The String Representation of Musical Phrases in µO

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last modified : 14 November 2013

Abstract

While `MusicalNote`s objects can be composed into a `MusicalPhrase` object by evaluating plain Smalltalk code, it is convenient to have a compact string representation for fast input of more or less complex motives. We present here the main format for such a representation, in effect an expressive domain-specific language. It is extensible in the sense that its vocabulary dynamically reflects specifically tagged selectors, so that it can be enriched by implementing new methods in `MusicalPhrase`, `MusicalNote`, `RhythmicCell` and `GenericEnvelope`.

1. Creation of musical notes and phrases

The E musical note can be instanciated in muO by the Smalltalk code `'e' knote`. This already uses the string representation we are describing in this paper. `'e'` is the string and the `knote` selector invoques a parser to read this string as a "key note"[1]. Similarly, a musical phrase such as the major chord can be instanciated by the code `'c e g' kphrase`.

It would be cumbersome to create a new E note without using the string parser. This would look like :

```
MusicalNote new midiPitch: 64
```

or

```
Mode major mediant
```

or

```
MusicalNote new pitch: 329.628
```

The major chord could be created by

```
Mode major I
```

or

```
MusicalNote new
  chordCollect: [:n : mp |
        MusicalNote new midiPitch: mp]
  with: #(60 64 67)
```

which is not really readeable.

These examples illustrate that a note pitch has to come from somewhere : it is either provided as a MIDI key number, or crudely given as a frequency in Hz, or come from the associated scale of a specific musical mode[2].

In µO it is the responsibility of a mode to name pitches .

2. Note names and modes

The first job of the string parser is to read a pitch via a note name. The way it does this is more sophisticated than simply mapping a symbol to a frequency ; it involves a musical mode, by default `Mode major`.

The main work here is performed by the `readNote:` method of class `Mode`. For example,

```
Mode major readNote: 'e'
```

and

```
Mode major perfectFifths readNote: 'e'
```

do not return the same note. The `#perfectFifths` selector set the mode scale to a 12-TET with an overall interval a bit larger than one octave, so that it features a just perfect fifth interval; since the default tuning of 440 Hz for A is unchanged, the pitch for E is 329.3617 where it was 329.628 in the standard major mode.

Some modes provide a list of note names mapping their underlying scale steps. This is a rather complex matter in the case of diatonic modes of a chromatic scale in which there is some support for enharmonic notation, French *solfège* syllables, and Indian sargam notation. We will not go into details about this here.

Whatever the mode however, even if it does not have a naming scheme, it is always possible to refer to the notes directly via their step numbers in the mode, offset by 1 so that the tonic is at step 1. Thus, the major chord can also be instanciated by

```
'1 3 5' kphrase
```

which is equivalent to:

```
Mode major readPhrase: '1 3 5'
```

The minor chord can similarly be obtained by

1 The KeyKit format designed by Tim Thomson is a subset of the langage implemented by the parser, so `knote` can also be taken as "KeyKit note". See http://nosuch.com/keykit/

2 In µO a mode is build upon a scale by selecting a subset of its steps. For details see the paper "Modes and Scales in µO"

```
'1 3- 5' kphrase
```

or by either

```
Mode major readPhrase: '1 3- 5'
```

or

```
Mode minor readPhrase: '1 3 5'
```

4. Absolute pitch representations

A MIDI pitch can be represented by a `p` followed by the MIDI number, for example `'p60'`.

A note pitch can also be expressed by its frequency in Hertz, prepended by a `h` like in `'h440'`.

5. Pitch modifiers for note names

A note name can be completed by one or more accidentals and an octave number. The accidentals symbols are `+` and `-` (or, equivalently, `#` and `b`) ; they transpose the note respectively one scale step up and one scale step down, so that `'e+' knote` is equivalent to `'f' knote` while `'c+' knote` is `'d-' knote`. Accidentals can be mixed freely : `'c+-+' knote` is a C#.

Quarter-tone inflection is supported via symbols `>` and `<` (respectively up and down) so that `'c>>' knote` is the same as `'c+' knote`, while `'e>' knote` is equivalent to `'f<' knote`.
It is legal to write something like `'a>-<++>' knote`, which is `'b->' knote`.

