Computer Printing: Current and Past Technologies

EVER SINCE THE DAWN of the computer age, producing printed output on paper has been one of the computer's principal functions. Furthermore, while other aspects of computer technology have advanced by leaps and bounds over the past few decades, printing techniques have changed only moderately. This essay will briefly review the techniques used in the past, and then will discuss in greater detail the printing methods most often used today for desktop computers and workstations.

The First Printers

Conceptually, computer printing is very much like typing correspondence with a typewriter, in a number of ways. For example, each printed document produced by a computer is typically one of a kind, containing information that has not previously been arranged in exactly that way, and probably never will be so arranged again. Because of this, the first computer printers were natural evolutions of ordinary mechanical typewriters.

A traditional manual typewriter functions by throwing metal type hammers against an ink-soaked fabric ribbon placed in front of a sheet of paper. The hammers have one or more characters—letters, digits, punctuation marks, and so on—molded in relief upon their surfaces. When the appropriate hammer is driven sharply against the ribbon, it causes an ink mark to be made on the paper in the shape of the character molded on its surfaces.

A later developed electrified the typewriter, using an electric motor to throw the hammers against the ribbon in response to a light touch from an operator on the corresponding keys of the keyboard.

The first computer printers evolved directly from these electric typewriters and used the same mechanism, the only difference being that the computer directed the machine to print characters, instead of a typist's fingers. Indeed, many of the first computer "printers" were little more than repurposed electric typewriters, with only a few minor changes in circuitry.

All of this worked well for a time. However, because of the very high and constantly increasing operating speeds of computers, it rapidly became necessary to use single-element typewriter mechanisms in place of hammers. In typewriters that use hammers, a separate hammer for each character is thrown against the ribbon and paper in the correct sequence as the paper is moved past a fixed point—but at high speeds (the speeds at which a computer is likely to type, for example), the hammers tend to collide with each other as they rise and fall. A *single-element* typewriter solves this by replacing the individual hammers with a single ball or cylinder that contains all characters molded into its surface. The entire element is rotated and raised or lowered to place the appropriate character in front of the ribbon, and then this element is thrown against the ribbon and paper, like a hammer. Because a single element does it all, there is no possibility of individual hammers colliding with each other, and higher operating speeds are possible. The IBM Selectric® typewriter and early Teletype® terminals are examples of typewriter mechanisms that use a single element. Indeed, both

of these were pressed into service as computer printers in the early days.

A much later development was the so-called *daisy-wheel* printer, which is is a single-element typewriter that uses a wheel with *petals* of plastic or metal as its typing element. Each petal contains one character, and the wheel is rotated to present the correct petal to the riboon and paper. The petal is then struck from behind by a hammer and forced against the paper. This type of printing device is still in use, although it has nearly disappeared. The other single-element mechanisms long ago became obsolete for computer use, even if they remain common in electric typewriters.

All single-element printers also place the typing element on a carrier that moves across the paper. This is much faster and more efficient than moving the paper in front of a typing station, as older typewriters using hammers once did. This change additionally increases printing speed considerably.

One Line at a Time

Despite the improvements we've described, standard typewriter mechanisms were unable to keep up with ever-increasing computer speeds; and so, in an effort to print still faster, the *line printer* was developed. The line printer is so called because it prints an entire line of text at a time, instead of just one character on a line at one time.

The basics of a line printer are similar to those of a typewriter, except that multiple hammers strike multiple type elements against the paper almost simultaneously, so that an entire line is printed in one operation. A typical arrangement involves a large rotating drum mounted horizontally and positioned in front of a very wide, inked ribbon. The drum contains characters molded onto its surface in columns around its circumference; each column contains a complete set of characters running around the circumference of the drum. The drum spins continuously at high speed when the printer is operating. In order to print a line, hammers positioned *behind* the paper strike the paper against the ribbon and against the drum in front of it at exactly the right instant, such that the appropriate character is printed in each column as it spins past on the drum. Once every column has been printed, the paper is advanced upward so that the next line can be printed. This technique makes it possible to print more than one hundred times faster than what would be possible with an older typewriter-like mechanism.

