Feature Variations: New substitution mechanism

Skef Iterum, Adobe Inc.

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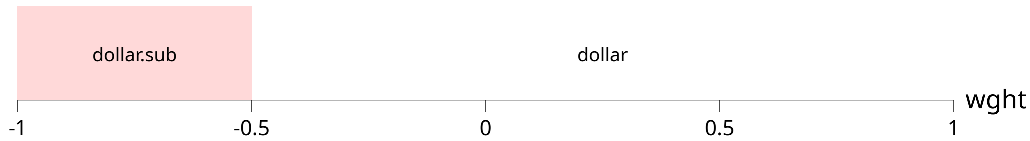
Contents

1 Introduction

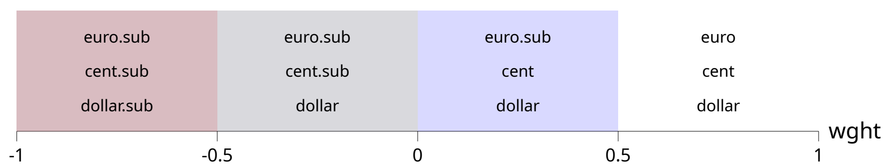
This document discusses a problem with the current feature variations substitution mechanism in OpenType and outlines an alternative mechanism to address it. The initial sketch of the new mechanism was developed by Behdad Esfahbod and Skef Iterum in discussion on GitHub.

2 Problem: Condition set permutations

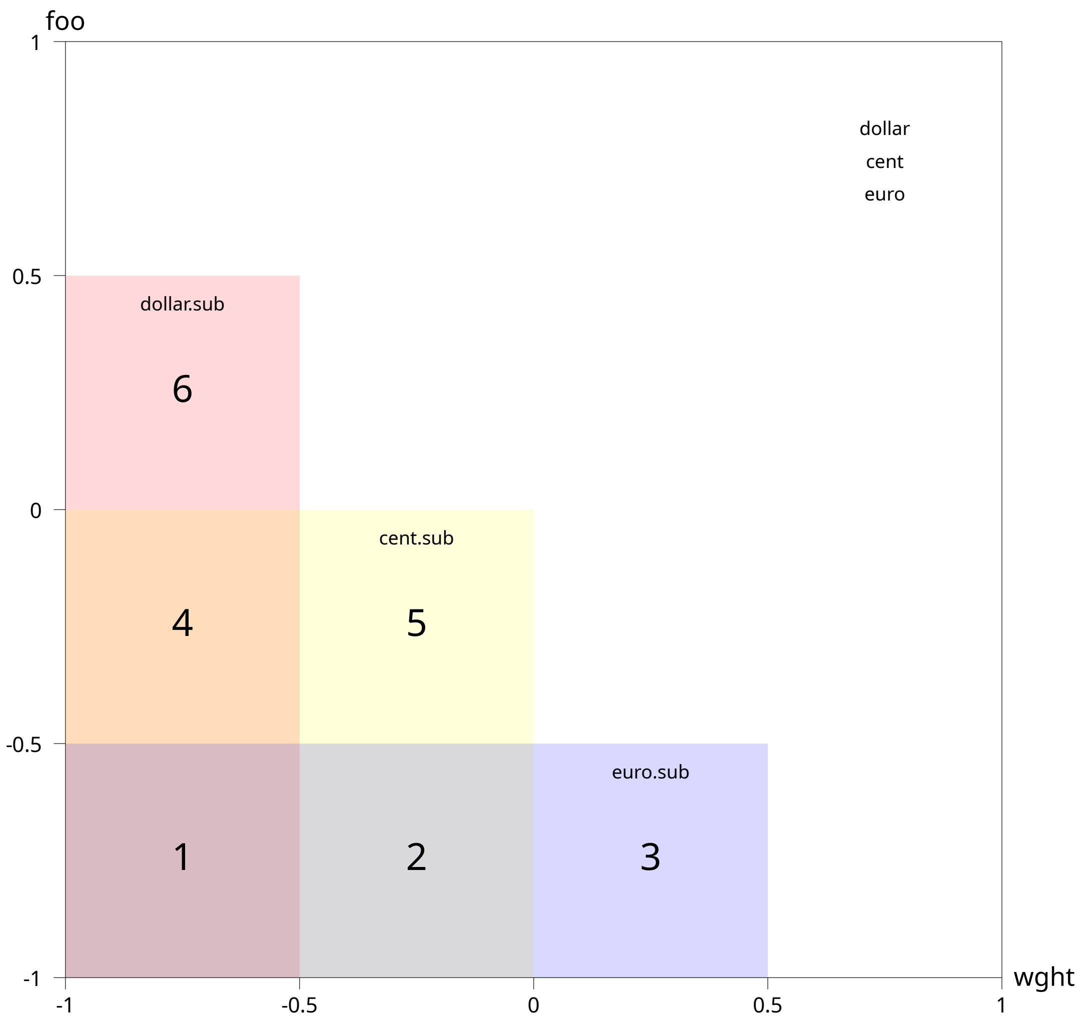
With the current feature variations system things are simple when you have one relevant axis and one substitution. For example you want to use `rvrn` to substitute a double-slash dollar sign at normalized `wght` -.5, with a single-slash dollar sign used elsewhere, you'll wind up with one feature variation record using the single condition `-1 <= wght <= -0.5` to override the default feature subtable containing the single-slash dollar sign.



