Science and history behind the design of Lucida

Charles Bigelow & Kris Holmes

1 Introduction

When desktop publishing was new and Lucida the first type family created expressly for medium and low-resolution digital rendering on computer screens and laser printers, we discussed the main design decisions we made in adapting typeface features to digital technology (Bigelow & Holmes, 1986).

Since then, and especially since the turn of the 21st century, digital type technology has aided the study of reading and legibility by facilitating the development and display of typefaces for psychological and psychophysical investigations. When we designed Lucida in the early 1980s, we consulted scientific studies of reading and vision, so in light of renewed interest in the field, it may be useful to say more about how they influenced our design thinking.

The application of vision science to legibility analysis has long been an aspect of reading research. Two of the earliest and most prominent reading researchers, Émile Javal in France and Edmund Burke Huey in the US, expressed optimism that scientific study of reading would improve the legibility and economy of written and typographic forms.

> "The object [of study] is the characters in use. We shall have to investigate their size, their form, their spacing." (Javal, 1878)
>
> "We therefore should seek to improve legibility without reducing the number of letters on the page." (Javal, 1905)
>
> "Certainly the letter-forms that have come down to us through the ages have never been pruned to meet the reader's needs, though the writer and printer have made conservative changes for their own convenience. There is not the slightest doubt that forms can be devised which will be much more legible than these ancient traditional symbols." (Huey, 1908).

A few years later, Barbara Roethlein, in her M.A. thesis at Clark University, formalized the questions to be asked of typographic legibility:

> "Every reader has observed that all of these variants of letter-forms are not equally legible — an observation which raises the theoretical question: What are the factors upon which legibility depends? And the practical question: How should one proceed if one set out to improve the legibility of printed letters?" (Roethlein, 1912)

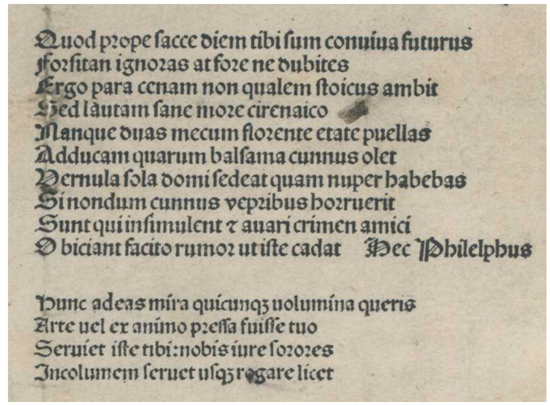

Figure 1: Earliest known type specimen sheet (detail), Erhard Ratdolt, 1486. Both paragraphs are set at approximately 9 pt, but the font in the upper one has a larger x-height and therefore looks bigger. (See text.)

Despite such early optimism, 20th century type designers and manufacturers continued to create type forms more by art and craft than by scientific research. Definitions and measures of "legibility" often proved recalcitrant, and the printing and typographic industries continued for the most part to rely upon craft lore and traditional type aesthetics. Moreover, the craft of type punch-cutting involved visual knowledge that vision science had not yet encompassed. For five centuries, type punch-cutters — type designers before the term — carved extremely tiny forms that had to be effortlessly recognizable by the greatest number of readers, and as well be visually pleasing to the casual glance. Renowned punch-cutters like Garamond, Granjon, Van Dijck, Bodoni, and others, though not scientists in the modern sense, were cognizant of some of the most refined aspects of visual perception.

2 Body size and x-height

The most universal feature of type is size. The ability to compose type at nearly any size is taken for granted today, but not in the early years of typography. The laborious creation of many sizes of type, the punches cut by hand, was the life work of highly skilled artisans over generations and centuries.

In the incunabula era, printing through 1500, very early books were printed in single sizes and styles of type, but later printers did employ a broader range of sizes. In 1486, Erhard Ratdolt, a German printer established in Venice, printed the first known type specimen sheet, showing 14 different typefaces (fig. 1). Ten were gothic rotunda fonts in sizes from 36 to 9 point (Ratdolt, 1486).[1]

[1] These measurements in point sizes are rounded to integers. The actual body sizes are a few fractions of points bigger or

A remarkable feature of Ratdolt's range of rotunda fonts is that at three of the sizes, 18, 13, and 9 point, he displayed two versions, one with a large x-height relative to the body, and one with a small x-height. Ratdolt's larger x-height versions look substantially bigger to us than the smaller x-height versions at the same body size. Ratdolt left no explanation, but we may reasonably suppose that visible differences between the different x-height versions appeared the same to the printer and his readers in the 15th century as they do to us today. A side observation is that Ratdolt's gothic fonts, as with most gothic types of the era, had larger x-heights than the roman types produced by printers in Italy at the time, yet the roman style soon replaced the gothic in Italian printing, and thence proceeded to do the same in French and eventually English and Dutch printing.