There are several variations on this line-printing theme. The drum printer just described was among the first line printers, but other arrangements include print *combs* or bars that slide vertically up and down in place of the drum, and print *trains* (ribbon-like bands) containing characters that fly horizontally past the paper at high speed. Some of these techniques are faster and/or more reliable than others, but all are hugely faster and more reliable than typewriter mechanisms.

At the same time that line printers became popular, ordinary sheets of paper were replaced by *tractor forms*. These are fan-folded, pre-perforated forms, with holes punched on both sides that can be literally dragged throught the printer at extremely high speeds by toothed wheels that engage the holes. The fact that pages are attached to each other makes the loading of individual sheets of paper unnecessary. Line printers simply suck tractor forms at high speed out of a carton and eject the printed forms into a bin behind the printer. The tractor forms are subsequently separated into individual sheets and relieved of the holes on either side by high-speed machines called *bursters*. When all goes well, this technique of printing is remarkably fast and efficient; however, when things go wrong (such as a paper jam), hundreds of sheets can be shredded in a few seconds by a misbehaving printer.

Line printers are still in use in applications where indelible marking or the ability to print through carbon or NCR Paper® is necessary. Although they are not used with desktop printers and home computers, they remain a fairly common site in computer rooms containing large, "mainframe" computer systems. You probably receive bills or other documents every month that are printed on line printers.

The line printers are among the last of the impact printers—printers that depend upon something striking the paper as part of their operation. Most of the printers we will be discussing in this essay

are *non-impact printers* (NIPs), meaning that they print on paper without any mechanical striking movement. The reason this distinction is made is that non-impact printers cannot print through multipart forms (such as carbon packs and NCR forms), whereas *impact printers* can. As long as there are multipart forms around, there will be impact printers; but this market segment is shrinking, and non-impact printers dominate in just about every other domain.

Pages and Pages

Line printers were adequate for several decades. However, as computers relentlessly increased in speed, eventually even line printers were simply too slow to keep up with large computers. At this point the *page printer* was developed. Page printers, as the name implies, are capable of printing an entire page at a time, instead of just one line. Page printers mark a significant departure from older computer printing methods, because the older hammer/ribbon/paper technique for printing cannot be practically extended to the printing of an entire page.

A typical page printer uses a printing process similar to that used by a photocopier. A page printer "paints" the entire image of a page onto a photosensitive drum using a laser beam that is scanned over the drum, thereby creating electrical charges on the drum's surface. These charges are used to attract and hold powdered *toner* (dry ink) to the drum, and the drum is then pressed against a sheet of paper that has been electrically charged to attract the toner, transferring the toner to the paper. A very quick exposure to intense heat then fuses the toner permanently to the paper, so that it won't rub off or smear.

Early page printers, like earlier photocopiers, used wet toner and special paper to print. This was quite messy and smelly, and it did not last long. Page printers rapidly evolved to use the same dry, xerographic printing process used by today's photocopiers and laser printers. In fact, the page printer was a descendant of the Xerox® machine (and Xerox was a pioneer in the design of page printers), and modern office laser printers are simply descendants of the page printers.

Page printers have many advantages over their predecessors. They are extremely fast, of course, and can print hundreds of pages per minute. They also produce extremely neat, clean output, with none of the fuzziness or misalignment of line printers and typewriters. Furthermore, since page printers use a technique of electronically painting an image onto a sheet of paper, they are not limited to printing simple text in one size and style; they can print any type of text in any style or size, and they can also print images and drawings; this allows page printers to not only print the contents of a form, but to print the form itself, all in one pass (eliminating the need for preprinted forms). Finally, page printers can use ordinary sheets of paper, like a copier—they don't require special tractor forms. Some page printers use paper drawn from a continuous roll and automatically cut into sheets of the required length as it is printed (this allows higher operating speeds).

