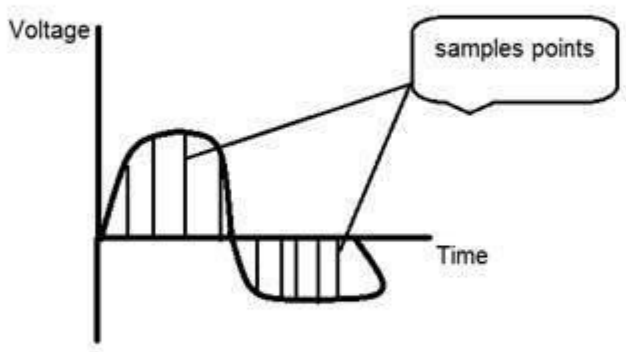
Digitizing a signal

Digitizing an analog signal into a digital, requires two basic steps. Sampling and quantization. Sampling is done on x axis. It is the conversion of x axis (infinite values) to digital values.

The below figure shows sampling of a signal.



Sampling with relation to digital images

The concept of sampling is directly related to zooming. The more samples you take, the more pixels, you get. Oversampling can also be called as zooming. This has been discussed under sampling and zooming tutorial.

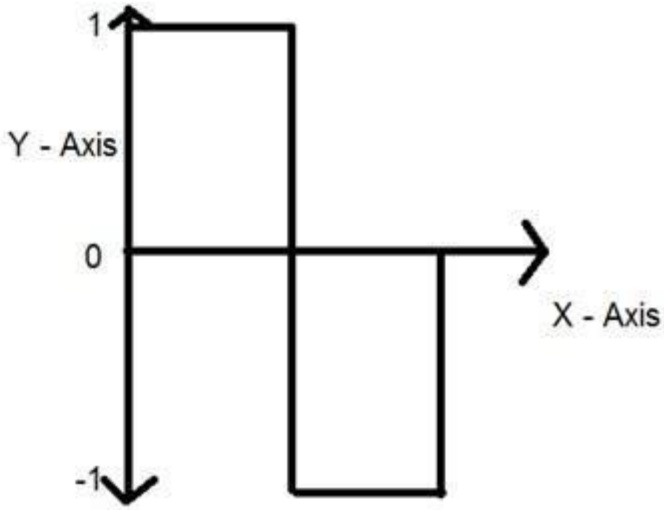
But the story of digitizing a signal does not end at sampling too, there is another step involved which is known as Quantization.

What is quantization

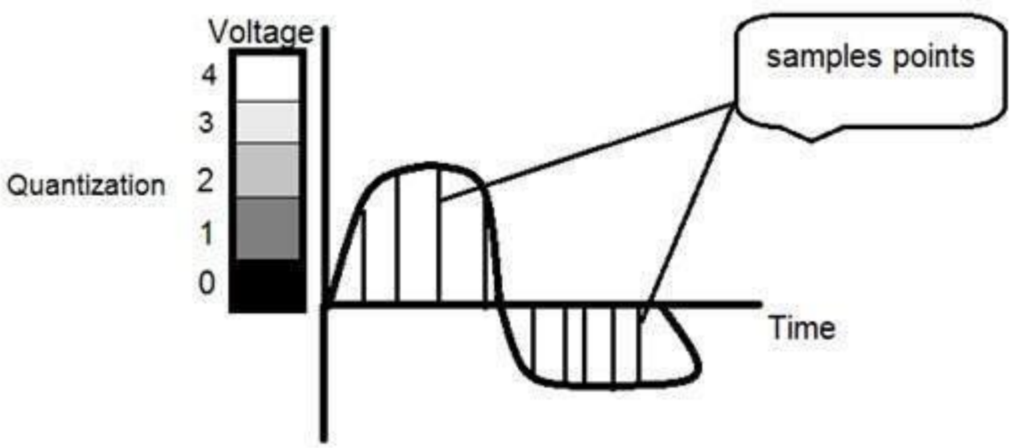
Quantization is opposite to sampling. It is done on y axis. When you are quantizing an image, you are actually dividing a signal into quanta (partitions).

On the x axis of the signal, are the co-ordinate values, and on the y axis, we have amplitudes. So digitizing the amplitudes is known as Quantization.

Here how it is done



You can see in this image, that the signal has been quantified into three different levels. That means that when we sample an image, we actually gather a lot of values, and in quantization, we set levels to these values. This can be more clear in the image below.



In the figure shown in sampling, although the samples has been taken, but they were still spanning vertically to a continuous range of gray level values. In the figure shown above, these vertically ranging values have been quantized into 5 different levels or partitions. Ranging from 0 black to 4 white. This level could vary according to the type of image you want.

