Photometric Image Formation

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Color Filter Array

Colour Filter Interpolation

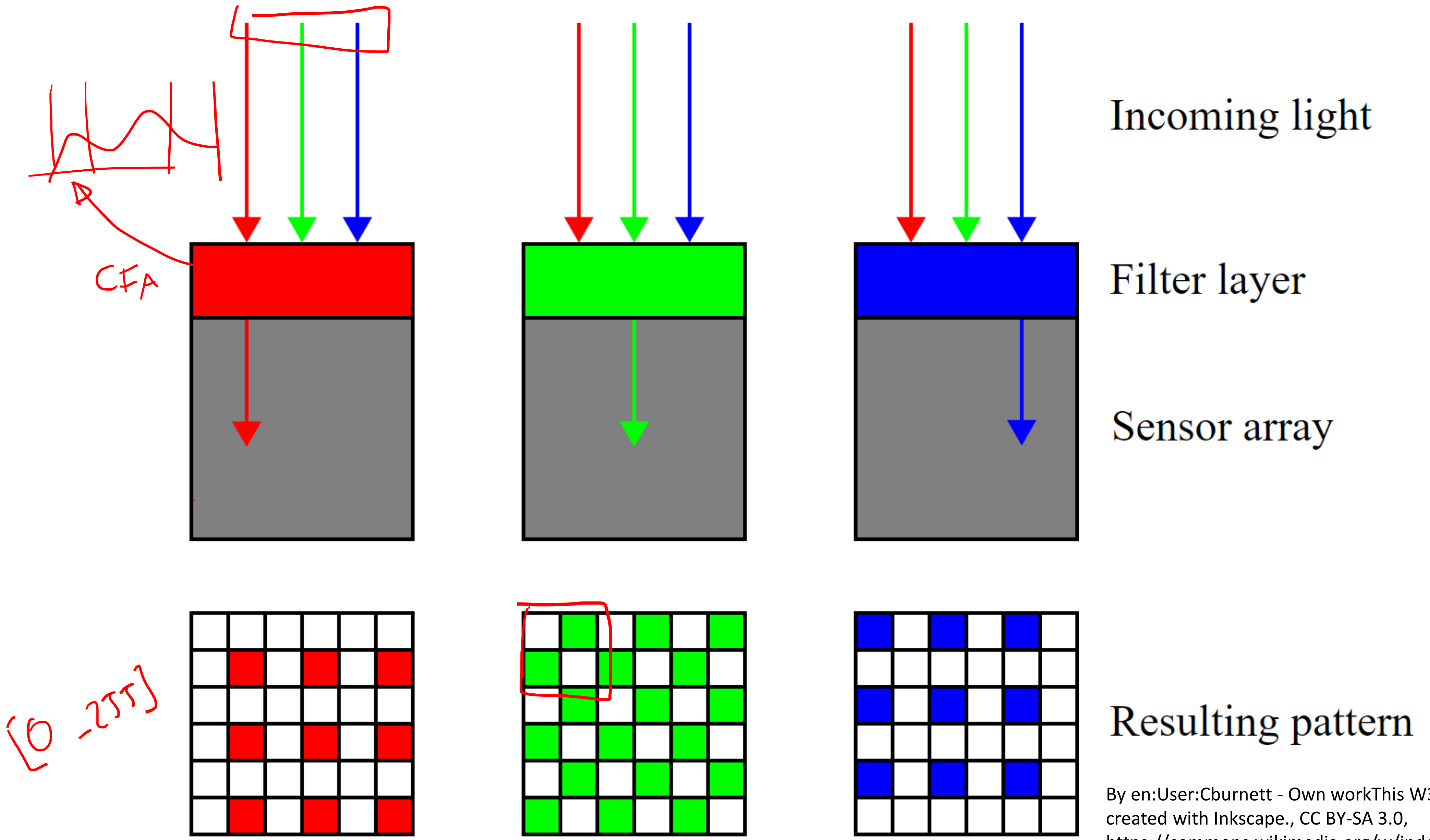
Typical photosensors detect light intensity with little or no wavelength specificity, and therefore cannot separate color information.