During the 16th century, average type sizes in use decreased by a few points. The main economic factor was cost of paper. Smaller type sizes enabled smaller page sizes, less paper, cheaper editions, and a larger market. Other factors have been suggested. One is greater production and usage of eyeglasses, to make smaller type more legible for older readers or others with vision difficulties. Another is technical improvement in the methods of punch-cutting and type casting, including improvements in metallurgy to produce harder, more durable type. A religious reason may also have been a factor during the Protestant Reformation and the Counter-Reformation: smaller type enabled books to be more economically printed and transported, and, if the contents were proscribed by religious authorities, easier to conceal.

But, as roman type body sizes decreased in the 16th and 17th centuries, their x-heights increased. For example, in 1569, Robert Granjon cut a "Gros Cicero" ("Big 12 point") in the style of Garamond but with a bigger x-height that made it look almost as big as the next larger body size, the St. Augustine (14 point) (Vervliet, 2010; M. Carter, 1985). In the 17th century, Dutch punch-cutters and typefounders continued the trend toward bigger x-heights, and in the 18th century, Pierre Simon Fournier cut alternative faces with large, medium, or small x-heights, in several sizes. He called certain of his large x-height, slightly narrow faces "in the Dutch style" (Fournier, 1766).

It has been said that Granjon's Gros Cicero was the eventual model for the Monotype face "Plantin" of 1913, which may have been the starting point for Times New Roman of 1931 (Carter, 1985).

Commenting on the longstanding trend to larger x-heights, Stanley Morison lamented the lack of documentation on the "development of type design consciously viewed as a means of reducing the real space occupied by the letters while maintaining their apparent size" (Morison, 1968).

In an influential essay on the "optical scale" in typefounding, Harry Carter (1937) pointed out that types intended for different reading sizes were traditionally designed differently. In particular, types for newspapers and other continuous texts composed at small sizes often had abbreviated descending strokes or "tails", as well as shortened ascending strokes, to increase the x-height fraction in relation to the body size. By "x-height fraction" we mean the portion of the total body height occupied by the x-height.

Although it had been evident for 500 years that larger x-height fractions made type appear bigger, in the 1980s we did not know of studies that proved that types with bigger x-height fractions were actually more legible in terms of speed of reading or degree of comprehension. Apparently, when type looked bigger, that was good enough to persuade printers and readers of its value, but several early 20th century legibility studies focused on the minimum sizes that were easily readable.

Javal (1905) stated that nine point type was most used for books and newspapers in France; the 9-point type in his book had an x-height of 1.5 millimeters. Huey (1908) recommended a minimum x-height of 1.5 mm for fast reading. Roethlein (1912) tested 10-point fonts, the majority of which had x-heights in the range of 1.4 to 1.5 mm (insofar as the heights could be determined).

Miles Tinker's *Legibility of Print* (1963) summarized decades of meticulous legibility research by Tinker and Donald Paterson on type size and legibility. Using body size in points as their measure, they found that type sizes of 10 and 11 point were read most quickly. By the early 1980s, many of the types tested by Tinker and Paterson a half-century earlier were no longer in common usage, but our measurements of those types and sizes in catalogs indicated that the x-heights averaged 1.5 mm.

Those early assertions of minimum type size for fluent reading were confirmed in a series of rigorous psychophysical reading studies by Legge et al. (1985, 2007), which found the "critical print size" below which reading speeds decrease markedly, but above which increases in type size do not appreciably increase reading speeds. Legge et al. measured

smaller. Typographic point systems were not promulgated until the 18th century and not stabilized until the 19th and 20th centuries (Ovink, 1979).

RQENbaegn (Lucida Bright)
RQENbaegn (Nimbus Roman)
`RQENbaegn (Nimbus Mono)`

Figure 2: Lucida, URW Nimbus Roman (Times design), and URW Nimbus Mono (Courier design) compared at 10 point.

the physical size of printed type and the distance at which it is read, defining psychophysical size as degree of visual angle subtended by the object — in this case x-height — at the retina of the reader's eye. Legge (2007) states that across a range of studies, the critical print size is around 0.20 degrees. This is equivalent to a 1.4 mm x-height read at 40 centimeters. For example, with familiar Times Roman, critical print size would be 9-point type read at a distance of 16 inches. Greater reading distances need larger type sizes for easy reading; closer distances allow reading at smaller sizes, as when teenagers easily read small text on smart phones at distances of 12 inches or less.