Page printers do have one disadvantage, though: Since they are non-impact printers (meaning that they work without striking anything against the paper), they cannot print through carbon packs or NCR Paper. This makes page printers unsuitable for a small handful of specialized applications. In many cases, page printers can compensate for their inability to print multipart forms by simply printing several copies of the same page, which can often serve the same purpose in many applications.

Page printers are very widely used today, but only on large computer systems. You won't see them attached to desktop computers. Nevertheless, most of the forms and bills you receive in the mail nowadays are printed on page printers (and the rest are printed on line printers). You can recognize page printer output by the neatness and sharpness of the printing.

The Move to the Matrix

The printers we've discussed up to this point are primarily used on large computer systems—the only computers that existed prior to the 1970s. Since the advent of the microcomputer, however, new types of printers have been developed to meet the different needs of desktop computer users. Desktop computers require printers that are small,

inexpensive, and quiet, whereas they do not require extremely high printing speeds. One of the first printers to be used primarily by small computers was the *matrix printer*.

A matrix printer is so called because it uses a pattern or *matrix* of dots to print characters on paper. A grid of very small wires are pressed rapidly against a ribbon, which in turn strikes the paper to be printed. The pattern of wires used to strike the ribbon determines the shape of the mark left on the paper. A print head containing the wire grid is swept smoothly across each line on the paper to print characters.

Although matrix printers are not so very different fundamentally from typewriters, the move from distinct characters to a pattern of dots makes much greater efficiency possible. It is not necessary to rapidly move hammers or a type element in order to print with a matrix printer; moving a group of thin, lightweight wires is sufficient. This makes it possible to print at much higher speeds than traditional typewriter mechanisms can manage. In addition, since the pattern of dots printed is controlled by a computer inside the printer, there is almost no limit to the number of different characters that can be printed; it isn't necessary to remain restricted to whatever characters are available on a type element or daisy wheel. Some matrix printers can even handle graphics and line drawings, simply by manipulating the pattern of dots printed by the wires as the print head sweeps across the paper.

Unfortunately, matrix printers still have disadvantages, most of which are related to the fact that they are impact printers, like typewriters or line printers. Since they have complex moving parts, like all impact printers, they are slower than non-impact printers. And, like all other impact printers, they are noisy, making a characteristic loud buzzing noise while operating (caused by the individual print wires tapping against the paper) that many people find extremely irritating. In addtion, since all characters are formed of dots, and since there is a practical limit to how small the individual dots can be made, the text and images printed by a matrix printer have a distinctive "dotty" look that some people find highly objectionable (particularly because it so clearly identifies a computer as the source of the printed document).

Over time, the disadvantages of matrix printers have outweighed their advantages, and today they are a rare sight. However, they are still used in situations where impact printing of multipart forms is required. You'll often see a matrix printer printing invoices and receipts in business offices and retail outlets. Matrix printers are also favored in situations that require compact and relatively simple (overall) construction, such as cash-register printers and automated-teller printers. In the past, however, matrix printing techniques have been pressed into service even for line printers, before other technologies negated the cost-effectiveness of that application.

A variation on the matrix-printer theme is the *thermal matrix printer*, which uses tiny laser-emitting diodes and special thermal paper for printing. Thermal printers have the advantage of being extremely compact and almost completely silent; however, the high cost of the special thermal paper and the tendency of printing to fade over time have limited their success. Thermal matrix printers are common in desktop calculators, some types of cash registers and point-of-purchase printers, and a handful of portable hard-copy computer terminals.

The Ink-Jet Invasion

One of the most successful printing devices ever invented for the small computer is the *ink-jet printer*. An ink-jet printer resembles a matrix printer in that it prints by placing dots on paper, but it resembles a non-impact printer in that nothing mechanically strikes the paper. Ink-jet printers have swept the desktop computer industry and can now be found in just about every home and office with a computer.

