Digital Image Processing

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Lecture - 26

Colour Image Processing

Hello, welcome to the video lecture series on digital image processing. In our last lecture, we have talked about image restoration image registration problem.

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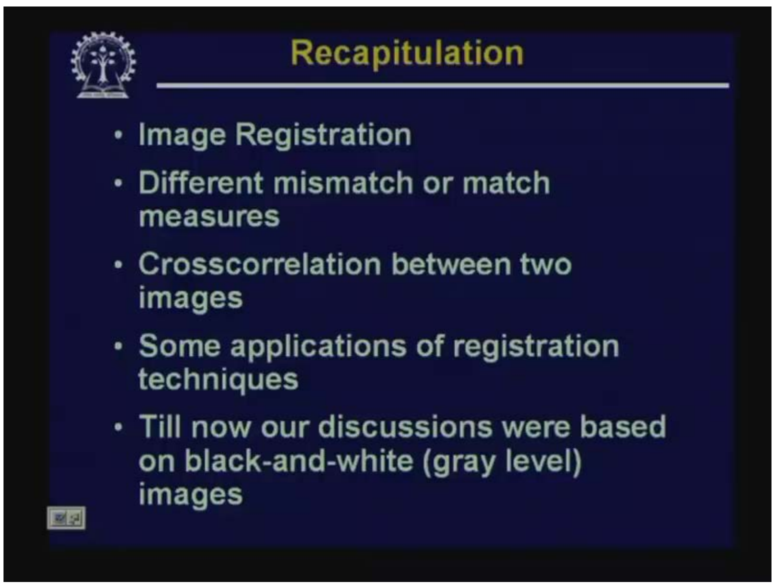

So, we have talked about different image mismatch or match measures, we have talked about the cross correlation between two images and we have also seen some application of registration techniques. Now, including this image registration technique, whatever we have done till now in our digital image processing course, we have seen that all our discussions where mainly based on black and white images that is we have not considered any colour image during our discussion. Now, starting from today and coming few lectures, we will talk about the colour image processing.

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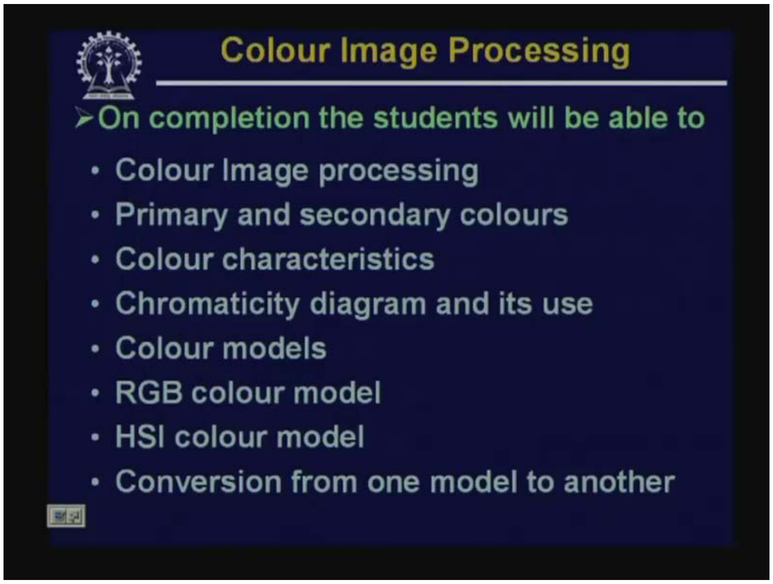

So today, what we are going to do is we are going to introduce the concept of colour image processing. We are going to see that what are primary and secondary colours, we are going to talk about colour characteristics, then we will see chromaticity diagram and how the chromaticity diagram can be used to specify a colour. We will see two colour models; one of them is RGB colour model or red, green and blue colour model and other one is HSI colour model and we will also see that how we can convert from one colour model to another colour model.

Now, first let us talk about why we want colour image processing when we get information from black and white images itself. The reason is colour is a very very powerful descriptor and using the colour information, we can extract the objects of interest from an image very easily which is not so easy in some cases using black and white or simple gray level image.

And, the second motivation why we go for colour image processing is that or we talk about colour images is that human eyes can distinguish between thousands of colours and colour shades whereas, when we talk about on the black and white image or gray scale image, we can distinguish only about 2 dozens of intensity distributions or different gray shades.

So, that is the reason the colour image processing gives a very very important topic. Firstly because, we can distinguish between more number of colours and secondly, we can identify some objects in a colour image very easily which otherwise may be difficult from a simple intensity image or a gray level image. Now, coming to colour image processing, there are two major areas.

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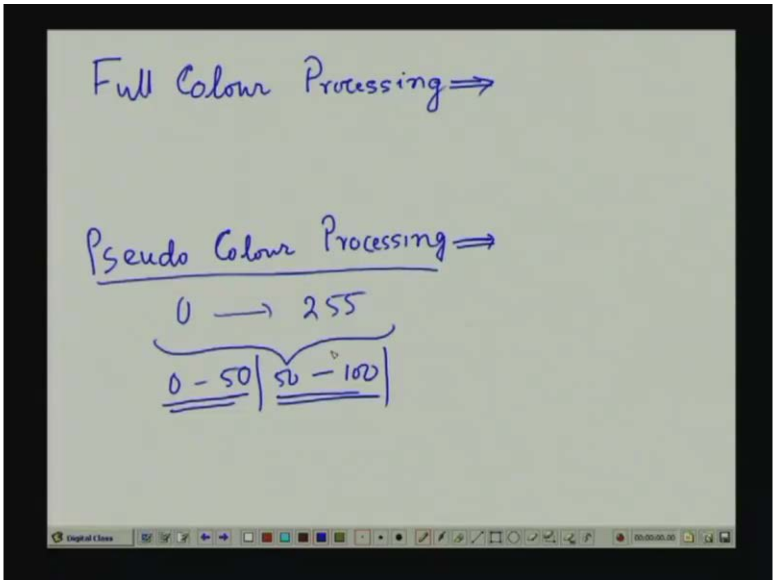

One of the area, we call as full colour image processing. We say, full colour processing and other area is pseudo colour processing. Now, what is meant by this full colour processing or pseudo colour processing? When we talk about full colour processing, the images which are acquired by full colour TV camera or by a full colour scanner, then you will find that almost all the colours that we can perceive, they are present in the images.

So, that is what is meant by a full colour image and when we try to such a full try to process such a full colour image, what we will try to process is we will take into consideration all those colours which are present in the image whereas, when we talk about this pseudo colour processing, the pseudo colour processing is a problem where we try to assign certain colours to a range of gray levels.

