UNIVERSITÀ DEGLI STUDI
DI MODENA E REGGIO EMILIA

Lecture notes for
Multimedia Data Processing

Hardware for color acquisition

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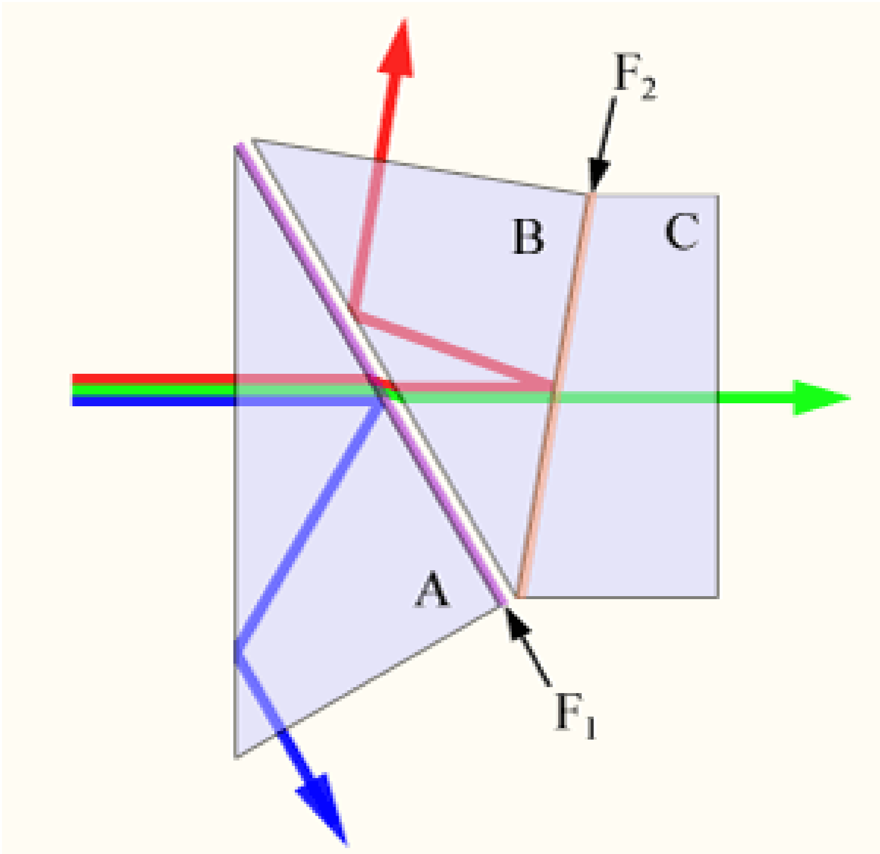
Dichroic prism

- The **photosensitive cell** converts the intensity of light, but is not sensitive to the wavelength, one color per pixel → Monochromatic acquisition.

