Fonts with Complex OpenType Tables
Fonty se složitými tabulkami ve formátu OpenType

Karel Píška

Abstract: The paper presents development of complex OpenType fonts. The sample fonts cover Czech and Georgian handwriting with numerous letter connections.

At the beginning, general principles of "advanced typography" are shown – complex metric data represented by OpenType tables (GSUB and GPOS) – and compared them with the ligature and kerning tables in METAFONT.

Then the history of the OpenType font production is described – approaches, tools and techniques. Crucial problems, critical barriers, attempts and ways how to reach successful solutions, are discussed and several tools for font creating, testing, debugging and conversions between various text and binary formats are demonstrated. Among these tools are, for example, AFDKO, VOLT, FontForge, TTX, Font-TTF. Their features, advantages, disadvantages, and also cases of possible incompatibilities (or maybe errors) are illustrated.

Finally, using the OpenType fonts in the TEX world applications are presented: XƎTEX and LuaTEX (ConTEXt MkIV), the programs allowing to read and process OpenType fonts directly.

Key words: font, font production, Unicode, OpenType, GSUB, GPOS; AFDKO, VOLT, FontForge, TTX, Font-TTF; TEX, METAFONT, TFM, XƎTEX, ConTEXt, LuaTEX.

Abstrakt: Článek popisuje vývoj složitých fontů ve formátu OpenType v letech 2009–2010. Ukázky zahrnují český a gruzínský rukopisný font s mnohočetnými spojeními mezi sousedními písmeny.

Na začátku ukážeme obecné principy „pokročilé typografie“: složitá metrická data reprezentovaná tabulkami GSUB a GPOS v OpenType, které porovnáme s tabulkami ligatur a kerningů v METAFONTu.

Potom popíšeme historii tvorby OpenTypového fontu: postupy, nástroje a techniky. Probereme klíčové problémy, závažné překážky, pokusy a způsoby řešení k dosažení úspěšného výsledku. Předvedeme několik nástrojů pro tvorbu, testování a ladění fontů a konverze mezi různými textovými a binárními formáty jejich reprezentace. Jsou to např. AFDKO, VOLT, FontForge, TTX, Font-TTF. Budeme ilustrovat jejich vlastnosti, výhody, nevýhody, také i případy možných nekompatibilit (anebo možných chyb).

Nakonec předvedeme použití OpenTypových fontů v rámci TEXu: XƎTEX a LuaTEX (ConTEXt MkIV) jsou programy dovolující číst a zpracovávat fonty OpenType přímo, tj. bez tradičních metrik TFM.

doi: 10.5300/2011-2-4/309

Klíčová slova: font, tvorba fontů, Unicode, OpenType, GSUB, GPOS; AFDKO, VOLT, FontForge, TTX, Font-TTF; TEX, METAFONT, TFM, XƎTEX, ConTEXt, LuaTEX.

1. Introduction

The presented fonts are successors of the METAFONT fonts designed in 1997–98 by Olšák [2] and Píška [3]. Last year (2009) it was not possible for me to create a complete font with OpenType tables that would work properly. This year, finally positive results have been reached. The current article can be considered as a report summarizing my recent studies, experiments and experiences for dialogs and future collaboration with involved people. My main direction prefers the usage of fonts within TEX based software providing Unicode and OpenType support – XƎTEX [9] and ConTEXt/LuaTEX [11]. For OpenType the abbreviation "OT" will also be used in the article.

2. Advanced typography

Under "advanced typography" not only so called OpenType font technologies but also our good "old" TEX&METAFONT capability providing sophisticated word-processing can be assumed.

2.1. TEX & METAFONT – clear and clean

In fact, advanced typography with METAFONT and TEX has been available for TEX users for many years. METAFONT contains powerful tools like generalized ligatures together with boundary characters [1]:

```
.mf: ligtable  % produces % .tfm/.pl
 a: b |=:|   c; % acb      /LIG/     1
 a: b |=:|>  c; % acb      /LIG/>    2
 a: b |=:|>> c; % acb      /LIG/>>   3
 a: b  =:|   c; % cb        LIG/     4
 a: b  =:|>  c; % cb        LIG/>    5
 a: b |=:    c; % ac       /LIG      6
 a: b |=:>   c; % ac       /LIG>     7
 a: b  =:    c; % c         LIG      8
```

where

1. retains both *a* and *b*, inserts *c* between: *acb*

2. retains both *a* and *b*, inserts *c* between;
   the processing continues after *a*: *acb*
3. retains both *a* and *b*, inserts *c* between;
   the processing continues after *c*: *acb*
4. retains *b*, inserts *c* before *b*: *cb*
5. retains *b*, inserts *c* before *b*;
   the processing continues after *c*: *cb*
6. retains *a*, inserts *c* after *a*: *ac*
7. retains *a*, inserts *c* after *a*;
   the processing continues after *a*: *ac*
8. substitutes both *a* and *b* by *c*.

Boundary characters. The METAFONT and TEX concept of the "word boundary" (the left and right boundary characters) allows "implicit" processing of the beginning and the end of the word, i.e., a substitution or adjustment of the letters in the "initial" and the "final" position of the word. In METAFONT sources the left boundary characters is denoted by `"||:"`, the right boundary character must be introduced as the "real" character using the `"boundarychar` *code*`";"` assignment.

These facilities allow to apply substitution and positioning rules with some restrictions: only the pair of two adjacent characters can be processed, it is impossible to look ahead for longer sequence in a simple way; the maximum of glyphs in one font is 256. However, definitions of ligatures and kernings in METAFONT and then in TFM, and also the processing algorithm in TEX are clear and clean. The actual position in the input stream and how to find the next rule from TEX metrics tables that have to be applied are always known.

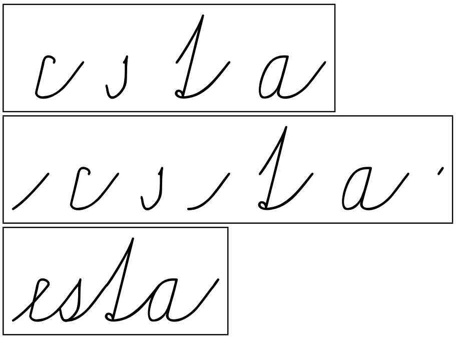
Abilities of METAFONT and TEX will be demonstrated by two short samples. Primarily, by default, the Latin (Czech) letters are in the "medial" form, without connecting strokes. Then the TEX&MF "machinery" joins the adjacent letters in words and adjusts the letters in the initial and final positions. The letter 'e' is preceded by one of the front-end strokes, 's' and 't' are joined by the corresponding inter-letter connecting stroke, and, finally, the last letter in the word is closed by the ending stroke. METAFONT defines several initial, medial and final strokes (depending on concerned letters), for example:

```
% left deflected end of character
beginchar(3, 6u#, 7u#, 0);
  draw (0,0){(3,2)}..{sklon2}(6,6);
endchar;
% shorter convex stroke for the pairs st,...
beginchar(6, 3u#, 7u#, 0);
  draw (-4,0){right}..{sklon2}(3,6);
endchar;
% right end of character
beginchar(1, .7u#, 7u#, 0);
  draw (0,6)..(.7,7);
endchar;
```

and the `ligtable` instructions

```
ligtable ||: "e" |=:|> 3; % ...
ligtable "s": "t" |=:| 6; % ...
boundarychar:=1;
ligtable "a": rightboundaries;
def rightboundaries =
      1 |=:> 1,
%     ........
enddef;
```

invoke inserting the requested strokes in the left boundary point (3), between ‘s’ and ‘t’ (6), and in the right boundary position (1).