The relation of quantization with gray levels has been further discussed below.

Relation of Quantization with gray level resolution:

The quantized figure shown above has 5 different levels of gray. It means that the image formed from this signal, would only have 5 different colors. It would be a black and white image more or less with some colors of gray. Now if you were to make the quality of the image more better, there is one thing you can do here. Which is, to increase the levels, or gray level resolution up. If you increase this level to 256, it means you have an gray scale image. Which is far better then simple black and white image.

Now 256, or 5 or what ever level you choose is called gray level. Remember the formula that we discussed in the previous tutorial of gray level resolution which is,

$$L = 2^k$$

We have discussed that gray level can be defined in two ways. Which were these two.

- Gray level = number of bits per pixel (BPP).(k in the equation)
- Gray level = number of levels per pixel.

In this case we have gray level is equal to 256. If we have to calculate the number of bits, we would simply put the values in the equation. In case of 256levels, we have 256 different shades of gray and 8 bits per pixel, hence the image would be a gray scale image.

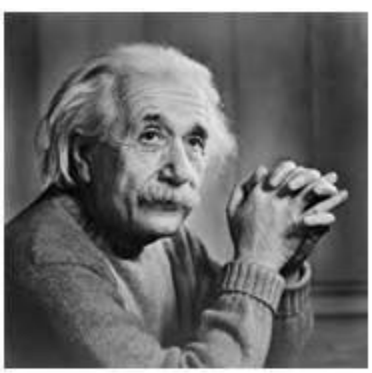
Reducing the gray level

Now we will reduce the gray levels of the image to see the effect on the image.

For example

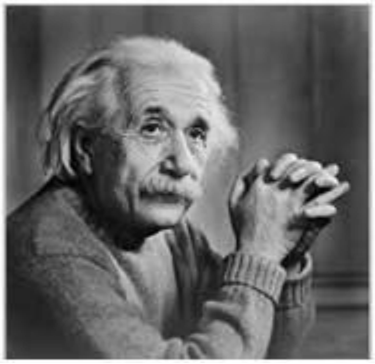
Lets say you have an image of 8bpp, that has 256 different levels. It is a grayscale image and the image looks something like this.

256 Gray Levels



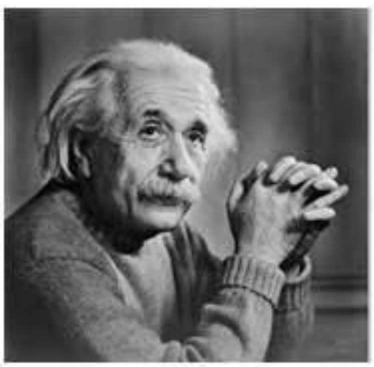
Now we will start reducing the gray levels. We will first reduce the gray levels from 256 to 128.

128 Gray Levels



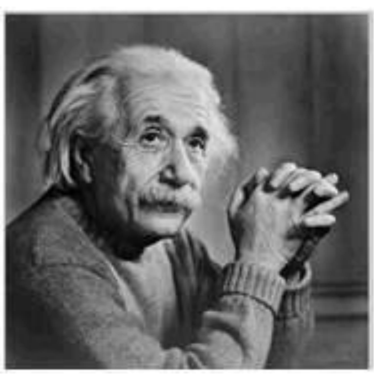
There is not much effect on an image after decrease the gray levels to its half. Lets decrease some more.

64 Gray Levels



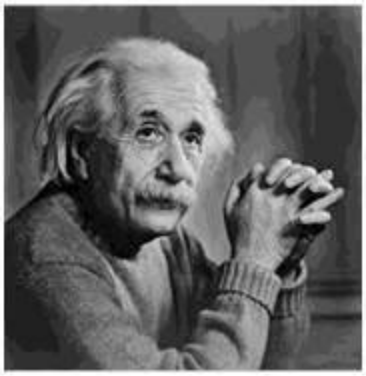
Still not much effect, then lets reduce the levels more.

32 Gray Levels



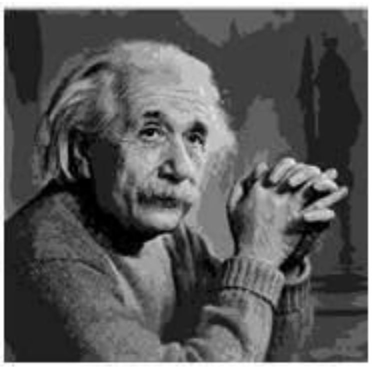
Surprised to see, that there is still some little effect. May be its due to reason, that it is the picture of Einstein, but lets reduce the levels more.