Color filters Array (CFA) are used to filter the light by wavelength range.

Separate filtered intensities include information about the color of light.

For example, the Bayer filter (shown to the right) gives information about the intensity of light in red, green, and blue (RGB) wavelength regions

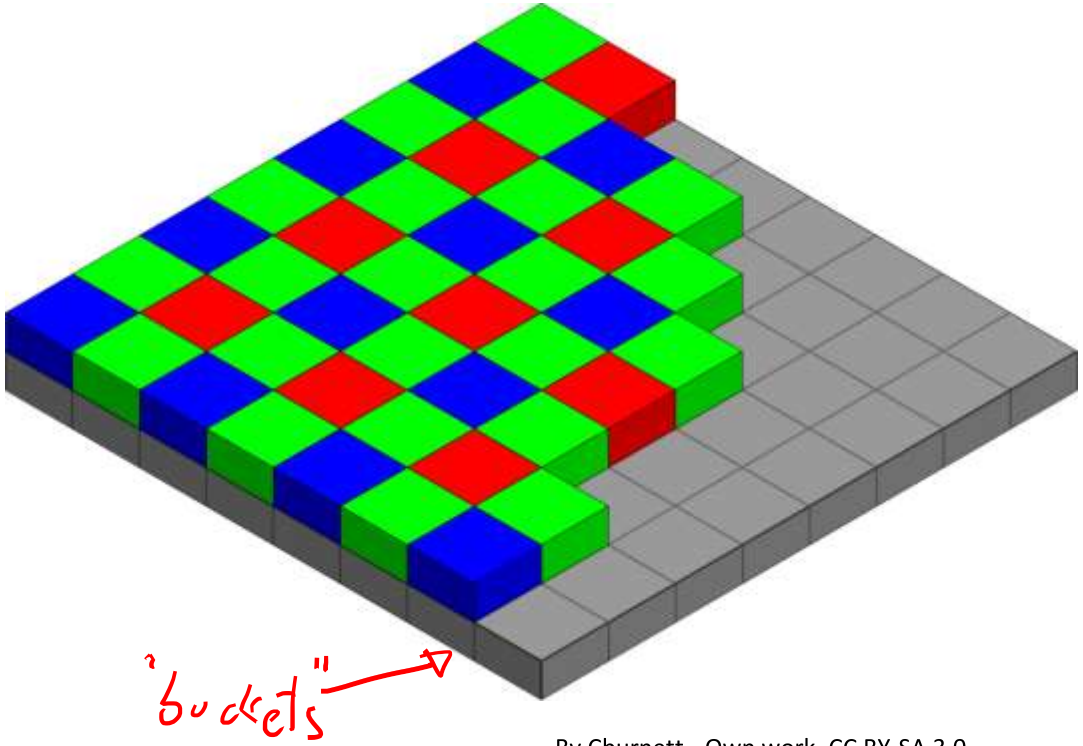
Colour Filter Arrays



Bayer Pattern

For example, the Bayer filter (RGGB) gives information about the intensity of light in red, green, and blue wavelength regions.

