Geographic Information Systems
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Lecture - 13
Georeferencing

Hello everyone! and welcome to new discussion on this geographic information systems course. And today we are going to discuss georeferencing and also people call as geometric corrections and by many other names. But currently the most popular name is georeferencing. As we have been discussing that basis of GIS is basically in mathematics and various tools which were available in mathematics, many of them have been implemented into GIS.

Though we do not directly you know derive the equations or any other thing but we use that mathematics. And in order to understand all these intricacies in GIS, how these things work, we have to sometimes go through some equations. And the mathematics which we are using in GIS on regular basis is like coordinate geometry.

The entire subject of mathematics which is being used here directly. Then if you recall that in our you know CBSE's high school, we were introduced polynomial equations. So, today we will be using those polynomial equations of different orders during this georeferencing. Other techniques like least square fit, overlay or Boolean's logic, set theory or your interpolation techniques. So, basis of basically GIS is mathematics.

And what people have done through computer scientist, we have got all these tools which are related with GIS available on different GIS platforms. But the fundamental of course, will remain same and these are coming only from mathematics. So, let us move now for the georeferencing. Why basically georeferencing is required?

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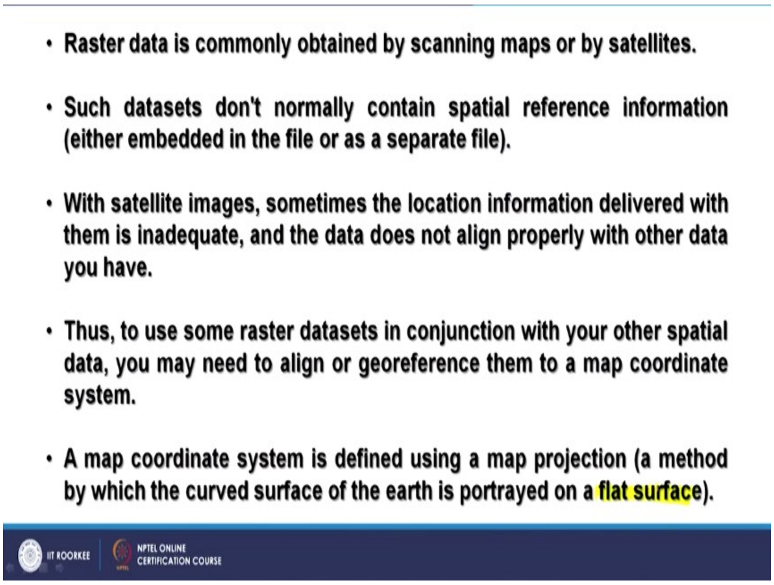

As you know that when data is acquired especially by satellite which are orbiting the earth like earth resources satellites for example starting with Landsat. Our own Indian satellite series like IRS 1A, IRS 1B and it continues. Then Cartosat and Resourcesat and many such our Indian satellites. If I talk about Landsat then Landsat 8 OLI series is the latest in the series.

And there are ASTER satellite, Sentinel satellites of European Space Agency and various such satellites data is available. And when they acquire the data basically, they are covering a curve part of the earth. This you have to remember that when we handle maps or satellite images, we handle them as a 2D. But when image is acquired by these satellites, it is in basically 3D.

So originally it records the 3D part of the curve and then we try to fit or make it as flat. And when we do it and plus when satellite moves; these are the moving objects. So, it is not necessary that they will move exactly how they have been designed in their orbits. Sometimes there are other movements also which we will also discuss. So, because of these reasons and one more reason is because of skewness which we will also discuss in detail.

So, because of these reasons, a satellite image when it is acquired by these satellites will have you know these distortions one and these images will not have geographic coordinates. This kind of image will always have its own origin which is on the top left corner. And whereas our maps and other things we assume that this origin or in like in geometric coordinate system, the origin is from bottom left corner.

So, because of this complication also we require georeferencing. So, commonly this raster data or satellite images are required. And as you know that most of digital elevation models which currently, we are using which is available on net, all of them have been created using satellite images. So, there also georeferencing becomes very-2 important.

So, this thing and when we want to use our satellite data and their derivatives like land use map or lithological map or forest cover map or soil map which are derived directly from satellite data along with other datasets which are in georeferencing or in geographic domain. Then we need to also do our georeferencing. And this will allow us to build up a coherent GIS database if we perform this georeferencing.

Another important point with georeferencing is a common technique between remote sensing digital image processing and GIS. So, it is a same technique which is applied for satellite images. Same technique we can also apply for a scanned map and that way, we can also do the georeferencing. Many times, we have to digitize from a toposheets; like in India, we do it with Survey of India toposheets. And they may be available in analog form.

So, when we scan it, they are in geometric domain. Now we have to transform through this georeferencing process from geometric domain to geographic domain. And then that image on which we will be working might be digitizing like contours and other features. So, everything will come then in geographic domain because we have already georeferenced that image.

So, this process is very-2 important to transform a data which is maybe in geometric domain into geographic domain. And this entire process, we call as georeferencing. And why we need? As I have mentioned because other sources of data may not be directly from satellites, they might be already geographic domain. So, in order to have you know coherent database generation GIS database generation, we need to do this thing.

Now another complication may come about the map projection. Basically, a map projection itself is a subject. Now our GIS softwares are capable of converting from one map projection to another without much problem. However little bit error’s introduction would be there but if we are covering a very large area. If area is not large then that issue will not come.

As I was mentioning that like a flat surface because the image data may be representing a curve surface. Through this process, what we do? We try to represent the data into a flat surface and for that also. Sometime people call as rubber sheeting because we treat a digital image representing a curved surface as rubber sheet to make it flat and the concept it will remain same.

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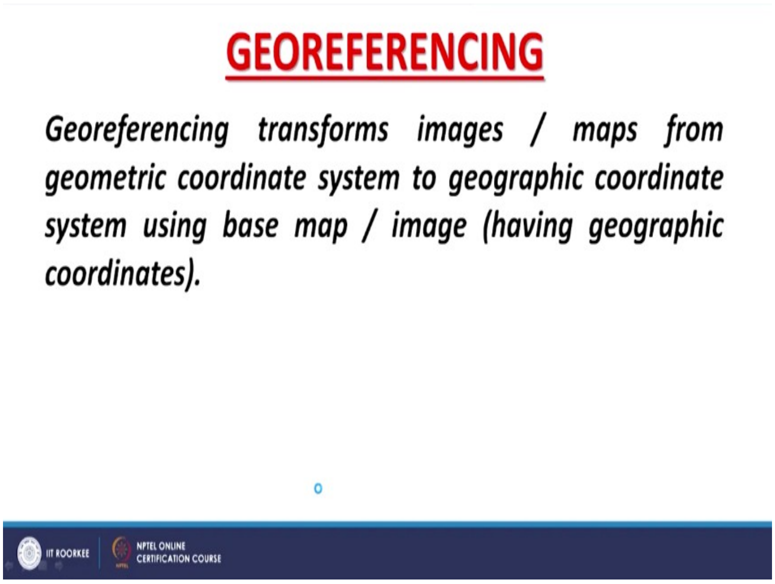

So, now we can define what exactly georeferencing is. The georeferencing basically transform scanned maps or images which are in geometric coordinate system to geographic coordinate system. Now in order to perform this thing, we use either base map or image having geographic coordinates or maybe some library which might be available to us. So, if we are having a good library of ground control points or in short, we call GCPs.

So, if we are having that library, we can also access that library. So, this reference how individual cells or pixel will be transformed from geometric domain to geographic domain. For which we require a reference. And that reference may come from a base map or already georeferenced image or a map or may be sets of or a library of GCPs or ground control points.

So by which, we can achieve this geographic coordinate system for our input data originally which may be in the geometric coordinate system.

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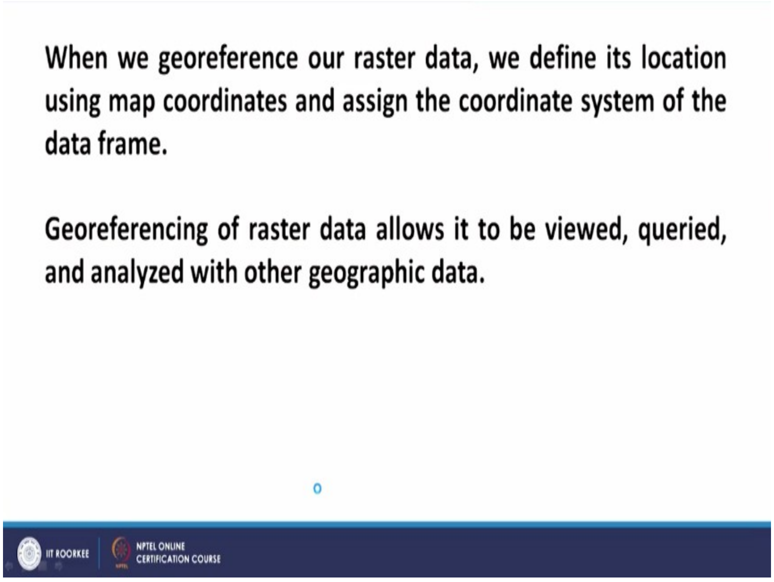

Now when we georeferenced data; raster data especially we are talking. Vector data can also be handled in the similar way. But most of the time in this discussion, we will be considering raster data because it has got more complications. So basically what? we assign the geographic coordinate system which involves basically 3 steps which we will discuss, how it is done.

