Photographic System Resolution (2)
Understanding DXOMARK Perceptual Megapixels

Sensor resolution is usually expressed in megapixels in the area of a rectangular image.

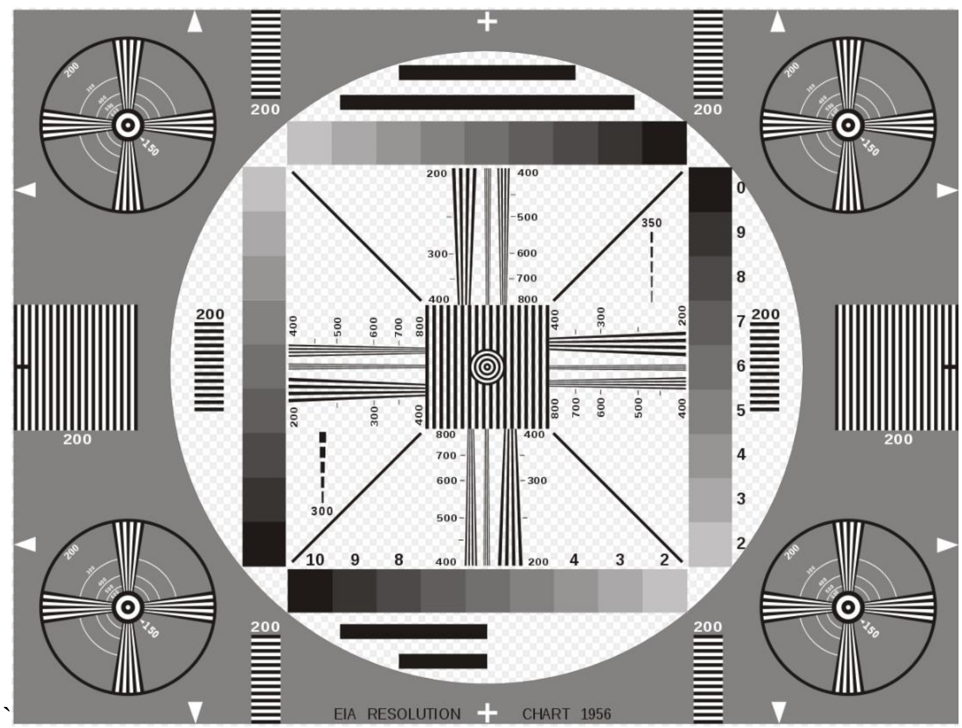
Sharpness is related to our ability to clearly see the edge of a transition from a dark to a light tone. This is a linear measurement, usually subjective.

Photographic System Resolution covered both film and digital resolution and sharpness and two ways it can be expressed:

- Linear – line pairs per millimeter (lp/mm), line widths per picture height (LW/PH), pixels per mm or pixels per inch (ppi)
- Area – megapixels (MP) or pixels per square millimeter (px/mm^2) or pixels per square inch (px/in^2)

When you double the linear resolution you quadruple the area resolution.

Sharpness is measured using a variety of targets like the IEEE target:



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They can help us determine how close line pairs can get before they appear to blend together. It is a subjective judgement and a linear measurement.

No lens performs the same corner to corner or with lines that are oriented in different directions. Colors can also be a problem since different wavelengths may not come into sharp focus at the same place.

Prime lenses have a single best aperture setting for peak sharpness. Zoom lenses also have an optimal focal length. Nevertheless, all of these different measurements can ultimately be reduced to a single lp/mm value.

Lenses cover a limited image circle and are normally designed for a particular format. If they are use with a smaller sensor format the average lp/mm value might be different. But if they are used on a sensor larger than their intended format the light falls off at the corners and there is no point in calculating their linear resolution.

Image megapixels are expressed as a nominal (objective) value, the product of the dimensions of the image in pixels. For example, an image that is 4000 pixels high and 6000 pixels wide has 24,000,000 or 24.0MP.

