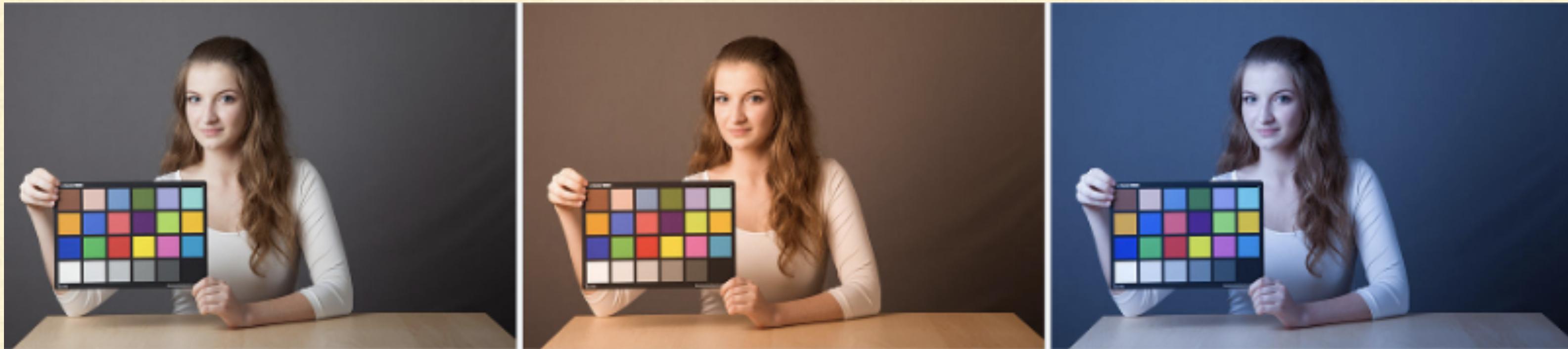


White Balancing

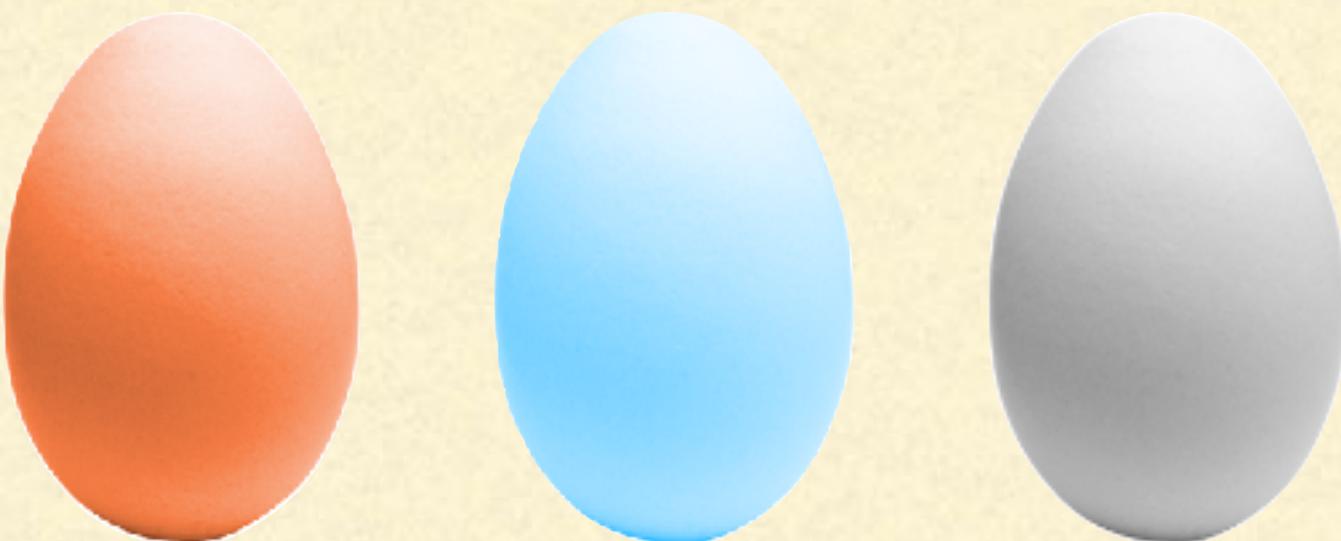


Color constancy and white balancing are related concepts, but not the same.

White-balancing is one way to standardize the light in a scene.

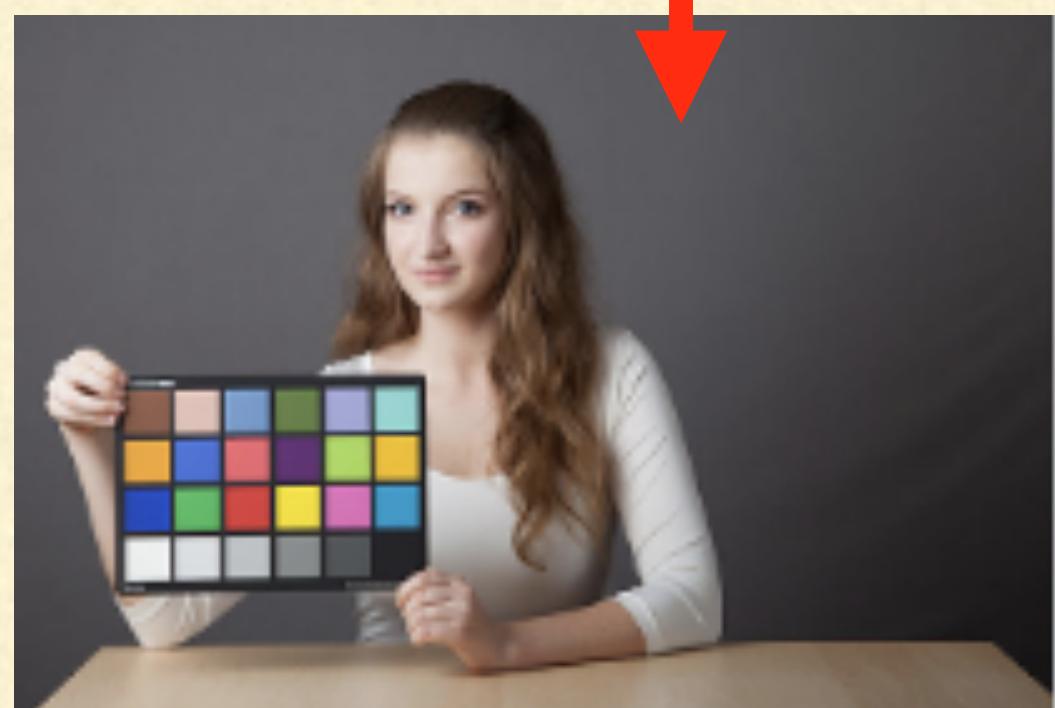
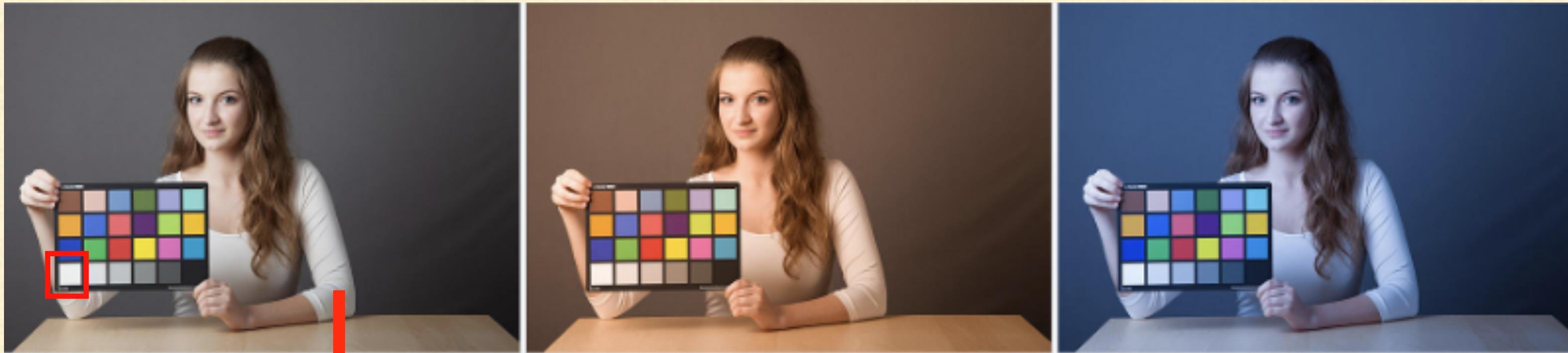


