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Stretching Letter and Slanted-baseline Formatting for Arabic, Hebrew, and Persian with ditroff/ffortid and Dynamic POSTSCRIPT Fonts[§]

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SUMMARY

This paper describes an extension to ditroff/ffortid, a system for formatting bi-directional text in Arabic, Hebrew and Persian. The previous version of the system is able to format mixed left-to-right and right-to-left text using fonts with separated letters or with connecting letters and only connection stretching, achieved by repeating fixed-length baseline fillers. The latest extension adds the abilities to stretch letters themselves, as is common in Arabic, Hebrew and Persian calligraphic printing, and to slant the baselines of words, as is common in Persian calligraphic printing. The extension consists of modifications in ffortid that allow it to interface with (1) dynamic POSTSCRIPT fonts to which one can pass to the outline procedure for any stretchable and/or connected letter, parameters specifying the amounts of stretch for the letter itself and/or for the connecting parts of the letter, and (2) POSTSCRIPT fonts whose characters are slanted so that merely applying show to a word ends up printing that entire word on a single slanted baseline. As a self-test, this paper was formatted using the described system, and it contains many examples of text written in Arabic, Hebrew and Persian.

תקציר

מאמר זה מתאר הרחבה של ditroff/ffortid, מערכת סדר־דפוס של כתב דו־כיווני בערבית, עברית, ופרסית. הגרסה הקודמת של המערכת יכולה לסדר כתב משמאל לימין ומימין לשמאל, בשימוש של גופנים עם אותיות נפרדות, או עם אותיות מחוברות ומתיחת הקישורים בלבד המתאפשרת באמצעות חזרה על מילוי קו־בסיס באורכים קבועים. ההרחבה החדשה מאפשרת את מתיחת האותיות עצמן, כמקובל בדפוס קליגרפי בשפות ערבית, עברית, ופרסית, וכן את הטיית קו־בסיס של מילים, כמקובל בדפוס קליגרפי בשפת פרסית. ההרחבה מכילה שינוים ב־ffortid, המאפשרים מימשק עם (1) גופנים דינמיים ב־POSTSCRIPT, אשר ניתן להעביר אל שגרת קו הגבול עבור כל אות נמתחת ו/או מקושרת, פרמטרים שמגדירים את מידת המתיחה של האות עצמה ו/או של חלקי האות המקושרים ו־(2) גופנים ב־POSTSCRIPT אשר אותיותיהם מוטות, כך שרק פנייה אל show יוצרת הדפסה של המילה השלמה על קו־ בסיס מוטה. לצרוך בדיקה עצמית, מאמר זה נסדר באמצעות המערכת שתוארה לעיל, והוא כולל דוגמאות רבות של כתב בערבית, עברית, ופרסית.

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خلاصة

هذه المقالة تصف توسيع ditroff/ffortid، برنامج تصفيف ذو-إتجاهين للغات العربية العبرية، والفارسية. النسبخة السابقة للبرنامج قادرة على تصفيف نص مختلط من اليسار-إلى-اليمين ومن اليمين-إلى-اليسار. باستعمال أحرف منفصلة أو أحرف متصلة وفقط مد الاتصال، بواسصة إعادة طباعة وصلات ذات طول نانت. التوسيع الأخير يضيف المقدرة على مدّ الأحرف نفسها، كما هو مُتَّبَعُ في فنون الخطوط الاعربية، العبرية، والفارسية، وبالاضافة إلى إمالة قاعدة الكلمات، كما هو مُتَّبَعُ في الخط الفارسي. الأضافة مبنية على تغييرات ل-ffortid والتي تسمع لها بالأتصال مَع (١) أحرف PostScript متغيرة (dynamic) والتي بالأمكان تمديدها لمعادلة القاعدة لأي حرف بالامكان مَدُّه أو/وَ وَصله، مع متغيرات تصف كمية مد الحرف نفسه أو/وَ الاحزاى التي تصل الأحرف بِبَعْضها، وَ (٢) أحرف PostScript مائلة لِدرجة show أنَّ ظباعة الكلمة تظهر على قاعدة مائلة واحدة. كإختبار ذاتي للبرنامج، هذه المقالة طُبِعَت بواسطة البرنامج الموصوف أعلاه، وتحتوي على عدة أمثال لِنُصُص كُتِبَت باللغات العربية، العبرية، والفارسية.

خلاصه

این مقاله بسطی بر ditroff/ffortid را تشریح میکند که سیستمی است برای نقشبندی دو جهتی نوشته‌ها به عربی، عبری، و فارسی. ورژن پیشین این سیستم میتوانست نوشته‌های مخلوط از چپ به راست و از راست به چپ را با استفاده از حروف جدا از هم یا بهم پیوسته، و تنها بوسیله کشیدن اتصالها با تکرار پرکن‌های پایه‌خطی با طول ثابت، نقشبندی کند. آخرین بسط این سیستم قابلیت‌های کشیدن خود حروف، که در چاپ خطاطی عربی، عبری، و فارسی معمول است، و کژ کردن پایه‌خط کلمات، که در چاپ خطاطی فارسی معمول است، را به آن اضافه میکند. این بسط متشکل از تغییراتی است در ffortid که به آن دو امکان زیر را میافزاید: (۱) استفاده از خط‌های دینامیك PostScript که میتوان به آنها برنامه پوش (قالب) هر حرف کشیدنی یا اتصالی را داد، بعلاوه پارامترهائی که اندازه کشیدن هر حرف یا هر بخش اتصالی هر حرف را

مشخص میکنند؛ و (۲) استفاده از خط‌های خمیده POSTSCRIPT بطوریکه انجام دستور show برای یك کلمه به تنهائی باعث چاپ تمام آن کلمه بر روی یك پایه‌خط خمیده یگانه میشود. بعنوان یك خودآزمائی، این مقاله با استفاده از سیستمی که در اینجا تشریح میشود نقشبندی شده و مثالهائی از نوشته‌های عربی، عبری، و فارسی در متن خود دارد.

خلاصه

این مقاله بسطی بر ditroff/ffortid را تشریح میکند که سیستمی است برای نقشبندی دوجهتی نوشته‌ها به عربی، عبری، و فارسی. ورژن پیشین این سیستم میتوانست نوشته‌های مخلوط از چپ به راست و از راست به چپ را با استفاده از حروف جدا از هم یا بهم پیوسته، و تنها بوسیله کشیدن اتصالها با تکرار پرکن‌های پایه‌خطی با طول ثابت، نقشبندی کند. آخرین بسط این سیستم قابلیت‌های کشیدن خود حروف، که در چاپ خطاطی عربی، عبری، و فارسی معمول است، و کژکردن پایه‌خط کلمات، که در چاپ خطاطی فارسی معمول است، را به آن اضافه میکند. این بسط متشکل از تغییراتی است در ffortid که به آن دو امکان زیر را میافزاید: (۱) استفاده از خط‌های دینامیك POSTSCRIPT که میتوان به آنها برنامه پوش (قالب) هر حرف کشیدنی یا اتصالی را داد، بعلاوه پارامترهائی که اندازه کشیدن هر حرف یا هر بخش اتصالی هر حرف را مشخص میکنند؛ و (۲) استفاده از خط‌های خمیده POSTSCRIPT بطوریکه انجام دستور show برای یك کلمه به تنهائی باعث چاپ تمام آن کلمه بر روی یك پایه‌خط خمیده یگانه میشود. بعنوان یك خودآزمائی، این مقاله با استفاده از سیستمی که در اینجا تشریح میشود نقشبندی شده و مثالهائی از نوشته‌های عربی، عبری، و فارسی در متن خود دارد.

KEY WORDS: Arabic; bidirectional; formatting; Hebrew; Keshide; multilingual; Persian; stretching; slanted-baseline; Troff

INTRODUCTION

The reader is assumed to be familiar with the paper 'Arabic Formatting with ditroff/ffortid' by Srouji and Berry, published in *Electronic Publishing* in December 1992 [1]. This paper described an Arabic formatting system that is able to format multilingual scientific documents which contain text in Arabic or Persian, as well as other languages, plus pictures, graphs, formulae, tables, bibliographical citations and bibliographies. ditroff/ffortid itself is a collection of pre- and post-processors for the UNIX ditroff (Device Independent Typesetter RunOFF) [2] formatter. The system was built without changing ditroff itself. The collection consists of a preprocessor, fonts and a postprocessor.

The preprocessor transliterates from a phonetic rendition of Arabic using only the two cases of the Latin alphabet. The preprocessor assigns a position, stand-alone, connected-previous, connected-after, or connected-both, to each letter. It recognizes ligatures and assigns vertical positions to the optional diacritical marks. The preprocessor also permits input from a standard Arabic keyboard using the standard ASMO [3] encoding. In any case, the output has each positioned letter or ligature and each diacritical mark encoded according to the font's encoding scheme.

The fonts are assumed to be designed to connect letters that should be connected when they are printed adjacent to each other.

The ffortid postprocessor is an enhancement of an earlier version [4] that arranges for right-to-left printing of identified right-to-left fonts. The main enhancement is stretching the final connection to letters of lines or words, using multiple fixed-sized baseline fillers, instead of inserting extra inter-word spaces, in order to justify the text.

This ffortid does not handle letter stretching, and the Srouji and Berry paper [1] observes in its conclusion that adding the ability to stretch letters would be left for future work. That future work, applied to Arabic, Hebrew and Persian, together with the abilities to stretch connections without a filler and to slant the baseline of words as in Persian is the subject of the present paper.

As usual for papers dealing with formatting issues, this paper was typeset with the software described herein.

STRETCHING

In high quality Arabic and Persian printing, stretching is preferred to inserting extra inter-word spacing to achieve left (end-of-the-line) justification. Figure 1 shows an example from an Egyptian textbook in Arabic calligraphy [5, 6]. This stretching is called *keshide* in both Arabic and Persian, from the Persian word *keshidan*, which means 'to stretch'.

In Arabic and Persian, there are two kinds of stretching,

1. stretching of the connection to the last connecting-previous letter in a line or words, and
2. stretching of the last stretchable letter in a line or words.

In Figure 1, the pronounced stretching at the (left) end of line 2 is of a letter, the connecting-previous *nun*, while those near the middles of lines 3 and 4 are of connections.

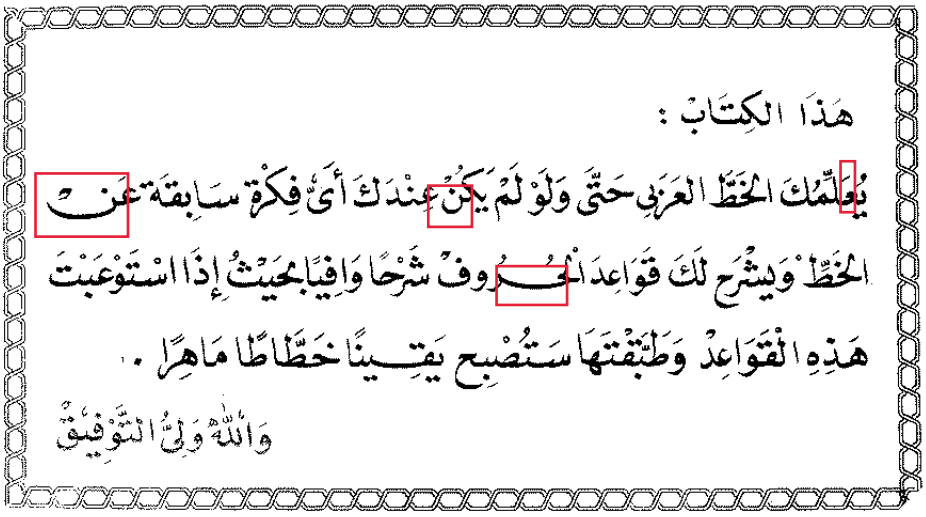


Figure 1. Sample of Arabic Calligraphic Writing

In high quality Hebrew printing, especially in the Torah and in prayer books, stretching is for the same purpose, to achieve justification without spreading words. Figure 2 shows some stretching in the first verses from the book of Genesis [7]. Since Hebrew letters are not connected to each other, only letter stretching is available, and it is usually applied to the last stretchable letter in a line. One sees in line 4 a stretched ב (*bet*), in line 20 a stretched ה (*he*), in lines 5, 10, 15, 16, 18 and 19 stretched ר*s* (*resh*es), all of differing amounts, and in lines 9 and 13 stretched ל*s* (*lamed*s), of differing amounts. Because the amounts of stretch are all different, a collection of stretched versions of letters of specific amounts of stretch is not likely to work. (All occurrences of words for G-d or G-d's name have been removed in order to avoid profaning these words.)