Add additional substitutions, all still on a single relevant axis, and things stay simple: the number of FeatureVariation records needed is the number of substitutions needed. So if the `cent` glyph needs a substitution at `wght 0` and the `euro` glyph needs one at `wght` 0.5, you just need three FeatureVariation records in addition to the base feature subtable. Each new substitution adds a new region.



Things get messier with two axes. Assume a second axis `foo` with these three substitutions: dollar at `wght` -.5, `foo` .5; cent at `wght` 0, `foo` 0; and euro at `wght` .5, `foo` -.5. These add 6 regions in addition to the feature table, for a total of seven combinations. (This would be worse if there was more than one substitution point per axis.)



Broadly speaking there are two ways of encoding these regions. One might be called "geometric", in which each region is distinct. This involves more conditions but smaller condition sets.

```
1)  -1    <= wght <=  -0.5 , -1    <= foo <= -0.5 : dollar.sub , cent.sub , euro.sub
2)  -0.5+ <= wght <=   0   , -1    <= foo <= -0.5 : dollar     , cent.sub , euro.sub
3)  -1    <= wght <= -.5   , -0.5+ <= foo <=  0   : dollar.sub , cent.sub , euro
4)  -0.5+ <= wght <=   0   , -0.5+ <= foo <=  0:  : dollar     , cent.sub , euro
5)   0+   <= wght <=   0.5 , -1    <= foo <= -0.5 : dollar     , cent     , euro.sub
6)  -1    <= wght <=  -0.5 ,  0+   <= foo <=  0.5 : dollar.sub , cent     , euro

Default: dollar, cent, euro
```

The other might be called "logical". This involves fewer conditions but larger condition sets.

```
 D => -1 <= wght <= -0.5 & -1 <= foo <=  0.5
 C => -1 <= wght <=  0   & -1 <= foo <=  0
 E => -1 <= wght <=  0.5 & -1 <= foo <= -0.5
```