White Balancing



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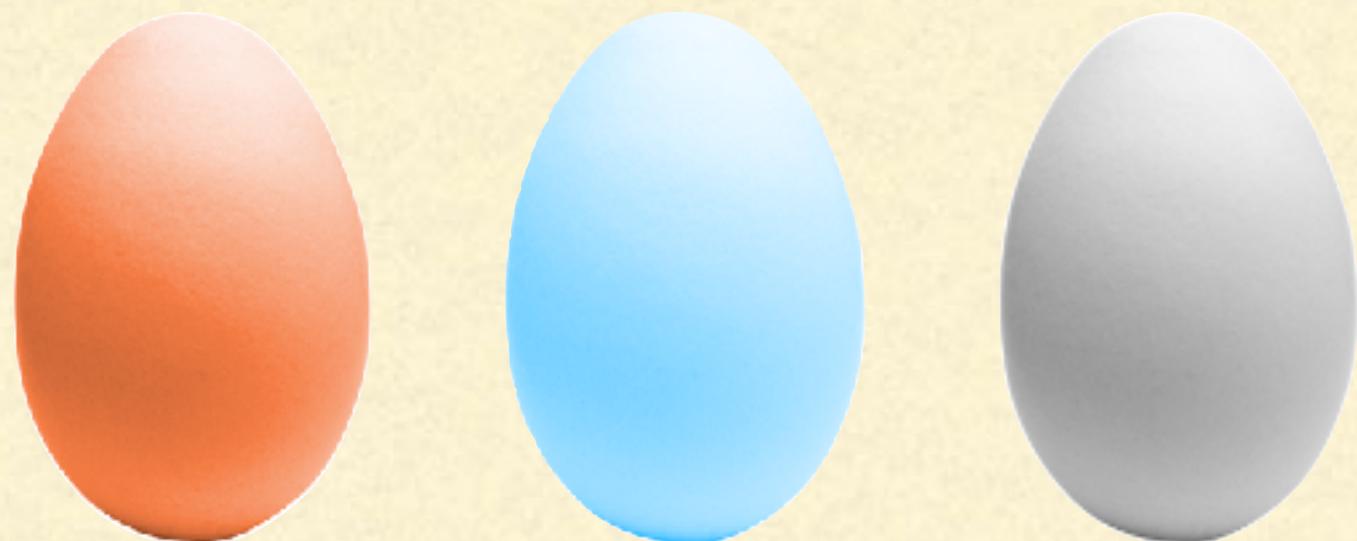
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Wikipedia

