

## The Right Print Resolution

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*This is the full frame of the Chicago River image I printed. The red square shows the active area shown in the Figures.*

There seems to be some confusion in the industry about how to prepare and optimize image resolution for fine-art printing from modern high-end inkjet printers. Some people say you can't really see any difference between prints made at higher or lower output resolutions. Well, I can.

Contrary to what some people may say, size really does matter (well, at least file size). By file size, I'm referring to the size of digital captures, not the size of the final print. A Canon EOS-1Ds Mark III camera has a capture size of 5616 pixels by 3744 pixels. Until processed, this capture size is not yet tagged as having a dimension or resolution. In fact, the dimension and resolution of an image are simply a ratio of size at a given pixel-per-unit designation. So, an image that's 5616×3744 pixels can have a dimension of 23.4×15.6 inches when set to a pixel-per-inch (ppi) of 240. If you set the resolution to 360 ppi, the print dimensions are reduced to 15.6×10.4 inches. Would there be a huge difference in the image quality of the two prints? No, but the print made at 360 ppi will have better image quality and finer detail. Why? Well, that's what I'm going to show. However, before I do that, I need to explain a few things.

### Resolution and The Eye

My good friend and colleague, the late Bruce Fraser, wrote about human visual acuity in his Real World Image Sharpening book (which I've taken over as coauthor for him). In the book, Bruce indicated that "the generally accepted definition of normal (20/20) visual acuity is the ability to resolve a spatial pattern whose features are separated by one minute of arc, or 1/60 of a degree." Unfortunately, that doesn't translate to printer-output resolution very easily. It involves trigonometry and calculations, which I hate. Fortunately, Bruce already did the math as shown in the table in Figure 1.

Viewing distance (in inches from a print)	Resolution of the eye (dpi)
8	428
10	355
12	286
18	191
24	143

*Figure 1*  
*Chart showing Viewing Distance and Eye Resolution*

As you can see, the closer the distance, the more resolution the eye can see when expressed as dots per inch (dpi). The normal viewing distance of a print is typically between 1.5 and 2 times the diagonal of a print. So a 3.5×5-inch print normally would be viewed from between 10 and 12 inches away, and the eye could resolve between 355 dpi and 286 dpi.

Now before you get too worked up about this, realize there are a lot of factors involved, such as the illumination on the print and the vision of the viewer. If a person has 20/20/20 vision (by that I mean 20/20 vision of a 20-year-old), they'll see more resolution than somebody who's 50 years old and needs reading glasses. But let's agree to agree on the general principles, okay? A printer that prints at 360 dpi such as the Epson line of printers, or 300 dpi such as the Canon line of printers, would seem to fit the needs of output resolution. Yes, well, that depends on the nature of the viewer and presupposes that they don't walk up to a print and view it from mere inches away. When you're talking about printed billboards seen from a highway, that's a safe bet, but if you're talking about people in a gallery where the prints are well lit, people will tend to walk into a print and view it closer than normal. Bruce used to say that the normal viewing distance for a photographer is limited only by the length of their nose. So, it would seem to behoove somebody who wants his or her prints to have excellent detail to print at high resolutions.

## **Printer Output Resolution**

Today's high-end, large-format inkjet printers are capable of outputting at high resolution. The Epson pro printers' print heads have a reported output resolution of 360/720 dpi, depending on the print mode. Canon and other printers that use similar thermal head technology have a reported 300/600 dpi. What do I mean by "reported"? The print driver communicates with the operating system print pipeline and states its resolution in dots per inch. You can send any output resolution to the print head, but the print pipeline will resample the input resolution and send the printer the resolution it asks for. Now there's some question of where and how this data gets resampled.

