Characterization of Construction Materials
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Lecture – 48
Image Analysis – Introduction and Image Mapping – Part 1

Hello, everyone. So in our discussions on microscopy, I had talked quite a bit about the importance of interpreting images the correct way. Most of the interpretation is done in a qualitative fashion. We try to understand, for example, when you are looking at cement paste under the scanning electron microscope, we would like to take a look at how widely the phases are distributed, what type of phases are more in number or quantity and so on and so forth.

However, very often, we would like to look at the image and perform some calculations from the image to try and understand the sizes of the features, the shape parameters, and so on and so forth. So the process of looking at the data from the image or extracting data from the image is what is known as image analysis. So, while we appreciate the qualitative differences that may exist between different phases as seen in the microscopic images, it is not easy to always base your interpretation on qualitative differences, very often we need to quantify. For instance, in cementitious matrices, we would like to quantify the extent of porosity in the system or we may want to quantify the extent of unhydrated material still left over in the system. So for all that, we need to actually work through a series of mathematical processes to come up with an estimate of these parameters inside the cement microstructure.

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Image interpretation can be difficult!!

Courtesy: Rajwa, Turek, and Robinson, Purdue University (2007)

So, this chapter in this course will talk primarily about what are the different methodologies and what is the sequence of techniques that is involved in extracting data from an image. But first just to make you appreciate the fact that image interpretation is not something which is easy for everyone, I will just show you some series of images that have been collected by a group of researchers at Purdue University who use it quite frequently in their courses dealing with microscopy and image analysis, just so that you appreciate this a lot better.

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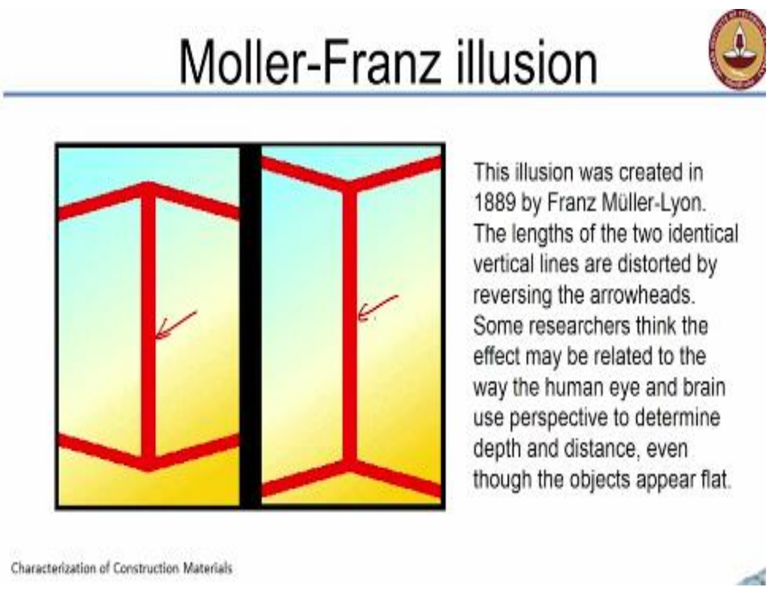

So this is the Moller-Franz illusion. Now, if you look at this picture here, the two vertical lines, many of you may think that they are of different lengths, but in reality, both of them have the same exact length. This is called the Moller-Franz illusion. So again, not all images create illusions obviously in your mind, but images can have different perspectives of looking at them, which may lead to completely different conclusions about them.

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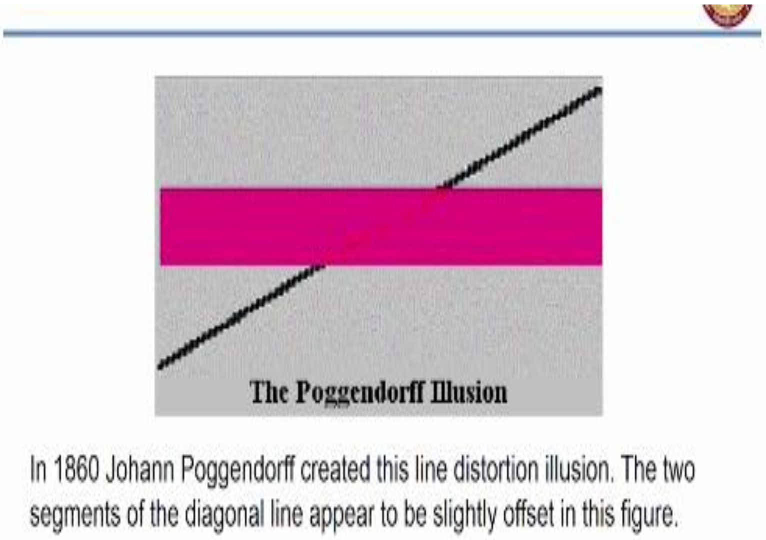

Another example is the Poggendorff illusion, again with a straight line, which is being intercepted by a block. So here, this line is actually continuing right across. It is one single line that goes right across, but because this block is in between, it makes it look as if there are two parallel lines and not just the same line. Now, of course, this is an easier illusion.