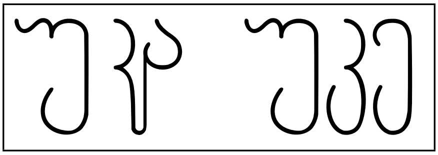
METAFONT cannot process in a single and natural way any character sequences consisting of three or more characters, e.g. triplets like "UN-KAN-AN" and "UN-KAN-EN" in Georgian handwriting.

Depending on the following character ("AN", "EN" or another) the original (“isolated” by default) glyph "KAN" is, or is not, replaced by its modified form:

```
ligtable GR_KAN: GR_AN  =:| GR_kan_;
```

and then it may be joined to the next character by the connecting stroke:

```
ligtable GR_kan_: GR_AN |=:| gr_en__an;
```



But no substitution and no kerning is defined for the pairs "UN-KAN" and "KAN-EN". After processing of the pair consisting of the second and third character and substituting of the second glyph there is no chance to return before the first character it is not possible to adjust the kerning between the first and the second, modified, glyph (left) – while "UN-KAN-EN" (right) needs no substitution or positioning changes. Two triplets above should be processed differently. It may probably be possible but the solution with METAFONT would not be trivial.

2.2. Advanced typography with OpenType

"Old TrueType fonts" can be "enriched" by adding "Advanced OpenType Typographic Tables" to produce fonts in OpenType format. Since the additional OT tables are common, two different format versions: "new" TTF and OTF will not be discussed.

Each *feature* is defined as a system of subsystems called *lookups*. Any *lookup* is described as a subsystem consisted of substitution and positioning rules. Depending on *script* and *language*, a *feature* may be enabled or disabled. If the *feature* is enabled and some *lookup*, contained in this *feature*, fulfill the given conditions, then the execution of the corresponding operations should be invoked. It is a signal and the real application must be executed by an application program or operating system, e.g., by means of a special library. OpenType introduces substitution (GSUB), positioning (GPOS), and several other tables.

These tables define the set of rules of several types specifying (from OpenType specification [4, 5]):

Glyph substitution (GSUB) rules – Single, Multiple, Alternate, Ligature, Contextuali, Chaining contextual, Extension, and Reverse Chaining Single Substitution;

Glyph positioning (GPOS) rules – Single adjustment, Pair adjustment, Cursive attachment, Mark-to-Base attachment, Mark-to-Ligature attachment, Mark-to--Mark attachment, Contextual, Chaining contextual, and Extension positioning.

>From METAFONT entire letters with accents are inherited. Therefore, there is no need to use marks and anchors and operations with them to assemble the complete letters from components (accents, signs, marks, ...) and the Mark positioning rules are not used. On the other hand, the fonts contain hundreds contextual substitution and positioning rules.

First, an OpenType font has to be created properly, using some suitable tools. Secondly, the font must be in agreement with the corresponding software to execute adequate operations according to the rules (instructions) defined in the font.

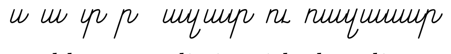
3. Tools to produce OpenType fonts

3.1. Creating OpenType fonts

Let us assume that Unicode encoded outline fonts have already been encoded, though without OpenType features. These have been generated earlier with Font-

Forge. The aim and task is to produce OpenType, i.e., to enrich the fonts with OT tables.

The fonts used/presented in this paper cover Czech, Georgian and also Armenian handwriting letter repertoire (taught in primary/elementary schools). Opposite to Czech and Georgian writing, the Armenian letters are designed and written in a simple way without no special joiners and there is no necessity to build any OpenType support/facility for Armenian.

Sample of Armenian: 

There is, however, another problem – to distinguish the adjacent letters.

In the following paragraphs the construction of OT fonts using various tools, namely VOLT, FontForge and AFDKO, are shown.

The specification of (binary) OT tables, data formats of the VOLT project files, variants of feature files accepted by AFDKO, FontLab, FontForge may all be different.

3.2. Managing OpenType with VOLT

VOLT (Visual OpenType Layout Tool) [6], free product developed by Microsoft and running only under MS Windows, offers an interactive approach to fill input areas with appropriate parameter values manually in the VOLT project window. Another possibility is writing and modifying source textual files in the VOLT project language. In the VOLT input area one can enter, or in a text editor we have to define glyphs (their names, types and code numbers), glyph groups (glyph sets or glyph lists), context conditions, substitution and positioning rules, and finally, to complete the hierarchy of scripts, languages, features, and lookups; those data can be saved and (re)read. Such method is reasonable and purposeful/meaningful for fonts with several hundreds contextual substitution and positional rules (our font contains about 350 glyphs, more than 600 substitutions and about 50 positionings). Of course, interactive design and especially proofing tools for testing tasks, have been used but the files defining OpenType data have been completed in the VOLT project (VTP) source/exchange format from some tables by scripting and editing texts. VOLT allows to read the font only in TrueType format, imports the VOLT project file, compiles OT data and then generates the font with binary OT tables. That is, VOLT adds OT tables and proofs the features and lookups; it accepts only the fonts with OT tables produced by VOLT, and deletes other OT tables. Moreover, (re)compilation must always be run before testing in the proofing window, even for fonts generated by program VOLT. These fonts embed additionally special tables 'TSID', 'TSIP', 'TSIS', and 'TSIV' for proofing.

A general structure of a lookup with substitutions in the VOLT project language (in my symbolic notation) is:

```
DEF_LOOKUP lookup_name lookup_parameters
[ IN_CONTEXT | EXCEPT_CONTEXT
  [ [ LEFT | RIGHT ] glyph_list ]
    ...
  END_CONTEXT
]                          ....
AS_SUBSTITUTION
  SUB glyph_list WITH glyph_list END_SUB
[ SUB glyph_list WITH glyph_list END_SUB ]
  ...
END_SUBSTITUTION
```

It is a sequence of one or more substitution rules and has the common contextual condition. The context may be defined as a compound logical expression. During the evaluation process the glyphs from the given glyph lists before (`LEFT`) or after (`RIGHT`) are compared relative to the current glyph according to their presence (`IN_CONTEXT`) or absence (`EXCEPT_CONTEXT`). Sequences of more `LEFT` and/or `RIGHT` subconditions can constitute left and right chains, their lengths depend of the numbers of the left and right conditions. In nested subexpressions, `IN/EXCEPT_CONTEXT` might be repeated more times, all of them are subsequently evaluated as a logical union.

The *lookup_parameters* contain the instructions for processing like `PROCESS_-BASE`, `PROCESS_MARKS`, `ALL`, `DIRECTION LTR` or `DIRECTION RTL`, etc. In our case – `DIRECTION LTR` ("left to right") – 'left' always means 'before'; similarly 'right' and 'after' have the same meaning.