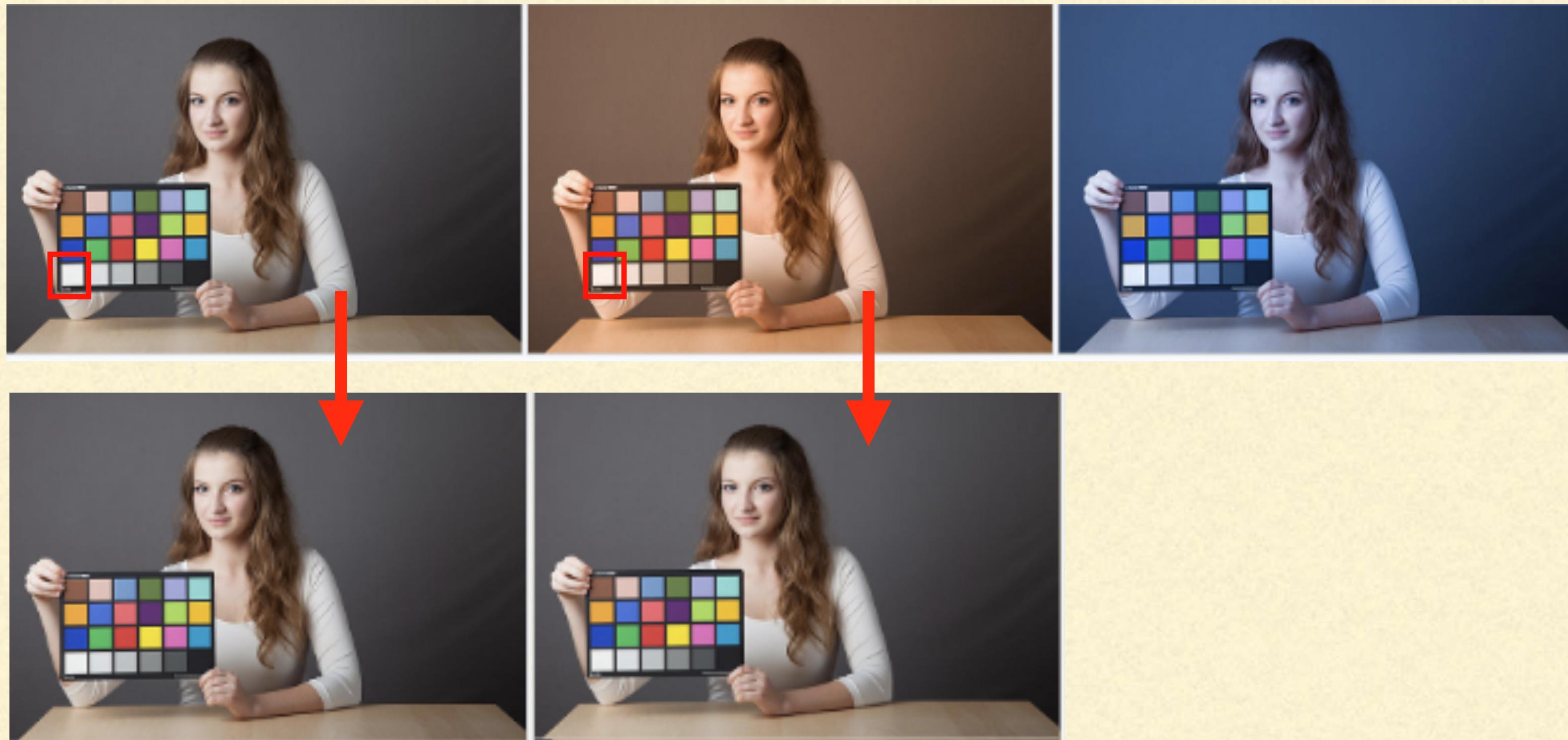


White Balancing



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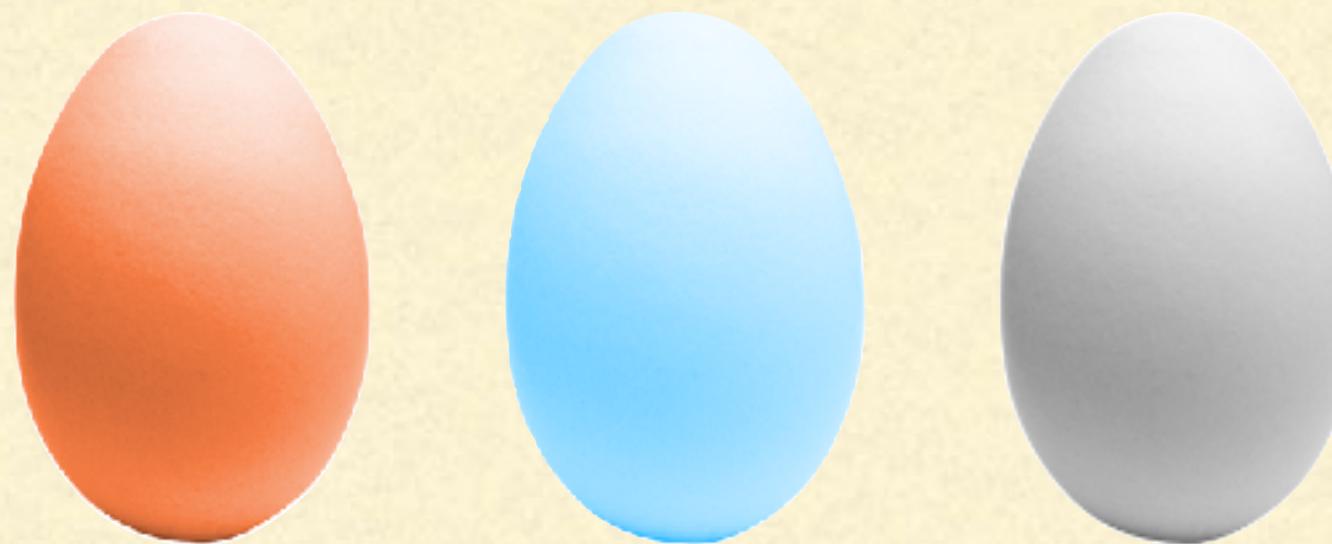
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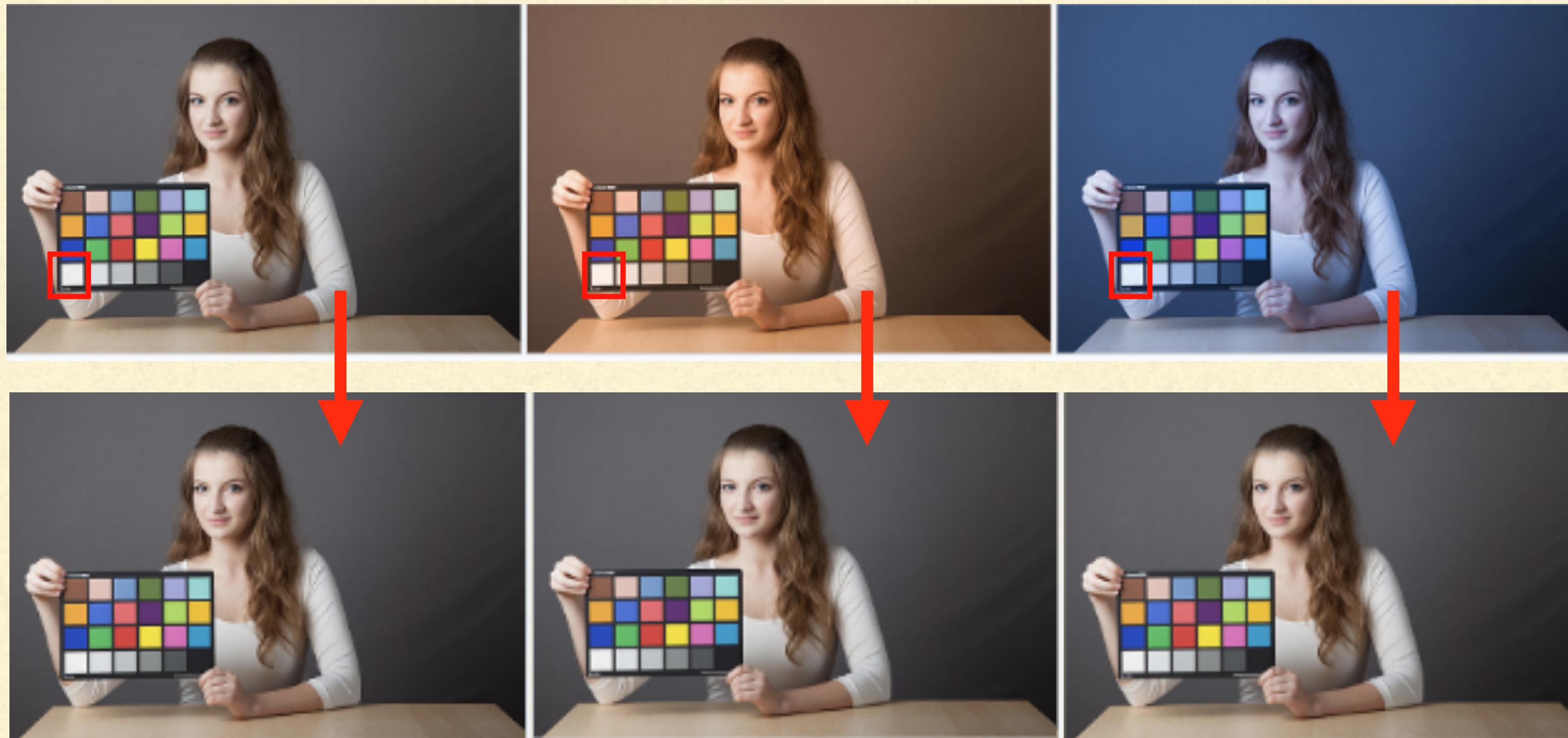


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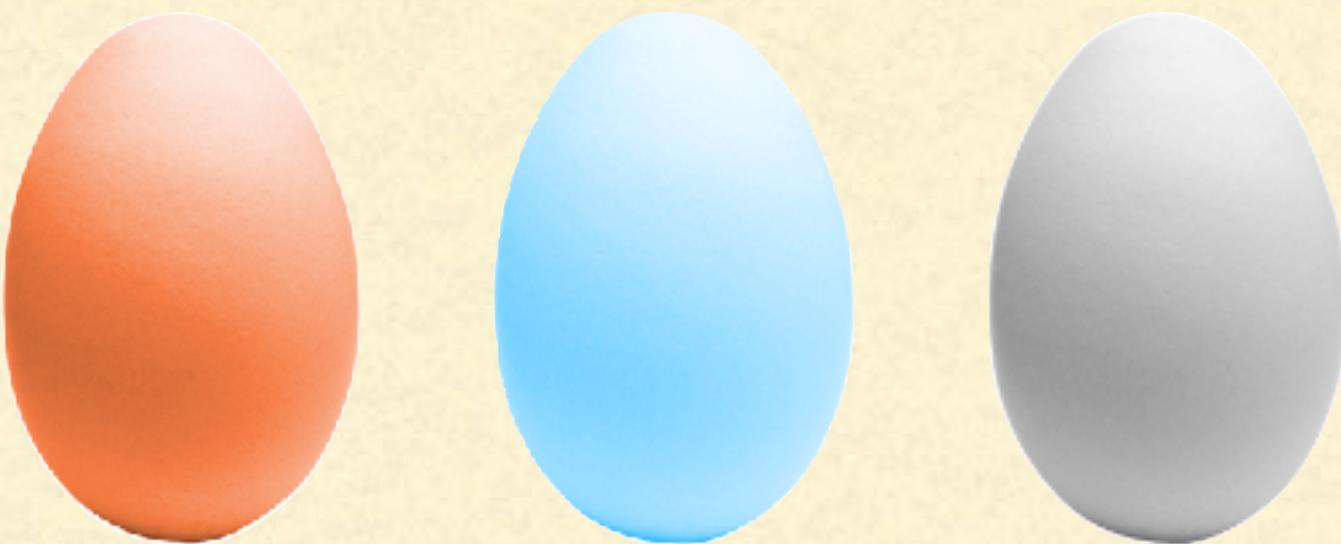
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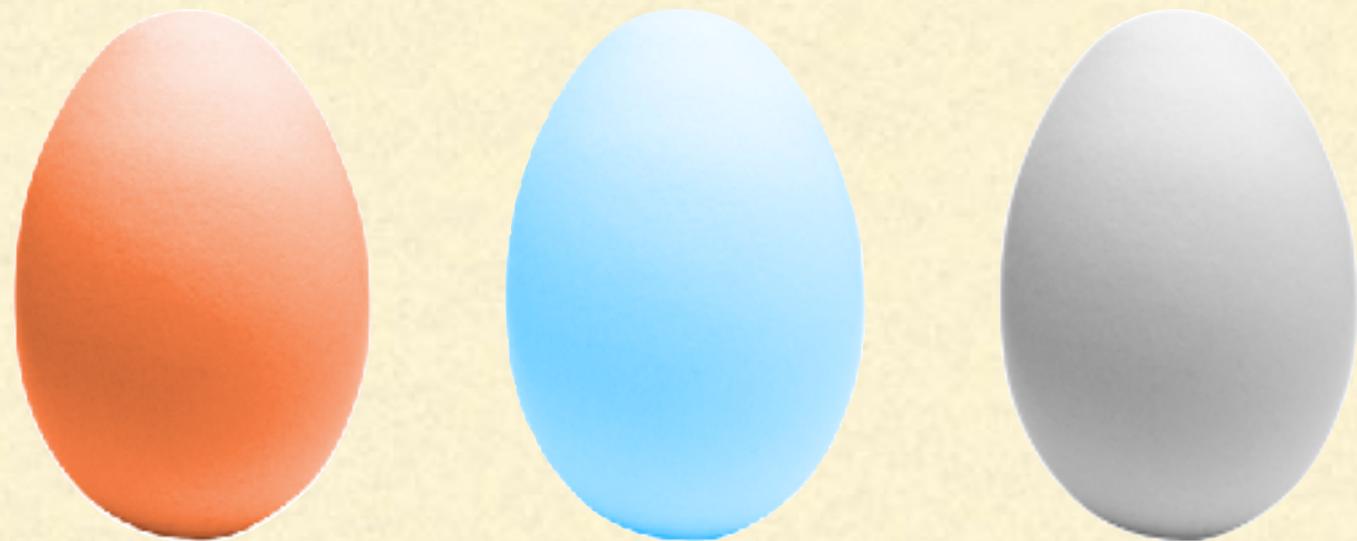
White Balancing



Invest in a high-quality color calibration target.