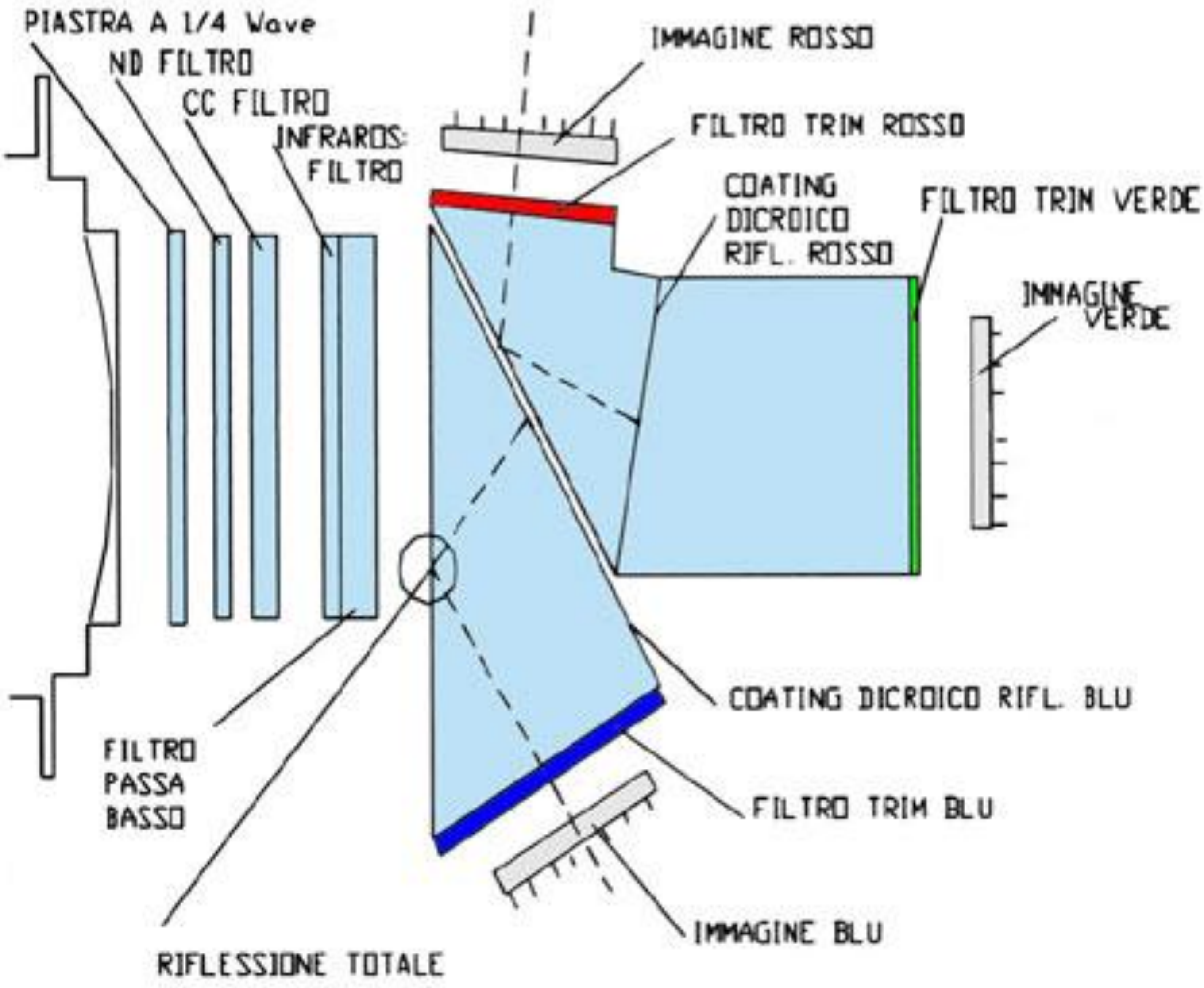
- **A dichroic prism is a prism that splits light into two beams of different wavelength** (color).
- They are usually made combining dichroic optical coatings that selectively reflect or transmit light depending on the light's wavelength.
- A typical application is to divide the light into three components inside some cameras (the so-called **3-CCD**).
- A **trichroic prism** combines two dichroic prisms to split an image into 3 colors, typically as red, green and blue of the RGB color model, measured by three different CCDs.

Dichroic prism

- A possible layout is shown in the diagram. A light beam enters the first prism (A), and the blue component of the beam is reflected from a low-pass filter coating (F1) that reflects blue light (high-frequency), but transmits longer wavelengths (lower frequencies).
- The blue beam undergoes total internal reflection from the front of prism A and exits it through a side face.
- The remainder of the beam enters the second prism (B) and is split by a second filter coating (F2) that reflects red light but transmits shorter wavelengths.
- The small air space between the two prisms allows total internal reflection.

