Computer Graphics
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Lecture - 4
CRT Display Devices

Hello everybody, and welcome back to the lecture on Computer Graphics. In the last couple of lectures we have been discussing about display devices specifically about CRT monitors. And I said earlier that there are three types of CRT monitors; the DVST, the random scan and the raster or the raster refresh raster scan. We have discussed about raster refresh quit at length and we continue in this lecture also. And if you recollect, what we have been doing in the last class is, specifically to do with the refresh raster scan it is different from the random scan or the DVST in the sense that those where line drawing stroke or command lines and in this case it was point drawing. So we came to know how to draw points on the screen.

We have also seen the architecture of the typical graster graphic system in terms of video controller, display processor, frame buffer, monitor and things like that. Of course, in addition to the keyboard, mouse, CPU and system box which a typical computer system will have. We had seen the internals of a video controller which takes in the input from the frame buffer in terms of the intensities of the pixel and it keeps on generating voltages for the horizontal and vertical deflection plates to make the beam move from right to left, down, below and also go back. We will talk about the retrace later on today. And at each point it must know what is the intensity of each pixel, based on that, it must control the intensity of the beam which is firing the spot on the screen.

We have seen internals of the video controller, we have also seen in the mechanism of drawing points as well as lines. Remember, a curve line and a straight line is also drawn on the screen in the case of a refresh or a raster scan by basically joining or drawing a set of points and this gives rise to the effect of what is called stair casing, jaggies or aliasing effect of a line.

In general, we have that effect except for very special cases of a line we will typically have the effect of aliasing of a line so we had seen that. We have also seen the memorizes requirement in terms of the frame buffer memory required by the video controller or display processor and we had seen the increasing size requirement of the frame buffer as the value of n that is the number of bits assigned for a single pixel or a point on the screen. If n is equal to 1 we call it as a big plane and we have a pure black and white image whereas in the case of n is increasing from 1 to 3 to 8 let us say we typically start having different colors or grey shades or a combination of both and also n can be raised to about 16, 24 or even 32 resolutions as considered to about 512/512, 1024/1024. But you go beyond that 1280, 1024 or even 1700 into 1800, then very high resolution monitors are also available which will require frame buffer sizes which is in the order of several mega bytes.

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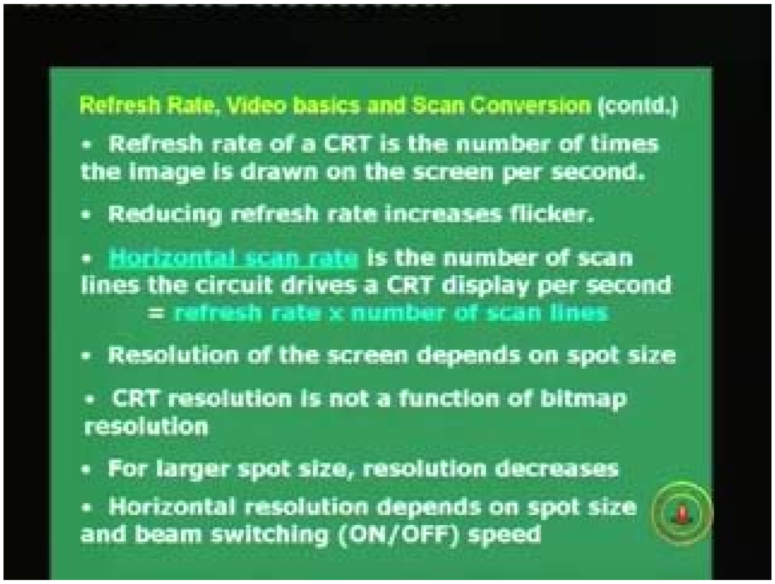

Refresh Rate, Video basics and Scan Conversion (contd.)

- Refresh rate of a CRT is the number of times the image is drawn on the screen per second.
- Reducing refresh rate increases flicker.
- Horizontal scan rate is the number of scan lines the circuit drives a CRT display per second = refresh rate x number of scan lines
- Resolution of the screen depends on spot size
- CRT resolution is not a function of bitmap resolution
- For larger spot size, resolution decreases
- Horizontal resolution depends on spot size and beam switching (ON/OFF) speed

If you look back into the last screen which we visited in last slide, we were talking about concepts of refresh rates, video basics and scan conversion. Just to keep the continuity I will go through this slide once again. We talked about the refresh rate of a CRT as given in the first line here or refresh rate of a CRT is the number of times the image is drawn on the screen per second. And we had seen that the minimum recommended rate is 30 hertz per second. But you should provide about 60 hertz per second or if possible more for a flicker free display that means the user does not feel an iteration of the picture which is flickering on the screen because we know that the next line says that the reducing the refresh rate increases the flicker in the screen so that is very natural. And the third line states that the 'horizontal scan rate' the term we are coining here is the number of scan lines in the circuit. That means the video controller basically drives a CRT display per second and it is basically the refresh rate multiplied by the number of horizontal scanlines.

The important part in the lower part of this frame as you see here is the resolution. What you mean by resolution? Resolution of the screen does not depend upon the system you are using which is the graphical card of the computer graphic system. It entirely depends on the monitor at the screen which we are using and which in turn depends on this physical dimension of the very small spot size on the screen. As we go along we will see about what do mean by spot size or the pixel size on the screen, we will see figures on that soon. But the resolution on the screen depends on the spot size.

The CRT resolution is not a function of the bitmap resolution which the programmer can set so we have to find out what is the maximum resolution a screen can support and corresponding to that he has to say the resolution of the frame buffer and draw his picture accordingly. He can never in fact draw a larger resolution picture on a smaller resolution screen. Well, the software can handle such effect of zooming which we will see later on. But typically if you try to draw 1024 points on a screen which has only 640/480 points in horizontal and vertical directions respectively you will never be able to do so. So you must know the resolution. The system supports and gives you the maximum resolution it can support. And if you want to have a larger spot size on the screen automatically the resolution comes down that means typically high resolution monitors have very very small spot sizes but it is of a finite small dimension.

The last point is the horizontal resolution which also depends on the spot size as well as the beam switching speed. This is a new term which we will see today. We will see what beam switching is. It means the rate at which the beam should turn on and off. You know why the beam has to be turned on and off. You remember the previous figure, in the previous slide as the beam was taken from the left of the screen to the right of the screen you had to put points on the screen. So, depending on the number of points which you have to draw on the screen for a horizontal scanline the beam has to be turned on that many times depending upon the number of points which you have on the screen and of course you have to switch it off that many times as well. So you have to switch on the beam as well as switch it off depending upon the number of points you have on a horizontal scanline. Let us talk more about that in the next slide as we continue our discussion on refresh rate, video basics and scan conversion. We talk of the bandwidth of a display.