Representation of the VOLT Project data allows insertions, and also different rule types may be in one lookup because the VOLT compiler accepts such rules and can compile them when converting the source data into binary OpenType tables. A final binary font then includes more than 100 internal features, numbered `zz01`,. . . , `zz99`,. . . It means, the higher level of the VOLT project language turns into greater complexity of the compiled product.

The following text demonstrates several complete examples describing the lookups in the VOLT project textual representation as they are present in my source files of the VOLT based fonts.

3.2.1. *Glyphs, scripts, languages and features*

But at first other elements of the VTP will be mentioned. All glyphs must be listed in the glyph definition section, each glyph command must have in the `DEF_GLYPH` its unique name, its ordinal number (index) in the font `ID`, its `TYPE` (`BASE`, `MARK`, `COMPONENT`, `LIGATURE`), the `UNICODE` number must be present for the Unicode coded glyphs and are missing for the glyphs from Private Use Area (PUA).

Glyphs can be grouped/collected in named groups to address the groups (glyph lists) in rules simply and shortly. DEF_GROUP commands may consist of glyph sequences GLYPH *glyph_name*, glyph ranges, and also other glyph groups, defined elsewhere but without ambiguity.

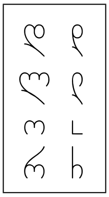
```
DEF_GROUP "czever"
 ENUM RANGE "a" TO "z" GROUP "accver"
 END_ENUM
END_GROUP
```

The names of glyphs and groups must be quoted, e.g., GLYPH "hyphen" or GROUP "czever".

3.2.2. *Single substitution*

Switching the corresponding feature we can invoke the substitution of the letters by their short variants.

```
DEF_LOOKUP "GeorAlt" PROCESS_BASE ALL DIRECTION LTR
AS_SUBSTITUTION
 SUB GLYPH "uni10D3" WITH GLYPH "GR_varD" END_SUB
 SUB GLYPH "uni10DA" WITH GLYPH "GR_varL" END_SUB
 SUB GLYPH "uni10DD" WITH GLYPH "GR_varO" END_SUB
 SUB GLYPH "uni10E0" WITH GLYPH "GR_varR" END_SUB
END_SUBSTITUTION
```



3.2.3. *Ligature substitution*

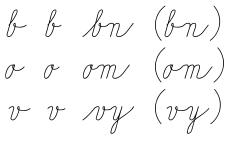
Typical ligatures can be defined by unconditional substitutions.

```
DEF_LOOKUP "liga" PROCESS_BASE ALL DIRECTION LTR
AS_SUBSTITUTION
 SUB GLYPH "comma" GLYPH "comma" WITH GLYPH "quotedblbase" END_SUB
 SUB GLYPH "quoteleft" GLYPH "quoteleft" WITH GLYPH "quotedblleft" END_SUB
 SUB GLYPH "hyphen" GLYPH "hyphen" GLYPH "hyphen" WITH GLYPH "dash" END_SUB
 SUB GLYPH "hyphen" GLYPH "hyphen" WITH GLYPH "minus" END_SUB
END_SUBSTITUTION
```

3.2.4. *Contextual substitution*

Before the letters defined by the right context the letters listed later will be changed to their narrower variants (the unadjusted versions in parenthesis).

```
DEF_LOOKUP "CZEbmnvwy" PROCESS_BASE ALL DIRECTION LTR
IN_CONTEXT
 RIGHT ENUM GLYPH "m" GLYPH "n" GLYPH "ncaron" GLYPH "v" GLYPH "w"
 GLYPH "y" GLYPH "yacute" END_ENUM
END_CONTEXT
AS_SUBSTITUTION
 SUB GLYPH "b" WITH GLYPH "bnarrow" END_SUB
 SUB GLYPH "o" WITH GLYPH "onarrow" END_SUB
 SUB GLYPH "oacute" WITH GLYPH "oacutenarrow" END_SUB
 SUB GLYPH "v" WITH GLYPH "vnarrow" END_SUB
 SUB GLYPH "w" WITH GLYPH "wnarrow" END_SUB
END_SUBSTITUTION
```



Following some letters (the left context) the letters “s” and “š” are substituted by their ‘depth’ forms.

```
DEF_LOOKUP "CZEgjqy" PROCESS_BASE ALL DIRECTION LTR
IN_CONTEXT
 LEFT ENUM GLYPH "g" GLYPH "G" GLYPH "j" GLYPH "J" GLYPH "q" GLYPH "Q"
 GLYPH "y" GLYPH "yacute" GLYPH "Y" GLYPH "Yacute" END_ENUM
END_CONTEXT
AS_SUBSTITUTION
 SUB GLYPH "s" WITH GLYPH "sdepth" END_SUB
 SUB GLYPH "scaron" WITH GLYPH "scarondepth" END_SUB
END_SUBSTITUTION
```

3.2.5. *Contextual insertion*

Between the selected glyphs and their right successors the joining stroke will be inserted.

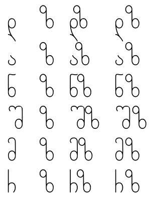
```
DEF_LOOKUP "CZEjoins_s" PROCESS_BASE ALL DIRECTION LTR
IN_CONTEXT
 RIGHT ENUM GLYPH "m" GLYPH "n" GLYPH "ncaron" GLYPH "t" GLYPH "tcaron"
 GLYPH "v" GLYPH "w" GLYPH "y" GLYPH "yacute" GLYPH "z" GLYPH "zcaron" END_ENUM
END_CONTEXT
AS_SUBSTITUTION
 SUB GLYPH "s" WITH GLYPH "s" GLYPH "joins" END_SUB
 SUB GLYPH "scaron" WITH GLYPH "scaron" GLYPH "joins" END_SUB
 SUB GLYPH "sleft" WITH GLYPH "sleft" GLYPH "joins" END_SUB
 SUB GLYPH "scaronleft" WITH GLYPH "scaronleft" GLYPH "joins" END_SUB
 SUB GLYPH "sdepth" WITH GLYPH "sdepth" GLYPH "joins" END_SUB
 SUB GLYPH "scarondepth" WITH GLYPH "scarondepth" GLYPH "joins" END_SUB
END_SUBSTITUTION
```

3.2.6. *Kerning positioning*

This lookup operating on glyph pairs defines the kern advances between several `FIRST` and one `SECOND` glyph (`uni10D6`). There are no explicit shifts for the first glyphs, otherwise the second glyph is moved by two values, DX and ADV, for left and ride sides, respectively. In other words, the value DX defines position of the second glyph to the first glyph, whereas the value ADV adjusts the position of the third glyph which follows the pair.