And in demonstration also, we will be seeing how it can be done. So, georeferencing basically of raster data will allow us view query and analyze with other geographic data only if the data has georeferenced now. Now the 3 steps which would be there. There are 3 steps like first is registration and then finding out the transformation function and third one would be resampling.

But before that we have to understand that what are the distortions which may be introduced while data is being acquired either by satellite or by some other sensors. Nowadays you know if you recall the history of remote sensing, you would find that initially remote sensing is started with some towers or like balloons, airborne platforms and slowly-2 through aircrafts and then we went to the satellites.

Now here sort of I call as a reverse process has started again that now lot of remote sensing is being done as per requirements by using drones or these you know unmanned vehicles. And these vehicles are having capabilities of carrying a very sophisticated payloads and which can provide data also. A good satellite images of very high resolution covering maybe a small area depending on the requirements.

And when one requires that is the advantage because satellites will have their own fixed overpass time or dates whereas with drones the biggest advantage is that with drones, we can acquire data whenever we want. So that is why, lot of emphasis is nowadays is on this how to employ drone in remote sensing. So, when you acquire images from drones, drones are again moving platforms may not be very stable.

And therefore, they may also introduce lot of geometric errors which might be because of scan skewness.

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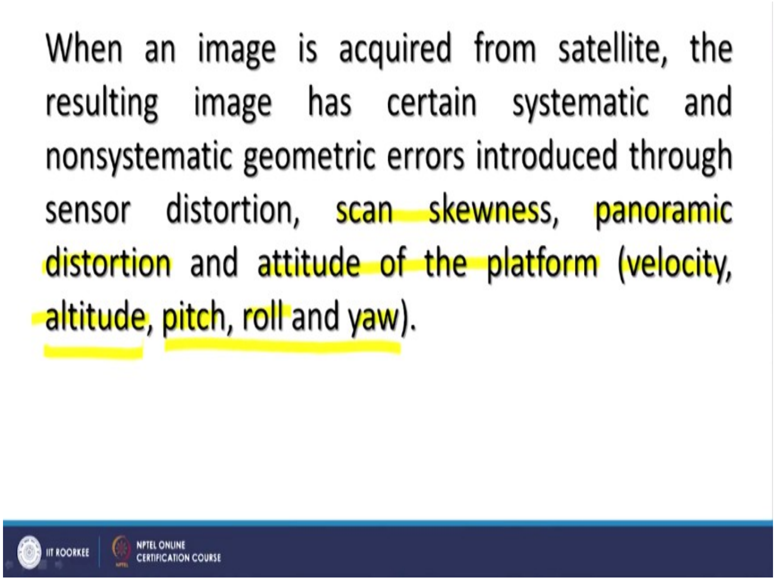

This is more prevalent in satellite images. May be panoramic distortions if drone or satellite is at very high altitude of the platform. This reason may be less in case of satellites. But it is more in case of drones. Like change in velocity of drone, the change in altitude of drone when the image is being acquired or data being acquired then the pitch, roll and yaw; these 3 we will also see what are these.

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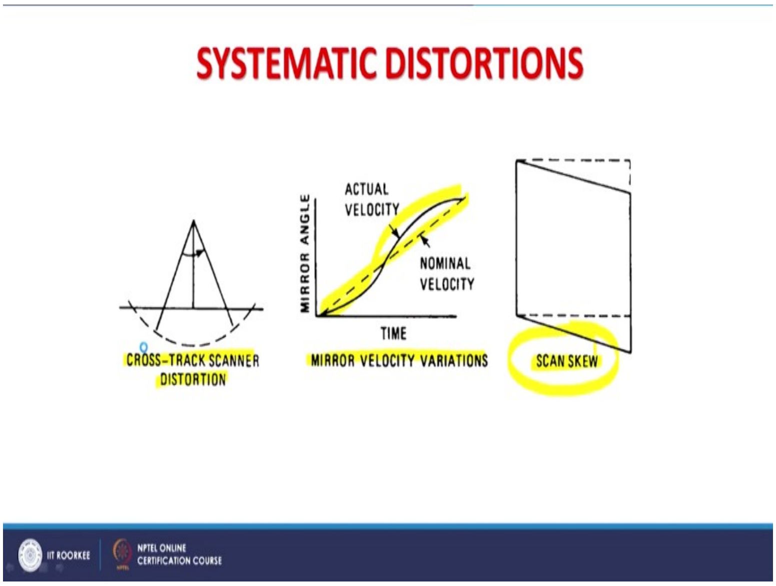

So, what happens basically that earlier we had these opto mechanical scanners. And they were doing scanning like this. So, we had this cross-track scanner distortion. So, if somebody for change detection studies which is involving more than 40 years of data like Landsat 1 or Landsat 2 then one has to remember that those images raw images were suffering from cross track scanner distortions.

So, when we do the georeferencing, almost all these geometric distortions are removed to large extent. So, that is why this georeferencing is very much required. Now as I said that these satellites were opto mechanical satellites. So, there were velocity of the mirror also and it might be varying if it is not following the normal velocity path. And if it is going like this, it may introduce geometric distortions.

Scan skewness is still persisting in satellite images because these are near polar orbiting satellite. And as you know that earth is not perfect spheroid and because of that and because of these designing of orbits, satellites are taking images in a such manner that suppose it is taking 10 minutes to acquire one image. Now between that 10-minute, earth will rotate.

And anyway, the orbit is also not exactly from north to south but it is having say roughly 9-degree angle in many cases. And it is moving around the earth like this. So, if it is moving and in between the earth rotates, this will bring this error in a large form which is called scan skewness. This error too can be removed by implying georeferencing. Now when I was also mentioning about the you know yaw; these 3 altitude variations and other things, how they affect in the images.

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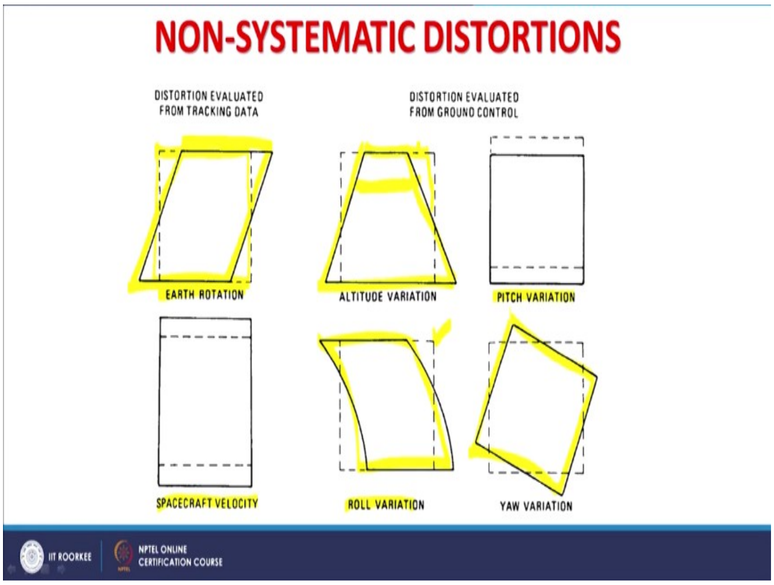

So, let us see. Like when earth rotation is there, skewness is there. We expect that image should have been in this form but it is coming like this. Similarly, altitude variation if suddenly the spacecraft or aircraft or drone changes its altitude, this kind of distortions might be there. The expected one is the dashed line. Whereas the image here the altitude has gone high. And therefore, it is covering a large area but at a smaller scale.

And here altitude has come down and bringing basically altitude distortions. Now pitch variation when suppose the aircraft is going like this or your drone and suddenly it dips like this. So, if there is a pitch, again there will be distortion. Spacecraft velocity suddenly changes the velocity. Again, there will be error. And roll; if it rolls like this which is perpendicular to the direction of the orbit then it may bring an error something like that.

That the image would be representing like this whereas we expect a dashed lined area. And if there is a moment like this on vertical axis while the drone or spacecraft is moving then you may be acquiring image like this. So, these may bring lot of geometric errors and to identify whatever the errors which I am seeing in satellite image is because of that particular reason is really very challenging.

So, the best solution is whatever the distortions any image or map is suffering from, remove it through the georeferencing process. And that way we can achieve a geographic coordinate system instead of geometric coordinate system. And we can get rid of all these distortions. There are other ways I can also explain.

