Micro-typographic extensions to the TEX typesetting system

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Dissertation

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This thesis is dedicated to my parents and my sister
who have been always hoping in me.

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Abstract

This thesis investigates the possibility to improve the quality of text composition. Two typographic extensions were examined: margin kerning and composing with font expansion.

Margin kerning is the adjustments of the characters at the margins of a typeset text. A simplified employment of margin kerning is hanging punctuation. Margin kerning is needed for optical alignment of the margins of a typeset text, because mechanical justification of the margins makes them look rather ragged. Some characters can make a line appear shorter to the human eye than others. Shifting such characters by an appropriate amount into the margins would greatly improve the appearance of a typeset text.

Composing with font expansion is the method to use a wider or narrower variant of a font to make interword spacing more even. A font in a loose line can be substituted by a wider variant so the interword spaces are stretched by a smaller amount. Similarly, a font in a tight line can be replaced by a narrower variant to reduce the amount that the interword spaces are shrunk by. There is certainly a potential danger of font distortion when using such manipulations, thus they must be used with extreme care. The potentiality to adjust a line width by font expansion can be taken into consideration while a paragraph is being broken into lines, in order to choose better breakpoints.

These typographic extensions were implemented in pdfTeX, a derivation of TeX. Heavy experiments have been done to examine the influence of the extensions on the quality of typesetting. The extensions turned out to noticeably improve the appearance of a typeset text. A number of 'real-world' documents have been typeset using these typographic extensions, including this thesis.

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1 Introduction

HANDWRITING

The need for book production has existed longer than it might seem. In the days before printing was invented, books were made by handwriting (therefore these books are called manuscripts). While writing the beautiful old-time manuscripts, the scribes had a tendency to keep the right-hand margin of the written text as straight as possible. Also, the spaces between individual words could not be very large. Certainly, uniform greyness of page and straight margins were generally treated as the standard of high-quality books. Such demands are, of course, very difficult to fulfil by handwriting. Book production at that time was certainly very elaborate and time-consuming. It required much skill and patience [6].

PRINTING

The most important impact on typography belongs to Gutenberg, who made printing practical by achieving "the art of multiplication of books" [6, 7]. Gutenberg was not the first who came up with the idea of either movable type or the printing presses. The principle of printing was invented about 500 years before Gutenberg's time, when the Chinese had printed from movable type. However, they discarded the idea of printing with movable type afterwards, evidently because of the difficulty of using it with thousands of Chinese characters. Gutenberg was the one who brought printing to the western world. He introduced two main concepts of modern printing, movable pieces of metal type that could be reused, and a printing press for fast and high-quality impression on paper or parchment. Even though it is not entirely sure that Gutenberg was the original inventor of both ideas, it is clear that his experiments made printing practical. The concepts of printing perfected by Gutenberg did not change much for nearly five centuries, until the widespread use of computer-controlled typography.

The main matter of typography consists in making letterforms and combining them into words, lines and pages to form a book. Thanks to the invention of movable type and printing press of Gutenberg, letterforms could be made once and reused many times, which greatly reduced the time and cost of book production. The placement of letterforms, however, could not be automated or reused, so it had remained to be always an elaborate and demanding task. Books are made for reading, so special attention and effort was paid to make the typeset text easy to read. To make a high-quality book, not only nice letterforms were needed, but also proper placement of the letterforms onto pages was demanded.

COMPOSITION AND PAGINATION

In traditional printing, the preparation of books consists in two main stages: composition and pagination. Composition is the task of arranging letters into lines of a certain width. A series of such lines is often called galley or galley proof. The second stage, pagination, is the placement of lines from the galley onto individual pages. Pagination also involves the placement of other elements of a book. Such elements can be, for example, footnotes, illustrations, headings, etc. While composition is horizontal arrangement of letters into words and lines, pagination is vertical arrangement of lines together with other elements onto pages or columns of pages. Since the beginning of printing history, text had been the main matter of typography, so it is obvious that the task of composition had been the most time-consuming and difficult one in traditional printing. With the evolution of typography over time, pagination has become more important than in the beginning, because today's books contain more non-textual elements like illustrations, tables, and the like. The involvement of those elements requires more attention to pagination. However, text composition still remains the basic component of book preparation, as the aim of books to be read does not change at all.

LINE BREAKING AND JUSTIFICATION

The task of text composition consists of two main components: choosing where to end individual lines and how to justify the lines. The first component also involves the task of word division, which is called hyphenation. As the objective of the first component is to find convenient places to *break* lines, this is often called *breaking paragraph into lines* or *paragraph formatting* or *line breaking*. Line justification is the task of fitting a line into a given width. Usually it is done by distributing the extra space into interword spaces in the line. Line justification is strongly dependent on line breaking. When line breaking is done properly, justification can be done without the need to change the interword spaces too much and thereby avoiding holes between words that would distress the eye of the reader.

COMPUTER-CONTROLLED COMPOSITION

Printing technology has changed much since computers were applied to book production. Today nearly everyone is using computers to produce all kinds of printing. However, the basic principle of printing remains unchanged: to produce text, one needs letterforms (called fonts) and needs a program that does the arrangement of letterforms onto pages, i.e. composition and pagination. In today's computer word processors (often called DTP – Desktop Publishing – systems), the engine for doing the composition task is called H&J, which stands for hyphenation and justification. This naming originated from traditional printing, when the job of line-justification was rather elaborate. Choosing line breaks was a minor point of composition. However, with the use of computers, line-justification is quite a simple task and line breaking has become more important to the quality of composition.

OPTIMAL LINE BREAKING

The research on the problem of line breaking took place a long time ago. An excellent overview of line-breaking algorithms is available in [20]. There existed a few line-breaking algorithms that considered more than a single line at a time. However, the algorithm designed by Knuth and Plass in [20, 31] became the most well-known one, often called the *optimum-fit* or *total-fit* algorithm. The main idea of the algorithm is to provide a way to break a paragraph into lines so that the interword spacing is balanced between *all the lines* of the paragraph. This is attained by choosing the sequence of breakpoints with the minimal total "cost" over all lines. The cost of a line depends on many factors that can effect the visual appearance of the line, such as the measure of interword space changing, the division of the last word of the line, etc.

The time complexity of the total-fit algorithm is $\min(O(n^2), O(mn))$, where n is the number of input words and m is the maximal number of words in a line. In practice, the average value of m is often quite small, so the algorithm runs in nearly linear time. It was integrated it into the typesetting system TeX [22, 24], which has been widely used for many years. Practical results have shown that this algorithm is not only efficient, but also general-purpose and flexible enough to handle most of the typographic aspects needed for practical use. After 20 years of existence, TeX line breaking is still among the most sophisticated H&J engines available nowadays. In fact, there are only a few typesetting systems which use a similar algorithm of line breaking like TeX does.

FURTHER RESEARCH ON LINE BREAKING

There is also further research on the problem of line breaking, mainly focusing on reducing the time complexity. Recent results of algorithm designers proved that it is possible to break a paragraph in linear time $O(n)$, independently on the number of words in a line [1, 8, 10, 11, 15, 16, 42]. To achieve a linear time complexity, these algorithms introduced a rather complicated construction and assume certain properties of the cost function of line breaking. They also omitted many implementation details that are important to practical typesetting. Therefore, these algorithms remain mainly an abstract presentation. Until now, I do not know of any typesetting systems with a linear line-breaking algorithm.

THE *hz*-PROGRAM

Apart from the study on an improvement of the line breaking problem (mostly concerning time complexity), an effort has also been put to the *visual improvement* of composition. The most significant work in this direction is undoubtedly the *hz*-program, named after its inventor Hermann Zapf. This program was developed at URW, and there are several papers available that describe the conception of the program as well as its capabilities and output samples [26, 40, 43].

The essential aim of the *hz*-program is to bring Gutenberg's standard of high-quality typography to today's typesetting. The authors went back to the earliest days of printing and examined the "secrets" of Gutenberg which made his books a masterpiece of the art of printing even up to today. The development of the *hz*-program investigated the use of the techniques of Gutenberg's composition into today's technology to examine their effect and practicability. The output samples of the *hz*-program, as shown by various reports and the brochure on the *hz*-program by URW, look very promising. The program itself, however, was not accessible to the public for purchasing, testing or reviewing. In addition, no information about the implementation was available and the development was limited to inside URW only. It seems that the *hz*-program was no longer developed since 1993.

TYPESETTING WITH VARYING LETTER WIDTHS

An attempt to apply the techniques used by Gutenberg and the *hz*-program to TeX was done by Miroslava Misáková [27]. The author demonstrated the potential of a simple method that allows typesetting with varying letter widths implemented by font expansion to attain better interword spacing of composition. The results were very interesting, even though the method was not flexible enough for practical use.

PDFTeX

This thesis describes my work on some typographic extensions to the TeX program. An extension of TeX, namely pdfTeX [33, 38, 39], was used as the development environment. This research originated in modifying the TeX program to produce PDF output directly from TeX source without passing through the intermediate steps of DVI (the original TeX output format) and PS, which is reflected in the name of the project. The first stage of the pdfTeX development was to implement features needed for a PDF backend. This means providing capabilities that are needed for generating PDF files, like font downloading, graphics inclusion, etc. The second stage consisted in experimenting with typographic improvements according to the *hz*-program. The first published work about experimentation with typographic extensions in pdfTeX was in 1998 [39]. The pdfTeX program was extended in such a way that the improvements could easily be applied to any TeX document. The extensions embodying the ideas of the *hz*-program are supposed to be used with PDF output, however they can also be applied for DVI output. The result is not only a prototype, but a fully functional program that has been used in practical typesetting.

InDesign

The development of the *hz*-program did not entirely disappear. Some modules of the *hz*-program were sold to Adobe and several functionalities of the *hz*-program have been made available in InDesign, a recent DTP product by Adobe. InDesign was introduced as "the next generation of the professional publishing software." In particular, InDesign is claimed to set the new standards for text composition. The paragraph builder of InDesign provides many advanced features for text composition, like multi-line composer (a H&J engine based on the total-fit line-breaking algorithm), optical margin kerning control, etc. InDesign got immediately great success, as it offers exactly what has been missing in the world of DTP systems. InDesign is a *very recent* product: the first version (1.0) of InDesign was released in September of 1999, and second version (1.5) was released in March of 2000. The release of Adobe InDesign brings the quality of microtypography to the world of DTP systems. This is a good sign for the direction of further development in computer typography, especially for low and medium cost publishing systems.[1]

Organization of the thesis

This thesis is supposed to be read continuously. Section 1 (this section) is a short introduction to the context. Section 2 describes some main issues of composition that affect the quality of typesetting. Section 3 is an overview of related works. Section 4 is about the motivation for doing the work. Sections 5 and 6 are the main part of the thesis, which describes in detail the design and implementation of the typographic extensions in pdfTeX, as well as appropriate running settings. Section 7 evaluates the chosen implementation. Section 8 contains conclusions and suggestions for further work.

[1] High-end industrial systems are often advertised to do everything and offer the highest quality of typesetting. Such systems, however, are available only to professional publishers due to very high prices. I do not have access to any such systems and I would like to make clear that all remarks in this thesis do not necessarily hold for that class of software.

2 Issues of composition

In this section we will discuss some essential issues of composition that influence the quality of a typeset text. The judgment of a good composed text is often a matter of human perception and thus cannot be defined very precisely by some formulae. On the other hand, typography is a long-time craft and after hundreds years of printing, certain factors are known that they influence the look and readability of a typeset text.

The main objective of text composition is to place letterforms together to form words and lines. While the objective sounds rather simple and straightforward, its implementation is not trivial at all. Composition is a difficult task, because it has to obey many rules. Some rules are easy to fulfil, because they are a fixed part of the typographic design, like line length, type size or line leading. Other rules, however, are difficult to follow, because their achievement requires decision based on human vision and thus cannot be precisely described. Examples are interword spacing, hyphenation, detection of rivers or spacing around punctuation.

The most important requirement of good composition is the harmony of the typeset text. It is often said that "typography should be invisible," i.e. well typeset text should not call attention to itself and distract the reader from the textual contents. The quality of composition depends on two main factors: the visual appearance of the text and the order of letters, words and spaces that form individual lines. Therefore, sometimes the rules governing composition are called *spacing rules* and *rules of orthography* [34]. Issues that may have an effect on the uniformity of spacing and legibility of typeset text must be considered carefully during composing. While issues related to spacing and arrangements of letterforms are a matter of human vision, issues of orthography also require the understanding of the meaning of the text which is being typeset.

2.1 Line breaking and hyphenation

The basic operation of composing is choosing places to break text into individual lines and justify them to a fixed width. In order to set a line to a given width, there must be some variable factor to increase or decrease the line width. Usually this factor is interword spacing. The interword space must be elastic, that is, its width can be increased or decreased continuously with respect to a maximal and minimal amount. The main object of line breaking is to split text into lines so that the interword spaces are changed as little as possible. Either too loose or tight interword spacing disturb the appearance of a text.

Hand composition

In traditional printing, usually a compositor (the person who composed individual letters into lines in the printing process) worked with a single line at a time. He put, in sequence, words and interword spaces onto the current line until he considered the length of line to be nearly equal to the desired width. Then he tried to justify the line to the margins. Justification was usually done by increasing or decreasing the interword spaces, according to a maximum and minimum allowed amount. The extra space was usually distributed equally between interword spaces in the line, i.e. all interword spaces in a line were increased or decreased by the same amount.

Apart from changing the interword spaces, the compositor might use other techniques to adjust the line width. Such techniques could be, for example, using abbreviations or ligatures to make a line a little longer or shorter, in order to achieve a better fit. Sometimes the compositor had to hyphenate the last word in the line because he could not fit the line in a reasonable way without changing the interword spaces too much. Hyphenation is not trivial and must be done with respect to many rules concerning the relevant language and custom. The compositor also had to deal with the dilemma of whether to prefer less-frequent hyphenation, or even extra interword spacing. Again, this is a matter of custom, expectation and personal choice.

LINE BREAKING BY COMPUTERS

The most common way to break lines by computers, as implemented in the H&J engines of most today's word processors, is similar to the manner that a human compositor operated in traditional printing: words are added in sequence into a line until the line width is equal or longer than the desired amount. If the line can be fit to the desired width by shrinking the interword spaces to no more than the minimal amount, then the line is accepted as it is and a next line is started. Otherwise, the last word is moved to the next line, and interword spaces are expanded to fit the line to the desired width. A line is justified to the desired width by distributing the extra space equally between interword spaces in the line. This is certainly a trivial task for computers that can be done in a flash, in comparison with the amount of time a human compositor would spend to align the margins of a typeset text.

Similar to a human compositor, computers can also use hyphenation to improve interword spacing. When the last word does not fit in a line, not the entire word needs to be moved to the next line but only a part of the word (called segment). To find appropriate places to hyphenate words is not easy at all. Human compositors do it by hand. It is certainly not a mechanical task but requires much skill and knowledge. Computers help to speed up and simplify the job of hyphenation very much, but it is still a challenge to attain perfect hyphenation by computers. All current typesetting systems use a dictionary of possible hyphenations and a dictionary of exceptions for missing or incorrect hyphenations. After years of use of computer typesetting, hyphenation systems have become more and more reliable, although, sometimes, human intervention is still needed.

PARAGRAPH-LEVEL LINE BREAKING

Another way to make interword spacing better is to use a paragraph-level line breaking approach, that is, to consider more than a single line at a time during line breaking. This way, the interword spacing is balanced better over the whole paragraph. The line-by-line algorithm does not take into consideration the dependency between the composed lines. When considering a single line at a time, the compositor (or the H&J engine) tries to find the best way to break the current line without looking at the effect it might have on breaking the next lines. However, sometimes it might be desirable not to break at the best place for the current line but at a sub-optimal place, because it would result in a better breaking of the following lines. In general, the result of composing each line might have an effect on all others as well.

In traditional typography, it was impossible for a compositor to look ahead to the potential results of the next lines when composing the current line. He could only work line by line in the forward direction when composing a paragraph. However, when he had finished a paragraph, he could see how the paragraph was typeset and if needed, he could go backward and apply further adjustments to attain a more satisfactory result. This is certainly very labour-intensive and slows down the composing process very much. A human compositor adjusted a typeset text at the paragraph level very rarely, mainly only when the high quality was the most important requirement of composition. On the other hand, with the use of computers, it is feasible to look at more than just one single line at a time. Here the benefit of the use of computers is clear. A human compositor cannot check many possibilities to break a paragraph, so he has to work mostly with a single line at a time. A computer, however, can have the text of the whole paragraph stored in memory and compare all possible variants of line breaking to choose the best one.

The most important result of research on the line-breaking problem was the total-fit algorithm, which was implemented in the TEX program. Compared to line-by-line composition, the total-fit algorithm produces much more even interword spacing. A few of today's typesetting systems use a paragraph-level approach to line breaking based on the total-fit algorithm.

Theoretically it is possible to improve the time complexity of the total-fit line-breaking algorithm. Later development on the line-breaking problem has shown that a paragraph can be broken into lines in a linear time. However, all of the linear algorithms have a rather complicated construction and only work under certain assumptions about the cost function. Furthermore, they omit many aspects that are important to practical typesetting. Such constraints make practicability of those algorithms rather limited. In order to implement such an algorithm into a real typesetting system, many problems have to be solved. Therefore, even though it is possible to extend these linear algorithms to handle requirements of practical typography, in fact it is rather a challenging task for the implementors of typesetting systems. So far, none of these algorithms has been implemented into a 'real' typesetting system.

Practicability of the total-fit algorithm

In this place it is necessary to stress that Knuth did not only design the total-fit algorithm, but also *implemented* it in TEX and therefore made its use *practical*. Until now, there is no known typesetting system with an H&J engine that can do a similar job as the total-fit line-breaking approach with a better time complexity. Another important point to consider is that the time complexity of Knuth's line breaking is already very close to linear. The performance of the line-breaking algorithms with linear time complexity is better than the total-fit algorithm only for the case of rather long lines (over 90 characters, according to [8]). Such long lines occur rarely in typesetting because they are hard to read. More common are the cases of narrow columns. For these considerations, there is no point to improve the line-breaking algorithm implemented in TEX, as the improvement in time complexity is not worthwhile in comparison with the effort needed to extend the implementation of the algorithm.

FURTHER TECHNIQUES USED IN COMPOSITION

So far, most of the existing algorithms investigate the aspect of finding places to break lines in composition, where the criteria to estimate the quality of line-breaking result is the amount of how much the interword spaces in individual lines must be adjusted for line-justifications. The only variable factor for choosing places to end the lines is the interword space. A paragraph is considered optimal when all interword spaces over all lines are set as close as possible to the ideal interword spaces. Therefore, an optimum paragraph is in fact a paragraph composed in such a way that the total contrast of interword spaces set in all lines with the ideal interword spaces cannot be reduced anymore. However, in practice it happens quite often that an optimally formatted paragraph is far from *visually pleasant*, mainly because the paragraph had to be composed under some difficult typographic requirements like a narrow column width, a limitation or prohibition of hyphenation, etc. Under such circumstances, an optimally-formatted paragraph still may have very loose interword spacing that would look awful to the reader. Even with use of a sophisticated line-breaking approach like the total-fit algorithm, better interword spacing is still demanded. In traditional printing, the interword spaces were not the only variable factor for composing. It appears that in Gutenberg's composition, heavy use of abbreviations and ligatures was allowed to facilitate line justification. Some letters were available in several alternatives in a single font so that the compositor could select the variant that would make the current line look better. Such techniques are however rarely used in computer typesetting.

There is always a conflict between favouring uniformity of interword spacing and the number of hyphenations in a paragraph. Prohibition or elimination of hyphenation results in worse interword spacing and vice versa. A reasonable typesetting system should allow user to specify certain constraints, as the number of hyphenations in a paragraph, or the desirability of consecutive hyphenations. There should also be the possibility to choose a compromise between favouring interword spacing and less-frequent hyphenation.

2.2 Interletter spacing and kerning

Spacing between adjacent letters in a word is usually part of font metrics. Letterforms are not the only object of typeface design, but also the space around individual letters, called sidebearings. The sidebearings of all letters should be set to make any combination of letters look good, i.e. no pair of letters should be set too tightly or too loosely to each other. Normally no adjustment of spacing is needed between pairs of letters. Nevertheless, for certain combinations of letters, the sidebearings of letters do not "fit," so fine adjustments of spacing are needed. This technique is called *kerning*. In traditional printing, kerning was done by hand. Computer-controlled typesetting systems maintain kerning data as part of the font metrics, often called kerning table.

Interletter spacing consists of two components: letter sidebearing and kerning. Normally they are determined from the used font, and thus the quality of interletter spacing depends mainly on the quality of the used font. They should not be changed unless there is a good reason to do so. Some sophisticated typesetting systems can calculate kerning data depending on the character shapes, in order to attain better interletter spacing. For example, new kerning data can be added for pairs of letters that need kerning but are not present in the kerning table. Or certain original kerning data can be overridden.

Some typesetting systems can change interletter spacing to prevent bad interword spacing. This technique certainly has its potential dangers, as interletter spacing belongs to the design of a typeface and even a slight change in interletter spacing can damage the appearance of the typeset text. Variable interletter spacing is widely used and often misused in today's printing. However, with careful and conservative use, it can help to reduce bad interword spacing.

2.3 Optically even margins and margin kerning

When looking at most typesetting products, it is obvious that when a text is typeset to a block, simple justification to both margins is not enough to attain optically straight margins. It often happens that some characters at the margins cause a line to look a little bit shorter than the others, because they give the impression that there are some "holes" at the margins. Characters that make such optical illusions are usually the hyphen character or punctuation marks. In general, characters that have dark strokes that are small in proportion to the white areas in their shapes cause this effect. The opposite effect can happen when certain characters appearing at the margins make a line look longer, e.g. the character 'f' in some italic fonts may cause this effect. This phenomenon often causes a typeset text to look ragged rather than justified. This does not apply only to a justified text, but also to the left margin of a ragged-right text.

Margin kerning is the task to optically align the margins of a typeset text by a slight shifting of certain letters at the margins that make the margin look ragged. In traditional composition, margin kerning could be applied by the compositor if the rules of composition required so. As all operations of composition were done manually, the compositor could see whether the margins were optically even and applied finer adjustment for the margins if needed. This technique is often called *hanging punctuation*, because mostly punctuation marks need such fine adjustment when they end up at the beginning or the end of a line. Hanging punctuation makes the task of composition more time-consuming and demanding, and probably it more or less disappeared for economic reasons. Production needs to be faster and cheaper, so the pressure of time and cost of printing does not allow the compositor to pay attention to such fine details of composition.

HANGING PUNCTUATION

In computer-aided automated composition, achievement of optically even margin is often ignored, though margin kerning is very similar to traditional kerning: it deals with fine adjustment of certain letters in order to attain better visual appearance of typeset text. Kerning in today's typesetting is often a matter of font design. Most fonts are provided with an associated table of kerning data that can be used by automated composition. Margin kerning, however, is completely ignored in most of today's typesetting systems because of technical difficulties.

Recently designers of typesetting systems are more and more aware of these issues. In recent versions of a few sophisticated typesetting systems like InDesign or 3B2, support for automated hanging punctuation has been added.

2.4 Color

Color (or greyness) is the term used for the overall darkness of a block of text. Color depends on four factors: interline spacing, interword spacing, interletter spacing and the font design. The font and interline spacing used in a book (or a document) is given by the layout design and therefore is pre-determined for composing. On the contrary, interword (and sometimes interletter) spacing depends on how line breaking is done and how extra spaces are distributed into interword spaces. The greyness of a paragraph therefore strongly depends on the uniformity of interword spacing. Even greyness of typeset text is difficult to achieve, as to attain even interword spacing is always a challenging demand. Moreover, the interword spaces in all lines must be optically rather than mechanically equal, which cannot be done without human vision yet. The interword space can appear wider or narrower than its mechanical width, depending on the shapes of the adjacent characters on either side. For example, a space after a period will look wider than it is, because there is a lot of white space in the shape of the period. For this reason, sometimes no interword space is needed between a period and some capital letters like T, V, etc.

All current systems try to make interword spaces to be mechanically equal, but there is also some effort to compensate the effect of such optical illusions. Some high-quality fonts can contain kerning data with respect to the space character for certain characters that need adjustment when ending up next to an interword space. Common cases of such characters are comma, period, quotes, etc.

However, there is no known typesetting system that tries to compensate interword space according to the shape of characters on *both* sides. So far this can be only achieved by hand composition.