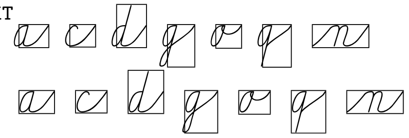
```
    DEF_LOOKUP "GEOzen" PROCESS_BASE ALL DIRECTION LTR
    AS_POSITION
    ADJUST_PAIR
     FIRST ENUM GLYPH "uni10D3" GLYPH "GR_varD" GLYPH "GR__don" GLYPH "uni10D4"
      GLYPH "uni10D5" GLYPH "uni10D6" GLYPH "uni10D7" GLYPH "uni10D8"
      GLYPH "uni10D9" GLYPH "uni10DA" GLYPH "GR_varL" GLYPH "GR__las"
      GLYPH "uni10DD" GLYPH "GR_varO" GLYPH "uni10DF" GLYPH "GR__jan"
      GLYPH "uni10E1" GLYPH "GR__san" GLYPH "uni10E7" GLYPH "uni10E2"
      GLYPH "uni10E3" GLYPH "uni10E4" GLYPH "uni10E6"
      GLYPH "GR__ghan" GLYPH "uni10EA" GLYPH "uni10EF" END_ENUM
```

```
  FIRST ENUM GLYPH "uni10D0" GLYPH "uni10D1" GLYPH "GR__ban"
   GLYPH "uni10ED" GLYPH "uni10EE" END_ENUM
  FIRST ENUM GLYPH "uni10DC" GLYPH "uni10DE" END_ENUM
  FIRST ENUM GLYPH "uni10E8" GLYPH "uni10E9" GLYPH "GR__chin" END_ENUM
  FIRST ENUM GLYPH "uni10DB" GLYPH "uni10E5" GLYPH "uni10EB" END_ENUM
  FIRST ENUM GLYPH "GR_varR" GLYPH "GR__rae" END_ENUM
  SECOND GLYPH "uni10D6"
  1 1 BY POS END_POS POS ADV -170 DX -170 END_POS
  2 1 BY POS END_POS POS ADV -120 DX -120 END_POS
  3 1 BY POS END_POS POS ADV  -70 DX  -70 END_POS
  4 1 BY POS END_POS POS ADV  -50 DX  -50 END_POS
  5 1 BY POS END_POS POS ADV  -40 DX  -40 END_POS
  6 1 BY POS END_POS POS ADV  -80 DX  -80 END_POS
 END_ADJUST
 END_POSITION
```



3.2.7. *Left boundary positioning*
If the selected letters are preceded by some non-letter character (its absence in the set "czebeg"marks the word beginning) they will be adjusted

```
DEF_LOOKUP "CZEbegpos" PROCESS_BASE ALL DIRECTION LTR
EXCEPT_CONTEXT LEFT GROUP "czebeg" END_CONTEXT
AS_POSITION
ADJUST_SINGLE
 GLYPH "a" BY POS ADV 80 DX 80 END_POS
 GLYPH "aacute" BY POS ADV 80 DX 80 END_POS
 GLYPH "c" BY POS ADV 80 DX 80 END_POS
 GLYPH "ccaron" BY POS ADV 80 DX 80 END_POS
 GLYPH "d" BY POS ADV 80 DX 80 END_POS
 GLYPH "dcaron" BY POS ADV 80 DX 80 END_POS
 GLYPH "g" BY POS ADV 80 DX 80 END_POS
 GLYPH "o" BY POS ADV 80 DX 80 END_POS
 GLYPH "oacute" BY POS ADV 80 DX 80 END_POS
 GLYPH "q" BY POS ADV 80 DX 80 END_POS
END_ADJUST
END_POSITION
```



The letters [a, á, c, č, d, ď, g, o, ó, q] in the medial positions follow the foregoing letters immediately. However, they have some left ‘overshots’ and have to be adjusted if they are in the initial position – when no letter is before them. The condition "EXCEPT_CONTEXT LEFT" is just fulfilled for non-letter glyphs.

3.3. Creating OpenType with FontForge

This subsection illustrates producing OpenType fonts using the files in “OpenType feature files” (FEA) [7], defined by Adobe, and generating the fonts by FontForge [8]. Because all attempts to convert metric data from METAFONT/TFM or VOLT project data failed, the procedure had to be started from scratch again.

Lookups with substitution and positioning rules into textual “feature language” file were rewritten, again “manually” which that the procedure started with some simple tables with the glyph names and an information about their transformations derived from METAFONT sources; then the files were produced by scripting and modified them with text editors to obtain the required format.

The syntax and lookup structure between VTP and feature file specification differs:

```
lookup lookup_name {
 [ sub glyph by glyph ; ]                #1
   ...
 [ sub glyph_list by glyph ; ]           #2
   ...
 [ sub glyph by glyph_list ; ]           #3
   ...
 [ sub glyph' glyph_list by glyph ; ]    #4
   ...
 [ sub glyph_list glyph' by glyph ; ]    #5
   ...
 [ sub glyph_list by glyph_list ; ]      #6
   .....
} lookup_name ;
```

In FEA the context is connected with each single rule. In the "feature language" the insertion is not supported, i.e., the character cannot appear at the same time on the left and right side of a substitution rule (opposite to the VOLT project). The rules like

```
sub glypha' glyph_list by glypha glyph ;
sub glypha' glyph_list by glyph glypha ;
```

are invalid and unsupported. Another restriction is that one low level lookup must contain a sequence of only one type of substitution rules (only one from type `#1` or `#2` ... `#6`, but those rules may be repeated many times). Violating the constrains results in compilation fatal errors. Generally, the sequence between `"sub"` and `"by"` may consist of more glyphs to substitute (with apostrophes) and more context elements (without apostrophes) constituting a longer chain and forming a compound conditional expression.

Because of different syntax and structure the commands had to be rebuilt completely. Therefore taking the rule set from the VOLT project each insertion rule had to be divided into two rules and also split some lookups into separate parts. It is necessary to append (in contradiction with the VOLT project) to the font explicitly many new additional intermediate glyphs, the number of glyphs increases from about 350 to 670, and the number of substitution rules increases from about 600 to 850.

VOLT accepts

```
SUB GLYPH "B"
WITH GLYPH "B" GLYPH "joinc" END_SUB
```

But in FEA

```
 sub B’ @CZEjoinc by B joinc;
```

is the fatal error.

Extra glyphs `glyph.ini` (absent in METAFONT font and VOLT) for all letters `[ A.ini - Z.ini, a.ini - z.ini ]` and also for all accented letters had to be added to the font. And every insertion rule must be divided in two rules using `glyph.ini` as the intermediate characters.

```
 sub B’ @CZEjoin by B.ini;
 sub B.ini by B joinc;
```

Moreover, the two rules above cannot be grouped in one lookup because of their different types. Similarly, we had to add the glyphs `glyph.fin` to solve both left and right boundary processing tasks. The initial and final glyph variants will be located in PUA.

3.3.1. *Single substitution*

```
lookup GeorAlt {
 sub uni10D3 by GR_varD;
 sub uni10DA by GR_varL;
 sub uni10DD by GR_varO;
 sub uni10E0 by GR_varR;
} GeorAlt;
```

3.3.2. *Ligature substitution*

```
lookup CZEliga {
 sub comma comma by quotedblbase;
 sub quoteleft quoteleft by quotedblleft;
 sub hyphen hyphen hyphen by dash;
 sub hyphen hyphen by minus;
} CZEliga;
```

3.3.3. *Contextual substitution*

```
@CZEbmnvwy = [ m n ncaron v w y yacute ];

lookup CZEbmnvwy {
 sub b’ @CZEbmnvwy by bnarrow;
 sub o’ @CZEbmnvwy by onarrow;
 sub oacute’ @CZEbmnvwy by oacutenarrow;
 sub v’ @CZEbmnvwy by vnarrow;
 sub w’ @CZEbmnvwy by wnarrow;
} CZEbmnvwy;
```

The glyphs to substitute are marked by apostrophes, other glyphs between "`sub`" and "`by`" denote the (right) context and the current glyphs will be substituted by the glyphs after "`by`".

