Printing Techniques

1

There are various methods of printing your own photographs. We only address one method in detail – printing using inkjet printers. In this chapter, we take a glance at different printing methods and discuss which are good and why. Most are not recommended for fine art printing.

The special focus of this chapter – and the general focus of the entire book – is fine art printing, and our reader is assumed to be the ambitious amateur, as well as the professional photographer. There are many reasonably good books on prepress work and commercial printing of books, magazines, brochures, or posters using offset printing, silkscreen printing, rotogravure or intaglio printing. We do not cover these methods, as they are either too complicated or too cost-intensive for the reader we target. Nor do they deliver the kind of quality that may be achieved with today's photo inkjet printers.

1.1 Basic Printing Techniques

The Journey from a Pixel to a Printed Point

In image processing, there are several terms used with a similar meaning, often used interchangeably for image and print resolution: **dpi** (*dots per inch*), **ppi** (*pixel (or points) per inch*), and **lpi** (*lines per inch*). Apart from this, the resolution of an image is stated by its dimensions in pixels or in inches (at a certain ppi or dpi resolution). So let's try to clean-up this mess:

When an image is captured by a camera or scanner, the result is a digital image consisting of an array (rows) of separate picture elements (called pixels). This array has a horizontal and vertical dimension. The horizontal size is defined by the number of pixels in a single row (say 1,280) and the number of rows (say 1,024), giving the image a horizontal orientation. That picture would have a "resolution" of "1,024 × 1,280 pixels" (yes, some years ago, there were digital cameras around with such a low resolution).

This is not a physical size yet. You could, for example, display this image on a 17" display (it would comfortably fill most such displays with each pixel of the image representing one pixel of the LCD monitor). It would probably have a display dimension of roughly 13.3 by 10.6 inches.* If you display this same image on a 19" monitor, its displayed size would be approximately 14.8 by 11.9 inches.

** A 17" display is diagonally roughly 17 inches*

The size of the image displayed is dependent on the number of pixels the monitor displays per inch. The "pixel per inch" resolutions (ppi) of monitors vary, and are usually in the range of 72 ppi to 120 ppi (the latter, larger 21" monitors). In most cases, however, with monitors the resolution is given as the number of pixels horizontally and vertically (e. g. 1,024 × 1,280 or 1,280 × 1,600). So the "size" of an image very much depends on how many pixels are displayed per inch. Thus, we come to a resolution given in 'pixels per inch' or ppi for short.

In Europe, "pixel per centimeter" (ppc) is used often instead of ppi.

With LCD monitors, their ppi resolution is fixed and can't be adjusted (at least not without a loss of display quality). With CRT monitors you have more flexibility (we won't go into this further).

When an image is printed, its physical size depends upon how many image pixels we put down on paper, but also how an individual image pixel is laid down on the paper.

How Image Pixels are Reproduced by Printer Dots

There are only a few printing technologies where a printer can directly produce a continuous color range within an individual image pixel printed. Most other types of printers reproduce the color of a pixel in an image by approximating the color by an $n \times n$ matrix of fine dots using a specific pattern and a certain combination of the basic colors available to the printer.**

Printing techniques that can produce continuous tone values are dye-sublimations, rotogravure and lightjet printing

*** These "basic colors" (or inks) of the printer are called 'primary colors'.*

If we want to reproduce a pixel of an image on paper, we not only have to place a physical printer's 'dot' on paper, but also have to give that 'dot' the tonal value of the original pixel. With bitonal images, that is easy. If the pixel value is 0, you lay down a black printed dot, and if the pixel value is 1, you omit the dot. However, if the pixel has a gray value (say 128 out of 256), and you print with a black-and-white laser printer (just to make the explanation a bit simpler), we must find a different way. This technique is called *rasterization* or *dithering*.

"Bi-tonal" means that there are only two colors in your image: pure black and pure white (or any other two colors) but no tonal values in between.

To simulate different tonal values (let's just stick to black-and-white for the moment), a number of printed dots are placed in a certain pattern on the paper to reproduce a single pixel of the image. In a low-resolution solution, we could use a matrix of 3 printed dots by 3 printed dots per pixel. Using this scheme, we could produce 10 different gray values, as may be seen in figure 1-1:

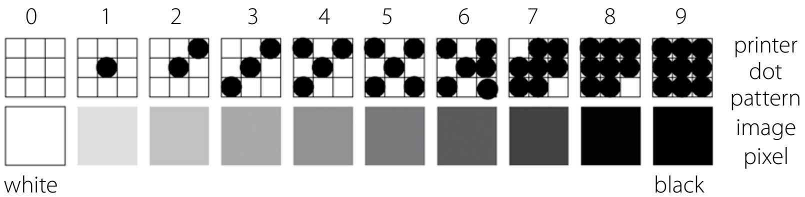


Figure 1-1: Different tonal values simulated by a pattern of single printed dots

Using more printed dots per image pixel allows for more different tonal values. With a pattern of 6 × 6 dots, you get 37 tonal grades, with a 16 × 16 pattern, 257 tonal grades, (which is sufficient). For a better differentiation let's call the matrix of printer dots representing a pixel of the image a *raster cell*.

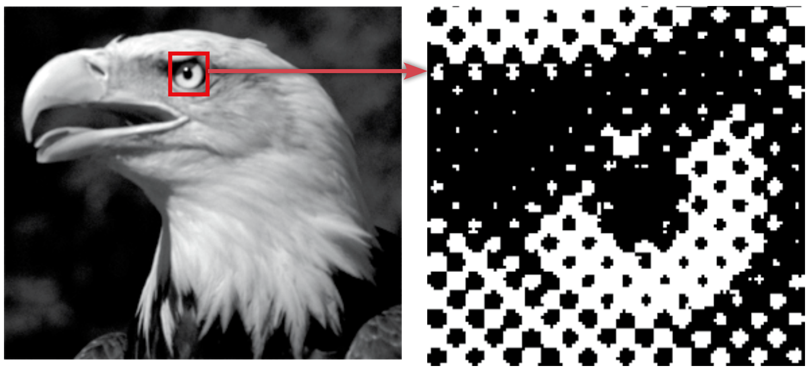


Figure 1-2: Enlarged printing raster of the eagle's eye in a printed image

Now we see why a printer's "dot per inch" (dpi) resolution has to be much higher than the resolution of a display (where a single dot on a screen may be used to reproduce a single pixel in an image, as the individual screen dot (also called a *pixel*) may have different tonal (or brightness) values.