When we take an intensity image or simply a black and white image which has intensity levels from say 0 to 255; what I can do is we can subdivide, we can divide this entire intensity range into a number of sub range. Say for example, I can divide 0 to say 50, this intensity level will be in 1 range may be 50 to 100, intensity levels will be in another range and to this range I can assign one particular colour whereas in this range 50 to 100, I can assign another particular colour and this pseudo colour image processing is mostly useful for human interpretation.

So, as we said that we can hardly distinguish around 2 dozens of intensity of gray shades whereas if we go for so in such cases, it may not be possible for us to distinguish between 2 gray regions which are very near to each other or the intensity values are very near to each other. So, in such cases, if we go for this pseudo colour pseudo colouring technique that is we assign different colours to different range of intensity values, then from the same intensity image of black and white image, we can extract the information much more easily and this is mainly useful as I said for human interpretation purpose.

Now, what is the problem with the colour image processing? The interpretation of colour as the colour is interpreted by the human beings, this problem is a psycho physiological problem and we have not yet been fully understand what is the mechanism by which we really interpret a colour. So, though the mechanism is not fully understood but the physical nature of colour we can represent formally, we can express it formally and our formal expression is really supported by some experimental results.

Now, the concept of colour is not very new. You know from your school level physics, from school level optics that way back in 1666, it was Newton who discovered the colour spectrum.

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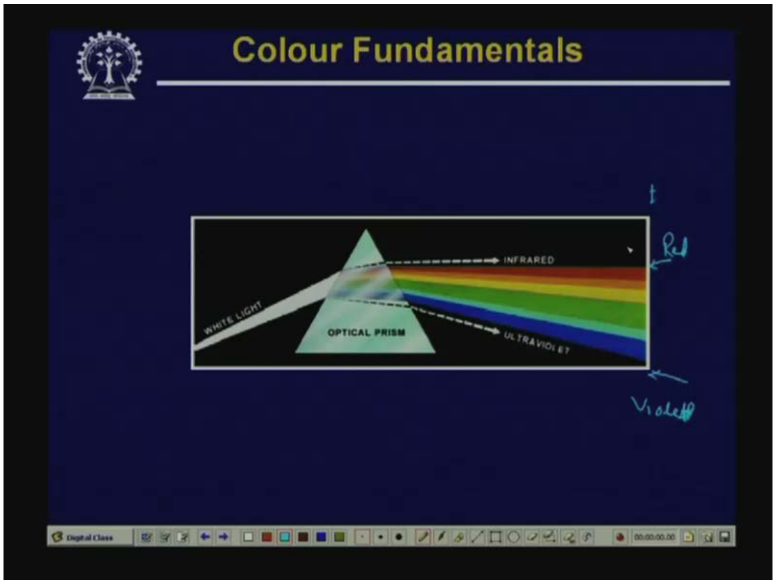

So, what he did is his experimental setup was something like this - you have an optical prism and you pass white light through this optical prism and as the white light passes through the optical prism, on the other side when this white light comes out of it, the light does not remain white any more. However, it is broken into a number of colour components which is known as spectrum. So, as has been shown in this particular diagram, you find that at one end of the spectrum what we have is the violet, at one end we have violet and at the other end, we have the red colour. So, the colour components that vary from violet to red and this was really discovered by Newton way back in 1666.

Now, the thing is how do we perceive colour or how do we say that an object is of a particular colour? We have seen earlier that we perceive an object, we see an object because light falls on the object or the object is illuminated by certain source of light, the light gets reflected from the object, it reaches our eye, then only we can see the object.

Similarly, we can perceive the colour depending upon the nature of the light which is reflected by the object surface. So, because we have to perceive this nature of the light, so we have to see that what is the spectrum of light which is or the spectrum of the energy which is really in the visible range because it is only in the visible range that we are able to perceive any colour.

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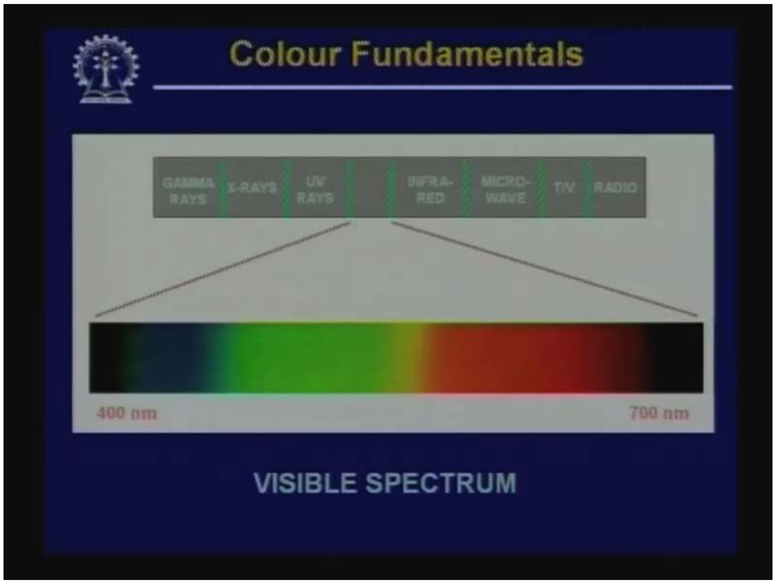

So, if you consider the electromagnetic spectrum; so as shown here, the electromagnetic the complete electromagnetic spectrum ranges from gamma rays to radio frequency waves and you will find that this visible spectrum, the visible light spectrum, it occupies only a very narrow range of frequencies in this entire electromagnetic spectrum and here you find that the wavelength of the visible spectrum that roughly varies from say 400 nanometer to 700 nanometer; so, at one end it is around 400 nanometer wavelength and at the other end, it is around 700 nanometer in wavelength.

So whenever, a light falls on an object and if the object reflects lights of all wavelengths in this visible spectrum in a balanced manner that is all the wavelengths are reflected in the appropriate proportion; in that case, that object will be appearing as an white object and depending upon the wavelength, pre dominant wavelength within his visible spectrum, the object will appear to be a coloured object and the object colour will depend upon what is the wavelength of light that is predominantly reflected by that particular object surface.

Now, coming to the attributes of light; if we have an achromatic light that is a light which does not contain any colour component, the only attribute which describes that particular light is the intensity of the light whereas if it is a chromatic light, in that case as we have just seen, the wavelength of the chromatic light within the visible range can vary from roughly 400 nanometer to 700 nanometer. Now, there are basically 3 quantities which describe the quality of light. So, what are those quantities?