2.5 Rivers

Rivers are vertical alignments of interword spaces in typeset text. This phenomenon disturbs the uniformity of typeset text and distracts the reader's attention from text contents. Usually rivers appear in typeset text with loose interword spacing, as larger interword spaces can easily form vertical "white strips" in typeset text. When text is typeset with tight and uniform interword spacing, there is less chance for rivers to appear. Improvement of interword spacing therefore helps to avoid an appearance of rivers. However, even in the case that interword spaces are tight and uniform, rivers can arise, as there is no guarantee that interword spaces will never be aligned vertically. So far, none of automated composing systems provides the ability to prevent rivers, as their appearance can be only easily detected by human eyes. This is still a challenge for implementors of typesetting systems to provide a "river detector" for automated composing.

A problem similar to rivers is the alignment of identical or similar words in consecutive lines. This effect is most disturbing at the margins of text, that is, when the first or the last word in consecutive lines are identical. Unlike rivers, this happens independently of interword spacing.

2.6 Evaluation of composition

Evaluation of most of the issues described above cannot be done very well without interaction of a skilled human composer. Moreover, when there are conflicts between the rules of composition, the human intervention is always needed to choose a reasonable compromise. For this reason, until now the highest quality of typesetting can be achieved only by craft typography [29].

3 Micro-typography

By micro-typography we understand the concern about very fine details of composition in order to attain better appearance of typeset text. Micro-typography deals with issues like skilful interword and interletter spacing, proper spacing around punctuation, optical scaling, etc. The object of micro-typography is to attain the uniformity of typeset text in all details so that nothing would distract reader's attention from the meaning of the composition itself.

In this section we take a brief look at important works in the area of micro-typography. The first one is the oldest piece of printing, the Gutenberg 42-line Bible [7, 41]. The following ones are computer typesetting systems with the most sophisticated composing engines: the TeX program, the *hz*-program and Adobe InDesign. An interesting experiment based on TeX is also mentioned in the end of this section.

3.1 Gutenberg and the 42-line Bible

When Gutenberg invented printing, his goal was to achieve a faster production of the books that had been made by handwriting. Therefore, his books had to look similar to the manuscripts made by the famous scribes at that time. The key to Gutenberg's success of printing was not only his enormous effort to experiment with techniques of printing and to put them into practice in book production. In order to compete with the scribes and put across his ideas about printing, Gutenberg had to persuade the readers that his art could make "the multiplication of books" not only faster, but also produce books that are no less beautiful than the most avowed books of that time. Probably he had to analyze the best features of the manuscripts in order to bring them into his books. This is not only a technical matter, but also an artistic challenge.

Gutenberg exhibited his talent of a technologist as well as an artist in his 42-line Bible, the height of Gutenberg's art of printing. This is also known as the Mazarine Bible because the first print described by bibliographers was located in the Paris library of Cardinal Mazarine. Today it is commonly referred to as the Gutenberg 42-line Bible, because most of its pages have 42 lines. Apart from its historical value, this is one of the most admired masterpieces of typography until today.

Closer examinations show that the key factors that make the Gutenberg Bible a fascinating typographic accomplishment are the design of page layout and the composition. While the principles used in Gutenberg's page layout design have been studied and can be repeated today, the essence of composition of the Bible often remains ignored in today's typography: it is composition that makes the pages of the Bible look so harmonic with optically straight margins and perfectly even greyness of columns. The right margin was justified carefully to have the appearance of a straight edge. Unlike nearly everywhere in today's printing, there are no wide holes between the words in the Gutenberg Bible that are distressing to the reader's eyes. In order to obtain the compensation of the right margin and the uniform color of columns, Gutenberg employed a number of tricks that are uncommon in latter printing.

Margin compensation

Gutenberg probably noticed that the margin of his composition would not look straight when all characters were right-justified. He achieved margin compensation by positioning certain characters a little bit out of the right margin when they appeared at the end of a line. Characters that were shifted into the right margin in Gutenberg Bible were hyphen, period, comma and some kind of 's' (which does not have any textual meaning; they were used to ensure optical sharpness at the end of lines).

Even interword spacing

The uniformity of interword spacing was treated as a very important issue in composition of the Gutenberg Bible. Interword spaces are set very evenly and close to the width of the letter 'I'. To achieve this difficult requirement, Gutenberg used two methods for justification: punctuation spacing and multiple variants of glyphs. The first method consisted in changing the spaces around punctuation. Spaces can be put before as well as after punctuation. However, there seems to be no case of a punctuation with more space before it than after it. Spaces around punctuation changed rather freely, from cases when punctuation was used without any space around to cases where the spaces around were as large as other interword spaces. The second method to adjust lines was the use of multiple variants of glyphs for some letters, some words or combinations of some letters. Gutenberg had prepared a large set of abbreviations and ligatures that could be used to replace certain words or combinations of letters. Apart from that, a letter in his composition could be typeset using several variants of a glyph with different width, depending on the requirements of typesetting a line. The alphabet used for typesetting the Bible contained about 290 characters, many of them were ligatures and multiple glyphs of certain characters. The main intention of use of multiple glyphs was most likely to achieve the constant distance between the vertical strokes of characters. The compositor therefore could select the glyph of a letter that seemed to be the best variant according to the position of the letter in the word or the line. The result is the "woven" or "grid" appearance of pages with perfectly uniform greyness. The multiple glyphs might also have been used for the adjustment of line width. However, this seems to be a minor effect.

Not all of Gutenberg's techniques can be used for today's printing, simply because the technology and the custom has changed so much. However, the masterpiece Gutenberg Bible remains the standard of high-quality typography that today's typesetting systems should aim to.

3.2 The TeX program

A brief history of TeX

Unlike most other typesetting systems, TeX was created by one man, Donald Knuth, professor of Computer Science at Stanford University. A short, but excellent, history of TeX comes from [12]:

> TeX (= tau epsilon chi, and pronounced similar to "blecch," not to the state known for 'Tex-Mex' chili) is a computer language designed for use

> in typesetting; in particular, for typesetting math and other technical (from greek "techne" = art/craft, the stem of 'technology') material.
>
> In the late 1970s, Donald Knuth was revising the second volume of his multivolume opus The Art of Computer Programming, got the galleys, looked at them, and said (approximately) "bleccch"! He had just received his first samples of the new computer typesetting, and its quality was so far below that of the first edition of Volume 2 that he couldn't stand it. He thought for awhile, and said (approximately), "I'm a computer scientist; I ought to be able to do something about this," so he set out to learn what were the traditional rules for typesetting math, what constituted good typography, and (because the fonts of symbols that he needed really didn't exist) as much as he could about type design. He figured this would take about 6 months. (Ultimately, it took nearly 10 years, but along the way he had lots of help from some people who should be well known to readers of this list – Hermann Zapf, Chuck Bigelow, Kris Holmes, Matthew Carter and Richard Southall are acknowledged in the introduction to Volume E, "Computer Modern Typefaces," of the Addison-Wesley "Computers & Typesetting" book series.)
>
> ...
>
> To produce his own books, Knuth had to tackle all the paraphernalia of academic publishing – footnotes, floating insertions (figures and tables), etc., etc. As a mathematician/computer scientist, he developed an input language that makes sense to other scientists, and for math expressions, is quite similar to how one mathematician would recite a string of notation to another on the telephone. The TEX language is an interpreter. It accepts mixed commands and data. The command language is very low level (skip so much space, change to font X, set this string of words in paragraph form, ...), but is amenable to being enhanced by defining macro commands to build a very high level user interface (this is the title, this is the author, use them to set a title page according to AMS specifications). The handling of footnotes and similar structures are so well behaved that "style files" have been created for TEX to process critical editions and legal tomes. It is also (after some highly useful enhancements in about 1990) able to handle the composition of many different languages according to their own traditional rules, and is for this reason (as well as for the low cost), quite widely used in eastern Europe.

As the main object of TEX was to get high-quality typesetting, special care was paid to very fine details of composing that had been secrets of typographers. TEX was among the first computer typesetting systems with support for advanced typography like ligatures, kerning, control of spacing around punctuation, hyphenation, etc. Moreover, Knuth introduced the most significant principle of line breaking in computer typesetting. The concept of considering a paragraph as a whole while breaking it into individual lines, i.e. the "total-fit" algorithm, in fact has become the fundamental algorithm for paragraph formatting by computers.

Here we will briefly describe the algorithm of line breaking used by TEX. We omit many of the technical details of the process because they are rather complicated. Only the concepts and terminology that are relevant to our interest will be explained. (For more detailed information about the algorithm and its implementation, see [20, 22]).

The model of TEX line breaking is based on three elements, namely *box*, *glue* and *penalty*. Therefore this model is also called the *box/glue/penalty* model. THE BOX/GLUE/PENALTY MODEL

- A *box* represents some material that should be typeset. A box can be a character or a sequence of characters from a font, but it can also be a much more complex object, e.g. a mathematical formula or a line or a composition of other boxes. The contents of a box, however, is not important for the line-breaking algorithm. The only relevant information about a box for the line breaking process is its width. We can simply think of a box as a word (or a segment of a hyphenated word), where its width is the sum of the widths of the associated letters. BOX

- A *glue* represents a blank space whose width can vary. Glue has *natural size*, standing for the normal width of the glue. Apart from natural size, glue may have *stretchability*, which is the maximum extra amount that the glue can be increased by. Similarly, glue *shrinkability* stands for the maximum amount that the glue can be decreased by. The natural size, stretchability and shrinkability together are called the *glue specification*. In the context of line breaking, the interword space is represented as glue with its specification depending on the selected font. GLUE

- A *penalty* is the cost we pay or the reward we gain for breaking a line at a certain place. Using penalties allows the control of line breaking in a flexible way by specifying appropriate values of the penalty at the desired places. For example, when we wish to limit breaking at a certain place, we can insert a high penalty. An infinite penalty means prohibition of breaking at its location. Similarly, a negative penalty indicates a desirable place for breaking and an infinite negative penalty forces breaking at its location. PENALTY

A paragraph is represented by a sequence of items, each of which can be a box, glue or a penalty. A *breakpoint* is a place where it is possible to end a line. A breakpoint usually occurs at a glue, a penalty or a *discretionary break*, i.e. the place where a word can be hyphenated. A sequence of breakpoints defines a way that the paragraph can be broken by dividing the paragraph into sub-sequences of items, where each such subsequence represents an eventual line. Line breaking can be then understood as the process of finding a "desirable" sequence of breakpoints. The total-fit algorithm examines "desirability" of all possible sequences of breakpoints and chooses the best ones. BREAKPOINT

In order to evaluate the desirability of a sequence of breakpoints, we need to define the desirability of individual lines that the breakpoints would result in. Given a sequence DESIRABILITY of breakpoints, a line is represented by a sequence of items between two consecutive breakpoints, which correspond to the beginning and the end of the line. The *natural width* of a line is the total width of all items in the line, where the width of each glue item is counted from the natural size of the glue only. We call the difference between the natural width and the desired width of a line as the *excess width* of the line. The *total stretchability* of the line is the sum of the stretchability of all glue items in the line. The *total shrinkability* is defined similarly. A line is justified to the desired width by stretching or shrinking the glue items in the line to compensate for the width excess of the line. When the natural width of a line is smaller than the desired width, the glue items are stretched in order to increase the total width of the line to be equal to the desired width. Similarly, shrinking is done for a line with natural width longer than the desired width. The amount that the glue items in a line are stretched or shrunk by is defined as the *adjustment ratio* of a line. Let us consider a line with the natural width L and the desired width l. The excess width is defined as $l - L$. The glue items in the line are $x_1, \ldots, x_n$ where each glue x_i has stretchability y_i and shrinkability z_i. Then the total stretchability is denoted as $Y = y_1 + \cdots + y_n$ and the total shrinkability as $Z = z_1 + \cdots + z_n$. The adjustment ratio of the line is calculated as:

NATURAL WIDTH

EXCESS WIDTH

TOTAL STRETCHABILITY AND SHRINKABILITY

ADJUSTMENT RATIO

$$r = \begin{cases} 0, & \text{if } L = l \text{ (a perfect fit, no need of stretching or shrinking);} \\ (l - L)/Y, & \text{if } (l - L > 0) \wedge (Y > 0) \text{ (a short line, stretching needed);} \\ (l - L)/Z, & \text{if } (l - L < 0) \wedge (Z > 0) \text{ (a long line, stretching needed);} \\ \Lambda, & \text{undefined otherwise.} \end{cases} \tag{1}$$

If the excess width is zero $(l - L = 0)$, we get a perfect fit: the natural width is the same as the desired width and no stretching or shrinking is needed. When a line cannot be stretched or shrunk because the total stretchability or shrinkability is zero, the adjustment ratio is undefined. Otherwise, it is calculated as the proportion of the width excess and the total stretchability or shrinkability, depending on whether the width excess is positive or negative. The value of the adjustment ratio is positive in case of stretching, and is negative in case of shrinking.

Glue items in a line are stretched or shrunk by amounts proportional to stretchability and shrinkability of individual glue items. Stretching or shrinking glue according to an adjustment ratio is called *glue setting*. In case of stretching, a line is justified to the desired width by adding an amount ry_i to the width of each glue item x_i in the line. The line width is increased by an amount $r(y_1 + \cdots + y_n) = rY$. According to the above definition, we have $r = (l - L)/Y$; thus, the line is stretched by $l - L$, which is exactly the amount needed to justify the line to the desired width (i.e. the excess width). Likewise, adding rz_i to the width of each glue item x_i adjusts the line by an amount of $r(z_1 + \cdots + z_n) = rZ = l - L$, i.e. the excess width again.

BADNESS

The *badness* of a line is a non-negative function depending on the ratio adjustment r as follows:

$$b = \begin{cases} \infty, & \text{if } r \text{ is undefined or } r < -1; \\ \lfloor 100|r|^3 + 0.5 \rfloor, & \text{otherwise} \end{cases} \tag{2}$$

Roughly speaking, the badness represents the quality of interword spacing of a line. The higher the badness, the worse the interword spacing is. When a line is too short or too long, the excess width may be larger than the total stretchability or shrinkability of the line. However, a line is allowed to be stretched by more than its total stretchability, but it cannot be shrunk by more than its total shrinkability. That is the reason why badness is treated as ∞ when $r < -1$. When $r > 1$ the value of badness may be very high, but it is still treated as finite. A sequence of breakpoints that would result in any line with infinite badness should never be chosen if there is another choice of breakpoints that would avoid having an occurrence of infinite badness.

DEMERITS

Apart from badness, the desirability of a line depends also on the penalty of the line. A line takes the penalty from the ending item if it is a penalty item; otherwise the penalty of the line is treated as zero. The cost of a potential line is defined as the *demerits*, which is roughly the sum of the squares of the badness and the penalty of the line. Given a line with badness b and penalty p, the exact formula for demerits calculation is:

$$d = \begin{cases} (k+b)^2 + p^2, & \text{if } 0 \leq p < \infty; \\ (k+b)^2 - p^2, & \text{if } -\infty < p < 0; \\ (k+b)^2, & \text{if } p \leq -\infty. \end{cases} \tag{3}$$

Here k is a constant that can be used to adjust the demerits of each line independently of the associated badness and penalty. This number can be increased to minimize the total number of eventual lines.

THE BASIC PRINCIPLE

The basic principle of the line-breaking algorithm is to generate all possible sequences of breakpoints of a paragraph and examine the corresponding total demerits. The best sequence of breakpoints is the sequence with least total demerits. The algorithm introduced a rather complicated construction to gain a time complexity that is reasonable for practical use.

FEASIBLE BREAKPOINTS

In fact the algorithm does not examine all sequences of breakpoints, but only *feasible* breakpoints are considered. A feasible breakpoint is a place where the text of the paragraph from the beginning to this point can be broken into lines whose badness does not exceed a given value, called *tolerance*. The number of feasible breakpoints of a paragraph is much smaller than the number of all breakpoints. Therefore, considering only feasible breakpoints helps to eliminate examination of lines whose badness is higher than the given tolerance. It is not necessary to take into account sequences of breakpoints which would result in such lines.

SHORTEST PATH

The algorithm works by constructing an oriented network whose nodes are feasible breakpoints and the distance between two nodes (the cost of the edge connecting two nodes) is the number of demerits corresponding to the line determined by the breakpoints represented by the nodes. According to the definition of feasible breakpoints, there is no edge with cost larger than the tolerance. Thus the higher the value of tolerance, the larger the network is, as there are more feasible breakpoints. The object of the algorithm is to find the *shortest path* in this network, where the start node represents the beginning of the paragraph and the target node represents the end of the paragraph.

DYNAMIC PROGRAMMING

The problem of finding the shortest path in a network is solved using a general algorithm, called dynamic programming. Its fundamental principle, called the *principle of optimality*, is:

> If the shortest path from 1 to k passes through j, then the part up to that point is the shortest path from 1 to j.

Its application to the line-breaking problem is then restated in [42]:

> If the best way of breaking words 1 through k causes a break after word j, then the part up to that breakpoint is the best way of breaking words 1 through j.

TIME COMPLEXITY

Time complexity of the algorithm for seeking the shortest path is $\frac{n(n+1)}{2}$, where n is the number of words of the whole paragraph. However, the number of outing edges from a node is limited by the number of words on a line, so time complexity of the line-breaking algorithm can be reduced to $\min(O(n^2), O(mn))$, where m is the maximal number of words in a line. In practice, the value of m is rather small, which results in a fairly reasonable running time.

After the sequence of breakpoints have been chosen, the paragraph is divided into individual lines and each line is justified to the desired width. The extra space is distributed into the glue items according to glue stretchability or shrinkability as described above. Thus, glue with larger stretchability will be stretched more than glue with smaller stretchability. However, in most cases, the glue items in a line (representing the inter-word spaces) are the same and therefore they are stretched or shrunk alike. This phase is similar to the justification part of composition. It is a trivial task when it is done by computers, compared to the work that a compositor would have to do in traditional printing.

TeX line breaking produces excellent output and text typeset by TeX is generally better in comparison to composition by most other typesetting systems. The algorithm implemented in TeX is very flexible and allows the control of line breaking in nearly every detail. The algorithm also handles other complicated elements for line breaking like math, hyphenation of ligatures, or the change of spelling of some compound words when they are hyphenated.

However, it is not true that TeX line breaking is perfect and always produces satisfactory output. There are still cases when TeX fails to get the best quality of composition [28, 29]. Examples of possible improvements of TeX composition are: avoiding rivers, better control on justification of the last line, number of hyphenations in a paragraph, better handling of ragged-right text, compensation of interword spaces according to the shapes of boundary characters, etc. Most of these issues have not been handled in any other typesetting systems yet. Until now such problems can only be solved manually.

AVAILABILITY

Another important aspect of TeX is that Knuth made its source code fully available to the public at no cost, thus not only the possibility to use but also to extend TeX is open to everyone.[2] Knuth has frozen his work on TeX and will not do any further development. There are several ongoing developments that extend TeX, namely Ω [30], ε-TeX [35–37] and pdfTeX. Each project aims at a somewhat different goal of extension.[3] A more radical project, NTS, is to rewrite TeX to another programming language which is more suitable for further extensions.

3.3 The *hz*-program

The *hz*-program is the result of the research on "micro-typography for advanced typesetting" by Hermann Zapf in conjunction with URW.[4] The developers returned to printing in Gutenberg's days [40] to find out the keys to success of the typographic masterpiece, i.e. the 42-line Bible. Some techniques used by Gutenberg, like the use of ligatures and abbreviations, were examined and later discarded. The reason is that reading habits and customs have changed from Gutenberg's time and the use of many ligatures and abbreviations that were common at that time is not acceptable today. Other techniques like multiple glyphs with varying widths or hanging punctuation turned out to be very worthwhile. The *hz*-program, however, does not only simply follow the techniques in Gutenberg's composition. In order to gain Gutenberg's typographic standard of even interword spacing and optically straight margins, the developers introduced the "ten typographic commandments," concerning three areas of typesetting: kerning, scaling and composing [40]:

KERNING

1. Every beginning character in a line should receive a special left side bearing and each last character, a special right side bearing.

2. Lines running short should receive only positive kerning, and those too long, only negative kerning.

3. Spacing should be dependent upon type body size. Inter-character spacing should be wider in proportion than character spacing for larger type sizes.

SCALING

4. Letterforms should fit their pointsize. Optical scaling should be applied.

[2] However, any extension of TeX should use other name than TeX if it does not pass the "trip" test that Knuth made for testing TeX compatibility.

[3] pdfTeX and ε-TeX have been merged into a single program called pdfε-TeX.

[4] URW Software & Type GmbH (former URW Unternehmensberatung Karow Rubow Weber GMBH) of Hamburg, Germany.

5. When working within a short line and setting in a specific pointsize, any expansion of characters should be approached very carefully.

6. Likewise, within long lines, any character condensing should be done sparingly.

7. Expansion or condensing should not be used overall, but rather to selected characters.

COMPOSING

8. When hyphenation is used, justification should be applied to an entire paragraph rather than line by line.

9. The adjustments made here should be applicable to single master fonts.

10. Displays permitting grayscaling should be used to give greater typographic control during typesetting.

The *hz*-program introduced three new variables for composition: improved letter spacing (kerning), typographically acceptable expansion or condensing of characters (scaling) and improved applied programming (composing). The *hz*-program is a set of modules for text composition that can bring these features into the H&J engine of DTP systems. The modules can be used together or separately.

THE *kf*-PROGRAM

The module to deal with kerning is called the *kf*-program. Kerning by the *kf*-program is used to improve interletter spacing as well as to obtain optically straight margins of typeset text. The most significant feature of the *kf*-program is the capability to calculate kerning on the fly instead of using a static kerning table.

In most of the current typesetting systems, kerning is handled using the data from the kerning table. The kerning table says which pairs of characters should be kerned, as well as the kern amount to be applied. The kerning table is usually a part of a font and is prepared by the font creator. The main flaw of this approach is that the same kerning data is used for different sizes. It has been known that kerning should depend on the pointsize in order to attain proper interletter spacing. The kerning data of a font, however, is often optimized only for a certain size (often for 12 pt).

With the *kf*-program, the kerning table only specifies which pairs of characters need kerning. The kern amount, however, is calculated on the fly, accordingly to the shape of the characters and the used size. The *kf*-program can be used to get optically-even interletter spacing at an arbitrary size, as well as for skilful spacing adjustment of a line by changing interletter spacing. Kerning can be negative as well as positive, depending on the line-justification demand.

The *kf*-program also calculates new sidebearings for the first and the last characters on a line. An artificial character "left white edge" is placed to the left of the beginning character in the line, and the kern between them is calculated on the fly to produce a new left side bearing for the beginning character. Similarly, the new right sidebearing for the last character on a line is calculated using a "right white edge." These two artificial characters do not exist in a font; they are used only inside the program and are not visible in the output.

THE *Kϱ*-PROGRAM

Scaling is controlled via two modules, the *Kϱ*-program and the *Ɛk*-program. In traditional typography, different fonts were designed for a single typeface at different sizes. With the advent of digital typography, this approach was abandoned and nowadays a typeface is often available as a single font that was designed for a certain pointsize (usually 12 pt). Use at other sizes is provided by scaling the font to the requested size. This method, however, does not give good results. Fonts for smaller size should have wider letterforms and heavier strokes.

The *Kϱ*-program was designed to eliminate this shortcoming. It calculates true optical scaling of character forms according to typographic requirements at various sizes. With the *Kϱ*-program a single font will look good even at very different sizes.

The companion *Ɛk*-program handles font expansion and condensing for adjustment needed during text composition. It can modify a font to vary the width of individual characters without visible distortion. The *Ɛk*-program does not expand or condense all characters proportionally. Characters that are more sensitive to deformation should be left unchanged or should be changed very slightly.

THE *jp*-PROGRAM

The last module, *jp*-program, is roughly a sophisticated H&J engine based on a similar algorithm to TeX line breaking. The most important advantage of the *jp*-program over TeX line breaking is that it can cooperate with the other modules of the *hz*-program. These modules provide new variable factors that can be used to adjust lines and therefore provide more flexibility for the *jp*-program to compose a paragraph. However, from the available documentation about the *hz*-program it is not clear how the *jp*-program uses other modules to choose breakpoints for a paragraph. There are two possibilities that can come into consideration. The first approach can be understood as post line-breaking adjustment, that is, the *jp*-program first breaks a paragraph in a similar manner like TeX without taking into consideration the potentiality of expanding/condensing by kerning or scaling. After the breakpoints are chosen, other modules are applied to improve interword spacing. The second approach, certainly more sophisticated, is to consider the potentiality of kerning and scaling, in order to find better breakpoints.

THE CURRENT STATE OF THE *hz*-PROGRAM

Not much documentation about the *hz*-program is available. A few reports about the program were published by the developers and a production brochure by URW was released. The *hz*-program itself, however, was not available even for reviewing or testing purposes. In addition, it is also unknown whether there exist further developments of the program or its state.

