Digital Image Processing

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Lecture – 4

Pixel Relationships

Hello, welcome to the video lectures series on Digital Image Processing. Till the last class, we have talked about the image digitization process and we have seen that there are 2 steps involved for digitization of an image.

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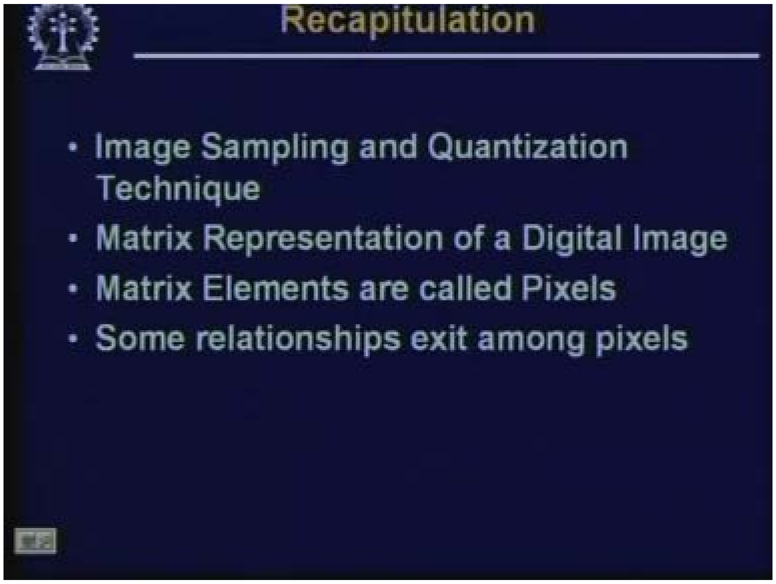

The first step is image sampling in which case instead of taking the possible intensity values at every possible location in the image; we think of, we take the pixels values or intensity values at some discrete locations in the 2 dimensional space and this is the process that we call as image sampling.

After sampling, what we get is some discrete set of points and at those discrete set of points, we get the sample values and the sample values or the intensity values at those discrete set of points are analog in nature.

So, the final step of digitization of image of an image is the quantization in which case those analog sample values are quantized to one of the discrete levels and depending upon the number of levels that we choose, the number of bits needed to represent each and every sample value is different.

So in general, what is used is 8 bits for digitization or quantization of every sample value. So, if it is a black and white image or a simple grey label image; then power point or power pixel we have 8 bits whereas, if it is a color image and we know that in case of color image, there are 3 different planes - the red plane, green plane and blue plane. For each of these different planes, every point is represented by 8 bits.

So, for a color image, normally we have 24 bits for every pixel; whereas for a grey level image or black and white image, we have 8 bits per pixel. So, after digitization, what we have found is that an image is represented in the form of a matrix or a 2 dimensional matrix which we call a digital image and each of the matrix elements are is now called a pixel.

Now, when we represent the image by a matrix and the different points are called pixels, then it is found that some important relationships exist among those pixels. And in today's lecture we will try to find out what are the different important relationships that exist among different pixels of an image.

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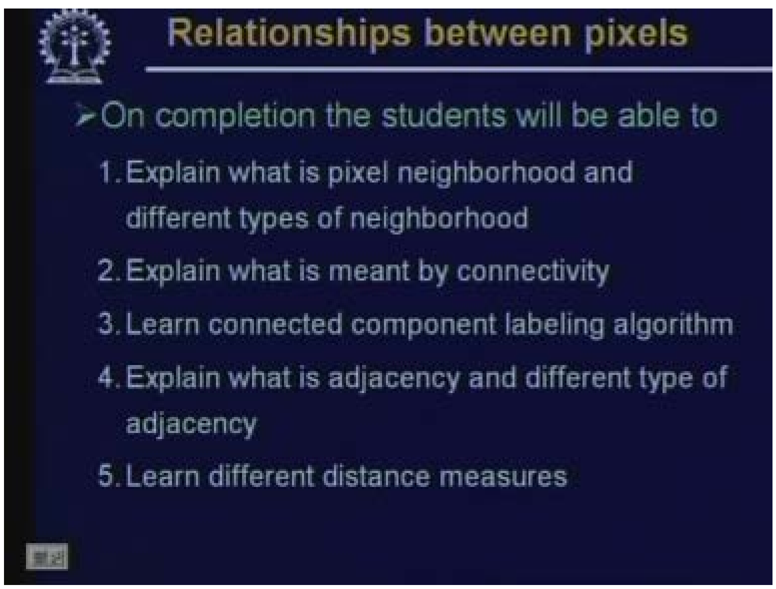

So, in today's lecture, we will try to see that what are the relationships that exist among the pixels of an image and among these relationships, the first relationship that we will talk about is the neighborhood and we will also see that what are different types of neighborhood of a pixel in an image.

Then we will also try to explain that what is meant by connectivity in an image. We will also learn the connected component labeling algorithm, the importance of this connected component labeling algorithm and the properties that is connectivity, we will discuss about later. We will also explain what is adjacency and will see what are the different types of adjacency relationships.

Then we will also learn different distance measures and towards the end of today lecture, we will try to find out what are the different image operations. We will try to see what are pixel by pixel operations and what are the neighborhood operations in an image. So, as we say that the first relationship is the pixel relationship or the neighborhood relation.

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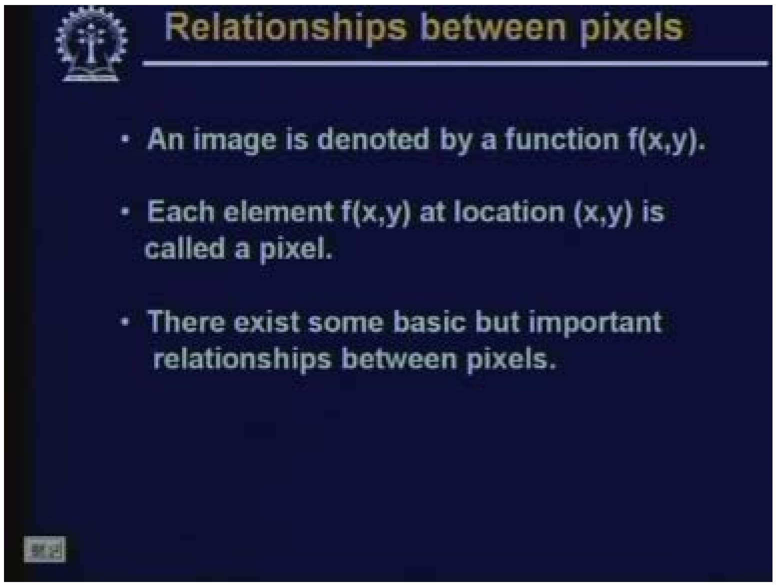

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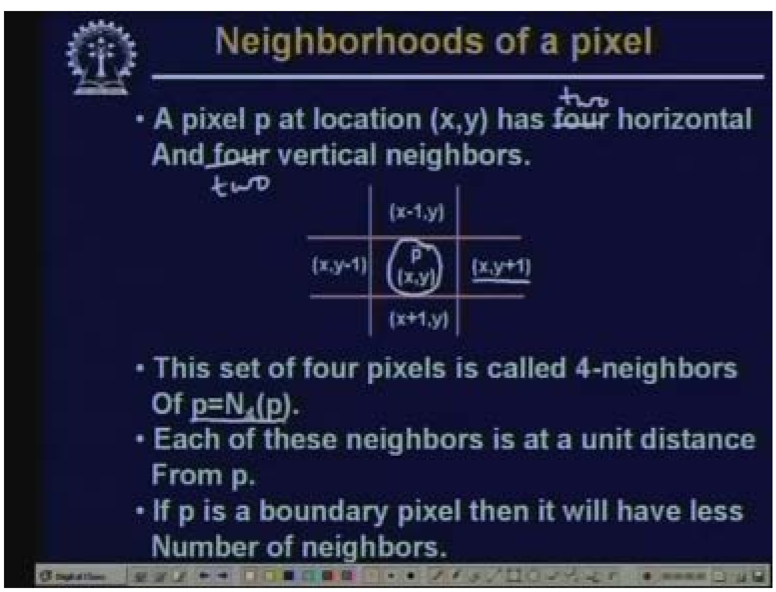

Now, let us first try to understand that what is meant by neighborhood. We say that the people around us are our neighbors or we say that a person who is living in the house next to mine is my neighbor. So, it is the closeness of different persons which forms the neighborhood of the person. So, it is the persons, who are very close to me, they are my neighbors.