When we designed Lucida in 1983–1984, we were not aware of Legge's studies of print size. We determined Lucida's large x-height fraction by a less rigorous method. Some ergonomic recommendations of the early 1980s specified that 20 to 24 inches was a suitable distance for reading text on a computer monitor, and although there were other recommendations, they all suggested that reading distance for screen displays should be greater than average reading distances for text on paper. When we viewed 10-point printed samples of popular typefaces like Times Roman and Courier at 20 to 24 inches, they seemed too small. A 12-point size seemed easier to read. But, as with paper in Renaissance printing, computer screen area was expensive, so simply enlarging type size on screen was not an ideal solution. We thought it would be better to give Lucida a big x-height, so that when set at a 10-point body size, it would look as big as Times or Courier at 12 point. (This article is set in 9-point Lucida Bright.)

We made the Lucida x-height fraction 53% of the body size. In other words, when Lucida is set at 10 point, its x-height is 5.3 points high. In comparison, the x-height fraction of Times Roman is 45% of body sizes and that of Courier nearly the same. Thus, at 10 point, Lucida appears bigger than Times or Courier, by roughly 17%, although the visual impression is affected by average letter widths. Times on average is narrower than Lucida, and Courier, a monospaced design, is wider than Lucida.

At 10 point, Lucida read at a distance of 16 inches has a visual angle of 0.26 degrees, well above the critical print size found by Legge et al. At a distance of 20 inches, 10-point Lucida has an x-height of 0.21 degrees, still above critical print size.

We wondered about drawbacks to such a big x-height. As ascenders and descenders are decreased in length in order to increase the x-height of the font, there must eventually be a stage at which ascenders and descenders are too short for readers to distinguish letter pairs like b/p, d/q, h/n, v/y. We did not know at what point such illegibility would occur. Some 32 years later, in an elegant study of design proportions and legibility, Larson & Carter (2016) tested different x-height fractions of a single typeface design and found that, indeed, beyond a certain point, reduced descenders impaired letter recognition.

Another reason for our choice of a big x-height was related to digital screen resolution. In the early 1980s, computer screens had resolutions around 72 to 75 pixels per inch, too low at text sizes to render more than a pixelated impression of letter shapes. Before deciding on the final forms and proportions of Lucida high-resolution outline characters, we hand-sketched bitmaps of letters at various resolutions on graph paper, to study how high resolution forms devolve into minimalist pixelations at low resolutions. The x-height portion always seemed more important for letter recognition than the ascenders and descenders; observations going back to Javal and Huey supported that view.

Later, using interactive bitmap editing tools, we produced hand-edited bitmap font sets, named "Pellucida", for screen displays (Bigelow, 1986). These had somewhat larger x-heights than the outline Lucida high-resolution fonts, and were used as user interface fonts on the DEC VAXstation 100, the Tektronix Smalltalk workstation, and in the operating system Plan 9 from Bell Labs.

A side trip to the future: in 2011, one of us (Bigelow) co-authored a review article with Legge, with illustrations of x-height and letterforms created by Kris Holmes (Legge & Bigelow, 2011). That paper reviews reasons in favor of x-height as the main indicator of perceived type size, cites historical, practical, and laboratory evidence to explain the "critical print size" and other aspects of type size in relation to reading. It should be noted, however, that some reading scientists and typographers favor capital height as an indicator of legibility, notably Arditi (1996) and the German DIN 16507–2 standard of 1999.

3 Open spacing

Lucida Sans (including Lucida Grande), and the original Lucida seriffed faces have slightly more space between letters than most modern types. In particular, Lucida Sans has more inter-letter spacing than popular sans-serif typefaces in the “neo-grotesque” style dating from the 1960s and 1970s, e.g., Helvetica and its clones. In the 1970s, there was a fad for very close or “sexy” letterspacing in seriffed as well as sans-serif typefaces intended for advertising typography. This was partly based on a hypothesis that we read by word shapes, not letters, which led to assaults on readers with dense tangles of crowded words. That hypothesis has since been discredited by further research (Pelli et al., 2003).

