

Binary bitmap image transforms for computer font hinting

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Abstract

The paper describes the approach for automatic font hinting. The main idea lies in structural analysis of font glyphs basing on skeleton representation and establishing incidence between this representation and the boundary.

Introduction

From the mathematical point of view design and use of computer font in general consists of several consequent transformations of images between continuous and discrete forms:

1. a designer is drawing a font on paper (continuous form);
2. images is scanned into a computer (discrete form);
3. bitmaps are transformed into outlines represented by splines (again continuous form);

4. outline samples are used for generating of scaled bitmaps for raster devices (again discrete form).

We are discussing stages 3 and 4 of this process. Their backbone lies in the design of an outline font description which in future could be reproduced on raster devices. Such outline representation consists of two parts: boundary and hinting description. Boundary description represents all font glyphs as regions limited by closed paths. Hinting description includes instructions on path distortion before scan-conversion in order of aesthetically correct reproduction of glyphs on a raster device.

Speaking about fonts we mean here two popular outline font formats: PostScript Type 1 and TrueType. Our considerations are applicable to both formats, but all samples and testing routines were performed over TrueType fonts, because TrueType hinting is open, more controllable and more time consuming.

Today outline font development is performed with special font editing software. The most popular tools are ScanFont/FontLab by FontLab Ltd. and Fontographer by Macromedia. Both of them provide all necessary components to design and build PostScript and TrueType fonts, but this work requires high human intervention. Formation of outline description could be more or less automated due to tracing algorithms of scanned images, though it requires thorough control of the artist, but high quality font hinting is practically always done manually, it requires high qualification and very hard work. Even the most powerful TrueType hinting tools like FontLab, VTT by Microsoft or StingRay/TypeMan by Type Solutions don't show acceptable quality in automated mode.

This article describes a certain approach to font hinting automation.

1. Outline Font Representation

Each font glyph could be regarded as some black region on the white background. Region boundary consists of several closed paths. Each outline is represented by a compound spline curve, consisting of parameter splines (Figure 1a). A compound spline curve, in its turn, is represented by a number of control points forming a so called control polygon (Figure 1b). Control points are of two types: ON type points lie directly on the boundary, and OFF type points are outside the boundary. Two closely standing control points of ON type give linear segment of the boundary - spline of order 1. A combination of ON and OFF points gives higher order splines. A control polygon is definitely deter-

mining a compound spline curve. Thus, control polygons give glyph outline in font formats.

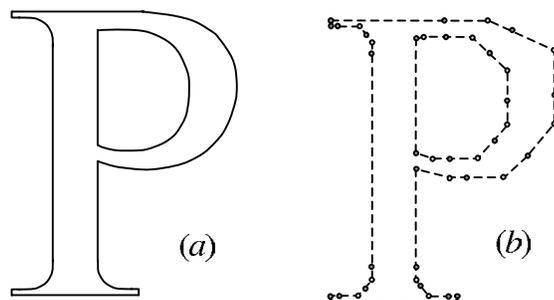


Figure 1: (a) Glyph outline representation by compound spline curves, (b) control polygons of compound spline curves.

Font glyphs on a raster device are reproduced by outline scaling with following scan-conversion. When scaling, coordinates of the control polygon vertex are multiplied by a certain scale factor depending on the device resolution and a required size of glyph image being formed. Scan-conversion includes activation of raster pixels, centers of which have fallen inside the region limited by outlines being scaled.

Nevertheless, one more operation is needed between scaling and scan-conversion due to the aesthetic requirements to font glyph images (stem widths in the letters should be the same, they should be symmetric etc.). It consists of special distortion of scaled outlines before scan-conversion, so that shifts inevitable in discretization could meet certain aesthetic requirements. Without this distortion (Figure 2) images are of low quality, in particular, stem widths are inconsistent and glyphs not always symmetric. Such effects are better seen on low resolution raster devices.