Similarly, in case of an image also, we say that the pixels are neighbor if the pixels are very close to each other. So, let us try to see formally what is meant by neighborhood in case of an image pixel. Here, let us consider a pixel at location a pixel p at location x y; as shown in this middle pixel.

Now, find that because the image in our case is represented by a 2 dimensional matrix; so the matrix will have a number of rows and a number of columns. So, when I consider this pixel p whose location is x y that means the location of the pixel in the matrix is in row number x, in row x and in column y. Obviously, there will be a row which is just before x that is row x minus 1, there will be a row just after the row x which is row x plus 1. Similarly, there will be a column just before the column y that is column y minus 1 and there will be a column just after column y which is column y plus 1.

So, come back to this figure. Coming to this particular pixel p which is at location x y, I can have 2 different pixels. One is in the row just above row x, other one is in the row just below row x but in the same column location y. So, I will have 2 different pixels. One is in the vertically upward direction, the other one is in the vertically downward direction. So, these are the 2 pixels which are called the vertical neighbors of point p.

Similarly, if I consider the columns, there will be a column pixel at location x i minus y minus 1 that is in row number x, column number y minus 1. There is a pixel x and y plus 1 that is row number x and column number y plus 1. So in this case, these are the 2 pixels which are the horizontal neighbors of the point p. So, in this case these are not 4, rather this should be 2. Here, this will also be 2. So, this pixel p has 2 neighbors in the horizontal direction and 2 neighbors in the vertical direction.

So, these total 4 pixels are called 4 neighbors of the point p and is represented by p equal to and is represented by N_4 (p). That is these pixels are 4 neighbors of the pixel p or point p. Each of these neighbors; if you find out the distance between these neighboring pixels, you find that each of these neighbors is at a unit distance from point p. Obviously, if p is a boundary pixel, then it will have less number of neighbors. Let us see why?

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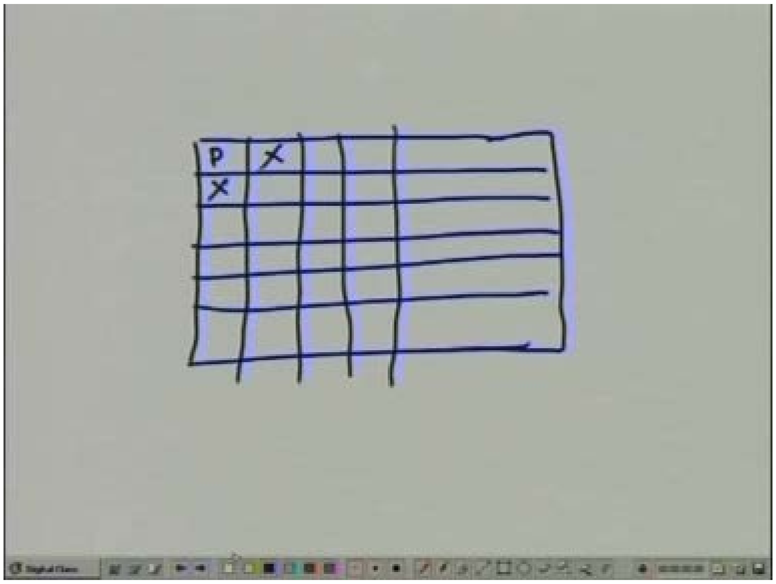

So, I have a 2 dimensional image where this image is represented in the form of a matrix. So, I have pixels in different rows and pixels in different columns. Now, if this pixel p, if the point p is one of the boundary pixels say I take this corner pixel; then as we said that for a pixel p usually there are 4 different pixels taken from a row above it, a row below it, the column before it and the column after it.

But when I consider this particular pixel p, this pixel p does not have any pixel in the row above this pixel; it does not have any pixel in the column before this particular column. So, for this particular pixel p, I will have only 2 neighboring pixels. One is in this location, the other one is in this location which are part of 4 neighbors or N_4 (p).

So, find that for all the pixels which belong to the boundary of an image, the number of neighboring pixels is less than 4. Whereas for all the pixels which belong to which is inside an image, the number of neighborhood pixels is equal to 4. So, this is what is the 4 neighborhood of a particular pixel.

Now, as we have done, as we have taken the points from vertically upward direction and vertically downward direction or horizontally from the left as well as from right; similarly, we can find that there are 4 other points which are in the diagonal direction. So, those points are here.

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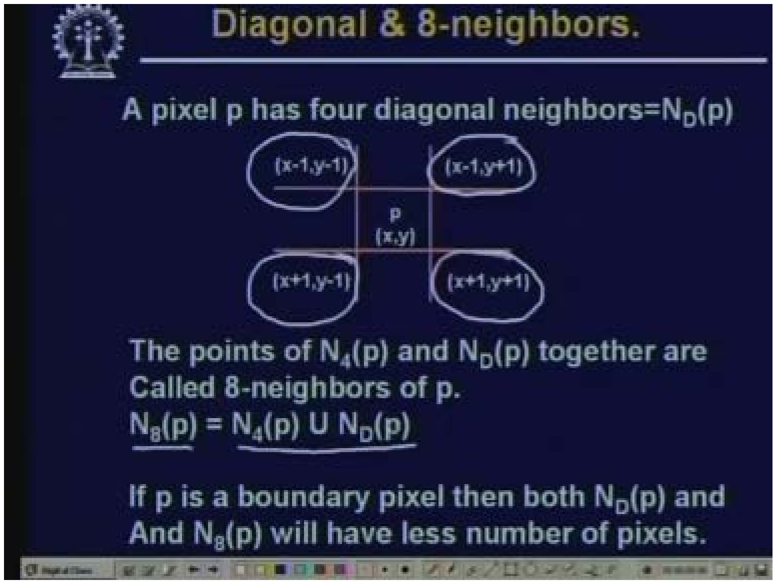

Again, I consider this point p at location x y. But now if I consider the diagonal points, you find that there are 4 diagonal images, there are 4 diagonal points. One at location x minus 1 y minus 1, the other one at location x plus 1 y plus 1, one at location x minus 1 y plus 1 and the other one is at location x plus 1 and y minus 1.

Now, we say that these 4 pixels because they are in the diagonal direction; these 4 pixels are known as the diagonal neighbors of point p and it is represented by N_D (p). So, I have got 4 pixels which belong to N_4 (p) that is those are the 4 neighbors of point p and I have got 4 more points which are the diagonal neighbors are represented by N_D (p).
Now, I can combine these 2 neighborhoods and I can say an 8 neighborhood. So, again coming back to this, if I take the points both from N_4 (p) and N_D (p), they together are called 8 neighbors of point p and represented by N_8 (p). So obviously, this N_8 (p) is the union of N_4 (p) and N_D (p).

And naturally, as we have as we have seen in the previous case that if the point p belongs to the boundary of the image, then N_D (p) - the number of diagonal neighbors of the point p will be less than 4. Similarly, the points belongs to N_8 (p) or the number of 8 neighbors of the point p will be less than 8. Whereas, if p is inside an image, it is not a boundary point; in that case, there will be 8 neighbors - 4 in the horizontal and vertical directions and 4 in the diagonal directions. So, there will be 8 neighbors of point p if point p is inside an image. So, these are the different neighborhoods of the point p.