Lucida took a different approach. Its letterspacing was influenced by the open spacing of early roman typefaces, like Jenson’s Venetian romans from 1470 to 1480, which remained legible despite the “noisy” environment of rough paper, easily worn types, and uneven pressures of early printing technology. The spacing of early roman typefaces tended to equalize the apparent space between letters with the space inside letters, an aesthetic practice believed to contribute to legibility, followed by later type punch-cutters and type designers through the 20th century. Equalized spacing was a visual judgment, not an exact measure of distance or area.

Related to the concept of “optical scale”, types intended for small sizes often have slightly wider inter-letter spacing, which can be seen in contemporary as well as historical types.

Another influence on Lucida letterspacing was a tremendously influential paper by Campbell & Robson (1968) which showed that the human visual system is more sensitive to certain spatial frequencies — alternating light and dark band patterns — than to others. Peak sensitivity occurs around 3 to 6 cycles per degree of visual angle, and becomes less sensitive as frequencies increase, that is, as the alternating bands are more tightly packed. At higher spatial frequencies, contrast between light and dark stripes must be increased for better perception. Campbell and Robson demonstrated this as a contrast sensitivity function, “CSF” (Ohzawa, 2008).

Type printed on light paper with black ink is generally high-contrast, but type rendered on the phosphors of cathode-ray-tube screens by a soft scanning spot is lower in contrast and fuzzier, so we tried to adjust the horizontal spacing frequency of Lucida characters at 10 and 12 point to fall near the peak visual sensitivity range of 3 to 6 cycles per degree. At 12 point, Lucida Sans has a vertical stem spatial (stem) frequency of roughly 5.5 cycles per degree of visual angle, and at 10 point, the frequency is around 6.7 cycles per degree — not quite ideal with reference to the Campbell & Robson CSF, but reasonably close.

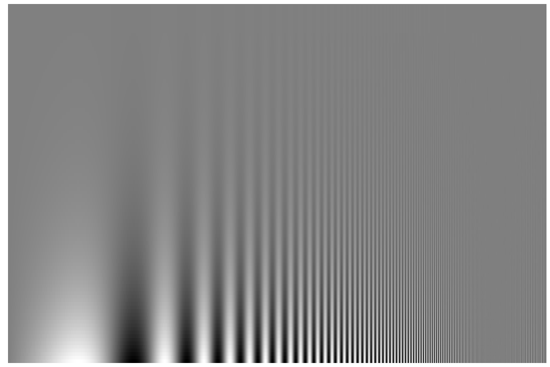

Figure 3: The Campbell-Robson contrast sensitivity function (from Ohzawa, 2008). Perception of the bands typically shifts as you view the image at closer or farther distances or scale the image larger or smaller.

The contrast sensitivity function concerns visual acuity, but a different aspect of letter spacing is the reader’s ability to recognize objects, namely letters, that are closely juxtaposed, as in standard typographic text strings. Herman Bouma called this “interaction effects in letter recognition” in Bouma (1970) and “visual interference” in Bouma (1973). Bouma found that the ability to perceive fine details is impaired when contours are close to the details to be recognized. In particular, recognition of letters is impaired when flanking letters are close by, and impairment worsens the farther the letters are from the fixation point of central vision. This effect is now commonly called “crowding” (Pelli et al., 2007; Levi, 2008). Bouma’s observations caused us to think that generous spacing could ameliorate some problems in recognizing type on screens. We already believed that the tight letter spacing of popular grotesque faces was a hindrance to reading at small sizes, and Bouma’s research tended to reinforce our impressions.

Crowding is the difficulty of recognizing letters near each other. It has two main factors: (a) the closer the letters are to each other; and (b) the farther off-center they are on the retina. (The “center” being the small, high-acuity region called the “fovea”.) In reading, our central vision fixates briefly on words or letters and then jumps several letters ahead to fixate again, and so on. During fixation, the more peripheral the letters are — that is, the farther they are from central vision — and the closer they are to each other, the harder they are to identify. The more crowded the letters, the slower the reading.

Although wider letterspacing may seem to improve recognition of text at a given type size at a certain distance, wider letter spacing also expands the whole text string, driving subsequent letters or characters further toward peripheral vision, where crowding becomes progressively worse.

In the era when we designed Lucida, texts would be read on computer screens at greater distances than on paper, and thus the type would look smaller and its inter-letter spacing tighter. Therefore, we made the spacing slightly wider, hoping it would reduce the risk of crowding and make reading easier despite the greater reading distance.