The color filter array (CFA) causes a significant degradation in linear sharpness but almost none in area MP resolution. A Bayer array, is a mosaic of 50% green, 25% red and 25% red blue filters. When these are combined into individual red/green/blue (RGB) pixels the sharpness is cut almost in half. The Fuji X-Trans array has slightly different proportions, 56% green, 22% red and 22% red blue filters and the loss of sharpness is about the same.

Removing the CFA can lead to much sharper B&W images. After removing the CFA from a 24MP Sony A7 II the results using the same Micro-Nikkor 60mm f/2.8D were compared to a B&W conversion from a 45.75MP Nikon Z7. The results at the same size (24MP at 100%) were indistinguishable, the resolution of the 24MP sensor just about doubled.

And as with lenses, the linear resolution is affected by direction. Horizontal and vertical lines have a slightly better linear resolution than diagonal lines. In addition to the CFA there is a UV filter to block invisible ultraviolet and an IR filter to block invisible infrared light. Some sensors also have an anti-aliasing or optical low pass filter (OLPF) to avoid moiré interference patterns. All of these filters can degrade sharpness.

Calculating system resolution

In order to calculate system resolution both the sensor and the lens resolution need to be expressed as either an area resolution:

$$1/\text{SystemMP} = 1/\text{LensMP} + 1/\text{SensorMP}$$

or as the square of a linear resolution $(\text{lp/mm})^2$.

$$1/Rs^2 = 1/Rl^2 + 1/Rd^2$$

where all of the terms are in lp/mm:

Rs is the system resolution

Rl is the lens resolution

Rd is the digital sensor resolution

DXOMARK Camera lens rankings report the sharpness of a lens as the system resolution of the lens combined with a specific sensor. They use area MP resolution because it eliminates all of the squares and square roots and makes it easier to understand. The following examples explain how this comes together.

Suppose that you have a 16MP sensor and a lens also capable of resolving 16MP.

$$1/16 + 1/16 = 1/8 \qquad \text{system resolution} = 8\text{MP}$$

That's not a particularly good lens resolution and the result is not very impressive. But suppose you replaced it with a lens that is twice as sharp. Since sharpness is a linear concept it would need to have an area resolution 4x greater, 64MP.

$$1/64 + 1/16 = 5/64 \qquad \text{system resolution} = 12.8\text{MP}$$

That's much better but the lens would probably cost more than 4 times as much. Now double the sharpness again.

$$1/256 + 1/16 = 17/256 \qquad \text{system resolution} = 15.06\text{MP}$$

Even with a lens that good and expensive the system resolution cannot go above the sensor resolution.

If we keep the original lens and increase the sensor resolution to 64MP and 256MP. The system resolution would never go above the lens resolution. But now the camera is very expensive or not even made yet.

So the only sensible approach is to create a better lens that works well with a better sensor.

How to calculate the lens MP

System MP is perceptual (somebody has to perceive it) so it's not something that can be calculated directly.

You cannot mathematically convert lens lp/mm into megapixels. Instead, you determine the system resolution (that's where "perceptual" comes in) of the lens mounted on the camera with the highest available sensor resolution. When you remove the effect of the sensor resolution you will be left with the lens resolution.

$$1/\text{SystemMP} - 1/\text{SensorMP} = 1/\text{LensMP}$$

Now that we know the lens resolution we can use it to calculate the system resolution for that lens with any other sensor.

$$1/\text{LensMP} + 1/\text{SensorMP} = 1/\text{SystemMP}$$

The accuracy of the estimation increases as the sensor MP increases.

50mm f/1.8G			
	MP	PMP	LMP
D700	12.2	9	34
Df	16.43	13	62
D610	24.49	16	46
D810	36.56	22	55
D850	45.75	25	55

The lens MP (LMP) is calculated by subtracting 1/MP term (the sensor's MP) from 1/PMP, DXOMARK's published perceptual megapixels to get 1/LMP then invert the result to get LMP.