When you print with a device using relatively low resolution for grayscale or colored images, you must make a trade-off between a high resolution image (having as many "raster cells per inch" as possible) and larger raster cells providing greater tonal value per cell.

The image impression may be improved when the printer is able to vary the size of its dots. This is done on some laser printers,* as well as with some of today's photo inkjet printers. If the dot size can be varied (also called *modulated*), fewer numbers of dots (*n* x *n*) are needed to create a certain number of different tonal values, (which results in a finer raster). This technique allows more tonal values from a fixed raster cell size.

** E.g., HP calls the technique ProRes on laser printers or PhotoREt with inkjet printers.*

There are several different ways (patterns) to place the single printed dots in a raster cell, and the pattern for this dithering is partly a secret of the printer driver. The dithering dot pattern is less visible and more photo-like, when the pattern is not the same for all raster cells having the same tonal values, but is modified from raster cell to raster cell in some random way (this is called *stochastic dithering*).

What are 'Lines Per Inch'?

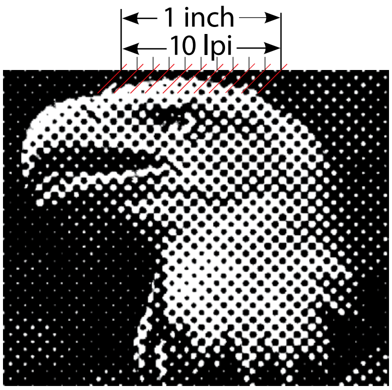


Figure 1-3: Enlarged version of very coarse raster of 10 lines per inch.

Using the technique described here to simulate different tonal pixel values, the rows of dots are not laid down exactly one below the other, rather the rows are slightly offset from one another. These macro-dots form a sort of line across an area. Raster cells and lines are not directly placed adjacent to each other, but have a slight gap (in most cases).

In black color, these lines are normally placed at an angle of 45°. The number of raster cells or lines in one inch (see figure 1-3) defines another kind of resolution called "*lines per inch*" or lpi for short (using metric names it becomes "*lines per cm*" or "l/cm" for short). When printing in color, a raster cell not only consists of a single color pattern, but the pattern process is repeated for all the basic (primary) colors found in the print.

Most color printers use cyan, magenta, yellow, and black as their basic colors (also called *primary colors*). Some printers (and almost all inkjet printers that are titled *photo printers*) use some additional basic colors to achieve a richer color gamut and a finer raster, yet, basically, they use the same scheme as printers using only four basic colors. In color printers, the simulation of tonal values is represented using a pattern of primary colors (see figure 1-4).

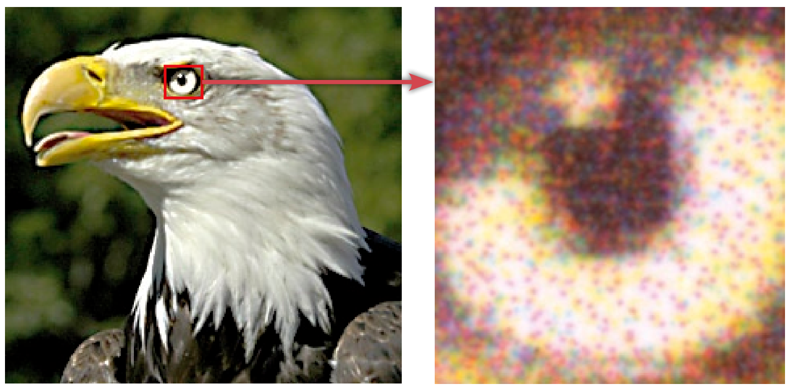


Figure 1-4: When printing color images, tonal values (in inkjet and offset printing) are produced by a dot pattern of tiny colored ink dots. With inkjet printers, this dot pattern is not totally regular, but uses some randomness. This kind of dot pattern is also called a 'stochastic pattern'.

Different basic/primary colors (in a CMYK print there are four primary colors), raster cell lines are printed by using different line angles. In a normal CMYK print – those encountered in most colored books and magazines –, cyan is printed at 71.6°, magenta at 18.4°, yellow at 0° and black at 45°. Other combinations are used, as well, but this is the common way to place lines of colored raster cells. To avoid moiré patterns stemming from overlapping rasters, line frequencies of colors vary slightly. Table 1.1 shows an example for a 106 lpi color raster.

Table 1.1: Example of a color raster using 106 lpi basic raster frequency

	Cyan	Magenta	Yellow	Black
lpi	94.86	94.86	100.0	106.0
Angle	71.56°	18.43°	0.0°	45.0°

The number of lines per inch of a print depends upon:

1. the number of tonal values one wants (more tonal values require larger macro-dots as more printed dots are required to provide broader tonal values), and
2. the size of the individual printed dot,* and
3. the paper used. If you use newsprint paper, which absorbs a lot of ink, you would use a wider raster cell spacing to avoid the single macro-dots merging into one another. Using coated paper, raster cells may be placed closer together resulting in a finer printing raster and finer image impression.

** The smaller the individual printed dot, the smaller the raster cell can be.*

Table 1.2 provides a guideline at which image resolution in pixels per inch and lines per inch is appropriate for different printing media – if you use a printing technique that works with a fixed raster (for inkjet printers, you don't use a fixed raster but a printer resolution setting in your printer driver or RIP).

RIP = Raster Image Processor, see chapter 6.