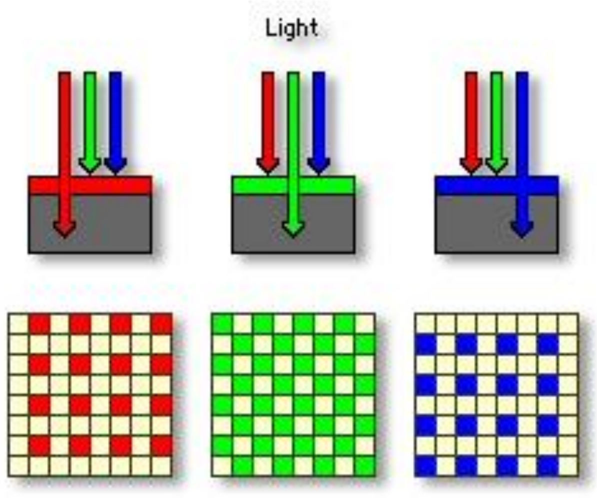


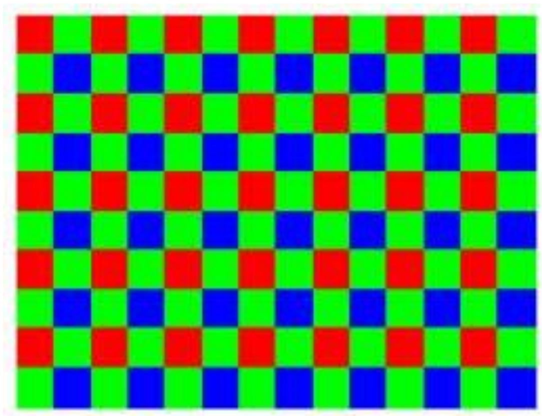
3-CCD camera schema



Bayer Pattern

- **Bayer Pattern** (Bryce Bayer, 1976 - Kodak)
  - RGBG - 2x2 cell, 2 green pixels, 1 blue, 1 red
    (Human eye more sensitive to green).
  - The filter decreases sensitivity to light, becomes 1/3 of the monochrome.
  - Variants: CMY-Y, CMY+G, RGB+E (Sony) more sensitive.

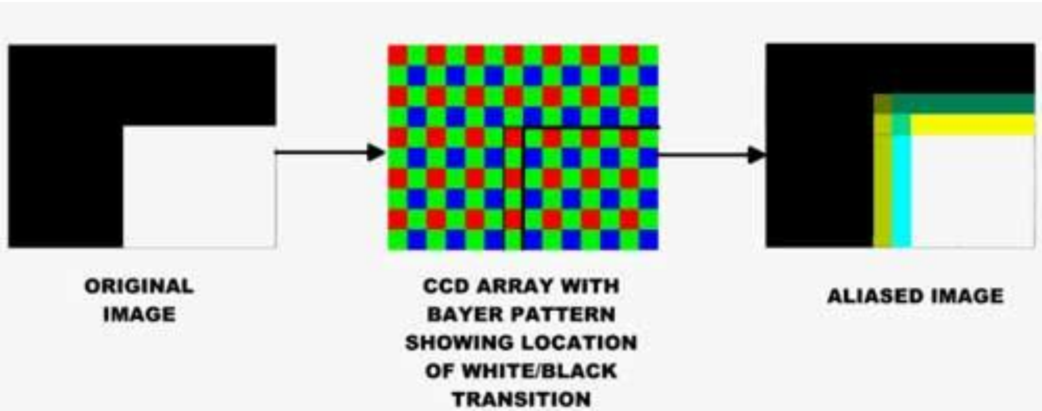


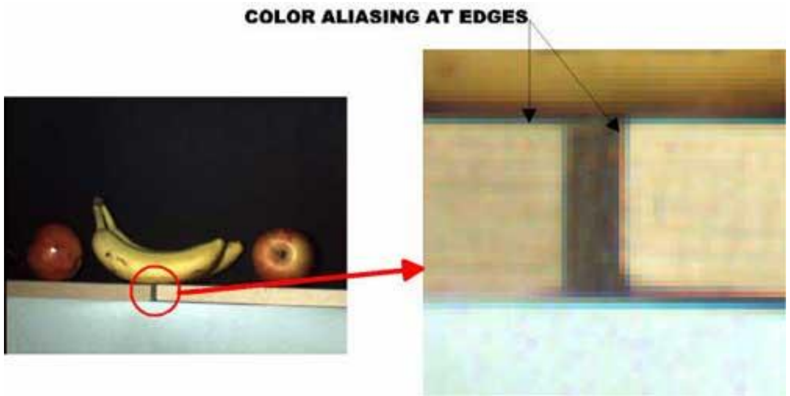


Bayer Pattern

The Bayer pattern has some advantages over 3-CCD technology:

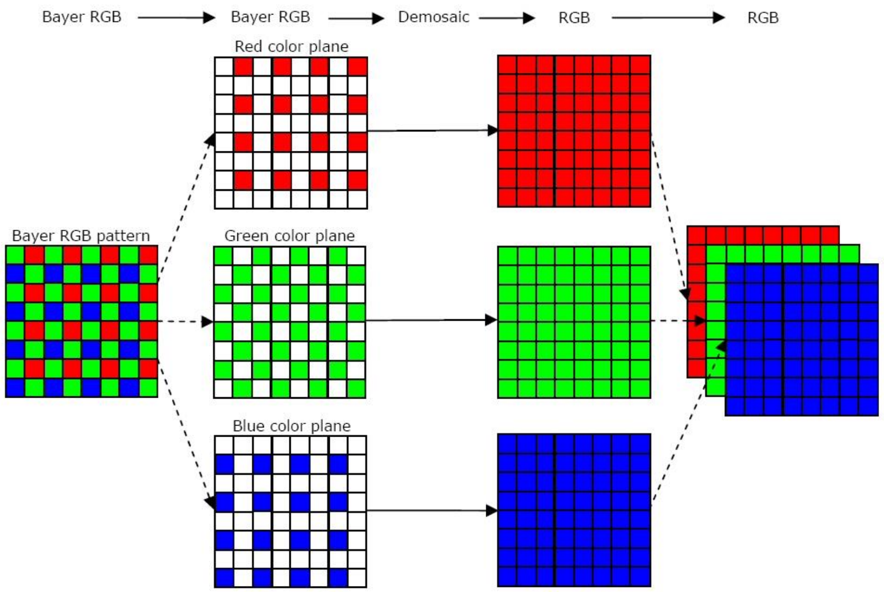
- Only one sensor needed;
- No prisms are needed;
- Lower cost and size;
- Lower weight: portable devices;
- On the other hand, the information of the Bayer pattern is sampled. In each pixel it is necessary to reconstruct the missing components → DEMOSAICING.





Demosaicing

- Transform the Bayer pattern into a full color RGB image.
- Interpolation by convolution: Nearest neighbor, bilinear, cubic [Sak98], [Ram02], etc.
- In this course we will analyze three:
  - Nearest Neighbor Replication (NNR)
  - Bilinear Interpolation (BI)
  - Linear Interpolation with Laplacian Second-order Correction Terms (LIL2)