The ink-jet principle is fairly simple: A print head ejects nearly microscopic blobs of liquid ink towards the paper to be printed. These blobs hit the paper and dry instantly. By "painting" tiny dots using these very small drops of ink, it is possible to print virtually any kind of text or graphic image on paper. The method used to eject the drops from the print head is often thermal (the ink is heated very

rapidly to produce a tiny steam bubble that blows the ink towards the paper), but many different methods have been used.

Ink-jet printers have many advantages. Their construction is not complicated and they do not cost very much to build. They operate almost silently (unlike their cousins, the matrix printers). Depending on the ink they use, the printing they produce can be fairly permanent. They can print on any type of paper, including envelopes and transparent plastic sheets. Finally, since the ink drops can be made much smaller than the dots produced by the wires in older matrix printers, it is possible to achieve print quality indistinguishable from that of a very good typewriter. Some ink-jet printers can print more than 1400 dots in the space of an inch—small enough that individual dots are invisible even under a magnifying glass. Very expensive professional ink-jet printers can do this on sheets of paper fifteen feet wide!

Another advantage of ink-jet printing is color. By using print heads containing several different colors of ink, it is possible to print in color. The print heads deposit drops of ink in a very fine, precisely-controlled pattern, so that individual colors blend together when seen by the naked eye; in this way, all the colors of the rainbow can be reproduced with good accuracy on paper. Color ink-jet printers are scarcely any more expensive to produce than black, and in fact most ink-jet printers sold today are color printers.

The precision of ink-jet printing is such that it can be used to print photographs, and not merely text and line drawings. Some ink-jet printers are designed specifically for this purpose. Under good conditions with the right type of paper, these printers can produce results that look just like conventional photographs.

Ink-jet printers have only a few disadvantages. They are non-impact printers, so they cannot be used for multipart forms—but that isn't much of a drawback nowadays, particularly for the average home or office user. The ink used in ink-jet printers is usually water soluble, meaning that it will smear on the paper if it it gets wet; whether or not this is a problem depends on the application. The ink cartridges for ink-jet printers are expensive and often don't last very long, especially when printing photographs; in addition, they can clog or dry out before they are completely used. Despite these problems, though, ink-jet printers are still the leading desktop printers at the time of this writing.

The Lure of the Lasers

Despite the success of ink-jet printers, for years the nec plus ultra of desktop computer printing has been the *laser printer*. A laser printer operates following the same basic principles as those used by page printers and photocopiers. The speed of laser printers and the quality of the output they produce, as well as their high cost, has kept them at the top of the desktop printer totem pole for well over a decade. They first appeared for the Apple® Macintosh,® and shortly thereafter they became available for IBM-compatible PCs. Now it is possible to obtain laser printers for connection to any kind of computer.

Desktop laser printers work in pretty much the same way as the page printers used on large computer systems. The main difference is one of speed: desktop printers typically produce eight or nine pages a minute at most, instead of a hundred. In addition, desktop printers often produce slightly neater, cleaner output than page printers, mainly because speed has been sacrified in part to favor print quality.

Laser printers (and page printers) print using a pattern of dots, not unlike those used by matrix and ink-jet printers. However, the dots produced by laser printers are much more consistent and precise in their shape, size, and placement than are the dots produced by matrix and ink-jet printers. This results in better print quality. Most laser printers can print at least 600 dots per inch, and the more expensive ones can go well beyond this. Good desktop laser printers can produce output of such high quality that no dots are perceptible even under magnification that otherwise shows the individual paper fibers.

The advantages of laser printers are print quality, speed, indelibility (the ink used by laser printers does not smear or smudge once the page is printed), reliability, and economy in applications that

print many pages per month. Laser printers often also support PostScript, which is something that will discuss a little later in this essay; most other desktop printers do not provide PostScript support (although professional versions of many printers do).