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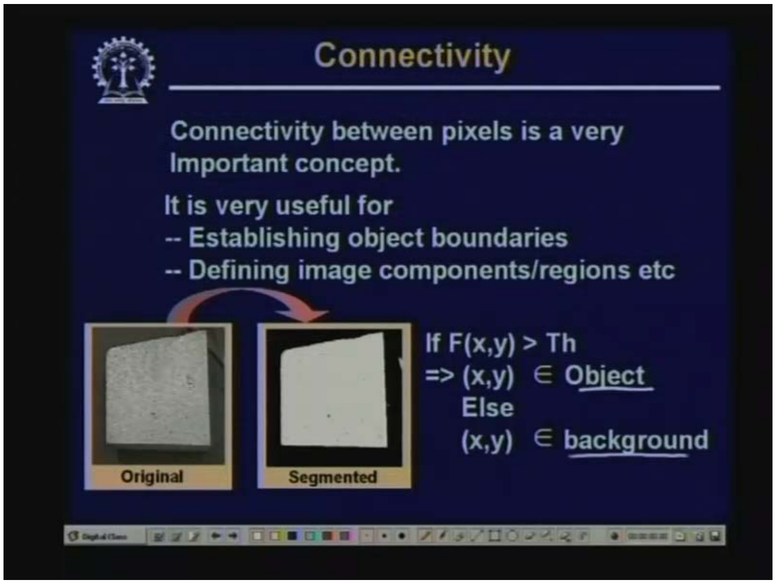

Now, after this we have another property which is called as connectivity. Now, the connectivity of the points in an image is a very very important concept which is used to find out the region property of an image or the property of a particular region within the image.

You recollect that in our introduce lecture, we have given an example of segmentation. That is we had an image of certain object and we wanted to find out the points which belong to the object and the points which belong to the background. And for doing that, we had used a very very primitive operation called the thresholding operation.

So here, in this particular case, we have shown that if the intensity value or if x y at a particular point x y is greater than certain threshold say Th; in that case we decided that the point x y belongs to the object. Whereas, if the point or the intensity level at the point x y is less than the threshold; then we have said, we have decided that the point x y belongs to the background.

So, by simply by performing this operation and if you represent every object point as a white pixel or assign a value 1 to it and every background pixel as a black pixel or assign a value 0 to it; in that case, the type of image that we will get after that the thresholding operation is like this.

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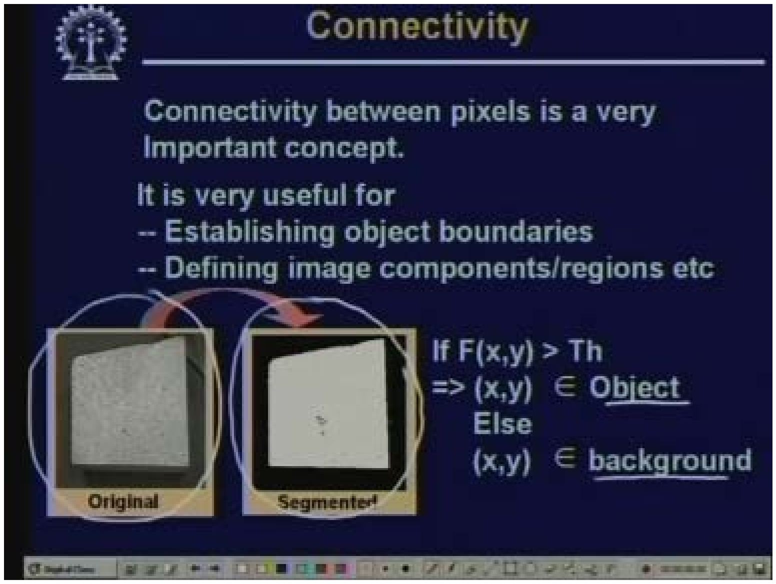

So, here this is the original image and you find that for all the points which belong to the object, the intensity value is greater than the threshold. So, the decision that we have taken is these points belong to the object, so in case of segmented image or the thresholded image; we have assigned a value 1 to each of those image points. Whereas, in other regions, say region like this; we decided that these points belong to the background. So, we have assigned a value 0 to these particular points.

Now, just by performing this operation, what we have done is we have identified certain number of pixels, the pixels which belong to background and the pixels which belong to the object. But just by identification of the pixels belonging to the background, I cannot or the pixels belonging to the object, I cannot find out what is the property of the object until and unless I do some more processing to say that those pixels belong to the same object. That means I have to do some sort of grouping operation. Not only this, I can have a situation like this.

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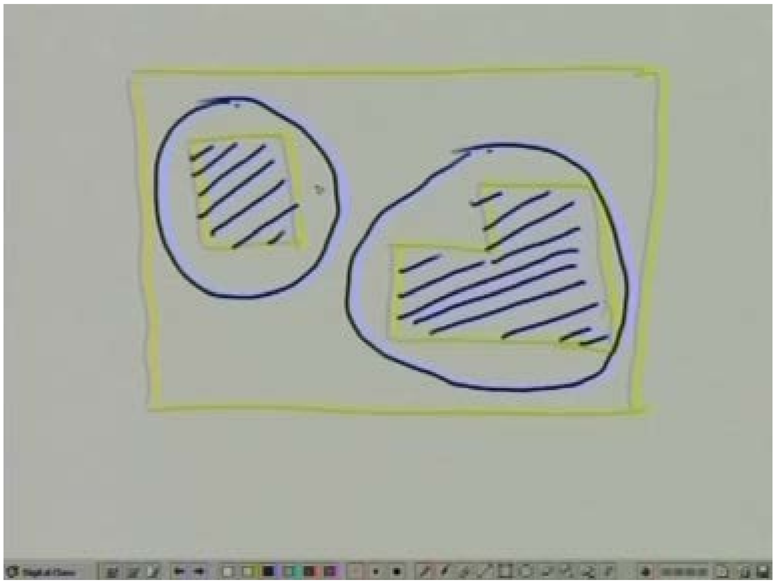

Say for example, I have in this entire image, 2 different objects; one object may be in this location and another object may be say somewhere here. So, just by using this thresholding operation, what I have done is I have decided that all the pixels in this region will get a value 1, all the pixels in this region will also get a value 1. So, both these 2 sets of pixels, they belong to the object.

But here, our solution does not end there. We have to identify that a set of pixels or this particular set of pixels belong to one object, this particular set of pixels belong to another object. They do not belong to the same object. So for this, what is needed is I have to identify that which pixels are connected and also I have to identify which pixels are not connected.

So, I will say that the pixels having value equal to 1 which are connected, they belong to one region and another set of pixels or points having value equal to 1 but not connected to the other set, they belong to some other object.

So, this connectivity property between the pixels is a very very important property and using this connectivity property; we can establish the object boundaries, we can find out what is the area of the object and likewise we can find out many other properties of the object or the descriptors of the object which will be useful for further high level processing techniques where we will try to recognize or identify a particular object. So, now let us try to see that what is this connectivity property? What do we mean by connectivity?