We also noted that a little extra spacing avoided some localized problems when errors in rasterization and fitting caused adjacent letters to accidentally merge, on screen or in print. This often happened with a popular grotesque sans-serif in early laser printers; the letter 'r' often collided with a following 'n' to make a spurious 'm', turning "fern" into "fem", "warn" into "wam", and so on.

The trade-off of loose letter spacing was that at larger text sizes on paper, Lucida text seemed airy compared to densely fitted grotesques. The higher resolution LCD and LED displays of modern smart phones, tablets, and laptops have made some of these Lucida adjustments unnecessary, but Lucida fonts still perform well on high resolution screens and e-ink readers at small sizes.

Much later research doubted that more space between letters ameliorates crowding. "There is no escape," declared Pelli et al. (2007). So, did generous letter spacing of Lucida make it more legible? Anecdotally, yes. Lucida (Sans) Grande functioned well as the system screen fonts on Macintosh OS X for 13 years at sizes ranging from 9 to 14 point, and users complained when the system fonts were changed from Lucida to a grotesque sans-serif. Monospaced Lucida Console has been a terminal and programming font in Windows operating systems since 1993. But, does generous letter spacing actually improve reading speed or comprehension? Perhaps, at best, only for certain sizes, reading distances, and readers. A recent paper by Xiong et al. (2018) compared legibility of fonts intended to ameliorate effects of macular degeneration and found that interletter spacing was a beneficial factor.

4 Open counter-forms

Counter-forms are the spaces inside letters; some are totally enclosed as in 'b', others non-enclosed as in 'c'. A few letters have both enclosed and non-enclosed counters, as in roman 'a', 'e', and 'g'. Enclosed counters can clog up in printing, so in giving Lucida a large x-height, we also made the enclosed areas relatively big. Wherever possible, we opened up counters in 'a', 'c', 'e', 'g' in the roman styles (fig. 4, left). In the italics, we adopted a chancery cursive style with a characteristic counter-form for *a*, *d*, *g*, *q* in one orientation, and a rotationally contrasting counter in *b* and *p*, to help distinguish letters easily confused. We thought of widening the letters as well, but this would have reduced economy of fitting, because we were also increasing the spaces between letters.

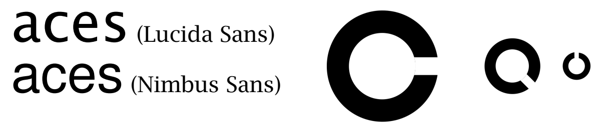

Figure 4: counter-form comparisons of Lucida and URW Nimbus Sans (Helvetica design), left; Landolt C, right.

The nearly enclosed counter-forms of 'c' and 'e' in "grotesque" style faces, while stylish at big sizes, appeared to close up the gap (also called "channel" or "aperture") separating the two terminals of 'c', and the eye and lower terminal of 'e', which tend to get blurred, get clogged or blurred, making them confusable with 'o'. There is a vision test that uses a circular figure called the "Landolt C", devised by a 19th century Swiss ophthalmologist (fig. 4, right). The Landolt C is a circular ring with a precisely cut gap equal to the thickness of the ring. Test subjects are asked to name the position of the gap but do not need to name letters. It resembles, in a rigidly geometric way, the aesthetic of several Swiss grotesque sans-serifs.

5 Distilled humanist letterforms

Because we were designing Lucida for text sizes and, often, coarse resolutions, we tried to distill the letter shapes to minimalist forms that we felt would be recognizable under most imaging conditions. We wanted Lucida typefaces to be without distracting details, essentially transparent as conveyors of information. Lucida Grande, Lucida Sans, and original Lucida seriffed have forms and thick-thin proportions derived from pen-written letter shapes written and read in the 15th century by Italian humanists, whose handwriting was the model for the first roman typefaces. A fellow typographer commented that Lucida is a "workhorse" design. We took that as a compliment. Lucida true italics are somewhat showier, exhibiting traces of the fast Humanist handwriting styles still called "cursive" or "running".

We had studied Humanist handwriting as students of Lloyd Reynolds and other calligraphy teachers, including Hermann Zapf. The Humanists based their writing on what they thought was the most legible ancient handwriting, written by scribes in the court of Charlemagne 600 years earlier. Early Humanist letterforms were simple and unadorned, crafted to be easy to write and easy to read, even by older scholars with declining vision, in an era when eyeglasses were rare and expensive. The Humanist style was therefore extensively "user tested" in two different historical eras. Of course, nearly all roman types descend from one or another era in the long evolution of type forms that began with Humanist bookhands in the 15th century, but the "humanist" sans-serifs pioneered by English lettering artists Edward Johnston and Eric Gill, and later refined by Swiss designers Hans Ed. Meier and Adrian Frutiger, followed the Renaissance style, not the 19th century English machine-like "grotesques". Influenced by the calligraphic teaching of Lloyd Reynolds and impressed by Meier's elegant Syntax and his persuasive reasoning (Schulz-Anker, 1970) that the humanist forms were inherently more legible, we followed the humanist aesthetic in Lucida Sans.