The next example shows the left context.

```
@CZEgjqy = [ g G j J q Q y yacute Y Yacute ];
lookup CZEgjqy {
 sub @CZEgjqy s' by sdepth;
 sub @CZEgjqy scaron' by scarondepth;
} CZEgjqy;
```

3.3.4. *Contextual insertion*

In FEA it must redefined as two separate substitutions using intermediate glyphs, their names are ended by ".s".

```
lookup CZEjoins_ss {
 sub s' @CZEjoins by s.s;
 sub scaron' @CZEjoins by scaron.s;
 sub sleft' @CZEjoins by sleft.s;
 sub scaronleft' @CZEjoins by scaronleft.s;
 sub sdepth' @CZEjoins by sdepth.s;
 sub scarondepth' @CZEjoins by scarondepth.s;
} CZEjoins_ss;
lookup CZEjoins_s {
 sub s.s by s joins;
 sub scaron.s by scaron joins;
 sub sleft.s by sleft joins;
 sub scaronleft.s by scaronleft joins;
 sub sdepth.s by sdepth joins;
 sub scarondepth.s by scarondepth joins;
} CZEjoins_s;
```

3.3.5. *Kerning positioning*

These rules define the adjustments for the glyph pairs. In a more general case the glyphs can be changed by glyph groups.

```
lookup PositGeor {
@GEOzen  = [ uni10D6 ];
@GEOzen1 = [ uni10D3 GR_varD GR__don uni10D4
 uni10D5 uni10D6 uni10D7 uni10D8
 uni10D9 uni10DA GR_varL GR__las
 uni10DD GR_varO uni10DF GR__jan
 uni10E1 GR__san uni10E7 uni10E2
 uni10E3 uni10E4 uni10E6 GR__ghan
 uni10EA uni10EF ];
@GEOzen2 = [ uni10D0 uni10D1 GR__ban uni10ED uni10EE ];
@GEOzen3 = [ uni10DC uni10DE ];
@GEOzen4 = [ uni10E8 uni10E9 GR__chin ];
@GEOzen5 = [ uni10DB uni10E5 uni10EB ];
@GEOzen6 = [ GR_varR GR__rae ];
 pos @GEOzen1  @GEOzen  -170;
 pos @GEOzen2  @GEOzen  -120;
 pos @GEOzen3  @GEOzen   -70;
 pos @GEOzen4  @GEOzen   -50;
 pos @GEOzen5  @GEOzen   -40;
 pos @GEOzen6  @GEOzen   -80;
} PositGeor;
```

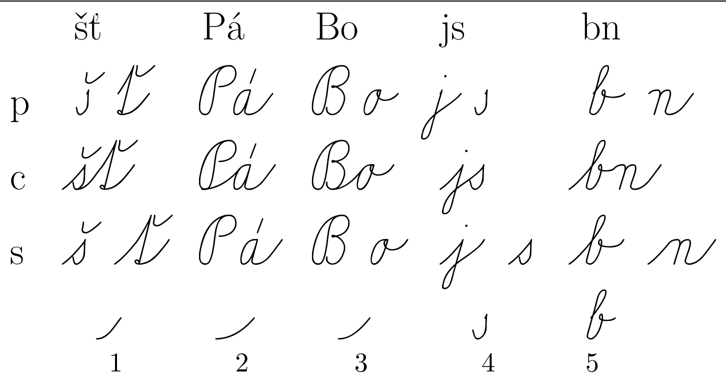
3.3.6. *Left boundary positioning*

The glyphs listed in `@CZEleftboundary` and `@GEOleftboundary` will be adjusted by 80 (70) units when the foregoing glyphs are **not** the letter that could be the first one in the word – `"ignore"` reverses the condition.

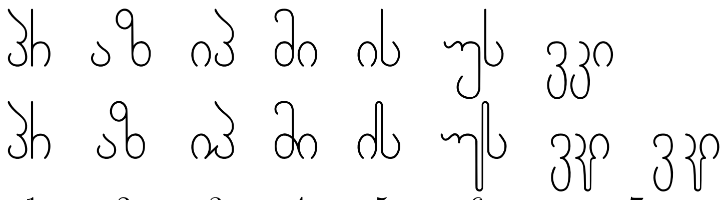
```
lookup CZEbegpos {
 ignore pos @czebeg @CZEleftboundary';
 pos @CZEleftboundary' < 80 0 80 0> ;
} CZEbegpos;

lookup LeftPositGeor {
@GEOleftboundary = [ uni10D1 ];
@geolet = [ uni10D0 - uni10F0
 GR_varD GR_varL GR_varO GR_varR ];
 ignore pos @geolet @GEOleftboundary';
 pos @GEOleftboundary' < 70 0 70 0>;
} LeftPositGeor;
```

3.3.7. *Several comparative examples*

The following examples illustrate several selected cases of rules in their METAFONT, VOLT and FEA implementations. After splitting a FEA rule in two steps we must usually put them in separate lookups depending of the type of the rules.



1.–3. Various letter pairs are joined by different connecting strokes.
4. The letters “s”/“š” have the modified forms after some letters (g, j, q, y).
5. The letters b, o, v, w are written narrower before m, n, v, y.


1 2 3 4 5 6 7

1. No connection between letters – no rules defined and applied.
2. Both letters without changes with adjusted kerning.

```
MF   ligtable GR_AN:  GR_ZEN kern kzz#+.2u#;
```

```
VTP  FIRST ...
     FIRST ENUM GLYPH "uni10D0" ... END_ENUM
     ...
     SECOND GLYPH "uni10D6"
     ...
     2 1 BY POS END_POS POS ADV -120 DX -120 END_POS
```

```
FEA  @GEOzen  = [ uni10D6 ];
     @GEOzen2 = [ uni10D0 ... ];
     ...
     pos @GEOzen2  @GEOzen  -120;
```

3. Letters connected but not modified.

```
MF   ligtable GR_IN: GR_PAR |=:| gr_in__an;
```

The connecting stroke inserted after "uni10D8" before "uni10DE".

```
VTP  IN_CONTEXT RIGHT GLYPH "uni10DE" END_CONTEXT
     SUB GLYPH "uni10D8" WITH GLYPH "uni10D8" GLYPH "gr_in__an" END_SUB
```

The new glyph "uni10D8_in__an" must be added and execution in two steps split in two different lookups (the rule types are not the same).

```
FEA  sub uni10D8' uni10DE by uni10D8_in__an;
     sub uni10D8_in__an by uni10D8 gr_in__an;
```

4. Only the first letter changed and connected.

```
MF   ligtable GR_MAN: GR_IN  =:| GR_man_;
```

```
VTP  IN_CONTEXT RIGHT GLYPH "uni10D8" END_CONTEXT
     SUB GLYPH "uni10DB" WITH GLYPH "GR_man_" GLYPH "gr_man__in" END_SUB
```

In FEA, changing the first glyph and inserting a junction after must be divided in two steps.

```
FEA  sub uni10DB' uni10D8 by GR_man_man__in;
     sub GR_man_man__in by GR_man_ gr_man__in;
```