White Balancing

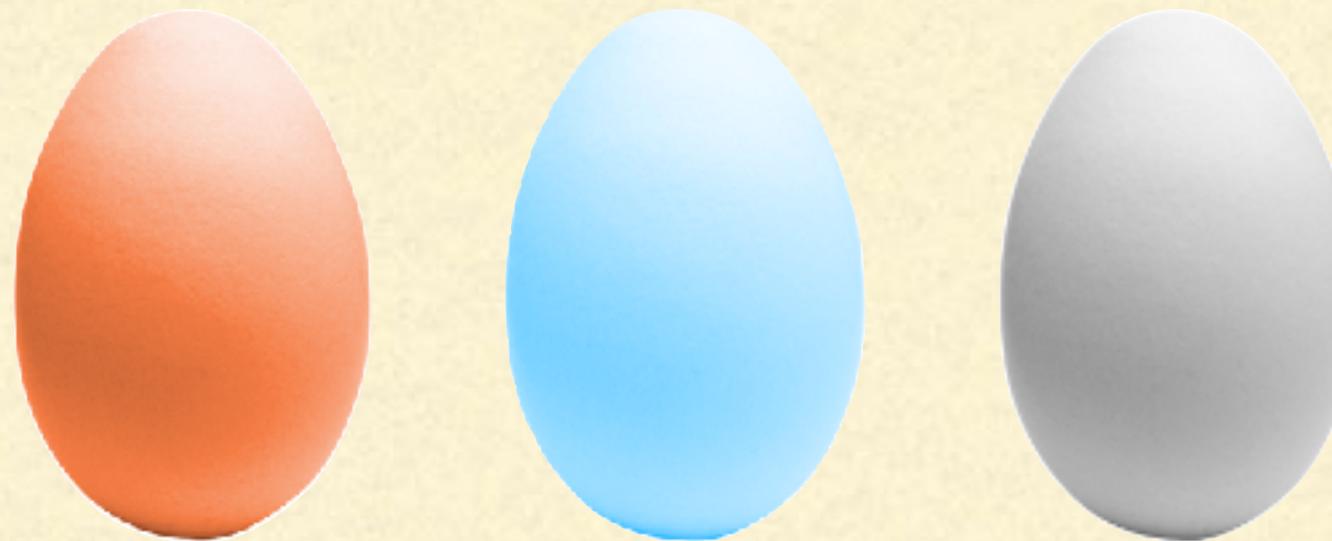


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- ▶ White-balancing is *usually* a global operation (e.g., applied to all pixels).



