FNAR 265 Spring 2002 — Intro to Digital Imaging
Tutorial Notes: Image Resolution (01/18/2002)
Bjoern Hartmann, bjoern@seas.upenn.edu

Why worry about image resolution?

All pixel-based images are inherently resolution-dependent – the quality of your output is directly determined by the resolution choices you make at different stages of the work process. Making the wrong choices can either result in inferior output quality (image resolution too low) or the waste of large amounts of memory and processing time (image resolution too high). To avoid making resolution mistakes, it is necessary to understand the resolution issues at all stages of your project. The following material is fairly technical, but please bear with me as mastering these concepts is essential for producting professional-quality work.

When you scan a source document, light sensitive elements inside the scanner sample the color or light intensity of your source document or object at different points. Imagine a square grid superimposed on your image; the scanner detects the average color of each grid cell and passes it on to your imaging software as a pixel value. The *sampling rate* or *scanning resolution* determines how many intensity samples are taken per unit area (ie. how many grid cells are fit into one square inch), while the *color depth* or *dynamic range* determines how many different colors or shades of gray can be distinguished for each sample.

Resolution is usually given in *dpi* (dots per inch), although it would be more accurate to speak of *spi* (samples per inch), since the concept of a dot is unrelated to the actual sampling process. The choice of scanning resolution depends on the intended output image size and the *device resolution* of your output target: a professional image setter has a higher output resolution than an average laser printer and hence will require a higher initial scanning resolution for best output quality.

Color depth is also variable, but the following standard values are used most of the time: 8 bits per pixel for grayscale images, which allows for 256 different intensity levels of gray to be recorded, and 24 bits per pixel for color images (8 bits each for the red, green, and blue components of a color, for a total of 8^3 = 16,7 million possible colors). High-quality scanners might offer you higher bit depth settings. Both resolution and color depth are directly related to the amount of memory needed to store the image on the computer:

Image Size [in bytes] =
Source Dimensions [in inches] $*$ Scanning Resolution [in spi] $*$ Color Depth [in bytes].

Be aware that the image size in memory quadruples when you double the scanning resolution, since the number of samples taken doubles in two dimensions – horizontally as well as vertically. A 1”x1” image scanned at 100 spi, with 8 bits = 1 byte per sample requires $100 * 100 * 1 = 10000$ bytes, while the same image scanned at 200 spi requires $200 * 200 * 1 = 40000$ bytes of memory. In RGB color at 200spi, $200 * 200 * 3 = 120000$ bytes are needed. Furthermore, every extra layer in Photoshop adds the same amount of memory as the base image to the total file size. The trick to effective scanning is then to set the resolution sufficiently high for image fidelity and reasonably low to save memory and processing time. If you are planning to alter your source image by applying filters or transformations, you should scan the image at a slightly higher resolution since subtle detail is frequently lost in the filtering process.

Once the image is scanned, the computer's internal representation of the image is characterized by its *Pixel dimensions* – the number of pixels along the height and width of a bitmap image – and the *image resolution* – the number of pixels displayed per unit of printed length in an image, measured in *ppi* (pixels per inch). The following simple formulas relate the source image, the scanning process and the internal image representation in Photoshop:

Pixel Dimensions [in pixels] = Source image size [in inches] ∗ Scanning Resolution [in spi].
Image Resolution [in ppi] = Scanning Resolution [in spi] ∗ 100/Zoom Percentage [in %].
Print Dimensions [in inches] = Pixel Dimensions [in pixels] / Image Resolution [in ppi].

As you can easily check, if you scanned at 100% zoom, your image resolution (in ppi) will be the same as your scanning resolution (in spi). At 200% zoom, the same amount of information is captured, but the image resolution is only half as big, resulting in doubled print dimensions (thus the 200% - once again, you should check the formulas to convince yourself). Some scanning programs also alow you to enter your desired print dimensions directly and then compute the other values, which can save you from doing the calculations yourself.

Once you have scanned an image, you can alter its print dimensions without changing any of the actual pixel information by changing the image resolution. To do this in Photoshop, choose *Image→Image Size*, uncheck the "Resample Image" box at the bottom of the dialog, and enter either a new image resolution or your desired print dimensions; Photoshop will automatically calculate the respective other values. You should also make sure that the "Constrain Proportions" box is checked to maintain the width-to-height ratio of your image (the Transformation tool offers more flexible distortions if you do want to alter the proportions).

Finally, the device resolution of your output device, measured in *dpi* (dots per inch) determines the number of toner or ink dots produced per inch by your printer. Since the monitor can also be considered an output device, it has its own dpi resolution. For older monitors, this used to be 72dpi; newer models range up to 100dpi. Laser printers usually offer 600dpi, and high quality ink jet printers up to 1440dpi. It is very important to understand that an image pixel is not the same as a printing dot. Image pixels are virtual entities, best visualized as the image elements of a flat-screen monitor when viewing your document at 100% zoom (it's yet a different story for traditional CRT monitors). Printing dots are physical things, round instead of squre-shaped, and one dot can generally *not* represent an arbitrary color or grayscale in the same way a pixel does. To simulate colors or intensities, multiple dots have to be arranged in varying shapes. The *line screen* describes the arrangement of these so-called halftone dots. However, modern desktop printers often use different proprietary methods of distributing ink/toner on the page. So what is the upshot of this whole device resolution mess? Willmore offers the following simple rule-of-thumb:

Image resolution [ppi] = Output Resolution [dpi] / 3

For output on a laser printer or a high quality ink jet printer, an image resolution of 150 to 300 ppi for continuous tone images is sufficient. Only type and line art will require significantly higher settings. If your image has a lower resolution, aliasing artifacts will be visible in your printout (you will be able to see individual boxy pixels). Higher image resolutions however will not improve the output since the printer simply cannot reproduce the additional detail.