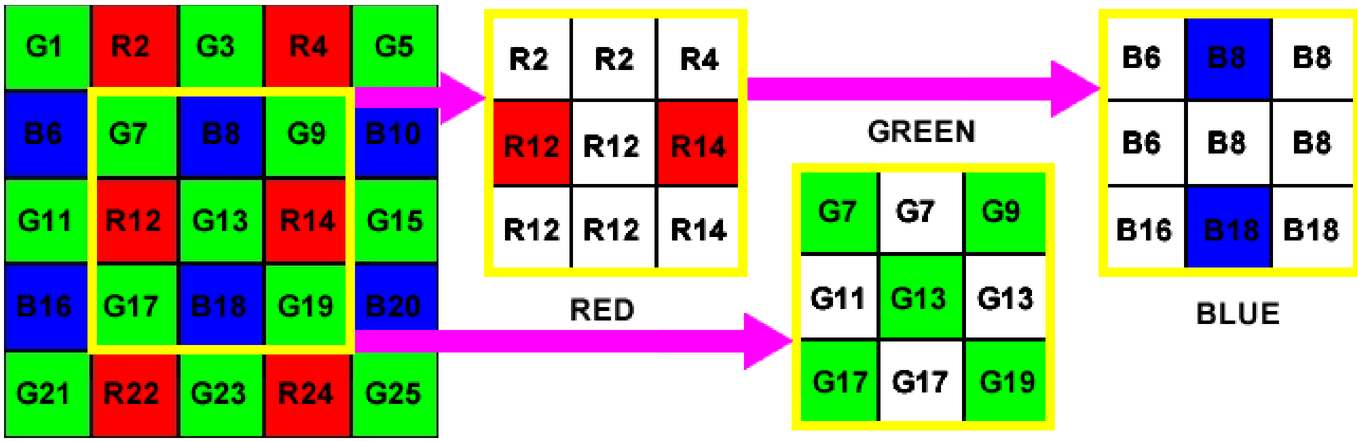


[Sak98] Sakamoto et al., Software Pixel Interpolation for digital still cameras suitable for a 32-bit MCU, IEEE Tran. Consumer Electronics, 1998

[Ram02] Ramanath et al., Demosaicking methods for Bayer color array, Journal of Electronic Imaging, 2002

Nearest Neighbor Replication

- Missing components are interpolated with neighboring pixel values.
- The closest pixel can be in any of the four fundamental directions, above, below, left or right.



STRENGTHS:

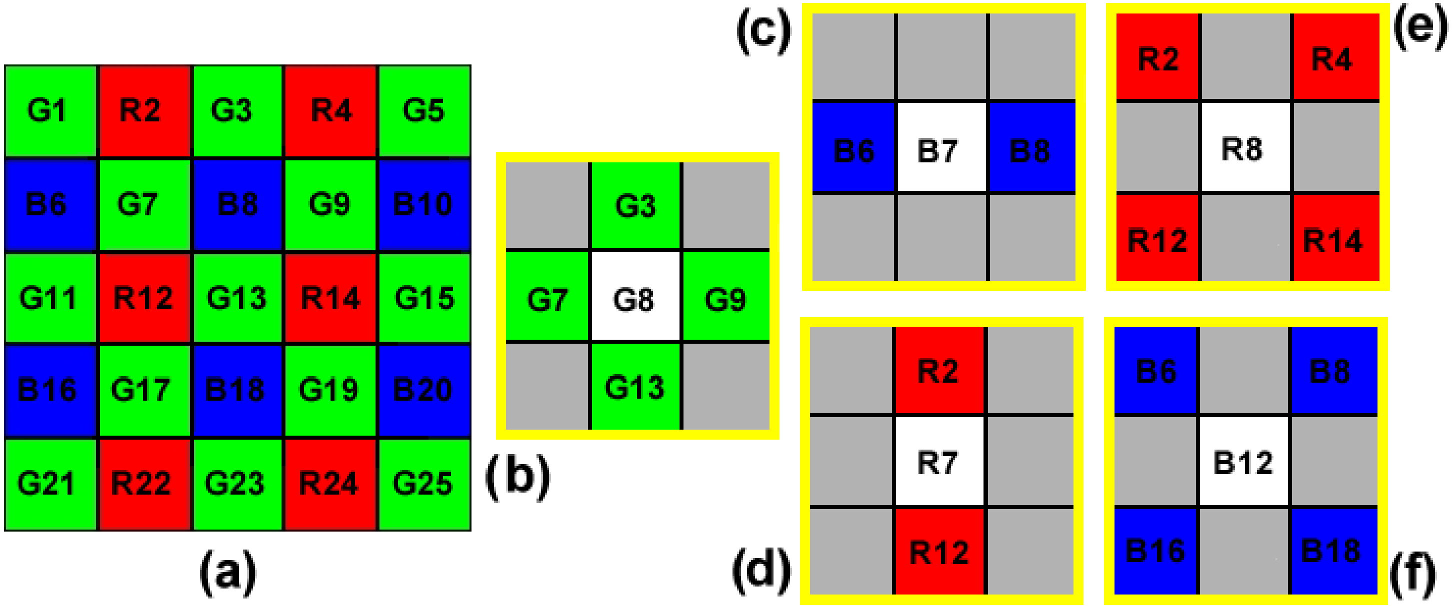
- Computationally faster interpolation.

WEAKNESSES:

- Creation of many false colors that can create problems for image processing.
- *Zipper effect*: high gradient transitions are very jagged.
- The interpolated image tends to be noisy.