- Green color is sampled twice



By Cburnett - Own work, CC BY-SA 3.0,
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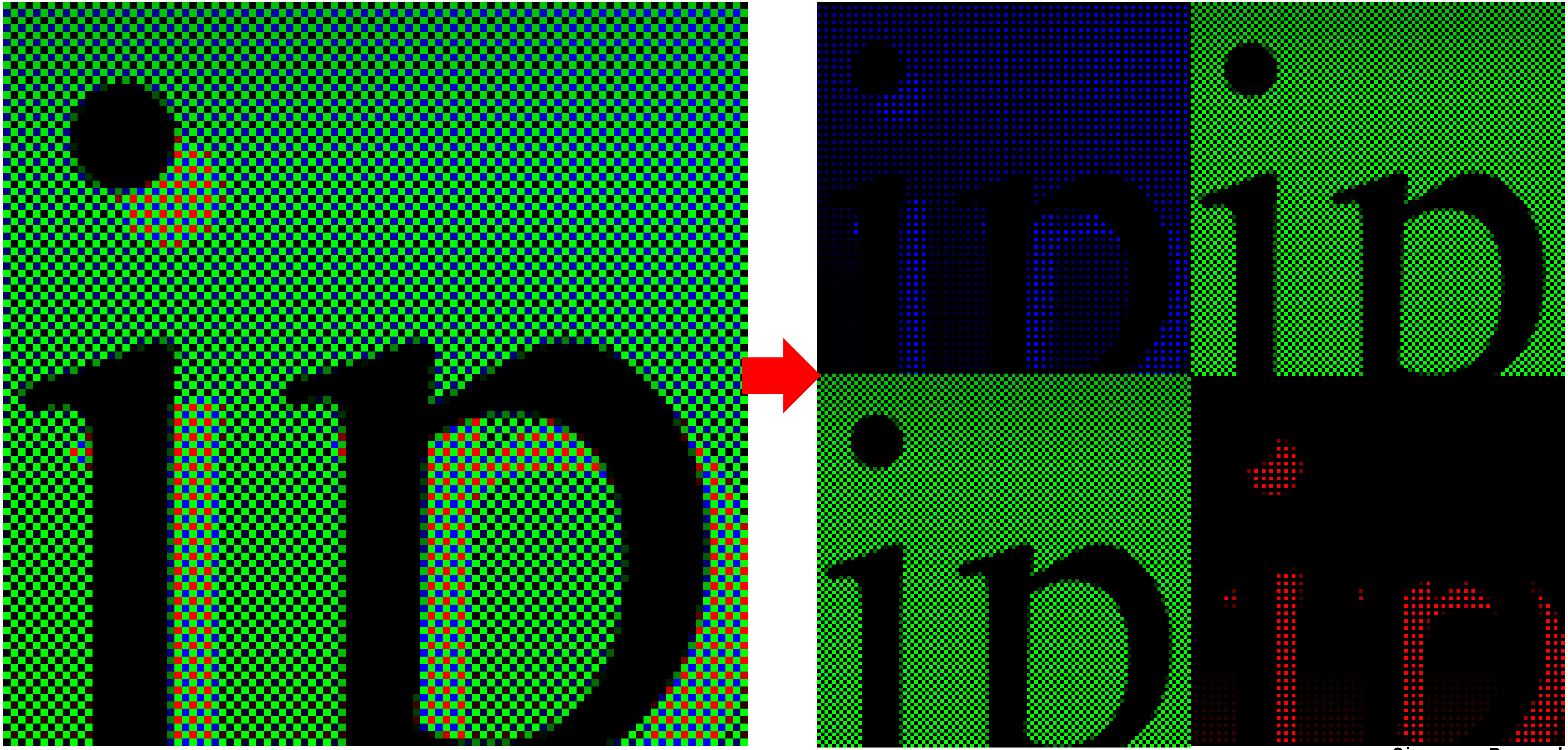
There are many different patterns, including RYYB which gives a better response in low-light conditions

The raw output of digital camera

Every pixel of the array is only sensitive to a single colour.