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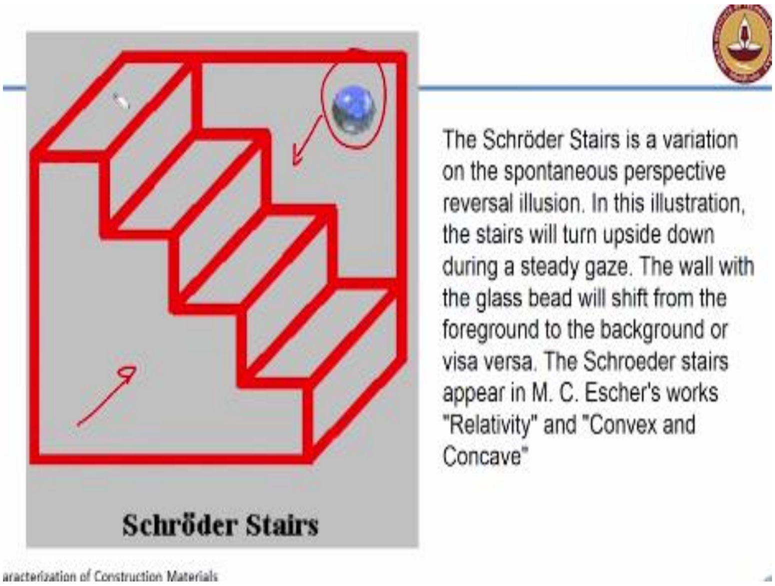

When you look at this Schröder stairs, it is a very crafty design or drawing, which makes you think about how we look at things with different perspectives. Now, if you look at it from this angle here (from top), it is as if you are climbing the stairs like this. You are climbing the stairs in this direction (up the stairs).

But change of perspective to here (from bottom) and it is as if you are looking at the underside of the stairs, like this is the bottom of the stairs that you are looking at, if you just change your perspective.

I do not know if all of you can see that clearly. You need some time to actually look at the image. This is quite easy to imagine - Looking at it from the top, so you are just climbing, this is your first step, second step, third step, fourth step; that is quite easy to imagine. That is the straight perspective. But if you look at it from underneath, try to imagine you are under the staircase and looking up. So you are looking basically at the folded slab staircase from underneath, which is what you will see from the bottom. Look at it in the slides or on the video and you will be able to make out quite easily.

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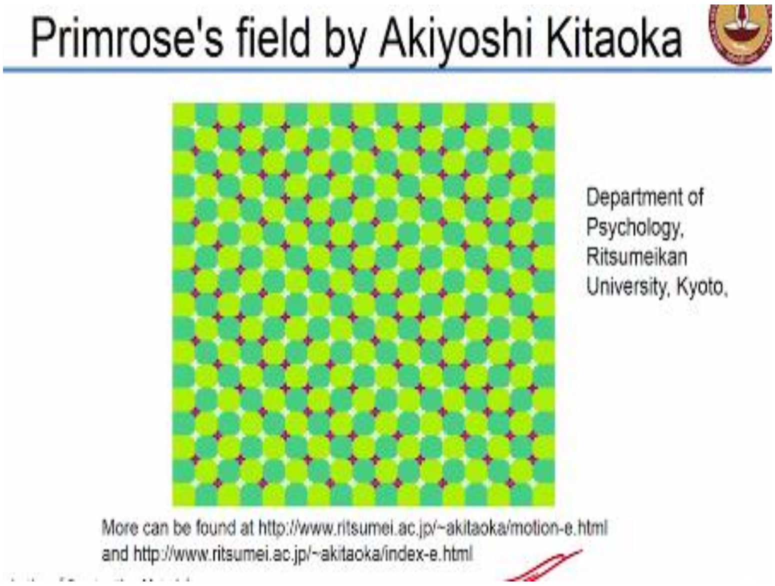

Now, this is something you can obviously see clearly, obviously the image is not moving, but it looks like the green field is sort of getting wavy and so on. That is because of the nature of the elements that have been chosen by Akiyoshi Kitaoka who has actually created this Primrose's field diagram. There are several more examples you can actually see for yourself at certain websites that have been listed here on the slide.