3.4 Adobe InDesign

InDesign is an advanced DTP system by Adobe. InDesign has support for much more sophisticated text composition in comparison with other DTP systems. The most advanced features of text composition in InDesign are the multi-line composing engine, automatic optical kerning and optical margin alignment.

MULTI-LINE COMPOSER

The multi-line composer of InDesign is a composing engine based on the algorithm of TeX line breaking. Even though the paper describing the algorithm was published

20 years ago (and for so long TEX has been around and available for free), InDesign is the first commercial DTP system that pays attention to the importance of line breaking and takes the advantage of the approach to break paragraphs at multi-line level.

The multi-line composer of InDesign, however, can do more than TEX. Apart from variable interword spacing, it can also use variable interletter spacing and glyph scaling to achieve a more even color of typeset text.

VARIABLE INTERLETTER SPACING

Variable interletter spacing is the trick to increase or decrease space between consecutive letters, in order to slightly expand or compress a line. InDesign allows the control of interletter spacing by expressing the maximum and minimum value of interletter spacing. These numbers are given in percentage of change of character width. By default, these limits are set to 0%, which means that no interletter spacing is allowed. A value of 2% of maximum interletter spacing means that each character width can be increased by 2% to make a line wider. This does not affect the character shape but only the right sidebearing will be expanded by 2% of character width. Similarly, character width can also be decreased to compress a line if needed. This technique has been widely used for a long time in DTP systems to compensate for bad interword spacing. Unlike other systems, InDesign considers the potentiality of variable interletter spacing in a multi-line composing approach, which gives a much better result.

GLYPH SCALING

Glyph scaling is the technique of expanding or condensing the shapes of individual characters, in order to lengthen or shorten a line. Similar to interletter spacing, the limits of glyph scaling are expressed in the percentage of variance in character width. Glyph scaling works very much like variable interletter spacing. The only difference is the way the excess width is distributed: interletter spacing means changing the right sidebearing, while glyph spacing means scaling the whole glyph (including the sidebearing) horizontally.

AUTOMATIC OPTICAL KERNING

InDesign supports automatic kerning between two adjacent letters by calculating the white area between the character shapes. Kerning information is available in most fonts, however they are suitable for only a certain size. Automatic optical kerning will generate kerning information based not only on the character shapes, but also on the pointsize. This feature is similar to the functionality of the *kf* module from the *hz*-program.

OPTICAL MARGIN ALIGNMENT

Optical margin alignment works by adjusting the placement of characters at the margins of text, in order to make the margins of text typeset to block appear more even. In InDesign it is set as a story-level attribute, which means that the effect is global to the whole text thread. The amount of adjustment is determined automatically, depending on the pointsize of the body text.

The benefit of optical margin alignment is most visible for punctuation marks, hyphens and quotes. However, it is more general than hanging punctuation, as certain letters are slightly adjusted as well. The result is that margins of typeset text are mechanically subtly ragged, but optically smooth to the human eye.

However, optical margin alignment in InDesign can only be switched on or off, but cannot be changed. It works best with most common fonts and pointsizes for body text. For italic fonts the result is not so satisfactory, and there is no way to control the amount of adjustment yet. It is not clear from the documentation how the amount of margin adjustment is calculated. From the behaviour of the program, it appears that the movement of individual characters is predefined at character-level.

InDesign and professional publishing

InDesign is a successful story of Adobe. It provides many features required by today's professional publishing, as well as its smooth integration with other Adobe's products. However, what mainly separates InDesign from other DTP systems is excellent typographic controls, an area that is often ignored in today's publishing. InDesign offers the advantages of DTP systems together with the control of advanced micro-typography. This combination makes InDesign a unique piece of program in the world of DTP systems.

3.5 Typesetting with varying letter widths

An interesting experiment on improvement of interword spacing was done by Miroslava Misáková in her Master thesis[5]. The author investigated the potential of improvement of line breaking by using "varying letter widths." The basic idea is to expand or condense the fonts used in a paragraph in order to improve interword spacing. The method was implemented by DVI postprocessing and a cooperation of Perl, TEX and METAFONT.

The author simulated a "font-expansion aware" line-breaking approach, i.e. to take into account the potential of making a line wider or narrower by font expansion. The line-breaking parameters were set to allow certain elasticity of the right margin. Thereby, after TEX composing, the result has the right margin subtly ragged. DVI postprocessing is then used to adjust individual lines to align the right margin. During this phase, lines that are longer than the desired width are condensed by using a narrower variant of the font in the line. Similarly, lines shorter than the desired width are expanded by using a wider variant of the font in the line. In this experiment, a font can be expanded by $-5\%, -4\%, \ldots, 4\%, 5\%$, according to the demand of line-justification. A font thus can be typeset at 10 variants. The variant that would minimize the amount of changing the interword spaces in a line would be selected. Font substitution is done in DVI postprocessing by Perl. A requested font can be generated on the fly if it does not exist yet. Font expansion was done in METAFONT.

This work was a worthwhile experiment on composing with font expansion. It has shown the potentiality of such a manipulation on composition, as well as the possibility to implement it in TEX. The practicability of the method, however, was rather limited, because of its complicated setup and its inflexibility.

[5] The thesis was written in Czech, but a reduced version in English is also available [27]

4 Motivation for micro-typographic extensions to TeX

Today's typesetting needs a revival of micro-typographic issues in text composition. While the development of typesetting systems goes mainly on issues that allow users to create all kinds of documents quickly and easily, not much attention is paid to the quality of text composition. This is especially true in the world of DTP systems.

The best comment for this situation comes from [9] by Stephen Edwards, editor of the Seybold Report on Publishing Systems.

> Why does text composition quality seem to get worse, rather than better? Why do we cringe when we read even the likes of the New York Times or Newsweek? It has never been a secret that text looks better, and is easier to read, if the spacing between words is balanced over a whole paragraph – a perfect application for a computer. TeX was doing it 20 years ago. A little UK company called Digital Publishing Systems was doing it ten years ago. Similarly, today's computers could easily handle the requirements of more sophisticated logic programs, better default kerning tables, hung punctuation to provide better visual margins, a reasonably good effort to make ragged text look inviting and perhaps an honest effort to deal with ligatures.

Another apposite comment on the lack of support for micro-typography – in particular hanging punctuation – in today's typesetting systems comes from [5]:

> Hanging punctuation is one of those typographical refinements you just don't see around that much anymore. And that's too bad, because the use of hanging punctuation – quotation marks or periods, for example, that print, or "hang," outside the left and right margins – is an excellent way to achieve a more balanced look in any justified block of text. Because quotation marks and periods don't take up the same amount of space or have the same weight as other characters, margins can easily appear offset from line to line. By placing the punctuation outside the text block, you can smooth out the ragged appearance of the margins by aligning the first and last text characters of all the lines. Not only does this result in the margins appearing more even, you also achieve a more consistent "color" balance (in other words, the overall proportion of black type to white space) throughout the paragraph.
>
> One of the reasons you don't see hanging punctuation so much anymore is that it's difficult to create with today's page layout programs. If you long for that ultimate typographic balance, however, there are several methods you can apply – though none are automatic. In fact, the techniques are

somewhat labour intensive, and the text is also difficult to edit afterward. But if perfection is your goal, no price is too high to pay.

The lack of fine typographic controls in today's typesetting systems is not completely ignored by their developers. The *hz*-program is an important step forward in the development of digital typography. It introduced new possibilities for advanced text composition. Even though the *hz*-program was not available for practical use, it has clearly shown the potentialities of advanced micro-typography.

On the other hand, the situation with TeX is a little different. TeX, as a low-level batch formatter is a stable and portable system which can produce very high quality output. There had not been any system with a better composing engine than TeX for long. However, recent development in micro-typography by the *hz*-program shows that there are also other potentialities to produce better typesetting quality that have not been implemented in TeX yet. Therefore, I think that TeX can be extended to do an even better job on composition. In the concrete, optical margin alignment and better interword spacing are two issues which I believe could be improved in the current implementation of TeX.

OPTICAL MARGIN ALIGNMENT

TeX does not have any explicit support for adjustment of positioning characters at the margin of typeset text. Hanging punctuation can be simulated at macro-level in TeX to make certain characters like comma, period, etc., to be hung out of the right margin [24]. The useability of this trick is however quite limited. It assigns a special meaning (called *active character* in TeX terms) to characters that should be hung out, which can cause certain conflicts. Moreover, it cannot be applied to the hyphen character, which is the most frequent case that needs adjustment. And not only punctuation marks and the hyphen character need such adjustment, but also certain letters. Similar to the situation in the DTP's world, hanging punctuation is rarely used in TeX for the lack of natural and systematic support. Such an extension to the typesetting engine of TeX is certainly a desirable feature.

INTERWORD SPACING

The evenness of interword spacing is generally considered to be dependent on line breaking, which is the strongest side of TeX. The line-breaking algorithm implemented in TeX is very flexible and allows very fine and precise control over line breaking. However, the only variable factor that is taken under consideration by the line-breaking algorithm is the changeability of interword spaces. In hand composition, on the contrary, a human compositor can also use other factors to justify lines, like multiple glyphs in the Gutenberg 42-line Bible, or slight interletter spacing. Moreover, the *hz*-program has demonstrated that glyph scaling can also be used to gain some more room for choosing better line breaks.

Using glyph scaling and variable interletter spacing in composition is potentially dangerous and is generally treated as an ugly trick that should be avoided in high quality typesetting. The reason for this presumption is that this is often misused by lamentable H&J engines of most word processors to recover interword spacing produced by poor, line-by-line composing. The *hz*-program, however, has shown that such manipulations, when used in a sophisticated composing engine with proper settings, can significantly improve interword spacing.

Another important point to consider is that TEX was created in a somewhat non-typical way of software development. The development of TEX and its companion, METAFONT, was described in almost every detail. The fully documented sources of the program are available to the public. By doing so, the author made the potential for further TEX extensions open to everyone.

From these considerations, I believe that it is worthwhile to integrate the concepts of the *hz*-program into TEX. As my aim is to improve *visual appearance* of the composition, and not the time complexity of line breaking, I believe that there is no better environment for this purpose than TEX. The intention of the author of TEX when designing the program was to "produce the finest books in the world." Indeed, the program is outstanding among computer typesetting systems with many advanced features that only became available in other DTP systems many years after TEX. Starting from TEX, I can also take the advantages of many superior capabilities that exist in TEX already.

pdfTEX and InDesign

It is necessary to emphasize here that InDesign is *not* a previous work to pdfTEX. It is not known how long the development of InDesign was inside Adobe before the first version was released. The work on typographic extensions of pdfTEX, however, had started about two years before the date of the first public release of InDesign. The development of typographic extensions in pdfTEX was motivated mostly by the capabilities of the *hz*-program, reported in some publications. Nevertheless, no information about implementation of the *hz*-program was available. The development of typographic extensions in pdfTEX was started "from scratch," which took a long time before there was some outcome. Plenty of experiments have been done in order to find out reasonable concepts and running settings. On the other hand, my work is open to the public and I believe that the lessons learnt from pdfTEX can be useful experiences for further work in this area.

There is an interesting point in the relationships between traditional typography, computerized typography and advanced micro-typography. At first Gutenberg invented and perfected the concepts of traditional printing. Then, with the advent of computers, Knuth wrote TEX to typeset books by computers. The most important principle of TEX to break a paragraph as a whole in fact became the standard for paragraph formatting in computer typesetting.[6] Hermann Zapf and URW explored the ideas of both Gutenberg and Knuth in the development of advanced micro-typography with the *hz*-program. The outcome of the *hz*-program has again a backward impact on TEX, as the *hz*-program was the essential inspiration for experimenting within TEX with the ideas of micro-typography that are not available in TEX yet.

[6] By 'standard' I mean the ideal or the rules that line-breaking approaches should aim to. Sadly, this is not true for the H&J engine in most of current typesetting systems.

5 Margin kerning

The implementation of margin kerning contains two main issues: a concept of managing margin kerning data and an incorporation of those data into the composing engine. After the implementing, it is also necessary to find appropriate margin kerning settings which give reasonable results for practical use.

5.1 The concept of character protruding

There are several possible approaches to managing margin kerning data. The most sophisticated approach seems to be the generation of kerning data on the fly as the *kf*-program does. This is certainly a very demanding task, as it requires the ability of a software to render a font and to analyze letter shapes to find out the appropriate kerning data. Implementation of such a program is out of the scope of my work and affordable time.

Another approach is to maintain margin kerning data in the same way as for normal kerning data, so that they can be either manually edited or automatically generated using another software separately from TEX. While this concept is quite clear and straightforward, its implementation would require to change not only the font handling mechanism in TEX but also the tools for generating fonts. Moreover, it would result in incompatible versions of fonts, which is strongly undesirable.

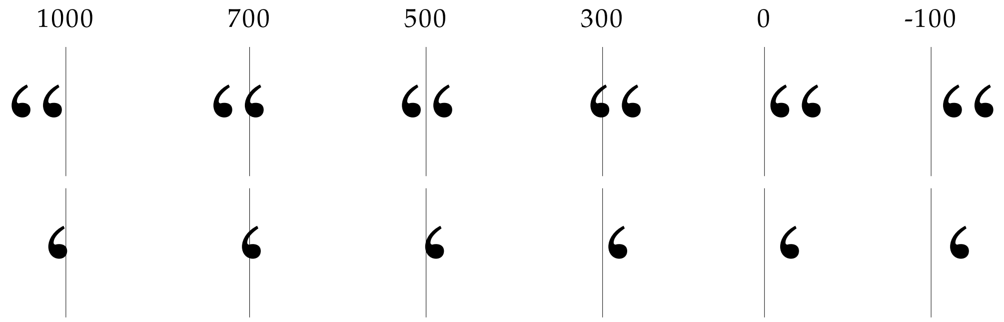
A simpler alternative of the above approach is to provide a way to specify the additional data for margin kerning to the current data of a font after loading the font into TEX memory. As my main objective is to examine the visual effect of margin kerning on typesetting, I choose this rather simple and flexible concept to implement margin kerning so that it can be easily applied to any existing document and fonts without much complicated setup.

CHARACTER PROTRUDING

PROTRUDING FACTOR AND UNIT

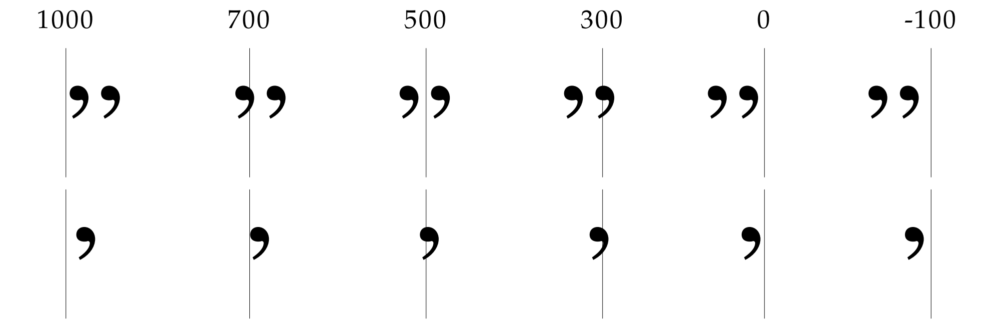
Margin kerning is implemented by introducing a mechanism called *character protruding*. Each character from a font has an associated parameter called the *left protruding factor*. This parameter is used for fine adjustment of the character position at the left-hand side of justified text. The parameter specifies the number of *protruding units*, which is the amount by which the character should "protrude" to the left margin if it appears at the beginning of a line. I define one protruding unit to be one thousandth of the character width. Thus, a character of width w and left protruding factor P_l should be shifted out to the left margin by an amount of $K_l = w\frac{P_l}{1000}$ if the character appears at the left margin. The parameter can have a negative value as well, which means that the character should be shifted to the opposite direction. This is necessary because certain characters at the margins can make a line look longer (for example, the letters 'f' or 'p' from an italic font). In such cases it is desirable to assign a negative value to the protruding factor of those characters to move them "inwards" away from the margins.

By default, all characters have the corresponding left protruding factor set to zero (no protruding at all). The effect of left protruding factor to character positioning at the left margin is shown in Sample 5.1.



Sample 5.1: Effect of various settings of left character protruding factor, applied to the left single quote and the left double quote. The vertical rule indicates the *left* edge of the text.

Similarly, the *right protruding factor* of a character is used for positioning adjustment of the character at the right margin. A character of width w and right protruding factor P_r will obtain a protruding amount of $K_r = w\frac{P_r}{1000}$ when it appears at the right margin. The effect of right protruding factor to character positioning at the right margin is shown in Sample 5.2.



Sample 5.2: Effect of various settings of right character protruding factor, applied to the right single quote and the right double quote. The vertical rule indicates the *right* edge of the text.

At the first stage of experimenting with character protruding, I implemented character protruding factors at character level, i.e. characters of all fonts have the same set of protruding factor settings. However, I soon found out that this approach is not flexible enough, as certain fonts require quite different settings. For this reason, I extended the concept of character protruding to be font-dependent, i.e. each font having a particular set of character protruding factors.

The definition of protruding unit is purely conventional. It could be defined to be relative to another unit different from character width, for example a fixed unit of the pointsize of the font. I believe that the current definition of protruding unit allows easy tuning of character protruding factors. This assumption does not need to be necessarily true. However I do not consider the re-definition of protruding unit to be an implementation problem if my assumption turns out to be wrong in the future.

5.2 Integration to text composition

Now, when we already have a mechanism to maintain the data needed for margin kerning, we can move to incorporation of character protruding into text composition. Character protruding can be applied to text composition at two levels.

LEVEL 1 CHARACTER PROTRUDING

The straightforward consideration is to implement it into the justification part, i.e. when a paragraph has been already broken into lines and the lines are being justified into the desired width. In this phase, before line justification is done, we check whether the beginning object of each line is a character with nonzero left protruding factor. If so, a kern of corresponding width (which can be either positive or negative) is put before the character. To be exact, a kern of width $-K_l$ as explained above is inserted. By doing so, after justification the character will be shifted to the left by the desired amount. If the beginning object of a line is not a character or a character with zero protruding factor, then K_l is treated as zero. The right protruding factor is applied to the rightmost character in a similar manner. K_r is set to zero if the rightmost object is not a character or a character with zero right protruding factor. Otherwise, a kern of $-K_r$ will be appended after the rightmost character. We call the above procedure *level 1 character protruding*.

Level 1 character protruding has no effect on line breaking, because it is applied *after* the breakpoints have been found. Therefore, the result of line breaking remains the same as in the case without use of character protruding. This property can be desirable in cases when it is necessary to keep the line breaks (and thus the page breaks) in a document unchanged for backward compatibility.

EFFECT ON INTERWORD SPACING

Level 1 character protruding can influence interword spacing. In most cases, interword spacing is a little bit looser than expected, because some lines have to be justified to a wider width than the desired width. This is caused by the fact that when choosing between sequences of breakpoints, the line-breaking algorithm did not take into consideration the amount needed to protrude the characters at the margins. After shifting the characters at the margins, the interword spaces can be stretched more than expected. On the other hand, character protruding does not always impair interword spacing. For a line longer than the desired width (shrinking needed for justification), character protruding has a desirable effect on interword spacing because the line can be shrunk by a smaller amount. The effect of character protruding can be treated as adding an amount of $K_l + K_r$ to the desired width before adjustment ratio is calculated for glue setting. Depending on the sign of the excess width, this addition can either increase or decrease the absolute value of the adjustment ratio. The adjustment ratio as stated in Eq. (1) now becomes:

$$r = \begin{cases} (l + K_l + K_r - L)/Y, & \text{if } (l + K_l + K_r - L > 0) \wedge (Y > 0); \\ (l + K_l + K_r - L)/Z, & \text{if } (l + K_l + K_r - L < 0) \wedge (Z > 0); \\ \Lambda, & \text{undefined otherwise.} \end{cases} \tag{4}$$

In plain words, the adjustment ratio formula with character protruding is obtained by substituting l with $l + K_l + K_r$, i.e. the original desired width is replaced by a new value according to the amount needed to protrude the character at the line endings. Adding the protruding amount $K_l + K_r$ to the desired width l can even change the sign of the final excess width and thus the adjustment ratio. Thus, stretching can become shrinking and vice versa.

In general, level 1 character protruding has some side effects (either desirable or undesirable) on interword spacing of individual lines. Usually these side effects are quite small and the difference between interword spacing with and without character protruding is not very significant. However, it is much better if these side effects are also considered while choosing the breakpoints.

LEVEL 2 CHARACTER PROTRUDING

To incorporate character protruding into line breaking, the line-breaking algorithm should be able to take into account the space amount needed to protrude the characters at the margins of potential lines. This way, after the justification phase, the interword spacing will be set as the algorithm expected, i.e. in an optimal manner for the whole paragraph. We denote the use of character protruding in this case as *level 2 character protruding*.

Let us recall that the basic concept of TeX line breaking is to examine all feasible sequences of breakpoints and choose the one with fewest total demerits, where the total demerits depend on badness and penalty over all potential lines. With character protruding being applied, the badness calculation for a potential line must be adjusted according to the protruding amount of the line that would be applied in the justification phase.

The badness, as given in Eq. (2), depends on the adjustment ratio, which is again calculated according to the excess width. We already mentioned in *level 1 character protruding* that shifting the margin characters causes an effect similar to increasing the desired width by the protruding amount, and the influence on the adjustment ratio is given in Eq. (4). Thus, what we need now is to increase the desired width of individual lines by the protruding amount $K_l + K_r$ associated with each line. By doing so, the badness calculation of a line will change accordingly. In the justification phase, the same amount will be added to the desired width again before the adjustment ratio will be calculated, so the interword spaces will be stretched or shrunk by the amount that the line-breaking algorithm calculated.

In level 2 character protruding, the badness calculation changes for individual lines, thus the demerits calculation can vary as well. The sequence of breakpoints with fewest total demerits in level 2 character protruding can differ from the case without applying character protruding. It can even produce a different number of eventual lines. The value of final total demerits can either increase or decrease. However, the variance of total demerits should not be very large in terms of percentage, because the variance of badness for potential lines is often small. Level 2 character protruding has a similar effect to line breaking like the case when the average desired width over all lines is increased a bit.

5.3 Choosing appropriate settings

To find good settings for the protruding factors is not a trivial task. It is mainly because it depends much on character shapes of a particular font, and the judgment of the optical evenness of the margin is more or less a matter of human vision.

I ran my system with the extensions described above and used the "trial and error" method to find the appropriate values of the protruding factors for individual characters. Various text samples were examined step by step. In each run I checked for lines that cause the margins look ragged and provided adjustment for the ending characters in such "problematic" lines. This way I eliminated "raggedness" of the margins step by step, until the results seemed satisfactory to me.

According to my experiments, the settings of protruding factors as given in Table 5.1 are reasonable to eliminate most "raggedness" of justified text with common fonts and sizes for body text. Further adjustments can be desirable for additional characters or for a particular font with atypical character shapes.

Character	P_{left}	*Character*	P_{right}	*Character*	P_{right}
‘	700	.	700	L	50
“	500	-	700	T	50
(	50	,	700	V	50
A	50	’	700	W	50
J	50	”	500	X	50
T	50	;	500	Y	50
V	50	:	500	k	50
W	50	–	300	r	50
X	50	—	200	t	50
Y	50	!	200	v	50
v	50	?	200	w	50
w	50	)	50	x	50
x	50	A	50	y	50
y	50	F	50		
		K	50		

Table 5.1: Common settings of character protruding factors

During experimenting with protruding factors I found the following rules useful for margin kerning:

1. As expected, the most prominent adjustments are required for the hyphen character, punctuation marks and quotes. However, to achieve the optical evenness, such characters should not be "protruded" out of to the margins by their entire width, as it is usually done in hanging punctuation. Punctuation marks hung by their whole width results in an effect opposite to the absence of margin kerning, i.e. lines with punctuation marks at the end appear longer than others.

2. Not only the hyphen character and punctuation marks should be protruded, but slight protruding of certain other characters is also desirable. Such characters often have a lot of white area in left-hand or right-hand sidebearing of their shapes, like A, V, J, T, L, r, v, etc.

3. Theoretically, the amount needed to protrude a character depends mostly on the character shape and size, thus it should be set according to an individual font as well as a particular pointsize. On the other hand, the differences in "optimal" settings for various fonts and size are often small, thus the values listed in Table 5.1 give quite good results for most common cases of body text.

4. Italic and boldface fonts will require considerably different settings of the protruding factors. In some cases it is even necessary to set the protruding factor of certain characters from an italic font to a negative value. Moreover, a default set of settings would rarely give satisfactory results for italic of boldface fonts. In most cases manual adjustments are required for getting it look right, which means that it should be set on a per font basis and not for all fonts.