Table 1.2: Recommended raster frequency for different printing situations

Raster width		Usage	Image resolution
53 lpi	21 l/cm	Laser printer (600 dpi, 65 grey levels)	70–110 ppi
70 lpi	27 l/cm	Newspaper print, typical rough paper	90–140 ppi
90 lpi	35 l/cm	Good quality newspaper print	140–180 ppi
120 lpi	47 l/cm	Acceptable quality for books and magazines. Raster-cell points can still be seen.	160–240 ppi
133 lpi	52 l/cm	Good quality for books and magazines. Raster-cell points can still be seen.	170–265 ppi
150 lpi	59 l/cm	Good offset or silk printing, individual raster-cell points may hardly be recognized	195–300 ppi
180 lpi	70 l/cm	Good offset and silk printing, very fine raster, individual raster-cell points hardly recognizable; good inkjet printing, individual raster point no longer recognizable at a reading distance of 20–30 cm (8–12 inches)	250–360 ppi
200 lpi	79 l/cm	Very good book prints, you need a very smooth paper for printing. Raster-cell points hardly recognizable.	300–400 ppi

When you use an inkjet printer for fine art printing, you do not have to concern yourself much with raster line width. The dithering pattern of your printer driver is more complex than just described. Don't worry. Learn the native printing resolution of your specific inkjet printer – usually between 240–360 ppi and scale (up- or upsize) your image to that size. The values do not have to be precise – close is good enough. In most cases, the printer driver (or Photoshop) will do the proper scaling when using a value close to the printer's native resolution. Using a modern inkjet printer, you need not bother much with color raster angles. This, too, is taken care of by the printer driver or the RIP.* Inkjet drivers do not offer settings for raster width or color raster angles. For offset printing, however, this may (in very few situations) be of interest and may be dealt with in Photoshop when separating colors.

** Printing using RIPs is described in more details in chapter 6.*

How Many Pixels or Dots Per Inch Do You Really Need?

There is no quick, general answer to that question. It depends on several factors:

- **Type of printing technique used:**
  Are you using a continuous-tone printing method (such as direct photo or dye-sublimation printing) or a method that produces halftones by dithering (such as inkjet or offset printing)?

  The ppi values you need will be roughly the same for both methods. However, the dpi values of the printers will have to change, as in dithering you need several printer points (or ink droplets) to build up a raster cell reproducing a pixel of the image.

- **Type of paper used:**
  If you use a rough, absorptive paper (e.g., as used in common newspapers), printed dots will bleed a bit and you must reduce the dots per inch frequency (as indicated in table 1.2).** If you use a good, smooth-coated paper, you may increase your resolution and get a finer, more detailed image.

  If you use glossy or luster paper, you will be able to reproduce even more details (allowing for higher ppi/dpi) than with matte paper or canvas.

*** The slightly increasing of the dot size caused by this bleeding is called 'dot gain'.*

- **Viewing distance:**
  Viewing distance is an important factor, as the human eye can only differentiate single points up to a certain viewing angle (about 0.01–0.02°). If the viewing angle is less, two separate points can no longer be differentiated and visually merge. For a 'normal reading distance' of about 12 inches (30 cm), this minimal size is about 0.08 mm (0.0032 inch). Bright light may reduce this size a bit, low light increase it a bit. Consequently for an Letter/A4-sized photo, a pixel size or raster cell

size of 0.08 mm is a good value (equivalent to a 300 ppi raster size). If the pixel size is smaller, visual image quality (in terms of visual differentiation of details) will not substantially improve.

If the photo is of Ledger/A3 size, viewing distance is usually increased (in order to see the whole image at a glance). Thus for Ledger/A3, the pixel size (or cell size if we use a dithering method), may increase the (raster) point size to 0.122 mm or about 210 ppi.

If you produce posters, the viewing distance will increase further, and the pixel size may increase accordingly (and the ppi may decrease accordingly). If you move up to large-format printing, your ppi may even go as low as 10–20 ppi. The viewing distance will usually be more than 10 yards (or meters). In a simplified formula, simply divide 300 into your viewing distance in feet and you have the required ppi value or:

$$\textit{resolution} \text{ (in ppi)} = \frac{300}{\textit{viewing distance} \text{ (in feet)}}$$

For this reason, a photo shot with a 12 megapixel camera may be enlarged to almost any size you want – **if the image is viewed from the appropriate viewing distance.**

- **Type of printer driver**, **driver settings and interpolation used:** For optimal results, you should use a ppi value close to, or even exactly that of, the printer's native resolution. The printer's native resolution varies from manufacturer to manufacturer. Epson inkjet printers, for example, usually have a 'native resolution' of 720 ppi, while most HP inkjet printer use 600 ppi. Canon inkjets usually use 600 ppi, as well.

Do you really need an image resolution as high as stated? It contradicts a statement given before. Well, yes and no. For optimal results with an Epson inkjet printer, use either 720 ppi or 360 ppi; for an HP printer, either 600 ppi or 300 ppi.[*]

You may leave (automatic) scaling either to Photoshop (as part of the print dialog) or to the printer driver. However, in both cases, you really can't know exactly which algorithms are used for scaling and how well those algorithms will work with your image and your scaling factor (Photoshop will use the scaling algorithm you set in your basic Photoshop Preferences).

If your image is close to the native resolution given above (at the size you intend to print the image), the algorithm will not matter too much. If, however, the image has to be upsized or downsized considerably, the scaling algorithm does matter (it will also influence the effect of sharpening done for printing). In this case, you should either scale an image before calling up the print dialog (and you may have to do this for each individual printing size of the image) or you may use a RIP (see chapter 6).

If you do your scaling in Photoshop, we recommend "Bicubic Smoother" for up-sizing and "Bicubic Sharper" for down-sizing.[**]

* *Here, we assume, no further scaling is necessary.*

** *If you leave the sizing to Photoshop (via the Print or Print with Preview dialog), Photoshop will use the resizing (Image Interpolation) method that was selected in your Preferences settings (Edit ▸ General; with Mac OS it is: Preferences ▸ General).*

1.2 Offset Printing

Technically, you differentiate between sheet fed offset printing and web offset printing. With the latter, the paper comes from a paper roll instead of separate sheets of paper. The basic printing technique however, is the same for both kinds of systems.

