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Foreword and Colophon

This paper appeared in "Proceedings of the International Conference on Raster Imaging and Digital Typography" (RIDT89), published by Cambridge University Press (CUP). The conference was held in Lausanne in 1989 and we made an early attempt to encourage authors to create electronic camera-ready copy by supplying copies of LaTeX and *troff* macros to emulate the CUP style for Conference Proceedings (MS-Word was **not** a contender at this early date …).

Accordingly, the enclosed paper has been re-typeset from the original *troff* source code using the *cup* macros originally supplied to authors. Reproducing the correct page breaks and page numbers took a little more effort because (just as today for conferences that have Word or LaTeX styles for authors) the publisher's version of the approved macros inevitably had several 'production' adjustments that were not present in the authors' version.

Nevertheless the necessary amendments to *troff* source text, and to the *cup* macros, in order to reproduce the published version were not too demanding. The time taken to rebuild this final draft form was about 90 minutes.

David F. Brailsford. February 2006.

On the noise immunity and legibility of Lucida fonts

Paul R. BOWDEN and David F. BRAILSFORD

Department of Computer Science
University of Nottingham
Nottingham NG7 2RD
UK

ABSTRACT : Modern digital typography often has to contend with output devices such as workstation screens and laser-printers which have a much lower resolution than metal type or phototypesetter machines. In this paper we present results of some legibility investigations in which volunteers were asked to read laser-printed and photocopied material produced in three different typefaces. Two of these faces were not designed with adverse imaging conditions in mind but the third, Lucida, had as one of its design aims that it should be robust and readable at low resolutions. Evidence is presented for Lucida's enhanced legibility in noisy conditions when compared to the other two faces. However, the difficulties of devising suitable tests and the subjective nature of much of the evidence are also discussed.

KEY WORDS : Times, Computer Modern, Lucida, legibility, fonts.

1. Introduction

Type design has evolved over many centuries with final print quality being determined largely by the skill of the punch cutter and the characteristics of ink on paper. It is interesting to observe that traditional typefaces continue to be popular even on devices for which they were not designed, such as the current generation of 300 lines per inch laser-printers. The legibility investigations reported here use laser-printed and photocopied material and they focus on three typefaces — Times, Computer Modern and Lucida — which have come into use at various times over the past 50 years. Of these three Times is the best known, having been developed by Stanley Morison, in 1931, for newspaper printing in general and for the *Times* newspaper in particular [Morison1967]. It has been consistently popular and is the font of choice for a vast number of technical books, reports and journals. The second typeface, Computer Modern, was created by Don Knuth just over 10 years ago, using his METAFONT program, and is included with distributions of the TEX text-formatting system. The Computer Modern fonts have been steadily revised and improved over the years [Knuth1979, Knuth1986].

Both Times and Computer Modern were designed before the era of low-cost workstation screens and laser-printers, whereas the Lucida family was designed

in the early 1980s, by Charles Bigelow and Kris Holmes [Bigelow1986], specifically to overcome the problems which arise when letterforms are imaged on devices which have only limited resolution (e.g video display terminals or laser printers), or where image quality may be degraded by the processes of photocopying or facsimile transmission (FAX). Traditional typefaces were not designed for use on low-resolution devices nor do they stand up very well to the 'noise' introduced into letterforms by the copying process. Documents produced under these conditions, e.g. from badly adjusted laser-printers or photocopiers, become difficult to read. Since Lucida claims to overcome many of these problems we shall devote a short section to describing its design characteristics.

2. The design of Lucida

Lucida was designed to provide 'acceptable legibility in an aliased image environment'. The most usual symptom of such environments are the 'jaggies' seen on angled lines whenever these are rendered on low-resolution devices. The designers of Lucida have sought to tune the letterforms with the needs of digital image processing and reconstruction very much in mind. For example, the *index of weight* (i.e. the ratio of the thickness of a straight stem, to the height of a lower-case 'x') was set at 0.18 in order to make the typeface resistant to extreme variations in overall 'colour' on the page. A low *contrast*, of 2:1, was chosen for the basic Lucida seriffed designs (contrast is the ratio of the widths of thick and thin strokes within a letterform) because text degraded by broken thins (e.g. due to photocopying) is often difficult to read.

The figures quoted above for Lucida's weight and contrast do not differ greatly from the values for Times (which are 0.17 and 2:1, respectively [Rubinstein1988]) so we have to look to other metrics in order to explain the markedly different appearance of Lucida.

Lucida has large counters and deep-branching on joins to combat the problem that 'write black' laser-printers are liable to clog up the counters of letters (e.g. the space in the loop of the letter 'e'). Furthermore, Lucida has thick serifs (to avoid erosion) but which are short and chamfered at the ends (to lighten the overall colour of the type). The x-height of the letters is 52% of the body size, which means that Lucida at 9 point can seem every bit as large as many other faces at 10 or even 11 point. This is a design feature used to enhance legibility in many situations. Capital letters in Lucida are similar in weight to lower-case letters to stop them seeming much darker at low resolutions. The capitals are slightly shorter than lower-case ascenders, to make them seem less 'emphatic' in situations where they need to be used frequently.