The main disadvantage of a laser printer is cost; laser printers often cost at least twice as much as comparable ink-jet printers. Another disadvantage is that color laser printers, apart from being fairly rare at the low end of the printer range, are extremely expensive, mainly because they roughly triple the number of internal parts so that they can print in the minimum of three colors that are necessary for color printing. Color laser printers that are precise enough to print photographs are astronomically expensive, being as much as one hundred times more costly than an ink-jet printer with the same capability. Because of this, it is rare to see a laser printer being used for desktop printing of documents in color. Some people also object to the whirring turbine-like noise made by most laser printers when they are printing, and to the ozone and airborne toner that once floated around them; recent printers, however, are much quieter, and use newer technologies that help prevent ozone or toner particles from escaping the printer. Early printers were also very heavy and bulky (like their photocopier cousins), but this, too, has been corrected in the most recent models, some of which are no larger or heavier than an ink-jet printer.

The PostScript Revolution

One of the most important evolutions in the microcomputer printing industry has nothing to do with actual printing technologies, and everything to do with computer software. This evolution is called *PostScript*.® PostScript is a programming language for printers, developed by Adobe Systems Incorporated. Since it first appeared on laser printers for the Apple Macintosh around 1985, it has brought about a revolution in high-end printing for microcomputers, as well as in the professional publishing industry itself, even though many home and office computer users have never heard of it. PostScript has had such a powerful influence on computer printing that we would do our readers a disservice by not saying something about it in an essay on computer printing.

Until PostScript was invented, most printers accepted information from computers in the form of text to be printed. In other words, the computer would simple send a string of characters to a printer over the cable connecting the two, and the printer would print those characters on paper. If the computer sent DEAR SIR to the printer, the printer would print DEAR SIR on paper. This process was simple and straightforward and worked well, as long as only very plain text of one style and size had to be printed. The problems arose when the computer needed to print something other than just one size or style of text, or when the computer wanted to print images or drawings.

For years, various less-than-satisfactory solutions were tried to get around the problem of printing anything other than plain text. Many printers were designed to accept special commands embedded in the text being sent by the computer. For example, the computer could send a special "control" character to a printer, followed by a few instructions, and thereby cause the printer to take some special action, such as moving to the top of a new page, or printing the text that followed in boldface characters. This worked to some extent, but extremely complex printing could become nightmarishly difficult or even impossible to accomplish using the special commands recognized by a printer, and worse yet, every printer manufacturer used a different set of codes! As a result, for the first few decades of computer history, printing was restricted for all practical purposes to simple plain text of a single style and size, with no graphics or drawings at all.

When PostScript first entered the market, all of this changed. PostScript is a programming language for printers. In other words, it is a way of giving very detailed instructions directly to a computer printer, instead of just strings of text to be printed. A printer that can understand PostScript can be given a complete program by the computer to which it is connected, and this program will explain to the printer exactly how to "paint" what-

ever text, images, or drawings the computer requires on a page. The computer simply sends the printer a PostScript program describing how to compose a page, and the printer executes the program and prints the result on paper.

Of course, executing a program requires a computer, and so a printer that understands PostScript is necessarily a printer that contains a tiny computer of its own. The computer inside such a printer is very simple and does nothing but execute PostScript programs and direct the printer's printing mechanism. Because a small computer is needed inside the printer for PostScript support, printers that can understand PostScript cost considerably more than printers that cannot. However, the increased price is often justified by the almost unlimited versatility of PostScript printing.

The advent of PostScript revolutionized not only the general layout of pages for printing, but even the way text is printed. In PostScript, individual letters, numbers, and punctuation marks are also described by tiny computer programs that tell the printer how to draw these characters in mathematical terms. These programs are much more versatile than the fixed type styles offered by non-PostScript printers, and they allow text to be printed in any style, size, or orientation anywhere on the paper. When PostScript was introduced, a standard way of programming typefaces was introduced with it, called *PostScript fonts* (now referred to as *Type 1 fonts*). Today, you can purchase tens of thousands of PostScript fonts, any one of which can be used to print on a PostScript printer, giving you almost unlimited choice over the style, size, and orientation of text in your documents.