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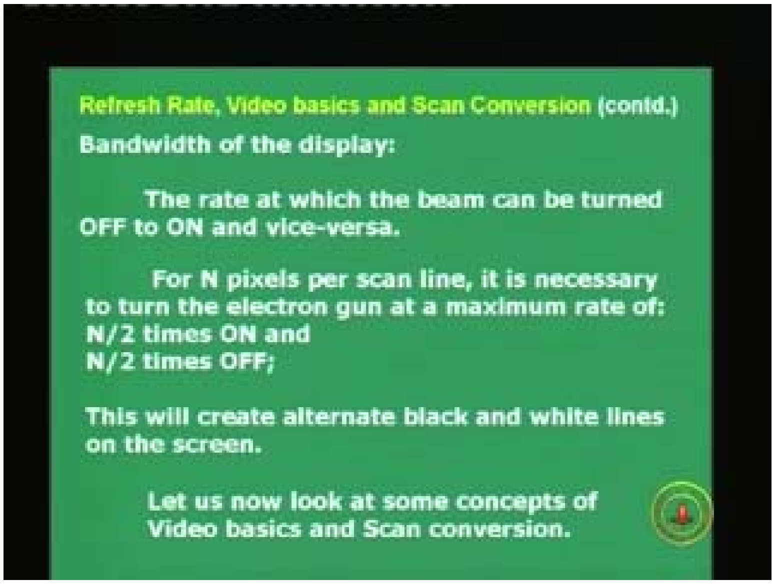

Refresh Rate, Video basics and Scan Conversion (contd.)

Bandwidth of the display:

The rate at which the beam can be turned OFF to ON and vice-versa.

For N pixels per scan line, it is necessary to turn the electron gun at a maximum rate of:
N/2 times ON and
N/2 times OFF;

This will create alternate black and white lines on the screen.

Let us now look at some concepts of Video basics and Scan conversion.

Typically the bandwidth terminology comes from signal processing theory. It typically talks of a range of frequencies which the system can support or you can visualize it to be the maximum frequency which the system can support. We talk about frequency that means the rate automatically comes somewhere and the bandwidth of the display is defined in this case of the rate at which the beam can be turned off to on and vice versa. I repeat the rate at which the beam can be turned off to on and vice versa means of course on which depends on the number of points you actually have on an individual scanline.

Let us take an example. If you have n pixels per scanline that is dictated by the resolution of the screen then it could be 512 or 640 or 1024 or even 1280. These are the typical values let us say for standard monitors per scanline that is the n pixels per scanline. It is necessary at the maximum to turn the electron gun at a maximum rate at the bandwidth of the display. So we are talking of the maximum rate at which the electron gun has to be switched on and off in the worst possible case it had to be turned on n by two times half of the resolution of the scanline n pixels. So, if you want alternate pixels to be on and off for n pixels per scanline you have to turn on the beam n by two times that means there are 512 pixels or points on the screen, you might have to do it 256 times on and 256 times off to cover alternate 512 pixels where alternate points will be white and alternate points will be black. And if you keep doing this for all horizontal scanlines what this will create you can almost imagine that the first pixel is white, the second pixel is black, the next pixel is white, white, black and so on alternately this goes on.

For each scanline this same pattern is repeated you typically have a texture pattern which is called I will say that you will start to visualize alternate vertical black and white lines on the screen. So I said here if you turned on the beam N by two times off and N by two times on this will create alternate black and white lines on the screen and it is at this situation you have the maximum rate at which the beam has to be turned off and on. That could be defined as the bandwidth of the display. Let us now look at some other concepts of video basics and scan conversion which are necessary for calculation of this bandwidth and also it is related to the memory size because memory size related by the value of n. This is the typical example of a raster scan highly simplified but just to illustrate you what the raster scan mechanism means.

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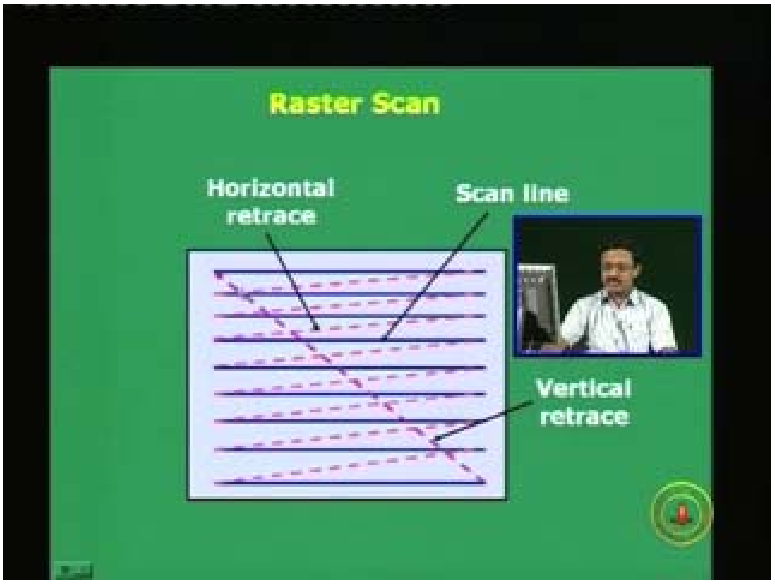

Raster Scan

The blue lines, blue horizontal continues lines are the scanlines. So just one example given here on the screen where there are about 1, 2, 3, 4, 5, 6, 7, 8, 9 so I take a very simple example just to show 9 horizontal scanlines as continuous blue lines. Those are the horizontal lines or which the beam will move. And once it starts let us take the first line as you start from the top left corner it scans and which is the top right the beam has to go back, the beam has to go back and start to scan once again from left to right. Again it goes back from right to left and again it goes to right. You can see as we are doing this for one cycle going forward and back this little bit of incremental displacement keeps happening in the vertical direction.

In some cases you will also find that when you move the horizontal scan from left to right in the screen that is also inclined but if that is not inclined definitely the red dashed line, discontinuous dashed line which you see is marked as horizontal retrace. The horizontal retrace can path which takes the beam from the right hand corner to the left hand corner is called the horizontal retrace. That means you have a horizontal scanline then a horizontal retrace back again horizontal scanline and again horizontal retrace back so these goes on for n such horizontal lines. In this figure is a very simple example we have taken where n is 9 but it typically should be few 100 to a 1000 or more. So these keep going on for n number of lines to the end of the last cycle.

What will happen is you will reach the bottom most part of the screen somewhere here, that is the horizontal scan line will take you there. You do not need a horizontal retrace here because there is no line beyond the last blue line of the last horizontal scan line. You basically need to go back, why do you need to go back? Remember, refresh rate, and remember refreshing which is necessary for flicker free display and which is necessary for the persistence of the password. The sort persistent of the password demands that you keep visiting the pixel at a very fast rate typically 30 to 60 hertz. So you need a mechanism by which the beam will now go back from the bottom right to the top left of the screen. And this path which is shown by slightly pinkish dashed line discontinuous line is called the vertical retrace. So that is called the vertical retrace, the vertical retrace takes the beam from your bottom right of the screen to the top left.

As you are watching this picture your bottom right will be here, top left will be here you keep on scanning horizontal scan, horizontal retrace, horizontal scan, horizontal retrace, horizontal scan, horizontal retrace. We will see an animation of this very soon with a simplified picture not with the slide. But as you are finished with your last horizontal scan at the bottom of the picture at the bottom of the screen you do not need to make the beam do a horizontal retrace any more because that is unnecessary. You need not do that because there is no line visible beyond this last horizontal line and it is new to basically refresh. To do the refresh from the bottom right of the screen you need to take the beam back to the top right and that is called diagonally the vertical retrace.

So, for horizontal scan, horizontal retrace, horizontal scan, horizontal retrace and so on till the end of the last line bottom right you need a vertical retrace. So you can now imagine the horizontal and vertical deflection plate voltages or voltages to be applied to the horizontal and vertical deflection plates which will make the beam move very fast horizontally retrace, horizontal retrace and so on. At the end you need both voltages to change in a linear manner such that the beam moves from the bottom right to the top left so that both the reflection plate voltages must be active to do that.