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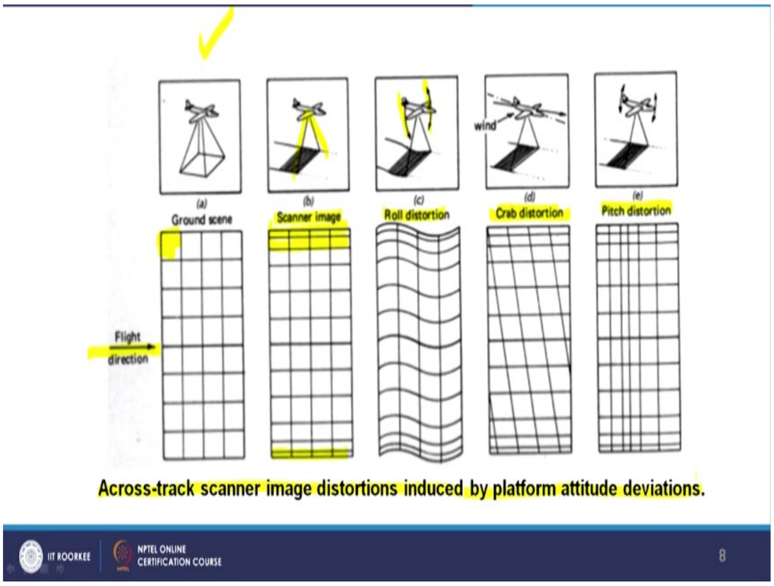

This is the flight direction and this is the grid suppose on the ground just to test it. So, it should have been acquiring data like this that each pixel should be square in shape that is what we know as the raster and especially in case of images also. That pixel has to be always square in shape. So, this is the ideal condition which we would prefer.

But if there is a scanner image, what happens on the margins because it is a not for the margins. It is particularly in nadir viewing but of nadir viewing on the side like this and this will bring you know distortions in my images. So, that is why these are instead of covering a squared area, they are virtually recording a rectangular area. Of course, the image will always have a square unit. Now when roll distortion is there as shown here that roll is something like this.

So, when roll distortions is there it will record an image something like this. And if then crab distortions is there because of wind, there might be shifting also which is called crab distortion. So, that may bring distortions like this. And if it is pitch distortion, it dips like this then or like this then again you may have some. So, across track scanner distortions introduced by platform altitude variations. These will bring lot of geometric errors in our images.

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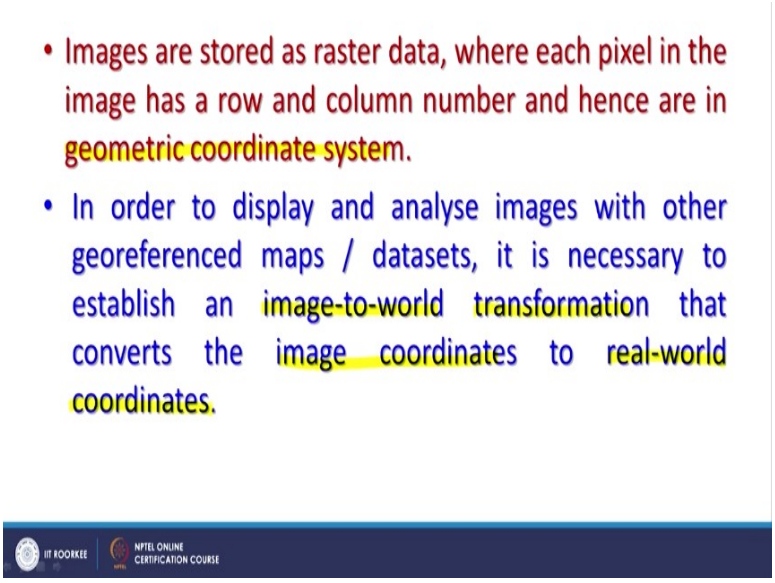

So, as you know that in raster each pixel in image has a row and column number. And also, I told you that the origin of the image is always from the top left corner. So, first row first column we start addressing from there. But this is in geometric coordinate system. But in geographic coordinate system, we always start from bottom left. So, this is another you know adjustment we have to do during georeferencing.

So, as we know that in order to display and analyze images with other datasets in our GIS database which are already georeferenced. It is essential to establish an image to world transformation basically which is what is georeferencing which converts your images coordinates. Image coordinates are starting from top left first, row first column like this to the real world coordinates which are our geographic coordinates.

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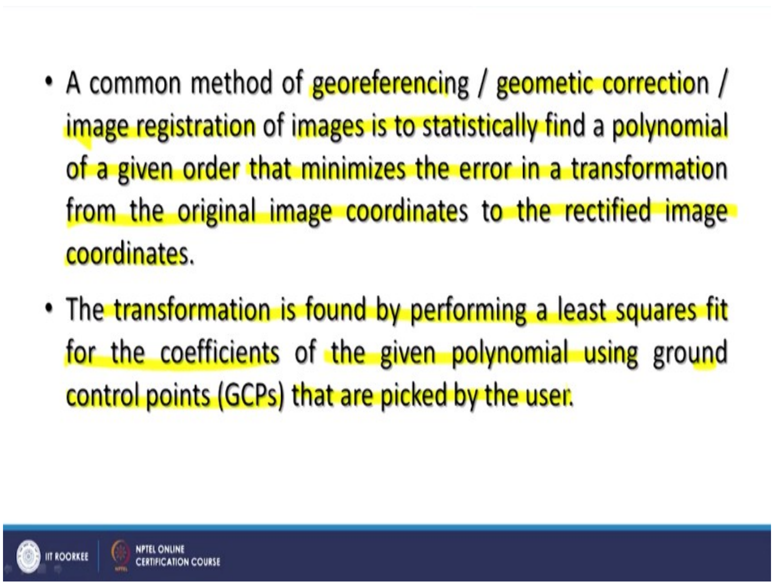

And this as I have said in very beginning that georeferencing can is also called in literature geometric corrections or image registration or sometimes people say you know rubber sheeting adjustment. So, here what images with the common method of georeferencing which involves the images to be statistically find a polynomial of a given order.

Polynomial equations which we have learned in our 10, plus 2 or in high school time, that minimizes the error in the in a transformation from the original image coordinates which are starting from top left to the rectified image coordinates which are in geographic coordinate system. So, like this we can perform georeferencing. Now in order to perform the first step to do the registration using ground control points.

So, transformation of this image will be found by performing a least square fit for the coefficients of a given polynomial using ground control points; GCPs that are picked by the users and this is what we have to provide interactively.

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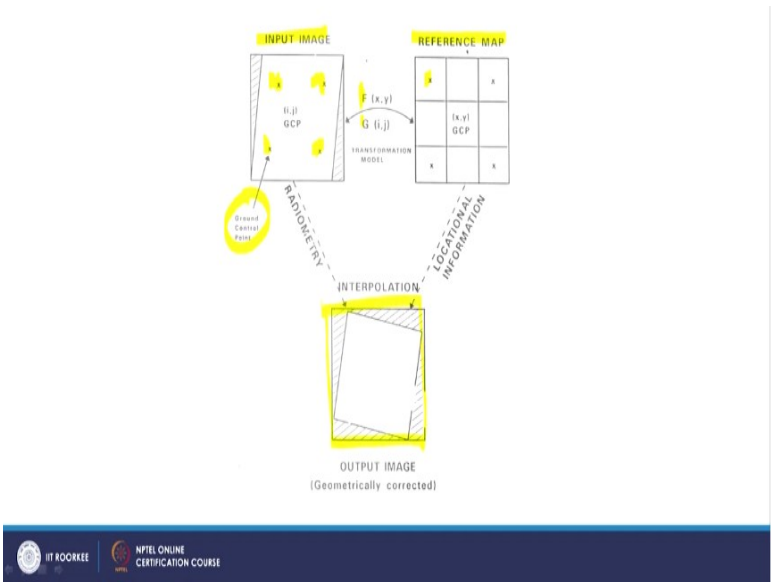

I am presenting a schematic here. Here we are having an input image and this is my reference map. So, I call as a master and left image; the input image I can call as a slave image. So, now this input image has to be georeferenced to our master image or master map. How it is done? This is just you know GCPs are shown in the form of cross and these we call as ground control points.

Now these polynomial transformation functions are there which we will found through least square coefficient. And using common ground control points that means the same point which I am seeing in my image, also in my master map which are called the GCPs or ground control point which has to be common. For example, there might be a crossroad which I am seeing in my satellite image.

And the same crossroad I am also seeing in my reference map. That can become my one GCP. Now there may be a GCP like a bridge on a river that may be also a GCP. A bridge on the railway track or rail bridge on a stream or a river that can also be taken as a reference. Any point with time which does not move can be considered as a reliable GCP. But the points like bending of a river in a plane area should not be taken as a ground control points because as you know that river migrates generally in flat areas.

So, that age difference means the time difference between input image and reference map is large then there are chances that I might be collecting a wrong GCP. And wrong GCP means I will have a wrong registration, wrong coefficient, wrong transformation and ultimately completely incorrect georeferencing. So, we have to take care about that part.

That when we collect GCPs, we should be very careful that I am seeing both control point which should be common in both the images and once I have found the transformation function. That means from the input image, a single individual pixel where exactly it will go in the master image or master empty frame that is decided through the transformation.

The third part comes then that what would be the value pixel value from original image to you know to the blank frame which has been already referenced with the master map. So, now the pixel value? I can have the original pixel value or because of other accuracy purposes, I can have some modified weighted average pixel value. And that process is called resampling.

So, 3 steps; first is the identifying GCPs and registering them with master map. Finding the polynomial coefficient transformation function and then finding the pixel value. And once these 3 steps are completed, we can achieve a georeferenced image which will fit with our other datasets which might be available in my GIS database. So, this is how we perform.