The octave number, if present, is the first modifier to appear. It can be a plain number, or be indicated with a `o`. The octave number corresponding to the scale index 0 is, by convention, always 3. When no octave number is specified, 3 is assumed : `'c+o4' knote` is one octave above `'c+' knote`, and can be spelled `'c+4'`.

Last but not least, the note pitch can be offset by any interval or just ratio, specified within parentheses. For example `'c(m3)' knote` is a minor third above C, that is Eb. `'c(-m3)' knote` is a minor third below C, equivalent to `'ao2' knote`. Just intervals are allowed, for example in `'c(h7)' knote` which is an harmonic seventh above C. The list of supported interval names (several hundreds accounting synonyms) can be accessed by inspecting `MusicTheory intervalsDictionary`. Intervals can also be specified directly as ratios : `'c(6/5)' knote`.

An interval can appear by itself, like in `'(m2)' knote`. In this case, the pitch reference is the mode tonic, C in the example. `Mode D minor readPhrase: '(U)'` would returns a D (`U` stands for unison).

At the end of the pitch specification, whatever format it uses, one can append `u` or `w:`
`u` will ensure that the note is higher than the previous note in the phrase, transposing it up by as many octaves as required[3]; similarly, `w` will ensure that the note is lower in pitch than the previous note.

Here ends the overview of the different ways to describe a note pitch.

A note without pitch, a rest, can be defined using `r` instead of a pitch specification.

6. Note modifiers

The other note modifiers can appear in any order :

`v`	and a volume
`d`	and a note length
`r`	and a note value
`c`	and a channel
`t`	and a starting time
`D`	and a duration
`A`	and an articulation factor

Volume is either an integer from 0 to 127, or a float from 0.0 to 1.0. Alternatively it can be a dynamics keyword from `:ppppp` to `:fffff`[4].

Note length, duration and starting time are either integers expressing time in clicks (there is 192 clicks per second) or floats expressing time in seconds ; note length is always positive.

Channel must be a positive integer.

Note value is an integer, a code number detailed below within the rhythmic canvas discussion.

The articulation factor is a positive number.

The default values are 0.5 for note length, 0.5 for volume (`:mp` dynamics), 0 for starting time, 1 for channel.

`'c'` fully explicited would then be `'ct0d0.5v0.5c1'`.

Note value is an alternative way to specify the note length ; on the other hand duration is a completely

3 To be precise: what we call "octave" here is the repeating interval of the reading mode underlying scale, which is indeed an octave in the case of a common diatonic mode. See the paper "Modes and Scales in µO" for details.

4 See "Working with Dynamics in µO" for details.

different thing.

Any musical element in µO has a duration used as reference for scaling, mixing and concatenation. Unless explicitely set, the duration of a musical element is equal to its end time. Giving a note a specific duration dissociates the note duration from its end time, allowing articulation control. A `D` modifier not followed by a numeric specification will make the note duration be equivalent to its end time again. In terms of articulation this is a return to legato.

The articulation modifier `A` provides a handy way to set both note length and duration in order to achieve a specific articulation : `A1` is a legato, `A0.7` a staccato, `A1.8` a fermata[5].

Volume, note length, duration, octave number and starting time modifiers accept relative numeric arguments : instead of an absolute number, an offset can be provided, which must begins with a `+` or a `-`. For example, `'cv+5' knote` is equivalent to `'cv68' knote`, and `'cv-5' knote` is `'cv58' knote`. As a special case, a relative argument for starting time must always begins with a `+`, even if it is negative, since a starting time can be negative. This way the parser can differentiate between `'ct-2.0'` , a C note starting at time -2 seconds, and `'ct+-2.0'`, a C note starting two seconds before the default time. The same applies to octave number, `'co+-1'` being a C note one octave below the current octave while `'co-1'` is a C at octave -1.

Relative arguments are not really useful when describing single notes, but they are in the context of a musical phrase (see below).

