Geographic Information Systems
Prof. A. K. Saraf
Department of Earth Sciences
Indian Institute of Technology-Roorkee

Lecture-36
Various Techniques to Generate Digital Elevation Models-1/3

Hello everyone! and welcome to a new discussion which we are going to have on various techniques to generate digital elevation models, and this is in 3 parts, so let us discuss the first one.

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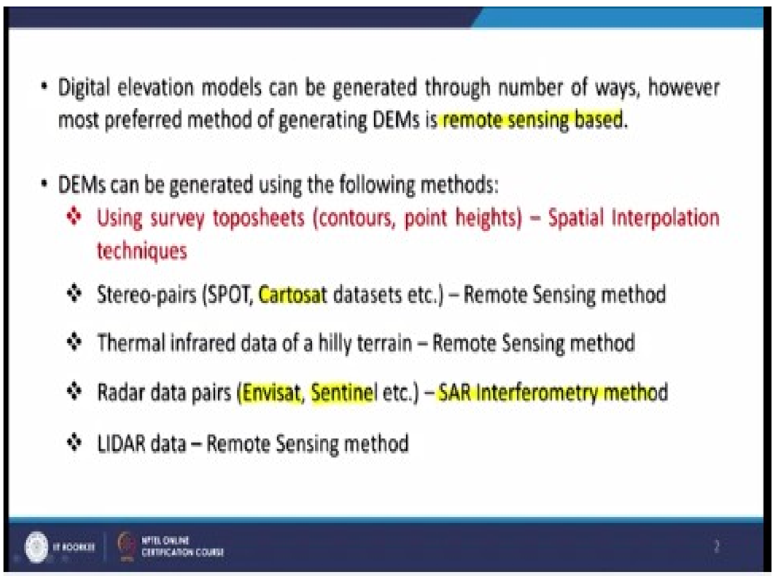

As you know that digital elevation model can be generated using various techniques and whatever the known techniques so far, we will be discussing one after another into these 3 discussions. And most preferred method nowadays is, which is based on remote sensing. Because ground-based technique is really very difficult, and it is very challenging in sense that there are many areas which are inaccessible to humans.

And some terrains are very difficult to cover on a vehicle or foot and therefore the best preferred method nowadays is generating digital elevation models which is based on remote sensing. So, whatever the methods which we are going to discuss so far, which are known also in the research domain or in literature. That is the earlier method which we used to have is about using survey toposheets or topographical maps.

And basically, using from these maps either point heights which are also available or contour lines. And as you know that contour lines are basically polylines made from several nodes and internodes. So, using those nodes or node points, we can do the special interpolation and various interpolation techniques which we have discussed under that topic.

And where the input is generally a point data, point thing or point vector data. So, contours can be converted to point or nowadays many softwares are capable of converting them within the software, in the background (you do not know on the screen) or you can use the point heights or data coming from other sources maybe GNSS, differential GNSS (Differential Global Navigation Satellite network) data or the data can come from other sources also. So, it does not matter.

As long as we are having point heights or contour lines, we can imply spatial interpolation techniques which are many and can generate digital elevation models. Though here in these methods it is among second but among remote sensing method, this is the first technique which was developed and it is started with the SPOT.

Earlier we use to have stereo pairs of aerial photographs but not a stereo pair acquired by satellites. So, this is SPOT which was a French satellite and launched in 80s and that has brought a new paradigm shift in case of a generation of digital elevation models employing stereo pairs. So, that was the first satellite which started providing stereo pairs and using them and implying photogrammetric techniques it became possible to generate digital elevation models.

Also, as you know that India is having our own satellite like Cartosat which was really innovative in many senses and designed for this purpose. Why I said innovative? Because SPOT used to take from say day 1 with the 1 different angle and on day 2 again the same area whenever there is overpass the same area used to be covered by a different angle. Because for stereo pairs the basic requirement that the same area should be covered with 2 different angles.

And these angles, if they are same then photogrammetric techniques can easily generate digital elevation models. So, in CartoSat what it was done? Because in case of a SPOT suppose on day 1 the sky was very clear and on day 2 when it is revisiting the same area with different angle, now there is clouds, so the entire pair used to go bad. Whereas in Cartosat the innovation was done that instead of looking sidewise, it is started looking forward and backward.

So, on the same day, at the same time, almost at the same time the stereo pair could be generated. And therefore, we can use that data which is about 5-meter resolution that means you can generate digital elevation models of about that resolution without much problem, again implying the photogrammetric technique. So, the advantage of forward and backward looking is, that these weather conditions will not change.

So, if in one scene there is a cloud, in another scene also it would be a cloud but if it is clear in one scene, it is highly likely that the another one will also be clear. So, Cartosat has really provided a great impact for the development of a digital elevation models. And also, if you visit the BHUVAN portal of NRSA, which is part of ISRO you can also download high resolution digital elevation models which has been generated now for entire India and they are available free of cost also.

And then few years back, when we started getting these thermal infrared data especially from NOAA AVHRR, though NOAA AVHRR sensor provides the thermal data at 1 kilometer resolution but the technique provided the insight, that how a digital elevation model can also be generated using thermal infrared data. And especially of hilly terrain which is most difficult for other techniques where many techniques may fail for a hilly terrain like Himalayas.

But this thermal infrared-based technique works very well; we will be discussing further on this with some examples. And now the other technique which has brought really a revolution in case of digital elevation model availability at a global scale was from the SAR interferometry method or InSAR we say in shorts. And this started basically with the SRTM (Shuttle Radar Topographic Mission) that was a mission for about 16 days.