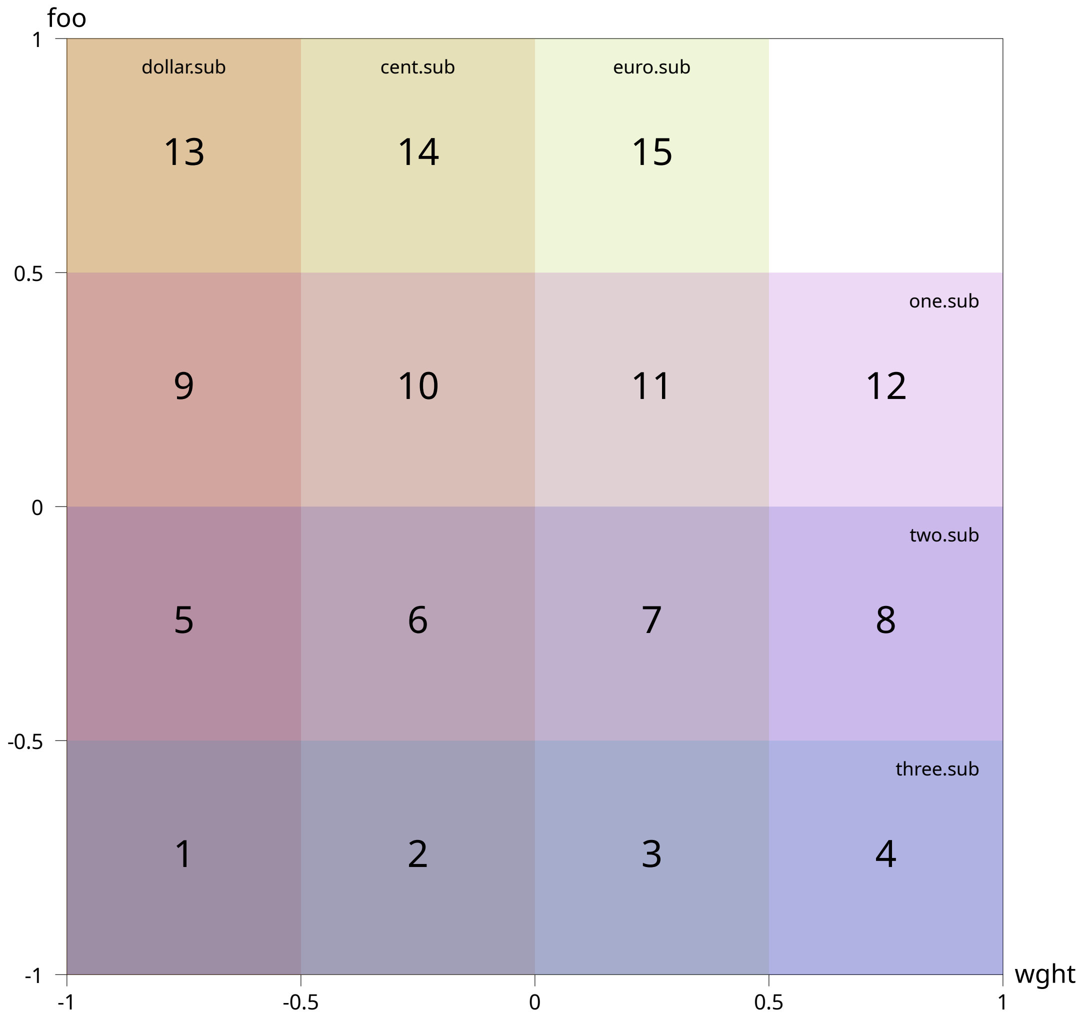
```
1)  D & C & E : dollar.sub , cent.sub , euro.sub
2)  C & E     : dollar     , cent.sub , euro.sub
3)  E         : dollar     , cent     , euro.sub
4)  D & C     : dollar.sub , cent.sub , euro
5)  C         : dollar     , cent.sub , euro
6)  D         : dollar.sub , cent     , euro

Default: dollar, cent, euro
```

The logical approach works because the search through feature variation records stops at the first record where every condition in the set is true. This means the list can start with a conjunction of all glyph-specific regions and then followed by less and less specific conjunctions. In effect, the more specific conjunctions earlier in the list mask regions of the less specific, later entries.

Note that because the mechanism is shared across all feature variations, the problem is no better even when layout features are unrelated. Suppose that you have a feature with three substitutions on one axis, as well as a different feature with three entirely unrelated substitutions on a different axis. For example, dollar changes at `wght` -.5, cent at `wght` 0, and euro at `wght` .5, while one changes at `foo` -.5, two at `foo` 0, and three at `foo` .5.

Although these substitutions do not seem to be related in the abstract, and will probably not appear to be related when encoded in a feature file, the feature compiler must treat them as related when building the GSUB feature variation subtable in its present form. This is because there is only one unified list of feature variation records per table (GSUB or GPOS). So the above pattern of substitution will not result in 6 regions plus the default (3 for `wght`, 3 for `foo`), but 15.