White Balancing

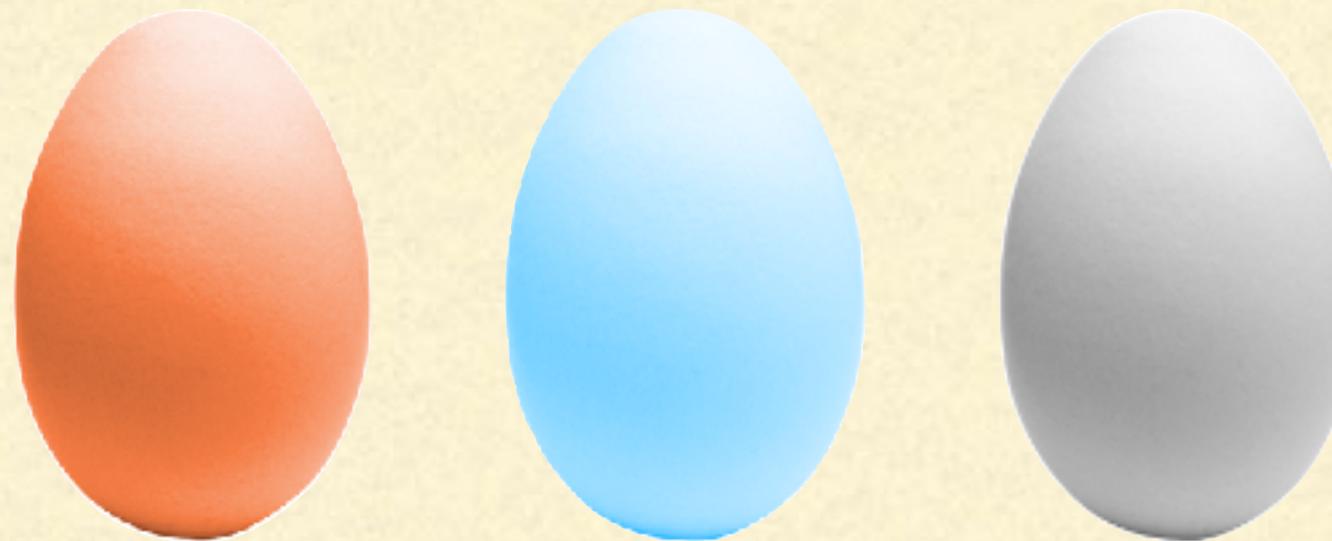


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White Balancing

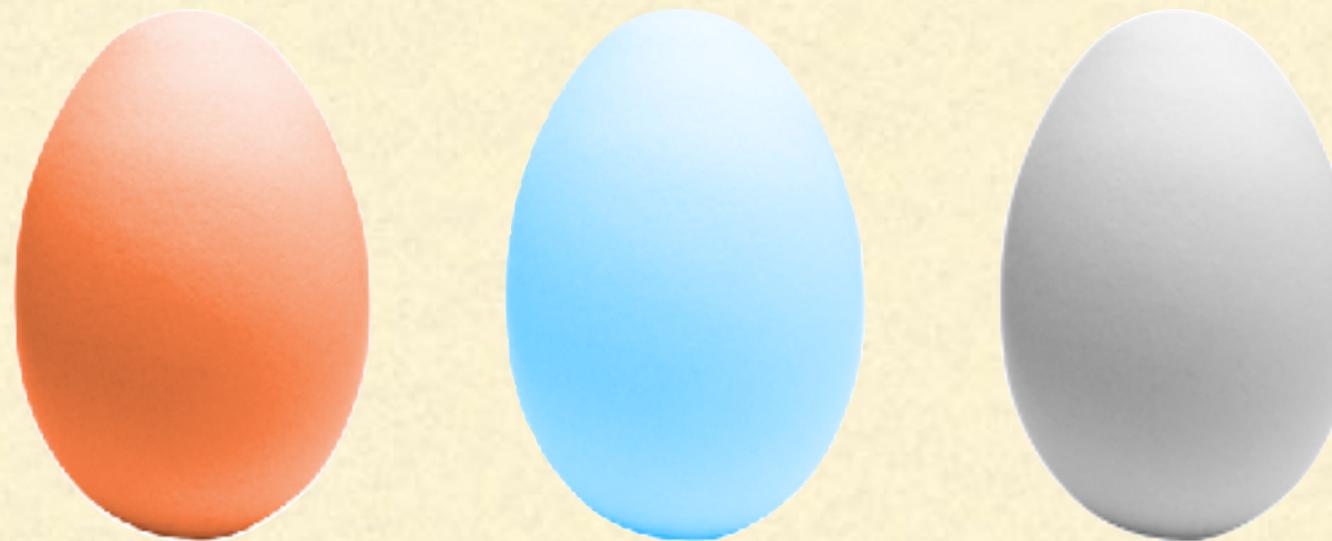


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White Balancing

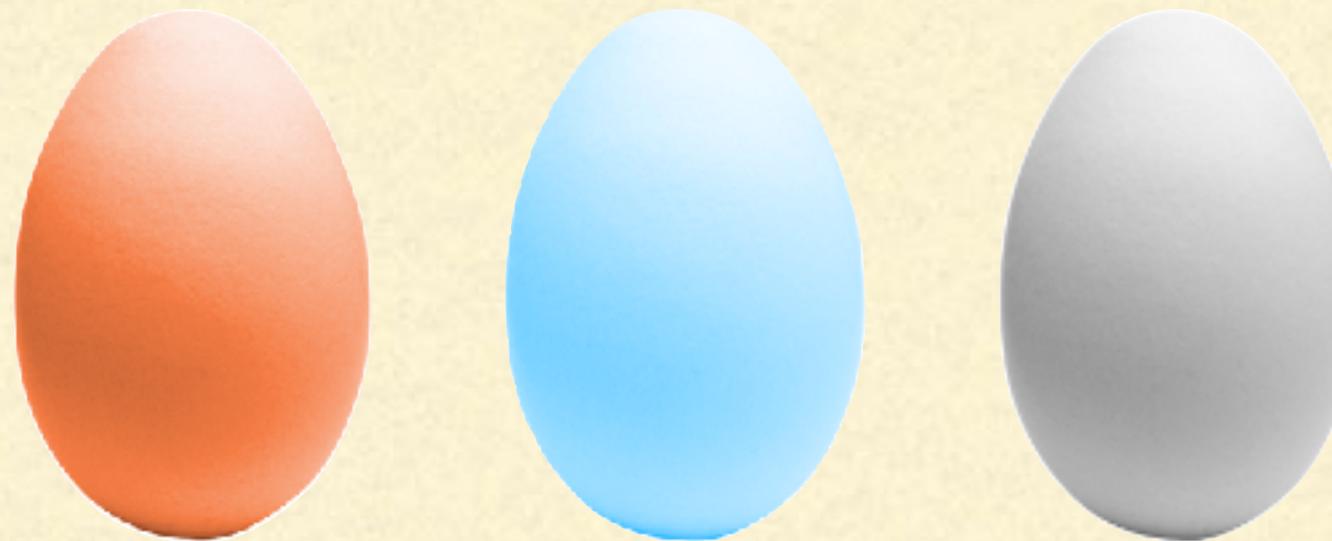


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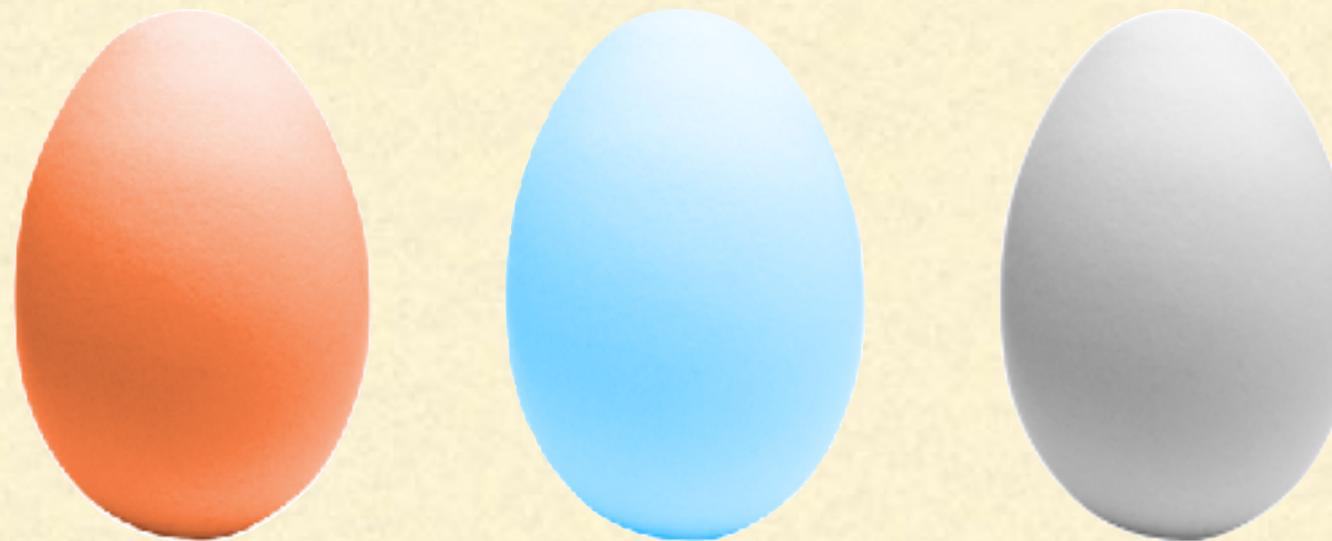


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White Balancing



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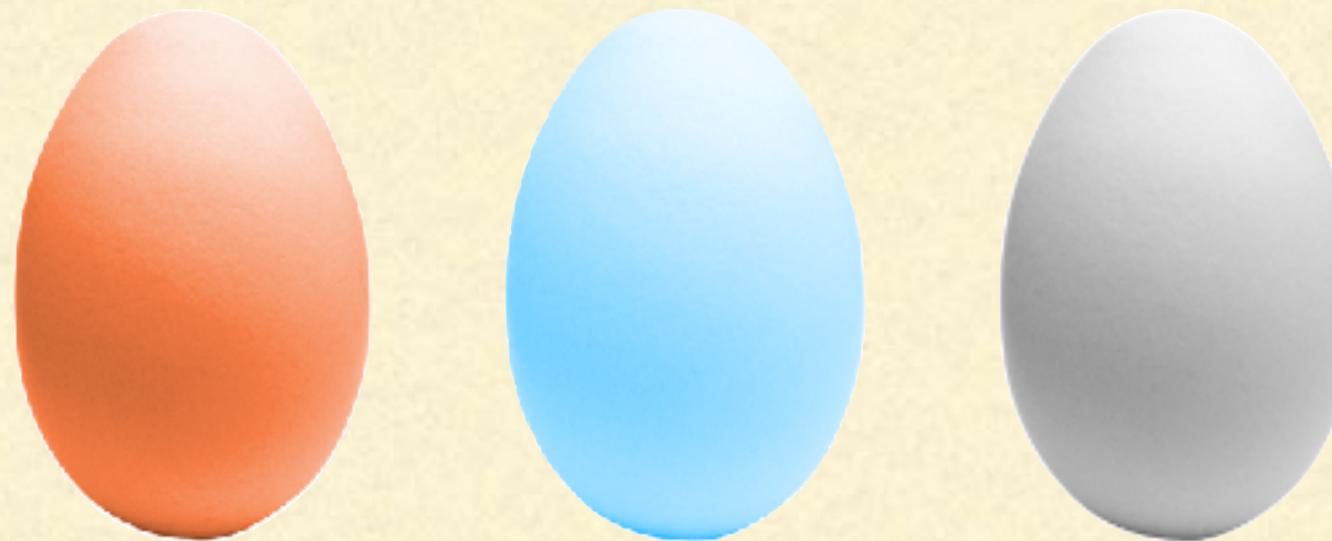
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HOW?



White Balancing



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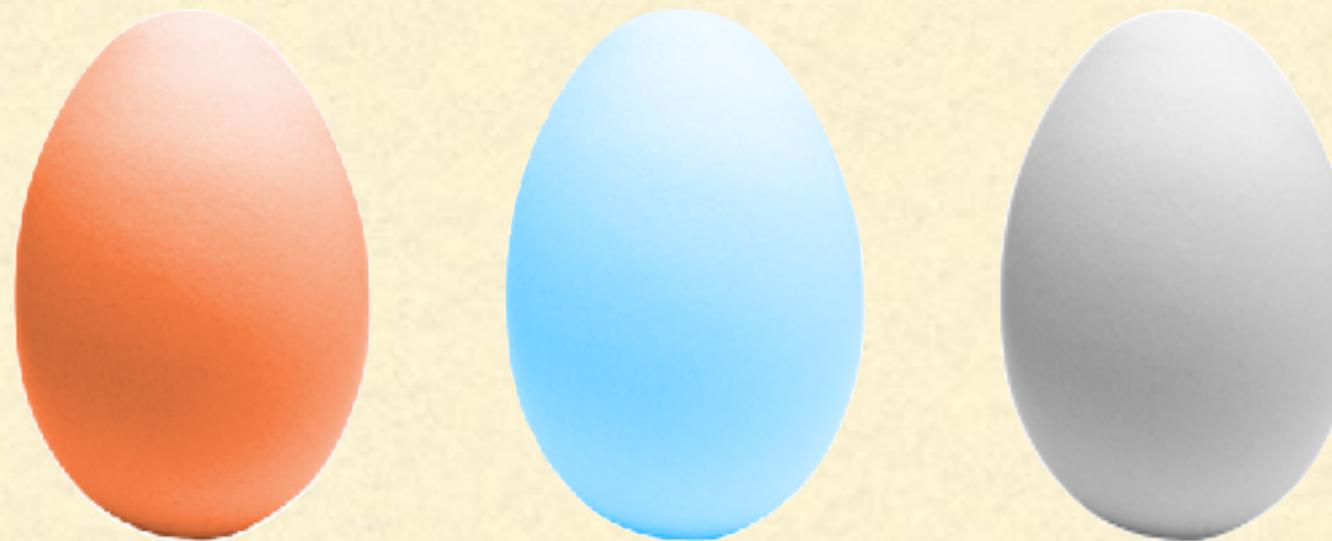


HOW?

- ▶ Use a calibration target with a “white” patch.