One can imagine a scribe in these languages, writing with indelible ink on expensive parchment, not having an opportunity to rewrite a line to left justify it after it is known what text can fit in the line. Stretching is applied near the end of the line, when it is easier to predict how much more can be written on the line. The scribe merely stretches either the last connection or the last stretchable letter as is available. It is the perfect way to achieve justification when there is only one pass over the material and there is no backtracking. Of course, with modern formatting software, it is not difficult to achieve justification by spreading words. However, old habits die hard, and still stretching is associated with high quality printing. Furthermore, not all stretching is applied at the end of the line in a one-pass mode. There are numerous examples of printing in which the scribe was careful to balance the stretching over several points in the line to achieve a pleasing appearance, as is shown in Figure 3, taken from the same textbook from which Figure 1 was taken. It shows the letters ب, ف, and a variation of گ, without and with stretching. The unstretched versions of the letters are said to be 5 points wide (the point is the width of the dot that appears in two of the letters), and the stretched versions are 11 points wide. This figure also

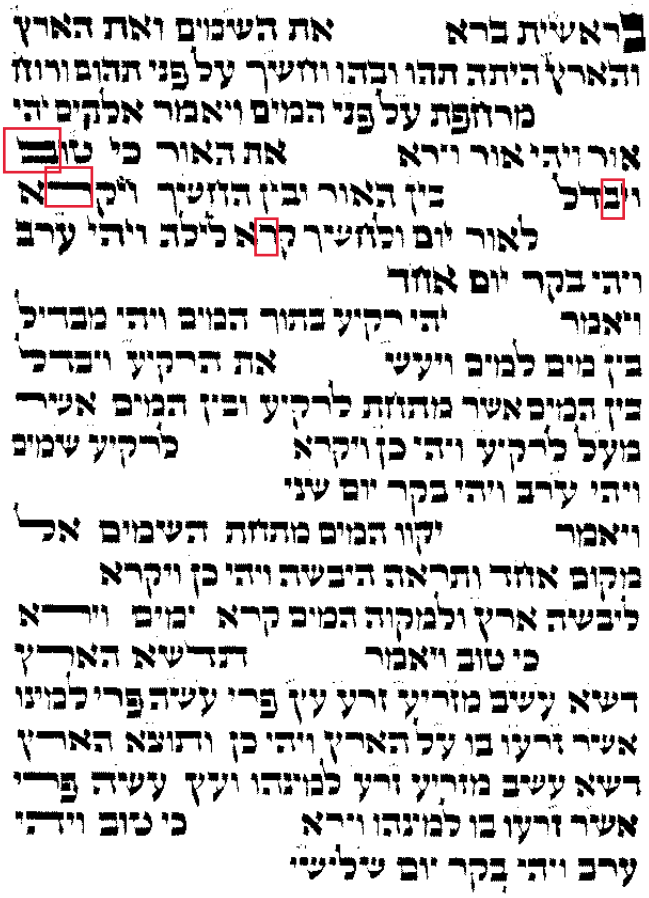


Figure 2. Sample of Hebrew Calligraphic Writing

shows the importance of aesthetics in stretching, an importance that precludes simple algorithms. Because the three letters that are stretched are structurally similar, for appearance's sake, they had to be stretched the same amount rather than individual amounts according to the needed justification. For this kind of situation, the human calligrapher must exercise lookahead.

STRETCHING PROBLEMS AND DYNAMIC FONTS

The following discussion is couched in terms of POSTSCRIPT [8] fonts, although the problems exist and the proposed solutions are available also in other outline-based font formats such as TrueType [9].

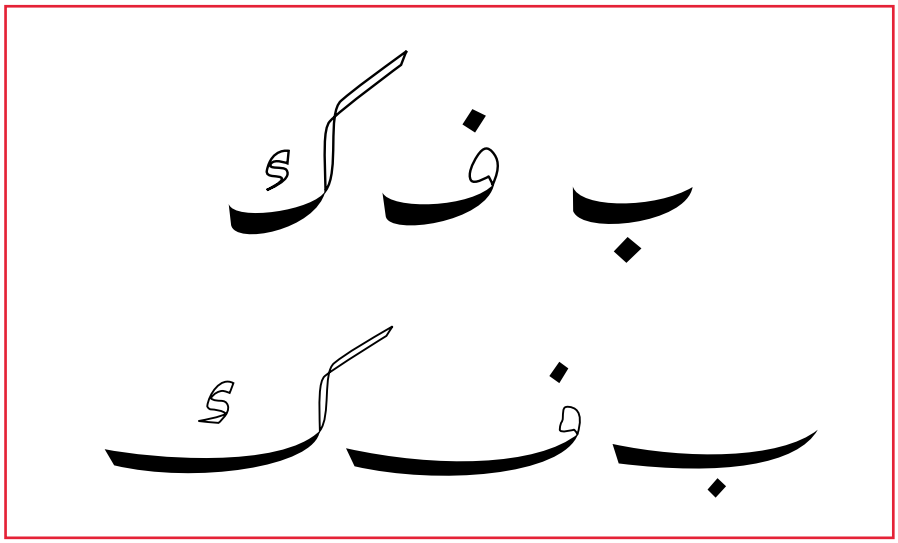


Figure 3. Non-stretched and stretched letters

A form of connection stretching is quite easy to achieve with most available fonts. It requires only that

1. all connecting letters connect via baseline strokes which meet their bounding boxes at the same *y* coordinates,
2. that the `show` command place the characters to be printed bounding box to bounding box, and
3. that the font provide a narrow rectangular baseline filler that connects on both sides to the connecting baseline of all connecting letters.

Figure 4 shows the connecting after and the connecting before forms of *baa* connected to each other, then disconnected, then with two fillers in between them but disconnected, and finally with the two fillers and all connected. Letter stretching is much more difficult to achieve, and that difficulty is probably the reason why it does not seem to appear in any of the available Arabic formatting systems.

One possible way to achieve letter stretching is for the font to provide additional stretched forms of each stretchable letter, each form being the stretching of one letter by a specific amount. The problem with this approach is the large number of additional letters required in the font to provide enough different sizes of each stretchable letter to cover most needs. Arabic fonts are usually quite full, taking up nearly all 256 available positions with all the letters and ligatures and the up-to-four forms of each letter and ligature. Moreover, there will always be specific stretching needs that are not covered by the available collection.

An alternative and probably better approach would be to make the procedure for each stretchable letter accept a parameter whose value, defaulted to zero, indicates the amount of stretch with which the outline of the letter is to be drawn. When it is necessary to stretch a letter by any specific amount, the `show` of that letter passes the amount to the letter's procedure and informs the font mechanism of the new length of the letter.

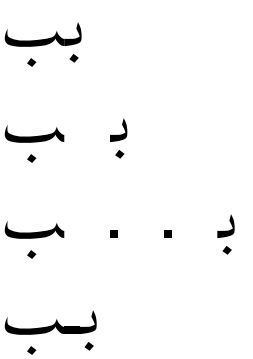


Figure 4. Baa*s with stretched connections*

The problem with the second approach is that it requires dynamic fonts, as proposed by André and Borghi [10]. Such dynamic fonts violate the basic assumption for Type 1 fonts [11], namely that for any given character code, scale (point size) and font name, the bitmap obtained by executing the character's procedure is constant. The holding of this assumption allows caching the bitmap so that it does not need to be computed again when a request to print the same character in the same scale and font comes later. Dynamic fonts thus print slower, because it is useless to cache a character's bitmap when, each time it is printed, it will have a different amount of stretch, and thus a different bitmap. Such dynamic fonts need to be Type 3, i.e. allowing use of the full POSTSCRIPT language, and thus are slower to print and lose other benefits of Type 1, i.e. the ability to provide hints to improve low resolution or small point size rasterization and the ability to be handled by the Adobe Type Manager (ATM). However, in this author's opinion, the beauty of what can be done with dynamic fonts, including dynamic optical scaling [12], outweighs the disadvantages. Moreover, as the use of dynamic fonts grows, Adobe will be given an incentive to extend hinting and the ATM mechanism to cover the needed dynamism, perhaps through a Type 2 font providing just enough capability from the full POSTSCRIPT to cover most needs for dynamic fonts. Note that Multi-Master Fonts (MMFs) do not fill the bill. Each can be thought of as a font definition macro, which when supplied with widths of the font to be simulated, generates a proper Type 1 font definition, each of whose characters prints to the specified width.

OPERATION OF ffortid

As shown in Figure 5, ffortid sits between ditroff and the device driver and converts from the ditroff intermediate form to the same form so that the device driver does not know that it did not get its input directly from ditroff. Recall that the ditroff intermediate form, besides showing the exact position of each character to be printed, has a specific marker at the end of each output line and a specific marker at the end of each input word. A program processing this form does not have to guess, and possibly be wrong, where the ends of lines and ends of words are. Recall, finally, that the characters come out of ditroff broken into lines but in logical order [13, 14, 4], that is from left to right in the order that one hears the characters as they are spoken.

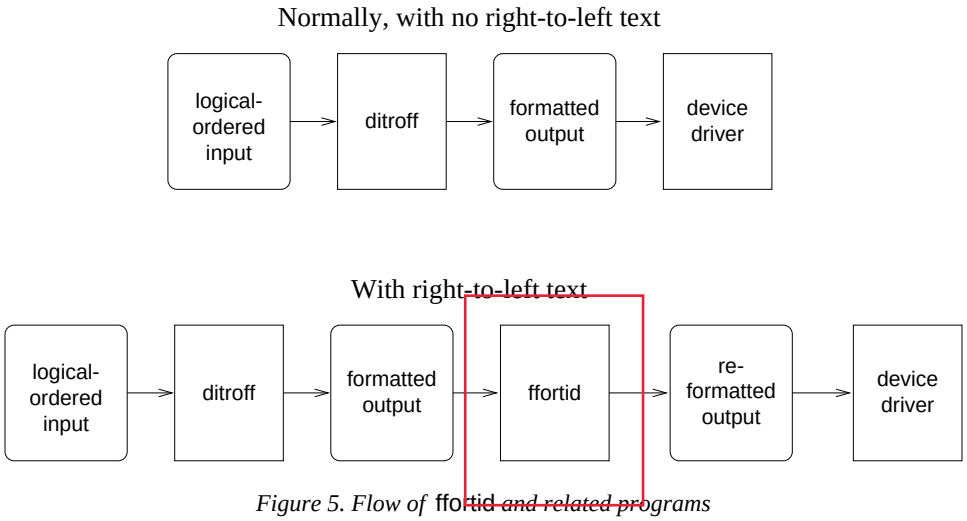


Figure 5. Flow of ffortid *and related programs*

The main job of ffortid is to reorganize the characters so that the text is in visual order, in which the text of each language is written in its own direction and the flow of the single-directional chunks in each line is consistent with the *current document direction*. ffortid works by totally reformatting each line as a function of the current document direction and the font of each character. For details on this reformatting, please consult Section 6 of the Srouji and Berry paper [1].

It is clear that the total amount of white space between the words in a line, δ, is calculable as the difference between the current line length and the sums of the lengths of the words and the minimal spacing. Stretching is achieved by not spreading the words and dividing δ by the number of stretching places to get an amount, σ, to stretch at each stretching place. When connection stretching is used, then a number of these fillers whose total length is greater than or equal to σ is put in each connection to be stretched. The last of these can be made to overlap its predecessor so that its end is precisely at the beginning of the character to which it connects. Clearly, if stretching of letters is added, then the simple strategy is to pass this σ amount as the length increase parameter to the letters to be stretched. Therefore, the problem is to modify the POSTSCRIPT definitions of the fonts so that the procedure for a stretchable letter takes the amount of stretch as a parameter and modifies the outline appropriately.