More relative modifiers for volume and note length are defined as single characters. They are :

`&`	double note length
`!`	halve note length
`.`	scale note length by 3/2 (dot)
`_`	scale note length by 2/3 (triplet)
`*`	scale note length by 3
`?`	scale note length by 1/3
`^`	dynamics up (e.g. from `:mf` to `:f`)
`"`	dynamics down (e.g. from `:mf` to `:mp`)

7. Notes in a musical phrase

Within a musical phrase string representation, the default values for absent note modifiers are determined by the previous note :

5 For a detailed discussion, see the paper "The Mixing Algebra of Musical Elements in muO".

```
'cd0.2 e g' kphrase
```

is equivalent to

```
'cd0.2 ed0.2 gd0.2' kphrase
```

This applies to the pitch, so a major chord could also be expressed as list of intervals :

```
'(U) (M3) (m3)' kphrase
```

Here is its just intonation version :

```
'(U) (5/4) (6/5)' kphrase
```

The interest of relative arguments now appears :

```
'c ed+0.1 gd+0.1' kphrase
```

is equivalent to

```
'c ed0.6 gd0.7' kphrase
```

Notes are separated by commas or white space ; the type of separator determines the default starting time of the following note : if it is a white space, the above rule applies and it is the same as the previous note starting time. If the separator is a comma or a semicolumn then the default starting time is the duration of the previous note which in most cases is its end time :

```
'c,e,g' kphrase
```

is an arpeggio, equivalent to

```
'c et0.5 gt1.0' kphrase
```

The note duration may not be its end time, for example when using the articulation modifier `A` :

```
'cA0.8,e,g' kphrase
```

defines a staccato equivalent to

```
'cd0.4 et0.5 gt1.0 l1.5' kphrase
```

In the presence of a rhythmic canvas (see section 10 below), multiple commas can be used to skip beats, otherwise they count as a single comma :

```
'c,,e , , g' kphrase
```

is the same as

```
'c,e,g' kphrase
```

For the sake of clarity carriage return, linefeed and tabulation characters act as white space.

The semicolumn character `;` acts as a comma. It can be

used to get the semantics of a comma in the presence of a rhythmic canvas (again see chapter 10 below).

8. Phrase duration

By default the duration of a musical phrase is equal to its length, that is the largest of its notes ending times. The duration can be explicitly set by using an `l` (or a `L`) followed by the duration.

A standalone `l` (or `L`) can alternatively appear anywhere among the notes in which case the duration of the phrase will be set to the default starting time at that position.

Note that 'c,e,g,l' kphrase is not exactly equivalent to 'c,e,g' kphrase : both do have the same duration (1.5 seconds) but the first one has an explicit duration while the second one does not :

```
'c,e,g' kphrase solidDuration          is    nil
'c,e,g,l' kphrase solidDuration        is    1.5
```

9. Chords and arpeggios

A single note is expanded into a chord or an arpeggio with the `:` and `::` modifiers. For example `c:maj` or `d::h7`. Unless explicitely cancelled, the modifier applies to the following notes :

```
c:maj, e, g
```

stands for

```
c:maj, e:maj, g:maj
```

To cancel simply use `:` (resp.`::`) without a chord name.

The list of implemented chords is available by inspecting or printing `MusicTheory knownChords`. Many chords have synomyms ; to see them inspect or print `MusicTheory knownChordsWithSynonyms`. Any chord name may be prepended with an underscore `_` : this indicate a negative chords, where intervals are stacked downwards[6].

A chord name may be completed by a bass note and a voicing. Both are separated by a `/` .

The bass note, when present, should appear first. If the note is present in the chord, the chord will be inverted accordingly; if it is not it will be added in bass position.

The voicing is a code, a combination of :

`i`	invert chord
`s`	skip (move an octave up)
`d`	drop (move an octave down)
`o`	double an octave up
`b`	double an octave down
`m`	omit
`+`	transpose whole chord an octave up
`-`	transpose whole chord an octave down

each followed by one or more digits(s), the index(es) of a note in the chord, bass included, 1 being the index for the lowest note. Note that in the case of `i` (invert) and `+`/`-` (transpose) which apply to the whole chord, the optional following digit indicates how many times the operation must be performed.