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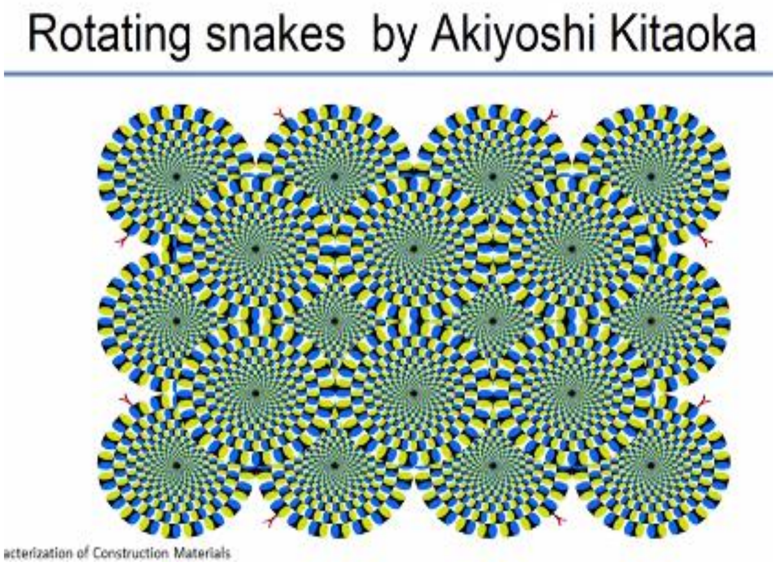

This is again an interesting one by the same person and this is a common one, you may have seen this in other publications also. This is called rotating snakes. So although nothing is moving, but if you look at the image with a certain perspective, we feel like all the circles are rotating.

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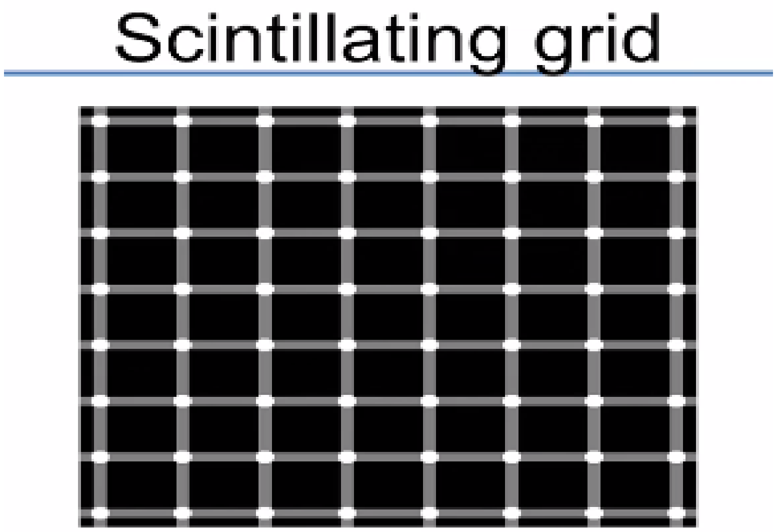

Again another interesting example of how you can make interpretation errors when you have a bright object surrounded by completely dark field. So here, you do not know which one is white which one is black. In truth, all the intersections are white spots, but because of the surrounding area being black, many of these white spots seem to turn on and off. You sometimes feel they are black, sometimes you feel they are white.

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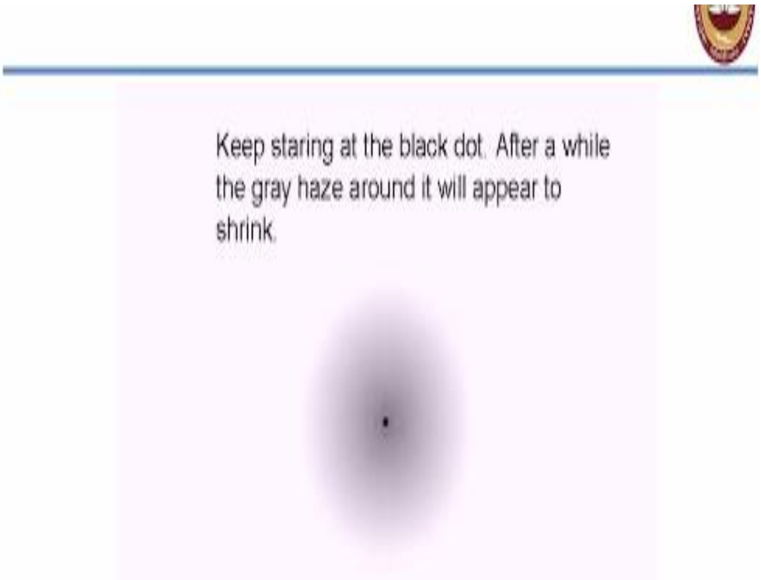

The other illusion here is if you stare at this black dot, because again you have a surrounding which is much whiter, if you keep staring at it, the whiteness, basically the diffraction halo caused by the whiteness will start enveloping the black and probably the dot will disappear. So again, this is all created because our perception of colors and the extent of diffraction that can happen within our eye lenses.