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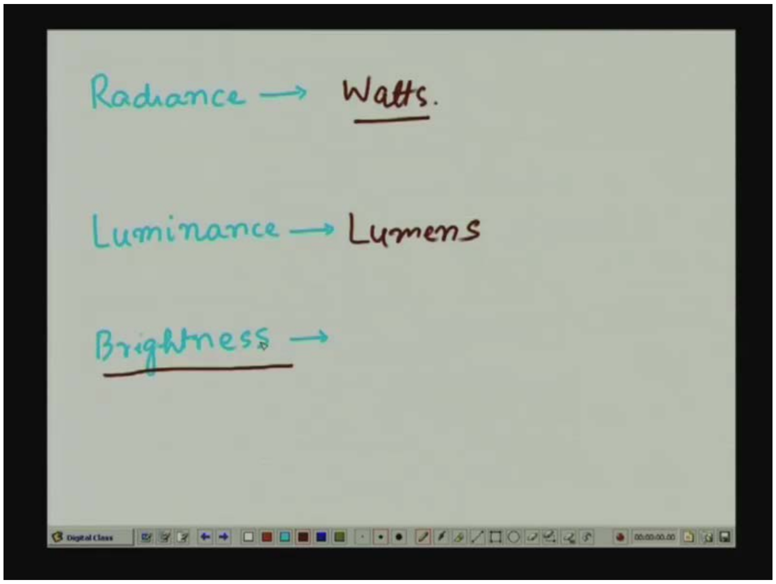

One of the quantities is what is called radiance, the second quantity is called luminance and the third quantity is called brightness. So, we have these 3 quantities – radiance, luminance and brightness which basically describe what is the quality of light. Now, what is this radiance? Radiance is the total amount of energy which comes out of a light source and as this is the total amount of energy, so this radiance is to be measured in the form of in units of watts.

Whereas luminance, it is the amount of energy that is perceived by an observer. So, you will find the difference between the radiance and luminance. Radiance is the total amount of energy which comes out of a light source whereas luminance is the amount of energy which is perceived by an observer.

So, as the radiance is measured in units of watts, it is luminance which is measured in units of what is called lumens whereas the third quantity that is brightness, it is actually a subjective measure and it is practically not possible to measure the amount of brightness. So, though we can measure the radiance, luminance, radiance and luminance but practically we cannot measure what is brightness.

Now, again coming to our colour images, our colour lights; most of you must be aware that when we consider colour, when we talk about colours, we normally talk about 5 primary colours and we say that the 3 primary colours are red, green and blue.

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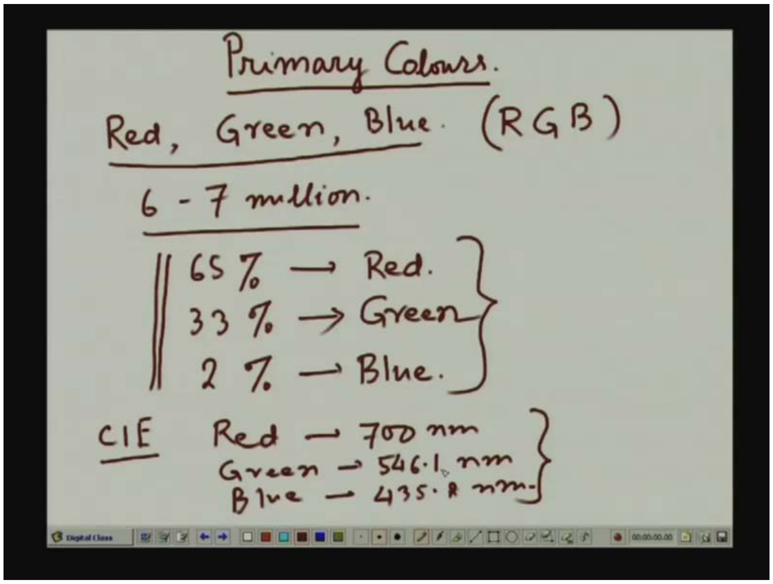

So, we consider the primary colours of light, coloured light. So, we consider the primary colours to be red, green and blue. So, we consider these 3 colours to be the primary colours and normally we represent it as R, G and B. Now, we find that from the spectrum which was discovered by Newton, there actually 7 different colours. But out of those 7 colours, we have chosen only these 3 different colours – red, green and blue to be the primary colours. And, we assume that by mixing these primary colours in different proportions, we can generate all other colours.

Now, why do we choose these 3 colours to be the primary colours? The reason is something like this that actually there are some cone cells in our eyes which are responsible for colour sensation. So, there are around 6 to 7 million cone cells around 6 to 7 million cone cells which are really responsible for colour sensation. Now, out of this 6 to 7 million cone cells, around 65% of the cone cells, they are sensitive to red light, 33% of the cone cells are sensitive to they sense green light and roughly 2% of the cone cells, they sense blue lights.

So, because of the presence of these 3 different cone cells in our eyes which sense red, green and blue, these 3 colour components; so we consider red, green and blue to be our primary colours and we assume that by you mixing these primary colours in appropriate proportion, we are able to generate all other different colours.

Now, as per this, CIE standard specified 3 different wavelengths for 3 different colours. So, CIE is specified red to have a wavelength of 700 nanometer, green to have an wavelength of 546.1 nanometer and blue to have an wavelength of 435.8 nanometer but the experimental result is slightly different from this. Let us see how the experimental result looks like.

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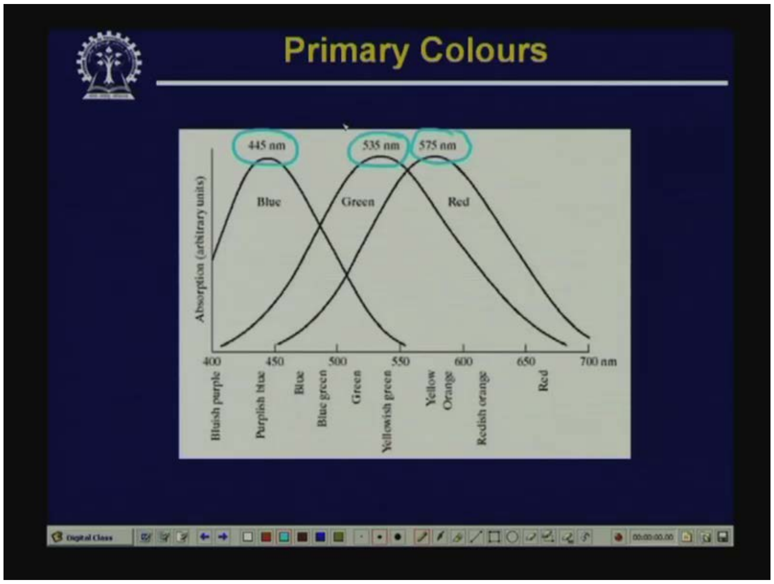

This one, this diagram shows the sensitivity of those 3 different cones in our eyes that we have just said. So, you find that the cones which are sensitive to blue light to blue colour, these cones actually receive wavelengths ranging from around 400 nanometer to 550 nanometer whereas, the cones which are sensitive to green lights, they are sensitive to wavelengths ranging from slightly higher than 400 nanometer to an wavelength of something around say 650 nanometer whereas, the cones which are sensitive to red light, they are sensitive to wavelengths stating from 450 nanometer to around 700 nanometer.