Inversion if present must always appear first. Notes indexes are not effected by an inversion as they are defined when the bass note is known, before applying the voicing.

Examples :

```
'c:maj/A/o1' kphrase
```
is
```
'ao2 co3 e g a' kphrase

'c:maj/A/io1' kphrase
```
is
```
'c e g a ao4' kphrase

'c:7sus4/o1s2' kphrase
```
is
```
'c g b- co4 f' kphrase
```

10. Rhythmic canvas

At any position between notes in the string representation of a musical phrase it is possible to insert a time signature.

`[...]` defines a rhythmic canvas[7] upon which the following notes will be read: when not explicitely given a time or length attribute, they are aligned in the canvas: each comma `,` note separator moves the reading time to the next beat in the rhythm. The semicolumn `;` note separators works as in the absence of a canvas, setting the reading time to the duration of the previous note.

Within a rhythmic canvas, a note duration can be specified as a note value using the `r` attribute: `r0` for a double whole note, `r1` for a whole note, `r2` for a half-note, etc down to `r128`.

Dotted and triplet notes can be specified by appending a

6 From jazz musician Steve Coleman ; see its essay at http://m-base.com/symmetrical_movement.html

7 For details about rhythmic cells and canvases, see "The Representation of Rhythmic Structures in µO"

`0` (resp. a `3`) to a note value: `r80` is a dotted eighth, `r43` a triplet quarter. Appending a `6` stands for a double triplet note (with the very special case of `r106` for a double triplet whole note, `r16` being a plain sixteenth).

A `r` alone, with no numeric argument, will strech the note up to the next beat in the rhythm.

After a comma `,` special operators can be used to jump to a specific following beat:

`||`	next downbeat (in most cases the beginning of next measure)
`|S`	next on beat that is not a downbeat
`|s`	next on beat, possibly a downbeat
`|w`	next off beat, possibly void
`|W`	next off beat that is not void
`|v` or `|V`	next void beat
`|b`	the next beat, whatever it is

These operators have no effect if the current beat already fits the specification.

The content of `[...]` may be:

- a key from the `RhythmicCell library`
  e.g. `[4/4]` or `[3/8]`

- a `RhythmicCanvas` signature,
  e.g. `[(1 ((2 2) 4) 2 (3 8))]`

- a `RhythmicCell` signature,
  e.g. `[((2 2) 4)]` or `[(M ((2 2) 4) 2 (3 8))]`

- a musical phrase, in which case it will be considered as a rhythmic cell template.

- if a nested phrase has been stored in variable *var*, it can be used via `[@`*var*`]` (see below for nested phrases).

- nothing, `[]`, for going back to free rhythm.

11. Nested phrases

A `{...}` section can be used to define a part in a phrase as a nested relative phrase.

What this means is that all the text within brackets is parsed first as a full phrase, then inserted at the current read time. The nested phrase is relative in the sense that upon parsing it inherits the current notes modifiers and the current rhythmic canvas (if any).

The nested phrase can be stored in a variable *var* by using the syntax `{...}@`*var*

A subsequent relative phrase with syntax `{@`*var*`}` or `{/.../ @`*var*`}` can then recall it.

The last nested phrase can always be recalled by a plain`{}` or `{/.../}`.

In the context of a rhythmic canvas, the exact way a relative phrase is inserted is controlled by one or more optional symbols:

`{...}` (no symbol) parallel insertion within a rythmic pattern: the nested phrase may get ahead the current beat.

`{...}!` overwriting insertion within a rythmic pattern: the nested phrase claims as many beats as required to fit.

`{...}#` force alignment of the relative phrase to the rhythmic pattern: the temporal structure of the nested phrase is reconstructed so that if follows the current rhythm.

`{...}##` force alignment in a similar manner as above, but also take care that no rest happens between notes.

`{...}1` force scaling of the relative phrase into the current beat
`{...}`*n* force scaling into *n* (an integer) beats

Other symbols defines specific behaviors :

`{...}%` the relative phrase defines the new rythmic cell
`{...}%`*n* ... from its first *n* notes only
`{...}%-`*n* ... from its last *n* notes only

`{...}>` keep attributes: all notes attibutes (except time) are passed back to the parent phrase.

