Computer Vision
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Lecture - 39
Color Fundamentals and Processing (Part VI)

We continue our discussion on color demosaicing and in the last lecture I have defined what is the problem of color interpolation.

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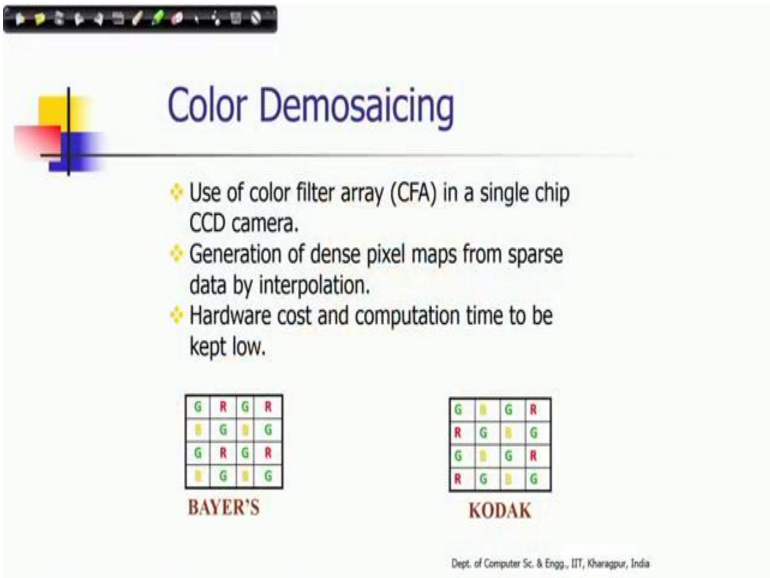

So, in this problem you are given a color filter array where there is a pattern by which you are sensing the colored image. So, in this pattern at every pixel only one spectral component is captured. So, the information of only one spectral component or spectral channel that is available. For example, say at this pixel only green value is available in its neighboring pixels red and blue are available.

So, the problem of interpolation is to compute the missing components at every pixel by taking care of its neighboring distributions. So, we will be discussing different methodologies for that and in particular here in the given problem what is already provided that the interleaved pattern of channels that is standardized with respect to the pixel coordinates. So, at every pixel of CFA I know that, at that coordinate locations or at that array location which spectral component is available.

So, you should note that this could be this positions could be encoded by two different two indexing schemes; I mean, two index by this kind of indexing schemes you can observe that in this interleaved pattern one row has the alternations of green and red pixels, green and red values and in the next row alternately blue and greens are available. So, we can consider the row where red samples are available along with green that is red row and the row where blue samples are available along with green that is blue row where as the column can be denoted as either green or non green. then the column positions are either green or non green.

So, in this way in an alternate in a periodic fashion we can determine for any pixel locations in the CFA in which type of row it is lying and which type of column it is lying and from that information itself we can find out that which spectral component is available there.

So, for example, if the position is a red row and green column, then it is the green pixel location. So, any column which is green in a position, there will be a green pixel locations will be available where as if it is blue row and non green column then say this is one example then the blue component is available. So, with this kind of background now let me discuss different methodologies of interpolation.

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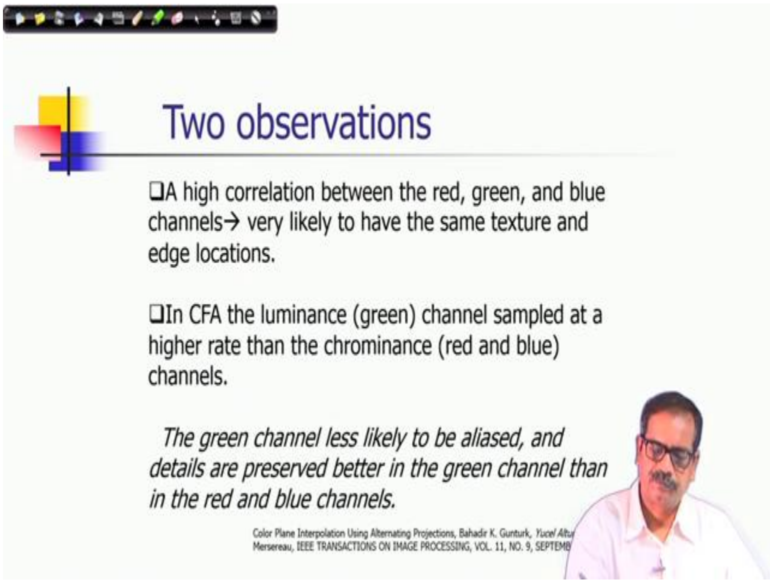