With a logical encoding those would be (with redundant conditions omitted):

```
D => -1 <= wght <= -0.5
C => -1 <= wght <=  0
E => -1 <= wght <=  0.5
1 => -1 <= foo  <= -0.5
2 => -1 <= foo  <=  0
3 => -1 <= foo  <=  0.5

 1)  D & 1 : dollar.sub , cent.sub , euro.sub , one.sub , two.sub , three.sub
 2)  C & 1 : dollar     , cent.sub , euro.sub , one.sub , two.sub , three.sub
 3)  E & 1 : dollar     , cent     , euro.sub , one.sub , two.sub , three.sub
 4)      1 : dollar     , cent     , euro     , one.sub , two.sub , three.sub
 5)  D & 2 : dollar.sub , cent.sub , euro.sub , one     , two.sub , three.sub
 6)  C & 2 : dollar     , cent.sub , euro.sub , one     , two.sub , three.sub
 7)  E & 2 : dollar     , cent     , euro.sub , one     , two.sub , three.sub
 8)      2 : dollar     , cent     , euro     , one     , two.sub , three.sub
 9)  D & 3 : dollar.sub , cent.sub , euro.sub , one     , two     , three.sub
10)  C & 3 : dollar     , cent.sub , euro.sub , one     , two     , three.sub
```

```
11)  E & 3 : dollar     , cent     , euro.sub , one     , two     , three.sub
12)      3 : dollar     , cent     , euro     , one     , two     , three.sub
13)  D     : dollar.sub , cent.sub , euro.sub , one     , two     , three
14)  C     : dollar     , cent.sub , euro.sub , one     , two     , three
15)  E     : dollar     , cent     , euro.sub , one     , two     , three

def   : dollar     , cent     , euro     , one     , two     , three
```

More generally, this means that whenever different condition sets are used in the same or different layout features in the same table (GSUB, GPOS, etc.) the compiler must carve up the geometry across all of them.

3 Proposal 1: Alternative lookup variations mechanism

3.1 Concept

As noted, in the current system a single list of condition sets is evaluated in order until one set evaluates all true, and then whatever feature indices are listed in that entry replace the original feature tables. Consider a different system in which the basic unit of replacement is not feature *tables* but *lookups*, and all elements in the list are evaluated. When all conditions in a set evaluate to true, a set of lookups associated with that condition set is added to the "current" set.

With this system, instead of building complete substitute feature tables for regions of designspace, one can simply associate individual lookups with their own condition sets and build the overall table by evaluating those condition sets.

At the end of the search, the total set of added lookups encountered is used as the list for the corresponding feature.

3.2 Tables

The idea here is to add a new lookup variation mechanism mostly analogous to the feature variation mechanism.

3.2.1 FeatureVariations Table Format 2

Type	Name	Description
uint16	majorVersion	set to 2
uint16	minorVersion	set to 0
Offset32	lookupVariationsOffset	Offset to lookupVariations table, 0 if unused
uint32	featureVariationRecordCount	Number of feature variation records.
FeatureVariationRecord	featureVariationRecords[featureVariationRecordCount]	Array of feature variation records.

This is the same as the current FeatureVariations table format, except with a new major version and an extra lookupVariationsOffset field. (It would also be possible to give the table a new minor version instead by moving the new field to the end, at the cost of making it a bit non-standard, as offset fields are usually positioned before record arrays.)

3.2.2 LookupVariations Table

Type	Name	Description
uint32	lookupVariationRecordCount	Number of lookup variation records.
LookupVariationRecord	lookupVariationRecords[lookupVariationRecordCount]	Array of lookup variation records (sorted).

As each LookupVariationRecord has an associated featureIndex, the record array will be required to be sorted by that field for faster searching.

3.2.3 LookupVariation Record

Type	Name	Description
uint16	featureIndex	The feature table index to match (sort key)
Offset32	featureLookupsTable	Offset to a FeatureLookups table

In contrast with the existing mechanism, the hierarchy puts the condition sets under the features rather than the features under the condition sets. This is because all records for a given feature must be searched, so it is better to only look through the records of those features that are enabled.