`{...}~`*style* inserts the relative phrase as a single inflected note, where *style* (optional) defines the pitch envelope shape ; see section 13 below for more about inflected notes.

Several symbols can be used; they must appear in the following order : `1..9 @ ! # @ % > ~`

12. Pluggable modifiers

What has been described so far could be considered as the static part of the string format for musical phrases and notes. Technically, it is mostly implemented in classes `MusicalPhrasePrinter` and `RelativeMusicalPhrase`.

The dynamic (or pluggable) part of the format is a three-fold system of routing allowing to modify either a whole phrase, a single note or the current rhythmic cell by directly sending it Smalltalk messages.

For example, `'c|cut| e g' kphrase` is a major chord

where all notes have been sent the message `cutAttack`.

The implementation of method `#cutAttack:` in class `MusicalNote` features the pragma

```
<muOPluggableAPI:
  #(Operation
        category: 'expression'
        keyword: 'cut')
        parameters:
                #((Number positive default: 0.1))>
```

Because of this pragma (a meta-statement not interpreted as Smalltalk code) the parser knows that when it finds a `cut` note modifier it has to send the message `cutAttack`: with argument 0.1 to the note[8].

The code `'c|cut0.2| e g' kphrase` would use argument 0.2 instead of the default value.

As another example the phrase `'a,b,c' kphrase` can be reversed by writing `'/rev/ a,b,c' kphrase`.

Again this is because the `#reverse` method in class `MusicalCollection` (parent of `MusicalPhrase`) includes pragma

```
<muOPluggableAPI:
        #(Operation category: 'basics'
                keyword: 'rev')>
```

which binds the `rev` keyword to selector `#reverse`.

Several modifiers can be chained, separated by semicolumns : `'/r5;acc/ c,e,g' kphrase` repeats notes C,E,G five times then shape the notes onsets into a accelerando.

A note about arguments: possibly optional, they are always numeric. Floats and integers, positive or negative, can be written as is. Fraction must be written in the form *n*`:`*m* instead of *n*`/`*m*.

In summary, modifiers provide a way to inject Smalltalk code into a phrase representation. Although this is limited to specific tagged methods of at most one argument, it is infinitely extensible: the composer familiar enough with Smalltalk can very easily implement its own methods, enriching the vocabulary of modifiers according to his style.

12.1. Note modifiers

Single note modifiers must appear in a `|...|` section immediately following the note specification.

The library of available modifiers is visible by inspecting `MusicalNote modifiers`.

Like most other note modifiers, the `|...|` section is passed implicitely from a note to the following one. The propagation is stopped by any new section, including the empty one `||`.

A `|...|` section is allowed after a chord or arpeggio definition. In that case the modifiers will apply to the expanded note, a musical phrase. The corresponding library is returned by `MusicalPhrase modifiers`.

For example,

```
'c:maj|strum|,a,b' kphrase
```

has the method `strum` sent to the three major chords.

To have only the first two chords strummed, we can write

```
'c:maj|strum|,a,b||' kphrase
```

Modifiers specified with syntax `|+...|` are local for a single note: they are not propagated; for example,

```
'c,e|+cut|,g' kphrase
```

only cuts the attack of note E.

If note modifiers are already defined, a new set of modifier specified with `|+...|` is added to them for the corresponding note; syntax `|-...|` is similar, with the difference that the local modifiers are prepended to the previously defined ones.

Finally, modifiers can be changed for all following notes using forms`|+=...|`and`|-=...|`, which work as described above with the only difference that their effect is not local.

12.2. Phrase modifiers

Full phrase modifiers must appear in a `/.../` section at the beginning of the phrase representation.

Several sections can appear consecutively. In that case, the sections are considered from right to left, the rationale being that it makes it possible to further process a musical phrase by simply appending a modifier section to its string representation.