Though the sensitivity is maximum for these type of cones, say blue cone is maximally sensitive at an wavelength of 445 nanometer as is shown in this diagram, so as is shown in this diagram; you will find that the blue cells, the blue cones, they are most sensitive to an wavelength of 445 nanometer, the green cones are most sensitive to an wavelength of 535 nanometer whereas, the red cones are most sensitive to an wavelength of 575 nanometer.

So, these experimental figures are slightly different from what was specified by CIE and one point has to be kept in mind that though CIE standard specifies red, green and blue to be of certain wavelength but no single wavelength can specify any particular colour. In fact, from the visible spectrum from the visible domain of the spectrum that we have just seen, it is quite clear that when we consider two spectrum colours, two adjacent spectrum colours, there is no clear cut boundary between those two adjacent spectrum colours. Rather, one colour slowly or smoothly gets merged into the other colour.

So, as you can see from the same diagram that whenever we have a transition from say green to yellow, you find that we do not have any clear cut boundary between green and yellow. Similarly, whenever there is a transition from say yellow to red, the boundary is not clearly defined. But we have a smooth transition from one colour to another colour. So, that clearly says that no single colour may be called or no single wavelength may be called red, green or blue.

But it is a band of wavelength which give you colour sensation, a band of wavelengths that gives you green colour sensation, a band of wavelengths that give you red colour sensation, at the same time a band of wavelengths that give you say blue colour sensation. So, having specific wavelengths as standard does not mean that these fixed RGB component alone components alone when mixed properly will generate all other colours.

But rather, we should have a flexibility that we should also allow the wavelengths of these 3 different colours to change because as we have just seen that green actually specifies a band of wavelength, red actually specifies a band of wavelengths, similarly blue also specifies a band of wavelengths. So, to generate all possible colours, we should allow the wavelengths of these colours are red, green and blue also to change.

Now, when I say that these are the different primary colours that is red, green and blue; mixing of the primary colours generate the secondary colours.

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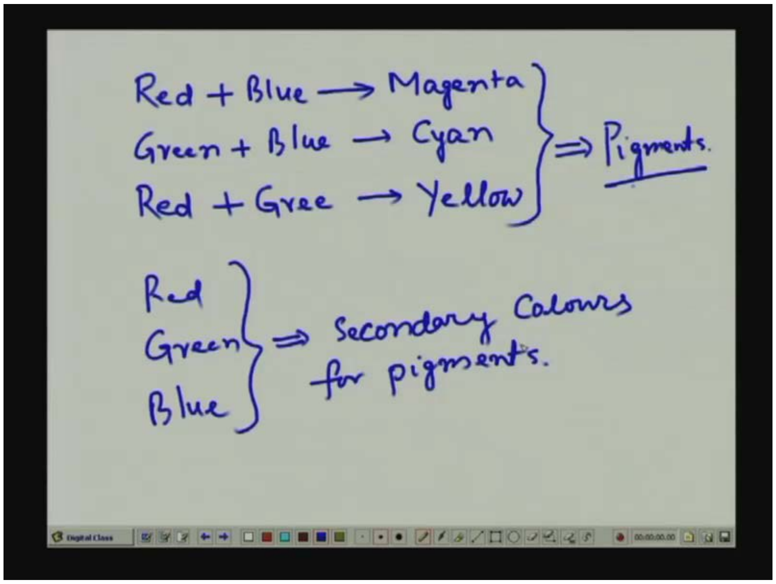

So, when we mix say red and blue, if we mix red and blue, you will find that both red and blue, they are the primary colours; red and blue will generate a colour called magenta which is a secondary colour. Similarly, if we mix green and blue, this will generate a colour which is called cyan and if we mix yellow sorry red and green if we mix red and green, these 2 generate colour yellow.

So, as we have said that red, green and blue, we consider these 3 colours as primary colours; by mixing the primary colours, we generate the secondary colours. So, these three colours – magenta, cyan and yellow, they will be called secondary colours of light. Now here, another important concept is the pigments.

As we have said that red, green and blue are the primary colours of light and if we mix these colours will generate the secondary colours of light which for example are magenta, cyan and yellow; when it comes to the pigments the primary colour of a pigment is defined as an wavelength which is absorbed by the pigment and it reflects the other 2 wavelengths. So, the primary colour of light should be the opposite of the primary colour of a pigment. So, as red, green and blue, they are the primary colours of the light whereas magenta, cyan and yellow, they are the primary they are the primary colours of a pigment. So, when it comes to pigment, we will consider this magenta, cyan and yellow, they are to be the primary colours. So, these are the primary colours for pigments and in the same manner, this red, green and blue which are the primary colours of light, these 3 will be the secondary colours for pigments.

And, as you have seen that for the colours of light, the primary colours of light if we mix red, green and blue in appropriate proportion, we will generate white light; similarly for the pigment, if we mix the cyan, magenta and yellow in appropriate proportion, we will generate the black colour. So, for pigments, appropriate mixing of the primary colours will generate black whereas, for light, the appropriate mixing of the primary colours will generate white.

Now so far, what we have discussed that is the primary colours of light which are red, green and blue are the primary colours of pigments which are magenta, cyan and yellow. These are the concepts of the colour components we consider when we talk about the colour reproduction or these are from the hardware point of view. That is for a camera or for a display device, for a scanner, for a printer, we talk about these primary colour components.

But when we perceive a colour, as human being when we look at a colour, we do not really think that how much of red component or how much of blue component or how much of green component that particular colour has. But the way we try to distinguish the colour is based on the characteristics which are called brightness, hue and saturation.