The people at Epson say that the print driver doesn't do the re-sampling, and since the application sending the print doesn't do the resampling unless asked to do so, the resampling must be happening in the print pipeline. I've tried, unsuccessfully, to get confirmation from Apple and Microsoft about their respective print engine activities regarding the resampling of the image data. So I really don't know where or how the resampling is being done. But I'm convinced some sort of resampling is being done. Is it an optimal resampling algorithm, or is it something done for speed? I don't know, but I suspect, at best, it's a compromise in favor of speed. I'm pretty sure there are better, optimized resampling algorithms that could do a superior job. In fact, Adobe Photoshop Lightroom resampling is a hybrid Bicubic algorithm that interpolates between Bicubic and Bicubic Smoother for upsampling and Bicubic and Bicubic Sharper for downsampling.

## Printing From Lightroom

First off, let me disclose the fact that I'm partial to and perhaps a bit biased toward the Lightroom Print functionality. I had a little something to do with the development of printing from Lightroom. I've worked with the engineers to optimize the printing workflow and incorporate output sharpening for printing directly in Lightroom. As a founding member of a company called PixelGenius, LLC, I was involved with former PG member Bruce Fraser when he developed a sharpening plug-in called PhotoKit Sharpener. PixelGenius worked with Adobe to incorporate the PhotoKit output sharpening for inkjet and screen display directly into Lightroom and Camera Raw.

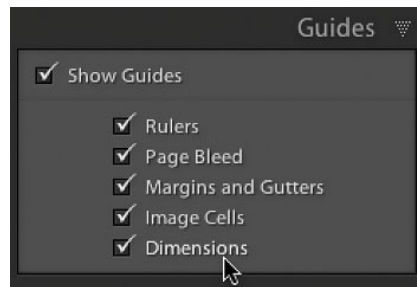


Figure 2

*I suggest checking the Dimension option in the Guides panel to see a readout of the dimensions and resolution of the image at the final print size.*

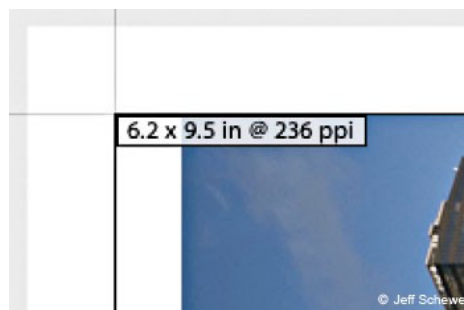


Figure 3

*This is the readout of the native resolution of 236 ppi of the image when printed at the final print size.*

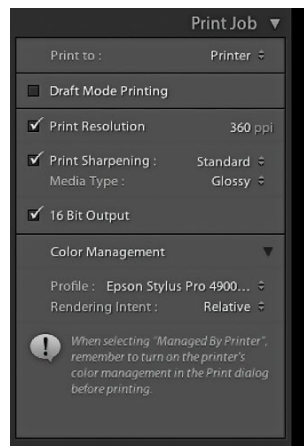
The output sharpening is processed at the end of the printing command just before the image data is sent to the printer. This offers a variety of benefits—not the least of which is the ability to upsample to a specific output resolution directly in the Print module and then apply the final output sharpening. If you want optimal inkjet output, you should be upsampling (never downsampling, because why waste pixels) before sending the image to the printer.

## Native Resolution Vs. Upsampled Resolution

Before I get into the details, let me outline exactly how I created the following print output tests. The original raw images were printed from Lightroom after setting the optimal capture sharpening in the Develop Module of Lightroom. As shown in the following figure, the image had the Amount, Radius and Detail sliders set for optimal sharpening. I also applied a bit of Luminance Noise Reduction because sharpening will often increase the perception of the noise (Fig. 4).



*Figure 4*  
The Sharpening and Noise Reduction settings adjusted in the Detail panel.



*Figure 5*  
Here, the Print Resolution option has been checked in the Print Job panel, and the resolution has been set to 360 ppi.

After preparing the image in Develop, I went into the Print Module of Lightroom 3.5. At the native size of the capture (a cropped portion of an image shot with a Canon EOS Digital Rebel XTi), the image would print at 6.2×9.5 at 236 ppi. Based on the normal viewing distance of about 22 inches, 236 ppi would be plenty of resolution. But there's a question of how the details in the image would reproduce after the print pipeline did the resampling to 360 ppi. High-frequency texture and high-contrast diagonal lines often can produce a jaggedness to edges that can be seen in the final print. Whether this is due to the error-diffusion dither process of the printer or the pipeline's resampling, I don't know (it's probably both). But I do know that upsampling to the reported resolution of the print can eliminate the problem.