Phrase modifiers are a definite part of the string format ; as such, they can appear within nested phrases :

```
'/r2/ a,b, {/r3/ c, d}' kphrase
```

is

8 This registration mechanism has other usages in µO. Notably it allows extensible menus in interactive editors.

```
'a,b,c,d,c,d,c,d,a,b,c,d,c,d,c,d' kphrase
```

The library of available modifiers is returned by the expression `MusicalPhrase modifiers`.

When a modifier appears prepended with a `!` it will operate on each of the phrase notes instead of the phrase itself; in that case it must be a valid note modifier (see previous section).

A modifier, be it for phrase or for notes, can always be prepended with a symbol defining a specific way for the transformed phrase to be handled (by default it replaces the original phrase).

These symbols are:

`+` the transformed phrase is appended to the original one.
`&` the transformed phrase is mixed to the original one.
`*` same as `+`, then the transformed phrase is being transformed a second time and also being appended.
`>` the transformed phrase is appended to the original one, then the resulting phrase is scaled to the original duration.

12.3. Rhythmic cell modifiers

Rhythmic cell modifiers change the current cell ; they can do so by either replacing it altogether or by first creating a child cell, in which case it is later possible to switch back to the parent cell.

The modifiers appear in a `[;…]` section. For example,

```
[3/8][;div;bpm160]
```

is a 6/8 time signature

A child cell is created with `[:]` while the return to the parent cell is done via `[.]` ; to create a new child of the current parent, use `[.:]`.

In summary we have the forms :

`[;…]`	modify current cell
`[:…]`	create a child cell, modify it
`[.…]`	back to parent cell, modify it
`[.:…]`	create a child of parent, modify it

13. Inflected notes

An inflected note is a note whose pitch is not constant over its duration. In the µO implementation such a pitch is represented by an envelope.

The envelope can be either read from a library :

```
c~up
```

or it can be built by connecting plain notes in a phrase :

```
{c,g,e}~
```

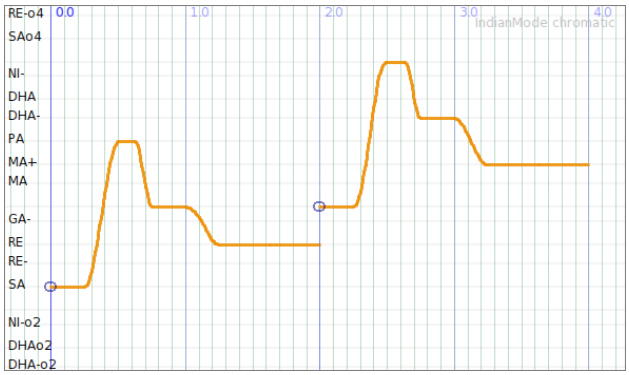
13.1. Pitch envelope structure & behavior

Each breakpoint in a pitch envelope behave like a modal note upon transposition: even for non eval-tempered scales, the vertical intervals follow the scale intervals.

For an example, let's define two inflected notes built on a phrase in a mode with a non equal-tempered scale :

```
IndianMode marwa readPhrase:
 '{{/stacc/ SA, PA!, GA&, RE.}~smooth}@inote,
        {/mt2/ @inote}'.
```

The second note is transposed two mode steps up. From the picture below we can see that its pitch inflexion shape has been modified (at the third breakpoint) in order to reflect the actual intervals it now covers ; it is kept in tune:



13.2. Pitch envelope libraries

A single note can be inflected by appending *~shape* , *~shape*n* or ~shape/n* , where *shape* is a symbol and *n* is a number.

Examples:

```
c~bump
c~up*3
c~dip/2.5
```

The symbol *shape* defines the shape of the inflexion. It is registered in a library associated to the reading mode. The user can modify or add to the library at will; this topic will not be covered here.

Send `#inflexionSymbols` to a mode to get its set of

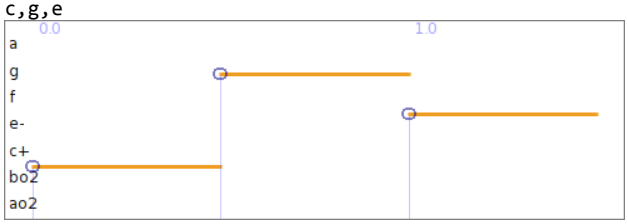
legal symbols for inflexion[9].