16 Gray Levels

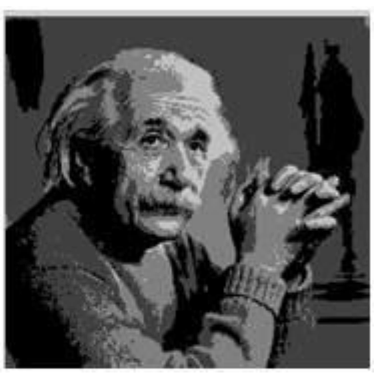


Boom here, we go, the image finally reveals, that it is effected by the levels.

8 Gray Levels



4 Gray Levels



Now before reducing it, further two 2 levels, you can easily see that the image has been distorted badly by reducing the gray levels. Now we will reduce it to 2 levels, which is nothing but a simple black and white level. It means the image would be simple black and white image.

2 Gray Levels

Thats the last level we can achieve, because if reduce it further, it would be simply a black image, which can not be interpreted.

Contouring

There is an interesting observation here, that as we reduce the number of gray levels, there is a special type of effect start appearing in the image, which can be seen clear in 16 gray level picture. This effect is known as Contouring.

Grayscale to RGB Conversion

To convert a grayscale image into color or RGB format, we have two methods. Both methods have their advantages as well as disadvantages.

Methods for conversion of grayscale image to RGB are as following:

1. Average method

It is the simplest method. We have to take an average of all the 3 colors.

Formula: (R + G + B)/3

For example:

RGB image Grayscale image

Explanation

As we can see, there are changes in the image by applying the average method. But the result is unexpected as we want a grayscale image, but it turned to be a black image.

Problem

This problem occurs because we have taken an average of 3 colors. All the 3 colors have different wavelength and have their contribution to the formation of an image. In the above image, we are taking 33% from each portion that is why the image does not occur in grayscale.

The solution to this problem is given by the weighted method.

Weighted method or luminosity method

As we have seen the problem in the average method. And for this problem weight method is the solution. In all the 3 portions of color, red color has more wavelength, and green color has less wavelength. But green color gives a more soothing effect to the eyes as compared to red color.

By decreasing the value of red color and increasing the value of green color and the value for blue color will be between these two colors.

The equation for a new grayscale image will be:

Let the new grayscale image be X

$$X = (0.3 * R) + (0.59 * G) + (0.11 * B)$$

According to the above equation, red is used 30%, green is used 59%, and blue is used 11%. The contribution of green is highest.

By Applying the equation in an image, we will get:

Original Image

Grayscale Image

Explanation

As we can see using the weighted method the image is properly converted into grayscale. Image is brighter as compared with the image which was generated using the average method.

Concept of Sampling

Sampling is done only on an independent variable. For example, if we digitize x-axis in sampling.

1. y=sinx (it is done on variable x)

Sampling is divided into two parts:

- upsampling
- downsampling

There are variations in the sampled signal which is due to noise. To reduce the noise more samples are taken which means more data or pixel which result in a better image with less noise present in it.

In an image, pixel is the smallest element which is represented in the form of a matrix.

In sampling, the number of samples taken in X-axis is continuous and refers to a number of pixels in that image.

Total number of pixels = Total number of Rows * Total number of Columns

In a CDD array

No. of sensors on a CCD array = No. of Pixels = No. of samples taken

Oversampling

As we have seen above, there are two types of sampling, up-sampling, and down-sampling.

Up-sampling is also known as oversampling.

In an image, oversampling means using a high-resolution image sensor as compare to camera output image resolution.

One of the oversampling applications in image processing is known as zooming.

Zooming

Increasing pixel quantity is known as Zooming. When we zoom in an image, more detail can be seen.

Increasing the number of pixels is done using oversampling.

Zooming has two steps:

1. In a new location, new pixels are created.

2. And assignment of the gray level to a new location.

Another, way to zoom an image is by zooming optically using the motor movement of the lens, and then the image is captured.

Optical Zoom vs. digital Zoom

Optical Zoom	Digital Zoom
Optical zoom is used by Photographer to capture an image without moving physically closer to that object.	Digital zoom is a part of digital cameras. It can crop the enti image, and the portion of an image which is zoomed can l digitally enlarged.
In a digital camera, the optical zoom ratio is used to measure lens, that how much it can be zoomed to make the object appear closer. Optical zoom enlarges an image, and it keeps the resolution and sharpness of the image high.	Digital zoom crops the image from the center with the san ratio from all the sides. And the image results in the origin dimension of the pixel. As this method involves cropping, the image quality and resolution are reduced.
There is no relation between the optical zoom and the resolution of an image. Because the optical zoom is used to enlarge the image and its quality depends on the megapixel of the camera.	As the digital camera can crop a portion of an image ar enlarge it to its original size. Due to this, the quality of tl image is reduced as compared to the original image.
Optical zoom is useful when an image is taken in landscape or if we want a closer view of an object without reducing the quality of the image. For example, taking a picture of the rainbow in the sky.	Digital zoom is used to take images from closer to the obje when the photographer wants to take pictures of a particul object For example, clicking pictures at the birthday party of tl birthday boy.