Fonts (that is, type styles) that are represented by small computer programs, such as Type 1 fonts, are called *outline fonts*. After the introduction of Type 1 fonts, another type of outline font, called *TrueType*,® was introduced, and it works in essentially the same way as a Type 1 font. Both types of fonts can be used on both Macintosh and PC computers today. Both types of fonts are compatible with PostScript printers.

Today, many non-PostScript printers provide a way to print both PostScript and TrueType fonts, but the best results are still obtained with a PostScript printer and Type 1 fonts.

PostScript support is most often seen nowadays on the more expensive laser printers, and on laser printers connected to Macs. High-end professional ink-jet printers often accept PostScript, too. Finally, in the commercial publishing industry, PostScript is the universal language used to create and compose documents electronically, and all commercial imagesetters and digital presses understand PostScript directly. Indeed, just about anything you read on paper today was originally defined in PostScript before being printed—including the essay you are reading now!

Printing Photographs

Printing photographs with a desktop computer presents special challenges. The need to print continuous tones and colors on a page creates requirements very different from those imposed by printing text or line drawings, and printers suited to the latter are not necessarily suitable for the former.

The best technology for printing photographs from a computer is called *dye sublimation*. A dye-sublimation (or dye-sub) printer deposits continuously varying amounts of several different colors on paper by evaporating special transparent dyes and allowing them to condense on the paper. The result is an extremely smooth, full-color image that can easily reproduce a photograph. There are no dots in a dye-sub print, and the use of transparent dyes superimposed on each other provides a very wide gamut of colors suitable for accurate reproduction of photographic images.

Unfortunately, dye-sub printers have many disadvantages. They are expensive. They use special inks and special paper to achieve their photographic quality. They print very slowly, sometimes taking 15 minutes to complete a page. The supplies (ink and paper) are expensive. In general, although dye-sub is well suited to printing photographs, a dye-sub printer is not useful or practical for any other type of printing. It would certainly be considerable overkill to use it for printing, say, a letter or invoice.

An alternative for printing photographs is the ink-jet printer. Some high-end ink-jet printers are specially designed to give good results in printing photographs, and they can produce prints that are almost as good as dye-sub prints, for far less money, and far more quickly. In addition, such printers can still be used for ordinary printing purposes.

Because of the above considerations, most people using dye-sub printers for printing photographs also have a different type of printer that they use for all other purposes. If their photographic needs cannot justify a dedicated printer, a good-quality ink-jet color printer can often serve both purposes admirably.

Currently, color laser printers produce results inferior to those of ink-jet and dye-sub printers for photographs, except at the extreme high end of the laser spectrum (professional color laser printers). Impact printers are not even in the running.

The Future

With so many technologies competing and such delicate balances determining the success or failure of each, it's difficult to try to predict the future of computer printing with any semblance of real accuracy. Nevertheless, it is possible to speculate on a few trends that are likely to continue at least for the immediate future.

Laser printing has held a leading position in the desktop computer domain since its introduction nearly twenty years ago, and it seems plausible that this remarkably durable leadership will persist for the time being. It may even be reinforced by a continuing decline in prices and increase in reliability for laser printers. It remains to be seen if and when color laser printing will begin to supplant technologies such as ink-jet printing.

The future of ink-jet printing also seems very bright, and it probably has many good years ahead of it unless unforeseen technological breakthroughs or a very dramatic increase in the lead of laser printers cut its useful lifetime short.

There seems to be little future for impact printing outside of a few very restricted niche markets. Dye-sub printers are also limited to a niche market and appear destined to remain that way.

However, few things are more hazardous than attempting to predict the future of the computer industry, and only time will tell for certain how our grandchildren and great-grandchildren will print the output from their computers (if they print it at all!). 💻