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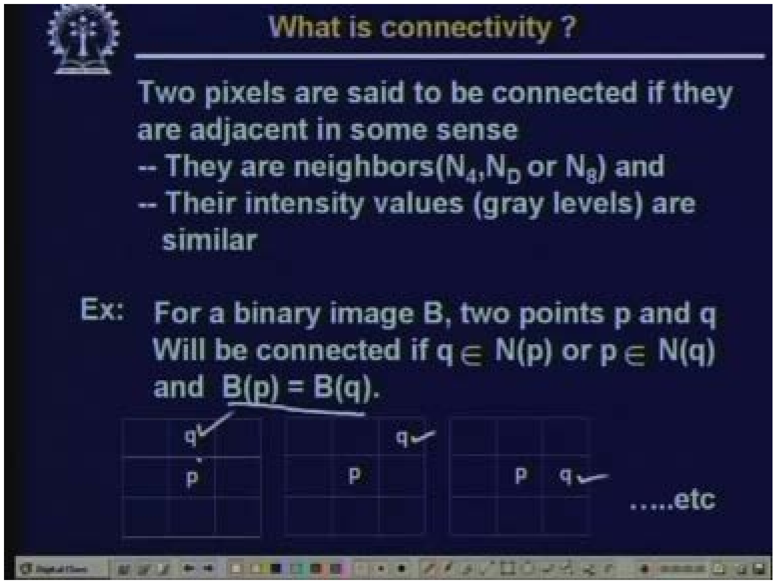

We say that 2 pixels are connected if they are adjacent in some sense. So, this term - some sense is very very important. So, this adjacent means that they have to be neighbors. That means one pixel, if i say that 2 pixels 2 points p and q are connected; then by adjacency, we mean that p must be a neighbor of q or q must be a neighbor of p. That means q has to belong to N_4 (p) or N_D (p) or N_8 (p) and in addition to this neighborhood, one more constant that has to be put is that the intensity values or the gray levels of the 2 points p and q must be similar.

So, let us take this example. Here, we have shown 2 3 different situations where we have taken points p and q. So, here you find that point q, it belongs to the 4 neighborhood of point p; here point q belongs to the diagonal neighborhood of point p, here again point q belongs to the 4 neighborhood of point p. And in this case, we will say that point p and q are connected. Obviously, the neighborhood restrictions holds true because q and p, they are neighbors and along with this, we have said that another restriction or another constant must be satisfied that their intensity values must be similar.

So, in this particular case, because we are considering a binary image; so we will say that if q belongs to the neighborhood of p or p belongs to the neighborhood of q and the intensity value at point p is same as the intensity value at point q, so because it is binary image, this value will be either 0 or 1.

So in this case, if I assume that if the pixels have value equal to 1, then we will assume that those 2 pixels to be connected. So in this case, if for both p and q, the intensity value is equal to 1 and since they are the neighbors, so we will say that points p and q are connected.

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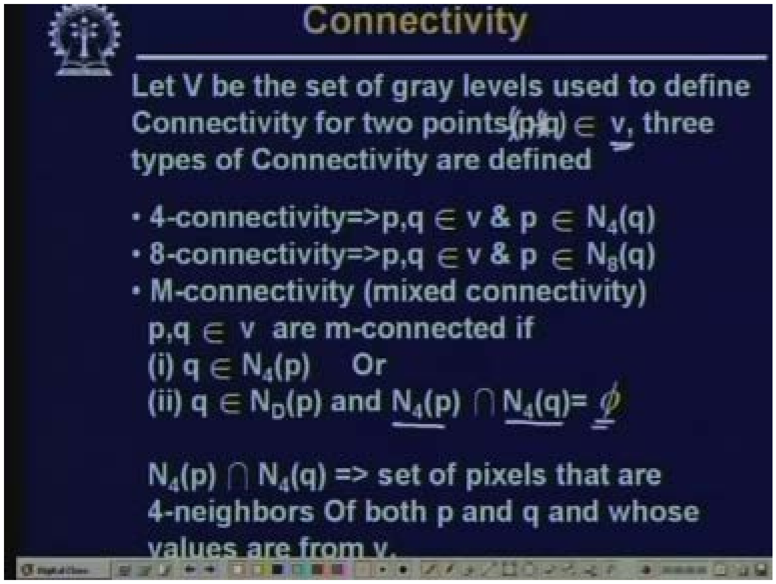

Now from this, connectivity can be defined in a more general way. So, the earlier example that we have taken is the connectivity in case of a binary image where the intensity values are either 0 or 1. This connectivity property can also be defined in case of gray level image. So, how do we define connectivity in case of a gray level image? In case of a gray level image, we define a set of gray levels.

Say for example, in this case, we have defined V to be set of gray levels which is used to define the connectivity of 2 points p and q so that if intensity values at points p and q belongs to the set V. So, this is not point p by p and q but the intensity values are fp and fq.

So, the if the intensity values at the points p and q, belong to set v and points p and q are neighbors; then we will say that points p and q are connected and here again, we can define 3 different types of connectivity, one is 4 connectivity. That is in this case, the intensity values at p and q must be from the set v and p must be a 4 neighbor of q or q must be a 4 neighbor of p; in that case, we define 4 connectivity.

Similarly, we define 8 connectivity if the intensity values at point p and q belong to the set v and p is an 8 neighbor of q or q is an 8 neighbor of p. There is another type of connectivity which is defined which is called M connectivity or mixed connectivity. So, in case of M connectivity, it is defined like this that p and q, the intensity values at points p and q; obviously, they have to be from the same set of v and if q belongs to neighborhood or p or q belongs to N_D (p) that is diagonal neighborhood of p and N_4 (p) intersection with N_4 (q) is equal to phi.

So, this concept extends or put some restriction on the 8 connectivity in the sense that here we say but either q has to be a 4 neighbor of p or p has to be a 4 neighbor of q or q has to be a diagonal neighbor of p. But at the same time, N_4 (p) intersection with N_4 (q) must be equal to phi and you find that this N_4 (p) intersection with N_4 (q), this indicates the set of points which are 4 neighbors of both the points p and q.

So, this says that if the point q belongs to the diagonal neighbor of p and there is a common set of points which have 4 neighbors to both the points p and q; then M connectivity is not valid. So, the reason why this M connectivity is introduced is to avoid some problems that may arise with simple 8 connectivity concept. Let us see what are these problems.

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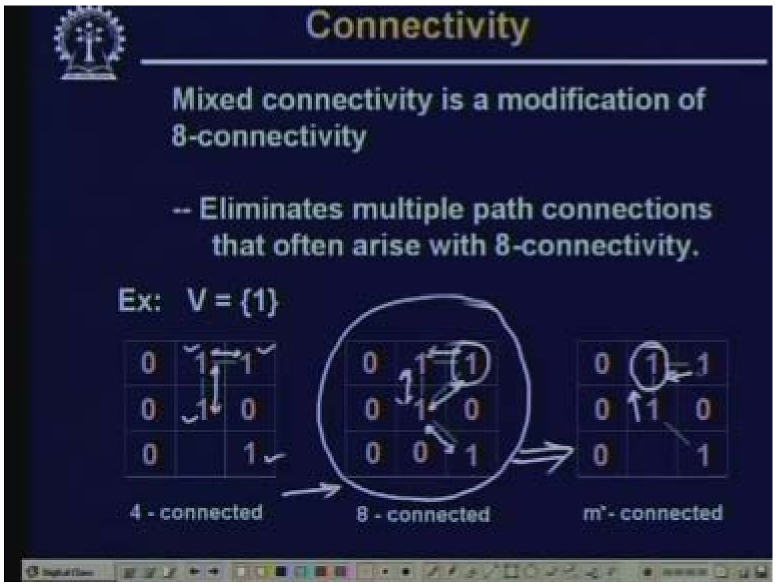

So, the problem is like this. Here again, we have taken the example from a binary image and in case of a binary image, we say that 2 points may be connected if the values of both the points equal to 1. So, set V contains a single intensity value which is equal to 1. Now, here we have depicted one particular situation where we have shown the different pixels in a binary image. So, find that if I consider this point at the middle of this image which is having a value 1, there is one more pixel on the row above this which is also having a value 1 and a diagonal pixel which is having a value 1 and a diagonally downward pixel which is also having a value equal to 1.

Now, if I define 4 connectivity; then you find that this point is 4 connected to this point, this point is 4 connected to this point because this particular point is member of the 4 neighbor of this particular point, this point is the member of 4 neighbor of this point. But by 4 connectedness, this point is not connected because this is not a 4 neighbor of any of these points.