White Balancing



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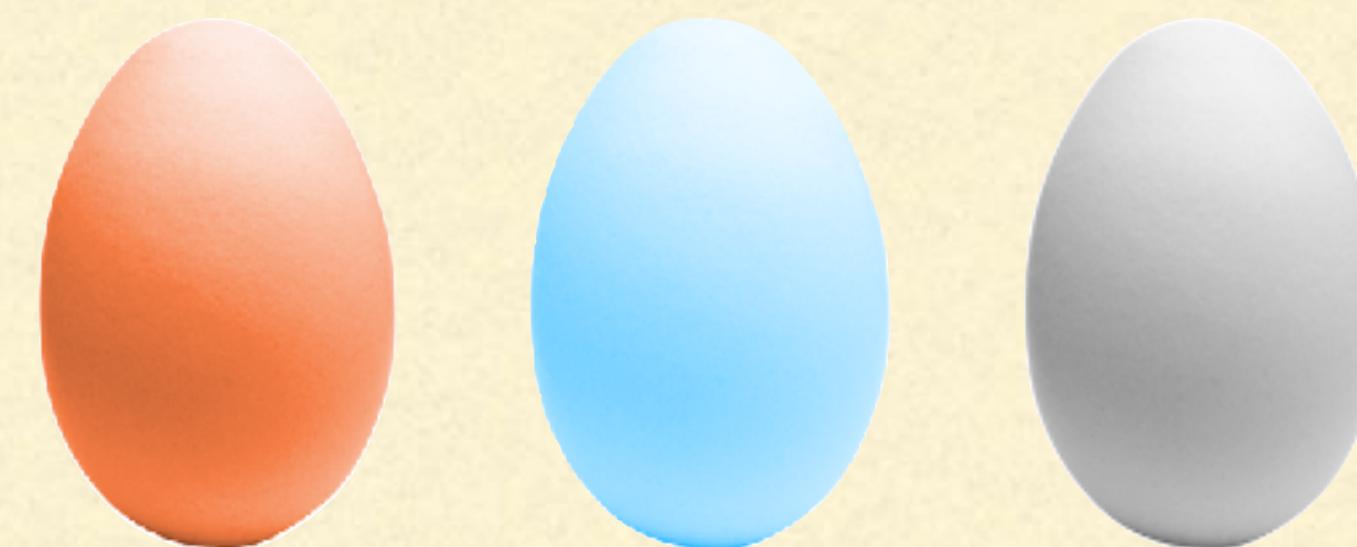


HOW?

- ▶ Use a calibration target with a “white” patch.
- ▶ Scale your image(s) so that the “white” patch has the same value all the time.

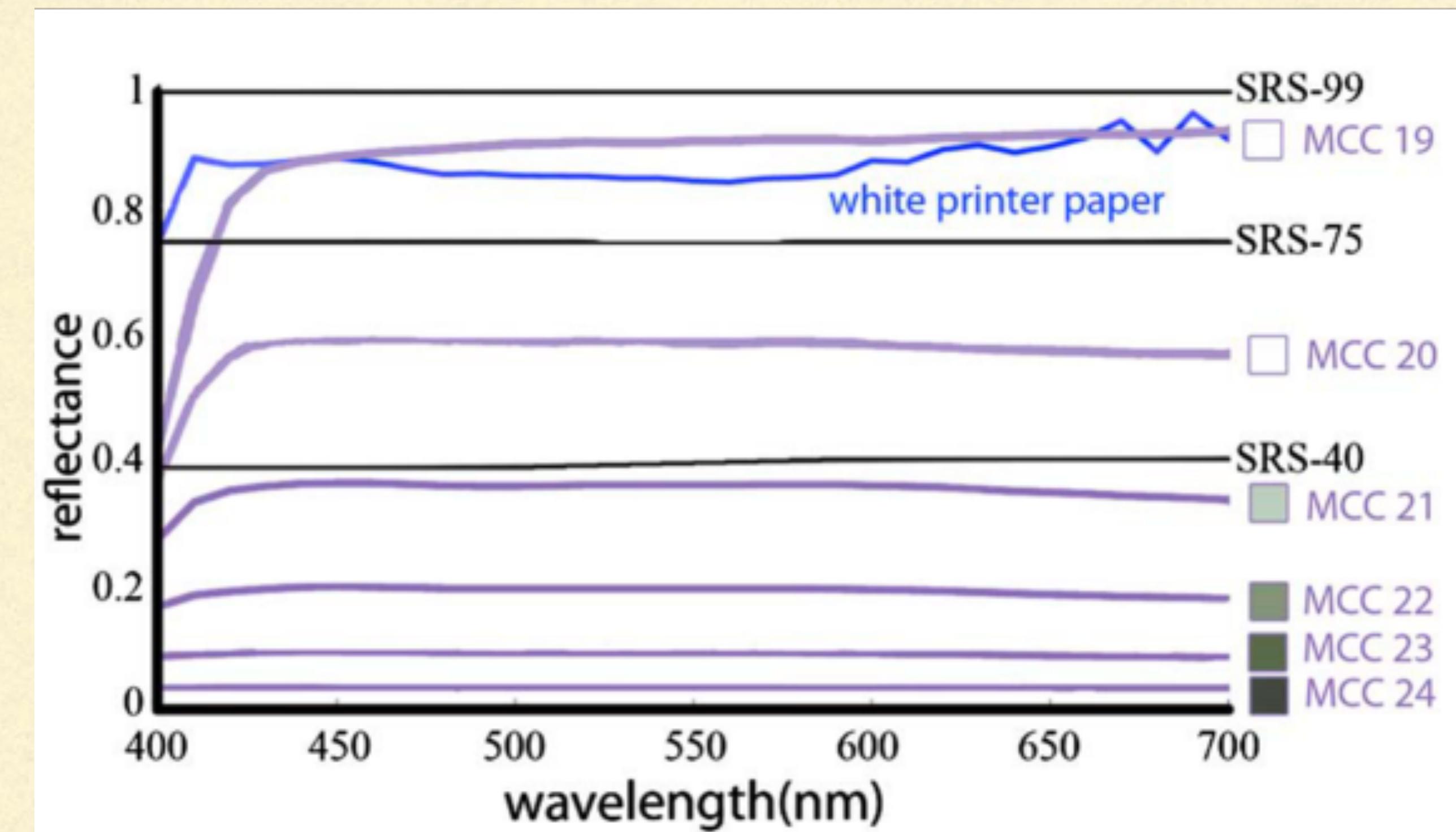


White Balancing

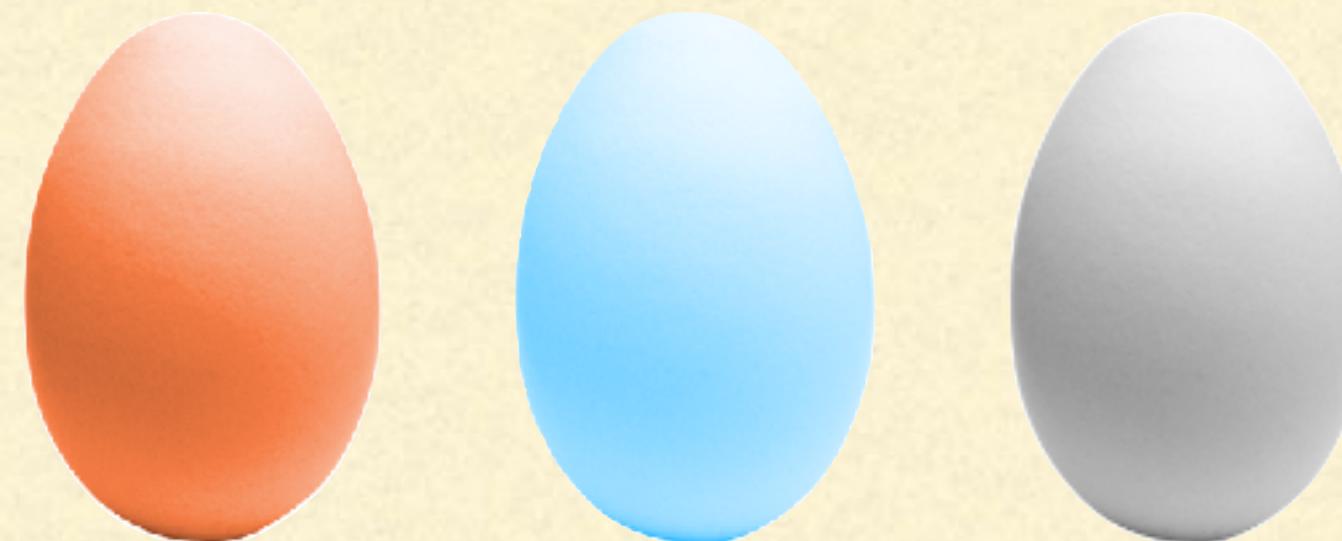


Invest in a high-quality color calibration target AND verify its reflectances with a spectrometer yourself.

