

Color image Demosaicing

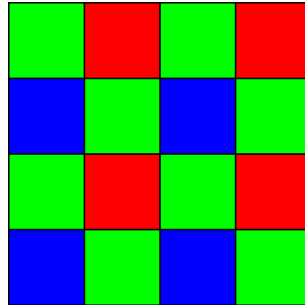
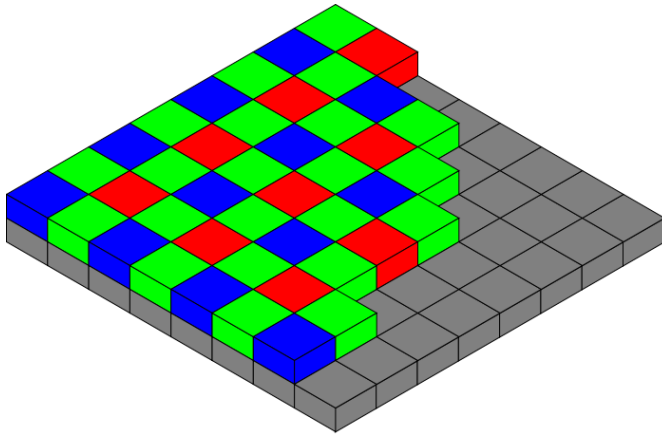
CS 663, Ajit Rajwade

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:



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

- The Bayer pattern collects information at red, green, blue wavelengths only as shown above.

*The word “mosaic” or “mosaiced” is not to be confused with image panorama generation which is also called image mosaicing.

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**.

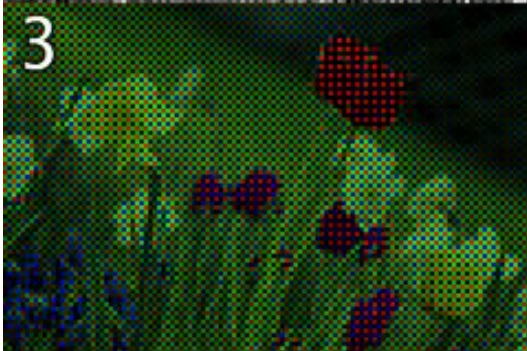


“original scene”

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



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.

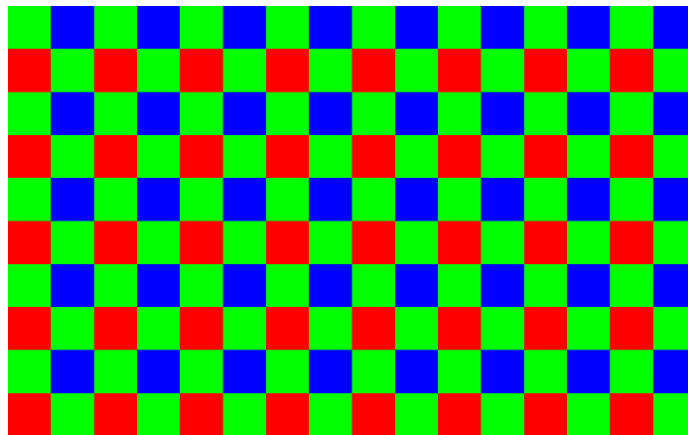
Malvar, H.S., L. He, and R. Cutler, *High quality linear interpolation for demosaicing of Bayer-patterned color images*. ICASPP, Volume 34, Issue 11, pp. 2274-2282, May 2004.

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.

$$\hat{g}(i, j) = \frac{1}{4} \sum_{(m,n) \in \{(0,-1), (0,1), (-1,0), (1,0)\}} g(i+m, j+n)$$



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)

Demosaicing algorithm

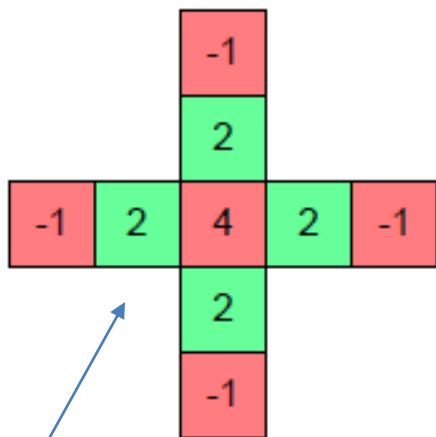
- Make use of the correlation between R,G,B color values for a more edge-aware interpolation!
- Edges in natural images have stronger luminance changes than chrominance changes.
- Consider the case of finding **G** at an **R** or a **B** pixel.
- The **R**-gradient can be useful information for determining 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:

$$\hat{g}(i, j) = \hat{g}_B(i, j) + \alpha \Delta_R(i, j) \quad \Delta_R(i, j) \triangleq r(i, j) - \frac{1}{4} \sum_{(m,n) \in \{(0,-2), (0,2), (-2,0), (2,0)\}} r(i+m, j+n)$$