When you are just doing a pure horizontal scan may be the horizontal deflection voltages are important you do not need a vertical deflection voltage to change in this direction. the beam is only traversing in the horizontal deflection voltages at the horizontal deflection plates which is essentially vertical we discussed about this earlier which is important which makes the beam move then again this is important when we retrace it back and at that retrace there is an incremental movement in the vertical direction the vertical deflection place also have a role to play at that point of time. It is switched on and at the end when you move for the entire vertical retraces both plates must play a role to make the beam move very fast from top down to bottom up on the screen.

So, coming back to this picture that is the mechanism of this raster scan we have horizontal scan blue lines, I repeat again; horizontal retrace dashed red line discontinuous one and a vertical retrace diagonally across which is given by the dashed line also. The arrow the vertical retrace shows in the path in which it is moving. Continuing with this picture let us take some basic video standards. Typically there are two video standards NTSC and PAL. NTSC is the American standard and Pal is European standard. In India we typically have the PAL standard video but I just have an example from the NTSC which is the American standard video which has 525 horizontal scanlines with a frame rate of about 30 frames per second. That is prescribed for video in the terms of TV transmission. Monitors will definitely have a larger frame rate. And the viewing aspect ratio is 4:3. So you can imagine the number of scanlines and the number of pixel per scanline will be different because the aspect ratio is not 1:1 but 4:3. Each frame this is interesting and different.

The first time we are introducing the concept of what are called the fields. Each frame has two fields which cover half of the picture. Now this half of the picture does not mean that you cover only the first half then the bottom half. These fields within each frame, there are two fields in each frame and these fields are interlaced. We will see that. So these fields are interlaced or interwoven and we see in the picture what do you mean by this interlaced or interwoven of fields. Each field is consisting of half the picture means half the number of total scanlines in each frame. Fields are presented alternately every 1/60-th of a second.

Since we talk about 30 frames per second that means you are talking of 30 hertz. Each frame being presented 30 times per second and each frame consists of two fields not successively let us assume there are two fields, field A and field B and both these frames must be present in one frame or they must be presented or scanned for each frame. So, if you doing the frame 30 times per second and there are two fields so 30 into 2 gives you 60 fields per second that means each field must be presented on the screen at the rate of 60 times per second or the field is basically standard 1/60-th of a second. That is the way in fact the sentence should be, the fields are presented alternately every other 1/60-th of a second so that is the correct way of talking about it. So, it is 1/60-th of a second one field and 1/60-th of a second for the second field and so on. This will go 60 times when you cover the field that when we have basically covered 30 times, the frame.

One field contains odd scan lines. If I number the horizontal scanlines in terms of starting from 0, 1, 2, 3 in digital world or 1, 2, 3, 4 in whatever way I say odd scanlines 1, 3, 5, 7 and so on are the odd scanlines corresponding to one field and second we have the other field which contains the even scanlines, you can start from 0 or you have taken the number from 1 but you can always say 0, 2, 4, 6, 8 strictly 0 is neither anyway an odd but if you have the numbering starting from 0 you can take that to be a part of the even scan field 0, 2, 4, 6, 8 and so on and so that is the even field.

We have the odd field with odd numbering scanlines and even field with even scanlines. Now you can see what they mean by the fields as interlaced or interwoven so when you covering one field you do not cover two fields simultaneously you finish one field go to the other field. So when you finishing one field or scanning one field basically it means that you are moving from scanline one to scanline 3 to scanline 5 and so on and finish that field come back to the next field and start from scanline 0, 2, 4, 6 and so on. So it is alternatively merged two interlaced, the scanlines are interwoven this is the even field let us say that is the odd field and they are interlaced in terms of horizontal scanline. You scan by 1, 3, 5, 7 and so on. And in the odd field and the even field you take 0, 2, 4, 6, 8 and so on so they are just interlaced.

We will see the picture of what they mean by interlacing or interwoven of these corresponding fields. And you see that now we need to have two types of retrace for each field because the same retracing will not work for both the fields. This is the picture which will probably show the interlacing action that is the small yellow gun on the left hand side of the screen on the beam will be coming out of the gun and scanning the horizontal scanlines.

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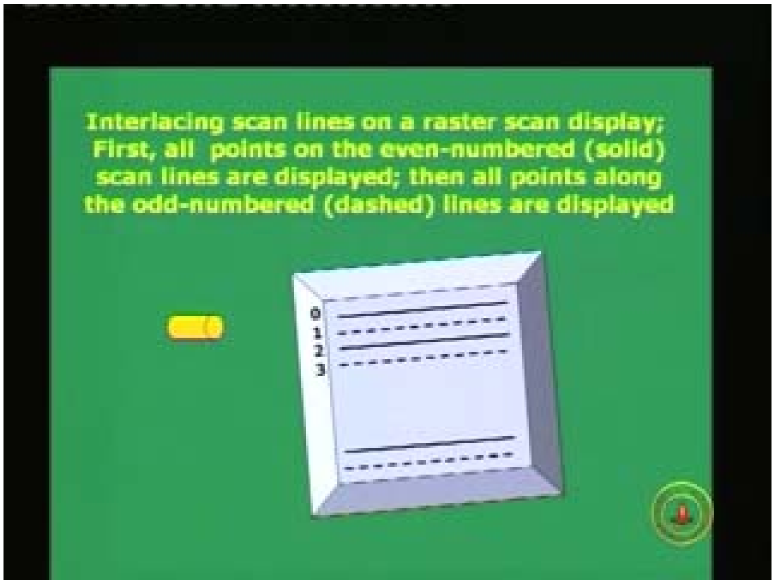

Interlacing scan lines on a raster scan display; First, all points on the even-numbered (solid) scan lines are displayed; then all points along the odd-numbered (dashed) lines are displayed

The interlacing scanlines or raster scan display is shown here. First all the points on the even number which are marked as 0, 2 then 4 and so on are solid, scanlines are displayed and they will be scanned and then all points on the odd number or dashed lines are displayed. The dash discontinuous lines are the odd number lines 1, 3, 5, 7 and so on and so that is the way to finish. So you will finish the odd and even or start with the even and then finish the odd. And of course at the end you are at the bottom right of the screen that is what we show. So the mechanism or retrace is not straightforward it is consistory similar to what we discussed about retrace. But since there are two fields now we will see what this mean.

Let us take a schematic diagram of a 7 line just to simplify the case because if I have taken 512 lines I could not have accommodated on a screen although the screen which you are seeing will consist of 640/480 lines or 512 or 1024 depending upon a TV monitor or a high resolution CRT monitor. But I cannot show so many lines so I have taken a very simple example to show how the scan is done in every alternate field. So we have taken a schematic of a 7 line interlaced scanline pattern and let us see what happens. Let us take this as a screen all that appears field but let us say it is completely pitch dark black, nothing is there and we start scanning.

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Schematic of a 7-line interlaced scan line pattern.

We start scanning with the line. At the top right if you can see there is a half horizontal scanline starting from the top middle of the screen and is going to the right. I will redraw it again; here you see, it is coming from the top middle of the screen then scanning and finishing at the top right somewhere. So that is a half scanline being drawn. We will see why it is like that and why it starts with half. Once we finish the entire cycle of both the fields this will be apparently very very clear. Go to the top right, you need a retrace back so now the retrace will come that is the retrace line. That is the horizontal retrace line for a particular field so this could be an odd field or even field does not matter you can take it to be anything.