5. Only the second letter changed and connected.

```
MF   ligtable GR_IN: GR_SAN |=:| gr_in__san;
```

```
VTP  IN_CONTEXT RIGHT ENUM GLYPH "uni10E1" GLYPH "GR_san_" END_ENUM END_CONTEXT
     SUB GLYPH "uni10D8" WITH GLYPH "uni10D8" GLYPH "gr_in__san" END_SUB
     ..........
```

```
      IN_CONTEXT LEFT GLYPH "gr_in__san" END_CONTEXT
      SUB GLYPH "uni10E1" WITH GLYPH "GR__san" END_SUB
```

```
FEA   sub uni10D8' uni10E1 by uni10D8_in__san;
      sub uni10D8_in__san by uni10D8 gr_in__san;
      sub gr_in__san uni10E1' by GR__san;
```

6. Both letters changed and connected.

```
MF    ligtable GR_UN:  GR_SAN =:| GR_un_;
      ligtable GR_un_: GR_SAN |=:|> gr_en__san
```

```
VTP   IN_CONTEXT RIGHT ENUM GLYPH "uni10E1" GLYPH "GR_san_"
         END_ENUM END_CONTEXT
      SUB GLYPH "uni10E3" WITH GLYPH "GR_un_" GLYPH "gr_en__san" END_SUB
      ..........
      IN_CONTEXT LEFT GLYPH "gr_en__san" END_CONTEXT
      SUB GLYPH "uni10E1" WITH GLYPH "GR__san" END_SUB
      SUB GLYPH "GR_san_" WITH GLYPH "GR__san_" END_SUB
```

```
FEA   sub uni10E3' uni10E1 by GR_un_en__san;
      sub GR_un_en__san by GR_un_ gr_en__san;
      sub gr_en__san uni10E1' by GR__san;
      sub gr_en__san GR_san_' by GR__san_;
```

7. The medial letter changed and kerned.

```
MF    ligtable GR_KAN: GR_IN  =:| GR_kan_;
```

Here is a weak point in METAFONT: After processing the second and third character there is no *simple* means how to return before the first letter and correct kerning (7 right).

```
VTP   IN_CONTEXT RIGHT GLYPH "uni10D8" END_CONTEXT
      ...
      SUB GLYPH "uni10D9" WITH GLYPH "GR_kan_" GLYPH "gr_en__in" END_SUB
      ....
      FIRST ENUM ... GLYPH "uni10D5" ...
      SECOND GLYPH "GR_kan_"
      ...
      1 1 BY POS END_POS POS ADV -80 DX -80 END_POS
```

```
FEA   sub uni10D9' uni10D8 by GR_kan_en__in;
      ...
      sub GR_kan_en__in by GR_kan_ gr_en__in;
      ...
      @GEOkan_ = [ GR_kan_ ];
      @GEOkanA_ = [ ... uni10D5 ...
      ...
      pos @GEOkanA_ @GEOkan_  -80;
```

3.3.8. *Lookup order in FEA*

According the specification of the feature files [5] the lookup order is determined by the order of their definitions in the file. Their calling order, for example, in a feature block is irrelevant. The order has to be changed by a manual swapping or permutation of the whole text blocks using any text editor. To avoid any misunderstanding it was decided to arrange the order of my lookup definitions:

```
lookup SubstGeorSingleA {
......
```

```
  } SubstGeorSingleA;
  lookup SubstGeorInsertA {...} ...
  lookup SubstGeorSingleB {...} ...
  lookup SubstGeorSingleC {...} ...
  lookup SubstGeorInsertC {...} ...
  lookup SubstGeorConnC   {...} ...
  lookup SubstGeorDoubleC {...} ...
```

and the order of their invocation

```
  feature ss12 { # "Stylistic Set 12"
  lookup SubstGeorSingleA; # stage 1: subst one
  lookup SubstGeorInsertA; #  insert - step 2
  lookup SubstGeorSingleB; # stage 2: subst one
  lookup SubstGeorSingleC; # stage 3: subst one
  lookup SubstGeorInsertC; #  insert - step 2
  lookup SubstGeorConnC;   #  subst two - step 1
  lookup SubstGeorDoubleC; #  subst two - step 2
} ss12;
```

in exactly the same way and thus to "synchronize" both lookup sequences. Having the lookup definitions in one order there is no chance to change this order by trying to call them in any other order.

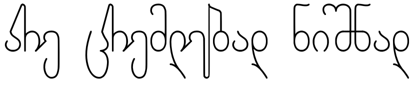
Resuming my experiences – several conditions must be fulfilled: lookups of different types must be divided in the differently named lookup blocks; the lookups of the same type may be joined together into the common lookup block; and, of course, all the lookups must be arranged in the appropriate order. Putting all the lookups within the font into a single one-level block would be impractical, if not impossible, although it has not been verified.

3.4. Tests of generated fonts

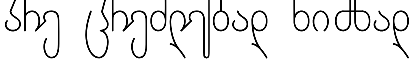
The OpenType tables have been defined, the corresponding VOLT project file created and the VOLT based font by VOLT generated. Also the feature file has been created and the FEA based font generated.

After successful tests of the VOLT based font by VOLT Proofing tool and testing both VOLT and FEA fonts using testing window in FontForge the fonts with OT tables are obtained and ready to be check and tested with XeTeX and ConTeXt and the results could be presented.

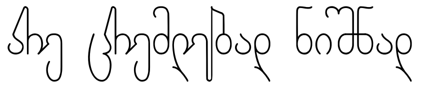
The VOLT based font gives the expected results with XeTeX (`xelatex`):



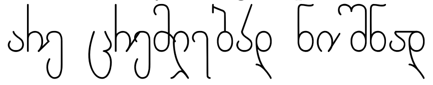
The VOLT font with `context` prints very similar output:



Also the FEA based font seems to be correct with `xelatex`:



But the FEA font generated by FontForge and processed with `context` produces evidently wrong output with many incorrect substitutions:



It looks like a total nonsense, and may signal a possible incompatibility between FontForge, LuaTEX and the author's fonts but it could not be said where exactly the bug was.

Let‘s try the next program package producing OpenType – AFDKO.

3.5. AFDKO

AFDKO (Adobe Font Development Kit for OpenType) is a free program package for OpenType font management. One of the programs, *makeotf*, is able to output only OTF with CFF tables but this fact is not important for us because we are interested mainly in OT features, and description of glyph outlines plays secondary role.

First thing we have met is a small syntactic difference between feature files read by FontForge and by *makeotf* (AFDKO).

FontForge fails on

```
@GDEF_Ligature = [quotedblleft quotedblbase
 minus dash ];
#@GDEF_Mark = [ ];
@GDEF_Component = [quoteleft comma hyphen ];
table GDEF {
  GlyphClassDef @GDEF_Base,
   @GDEF_Ligature, , @GDEF_Component;
} GDEF;
```

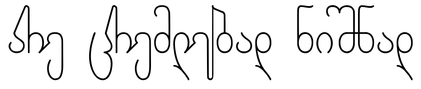
because it does not allow commas in GDEF; while AFDKO corrupts on

```
@GDEF_Ligature = [quotedblleft quotedblbase
 minus dash ];
@GDEF_Mark = [];
@GDEF_Component = [quoteleft comma hyphen ];
table GDEF {
  GlyphClassDef @GDEF_Base
   @GDEF_Ligature @GDEF_Mark @GDEF_Component;
} GDEF;
```

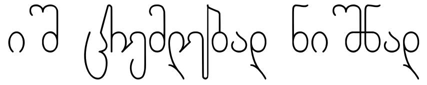
because it must have the commas in GDEF, and `@GDEF_Mark = [];` is invalid.