6 Differentiated details

A problem at low resolutions is that letters begin to look alike because there isn't enough information to distinguish shapes quickly and easily. Type styles that assimilate forms, like geometric and grotesque sans-serifs, are particularly prone to this problem, especially along the upper region around the x-height, where traditional typefaces rely on details of shaping to differentiate letters.

For example, in an ostensibly simple sans-serif 'n', there is a white cut or crevice where the arch joins the left stem. This cut, along with the square corner of the left stem, keeps 'n' from being confused with 'o'. At low resolutions, these differentiating details can get obscured or lost, so we lowered the arch join, cutting more deeply into the shape. This also tended to increase the thickness of the arch, further distinguishing 'n' from 'o'. H. Carter (1937) noted both that the 18th century punch-cutter Fleischman made low cuts in the joins of h m n, and that Times Roman emphasized the strong arches of those same letters, so our decisions on these features had historical precedents as well as contemporary technical reasons.

We cut off terminals of curved strokes and diagonals vertically, to align with the vertical axes of digital rasters. However, we kept the serif-like terminal on 'a', to differentiate it from other letters. We tried to use the elegant Humanist 'g' with closed lower loop, but our bitmap tests showed that the letter shape did not survive at low resolutions and small sizes, so we settled on the "grotesque" style 'g' in Lucida Sans and Lucida Grande. As in Aldine humanist typefaces, we drew ascenders taller than capitals, to distinguish lower-case 'l' from capital 'I', and also to de-emphasize capitals slightly so that all-capital composition like acronyms, common in high-tech prose, and texts with frequent capitals, as in German orthography that capitalizes nouns, did not unduly interrupt the pattern of text. At lower resolutions, the distinguishing difference in height between capital 'I' (Eye) and lowercase 'l' (el) was neutralized, so for some purposes in later Lucida designs, we added serifs to capital I. These can still be found in Lucida Grande in Apple OS X, but are not the default forms.

7 Adjusted contrast of thick/thin strokes

We observed that in early laser printing and screen displays, thin hairlines were often "broken" by white gaps because of errors in rasterization. Such breaks made letters difficult to recognize and text annoying to read, so we thickened hairlines and serifs to avoid breakage and drop-outs. In the original Lucida seriffed faces, the thickness ratio of main stems to hairlines was 2 to 1, much thicker than in a face like Times Roman, giving Lucida a low contrast and less bright look. For Lucida Sans and its twin sibling, Lucida Grande, we used a thin-thick contrast of roughly 3 to 4, echoing the ductus of pen-written Renaissance roman and italic hands. As noted above, this also helped distinguish 'o' from 'n' because of the difference in thickness between the arch of 'n' and the curve of 'o' at the x-line.

In terms of laser-printer technology, the slightly thinner "hairlines" (which weren't very hair-like) of Lucida Sans helped keep the text from darkening too much on write-black laser printers. Aesthetically, we wanted to give our sans-serif more graphical modulation in its thick-thin contrast than in the stolid sans-serifs.

8 Regularization & repetition

We drew Lucida by hand but digitized it with the Ikarus software system developed by Peter Karow at URW in Germany. We edited the digital outlines to achieve precise regularity of base-line, x-line, capital line and other alignments, and to ensure that repeatable letter elements like stems, bowls, and serifs were digitally identical. This made it easier for software to recognize and adjust outlines, as was first achieved in Ikarus modules, and later implemented in the "hints" of PostScript Type 1 and "instructions" of TrueType font rendering technologies.

Following research done by Philippe Coueignoux (1975) in his MIT PhD dissertation, we experimentally decomposed Lucida letter shapes to a small set of repeatable component parts from which all the letters could be assembled, in case extreme data compression was needed. This intriguing and instructive sort of data reduction turned out to be unneeded in the dominant commercial font formats for Latin fonts, so we didn't pursue it further.

Although regularization and repetition remain popular approaches in type design more than three decades later, there are sometimes objections to the homogeneous look. Against this tendency, in 1992 we explored an opposite path, freely written forms of expressive letters in Lucida Handwriting, a connecting, casual script that we see often, especially in France, on Parisian bistro awnings, French perfume bottles and other Gallic expressions of charming exuberance.

