# Color image Demosaicing

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Color Filter Arrays

- It is an array of tiny color filters placed before the image sensor array of a camera.

- The resolution of this array is the same as that of the image sensor array.

- Each color filter may allow a different wavelength of light to pass – this is pre-determined during the camera design.

Color Filter Arrays

- The most common type of CFA is the Bayer pattern which is shown below:
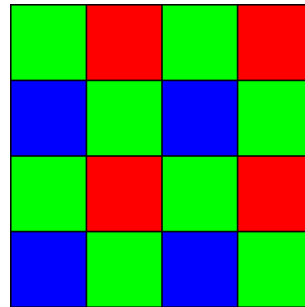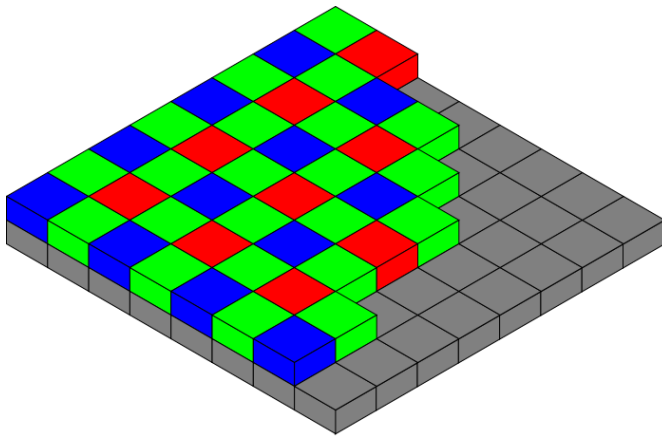
- The Bayer pattern collects information at red, green, blue wavelengths only as shown above.

Color Filter Arrays

- The Bayer pattern uses twice the number of green elements as compared to red or blue elements.

- This is because both the M and L cone cells of the retina are sensitive to green light.

- The **raw** (uncompressed) output of the Bayer pattern is called as the **Bayer pattern image** or the **mosaiced** (*) **image**.

- The mosaiced image needs to be converted to a normal RGB image by a process called color image **demosaicing**.
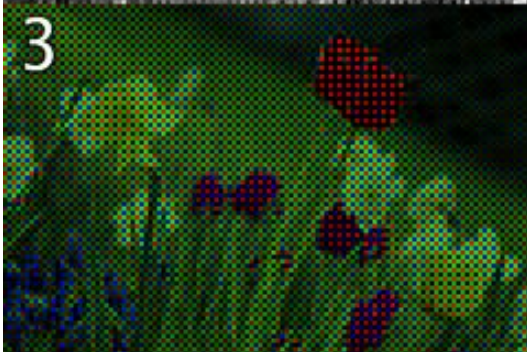
"original scene"

Mosaiced image

Mosaiced image – just coded with the Bayer filter colors

"Demosaiced" image – obtained by interpolating the missing color values at all the pixels

A Demosaicing Algorithm

- There exist a plethora of demosaicing algorithms.

- We will study one that is implemented in the **"demosaic"** function of MATLAB.

- The algorithm implemented by this function was published in 2004.

Malvar, H.S., L. He, and R. Cutler, *High quality linear interpolation for demosaicing of Bayer-patterned color images*. ICASPP, Volume 34, Issue 11, pp. 2274-2282, May 2004.

https://www.microsoft.com/en-us/research/wp-content/uploads/2016/02/Demosaicing_ICASSP04.pdf

Demosaicing Algorithm

- Demosaicing involves interpolation of missing color values from nearby pixels.

- The easiest way is to perform linear interpolation – given the structure of the Bayer pattern.