And during that time 80% of the globe was covered and this radar data pairs were generated and then SAR interferometry technique was employed and initially they provided 90-meter resolution digital elevation model for entire globe except for polar regions. Later on, 30-meter spatial resolution SRTM DEM on global scale is also available.

But for countries like America or Canada, they can have even much higher, but when you go for downloading the data of SRTM there are various portals and during this course we will also be discussing that from where you can get the data? and how you can download the data? So, when you go for this SRTM data you may find that instead of writing a 90-meter resolution or a 30-meter resolution, they write 3 arcs second or 1 arc second respectively.

So, 3 arc second roughly equals to 90-meter and 1 arc second equals to about 30-meter. So, I mentioned this because some people may get confused that I talked here in 90-meter and 30-meter, but on the portals, you are finding 3 arc second and 1 arc second. So, it is not 3-meters or 1 meter; 3 arc second means 90 meter roughly. Now these radar pairs also later became available from a satellite called Envisat which is a European satellite and also from satellite Sentinel, which is also European satellite.

And ALOS PALSAR and one more satellite which is started the SAR interferometry also RADARSAT of Canada. So, many such satellites especially in the microwave region of EM spectrum started providing radar data pairs and we have employed these to generate digital elevation models using this SAR interferometry technique. And definitely resolutions also started improving since then.

Now latest method is based on the LIDAR data and again it is also a remote sensing method. Earlier the development has taken place, which was for the ground-based 3D mapping and now the satellites are coming with LIDAR sensors and they can provide LIDAR data as well. So, there are at least 5-6 methods which are available for generating digital elevation models and which are completely based on the remote sensing.

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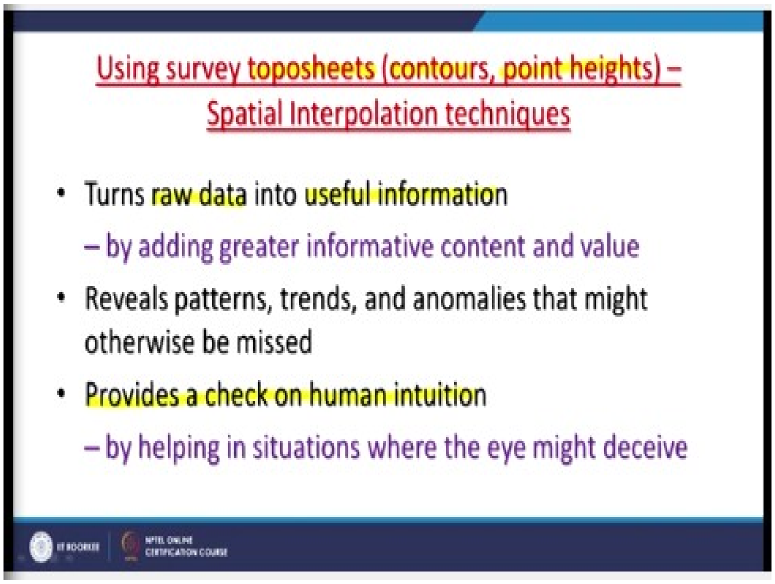

Now, one by one we start discussing all in these 3 lectures. So, the first one is based on the survey toposheets, using contours or point heights and spatial interpolation techniques. So, from this perspective, I am discussing little bit about spatial interpolation also. As you know that interpolation techniques, basically they turn the raw data into useful information, raw data here is the point heights.

So, if you see a point height data, you do not get much information or you cannot have a recognition of a pattern or anomaly any other such thing. But if you develop surface using interpolation techniques, then that raw data or point data becomes a very useful information. So, this is the advantage of implying interpolation techniques, this becomes more informative content. And also Reveals patterns, trends, anomalies that I have just mentioned, otherwise in simple by looking point data, you may have missed this.

And also, it provides a check on human intuition because it is based on mathematical things. So, nothing like that one person is perceiving something another one is not. In this case, it is a check on human intuition and sometime in the point data where we can miss some anomalies but here you can really get good details about the data through these surfaces which is interpolated surfaces.

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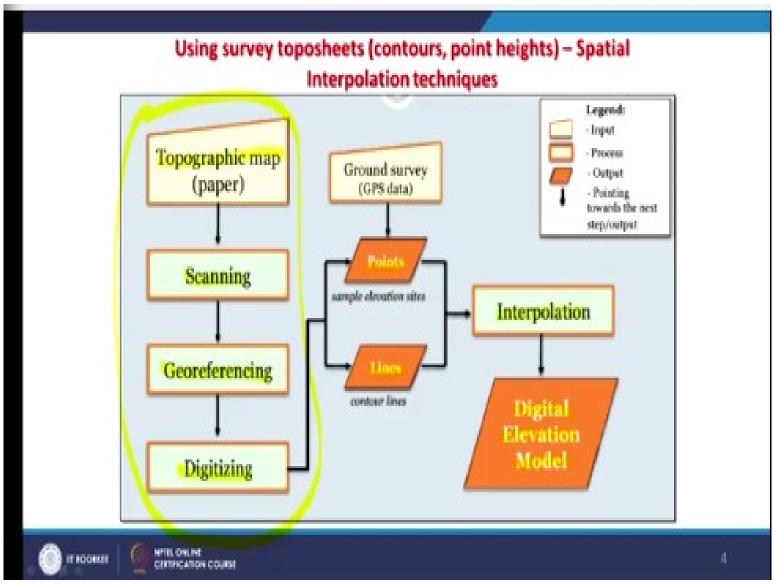

So, if we imply a survey topo sheets like here in this flowchart it is shown. Generally, these used to be in paper form and still they are popular in paper form. So, first these have to be scanned, that I also discussed when we did the geo referencing of a toposheet. So, at that time I have mentioned, that we have found through our iteration or and experience, and if I have to handle a 50,000 scale topo sheet, then scanning at 300 DPI dots per inch would be optimum and there is no need for going 600 DPI or 1200 DPI. Because by going for very higher DPI that may result a very huge file but no benefits in terms of quality. Because whatever is printed on the paper, if it is in poor quality, no matter how good resolution you are having, sometimes it may not bring good results.