The number *n* and operator * or / scale the inflexion in the frequency domain: where `c~up` ends one semitone higher, in C#, `c~up*3` ends three semitones higher in Eb

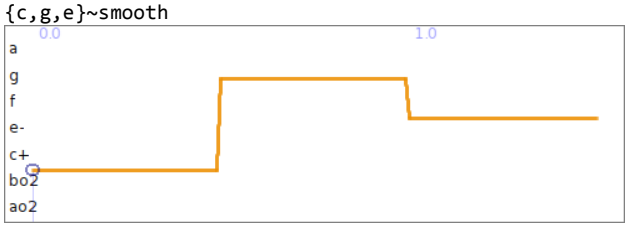
13.3. Musical phrase as inflected note

An alternative way to define a pitch envelope is to construct it from a musical phrase template. Each note in the phrase gets transformed into a breakpoint; its articulation defines how long after the breakpoint will the envelope remains flat.

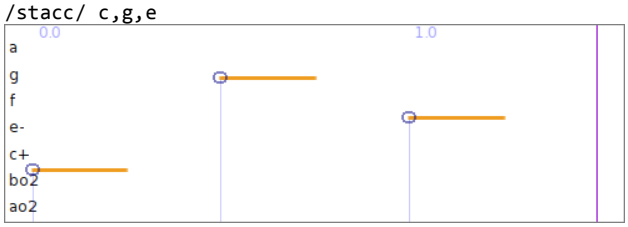
`c,g,e`



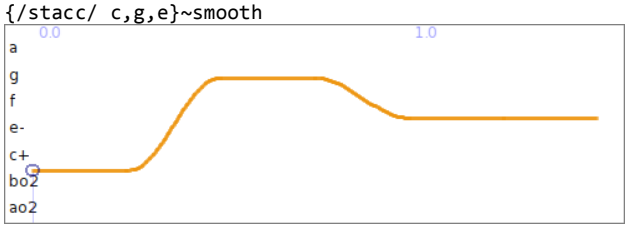
`{c,g,e}~smooth`



`/stacc/ c,g,e`



`{/stacc/ c,g,e}~smooth`



The format is `{...}~style`, where *`style`* is optional.

9 At the time of this writing, `Mode major inflexionSymbols` returns `#(#bump #cBump #cDip #cDown #cUp #dip #down #earlyBump #earlyDip #endBump #endDip #erfDown #erfUp #example #expDown #expUp #fastDown #fastUp #linDown #linUp #logDown #logUp #tDown #tUp #up #vcDown #vcUp)`.

When present, *`style`* must be a method of class `GenericEnvelope`.

Such relevant methods are: `smooth`, `linear`, `slur`, `circular` ; more can be defined at will by implementing the corresponding methods.

14. MIDI drums

A specific syntax allows the insertion of MIDI drums:

`+(someDrum)` is equivalent to `pNNc10`

where *`someDrum`* is a value in the `MIDI drums` dictionary[10] and *`NN`* the corresponding numeric key. For example:

`+(hiWoodBlock)` is equivalent to `p76c10`

For convenience, it is allowed to omit arbitrary letters in *`someDrum`*. If *`somDrm`* is a registered MIDI drum, it will be interpreted as is; if it is not, then the first registered drum matching the letters in *`somDrm`* will be considered.

For example,

`+(iBlck)` is equivalent to `+(hiWoodBlock)`
`+(loFTom)` is equivalent to `+(lowFloorTom)`
`+(loTom)` is ambigous: `+(lowTom)` or `+(lowFloorTom)`
`+(lowTom)` is not ambigous: it is a value in `MIDI drums`.

Channel, panning and volumes attributes can be used in drum notes, but they will not be transmitted to upcoming regular notes, only to other drum notes.

15. MIDI messages

For compatibility with KeyKit, arbitrary MIDI bytes can be represented within a musical phrase by using `x` followed by hexadecimal characters. For example, the `'xb07b00'` would be a phrase consisting of a 3-byte MIDI message - an all-notes-off for channel 1. The only modifier allowed for MIDI byte messages is the `t`ime modifier: `'xfe,xfet24'` is a phrase containing two single-byte messages, the second one occurring at click number 24.