So, there are two key observations that we should make here; one thing is that there is a high correlation between the red green and blue channels. And which means that if you can if you have the informations of any of these channels, the other channel information also you can exploit this correlation to derive that information. They should very likely to have the same texture and edge locations particularly.

So, particularly the gradient estimations, cross channel gradient estimation is useful in this respect we will elaborate when we discuss different methodologies. The other observations from the CFA arrangement I mentioned these things in the previous lecture also that the green channels they are sampled at a higher rate and particularly in Bayer's pattern their sampled at twice the rate of red and blue channels.

So, usually green channel represents the intensity values they are more akin to representing intensity of values and the chromatic information is more embedded on red and blue occurs green also has its part there. So, that is why you know sometimes in the in the jargon of color interpolation green is considered synonymous to luminance channels. So, if you want to estimate luminance first we interpolate green and use that value kind of a luminance value in subsequent processing.

So, these are some of the advantages since you are having higher sampling rate in green channel because we are very sensitive to the green component of the color our vision system is very sensitive to that component. So, you would like to have higher quality of reconstruction of green channel and that is why there is it sampling rate is high. Andthat is why it should be less likely to be aliased and its details are preserved better in this channel than the other two chroma channels.

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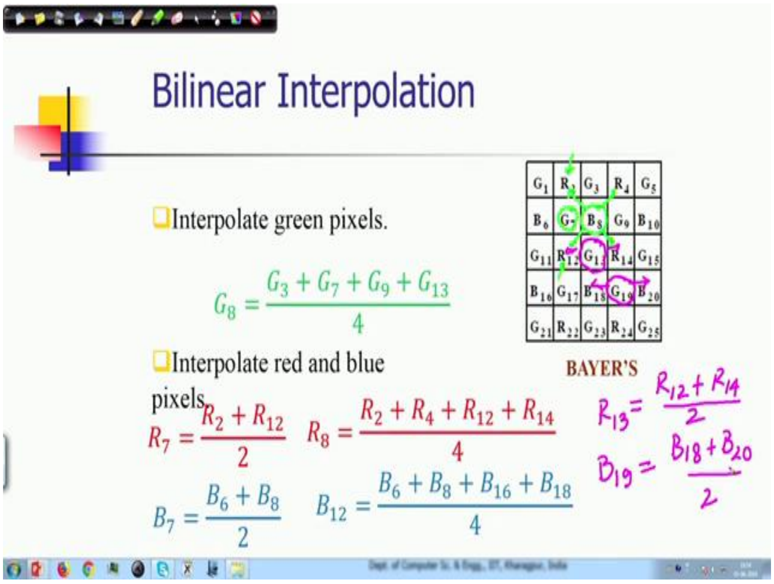

So, first we will be discussing about very simple technique of bilinear interpolation since this is a two dimensional distribution. So, we will be considering interpolations in both the directions. So, that is why linear interpolation in both the directions and this is quite simple and direct as we can see here.

For example if you want to interpolate the green pixels let us observe that what kind of arrangement we have. So, when you are going to interpolate green pixels means, these information we need to find out in a location where green samples are not available. For example, a location like this which is shown here as say B_8 or a location say like this which is shown here as R_{14}. So, these are the locations where you need to compute the missing green component.