5.4 Output samples

The samples on pages 45–51 show the visual effect of character protruding on paragraph layout. The text used in the samples comes from *"The tale of a youth who set out to learn what fear was"* by the brothers Grimm. The settings of the protruding factors used in these samples are listed in Table 5.1.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here?

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Sample 5.3: Justified text without margin kerning. Both left and right columns were typeset without character protruding. Margin edges were put to the right column to show that the margins are mechanically justified although they optically appear quite ragged. Text was typeset using font Palatino Roman.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here?

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Sample 5.4: Justified text with margin kerning. Both left and right columns were typeset with level 1 character protruding. Margin edges were put to the right column to show that positions of certain characters are slightly adjusted. The margins are mechanically subtly ragged but they appear more smooth to the human eye. Text was typeset using font Palatino Roman. Level 1 character protruding does not affect line breaking, thus line breaks in this sample are identical to the line breaks in Sample 5.3.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here?

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Sample 5.5: Comparison between level 1 and level 2 character protruding. The left column was typeset with level 1 character protruding, the right column with level 2. Text was typeset using font Palatino Roman. Line breaks in the two columns are slightly different. Interword spacing in the right column is noticeably better than in the left column.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He

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Sample 5.6: Character protruding with font Computer Modern Roman. The left column was typeset without character protruding, the right column with level 1 character protruding.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He can’t mean that in earnest,” so gave forth no sound, and stood as though

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Sample 5.7: Character protruding with font Times Roman. The left column was typeset without character protruding, the right column with level 1 character protruding.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He can’t mean that in earnest,” so gave forth no sound, and stood as though he were made of stone. Then the youth shouted out to him the third time, and as that too had no effect, he made a dash

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Sample 5.8: Margin kerning can be also used for optical compensation of the left margin of ragged-right text. The left column was typeset without character protruding, the right column with level 1 character protruding. Text was typeset with font Minion Roman.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He can’t mean that in earnest,” so gave forth no sound, and stood as though he were made of stone. Then the youth shouted out to him the third time, and as that too had no effect, he made a dash

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Sample 5.9: Margin kerning with ragged-left text. The left column was typeset without character protruding, the right column with level 1 character protruding. Text was typeset with font Minion Roman.

6 Composing with font expansion

The basic principle of composing with font expansion is to use the variance in character width when a font is expanded, to attain better interword spacing. For example, characters in a short line can be slightly expanded so when justifying the line, the interword spaces do not have to be stretched too much. On the contrary, when a line is longer than the desired width, characters in the line can be slightly condensed to achieve a better fit.

6.1 A brief description of TEX's font concept

FONT METRIC AND SHAPE INFORMATION

Before we go into further details about the concept of font expansion[7] in pdfTEX, we will briefly describe the font mechanism of TEX. In TEX, a font consists of two components: the metric information and the shape information. The metric information describes dimensions of individual characters in the font, kerning data, ligatures, etc. The shape information of a font contains data needed to render individual characters, i.e. to display or print them on a particular device. In other words, the metric information is needed to compose characters from a font, whereas the shape information is used to draw them. TEX only works with the metric information and does not need to know anything about the shape information of a font. The output of TEX, a DVI (DeVice Independent format) file, contains only information about positions of individual objects in the final page description, like a character from a particular font or a rule, etc. The way how these objects will be displayed or printed, however, is the task of another program, often called a DVI driver. Therefore, to compose characters from a font, TEX does not need any further information apart from the font metrics.

TEX FONT METRICS

The format containing the font metrics is called TFM (TEX Font Metrics). The separation of metric information from shape description provides an effective and flexible way to deal with fonts. From TEX's view, a font is simply a TFM file that covers all information TEX needs during its run. The shape information associated with a TFM file can be arbitrary and does not have any influence on TEX output. Thus, it is possible to typeset using various types of fonts by TEX without difficulty. In order to use a font with TEX, a TFM file has to be created so that TEX can get knowledge about the font metrics. When the TEX output file is finished and being viewed or printed, a DVI driver will access the shape information of the font to render individual characters. In short, all relevant information for a font is available to TEX from TFM, and a font in TEX is equivalent to a single TFM file.[8] We will use the term font to denote either a TFM file or the metric information read from a TFM file into TEX memory.

[7] From now on, we will use font expansion for both expansion and condensing. Condensing can be treated as expanding by a negative amount. We will use the term font stretching or font shrinking when it is necessary to distinguish the effects of expansion.

[8] As pdfTEX acts as a PDF back-end, it also needs access to the shape description of the used fonts in order to produce PDF output. However, this part is driver-specific and does not influence the composing task of pdfTEX.

6.2 The concept of font expansion in pdfTEX

EXPANDABLE AND EXPANDED FONT

The basic principle of the mechanism of font expansion used in pdfTEX is to maintain a set of extra fonts associated with each font that is supposed to be used with expansion. These extra fonts are usually identical to the base font, except that they are slightly wider or narrower. We call them *expanded fonts*. A font that has a set of associated expanded fonts is called an *expandable font*. Characters from an expandable font can be replaced by their counterparts from the associated expanded fonts during composing. This way, a character from an expandable font can be "stretched" or "shrunk" by using a wider or narrower alternate from the associated expanded fonts. A character from an expandable font is called an *expandable character*.

EXPANSION AMOUNT AND UNIT

To control the degree of font expansion, we introduce *expansion amount*. Each expanded font is associated with its expansion amount, which is a number given in *expansion units*. Thus an expanded font is determined by the base font (which must be an expandable font) and the expansion amount. A positive value of expansion amount stands for font stretching, while a negative value stands for font shrinking.

FONT STRETCH LIMIT AND SHRINK LIMIT

An expandable font is not the same as an expanded font. An expanded font has a nonzero expansion amount, while an expandable font does not have any associated expansion amount. An expandable font has the *stretch limit* and the *shrink limit*, which is the maximum respectively minimum allowed value of expansion amount of the associated expanded fonts. The expansion limits are given in expansion units. Stretch limit must be a positive integer. Shrink limit is also given as a positive integer; its negation specifies the minimum allowed expansion amount.

EXPANSION STEP

In order to maintain a reasonable number of expanded fonts, we introduce another parameter, called *expansion step*. The expansion amount of an expanded font must be a multiple of the expansion step. This way, a font cannot be expanded by an arbitrary amount between the expansion limits, but only by certain discrete steps within the expansion limits.

EXPANSION SPECIFICATION

To enable font expansion, a font must be activated to be expandable by giving the *expansion specification*, which consists of the stretch limit, the shrink limit and the expansion step. The stretch and shrink limit are given separately. A font can be specified to be stretched only (by giving a non-zero stretch limit and zero shrink limit), shrunk only, or stretched and shrunk with different limits (concerning the absolute value). The higher the limits and the smaller step, the more fonts will have to be maintained. For example, an expandable font of stretch limit 20, shrink limit 10 and expansion step 5 will have the associated expanded fonts corresponding to the discrete expansion amounts $\{20, 15, 10, 5, -5, -10\}$.

NAMING EXPANDED FONTS

An expanded font has the same TFM name as the name of the expandable font, followed by a number specifying the expansion amount. For example, when a font named `cmr12` (Computer Modern Roman at design size 12pt), has to be expanded by 20 units (i.e. stretched), pdfTEX will try to load a TFM file named `cmr12+20`. Similarly, `cmr12-10` is used for -10 units of expansion (i.e. shrinking). When the required TFM file does not exist, it will be created on the fly by calling an external program. The way how an expanded font is created depends on the format of shape description of individual fonts and is done independently on pdfTEX. Font expansion can be applied to various formats of fonts and will be explained later.

At the moment when an expandable font is searched, pdfTEX will first load into memory the associated expanded fonts corresponding to the stretch and shrink limits. This is needed to calculate the maximum and minimum width of individual characters from the expandable font. Other expanded fonts will be loaded on demand of composing, in order to avoid unnecessary loading of fonts which are not used.

Let us consider the above example again, where we have an expandable font named `cmr12` of stretch limit 20, shrink limit 10 and expansion step 5. pdfTEX will first load fonts `cmr12+20` and `cmr12-10` into memory to determine the bounds of the font metrics. Then the width of a character, for example the character 'A' from font `cmr12`, can be increased at most to the width of the character 'A' from font `cmr12+20` and decreased at most to the width of the character 'A' from font `cmr12-10`. The character 'A' from font `cmr12` then can be replaced by its counterpart from any of fonts `cmr12+20`, `cmr12+15`, . . . , `cmr12-5`, `cmr12-10`, depending on the demands of line-justification.

There is no explicit relationship between expansion specification and the available variance in character widths of an expandable font. Expansion specification is used to maintain expanded fonts associated with an expandable font only. Available variance in character widths of a font, however, depends on the metric information in the corresponding TFM files. A TFM file is generated according to the shape description of a font, therefore the metric information in an expanded TFM file is determined by the method used to expand the shape description of the font.

6.3 Making expanded fonts

Now we go to the details of making expanded fonts. This is done outside pdfTEX to provide a flexible mechanism that allows experimentation with various types of fonts. Similar to TEX, pdfTEX does not need to know about the shape information during composing. When font expansion is being used, pdfTEX simply loads the expanded fonts, where names of expanded fonts are created by appending a number equal to the expansion amount to the name of the base font as described before. When such a font does not exist, it will be created on the fly by calling an external program. This program will examine the requested name so as to determine the real type and generates the requested font accordingly to its type.

CONVENTIONAL DEFINITION OF EXPANSION UNIT

By convention, I choose one expansion unit to be approximately equivalent to one thousandth of character width. For example, when I want to expand a font by 20 units, my aim is to make a font that each character is approximately 2% wider than its counterpart in the original font. I used the term *approximately*, because the variance in character width is not always equal the required expansion amount. More appropriately, a font expanded by 20 units has the *average* character width over all characters of the font wider by about 2%.

Font expansion must be done in such a way that the dissimilarity of an expanded font from the original font is imperceptible. The most important requirement is to keep the stroke widths of letterforms unchanged or to change them very slightly, because even a tiny change in stroke width has a big impact on the darkness of letterforms. So far, I have experimented with font expansion in METAFONT (Computer Modern), Multiple Master and Type 1 fonts.

6.3.1 METAFONT

Together with TEX, Knuth also wrote a companion program called METAFONT in order to create the fonts to be used with TEX, which are generally known as Computer Modern fonts [21]. METAFONT is a very powerful tool for creating fonts. The basic idea and concept of METAFONT is described in [18]:

> . . . "meta-font" is *a schematic description of how to draw a family of fonts*, not simply the drawings themselves. Such descriptions give more or less precise rules about how to produce drawings of letters, and the rules will ideally be expressed in terms of variable *parameters* so that a single description will actually specify many different drawings. The rules of a meta-font will thereby define many different individual fonts, depending on the settings of the parameters.

COMPUTER MODERN FONTS

Knuth exhibited the idea as well as capabilities of METAFONT in Computer Modern fonts. According to the METAFONT concept, a font is represented as a set of "programs" containing instructions on how the shapes of individual letters should be drawn. The Computer Modern fonts family has over 70 fonts, and all of them are generated from the same sources. Each Computer Modern font is created by running METAFONT (the program) on a file called the *parameter file*. The parameter file assigns values to about 60 independent parameters of the Computer Modern font family and then calls further subroutines to draw individual characters, according to the assigned values of parameters. Apart from many interesting and unique features, Computer Modern fonts are suitable for my experiments in the sense that they are generated from the same sources with various settings of parameters independent of each other. In particular, Computer Modern fonts can be expanded without changing stroke widths of letterforms. This is done by altering a parameter called *width unit* of Computer Modern fonts. A Computer Modern font is expanded by increasing the width unit by the requested amount.

For example, if a font named `cmr12+10` is requested to be loaded and does not exist yet, then it will be generated by increasing the width unit by 1% of the original unit width of font `cmr12`. The source of the expanded font (`cmr12+10.mf`) is created by copying the source of the base font (`cmr12.mf`), with a line appended after the place where the unit width is defined as follows (the notation '`u`' is used for unit width in Computer Modern fonts, and '#' stands for "sharp" dimension unit, i.e. device-independent).

```
u#:=20/36pt#;      % unit width
u#:=u#+10/1000u#;
```

Afterwards, the corresponding TFM is generated and loaded into pdfTEX memory. The source will also be used to display or print the final output as well. Sample 6.1 shows the effect of font expansion on Computer Modern fonts.

−20 units	Hamburgefons
−10 units	Hamburgefons
no expansion	Hamburgefons
10 units	Hamburgefons
20 units	Hamburgefons

Sample 6.1: Expansion of font cmr12 (shown at 36pt)

EFFECT ON CHARACTER WIDTHS

All characters of Computer Modern fonts are expanded alike, regardless of the character shapes. The variance in character widths caused by expansion is approximately the same as the expansion amount. E.g. a font expanded by 20 units will have every character width approximately 2% wider than its counterpart in the original font.[9] Not only character shapes are expanded, but all related metric information like character sidebearing, kerning, etc. are also changed accordingly.

Font expansion in this way can be applied easily to any fonts based on Computer Modern sources, like VNR (Vietnamese Computer Modern) or CS (Czech and Slovak Computer Modern) fonts. Sample 6.2 and Sample 6.3 were typeset with the Vietnamese and Czech fonts using font expansion in a similar manner as for font `cmr12`.

Variance in character widths of a Computer Modern font at various expansion amounts is listed in Table 6.1.

[9] This is not true with all Computer Modern fonts, as an amount of $2 \times$ *letter_fit* is added to the width of all characters of a Computer Modern font. *letter_fit* is a parameter of Computer Modern fonts that is used to control extra space added to the sidebearing of each character. Most of Computer Modern fonts have this parameter set to zero, but some fonts with small pointsize can have this parameter positive. In such cases, expansion by 20 units does *not* widen the average character with by 2% but a smaller amount.

−20 units	thời khóa biểu
−10 units	thời khóa biểu
no expansion	thời khóa biểu
10 units	thời khóa biểu
20 units	thời khóa biểu

Sample 6.2: Expansion of font vnr12 (shown at 36pt)

−20 units	měšťáčtější
−10 units	měšťáčtější
no expansion	měšťáčtější
10 units	měšťáčtější
20 units	měšťáčtější

Sample 6.3: Expansion of font csr12 (shown at 36pt)

It is worthwhile to mention that not every font created by METAFONT will have the same properties as Computer Modern regard of metaness and can be expanded without changing the stroke widths. METAFONT is only a tool that allows implementing the idea of metadesign. However, its use is quite demanding [23]:

> Meta-design is much more difficult than design; it's easier to draw something than to explain how to draw it. One of the problems is that different sets of potential specifications can't easily be envisioned all at once. Another is that a computer has to be told absolutely everything. However, once we have successfully explained how to draw something in a sufficiently general manner, the same explanation will work for related shapes,

lowercase letters			uppercase letters			digits and other		
expansion:	10	20	expansion:	10	20	expansion:	10	20
a	1.00	2.00	A	0.96	1.93	0	1.00	2.00
b	1.00	2.00	B	0.98	1.96	1	1.00	2.00
c	1.00	2.00	C	1.00	2.00	2	1.00	2.00
d	1.00	2.00	D	0.98	1.97	3	1.00	2.00
e	1.00	2.00	E	0.98	1.96	4	1.00	2.00
f	1.00	2.00	F	0.98	1.96	5	1.00	2.00
g	1.00	2.00	G	0.99	1.98	6	1.00	2.00
h	1.00	2.00	H	0.96	1.93	7	1.00	2.00
i	1.00	2.00	I	0.92	1.85	8	1.00	2.00
j	1.00	2.00	J	0.97	1.95	9	1.00	2.00
k	1.00	2.00	K	0.97	1.93	(	1.00	2.00
l	1.00	2.00	L	0.98	1.96	)	1.00	2.00
m	1.00	2.00	M	0.97	1.94	.	1.00	2.00
n	1.00	2.00	N	0.96	1.93	,	1.00	2.00
o	1.00	2.00	O	1.00	2.00	!	1.00	2.00
p	1.00	2.00	P	0.98	1.96	;	1.00	2.00
q	1.00	2.00	Q	1.00	2.00	:	1.00	2.00
r	1.00	2.00	R	0.98	1.96	-	1.00	2.00
s	1.00	2.00	S	1.00	2.00	‘	1.00	2.00
t	1.00	2.00	T	1.00	2.00	“	1.00	2.00
u	1.00	2.00	U	0.96	1.93	’	1.00	2.00
v	1.00	2.00	V	0.96	1.93	”	1.00	2.00
w	1.00	2.00	W	0.97	1.95	&	1.00	2.00
x	1.00	2.00	X	0.96	1.93	%	1.00	2.00
y	1.00	2.00	Y	0.96	1.93	$	1.00	2.00
z	1.00	2.00	Z	1.00	2.00	@	1.00	2.00

Table 6.1: Listing of variance in character widths of a Computer Modern font (`cmr12`) at expansions of 10 and 20 units.

> in different circumstances; so the time spent in formulating a precise explanation turns out to be worth it.

In practice, both traditional artists and computer scientists have had great difficulty in creating high-quality typefaces with METAFONT [32]. METAFONT requires the user to have the typographic skill to draw letterform as well as the skill to express the drawing by algebraical expressions. For this reason, there are not many good original typefaces available in METAFONT.

6.3.2 Type 1 fonts

The Type 1 font format has been developed by Adobe [2]. A Type 1 font is a special case of a PS language program. Type 1 font format was designed so that PS interpreters can render the font intelligently, effectively and device-independently, which is strongly desirable for creating fonts that can be rendered on many various devices at many different resolutions. Most of today's high quality fonts are available in Type 1 font format.

A Type 1 font contains instructions at very low level to draw the characters. Unlike Computer Modern fonts, Type 1 font format does not support any generic parameterizing to change a font. The only manipulation that can be applied to a Type 1 font is to change the *transformation matrix* of the font, called *FontMatrix*. By changing this matrix, it is possible to apply various linear tranformations to a Type 1 font, like horizontal or vertical scaling, skewing, etc. Type 1 can be expanded by applying *horizontal scaling* to the font matrix. This transformation causes every part of the letterforms to be horizontally scaled. This means that the stroke widths of letterforms are also changed. Given that fact, theoretically Type 1 fonts are not suitable for my purpose. However, at a very small amount of expansion, the letterforms distortion is so tiny so that it cannot be detected by the human eye. Therefore, it makes sense to apply the optimization using Type 1 fonts as well. Type 1 font expansion has the same characteristics as Computer Modern font expansion concerning changes of character widths, i.e. the variance in character widths is approximately the same for all characters and is nearly equal to the required expansion amount. E.g., a Type 1 font expanded by 20 units will have all characters wider by about 2% than their counterparts in the original font. Sample 6.4 shows the effect of Type 1 font expansion.

−20 units	Hamburgefons
−10 units	Hamburgefons
no expansion	Hamburgefons
10 units	Hamburgefons
20 units	Hamburgefons

Sample 6.4: Expansion of font Palatino Roman (shown at 36pt)

The listing of variance of character width causes by Type 1 font expansion is given in Table 6.2.

lowercase letters			uppercase letters			digits and other		
expansion:	10	20	expansion:	10	20	expansion:	10	20
a	1.00	2.00	A	1.03	2.06	0	1.00	2.00
b	1.08	1.99	B	0.98	1.96	1	1.00	2.00
c	0.90	2.03	C	0.99	1.97	2	1.00	2.00
d	0.98	1.96	D	1.03	1.94	3	1.00	2.00
e	1.04	2.09	E	0.98	1.96	4	1.00	2.00
f	0.90	2.10	F	1.08	1.98	5	1.00	2.00
g	1.08	1.98	G	1.05	1.97	6	1.00	2.00
h	1.03	2.06	H	0.96	2.04	7	1.00	2.00
i	1.03	2.06	I	0.89	2.08	8	1.00	2.00
j	0.85	2.14	J	0.90	2.10	9	1.00	2.00
k	1.08	1.98	K	0.96	2.07	(	0.90	2.10
l	1.03	2.06	L	0.98	1.96	)	0.90	2.10
m	1.02	2.04	M	0.95	2.01	.	1.20	2.00
n	1.03	2.06	N	0.96	2.05	,	1.20	2.00
o	0.92	2.01	O	1.02	2.04	!	1.08	2.16
p	1.00	2.00	P	0.99	1.99	;	1.20	2.00
q	1.07	1.96	Q	1.02	2.04	:	1.20	2.00
r	1.01	2.03	R	1.05	1.95	-	0.90	2.10
s	0.94	1.89	S	0.95	2.10	‘	1.08	2.16
t	0.92	2.15	T	0.98	1.96	“	1.00	2.00
u	1.00	1.99	U	1.03	2.06	’	1.08	2.16
v	1.06	1.95	V	0.97	1.94	”	1.00	2.00
w	0.96	2.04	W	1.00	2.00	&	1.03	2.06
x	0.97	1.94	X	1.05	1.95	%	0.95	2.02
y	1.08	1.98	Y	1.05	1.95	$	1.00	2.00
z	1.00	2.00	Z	1.05	1.95	@	0.94	2.01

Table 6.2: Listing of variance in character widths of Type 1 font (Palatino Roman at 12pt) at expansion of 10 and 20 units.

6.3.3 Multiple Master fonts

Multiple Master fonts [3, 4] were developed by Adobe as a supplement to Type 1 fonts. The object of Multiple Master is to "parametrize" Type 1 font format by introducing one or more *design axes*. A design axis represents a dynamic range of one typographic parameter, which is usually weight, width or optical size. A Multiple Master font can be used to generate various Type 1 fonts, called *instances*. To create an instance, valid values must be given to all design axes. For my experiments, Multiple Master fonts with *width axis* are interesting, as they can be expanded without distortion of the letterforms. A Multiple Master instance is expanded using a similar principle like a Computer Modern font. An external program examines the width of the Multiple Master instance and generates a new instance with the same values assigned to the design axes, only with the width value increased by the requested amount. If the Multiple Master instance corresponding to the base font has the width value of W, then expansion by an amount of e units is done by generating a new instance with the width value of $W(1 + \frac{e}{1000})$.

For example, the Multiple Master instance of font Minion used in this thesis has the width value of 535, weight value of 400 and optical size value of 12. Expanding a font by 20 units is done by creating a new instance with the width value $535(1 + \frac{20}{1000}) = 545.7$. Generation of Multiple Master instances is done by the utilities MMTOOLS [25] as follows:

```
mmpfb --weight=400 --optical-size=12 \
    --width=535 --output pmnr8a12.pfb MinionMM.pfb

mmpfb --weight=400 --optical-size=12 \
    --width=545.7 --output pmnr8a12+20.pfb MinionMM.pfb
```

The corresponding font metrics (AFM files) are generated in the same manner. Afterwards the AFM file is converted to TFM and loaded to pdfTEX memory.

Like Computer Modern and Type 1 fonts, Multiple Master fonts are expanded not only in letterforms, but also in character sidebearing, kerning, etc. However, characteristics of Multiple Master font expansion strongly differ from either Computer Modern or Type 1 fonts. The stroke width *is* slightly expanded, in order to keep the darkness of the font to be constant. Moreover, characters of Multiple Master fonts are *not* expanded by the same proportion. Instead, the variance in character width depends on individual character shapes. Normally, uppercase letters and non-letter characters are expanded much more than lowercase letters. In comparison with Computer Modern fonts, usually a Multiple Master instance that is expanded by the same amount as a Computer Modern font has much smaller variance in character widths (in percentage), but in some rare cases these changes can be larger as well, mostly in cases of uppercase letters. As it can be seen from Sample 6.5 and Sample 6.6, the variance in character widths gained by font expansion of Multiple Master fonts is much smaller in comparison to Computer Modern and Type 1 fonts.