And you have also seen this part while we discuss geo referencing, because deliberately I did geo referencing on toposheet. So, there will be that link, so first you have to do the geo referencing of the scanned toposheet that becomes basically your raster. And then you can digitize different features which are present in a topo sheet for example maybe contour lines, maybe point heights, maybe stream network, drainage network, maybe road network, maybe rail network and so on.

So, there are about 8 themes which are presented or printed on a topographic map and all of these can be digitized. Since a decade, now we have started getting digital toposheets also in different layers. So, there is a separate layer for contour, for point height and for drainage network. So, if digital things are available, then this left side flow chart that means this much will not be required at all and we will have a very good data available.

We can imply these point data or line data or both, and directly can do the spatial interpolation and can develop a digital elevation model. So, it depends, in what format you are going to have the data for this kind of generation or DEM implying to toposheet. If you are having digital toposheets, it is really wonderful, this is what we desire. But if it is not, then you have to follow these 4 steps basically, rather 3 steps first and then you do that one.

Also, for geo referencing you can use the GPS data to collect the GCP's ground control points or maybe using GPS you can update some information on the map, if it is required. And then digital elevation models can be generated, if already digital data is being provided then of course your interpolation or digital elevation model will have relatively high accuracy compared to manual methods.

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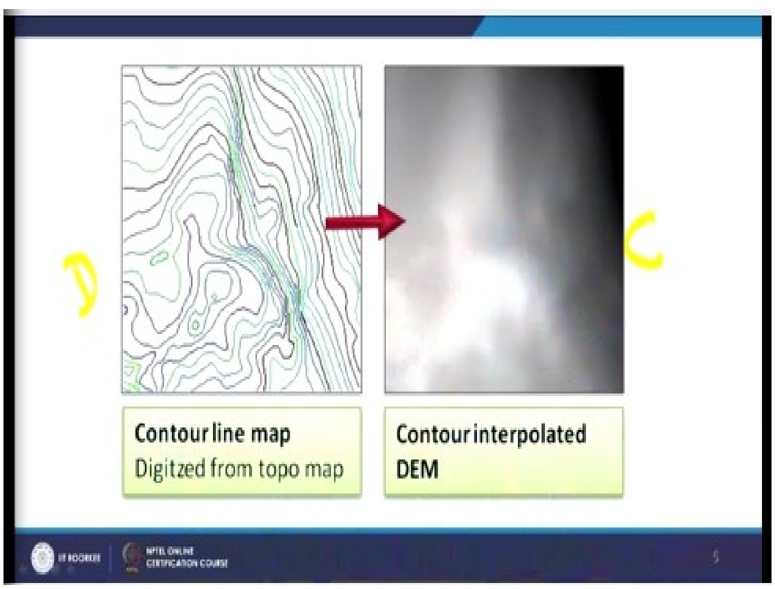

This is just example; in the left image we are seeing the contour lines which are digitized from topographic maps or topo maps and by implying these contour lines we can generate a digital elevation model. So, from the discrete we get a continuous surface. This way, we can definitely generate a digital elevation model.

When we did not have the satellite based or remote sensing-based techniques for generating digital elevation model, these were the only techniques available for us and we generate it. One example in the previous demonstration I have brought about the USGS topographic maps. So, these USGS topographic maps were also generated implying 250000 survey topo sheets of almost entire globe.

So, the contours which were printed on those 250000 topo sheets, were digitized manually and then some appropriate interpolation techniques were employed. And for entire globe at 1-kilometer spatial resolution, digital elevation model was developed by USGS. So, this technique is well established techniques sometimes when we do not get high resolution digital elevation model for a small area.

But we are having at the same time a survey toposheets; we can definitely use that one and can do the digitization. One more point which I want to mention here, that earlier for digitization we used to imply hardware which used to be called digitizer. Like for scanning you need a scanner, a big scanner or flatbed scanner or rolling scanner. But for digitization there used to be a digitizer like a big table. And nowadays, we do not use those peripherals but now after this scanning and geo referencing, we can directly digitize on our screen.

So, the techniques have developed so much, that from that manual kind of digitization, now we can go on screen digitization or also sometimes in literature you will find a little fancy word that is head up or heads up digitization, where you do not look downward, where you look towards the screen.