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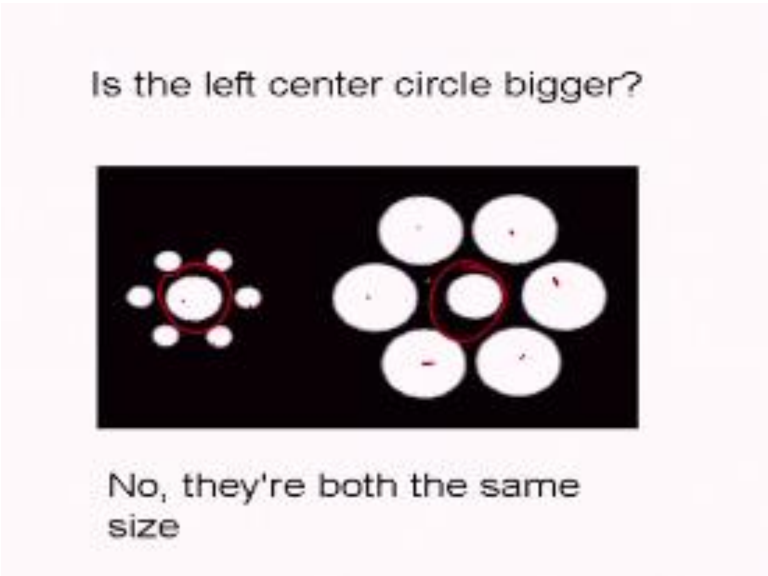

Another example of comparing features in an image. In comparison with the smaller circles here, you can clearly make out this a larger circle okay, but the same thing when you compare it with even larger circles, you start thinking that it is of a different diameter, but actually it is the same size as here. Both are exactly the same size.

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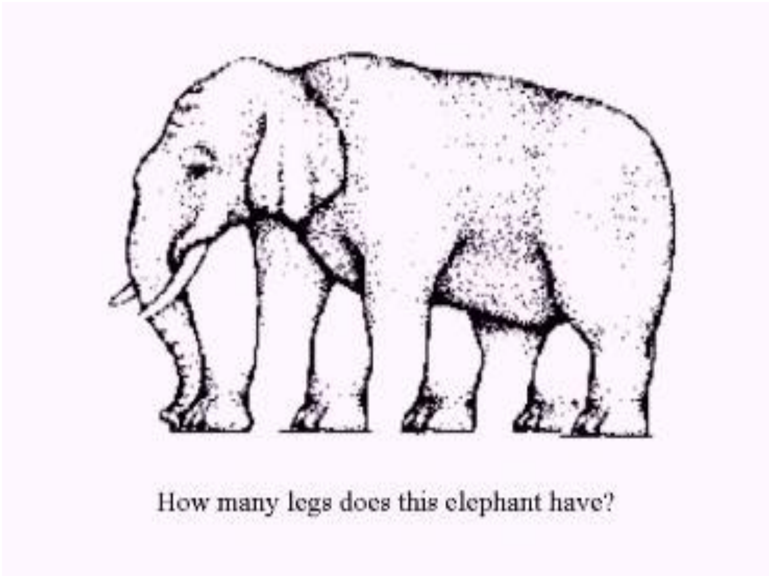

This is a classic one. This elephant has been drawn, but you never know which one is the leg, how many legs it actually has. So you need to appreciate that you can look at images in multiple ways. All you need to do is break the image down into several sequences so that you have an objective way of quantifying the features that you actually see in the image.