Now, from 4 connectivity, if I move to 8 connectivity; then what I get? Again, I have the same set of points. Now, you find that we have defined 8 connectivity to be a union of or 8 neighborhood to be a union of 4 neighborhood and diagonal neighborhood. So, because this is union of 4 neighborhood and diagonal neighborhood, so I will have set of points which are connected to 4 neighbors. I will also have set of connections or set of points which are connected through diagonal neighbors.

So, as shown in the second figure, here you find that when I consider this central pixel; again these 2 connectivity which are 4 connectivity, they exist. In addition to this, this point which was not connected considering the 4 neighborhood, now gets connected because this belongs to the diagonal neighborhood of this central point. So, these 2 points are also connected.

Now, the problem arises here. This point was connected through 4 neighborhood and at the same time, this point because this is a diagonal neighbor of the central point; so this point is also connected to this diagonal neighborhood. So, if I consider this situation and I simply have 8 connectivity, I consider 8 connectivity; then you find that multiple number of paths for connection exists in this particular case.

So, the M connectivity or mixed connectivity has been introduced to avoid this multiple connection path. So, you just recollect the restriction that we have put in case of mixed connectivity. In case of mixed connectivity we have said that 2 points are M connected if one is the 4 neighbor of other or one is 4 neighbor of other and at the same time, they do not have any common 4 neighbor.

So, just by extending this concept in this case; you find that for M connectivity, these are diagonal neighbors, so they are connected. But these 2 points, though they are diagonal neighbors, but they are not M connected because these 2 points have a point here. This point is a 4 neighbor of this, at the same time; this point is 4 neighbor of this.

So, when I introduce this 4 connectivity concept, you find that the problem that arises that is the multipath connection which have come in case of 8 connectivity, no more exists in case of M connectivity. So, in case of M connectivity, even if we consider the diagonal neighbors but the problem of multiple path does not arise. So, this is the advantage that you get in case of M connectivity.

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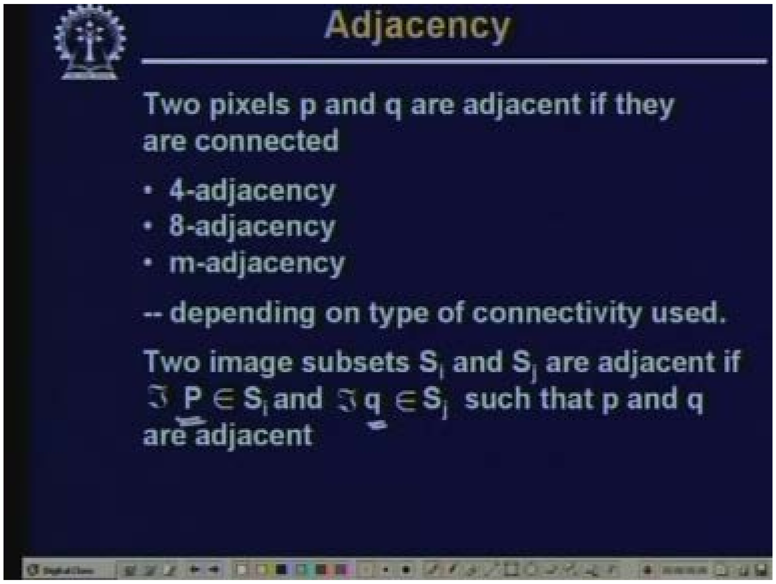

Now, from the connectivity, we come to the relationship of adjacency. So, you say that 2 pixels p and q are adjacent if they are connected. So, since for connectivity we have introduced 3 different types of connectivity; that is 4 connectivity, 8 connectivity and M connectivity. So, for all these 3 different types of connectivity, we will have 3 different types of adjacency because our adjacency definition is 2 points are adjacent if they are connected.

So, just by extension of this definition, you find that we have got 3 different types of adjacency. The first one is 4 adjacency, the second one is 8 adjacency and the third one is m adjacency and you define this type of adjacency depending upon the type of connectivity that is used.

Now, this is about the adjacency of 2 different points or 2 or more different points. We can extend this concept of adjacency to image regions. That is, we can also say that 2 image regions may be adjacent or they may not be adjacent. So, what is the condition for adjacency of 2 image regions?

So, in this case you find that we define the adjacency for 2 image regions like this that if there are 2 image subsets - S_i and S_j, we say that S_i and S_j will be adjacent if there exists a point p in image region S_i and a point q in image region S_j such that p and q are adjacent.

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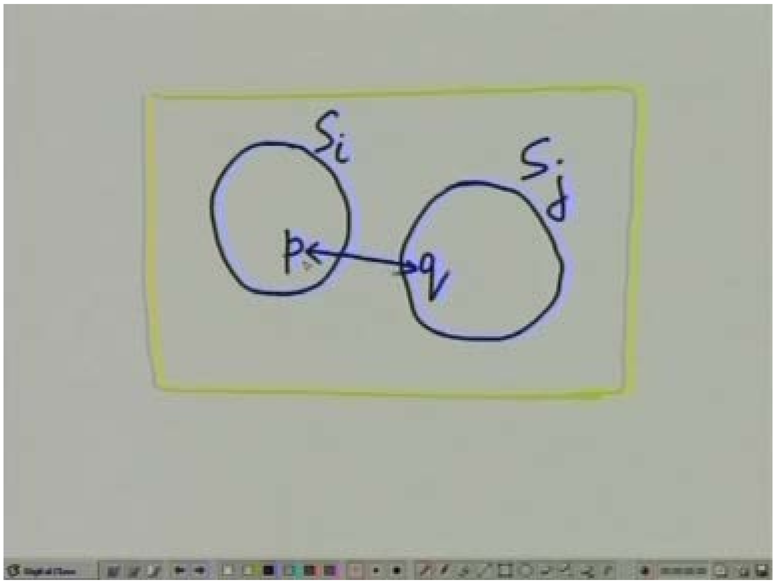

So, just let us try to elaborate this. So, I have this overall image region. This is the whole image and within this image, I have 2 image regions; one is here, the other one is here. So, the adjacency relation between 2 image regions is defined like this that I have to have some point in one region which is adjacent to a point in the other region.

So, if I call, say this is image region S_i and this is image region S_j; then I must have some point p in image S_i and some other point q in the image S_j so that this p and q, they are adjacent. So, if p and q are adjacent, then I say that this image region S_i is adjacent to image region S_j. That means S_i and S_j; they must appear one after the other, one adjacent to the other. So, this is the adjacency relation.

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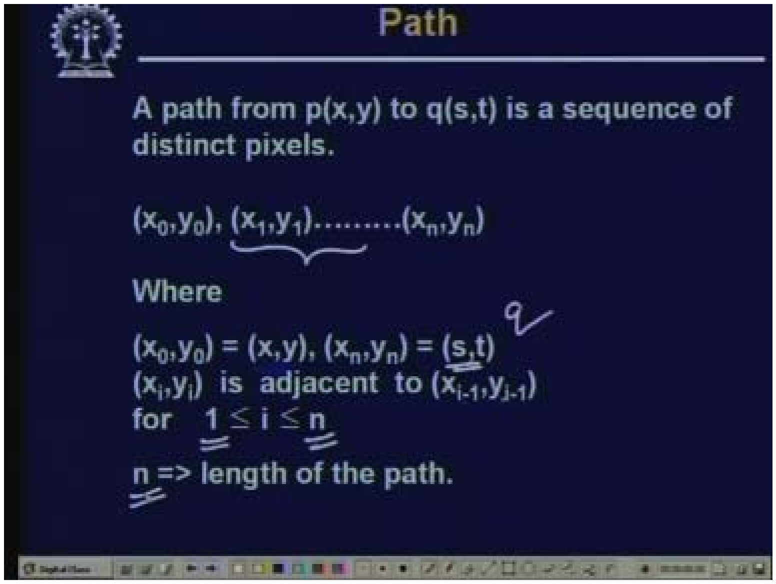

After the adjacency relation, we can also define a path between 2 points p and q. So, the definition of a path is like this that we say that a path exists from a point p having a coordinate (x, y) to a point q having coordinate (s, t) if there exists a sequence of distinct pixels say (x_0, y_0) (x_1, y_1) (x_2, y_2) and so on upto (x_n, y_n) where (x_0, y_0) is equal to (x, y).