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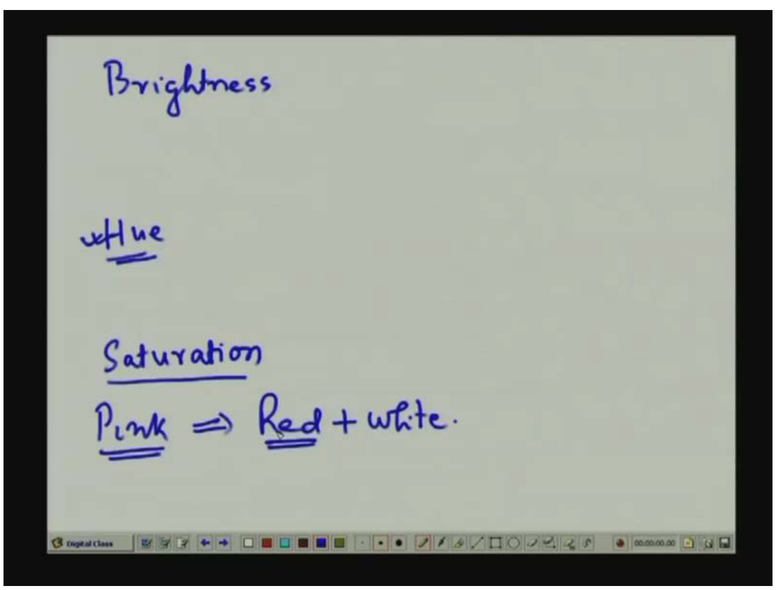

So for us, for the perception purpose, the colour components will be taken as or the characteristics are brightness, hue and saturation instead of the red, green and blue or cyan magenta and yellow. Now, let us see that what does these 3 attributes mean? So, what is brightness? Brightness is nothing but achromatic notion of intensity. As we have seen that in case of a black and white image, we talk about the intensity; similarly for a colour image, there is a chromatic notion of intensity, it is not really intensity which we call as bright or brightness.

Similarly hue, it represents the dominant wavelength in a mixture of colours. So, when you look at a secondary colour which is a mixture of different primary colours, there will be one wavelength which is a dominant one, dominant wavelength and the overall sensation of that particular secondary colour will be determined by the dominant wavelength. So, this hue, this particular attribute, it indicates that what is the dominant wavelength present in a mixture of colours.

Similarly, the other term saturation, you find that whenever we talk about a particular colour red, there may be various shades of red. So, this saturation indicates that what is the purity of that particular colour or in other words, what is the amount of light which has been mixed to that particular colour to make it a diluted one. So, these are basically the 3 different attributes which we normally use to distinguish one colour from another colour.

Now, coming to the spectrum colours, because the spectrum colours are not diluted, there is no white light white component added to a spectrum colour; so spectrum colours are fully saturated. Whereas, if we take any other colour which is not a spectrum colour, say for example if we consider a colour say pink, pink is nothing but a mixing of white with red. So, red plus white, this makes a pink colour. So, red is a fully saturated colour because it is a spectrum colour and there is no white light mixed in red. But if we mix white light with red, the colour generated is pink. So, pink colour is not fully saturated but red is fully saturated.

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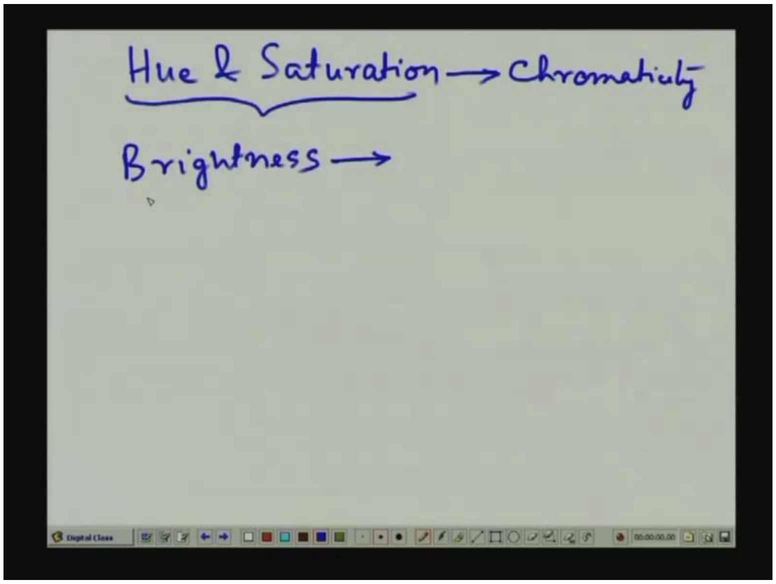

So, we have these 3 concepts for colour perception that is hue and saturation and the other one is brightness and as we said that brightness indicates a chromatic notion of the intensity whereas hue and saturation, they give you the colour sensation. So, we say that hue and saturation together, they indicate what is the chromaticity of the light whereas this brightness, gives you some sensation of intensity.

So, using this hue saturation of intensity, what we are trying to do is we are separating the brightness part and the chromaticity part. So, whenever we tried to perceive a particular colour, we normally perceive it in the form of hue, saturation and brightness whereas from the point of view of hardware, it is the red green and blue or magenta cyan and yellow which are more appropriate to describe the colour.

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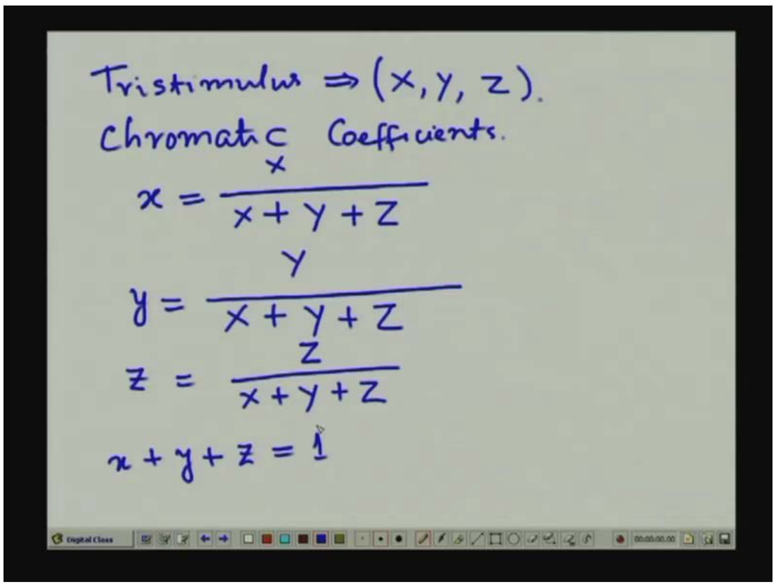

Now, the amount of light or the amount of red, green and blue lights which are required to form any particular colour is called a Tristimulus, we call it tri stimulus and obviously because this indicates what is the amount of red, light green light and blue light which are to be mixed to form any particular colour; so, this will have 3 components - one is x component, y component and z component and a colour is normally specified by what is called chromatic coefficients. So, we call them as chromatic coefficients and this chromatic coefficients are obtained as the coefficient for red is given by x lower case x is equal to capital X by capital X plus capital Y plus capital Z.