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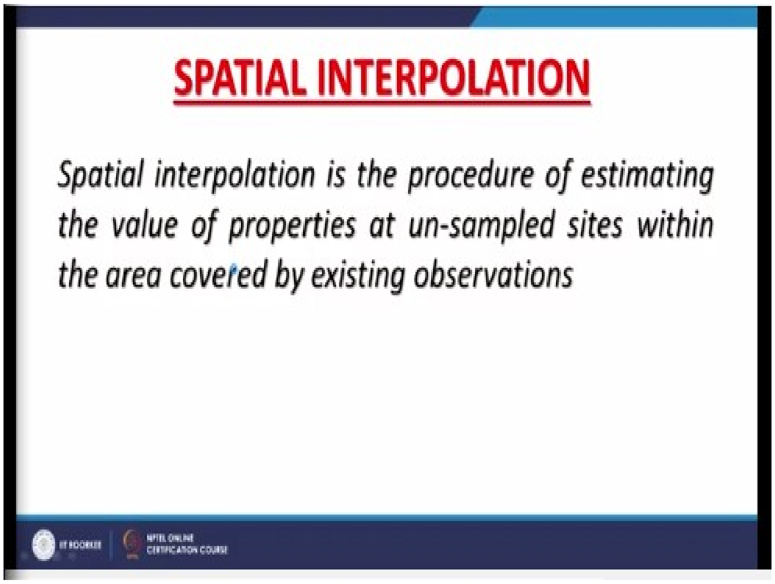

Now as you know that a spatial interpolation is the procedure of estimating the values of properties and properties here are elevations when we are discussing digital elevation model. So, value of elevations at un-sampled sites within the area covered by existing observations, as you also know that these contours are interpolated from point data. So, in the field, especially while making these survey toposheets only the point heights is collected or that data is collected.

And then later on the contours are generated. So, contours are interpolated from point data. So, using those informations, we can definitely go for a spatial interpolation.

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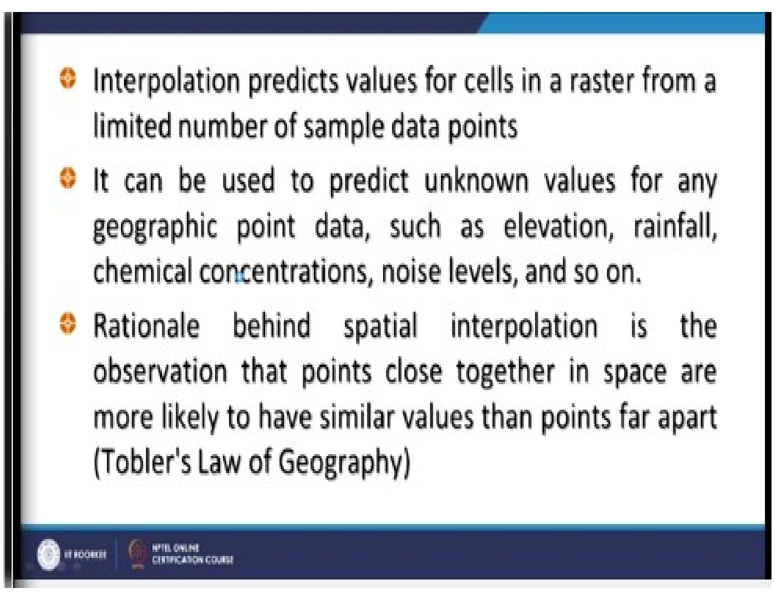

As you also know, this we have also discussed while discussing this topic of spatial interpolation that basically interpolation estimates or predict values for the cell and, of course, it is a raster, from a limited number of sample data points. Because for every location you do not have the observations, so whatever the observation, whatever the number of points, you can still imply them and in this spatial interpolation and still you can generate a digital elevation model to some accuracy.

And basically, it predicts unknown values for any geographic point data and since your raster is a regular grid, is a continuous. So, for each cell there will be a prediction or evaluation, if elevation values are being used or some other properties like rainfall, chemical concentration, noise levels, pH and so on and so forth. Second as you know that the purpose here is, rationale behind the spatial interpolation is the observation that point close in a space are more likely to have similar values than points far apart.

And this Tobler's law of geography, is basically implied extensively in spatial interpolation and because the point which is very close to observations will have more influence while doing the prediction in spatial interpolation, then the point which is very far or cell which is very far.

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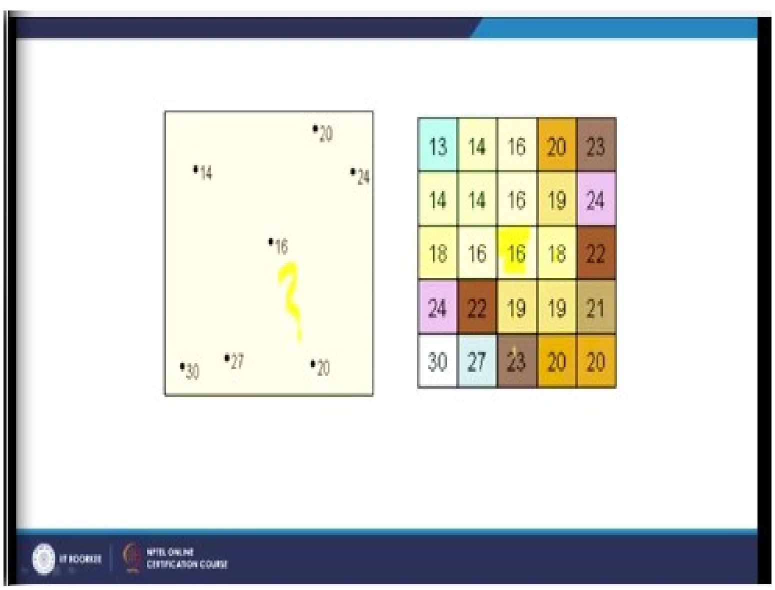

For example, here I am having just 7 points and these points are also having some values, assume that these are elevation values, implying these points and using spatial interpolation techniques, a surface can be generated like this. So, in between like for point 16 it has created a cell here 16 and it has also created a cell for 20. Now but in between, we do not have any observation here. But because of interpolation it is filling those values and getting influence of the nearest neighbour or following the Tobler's law of geography.