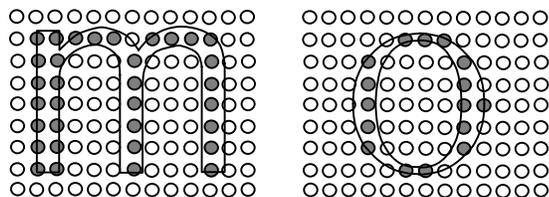


Figure 2: Scan-conversion of unhinted outlines.

Instruction preparation process for such distortion is called font hinting. Hinting is an important stage in computer font development. Quality of the font to a great extent depends on it. This is a long and labor consuming procedure which requires a high qualification of the operator. Hinting is based on the analysis of font glyph structure, exposure of stems, serifs, symmetric elements etc. This procedure could hardly be automated. A human eye easily finds structure elements of glyphs, but automatic exposure of them through outline representation is a very hard task. Two points in different boundary paths "do not know" that they belong to one stem and in distortion process should move simultaneously. Belonging to one stem is a global property of the points, but outline representation of the boundary gives only local properties: each point "knows" only its neighbors in the outline.

In order to determine global structure properties of the glyph boundary, let us use its skeleton representation.

2. Hinting Based on Glyph Skeleton Representation

A region skeleton is a set of all medial axes. A medial axis consists of points having at least two closest equidistant points on the region boundary. A skeleton part inside the region forms its internal skeleton, and the one outside the region - its external skeleton. Internal skeletons of font glyphs are enough to analyze their structure.

Each point of the internal skeleton is closely related to a circle (the above point being its center), covering at least two nearest points of the region boundary. As inside this circle there are no other boundary points it is called an empty circle. A conjunction of all empty circles is definitely determining an initial region. In reality each empty circle is fully inside the region, each point of the region belongs to a certain empty circle, and a curve turning round the whole circle family (envelope curve) forms a region boundary.

An internal skeleton together with the set of empty circles is called a skeleton representation of the region. Figure 3 shows a skeleton and skeleton representation of glyph P of Figure 1a. It is natural that Figure 3b shows only randomly chosen empty circles, as the number of them is infinite.

Skeleton representation carries information about global structure properties of the image. Actually, long line segments of the skeleton correspond to line stems. At the same time it is easy to find out which of them are vertical, horizontal and sloping. Besides, it is possible to judge upon the belonging of boundary fragments to the same stem, as in this case we could find circles touching the counter sides of the stem line.

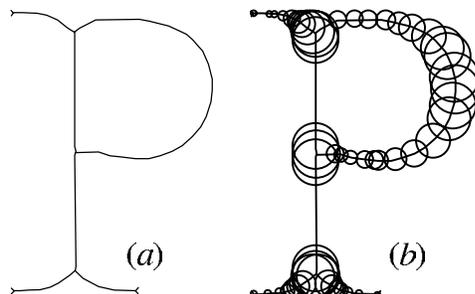


Figure 3: (a) skeleton, (b) skeleton representation.

Evidently it would be convenient to describe hinting also by skeleton terms, as it is easy to move stems and change their thickness by displacing the centers and changing the diameters of empty circles. Nevertheless, all common font formats are operating with outlines, as existing algorithms and raster-display devices are the most effective in solving the problem of region scan-conversion having an outline representation of its boundary. Thus, it would be desirable to combine possibilities to manage the form of the object, given by the skeleton representation, with effective rasterization of outline representation. In the suggested approach we try to implement this idea, the approach includes the following stages:

- forming a skeleton representation of the glyph based on its outline representation;
- exposing structure elements of the glyph by its skeleton representation, the form of structure elements description being subset of empty circles, called control discs;
- establishing incidence of glyph structure elements (control discs) and control polygons describing a glyph boundary;
- describing deformation of glyph skeleton representation in rasterization as distortion of control discs and alteration of their diameter;
- describing deformation of glyph outline representation as distortion of control polygon vertexes according to the shift and distortion of control discs.