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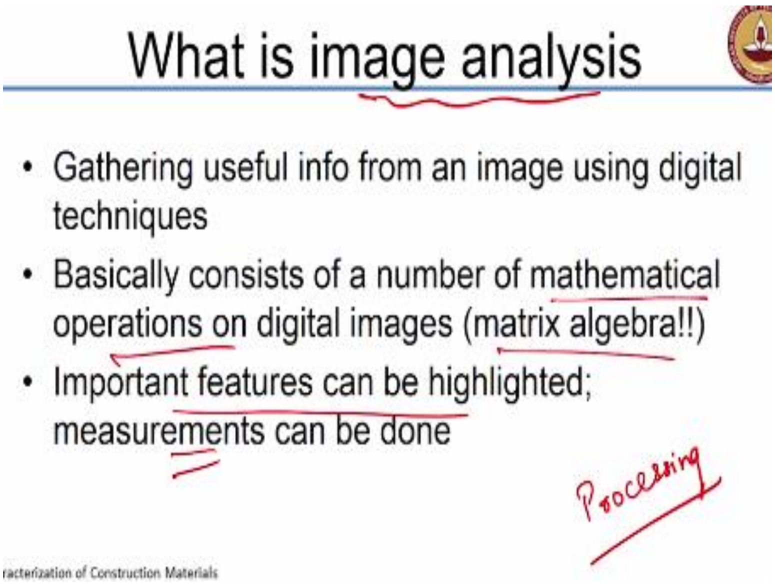

So that is what we are talking about in image analysis. So, gathering useful information from an image using digital techniques. Of course, these days our job is much simpler, because our image capturing is already digitized. In the past, if you remember, you had to actually take the pictures on a screen or on a photograph, you need to scan that photograph and then convert that into a digital image. So all those processes are not necessary these days, you can actually directly take the digital image and do operations on it to get the required data.

So although these operations are performed by certain features in your software, for example, many of you must have used Adobe Photoshop or even Microsoft photo editor for instance, you might have cropped the images, you may have applied some extra contrast to images, extra brightness, and so on. So, all these are actually just done by clicks of the button in the software, but what is happening in the background is a mathematical operation on a digital image, which is nothing but matrix algebra. You are essentially taking the series of pixels that are capturing that image and then performing mathematical operations on those pixels to change the values in the pixels, and I will come back to that in more detail. So essentially, whenever you do any processing or analysis, you are essentially doing matrix algebra and I am sure many of you still remember matrix algebra. There are addition operations, there are multiplication operations, there are converse operations and so on and so forth.

The idea about doing all this is that you can highlight important features and most importantly do measurements on the image and that is the crux of image analysis. If you do not do any measurements, if your aim is to just make the photograph look different and better, that is called image processing. That is what you actually do with your software like Adobe Photoshop or even your basic image processing software, Google Photos also has some features, which helps you edit images and so on. So that is basically image processing, you are not really doing image analysis until you are doing measurements on the image.

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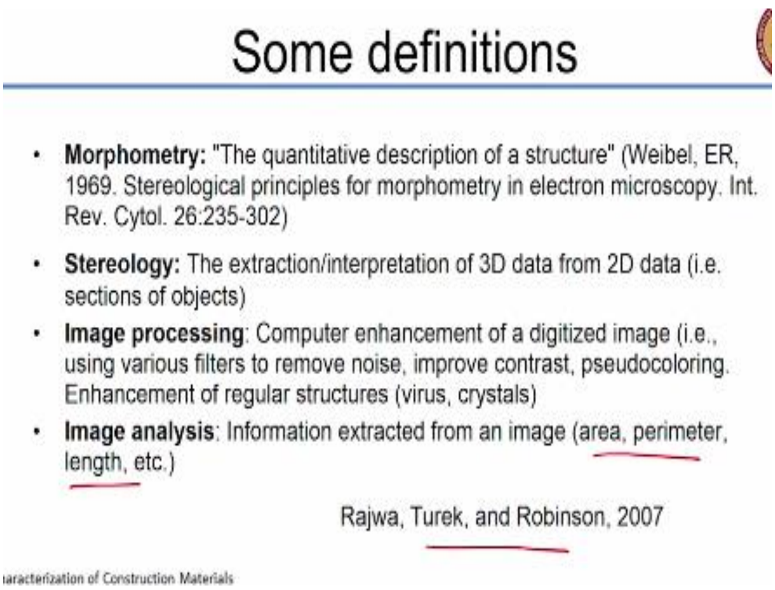

Now, some definitions are given here, again from the same set of authors who had given those examples of those interesting images. So you have morphometry on one hand, which is basically quantitative description of a structure. ‘Morph’ obviously means structure, ‘metry’ means some sort of quantification - morphometry.

Stereology is nothing but extraction or interpretation of 3D data from 2D data. Now that is very important, because we are always looking at images in 2D, we do not have all our imaging assessments done on 3D images, we have 2D images, which we need to recreate into a three dimensional information about the material or the object or the phenomenon. So that is basically stereology.