Now, you can observe that the neighboring information of green samples are available in the form of four neighbors. So, in the discrete rate we call this neighborhood definition; 4 neighborhood definition is quite straight forward. Suppose you have a pixel location and in a discrete rate say this is a pixel location and if I denote this location as say (x, y) then this neighboring pixels, these are the 4 neighbors of this grid or this pixel.

So, which means this co ordinate is say array indexing should be $(x+1, y)$ this should $(x, y+1)$ this is $(x-1, y)$ and this one is $(x, y-1)$. So, if I considered for example, computation of green at this location I can see these are the 4 neighbors.

Say this one, this one, this pixel and this pixel is 4 neighbors. So, what I can do I can take simple average of this pixels. So, that is how we interpolate green because everywhere wherever green sample is missing you will always find that in the 4 neighbors of that sample there are two green values are available. So, you simply take the average.

So, you can see this is the example of the average of 4 neighbors in the pixel location B_8 where you have the green sample missing. So, this is the location and you are considering this then G_7, then G_9 and G_{13} and you are dividing it by 4, the sum of them you divide by 4, then you get the average.

Similarly, when you are going to interpolate the red and blue pixels there also you should consider only the neighboring samples which contain true pixel values of the corresponding channel which means that suppose I have a pixel where say red component is missing. So, there are two types of pixels the red component is missing in a pixel while green sample is available and red component is missing in a pixel where blue sample is available. So, these are the two scenarios say this is also another case.

So, in this green sample particularly note this location. So, here you observe that these are the red samples, two red samples are available. there is no other red samples in its neighborhood. So, you simply take the average of this two. So, what you need to do? You need to identify the type of pixel in a CFA that be which type of row and which type of column it is.

For example, this is a blue row and green column that is how you designate this pixel positions and for that case you have to consider the top neighbor and bottom neighbor and then you take the average. Where as if it is in red row and green column then you have to consider this one and this one; that means the left neighbor and the right neighbor and take the average.

If it is a blue column and blue row; that means, this is a scenario then you should consider in addition all this diagonal neighbors of this pixel and you take the average. So, these are the three cases which are available for interpolating red similarly you carry out the same operations for blue. So, what we get let us see these expressions.

$$R_7 = \frac{R_2 + R_{12}}{2} \quad R_8 = \frac{R_2 + R_4 + R_{12} + R_{14}}{4}$$

So, as I mentioned that if I considered the location G_7 say this is the location G_7. So, this is a blue row and green column location. So, you get the top neighbor and bottom neighbor R_2 and R_{12} and you divide it by 2 that is averaging of those two values.

Similarly, you consider this case. So, here you have R_8 it is just the location beside the previous one this is the location and now the red samples are available in its diagonal neighbors. So, you can see that R_2, R_4, R_{12} and R_{14} and then you take the average. So, this is a second condition for interpolating red second case for interpolating red.

$$B_7 = \frac{B_6 + B_8}{2} \quad B_{12} = \frac{B_6 + B_8 + B_{16} + B_{18}}{4}$$

The third case as I mentioned, it could be blue row and blue column oh sorry this is in the same way you are doing B_7 and B_{12}, but no the other case could be as I was mentioning .these are the only two cases of red. No other case is missing here. So, which is not shown let me tell you. So, it is basically red row and green column. So, you consider this particular location. So, I should write missing component red and that location indexing the convention whatever we are following we call it R_{13} then I should take the average of left neighbor and right neighbor. $R_{13} = \frac{R_{12} + R_{14}}{2}$

And for the blue cases also, it should be the green column and blue row. So, which is this one, one example is this and I can write as say B_{19} that is equal to this is just for typical example we are use those using the indexes of those pixels. Anywhere where you satisfies this property of characterization of locations of the pattern what you mentioned that is the type of row and type of column you should apply the same technique.