So, this capital X is the amount of red light, capital Y is the amount of green light and capital Z is the amount of blue light which are to be mixed to form a particular colour. So, the chromatic coefficient for red which is given by lower case x which is computed like this; similarly chromatic coefficient for green is computed as lower case y is equal to capital Y by capital X plus capital Y plus capital Z and similarly for blue, it is capital Z by capital X plus capital Y plus capital Z. So, this lower case x, y, z, these are called the chromatic coefficients of a particular colour.

So, whenever we want to specify a colour, we have to specify it by its chromatic coefficients and from here, you find that this sum of the chromatic coefficient that is lower case x plus lower case y plus lower case z is equal to 0 is equal to 1. So, this is represented in normalized form. So, as any colour can be specified by its chromatic coefficients, in the same manner, there is another way in which a colour can be specified. That is with the help of what is known as a CIE chromaticity diagram.

So, a colour can be specified both by its chromatic coefficients as well as it can be specified with the help of a chromaticity diagram. So, let us see what is this chromaticity diagram.

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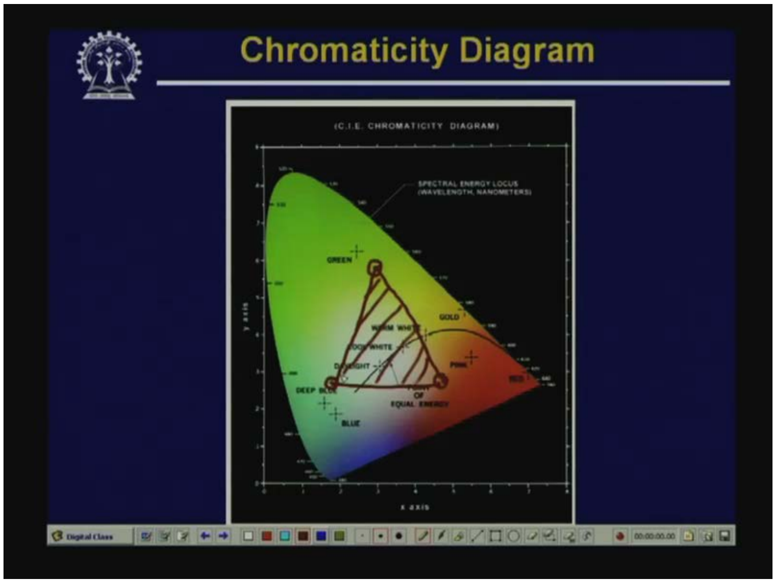

So here, we have shown this chromaticity diagram and you find that it is a colour diagram in a two dimensional space; we have the horizontal axis which is the lower case which is the axis representing the lower case x and we have the vertical axis which is the axis representing lower case y. That means the chromatic coefficient for red is along the horizontal axis and the chromatic coefficient for green is along the vertical axis and if we want to specify any particular colour; say for example, I take this particular point and I want to find out that how this particular colour can be, say here, how this particular colour can be specified?

So, as we have said that we can specify it by its the chromatic coefficients; now 2 of the components of the chromatic coefficients that is x and y that is red component and green component, we get we can get from the horizontal axis and the vertical axis and the third component that is z obviously in this case will be given by z is equal to 1 minus x plus y. So, x and y are obtained from this chromaticity diagram and I can get the chromatic coefficient component z simply by using the relation that x plus y plus z is equal to 1 and if you study this chromaticity diagram, you will find that all the spectral colours, they are represented along the boundary of this chromaticity diagram.

So, along the boundary, we have all the spectral colours. In this chromaticity diagram, there is a point which is marked as say this point which is marked as point of equal energy. That means all the red, green and blue components, they are mixed in equal proportion and this is the one which is the CIE standard of white. And as we said, the notion of saturation, you will find that all the points on the boundary because they are the spectrum colours; so all the colors along the boundary, they are fully saturated and as we move inside the chromaticity diagram away from the boundary, as you move away from the boundary, the colour becomes less and less saturated.

So, one use of this chromaticity diagram is that we can specify a colour using this chromaticity diagram, we can find out what are the chromatic coefficients x, y and z by using this chromaticity diagram and not only that, this chromaticity diagram is also useful for colour mixing. Let us see how? Say for example, within this I take 2 colour points, say I take one colour point somewhere here and I take one point somewhere here and I consider another point somewhere here and if I join these two points by a straight line say like this; in that case, this straight line indicates that what are the different colours that I can generate by mixing the colour present at this location and the colour present at this location.

So, all possible mixture of these 2 colours can create all the colours which are lying on this straight line segment connecting these 2 colour points and same is true for 3 points. Say instead of just taking these 2 points, if I take a third point somewhere here; then you form a triangle connecting these 3 colour points. Then if I take the colour present on this location, the colour present at this location and the colour which is specified at this location and by mixing all these different all these three colours in different proportions, I can generate all the colours lying within this rectangular region.

So, this chromaticity diagram is also very helpful for colour mixing operation. For example, we can get some other information from this chromaticity diagram like this. So, as we have said that we have this point of equal energy which is the CIE standard of white; now if I take any colour point on the boundary of this chromaticity which we said that this is nothing but a colour which is fully saturated and we mention that as we move away from this boundary, the colours that we get, they are getting less and less saturated and saturation at the point of equal energy which is the CIE standard of white just we have said, here the saturation is 0, the point is not saturated at all.

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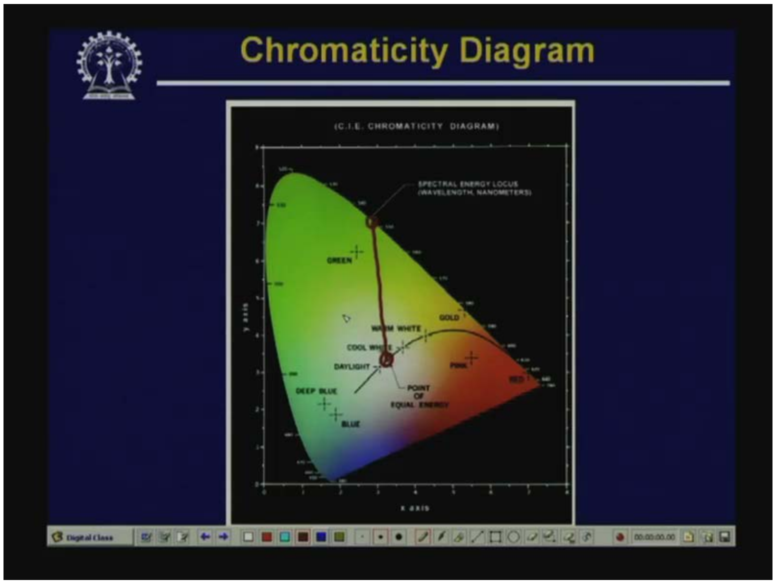

Now, if I draw a straight line from any of these boundaries joining this point of equal energy like this; so, this indicates that what are the different shades of colour of this particular saturated colour that we can obtain by mixing white light to this saturated colour? So, as we have said that as we mix white light, the saturation goes on decreasing that is we can generate different shades of any particular colour.