The raw output of digital camera



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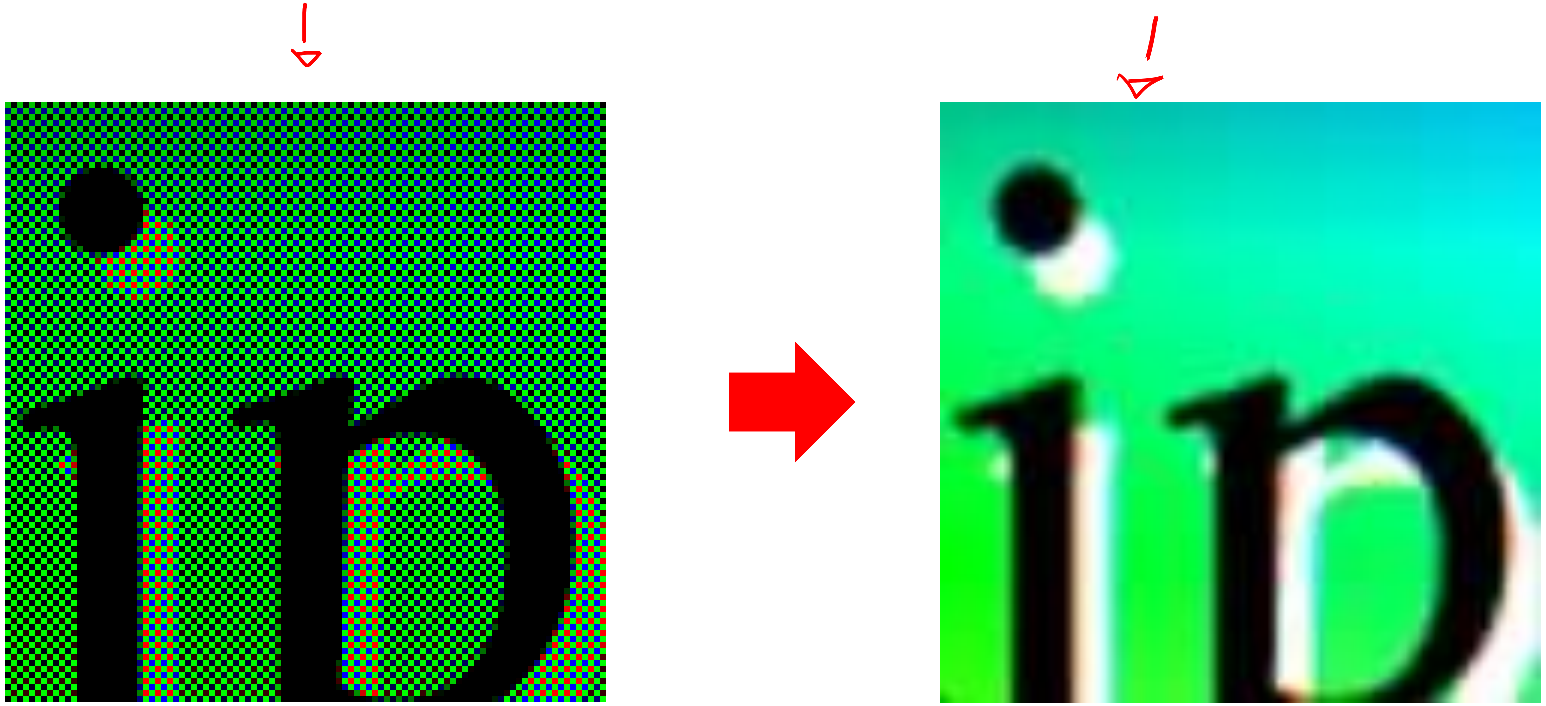
Demosaicing - CFA interpolation

Algorithm to reconstruct a full color image (3 colours per pixel) from the incomplete color output from an image sensor (CFA).



Demosaicing - CFA interpolation

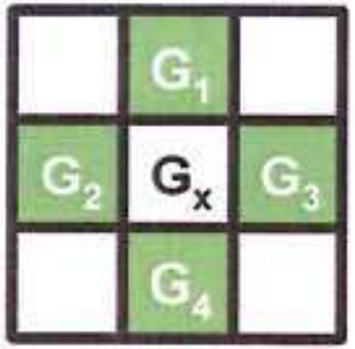
Issues:

- In Bayer pattern each pixel is sensitive to a single colour, while in the image each pixel portrays a mixture of 3 primary colours