So, in this case you have again left neighbor left blue neighbor and right blue neighbor. So, that should be $\frac{B_{18} + B_{20}}{2}$. So, this is how bilinear interpolation is carried out.

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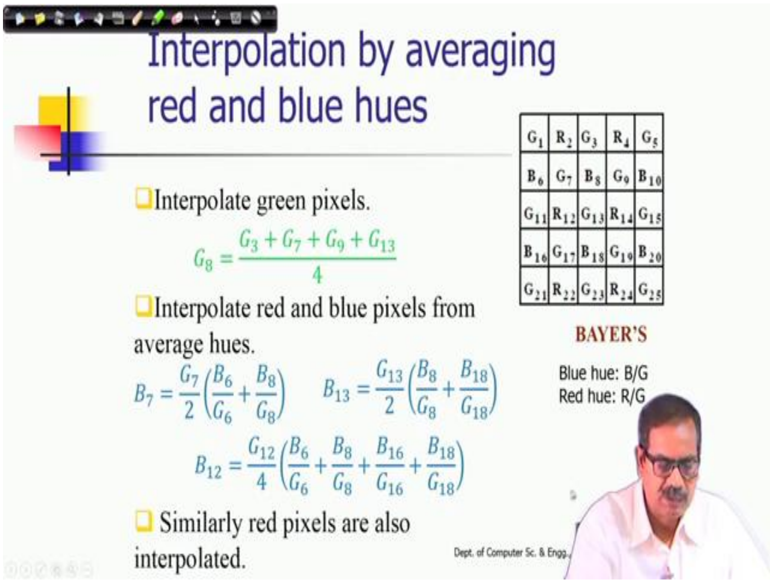

So, next we will be discussing about a technique where we would like to exploit the correlation between green and blue and green and red samples. So, this technique what it is considering that at every point you can estimate hue and you are averaging over the corresponding hues.

first hue interpolate green pixels using the simple bilinear interpolation. So, in that case at every pixel you have all the green values. So, all the pixels wherever green samples were missing through bilinear interpolation you have computed it. So, once you have done it then actually you are able to compute this blue hue and red hue correspondingly in respective positions wherever blue sample is available, then you can compute blue hue wherever red sample is available you can compute red hue.

So, while performing interpolating blue sample at a pixel where blue sample is missing you consider its neighboring blue hues, then average it and then you multiply with the respective green value at that pixel that would give you the corresponding blue sample. So, this is a modifications it requires, similarly you do it for red hue. So, it is nothing, but bilinear interpolations of hues once you have computed green and then you convert it to the pixel value by multiplying the respective hue with the green channel, green component.

So, let me describe it further. So, as you can see that interpolation of green sample is the same as it is done in bilinear interpolation technique. You are simply averaging out the

the 4 neighbors of every non green pixel locations where 4 neighbors are always green neighbors that we have we can observe from this Bayer's pattern.

So, now we will be discussing about the interpolation of red and blue pixels. So, there you can find out this situation's; so, will be considering interpolation of blue pixels in this case. So, as you can see here that the location where you are interpolating that is this(G_7) location. Now, in this location you have the green sample that is available. So, its neighbors and it is a blue row; so it is left neighbor and right neighbors the two blue samples are available. Since you have already interpolated green, so we have the estimation of G_6 and estimation of G_8 these are available.

$$B_7 = \frac{G_7}{2}\left(\frac{B_6}{G_6} + \frac{B_8}{G_8}\right) \qquad B_{13} = \frac{G_{13}}{2}\left(\frac{B_8}{G_8} + \frac{B_{18}}{G_{18}}\right)$$

So, I can compute the blue hue at in those neighboring locations and you take the average of them. So, you divide it by two and then multiply with G_7 that is how you will get the blue value at that location. So, let us find out what you are doing in the other locations. So, in the location B_{13} as you can see here. So, this is the location where blue is missing and we need to compute the blue component, once again instead of left and right neighbor we have to consider top and bottom neighbors because this is in the red row and green column.