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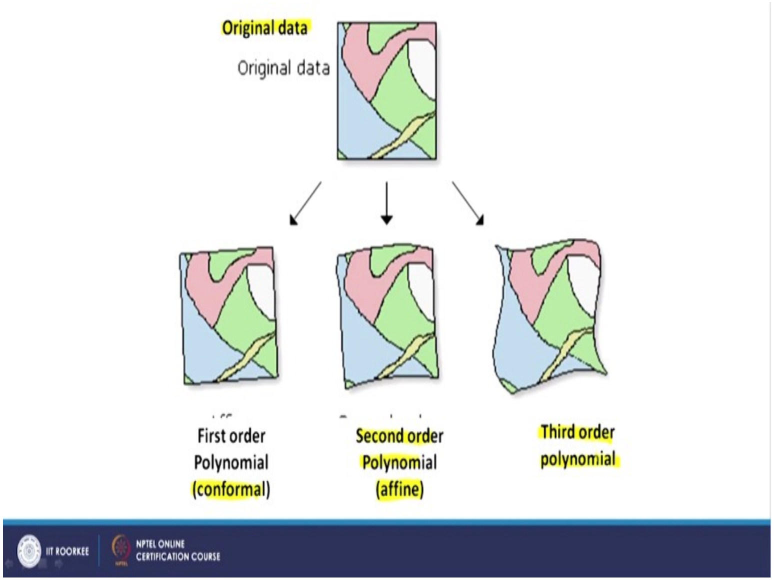

Now which order of polynomial equation I should choose that will depend on the how much distortions in my image is presenting. In this what you are seeing, this is my original data. Now if it is just a transformation from geometric domain to geographic domain. For example, this is my master image and this is my you know the image to be georeferenced.

So, if I am just transforming from geometric domain to geographic domain then first order polynomial or conformal transformation would be sufficient. If my image requires some rotation and change in scale that this input image in order to fit with my master image if it requires rotation as well as change in scale then I would choose the second order of polynomial or also called in literature you may find for first order conformal transformation or in second order, you find affine transformation.

Now there might be even a situation where we need a transformation. We need a change in scale. We need you know a warping because my image is covering large part of the earth. And it is representing the curve part of the earth. So instead of that curve part, I want to make it as flat. So, therefore this warping issue will also come.

So, transformation, rotation, change in scale and warping; if all these 4 requirements are there then I will go for the third order of polynomial equation. Now mathematically we can go you know I have seen some GIS softwares where they allow you to go up to even 12th order of polynomial equation. But basically, in our case in GIS, we do not really require to go beyond third order. Why?

Because whatever the geometric distortion which might be present in our maps or satellite images, they can be maximum of only third order transformation. They can be resolved. All those distortions can be taken care only by third order. Second point is that as you move higher in order, more the control points would be required.

And sometimes if image is representing like forest area or a desert area or a snow-covered area then finding reliable common ground control points in my input image and master image becomes really very challenging; very difficult. So, unless until it is required, one should not always even resort to the third order. If suppose I am covering a small area of the ground or earth then maybe second order of polynomial would be sufficient.

So, what is the way I would know beforehand how much minimum number of GCPs are required against different order of polynomial equation. So, there is a very simple formula that [(P+1)(P+2)]/2.

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Number of Ground Control Points (GCPs) required

$$= [(P+1)(P+2)] / 2$$

Model Order	No. of GCPs required
1	3
2	6
3	10
4	15
5	21

×3

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And P is basically order of polynomial. So, like here if order of polynomial I choose one then minimum ground control points are required only 3. If I go for second order polynomial then I require a minimum 6. Minimum does not mean that I will collect only 6. No, this is not a good practice. So, in my experience and understanding and to achieve a better georeferencing or people say you know within pixel georeferencing referencing accuracy then it is better to multiply by 3.

So, if first order then we should collect 9. If it is second order then 18 and likewise. So, if I do not require for example if I do not require more than third order, why I should go? Because most of these geometric distortions might be introduced by the satellite images or drone can be resolved maximum up to third order in most of the cases.

If really like in case of drone situation, wind speed and another thing still image has been acquired then probably fourth order may be sufficient. But again, finding reliable common ground control points in both images; input and master may be very challenging. So, one has to be very judicious about choosing a polynomial equation, one and accordingly also choosing very reliable common ground control points.

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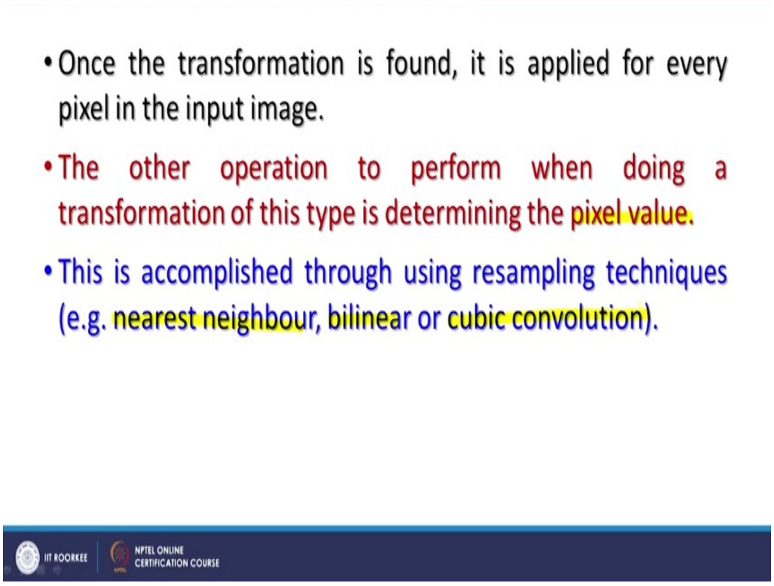

So, once this transformation is found through this order of polynomial equation then it is applied to every pixel. Because now every pixel from input image has to transformed to a new location in you can imagine a empty you know wire mesh kind of situation. So, every cell of that wire mesh has to be filled with a pixel value. Now that pixel value as I have said may be original or may be averaged or weighted average.

That we will decide little later. So, the other operation which we perform doing a transformation of this type is determining the pixel value. And this is accomplished through using resampling techniques. And when we have been discussing this raster data compression technique, at that time referenced to these techniques also came; nearest neighbor, bilinear, cubic convolution.

And at that time, I mentioned that later on when we will discuss georeferencing, we will discuss these things in detail. So, today is the right time to discuss with these things.

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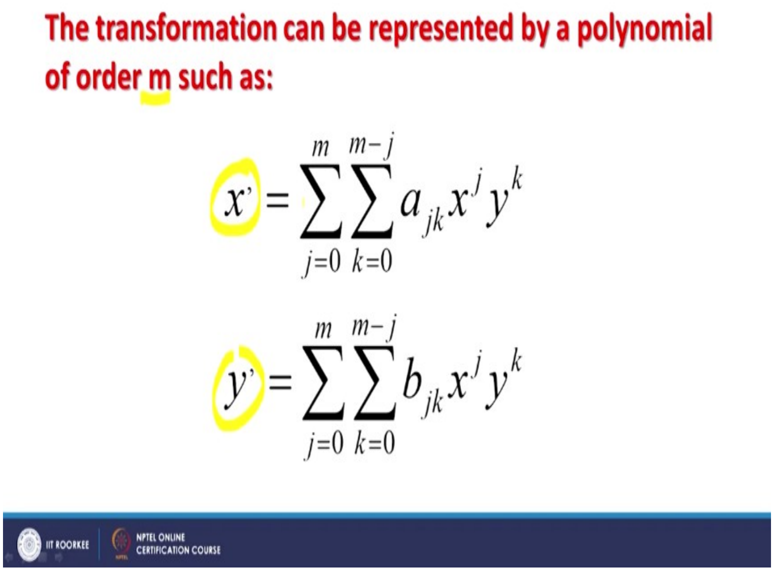

Now the transformation of these polynomial of given order like here m can be expressed in these 2 equations. Basically, what we are trying to find out that the new location in form of x and y against the input location of a distorted image or image which is in geometric coordinate system. So, by providing the input from the image coordinates, we are trying to find out the new location for all these pixels through these 2 polynomial equations.

So, this is the common equation where m value can be replaced with the order of polynomial.

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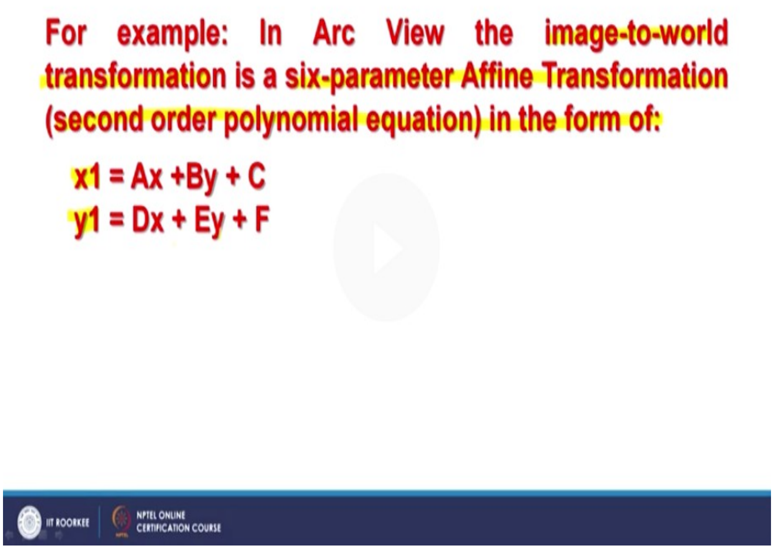

Now if I take the example of ArcView and ArcGIS also that the image to world transformation is a 6-parameter affine transformation. And that is basically second order of polynomial equation in the form of very simple that as you go higher in order, our polynomial equation becomes much complicated. So, in case of second order; what second order will do?