3.2.4 FeatureLookups Table

Type	Name	Description
uint16	majorVersion	set to 1
uint16	minorVersion	set to 0
uint16	flags	FeatureLookups qualifiers — see below
uint32	lookupConditionCount	Number of LookupCondition records.
LookupConditionRecord	lookupConditionRecord[conditionCount]	Array of LookupCondition records.

This table provides offsets to a list of LookupCondition records for the feature pointing to it. As all records will be evaluated they can be in any order.

Flags can be assigned to indicate certain uses or behaviors for a given FeatureLookups table. The following flags are defined.

Mask	Name	Description
0x0001	ADD_DEFAULT_LOOKUPS	When this bit is set, set the initial lookup set to the lookups included in the default Feature table for this featureIndex. Otherwise set the initial lookup set to the empty set.
0xFFFE	Reserved	Reserved for future use — set to 0.

3.2.5 LookupCondition Record

Type	Name	Description
Offset32	conditionSetOffset	Offset to a condition set table
Offset32	trueLookupIndexSetOffset	Offset to a LookupIndexSet table to add when all conditions are true (0 if unused)
Offset32	falseLookupIndexSetOffset	Offset to a LookupIndexSet table to add when at least one condition is false (0 if unused)

This table is equivalent to an if/else structure. When all conditions are true all lookups from the trueLookupIndexSet are added. When at least one is false the lookups from the falseLookupIndexSet are added. Either entry (but not both) can be disabled by setting it to 0. As with other condition sets a 0 offset indicates the set is always true, and therefore the entries from the trueLookupIndexSet will be added.

3.2.6 LookupIndexSet Table

Type	Name	Description
uint16	lookupIndexCount	Number of LookupList indices in this table.
uint16	lookupIndices[lookupIndexCount]	Array of indices into the lookup list.

This table simply encodes an array of lookupIndices to be added to a set.

3.3 Algorithm

The "default" Feature table corresponding to featureIndex contains an offset to a `featureParams` table and a list of lookupList indices. This algorithm allows either or both of these to be substituted in relation to the chosen position in design space.

1. Process the featureVariationRecords in the same way as for a version 1 FeatureVariations table:
   a. Evaluate the condition set of each FeatureVariationRecord in order until every condition of one evaluates to true.
   b. If there is such a record, associate the each featureIndex listed with its new Feature table offset

2. For each active feature with a LookupVariationRecord:

   a. Allocate an empty feature table structure.
   b. Copy any FeatureParams from the current feature table (either the replacement from step 1 if there is one or the original Feature table for this feature).
   c. If ADD_DEFAULT_LOOKUPS is set, copy list of lookups from current feature table into the set for this feature.
   d. For each LookupCondition record:

      i. If all conditions are true set o = trueLookupIndexSetOffset
      ii. Otherwise set o = falseLookupIndexSetOffset
      iii. Copy each lookup in the LookupIndexSet at o into the set for this feature

3. For each active feature that lacks a LookupVariationRecord, use the current Feature table for that featureIndex (either the replacement from step 1 if there is one, or the original Feature table for the feature).

3.4 Requirements

- The initial feature table in `GSUB` for a given tag should be equivalent to the output of the algorithm of that feature for the (format) default instance (all axes `0`).

3.5 Typical patterns

- A given feature will typically use either the FeatureVariation or the LookupVariation subtable but not both. The exception is if a feature alters its featureParams at points in design space but specifies its lookups with the LookupVariation system.
- When a feature has some lookups used at every point in designspace, but cannot copy those from the initial feature table, they can be added to the set with an initial LookupCondition Record with a `0` conditionSetOffset. The empty condition set always evaluates to true so the entries in the trueLookupAdditions subtable will always be added.

3.6 Formal Properties

For the purposes of this discussion assume there is an easy way to logically negate any condition. And for the sake of simplicity ignore the falseLookupIndexSet subtable.

When a feature uses the LookupVariations system the set of lookups will be union of those added for each condition set that evaluates to true. This is analogous to a logical "or". A condition set evaluates to true when all of its conditions evaluate to true, analogous to a logical "and". Therefore lookups are added to the set based on a disjunction of conjunctions.