So, in its top and bottom neighbor two blue samples are available. So, you can estimate the blue hues take the average and multiply with the green value what is available at that location. So, this is the second case. And the third case is shown here where you have the blue values all in the diagonal locations. So, you can consider this particular guess say let me use a different colour just to say this is a location where blue sample is missing and you are going to estimate. So, once again the diagonal neighbors contains two blue pixels blue values and their greens are already estimated.

$$B_{12} = \frac{G_{12}}{4}\left(\frac{B_6}{G_6} + \frac{B_8}{G_8} + \frac{B_{16}}{G_{16}} + \frac{B_{18}}{G_{18}}\right)$$

So, you take the average of hues of those locations; that means, sum those hues and then divide it by 4 because there are 4 instances of estimation of blue hues and then you multiply with the green sample. So, here green is also estimated because it was a red. So, the green value what is estimated by the green interpolation stage you can use that value to get the missing blue sample. So, this is how you compute the blue components wherever it is not there in the color filter array. In the same way you can do it for the red components. So, this is what you can perform these operations for red pixels.

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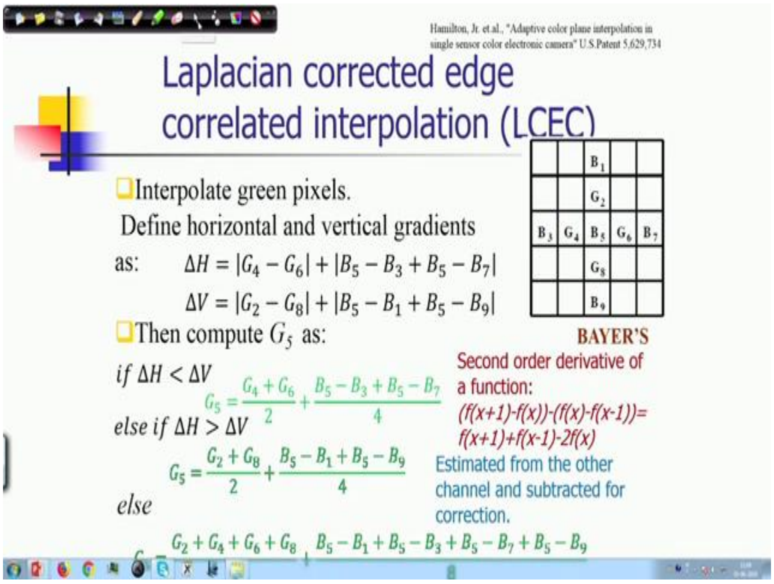

So, now I will be discussing another very effective technique where it is exploiting the information of gradient. So, let me discuss this particular property of interpolation this is very commonly used that when you interpolate the pixels you should interpolate along the directions of the least gradient. Because you can see particularly when you have edges let me give you an example through the sketches. Suppose you have a region where this side you have a brightness value say I_0 and this side you have a brightness value say I_1.

So, suppose this pixel value is not available and this pixel values are available. Now, if I am going to interpolate along these directions there is a direction of maximum gradient change. So, as you can see that these interpolated value will be in between I_0 and I_1 and there will be blurriness in the corresponding edge values edges. Where as if I interpolate along this direction we will be preserving this edges because those values they are similar and they are the least gradient changes there is the direction of least gradient change in this case.

So, we can consider that value should give you better interpolation. So, there is a principle by which you can perform this interpolation along the directions of low gradients. Since we have two directions natural directions in this pattern and by the definition of neighborhood there are horizontal and vertical gradient directions of course, you have also diagonal directions. So, other directions are also available, but depending upon the availability of your samples either they are horizontal neighbors or vertical neighbors or diagonal neighbors you can compute the corresponding gradients along those directions.