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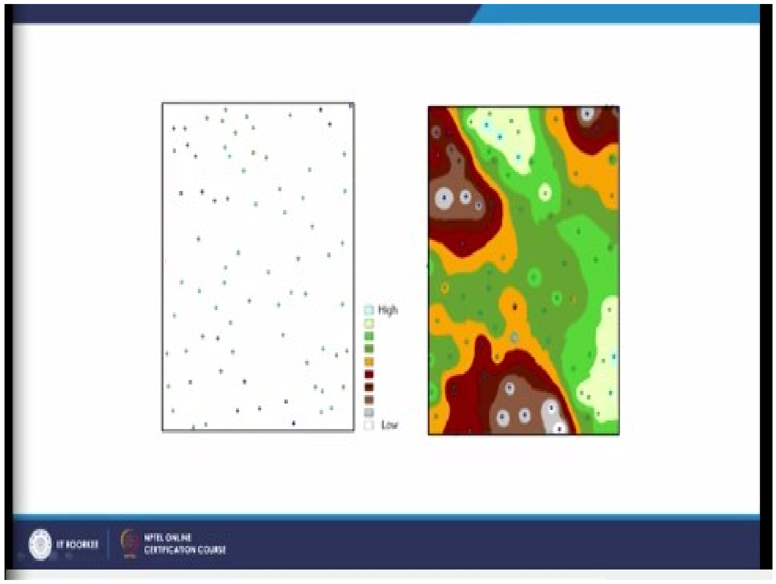

Similarly, there are now instead of 7 there are about 60-70 points and again if the density of points or density of observations is very high obviously you are going to have a better prediction or better highly accurate digital elevation model. But if you are having just few points as input for a spatial interpolation the level of confidence in your output may not be as high as in this case.

So, one has to remember if possible, bring as much as observation or bring as much as points possible before interpolation. So that if you are having more observations, it is likely that you will get high accuracy. Now as you know that digital elevation model is a surface and a surface is continuous.

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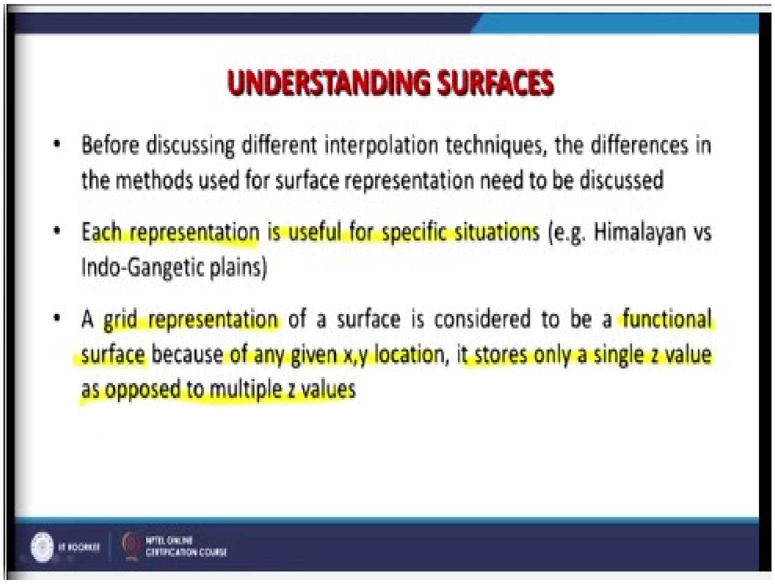

And what your interpolation is doing, basically it is creating the surface. And therefore, better understanding about the surface is very much required. So, here what we are going to discuss that each representation or surface representation is useful for a specific situation, what it means basically? If I am going for Himalayan terrain digital elevation model, then the same technique may not be useful as it is good for plain area like Indo-Gangetic plain.

So, we must understand or we should have a prior information about the area or the ruggedness of the terrain. So, that knowledge will always help us to choose appropriate spatial interpolation technique and different variants of those. Obviously, this is always true for whether you are having plain area like Indo-Gangetic plain or you are having Himalayan terrain that more observations will always bring better results.

So, also this digital elevation model is a grid representation, as a surface is a raster. And this can be used or considered as a functional surface because at any given location for example x and y, it stores only a single attribute or single value that is z value. So, it cannot store multiple z values, so you can say that this is the drawback in that sense, but at the end it is not truly a drawback.

Because you can still have multiple z values in different layers for the same area, for the same x, y location. So, you can have different themes, suppose on one surface, I am having for elevation or truly a digital elevation model, on another surface I am having for groundwater or rainfall, another surface I am having for pH value, no problem. So, that means, in each of these layers, I will have different z values.

So, still I can carry multiple z values and in any spatial analysis, I can involve multiple layers at one time, so there I can. So, by a media by which we can definitely get multiple z values, otherwise in a single grid file you will have only single attribute. If it is a typical digital elevation model, you would have only elevation value as cell value. Now, these functional surfaces are as you know continuous surfaces.

So, the advantage here is that a lot of mathematical techniques which have been developed for these functional surfaces can be directly employed in our domain that is for analysis and creating new derivatives of digital elevation model. So, in future lectures, we will be discussing how various derivatives can be generated using this functional surface a digital elevation model.