DYNAMIC FONTS

With the general strategy laid out, the step of highest technological risk was the production of the dynamic fonts with parameterized stretchable characters. Hence, this was the first step to work on.

In Arabic, Hebrew and Persian, all stretching is across horizontal portions of a letter such that stretching them does not cause the result to look like another letter. Letters, such as the *alif* (ا) in Arabic and Persian and the *vav* (ו) in Hebrew, that are entirely vertical cannot be stretched. In Hebrew, all horizontal portions involve sections bounded by parallel

horizontal straight line segments. In Arabic and Persian, the horizontal portions are not straight; they involve smooth curves that are mostly horizontal. Thus, stretching Hebrew letters is straightforward, but stretching Arabic and Persian letters involves stretching curves in such a way that the curvature, in the vernacular sense of the word, is somehow preserved and that the stretched sections flow smoothly to the rest of the letter. Therefore, it was decided to build a stretchable Hebrew font first. This way, the details of the parameterization could be worked out independently of dealing with the æsthetics of curve stretching.

DYNAMIC HEBREW FONTS

The stretchable Hebrew letters are those with horizontal portions for which stretching the horizontal portion would not cause the result to look like another letter. Therefore, the stretchable letters are בּ (*bet*), ד (*daled*), ה (*heh*), ח (*khet*), ך (*khaph sofit*), כ (*kaph*), ל (*lamed*), ם (*mem sofit*), ר (*resh*) and ת (*tav*). This author has seen א (*aleph*), מ (*mem*) and ק (*quf*) stretched in some documents. Note that ו (*vav*) is not stretchable because stretching its small horizontal portion would cause the result to look like ר (resh).

It was decided to stick to the definite set for now. Once the technique is understood, it is easy to add additional stretchable letters. Indeed, the software has been carefully designed so that the parts affected by adding additional letters to the stretchable set are completely table-driven from human-editable ASCII tables.

First it was necessary to decide how to pass the amount of stretch to each letter to be stretched. It was decided that before the `show` of the letter to be stretched, a global variable called `fact` would be set to the amount of stretch. The procedure for this letter could use this value as it sees fit to adjust the values of mostly *x* coordinates in the outline path. Following this `show`, `fact` would be reset to zero, with the intention that a stretchable letter finding `fact` set to zero would end up not being stretched. Initially, the units of `fact` were those of the `FontMatrix` of the font. However, such a unit requires the invoker to know the `FontMatrix` of the font, which is normally considered a hidden implementation detail. Later, it was decided to make the unit of `fact` be ems. The letter's procedure is required to convert the value of fact into `FontMatrix` units by multiplying `fact` by the *x* value in the `FontMatrix`, and does so with the POSTSCRIPT code

```
/fact fact Name-of-font-definition-dictionary
     /FontMatrix get 0 get div def
```

To stretch a character, it is necessary to examine its outline and to find the points defining the straight line segments to be stretched. The simplest situation is when the definition of a character's outline does an absolute move to a starting point and then draws the path using only relative commands thereafter. Recall that all stretching in Hebrew is across straight line segments; if the path is described with relative commands, each such segment is defined with an `rlineto` whose prefix arguments are the *x* and *y* of the ending point, the starting point assumed to be where the current point is at the start of the command. Therefore, it suffices to decide which `rlineto` segments are to be stretched and to add or subtract `fact`, depending on the direction in which the segment is being drawn, to the *x* argument of the `rlineto`. Thus, the definition of the Hebrew letter *bet* from one font,


```
/bet {
464 0 -61 -26 482 541 setcachedevice
0 0 moveto
127 388 rmoveto
-127 0 rlineto
-2 0 35 52 44 62 rcurveto
9 11 54 67 54 65 rcurveto
0 -47 rlineto
22 0 rlineto
114 0 rlineto
30 0 80 0 107 -32 rcurveto
25 -30 19 -90 19 -104 rcurveto
0 -252 rlineto
61 0 rlineto
-61 -80 rlineto
-360 0 rlineto
56 80 rlineto
233 0 rlineto
0 0 -1 221 0 238 rcurveto
0 9 0 42 -9 56 rcurveto
-9 15 -28 14 -46 14 rcurveto
-107 0 rlineto
fill } def
```

is converted to

```
/bet {
%%464 0 -61 -26 482 541 setcachedevice
543 fact add 0 setcharwidth
0 0 moveto
127 fact add 388 rmoveto
-127 fact sub 0 rlineto
-2 0 35 52 44 62 rcurveto
9 11 54 67 54 65 rcurveto
0 -47 rlineto
22 0 rlineto
114 fact add 0 rlineto
30 0 80 0 107 -32 rcurveto
25 -30 19 -90 19 -104 rcurveto
0 -252 rlineto
61 0 rlineto
-61 -80 rlineto
-360 fact sub 0 rlineto
56 80 rlineto
233 fact add 0 rlineto
0 0 -1 221 0 238 rcurveto
0 9 0 42 -9 56 rcurveto
```

```
-9 15 -28 14 -46 14 rcurveto
-107 fact sub 0 rlineto
fill } def  .
```

Observe that the `setcachedevice` command was replaced by a `setcharwidth` command that implements the same net character width. Since a dynamic character may produce different outline each time it is called, its bitmap cannot be cached; if it were, then the next time the character is shown, the procedure would be totally ignored and the previously produced bitmap would be used, possibly of the wrong width. The defined character at point size 30 and a 1 em stretching of it are

The stretching occurs at the boundary between the curves leading to the straight line segments and the straight line segments both upstairs and downstairs. If the path definition is not a series of relative commands, but a series of absolute commands, it is necessary to calculate the *x* coordinate of all points in terms of the `fact` parameter. Generally, the *x*s to the right of the stretching are all increased by the value of `fact` and those to the left of the stretching are left alone.

Erez Manor, a student, implemented much of the stretching of the Hebrew font used in this paper as a project for the author's electronic publishing seminar.

DYNAMIC ARABIC FONTS

There are two parts of Arabic and Persian letters to be stretched: the letter itself in the cases of stand-alone as well as connecting letters; and the connecting parts in the cases of connecting letters only.

Stretching letters

In Arabic and Persian, the situation is more complex than in Hebrew. No letter has portions bounded by horizontal straight line segments. There are letters with curved strokes in which the predominant flow of the stroke is horizontal. It is more correct to say that there are forms of letters with these predominantly horizontal curved strokes; not all forms of the same letter have these strokes. Therefore, a form is stretchable if it has a predominantly horizontal curved stroke such that stretching it does not yield a result that looks like a form of another letter. On this basis, the stretchable forms are ب (stand-alone *baa*), س (stand-alone *seen*), ص (stand-alone *sad*), ف (stand-alone *faa*), ق (stand-alone *qaf*), ك (stand-alone *caf*), گ (stand-alone *Gaf*), ل (stand-alone *lam*), ن (stand-alone *noon*), ى (stand-alone *alifmaksura*), ک (connecting-after *caf*), گ (connecting-after *Gaf*), ک (connecting-both *caf*), گ (connecting-both *Gaf*), ب (connecting-previous *baa*), س (connecting-previous *seen*), ص (connecting-previous *sad*), ف (connecting-previous *faa*), ق (connecting-previous *qaf*), ك (connecting-previous *caf*), گ (connecting-previ-

ous *Gaf*), ـلـ (connecting-previous *lam*), ـنـ (connecting-previous *noon*), ـى (connecting-previous *alifmaksura*), ـفي (stand-alone *faa_yaa*), ـلى (stand-alone *lam_alifmaksura*), ـلى (connecting-previous *lam_alifmaksura*), and all other forms that vary from these by additional or fewer dots or *hamza*s. In particular, ا (stand-alone *alif*) is not stretchable because it has no horizontal strokes.

The outline of any character is a series of elements, each of which is a line, four-point Bézier curve, circle or arc. As shown in Figure 6, elements that share an end point p are

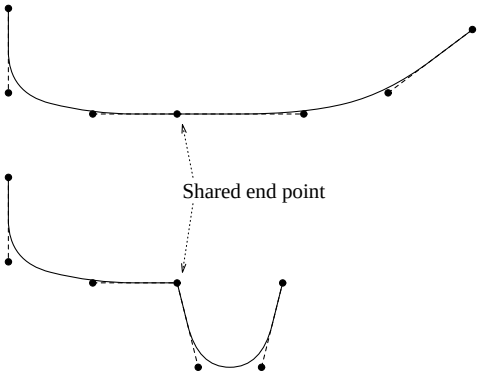


Figure 6. Smooth meeting and cornered meeting

tangent to the same line which passes through p if the outline is supposed to be smooth through p, and elements that share an end point p have tangents at an angle at p if the outline is supposed to have a corner at p. As a rule, stretching should not introduce, remove or change any corner. Therefore, tangents at end points of all elements should not change. While horizontal stretching will definitely change x values in the outline, for other reasons, it is not good that y values change. For example, it should be possible to vertically position a diacritical over or under a stretched character as it is positioned over or under the unstretched version. Furthermore, it should not be necessary to have to adjust vertical spacing dynamically as a part of stretching.

With Arabic and Persian, all stretching is across curved portions of letters. Therefore, the issue is how to stretch curves that are described in the font definition as four-point Bézier curves. A four-point Bézier curve is easy to stretch, if, as shown in Figure 7, the stretching is in the interior of the curve between the two middle control points. To stretch such a curve by A units, simply add A to the x values of the two right-hand points and to all points to the right of the left-hand one of these. Note that the stretched curve connect with its neighbors with the same slope and at the same y values as before. Moreover, it appears that stretching four-point Bézier curves in the middle in this manner always gives æsthetically pleasing results.

It is a problem to stretch through the shared end point of two Bézier curves whose tangents are the same at the shared point. As shown in Figure 8, adding A to the x values to the three rightmost points of the right-hand curve in order to stretch between the first and second point introduces a corner into what was a smooth meeting at the shared point.

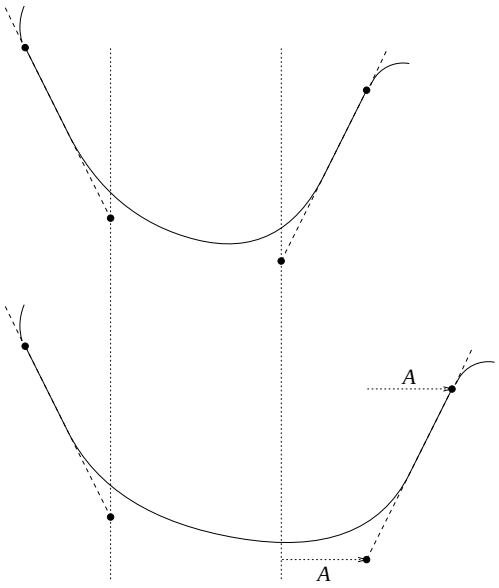


Figure 7. Stretching four-point Bézier curve

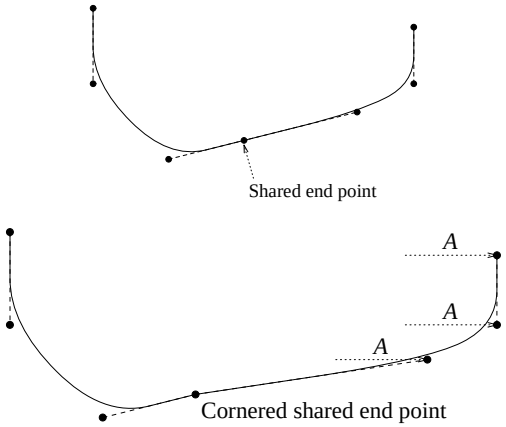


Figure 8. Cornered shared end point

As shown in Figure 9, the corner can be avoided by preserving the slope in the left-hand tangent of the right-hand curve by increasing both the *x* and *y* values by amounts consistent with the slope of the tangent. However, now the right end of the combined curve does not have the same *y* value as before. One proper solution requires redesign of the two adjacent Bézier curves into one or three adjacent curves so that the place of stretch is in the middle of one four-point Bézier curve. One special case of stretching through a shared end point works, specifically, when the tangents through the shared end points are completely horizontal, as suggested by Figure 10.

