Just a note

# DEALERS OF LIGHTNING

## Xerox PARC and the Dawn of the Computer Age

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room seemed to flow in a limitless cascade. At Webster the lab management had pissed and moaned about the purchase of a single $2,500 laser. Here no one so much as blinked at his order for a $15,000 half-watt behemoth (or for the water lines and pump that had to be specially constructed to keep it cooled). Rather than make do with an old surplus copier for his experiments, Starkweather ordered up a Model 7000 capable of turning out sixty pages a minute. This duly arrived, attended by a Xerox field technician perplexed at his assignment to set up a top-of-the-line office copier on the bare concrete floor of an unfurnished lab.

He would have been even more surprised to see what Starkweather was planning to do to it.

Computer printers had existed for years, yet none had ever been endowed with enough brainpower to take full advantage of the digital bit. They were huge, awkward affairs, messy mechanical systems of solenoids driving hammers into carbon strips, rather like electric typewriters as imagined by a Soviet design team—the epitome of the sort of contraption engineers dismissed as a "kludge" (pronounced "klooge"). From a functional standpoint they were slow, clumsy, and lacked any graphic flexibility. Most were limited to printing the 128 characters comprising the so-called ASCII character set (the acronym stood for "American Standard Code for Information Interchange").

ASCII encoded every numeral and English-language letter, along with a handful of line-setting characters, as a sequence of seven digital bits—hence the constraint to 128 characters, the maximum number that can be expressed in seven binary digits. If you wanted something unusual, like a German *ü* or French *ç*, much less lettering of an unconventional size and a fancy typeface, you were out of luck. Computer designers were happy enough that the seven-bit code at least allowed them to have upper- *and* lower-case letters.

Starkweather's assignment was to build a machine that could print on paper almost any image a computer could create. The first problem he needed to solve was how to build a machine that could make, as he put it, "intelligent marks on the sheet at a page a second" to match the 7000's capacity. This was essentially a speeded-up version of the task he had been working on at Webster all those long years. Solving it at PARC took another eleven months, or until November 1971.

His design was deceptively uncomplicated. At its heart was a spinning disk about the size and shape of a hockey puck. Milled around the rim were twenty-four flat mirrored facets, which gave it the appearance of a cross-sectional slice of a discotheque ball. As the disk spun, each mirror picked up the beam of the laser and redirected it onto the photoreceptor as a sweeping line of modulated light. (Think of a lighthouse beam sweeping horizontally across a wall—thousands of times per second.) The process produced an image that looked clean and solid to the naked eye, but was in fact comprised of millions of minute dots etched on the photoreceptor (and transferred in turn to a blank page) at a resolution of five hundred horizontal lines to the inch.

Considerable fine-tuning was necessary to keep this complicated system humming along. Assembling the hardware and synchronizing the components was like getting a herd of cats to sing in unison. Since the polygonal disk spun at 10,000 revolutions per minute (the original glass prototype was soon replaced by aluminum), even the way the facet edges "paddled" the air produced measurable resistance. The laser itself had to be modulated up to fifty million times a second by a "shutter" fashioned from a polarizing filter driven by a $10,000 piezoelectric cell. And because it had to conform to the speed of the copier, Starkweather's laser apparatus had to mark more than 20 million dots on a page every second.

Still, the most troublesome problem was not electronic. Instead it fell squarely within the domain of traditional optics. Starkweather knew that if the mirrored facets were even microscopically out of alignment, the scan lines would be out of place and the resultant image distorted or unintelligible, for the same reason a wobbly tape deck makes an audiocassette warble as though recorded under water. To produce clean images, he calculated, the facets could not be out of vertical alignment by more than an arc-second—a microscopic variance. In visual terms, the mirrors could not be off by more than the diameter of a dime as viewed from a mile away.

Disks fabricated to such an exacting standard would cost at least $10,000 each—assuming this were technically possible, which Starkweather doubted. It was true that there existed servo-mechanical and optical devices that could quite effectively redirect an errant scan back in place. But they were even more expensive and, as a further drawback, meant adding another complicated and failure-prone component to his printer. Starkweather understood that the tolerance issue was critical. If he could not solve it, he would have designed a machine that could not be cost-effectively manufactured.

For more than two months he wrestled with the puzzle. "I would sit and write out a list of all the problems that were difficult. One by one they would all drop away, but the mirrors would still be left."