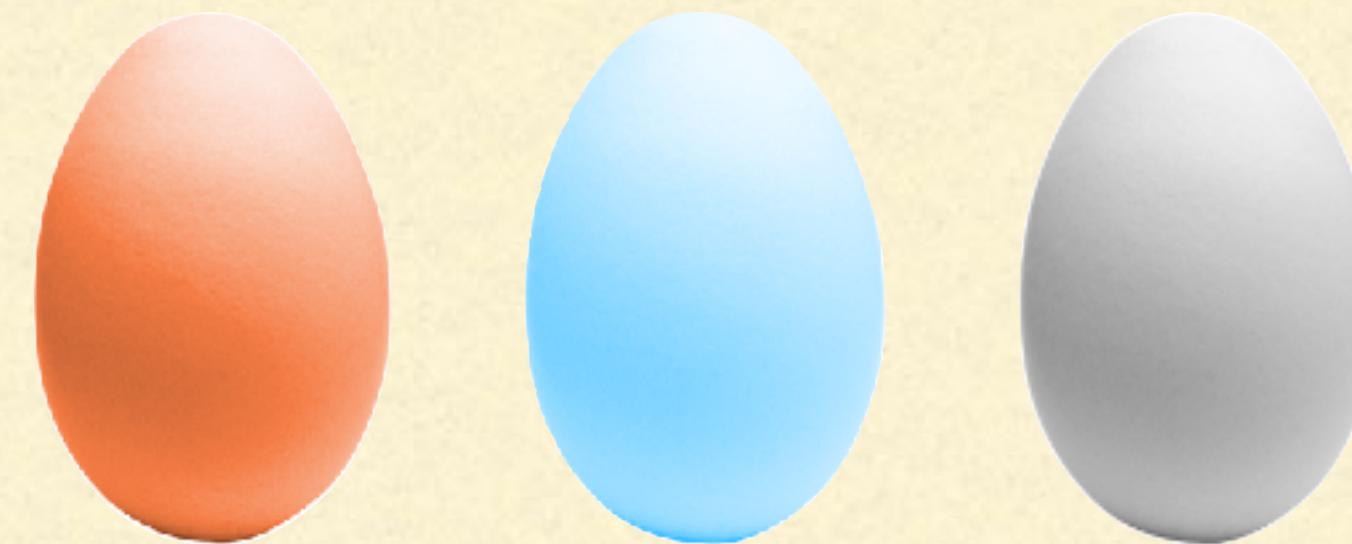
Not all white is white! This is called *metamerism*.



White Balancing



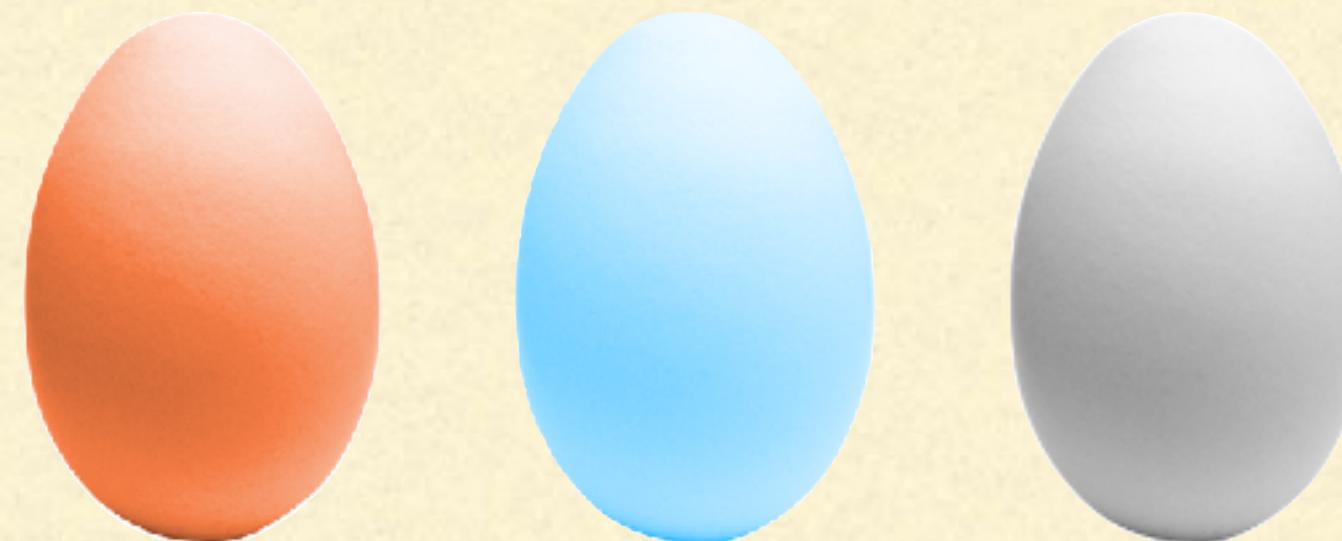
White Balancing



► Pick a patch with a uniform reflectance (i.e., achromatic patch).

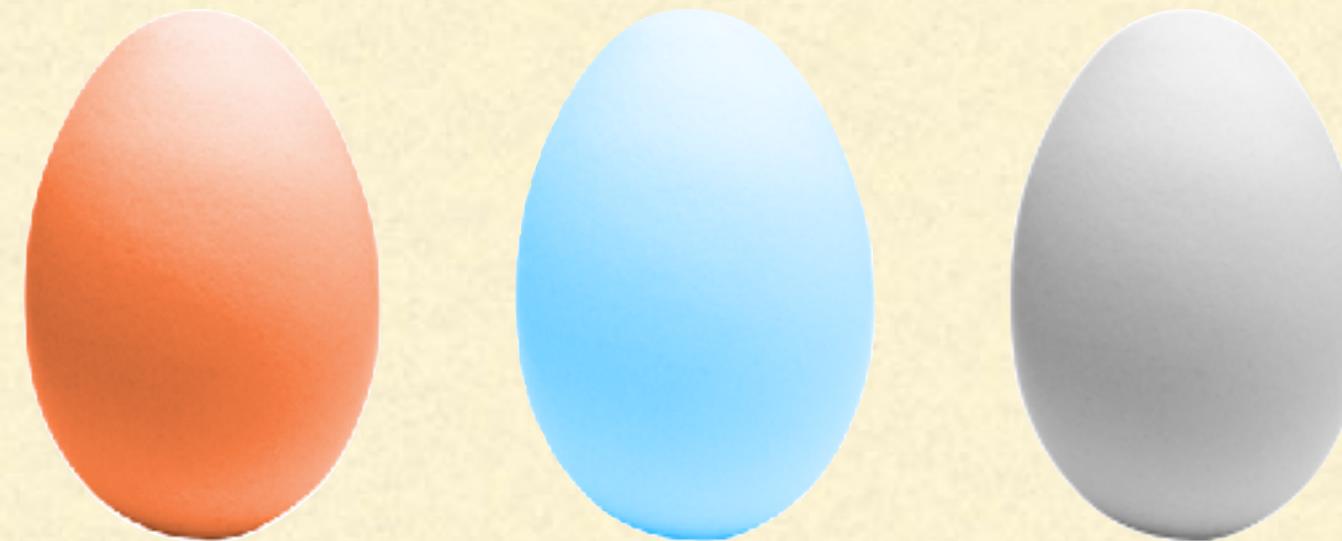


White Balancing



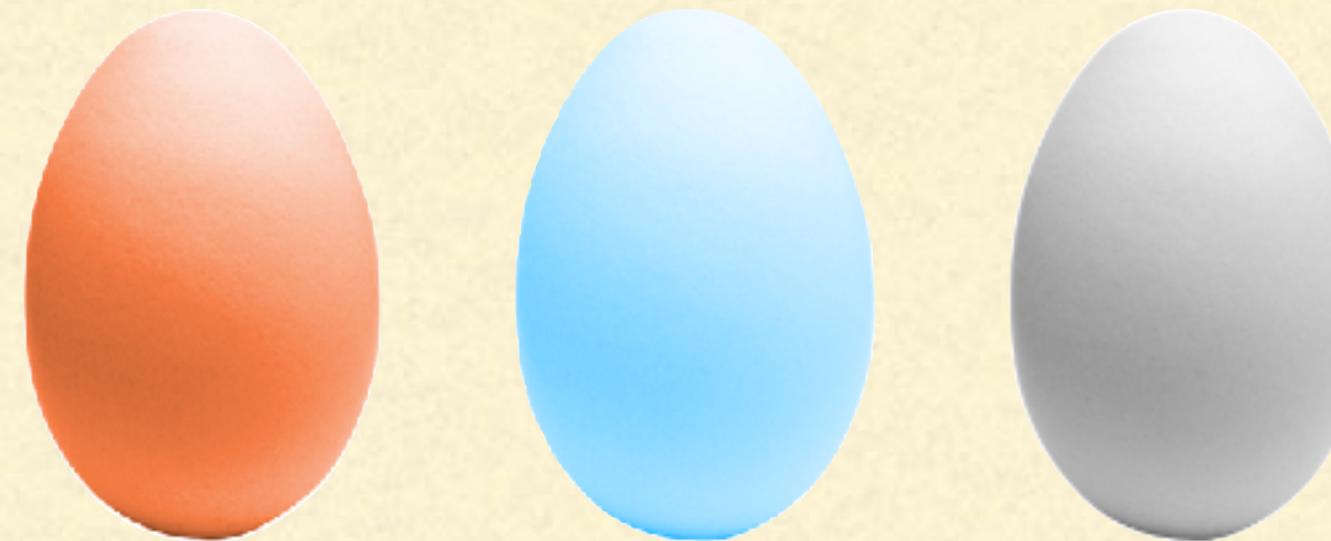
- ▶ Pick a patch with a uniform reflectance (i.e., achromatic patch).
- ▶ Let the RGB values of this patch be: R_w, G_w, B_w

White Balancing



- ▶ Pick a patch with a uniform reflectance (i.e., achromatic patch).
- ▶ Let the RGB values of this patch be: R_w, G_w, B_w
- ▶ Linearly transform the image values so $[R'_w, G'_w, B'_w] \rightarrow [1 1 1]$.