That is the same as point p and (x_n, y_n) is equal to (s, t) which is the same as point q. And all the other intermediate points like a (x_1, y_1) x_2 and y_2, they must be adjacent; the subsequent points must be adjacent. In the sense that (x_i y_i y_i) has to be adjacent to x minus 1 y minus 1 for all values of i lying between 1 and n.

So, if I have such a sequence of points between p and q such that all the points which are traversed in between p and q, all those subsequent points; they are adjacent, then we say that a path exists between from point p to point q. And we also define the length of the path to be the n. That is considering both point p and q, if I have n plus 1 number of points including the end points p and q and all the points in between; then the length of the path is said to be n. So, this is what we define as path.

Now, very important concept that can arise from here, that is how to define a connected region. We have said that 2 pixels are connected, we said 2 pixels are connected if they are adjacent in some sense that is they are neighbors and their intensity values are also similar. We have also defined 2 regions to be adjacent if there is a point in one region which is adjacent to some other point in another region and we have also defined a path between a point p and q if there are a set of points in between which are adjacent to each other. Now, this concept can be extended to define what is called a connected component.

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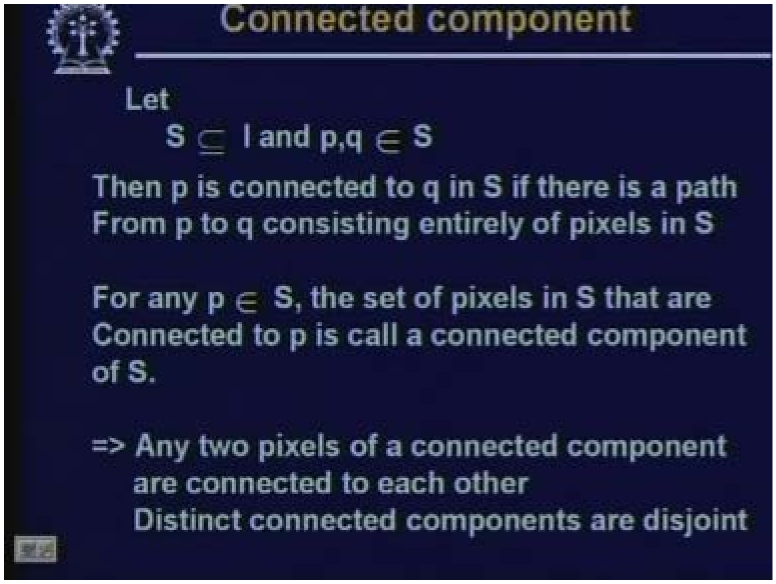

So, let us see what is a connected component. We take a sub set S of an image I and we take 2 point p and q which belong to this subset S of image I. Then you say that p is connected to q in S. So, you just mind this term that p is connected to q in the subset S if there exists a path from p to q consisting entirely of pixels in S. For any such p belonging to S, the set of pixels in S that are connected to p is called a connected component of S. So, the concept is like this.

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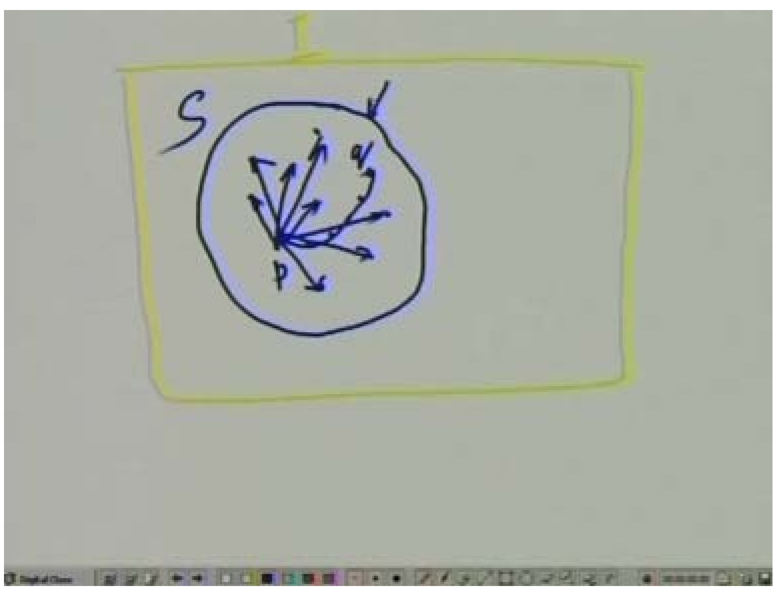

Say, this is my entire image I and within this image, I take a sub image say S and here say we have a point p and we say that take any other point q if there exists a path from p to q consisting of all other intermediate points, this intermediate points must also belong to the same subset S. So, there exists a path between a p and q consisting of intermediate points belonging to the same subset S; then we say that the point p and q they are connected. And, if there are a number of such points to which a path exists from p, then set of all these points are said to be connected to p and they form a connected component of S. So, find that just by using this concept of connected component, I can identify a region in an image.

So, going back to our earlier example where we have said that simply by identifying that a pixel belongs to an object, does not give me the entire solution because I have to group the pixels which belong to the same object and give them some identification that these are the group of pixels which belong to the same object and then I can go for extracting the region property which will tell me what is the property of that particular object.

And now, that belongingness to a particular object can be found out by using this concept of connected component. So, any 2 pixels of a connected component we say they are connected to each other and distinct connected components are disjoint. Obviously, the points belonging to one particular region and points belonging to another particular region, they are not connected but the points belonging to a particular region they are connected with each other. So, for this identification or group identification, what you have to do is when we identify a set of pixels which are connected; then for all those set for all those points belonging to a particular group, we have to assign a particular identification number.

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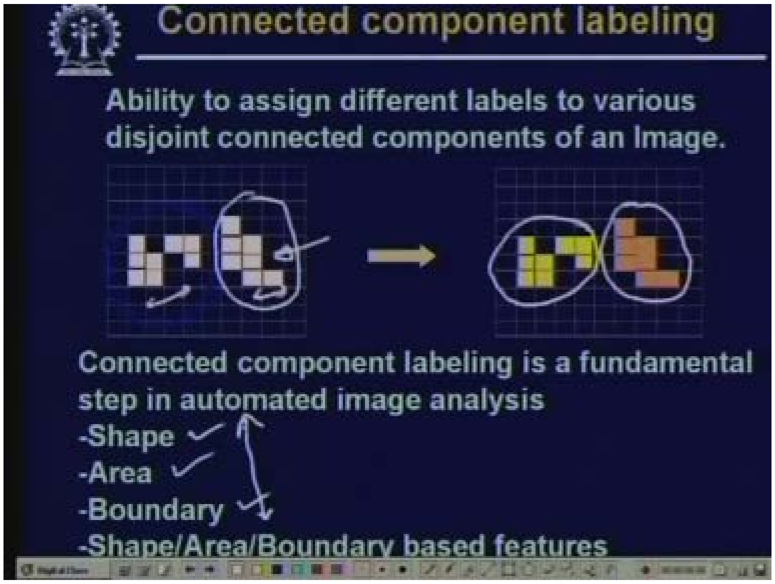

Say for example, in this particular figure, you find that there are 2 group of pixels. So, in the first figure we have a set of pixels, here we have another set of pixels here. So, find that these set of pixels are connected, these set of pixels they are also connected. So, this forms one connected component, these set of pixels form another connected component.

So, this connected component labeling problem is that I have to assign a group identification number to each of these pixels. That means the first set of pixels which are connected to each other; I have to give them one group identification number. In this particular case, all these pixels are identified to be yellow and I have to give another group identification to this second set of pixels. So, in this particular case all these pixels are given the color red.