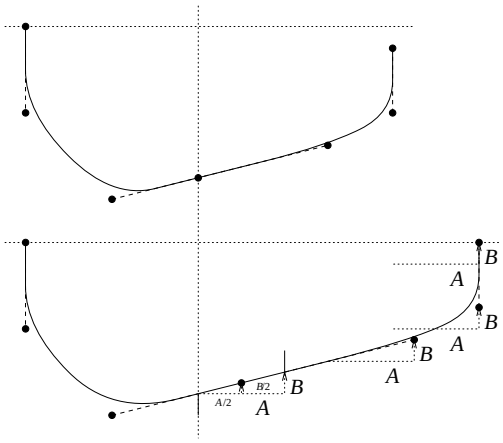


Figure 9. Avoiding cornered shared end point

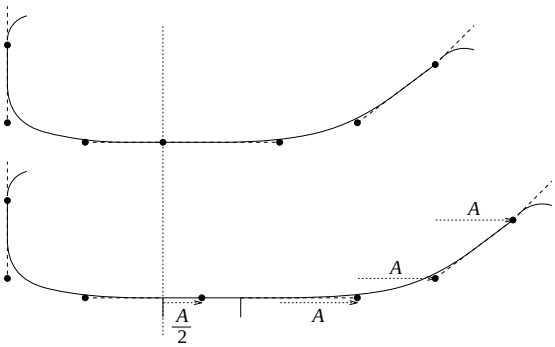


Figure 10. Stretching through shared end point with horizontal tangents

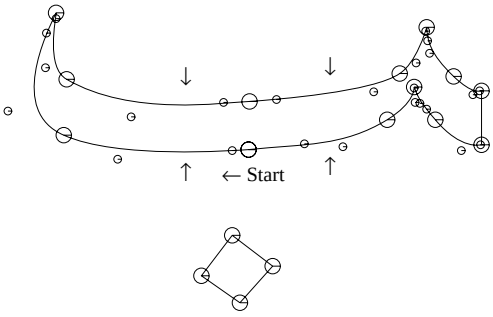


Figure 11. Plot of outline of connecting-previous baa

Another solution was discovered during the first experiments, with the connecting-previous form of the *baa*. This turned out to be a case of wanting to stretch across a shared end point when the tangents going into this point are not completely horizontal.

First it was necessary to plot the outline of this letter in order to see the locations of the end and control points of the Bézier curves defining the outline. Figure 11 shows the result of systematically converting the POSTSCRIPT code for the outline of the form into a drawing of its outline with points marked by circles; the starting point of the path that is stretched is labelled with 'Start', the direction of flow is indicated by the arrow coming out of the label, end points of curves and lines are big circles, control points of curves are little circles, and the stretched curves are marked with vertical arrows.

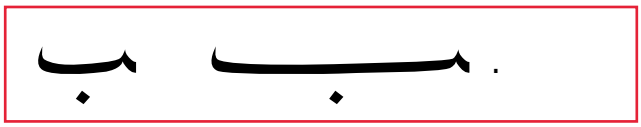
Each of the upper and lower strokes defining the horizontal portion to be stretched consists of two Bézier curves meeting at a shared end point which is right in the middle of the strokes to be stretched. Each end point is marked with a bigger circle with a radius line, and each interior control point is marked with a smaller circle with a radius line. The shared end points mentioned above are the bigger circle near the word 'Start' and the bigger circle almost directly above. Stretching through the upper and lower shared points would introduce corners. Rather than rebuilding the adjacent curves as one curve or adding an additional curve, it was decided to split the amount of stretch A into two equal parts $A/2$, and to stretch each of the adjacent curves in its own middle by $A/2$. The stretched Bézier curves are all marked with pluses in the figure. The result was that the normal code for the outline of the connecting-previous *baa*,

```
/baa_CP
{ 502 0 -15 -180 527 153 setcachedevice
0 0 moveto
243 -94 rmoveto
42 -32 rlineto
-34 -38 rlineto
-40 28 rlineto
closepath
0 0 moveto
260 -5 rmoveto
-17 -1 -136 -10 -192 15 rcurveto
-58 25 -18 106 -8 127 rcurveto
0 -6 -11 -57 11 -69 rcurveto
67 -39 163 -24 190 -23 rcurveto
28 2 129 10 156 29 rcurveto
17 11 27 44 28 48 rcurveto
1 -14 3 -27 28 -51 rcurveto
20 -19 27 -15 29 -15 rcurveto
0 -56 rlineto
-1 0 -21 -6 -48 26 rcurveto
-9 11 -16 17 -22 34 rcurveto
0 -1 1 -16 -28 -34 rcurveto
-46 -28 -86 -25 -144 -31 rcurveto
closepath 0 0 moveto fill } def
```


is converted into the following code that uses `fact` initialized to the amount of stretch in ems (with the changes emboldened):

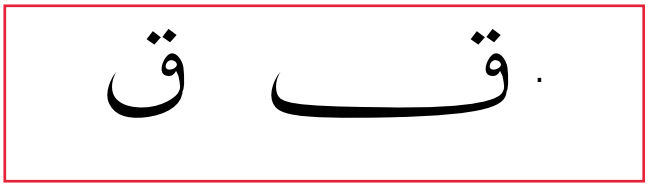
```
/baa_CP
{ /fact fact Arabic-NaskhFont /FontMatrix get 0 get div def
502 fact add 0 setcharwidth
/fact_2 fact 2 div def
0 0 moveto
243 fact_2 add -94 rmoveto
42 -32 rlineto
-34 -38 rlineto
-40 28 rlineto
closepath
0 0 moveto
260 fact_2 add -5 rmoveto
-17 -1 -136 fact_2 sub -10 -192 fact_2 sub 15 rcurveto
-58 25 -18 106 -8 127 rcurveto
0 -6 -11 -57 11 -69 rcurveto
67 -39 163 fact_2 add -24 190 fact_2 add -23 rcurveto
28 2 129 fact_2 add 10 156 fact_2 add 29 rcurveto
17 11 27 44 28 48 rcurveto
1 -14 3 -27 28 -51 rcurveto
20 -19 27 -15 29 -15 rcurveto
0 -56 rlineto
-1 0 -21 -6 -48 26 rcurveto
-9 11 -16 17 -22 34 rcurveto
0 -1 1 -16 -28 -34 rcurveto
-46 -28 -86 fact_2 sub -25 -144 fact_2 sub -31 rcurveto
closepath 0 0 moveto fill } def
```

The defined character at point size 30 and a 1 em stretching of it are



Good

The next form considered was the stand-alone form of the *qaf*. This proved to be a case of stretching across the middle of a single Bézier curve. Figure 12 shows the outline of the form in a form similar to that of Figure 11. Only the start of the path that has to be stretched is marked. The defined character at point size 30 and a 1 em stretching of it are



Bad

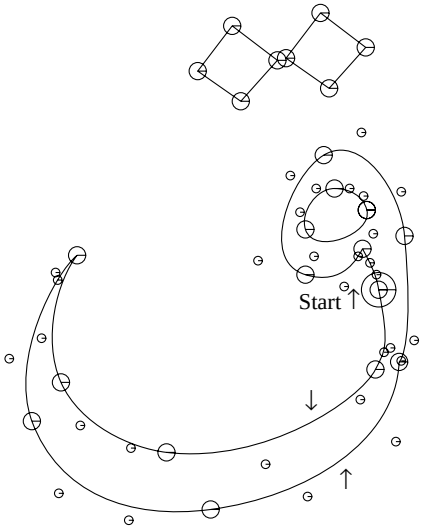
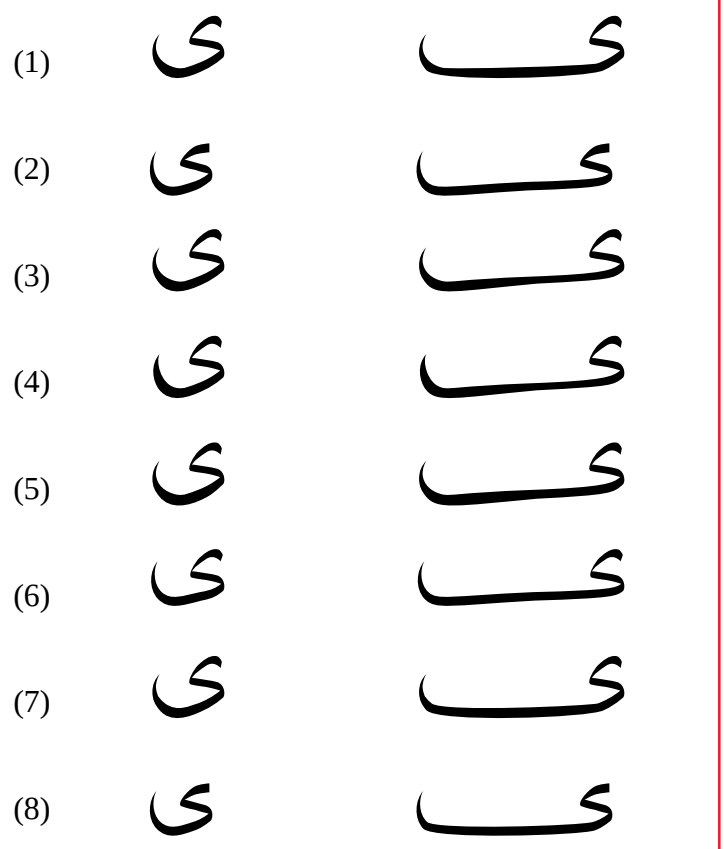


Figure 12. Plot of outline of stand-alone qaf

Once it was clear how to proceed, the author got the assistance of a student, Asaf Segal, to carry out the stretching on the entire font. For the most part, adding stretching to the stretchable forms went quite straightforwardly after seeing the path followed by the outline for the form. However, one form, the stand-alone *alif maksura*, proved to defy an æsthetic stretching. Items 1, 3, 4 and 5 of Figure 13 show various different attempts. The outline of this form had a strange situation that had never appeared before. In all but this form, the upper and lower strokes surrounding the stretched portions were implemented as the same number of four-point curves. For example, in the connecting-previous *baa*, both the upper and lower strokes consisted of two curves and in the stand-alone *qaf*, both the upper and lower strokes consists of one curve. Therefore, in both of these cases, the method of stretching both strokes is the same. In the stand-alone *alif maksura*, the lower stroke consists of one curve while the upper curve consists of two curves. It appeared that no matter how stretch in these curves was divided, the results were ugly.