Accordingly, the system is "complete" in that any lookup can be included (or excluded) according to any arbitrary boolean formula using the following convention:

1. Convert the formula for each lookup to disjunctive normal form.
2. Pool the conjunctions used among the lookups together.
3. Create a LookupConjunction records corresponding to each individual conjunction with a trueLookupIndexSet containing each lookup that had that conjunction in its DNF.

3.7 Motivation for falseLookupIndexSet table

Although the system is formally complete with the falseLookupIndexSet field, which is conceptually analogous to an "else", it simplifies some cases.

GSUB substitutions are typically present or absent, but the variable substitution mechanism can also be used with GPOS. Consider the archetypal GPOS case of a sudden change in kerning between "T" and "o" when the weight (or other axis) makes the latter no longer fit under the former. One can implement that change with clever variable kerning values but one can also implement it by specifying two separate kerning values and switching between them.

When doing the latter, one wants one value used when a specified set of conditions is true and the other in other cases, e.g. when at least one is false. *Positively* expressing the latter without an "else" might take many separate conjunctions (according to how the conditions overlap). The analysis is much easier with the "else".

3.8 Comparative sizes

Using the existing system and a geometric encoding, the first dollar/euro/cent example uses the following:

1. One Version 1 Feature Variations Table with 6 records (32 bytes)
2. Six condition set tables (36 bytes)
3. Twelve condition tables (96 bytes)
4. Six FeatureTableSubstitution Table headers (36 bytes)
5. Six FeatureTableSubstitution Records (36 bytes)
6. Six Feature Tables (44 bytes)

For a total of 280 bytes

With the alternate system the amounts are:

1. One Version 2 Feature Variations Table with 0 records (12 bytes)
2. One LookupsVariations table with 1 record (10 bytes)
3. One FeatureLookups table with 3 records (46 bytes)
4. Three condition set tables (18 bytes)
5. Six condition tables (48 bytes)
6. Three LookupIndexSet tables, each with one record (12 bytes)

For a total of 146 bytes

Obviously, the more one needs to decompose conditions with the existing system, the greater the relative savings with the new system.

4 Proposal 2: Simplified condition negation

4.1 Concept

Many forms of logical analysis, such as reduction to disjunctive normal form benefit from an easy means of negating a boolean variable, which in the case of feature variations corresponds to a condition. With the current condition format 1, conditions that use only one of filterRangeMinValue or filterRangeMaxValue can be negated by adjusting the F2DOT14 value by the minimum increment, moving it to the other field, and adjusting the original field to -1 or 1. However, there is no general way of negating a condition that uses both filterRangeValues with a single condition.

Adobe has also introduced a separate proposal for a format 2 "Condition value", which is not straightforward to negate without additional support.

Therefore we suggest providing easy negations for the existing and proposed condition formats by introducing two new versions to negate them. In effect, we use a bit in the format field to negate the "positive" formats.

4.2 Tables

4.2.1 Condition Format 3 table

Type	Name	Description
uint16	format	Format = 3
uint16	axisIndex	Same as in format 1
F2DOT14	filterRangeMinValue	Same as in format 1
F2DOT14	filterRangeMaxValue	Same as in format 1

The only difference between format 1 and format 3 is that when the former evaluates to false the latter evaluates to true and vice-versa.

An alternative to using a new format would be to stipulate that, in format 1, when the filterRangeMinValue is greater than the FilterRangeMaxValue, the condition is negated. We would need to decide if the inequalities were then exclusive, or if the values need to be adjusted by the minimum F2DOT14 increment to correspond to inclusive inequalities. This saves a version number but is not strictly compatible with existing implementations of format 1, so the specification would need to be careful about the versioning of tables that use this new format.

4.2.2 Condition Format 4 table

Type	Name	Description
uint16	format	Format = 4
int16	default	Same as in format 2
uint16	deltaSetOuterIndex	Same as in format 2
uint16	deltaSetInnerIndex	Same as in format 2

The only difference between format 2 and format 4 is that when the former evaluates to false the latter evaluates to true and vice-versa.

An alternative is to add a flags field to the format 2 with a flag to indicate that the condition should be negated. (Some form of explicit negation is preferable to "inverting" the interpolated value.)

Note: If the new format values are added, and assuming the various proposals are accepted together, it might make more sense to renumber the formats to put the positive and negative versions together.