The effect of all these design decisions should be to give better-than-average performance on metrics such as counter-clogging rate, thin-erosion rate, subjective legibility for a given point size, colour change with point-size change, serif-erosion rate and effects of boldness/italics on legibility.

It should be noted that the design features of Lucida just described are those of the original design which was first released about four years ago. More recently the design has been re-worked into a higher-contrast form, called Lucida Bright [Bigelow1987], which has been adopted, since September 1987, for use in the *Scientific American* magazine.

3. Test Descriptions

The tests described below are designed to evaluate the effectiveness of the Lucida design decisions and also to assess the subjective acceptability and legibility of all three faces in original (laser printed) form and after severe degradation of quality following repeated photocopy-of-photocopy operations.

All test sheets were generated on a Chelgraph ACE laser printer based on the Canon CX engine. Seriffed fonts were used for most of these tests and the Lucida set was compared with the corresponding fonts from the Bitstream Inc. 'Dutch' family (which is very similar to Times) and from the Computer Modern family (available from the TEX distribution). A sample of these three faces, in the Roman style, is shown in Figure 1. When constant-width fonts were needed the Bitstream typewriter font was compared with the corresponding typewriter fonts in the Lucida and Computer Modern families.

The tests performed are now summarised. For each test we describe its purpose, the test sheets used and the questions posed to the volunteers.

Test 1 PURPOSE: To establish overall typeface preference
TEST SHEETS: Eight in all, each containing a text sample printed in each of the three faces with identical layout and line breaks
QUESTIONS: Which of these typefaces do you prefer and why?

Test 2 PURPOSE: To test subjects' typeface preferences for reading technical material e.g. mathematics, line diagrams, chemical symbols and graphs.
TEST SHEETS: Four sheets — one for each of the above types of material and with the three different families on each sheet.
QUESTIONS: Which of these faces do you prefer for the technical material that you see here and why?

Few things are more distressing to a well-regulated mind than to find someone *who ought to know better* failing to appreciate the finer points of Quaternions, Fluxions and the Phlogiston Theory.

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Figure 1: Sample text in the Times, Computer Modern and Lucida faces

Test 3 PURPOSE: To test the capacity of different fonts to withstand photocopies-of-photocopies.
TESTSHEETS: Four different test sheets with all three families of fonts being used on each sheet.
QUESTION: Which of the three sheets is easiest to read ?
NOTES: The sheets handed to the subject went through an *n*-fold photocopy-of-photocopy process. The value of $n = 10$ was arbitrarily chosen as the stage at which all of the font families had become severely degraded.

Test 4 PURPOSE: To test the abilities of fonts to withstand repeated photocopying, with a 64% size reduction applied at each iteration of the copying process.
TESTSHEETS: Two sheets, each sheet using all three font families, with successive photocopier-generated size reductions as described below
QUESTIONS: Tell me when you can read some of the words in any sheet which I give you. Tell me when one or both of the two sheets is fully legible.
NOTES: Two testsheets were used which employed the Roman (upright) font from each of the faces. Each of these two sheets was then photo-reduced successively, until judged illegible, which occurred after 4 iterations of the reduction/degradation process.

4. The Testing Procedures

The test subjects used for these experiments were all student volunteers from the departments of Computer Science and Psychology at the University of Nottingham. To keep test conditions for all subjects as similar as possible only one set of test sheets was prepared, and this same set of test sheets was used for all the test subjects in turn.

At the start of the test session the test subject was asked to put on spectacles, if usually worn for reading, or to insert any required contact lenses (if not already in place). In an attempt to remove at least one source of experimental error the subjects were asked whether they had consumed any alcohol that day, and any who answered in the affirmative were not tested.

In all the tests, subjects were not allowed to hold the sheets closer than 380mm (15 inches). A wooden rod was used to test this distance. Each test session lasted about 30 minutes. The subject was shown the relevant sheet(s) required for the test and asked the questions for that test. If the subject could not understand the question, it was carefully rephrased in a different form. The lighting conditions at the time of each test session were also noted on the Standard Answer Sheet.

5. Results

5.1. Subjective preferences (Tests 1 and 2)

Test 1 showed a clear and consistent preference for the Lucida fonts when reading straightforward textual material under test conditions.

A total of eight test sheets were used, made up of two sheets in each of the four styles (Roman, Bold, Italic and Constant Width). The results in the table below show the total number of votes in these four styles for each of the three families. The maximum possible number of votes for any style/family combination is 20, The subjects were given the option of replying “don’t know” when asked for their preferred fonts, but none of them exercised this option.

	Roman	Bold	Italic	Constant Width
Lucida	18	4	18	14
Times	2	16	0	6
Computer Modern	0	0	2	0

Table 1: Preferred typefaces for reading test paragraphs of non-technical text in each of four type styles.
(Maximum possible score = 20 in any table position)

This test also asked the subject why a particular family of fonts was preferred. For the Roman and Italic faces, Lucida was preferred because it seemed 'bigger' and 'clearer' than the others, but Lucida Bold was not favoured, the main objection being that it seemed to be *too* bold.