Offset printing is the technique used for most books, brochures, magazines, and newspapers. It is plate-based printing. The image is rasterized – as described under "*Basic Printing Techniques*" – for the print and transferred onto a printing plate by projection. This projection currently is done with lasers or LED arrays. First, a plate is coated with a light-sensitive layer. The laser (or LED array) inscribes the image pattern onto this layer. The printing plate is chemically developed, then wrapped around the printing cylinder ③. Those parts of the plate not printed are smooth and do not pick up water when passing the wetting roller ①. The parts of the plate to be printed are rougher and pick up ink when passing an ink-soaked roller ②. This ink-pattern is transferred (by offset) to a rubber-coated rotating cylinder ④ (this is why the printing technique is called "offset printing"). The paper to be printed passes between this rubber cylinder and the paper roller ⑤ pressing the paper against the rubber cylinder. Thus, ink is transferred onto the paper and the image is transferred. In color printing, this process is repeated in additional printing units – one for each primary color (normally C, M, Y, and K).

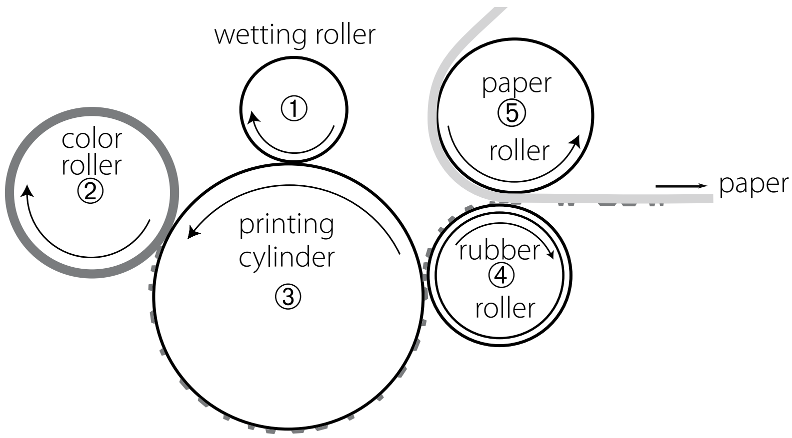


Figure 1-5: Functional model of offset printing (traditional analog offset printing)

The image quality achieved with this technology is quite good in terms of resolution and longevity – provided a good, coated, acid-free paper is used and the image is viewed from a correct (reading) distance. The richness of the color gamut is clearly below that of good photo inkjet printing (see figure 1-6).

The gamut of an offset print may be enhanced if six rather than the normal four (CMYK) inks are used. Printing with six inks is also called *hexachrome printing* (in addition to CMYK, green and orange are used). However, this requires special printing presses having additional print units. Hexachrome printing is far more expensive than CMYK (4C or 4-color) printing, and also requires a special color separation process and special plug-ins for Photoshop to prepare images or DTP documents).

Traditional offset printing might be considered if you intend to make a print run of 1,000 or more copies. As few, if any, home-users or small offices can justify printing equipment for offset printing, we will not discuss it any further (additionally, we have a very limited knowledge of the techniques involved).

In recent years, digital offset printing has come onto the market (e.g. HP Indigo press). These systems work with printing techniques similar to that of laser printers. These digital offset printers are mainly used for smaller print runs (typically 50–1,000). With most models, the maximum print size is restricted to A4 or A3. The resolution of digital offset printing is greatly inferior to that of analog offset printing (e.g. HP Indigo press 5000 has a resolution of 812 × 812 dpi, while analog offset printers work with typically 2,400 × 2,400 or even 3,200 × 3,200 dpi). Printing photos, this leads to a visible reduction of image quality. As for color gamut, some digital offset printers exceed the gamut of traditional CYMK offset presses. They, however, are still inadequate for high-quality fine art prints.

Traditional offset printers, as well as digital offset printers are quite fast. For example, HP gives a printing rate of about 4,000 A4 pages per hour for its HP Indigo press 5000. The speed of traditional offset printing presses may exceed 100,000 pages per hour.

The costs of digital offset printers starts at about $50,000 US and up. The price of a traditional offset press may easily exceed one million dollars.

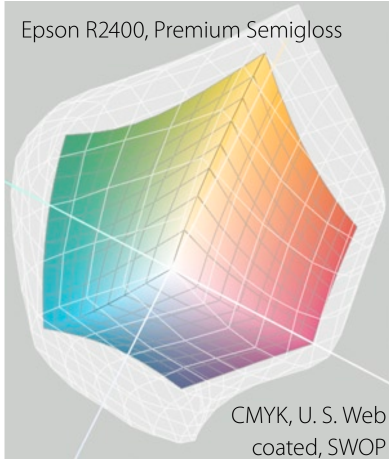


Figure 1-6: The gamut of a photo inkjet printer (light-gray area) is larger than the gamut with traditional analog offset printing (colored area).

1.3 Laser Printers

Laser printers are well established, reasonably fast (from four pages per minute up to 100 pages per minute) and reasonably inexpensive for the cost per page (typically about 4–6 cents per Letter/A4 page in black-and-white at an ink coverage of 5% per page and about 16–20 cents at an ink coverage of 90% per page). While color laser printers were quite expensive formerly, in 2004 and 2005 their price dropped dramatically. You can buy a color laser printer for less than $500 US currently. With low-priced color laser printers, manufacturers use a business model similar to low-cost inkjet printers: they sell inexpensive printers and earn their return via rather expensive toner units. A color toner set – lasting for about 3,000–5,000 pages at 5% medium ink page coverage – costs about the same as the basic laser printer unit ($300–$400 US), resulting in a cost per page (Letter/A4) of roughly $0.10 US with a 5% medium ink coverage per page and about $1.60 US when printing full page size colored images. Nevertheless, printing of text and graphic pages with a color laser printer is much faster and somewhat cheaper than using an inkjet printer.

Laser printers use very much the same technique (see figure 1-7) used by modern photocopy systems (some models even combine both functions: scanning and printing).