One day he was sitting glumly in his optical lab. The walls were painted matte black and the lights dimmed in deference to a photoreceptor drum mounted nearby, as sensitive to overexposure as a photographic plate. Starkweather doodled on a pad, revisiting the rudimentary principles of optics he had learned as a first-year student at Michigan State. What was the conventional means for refracting light? The prism, of course. He sketched out a pyramid of prisms, one on top of another, each one smaller than the one below to accommodate the sharper angle of necessary deflection. He held the page at arm's length and realized the prisms reminded him of something out of the old textbooks: an ordinary cylindrical lens, wide in the middle and narrowed at the top and bottom. "I remember saying to myself, 'Be careful, this may not work. It's way too easy.' I showed it to one of my lab assistants and *he* said, 'Isn't that a little too simple?'"

It *was* simple. But it was also dazzlingly effective. Starkweather's brainstorm was that a cylindrical lens interposed at the proper distance between the disk and the photoreceptor drum would catch a beam coming in too high or low and automatically deflect it back to the proper point on the drum, exactly as an eyeglass lens refocuses the image of a landscape onto a person's misaligned retina.

"I ran to the phone and called Edmund Scientific, my supply house, gave them my credit card, and bought ten bucks' worth of war surplus lenses," he recalled. "I could hardly sleep the two days before they arrived. But then they came, I put them in, and sure enough they worked." The lens scheme was foolproof. It involved a simple physical relationship, so it could never fail. It had no moving parts, so it could never malfunction. And it permitted the polygonal disks to be stamped out like doughnuts—not at $10,000 apiece, but $100.

"The mirrors no longer had to conform by the diameter of a dime at a mile's distance," Starkweather recalled. "They could be off by the diameter of a tabletop, which was a standard anyone could meet. I made a lot of discoveries building that machine, but it was the cylindrical lens that made me say 'Eureka!' "

Starkweather's finished printer was a large, bulky machine. His open arrangement of plump black-tubed lasers, mirrors, and wires sat atop the clean but stolid Model 7000 copier like a ridiculous hat on a dowager aunt. He christened the machine SLOT, for "scanning laser output terminal."

"I would have called it the scanning laser output printer," he said, "but that wouldn't have made a very good acronym."

Building the SLOT solved only half the riddle of how to convert digital images to marks on paper—the back end, so to speak, of how to apply toner once the image was delivered to the laser beam. The front end involved translating the computer's images into something the laser could actually read.

That half was solved by the invention of the so-called Research Character Generator (RCG), another healthy piece of iron and silicon, by Lampson and a newly hired engineer named Ron Rider. The RCG, which stood several feet high and nineteen inches wide, and housed 33 wire-wrapped memory cards holding nearly 3,000 integrated circuits, was a sort of super memory buffer, spacious enough to accept a digital file from a computer, evaluate it scan line by scan line, and tell the printer which dots to print at which point. This generated on paper an image created by pure electronics.

Today this procedure is trivial. Memory is so cheap that the computer and printer both come with enough to hold several pages at a time. As a page comes in from a word-processor program, it is fitted into a print buffer the way craftsmen of the old printing trades clamped lines and columns of leaded type into rectangular frames. Once in memory, the page image can be manipulated in an almost infinite number of ways. It can be fed to the printer narrow or wide end first, backwards, upside-down, or wrapped around a geometrical design. The most unassuming desktop computer can store character sets in dozens of font styles and sizes, any of which can be summoned at will and applied to a document as a paintbrush swipes color at a wall.

Nothing like this was simple in 1972 because of the cost of memory. Nor was it enough for Rider's machine to generate only the bland standardized ASCII text of conventional line printers. The RCG had to incorporate a large number of custom typefaces that were to be drawn by hand, converted into digital bits, and stored somewhere in memory until needed, as if on an electronic shelf.

This meant an exponential increase in the complexity of the task. ASCII characters were all the same size and each fit into the same squared-off shape. The only formatting a conventional document normally required was a command instructing the printer when to move to the next line. By contrast, the custom-designed characters PARC desired to print would be proportionately spaced: some fat, some thin, some reaching above the print line, some dangling below; some roman, some *italic*, some **BOLD**.

Finally, the character generator had to adapt to the Model 7000's system of feeding in pages wide-edge-first, which moved paper through the machine at a faster rate. For copiers this posed no problem—one simply aligned the originals along the same axis. For a printer, however, it was a horror. The image coming from the computer would somehow have to be rotated before it could be printed out. Instead of printing a page in prim linear order like a typewriter, SLOT would have to reproduce the characters in vertical slices, somehow keeping its place on twenty or thirty lines of print per page.

Rider ultimately came to see the proliferation of complications as a blessing in disguise. "It forced you to think about the problem of printing in a much more generalized fashion, so the solution turned out to be much more robust." Despite its name, the research character generator