The Magnification Myth

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Recently, a question popped up on the Microscopy mailing list (http://www.microscopy.com) regarding the use of CCD cameras in a TEM that can be summarized as "why use a 4 megapixel camera instead of simply magnifying twice as much and use a 1 megapixel camera?" One of the assumptions was that the computer screen used to display the image only has so many pixels anyway (usually in the order of one megapixel), that even printers could not print out the image in sufficient resolution, and that stretching the image to render all available pixels would "change the magnification".

It is our experience that these things can be confusing to beginning microscopists and casual users of an instrument, and this was confirmed by several people on the mailing list. So, how best to explain the concepts "magnification" and "resolution", which beginners often consider interchangable?

First of all, it is important to have them realize that the primary purpose of a microscope is not to magnify. It is to *resolve*. After all, it wouldn't be of much use if all a microscope did was enlarge a barely visible, tiny feature to a cleary visible, huge fuzzy blob. They want to get a *sharp* feature, so they can see its details. This is the major *raison d'etre* for electron microscopes: they can resolve smaller details.

For this visualization, the image needs to be magnified of course (otherwise their eye still could not resolve the detail) but this is not a fundamental prerequisite. Especially in automated QA-type applications, a microscopist is usually only interested in questions like "how big are these particles" or "how thick are these layers", and she does not need to *see* them.

It is also important to realize that the "magnification" value is a property of a certain *rendering* of an image, and not of the image *itself*. It is a strange fact of life that so many microscopists insist on putting the "magnification" in a data bar which is burned into the image. For example, if an image on your (calibrated) computer screen is "1000×", then using a projector to display the image on the wall easily adds another 10-fold magnification – yet it still claims to be "1000×". This also clearly illustrates the point that further magnification does not necessarily bring out more detail.

Of course, the microscopist often adds this number because it says something about the settings of the microscope at the time the image was taken. Many microscopes do not offer a continuous range of magnifications, so the number is an easy shortcut to remember how the microscope was set up for this image.

Note that a scale bar is a much better way of indicating the size of the features in an image, because it scales *with* the image. Saying "this bar represents 5μm" remains a true statement regardless of the size at which the image is displayed.

It is unfortunate that the word "resolution" is used to mean different things. To a microscopist, it means the smallest distance between two features at which the features can still be distinguished. In digital images and computer screens it is simply the total number of pixels, and for printers it usually means the "dots per inch" rating, *i.e.,* the accuracy at which a dot of ink or toner can be positioned on the paper. Note that the dots themselves are usually larger than their positioning accuracy, so adjacent dots overlap. To make it even more confusing, a "pixel" on a printer is often built up out of multiple dots to create the illusion of grey levels using only black toner.

It can be useful to have images in a higher resolution (*i.e.,* having more pixels) than you can display, especially if you are doing image processing. Suppose you need to measure certain features, then the number of pixels that such a feature takes up in your image roughly determines the accuracy at which such measurements can be performed. It also means that you can use a lower magnification to get the same number of pixels per feature, so you can have more features per image, and hence better statistics.

However, there is also a limit to the number of pixels that makes sense. In an SEM for instance, acquiring an image where the pixel size is much smaller than the probe size is not going to bring out any new information. In a TEM, the CCD needs to be carefully matched to the fiber-optic coupler and the scintillator. Here, a lot of factors come into play, so you can't just divide the CCD chip size by the number of sensor elements to arrive at "the" resolution in the image plane.

Also, cameras can have differently sized CCD chips, even if they have the same number of pixels. Larger CCD chips are more sensitive and therefore more useful in low-dose applications, but they are also more expensive. A high-end CCD for use in a TEM can be as large as 6x6cm. It is not uncommon to have two cameras on a TEM; one with a smaller (and faster) sensor to conveniently locate the area of interest, and one big (expensive) one for the "golden shot".

In conclusion, there is much more to the concepts of "resolution" and "magnification" than meets the eye. For beginners, it can be beneficial to avoid the use of "magnification" altogether, especially in printed or displayed images. Otherwise, it may be too tempting to use this value as a "scale", like it is used in maps and technical drawings, expecting that measuring a feature with a ruler and dividing this by the magnification number yields its real size. ■