After I had failed to get a pleasing stretch for the stand-alone *alif maksura*, I recalled Don Knuth's difficulties with getting a pleasing letter S when he was building the first version of the computer modern fonts with his then new METAFONT system. Interestingly, in a fashion, the *alif maksura* can be considered S shaped. After failing many times, he even considered writing his next book without the letter S. He remarked that the most important words, 'Donald E. Knuth' did not require a letter S. Well, I too despaired of producing a stretchable stand-alone *alif maksura* and considered writing this paper without a stretched stand-alone *alif maksura*, but in my case, the most important words 'Daniel M. Berry' requires a stand-alone *yaa* at the stretchable end of the second word, and the *yaa* is an *alif maksura* with two dots added underneath. So I *had* to find a solution. Knuth finally found a solution when his wife suggested making the S S-shaped. When I showed the problem to my wife, she did not suggest anything. Moreover, the obvious dictum of making the



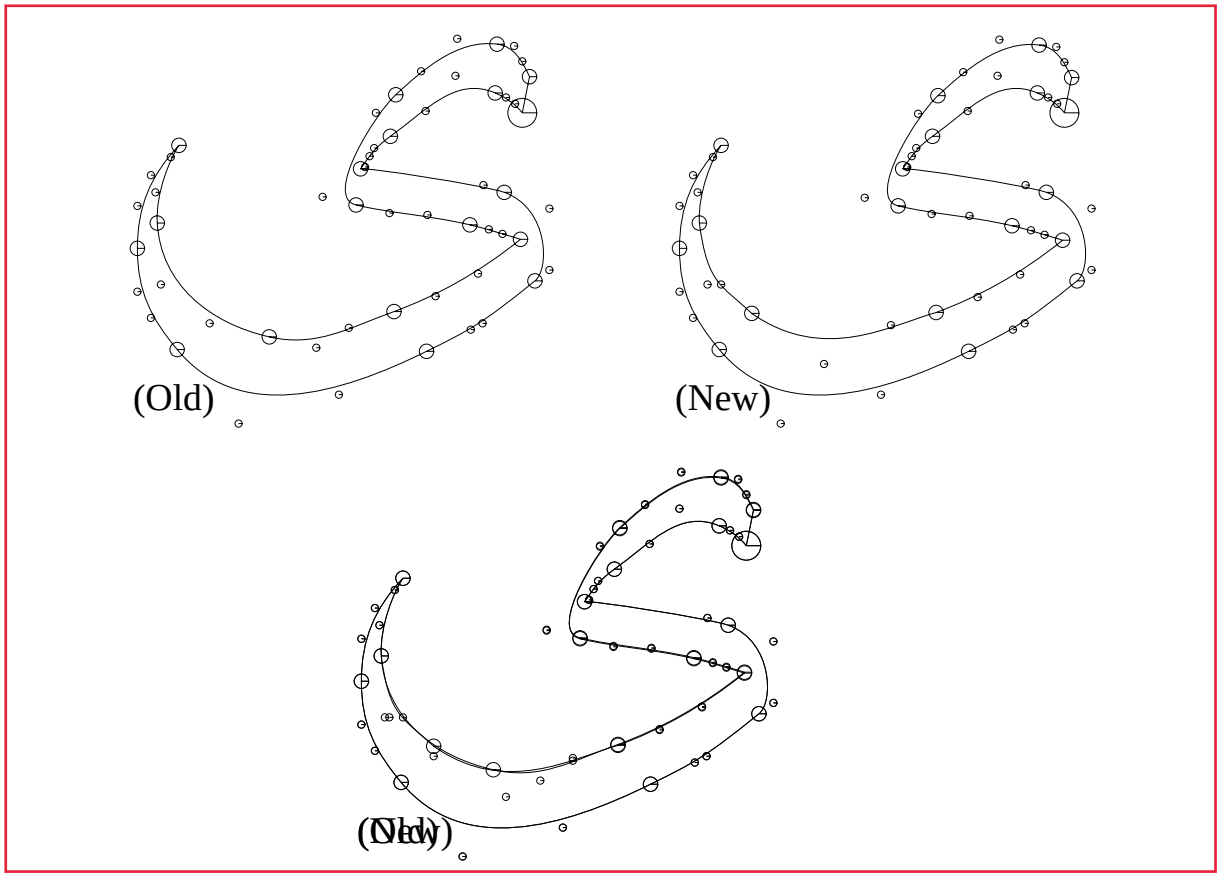
Bad

Figure 13. Various attempts to stretch the stand-alone alif maksura

stand-alone *alif maksura* stand-alone-*alif-maksura*-shaped did not help me think of any solution.

Realizing the hopelessness of trying to get along without the stand-alone *alif maksura* and its relatives, I cheated! I had noticed, as shown in item 2 of Figure 13, that the connecting-previous *alif maksura* stretched just fine. So I built a new stand-alone *alif maksura* from the bottom portion of the connecting-previous *alif maksura* and the top portion of the stand-alone *alif maksura.* This construction is item 6 of the same figure. This version stretched properly, but the new letter did not go as deeply below the baseline as it should. In the meantime, another student, Yaniv Bejerano, started working on the problem. His final solution was to change the outline of the form so that the upper stroke consists of only one four-point Bézier curve. It proved impossible to duplicate with one fewer curve the original outline, but by fine adjustment of the control points, Bejerano managed to come very close, closer than can be discerned by the human eye at even phototypesetter resolution. Furthermore, when we showed the results to a small sample of people here no one could see the difference at the usual point sizes. Figure 14 shows the old and new outline side-by-side and below that superimposed; note that the words ‘Old’ and ‘New’ overlap. The reader can see, in the superimposed outlines, that the upper strokes of the bottom

portion is slightly different. Item 7 of Figure 13 shows the final form adopted and a stretched version. As a side-effect to the investigation, Bejerano found an improved way to stretch the connecting-previous form, as shown in item 8 of the same figure.



Suitable fix

Figure 14. Old and new alif maksuras *individually and superimposed*

Stretching connections

Once it is understood how to stretch letters themselves with dynamic fonts, the same approach can be used to provide alternative, improved and more æsthetic methods to stretch connections, with and without the baseline filler. First, by making the filler a stretchable letter with a normal width of zero, it is possible to get smaller connection stretches than the size of one fixed-length filler. This makes it possible to avoid the problem of what to do when the needed stretch is not an integral multiple of the length of the fixed-length filler. Secondly, by applying the letter stretching technique directly to the connecting parts of connecting letters, it is possible to avoid using the filler entirely. The result is a smoother connection stretch; gone are the long flatness and the sudden corners where the filler or fillers meet the connecting parts of its neighbors. In their place is a gently sweeping curve with a slope of zero only momentarily where the two connecting parts connect. Figure 15

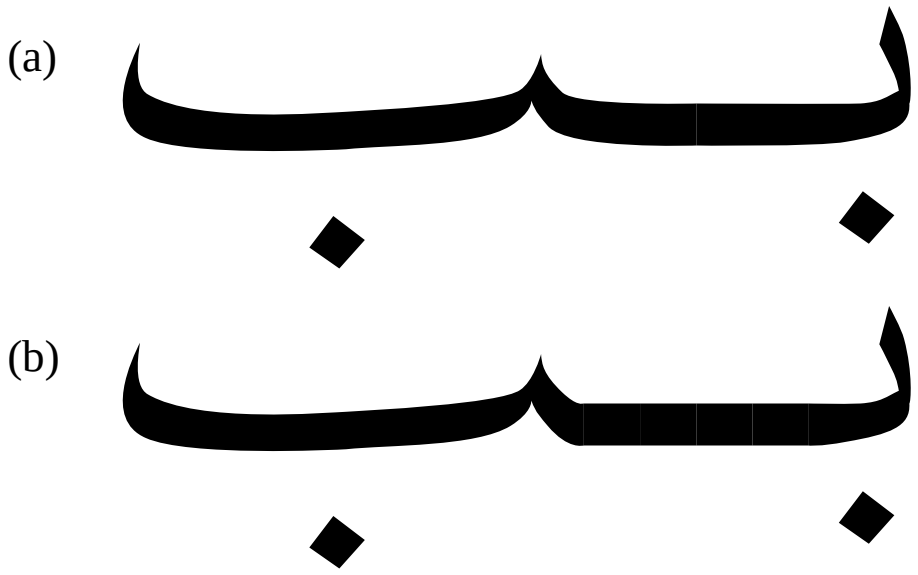


Figure 15. Stretchable connecting parts (a) vs. fillers (b)

shows the connection between the connecting after *baa* and the connecting before *baa* first done with stretching the connecting parts and then with a filler. The amount of stretching is the same difference accentuating amount in both cases.

In the POSTSCRIPT outlines, it is much easier to find the connecting parts of letters than the parts of letters themselves to be stretched, and once the connecting parts are found, it is easier to modify them for stretching than the parts of letters themselves to be stretched. Each connecting part consists of a four-point Bézier curve arriving at a vertical line segment, the vertical line segment, and a four-point Bézier curve leaving the vertical line segment; moreover, all such vertical line segments are exactly the same length since they have to be placed adjacent to each other. In the Arabic font used in this paper, each such line segment was either `0 56 rlineto` or `0 -56 rlineto`. Still moreover, the Bézier curves going in and out of the line segment have a slope of zero at the corner with the line segment. It is straightforward to stretch these zero-sloped Bézier curves in the method suggested by Figure 10.

MODIFICATIONS TO ffortid

The major changes required to ffortid are

1. the addition of the possibility of stretchable letters when replacing justification by stretching,
2. the addition of the possibility to stretch connections via a single stretchable filler of zero length rather than via sequences of fixed-length fillers,
3. the addition of the possibility to stretch connections by stretching the connecting parts of letters, say by putting half of the stretch amount into the connecting part of

the before letter and the other half into the connecting part of the after letter,
4. the addition of some more command line options to control the nature of stretching,
5. the addition of some new fields to the width tables shared by ditroff and ffortid.

The description of the changes is driven by explaining the new command line options and the new width table fields. The changes to the algorithm are apparent in this discussion.

The command line to invoke ffortid is of the form

`ffortid` [`-r`*font-position-list*] ... [`-w`*paperwidth*] [`--`*font-position-list*] ...
[`-s`[`n`|[[`l`|`c`|`e`|`b`][`f`|`2`|`m`[*amount*]|`a`|`ad`|`al`]]] [`-ms`[`c`|`l`|`w`] ... .

The job of ffortid is to take the ditroff output, which is formatted strictly left-to-right, to find occurrences of text in a right-to-left font, and to rearrange each line so that the text in each font is written in its proper direction. The `-r` and `-w` options were explained in detail in Section 8.2.5 of the Srouji and Berry paper [1].

The `--`*font-position-list* argument is used to indicate which font positions, generally a subset of those designated as right-to-left, contain fonts for Arabic, Hebrew, Persian or related languages. For these fonts, left and right justification of a line can be achieved by stretching instead of inserting extra white space between the words in the line. If requested by use of the `-s` argument described below, stretching is done on a line only if the line contains at least one word in a `--` designated font. If so, stretching is used in place of the normal distributed extra white space insertion for the entire line. The intention is that stretching soak up all the excess white space inserted by ditroff to adjust the line. If there are no opportunities for stretching or there are too few to soak up all the excess white space, what is not soaked up is distributed in between the words according to ditroff's algorithm. There are several kinds of stretching, and which is in effect for all `--` designated fonts is specified with the `-s` argument, described below. If it is desired not to stretch a particular Arabic, Hebrew, Persian, or other font, while still stretching others, then the particular font should not be listed in the `--`*font-position-list*. Words in such fonts will not be stretched and will be spread with extra white space if the original containing line is spread with extra white space.

The `-r` and the `--` specifications are independent. If a font is in the `--`*font-position-list* but not in the `-r`*font-position-list*, then its text will be stretched but not reversed. This independence can be used to advantage when it is necessary to designate a particular Arabic, Hebrew, Persian, or other font as left-to-right for examples, or to get around problems in the use of eqn, ideal, pic or tbl.

The kind of stretching to be done for all fonts designated in the `--`*font-position-list* is indicated by the `-s` argument. There are two relatively independent dimensions that must be set to describe the stretching, what is stretched and the places that are stretched. A stretch argument is of the form

`-s`*mp*

or

`-sn`

where *m* specifies the stretching mode, i.e. what is stretched, and *p* specifies the places that are stretched. The *m* and *p* must be given in that order and with no intervening spaces. The `−sn` means that there is *no* stretching and normal spreading of words is used even in `−−` designated fonts. The choices for the mode *m* are

1. `l` (letter ell): in the words designated by the *p*, stretch the last stretchable letter.
2. `c`: in the words designated by the *p*, stretch the last connection to a letter.
3. `e`: in the words designated by the *p*, stretch either the last stretchable letter or the last connection to a letter, whichever comes later.
4. `b`: in the words designated by the *p*, stretch either the last stretchable letter or the last connection to a letter, whichever comes later, and if it is a letter that is stretched and it is a connecting-previous letter then also stretch the connection to the letter.

The stretch arguments used to format this paper, except for the examples of the sections titled 'Stretching Examples' and 'Slanting Examples', are `−sea` and `−msw`.