That it will transform geometric coordinate system to geographic coordinate system one and also it will allow us to rotate and maybe change in scale. So, when these 3 things can be adjusted then second order polynomial is good. So, how second order polynomial will look like we are trying to determine the new location for pixels. So, x1=Ax+By+C and y1=Dx+Ey+F.

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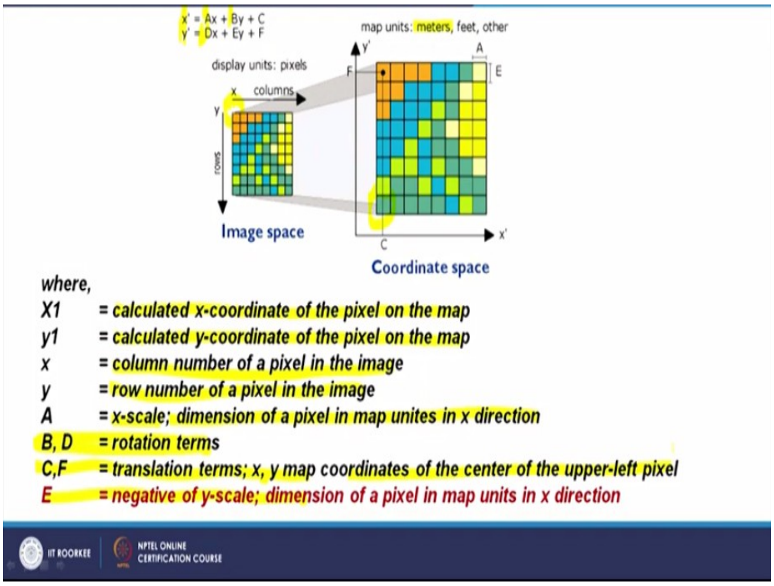

So, how these values will come or here the same equation but instead of x1, y1, it is x’, y’ is given. And what we are trying that our coordinate system may be in meters or maybe in geographic coordinate does not matter. So, with these equations where we trying to calculate the x coordinate of the pixel on a map and also y coordinate of the pixel on the map. x is the column number of input image and y is the row number of the input image.

Because as I have said remember that image coordinates start from top left corner here and whereas our geographic coordinate system, the coordinate system starts from bottom left. So, that is why this is very important. Now A will allow in these this equation. A will allow the scale x scale dimension of a pixel in x direction. Then also we will have a y scale change but it is negative. y scale will have negative value because we are coming from top to bottom.

Because of different coordinate system which are followed in image and map. And then of course rotation terms which is B and D here. And C, F are the translation terms. x, y map coordinates of the center of upper left pixel. So, when these things are resolved, we get a geometric correction. Now by further explanation I would like to give about this why this negative is.

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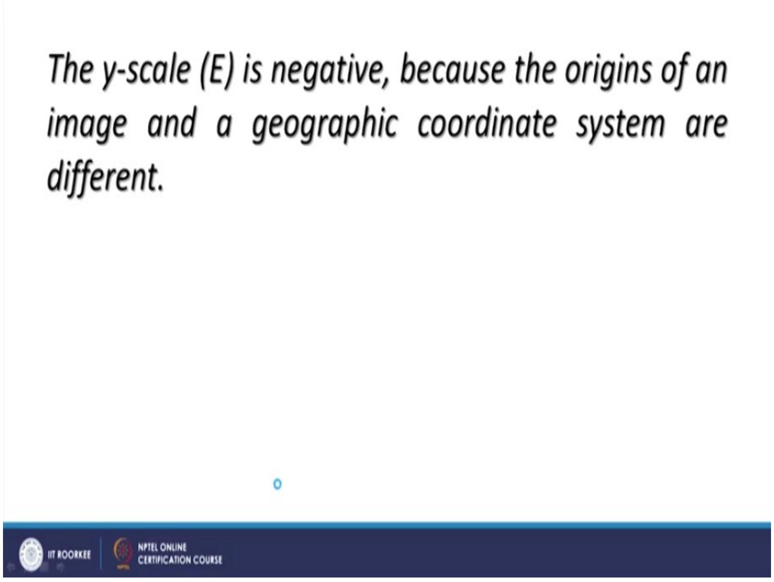

As I have already mentioned that the y scale is negative because the origin of an image and a geographic coordinate system are different. Origin of image is from the top left corner whereas a geographic coordinate system is in bottom left corner. And because of that y is kept 0.

After this we will get the statistical; this root mean square. And error we always try that it should be if suppose I am handling an image of 10-meter resolution then my error should be less than 10 meters. So, then we call as within pixel accuracy. So, one always tries with the choosing correct these ground control points and also you know appropriate polynomial equation.

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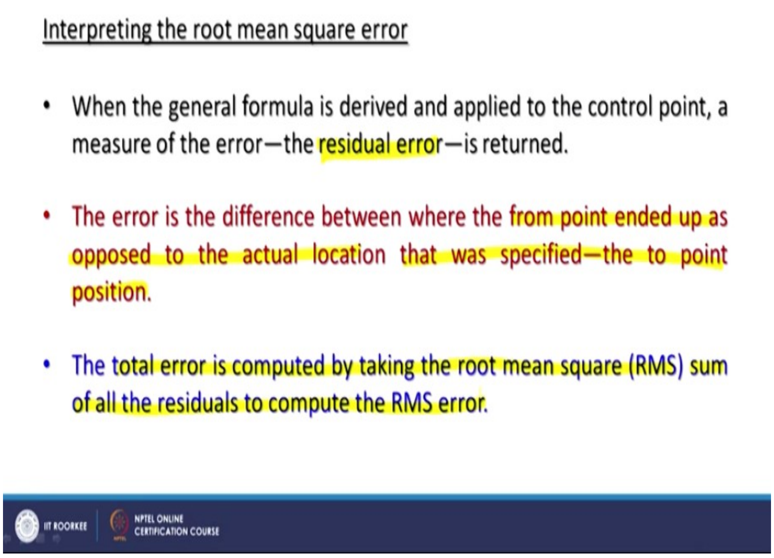

So, the general formula is derived and applied to the control point, a measure of error that is the residual error is returned. Now when we use the softwares which has become very smart like this modern software like ArcGIS or others. While doing this you know geometric registration that means identifying ground control points and putting you know registering with the master map.

At that time, it will keep giving you the residual error against the total one and also against individual ground control point. So, if you are not happy against individual collection of GCPs, you can delete it and again select another one or may be same with more care and you can achieve better. So, it has become more interactive rather than a sequential one.

This is the point which I wanted to bring that rather than sequential though our discussion looks like we are doing a sequential but here, it is not exactly sequential. As you keep collecting the GCPs it will keep giving you the error information. And as soon as you realize that point number say 2 is having large residual errors compared to other points. And therefore, this root means square total one is coming bad.

So, you can remove the number 2 and recollect a different location or maybe recollect at the same location but with more care. And the error difference between where the point ended up as opposed to the actual location was specified. That is the point position and nowadays the graphic has been introduced in this. So, you exactly also know on the screen when we will see the demonstration.

We will see that on a screen, you exactly know that how much error even in form of graph red part, green part of a vector will be also visible. So, the total errors are computed by taking root mean square (RMS), sum of all the residuals to compute the RMS error. And that becomes our total error which has to may be there which we have to manage.

So, manage means here that if we can achieve this root mean square value within spatial resolution of satellite image that is the best possible georeferencing one can achieve. Because beyond that you cannot have an accuracy. So, this value; the root mean square describes how consistent the transformation is between different control points or also links in like in ArcGIS.

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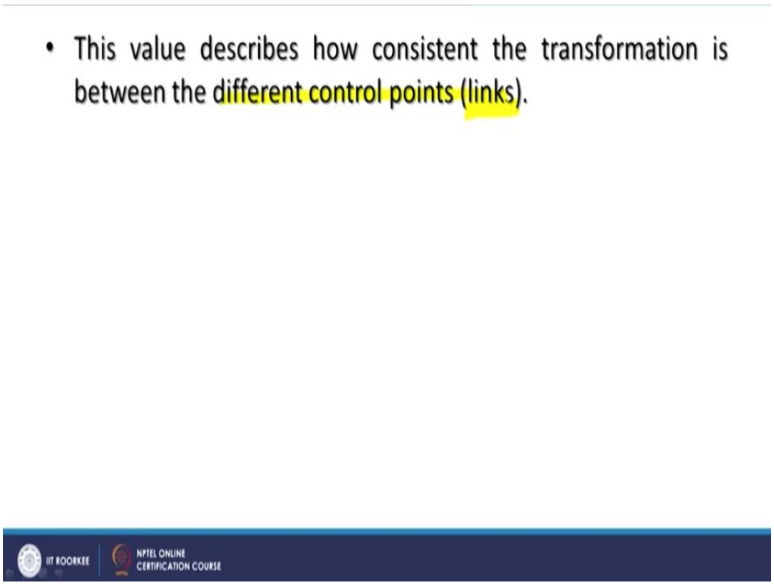

They also use word links between a slave map and master map; between input image and your target map. So, like here this link is shown here.