A photo drum ① is charged positively by a charging unit ②. The image of the print is rasterized by the printer's RIP (*Raster Image Processor*), and this raster is applied onto a drum using a laser beam and rotating mirror ③ (or alternatively by an array of LEDs). Where the light hits the drum, the positive charge is erased. Then, the drum passes the toner unit ④. Those parts that saw light pick up the positively charged toner, while those parts that bear a positive charge reject the toner. Further on, the toner is transfused onto the paper and burned in by a heated roller (fuser) ⑤.

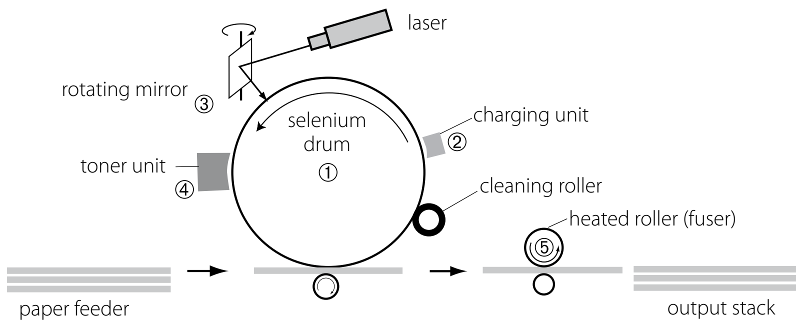


Figure 1-7: Functional model of a laser printer

Color laser printers use four inks – cyan, magenta, yellow, and black (CMYK). They either use four drums or a transfer belt that picks up toner from four separate drum rotations and four toner units and transfers the complete color image onto the paper with one rotation.

As for image quality, the limiting factor of today's color laser printers is the resolution used (600–2,400 dpi, usually just 600 or 1,200 dpi) and the number of colors they use – which is only four (CMYK). A further limitation stems from the size of the toner particles, much larger than those of dye-based or even pigment-based inks on inkjet printers.

Most laser printers have problems producing homogeneously colored areas or fine tonal gradients (you usually see smaller blotches of unevenly printed colors). With several of the color laser printers, the image shows a gloss, which may impair viewing with some images. You cannot avoid the gloss even when using matte papers. This is especially true for solid inks used by some XEROX color laser printers.

For this reason, image quality with color laser printers is clearly inferior to all other printing methods described here and can't touch that of photo inkjet printers. If, however, you have a color laser printer, we recommend using it for fast index printing. The color and detail quality, in most cases, is good enough for a first, fast inspection.

Image longevity very much depends on the type of paper and inks (toner) used and ranges from about 10 to 20 years. The permanence of black-and-white prints is much better, and may be used for archiving documents (provided you use the appropriate paper).

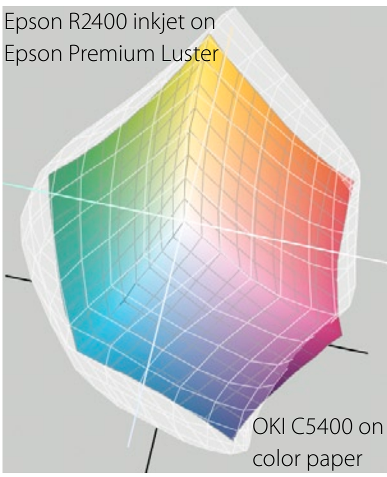


Figure 1-8: Gamut comparison of a color laser printer (OKI C5400) (inner colored figure) and a photo inkjet printer (Epson R2400, using Epson Premium Luster paper, light-gray area).

1.4 Dye-Sublimation Printers

Thermo-sublimation printers are frequently used for the fast and simple production of photographic prints, often directly from the digital camera via a USB cable using the DPOF (*Digital Print Order Format*) or PictBridge protocol supported by today's digital cameras – even the cheaper consumer models. Alternatively, you may plug your camera's memory card into a card-slot the printer provides.

With thermo-sublimation printing (also called *dye-sublimation* or *dye-sub* for short), color is transferred from a color-coated ribbon (foil) onto the paper. The transfer is done by an array of tiny heating elements (integrated into the print head). Where the ribbon is heated, the color on the foil evaporates (sublimates) and enters the paper where it cools down. CMY as well as CMYK ribbons are used. Three or four passes (or sections) of colored ribbons are needed to produce a complete image on the paper. Usually the ribbon consists of sections with the alternating basic colors (three for CMY or four for CMYK). The used portion of a ribbon becomes unusable, is rolled up and finally discarded. The paper must make three (CMY) or four (CMYK) passes under the print head. Individual color intensity is determined by the amount of heat. When the next primary color is added (to those colors previously composed of several primary colors), their colors merge into a combined color due to the heat. The three or four colors merge in the paper and form an (almost) continuously toned color.

Figure 1-9: Canon SELPHY CP750 dye-sublimation printer, 300 dpi, print-size up to 10 x 20 cm, (Courtesy Canon Germany)

With these systems, production costs are independent of the number and kinds of colors and the amount of color a printed page has, as a ribbon section is used only once and then discarded.

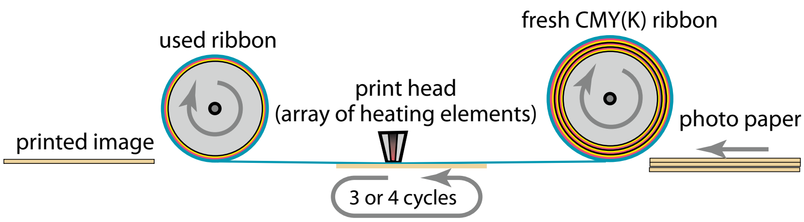


Figure 1-10: Working scheme of a thermo-sublimation printer

The typical resolution of dye-sublimation printers is 240–300 dpi, which sounds very low. However, keep in mind that dye-sub printers do not render a color via dithering, but do it by merging their basic colors by sublimation, thus achieving an (almost) continuous color tonal range for every dot and a highly photographic image at these resolutions.

Typical dye-sub printers today range from 4 × 6 inch to A4 in print size, the lower-cost models (partly portable) are mainly in the 4 × 6 inches (10 × 15 cm) range. A typical print speed is about 30–100 seconds for a 4 × 6 inch photo. Some printers are much faster (e.g. Kodak Photo Printer 6850, claims 300 dpi, 8 sec. for 4 × 6 inch – but it costs $2,200 US).