3. Formation and Analysis of Glyph Skeleton Representation

To form a skeleton of the region with nonlinear boundary is rather a difficult task. It is easier to form a skeleton of the region with piecewise linear boundary, the so called polygonal region [1]. A polygonal region skeleton consists of straight line and parabolic segments. Therefore, let us first approximate outline boundary by polygons formed by chords of source outline (Figure 4). Chord length is chosen to make approximation accurate enough, that is deviation of the chord from the boundary should not exceed a predetermined value.

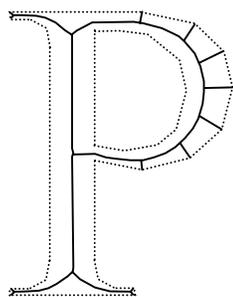


Figure 4: Skeleton of the polygonal region.

The skeleton of the formed polygonal region is not isomorphic to the skeleton of the source region - it has "weed" branches leading to "corner" points of the boundary. But these branches can easily be revealed and excluded from the process [2]. Thus, cleaned in such a way skeleton is very well approximating the skeleton of the source region.

There is a finite and small number of empty circles enough to describe structure elements of glyphs. We call them control discs. Through analysis of skeleton representation of polygonal region we will find control discs which determine such structure elements of glyphs as line, extreme and tail stems. First of all these elements are needed for correct rasterization of the font.

Straight line stems are related to long line edges in the skeleton. If at the same time empty circles centered on the ends of a linear edge have equal diameter, then the edge is responsible for the straight line stem of a constant width. These edge circles are control discs.

Extreme stems are found by search of vertical and horizontal extreme points of the skeleton. Empty circles with the centers in these points also are control discs.

End stems are found based on revealed end vertex of the skeleton. Empty circles with the centers in these points touch the glyph boundary in three places. These circles also become control discs.

Figure 5 shows examples of control discs for different stems: vertical (grey circles in letters E and N), horizontal (black circles in E), diagonal (white circles in N), extreme by width (grey in C), extreme by height (black in C), end (white in C).

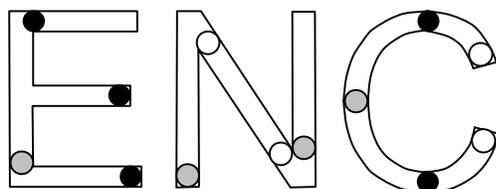


Figure 5: Control discs for different stems.

We will take the whole set of control discs as a conjunction of three subsets, partially intersect: vertical, horizontal and diagonal discs. Control discs of vertical, extreme by width and end stems belong to vertical ones. Discs of horizontal, extreme by height and end stems we will put to horizontal group. Discs of diagonal stems will become diagonal control discs. In the Figure 5 vertical control discs are grey and white, horizontal are black and white, diagonal are white.

4. Incidence of Control Discs and Boundary

Revealed control discs are describing glyph structure by showing the stems which form the glyph. As the main problem in rasterization lies in correct placing of the stems on a raster device, control discs become a convenient tool to modify stems according to a certain glyph size and raster resolution. Small shift of stem really can be represented by a shift of corresponding control discs and changes in stem width - by change in diameter of the control discs. But as is mentioned already, it is not enough as outline representation of the glyph is needed for the effective region scan-conversion on a raster device. Thus, we need to distort outlines adequately to the distortion of control discs. In order to do that we must establish incidence between outlines and corresponding control

discs. Incidence is easily represented by relating control polygon vertexes with control discs. In this process we would be interested not in all, but only in the most important incident relations. For a "vertical" disc we must find incident vertical sites of a control polygon, for a "diagonal" one - diagonal, etc. Figure 6 gives an example of establishing such relations. Vertex incidence of control polygons and discs is shown by lines connecting these vertexes with the centers of the discs.