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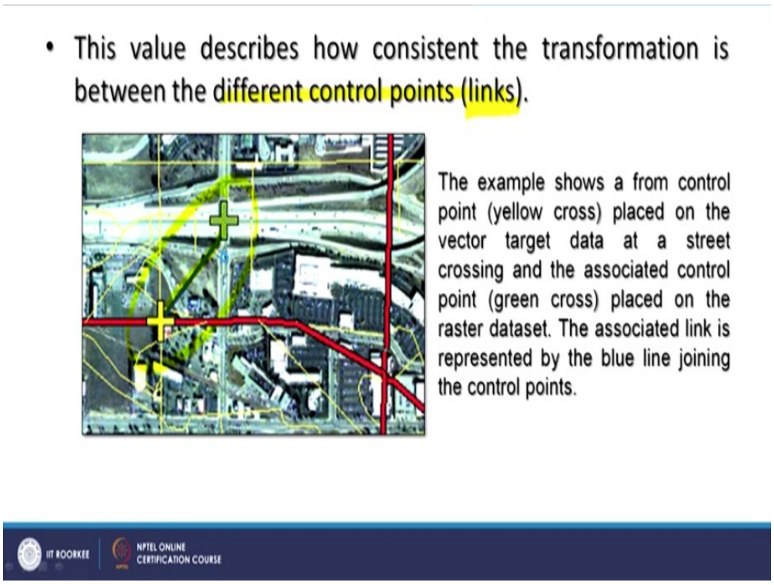

That this supposed to be here but it is there somewhere. So, this is showing. The example shows from a control point yellow cross placed on vector target data at a street crossing and associated control point that the green cross placed on the raster dataset. The associated link is represented by the blue line joining the control points. So, this is what it is. So, this much graphically this root mean square error is being displayed here.

So, if you are having say 20 points, any point which is showing the large value, automatically it is having you know major error or largest error and therefore because instead of going through the numbers, you can see graphically and you can rectify that issue there itself. As I have been saying also in case of GIS that error is very important part because error propagates in GIS. And I have said that after each and every operation in GIS, check for errors.

And if found, correct it then go for the next do not leave error for other to correct it. So, that is why here while doing the georeferencing or while doing this first step that is registration of ground control points or registration of GCPs of your input image to the master image. Whenever you see that any GCP is giving large error just remove it and recollect it or go for a new GCP.

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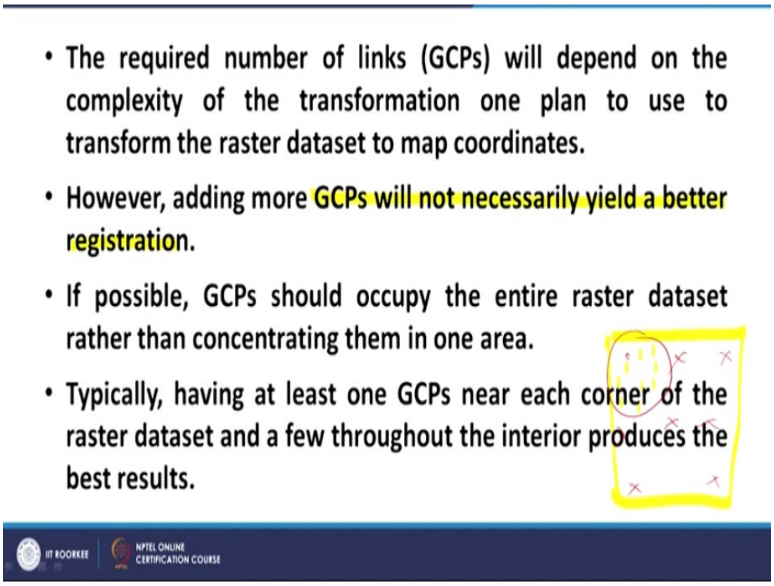

Now of course, the requirement of GCP will be depend on the complexity of transformation or order of polynomial. And how your image is? Like some drone images may be suffering from lot of distortions and therefore one has to be very-2 careful with those. Most of the satellite images as I have said would be corrected to large extent using just third order of polynomial.

So, adding more GCPs will not necessarily yield a better georeferencing that means like first order minimum, 3 are required or for second order, 6 are required. So, I suggested through my experience multiply by 3. But instead of if suppose 18 are required for second order and you keep collecting 50 that will not basically yield better registration or results. So, do not then waste your time.

Minimum 6 required for second order, maximum you can go to 18, 16 something like that. And also, one has to remember that GCP should occupy the entire raster dataset. But it means that if I am having this much area of image that means my all-control points should not be located here. They should be located in other places also. Like, I should have a control point here. I should have a here, here, here, here.

So, if possible GCP should occupy the entire raster dataset rather than concentrating in one area like here which is not good. And typically having at least one GCP near each corner. You know when I was drawing this you know drawing then I deliberately put all in 4 corners. So, one should try to put in the corners of the interior to get the best results. So, you start with corners then put in interior and think that you are handling a digital rubber sheet.

And in order to fit a rubber sheet from one domain to another, you start doing. This is an analogy. Let me give you analogy here before I move to the next point. If you might have observed how a shoemaker makes a shoe. So, he generally is having a flat sheet of leather and the same time he is having a wooden mould which is having a more or less shape of a you know shoe.

So, what he does that he takes first this flat leather sheets and he start putting that leather sheet through nails over that the wooden mould. And first generally what they will do? Either they will nail first at the toe side or on the heel side. So, suppose he has started from toe then the next he will pull and then he will do next at the heel then on the sides and slowly-2 then he will nail the entire leather over that wooden mould like this.

And so that it fits everywhere and then they provide the heat. And when this wooden mould is taken out of that curved leather sheet now then it is it will remain in the same shape as it was targeted. What we are doing? Almost exactly the same process we are doing. But we are doing digitally, instead of leather sheet we are having a distorted image which is in geometric domain.

And our mould is basically the master image or master map and these nails are nothing but the GCPs. So, GCP is like the shoemaker put nails all around; we should also do it, all around and also in the center. So, when we treat our input image as a rubber sheet then we can get better results like that. So, that is why I give this analogy. Lot of things say in science or other domain comes basically from observations.

So, one should be very you know interesting for taking such observations and try to correlate, find out the analogies in our which will provide the better understanding. Now let us come back to this discussion is that when error is particularly large; this root mean square(RMS) error.

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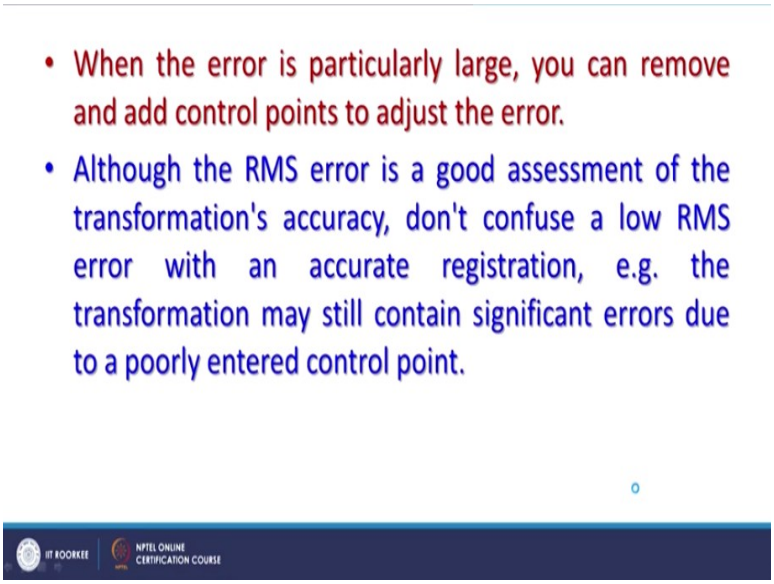

You can remove and add control points to adjust the error. Whenever you see a particular point is giving large error or out of say 20 points, 4 or 5 giving are large error remove them. And as you keep removing your root mean square value will also keep changing. So, although this RMS error is good assessment of transformations accuracy but do not confuse with a low RMS error with an accurate registration.

It is not necessary because the transformation may still contain significant errors due to poorly entered control points. If control points itself which are common between input and master image are different then there is a problem.