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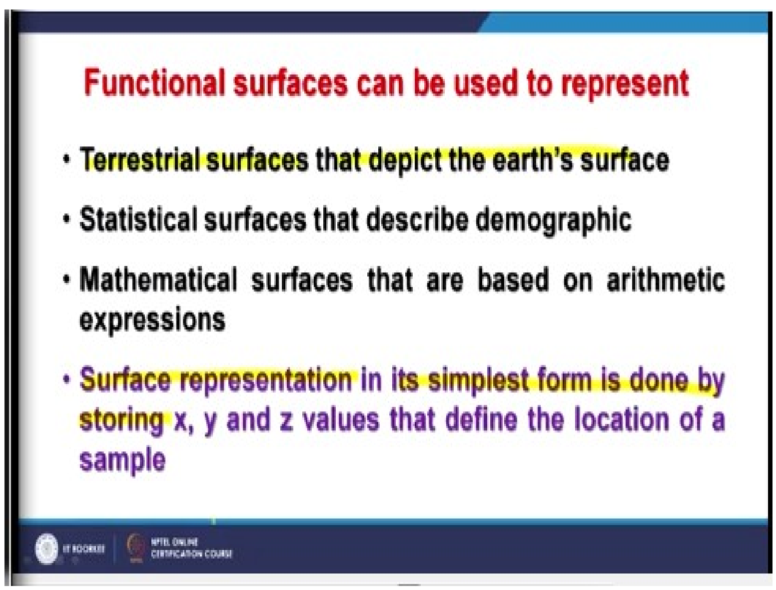

So, as you know that when we talk about typical digital elevation model then it is basically representing the terrestrial surface or terrain and basically depicting the earth surface, statistical surfaces that describe demographic that is also in that sense is a raster and is a functional surface. So, statistical techniques which have been developed there can also be implied in our domain.

Mathematical surfaces that are based on arithmetic operations expressions, those too we can imply and then this surface representation is the best way to represent the form which is storing x, y and z values, that define the location of a sample. Recall, in vector data, we can have multiple attributes for each point each polyline or polygon. But in case of raster for each cell we can have only single attribute.

So, that is why it is a simple, so when we have been discussing about comparison between vector and raster, we made a statement or we developed an understanding that raster structure is simpler to understand, to use also, as compared to the vector data because it is in the simplest form, what is that form from mathematical point of view is a just 2-dimensional matrix.

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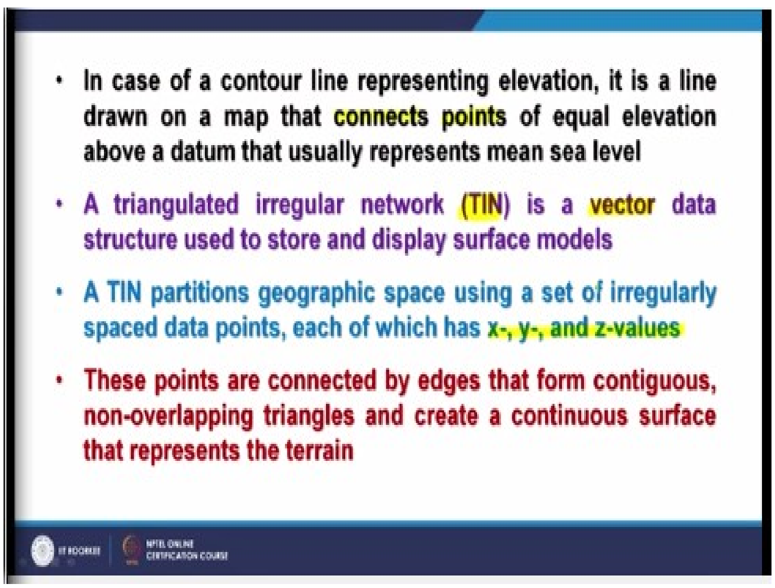

If we are using contour lines representing elevation, then as you know that these lines are drawn using points and these polylines basically connects those points or equal elevation or iso heights. And generally, when we talk about elevation, this point also we discussed in earlier lectures that generally in case of elevation it is measured above mean sea level. Now there is another surface which we have discussed.

So, one surface representation is possible from vector that is implying contour lines, one surface representation is from raster that is a typical digital elevation model and the third type of surface representation is possible implying the TIN. Though here it is mentioned vector data surface but truly it is not, this is neither vector nor raster. But it is in some way it is quite close to vector. So, sometimes we also mentioned that one.

Now as you know that TIN is a triangulated irregular surface and there are a lot of facets which are in form of triangles and they basically partition the entire terrain based on our observations, input points x, y and z values. So, what we find ultimately in a TIN, is irregularly spaced data points and these data points are used to create an irregular network of triangles. Now these points which we use, say for the same point data can be used for generating a digital elevation model, a typical raster surface or the same points can also be used to generate a TIN.

So, when we will see the demonstration that time, we will see 2 ways of generating digital elevation models using the same point. And these points in TIN basically, they connect the edges and which then forms the contiguous, non-overlapping (this is very important) and create a continuous surface that represents the terrain, so terrain can also be represented using TIN.