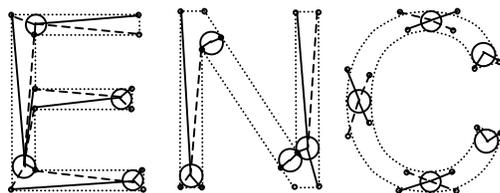


Figure 6: Incidence between control discs and control polygon.

Most of control polygon vertexes are incident to some discs, some vertexes being incident to several discs at the same time, for example, vertical and horizontal. As incident relations are an integral part of hinting representation, and consequently require memory resources in a font code, it would be desirable to reduce the number of them. We can considerably reduce the number of incident relations for vertical and horizontal discs, being saved, by interpolation. The essence of it lays in the fact that if a couple of control polygon vertexes is distorted, then it would be possible to change coordinates of all the vertexes between them proportionally. It allows to store only relevant incident relations. In the example in the Figure 6 these relations are shown by solid lines.

Incidence representation for diagonal stems should be stated specially. The following artificial method is used here. It consists of introducing additional vertexes into control polygon in points where its sites touch diagonal control discs. In given example such additional vertexes appear in the outline of the letter N.

Thus, analyzing outline and skeleton representations of font glyphs we determine the glyph structure and form interrelation of global (structural) properties with local boundary description. This analysis is made on the stage of computer font hinting, that is why there are no high requirements to its speed.

Now let us study the problem of transforming (distorting) a glyph in the process of its representation on a raster device using the revealed structural elements.

5. Distortion of Skeleton Representation on a Raster Device

In bitmapping font glyphs should be of certain height expressed in the number of raster points which is calculated through raster resolution and required size of the glyph being imaged. Glyphs are reduced to this size by scaling the skeleton and outline representations. Scaling is a simple multiplication of center coordinates and angle diameter values as well as coordinates of control polygon vertexes by a scale factor.

Distortion of skeleton representation includes two subsequent operations with scaled control discs: diameter correction and center correction. Diameter correction is performed separately for discs of different type.

Diameters of vertical and horizontal discs are simply rounded. If the diameter value is below zero it is rounded to one, in other cases the value is rounded to the nearest integer.

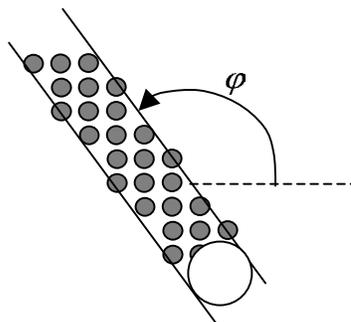


Figure 7: Diagonal stem of the constant width.

A special rule is used in correcting diagonal discs diameter. In this case a change in stem width should be chosen in such a way that the stem after rasterization also had a constant width. It is done as follows: diagonal stem has constant width on a raster device if its size is equal along each row or each column (depending on the slope angle of the glyph). If the slope angle j is within the limit from $\frac{\pi}{4}$ to $\frac{3\pi}{4}$ (this case is shown in the Figure 7), a constant width is needed along the rows, and if the angle is within 0 and $\frac{\pi}{4}$ or $\frac{3\pi}{4}$ and π - it is needed along the columns. Disc diameter correction giving the above property to the stem provided as a result of the distortion is found in the

following formula. Here the old diameter value is d , and a new value - D .

$$D = \begin{cases} \text{Round}\left(\frac{d}{\cos \phi}\right) \cos \phi, & \text{if } \phi \in \left[\frac{\pi}{4}, \frac{3\pi}{4}\right] \\ \text{Round}\left(\frac{d}{\sin \phi}\right) \sin \phi, & \text{otherwise} \end{cases}$$

$\text{Round}(x) = \max\{1, [x]\}$ means a rounding operation: if $x < 1$, then $\text{Round}(x) = 1$, in other cases $\text{Round}(x)$ is a maximum integer, less or equal to x .