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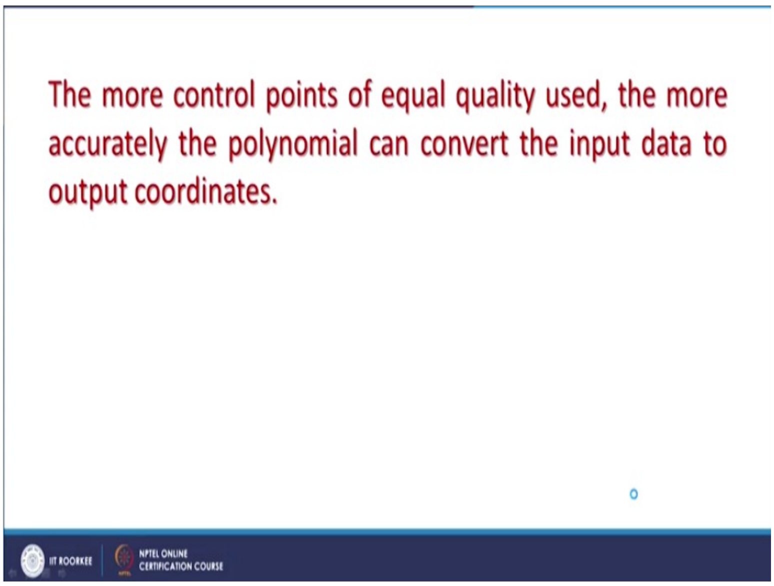

More control points of equal quality used the more accurately the polynomial can convert the input data to output coordinate.

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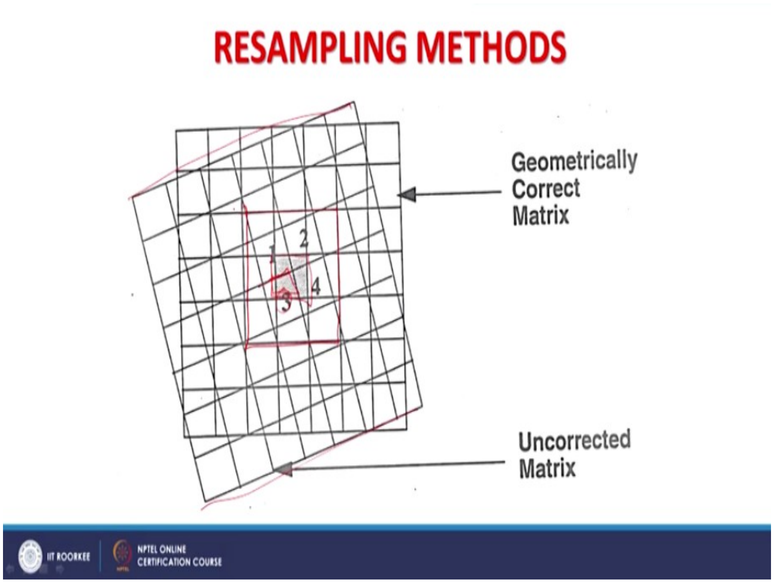

Now we come to the last part of this discussion of georeferencing that is resampling methods. Very quickly we will go through this. Now in the background what you are seeing is my sort of wire mesh which has to be filled with pixel values which would be coming from this image which is here uncorrected matrix. Now for each pixel which I have to transform from here to the master grid then what should be the pixel value.

So, let me explain first here then we will see further details. So, say for the center pixel, I want to transform to the target which is this one in my target grid then what I will do. Instead of doing anything, just take this value. Suppose this is 75-pixel value. So, the same 75 is assigned to this in this master grid. So, this value; supposes this is 75 this is assigned to my master pixel. Same way I will keep doing for others pixels also.

Now when this situation is not there and for example if I am having another way of doing this then what I can do? I can find out the weighted average. That this is you know, my target pixel area is this one whereas these 4 pixels which are overlapping with my target pixel in different way. So, one which is marked you know 3 here is occupying the largest area, this much and the other one accordingly which one is occupying.

So, I can use a weighted average concept that whichever is having the largest coverage will have the maximum influence for my target pixel. It is the Tobler's concept which we also discussed during this raster data compression techniques. And this Tobler's concept will also be discussed when we come to this interpolation techniques. So, whoever is occupying our nearest neighbor, whoever is having the maximum overlap will have maximum influence while deciding the new pixel value.

And then weighted average is taken and new pixel value is determined and given to the that location. And likewise, for each pixel, this way the calculation can be done. So, the first one where no changes are done and as it is the pixel value is transform is called nearest neighbour. The second one which I have just explained is called bilinear where only 4 surrounding pixels generally will be involved.

Now instead of taking 4, I can take 4 by 4 or 3 by 3 kind of this situation and then I will find out that which one is having maximum influence or which one is less. So, these 16 pixels of input image would be considered to decide a new pixel value for my target image. And this way this method or resampling is called cubic convolution. So, we will discuss in detail about these and pros and cons also very quickly.

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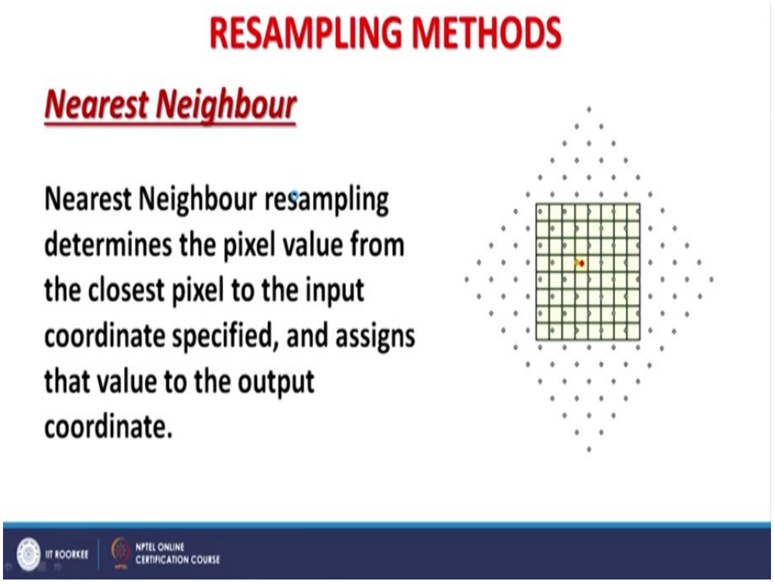

The nearest neighbour resampling determines the pixel value from the closest pixel to the input coordinate. As I told you that 3 in this one will have the maximum influence. So, that will carry forward to the new cell and that method is called nearest neighbour, also shown here.

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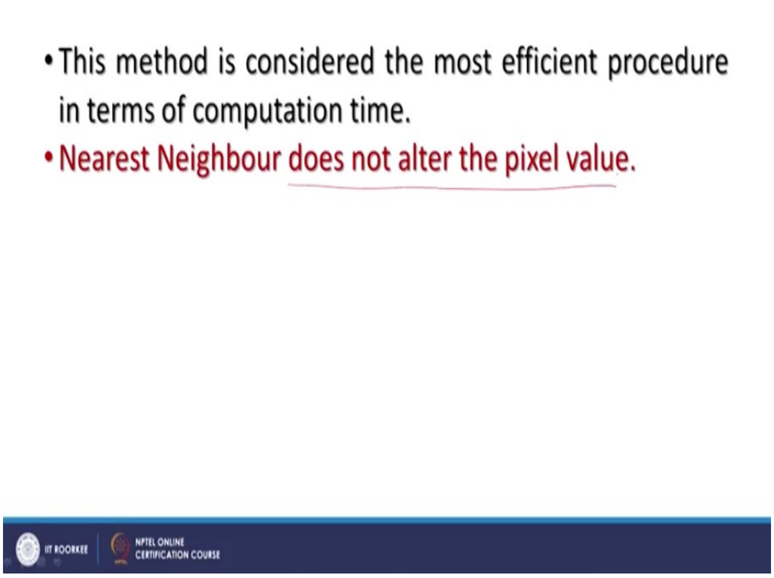

Now this method is the considered the most efficient procedure in terms of computer time because no further calculation is required. Just reading the pixel value and giving to a blank grid. And therefore, there will not be any modification in the quality of input image. Sometimes we have to keep the intact the quality because if we do not want to compromise with the quality of image then nearest neighbour resampling method is the best. However, there are some problems. This is the advantage that does not alter the pixel values.

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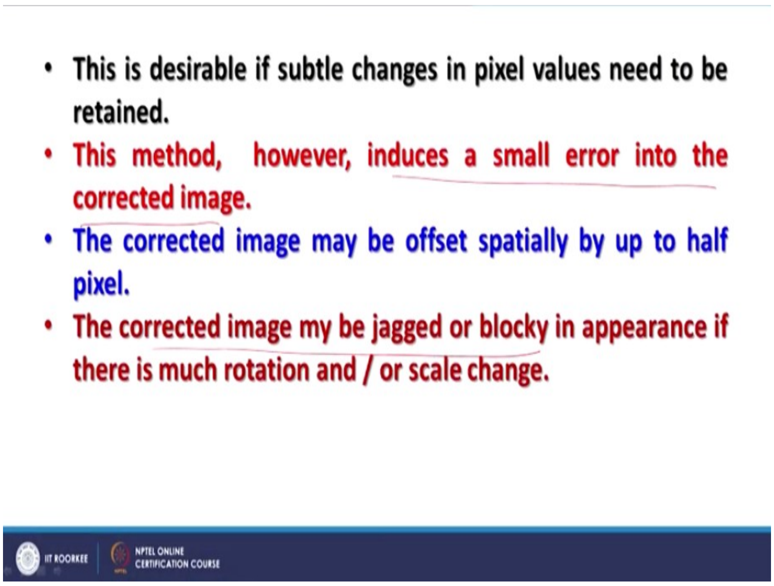

But there may be some errors like into the corrected image because of jagged felling it will be or stair steps kind of thing. So, corrected image may be offset especially by up to half pixel. So, from georeferencing point of view that may not be very accurate approach of resampling. But from image quality point of view, it is the best approach. Now this there is a tradeoff. You are losing little bit georeferencing quality.