−40 units Hamburgefons

−20 units Hamburgefons

no expansion Hamburgefons

20 units Hamburgefons

40 units Hamburgefons

Sample 6.5: Expansion of font Minion (shown at 36pt)

−40 units Hamburgefons

−20 units Hamburgefons

no expansion Hamburgefons

20 units Hamburgefons

40 units Hamburgefons

Sample 6.6: Expansion of font Garamond (shown at 36pt)

As the variance in character widths of a Multiple Master font depends on the shape of individual characters, two different Multiple Master fonts can have quite different variance in character widths at the same expansion amount, as can be seen in Table 6.3 and Table 6.4. Moreover, the width of some characters can stay the same when the width value is increased (see non-letter characters of font ITC Garamond in Table 6.4).[10]

Most Multiple Master and Type 1 fonts are available in Adobe Standard Encoding and therefore are suitable for use with English only. To apply font expansion to non-English

[10] I found out that character width can be even *smaller* when the width value is *increased*, as the case of the character '@' in Table 6.4. However, it is also necessary to mention that Multiple Master ITC Garamond is an atypical font. I am thankful to Edward Kohler for his patience to get the font work with MMInstance and pdfTEX.

lowercase letters			uppercase letters			digits and other		
expansion:	20	40	expansion:	20	40	expansion:	20	40
a	0.70	1.40	A	1.42	2.85	0	0.88	1.75
b	1.01	2.01	B	1.07	2.15	1	0.88	1.75
c	0.99	1.98	C	2.01	4.19	2	0.88	1.75
d	0.98	2.15	D	1.78	3.42	3	0.88	1.75
e	0.98	1.71	E	1.12	2.06	4	0.88	1.75
f	0.71	1.77	F	1.00	2.00	5	0.88	1.75
g	0.90	1.79	G	2.03	3.90	6	0.88	1.75
h	0.99	1.97	H	1.69	3.38	7	0.88	1.75
i	0.78	1.56	I	1.23	2.15	8	0.88	1.75
j	0.81	1.63	J	0.94	1.88	9	0.88	1.75
k	1.04	2.07	K	1.27	2.53	(	0.86	1.72
l	0.83	1.67	L	0.78	1.75	)	0.86	1.72
m	0.90	1.79	M	1.33	2.54	.	0.86	1.72
n	0.96	1.92	N	1.62	3.09	,	0.86	1.72
o	1.22	2.45	O	2.25	4.34	!	1.17	2.34
p	1.18	2.17	P	1.13	2.25	;	0.86	1.72
q	1.01	2.02	Q	2.25	4.34	:	0.86	1.72
r	0.56	1.40	R	1.16	2.33	-	1.17	2.64
s	0.27	0.55	S	0.87	1.96	‘	1.29	2.15
t	0.68	1.36	T	1.40	2.81	“	0.95	1.90
u	0.98	1.96	U	1.62	3.10	’	1.29	2.15
v	0.90	1.80	V	1.53	3.07	”	0.71	1.66
w	0.93	1.71	W	1.44	2.89	&	1.20	2.41
x	1.10	2.20	X	1.31	2.61	%	1.03	2.06
y	0.90	2.04	Y	1.37	2.90	$	0.88	1.75
z	1.00	2.26	Z	1.63	3.25	@	0.98	2.10

Table 6.3: Listing of variance in character widths of Multiple Master font (Minion at 12pt) at expansion of 20 and 40 units.

languages, a mechanism called *virtual fonts* [17] can be used to compose accented characters from the existing glyphs in a font. A virtual font does not contain the shape description of individual characters of a font, but instructions to typeset the characters using other fonts. pdfTEX also has direct support for virtual fonts, which makes use of

lowercase letters			uppercase letters			digits and other		
expansion:	20	40	expansion:	20	40	expansion:	20	40
a	0.68	1.58	A	2.13	4.26	0	1.09	2.19
b	1.46	2.92	B	1.64	3.27	1	1.09	2.19
c	1.50	2.76	C	1.51	2.82	2	1.09	2.19
d	1.46	3.12	D	1.61	3.38	3	1.09	2.19
e	1.67	3.34	E	1.18	2.17	4	1.09	2.19
f	1.47	2.56	F	1.30	2.61	5	1.09	2.19
g	1.31	2.61	G	1.63	3.42	6	1.09	2.19
h	0.97	1.95	H	1.60	3.37	7	1.09	2.19
i	0.80	1.60	I	0.64	1.60	8	1.09	2.19
j	0.43	0.43	J	1.41	3.18	9	1.09	2.19
k	1.47	3.16	K	1.79	3.57	(	0.28	0.57
l	0.80	1.60	L	0.90	2.03	)	0.28	0.57
m	0.93	1.86	M	1.26	2.38	.	1.29	2.59
n	0.98	2.15	N	1.50	3.01	,	1.29	2.59
o	1.47	2.93	O	1.89	3.77	!	0.00	0.43
p	1.64	3.28	P	1.17	2.14	;	1.29	2.59
q	1.67	3.14	Q	1.89	3.77	:	1.29	2.59
r	0.91	1.82	R	0.72	1.61	-	0.34	0.67
s	1.43	3.15	S	1.12	2.01	‘	0.44	0.44
t	1.13	2.26	T	1.17	2.52	“	0.00	0.00
u	0.98	1.96	U	1.51	3.02	’	0.44	0.44
v	1.67	3.33	V	2.14	4.29	”	0.00	0.00
w	1.86	3.57	W	1.70	3.40	&	1.11	2.23
x	1.31	2.62	X	1.65	3.49	%	1.06	2.28
y	1.90	3.56	Y	2.30	4.60	$	0.87	1.96
z	1.26	2.77	Z	1.83	3.86	@	−0.39	−0.91

Table 6.4: Listing of variance in character widths of Multiple Master font (ITC Garamond at 12pt) at expansion of 20 and 40 units.

font expansion possible with non-english languages. For example, a Czech text typeset with Multiple Master font Minion is shown in Sample 6.7.

I do not apply any internal skilful kerning nor interletter spacing to fonts like the *kf*-program does. I rely on the fact that kerning and interletter spacing are changed accordingly when a font is expanded. Therefore, by using the new metrics I expect the

−40 units	měšťáčtější
−20 units	měšťáčtější
no expansion	měšťáčtější
20 units	měšťáčtější
40 units	měšťáčtější

Sample 6.7: Expansion of font Minion with Czech letters (shown at 36pt)

desired effect on kerning and interletter spacing as well. This is only a sub-optimal solution and surely the *kf*-program does a better job. I consider this as the main shortcoming of my work in comparison with the *hz*-program.

6.4 Integration to the box/glue/penalty model

In TEX, the only variable for adjusting the width for line-justification is to change the interword spaces (glue items) in the line. Now, with font expansion, the amount of stretching or shrinking of the interword spaces can be reduced by adjusting the character widths in a line according to the demands of line-justification. Thus, font expansion can be used as a new variable to accomplish a better result of composition. In order to combine font expansion with the machinery of glue setting of TEX, we need to deal with the variance of character width in a systematic manner so that it can be easily integrated into the current mechanism.

CHARACTER STRETCHABILITY AND SHRINKABILITY

Similar to glue, we introduce a concept of "stretching" and "shrinking" characters. A character from an expandable font is stretched when it is substituted by its wider counterpart of an associated expanded fonts. The width of a character can be stretched at most to the width of its counterpart from the widest associated expanded font. We define *character stretchability* as the maximum amount by which a character width can be increased. Characters from non-expandable fonts have character stretchability of zero. For an expandable font, this amount is the difference between the character width from the expandable font and the corresponding widest expanded font. *Character shrinkability* is defined similarly, i.e. as the variance in character width between an expandable font and the narrowest associated expanded font.

Let us have a font f with the widest variant among the associated expanded fonts k and the narrowest variant l. A character of width w_f from font f will have character stretchability $w_k - w_f$ and character shrinkability $w_f - w_l$ where w_k and w_l is the width of the character from fonts k and l. It is not necessarily true that a character from an expandable font will have nonzero stretchability or shrinkability. According to the above description, the amount of character stretchability depends on the variance of the character width between the expandable and expanded font, which can be zero or negative in some cases. But this rarely happens.

TOTAL CHARACTER STRETCHABILITY AND SHRINKABILITY

Like the total stretchability of glue items in a line, *total character stretchability* of a line is the sum of character stretchability over all characters in the line, where characters from non-expandable fonts have stretchability of zero as described above.[11] *Total character shrinkability* is defined similarly.

When calculating the amount needed to stretch or shrink interword spaces in a line for justification, font expansion is used to adjust the natural width of the line closer to the desired width. The use of font expansion to help line justification can be described roughly as follows: If the desired width of a line is larger than the natural width, every character with nonzero stretchability will be "stretched," i.e. be replaced by a wider variant. By doing so, the difference between the desired width and the natural width can be reduced. If this difference is larger than the total character stretchability, every character will be stretched by its stretchability, i.e. it will be replaced by the widest possible variant. E.g. characters from font `cmr12` with stretch limit of 50 will be replaced by the corresponding characters from font `cmr12+50`. When the total character stretchability is larger than the space amount to be stretched, all expandable characters in the line will be stretched to the variant that would make the line width as close as possible to the desired width, thus the interword spaces will be stretched by a minimal amount.[12] The case of shrinking is handled in a similar manner.

EXPANSION RATIO

The effect of font expansion on interword spacing (i.e. glue setting) in a line can be described as the reduction of adjustment ratio of the line. In order to describe the amount of font expansion applied to a line, we introduce the *expansion ratio* of a line, which is similar to the adjustment ratio. Suppose that a line is being justified by setting glue items according to an adjustment ratio r. Without use of font expansion, the value of r is defined as $(l - L)/Y$ or $(l - L)/Z$ where l, L, Y, Z have the same meaning as in Eq. (1). Now, with font expansion being enabled, we denote the total character stretchability of the line as $S = s_1 + \cdots + s_n$ and the total character shrinkability as $T = t_1 + \cdots + t_n$, where $s_1, \ldots, s_n$ and $t_1, \ldots, t_n$ are stretchability and shrinkability of all characters in the line. The definition of the expansion ratio does not differ much from the adjustment ratio:

[11] This definition is not complete, as pdfTEX also takes the variance of *kern widths* into account when expanding a font. In the context of font expansion, we can simply treat a kern as a character with the corresponding width (which is usually negative)

[12] This is not completely true if the total width of a line does not change linearly with the change in the expansion amount, which is the case of some characters in some Multiple Master fonts. However, such cases are really rare, and we can assume that the average change in total character stretchability/shrinkability is approximately linear with the change of the expansion amount.

$$R = \begin{cases} 0, & \text{if } L = l \text{ (no need to stretch or shrink font);} \\ (l - L)/S, & \text{if } (L < l) \wedge (S > 0) \text{ (font stretching);} \\ (l - L)/T, & \text{if } (L > l) \wedge (T > 0) \text{ (font shrinking);} \\ \Lambda, & \text{undefined otherwise.} \end{cases} \tag{5}$$

The absolute value of the expansion ratio is stripped down so that $|R| \leq 1$ before font expansion is applied to the fonts in the line. The reason is that a font is not allowed to be stretched or shrunk more than its stretch and shrink limit. Applying font expansion to a line causes each expandable font f with stretch limit P and shrink limit Q to result in an *expansion amount* of the font as follows: EXPANSION AMOUNT

$$M = \begin{cases} RP, & \text{if } R > 0; \\ RQ, & \text{if } R < 0; \\ 0, & \text{otherwise.} \end{cases} \tag{6}$$

In the above formula, P, Q and M are given in expansion units. A font cannot be expanded exactly to a required expansion amount because it would result in too many expanded fonts in memory. This is the reason why we had to introduce the step of font expansion. Given an expansion ratio, an expandable font is always expanded to the variant closest to the required expansion amount. Let us denote the expansion step of a font by E. The exact formula for the final expansion amount of a font is:

$$M' = \text{sign}(M) \times E \times \lfloor |M|/E + 0.5 \rfloor \tag{7}$$

Here $\text{sign}(M)$ indicates the sign of M. In short, the final expansion amount of a font is always rounded to a multiple of the step expansion that is closest to the expansion amount required. For this reason, the stretch and shrink limit of a font is always rounded to a multiple of the expansion step.

ADJUSTMENT RATIO AFTER FONT EXPANSION

After font expansion has been applied to a line, every character of width w_f from an expandable font f will be stretched by an amount $d = w_{f_{M'}} - w_f$, where $w_{f_{M'}}$ is the width of the same character but from the font expanded to the final expansion amount. The amount gained by font expansion is the sum D of all d over every character from every expandable font in the line. Then the adjustment ratio of the line as defined in Eq. (1) would become:

$$r = \begin{cases} (l - L - D)/Y, & \text{if } (L < l) \wedge (Y > 0); \\ (l - L - D)/Z, & \text{if } (L > l) \wedge (Z > 0); \\ \Lambda, & \text{undefined otherwise.} \end{cases} \tag{8}$$

As we have $\text{sign}(D) = \text{sign}(M') = \text{sign}(M) = \text{sign}(R) = \text{sign}(l - L)$, so applying font expansion to a line results in decreasing the absolute value of the adjustment ratio $|r|$ according to the above formula. Thus the interword spaces in the line will be stretched or shrunk by a smaller amount than in the case without expansion. The value of D can be treated as the variance in natural width of a line after font expansion has been done according to the expansion ratio R. In case $|R| = 1$, D is equal to the total character stretchability or shrinkability, depending on the sign of R. In fact, D is the only thing we need in order to calculate the new adjustment ratio for a line after font expansion has been applied. The value of D is actually the possible reduction that can be applied to the excess width. Then a line with zero excess width (a perfect fit) will have $D = 0$ as well, as there is no sense in applying font expansion to a line where there is no need of glue stretching or shrinking.

PROPORTION OF FONT EXPANSION

The way how font expansion is applied to line-justification, as described above, always tries to use *as much as possible* the room provided by font expansion to reduce the adjustment ratio. This way, in most cases, expandable fonts will be expanded by the maximum expansion amount in loose lines and by the minimum expansion amount in tight lines. It is possible that a line with the maximum expansion ratio (which is 1) will have the same (or very close) adjustment ratio as a line with the minimum expansion ratio (which is -1). The reason for this behaviour originated in the assumption that font expansion should be applied within such limits that the distortion could not be visible. A font expanded at its maximum and minimum expansion amount must appear the same to the human eyes. For this consideration, I do not distinguish desirability of different expansion ratios at all. In other words, font expansion is not considered to influence the desirability of a formatted line.

It may be desirable to change the concept of font expansion so that adjustment ratio is also changed according to font expansion ratio. For example, when the font in a line is expanded by 1%, it may be better also to increase the natural size of the interword space by 1% when calculating the adjustment ratio. I did not implement this alternative yet. Even though such an objective seems rather simple, its calculation and implementation is far more complicated. The main difficulty consists in the fact that TeX turns every character space from input to a glue. This makes glue items which represent interword spaces indistinguishable from other glue items that can occur in a paragraph.

In general, when a font is expanded, it may be desirable to change items whose width and placement are font-dependent. Among them, the specification of the interword space is the most important factor, but it can also be other font-dependent dimensions like italic correction, or various font dimensions in math typesetting. Such issues are surely worth to consider and it is worthwhile to examine their effect in practice. However, due to a time limitation I could not implement all ideas that might lead to better results.

6.5 Integration to text composition

Similarly to character protruding, we implemented font expansion to adjust interword spacing at two levels.

6.5.1 Level 1 font expansion

Level 1 font expansion is applied only in the justification phase, when line breaking has been done already. When a line is being justified to the desired width, we check for the total character stretchability and shrinkability of the line to see whether font expansion can be applied to the line to reduce glue setting of the line. If so, we calculate the expansion ratio according to Eq. (5) and expand each expandable font by the expansion amount given in Eq. (6). Afterwards, the line is justified to the desired width in the normal manner, i.e. the natural line width is calculated and the interword spaces are stretched or shrunk to compensate the excess width. The final glue setting corresponds to the new adjustment ratio given in Eq. (8).

FONT EXPANSION AND GLUE SETTING

Font expansion is applied to all fonts in a line according to an expansion ratio. This is similar to glue setting, where stretching or shrinking is applied for all glue items in a line according to an adjustment ratio. Thus, each expandable font will be expanded by an amount proportional to its expansion limit. Fonts with the same expansion limit will be expanded by the same amount.[13]

An important point here is that the natural line width must be calculated *after* font expansion has been applied. As we mentioned above, applying font expansion according to a certain expansion ratio does not give exactly the required amount, because the final expansion amount of a font is always rounded to a variant corresponding to a multiple of the expansion step. That way, the final expansion amount of a font is always slightly different from the required amount. In order to keep the glue setting correct for individual lines, we must re-calculate the new adjustment ratio as stated in Eq. (8). It means that we first substitute the expandable fonts in a line according to the required expansion ratio, then re-calculate the natural width where the characters from expandable fonts obtain the new width from the corresponding substituted fonts. The new natural width is in fact equal to $l - L - D$ in Eq. (8). Afterwards, the glue items in the lines will be set (stretched or shrunk) to the new adjustment ratio.

The smaller a font expansion step is used, the closer is the final expansion amount to the required amount. Thus, the accuracy of font expansion depends on the expansion step used. On the other hand, it is not desirable to use too small an expansion step, because it would increase the number of expanded fonts that have to be kept in memory and slow down the speed of the program. I think that a value of 5 units (i.e. 0.5% expansion) is reasonable. The minimal allowed value is 1, corresponding to 0.1% expansion.

EFFECT ON COMPOSITION

Level 1 font expansion only helps to reduce the amount of interword spacing in individual lines. It does not have any effect on the choice of breakpoints. Level 1 font expansion can be helpful in cases when changing line breaking is not desired for backward compatibility. It can be combined with level 1 character protruding to compensate the negative effect on interword spacing caused by character protruding. The effect of

[13] Usually only the main font (i.e. the body font) should be activated as expandable, but it is also possible to use simultaneous expandable fonts.

level 1 font expansion is often more useful for paragraphs where interword spacing is already "relatively good," i.e. all interword spaces are rather close to the ideal size.

It is possible that the sign of adjustment ratio of a line can change after font expansion. It means that glue stretching can become shrinking and vice-versa. This can happen when the total character stretchability or shrinkability of a line is larger than the amount by which the line has to be stretched or shrunk. Because a font is expanded to a multiple of the expansion step, it is impossible to expand a line exactly by an arbitrary amount. Thus, sometimes font expansion can be "overdone" a little, in order to minimize the absolute value of the adjustment ratio. The final adjustment ratio in such cases is usually very small. The smaller expansion step is used, the closer the final adjustment ratio is to zero.

Font shrinking has a bigger impact on reduction of the adjustment ratio, in comparison to font stretching. The variance in character width caused by font stretching and font shrinking are roughly the same, but the total glue stretchability and shrinkability of a line are often different. Usually the total glue shrinkability is much smaller than the total glue stretchability. Shrinking the interword spaces is less desirable than stretching, because it can heavily impair readability. As stated in Eq. (8), the new adjustment ratio is calculated as $(l - L - D)/Y$ or $(l - L - D)/Z$ according to the demands of justification. Often Z is smaller than Y, therefore the same amount of D has more influence than adjustment ratio in case of shrinking (Z is used) than case of stretching (Y is used).

The visual effect of improvement on interword spacing gained by level 1 is not significant, compared to composing without font expansion. This is caused by the fact that the variance in line width gained by font expansion is rather small in comparison with the amount the interword spaces have to be stretched, especially in case of narrow columns.

In general, level 1 font expansion is useful as a way to examine the effect of font expansion on readability and glue setting. The main intention of font expansion, however, is to bring the variance in character width to the line breaking algorithm so as to provide more elasticity for choosing breakpoints. So in next step we integrate the mechanism of font expansion into the line-breaking algorithm.

6.5.2 Level 2 font expansion

The basic principle of *level 2 font expansion* is based on the modification of the badness calculation of individual potential lines while examining the sequences of breakpoints. Let us state again that according to Eq. (2), the value of the badness depends only on the adjustment ratio, which is calculated using Eq. (1). When font expansion is being used, we know that the adjustment ratio of a line can be reduced to a smaller amount according to Eq. (8). Thus, using the new formula for the adjustment ratio would give the desired effect on line breaking, i.e. to take the character stretchability and shrinkability into consideration when choosing breakpoints.

BADNESS CALCULATION

The badness is calculated *solely* according to the new adjustment ratio after font expansion. The font expansion ratio is not considered in the badness calculation of a line. Therefore, two lines with different expansion ratio can have the same badness. This behaviour favours the use of font expansion as much as possible, to reduce the adjustment ratio. In my implementation, it means that I do not change the formula of badness calculation of a line. I simply apply font expansion to reduce the excess width before badness calculation is done. This way, the line-breaking algorithm does not try to reduce the amount of font expansion, but uses it completely freely. I rely on the assumption that the font expansion limits must be given strictly enough, so that the effect of font expansion would not need be penalized at all. The effect of glue setting is *expected by the reader* and thus, it *can be visible*. The objective of line breaking is to reduce the average adjustment ratio over all lines. For this reason, it is logical to consider desirability of a line according to its adjustment ratio. By the contrast, font expansion is *not expected by the reader* and thus, it *must not be visible*. In this case, it is logical to consider desirability of a line regardless to the font expansion amount. This is, however, only my hypothesis and there are certainly other heuristics to integrate font expansion to line breaking. Further experimentation is needed to examine which concept would give the best results.

Due to the concept of not penalizing the font expansion amount, it is rather straightforward to make the line-breaking algorithm "font-expansion aware." We need to keep track of the total character stretchability and shrinkability of individual lines, in order to reduce the adjustment ratio of each potential line during choosing breakpoints. The construction of the new adjustment ratio, however, is not very suitable to integrate into the badness calculation. Its exact calculation requires the following steps to be done:

1. calculate the expansion ratio by Eq. (5);
2. obtain the final expansion amount by Eq. (7) for each expandable font;
3. substitute each expandable font by the corresponding variant;
4. calculate the variance in character widths in order to obtain D in Eq. (8);
5. restore the fonts that have been substituted, so that examination of the following sequences of breakpoints would be done correctly.

The objective of this complicated process is only to calculate the excess width after font expansion. Checking the badness of each potential line in a sequence of breakpoints, however, is an inner operation of line-breaking algorithm. Thus, we cannot afford much calculation here because it would slow down the line-breaking process. To avoid this problem, we use an approximate calculation of the excess width instead of the exact computation as described above.

APPROXIMATION OF BADNESS CALCULATION

Let us consider a line where all characters are from only one expandable font f with stretch limit P, shrink limit Q and expansion step E. The stretch and shrink limit of a font are always rounded to a multiple of the expansion step; thus, we have $P = mE$

and $Q = nE$ for certain integers m and n. The total character stretchability S and shrinkability T as described in Eq. (5) are the bounds of D, i.e. $-T \leq D \leq S$. In case of stretching, the font can be expanded by m discrete steps. Because of the fact that the variance of character width is usually proportional to the expansion amount, we can assume that each step of font stretching would increase the total width over all characters in the line by the approximate amount S/m. Similarly, each step of font shrinking causes the approximate variance of T/n in total character width. The approximate value of the excess width after font expansion can then be calculated as follows:

$$l - L - D' = \begin{cases} l - L - S, & \text{if } (S \leq l - L) \wedge (S > 0); \\ S/2m, & \text{if } (0 < l - L \leq S) \wedge (S > 0); \\ l - L + T, & \text{if } (l - L \leq -T) \wedge (T > 0); \\ -T/2n, & \text{if } (-T \leq l - L < 0) \wedge (T > 0); \\ l - L, & \text{otherwise.} \end{cases} \tag{9}$$

In plain words, if a line has to be stretched and the excess width is larger than the total character stretchability, then we subtract the whole total character stretchability from the excess width. Otherwise the font will be expanded to the step that would minimize the excess width (in absolute value). The variance in total character width between two consecutive steps of stretching is approximately S/m as stated above. Because the step that is closer to the required expansion amount will be chosen, the excess width in this case is smaller or equal to half of the difference between two consecutive steps, which is $S/2m$. The case of shrinking is handled similarly.

Generalizing this concept to simultaneous expandable fonts is not very complicated. If all expandable fonts have the same expansion specification (stretch limit, shrink limit and expansion step), then the number of the discrete steps of available expansion amounts for each font is also the same. So is the difference between two consecutive steps. In fact, the values of S, T, m and n in Eq. (9) depend only on the expansion specification regardless of the stretchability and shrinkability of individual characters. For this reason, the current implementation requires the expansion specification of simultaneous expandable fonts in a paragraph to be identical, i.e. all expandable fonts must have the same expansion limits and step.

We recall that there is no explicit relationship between font expansion specification and font metrics. Thus, simultaneous fonts with the same expansion specification do not need to have any dependence in variance of character widths. The only assumption is that the variance in character width of each font must be proportional to the expansion amount. This is needed because the difference between arbitrary two consecutive discrete steps of expansion amounts must be approximately the same (which is the amount corresponding to the expansion step).

To clarify this issue, let us consider a font with stretch limit P, shrink limit 0 and expansion step E. The discrete steps of expansion amounts are $\{E, 2E, \ldots, sE\}$, where $s = P/E$ (thus $sE = P$). Each two consecutive steps of expansion amounts differ from each other by the an amount equal to the expansion step E. The above assumption says that when a font is expanded by nE units where $0 \leq n \leq s$, the character widths are increased approximately by ne, where e is the variance in character widths corresponding to E units (the expansion step). This assumption holds for all three types of font we experimented with (Computer Modern, Type 1 and Multiple Master fonts[14]).