So, whenever there is a possibility of choosing samples among those directions. For example, in this particular case see we would like to compute green. Now, you can take the average of these two values that is in the horizontal directions or you can take the average of these two values that is in the vertical directions. So, which one you should choose? Now, if you find that vertical gradient is significantly smaller than the horizontal gradient which means there exists an edge then you should prefer the vertical direction.

So, that this is what and if you find then it is not much of difference then you can use all the neighbors. And if it is a diagonal directions where we coming to those situation there we have to consider again two directions diagonal directions which are also perpendicular and follow the same principle. So, estimation of gradient is important here, the other case what this algorithm does that estimation is further defined by considering the second order derivative of the distribution. So, I will be now discussing this algorithm in more details.

So, as I mentioned that first you have to compute say green interpolations. So, we are considering for example, this pixel location. So, the gradient value in the horizontal direction, this is an horizontal gradient direction is the difference between these two and you take the absolute amount because that is of your interest.

$$\Delta H = | G_4 - G_6 | + | B_5 - B_3 + B_5 - B_7 |$$

And then you can find that actually this is also added with it because what we are doing we are computing the difference of the difference which means the second order derivative; that means, if I take the difference of these two. Say $B_7 - B_5$ and then again take the difference of these two and you subtract it say $B_7 - B_5$ and then again take it and subtract it $B_5 - B_3$, then you will get the, if you take the magnitude you will get the same value here. So, this is how you are estimating, but you are estimating the second order derivative from the blue channels as we mentioned in the very beginning of this today's lecture that there is a high correlation in the higher order derivatives across the channels.

So, we are estimating that same derivative should be also observed in the green channel when you can estimate it form the blue channel. So, this is how the gradient it estimate along the horizontal direction, similarly you can perform the estimation. So, this is just explaining that second order derivative of a function what I just have mentioned this is how you can compute.

$$\Delta V = |G_2 - G_8| + |B_5 - B_1 + B_5 - B_9|$$

And the vertical gradient can be estimated in this form you can see that the top neighbors of B_5 are considered for estimating the vertical gradient first order derivative and the second order derivatives are also computed from the vertical columns of blue components.

So, now the algorithm is that you have to find out in which direction the gradient is minimum. So, you have to compute G_5 like if ΔH is less than ΔV then if this is a scenario then you should consider the interpolation using this pixels. So, but what it does I could have taken $\frac{G_4 + G_6}{2}$ that is know 1 value, but it is further refined by a correction by a cross channel estimation of Laplacian derivative.

$$if \Delta H < \Delta V$$
$$G_5 = \frac{G_4 + G_6}{2} + \frac{B_5 - B_3 + B_5 - B_7}{4}$$

So, I will show you the final expression. So, this is the expression you can see that this estimate is refined by this second order derivative or you call it Laplacian value which is estimated from the blue channel because from the other channel which is available and it is subtracted from the value of $\frac{G_4 + G_6}{2}$.

So, this is one thing interesting because if you use the Taylor series expansion, then you will see that actually this value should be added during interpolation, but that performs poorly than this particular correction. And this is a technique which has been you proposed in this particular work and it is a very effective technique that what we have found out.

So, this is the work what is referred here and it has been observed that it gives very good interpolation quality of interpolation is very high good. So, this is further elaborated I mean used to repeated in other locations also same thing like if now the horizontal gradient is you know greater than vertical gradient, then you should use a vertical directions for interpolating green.

And otherwise if they are equal use all possible green values; that means, all the diagonal neighbors sorry not diagonal in this case they are all four neighbors in the non green locations. And then also use the corresponding estimates of derivatives using the both the directions vertical and horizontal directions and refine it.