Let us take this as any field so something like a 0 scanline, scan half of it half of the screen and then full horizontal retrace which is given by this dashed discontinuous line with somewhat of approximately about grey or a brown color and is what you see and this goes on. So the next horizontal scanline will be full starting from the finishing point of the retrace horizontal retrace to the extreme right so these arrow marks are also shown, remember this is going at a very fast rate but I am marking it very slowly that you can feel what is going on so you keep doing this horizontal scan and now it is inclined. Both the vertical retrace and the horizontal scanlines are purposefully made to that the circuit design for the video controller in terms of implementing the horizontal deflection voltages and vertical deflection voltages are made very easy.

Sometimes in most occasions we have the horizontal scan also inclined little bit to the right almost in a similar slope like the horizontal retrace so this goes on so again horizontal retraces come, again a horizontal scan for a particular if the blue lines correspond to horizontal scanlines for only one particular field so this could be some odd number or even number of line. So you are skipping one line. You can see that the gap is very large that means the other alternate scanlines for the other field is untouched in this case and that will come once this field is over and again a retrace back.

Now let us assume that we have drawn about 3 1/2 lines that typically makes it up because we discussed about 7 lines of display 7/2 in each field that makes 3 1/2 lines so we have drawn 3 ½ lines and typically finished one field. We have finished drawing one field on the screen and we have reached the bottom right. Now what do you need? You need typically a retrace back a vertical retrace back and it is almost diagonal.

We can see I am going to drawn on the screen, it will come up, the vertical retrace which will take the beam now which is on the bottom right of the screen we will keep it back to somewhere on the top left. Let us see how this beam traversal path for the vertical retrace, that is the one, I hope this will be visible and the arrow indicator shows that the beam is not taken back by vertical retrace diagonal across this. This is very easy. We have seen this diagram almost earlier except this field part which is basically known. Now remember, it is stopped at a particular location ready to draw a horizontal scanline, the first of the other alternate field.

Remember, 3 1/2 lines of field A or field one which consists of even lines 0, 2, 4, 6 are over. So I am talking about the alternate field to start and it will start in this form. I have used a different color with an arrow mark to show you the first horizontal scanline of the second field or the field B or the even field. If you have started with the even field, this is the odd field, after you finish the odd field this is the first line of the even field. You can start in whatever way you want and with any numbering do not worry about the numbering at this point.

So again the pattern is same, the pattern is same now as we did in the other fields so you need a horizontal retrace back, the picture is starting to get little clogged up but the lines are having good spacing. I hope you will be able to follow the same. I use the same color for the horizontal retrace for the other field, again horizontal scan for field B or horizontal retrace back the horizontal scan again and finally a horizontal scanning. Now we have reach the bottom left of the screen, if you see the pattern the picture is not complete before completing it I want to show you something I have, 3 1/2 lines of blue for field A and just 3 reddish or pink colored lines for field B.

So the two fields, one of it is fully complete field A has 3 1/2 lines, field B has 3 lines, where is the half line coming? It is coming here, so the end of field B the beam will now be at the bottom center of the screen. It is very nice because we started in the bottom top center, we started at the top center and the iteration here and after two fields have been scanned it is very nice and ideal to see that the beam is now at the bottom center of the screen. And if you again see the picture very nicely if the picture is probably scanned and opened up for the entire screen we will see that there are 3 ½ lines drawn and this picture is suitable.

You should be able to visualize here that the 3 1/2 blue lines for the field A and 3 1/2 pink colored lines for the field B. So totally I have drawn 7 lines we talked about the heading of this slide schematic of a 7 line interlaced scanline pattern so 7 lines have been drawn. But there is one because we need retrace so there must be a vertical retrace. The final vertical retrace is drawn by this reddish line here which brings back the beam to the top center of the screen where we started. So we have finished the complete cycle of a single frame or two interlaced fields, adjacent fields, interlaced or interwoven is the particular word used. Remember, I did not ever say that the fields are consecutive. We will finish A first and then field B. They are all interlaced so you finish field A with odd lines let us say or even whatever the case may be and then the next field is interwoven is also covered with corresponding other odd or even scanline.

So let me retrace back the entire sequence of that you follow what is going on the screen. We start from the top center of the screen and go through horizontal and horizontal retrace and cover field A. We can see the arrows marked for the blue lines and the retrace back. So 3 1/2 lines over then we come across the vertical retrace field B will start, scan, retrace, scan retrace, scan, retrace, scan, 3 1/2 lines both fields finally a vertical retrace. So I hope this concept is very clear as to how this is done. This is done for 7 lines and now you can extrapolate it and then think about 525 lines or 512 lines as the case may be and put the numbering for you to understand.

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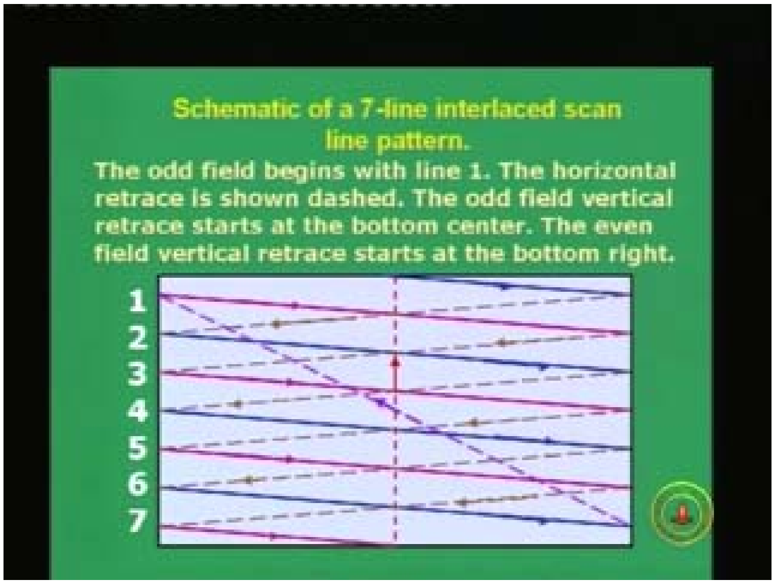

Schematic of a 7-line interlaced scan line pattern.

The odd field begins with line 1. The horizontal retrace is shown dashed. The odd field vertical retrace starts at the bottom center. The even field vertical retrace starts at the bottom right.

The numbering of the lines is also now there. As you can see the blue line should be numbered as 0, 2, 4 and 6 and the odd numbers are marked as 1, 3, 5 and 7. So 3 1/2 lines and the statement also says what I have been describing so far. The odd field begins with 1, the horizontal retrace is shown in dashed the odd field, vertical retrace starts at the bottom center of the screen and the even field vertical retrace starts at the bottom right, even field vertical retrace is the one which ends with blue line at the bottom right that is the diagonal vertical retrace for the even field and for the odd field, it is a simple vertical retrace so the entire cycle can go on.

Continuing with horizontal retrace; as the electron beam reaches the right edge of the screen it is made invisible and rapidly returned to the left edge. The word rapidly is very interesting here. It means that the time taken for the beam to move from left to right when it is scanning is much much more than the retrace. In retrace it may be switched off here. That is the value numerically.