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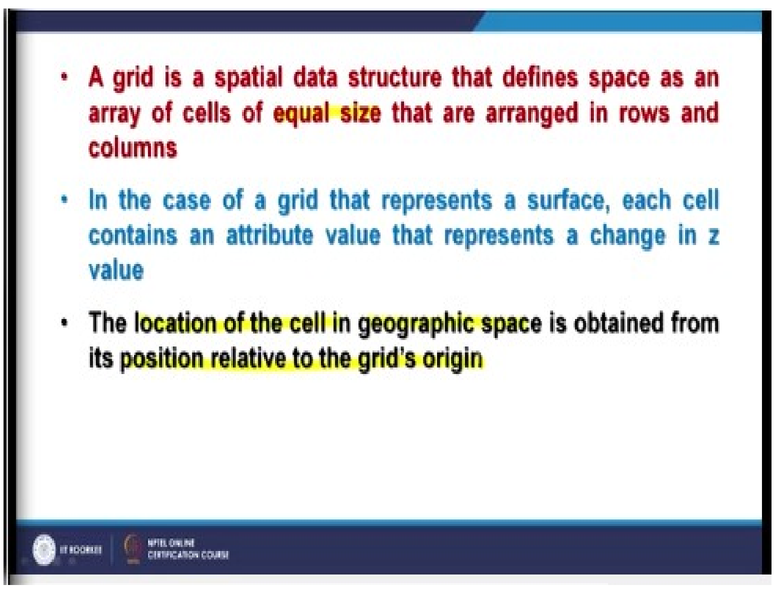

Now in raster as you know that the grid is the spatial data structure, which is part of raster and define space as an array of cells of equal size or a square shape and square shape are arranged in rows and columns. And in case of grid representation, each cell contains a single attribute value and generally in typical digital elevation model that is the z value and whereas, we can also have some other properties also.

And the location of these each cell in geographic space can or in terms of latitude, longitude or easting-northing can be obtained from position relative to grid origin. So, if the grid is geo reference, then you would get the geographic coordinates.

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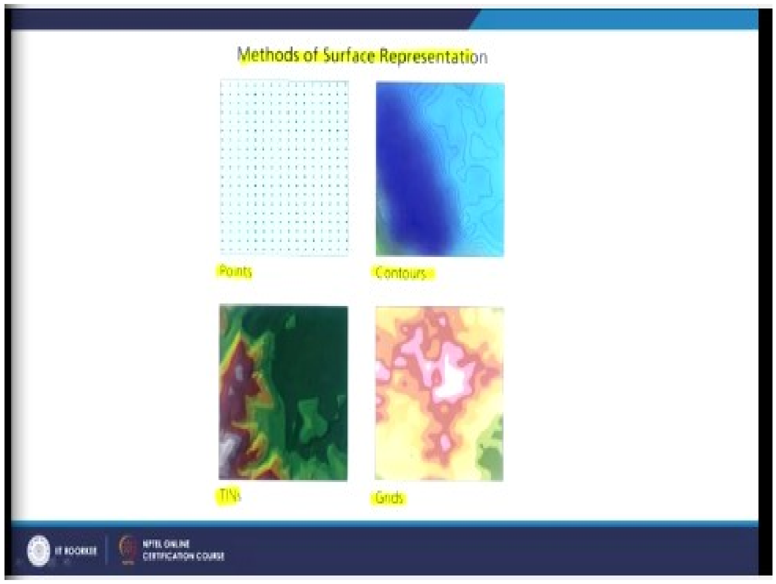

If it is still in geometric domain, you would get geometric coordinate. So, generally if you download the digital elevation model whichever the free digital elevation models, which are available from different portals based on different techniques, all of them are nowadays geo reference. So, for each point location or each cell location, you not only get the z value but you also get x and y in terms of latitude longitude.

Now methods of surface representation in nutshell, a point becomes basically input just looking points, though here it is systematic collection of point but still, it does not give any feeling of the surface or neither pattern or anomalies which are present about a particular property. Whereas contours can give you a feeling of a terrain or a surface but the most appropriate surface representations are through either grid, like after interpolations in form of raster or TIN which you see here which we have just discussed and that is triangulated irregular network.

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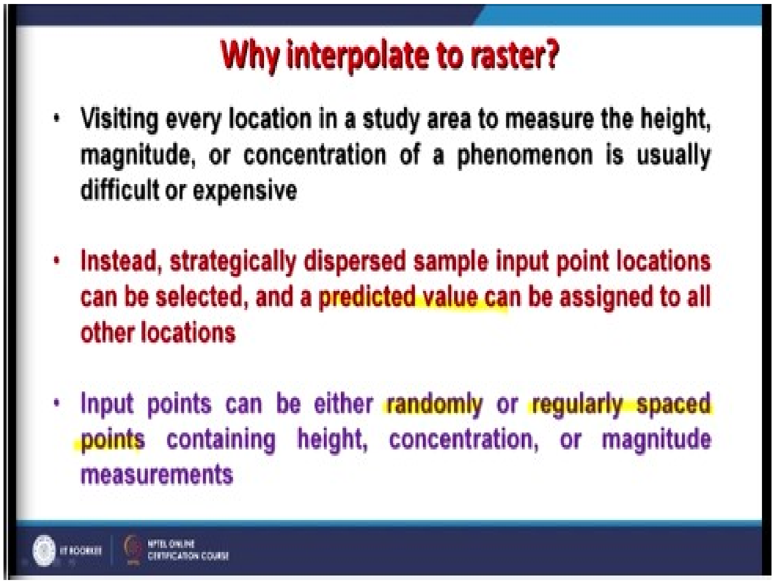

This part also we have discussed in length while discussing this spatial interpolation but since we are discussing how to generate a digital elevation models, implying interpolation and data is coming generally from toposheets. So, for that point of view, I will very quickly go through that visiting every location on the surface of the earth and collecting the height information is impossible.