Diameter correction of control discs provides constant width of stems on a raster device. Nevertheless, if we limit ourselves only with this correction, then raster images of symmetric glyphs and rounded extreme elements will have significant defects, like for example the letter "o" in the Figure2. To avoid that the location of control discs should be changed.

Font symmetry is rather diversified. besides the general axial and center glyph symmetry there is a symmetry of separate glyph elements, and it is very important to keep it in rasterization. It seems that only a designer can consider all the details of symmetry in the process of scrupulous manual font hinting. Nevertheless, a suggested approach is well agreed with symmetrical criteria and, as experiments show, in most cases gives good results.

Let us introduce the term of pixel and interpixel raster lines. Pixel raster lines are two families of vertical and horizontal straight lines going through pixel centers. Interpixel lines are also two families of straight lines, but they are coming directly in the middle between neighbor pixels.

On a set of control discs there is performed a natural pass round starting from the disc on the very left. Taking a skeleton as a connected graph with vertexes in the centers of control discs, we could find the routes of successive passes round the discs along the skeleton lines from the initial one.

Disc center correction is made based on the following rules.

1. Centers of all vertical and horizontal control discs should be put to vertical and horizontal raster lines correspondingly. It is made by shifting vertical discs along the X axle, and horizontal - along the Y axle. If the diameter of the disc is an odd number, then the disc center is put to pixel line, if it is even, then the center is put to interpixel line (Figure 8). It must be kept in mind that after correction, disc diameters of the above types are integer. The example shows setting vertical (grey) and horizontal (black) control discs with odd and even diameters. Movement directions are shown by arrows. The left part of the figure shows initial location of the discs, the right one - their location after the shift.

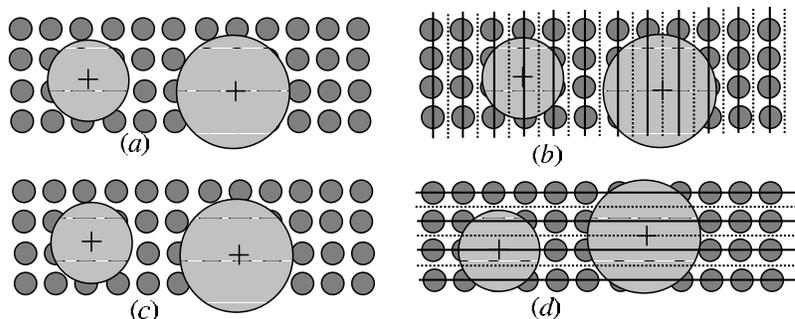


Figure 8: Shifting discs to raster lines. a - source vertical control discs, b - shifted vertical control discs, c - source horizontal control discs, d - shifted horizontal control discs

2. Vertical discs are distorted along the X axle and horizontal - along the Y axle. The rules for choosing a certain raster line are specific for each coordinate axle. It can be explained by the fact that font glyphs should have exact height, and there is no such a requirement to the width of the stem.
3. Horizontal control discs are distorted along the Y axle as follows: First, all basic lines along interpixel lines are set. The discs incident to the basic lines are set so that to keep contact with these lines, and centers of the rest of the discs are shifted simply to the nearest raster lines in the family corresponding to the evenness of their diameter. Figure 9 shows setting of horizontal (black and white) discs for glyph G. Basic lines are horizontal dashed dotted and raster pixel lines are solid, interpixel - dotted.
4. Vertical control discs are shifted along the X axle starting from the circle being at the very left. Then as a part of skeleton pass round process all counter vertical discs are set. Each following disc is set relative to preceding one in the pass round. It is based of the analysis of the distance between centers of control discs. In the Figure 9a numbers show setting sequence of vertical discs. Assume disc C_1 is already set, and we have to set disc C_2 following it in the pass round the skeleton. Let the coordinates of disc centers before setting be x_1 and x_2 and after setting X_1 and X_2 correspondingly. Let $L = |x_1 - x_2|$ be a distance along the X axle between the disc centers before the shift of both of them. X_2 is determined as follows: if disc C_1 is more left than C_2 , then the center of C_2 is set to the vertical raster line (pixel or interpixel depending on the evenness of C_2 diameter), which is closer to the right than $X_1 + L$. And if C_1 is more