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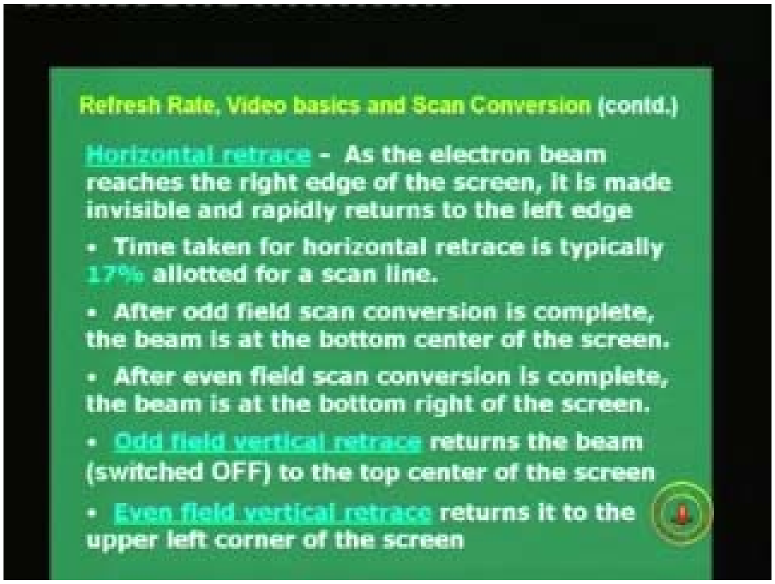

Refresh Rate, Video basics and Scan Conversion (contd.)

Horizontal retrace - As the electron beam reaches the right edge of the screen, it is made invisible and rapidly returns to the left edge

- Time taken for horizontal retrace is typically 17% allotted for a scan line.
- After odd field scan conversion is complete, the beam is at the bottom center of the screen.
- After even field scan conversion is complete, the beam is at the bottom right of the screen.
- Odd field vertical retrace returns the beam (switched OFF) to the top center of the screen
- Even field vertical retrace returns it to the upper left corner of the screen

The time taken for a horizontal retrace is typically about 17 % allotted for a scanline that means if you take about say 100 units not 100 milliseconds or even less 100 micro seconds for a scanline actually they were much less horizontal milliseconds 100 millisecond for a horizontal scanline to go from left to right the retrace will take 17 milliseconds more or if the total inclusive of the horizontal scan come retrace is 100 milliseconds you can start to visualize it will be about 83 milliseconds here and about 17 milliseconds here or 85 and 15 of that order is what you will get.

After every odd scan conversion is complete the beam is bottom center of the screen that we have seen with the previous diagram and after even field scan conversion is complete the beam is at the bottom right of the screen. These are again retracing the points which we have just discussed in the animation in the previous slide. We know what is the bottom center top center and bottom right and bottom center as well of the screen and what alternate fields it will happen. The odd and even words could be interchanged. Odd field vertical retrace returns the beam switched off to the top center of the screen and the even field vertical retrace returns it to the upper left corner of the screen.

So the vertical retrace are of two different types unlike the common model which we have picked up earlier. Now the two fields which are interwoven the vertical retrace are of two different types; one for an odd field, one for an even field, one returns the top center, another returns it to the upper left corner of the screen. So, we have seen that with the animation in the previous slide.

Two fields have to be presented alternately for each frame so if you are presenting 30 frames per second then we talking of 60 fields per second and if you present 60 frames per second we are almost talking of 120 fields per second and that is typical.

In NTSC I did say sometime back in a few slides back that this number should not be astonishing for you that it has 525 lines but 483 lines are visible and that will come easily. If you do a little bit of calculation you will come to know why purposefully 483 lines out of five 525 are made visible, not all of this. It is something to do with the vertical and horizontal retrace times. This is because the vertical retrace after each field, remember there are two fields. So the vertical retrace of each field requires a time equivalent of 21 scanlines. So 21 scanlines are required for a vertical retrace for each field, there are two fields, if there are two fields we are losing time for about 42 scanlines that is 21 into 2. So we are talking of each field we have the time to display 525 lines divided by 2 for each field which is 262.5 – 21 which gives you 241.5 lines per field. And 241.5 lines per field multiplied by 2 gives you a simple figure which you have at the top middle of the screen, the 483 lines. This 483 comes out of this multiplied by 2, 241.5 multiplied by 2 you can easily get it.

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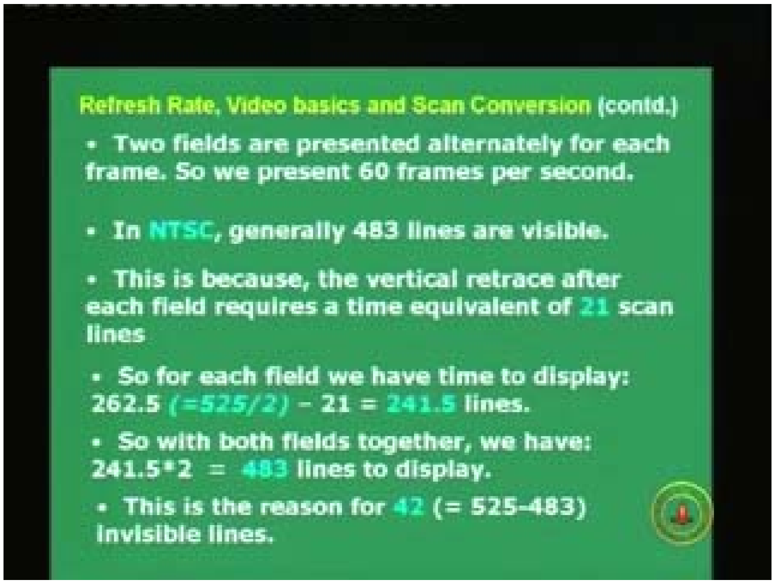

Refresh Rate, Video basics and Scan Conversion (contd.)

- Two fields are presented alternately for each frame. So we present 60 frames per second.
- In NTSC, generally 483 lines are visible.
- This is because, the vertical retrace after each field requires a time equivalent of 21 scan lines
- So for each field we have time to display: 262.5 *(=525/2)* – 21 = 241.5 lines.
- So with both fields together, we have: 241.5*2 = 483 lines to display.
- This is the reason for 42 (= 525-483) invisible lines.

You can actually subtract 42 from 525 you will also get 483 so that is another way by which you can do the calculation. So purposefully to account for the time for the vertical retrace not all the 525 lines are made visible, 483 lines or 241 and 1/2 line per field is made visible. So both fields together we have 483 lines. We just discussed about that right now. Either you can multiply this or you can subtract from 525 a number 42 and you should able to get 483.

This is the reason why 42 invisible lines exist in NTSC type of display. Actually you are supposed to have 525 physically 483 lines are visible. Physically there are 483 but it is visualized as if there are 525 lines and time spent in the vertical retrace is equivalent to as if you are trying to scan 42 lines so that is the way you should try to visualize. You can visualize as if the system does not have a vertical retrace or there is no time for a vertical retrace, it just tries to scan all the 525 lines that is the way to visualize it. But basically out of those 525 only 42 are not visible because that time is used for the vertical retrace.