The range of printing material used with dye-subs is very limited and highly restricted to papers provided by the manufacturer of the printer – one kind for glossy and another kind for matte paper, in most cases. The same is true for inks (color ribbons).

The lightfastness and longevity of dye-sub prints is about five to fifteen years (considerably more in dark storage).

Prices for small dye-sub printers start at about $120 US and go higher with print/printer size; about $500–$1,500 US for a Letter/A4 size printer. The cost per print is about $0.20–$0.30 for a 4 × 6 inch print and about $1.5–$2.5 for an Letter/A4-sized print.

1.5 LightJet® Printing (Digital Photo Print)

There are various names for this technique: *digital photo print* or *LightJet® printing** or *direct digital printing* or *direct photo printing*. Here, in essence, the image is imposed onto conventional photographic material by lasers. To produce an RGB print, three lasers are used. The material may be photographic paper used for traditional color photos or may be photographic film for translucent prints. The exposed material is then developed in a traditional wet process. The resolution used by most printers is either 300 dpi (or ppi) or 400 dpi. Lower resolutions may be used, as well, and will be interpolated to the printer's native resolution. This seems very low, compared to the resolution of inkjet printers or offset presses. With direct photo printing, however, no dithering is required to produce halftones, and every exposed dot on the paper combines red, green, and blue, thus resulting in (almost) continuous tone dots. For this reason, 400 dpi or even 300 dpi will produce a very fine image quality.

* LightJet is a trade name of Cymbolic Science, nowadays a subsidiary of Océ.

Figure 1-11: Durst Lambda® large-format photo laser imager (Courtesy Durst Phototechnik AG, Brixen, Italy)

There are a number of different makers and models of this type of digital photo printer (e.g. Fuji Frontier minilab, Agfa D-Lab, Lambda, Océ LightJet®, Chromira). Print image size may vary from 4 × 6 inches up to 50 × 50 inches). With some digital photographic printers, you may even go much larger (e.g. the Durst Lambda photo laser imager may produce prints up to a width of 50 inches and a length of 262 feet).

As direct photo printers are quite expensive,* this technique is almost exclusively used by service shops – often the very largest ones.

* They start from about $ 100,000 US.

There are two kinds of photographic print shops:

1. **Consumer-oriented photographic print shops**
   They produce a very large quantity of prints per day at very low prices (typically from 15 cents for a 4 × 6 inch print to about $5 US for a Letter-sized print). The processing is done fully automatically and in large quantities. Special requests are usually not handled by these shops. In most cases, an automatic image optimization is performed. This may be disabled at most shops when you place an order, which you should do if you have done your own optimization.
   The quality of their prints is usually quite reasonable and uniform, in most cases.
   Currently, ICC profiles are ignored by these printers; all images are assumed to be in sRGB. If you send an image to them for processing, you should convert it to sRGB (if not already in this format).
   Most of these shops offer only standard image formats. If your image format differs from those supported, you have the option of using either the full width with some parts of the image being trimmed off or receive an image with white borders – which, for fine art prints, may be what you want, anyway. In most cases, it is preferable to set your image to one of their standard formats and decide where and what kind of white frame (or other colored frame) you wish to use.

ICC profiles describe the color space of an image or the color behavior of a device. For more on ICC profiles, see section 3.2.

2. **Professional photographic service bureaus**
   They specialize in high quality prints (usually in smaller quantities), also accommodating special requests. They may even offer to optimize your image for printing, which may or may not be appropriate. These bureaus should provide you with a printer's ICC profile (often, you may download this from their Web home-page). These profiles may be used for two purposes:

   A) Use as soft-proofing to assess how your image will appear when printed.

   B) To convert your image to another profile. When you send your images to a service bureau, the image should be converted to the correct profile as other embedded profiles are ignored by the printing process. This hopefully will change in the future!

For soft-proofing, see section 3.12.

Print permanence of digital photographic prints is the same as that of photographic paper (silver-halide color prints), which typically range from

17 years (e.g., Konica Minolta QA Paper Impressa) to 40 years (e.g., Fuji Crystal Archive paper), depending on the kind of paper used. All these data assume that all the chemical residues are removed from the photographic papers. If not, its lifetime will be substantially reduced.

Most shops offer three to four kinds of paper (glossy, semigloss, pearl, and matte). As standard photographic papers may be used for printing, there is sometimes a choice of several papers from different suppliers. For higher quality, often Fuji Crystal Archive paper is used due to its high print permanence.

Some digital photo printers allow printing on transparent and translucent photographic film.

Print speed is quite fast – at least compared to inkjet printers. The Océ LightJet 5000, for example, prints a 50" × 50" print at 405 dpi in about 12 minutes.

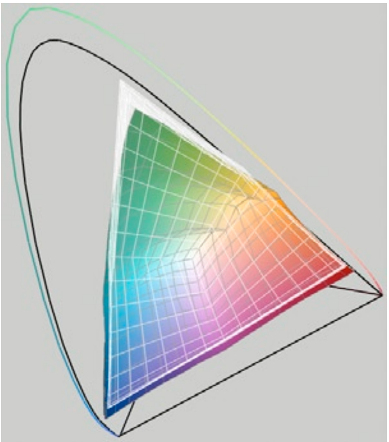


Figure 1-12: Color gamut of Adobe RGB (1998) (white frame) and that of a digital photo laser printer (Océ LightJet 5000) (colored frame)

The color gamut of modern direct photo printers is about that of Adobe RGB (1998) (slightly larger).

If you want to produce many prints of the same image with the papers offered and their lightfastness (print permanence) is sufficient for your purpose, direct photo prints ordered via the Internet may be an easy and cost-effective way to go.

It is best to start with a test order, and only order more if the results are satisfactory. While you may have your pictures the next day with consumer photographic print shops (at least in Europe, where even snail mail is reasonably fast), prints from a professional service bureau usually take three to five days, plus delivery time.