Level 2 font expansion decreases badness of individual lines, thus the final total demerits are smaller. The reduction of total demerits depends mainly on the chosen expansion limits. The sequence of breakpoints with fewest total demerits can be different from the case without font expansion. Even the number of eventual lines can differ from the case without font expansion. Usually a paragraph formatted with font expansion results in an equal or smaller number of lines. However, if there is not much variance in character widths available (because of low expansion limits and/or narrow column width), then the algorithm often produces the same breakpoints for a paragraph layout as the TeX line breaking does.

6.6 Choosing appropriate settings

In general, the limits of font expansion strongly depend on the characteristics of individual typefaces. Choosing a reasonable value for a typeface requires a lot of experimenting with the expansion limit as well as further parameters that influence interword spacing in a paragraph. To draw a general rule that would apply to every case is impossible. The higher a limit of expansion is used, the better the interword spacing but also the more distortion of the text. It is not trivial to find the boundary settings for which the effect of font expansion becomes visible.

The judgment of font distortion is a matter of human vision and it can differ from person to person. The normal reader can recognize the effect of font expansion only at very high limits. Choosing an appropriate compromise seems to depend on the personal choice of the user. However, I think that it is always better to limit the settings to such values so that it cannot be detected by most readers.

The estimation I suggested here comes as the result of many experiments, mostly done with TeX users at various meetings. According to the experiments, the reasonable limit of font expansion (font stretch as well as font shrink) is about 20 for Computer Modern and Type 1 fonts. For Multiple Master fonts, this limit is about 30–40, depending on the characteristics of individual fonts. It seems that Type 1 and Computer Modern fonts can be expanded by nearly the same amount, although Computer Modern fonts can be expanded without changing the stroke widths of letterforms. Multiple Master fonts can be expanded to higher limits, but the variance in character widths gained by font expansion is nearly the same as in the case of Computer Modern and Type 1 fonts. In general, the variance in character widths must be limited to about $\pm 2\%$. If the font stretch limit is lower, the font shrink limit can be increased. However, the font shrink

[14] Apart from the cases of some pathological characters in Multiple Master fonts, which rarely occur in a normal text and thus do not influence the average change of the line width very much.

limit should not be increased by the same amount by which the font stretch limit is decreased. For example, if the font stretch is zero, the font shrink limit can be increased only to about 30 for Computer Modern and Type 1 fonts, and about 50–60 for Multiple Master fonts. Similarly, when the font shrink limit is lower, the font stretch limit can be increased.

6.7 Selected expansion

In the next step we introduced another concept to allow finer control on font expansion, called *selected expansion*. The basic idea is that some characters are more sensitive when expanded than others, i.e. when a font is expanded by a certain amount, the font distortion is not the same with every character. Some characters are sensitive to font expansion and the deformation of such characters can be seen at quite a low expansion limit. Other characters are less sensitive and the deformation is seen only at a higher expansion limit. Thus, it is worthwhile to limit the effect of font expansion on characters that are not suitable for font expansion, so that they would be expanded by a smaller amount than others.

CHARACTER EXPANSION FACTOR

For this purpose we introduced a new parameter called the *character expansion factor* associated with each character. This parameter specifies how much of the stretchability and shrinkability of a character can be used. One unit of character expansion factor is defined to be equivalent to the fraction $\frac{1}{1000}$. Thus, the stretchability and shrinkability of a character of expansion factor f will be scaled down by a fraction $\frac{f}{1000}$. E.g. a character with expansion factor 300 will be expanded to 30% compared to other characters with expansion factor 1000. It means that if in a line all characters with expansion factor 1000 are expanded by 20 expansion units, then the character with expansion factor 300 will be expanded by $20\frac{300}{1000} = 6$ expansion units. The final expansion amount of a character is then rounded to the nearest allowed value, which must be a multiple of the expansion step (which is 5 in the above case, given that the expansion step is 5). The valid range of expansion factor is from 0 (no expansion) to 1000 (full expansion).

I found the settings of expansion factors by a similar method to the one which I used to tune the settings for character protruding. I examined in sequence various samples at the expansion limits that become observable. In each step I adjusted the expansion factor for characters that seemed to be more noticeable than others.

I found the following cases to be more sensitive to font expansion (even without changing the stroke widths of letterforms).

1. Characters with long and strong strokes in a non-vertical direction (horizontal or diagonal). When the character width is changed, those strokes often make the character shape darker. Typical examples for such characters are A, K, R etc.

2. Characters with white areas in letterforms bounded by strokes in the non-horizontal direction (vertical or diagonal). Those areas also have a strong in-

fluence on darkness of letterform and therefore make the character sensitive to expansion. There are many of such characters, like o, u, e, p, q etc.

3. Letters are more sensitive to expansion than digits and non-letter characters.

Based on these factors, I adjusted the character expansion factors as listed in Table 6.5.

Char	*Expansion factor*	*Char*	*Expansion factor*	*Char*	*Expansion factor*
A	500	a	700	2	700
B	700	b	700	3	700
C	700	c	700	6	700
D	500	d	700	8	700
E	700	e	700	9	700
F	700	g	700		
G	500	h	700		
H	700	k	700		
K	700	m	700		
M	700	n	700		
N	700	o	700		
O	500	p	700		
P	700	q	700		
Q	500	s	700		
R	700	u	700		
S	700	w	700		
U	700	z	700		
W	700				
Z	700				

Table 6.5: Common settings of character expansion factors. If the expansion factor of a character is not listed here, it is implicitly set to 1000.

Using selected expansion, it is possible to increase the limits of font expansion (both font stretch and font shrink) while the deformation in letterforms is not noticeable yet. This limit is about to 30 for Computer Modern and Type 1 fonts, and to 60 for Multiple Master fonts. This technique, however, did not turn out to be as much useful as I expected. As the character stretchability and shrinkability is scaled down, the variance in character width is also decreased, thus it does not provide much more room for line breaking. The total demerits go up when selected expansion is being used, even at a little higher expansion limit as stated above. Moreover, when the expansion limit is increased, the darkness of individual lines starts to differ from line to line. Although the difference between individual character shapes is not visible, one can still recognize that certain lines are much darker or lighter than others.

This is related the fact that given a line with the desired width, our objective is to change interword spaces as little as possible. This happens when all interword spaces are set equal or very close to their natural size. In order to achieve this, the extra amount of space (the difference between natural line width and the desired width) must be divided into some other kind of space consuming entity, which can be:

1. the stroke widths;
2. the white area bounded by the strokes in character shape;
3. the sidebearings.

Suppose that we want to make a font wider. According to the font type, we have the following possibilities:

1. Computer Modern font expansion does not change the stroke width but only the two later entities. This causes the expanded font look lighter because of the wider space between strokes.
2. Type 1 font expansion widens all three entities. The strokes are also thicker, which partly compensates the effect caused by the two other entities. Unfortunately, the change of stroke width is also undesirable, because it strongly distorts the character shapes.
3. Multiple Master font expansion can be considered as a compromise between the above cases. Stroke width is expanded slightly to keep the darkness unchanged. However, experiments have shown that at certain limits, lines start to look different, caused by both wider space between strokes and thicker stroke width.

Thus in any case, the variance in character width gained by font expansion seems to be very limited. It appears that letterforms cannot be expanded beyond a certain limit, regardless of the method of expansion. According to the experimental results, a variance of about $\pm 2\%$ in character widths is the limit in most of cases.

6.8 Interletter spacing

Taking the previous consideration in the next step, I tried not to expand the fonts only, but also to change the space between adjacent characters. This technique, known as *interletter spacing* or *tracking*, is widely used even though it is not encouraged by many typographers. However, for my purpose, I think that distributing the extra amount of space between individual characters (i.e. changing character spacing) is acceptable when applied in very small quantities and as a part of a sophisticated line-breaking algorithm like the one present in TEX.

FONT EXPANSION SCALE FACTOR

To implement this idea, we maintain a parameter associated with each expandable font, called the *font expansion scale factor*. This parameter is applied after paragraph composing and does not affect the result of line breaking. It only has effect on how the characters will be rendered in the final output. The parameter says how much of the expansion amount of the *shape information* of an expanded font must be scaled down. Similar to character expansion factor, the font expansion scale factor is given in units equivalent to thousandths. Thus the valid range is from 0 to 1000. If we have an expandable font with the expansion scale factor s, then the expansion amount of the corresponding shape information will be scaled down by a fraction $\frac{s}{1000}$. When $s < 1000$, the shape information used to render the characters is expanded *less* than the corresponding font metrics. Thus, a little space will be added at the right bearing side of those characters. The size of this space depends on the value of the font expansion scale factor and can be either positive or negative.

Let us denote the width of a character c from a font expanded by n units as w_n. The expansion amount of the corresponding shape information is $m = n\frac{s}{1000}$, according to the above description. The width of c from the font expanded by m units is denoted as w_m. Then after c there will be a space of width $w_n - w_m$. A value 1000 of s means "normal" or "full" expansion as described previously. A value 0 of s means that expanded glyphs are scaled down to non-expanded ones. A value of 500 means that if a character has been treated as expanded by e.g. 20 units while breaking lines, in the final output it will be expanded by only 10 units.

During line breaking, the font expansion scale factor is not used, because the line-breaking algorithm only works with font metrics. Thus setting the scale factor only has effect on how individual characters will be drawn at the final output. Two paragraphs with the same settings except for the scale factor will be formatted identically at the same total demerits.

FONT EXPANSION OR INTERLETTER SPACING?

The effect of interletter spacing is nearly identical to the effect of font expansion. At *very close* inspection by extremely sensitive eyes, it seems that interletter spacing distorts the typeset text *slightly more* than font expansion. On the other hand, interletter spacing may be desirable in some cases, because it allows reducing the number of font resources (the shape information) that are needed to display or print the output.

6.9 Output samples

This section shows the samples of typesetting with level 2 font expansion only. The difference between composing without font expansion and with level 1 font expansion is imperceptible in most cases. When font expansion is used strictly so that the distortion is not noticeable, the variance in line width is also rather small, thus the possible compensation of interword spacing is very slight. Thus, it is not necessary to show output samples of level 1 font expansion.

Level 2 font expansion gives much better results, because it takes the potential variance in line width over *all lines* to produce a better paragraph layout. Comparison between level 1 and level 2 font expansion is similar to line breaking based on a line-by-line and multi-line manner; the first approach works "locally" by considering only a single line at a time, whereas the second one works "globally" by treating the paragraph as a whole.

The samples on pages 79–90 show the effect of level 2 font expansion, applied to all three types of fonts (METAFONT, Type 1 and Multiple Master) at various settings. In the samples, font Computer Modern Roman (cmr12) was chosen as the representative of METAFONT, font Palatino Roman of Type 1 fonts and Minion Roman of Multiple Master fonts. The following description is common for all samples:

- The pointsize used in all samples is 12pt.
- Each sample has the left column typeset without font expansion and the right column with level 2 font expansion.
- Stretch limit and shrink limit have the same value and are referred together as expansion limit. For example, an expansion limit 20 means that both stretch limit and shrink limit are set to 20.
- In samples where selected expansion is applied (mentioned explicitly in the caption), the character expansion factors were set according to the values in Table 6.5.
- If not mentioned explicitly, the font expansion scale factor is set to 1000.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He

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Sample 6.8: Font Computer Modern Roman at expansion limit 20.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He

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Sample 6.9: Font Computer Modern Roman at expansion limit 30, with selected expansion applied.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He

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Sample 6.10: Font Computer Modern Roman at expansion limit 20, with font expansion scale factor set to 500.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He

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Sample 6.11: Font Computer Modern Roman at expansion limit 20, with font expansion scale factor set to zero.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here?

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Sample 6.12: Font Palatino Roman at expansion limit 20.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here?

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Sample 6.13: Font Palatino Roman at expansion limit 30, with selected expansion applied.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here?

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Sample 6.14: Font Palatino Roman at expansion limit 20, with font expansion scale factor set to 500.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here?

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Sample 6.15: Font Palatino Roman at expansion limit 20, with font expansion scale factor set to zero.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He can’t mean that in earnest,” so gave forth no sound, and stood as though he were made of stone. Then the youth shouted out to him the third time, and as that too had no effect, he made a

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Sample 6.16: Font Minion Roman at expansion limit 30.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He can’t mean that in earnest,” so gave forth no sound, and stood as though he were made of stone. Then the youth shouted out to him the third time, and as that too had no effect, he made a

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Sample 6.17: Font Minion Roman at expansion limit 50, with selected expansion applied.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. "Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder." "If that's all he wants," said the sexton, "I can teach him that; just you send him to me, I'll soon pol-ish him up." The father was quite pleased with the proposal, because he thought: "It will be a good discipline for the youth." And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. "Now, my friend, I'll teach you to shudder," thought he. He stole forth se-cretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. "Who's there?" he called out, but the figure gave no answer, and neither stirred nor moved. "Answer," cried the youth, "or begone; you have no business here at this hour of the night." But the sexton remained motion-less, so that the youth might think that it was a ghost. The youth called out the second time: "What do you want here? Speak if you are an honest fellow, or I'll knock you down the stairs." The sexton thought: "He can't mean that in earnest," so gave forth no sound, and stood as though he were made of stone. Then the youth shouted out to him the third time, and as that too had no effect, he made a

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Sample 6.18: Font Minion Roman at expansion limit 30, with font expansion scale factor set to 500.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. "Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder." "If that's all he wants," said the sexton, "I can teach him that; just you send him to me, I'll soon polish him up." The father was quite pleased with the proposal, because he thought: "It will be a good discipline for the youth." And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. "Now, my friend, I'll teach you to shudder," thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. "Who's there?" he called out, but the figure gave no answer, and neither stirred nor moved. "Answer," cried the youth, "or begone; you have no business here at this hour of the night." But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: "What do you want here? Speak if you are an honest fellow, or I'll knock you down the stairs." The sexton thought: "He can't mean that in earnest," so gave forth no sound, and stood as though he were made of stone. Then the youth shouted out to him the third time, and as that too had no effect, he made a

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Sample 6.19: Font Minion Roman at expansion limit 30, with font expansion scale factor set to zero.

7 Discussion

The development of the typographical extensions in pdfTEX is an experimental research rather than a well-planned project. For the absence of relevant literature and information on this area, I had to change the concepts many times before I could figure out the reasonable approach. Finding appropriate data settings also required plenty of experiments.

THE FIRST EXPERIMENTS

Based on experimental data, it seems that the average user tends to pay attention to other things than greyness of paragraph layout, mostly the number of hyphenations, kerning, rivers, etc. The distortion of typeset text caused by font expansion, however, is not noticed by most of users, even if it was used at very high expansion limits and was explained explicitly. For this reason, it is rather difficult to give a reliable expansion limit for every case, as well as to evaluate the effectiveness of the extensions. While the design and implementation of such extensions is a technical issue, the judgment of the visual improvement as well as finding the reasonable settings is a matter of human vision and requires help from experienced typographers. During the development I tried my best to invite people to involve in my experiments and get feedback on my experimental results. However, such fine details of micro-typography do not seem to be of much interest of today's typesetting and my effort on making the development more open did not get much success.

I do not consider necessary to describe in detail all the experiments that have been done. A quick survey of the very first experiments (done by Hans Hagen and Taco Hoekwater) was made by Hans Hagen (May 1999). At the meantime, only level 1 font expansion was available.

1. Every respondent got 2 × 6 random sets of two and three column texts and was asked to rate those from low to high. Each session had 60–75 respondents, and each one had a different set, so looking over the neighbours shoulder did not help. Each set of 6 had a zero (no influence) sample too.

2. At the NTG[15] meeting, we used pdfTEX method 1, which did stretch/shrink by changing the scaling.[16] No real significant differences were seen by the participants, while differences clearly were visible once one knew what to look at! People were far more sensitive for things like hyphenation and rivers. It sort of demonstrated that although TEX users praise TEX's quality, everyone has his own ideas on what this quality is. There was a small significant optimum in the 3% manipulation area, two columns only.

[15] The Netherlands TEX Users Group

[16] In the beginning, pdfTEX expanded fonts by using horizontal scaling. This approach is based on the same concept as Type 1 font expansion, i.e. changing the transformation matrix of certain objects in the page description. It can be used without having the expanded font metrics. However, it turned out to be too cumbersome and fragile, because the horizontal scaling is applied on a per line basis, thus everything on a line was expanded. In order to use this method, only text typeset by a single font is allowed. So later this approach was discarded

3. At the DANTE[17] meeting, we used method 2, using different instances of a font.[18] Again, most people were far more sensitive to things like rivers, occasional bad kerning, and many hyphenations in a row. No significant differences were seen there.

4. The GUST[19] experiment again showed that, although especially 8% stretch simply looks bad, people were far more sensitive to other things. In this experiment we used Taco's CMR multiple master fonts, but unfortunately the tfm-afm conversion programs have some bugs concerning kerning, which resulted in touching glyphs. Those were rated bad, and played a disturbing role. Even in normal cmr fonts some kerning pairs are rather bad (for Dutch) and it sort of proves that it makes sense to look at more than *hz*-ing. This time we decided to explain on beforehand what pdfTEX was doing, and again, only a few people saw the differences (while again, extreme stretching and shrinking clearly spoils the grayness!).

The next demonstrations of *hz*-like experimenting in pdfTEX was done at the GUTenberg's meeting by Thierry Bouche, then by me at DANTE'2000 and TUG'2000. This time, level 2 font expansion was already available and used instead of level 1 font expansion in the presented samples. Again, the opinions on the effect of the extensions were rather fuzzy.[20]

MORE SIGNIFICANT EXPERIMENTS

At DANTE'2000 I had the good luck to meet Hermann Zapf, who was very kind to accept my plea to provide comments on my work. So after DANTE'2000 I prepared a large set of samples typeset at various settings together with a paper describing in short the typographic extensions in pdfTEX.

In the samples, 3 types of fonts were used: METAFONT, Multiple Master fonts and Type 1 fonts. From each type two representative fonts were chosen, one roman and one sans serif. The following table shows the fonts used in the samples:

	METAFONT	Multiple Master	Type 1
roman	Computer Modern Roman	Minion	Palatino
sans serif	Computer Modern Sans Serif	Myriad	Helvetica

Samples for each font are made at 3 pointsizes: 8pt, 10pt and 12pt. CMR and CMSS fonts have design sizes for all of these sizes, so the fonts at the design size were used. Multiple Master Minion has an optical size axis, and I used instances at the requested size to get the best optical scaling. For the Multiple Master Myriad and Type 1 fonts, one single font was scaled for all sizes. The text used in samples comes from *The tale of a youth who set out to learn what fear was* by the brothers Grimm. Samples at different font sizes have different column setting, as shown in the following table:

[17] The German Speaking TEX Users Group

[18] This method is the current one in pdfTEX, which is very robust and flexible.

[19] The Polish TEX Users Group

[20] In total about 300 people participated the experiments.

	8pt	10pt	12pt
number of columns	5	4	3
column separator	3 mm	4 mm	5 mm
column width	33 mm	42 mm	56 mm

The basic set had 18 samples (6 fonts×3 pointsizes), which were typeset without any typographic extensions. There were totally 8 sets of samples. Each set apart from the basic one demonstrated an application of the typographic extensions of pdfTeX:

Set 1	the basic samples (without typographic extensions)
Set 2	margin kerning (protruding factors as listed in Table 5.1)
Set 3	margin kerning; font expansion at limit 20 units for Computer Modern & Type 1 fonts, 40 units for Multiple Master fonts; font expansion scale factor set to 1000
Set 4	margin kerning; font expansion at limit 30 units for Computer Modern & Type 1 fonts, 50 units for Multiple Master fonts; font expansion scale factor set to 1000
Set 5	margin kerning; selected font expansion at limit 30 units for Computer Modern & Type 1 fonts, 50 units for Multiple Master fonts; selected expansion (character expansion factors as listed in Table 6.5); font expansion scale factor set to 1000
Set 6	the same settings as set 3, but font expansion scale factor set to 0
Set 7	the same settings as set 4, but font expansion scale factor set to 0
Set 8	the same settings as set 5, but font expansion scale factor set to 0

Thus, there were totally 144 samples (8 set×18 samples of each set).[21] The samples and the article were sent to Hermann Zapf, Donald Knuth and Richard Rubinstein. The article was also sent to a few additional people (but without the samples, as they are quite large). I got some few feedbacks, from which the most detailed comments came from Knuth and Zapf.[22] Due to a time limitation, not all the suggestions could be implemented. However, the most relevant ones will be mentioned in the following discussion.

7.1 On margin kerning

The concept of character protruding is rather simple and straightforward and has turned out to be very useful. This is most desirable for composing text to justified blocks, but it

[21]The samples presented in this thesis have the same settings (regard of used typefaces and font expansion settings) to the one which were sent, apart that some samples with the expansion font scale factor 500 were added.

[22]Most of other reactions were similar to the feedbacks from the previous experiments, i.e. most of people do not see a difference.

is also useful for getting the left margin of ragged-right text (or vice versa, the right margin of ragged-left text) look smooth. The improvement of typeset text with use of margin kerning is definitively significant in most cases. Margin kerning does not influence interword spacing and does not damage the legibility of composed text at all. It seems to be the most visible improvement and moreover, it can be used without any extra setup. Therefore it is safe (and good) to apply this technique to text composition.

BACKWARD COMPATIBILITY

The possibility to apply character protruding to text composition at two levels has certain benefits. Level 1 character protruding, as done without interference to line breaking, guarantees backward compatibility so as to keep the same line breaks (and thus page breaks) of a document. On the contrary, level 2 character protruding chooses line breaks according to the effect of margin kerning on individual lines, thus it produces better interword spacing. Both have their use that can be considered more appropriate in individual applications. Character protruding was also implemented effectively: its use does not slow down paragraph formatting noticeably.

IMPLEMENTATION AND USEABILITY

While integration of margin kerning to font metrics would be a more systematic way to implement it, the current mechanism provides a flexible way to attain the desired effect quite easily and quickly. The mechanism is even more flexible than in InDesign, as it allows finer control on settings of individual fonts. Usually this is not necessary, but it can be desirable for an atypical font. Practical use has shown that the default settings work rather reasonably for most common cases of body text. Moreover, it can be applied without complicated extra setup to any existing document. Zapf remarked on the settings of margin kerning in the samples: "I think they are looking good for you get a perfect optical vertical line." Knuth also mentioned that "the margins are noticeably better in all samples of margin kerning" and "I can see that it could be desired by many typographers, but I'm not so enamoured of it myself that I would put it into *The Art of Computer Programming*."

KNUTH'S SUGGESTION FOR MARGIN KERNING

But Knuth does not agree with the way how margin kerning was implemented in pdfTeX. At the time when the samples were prepared, character protruding factors were implemented at character level, i.e. they are the same for all fonts.[23] Besides that, Knuth thinks that character protruding unit should not be relative to the character width, but rather to a fixed unit relative to `em`.[24] Knuth also suggested a mechanism that he thinks it should be used to implement margin kerning:

> Thus I strongly prefer including the margin kerning in a TFM file. I would probably handle it by putting the corrections into the ligature/kern table, introducing a "marginchar" m analogous to the present "bound-

[23] This limitation was removed afterwards; the current implementation of character protruding is font-dependent.

[24] It should be fairly easy to change the current implementation of character protruding in pdfTeX according to this suggestion. In the future it would certainly be worthwhile to do so and examine the results compared with the current approach. Another thought suggested by Hans Hagen is that the protruding amount may be set to be dependent on the paragraph width. This can easily be done within the current implementation, but I did not examine the benefit of this idea yet.

arychar." The amount of projecting of char c into left margin is the kern between m and c; it's a mistake if mc form a ligature. Similarly, `rpcode`[25] is replaced by the kern between c and m. The user specifies `\marginchar<font>`; this is -1 by default, meaning no margin kerning.

I wouldn't consider it illegal for people to change `cmr10` by adding such kerns; however, this can't be done without some change to e.g. TFtoPL since it will complain about kern with a nonexistent character. (I would extend TFtoPL by allowing a command-line parameter e.g. '`-c n`' if character n is to be permitted in kerns.) I'd also have `\nomargin` analogous to `\noboundary`, to shut off margin kerning locally.

This concept is certainly more systematic and more compatible with TeX than the current approach of character protruding in pdfTeX. On the other hand, it would require much more effort to implement. Not only the font handling mechanism in TeX would have to be changed, but also the tools for generating font metrics. Its use would be also more difficult and cumbersome, as it can be used only with font metrics which contain data for margin kerning. Thus, this concept can be highly desirable for a new typesetting system like NTS, whereas its implementation in an existing implementation of TeX or its derivation (like pdfTeX) would make its flexibility and useability rather limited.