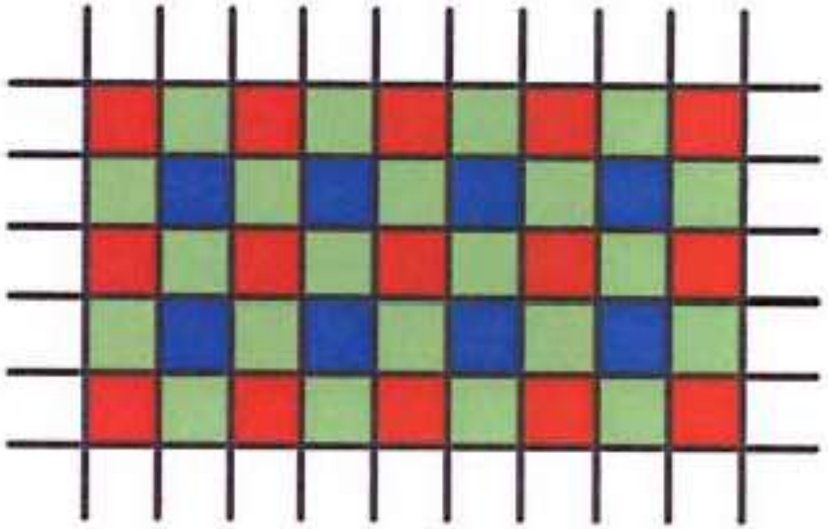
Desiderata:

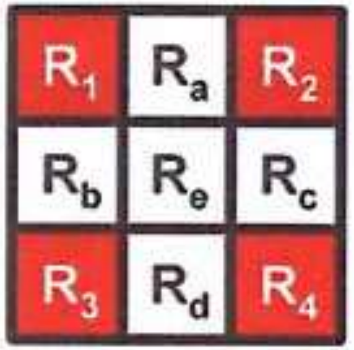
- Avoid colour artefacts
- Maximum preservation of the image resolution
- Low complexity or efficient in-camera hardware implementation
- Amenability to analysis for accurate noise reduction

Demosaicing - CFA interpolation

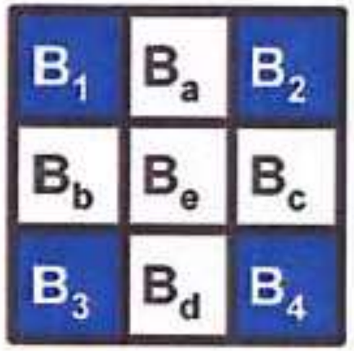


$$G_x = (G_1+G_2+G_3+G_4)/4$$





$$R_a = (R_1+R_2)/2$$
$$R_b = (R_1+R_3)/2$$
$$R_c = (R_2+R_4)/2$$
$$R_d = (R_3+R_4)/2$$
$$R_e = (R_1+R_2+R_3+R_4)/4$$



$$B_a = (B_1+B_2)/2$$
$$B_b = (B_1+B_3)/2$$
$$B_c = (B_2+B_4)/2$$
$$B_d = (B_3+B_4)/2$$
$$B_e = (B_1+B_2+B_3+B_4)/4$$

Blur & Noise

Noise

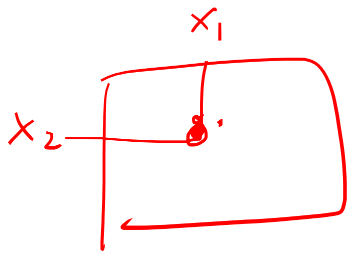
The acquired image is different from the original scene because of sensor limitations

The CCD sensors and the whole acquisition pipeline are affected by different sources of noise:

- Thermal noise
- Quantization noise
- Dark current noise
- Photon-counting noise

And other aberrations such as dark fixed-pattern noise, light fixed-pattern noise,…