So, this particular straight line which connects the point of equal energy which is nothing but the CIE standard of white and a colour on the boundary which is a fully saturated colour, then what I can get is all the shades of this particular colour is actually lying on this particular straight line which joins the boundary point to the point of equal energy.

So, you find that using this chromaticity diagram; we can generate different colours, we can find out that in what proportion the red, green and blue they must be mixed so that we can generate any particular colour and this we can do for 2 colours mixing of 2 colours, we can use it for mixing of 3 colours and so on.

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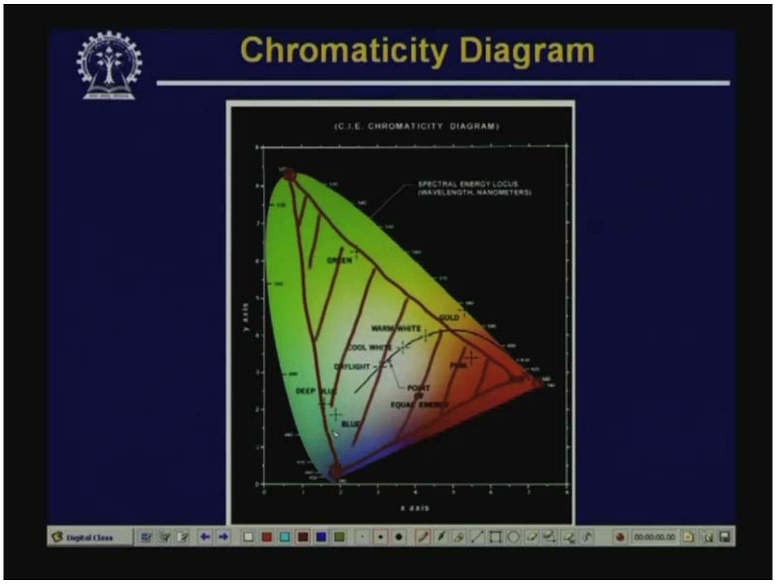

Now, just to mention that as we have said that we have taken red, green and blue as primary colours; you find that in this chromaticity diagram, your green is if I take green to be somewhere here, say if I consider this point to be the green point, so this point is the red point and the blue is somewhere here and if I join these 3 points by straight lines, what i get is a rectangle.

So, by using this red, green and blue; I can generate, as we have just discussed all the colours which are present within this triangular region. So, as this triangular region does not encompass the inter part of this chromaticity diagram because this chromaticity diagram is not really triangular diagram. So, just we have said that using 3 fixed wavelengths as red, green and blue, we cannot generate all the colours in the visible region and that is also quite obvious from this chromaticity diagram because if we consider only 3 fixed wavelengths to represent red, green and blue points; using those 3 wavelengths, we can just form a triangular region and none of the triangular regions, single triangular region can fully encompass the chromaticity diagram.

So, as a result of that, by using fixed wavelengths for red, green and blue as primary colours; we cannot generate all the colours as given in this chromaticity diagram. But still using the chromaticity diagram, we can have many informations, many useful informations; as we said, we can go for colour mixing, we can find out different shades of colour, we can specify colour and so on.

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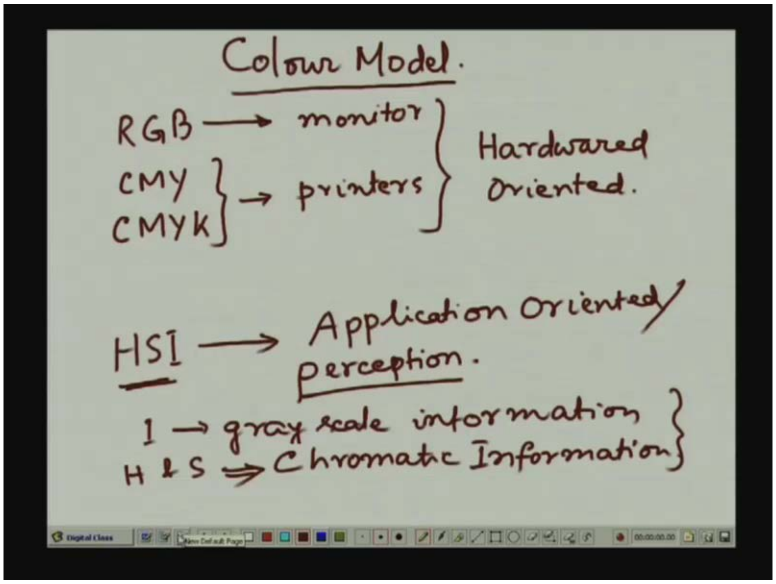

Now, coming to this next topic that is colour model; now we need a colour model to specify a particular colour. A colour model helps us to specify a particular colour in a standard wave. Now, what is a colour model? Colour model is actually a space or we can represent it as a coordinate system within which any specified colour will be represented by a single point.

Now, as we have said that we have 2 ways of describing a colour; one is by using the RGB model by using the red, green and blue components or cyan, yellow and magenta component which are from the hardware point of view and similarly from the perception point of view, we have to consider the hue saturation and brightness. So, considering these 2 aspects, we can generate 2 different colour models, 2 types of colour models. One colour model is oriented towards hardware that is the colour display device or colour scanner device or colour printer and the other colour model is to take care of the human perception aspect and we will see that this is not this will not only take care of the human perception aspect, it is also useful for application purpose.

So accordingly, we can have a number of different colour models. One of the colour model, we will call it as RGB model or red, green blue model and the other colour model is cyan, magenta and yellow and there is an extension of this that is CMYK that is cyan, yellow magenta and black. This RGB colour model, this is useful for image displays like monitor; CMY or CMYK colour model, these are useful for image printers and you find that both these colour models are hardware oriented because both of them try to specify colour using the components as primary colour components either red, green and blue or cyan magenta and yellow and as we have said that red green and blue, they are the primary colours of light whereas cyan magenta and yellow, they are the primary colours of pigments.

And the other colour model that we will also consider is HSI colour model. That is hue, saturation and intensity or brightness and this HSI colour model, it is application oriented or also, it is perception oriented. That is how we perceive a particular colour and we have also discussed that this HSI colour model, this actually decouples the colour from the gray scale information.

So, we have said that this I part, this actually gives you the gray scale information whereas hue and saturation taken together gives you the chromatic information. So because of this, as in HSI model, we are decoupling the intensity information from the chromatic information. So, the advantage that we get is many of the applications or the algorithm which are actually developed for gray scale images, they can also be applied in case of colour images because here, we are decoupling the colour from the intensity.