Do some other calculation; for example a little bit of geometry, algebra whatever you say. Let the time available for each scanline be T and now we talk of 525 lines, remember although 483 lines are visible we consider 525 because that it takes into account the time for vertical retrace. So we are talking about 525 lines which are 483 visible lines and 42 invisible lines which account for the time for the vertical retrace of both the fields. So we are presenting 525 lines actually 483, 525 lines multiplied by 30 frames per seconds and T is the time to scan each line 525 lines 30 times per second. That is the calculation which means one second. This gives raise to a value which tells you that the value of T is as low as 63.5 microsecond, forget millisecond and that is the time for a scanline which is 63.5 microseconds because as low about that and this includes the vertical retrace time. That is the time. So typically what this means is probably you have 17% less time of T for each scan line because we talking of the T actually you are visiting 483 and the 42 lines time is inbuilt in the T so this includes the vertical retrace time.

When we consider the horizontal retrace time that also has to be considered because that is about 17% of the time for a scanline spent for a horizontal retrace. So when we consider the horizontal retrace time the actual time to display all pixels in a scanline that is the time in bracket which we see on the screen here, the time to scan from left to right only. Forget about the retrace time that is part of 63.5 microsecond so 53 microseconds 0.83 multiplied by 63.5 will approximately give a 53 I have rounded the value and 53 microseconds is spent on scaling from left to right and about ten seconds is left over for the horizontal retrace of the beam to come back from right to left. So that is the typical calculation which you have for the typical scanline; 53 microseconds spent for just scanning and the rest of the 10 seconds goes for retracing back.

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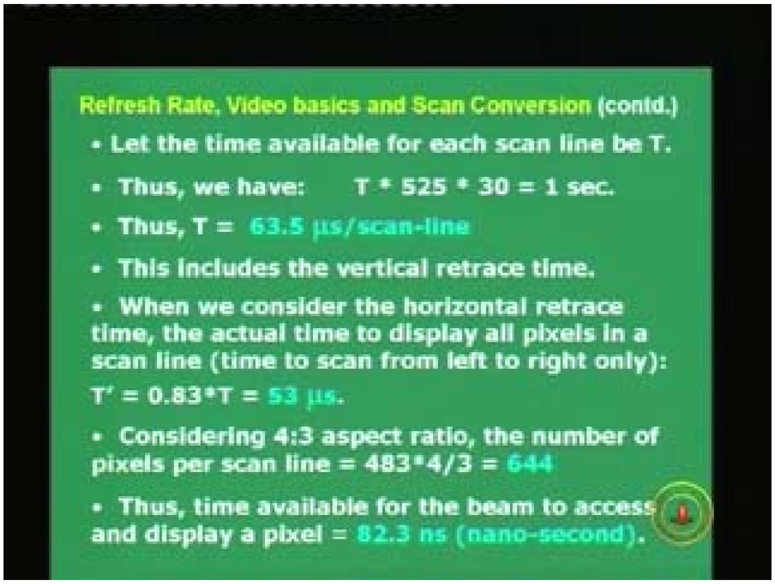

Refresh Rate, Video basics and Scan Conversion (contd.)

- Let the time available for each scan line be T.
- Thus, we have: T * 525 * 30 = 1 sec.
- Thus, T = 63.5 μs/scan-line
- This includes the vertical retrace time.
- When we consider the horizontal retrace time, the actual time to display all pixels in a scan line (time to scan from left to right only):
T' = 0.83*T = 53 μs.
- Considering 4:3 aspect ratio, the number of pixels per scan line = 483*4/3 = 644
- Thus, time available for the beam to access and display a pixel = 82.3 ns (nano-second).

And considering the 4:3 aspect ratio for NTSC display we can take the calculation for PAL but since we started the NTSC let me stick to that. The books deal more about the NTSC. Considering 4:3 aspect ratio the numbers of pixels per scanline is 4/3rd of 483 that means if you have 483 scanlines each scanline will have about 30% more than the number of scanline. That means typically more vertical columns in the array then the horizontal rows.

Typically a screen in a picture TV or video or a monitor you will see that the aspect ratio such that the horizontal width is purely more than the vertical height and that is because the number of pixels on each scanline is actually more than the number of rows. So if you have n rows you have more than n in terms of the number of pixels. So, if we talking of a matrix of array for a refresh screen and you have size of m cross n so this is n, that is m and that is n number of rows the number of columns which is typically more so aspect ratio is 4 times 3 here. So the number of pixels per scanline will be 4 into 483/3 the number is about 644. So this screen shows that the number of pixels per scan line is 644 so that is more than the number of horizontal scanlines. If that is so and if you have 53 microsecond to scan a horizontal line from left to right and there are 644 pixels per scanline you can now imagine the time crunch you have to display the pixel in terms of, let us read this sentence: the time available for the beam to access and display a pixel is 53 micro seconds which is T prime the value here divided by 644. So you get a value about 82.3 nanoseconds 10 to the power – 9 that is the time allocated for the beam to access a pixel and move to the next one and within this time the beam must switch on and switch off if it is so required. So you can imagine the amount of bandwidth which is demanding for a typical CRT monitor or for a video in terms of trying to access a pixel and display it and that is the rate at which the beam must move and also work.

You can do these same calculations for different values of frame rate and different display resolutions. These are typical examples of frame rates and display resolutions and the first row says that if you have 30 frame rate and a 512 into 512 resolution you can work in the same way which I did. I have shown the calculation in the previous slide and it works out to 105 nanoseconds.

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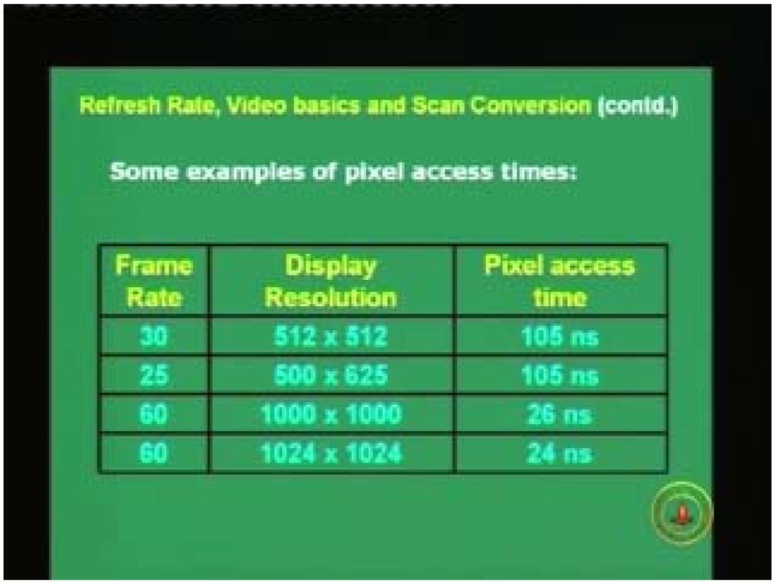

Refresh Rate, Video basics and Scan Conversion (contd.)