White Balancing

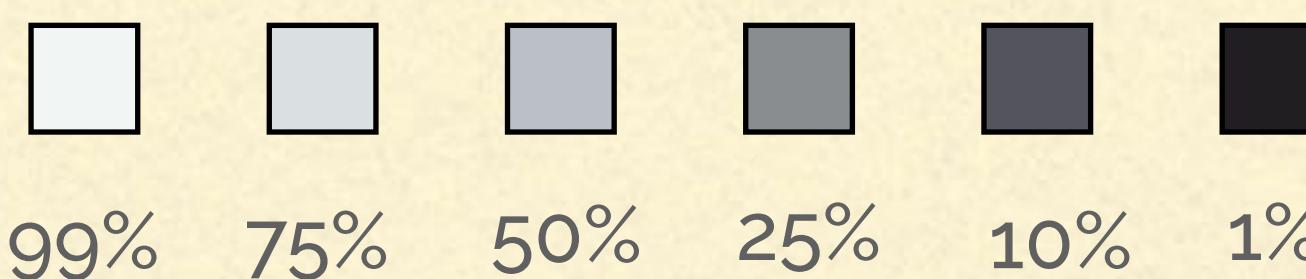
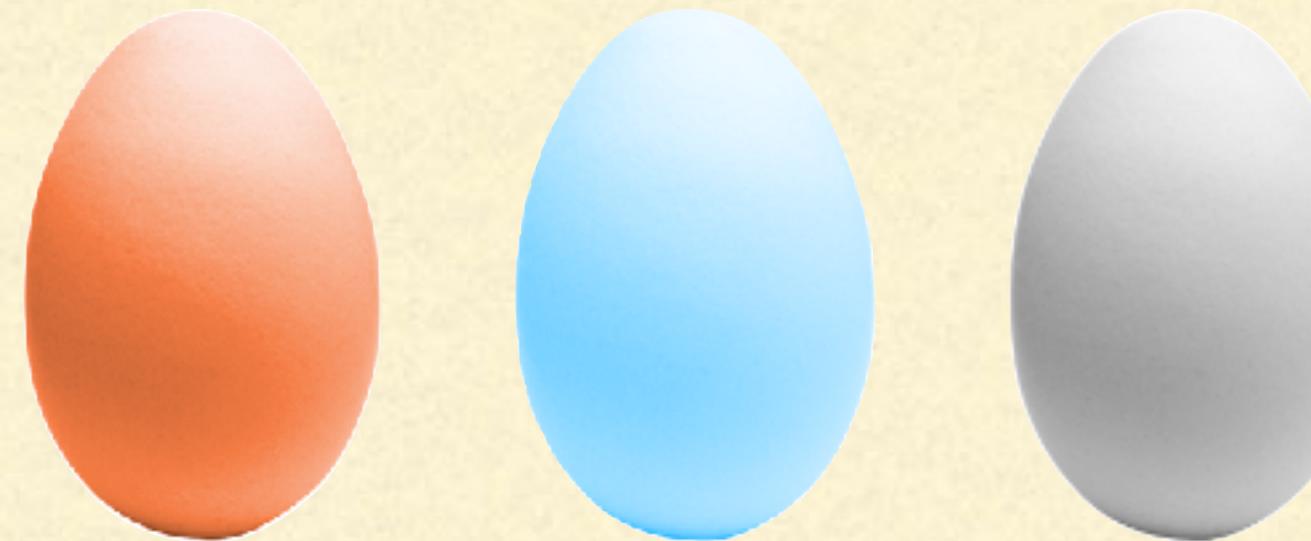


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$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1/R_w & 0 & 0 \\ 0 & 1/G_w & 0 \\ 0 & 0 & 1/B_w \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



White Balancing

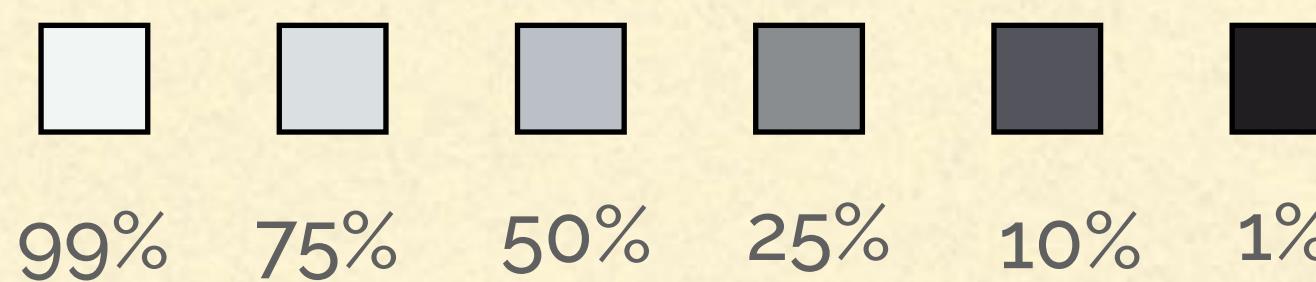
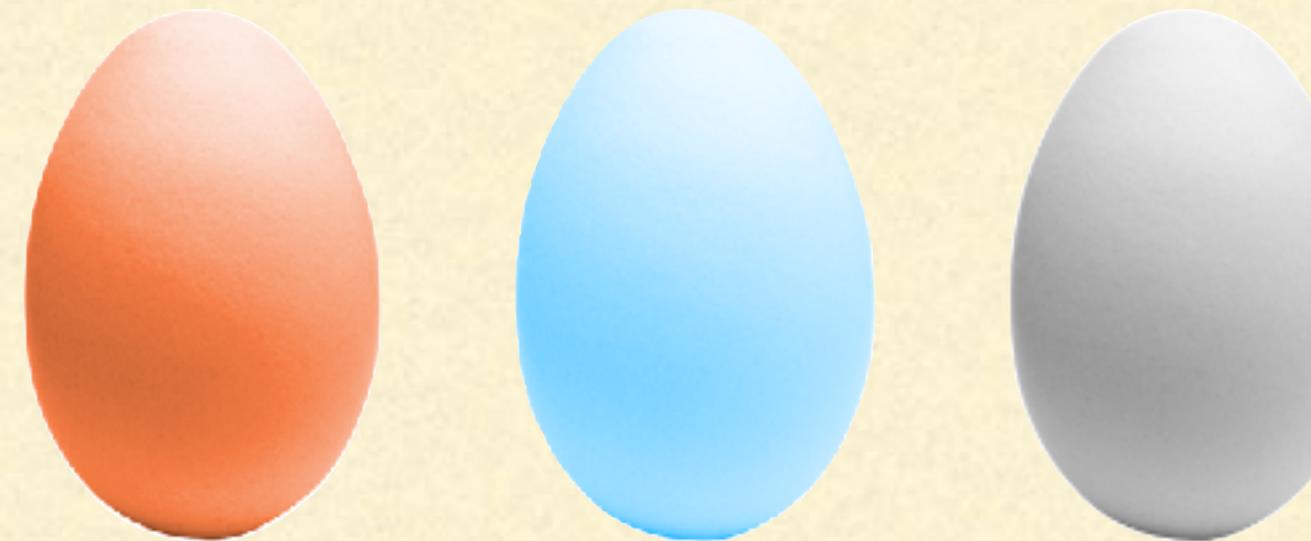


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- ▶ Scale by the luminance (Y) of that patch.

White Balancing



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- ▶ Scale by the luminance (Y) of that patch.

Break

- Thank you for not using your cell phones during the lectures.
- **Phubbing:** the act of ignoring someone you are with and giving attention to your mobile phone instead.