Not all modes are available for all fonts. For example, fonts for Hebrew, whose letters are not connected do not support connection stretching. While Arabic, Hebrew and Persian traditionally do have letter stretching, not all fonts for them support letter stretching. ffortid attempts to stretch all `−−` designated fonts in the specified modes, but in any text, ends up doing only those stretches that are possible given in the text's current font. To allow ffortid to know what stretches are possible, the width tables for stretchable fonts have some additional lines that must come somewhere after the `name` line and before the `charset` line.

```
stretchable: letters connections
stretchable: connections letters
stretchable: connections
stretchable: letters
```

Each such stretchable font must have one of the first four lines. We now discuss the various ways that different kinds of stretch are achieved in the available fonts and how ffortid deals with each.

Stretching of letters requires a dynamic font which, by its very nature of not having a constant bitmap for a given font name, point size and character name, cannot be Type 1, in POSTSCRIPT terminology, and cannot be a bitmapped font. Therefore, not all Arabic and Persian fonts support stretching of letters. Moreover, within a dynamic font, not all characters are stretchable. Historically, only characters with strong horizontal components are stretchable, such as those in the stand-alone and connecting-previous forms of the *baa* family. Obviously, one cannot stretch totally vertical characters such as *alif*. Therefore, it is necessary to specify by additional information in the ditroff width table for a font which characters are stretchable. In the width table for an Arabic or Persian font, for each character that is not also an ASCII character, i.e. not also a digit or punctuation, and thus is neither connected or stretchable, one specifies after the name, width, ascender-descender information and code, two additional fields, the connectivity and the stretchability of the character, in that order. The connectivity is either

`N` for stand-alone,
`A` for connecting-after,

P for connecting-previous,
B for connecting-both or
U for unconnected, because it is punctuation or a diacritical, etc.,

and the stretchability is either

N for not stretchable or
S for stretchable.

Some examples of width table lines are

```
%%    125 2 045  percent

---   55 0 0101  U     N     comma
---   70 0 0105  U     N     hamza

---   129 0 0106 N     S     baa_SA
---   36 2 0102  N     N     alif_SA

---   113 0 0177 A     N     sad_CA
---   66 2 0215  A     S     caf_CA

---   43 2 0225  P     N     alif_CP
---   120 0 0274 P     S     baa_CP

---   53 0 0230  B     N     baa_CB
---   73 2 0261  B     S     caf_CB
```

Recall that `---` in the name field of a character means that it can be addressed only by `\N'`*n*`'`, where *n* is the decimal equivalent of the character's code. Only such lines will have the connectivity and stretchability fields. Also in the character name which is a comment in the table , `_SA` means 'stand-alone', `_CA` means 'connecting-after', `_CP` means 'connecting-previous', and `_CB` means 'connecting-both'.

For a Hebrew font, for which there is no notion of connectivity of letters, and therefore the position of the letters is irrelevant for deciding stretching, there is only the possibility of stretching letters. Some examples of width table lines for such fonts are

```
%     132 3 045  percent

---   95 3 0140  U     N     quoteleft=alef
---   92 3 0141  U     S     a=bet
```

In a dynamic font, there are two additional, alternative ways that stretching of connections can be achieved:

- The filler is a stretchable letter, normally of width zero, to which the total width of the filler is passed as the stretch amount.

- The connecting portions of all connecting letters are themselves stretchable in the same way as are the stretchable letters. In this situation, to achieve a total connection stretch of *x*, one would pass *x*/2 to each of the connecting-after portion of the before letter and the connecting-previous portion of the after letter.

The use of the first of these solves the problems caused by the fact that amount of a given connection stretch may not be integrally divisible by the width of the filler. A stretchable filler can be stretched to any amount. The use of the second improves the appearance of the connection stretch. While letter stretching is done with nice, smooth curves, connection stretching using the very straight filler is noticeably flatter and there are observable corners where the filler meets the generally curved connecting parts of its adjacent letters. While the fixed-size filler seems to be available on all Arabic and Persian fonts, stretchable fillers and stretchable connecting parts are available only with Type 3 POSTSCRIPT fonts, although it would be possible to provide a stretchable filler as the only locally defined character in a Type 3 font that falls to another Type 1 font for all the other characters, which are only virtual in the Type 3 font.

The ditroff width table for any font providing a stretchable filler or stretchable connecting parts must have an additional line to specify the nature of the connection stretch in the font, which must be one of the following.

```
connection stretch: fixed filler
connection stretch: stretchable filler
connection stretch: stretchable connections
```

This line must come somewhere after the `name` line and before the `charset` line. If none is specified, it is assumed to be the first. Therefore, it is not necessary to say anything new for the typical Type 1 or bitmapped font with a fixed-sized filler. Note that if a font allows different kinds of connection stretching, only one can be specified per mounting of the font specified in a single width table. If one wants to use the same font with different ways of stretching connections, one must mount the same font under different names in different width tables, each specifying a different kind of connection stretching.

ffortid implements the connection stretching that is requested by the `-s` command-line argument as well as it can using the kind of connection stretching available for the font being used. Thus, if one is not using fixed-sized fillers, ffortid ignores the various options put in to deal with the fact that an integral number of fillers may not fulfil the needed stretch.

Below, 'stretchable unit' refers to what is a candidate for stretching according to the mode. The choices for *p*, which specifies places of stretching, are

1. `f`: in any line, stretch the last stretchable unit.
2. `2`: assuming that the mode is `b` (both), in any line, stretch the last two stretchable units, if they are the connection leading to a stretchable connecting-previous letter and that letter, and stretch only the last stretchable unit otherwise. If the mode is not `b`, then this choice of places is illegal.
3. `m`*n* or `m`: in any line, stretch the last stretchable unit by an amount not exceeding *n* ems. If that does not exhaust the available white space, then stretch the next last stretchable unit by an amount not exceeding *n* ems, and so on until all the available white space is exhausted. If *n* is not given, it is assumed to be `2.0`. In general, *n* can be any number in floating point format.

4. `a`, `ad`, or `al`: in any line, stretch all stretchable units. In this case, the total amount available for stretching is divided evenly over all stretchable units on the line identified according to the mode. Since the units of stretching are the units of device resolution, the amount available might not divide evenly over the number of places. Therefore, it is useful to be able to specify what to do with the remainder of this division. This specification is given as an extension of the stretching argument. The choices are `d` or `l`, with the former indicating that the excess be distributed as evenly as possible to the spaces between words and the latter indicating that the excess be distributed as evenly as possible in stretchable letters only. The latter is the default if no choice is specified.

Sometimes, it is desirable to be able to manually stretch connections or letters to achieve special effects, e.g. more balanced stretching or stretching in lines that are not otherwise adjusted (e.g. centered lines). Stretching a connection can be achieved by using the base-line filler character explicitly as many times as necessary to achieve the desired length or in the ditroff line drawing escape sequence to whatever length is desired, e.g.

```
\l'2m\(hy'
```

will draw a string of adjacent base-line fillers of length 2 ems.

To achieve stretching of letters, one should immediately precede, with no intervening white space, the letter to be stretched by the escape sequence

```
\X'stretch'\h'n'
```

where *n* is a valid length expression in ditroff's input language. ffortid is prepared to deal with the output from ditroff generated by this input to generate output that will cause the letter immediately following it to be stretched by the length specified in *n*. For example,

```
\X'stretch'\h'1m'\N'70''
```

will cause the character whose decimal code is 70 to be stretched by 1 em. The output will fail to have the desired effect if the letter following the escape sequence is not a stretchable letter.

Two similar additional escape sequences are provided for explicit stretching of connecting parts of letters.

For finer control over stretching, it may be desirable to inhibit automatic stretching on manually stretched connections and letters. Accordingly, three command line flags are provided for this purpose:

1. `–msc`: do not automatically stretch manually stretched connections.
2. `–msl`: do not automatically stretch manually stretched letters.
3. `–msw`: do not automatically stretch any word containing any manual stretching.

STRETCHING EXAMPLES

All of these samples use a very narrow column width to exaggerate the differences and to

force whatever stretching that is done to be very pronounced. In all the samples, the last line has no stretching since it is not full and, in the normal word-spreading realm, no additional space would appear between the words. Because only one setting of the stretch option applies for the whole of a given document, all the samples were typeset as other documents and were included in this paper as encapsulated POSTSCRIPT figures. Finally, each example is designated by its language and the stretch option that was used to typeset it.

In Hebrew, letters are not connected. Therefore, only letters are stretchable, and the width tables reflect this fact. Therefore, all −sc*P*s, for any place *P*, look like −sn, and each −sb*P* and −se*P* looks like the corresponding −sl*P*, with the special case of −sb2 looking like −slf. Therefore, only the −sla and the −slf examples are shown in Figures 16 and 17.

In Arabic, both letters and connections are stretched. The first group of examples, the −s*M*fs, show stretching in final places in a line and the second group, the −s*M*as shows stretching in all places on a line. As expected, the stretching is more pronounced in the −s*M*fs. For −scf, shown in Figure 18, in all non-last lines, the connections absorb all of the stretch. The effect is most pronounced in lines 2 and 3.

Figure 19 shows the result of the −slf option. The final stretchable letter of each line absorbs all the stretch, with the effect being most pronounced in line 2. In lines 1 and 6, the last stretchable letter is not the last letter in the line. In line 3, there is no stretchable letter at all, so the words are left spread apart.

For −sef, as shown in Figure 20, the final stretchable letter or connection, whichever is later (left most), and not both, gets stretched. The effect is most pronounced in lines 2 and 3. In line 2, the last letter is stretchable so it gets all the stretch. In line 3, the final letter is not stretchable, but it is connected to the previous letter, so that connection absorbs all the stretch.

The −sb2 option is similar to the −sef option, except that, as shown in Figure 21, when a letter would be stretched and that letter is connected, then the letter and its connection split all the stretch. In line 2, each of the main body and the connecting part of the final *taa* absorbs half of the total stretch. In line 3, the final letter is not stretchable, but it is connected; so, that connection absorbs all the stretch. In line 4, the final letter is stretchable, but it is not connected; therefore the letter absorbs all of the stretch.

For the −s*M*as, the total stretch is distributed over all candidates according to the *M*. Thus, each individual stretch tends to be shorter than for the −s*M*fs. Figure 22 shows the result of the −sca option, which causes only and all connections to be stretched.

For −sla, it is expected that all stretchable letters in a line be stretched the same amount. As is shown in Figure 23, for all lines, except lines 2 and 3, the stretches are hardly noticeable, since each stretch is a fraction of the total stretch for the line. Line 2 has only one stretchable letter, and it absorbs all the stretch. Line 3 has no stretchable letter; therefore, the words remain spread with additional white space.

For −sea, each word has at most one stretch, which is either in the body of the last stretchable letter or in the last connection, whichever is later in the word. In lines 2 and 3 of Figure 24, there are few enough such places that the stretch per place is quite pronounced.

As can be seen in Figure 25, the −sba case differs from the −sea case in line 2. Both the last letter and its connection are stretched the same amount as the other stretchable places in the line, which just happen to be connections.

For Persian, only examples with results differing significantly from the corresponding Arabic examples are shown. With the Persian text, the –sb2 case yields more pronounced results. There are several occurrences of connecting before *ye*s in lines 5, 6 and 7 of Figure 26 that end up being the stretch places of their lines. Each of these lines shows that *ye* and its before connection stretched the same amount.

In the –sef, –scf and –slf examples, which are not shown, the same *ye*s are stretched, but all the stretch is absorbed by the body of the letter, the connection, and the body of the letter, respectively. Among the –s*M*as, which are not particularly remarkable, only the –sea example is shown in Figure 27.