9 Weight

The ratio of x-height to vertical stem thickness in Lucida normal weight fonts is 1 to 5.5. This is slightly heavier than many seriffed text faces. Although Times Roman has about the same stem to x-height ratio, it has thin hairlines and serifs that lighten the overall tone. The normal or regular stem weights of several popular grotesque sans-serifs are slightly lighter than Lucida Sans normal or regular weights, but the corresponding hairlines are slightly thicker, so the weight of Lucida seems comparable.

When we designed the first Lucida fonts, we chose a slightly dark weight to compensate for erosion around the edges of black letters on white background-illuminated screens and on write-white laser printers, which visually reduce weight, making text look weak in small sizes. The slightly dark weight made Lucida well adapted to most screen displays for almost 30 years, but printing on 300 dot-per-inch write-black laser printers had a slightly darker tone than we desired. When common printer resolutions increased to 600 dpi, this darkening tendency was mostly alleviated, because the percentage of weight added by write-black laser technology was reduced at the higher resolution. A fortuitous outcome of our choice of stem weight was that at 10 point, our target size, the main stems were four pixels thick when printed at 300 dots per inch, enabling thinner strokes to be 3, 2, or 1 pixel thick and a greater gamut of thickness modulation.

In 2014, we developed more than a dozen additional weights, ranging from UltraThin (1:22) to UltraBlack (1:2.3). With Ikarus we interpolated and extrapolated digital outlines of the hand-drawn weights, and with FontLab we hand-edited the results. The interpolations needed mostly minor editing but the extrapolations needed extensive editing. Both the interpolations and extrapolations first required the outlines to be edited so their spline point structures were isomorphic, that is, having the same numbers and kinds of points in the same orders. The whole process involved several iterations.

UltraThin ExtraThin Thin ExtraLite
Lite Book Text Normal Thick
ExtraThick Dark ExtraDark Bold
ExtraBold UltraBold Black
ExtraBlack UltraBlack

10 1984: First showing

Lucida was first shown at a meeting of the Association Typographique Internationale (ATypI) in London, September 1984, in the form of a type specimen chapbook from Imagen Corporation, a Silicon Valley laser printer manufacturer that was the first to license Lucida fonts. The Lucida booklet was designed by Michael Sheridan, Imagen's type director whose appreciation of fine typography stemmed from his prior experience working at Grant Dahlstrom's Castle Press, a Pasadena, California printing firm renowned for fine typography and printing. (The booklet is available at `tug.org/interviews/holmes-imagen-lucida.pdf`.)

Today, new and original typefaces are released in an unceasing flood, so it may be hard to recall that three decades ago, there were nearly none. As typography shifted from analog to digital technology in the 1970s and 1980s, typefaces for digital typesetters and printers were, with very few exceptions, digitizations of existing typefaces from previous eras of metal or photo-typography. (Among the few instances of original designs for high-resolution digital typesetters were the Marconi (1976) and Edison (1978) type families intended for use in newspapers, designed by Hermann Zapf for the Hell-Digiset firm, which had invented and demonstrated the first digital typesetter.) In the article "Digital Typography", Bigelow and colleague Donald Day wrote (1983) that the initial, imitative phase of digital typography would eventually be followed by a creative phase of original design, but that had not happened by 1984. So one more reason we developed Lucida was to show that original digital designs could be effective and successful.

References

Arditi, A. (1996). Typography, print legibility, and low vision. *Remediation and Management of Low Vision*, Cole, R., ed., 237–248.

Bigelow, C. (1986). Principles of Type Design for the Personal Workstation. *Gutenberg-Jahrbuch*, 61, 253–270.

Bigelow, C. & Day, D. (1983). Digital typography. *Scientific American*, 249(2), 106–119.

Bigelow, C. & Holmes, K. (1986). The design of Lucida: An integrated family of types for electronic literacy. *Text Processing and Document Manipulation*, 1986, 1–17.

Bigelow, C.A. & Holmes, K. (1993). The design of a Unicode font. *Electronic Publishing*, 6(3), 289–305.

Bigelow, C.A. & Zanibbi, R. (2015). Analysis of typographical trends in European printing 1470–1660: Comparison of automated methods to palaeotypographical approaches. Presentation, American Printing History Association Conference: Printing on the Handpress & Beyond, 2015.

Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature*, 226(5241), 177.