Then you have image processing, which is nothing but computer enhancements of a digitized image that is using filters to remove noise. We also saw that they could use filters earlier to narrow the wavelength, so that we transmit only a certain wavelength through and that improves the resolution to some extent. All that is part of your processing technique. Improving contrast, pseudocoloring, which means you select certain phases and apply a color to it for instance, and enhancement of regular structures, like if you are looking at microscopic images of viruses and crystals, you can enhance the sharpness and so on and so forth. So that is basically your image processing.

Image analysis on the other hand, you are trying to get area, perimeter, length, and other such features of the object that define the characteristics. For example, you are looking at a crystal, you would like to understand what the long dimension of the crystal is, what the cross sectional area of the crystal is and so on. So, those are part of image analysis.

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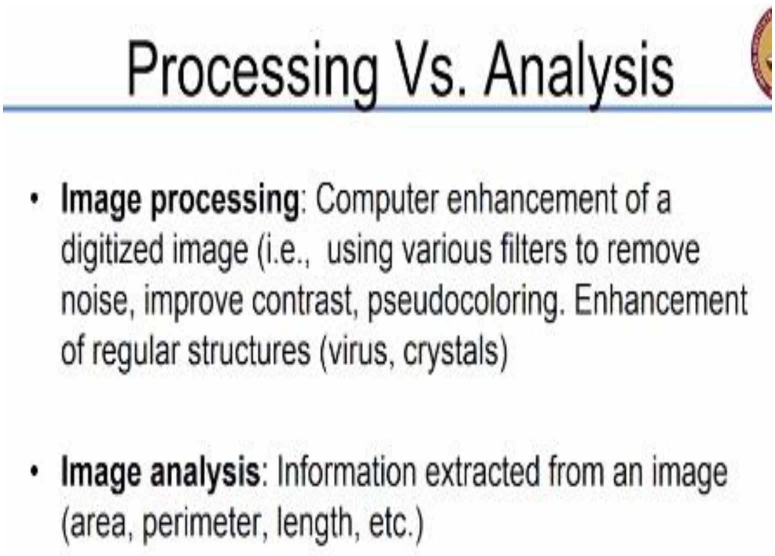

So, again just to recapture processing versus analysis - you have computer enhancement as image processing, whereas information extraction from the image that is image analysis.

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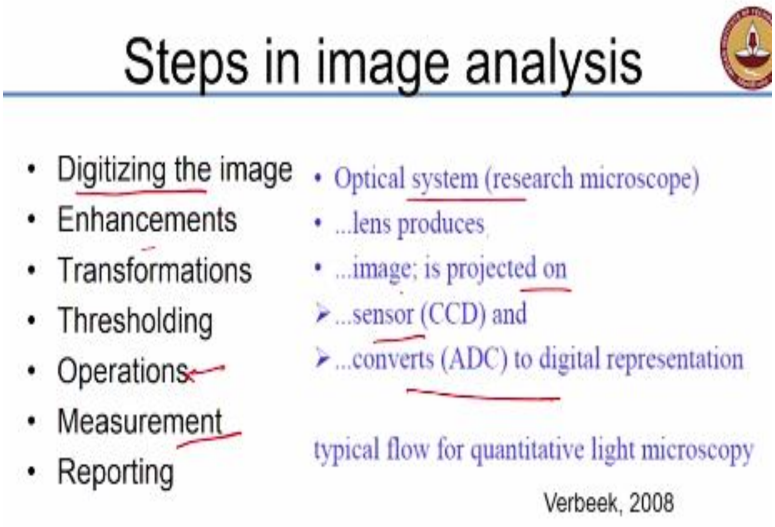

So, what are the steps in image analysis? First and foremost is to digitize the image and as I said earlier, digitizing today is a very easy phenomenon. Whatever pictures you take with your mobile camera or with your other sophisticated cameras or even on your computer directly taking images, those are basically already digitized. Next is to do enhancements, just to make sure that the image has the right degree of clarity for you to understand it. The next process is transformations. So transformation ensures that you can transform the image in a certain way so that you can extract a lot of information from it.

That is followed by thresholding. I will go through the sequence of operations later when we actually take the use of examples. Thresholding means you set up certain thresholds for the levels of gray that are exhibited by your image and set objects which are above the gray level to a certain color, whereas below the gray level is another color. So, if you do a binary thresholding, you convert every object in your image to either white or black, but you need to select the specific threshold below which everything is black. For example, we have porosity in cementitious matrices. So porosity can be turned completely black and the non-porous region or the solids can be turned completely white, that is binary thresholding. But you will see later that cement paste has several degrees of gray. So, you can do multiple thresholds to actually quantify the extent of phases present in the cementitious paste.