In the most simple settings



Observation model is

$$z(x) = y(x) + \eta(x), \qquad x \in \mathcal{X}$$

i.i.d

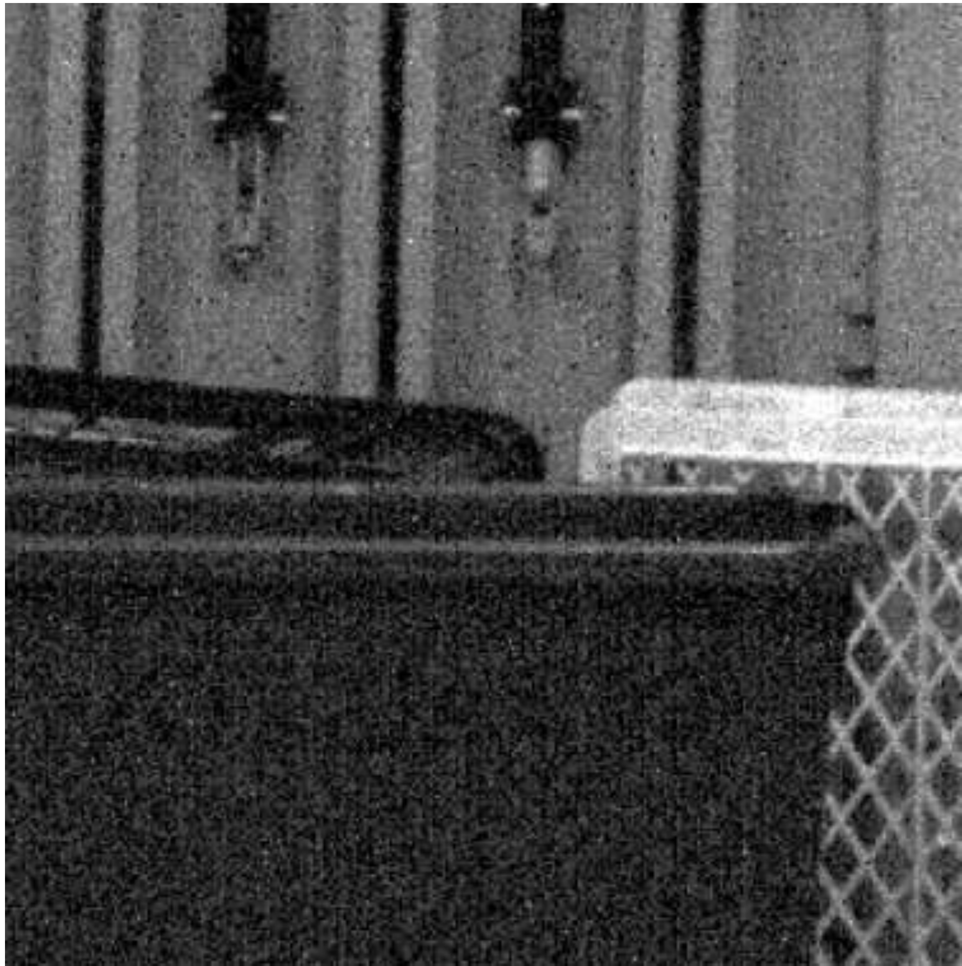
$\eta \sim N(0, \sigma^2)$

Where

- x denotes the pixel coordinates in the domain $\mathcal{X} \subset \mathbb{Z}^2$
- y is the original (noise-free and unknown) image
- z is the noisy observation
- η is the noise realization

denoising

estimate $\hat{y} \approx y$



Additive Gaussian White Noise

Additive White Gaussian Noise is a frequently encountered assumption

White Gaussian noise is a very practical approximation not to account for each noise source.

However, this is a very coarse approximation, since we all have experienced that dark regions are typically more be noisy than correctly exposed ones.

Signal Dependent Noise

Photon counting, like other counting processes, are modelled by a Poisson distribution.

This can be conveniently approximated as:

$$z(x) = y(x) + \sigma\big(y(x)\big)\eta(x), \qquad x \in \mathcal{X}$$

Where

- σ is a function defining the noise variance of the overall noise component that depends on the true image intensity y. A good model $\sigma^2 = ay(x) + b$, where the parameters a, b depend on the camera
- $\eta \sim N(0,1)$ is white noise

Signal and Time Dependent Noise

The exposure time heavily impact on noise, since the noise variance ultimately depends on the amount of light reaching the sensor.