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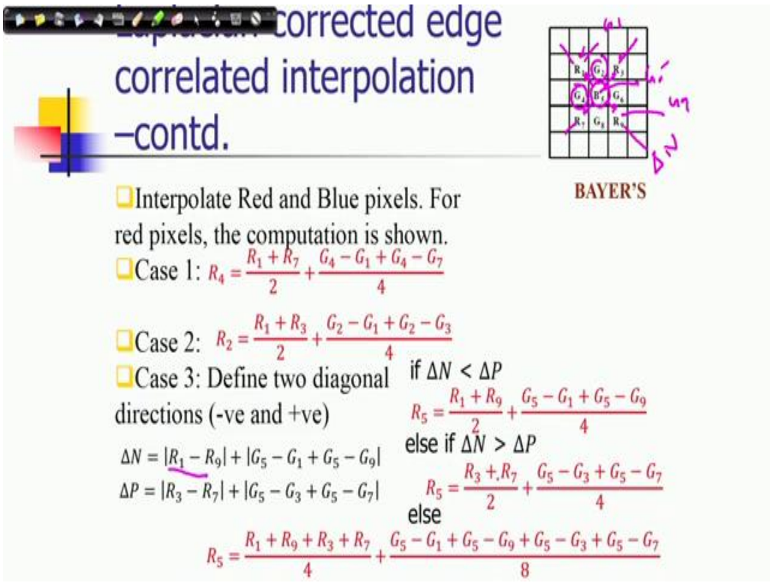

So, this is how the green pixel is interpolated and the blue and red pixel is also interpolated it in the same fashion on already you have green pixel. So, now, what you can do you since you have green values at every locations your cross channel estimation of Laplacian should be through green only. So, now, you have once again the condition of interpolation of red pixel. So, if it is at the location here you can see this is the location where the missing red is computed and since there is there are no vertical this only the vertical neighbors are available for red true sample.

So, there is no question of comparing horizontal and vertical gradient in this case because only in one directions information is available and that is more reliable than the other values. So, we will be using them while doing interpolations and also we will be refining this estimate using their cross channel Laplacian estimate as we mentioned. And, but in other case also when it is the horizontal neighbors are available in the missing red location.

So, this is this particular location you see the only horizontal neighbors are available for red vertical there are blues. So, again you do not do any comparisons of horizontal and vertical gradient use similar kind of estimation process.

And the third case would be where actually the red neighbors, the neighboring red samples are in the diagonal directions. For example, this is the case where you have neighboring red samples in the CFA. So, now here you would like to apply the same technique of finding out the doing interpolations in the least gradient directions.

So, only thing is that your estimation of gradient should be along this direction, along these two perpendicular directions and that estimates once again can be refined using the Laplacian correction. So, what we are defining here as you can see that two directions; one is called ΔN. So, this direction ΔN you can see it is $R_1 - R_9$ and then you are also considering the Laplacian estimate along this. So, you are using G_5, so this is G_5, this is G_1 and this is G_9.

$$\Delta N = | R_1 - R_9 | + | G_5 - G_1 + G_5 - G_9 | \qquad \Delta P = | R_3 - R_7 | + | G_5 - G_3 + G_5 - G_7 |$$

So, using this value itself you can perform this Laplacian estimate here and in the other direction also you are doing this and then which one is smaller you are choosing that value. So, if ΔN is less than ΔP, then you are performing your interpolations using R_1, R_9 and those Laplacian corrections. And if ΔN is greater than ΔP, then you are doing this and if they are equal, then in the same way you are using all the diagonal neighbors take the average and also perform the Laplacian corrections.

If $\Delta N < \Delta P$

$$R_5 = \frac{R_1 + R_9}{2} + \frac{G_5 - G_1 + G_5 - G_9}{4}$$

Else if $\Delta N > \Delta P$

$$R_5 = \frac{R_3 + R_7}{2} + \frac{G_5 - G_3 + G_5 - G_7}{4}$$

Else

$$R_5 = \frac{R_1 + R_9 + R_3 + R_7}{2} + \frac{G_5 - G_1 + G_5 - G_9 + G_5 - G_3 + G_5 - G_7}{8}$$

So, this is how this particular interpolation technique is carried out. So, let me give a break at this point, we will continue this discussion in the next lecture.

Thank you very much for your attention.