I printed the image at both the native resolution and the upsampled resolution from Lightroom. I used the Standard setting on the Print Sharpening option and chose Glossy as the Media Type. In general, you'll want to select the glossy settings for papers considered photo papers and the matte settings for matte and watercolor papers. The sharpening requirements are different due to factors such as ink absorption, dot gain and the texture and reflectance of the paper. Lightroom automatically applies the proper output sharpening, based upon the resolution being sent to the print.



For the purposes of the test prints, I used two printers; an Epson Stylus Pro 4900 and a Canon imagePROGRAF iPF6300. Both printers represent the state-of-the-art, 12-color, high-end fine-art printers. The respective print dialogs were set up as shown in Figures 5 and 6. For the Epson printer, I used 8.5×11-inch Epson Ultra Premium Photo Paper Glossy. For the Canon printer, I used Canon's Photo Paper Pro II.

You'll notice that in both drivers' settings, I've chosen to turn off bidirectional printing. The odds are, printing normal output at these resolutions using bidirectional printing wouldn't negatively impact the final output. However, unidirectional printing eliminates any potential issues.

## The Epson Results

In Figure 6, the image is printed with the image's native output resolution of 236 ppi. In Figure 7, the image is printed at the upsampled resolution of 360 ppi from Lightroom. One pretty obvious difference is the way the light and dark diagonal edges in the building show a jagged edge in the native resolution, while the edges are smoother in the upsampled print. Remember that what you're looking at here is at about 10x life-size. However, I can see the difference with my naked eye (Figs. 6 and 7).



*Figure 6*

*Print scan of the native resolution output from the Epson 4900 printer.*



*Figure 7*

*Print scan of the upsampled output resolution the Epson Printer*

## The Canon Results

The native resolution image of the Canon print shows the same jagged-edge problems that the Epson print showed. You might think that, since the Canon uses a lower 300 ppi output resolution, there wouldn't be as much difference when upsampling. However, upsampling from the native 236 ppi to 300 ppi does improve the edge detail (Figs. 8 and 9).



*Figure 8*

*Print scan of the native resolution output from the Canon 6300 printer.*



*Figure 9*

*Print scan of the upsampled output resolution the Canon Printer*

## My Conclusions So Far

From this test, I've concluded that upsampling to the reported resolution of the printer will produce better results than printing with the native resolution of the image. The upside is a reduction in artifacts caused either by the print pipeline or the dither of the printer. The only real downside to doing the resampling in Lightroom is that the processing time for the print-spool file is a bit longer. The actual print time, once the printer starts printing, seems the same. I'll admit that printing with the bi-directional off is slower by a factor of two—twice as slow. I would normally suggest printing with bidirectional on for these resolutions.

The other thing I learned is that the difference between the high-end Epson and Canon printers is negligible when it comes to output detail. There's a slight difference between colors, which I didn't care about. My thanks to Kelly Blok at Canon for letting me come out to the Canon offices here in Chicago to use their 6300 printer.

## But Wait, There's More

Saying you should upsample to the reported resolution of the printer when the native resolution is under that of the printer is fine. What about when the native resolution is above the reported resolution of the printer? Should you downsample to 360 ppi for Epson and 300 ppi for Canon printers? I answer with a resounding NO! The only time you should consider downsampling for output is for the web or if you're supplying CMYK output. In the case of CMYK output, most RIPs will do their own downsampling of an unknown flavor and suffer potential softening of the image.