Some examples of pixel access times:

Frame Rate	Display Resolution	Pixel access time
30	512 x 512	105 ns
25	500 x 625	105 ns
60	1000 x 1000	26 ns
60	1024 x 1024	24 ns

Remember, in the NTSC we considered 512 into 644 resolution 30 frames per second frame rate 30 gave you as 82.3 nanoseconds. So 512/512 into 30 will give you a little bit more. It gives you 105 nanoseconds and it is same for a 500 into 625 resolution display with the frame rate about 25 gives you 105 nanoseconds. Now let us start go for a higher frame rates and higher resolutions, CRT monitors and the last two rows. For 60 frames per second 1000 into 1000 resolution you just have 26 nanoseconds to access a particular pixel, 60 frames per second 1024/1024 display resolution you just have a 24 nanosecond access time for accessing a pixel you have a 24 nanosecond to get the beam on display and then turn it off. If that is the rate at which information must pass on, pass on from where?

We are taking the information whether the beam has to be switched on or off between two adjacent pixels from the frame buffer, from the frame buffer through the video controller, registers and access registers, data registers, up to the deflection voltages, in terms of the electronic guns strength 24 nanoseconds turn on and off and the on time is even half of that. We discussed about n by 2 n by 2 so the beam on time will be even less than that.

We are talking about a few tens of mega hertz already in terms of almost hundred mega hertz close to about few tens to hundred mega hertz type of bandwidth frequency rate. You can calculate that easily by 1/24 or 1/12 nanoseconds and that is how the display will go. Coming back to the frame buffer we talked about lot of video basics and timing bandwidth and we talked about architecture earlier and we talked of memory requirement also, we move on to the capacity of the monitor system in terms of grey scales and color and how does it depend on the value of N? The bit plane size N could be 1 black and white we talked about this earlier more larger than N more the feasibility or the programmer you may have in fact in terms of controlling the number of grey scales or colors. So the choice of the number of grey scales and colors depend on the value of N that the bit plane size N.

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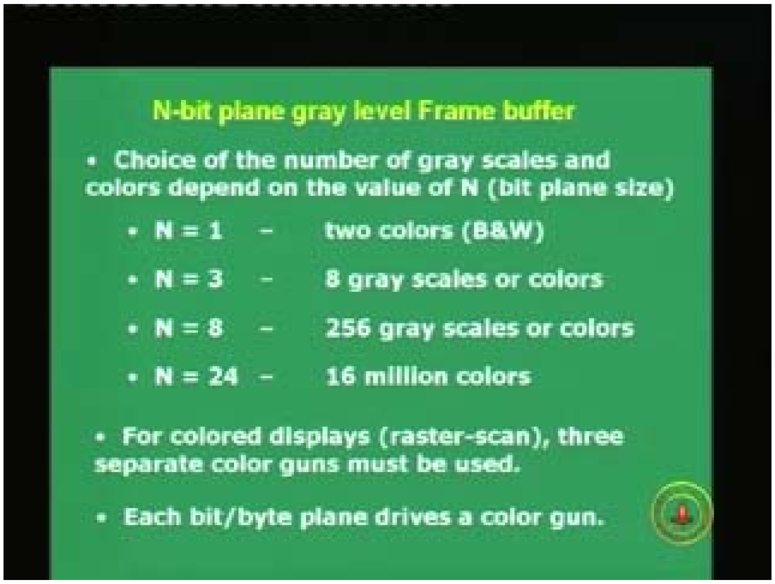

N-bit plane gray level Frame buffer

- Choice of the number of gray scales and colors depend on the value of N (bit plane size)
  - N = 1 – two colors (B&W)
  - N = 3 – 8 gray scales or colors
  - N = 8 – 256 gray scales or colors
  - N = 24 – 16 million colors
- For colored displays (raster-scan), three separate color guns must be used.
- Each bit/byte plane drives a color gun.

If N is equal to 1 we talked about this earlier. I repeat again two colors N equal to 3 you have 8 grey scales or colors, N equal to 8 you can have 2 to the power 8 or 256 grey scales or colors, N equal to 24 you can have 16 million colors. For colored displays raster scan we need three separate color guns to operate simultaneously. So far you have been talking about one electronic gun the bit value passed on to that by a register, a digital to analog converter will convert that bit value to an analog voltage not for the deflection plate but for the strength of the electron gun which must control the strength of the beam which will in turn control the intensity of the pixel or that color spot will grow on this screen. So you cannot do that with color display with just single gun you need a separate gun for each three separate colors typically RGB is used. We talk of each bit or a byte plane having a separate gun or each byte plane been driven by a color gun.

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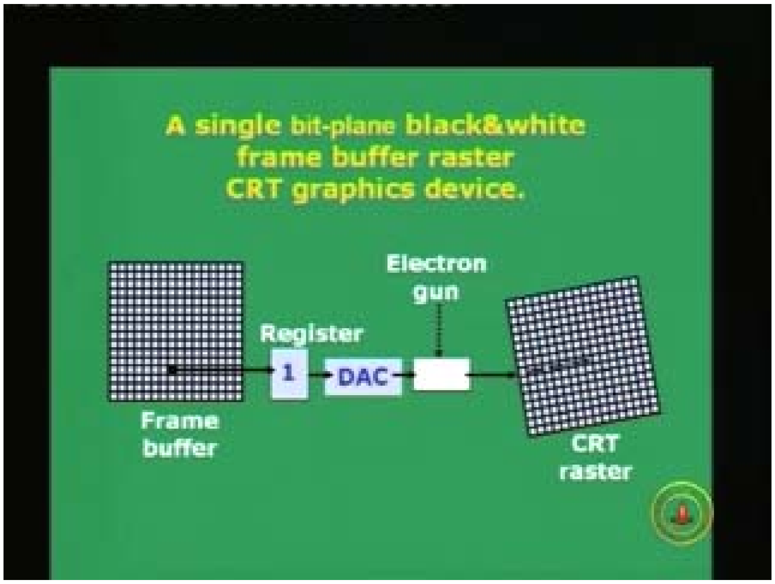

A single bit-plane black&white
frame buffer raster
CRT graphics device.

Let us take a very simple example of a single bit plane black and white frame buffer raster CRT graphics device. On the left hand side we have an array of pixels of the frame buffer, we have a one bit register which will take this out and this is all controlled by the video controller. The program have do not have to worry about this, you just access the frame buffer the rest of it is automatically done by the video controller which is part of your graphics electron card with sits between your system box and the monitor. It has an analog output but text in digital values from the frame buffer it will have a value 0 or 1 which will be converted by the DAC or digital to analog converter into a voltage 0 or some high voltage.

You have an electronic gun which will fire on to the corresponding same point on to the CRT raster or the screen. That is a very simple example of the mechanism which happens for CRT graphics device in terms of a single bit plane. Let us now stretch that single bit plane to N-bit planes. If you have N-bit planes we can visualize the N on the left hand side of the screen as N layers are single bit plane. If you take a single N-bit value there are about N bits for a single byte or a word as you can see. So you can visualize that instead of having a single bit you have N-bits some N layers of bit planes which is our frame buffer.