The other thing is after thresholding, you can do operations to the features in the object. For example, if there are irregular looking features, through some operations, you can actually convert this into a smoother circular feature for instance. Why does it help? Measurement becomes much easier. If it is a circle, you can measure a diameter and area. So all you are doing is converting an irregular image to a circular image or sometimes you may actually see some artifacts in the image. You might see black spots where you do not expect there to be black spots because of either specimen preparation or the way that the image has been captured. What you then do is you take the surrounding area and fill that up into the location where you do not expect the porosity to be there. So that is called a hole filling operation. So you are filling up holes, which you do not expect to find in the image okay, so that is hole filling - that is also one type of operation that you can do.

And of course, next is measurement, because you can actually convert your features or count the number of features also, that is also a measurement. For example, count the number of white spots in the image, so that is an example of a measurement. And then you have reporting, of course, ultimately everything has to be reported as to how you interpret the image and what kind of data you are capturing from the image

So again, just to give an example from an optical microscopy study, in an optical lens or optical microscope system, the lens produces an image which is projected on the sensor, which is a charge coupled device (CCD), basically that is nothing but your camera. And using an analog to digital converter (ADC), it converts the image to a digital representation that is shown on your computer screen. So this is a typical flow of image analysis for quantitative light microscopy or optical microscopy.

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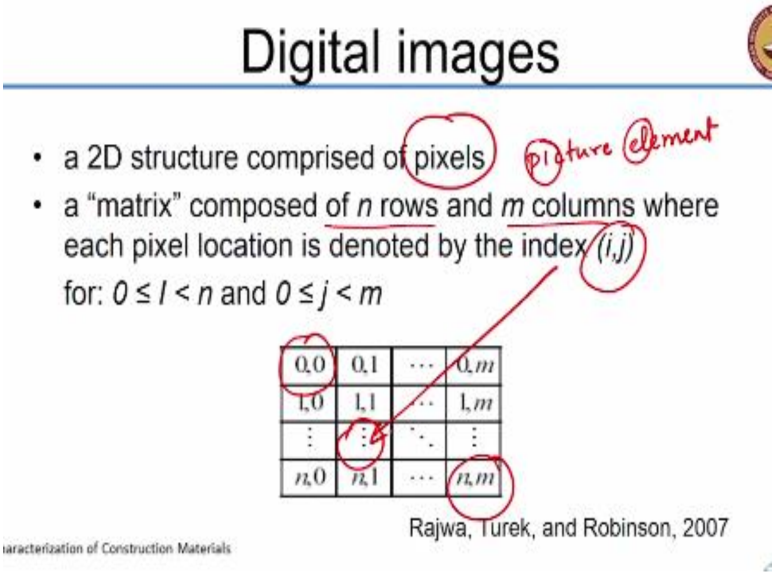

So, what are digital images? Now this is something that you know of, when you buy your mobile phones everybody claims that they have 13 MP cameras or 5 MP cameras. These are basically 13 million pixels. So, your image is described by a 2-dimensional matrix, a 2D structure, which is comprised of what we call us pixels. What is the full form of pixel? It is nothing but picture element. So pic-el, so that makes it pixel. A pixel is nothing but a picture element. So, this picture element or pixel is the smallest unit of your digital image. So, you have a 2D structure comprised of pixels.

The image is represented as a 2D matrix which is composed of n rows and m columns where each pixel is denoted by the index (i,j). This is just a matrix from $(0,0)$ to (n,m) and any particular instance you can select, some value for that pixel will be denoted, either in terms of color or in terms of gray level. When you go from one monitor to the other, the color specs keep changing. Each new monitor comes up with more wide variety of colors, the TFT monitors they have 16 or 24 million colors, sometimes that is what they say. All they are doing is basically representing the image with multiple color combinations. So eye perceives other colors in terms of what can be resolved by the eye, right? But sometimes when you look in computer screens, the image that you see of an object that you actually naturally see can be sometimes looking quite different. The colors may be a lot sharper in the image that you actually observe on the TFT screen, for instance. That happens because each pixel can be given color values that are ranging between large numbers. So, higher the resolution or the more number of colors that are possible in a particular screen, shows the ability of that screen to actually show the image in very sharp clarity. So, the more the number of pixels, the greater obviously will be the clarity if you can break down your image into several pixels.