7.2 On composing with font expansion

Unlike margin kerning, where the benefit is clear, composing with font expansion is not encouraged by many typographers. Many people working with typography implicitly treat font expansion as a "typographic evil" and do not want to hear anything about such manipulations with typefaces. The reason of this behaviour probably originated in the fact that font expansion and interletter spacing is often misused in computer typesetting.

LIMIT OF FONT EXPANSION

The experiments have shown that font expansion does help to make interword spacing more even, but it also impairs text appearance. Limits of font expansion depend on many factors and must be chosen very carefully A very rough estimation is that the variation in character width caused by font expansion must be limited to $\pm 2\%$. Of course there are exceptions to this estimation, where the expansion limit can be different. Expansion of selected characters can help to increase this limit. However the benefit of this technique is not noticeable, because the gained variation in character width in most of cases remains the same or even smaller. Moreover, with selected expansion, more fonts are used which leads to larger and more complicated output.

In the current implementation of font expansion, the expansion amount of a line is not "penalized." The badness of a line counts only for adjustment ratio of a line after font expansion, which causes the algorithm to use font expansion as much as possible

[25] In pdfTeX's term, `lpcode` stands for the left protruding factor and `rpcode` for the right one.

to prevent uneven interword spacing. I think this behaviour is simple to implement and also reasonable, supposing that the effect of font expansion is imperceptible.

KNUTH'S SUGGESTION FOR BADNESS CALCULATION

Knuth thinks that badness calculation should take into account the expansion amount and suggested the following model for this purpose:

> Suppose for example you have a line that contains 200 units of box stretchability and 500 units of glue stretchability. (I say 'box stretchability' instead of 'character stretchability' because it may be desirable to generalize the concept; but you can restrict to character boxes if desired.)
>
> Suppose further that the actual amount of box stretchability is limited to the discrete amounts $\{0, 50, 100, 150, 200\}$; but the glue stretchability is not limited by discreteness.
>
> Then if we stretch the boxes by α and the glue by β, we define the badness of the line by $100\rho^3$, where
>
> $$\rho = \max\left(\frac{\alpha}{200}, \frac{\beta}{500}\right)$$
>
> and we choose α and β to minimize this quantity when we try to stretch by a total amount $\rho = \alpha + \beta$.

Knuth also suggested that when the font is being expanded by 1%, the natural size of interword spaces should be increased by 1% too, on the contrary to the current implementation where the algorithm tries to keep all spaces as even as possible.

I think it would be desirable to calculate the badness of a line when using font expansion according to the formula of Knuth. However, the idea of increasing the natural size of interword spaces when the font is being expanded could not be easily implemented, due to the concept of TEX treating interword spaces as glue items.

In Knuth's opinions, the results of set 3 and set 6 of the samples are excellent (i.e. expansion limit 20 for Computer Modern/Type 1 fonts and 40 for Multiple Master fonts; no selected expansion). Unlike my opinions, he preferred variable interletter spacing (set 6) to font expansion (set 3).

> About tiny amounts of letter spacing as an alternative to font expansion: Contrary to what you say in the paper, I actually prefer set 6 to set 3 (in my first impression at least). Obviously that alternative is also a lot simpler, because it does not increase the number of fonts and it does not lead to the complications of discreteness in point (2)[26] above.
>
> ...
>
> But based on what I see here, I would not go to the bother of making slightly expanded/condensed fonts. Also therefore I wouldn't bother to select characters. The letter spacing would look worst in lines with fi – ff – fl ligatures, but I couldn't see any bad lines in the samples I checked of set 6.

[26] I.e. the model of badness calculation suggested above

> ...
>
> I really think set 6 represents essentially the best that can be achieved with such narrow columns and such frequent occurrences of sentences ending with close-quotes followed by sentences beginning with open-quotes.
>
> ...
>
> Since I found slight letter spacing acceptable, you can avoid downloading excessive fonts. Still you may have to generate the TFMs somehow in order to find how to letterspace a font like Minion, since you say they expand e.g. uppercase more than lowercase.
>
> ...
>
> My current recommendation is to try to simply expanding-via-letterspacing every character of a font like Minion by a fixed proportion, not to exceed a user-specified limit. Then you can use the ordinary TFM file. (Don't get more complicated unless this simple scheme is unsuitable.) A character with negative width has negative stretchability and negative shrinkability. It is quite tricky to get the rules right with respect to accents, especially since you can place an accent from font X on a character from font Y.

It is true that the current implementation of font expansion is more complicated than necessary in order to attain the actual results. The benefit brought by font expansion is not very large, compared to complexity of the approach (and the effort to do the implementation as well as the experiments).

However, I believe that all the experiments with font expansion were worth doing, even though the visual improvement of composition is not so significant as I expected in the beginning of the work. The outcome of my experiments with font expansion is not only the improvement in interword spacing. I think that no less important are also the results of examination of the effect of font expansion on composing. Unless it has been examined and tested in practice, we could not know how far we can go with composing using font expansion and how much is the potential improvement.

Zapf said that composing with font expansion should be used for book composition, where there are at least 8 words within a line. At very narrow columns as in the samples I prepared, composing with font expansion cannot help much to improve interword spacing, due to small number of words in a line. On the other hand, Knuth thinks that the benefit of font expansion is considerable mainly for typesetting narrow columns. With a comfortable line size, TeX can handle line breaking quite well as is. Dr. Rubinstein's opinion is that anything that improves line breaking is interesting to consider, especially for narrow lines. I think that font expansion is also desirable when the line width is suitable, but hyphenation is forbidden.

Selective use of multiple glyph

The current implementation of font expansion also allows experimenting with further applications of font expansion. Such an interesting use is what I would call "selective use of multiple glyph." The idea is not to apply overall font expansion as it has been done so far, but only to certain selected characters. It requires the font being used to have several wider letters that can replace their counterparts to achieve a better line-justification. These characters should be the most frequently used.[27] For example, for English text one should consider characters like 'e' and 't'. Such characters should have several variants of their shapes (also called glyphs) existing in the font. On the other hand, it is difficult to have e.g. several variants of 'o' (which is also frequently used in English text), because it would look awful. This method is similar to the one used in Gutenberg's Bible typesetting. Later it was sometimes used in books typeset by traditional typographers, for example the tongue of a terminal 'e' can be of variable length. Usually only the terminal letters are expanded, because it is hard to get right spacing of such an expanded letter followed by another letter (i.e. not the interword space). It is also occasionally used in biblical Hebrew typesetting. The idea to apply this technique for choosing better line breaking is not new; the authors of the total-fit line-breaking algorithm already mentioned it in [20]:

> It is interesting to consider how to extend the total-fit algorithm so that it could handle cases like the dropping of m's and n's in Figure 22.[28] The badness function of a line would then depend not only on its natural width, stretchability and shrinkability; it would also depend on the number of m's and the number of n's on that line. A similar technique could be used to typeset biblical Hebrew, which is never hyphenated: Hebrew intended for sacred texts usually includes wide variants of several letters, so that individual characters on a line can be replaced by their wider counterparts in order to avoid wide spaces between words. For example, there is a super-extended aleph in addition to the normal one. An appropriate badness function for the lines of such paragraphs would take account of the number of dual-width characters present.

The principle of "selective use of multiple glyph" is thus similar to overall font expansion, i.e. to select the variant that would fit best the demand of line-justification to typeset a character. However, the number of characters that can be expanded in this case is much smaller, and more important, the effect of font expansion on these characters *can be visible*. They do not have to look similar as in case of overall font expansion. In fact they *should* look different, in order to keep visual compatibility with the other glyphs in the font. The objective of having these characters is to have as large a variance in width as possible, to provide reasonable room for line-justification.

Such a font that contains several variants for certain characters only existed in traditional typesetting.[29] In my example, only letters e, t, and r are expanded. Font expansion

[27] This is of course language-dependent.

[28] The figure shows a sample of Latin text where some vowels followed by an m or n were typeset by placing the tilde above the vowel and dropping the m or n.

[29] To find such a font in digital form is not easy. In fact I could not manage to find any. So I had to find a book typeset with the mentioned technique and tried to imitate the extended glyphs. Luckily I had the digital version of the font (without the extended glyphs of course), so all what I had to do is to scan the extended glyphs and add them to the existing font using a font editor.

is applied to terminal letters only, because such an extended letter followed by another letter would look bad. The result is shown in Sample 7.1. The principle of "selective use of multiple glyph" is clear from the sample: the shapes of terminal letters changed according to the need of line-justification, in order to minimize the amount of glue stretching or shrinking. The line-breaking algorithm takes into account the potential of such variance over all lines, and chooses such line breaks that give the best interword spacing. The concept of character stretchability and shrinkability in pdfTEX makes such "non-standard" applications fairly feasible. However, the sample does not look very nice, due to the fact that creating the extended glyphs should be done by a good typeface designer.

I also attempted to apply font expansion in pdfTEX to biblical Hebrew typesetting. However, due to the complexity of placing floating diacritics in Hebrew text [14], characters are typeset as composition of boxes containing letters and diacritics. Font expansion, however, can be applied only to characters but not to boxes. Wrapping characters into boxes thus forbids applying font expansion to these characters. It would be interesting to generalize the concept of character stretchability and shrinkability as Knuth suggested, but it could make the implementation too complicated, compared to the potential benefit in practice.

TYPESETTING LATIN

Another try was to apply "selective use of multiple glyph" to typesetting Latin. The principle is rather straightforward: every combination of a vowel followed by an m or n is treated as a single character. Such a character can be typeset by two variants: one variant is to place the m or n following the vowel; the other is to place a tilde above the vowel. Thus a line can be shrunk by dropping the m's and n's following a vowel. Sample 7.2 shows the effect of this technique. The problem in this case was that font expansion is applied according to the same expansion ratio to all expandable characters in a line. Thus, it is impossible to drop only *some* of the m's or n's following a vowel in a line, but *all* or *none* of them. This problem was partly eliminated by introducing more expansion steps: the first step involved dropping only the n's following a vowel, the second step only the m's and the third step all the m's and n's. Thus the expansion specification is font stretch 0, font shrink 3 and expansion step 1. But this also confused the line-breaking algorithm, because the variance in character width is *not* proportional to the expansion amount and thus Eq. (9) is no longer true. For this reason, *some lines in Sample 7.2 are longer than the desired width.* For example, when the line-breaking sees that there is 100 units of total character shrinkability of a line and line-justification requires approximately 30 units, it supposes that the expansion ratio -0.3 is the best choice. Therefore, it will try to drop all the n's following a vowel in a line (corresponding to an expansion amount -1, according to the calculation as described in 6.5). Unfortunately, the actual reduction in the line width depends on the number of the n's following a vowel in the line and the width of such an n. Thus expanding the line by a ratio -0.3 can give a completely different result than the algorithm expected. To handle such cases, the current approach of font expansion in pdfTEX must be extended to be more general and flexible.

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The

Shortly after this, when the sexton came to pay them a visit, the father broke out to him, and told him what a bad hand his youngest son was at everything: he knew nothing and learned nothing. “Only think! when I asked him how he purposed gaining a livelihood, he actually asked to be taught to shudder.” “If that’s all he wants,” said the sexton, “I can teach him that; just you send him to me, I’ll soon polish him up.” The father was quite pleased with the proposal, because he thought: “It will be a good discipline for the youth.” And so the sexton took him into his house, and his duty was to toll the bell. After a few days he woke him at midnight, and bade him rise and climb into the tower and toll. “Now, my friend, I’ll teach you to shudder,” thought he. He stole forth secretly in front, and when the youth was up above, and had turned round to grasp the bell-rope, he saw, standing opposite the hole of the belfry, a white figure. “Who’s there?” he called out, but the figure gave no answer, and neither stirred nor moved. “Answer,” cried the youth, “or begone; you have no business here at this hour of the night.” But the sexton remained motionless, so that the youth might think that it was a ghost. The youth called out the second time: “What do you want here? Speak if you are an honest fellow, or I’ll knock you down the stairs.” The sexton thought: “He

Sample 7.1: Font Cheltenham-Book. Left: normal TeX output. Right: some terminal letters (‘e’, ‘r’ and ‘t’) were typeset using wider variants of glyph, according to line-justification demand.

1:1 in principio creavit Deus caelum
et terram 1:2 terra autem erat inanis
et vacua et tenebrae super faciem
abyssi et spiritus Dei ferebatur super
aquas 1:3 dixitque Deus fiat lux
et facta est lux 1:4 et vidit Deus
lucem quod esset bona et divisit
lucem ac tenebras 1:5 appellavitque
lucem diem et tenebras noctem
factumque est vespere et mane dies
unus 1:6 dixit quoque Deus fiat
firmamentum in medio aquarum et
dividat aquas ab aquis 1:7 et fecit
Deus firmamentum divisitque aquas
quae erant sub firmamento ab his
quae erant super firmamentum et
factum est ita 1:8 vocavitque Deus
firmamentum caelum et factum est
vespere et mane dies secundus
1:9 dixit vero Deus congregentur
aquae quae sub caelo sunt in locum
unum et appareat arida factumque
est ita 1:10 et vocavit Deus aridam
terram congregationesque aquarum
appellavit maria et vidit Deus quod
esset bonum 1:11 et ait germinet
terra herbam virentem et facientem
semen et lignum pomiferum faciens
fructum iuxta genus suum cuius
semen in semet ipso sit super
terram et factum est ita 1:12 et
protulit terra herbam virentem et
adferentem semen iuxta genus suum
lignumque faciens fructum et habens
unumquodque sementem secundum
speciem suam et vidit Deus quod
esset bonum 1:13 factumque est
vespere et mane dies tertius 1:14 dixit

1:1 in principio creavit Deus caelum
et terram 1:2 terra autem erat inanis
et vacua et tenebrae super faciem
abyssi et spiritus Dei ferebatur super
aquas 1:3 dixitque Deus fiat lux et
facta est lux 1:4 et vidit Deus lucem
quod esset bona et divisit lucem ac
tēebras 1:5 appellavitque lucem diem
et tenebras noctem factumque est
vespere et mane dies unus 1:6 dixit
quoque Deus fiat firmāentū in medio
aquarum et dividat aquas ab aquis
1:7 et fecit Deus firmāentū divisitque
aquas quae erant sub firmamento ab
his quae erant super firmamentum et
factum est ita 1:8 vocavitque Deus
firmāentū caelū et factū est vespere
et mane dies secundus 1:9 dixit vero
Deus congregentur aquae quae sub
caelo sūt ĩ locum ūum et appareat
arida factūque est ita 1:10 et vocavit
Deus aridā terrā congregationesque
aquarū appellavit maria et vidit Deus
quod esset bōum 1:11 et ait germĩet
terra herbam virentem et facientem
semen et lignum pomiferum faciens
fructū iuxta genus suū cuius sēen in
semet ipso sit super terram et factum
est ita 1:12 et protulit terra herbam
virentem et adferentem semen iuxta
gēus suum lignumque faciēs fructum
et habens unumquodque sementem
secūdū speciē suā et vidit Deus quod
esset bonū 1:13 factūque est vespere
et mane dies tertius 1:14 dixit autem
Deus fiant lūinaria in firmāento caeli ut
dividant diē ac noctē et sint in signa et
tēpora et dies et annos 1:15 ut luceant

Sample 7.2: Font Cheltenham-Book. Left: normal TEX output. Some m's and n's following a vowel were dropped to make a line shorter if desired. Some lines are longer than the desired width, due to the problem of non-linearity of font expansion.

Even interword spaces is not the only factor to uniform grayness of composed text, since the darkness of a line depends on the letterforms of characters in the line as well as letter space. Moreover, letter space seems to be more sensitive to darkness and legibility than letterforms. Therefore I think that in order to get better results, a program which can do skilful kerning on the fly like the *kf*-program is a must.

Darkness of a line depends not only on interword spaces, but also on darkness of individual letterforms in the line. Moreover, equal interword spaces on a line need not to look optically uniform because of the white area in sidebearing of characters adjacent to the interword spaces. So far, the objective of TEX line breaking is to make the interword spaces *mechanically* even. Font expansion provides more room for the line-breaking algorithm to achieve this objective. However, uniform greyness requires the interword spaces to be *visually* even rather than mechanically.

Even interword spaces do not guarantee that there will be no rivers in composed paragraphs. Rivers can also appear in cases when interword spaces are set to be very even, because rivers are formed rather by position than size or uniformity of interword spaces. Therefore it would be very useful to integrate a "river detector" into the mechanism of line breaking.

SAMPLES OF PRACTICAL USE

In the end of this section, I show some samples of practical use of the typographic extensions in pdfTEX in Sample 7.3–Sample 7.6.[30] Font expansion specification is given in the order: stretch limit, shrink limit, expansion step. Font expansion scale factor was set to 1000 in all these samples.

[30] I am thankful to Ondřej Koala Vácha for the permissions for re-printing the samples as well as kindly providing the samples.

znázorněné platit. Na polích a planýrkách vyrůstaly šmahem nové ulice, plné velkých domů projektovaných v duchu poválečného geometrického dekorativismu, který ledasco ještě přejímal ze secese.

Brněnská secese – inspirovaná bezprostředně ze svého nedalekého vídeňského matečního lůna – byla mimochodem jevem, který hraničí téměř až s velkolepostí. Dík svému „zeměpisnému“ umístění jsem byl odmala bezděčně odkojován z jejích mocných prsů. Na Konečného náměstí padaly do mých očí pod boudičku dětského kočárku mohutné kopule bohatě dekorovaných věží a efektní balkony ozdobené sochami nahých paní. Divil bych se, kdyby se něčím nebyly navždy vryly do mé mysli. Později jsem pochopil, jak vzácnou rezervací secese je tento mohutný, stylově jednotný komplex, který co do celistvosti nemá snad obdobu ani v samotné Vídni. Takže jsem vlastně nikdy moc nesdílel úsměšky nad secesí, které bývaly módní v letech vzedmuté funkcionalistické vlny. To náměstí, které, jak stárnu, čím dál víc miluju, je možná i bombastické, ale ve svém celku myslím určitě tvoří mimořádně působivý monument.

Hluboko pod těmi až marnotratně nafintěnými fasádami tam stála a dosud stojí na rohu parčíku lavička, kde jsme se ve druhé polovině třicátých let slézali s kamarády z okolních domů. Tady jsme se s Mirkem Janouškem přezdívaným Bazilišek nebo něžněji Bazilka a Frantou Benešem zvaným Benýsko odhodlávali k prvnímu vstupu do kavárny, která na nás hleděla vysokými okny odnaproti z rohu. Bylo nám zhruba patnáct; Bazilka, o čtvrt hlavy vyšší, už nosil proužkovaný dvouřadový oblek, o jakém se mi ani nesnilo, kouřil cigarety a mluvil dospělým hlasem, kdežto mně – holobrádkovi v pumpkách – ještě pískala v hlasivkách jako myš opožděná mutace a Frantík byl na tom asi tak stejně. Nebyli jsme si vůbec jisti, jestli by nás vrchní nevyhodil, ale jednoho červencového prázdninového odpoledne jsme přece jen sebrali odvahu a vešli. V kavárně bylo jen několik málo hostí, skrytých za pláty novin v rámech, a pokojně v ní voněla káva smíšená s dýmem tabáku. To všechno dohromady z nás snímalo část trémy. Sedli jsme si do rohu k mramorovému stolku a dychtivě pozorovali brčálově zelené sukno kulečníkového stolu.

Rychlým neslyšným krokem se před námi zjevil číšník a namísto toho, aby nás vykázal, vyslovil nádhernou formuli, která se rovnala biskupovu biřmovacímu aktu – „Co to bude pánové?“ Zaplavila nás vlna štěstí. Docela bez potíži jsme byli přijati do rangu pánů. Ale vzápětí jsme upadli do nových rozpaků; nevěděli jsme, co si máme poručit. Limonáda to být nemohla, když jsme se právě stali pány. Kávu jsme zcela pominuli, ta se pila jen doma o nedělích po obědě

8

Sample 7.3: *Brno – Můj Amarcord II* by Vojtěch Jestřáb, publ. Doplněk, ISBN 80-7239-062-7. Typeset with font Dutch801BT. Font expansion specification: 30, 30, 10.

stranou, která je schopna oslovit voliče velmi různorodé provenience. Připusťme, že lidé se mohou mýlit a vyvíjet. Když bývalý člen jiné strany vstoupí do ČSSD, dokazuje tím, že své názory změnil. Jistý klasik napsal, že jen hlupák nemění v průběhu života své názory.

** Někteří lidé říkají: já bych volil sociální demokraty, kdyby je nevedl Zeman. V případě vítězství vaší strany se neobávají ani tak jejích totalitních záměrů, z nichž ČSSD čas od času obviňuje pravice, jako vašich osobních vlastností – samolibosti či nedostatku sebereflexe, který cítí ve vašem vystupování.*

Politik, který je do určité míry kontroverzní, se samozřejmě líbí méně voličům než ten, který si to s nikým nerozhází. Na druhé straně bych chtěl připomenout, že na naší politické scéně působili nejméně dva takzvaně konsensuální politici, kteří se dlouho drželi vysoko na žebříčcích popularity – Jiří Dienstbier a Vladimír Dlouhý. Všichni víme, jak dopadli oni i jejich politické strany. Myslím, že politik by měl sloužit především své straně a ne sám sobě.

** Zkusím být konkrétnější: lidem často nevadí ani tak to, co říkáte, spíš jak to říkáte. Mám na mysli například některé urážlivě znějící výroky na adresu vlády nebo jejích členů...*

Vycházím z toho, že Česká republika směřuje k západoevropské, nebo chcete-li, k euroatlantické politické kultuře. A každý, kdo jen trochu rozumí politice, ví, že z úst tamních předáků opozice zaznívají na adresu vlády daleko tvrdší slova než z mých.

** Jenže u nás máme přece jen trochu jinou kulturní tradici. A dost lidem vadí, když cítíte potřebu uvést nějaký argument slovy jako „každá duševně zdravá vláda by musela...“, nebo když označíte určitého ministra za nejhloupějšího člena kabinetu.*

Když už se odvoláváte na naši tradici, ocituji vám výrok Rudolfa Bechyně z jedné parlamentní rozpravy za první republiky. Jak uvádí Ferdinand Peroutka v Budování státu, Bechyně tehdy řekl šéfovi lidovců monsignoru Šrámkovi: „Ty černý pope, ty tady už dlouho smrdět nebudeš!“ A potom po něm mrštil kalamářem. Já jsem zatím po nikom kalamářem nemrštil – mimo jiné i proto, že v dnešním parlamentu kalamáře nemáme.

** Přesto jistě víte, že váš styl mnohé lidi odrazuje. Býváte ironický, máte sklon k poučování – často to působí, jako byste tazateli či oponentovi dával najevo svou nadřazenost. Pěstujete si nějaký korektiv? Pokud máte mediální poradce, dáte na jejich rady?*

Jedním z mých mediálních poradců je náš tiskový mluvčí Jiří Kantůrek. Dalším je senátor Egon Lánský, který, jak víte, dlouho působil jako novinář v BBC a ve Svobodné Evropě. Snažím se dbát jejich rad a souhlasím, že každý politik by si měl být vědom svých nedostatků. Já sice nemám nic proti svým názorovým oponentům a různost názorů mě inspiruje, ale přiznávám se, že nesnáším hlupáky a lumpy. Jedna známá mi kdysi řekla: „Miloši, normální člověk se hlupákovi vyhne. Ty, když nějakého uvidíš, přiběhneš k němu a řekneš: Pane, tak dokonalý exemplář idiota, jako jste vy, jsem ještě v životě neviděl. Mohl byste se laskavě otočit do profilu?“ Chápu, že tato vlastnost mi může někdy škodit, ale vzpomínám si na krásné Voltairovo heslo: „Zničte hanebnost!“

8 *Alexander Kramer: Interview s Milošem Zemanem*

Sample 7.4: *Rozhovory* by Alexandr Kramer, publ. Doplněk, ISBN 80-7239-070-8. Typeset with font BookmanITCbyBT-Light. Font expansion specification: 20, 20, 10.

Úvod

Téma předkládané práce je sice velmi staré, leč v české literatuře v souhrnu a naznačení vzájemných souvislostí dosud nezpracované. Je součástí úvah mnohých myslitelů již nejméně 2 500 let. Některé jeho aspekty jsou traktovány takříkajíc tradičně, pouze s drobnými obměnami určenými např. ideovými východisky autora, jiné rysy vystupují či ustupují podle doby a společenské situace, v níž je toto téma pojednáváno. Přes poměrně dlouhou dobu, po kterou koncept práva na odpor figuruje v dějinách politického myšlení,[1)] nelze říci, že by uvedené učení bylo „stálicí“ politické filosofie. Snad by se dalo charakterizovat příměrem ponorné řeky, někdy je velmi frekventované, jindy mizí na celá desetiletí či staletí. Objevuje se v různých souvislostech, což je činí velmi komplikovaným, složitě strukturovaným. V každém případě však platí, že není dítětem moderní doby, věku revolucí.