$$\hat{g}(i,j) = \frac{1}{4} \sum g(i+m, j+n)$$

$$(m,n) = \{(0,-1), (0,1), (-1,0), (1,0)\}$$
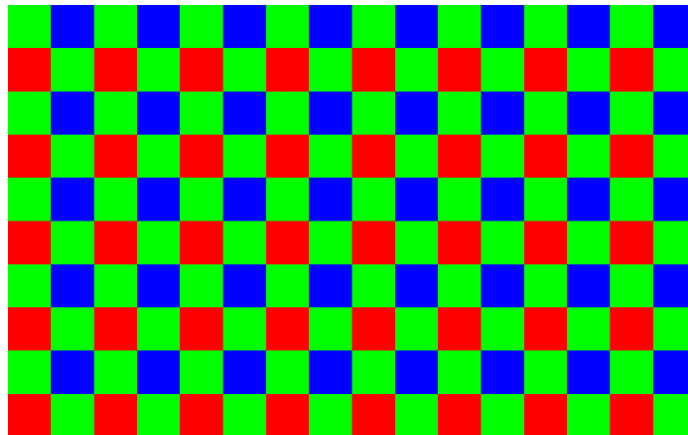
Demosaicing Algorithm

- But such an algorithm gives highly sub-optimal results at **edges** – as seen in the simulation below.

Original image (top left), o/p of bilinear interpolation for demosaicing (top right), o/p of MATLAB's demosaic algorithm (bottom left)
More results:
http://www.ipol.im/pub/art/2011/g_mhcd/article.pdf
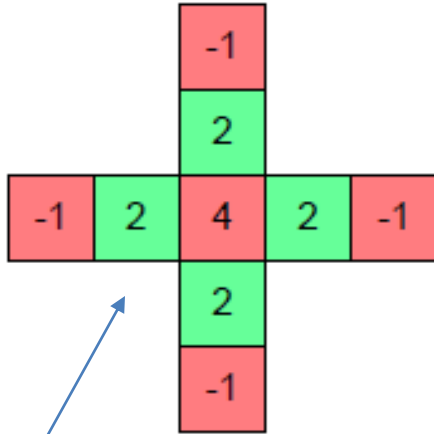
Demosaicing algorithm

- Make use of the correlation between R,G,B color values for a more edge-aware interpolation!

- Consider the case of finding G at an R or a B pixel.

- The R-gradient can be useful information for determining the G value.

Demosaicing algorithm

- Consider the case of finding G at an R or a B pixel (x,y).

- Obtain an estimate of the R value at pixel (x,y) by bilinear interpolation.

- If the actual R value at (x,y) differs considerably from the bilinearly interpolated R value at (x,y), it means that there is a sharp luminance change at that pixel.

- The corrected value of G is given as follows:

$$\hat{g}(i,j) = \hat{g}_B(i,j) + \alpha \, \Delta_R(i,j) \qquad \Delta_R(i,j) \triangleq r(i,j) - \frac{1}{4} \sum r(i+m, j+n)$$

Bilinearly interp.
value

Gain factor

$$(m,n) = \{(0,-2), \ (0,2), \ (-2,0), \ (2,0)\}$$

G at R locations

G at B locations

$$\hat{g}(i,j) = \hat{g}_B(i,j) + \alpha\,\Delta_R(i,j)$$

$$\widehat{g}(i,j) = \widehat{g}_B(i,j) + \gamma\Delta_B(i,j)$$

$$\Delta_R(i,j) \triangleq r(i,j) - \frac{1}{4}\sum r(i+m,j+n)$$

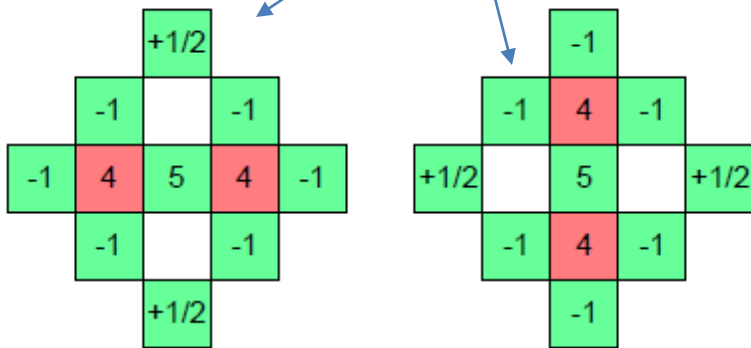$$(m,n) = \{(0,-2),\ (0,2),\ (-2,0),\ (2,0)\}$$
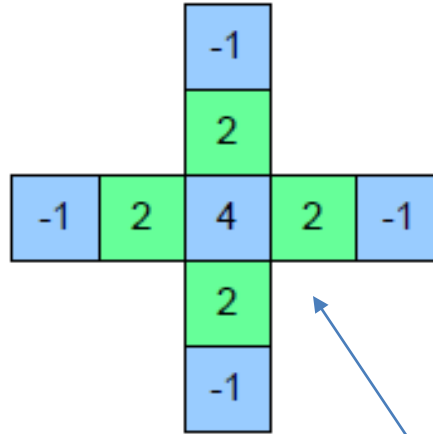
$$\Delta_B(i,j) = b(i,j) - \frac{1}{4}\sum_{\substack{(m,n)=\{(0,-2),(-2,0),\\(2,0),(0,2)\}}} b(i+m,j+n)$$