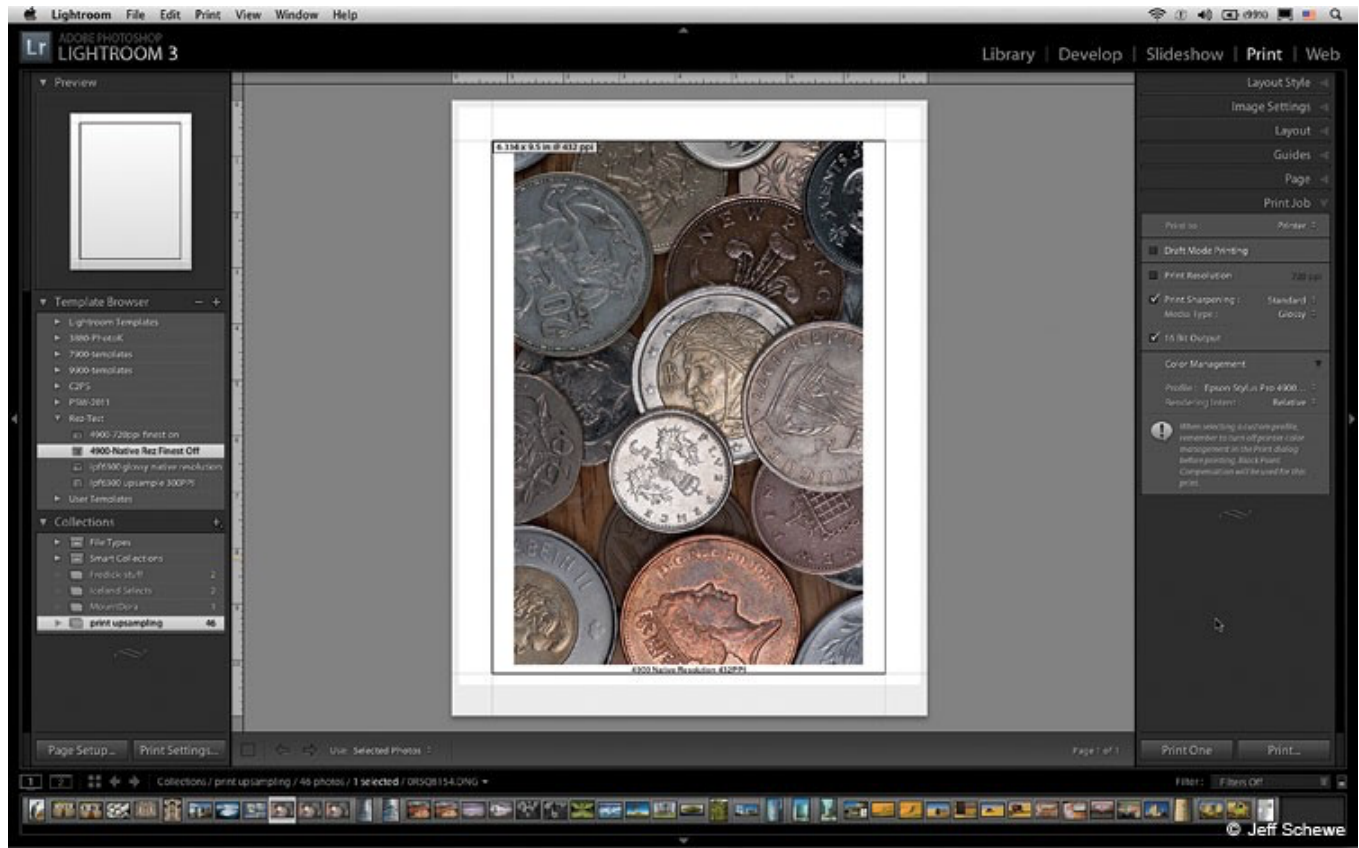


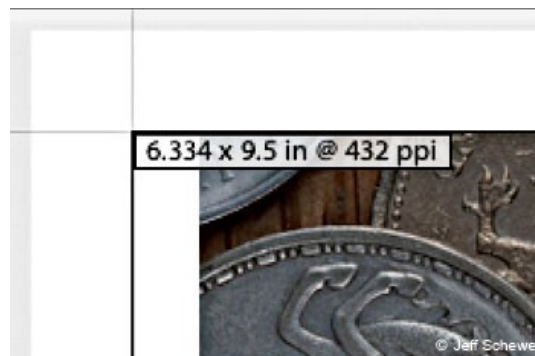
Figure 10  
*The image I used for this test in the Lightroom 3 Print Module.*