While most photo services will even print black-and-white prints on C4 paper (photo paper designed for color prints), there are a few pure black-and-white papers available nowadays for direct photo printing. They will probably result in better neutral prints. If your service provider only offers C4 paper, make sure that the system is well (neutral) calibrated – otherwise you may get an undesired color cast in your black-and-white prints. It is best to try the service with a small black-and-white print first.

1.6 Inkjet Printing

Having taken a glance at other printing techniques, we want to dig deeper into inkjet printing. While some techniques mentioned are rather old, inkjet printing is rather young. The first color inkjet printers came to the market in about 1985. Compared to today's inkjet printers, they were very slow and showed extremely poor image quality. They were used largely to render simple color plots and production of transparencies for presentations. Print permanence of that first generation of color inkjet printers was quite poor.

Soon, however, some specialized high-end printers came on the market. The IRIS printer – made by IRIS Graphics of Bedford, Massachusetts (later acquired by Scitex) – was one such machine. The IRIS printer, at an early stage of inkjet history, provided a reasonably high print speed and considerable resolution and image quality, while print permanence and maintenance were problems. Prints produced by IRIS printers are sometimes called *Giclée prints*.

A very nice page by Harald Johnson on Giclée prints may be found on www.dpandi.com/giclee/.

Along with the growth of the PC and Macintosh markets, the need for inkjet printers grew, and today you scarcely find a home PC without an inkjet printer, their cost dropping from several thousands of dollars US to about 150–800 dollars (depending on the maximum print size) for quite acceptable desktop photo inkjet printers. For large-format inkjet printers (those beyond a print size of A3+/Super B), you will have to spend several thousand dollars.

Inkjet Technology

There are a number of different inkjet technologies in use. The basis of all of them is that tiny ink droplets are ejected from a printhead and projected onto a paper. To increase print speed, a printhead now consists of many nozzles – up to about 3,000 per ink channel on contemporary printers.

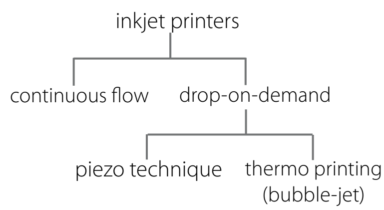
The technique making the ink droplets eject differs with various printers and printer makers (most printer manufacturers use a single technique in all machines).

The main techniques are:

- Continuous flow inkjet printers

The following methods are also called *drop-on-demand*, as they eject a droplet only when needed on the paper:

- Thermal inkjet printers (e.g., used by most HP and Canon printers). Canon calls this technique *bubble-jet*.
- Piezoelectric inkjet printers (e.g., used by most Epson printers)



Classification of inkjet printer techniques

Continuous Flow Inkjet

This technique was developed by IBM in the 1970s. With continuous ink flow systems, a continuous stream of charged ink droplets is produced. Those droplets intended to print fly straight onto the paper, while undesired droplets are electronically deflected into a gutter for recirculation. This is the oldest inkjet technology and is used for high-speed production lines. The complex ink-circulation system makes these printers costly in maintenance. They can be very fast compared with the typical drop-on-demand type printers.

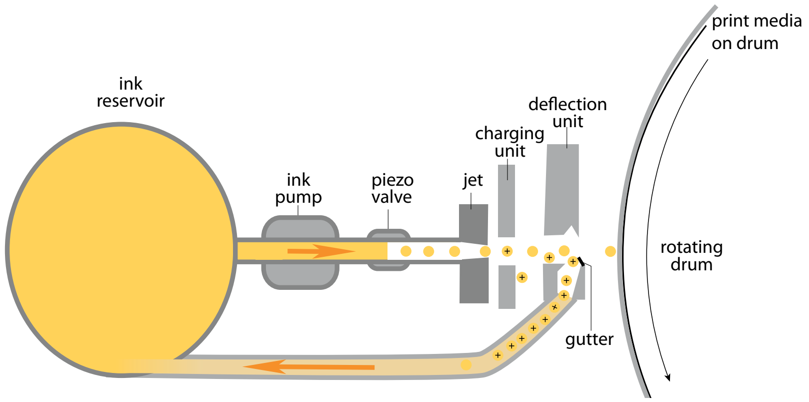


Figure 1-13: Principal ink flow in a continuous flow inkjet printer

This technique is used by the famous IRIS inkjet printer, where the paper is mounted on a rotating drum. These systems are quite expensive and not suited for desktop usage or smaller installations. Usually solvent-based inks are used with these printers.

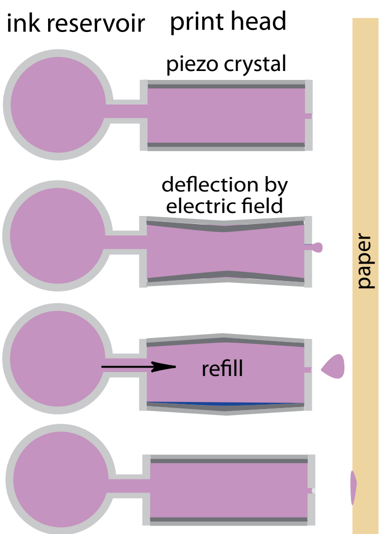


Figure 1-14: Different phases of the ejection of a droplet with a piezo print head

Piezo Inkjet

Certain kinds of crystals expand or contract when subjected to an electrical charge. This piezoelectric effect is used in certain inkjet printers. To eject a droplet, a voltage is applied to the crystal in the print head, the crystal deflects inward, forcing a droplet out of the nozzle. The returning deflection pulls fresh ink from the reservoir, and the cycle repeats. A print head consists of many of these miniature jets (nozzles), and the system allows variations in the size of droplets to produce a finer pattern and smoother color gradients.