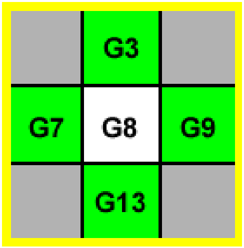
Bilinear Interpolation

- The missing components are interpolated with a bilinear interpolation of neighboring pixels.
- The components can be interpolated simultaneously.

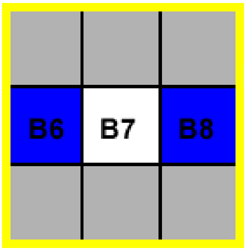


Bilinear Interpolation

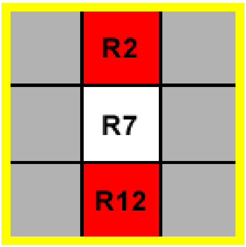
$$G8 = \frac{(G3 + G7 + G9 + G13)}{4};$$



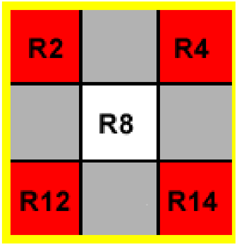
$$B7 = \frac{(B6 + B8)}{2};$$



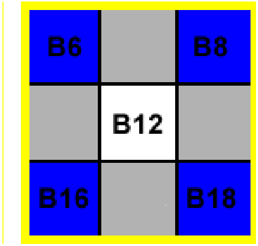
$$R7 = \frac{(R2 + R12)}{2};$$



$$R8 = \frac{(R2 + R4 + R12 + R14)}{4};$$



$$B12 = \frac{(B6 + B8 + B16 + B18)}{4};$$



Bilinear Interpolation

STRENGTHS:

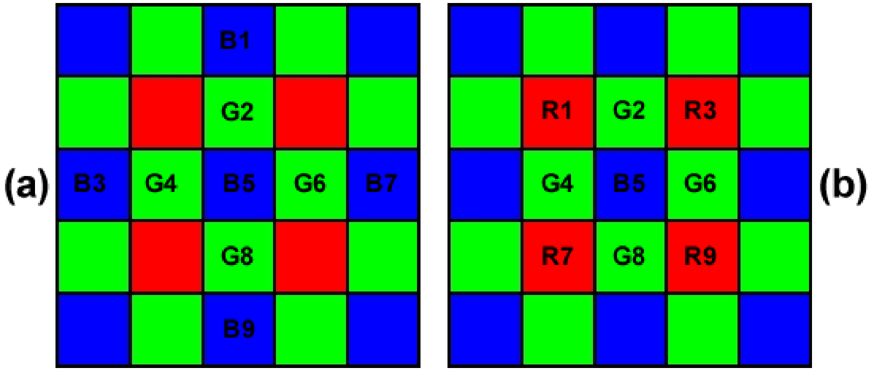
- This algorithm is very efficient and often forms the basis for other better ones.

WEAKNESSES:

- The "pure" color of adjacent pixels can change abruptly.
- *Blur effect*: the whole image is subject to low pass filtering.
- *Zipper effect* reduced but not eliminated.

Linear Interpolation w. Laplacian 2° Correction

- The missing components are interpolated in an adaptive way, following the chromatic gradients.
- **Maximum performance** in the case of images with vertical or horizontal edges.
- Interpolation of green pixels has priority.
- Assumption: the color planes are perfectly correlated in small areas of the image. That is, the following equation is true for the constants k and j:
  - $G = B + k$
  - $G = R + j$
- Adaptive = operates in a different way adapting to the typical variability of the addressed image.