This can be conveniently approximated as:

$$z_T(x) = u_T(x) + \eta(x), \qquad x \in \mathcal{X}$$

Where

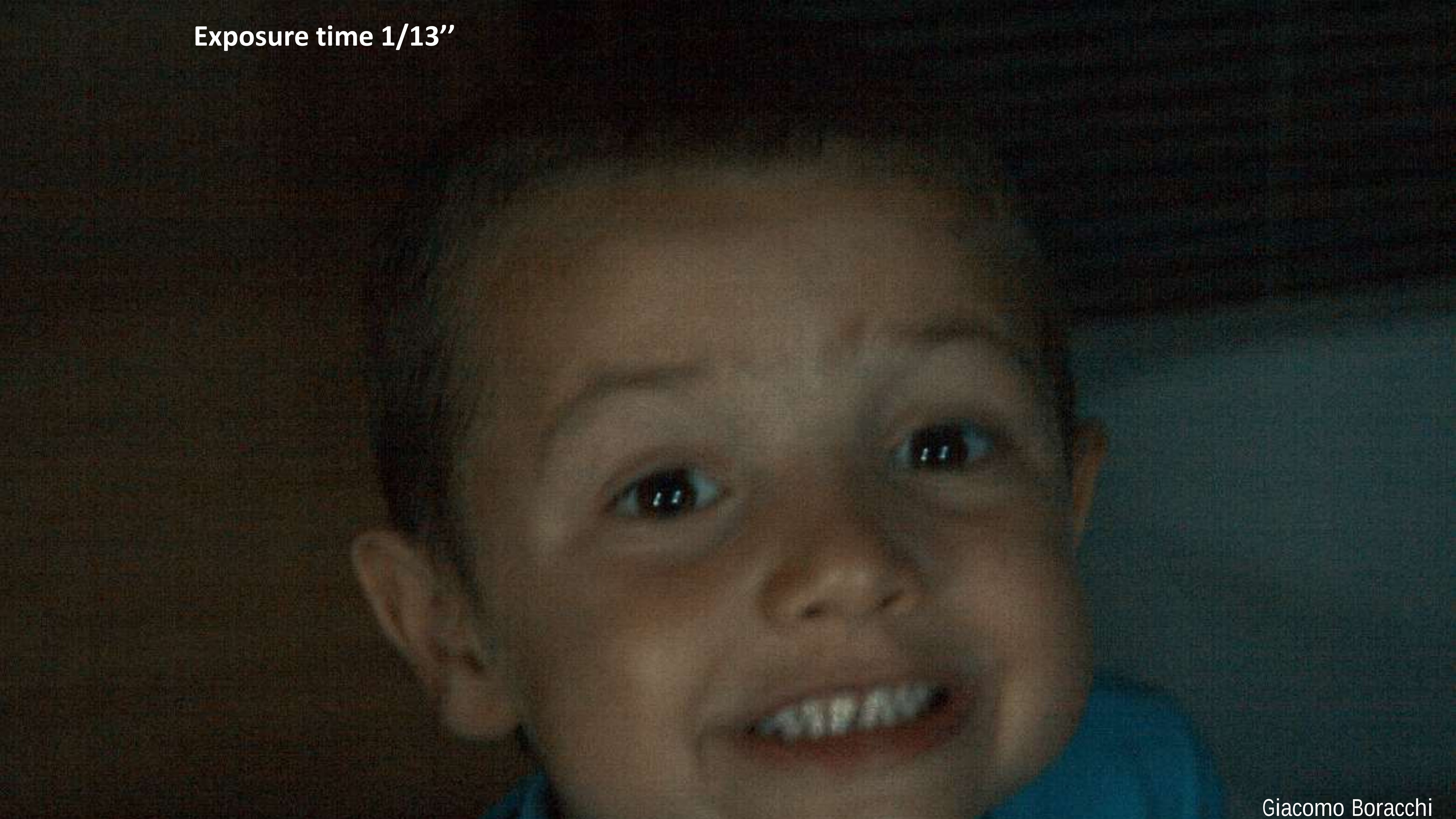
$$u_T(x) \sim \mathcal{P}\left(\lambda \int_0^T y(x - s(t))dt\right)$$

And $\mathcal{P}$ denotes the Poisson distribution, λ is the quantum efficiency and $s(\cdot)$ is the trajectory of the sensor due to motion.