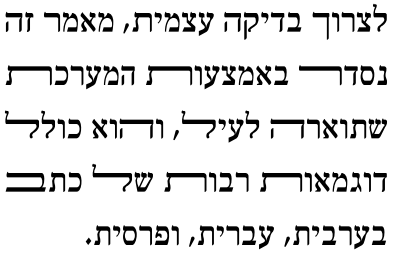


Figure 16. Hebrew with –sla

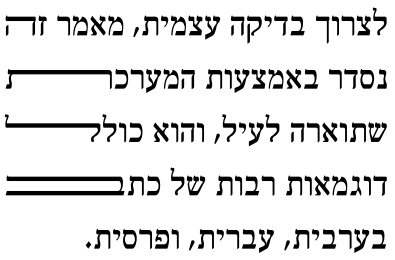


Figure 17. Hebrew with –slf

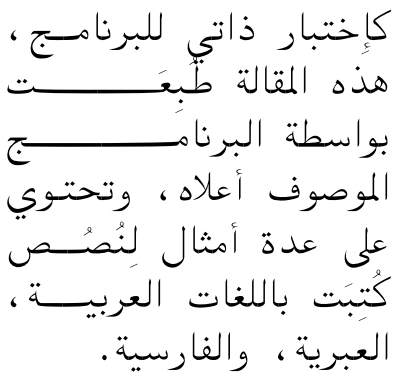


Figure 18. Arabic with –scf

كإختبار ذاتي للبرنامج، هذه المقالة طُبِعَت بواسطة البرنامج الموصوف أعلاه، وتحتوي على عدة أمثال لِنُصُص كُتِبَت باللغات العربية، العبرية، والفارسية.

Figure 19. Arabic with –slf

كإختبار ذاتي للبرنامج، هذه المقالة طُبِعَت بواسطة البرنامج الموصوف أعلاه، وتحتوي على عدة أمثال لِنُصُص كُتِبَت باللغات العربية، العبرية، والفارسية.

Figure 20. Arabic with –sef

كإختبار ذاتي للبرنامج، هذه المقالة طُبِعَت بواسطة البرنامج الموصوف أعلاه، وتحتوي على عدة أمثال لِنُصُص كُتِبَت باللغات العربية، العبرية، والفارسية.

Figure 21. Arabic with –sb2

كإختبار ذاتي للبرنامج، هـذه المقالـة طُبِعَـت بواسطـة البرنامـج الموصوف أعلاه، وتحتوي على عدة أمثال لِنُصُص كُتِبَت باللغات العربيـة، العبرية، والفارسية.

Figure 22. Arabic with –sca

كـإختبار ذاتي للبرنامج، هذه المقالة طُبِعَـت بواسطة البرنامج الموصوف أعلاه، وتحتوي على عدة أمثال لِنُصُص كُتِبَت باللغات العربية، العبرية، والفارسية.

Figure 23. Arabic with –sla

كإختبار ذاتي للبرنامج، هـذه المقالـة طُبِعَـت بواسطـة البرنامـج الموصوف أعلاه، وتحتوي على عدة أمثال لِنُصُص كُتِبَت باللغات العربيـة، العبرية، والفارسية.

Figure 24. Arabic with –sea

كإختبار ذاتي للبرنامج، هـذه المقالـة طُبِعَـت بواسطـة البرنامـج الموصوف أعلاه، وتحتوي على عدة أمثال لِنُصُص كُتِبَت باللغات العربية، العبرية، والفارسية.

Figure 25. Arabic with –sba

بعنوان يك خودآزمائی، اين مقاله با استفـاده از سيستمی كه در اينجـا تشريح ميشود نقشبندی شده و مثالهائـی از نوشته‌های عربـی، عبری، و فارسـی در متن خود دارد.

Figure 26. Persian with –sb2

بعنوان يك خودآزمائی، اين مقاله با استفاده از سيستمی كـه در اينجـا تشريح ميشود نقشبندی شـده و مثالهائی از نوشته‌های عربی، عبری، و فارسی در متن خود دارد.

Figure 27. Persian with –sea

An imitation, in which each letter is stretched by one em, of the calligraphic example of Figure 3 is shown below.

This example shows that the balanced stretching can be achieved by manual control, but it also shows that the font being used is not very good for stretching. Now that the technique to do stretching has been demonstrated, it is necessary to design a font whose letters stretch more gracefully.

On the first page of the paper, the stand-alone *yaa* in the author's Arabic name and the *resh* in the author's Hebrew name were stretched manually for the purpose of making each family name approximately the same length as its corresponding private name.

SLANTED BASELINE WRITING

Examination of examples of Persian printing shows that

1. it uses fonts whose characters are observably different from those of fonts typically used for Arabic,
2. stretching of characters seems to be more prevalent than in Arabic printing, almost to the exclusion of stretching of connections, and
3. words, but not lines seem to be written on a slanted baseline.

These observations are clear in Figure 28, which shows a sample of some Persian printing from the author's favorite Persian cookbook [15]. The font that is used in the cookbook excerpt is called Nastaliq. To date, neither the author nor any others contributing to an Internet Arabic Script group have seen a decent POSTSCRIPT outline font for Nastaliq or any other font with the distinctly Persian flavor. As a consequence, at present, computer-aided Persian typesetting seems to be done using Arabic fonts for results that are not entirely æsthetic to the Persian eye.

First, by making copies of a large variety of samples and marking these copies up with lines showing the flow of words and lines running through the slanted baselines, it was determined that while the line flows horizontally, the baseline of individual words or individual groups of consecutive short words is generally slanted 22° downward from the horizontal. (Recall that Persian text flows from right to left, so the slant is described in these terms.) The sequence of the center points of the slanted-word-or-group-of-words baselines for a single line of text describe a single horizontal line segment, which is taken as the axis or baseline of the whole line of text. Figure 29 shows a schematic of the baselines of words or groups of words that form a single line.

Furthermore, it appears that the beginning of any but the first word on a line is immediately above the end of the previous word. That is, from the point of view of projections of the words onto the horizontal axis of the line, there is no spacing between words. The separation of the words is achieved by the vertical clearance between the end of one word and the beginning of the next right above it. In the above, when a group of consecutive short words is treated as a unit for slanting, there is some horizontally visible white space between the words. It appears that merging short words into a larger unit for slanting is a physical necessity as there would not be enough vertical clearance between one short word

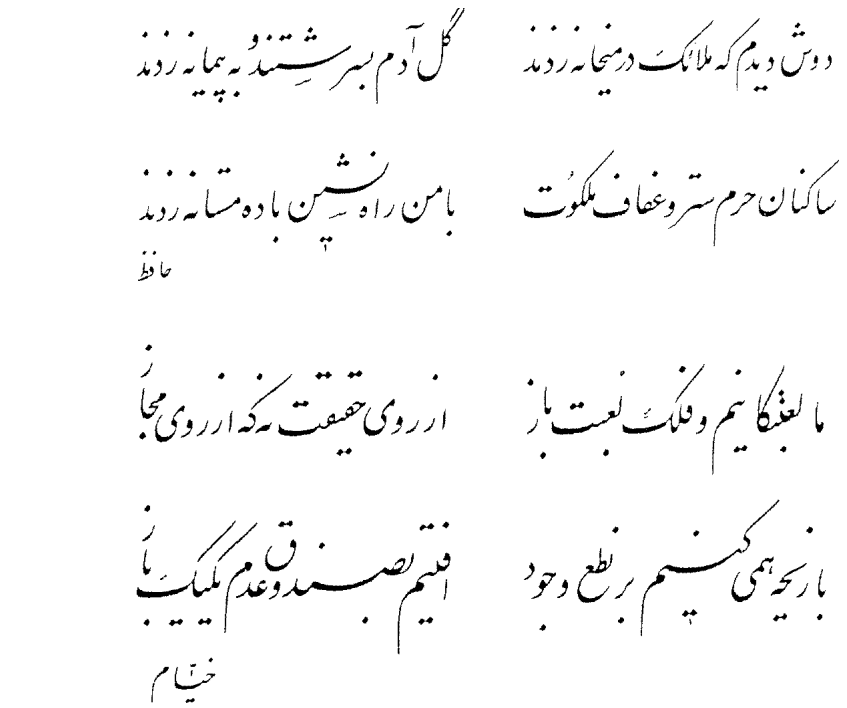


Figure 28. Persian printing

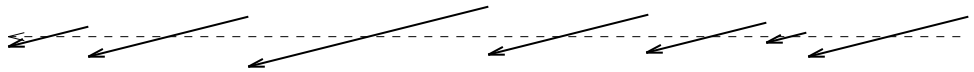


Figure 29. The slanted baselines of words in one line

and the next if each were slanted separately. Finally, it appears that stretching is applied mainly to letters and not to connections.

It is this author's opinion that the reason no one has invested the considerable effort to produce a suitable Nastaliq font is that it was not understood how to implement in POSTSCRIPT and use in formatters the slanted baseline aspect. This section remedies this problem by analyzing the slanted baseline requirement and showing how it can be implemented in POSTSCRIPT fonts and used by formatters to achieve a very Persian appearance. Since the author does not even have a flat version of Nastaliq available as a Type 3 POSTSCRIPT font, the author applied the slanting to the Arabic Naskh font with stretchable forms to produce a font named Persian Naskh also with stretchable letters, and he used this font with a modified ffortid that knows how to use a slanting font to achieve the proper baseline slanting. It is hoped that the availability of the technology to define and use slanted-baseline-printing fonts with stretchable forms will provide the incentive for a good typographer to develop a high quality Nastaliq POSTSCRIPT font definition.

First, the method of slanting POSTSCRIPT fonts is described. Then the modifications to ffortid and to ditroff width tables to support the use of slanting fonts is described.

SLANTING FONTS

As mentioned, it was decided to apply slanting to a new font called Persian Naskh which is a copy of a stretchable Arabic Naskh except for the stretching. The simplest way to achieve the slanting in all characters is to modify the font matrix so that what was horizontal is now slanted 22° upward (POSTSCRIPT fonts view characters as being laid out from left to right; therefore the slant is considered in the opposite direction from for the normal right-to-left flow), and what was vertical is still vertical. Thus the font matrix defining line was changed from

```
/FontMatrix [.001200 0 0 .001200 0 0] def
```

to

```
/FontMatrix [.00120 .0004495 0 .00120 0 0] def %22 degrees
```

The value 0.0004495 is $tan(22°)\times 0.0012$, where 0.0012 is both the x and the y value from the matrix

```
[.001200 .0004495 0 .001200 0 0] .
```

Once this font is defined and set, one can print any word with a slanted baseline by moving to the position of the right end of the word, below the line's axis and then showing the word. Figure 30 shows a slanted printing of the word *salaam*. This output was achieved by

Figure 30. Slanted salaam

simply finding and setting the Persian-Naskh font and issuing a `show` command with the characters, from left to right, of the word *salaam*, as its string argument. The use of the font matrix to achieve the slanting insures that what the POSTSCRIPT `show` mechanism believes is a move in the x direction by the width of the last printed character is in fact a move upward and to the right. Figure 31 shows the example of Figure 5 of the Srouji and

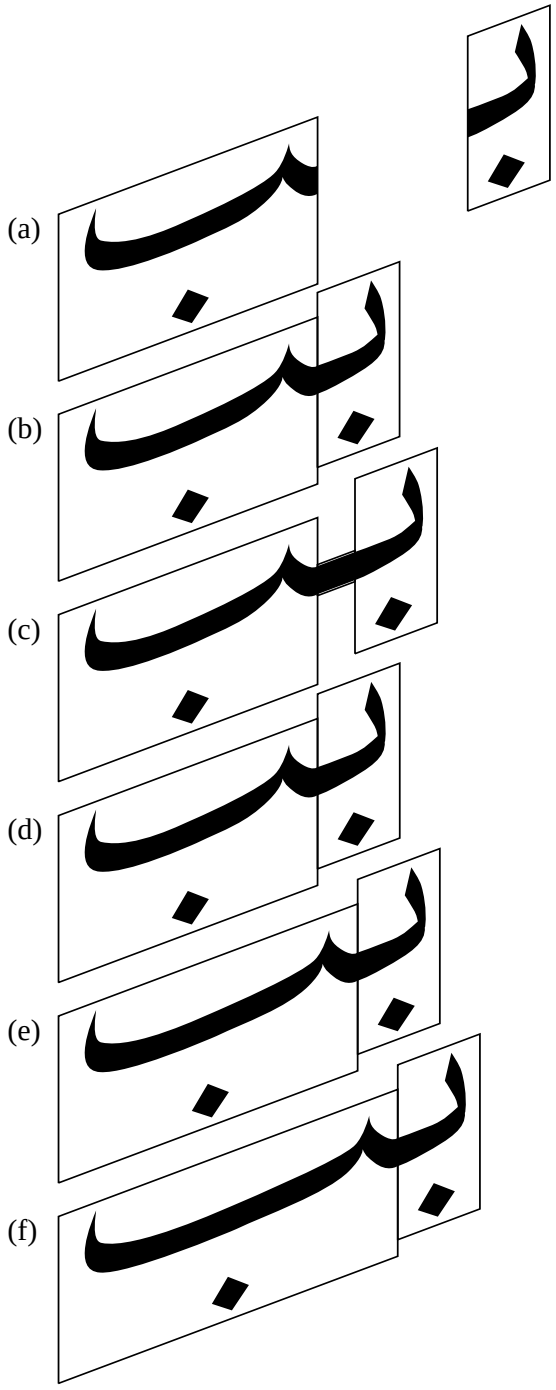


Figure 31. Non-stretched and stretched

Berry paper [1] printed using the Persian Naskh font. The purpose of this example is to show that both forms of stretching work quite handily in the presence of slanting.