All other definitions (features, lookups, sub and pos rules) are absolutely identical. Some warnings are reported during generating OTF by *makeotf*; however, the reason for the failure could not be found. Generally, the source inputs for FontForge and AFDKO are nearly identical, in contrast to the entirely different VOLT project regarding syntax and structure.

Reading the appropriate input feature file by AFDKO we should satisfactorily generate the OTF file. The first extensive tests with ConTeXt look like a great success:



All tested substitutions seems to be correct also in XeTeX. No mistake has been found in the GSUB table:

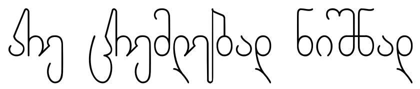


However, not all positioning rules work properly.

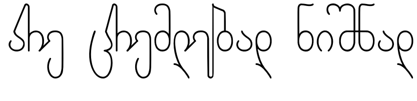
The GPOS table produced by AFDKO is not correct (not compatible with XeTeX) although with FontForge we did not observe such problem.

3.5.1. *Final mix*
The last attempt mixes (using TTX) the font generated by AFDKO's *makeotf* connected together with the GPOS table created by FontForge, where both GSUB and GPOS have been derived from the common source feature file.

XeTeX:



ConTeXt:



Only now no mistakes are seen.

3.6. A short intermediate summary

There are several different source (textual) representations of OpenType tables.

1. VOLT project (`hwu.vtp`) – the correct font, (`hwuv.ttf`) *only* TTF flavoured can be produced.

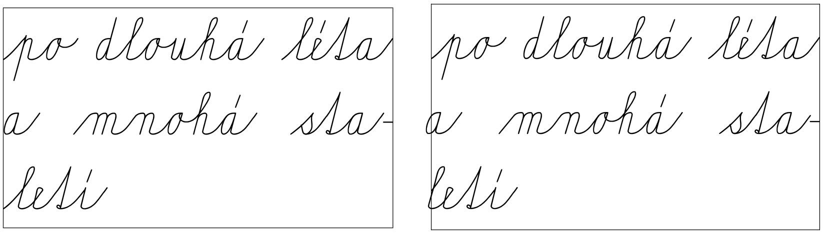
2. First feature file (`hwuf.fea`) – FontForge produces OpenType with erroneously ordered lookups.

3. Second feature file (`hwuff.fea`) – FontForge produces OpenType working with XeTeX, errors with ConTeXt (GSUB looks correct).

4. Third feature file (`hwufa.fea`) – *makeotf* (from AFDKO) generates the font (only CFF flavoured) with wrong GSUB; GPOS looks correct.

The 5th OT font (`hwufo.otf`), combined together with TTX from the product of AFDKO (GSUB) and GPOS generated by FontForge, works properly with XeTeX, only small errors are observed in ConTeXt.

The "boundary processing" does not work in the line breaking points, including the points of word hyphenation. The following examples demonstrate the problem – in XeTeX (left) and in ConTeXt (right):



where the initial (isolated) 'a' is not adjusted; 'a' in "sta-" does not have the "final stroke"; and the next 'l' is without the "initial stroke".

3.7. Other programs

Alongside with the software tools generating OpenType fonts several other programs have been employed or tried, mostly for the purpose to find errors, verify, compare, convert font data or acquire any relevant information about fonts and their OpenType features. Unfortunately, many of them could not respond to requested questions and do not give any important information.

Predominantly, work has been done on Linux systems, while MS Windows has been used rarely: AFDKO (*makeotf*) and VOLT only to generate VOLT based and FEA based fonts, and VOLT for proofing as well.

3.7.1. *Visual proofing tools and displaying binary data in readable form*

MS VOLT "Proofing Tool" is very sophisticated and powerful facility. It allows to test the result of complete processing of a given glyph sequence (the glyphs must be denoted by their names according the VOLT project and separated by commas), to check all features separately or step by step detailed behaviour of each lookup, and even to trace the changes glyph by glyph in the string.

FontForge can create and modify PostScript, TrueType, OpenType, SVG, and other fonts; in addition, it comprises other suitable instruments. The "Kerning Metrics Window" allows to check kernings and other features. The results of application of actually selected (activated) features for entered Unicode glyph string can be examined.

In ConTeXt the `\showotfcomposition` command provides similar tracing during lookup processing, prints all intermediate results and informs about the features and lookups that have been just applied, step by step until the final result. The “only” a crucial problem is that it is not clear why the activated lookup has not been applied or why is the behaviour of ConTeXt and XeTeX different when processing my font.

The internal FontForge format (SFD) has a readable ASCII representation. The `"Print"` command provides displaying and printing font tables and sample multiscriptal and multilingual texts. Another program from the FontForge package, `showttf`, displays a font file tables, and `mensis` allows you to examine and modify some of the tables in a TrueType or OpenType font. But usually an overview of tables and subtables can say nothing about the exact font behaviour and about interaction or interference of features and lookups.

TrueType and OpenType fonts can be converted by the program `ttx` to/from a human-readable XML-based format (TTX). This textual data may be modified using any plain text editor. It was difficult to orientate oneself and it was possible to make only minor changes.

3.7.2. *Validation*

“MS Validator” has been tried only once when the present author’s font did not work properly. A very long output file with complete list of tables, items, features, lookups, etc. in my font was obtained but the only information was that the font is without errors and, of course, nothing about behaviour of the font and the feature execution order.

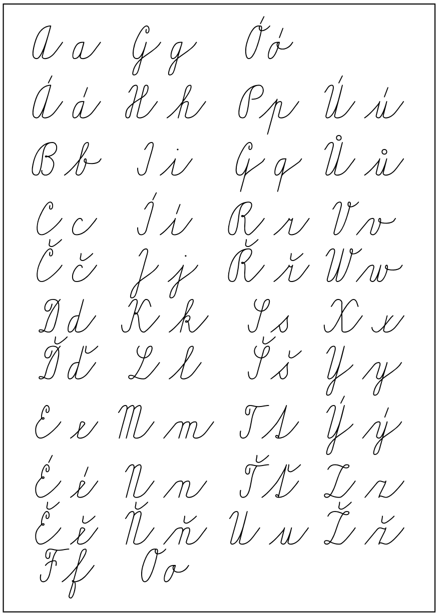
3.7.3. *Comparison*

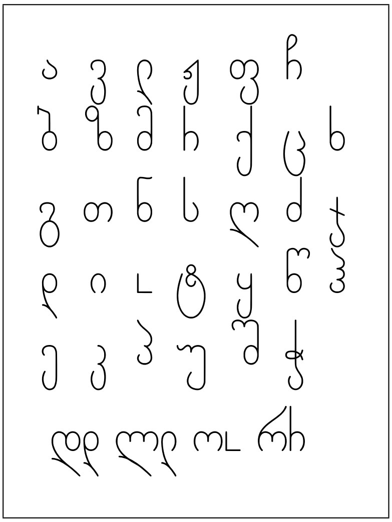
To compare TTX files is possible, but it is purposeful only if changes are small. Also FontForge’s `"Font compare"`, and its command version `sfddiff` afford low benefit if there are significant differences between fonts, e.g., a comparison of a VOLT based font and its FEA version produces vast amount of data, greater than in both fonts, because their internal structures are dissimilar and totally unmatched.