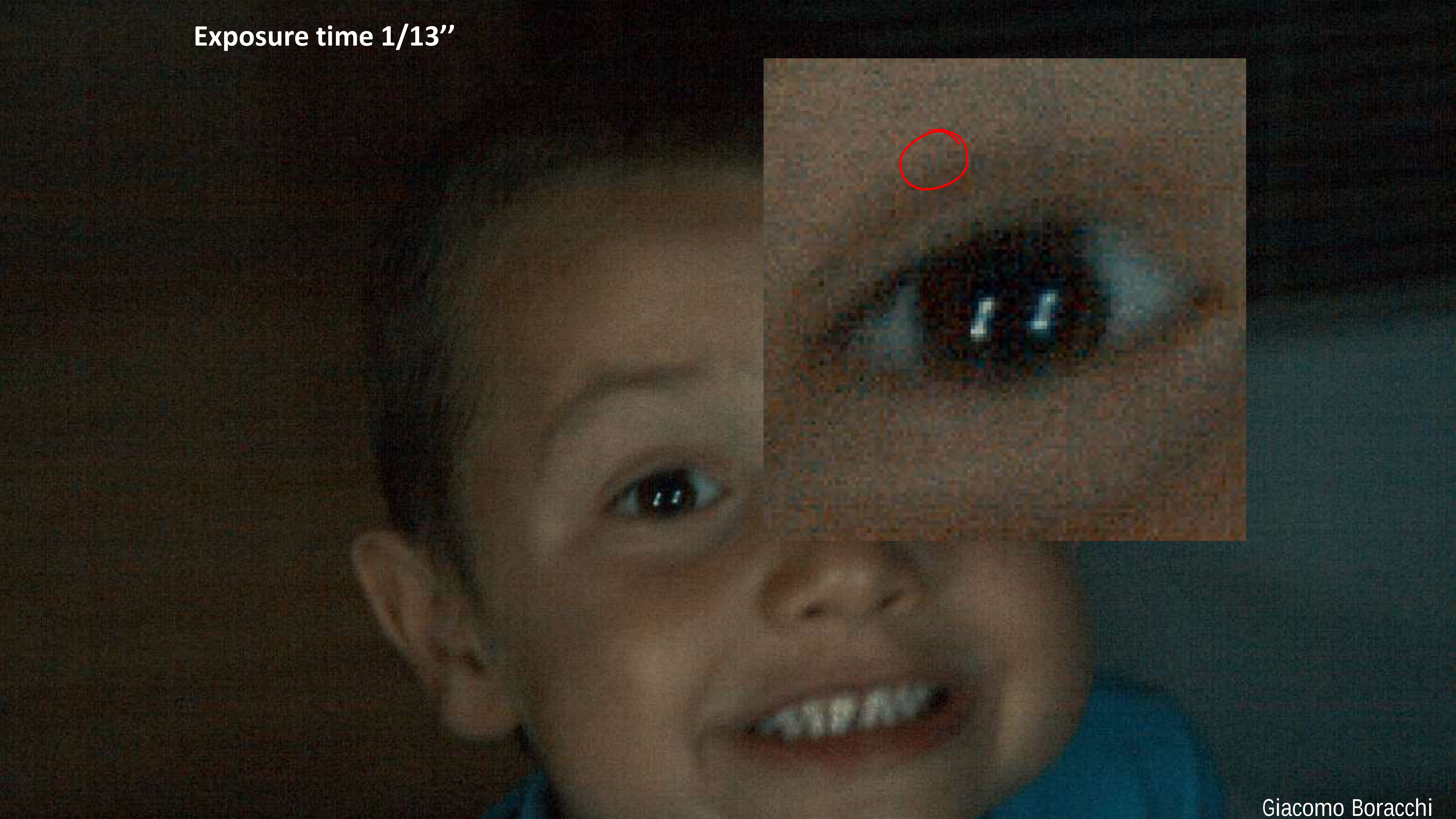
Motion results in Motion Blur

G. Boracchi, A. Foi *Modeling the Performance of Image Restoration from Motion Blur* IEEE TIP 2012

Exposure time 1/13''



Exposure time 1/13''



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Exposure time 0.8’’

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Exposure time 0.8''