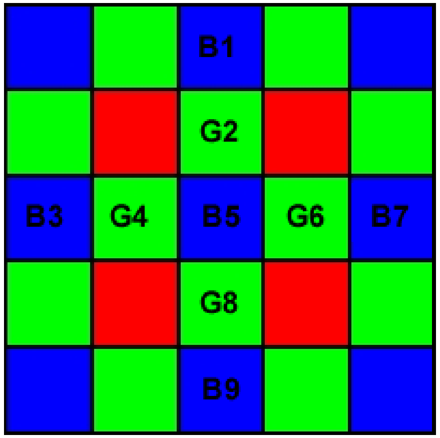
Laplacian 2° Correction

- GREEN: horizontal and vertical gradients are defined,

$$\Delta H = |G4 - G6| + |B5 - B3 + B5 - B7| \; ;$$

$$\Delta V = |G2 - G8| + |B5 - B1 + B5 - B9| \; ;$$

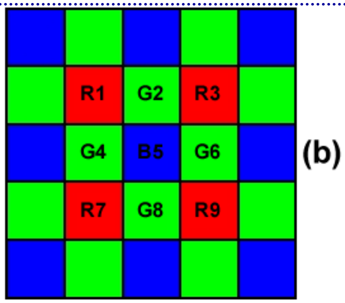
(a)



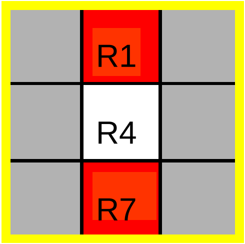
- Interpolation follows the algorithm

for all i such that i is a RED or BLUE pixel do
if $(\Delta H < \Delta V)$ then
$$G5 = \frac{(G4+G6)}{2} + \frac{(B5-B3+B5-B7)}{4}$$
else if $(\Delta H > \Delta V)$ then
$$G5 = \frac{(G2+G8)}{2} + \frac{(B5-B1+B5-B9)}{4}$$
else
$$G5 = \frac{(G2+G4+G6+G8)}{4} + \frac{(B5-B1+B5-B3+B5-B7+B5-B9)}{8}$$
end if
end for

Laplacian 2° Correction

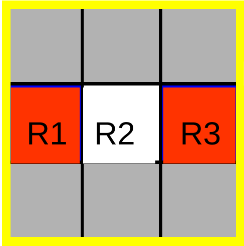


- RED: there are 3 possible cases
  - The two nearest pixels of the same color of the missing component are in the same column:



$$R4 = \frac{(R1 + R7)}{2} + \frac{(G4 - G1 + G4 - G7)}{4} \; ;$$

  - The two nearest pixels of the same color of the missing component are in the same row:



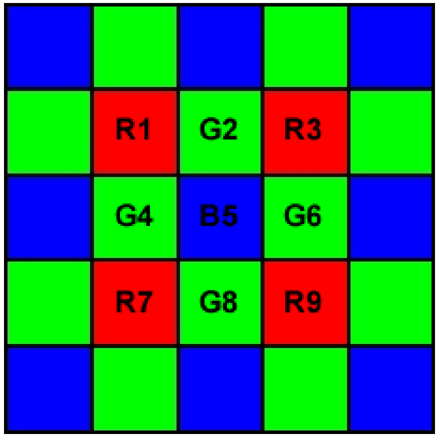
$$R2 = \frac{(R1 + R3)}{2} + \frac{(G2 - G1 + G2 - G3)}{4} \; ;$$

Laplacian 2° Correction

- RED: We define compound gradients,

$$\Delta N = |R1 - R9| + |G5 - G1 + G5 - G9| \; ;$$

$$\Delta P = |R3 - R7| + |G5 - G3 + G5 - G7| \; ;$$



(b)

- Interpolation follows the algorithm

for all i such that i is BLUE pixel in case 3 do
    if $(\Delta N < \Delta P)$ then
$$R5 = \frac{(R1+R9)}{2} + \frac{(G5-G1+G5-G9)}{4}$$
    else if $(\Delta N > \Delta P)$ then
$$R5 = \frac{(R3+R7)}{2} + \frac{(G5-G3+G5-G7)}{4}$$
    else
$$R5 = \frac{(R1+R3+R7+R9)}{4} + \frac{(G5-G1+G5-G3+G5-G7+G5-G9)}{8}$$
    end if
end for

- The interpolation of the blue color is the same as that of the red.

Comparison Interpolation


Original


Nearest


Bilinear


Laplacian

Comparison Interpolation

Original

Nearest

Bilinear

Laplacian