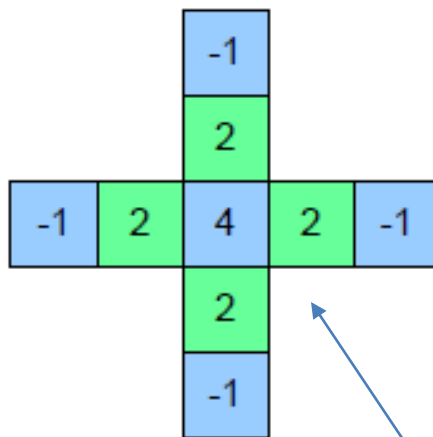
Bilinearly interp. value Gain factor



G at R locations

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

$$\Delta_R(i, j) \triangleq r(i, j) - \frac{1}{4} \sum_{(m,n) \in \{(0,-2), (0,2), (-2,0), (2,0)\}} r(i+m, j+n)$$



G at B locations

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

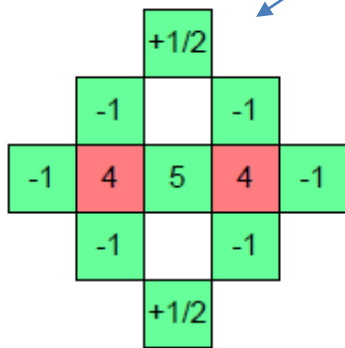
$$\Delta_B(i, j) = b(i, j) - \frac{1}{4} \sum_{(m,n) \in \{(0,-2), (-2,0), (2,0), (0,2)\}} b(i+m, j+n)$$

Demosaicing algorithm

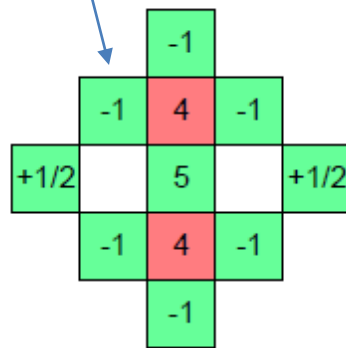
- We have seen how to obtain **G** at an **R** or a **B** pixel.
- To obtain the **R** value at a **G** pixel, the corresponding formula is

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

Bilinear interp. value



R at green in
R row, B column



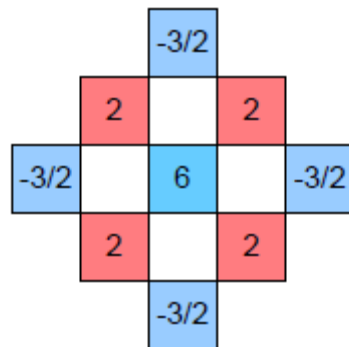
R at green in
B row, R column

Demosaicing algorithm

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

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

Bilinear interp. value



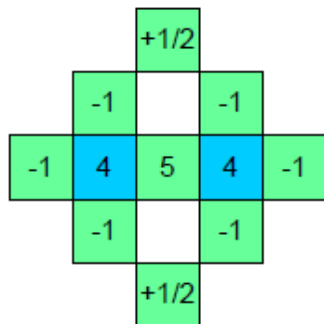
R at blue in
B row, B column

Demosaicing algorithm

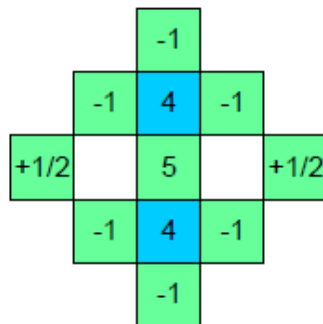
- To obtain a **B** value at a **G** pixel, the corresponding formula is

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

Bilinear interp. value



B at green in
B row, R column



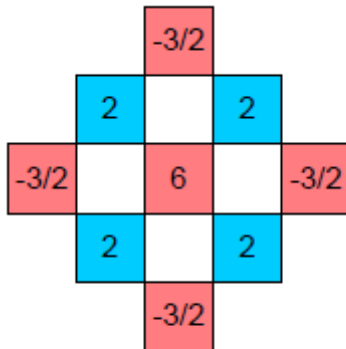
B at green in
R row, B column

Demosaicing algorithm

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

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

Bilinear interp. value



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!