Test 2 presented subjects with a variety of material prepared using the *troff* pre-processors *eqn* (for mathematical equations), *pic* (for line diagrams), *grap* (for graphs) and *chem* (for chemical diagrams). All three of the font families were used on the test sheets, and subjects were asked to indicate their preferred face for the various forms of technical material.

The results of this test were much less clear-cut than for Test 1 with quite a few "don't know" answers but it seems that Lucida does not score so well on these (admittedly very subjective) tests. From the comments made by the volunteers during the tests it would seem that the font used within or near diagrams is not deemed to be of much significance but there seems to be some preference for a traditional face such as Times when studying mathematical equations.

	Lucida	Times	Computer Modern	Don't Know
Equations (*eqn*)	4	6	0	0
Line diagrams (*pic*)	3	5	0	2
Chemical formulae (*chem*)	3	2	0	5
Graphs (*grap*)	5	0	2	3

Table 2: Preferred typefaces for studying technical material
(Max. individual score = 10, total votes = 40)

5.2. Repeated photocopying (Test 3)

The results of the photocopy-degradation tests are shown in Table 3, where the numbers represent the votes cast for each of the families as being the easiest to read after 10th-order photocopying.

	Lucida	Times	Computer Modern	No Preference
Test sheet 1 (Roman)	10	0	0	0
Test sheet 2 (Bold)	3	6	0	1
Test sheet 3 (Italic)	7	1	0	2
Test sheet 4 (CW)	4	4	0	2

Table 3: Preferred typefaces after 10th-order photocopy degradation
(Max. individual score = 10, total votes = 40)

Note that Lucida is perceived as the most easily read in the Roman and Italic cases, and that the Computer Modern fonts seem to be rated very badly when subjected to this degree of ill-treatment.

The 10th-generation copies used in this test are a good example of the degradation caused by photocopying. The sheets show geometrical distortion, erosion of thins and severe 'blobbing'. Although it was generally agreed that the Lucida sheets were easier to read than those using either Times or Computer Modern it was interesting to note that this cannot be ascribed to any improved resistance to counter-clogging (by 'clogged' it is meant that the counter is completely filled-in). To take just one of the test sheets as an example, it was found that the 10th-generation samples showed 200 clogged counters *in all three font families* (out of a total of 334 counters).

5.3. Repeated photocopying and reduction (Test 4)

This test shows that Lucida Roman is easier to read at very small point sizes than is the Roman style in the other two faces. Given that the photoreduction process introduces noise, at the same time as reducing the type size, this test amply demonstrates the clarity of Lucida even under adverse conditions. All the test sheets were judged to be totally illegible, by all subjects, at the 4th generation of photoreduction, with first visibility of a few words being seen by some subjects at generation 3 and others at generation 2. When test sheets were just capable of being fully read, the subjects were asked to read out the text in its entirety. All subjects commented that the Lucida sheet was the easiest to read at this stage. At no time was another font family found to be readable before Lucida.

6. Conclusions

It rapidly became apparent, when conducting these tests, that the psychological and typographical variables could only be brought under control by using a much larger number of volunteers than was available to us. The classic studies of Tinker [Tinker1965], involving thousands of test sessions, give some idea of the efforts required. Many of the subjective reactions we have reported were given by a large number of our volunteers but proved remarkably difficult to tie down in any objective way. At least one set of tests, which was devised to measure the ease of detecting spelling mistakes in the three typefaces employed, had to be abandoned when it was found that many of our subjects were so bad at spelling that they found it very difficult to spot 'typos' in *any* typeface.

However, we are convinced, even from our small-scale tests, that Lucida is much easier to read than 'traditional' typefaces when reproduction conditions are

poor, but there are still some speculative elements when we analyse why this should be so. We believe that the legibility of Lucida under adverse conditions owes much to its large apparent size and the careful design of stroke weights. Certainly the design aim of making Lucida appear to be a 'big' face is borne out in practice. Our test subjects consistently perceived it as being one or two points larger than other families at the same point size and we have no doubt that this is a major factor in its legibility. However, Lucida had no better resistance to counter-clogging than the other two families tested; indeed, the sheer heaviness of the Lucida Bold face, and the quantity of ink needed to image it, gave rise to worse counter-clogging performance than the Bold styles in the other two faces.

In the more recent Lucida Bright, which is a re-working of Lucida for use in higher resolution typesetter equipment, the ratio of thicks to thins is larger than in standard Lucida, and the density of high frequency components (thinner hairlines, longer and thinner serifs etc.) is much greater. In the light of the remarks from our test subjects about Lucida Bold being too heavy it is interesting to note the adoption of a Demi Bold in Lucida Bright for captions and sub-heads.

It would be interesting to extend our studies to Lucida Bright, when imaged at low resolution and subjected to photocopier noise, to assess the erosion of stems and serifs and to find out whether it is still the preferred typeface in 'noisy' viewing conditions.

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