The Epson pro printers have an option in the print driver called Finest Detail. When that option is checked, the driver actually reports its resolution to be 720 dpi. The Canon also can report to the system as a higher-res 600 dpi printer. In the past, Epson has told photographers they didn't need to use the Finest Detail option when printing. Epson says that it's useful for vector graphics and type, but not images. I beg to disagree. I decided to go about proving that upsampling to 720 ppi for Epson and 600 ppi for Canon printers can be useful.

This whole thing really came about when I got a Phase One P65+ medium-format 60 MP digital back. It really ticked me off that all that resolution went to waste when printing smaller images. The capture size of a P65+ is 8984×6732 pixels. To make a print on 13×19-inch paper with a minimum one-inch margin results in an image size of 14.68×11 inches and a resolution of 612 ppi, so why waste it? When Lightroom 3 was being developed, I worked with the engineers to increase the previous hard cap of output resolution from the previous 480 ppi. In Lightroom, the hard cap is now set at 1,440 ppi.

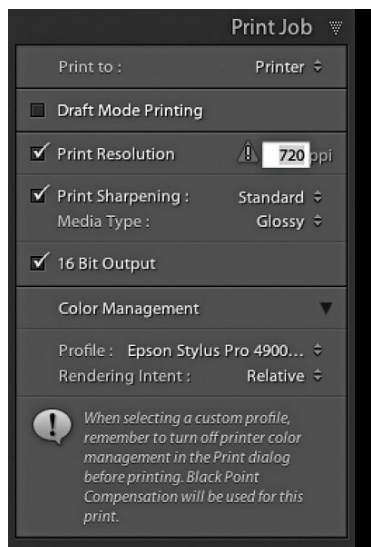


I chose an image whose native resolution at the print size of 6.34×9.5 inches would be 432 ppi. The image was captured with a Canon EOS-1Ds Mark II with a 100mm macro lens (Figs. 10 & 11).



*Figure 11*  
*Detail of the print dimensions and native resolution.*

In the Print Job panel, I checked the Print Resolution option and entered 720 ppi in the field as shown in Fig 12). Note, in earlier versions of Lightroom the resolution setting was hard capped to 720ppi, it's currently now set to a max of 1,440. I haven't tested whether there would be any benefit to upsampling beyond the native maximum resolution of the printers though.



*Figure 12*  
*Setting the print resolution to 720 ppi in the Print Job panel.*

In the Epson 4900 print driver, I checked the option for Finest Detail. This makes the print driver report to the pipeline as a 720 dpi device. Unlike the lower-resolution printing, when using Finest Detail for maximum quality, I also suggest printing in unidirectional mode. In the Canon print driver, I had already been using the Print Quality set to Highest (600 dpi).

## **The Results Of The Highest Output From Epson And Canon**

The prints of the coins were printed and scanned in the same way as the previous tests. The magnification is 10.66x life-size. The differences between the native resolution and the upsampled resolution with Finest Detail on are pretty indisputable. Upsampling to 720 ppi in Lightroom and using the Finest Detail setting in the print driver produce a much-improved result. Whether this is due to the



upsampling or the use of the Finest Detail setting, or a combination of both, I don't know. What I do know is that looking at the prints on my viewing box, even without a loupe, I could see the improvement.

The differences on the Canon prints between native resolution and upsampled resolution aren't quite as noticeable. The upsampled print is smoother without some of the jaggies seen in the native resolution print. I still think the output from the Canon is improved by upsampling in Lightroom before printing (Figs. 13-16).