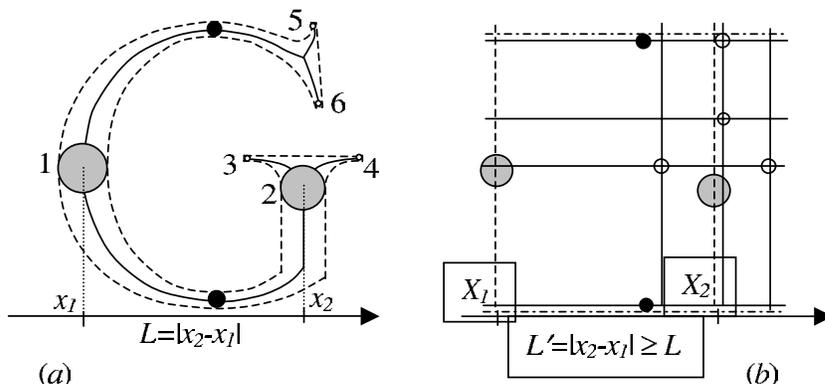


Figure 9: Setting of control discs (a) source position, (b) destination position.

right than C_2 , than it is put to the line closer to the left than $X_1 - L$. In the Figure 9b one can see setting disc 2 relative to disc 1.

- Centers of all diagonal discs are set by interpolation of their coordinates between centers of vertical and horizontal discs.

Thus, by changing size and location of control discs skeleton representation of the glyph is distorted adequate to raster. Now it is needed to distort outline representation of the glyph accordingly.

6. Distortion of the outline representation on a raster device

Distortion of the outline representation includes shifts of control polygon vertexes. Control polygon vertexes incident to control discs are shifted according to deformation and shift of these discs. Sites of control polygons incident to control discs are tangent to these discs. That is why the shift of these sites should keep them tangent to the changed discs. Control polygon vertexes incident to vertical discs are shifted with them along the X axle, and incident to horizontal discs - along the Y axle.

As vertexes incident to diagonal discs lie directly on these discs, they are shifted staying on these discs adequate to the changes in them. All the rest of vertexes not incident to control discs are shifted according to the linear interpolation between the set vertexes. Rasterization example of R glyph in

Figure 10 illustrates distortion of skeleton and outline representations in case when the height of the glyph should be 7 raster points.

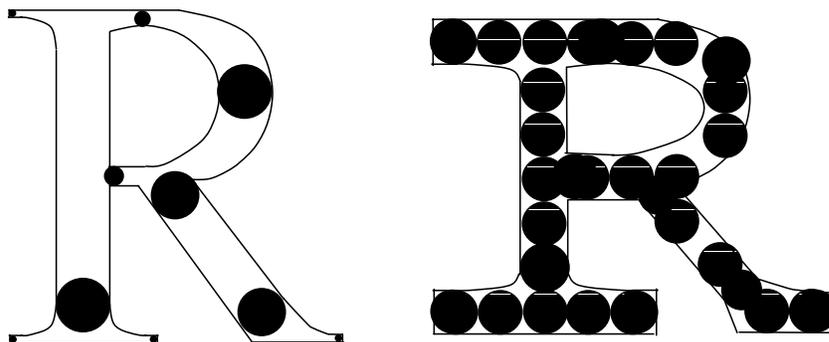


Figure 10: Distortion of skeleton and outline representations.