Na toho, kdo by se téma práva na odpor pokusil zpracovat v jeho celistvosti, by tento úkol kladl značné nároky, rozhodně takové, jež přesahují omezené možnosti a schopnosti autora této práce. Proto je tedy nezbytné omezit se pouze na některé aspekty konceptu práva na odpor, jak jej znají dějiny politického myšlení, a na stručné seznámení s pozitivněprávními úpravami práva na odpor v ústavních řádech současných států. Některým prvkům, dle autorova soudu závažným, zajímavým nebo v české literatuře příliš nezdůrazňovaným, je možné věnovat větší pozornost, jiné spíše naznačit.

Komplex problémů ukrývajících se pod etiketou práva na odpor má značný rozsah, zahrnující přinejmenším filosofii (a to jak obecnou, tak politickou a právní), etiku, právní vědy, politologii, sociologii,

[1)] Nehodláme se zde zabývat subtilními úvahami o významových rozdílech mezi kategoriemi „dějiny politického myšlení“, „dějiny politické filosofie“ či „dějiny politických ideologií“. Prvních dvou pojmů je v této práci užíváno promiscue, na sporný charakter nehodnotícího resp. pejorativního podtextu „ideologií“, případně též „politických ideologií“ upozorňujeme skrze *Obranu politiky* Petra Pitharta (Praha, 1990), *Politické ideologie* Andrew Heywooda (Praha, 1994) nebo *Ideologii a utopii* Karla Mannheima (Bratislava, 1991).

Sample 7.5: *Právo na odpor a občanská neposlušnost* by Jan Kysela, publ. Doplněk, ISBN 80-7239-??-?. Typeset with font Dutch801BT. Font expansion specification: 30, 30, 10.

2

Jane vyjela z pouště do Los Angeles v plném ranním provozu a zářící slunce pronikalo zadním sklem do jejího auta, místo aby ji jeho paprsky oslňovaly. Auto si půjčila na MasterCard na jméno Wendy Aguilarová, takže i kdyby někdo v Las Vegas zjistil číslo jejího řidičského průkazu a položil ty správné otázky, dostal by se jen k neexistující ženě, která zmizela v Los Angeles.

Jane nikdy nepoužívala pravé jméno, nikdy nemířila přímo ke svému konečnému cíli a nikdy nepropásla jedinou možnost zamést za sebou stopy, zároveň však nikdy nesázela svůj život na žádný předem připravený plán. Během dvanácti let, kdy pracovala jako průvodce, ji udržovala naživu ne pouhá mechanická rutina, ale nepřetržitá ostražitost. Přežívala díky detailnímu zkoumání prostředí, v němž se pohybovala. Nahromaděný dav, drobné finanční transakce, přeplněné dopravní tepny – tam hledala příležitosti k úhybným manévrům.

Když jela pronajatým autem po Century Boulevardu, aby je vrátila do agentury, zahlédla příhodné místo, kde mohla uskutečnit další malé bezpečnostní opatření. Odbočila a za vysokým bílým poutačem, který se tyčil nad myčkou aut, zastavila u ústí tunelu vroubeného tryskami a otáčivými kartáči. Vystoupila z auta a nechala dva muže poflakující se opodál nastoupit na přední a zadní sedadlo. Muž za volantem popojel s autem k dopravníku, který zachytil přední kola a provezl je tunelem. Tam se setřely všechny otisky z každého okna a z každého kousku kovu, zatímco druhý muž vysával z vnitřního prostoru vlasy a vlákna. I kdyby ti dva něco přehlédli, mezitím se do auta dostanou další lidé a zanechají tam své vlastní vlasy, nitky a otisky prstů. Deset minut, které jí mytí auta poskytlo, strávila postáváním u pokladny a pozorováním ulice, aby se ubezpečila, že tam nečeká žádné další auto se spuštěným motorem.

Když byla osádka s prací hotová, zajela Jane k benzinové pumpě s obsluhou a nechala si naplnit nádrž, takže otisky na dvířkách a uzávěru nádrže budou patřit jen dalšímu muži. Objela autem několik bloků, aby je usušila, pár minut křižovala vlastní trasu, a pak se vrátila do půjčovny, kde si auto před dvěma týdny pronajala.

Spolu s dalšími šesti lidmi odjela kyvadlovou dopravou na letiště. Bylo přeplněné jako vždy v tuto ranní dobu, protože chce-li se člověk dostat na Východní pobřeží před koncem pracovní doby, musí se dostat do vzduchu nejpozději do osmi. Mikrobus zastavil těsně u vchodu. V davu lidí, kteří měli naspěch stejně jako ona, jí stačilo pět rychlých kroků, než se octla uvnitř. Neměla žádná zavazadla, jen přes rameno plátěnou tašku, kterou schovávala v kufru auta.

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Sample 7.6: *Žena stínů* by Thomas Perry, ISBN 80-7239-068-6. Typeset with font BookmanITCbyBT-Light. Font expansion specification: 30, 30, 10.

8 Conclusions and further developments

8.1 Conclusions

In this thesis, essential aspects of composition were discussed and a brief survey of the most important works in this area was provided. Afterwards, two issues were investigated: margin kerning and composing with font expansion. These issues have been implemented in the *hz*-program and have seemed to significantly improve the quality of typesetting. However, due to the unavailability of the program from outside URW, these micro-typographic improvements have not been tested and used in practice yet. Because of the lack of any systematic, automated support, these features are rarely used in today's typesetting.

I used pdfTEX, an extension of TEX, as the development environment for my experiments with margin kerning and composing with font expansion. pdfTEX was originally developed as a PDF backend to TEX. The following development consists in implementation of these typographic extensions and examination of their effects on composition.

8.1.1 Margin kerning

Margin kerning was implemented in pdfTEX by introducing the concept of character protruding. Left character protruding factor is a parameter specifying the amount of character shifting to the left margin, and is a number relative to the character width. Right character protruding factor is defined similarly.

Character protruding was integrated into the TEX composing engine at two levels. Level 1 character protruding is applied after line breaking, thus it does not change the final breakpoints of a paragraph. Level 2 character protruding is applied within line breaking, so the final breakpoints of a paragraph can be different than in cases without character protruding. Level 1 character protruding is mostly desirable in case when one wishes to keep line breaking unchanged for backward compatibility. Level 2 character protruding, on the other hand, gives better interword spacing, because the line-breaking algorithm also considers the amount needed to protrude the characters at the margins when choosing breakpoints.

The settings for character protruding were made out manually by sequential elimination of raggedness of the margins of various typeset text. Usually characters with little dark strokes in their shapes like the hyphen character, quotes and punctuation marks need the most prominent settings. It is also desirable to shift out to the margin certain letters with a lot of white area in sidebearing. A set of common character protruding factors gave quite reasonable results in most cases. Non-typical typefaces may require further adjustments, which can be done easily.

The improvement provided by character protruding is very considerable. In most of cases, the margins of a typeset text with character protruding look much more even. Furthermore, it does not cause any undesirable side effects and can be easily applied to any

TeX document without complicated setup. I strongly recommend character protruding for regular use, as the benefit of this extension is certain.

8.1.2 Composing with font expansion

Composing with font expansion exploits the variance in character widths when a font is being expanded in order to compensate for the amount of interword stretching or shrinking in individual lines.

I introduced an approach to manage font expansion in a similar way as glue setting. A font is activated to be expandable by giving it a font specification, which consists of stretch limit, shrink limit and expansion step. These values are given in expansion units. By convention, one expansion unit corresponds to one thousandth of the average character. Fonts in a line are expanded by discrete steps within the expansion limits, according to an expansion ratio. A character is expanded by using a counterpart from an expanded font. Character stretchability and shrinkability are the amounts that a character can be mostly widened or narrowed. Character stretchability and shrinkability are determined from the expanded font metrics, whose names are created according to font specification.

Making expanded fonts is done outside pdfTeX by calling an external program. Font expansion was examined with three types of fonts: METAFONT (Computer Modern), Multiple Master and Type 1 fonts.

Computer Modern fonts can be expanded without changing the stroke widths of letterforms by altering the unit width of the METAFONT source. Computer Modern fonts are expanded linearly to the expansion amount, i.e. the change in character widths is proportional to the expansion amount. All characters are expanded alike.

Type 1 font expansion is done by horizontal scaling. A Type 1 font is expanded by altering the FontMatrix according to the requested expansion amount. Concerning variance in character width, Type 1 font expansion has very similar properties as Computer Modern font expansion, i.e. all characters are expanded linearly to the expansion amount. However, Type 1 fonts are expanded in the strokes of letterforms as well, which can distort the appearance of a font at a high expansion amount.

Multiple Master fonts are expanded by changing the width value of an Multiple Master instance by the requested expansion amount. Multiple Master font expansion has a slight effect on the stroke widths of letterforms. Unlike Computer Modern and Type 1 fonts, Multiple Master fonts are expanded depending on the design of individual fonts. All the characters are not expanded linearly with the requested expansion amount. The variance in with of individual characters is also different. Normally, lowercase letters and other characters are expanded less than uppercase letters.

Font expansion can be applied to composing at two levels. Level 1 font expansion is applied after line breaking and does not influence the final breakpoints of a paragraph. The improvement of interword spacing gained by level 1 font expansion, however, is not significant. Level 2 font expansion is applied during line breaking to provide more room for choosing breakpoints. Interword spacing is noticeably improved with level 2 font expansion.

The improvement of interword spacing depends on the expansion limits. On the other hand, too high expansion limits causes that the effect of font expansion to be visible and thus detracts from the appearance of the typeset text. Choosing expansion limits for a font is thus not trivial and must be done carefully so the effect of font expansion cannot be visible. My experiments have shown that it is safe to expand fonts within such a limit so the variance in character width must not exceed $\pm 2\%$.

It is possible to restrict the expanding of a character by changing its font expansion factor. This is intended to reduce the effect of font expansion on characters which are more sensitive. By using this technique, the expansion limits for a font can be increased a bit. However, the gained average variance in character widths often remains unchanged or even goes smaller.

Interletter spacing has also been examined as an alternative to font expansion. The expansion scale factor of each expandable font is used to control the expansion amount of the shape description of the font, which can differ from the expansion amount of the expanded font metrics. The effect of font expansion is nearly the same at various settings of expansion scale factor. However, to very sensitive eyes, the effect of interletter spacing can be more visible than font expansion.

Font expansion helps to improve interword spacing and thus uniform greyness of a typeset text, but it must be used with great care. To draw general rules for its use is not easy, since people tend to value the quality of a typeset document differently. While top quality typographers seem to agree on aspects like optimal grayness and what kind of manipulations are permitted, the average desk top publisher is very tolerant in applying generous spacing and seemingly arbitrary stretching of glyphs and kerns to achieve his personal objectives. Since the focus of this work is on the computer science side of the problem, I leave the more subjective conclusions to the ergonomist.

8.2 Further developments

At the moment, character protruding factors are implemented to be relative to the character widths. The current meaning of protruding factor allows to have the common settings that give fairly reasonable results in most of cases. However, it would be interesting to change the implementation of character protruding so that character protruding factors are relative to a fixed unit relative to `em` as Knuth suggested and compare the effects of both methods. Integration of margin kerning to a TFM file, as Knuth described, would certainly be more orderly than the concept of character protruding. On the other hand, it is desirable for new systems rather than a system derived from TeX like pdfTeX.

It would be interesting to examine how pdfTeX works with some modules which can provide the similar functionalities as the *hz*-program. As making expanded fonts is done outside of pdfTeX, it should be fairly easy to use an external program that can widen or narrow a font to make expanded fonts.

The current concept of font expansion to expand all fonts in a line according to an expansion ratio turned out to have certain limits, as it has been shown in the sample of dropping the m's and n's following a vowel in a Latin text. To generalize the concept of font expansion to handle such cases would be another issue to consider in the future.

Another area that has not been examined yet is math typesetting. The current implementation of font expansion works with math fonts as well, as math material is converted to sequence of characters, boxes and glue. However, in order to make it work well with math typesetting (in TEX of course), a number of extra issues need to be considered, especially the spacing around math symbols.

Appendix: New primitives for typographic extensions in pdfTEX

This appendix gives a short introduction to the new primitives of pdfTEX that are relevant to the typographic extensions described in this thesis. We would like to emphasize that this is not a complete description of all primitives introduced by pdfTEX. Only those that are related to margin kerning and composing with font expansion will be mentioned.[31] The description here holds for pdfTEX version 0.14g and later.

A brief description of relevant commands

`\pdfprotrudechars`

This integer parameter specifies the level of character protruding that should be used as follows:

$$\begin{cases} \leq 0 & \text{no character protruding} \\ 1 & \text{level 1 character protruding} \\ \geq 2 & \text{level 2 character protruding} \end{cases}$$

By default, `\pdfprotrudechars` is set to zero. This parameter acts similarly as other TEX line-breaking parameters, i.e. on a per paragraph basis. Therefore, it is impossible to apply character protruding to a selected part of a paragraph. Character protruding is applied for the whole paragraph, or not applied at all. The value of `\pdfprotrudechars` when a paragraph is ended will be used for formatting the whole paragraph.

`\pdfadjustspacing`

This integer parameter specifies the level of composing with font expansion. Its use is similar to `\pdfprotrudechars`:

$$\begin{cases} \leq 0 & \text{no font expansion} \\ 1 & \text{level 1 font expansion} \\ \geq 2 & \text{level 2 font expansion} \end{cases}$$

By default, `\pdfadjustspacing` is also set to zero. This parameter also works on a per paragraph basis like `\pdfprotrudechars`.

`\lpcode` *<font> <8-bit number>*

`\rpcode` *<font> <8-bit number>*

These restricted integer parameters allow access to the left (respectively right) character protruding factor of a character from a font. Assignment to a character protruding factor

[31] Most of pdfTEX primitives have the prefix `\pdf`. This naming, however, is not relevant in some cases, when the primitive can be used for DVI output as well.

is always global, even if it is done inside a group. By default, left and right character protruding factor of a character of a font is set to zero. Character protruding factors for expanded fonts are copied from settings for the base font. The same holds for local fonts inside a virtual font.

`\efcode` *<font> <8-bit number>*

This parameter allows access to the character expansion factor of a character from a font. `\efcode` also acts similarly to `\lpcode` and `\rpcode`.

`\pdffontexpand` *<font> <stretch> <shrink> <step> <scale factor>*

This command activates a font to be expandable. The effect of this command is also global.

Examples

Next, we give some examples of how the described primitives can be used in practice. A minimal setup to activate character protruding and font expansion for the main font (supposed to be the current font) looks as follows:

```
\pdfadjustspacing=2 % activate level 2 font expansion
\pdfprotrudechars=2 % activate level 2 character protruding
\input protcode.tex % define \setprotcode; file
                    % ‘protcode.tex’ looks like follows:
                    % \def\setprotcode#1{
                    %     \rpcode#1‘\!=200
                    %     \rpcode#1‘\,=700
                    %     \rpcode#1‘\-=700
                    %     \rpcode#1‘\.=700
                    %     ....
                    % }
\input efcode.tex   % define \resetefcode and \setefcode;
                    % file ‘efcode.tex’ looks like follows:
                    % \newcount\N
                    % \def\resetefcode#1{
                    %     \N=0
                    %     \loop
                    %         \efcode#1\N=1000
                    %         \advance\N 1
                    %     \ifnum\N < 256 \repeat
                    % }
                    % \def\setefcode#1{
```

```
                    %     \efcode#1`\2=700
                    %     \efcode#1`\3=700
                    %     ...
                    % }
\setprotcode\font   % set character protruding factors for
                    % the current font; setting character
                    % protruding factors must be done before
                    % activating a font to be expandable, so
                    % the protruding settings will be copied
                    % to the expanded fonts
\resetefcode\font   % set character expansion factors of all
                    % characters to 1000; \setefcode\font can be used
                    % *after* this command to adjust the expansion factors
                    % of some characters.
\pdffontexpand\font % activate the current font to be expandable
    20              % stretch limit
    20              % shrink limit
    5               % expansion step
    1000            % font expansion scale factor
```

The above example assumes that the needed expanded fonts are already available. In my environment they can be generated on the fly if needed. Detailed description of making expanded fonts is, however, out of the scope of this thesis.

A working setup for a LaTeX document can looks as follows (supposing that selected expansion is not used):

```
\input protcode.tex
\input efcode.tex
\def\setupfont{
    \setprotcode\font
    \resetefcode\font
    \pdffontexpand\font 20 20 5 1000
}
\def\setupfam{
    \setupfont
    {\itshape\setupfont}
    {\bfseries\setupfont}
    {\itshape\bfseries\setupfont}
}
\AtBeginDocument{
    \setupfam                      % activate the main font
```

```
    {\small\setupfam}               % activate the small font
    {\footnotesize\setupfam}        % activate the footnote font
}
```

References

[1] J. O. Abughue. On the line breaking problem in text formatting. *j-SIGPLAN*, 16(6):117–122, June 1981.

[2] Adobe Systems, Inc. *Adobe type 1 font format*. Addison-Wesley, Reading, MA, USA, 1990.

[3] Adobe Systems, Inc. Type 1 font format supplement, 1994.

[4] Adobe Systems, Inc. *Designing Multiple Master Typefaces*. Reading, MA, USA, 1995.

[5] Diane Burns. Letting it all hang out, July 1998. URL: `http://www.publish.com/tech/9807/workshop.html`.

[6] Richard W. Clement. A survey of antique, medieval, and renaissance book production. *In Art Into Life: Collected Papers from the Kresge Art Museum Medieval Symposia*, pages 9–28, 1995.

[7] Martin Davies. *The Gutenberg Bible*. The British Library Board, 1996.

[8] Oege de Moor and Jeremy Gibbons. Bridging the algorithm gap: A linear-time functional program for paragraph formatting. *Science of Computer Programming*, 35(1):3–27, September 1999.

[9] Stephen Edwards. H&J: Whatever happened to progress? *The Seybold Report on Publishing Systems*, 1(46), 1996.

[10] D. Eppstein, Z. Galil, R. Giancarlo, and G. F. Italiano. Sparse dynamic programming II: convex and concave cost functions. *JACM*, 39(3):546–567, July 1992.

[11] Zvi Galil and Raffaele Giancarlo. Speeding up dynamic programming with applications to molecular biology. *Theoretical Computer Science*, 64(1):107–118, April 1989.

[12] TeX Users Group. What is TeX? What is METAFONT? A bit of history. URL: `http://www.tug.org/whatis.html`.

[13] Yannis Haralambous. Parametrization of PostScript fonts through METAFONT—an alternative to Adobe Multiple Master Fonts. *Electronic Publishing—Origination, Dissemination, and Design*, 6(3):145–157, September 1993.

[14] Yannis Haralambous. Typesetting the holy Bible in Hebrew, with TeX. *TUGboat*, 15(3):174–191, September 1994.

[15] D. S. Hirschberg and L. L. Larmore. The least weight subsequence problem. In *26th Annual Symposium on Foundations of Computer Science*, pages 137–143, Los Angeles, Ca., USA, October 1985. IEEE Computer Society Press.

[16] D. S. Hirschberg and L. L. Larmore. New applications of failure functions. *Journal of the ACM*, 34(3):616–625, July 1987.

[17] Donald Knuth. Virtual Fonts: More Fun for Grand Wizards. *TUGboat*, 11(1):13–23, April 1990.

[18] Donald E. Knuth. The Concept of a Meta-Font. *Visible Language*, 16(1):3–27, winter 1982. French translation by M. R. Delorme in *Communication et Langages* no. 55, (1983), 40–53; reprinted in *Typographie et Informatique*, proceedings of INRIA conference held 21–25 January 1985, organized by Jacques André and Patrick Sallio (Rennes, France: INRIA/IRISA – CCETT, 1985), 119–132.

[19] Donald E. Knuth. *Digital Typography*. CSLI Publications, Stanford, CA, USA, 1999.

[20] Donald E. Knuth and Michael F. Plass. Breaking paragraphs into lines. *Software – Practice and Experience*, 11(11):1119–1184, November 1981.

[21] Donald Ervin Knuth. *Computer modern typefaces*, volume E of *Computers and typesetting*. Addison-Wesley, Reading, MA, USA, 1986.

[22] Donald Ervin Knuth. *TEX: the program*, volume B of *Computers and typesetting*. Addison-Wesley, Reading, MA, USA, 1993 corrected edition, 1993.

[23] Donald Ervin Knuth. *The METAFONTbook*, volume C of *Computers and typesetting*. Addison-Wesley, Reading, MA, USA, 1993.

[24] Donald Ervin Knuth. *The TEXbook*, volume A of *Computers and typesetting*. Addison-Wesley, Reading, MA, USA, 1994.

[25] Eddie Kohler. Multiple master tools: mmafm & mmpfb. URL: `http://www.lcdf.org/~eddietwo/type/#mmtools`.

[26] J. Lau and P. Karow. *hz*-Program: Micro-Typography for Advanced Typesetting. In J. Morreale, editor, *Seminar: Annual meeting — May 1993, Seattle, WA*, volume 24 of *SID International Symposium Digest of Technical Papers 1993*, pages 58–60. SID, 1993.

[27] Miroslava Misáková. Typesetting with varying letter widths: A new hope for your narrow columns. In *Proceedings of the 19th Annual TEX Users Group Meeting*, pages 151–161, 1998.

[28] Frank Mittelbach. E-TEX: Guidelines for future TEX. *TUGboat*, 11(3):337–345, September 1990.

[29] Frank Mittelbach and Chris Rowley. The pursuit of quality: How can automated typesetting achieve the highest standards of craft typography? In C. Vanoirbeek and G. Coray, editors, *EP92—Proceedings of Electronic Publishing, '92, International Conference on Electronic Publishing, Document Manipulation, and Typography, Swiss Federal Institute of Technology, Lausanne, Switzerland, April 7-10, 1992*, pages 261–273, New York, 1992. Cambridge University Press.

[30] John Plaice and Yannis Haralambous. The latest developments in Ω. *TUGboat*, 17(2):181–183, June 1996.

[31] Michael F. Plass and Donald E. Knuth. Choosing better line breaks. In J. Nievergelt, G. Coray, J.-D. Nicoud, and A. C. Shaw, editors, *Document Preparation Systems: A Collection of Survey Articles*, chapter ??, pages 221–242. Elsevier North-Holland, Inc., New York, NY, USA, 1982.

[32] Richard Rubinstein. *Digital Typography*. Addison-Wesley, 1988.

[33] Petr Sojka, Hàn Thế Thành, and Jiří Zlatuška. The joy of TEX2PDF— Acrobatics with an alternative to DVI format. *TUGboat*, 17(3):244–251, September 1996.

[34] Richard Southall. Presentation rules and rules of composition in the formatting of complex text. In C. Vanoirbeek and G. Coray, editors, *EP92—Proceedings of Electronic Publishing, '92, International Conference on Electronic Publishing, Document Manipulation, and Typography, Swiss Federal Institute of Technology, Lausanne, Switzerland, April 7–10, 1992*, pages 275–290, New York, 1992. Cambridge University Press.

[35] Phil Taylor. ε-TEX V2: a peek into the future. *TUGboat*, 18(4):239–242, December 1997.

[36] Philip Taylor. ε-TEX & NTS: A progress report. *TUGboat*, 15(3):353–358, September 1994.

[37] Philip Taylor. NTS & ε-TEX: a status report. *TUGboat*, 18(1):6–12, March 1997.

[38] Hàn Thế Thành. Converting TEX Into a PDF-Generating Tool. In *Proceedings of the Eighth ACM Conference on Hypertext — Posters and Demonstrations*, Demonstrations, 1997.

[39] Hàn Thế Thành and Sebastian Rahtz. The pdfTEX user manual. *TUGboat*, 18(4):249–254, December 1997.

[40] URW. *hz*-program: Micro-typography for advanced typesetting. URW Software Hamburg, 1993.

[41] Adolf Wild. La typographie de la bible de gutenberg. *Cahiers Gutenberg*, 1995.

[42] Ian H. Witten. Elements of computer typography. *International Journal of Man-Machine Studies*, 23(6):623–687, 1985.

[43] Hermann Zapf. About micro-typography and the *hz*-program. *Electronic Publishing—Origination, Dissemination, and Design*, 6(3):283–288, September 1993.