*Figure 13*  
*Epson output at native resolution with Finest Detail unchecked.*



*Figure 14*  
*Epson output upsampled to 720 ppi with Finest Detail on.*



*Figure 15*  
*Canon output at native resolution*



*Figure 16*  
*Canon output upsampled to 600 ppi.*

## The Bottom Line

The bottom line is, if the image you're printing to a high-end inkjet printer has a native resolution at the print size of less than the printer resolution, upsample to the printer's dpi. In the case of Epson, that's 360 dpi, and it's 300 dpi with Canon and other printers with similar print heads. If the native resolution is above the resolution, upsample the image to the higher reported resolution of the printers (720 ppi for Epson and 600 ppi for Canon). In the case of the Epson line, also check the option for Finest Detail. So, does this hold true for the consumer, professional and commercial versions of inkjet printers? Yes, for the recommendation to upsample to 360/300 dpi. I'm not sure the same argument can be made for upsampling to the higher 720/600 ppi case. I've not printed on any Canon consumer photo printers, although I have printed to an Epson R3000 printer and I've been able to detect some benefit to upsampling to 720 ppi. But since that printer doesn't have the same Finest Detail option, the differences are more akin to the differences seen in upsampling to 600 ppi on the Canon prints.

How does the paper you print on impact the results? Well, I specifically chose glossy paper for the purpose of scanning. My normal paper is Epson Exhibition Fiber Paper or Luster. Both papers can hold the Finest Detail settings when printing to Epson, and I presume (although I didn't test this) that similar papers would show some benefit when printing on Canon. How about matte or watercolor papers? Not so much. I'd still suggest upsampling to the base-level resolution of 360/300 dpi, but the paper's ability to hold detail at the higher resolutions of 720/600 dpi is doubtful. Personally, I've not seen the higher resolution provide much, if any, benefit.

Does print size have any impact on the output resolution? Yes, as indicated before, you need more resolution when printing small and less when printing big. Aside from the whole "photographer's nose" issue, for even the largest prints, I'd still suggest upsampling to the base-level 360/300 ppi resolutions.

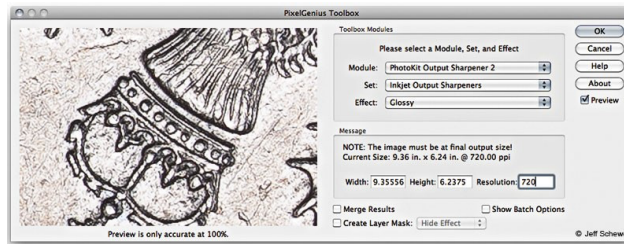
## Not Printing From Lightroom?

What if you don't print from Lightroom? Well, first off, I suggest you think about doing so for the reasons mentioned in the article—as well as for the improved printing workflow. Rather than have to spawn off multiple file iterations for printing various image sizes and resolutions, you can print directly from your raw file or a rendered and retouched TIFF file from within Lightroom.

If you print from Photoshop, you'll need to do some additional steps to take advantage of upsampled printing. You'll need to use the Image Size command to upsample your image to the desired output resolution.

Of course, you'll need to do your own flavor of output sharpening after the upsampling. Photoshop hasn't seen fit to add output sharpening to the Photoshop Print command. My biased suggestion would be to use PhotoKit Sharpener 2 to do your final output sharpening for print (Fig. 17).

**NOTE:** sadly, PixelGenius has decided to "end-of-life" the PhotoKit line of Photoshop plug-ins. While PG offers the plug-ins as freeware on their home page at <http://www.pixelgenius.com>, one has to "bless" the plug-ins to run in the current Mac OS (Big Sur) using Terminal, they should still run in Windows.



*Figure 17*  
*Output sharpening using PhotoKit Sharpener 2 by PixelGenius.*

If you're using a third-party print application, then you won't really be able to take advantage of the benefits of the upsampling beyond the base-level output resolutions. For example, it's unclear if the ImagePrint RIP from ColorByte Software is locked into the base-level resolution of 360 ppi for Epson printers (I'm not sure about Canon printer support). There's a third-party printing software called Qimage that can take advantage of the higher reported resolutions of Epson and Canon printers.

Your mileage may vary...