MORE MODIFICATIONS TO ffortid

Again, there were three main kinds of modifications to ffortid:

1. The layout algorithm of ffortid is changed so that it puts each word, after justification, either by spreading words or stretching, into its own slanted baseline.
2. New command-line options are added.
3. The width tables shared by ditroff and ffortid are modified slightly.

These changes are discussed in reverse order.

The width tables have to be modified slightly so that there is a line announcing that the font described by the table is slanted and that line gives the amount of slant in degrees, which must agree with the angle implicit in the font matrix of the font. In addition, to cause the beginning of one word to be just above the end of the previous with no horizontal movement, it is necessary to lie to ditroff and tell it that the normal interword space is 0, while providing another unpaddable space to be used explicitly by the input document to group short words together into a single slantable unit. First, ditroff would not accept a width of 0 for the space; it took it as the default width of ⅓ em. So, a space of width 1 was tried, and it was accepted by ditroff and it produced visually acceptable results which the human eye could not distinguish from a space width of 0. Recall that the units of the space width is the unit of device resolution. Thus, for Adobe transcript's psc device, a width of 1 is a width of 1/576 inches. Figure 32 shows the second paragraph of the Persian abstract with the same spacing between the words but with nothing slanted. The reader can see that the words appear run together with no space between them. The unpaddable space was provided as the character named by the ditroff special character `\(ps`, for 'permanent space' whose width is set to what was the width of the space before setting it to 1. The name for the unpaddable space had to be a two-character name that is mnemonic and is not in the special font; if it were in the special font, then it would not be possible to address the like-named special font character without explicitly mounting the special font.

بعنوان یك خود آزمائی ، این مقاله با استفاده از سیستمی که در اینجا تشریح میشود نقشبندی شده و مثالهائی
از نوشته‌های عربی ، عبری ، و فارسی در متن خود دارد .

Figure 32. Unslanted Persian text spaced as for slanted printing

The new command-line option is to indicate which font positions contain slanted fonts. Of course, it will not work to attempt, through the setting of this option, to slant a font whose width table does not say that it is slanted. However, the slanting algorithm, described in the next paragraph, does not happen to a font not in this list.

The change to the ffortid layout algorithm is that after all characters have been put in visual order and all justification and stretching requested by the user have been applied, the projection of the starting position of each word on its text line's axis is known. Note that the justification and stretching are affected by the fact that the space is of width 1. Of course, if stretching is not indicated, then as a result of justification, words may be more than 1 unit apart as a result of the additional white space inserted by the spreading of the words. If stretching is specified, then if there are stretchable places none of the interword gaps should be spread, as stretching should absorb all of the excess white space.

At this point ffortid calculates the width of each word and then inserts before the beginning of each word, of length *len_word*, a vertical movement to $v = \tan(\alpha) \times \frac{len\_word}{2}$ units below the line's horizontal axis, where α is the angle of slant, usually 22°, determined from the font's width table. To avoid the line's axis drifting as a result of round-off error in digitizing the floating point tangent values, the vertical positioning before the printing of each word is accomplished by using the absolute vertical positioning instruction with an argument that is the sum of the *y* of the line's axis and the calculated movement *v* for the word.

The Persian abstract of this paper was typeset in this slanted pseudo-Persian font. In preparing this example, it was learned that it is not a good idea to slant text that contains non-slantable text such as that in Latin letters. However, if one is going to slant such text anyway, then Persian text which is immediately adjacent to Latin text, such as parentheses and other punctuation or a single letter grammatical article or conjunction, should be in a non-slanting font whose appearance is coordinated to the slanting font. In this case, since the slanting Persian Naskh is a slanting version of Arabic Naskh, Arabic Naskh was used as the non-slanting font whose appearance is coordinated to that of Persian Naskh!

SLANTING EXAMPLES

The same text used earlier for Persian examples is used for the slanted Persian examples. Only the −sl*P*, for any place *P*, examples are exhibited, because it appears that connection stretching is not used in slanted writing. The slanted Persian abstract at the beginning of the paper is typeset, as are all the abstracts, with −sea, and it shows connection stretching in slanted text. In these examples, shown in Figures 33 and 34, consecutive words are grouped together as single slanted units, in order that all slanted units in a line are approximately the same length. This way, no individual word extends far beyond the others and no individual word is so short that it does not have a clear separation from its neighbors. Between two consecutive words of a single slanted unit is an unpaddable space built into the slanted Persian font, addressed by \(ps in ditroff. These unpaddable blanks are not candidates for stretching if there is nothing stretchable in the line and are not candidates for shrinking to give way to stretching. They ensure horizontal separation of the words that make up a single slanted unit.

EVALUATION OF SLANTED BASELINE WRITING

Farhad Arbab was being very polite to an old friend when he said, about the above examples of slanted baseline writing,

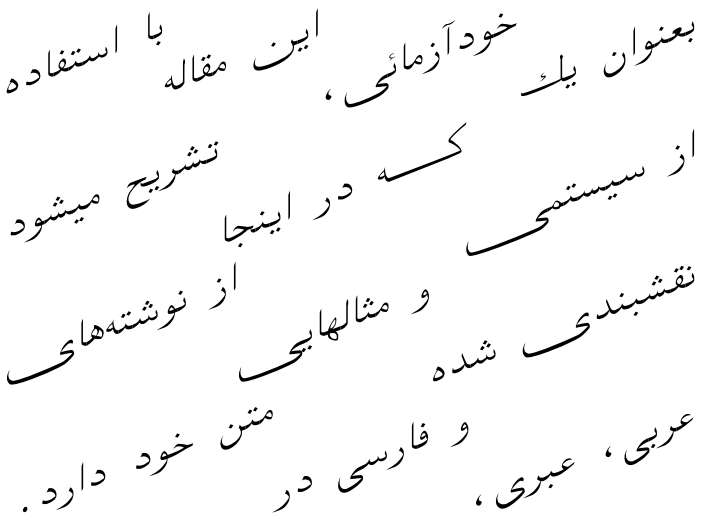


Figure 33. Slanted Persian with –sla

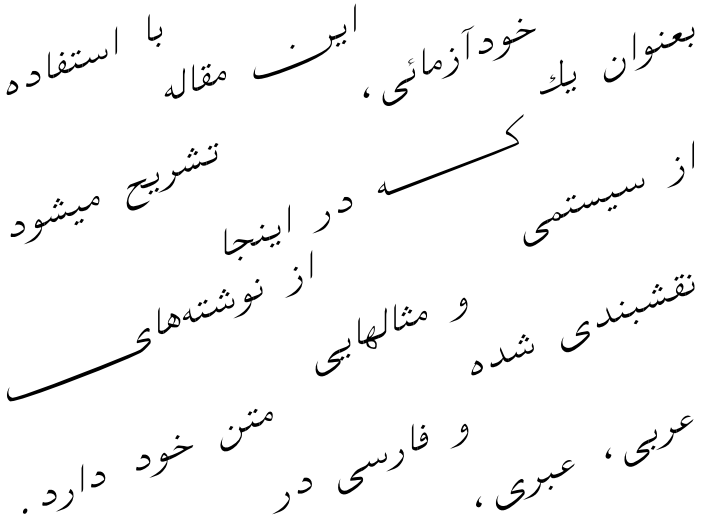


Figure 34. Slanted Persian with –slf

Your slanted version looks interesting, but I have never seen this style used anywhere in printing! What I see is something between using a slanted font in printing (which is common) and a certain calligraphic style (which I've never seen it

> with printed text) where words are not only slanted, but also somewhat curved. What you have is neither. It is certainly interesting as a new style, but it is not very natural to read. The problem with it is that there is too much distance between the ending of a word (somewhere below the baseline, and the start of the next word (somewhere above the baseline) and these discontinuities make it difficult to read. In calligraphy, they play all kinds of tricks, including subtle curving of the baseline, to make the inter-word flow continuous for the readers' eyes. What you have here is too mechanical and the inter-word discontinuities make it not easy to read. Nevertheless, I think one could use it as a specific style for situations that can tolerate special effects.

I had countered that it was clear that I was not using the right font, because it was simply not available, and that perhaps if the technique were applied to a more Persian font, the results would be more pleasing. However, his remark about the baseline being curved prompted a closer examination of the examples of Figure 28. The baselines indeed are not straight lines, but curves that start off downward right-to-left at 22° and end up horizontal. As suggested by Figure 35, such a curve is quite naturally a Bézier curve with a 22° and a 0° tangent lines.

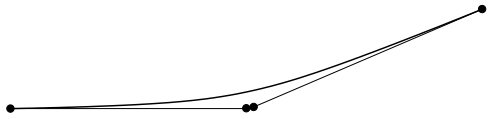


Figure 35. Curved Baseline as a Bézier Curve

This sort of warping of the baseline of text is precisely the function of Adobe's TypeAlign [16]. However, TypeAlign seems to be able to bend only text from Type 1 fonts, and stretching requires Type 3 fonts. Perhaps TypeAlign's transformations can be applied directly by a more general Type 3 font BuildChar routine. This is left as future work.

RELATED WORK

As far as this author has been able to determine, no other Arabic, Hebrew or Persian formatting system targeted for high quality fonts provides letter stretching and slanting the baselines of words. This author is aware of Yannis Haralambous's ScholarTEX [17], Klaus Lagally's ArabTEX [18], and Don Knuth and Pierre MacKay's TEX-XET [19]. The closest that this author has seen are systems that provide multiple forms of stretchable forms that can be selected by the user. TEX systems typically use fonts generated by METAFONT, which are usually bitmaps. Bitmap-based formatters would be hard put to provide dynamically stretchable characters that are necessary to implement the solution outlined in this paper and implemented with ditroff/ffortid, a system that supports easy use of POSTSCRIPT outline fonts. There are options to use POSTSCRIPT outline fonts with TEX, but to date, only Type 1 fonts seem to be available for the METAFONT-generated fonts. It would be necessary to obtain Type 3 versions of these fonts so that the character definitions can be edited to make them dynamic.

The work of Ameur Khettar at Academie de Montpellier [20] provides a number of algorithms for dealing with ligatures and with stretching and *shrinking* of letters. The work appears to carry out these algorithms with very low resolution bitmapped screen fonts with very flat, one-pixel wide strokes, which are easy to stretch by adding more pixels to the flat stroke to be stretched. The algorithms are very useful because they are intended to be carried out in real time in a WYSIWYG editor formatter in which a letter's form changes as soon as its after-neighbor is entered or changed.

CONCLUSIONS

This paper has described the addition of full stretching and slanting to Hebrew, Arabic and Persian typesetting with ditroff/ffortid. The changes necessary to the POSTSCRIPT fonts and the ffortid ditroff postprocessor were described. As to whether the results are æsthetically pleasing is left to the reader. However, if the æsthetics are lacking, perhaps applying the techniques described in this paper to better designed fonts, perhaps designed specifically to be stretched and slanted, will yield more pleasing results. It is hoped that the proof of principle given in this paper increases the incentive for developing these better fonts.

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