Now, once we identify this group of pixels to belong to the belong to a particular region; then we can go for finding out some region properties and those region properties may be shape up that particular region, it may be area of that particular region, it may be the boundary, the length of the boundary of this particular region and many other shape, area or boundary based features can be extracted once we identify these different region properties.

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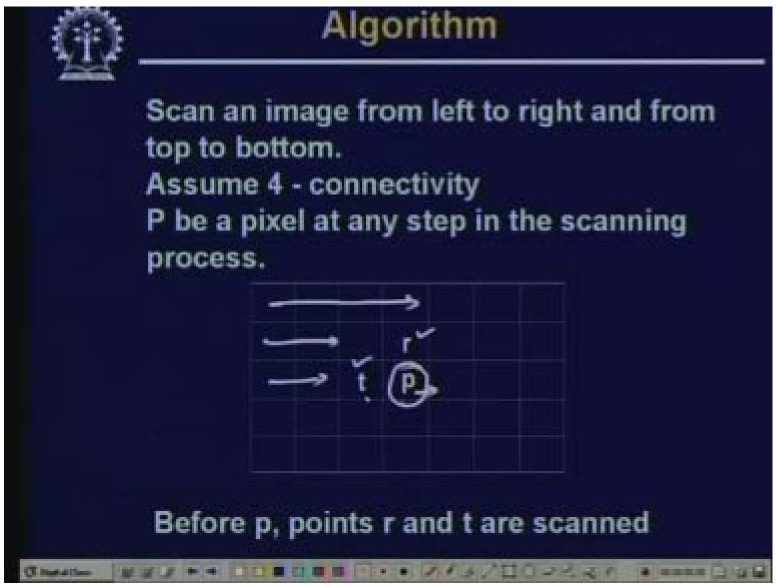

Now, let us see that what will be the algorithm that has to be followed to find out what is the group identification for a particular region or the pixels belonging to a particular region. So, the idea will be the algorithm like this that you scan the image from left to right and from top to bottom.

So, as shown in this particular figure, if I scan the image like this, from left to right and from top to bottom, so this will be our scanning order and for the timing being let us assume that we are using 4 connectivity; so by using this 4 connectivity, whenever we reach a particular point set p, you find that before reaching this particular point p and following this order of scanning, the other 4 neighbors of point p which will be a scanned is the points which is above this that is point r in this particular figure and the point which is just left to p that is point t before this figure.

So, before this particular point p is scanned, the point belonging to 4 neighbors of p which will be scanned are points r and point t. So, by using this particular fact that which are the points which will be scanned before you scan point p; we can develop a component leveling algorithm.

The purpose of the component leveling algorithm is to assign an identification number to each of the pixels, connected pixels which will identify it to belong to a particular region.

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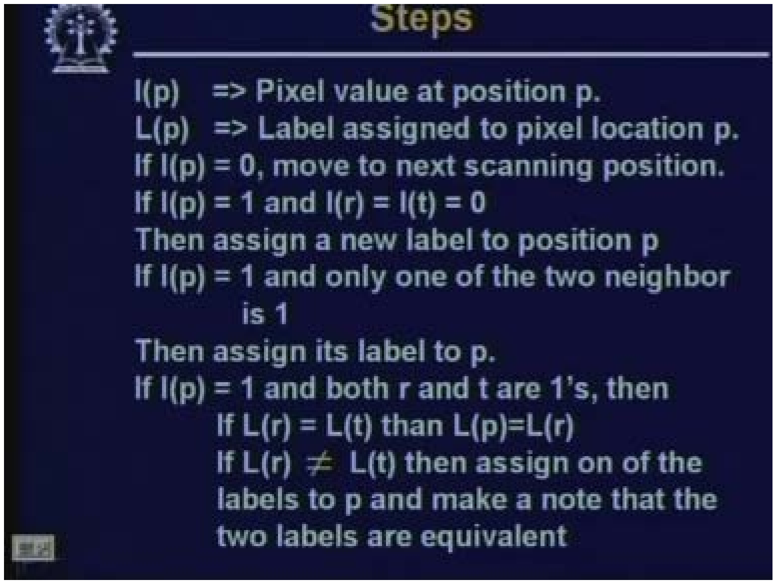

So, the steps involved will be like this. So, when I consider a point p, I assume that I (p) is the pixel value at that particular location and I also say that L (p) will be the label assigned to the pixel at location p. Then the algorithm steps will be like this that if I (p) equal to 0 because as we have seen in the previous case that after segmentation, we say that whenever the intensity value at a particular location is above certain threshold, we assign a value 1 to that particular location. Whereas, if the intensity value is less than the threshold; we assign a value 0 to that particular location.

So, by using this convention when I wanted to find out the region property based on the shape, the pixels which are of important or the points are which points which are of important or the points having a value equal to 1 and we assume the points having a value equal to 0 that belong to the background, so they are not of importance.

So, just by this, if a point has a value equal to 0 that is I (p) equal to 0, we do not assign any label to this. So, we just move to the next scanning position; either to the left or either to the right or to bottom. But if I (p) equal to 1, that is the value at a particular point equal to 1 and we find while scanning this, we have come across 2 points r and t, so when I find a point p for which value equal to 1 and the values at both the points r and t equal to 0; then we assign a new label to position p.

If I (p) equal to 1 and only one of the 2 neighbors that is r and t is 1 and because r and t has been already been scanned, so both r and t if those values were equal to 1 should have got a particular label L. So, in this particular case if I (p) equal to 1 and 1 of r and t is equal to 1; in that case, to p we assign the same label which was assigned to r or t whichever was1 before.

So, if I (p) equal to 1 and only one of the 2 neighbors is 1; then assign the label of that neighbor to point p. But the problem comes if I (p) equal to 1 and both r and t are equal to 1. So, the problem becomes simpler or assignment is simple if the label which was assigned to t and the label which was assigned to r, that were same. So, if L (r) equal to L (t), then you assign the same label to point p. So, you see in this particular case that if L (r) equal to L (t), then L (p) gets L (r) which is obviously same as L (t). But the problem comes if the label assigned to r and the label assigned to t, they were at not same.

So, in this particular case what we have to do is we have to assign one of the 2 labels to point p and we have to note that these 2 labels are equivalent because p and t or p and r, they are adjacent and for r and t the labels were different. So, after doing the initial labeling, we have to do some post processing so that all these pixels p, r and t, they get the same label.

So, here what we have to do is we have to assign point p one of the labels, the label of r or the label of t and we have keep a note that the label of the other pixel and the label of this the label which is assigned to p, they are equivalent so that in the post processing space, this anomaly that has been generated that can be avoided.

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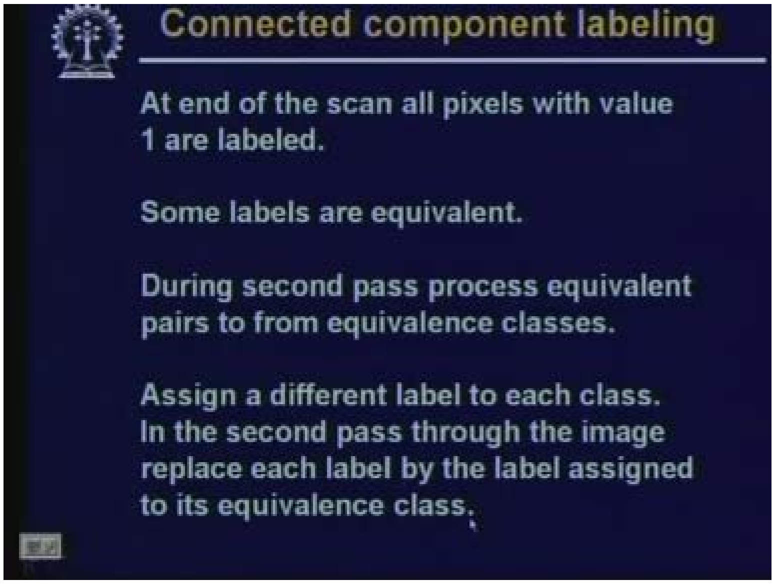

So, at the end of the scan, all pixels with value 1 will have some labeled and some of the labels will be equivalent. So, during post processing or the second pass, what we will do is we will identify all the equivalent pairs to form an equivalence class and we can assign a different label to each of this equivalence classes and in the second pass, you go through the image once more and for all the labels which belongs to a particular equivalence class, you replace its original label by the label that has been assigned to the equivalence class.