Bouma, H. (1973). Visual interference in the parafoveal recognition of initial and final letters of words. *Vision Research*, 13(4), 767–782.

Campbell, F.W. & Robson, J.G. (1968). Application of Fourier analysis to the visibility of gratings. *The Journal of Physiology*, 197(3), 551–566.

Carter, H. (1937). Optical scale in type founding. *Typography* 4. Reprinted in *Printing Historical Society Bulletin*, 13, 144–148, 1984. `issuu.com/letterror/docs/harry_carter_optical_scale_in_typefounding`

Carter, M. (1985, December). Galliard: A revival of types of Robert Granjon. *Visible Language*, 19(1).

Coueignoux, P. J.-M. (1975). Generation of Roman printed fonts, Ph.D. dissertation, Massachusetts Institute of Technology. `http://dspace.mit.edu/handle/1721.1/27408`

Fournier, P.S. (1764). *Manuel typographique utile aux gens de Lettres (etc.)*, Vol. 1. L'auteur. (1766: Vol. 2.)

Huey, E.B. (1908). *The Psychology and Pedagogy of Reading.* The Macmillan Company.

Javal, E. (1879). Essai sur la physiologie de la lecture. Annales D'Oculistique 82, 242–253. [English translation: "Essay on the physiology of reading", Ciuffreda, K.J. & Bassil, N. (1990, October). *Ophthalmic and Physiological Optics*, Vol. 10.]

Javal, E. (1905). *Physiologie de la lecture et de l'écriture.* Félix Alcan.

Larson, K. (2004). The science of word recognition. `microsoft.com/typography/ctfonts/WordRecognition.aspx`

Larson, K., & Carter, M. (2016). Sitka: A collaboration between type design and science. In *Digital Fonts and Reading*, Dyson, M. & Suen, C.Y., eds., 37–53, World Scientific Publishing Co.

Legge, G.E. (2006). *Psychophysics of Reading in Normal and Low Vision.* Lawrence Erlbaum Assoc., CRC Press.

Legge, G.E., & Bigelow, C.A. (2011, August). Does print size matter for reading? A review of findings from vision science and typography. *Journal of Vision*, 11(5), 8. `jov.arvojournals.org/article.aspx?articleid=2191906`

LiVolsi, R., Zanibbi, R., & Bigelow, C. (2012, November). Collecting historical font metrics from Google books. In *Proceedings of the 21st International Conference on Pattern Recognition (ICPR2012)*, 351–355, IEEE.

Morison, S. (1997). Letter forms: typographic and scriptorial: two essays on their classification, history and bibliography (Vol. 45). Hartley & Marks Publishers.

Ohzawa, I. (2008). `ohzawa-lab.bpe.es.osaka-u.ac.jp/ohzawa-lab/izumi/CSF/A_JG_RobsonCSFchart.html`

Ovink, G.W. (1979). From Fournier to metric, and from lead to film. *Quaerendo*, 9(2), 95–127.

Pelli, D.G., Farell, B., & Moore, D.C. (2003). The remarkable inefficiency of word recognition. *Nature*, 423(6941), 752.

Pelli, D.G., Tillman, K.A., Freeman, J., Su, M., Berger, T.D., & Majaj, N.J. (2007, October). Crowding and eccentricity determine reading rate. *Journal of Vision*, 7(2), 20. `jov.arvojournals.org/article.aspx?articleid=2122073`

Ratdolt, E. (1486). `bsbipad.bsb.lrz.de/nas/einblattdrucke/300001993_0_r.pdf`

Rubinstein, R., Bigelow, C., Baudin, F., Lynch, E., & Levy, D. (1985). Proceedings of the typography interest group ACM CHI'85. *ACM SIGCHI Bulletin*, 17(1), 9–15.

Schulz-Anker, E. (1970). Syntax-Antiqua, a sans-serif on a new basis. *Gebrauchsgraphik*, *7*, 49–56.

Tinker, M. (1963). *Legibility of Print.* Iowa State U. Press.

Vervliet, H.D.L. (2010). *French Renaissance Printing Types: A Conspectus.* The Bibliographical Society, The Printing Historical Society, Oak Knoll Press.

Xiong, Y.Z., Lorsung, E.A., Mansfield, J.S., Bigelow, C., & Legge, G.E. (2018). Fonts Designed for Macular Degeneration: Impact on Reading. *Investigative ophthalmology & visual science*, 59(10), 4182–4189.

◇ Charles Bigelow & Kris Holmes
`lucidafonts.com`