Because there are terrains which are very-2 difficult for humans and it is not possible to generate a surface for entire globe. So, some techniques have to be employed. So, one technique is wherever it is possible collect the heights, imply the interpolation techniques and generate a surface or predict values for each cell, that is what we are doing in interpolation or, of course, as you know that interpolation starts with a belief and if you do not have that belief, that things are what it is predicting?

Then the only solution is to go and check in the field if it is possible. If it is not, then you have to rely on some interpolation techniques. In one other previous example, we have seen a systematic or regularly spaced points were there. But generally, it is not possible in real sense even if you are using survey toposheets and you have already digitized these point heights, they would be basically distributed randomly.

And if these are not distributed randomly or if you are not having regularly spaced points, these regularly spaced points are near impossible and then at one end, if the points between 1 topo sheets point are only located in one corner, these for heights and if you imply that one for a spatial interpolation, you may get very poor results regarding accuracy.

So, the requirement here when we provide the points that they should be distributed randomly not in clustered form or regularly spaced, of course, is not possible. So, if that is there, then definitely we can create a better digital elevation model rather than using points which are clustered in one corner or in some part of your toposheet. As you know that interpolation assumes something, and that because it is based on that belief, which I have said.

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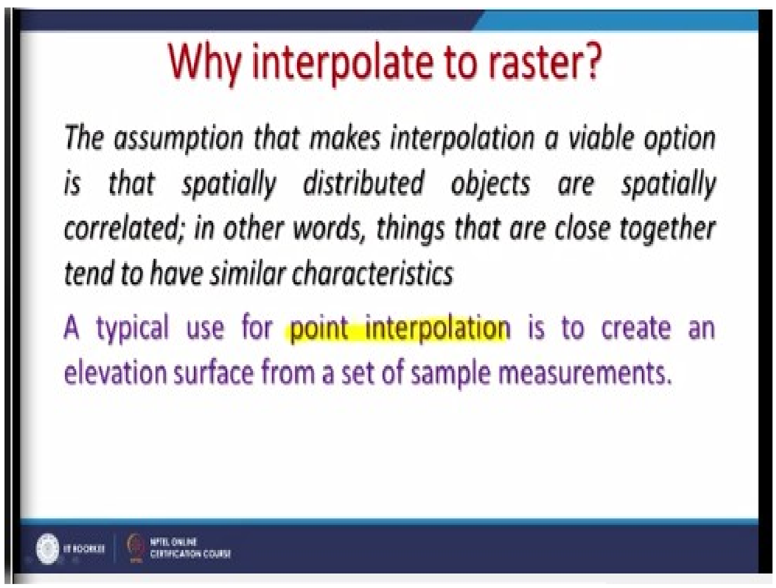

So, the assumption that makes interpolation a viable option is that a spatially distributed objects are spatially correlated or auto correlated. In other words, that thing which are close together tend to have similar characteristics, that is the Tobler's law of geography and this is what it is exploited in interpolation. So, generally though we say spatial interpolation, but in general it is also a point interpolation.

And which is used to create a surface where measurements are not possible and there might be some issues about the interpolations, the accuracy part. So, few times in this discussion, I have already mentioned that how accuracy gets influenced by our input data. So, if input data is having a high density and input data is distributed in space randomly, you have chosen a correct interpolation technique, you may get a very high accurate digital elevation model.

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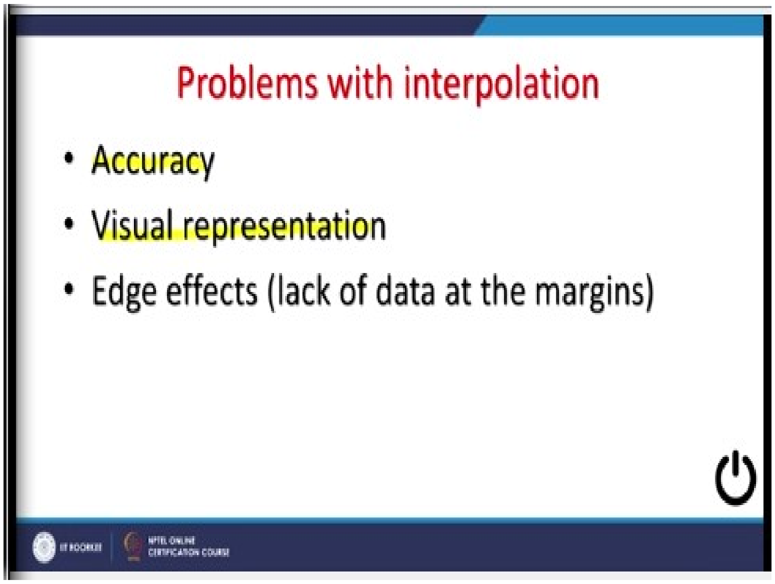

In future lectures, we will also discuss how to check that whether my digital elevation model implying a particular, a spatial interpolation technique is really accurate, that part can also be checked. Visual representations or visual checking is also possible; edge effects sometimes because on the boundary area you may not have observations and therefore it is going for extrapolation and that may bring again accuracy issues.

So, these are some issues or problems with the interpolations, otherwise, it is extensively used to generate digital elevation models implying either point data or polyline data like contours. So, with this I end this discussion, thank you very much.