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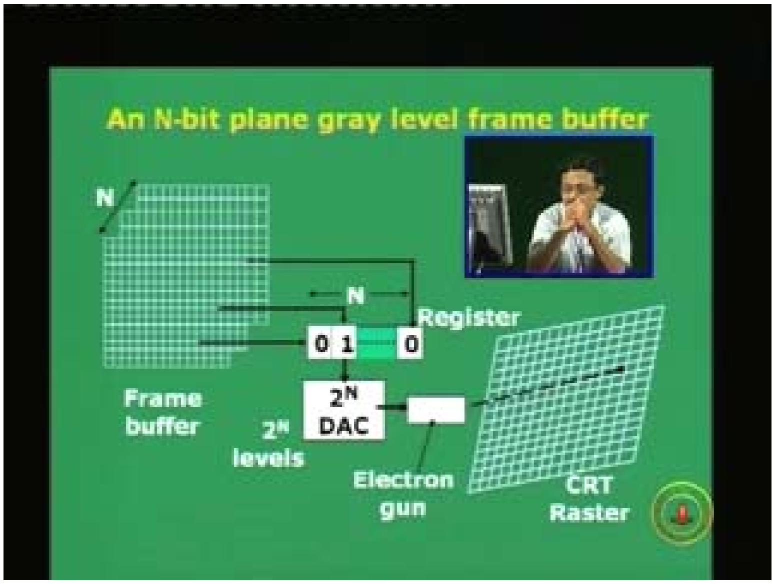

An N-bit plane gray level frame buffer

There are N such layers, although three layers are shown but typically there are N layers and what at any particular time when you want to display a pixel earlier we have taken a single bit value now simultaneously all the bits for that corresponding byte or word for a intensity of a screen is taken out and loaded on to an N-bit register. We have an N-bit register the center of the screen which you can see, so that N-bit register takes values from N-bit locations or from the N-bit frame buffer or N-bit plane where terminologies are used and the register is very fast it immediately sends out the digital value to what I will call as now 2 to the power N digital to analog converter, and 2 to the power N was the case.

In the previous case N was only 1 so 2 to the power of N should have had only the 0 or 1 output 2 levels. Now we have 2 to the power N different output 0 2 to the power N – 1, different levels a digital to convert those with electronic circuit back ground or even electronics engineers with a background will easily follow this that it takes an N-bit value and it will have 0 to 2 to the power N – 1 levels or totally 2 to the power N levels. So the electronic gun takes in analog voltage at 2 to the power N different levels so the output of the electron gun which is the electron beam will have 2 to the power N different type of strengths from 0 to 2 to the power N level which is the maximum. That can be controlled by the analog voltage which is the output of the DAC.

The DAC input is N-bit register so N-bit register can input from the frame buffer so in fact the words come out from the frame buffer to the register to the DAC analog voltage generator given to the electronic gun. The electronic gun gives out an electron beam with intensity which is propositional to the analog voltage given out for DAC. And the CRT raster now has a beam which will be the spot at the CRT raster that will be hit by the beam of corresponding strength as given by the bit value in the frame buffer and it will glow with certain intensity.

This is the N-bit plane frame buffer. The next question is, well, when you are talking of N-bit planes you have a either an N-bit a grey level or N-bit color. When we have an N-bit grey scale in terms of monochrome grey shades from dark to white and all grey shades are black and white in between, then also this model is fine but we can still move toward color model with N bits. It gives an option. And when we talk of a color screen you need to have three guns and not one particular gun as shown before in the previous two examples. You need to have three guns for three different colors and N-bit plane where N could be 8 or even more and you will need to have separate registers for each electron gun in density n 2 to the power n, several DACs separate register, separate DACs for each color, separate gun for each color, frame is same, CRT buffer will be the same and so on. So we move to the next lecture when we talk about the N-bit plane but colored frame buffer and not grey level buffer. So we will meet next time. Thank you.

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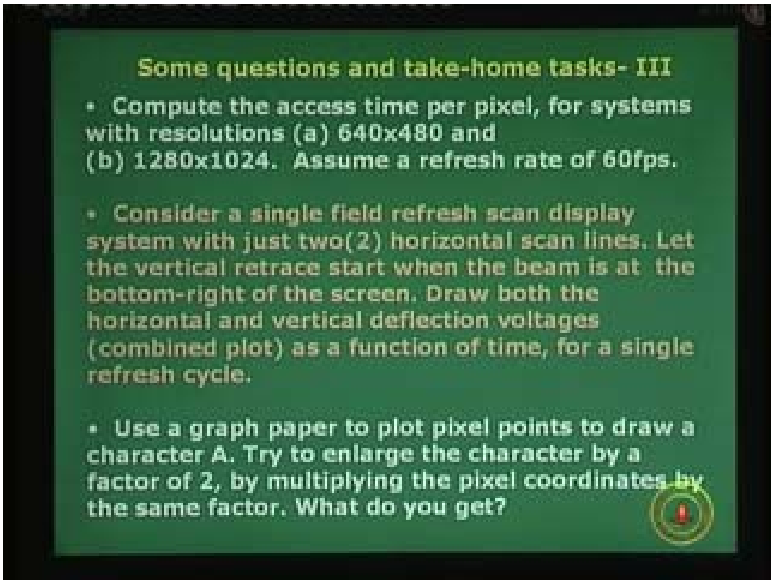

Some questions and take-home tasks- III

- Compute the access time per pixel, for systems with resolutions (a) 640x480 and (b) 1280x1024. Assume a refresh rate of 60fps.
- Consider a single field refresh scan display system with just two(2) horizontal scan lines. Let the vertical retrace start when the beam is at the bottom-right of the screen. Draw both the horizontal and vertical deflection voltages (combined plot) as a function of time, for a single refresh cycle.
- Use a graph paper to plot pixel points to draw a character A. Try to enlarge the character by a factor of 2, by multiplying the pixel coordinates by the same factor. What do you get?

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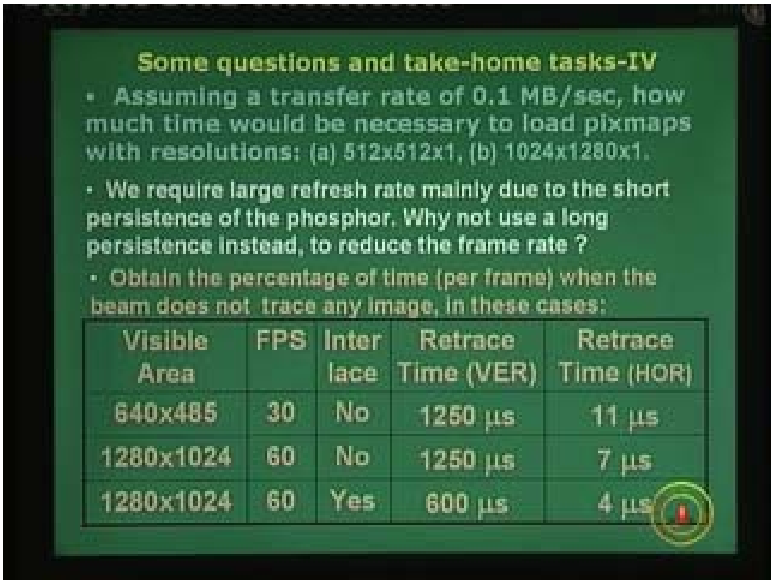

Some questions and take-home tasks-IV

- Assuming a transfer rate of 0.1 MB/sec, how much time would be necessary to load pixmaps with resolutions: (a) 512x512x1, (b) 1024x1280x1.
- We require large refresh rate mainly due to the short persistence of the phosphor. Why not use a long persistence instead, to reduce the frame rate ?
- Obtain the percentage of time (per frame) when the beam does not trace any image, in these cases:

Visible Area	FPS	Inter lace	Retrace Time (VER)	Retrace Time (HOR)
640x485	30	No	1250 μs	11 μs
1280x1024	60	No	1250 μs	7 μs
1280x1024	60	Yes	600 μs	4 μs