But the same time you are keeping intact the image quality. So, you have to decide depending for which you are going to use such data. And as I have already said that this corrected image will have the jagged or blocky appearance sometimes if it is coarse resolution.

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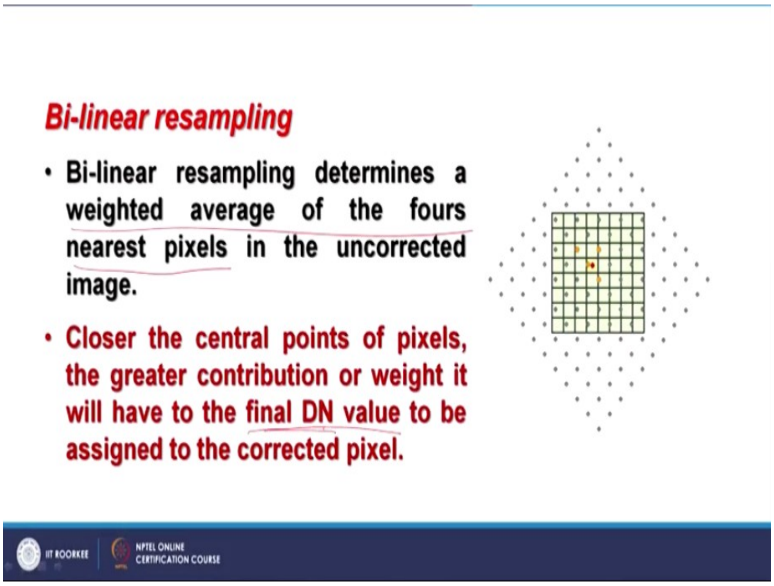

But if it is reasonably high-resolution images such issue will not come. Now the next method is the bilinear method. As I have already discussed that it will take the weighted average of the nearest 4 pixels of the uncorrected image and then will assign the new value to the final DN value or digital number or pixel value. So, the closer the center point of the pixels the greater contribution or weight it will have.

So, whichever the point which will occupy or having the less distance will have the maximum influence. This also happens in real life also. Even in case of corona. So, this concept is there. This is Tobler's theorem. Now there are advantages, disadvantages. So, in this technique also that bilinear sampling will generate a smoother appearance though jagged issue may not come as we have been discussing in case of nearest neighbour.

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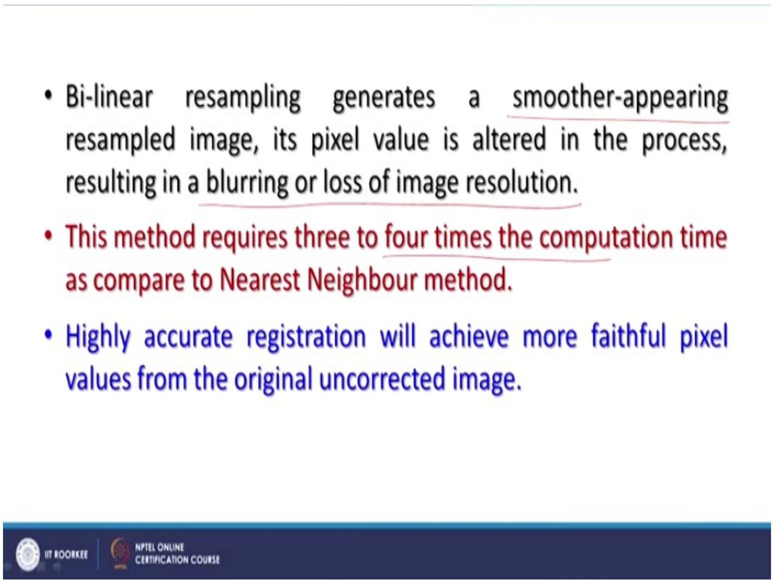

So, this will produce a very smooth appearance image but may be blurring or loss of image resolution. So, what it is doing? It is though providing better you know geographic accuracy or georeferencing accuracy. But the same time, it is reducing the image quality. So, you say compromise between georeferencing accuracy and image quality. So, you have to choose again as per requirements.

If you are ready to lose the image quality little bit but you do not want to compromise on the georeferencing accuracy then this method is quite good. Now as you can imagine that it has to take the weighted average of 4 surrounding pixels and therefore generally the computation time, it might be 4 times. See for small images you know 30 second extra here and there does not matter.

But when we are handling large images then one has to be very-2 careful about deciding these techniques. And highly accurate registration of course, will achieve more faithful pixel values from original uncorrected image. This is true in all the cases.

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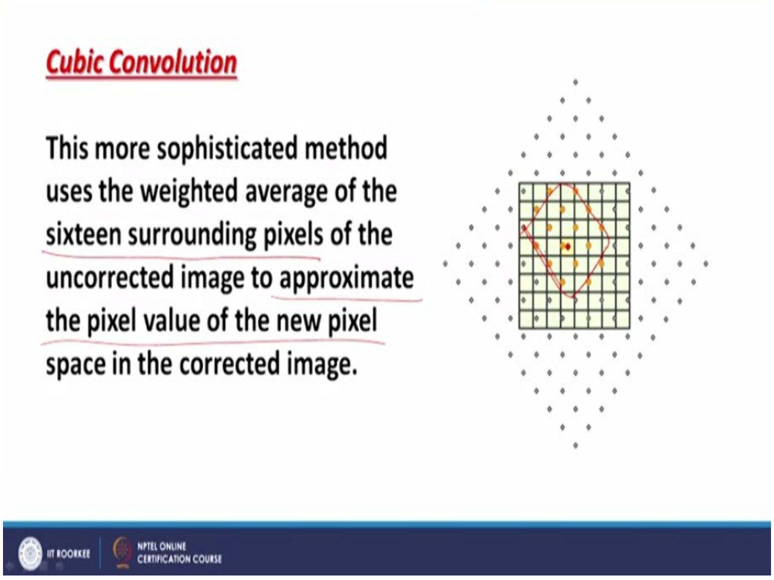

Now last this technique is cubic convolution in which we are involving now 16 surrounding pixels of uncorrected image to approximate or estimate the pixel value of the new pixel in the corrected space. And by which like here all these orange dots which are shown here, they are all considered for the new pixel value. What are the advantages?

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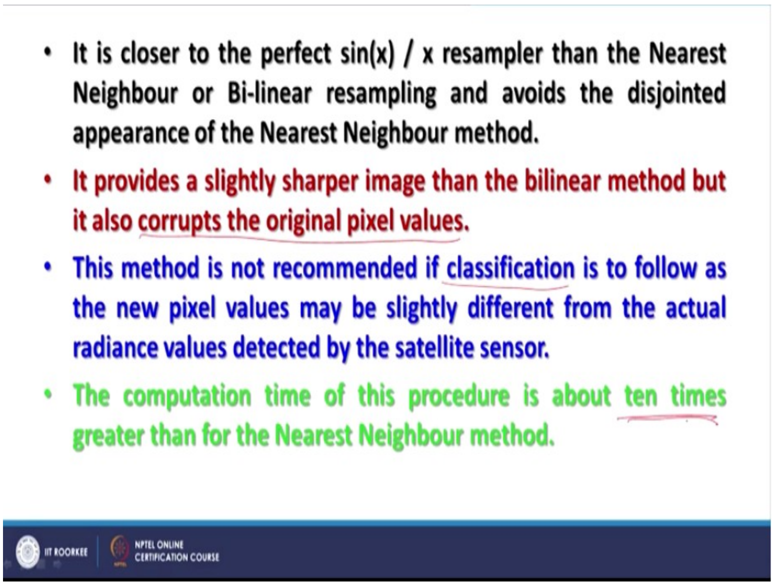

That it is closer to the perfect sin(x)/x resampler then the nearest neighbour or bilinear sampling and avoids disjointed appearance of the nearest neighbour. This jagged or disjointed appearance which might be possible in coarse resolution images if they are subjected to nearest neighbour, those things will not be seen in cubic convolution.

Of course, it is modifying your original pixel value. Basically, it will corrupt your original pixel value. So, it is more harsh word here that it will corrupt your pixel value to a large extent because in order to drive a new pixel value, 16 surrounding pixel values are considered depending on the distance and then calculations are done. So, again judicious you know statement has to be there or as per requirements that what you are basically trying to do with the output.

So, if you are going for classification that is image classification then I would not suggest that you should go for cubic convolution, not even for bilinear then do not compromise on the quality of image and do not corrupt your original pixel values. Just keep them intact and go for nearest neighbour method. And of course, computation time compared to other 2 techniques are going to be much more.

Compared to nearest neighbour, it may be more than 10 times. Compared to your bilinear, maybe 4 to 6 times. So, that is very-2 important. One has to be very judicious in entire process which polynomial order, how much ground control points and then which resampling techniques one need to adopt.

So, with this though this have been little longer but in order to complete the discussion and keep everything in one presentation, one lecture, I thought that I will exceed the limit. But anyway, I hope you must have enjoyed this discussion. This is my very favorite you know subject within the GIS. Thank you very much.