So, these 2 passes gives at the end of the second pass, you get a labeled image where you maintain where you identify the region belongingness of a particular pixel by looking at what is the label assigned to the particular pixel.

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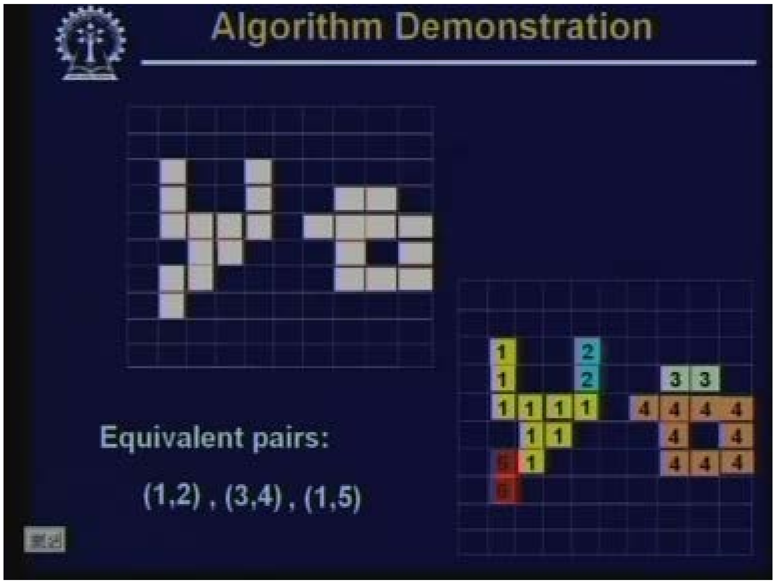

So here, let us come to see an example. So, in this particular example, you find that we have shown 2 different regions or 2 different connected regions of pixels having value equal to 1. So, here what we do is during the initial pass, as we scan this image from left to right and from top to bottom; what we do is the first image that I get, I assign a label 1 to it.

Then you continuous you your scanning. When I when you come to the second pixel - I, second white pixel, you find that by connectivity it belongs to the same region. But when I come to this particular pixel; if I go through the … top pixel and the left pixel, I find that there is no other pixel which is having a value equal to 1. So, I have to assign a new value to this particular pixel and this pixel gets a value equal to 2.

Come to the next one. This pixel again gets a value equal to 1 because its top pixel is equal to 1. Coming to the next one, this one gets a value equal to 2 because its top pixel has a value equal to 2. Come to the next one. This gets a value 3 because it has to be a new label because neither its top neighbor nor the left neighbor has any other label. The next one again gets a value 3 because its left neighbor has the label 3.

Again this gets a value one because top neighbor is equal to 1. This gets a value one because the left neighbor is equal to 1. This gets a value 1, this gets a value 1. Now, you find that in this case, there is an anomaly because for this pixel, the top pixel has label equal to 2 and the left pixel has value equal to 1. So, I have to assign one of these 2 labels to this particular pixel.

So here, we have to assigned label 1 to this pixel and after this, what we have to do is we have to declare that 2 and 1; they are equivalent. Then you continue your processing. Here again, I have to assign a new label because none of the top or the left pixels of this, neighbors of this have got any label. So, it gets the label 4.

Coming to the next one, here you find that its top one has got label 3 and left one has got label 4. So, I have to assign one of the labels and in this case, the label assigned is 4. But at the same time, I have to keep a note that label 3 and label 4, they are equivalent. So, you mark 3 and 4 equivalent. So, if you continue like this; the next one is again 4, the next one again gets 4, this one gets 1, this one again gets 1, this one gets 4, this one gets 4, this one gets the 5 and that is a new label because for this particular pixel its top or left one does not have any label.

Coming to the next one, it gets a label 1 because here the top pixel has already had a label 1 but at this particular point, we have to keep a note that 5 and 1 are equivalent. So, you note 5 and 1 to be equivalent. You continue like this. The other pixel gets the label 4, this pixel gets the label 4, this pixel gets the label 4, this pixel again gets the label 5 because its top pixel is already having a label equal to 5.

So, at the end of this scanning, I get 3 equivalent pairs. One equivalent pair is (1, 2), the other equivalent pair is (3, 4) and the third equivalent is (1, 5). So, in the second pass, what I have to do is I have to process this equivalent pairs to identify the equivalence classes. That means the labels all the labels which are equivalent.

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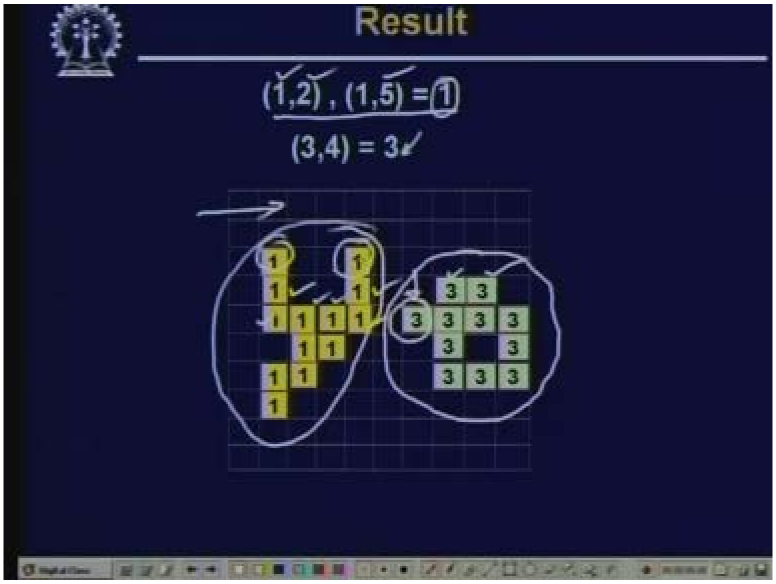

So, by processing this, you find that 1 and 2 and 1 and 5, they are equivalent. So, 1 and 2 and 5, these 2 labels form a particular equivalence class and similarly 3 and 4, they are equivalent forming an equivalence class. So, if I assign a label 1 to the equivalence class containing the labels 1 2 and five and at the same time, I assign a label 3 to the equivalence class containing labels 3 and 4; then during the second pass, what I will do is I will scan over this labeled image which is already labeled or I will reassign the labels.

So, wherever the label was equal to 1, I will maintain that equal to 1 and wherever I get a label which is 2 or 5, I will reassign that label to be equal to 1. So, in this particular case, if you remember this pixel had got a label equal to 2, I reassign because 2 belongs to an equivalence class consisting of the labels 1, 2 and 5 to which we have assigned the label equal to 1. So, wherever i get label to 2, I reassign that label equal to 1.

So, continuing this way; this was already 1, this was 2 which has been reassigned to be 1, this was 3 which remains because 3 and 4 form equivalence class and the label assigned to this equivalence class was 3. This is also 3 that remains, this was 1 that remains, this was 1 that remains, this was 1 that remains, this was say possibly 2 or 1. So, I make it equal to 1. This had got a label equal to 4. So, that has been reassigned the label value equal to 3.

So, find that at the end of this second pass, I identify all the pixels belonging to a particular group to have a single label and similarly all the pixels belonging to this particular group to have another label. So, I will stop here today, I will continue with this lecture in the next class.

Thank you.