Demosaicing algorithm

- We have seen how to obtain G at an R or a B pixel.

- To obtain the R value at a G pixel, the corresponding formula is

Bilinear interp. value

$$\hat{r}(i, j) = \hat{r}_B(i, j) + \beta \Delta_G(i, j)$$

R at green in
R row, B column
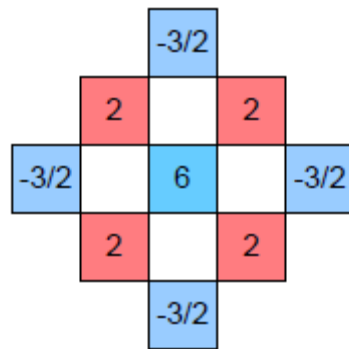
R at green in
B row, R column

Demosaicing algorithm

- To obtain a R value at a B pixel, the corresponding formula is

Bilinear interp. value

$$\hat{r}(i,j) = \hat{r_B}(i,j) + \gamma \, \Delta_B(i,j)$$

	-3/2	
2		2
-3/2	6	-3/2
2		2
	-3/2	

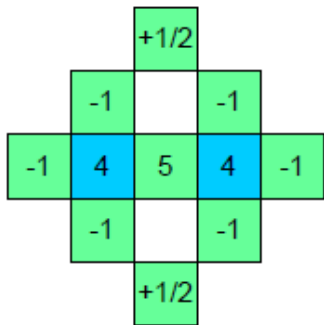R at blue in
B row, B column

Demosaicing algorithm

- To obtain a B value at a G pixel, the corresponding formula is

Bilinear interp. value

$$\hat{b}(i, j) = \hat{b}_B(i, j) + \beta \Delta_G(i, j)$$

B at green in
B row, R column
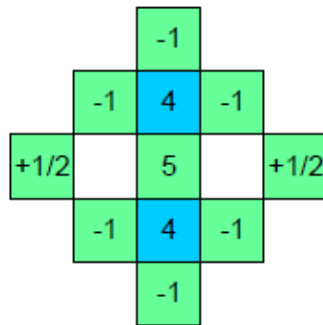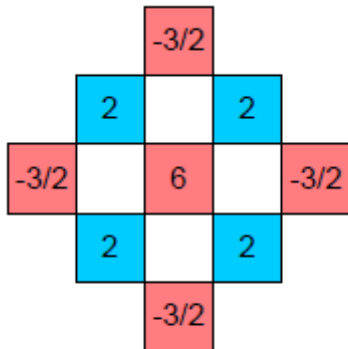
B at green in
R row, B column

Demosaicing algorithm

- To obtain a B value at a R pixel, the corresponding formula is

Bilinear interp. value

$$\hat{b}(i, j) = \hat{b}_B(i, j) + \gamma \Delta_R(i, j)$$

B at red in
R row, R column

Gain factors

- The values α, β, γ are gain factors for the correction due to gradients in the R,G,B channels respectively.

- How are they estimated? In a training phase of the algorithm – performed offline.

- The gain factors were designed to optimize a mean square error criterion.

Demosaicing: when does it happen?

- Your camera acquires images in a raw format, with 12 bits per pixel.

- Remember: at each pixel, only one of the R,G,B values is measured.

- That is, the camera measures just the CFA image.

- The camera then runs a demosaicing algorithm internally to generate the full RGB image.

- This image then goes through various intensity transformations after which it is JPEG-compressed and stored in the camera memory card.

- The demosaicing algorithm described earlier does not perform any noise removal – which can lead to noisy artifacts in the final image!