To test this, PMP' is calculated by subtracting 1/SensorMP from 1/LensMP and inverting the result.

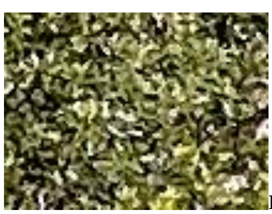
50mm f/1.8G MPl		
Lens MP	55	
	DxO PMP	PMP'
D700	9	10
Df	13	13
D610	16	17
D810	22	22
D850	25	25

This comes within +/-1 of the published DXOMARK perceptual MP. But since the published PMP was rounded off, the deviation may be as little as +/-0.5 MP.

The same is true of lens MP taken directly from the lens as a linear measure of sharpness. Someone has to look at the result and decide at what point the lines are blurred together for anyone to say, "That's the limit." No matter how much math and algebra you throw at it it's still a matter of perception.

The bottom line is that pixels can be objectively counted but everything else depends on somebody's perception.

We can modify perceived sharpness in an image by adjusting the acutance. If it is overdone the transition from a dark to a lighter tone might look unnatural.


normal


too sharp

Different sensor sizes

Here are four different lenses mounted on a D750 that has an Fx full frame sensor and 24.32MP:

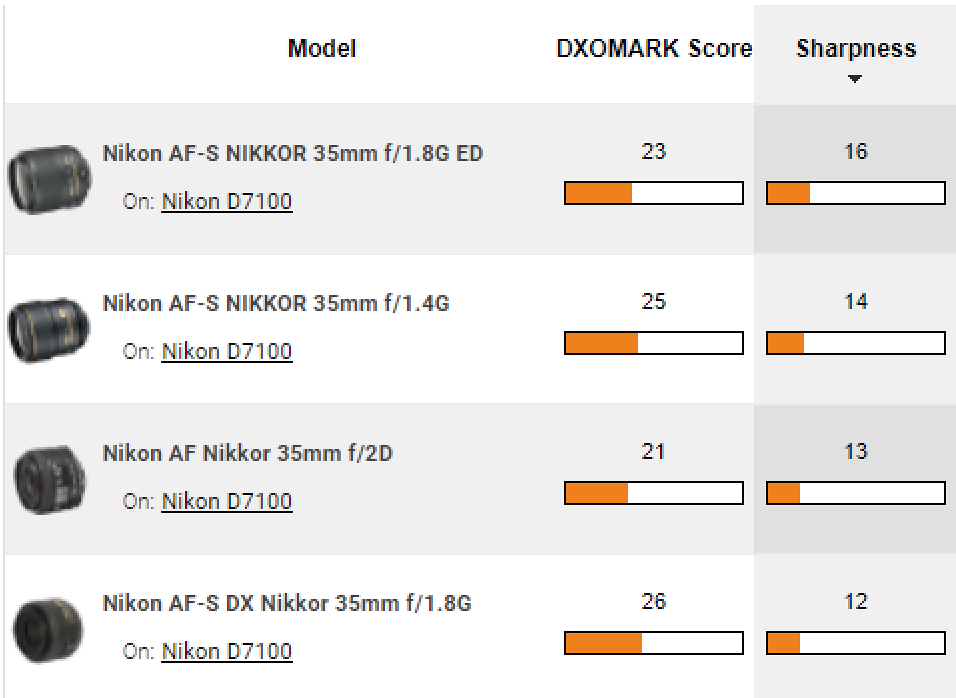
Model	DXOMARK Score	Sharpness
Nikon AF Nikkor 50mm f/1.8D On: Nikon D750	29	19
Nikon AF-S Nikkor 50mm f/1.4G On: Nikon D750	31	18
Nikon AF Nikkor 50mm f/1.4D On: Nikon D750	33	18
Nikon AF-S NIKKOR 50mm f/1.8G On: Nikon D750	30	17

Here are the same four lenses mounted on a D7100, a Dx crop sensor with 24.26MP:

Model	DXOMARK Score	Sharpness
Nikon AF Nikkor 50mm f/1.4D On: Nikon D7100	24	14
Nikon AF-S NIKKOR 50mm f/1.8G On: Nikon D7100	22	14
Nikon AF-S Nikkor 50mm f/1.4G On: Nikon D7100	23	13
Nikon AF Nikkor 50mm f/1.8D On: Nikon D7100	20	13

The drop in system resolution is because less of the lens's projected image is used by the smaller sensor. It also captures a smaller image and provides the field of view of a 75mm lens on a full frame sensor. But the main difference is that the image from the smaller sensor needs to be enlarged more to make a print the same size as the one from the larger sensor. Cropping and enlarging will always make the edges appear less sharp. It also reduces the apparent depth of field.

To capture about the same field of view we would have to use a 35mm lens on the smaller sensor:



Model	DXOMARK Score	Sharpness
Nikon AF-S NIKKOR 35mm f/1.8G ED On: Nikon D7100	23	16
Nikon AF-S NIKKOR 35mm f/1.4G On: Nikon D7100	25	14
Nikon AF Nikkor 35mm f/2D On: Nikon D7100	21	13
Nikon AF-S DX Nikkor 35mm f/1.8G On: Nikon D7100	26	12

Of course, different lenses will have different resolution. But notice the difference in performance between the Nikkor 35mm f/1.8G ED and the Dx Nikkor 35mm f/1.8G. The Fx lens costs 3x as much and it performs much better on a full frame camera.

Reality check – How many MP do we really need?

We may have been led to believe that we should spend lots of money on high resolution lenses and sensors. That's great for the camera industry but hard on your wallet.

There has been a lot of 35mm film photography that produced excellent images for decades with lens resolutions that might be considered inadequate today. How much resolution was coming from those film cameras? Some excellent image can be printed when scanned between 16MP and 22MP even though the scanning process can degrade the sharpness.

What about the minimum digital requirements? You only need a minimum of 300 pixels per inch on an 8x12 inch (20x30cm) image to be viewed from 10 inches (25cm). Nobody is likely to get closer to one of those prints than this normal viewing distance. If they did they would not be able to see the entire image.

That works out to (300 pixels) x (8 inches) x (300 pixels) x (12 inches) = 8.648MP.

If you keep your viewing distance proportional to your print dimensions you can enlarge as much as you want to, even up to the size of a billboard.

Anyone looking a larger print might get closer than the normal viewing distance. So (300 pixels) x (12.5 inches) x (300 pixels) x (18.75 inches) = 21MP. This should be plenty when viewed from 12 inches.

All of this assumes that you don't substantially cropping the initial image. Cropping means that you will need to enlarge the surviving image more and enlarging reduces sharpness. Even though a zoom lens is less sharp than a prime lens it can help you avoid excessive cropping.

You only need sharpness in the part of the image that is within the depth of field. Beyond that or in the dark areas you can't actually see sharp edges.

Conclusion

There are several benefits from the perceptual megapixel approach.

- It is easy to understand system resolution expressed in megapixels. It's a simple number. We don't need to get hung up on sharpness values expressed in line pairs per millimeter, lines per picture height, etc.
- The consumer can get a simple assessment of the system resolution without having to do a lot of complicated calculations or research into MTF charts, diagrams and tables or learn a lot of new terms and brush up on their algebra. Going to Imatest to learn about all of the nuances is optional.
- DXOMARK doesn't have to keep and maintain a large inventory of old cameras and test every new lens with all of them.
- If we want to use a lens from a different system and can find an appropriate adapter, we can get a good idea of how it will work. We can also figure out how this works for camera's that DXOMARK has never tested. All we need to do is to calculate the lens resolution and then combine it with the sensor's resolution. But if they never tested the lens on any camera we may be out of luck. We will have to do our own testing and see if we can perceive the sharpness.