Zooming methods

There are three types of methods used in zooming; they are as follows:

1. Pixel replication or (Nearest neighbor interpolation)
2. Zero-order hold method
3. Zooming K times

Pixel replication

Pixel replication is also known as Nearest neighbor interpolation. In this method, a copy is produced of the neighboring pixels. This algorithm works the same as zooming.

Working:

In this method, new pixels are generated from the originally given pixel. Each pixel is copied from its neighboring pixel n time row and column-wise, and we get a zoomed image.

For example, we have 2 row and 2 columns of an image. And we zoom the image twice.

5	6
7	8

ROW WISE ZOOMING:

When an image is zoom row-wise, it copies the pixels from row to the new cell

5	5	6	6
7	7	8	8

COLUMN SIZE ZOOMING:

Next step is to copy the pixel column-wise to the new adjacent column.

5	5	6	6
5	5	6	6
7	7	8	8
7	7	8	8

As we can see that the original image was having2 rows and 2 columns, but after zooming the image, it is converted into 4 rows and 4 columns.

Original image rows * zooming factor, original image cols * zooming factor.

Advantages

It is very simple, and we have to copy the pixels.

Disadvantages

When we zoom an image, the output is very blurry. As a result, we have a full blurred image.

Zero order hold

It is another method of zooming. Zero order hold is also known as zoom in twice, as it can only be zoomed twice.

Working

In this method, two adjacent elements are taken from the row, then elements are added, and the result is divided by two. The result is placed in between the elements.

For example:

We have 2 rows and 2 columns of an image and we zoom in the image twice.

5	6
7	8

Row Wise Zooming

5	5	6
7	7	8

When an image is zooming in row-wise, then rows are added (5+6) =11 and then it is divided by 2. We will get 5.5 approximate to 5 and the operation is performed in the second row.

Column Wise Zooming

5	5	6
6	6	7
7	7	8

When an image is zoomed column-wise, then columns are added (5+7) = 12 and then it is divided by 2. We will get 6, and this operation is performed in all the columns.

As we can see that the original image was having 2 rows and 2 columns but after zooming, the image it is converted into 3 rows and 3 columns.

(2(number of rows) minus 1) X (2(number of columns) minus 1)

It is very simple and it does not create a blurry picture.

Disadvantage

It works on the power of 2.

Reasons behind Twice Zooming

As we have seen in the above example, we have an image of 2 rows and 2 columns. If we want to zoom in an image 7 or 9 times then it cannot be done.

It can only zoom in the power of 2 i.e 2, 4, 8, 16, 32, etc.

K-Times zooming

K-Times Zooming is the perfect zooming algorithm. In this algorithm, k stands for the zooming factor.

Following are the steps to get a zoomed image which are used in both row and column:

1. Two adjacent pixels are taken.
2. Greater pixel is subtracted by a smaller pixel and the result is called OP.
3. Now, OP is divided by the zooming factor (k).
4. Now, the result is added in smaller pixel, and then it is placed in between those pixels.

For example:

We have 2 rows and 3 columns of an image. And we have to zoom in the image thrice.

2	3	4
5	6	7

In this case, the zooming factor (k) is 3. So, the number of values to be inserted is k-1 = 3-1 = 2.

Row Wise Zooming

Let's take 1st two adjacent pixels. i.e. 2 and 3.

Now, subtract 3 from 2.
3-2=1.
Divide 1 by k
1/3=0.3
Let 0.3 be OP.
Add OP with the lower number
0.3+2=2.3 (approx 2)
And again add OP with a higher number
0.3+3=3.3

Note: We have calculated two values because we have to insert k-1 values.

Now, repeat the above steps for the next two pixels.

2	2	3	3	3	4	4
5	2	3	6	3	4	7

Column Wise Zooming

In column wise zooming, the same steps are performed as done in row-wise zooming.

2	2	3	3	3	4	4
3	0	0	4	0	0	5
8	0	0	7	0	0	8
5	2	3	6	3	4	7

As, we can see that the original image was having 2 rows and 3 columns but after zooming, the image it is converted into 4 rows and 7 columns.

(K(number of rows minus 1) + 1) X (K(number of columns minus 1) + 1)

Advantages

It can be zoomed to any factor, thrice or four times or even more.

Disadvantages

Cost of computation is increased due to the additional step in the end.