Thermal Inkjet

With thermal inkjet printing – also called bubble-jet printing – there is a resistor in the print head chamber. When it is heated by a short pulse of electrical current, a vapor bubble forms in the chamber increasing pressure. This pressure forces an ink droplet out of the nozzle. Then the bubble collapses and draws in more ink from the reservoir. For the next droplet, the cycle repeats. This technique is used by some HP printers (e.g. HP Designjet 30), as well as by most Canon printers (e.g. Canon i9900, W6200). Also some wide-format printers like the HP Designjet 130 and the ENCAD Novajet 1000i use thermal print heads. The technique may be used with dye-based, as well as pigment-based inks, however, it does require an ink suited for thermal inkjet printing (with a low boiling point). The life-cycle of these printers is a bit shorter than that of piezo-based print heads, but the production cost is lower.

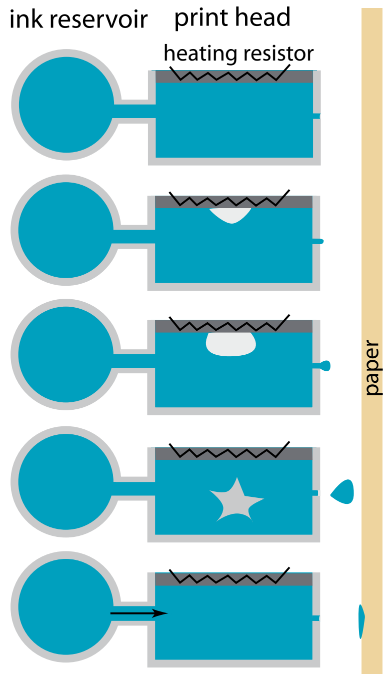


Figure 1-15: Phases of a thermal inkjet printer

Droplet Size

Along with increasing printer resolution, the size of the individual ink droplets has decreased. A smaller droplet allows production of a finer raster of dots on the paper. Today, photo printers use a droplet size down to 1–5 picoliters (1 picoliter is 0.000 000 000 001 liter or 1×10^{-12} liter), thus allowing a single pixel (a raster cell) of the image to be built by many tiny dots, achieving a fine raster (e.g. 360 ppi or even 600 ppi) with a broad range of tonal values.

With some photo inkjet printers (e.g., with piezo-based ones) the droplet size can vary. For dark colors – especially colors of a primary ink color – larger droplet sizes are used. This allows increasing print speed. For light colors, a smaller droplet size and wider droplet spacing is used.

Printer Resolution

When inkjet printers first arrived, a resolution of 150 dots per inch was considered good. Today, resolutions of 2,400 dpi, 4,800 dpi, 5,800 dpi, and even 9,600 dpi are normal for photo printers. Please do not be mislead by these advertising claims, as they refer to resolution only in one direction, e.g., horizontal. Canon's i9950 photo printer has a maximum resolution of 4,800 x 2,400 dpi, where the higher resolution is seen in the horizontal direction (achieved by the horizontally moving print head) and the lower resolution in the vertical direction. Here, the increments are determined by the step motor that moves the paper. The same is true for most inkjet printers.

➜ Please do not confuse the 'printer resolution' – given in 'dots per inch' (dpi) – and the resolution of the image sent to the printer (the latter given in pixel per inch – ppi). The printing resolution has to be much higher as inkjet printers produce halftones using a pattern of single dots and need several of these dots to simulate the halftone of a single image pixel on paper.

Before you invest your money in one of these high-resolution printers, consider carefully whether you actually need the maximum resolution advertised by these printers. To take advantage of a manufacturer's maximum resolution, you need a paper or other printing medium that can accommodate the fine pattern of ink droplets, so the ink will not bleed noticeably into the open area. The paper (or its coating) must absorb ink very quickly to keep it localized. Ensure your paper can accommodate the resolution you wish to use.

We have found that a horizontal resolution of 1,400 dpi or 2,800 dpi, both of which are typical for Epson printers, is sufficient, even for fine art prints. For higher resolutions, the print speed decreases dramatically and ink usage increases, neither of which result in noticeably better image quality. Of course, print speed and ink usage can vary among different printers, even from the same manufacturer.

Number of Inks

While inkjet printers originally used a single black ink, three more inks (CMY) were added to produce what we now take for granted as the norm: CMYK. All of today's photo inkjet printers use at least six inks: CcMmYK (c = light cyan, m = light magenta).

"light cyan" and "light magenta" are also called "photo cyan" and "photo magenta".

To enhance the color gamut of these printers, more inks are often used. Epson's Stylus Photo R1800, for instance, uses Red and Blue (and, optionally, a gloss optimizer) but has no Light Cyan nor Light Magenta. Epson's R2400 uses three shades of black inks: a Photo Black (or alternatively Matte Black), a Light Black, as well as a Light Light Black, in addition to the CcMmYK, thus totaling eight inks. This latter collection of inks produces neutral black-and-white prints with very fine tonal gradients.

Figure 1-16: Though the Epson R2400 may use 9 different inks, only 8 cartridges may be in place at any point of time. You may either have either 'Photo Black' (PK) or 'Matte Black' (MK) in place.

The color gamut and print permanence of today's professional and semi-professional inkjet prints now surpasses that of traditional silver-halide photographic prints, although there are some weak spots: e.g., saturated blue and red. For this reason, the number of different inks used in a fine art printer will likely increase to 11, with the addition of R, B and a gloss optimizer.

In 2006, Canon announced its "imagePROGRAF iPF5000". This printer accommodates 12 single inks: CcMmYK plus RGB plus Light Black (Canon calls it *Grey*) and Light Light Black (which Canon calls *Photo Gray*). For Black there is a *Photo Black* and a *Matte Black* (all in the printer at the same time). This 17" printer uses pigment inks.

Practically, though, the number of inks that may be used is limited by the size and weight of the print heads, and the cost of the numerous ink cartridges.

Type of Inks

Two different types of inks are mainly used in today's normal inkjet printers:

For more details on dye-based and pigment-based inks, see section 2.2.

- dye-based
- pigment-based

There are, however, several other types of inks on the market, e.g., inks with an oil base that are primarily for large-scale printing and weatherized and/or ruggedized prints for outdoor use. Other inks are formulated for printing on fabric, and are usually solvent based. Some printers use hybrid inks: dye-based for colors, and pigment-based for black to achieve a dark, deep black, a technique used by some Canon printers.