7. Approach Implementation

The suggested approach allows to choose specific implementation algorithms. This is especially true for distortion of glyph skeleton representation. At the same time the role of heuristic methods is rather high. We implemented specific hinting algorithms in True Type Fonts and performed a number of experiments in order to evaluate conceptual quality of the idea. The idea was implemented by making a hinting program, where any font described in the True Type Format can become an input for it. In the process only outline boundary representation of the glyph is used, the rest of information is ignored. The output of the program is a new representation of the above font in the True Type Format where hinting is automated according to the suggested approach. All the above operations of skeleton and raster representations are given as True Type Instructions.

Experiments were made in regard to two fonts: Arial (Monotype Corp.), and Newton (ParaType, Inc.), where only 52 the most commonly uses glyphs were evaluated. The samples show rasterization results (Figures 11, 11a). In the upper lines the alphabet is given by font without hints. The second lines illustrate comparative results of fonts aumatatically hinted with proposed algorithm, third lines present fonts manually hinted in a traditional way.

In the following Table 1 one could find data about the value of the instruction code got. Font Arial Newton Average point number in outlines per glyph

ABCDEFGHIJKLMNOPQRSTUVWXYZ
 ABCDEFGHIJKLMNOPQRSTUVWXYZ
 ABCDEFGHIJKLMNOPQRSTUVWXYZ

abcdefghijklmnopqrstuvwxyz
 abcdefghijklmnopqrstuvwxyz
 abcdefghijklmnopqrstuvwxyz

ABCDEFGHIJKLMNOPQRSTUVWXYZ
 ABCDEFGHIJKLMNOPQRSTUVWXYZ
 ABCDEFGHIJKLMNOPQRSTUVWXYZ

abcdefghijklmnopqrstuvwxyz
 abcdefghijklmnopqrstuvwxyz
 abcdefghijklmnopqrstuvwxyz

Figure 11: Rasterization results. Non-hinted fonts - 1st lines, automatically hinted fonts - 2nd lines, manually hinted fonts - 3rd lines for two fonts.

24.5 44.0 Average number of control discs per glyph 7.0 9.9 Average number of instructions per glyph 24.1 37.1

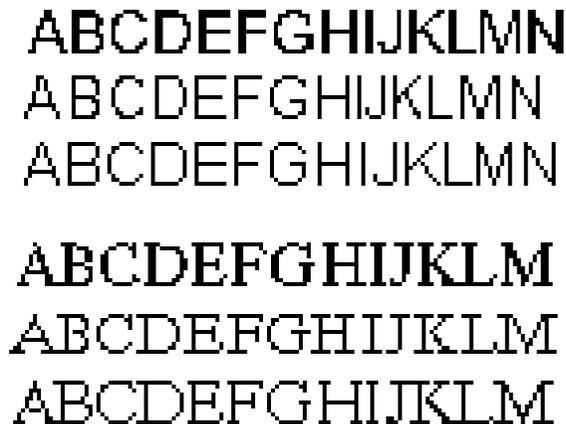


Figure 12: Enlarged fragment of Fig.11

Table 1: Instruction code length.

Font	Arial	Newton
Average point number in outlines per glyph	24.5	44.0
Average number of control discs per glyph	7.0	9.9
Average number of instructions per glyph	24.1	37.1

8. Conclusion

The paper describes the approach for automatic font hinting. The main idea lying in structural analysis of font glyphs basing on skeleton representation and establishing incidence between this representation and the boundary, seems rather promising. Our analysis and approach implementation are of a research character. The experiments not only showed the advantages of our approach, but also revealed some problems requiring additional work. The main problem is in making the algorithm effective. The rules of skeleton representation distortion in rasterization process need special improvement. Here we see the biggest resources to improve the quality of font representation on a raster device.

It should be noted that computer font preparation, being to a large extend a routine work, still is a kind of art. That is why speaking about automation

of font hinting, it would not be reasonable to expect a fully automated operation. High quality font will always require time consuming routine work of a designer. Here we see only the opportunity to increase the automation level of routine work. From this point of view it should be noted that the use of skeleton representation and mechanism of incidence of it to outline representations provides an efficient tool not only for automated, but also for manual font hinting.

Bibliography

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