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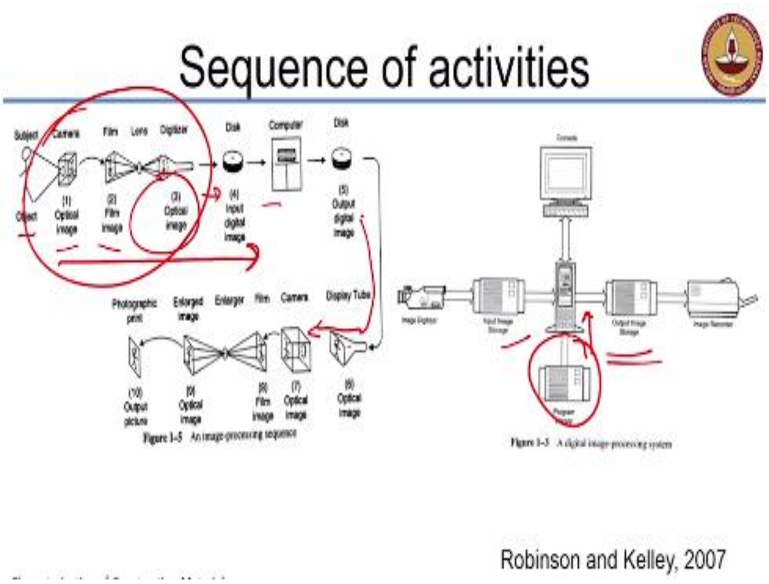

Now, again, this is just recounting the sequence of activities. You have the object which is being captured using the camera. You produce an optical image. The image is transformed into a film. The film comes through a digitizer to the disk and to the computer. Of course, all these steps are now single; you can directly take a digital image of the object and transform it to an output digital image. So this is a process where this digital image is actually taken for a print. But ultimately what we are doing with respect to image processing system is that we take the input image storage. We have the program library, which does the operations on the image and then we have the output image, which is basically nothing but a processed and analyzed version of this image that goes in. So, all these processes of multiple steps in between have now been simplified because of the use of digital sources of photography.

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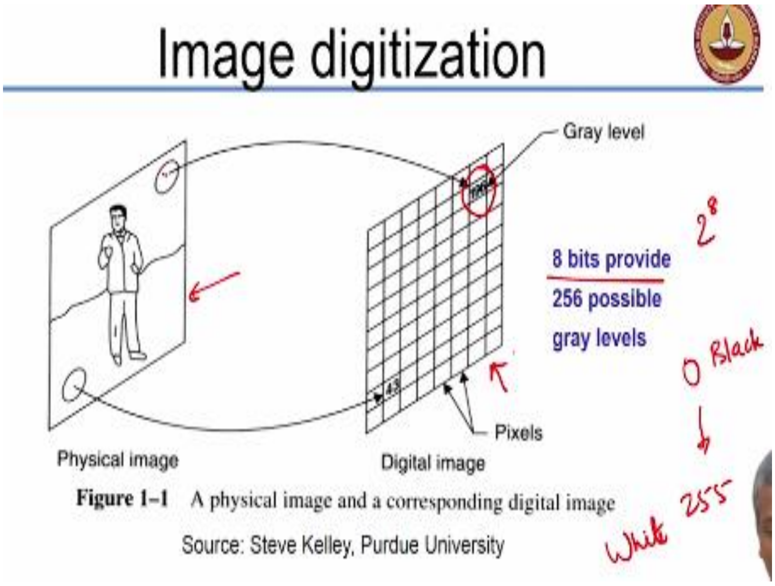

So, what is image digitization? For example, you have this picture here on the left, that is a physical image. So each and every aspect on the picture gets a certain value in the matrix that describes your pixels. Now, of course in this case, the matrix is a black and white image. So that is why each spot in the image gets a gray level. So, as far as a black and white image is concerned or a gray level image is concerned, you have 8 bits. Typically, these are 8 bit images, that means there are 2^8 possible levels of gray. If there is a single bit image, what are the 2 levels possible = 2^1, you have either black or white. So the case of a gray level 8 bit image, you have 2^8 possible gray levels. The smallest gray level is 0 and the highest gray level is 255, where 0 represents black and 255 is white and all the levels in between 0 and 255 are various levels of white if you are going in the ascending order or various levels of black if you are coming in the descending order.

So this is your digital image, which is nothing but your *n* x *m* pixels and each cell in the matrix has a certain value, which corresponds to the gray level of that location in the image. So even if you take a color picture, you can actually transform that into a gray level image and then digitize the gray level image. However, you can also do color operations, but then please remember, when you are trying to do a color operation, your number of colors and the number of bits for the resolution that you have, may make the combinations that are possible to be extremely large and processing those images will require major computing power. It is not easy to do that. So, if you have multiple combinations possible, if you have 16 million colors that are possible for instance, then that gives you a wide range of possibilities in terms of your representation of the image, but then the processing time on the computer becomes very cumbersome. So you want to operate on images that are easy to understand because you can break down into phases, which could measure using the images that have been provided.