3.7.4. *Conversions*

The programs from the `Font::TTF` package allow to process TrueType/OpenType fonts: `ttf2volt` creates VOLT project or VOLT based font from existing Open-Type font file, while `volt2ttf` compiles VOLT source into OT tables in the font.

It was not successful: `volt2ttf` ends with “Can’t use an undefined value as an ARRAY reference at /usr/local/bin/volt2ttf line 574” and for the result of `ttf2volt` (the conversion was executed without errors, only some warnings were reported) VOLT always colapses showing an uninformative message “Compilation failed”.


Czech alphabet.


Georgian alphabet (in the last line:
long and short letter variants of d, l, o, r).

With FontForge we can generate a font in other font format; the features of an opened font can be saved into a feature file that can be reread later. However, these files are very similar to input FEA written manually, and – for VOLT based files – are too complicated, less transparent, probably incorrect and unusable.

Therefore such facilities have been found to be rather purely theoretical.

4. Be positive

Two types of font can be produced:

1. TTF flavoured – with VOLT generated from VTP,
2. OTF (CCF/PS) flavoured – with common effort of AFDKO, FontForge and TTX generated from FEA.

The fonts work properly (i.e. corresponding to actually defined substitution a position rules) under XƎTEX (`xelatex`) and under LuaTEX/`context` – only with some small errors. One could be satisfied despite of many deadlocks during font development and the fact that the font collection has not been finished completely.

The original METAFONT Czech font `slabikar` was created by Olšák [2]. Czech language uses Latin script with extensions, however, local traditions may be different from other Latin-scripted languages. The letters in words are always all connected together.

Both Czech and Armenian handwriting are usually slanted and use uppercase and lowercase letters. Modern Georgian script does not distinguish capital and small letters and handwriting is traditionally upright (at least, in the form taught in schools). Not all adjacent letters in words are joined together.

Besides the `'liga'` feature the feature names were chosen from the user "stylistic sets":

`'ss01'` for single substitutions to replace letter variants;
`'ss02'` – Czech substitutions;
`'ss03'` – Czech positioning rules;
`'ss12'` – Georgian substitutions;
`'ss13'` – Georgian positionings, e.g. kernings.

For the Czech part to set on all features is obligatory. For Georgian it is possible to select more combinations, only the kerning adjustment is requested in all cases to avoid gaps and letter overlaps.

XƎTeX/XƎLaTeX can define the font features (for testing purposed our fonts in many version are not "installed" but they are located in the current directory), for example Georgian without substitutions and without letter connections:

```
\font\hwugn="[./hwufo.otf]:+liga,
  +ss13" at 28pt
```

ყველა ადამიანი იბადება თავისუფალი და თანასწორი
თავისი ღირსებითა და უფლებებით. მათ მინიჭებული
აქვთ გონება და სინდისი და ერთმანეთის მიმართ უნდა
იქცეოდნენ ძმობის სულისკვეთებით.

Georgian with all defined substitutions and letter connections:

```
\font\hwugs="[./hwufo.otf]:+liga,
   +ss01,+ss12,+ss13" at 28pt
```

ყველა ადამიანი იბადება თავისუფალი და თანასწორი თავისი
ღირსებითა და უფლებებით. მათ მინიჭებული აქვთ გონება
და სინდისი და ერთმანეთის მიმართ უნდა იქცეოდნენ ძმობის
სულისკვეთებით.

ConTeXt uses other commands to flip/flop the features:

```
\definefontfeature[cz][script=DFLT,lang=dflt,
 mode=node,liga=yes,ss02=yes,ss03=yes]
\font\hwuc = hwufo*cz at 26pt
```

*Všichni lidé se rodí svobodní a sobě rovní
co do důstojnosti a práv. Jsou nadáni
rozumem a svědomím a mají spolu jednat
v duchu bratrství.*

5. Conclusion

It has been possible to generate the fonts with OpenType tables producing the expected results, especially with XƎTEX and ConTEXt. There are several different representations of OpenType data: the OpenType specification itself, VOLT project source format, feature language and its interpretations in AFDKO and FontForge. Subsequently, the internal binary files produced by various programs should be and (really) are (very often very) different and then also any effective comparison is impossible. Unfortunately, the program tools like AFDKO, FontForge, FontUntils and other have problems either with uniformity and reliability or with compatibility with the TEX based text processors like XƎTEX or ConTEXt. However, some errors in fonts cannot be excluded even when correct results are produced.

Acknowledgements

I would like to thank all authors of OpenType software, Adam Twardoch for consultations about OT, Hans Hagen and Taco Hoekwater for information about ConTEXt and its font support.

References

[1] Donald E. Knuth. *The METAFONTbook,* Volume C of *Computers and Typesetting*, Addison–Wesley, p. 317, 1986.

[2] Petr Olšák. *Psané písmo ze slabikáře.* Zpravodaj CSTUG 4(7), pp. 191–197, 1997; `petr.olsak.net/ftp/olsak/slabikar`; `bulletin.cstug.cz/pdf/bul974.pdf`; Jiří Žáček, Helena Zmatlíková. *Slabikář*, Alter, 1996, 2006 (in Czech).

[3] Karel Píška. Georgian scripts. *TUGboat*, 19(3), 1998; `http://www.tug.org/TUGboat/Articles/tb19-3/tb60pisk.pdf`.

[4] Adobe: OpenType. `http://www.adobe.com/type/opentype/`; Microsoft Typography: What is OpenType? `http://www.microsoft.com/typography/WhatIsOpenType.mspx`.

[5] Microsoft: OpenType specification. `http://www.microsoft.com/typography/otspec/`.

[6] Microsoft: Visual OpenType Layout Tool (VOLT). `http://www.microsoft.com/typography/VOLT.mspx`.

[7] Adobe: OpenType Feature File Specification. `http://www.adobe.com/devnet/opentype/afdko/topic_feature_file_syntax.html`; `http://partners.adobe.com/public/developer/opentype/afdko/topic_feature_file_syntax.html`.

[8] George Williams. Font creation with FontForge. *EuroTEX 2003 Proceedings*, *TUGboat*, 24(3):531–544, 2003; `http://fontforge.sourceforge.net`.

[9] Jonathan Kew. The XƎTEX typesetting system. `http://scripts.sil.org/XeTeX`; `http://www.ctan.org/tex-archive/info/xetexref/XeTeX-reference.pdf`.

[10] Martin Hosken. Font-TTF, FontsUtils. `http://search.cpan.org/~mhosken/`; `http://scripts.sil.org/FontUtils`.

[11] ConTEXt and LuaTEX. `http://wiki.contextgarden.net`.

Institute of Physics, Academy of Sciences
Prague, Czech Republic
piska (at) fzu (dot) cz