So, all the intensity oriented, all the algorithms which are actually developed for gray scale images can also be applied on the intensity component or I component of this colour image.

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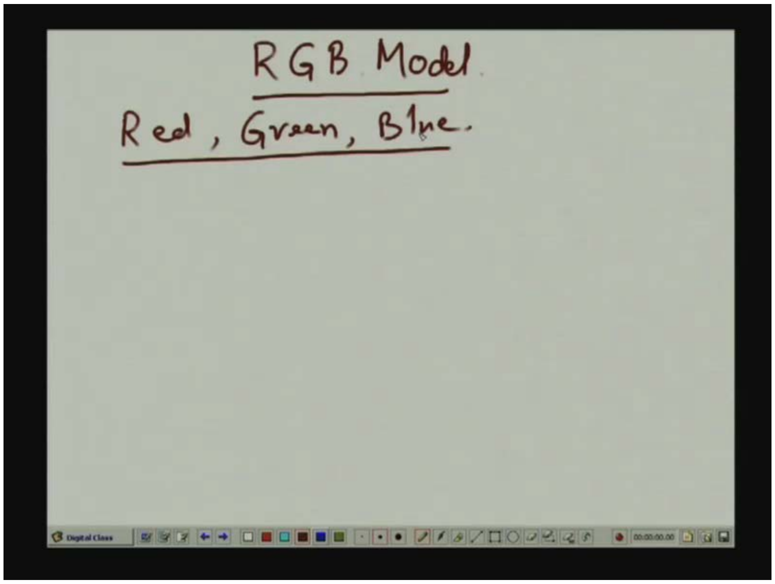

Now first, let us discuss about the RGB model. So, we will talk about RGB colour model first. As we have said that in case of RGB, a colour image is represented by 3 primary components and the primary components are red, green and blue. So, these are the 3 components, 3 colour components which mixed which when mixed in proper form, in appropriate proportion; this generates all possible colours.

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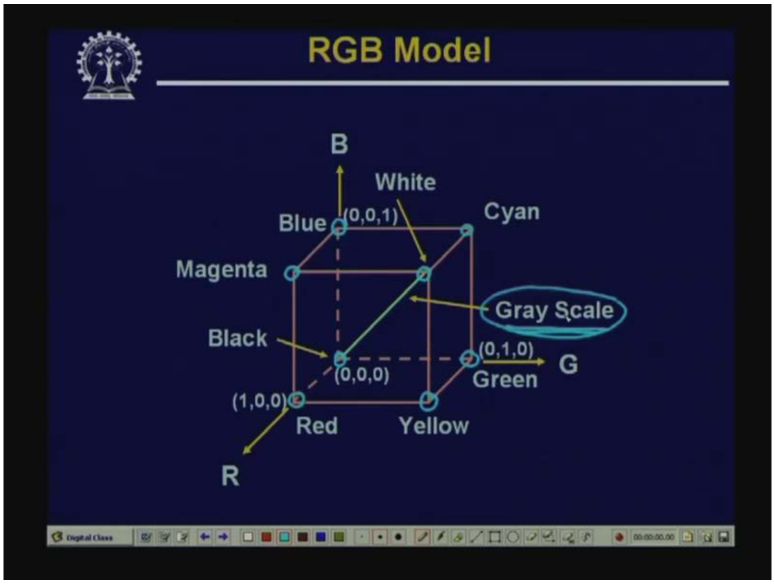

So, our RGB colour model is based on Cartesian coordinate system and we will see in this diagram that this shows diagrammatically an RGB colour model that we normally use. So, you find that this RGB colour model is based on the Cartesian coordinate system where the red, green and blue – R, G and B these components are placed along the coordinate axis. And, the red component is placed at location (1, 0, 0) as shown in this diagram; so this is the location which contains the red, this is the location (0, 1, 0) which contains which is the green point and (0, 0, 1), this is the blue point.

So, we have this red point, green point and blue point; they are along 3 corners of a cube in this RGB, in this Cartesian coordinate system. Similarly, cyan, magenta and yellow, they are at other 3 corners in this scale. Now here, let me mention that this model which is represented, it is in the normalized form. That is all the 3 colour component that is red, green and blue, they are varying within the range 0 to 1. So, all this colour components are represented in a normalized form. Similarly, the cyan, magenta and yellow, they are also represented in normalized form.

Now, the origin of this colour model that is at location (0, 0, 0), this represents black and the farthest vertex that is (1, 1, 1) that represents white and you find if I join a straight line connecting the origin to this white point; so this straight line actually represents a gray scale and we also call it an intensity axis.

So, as you move from the origin which is black to the farthest vertex in the cube which is white, what we will generate is different intensity values. So, as a result of this, we also call it the intensity axis or the gray scale axis. So, we stop our discussions today. We have just introduced today the RGB colour model and we will continue with our discussion in our next class.

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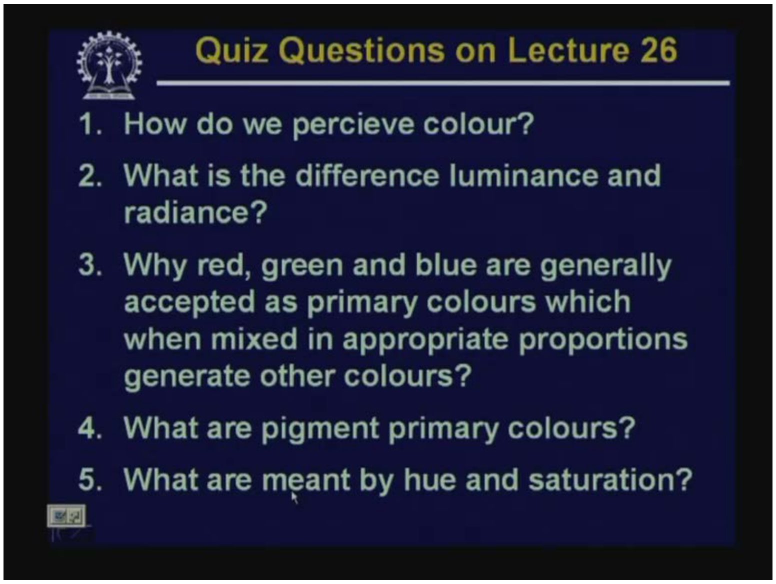

Now, let us have some questions on today's lecture. So, the first question is how do we perceive colour? The second question, what is the difference between luminance and radiance? The third question is why red, green and blue are generally accepted as primary colours which when mixed in appropriate proportions generate other colours? The fourth question, what are pigment primary colours? The fifth, what are meant by hue and saturation?

Thank you.