10 Here is the complete list: `#(openCuica muteTriangle openTriangle acousticBassDrum bassDrum1 sideStick acousticSnare handClap electricSnare lowFloorTom closedHiHat highFloorTom pedalHiHat lowTom openHiHat lowMidTom hiMidTom crashCymbal1 highTom rideCymbal1 chineseCymbal rideBell tambourine splashCymbal cowbell crashCymbal2 vibraslap rideCymbal2 hiBongo lowBongo muteHiConga openHiConga lowConga highTimbale lowTimbale highAgogo lowAgogo cabasa maracas shortWhistle longWhistle shortGuiro longGuiro claves hiWoodBlock lowWoodBlock muteCuica)`

MIDI bytes can be combined with normal notes in the same phrase, e.g. `'e,f,g,xc005,a,b'` is a phrase that contains a program change command in the middle of several normal notes. Note that it is much more practical to generate such phrases via proper MIDI objects:

```
ph := 'e,f,g' kphrase, ProgramChange electricPiano2,
'a,b' kphrase.
```

In the case of program changes a specific format is implemented:

`P[`*instrument*`]`
inserts at read time the program change for *instrument* in channel 1.

`P[`*n*`:`*instrument*`]`
inserts the program change for *instrument* in channel *n*.

`P[n:instrument1 p:instrument2 …]`
inserts the program changes for *instrument1* in channel *n*, *instrument2* in channel *p*, etc.

`P[]` inserts 16 messages setting `grandPiano` as the instrument for all MIDI channels.

So the example above can be written:

```
'P[],e,f,g,P[1:electricPiano2],a,b' kphrase
```

All `P[...]` forms offset the reading time by 1 millisecond, to ensure the program changes take effect before the next note is played.

16. Mode changes

The mode for reading[11] can be changed at any position between notes by inserting `M[`*mode*`]`, where mode is a full or partial `Mode` specification.

A partial specification modifies the current mode; for example:

`M[minor]` `M[G lydian]`	switch to C minor
`M[G2 lydian]`	switch to G lydian at octave 2
`M[perfectFifths]`	change temperament
`M[withHandelFork]`	change tuning

A full specification defines another mode altogether; any Smalltalk expression evaluating to a Mode instance is valid:

`M[IndianMode bilawal]`	an IndianMode
`M[Mode major perfectFifths withHandelFork]`	
`M[Mode ET: 31]`	31-TET

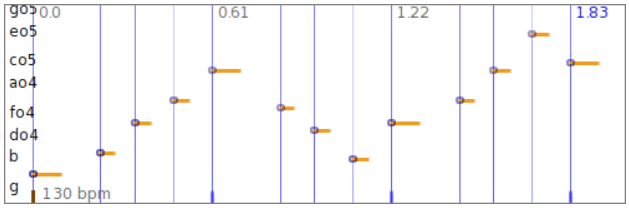
11 See section 2 at the beginning of this document.

17. Examples

17.1. A modal exploration

Here is a real-world example of musical phrase defined by a complex string representation. It looks obfuscated, but one must keep in mind that is was elaborated incrementally with real-time feedback in a interactive notebook: actually it came very naturally.

```
M[E harmonicMinor]
[(M 1 (1 8) 1 (1 16) 1 (2 14))][;bpm130]
{/art0.4/
  {4|mf;ninth;ap;dim;dim|,
   1|+rev;fn3|,
   4|+ln3|,
   7|+rev;fn2|}##}
```



The compactness of the format is better appreciated when one look at the equivalent Smalltalk code, albeit very concise in itself:

```
mode := Mode E harmonicMinor.
rcanvas := (#(M 1 (1 8) 1 (1 16) 1 (2 14)) sig
                bpm: 130) asCanvas.
phrase :=
  (mode subdominant mf ninth
        arpeggiate diminuendo diminuendo),
  (mode tonic mf ninth arpeggiate diminuendo
        diminuendo reverse firstNotes: 3),
  (mode subdominant mf ninth arpeggiate diminuendo
        diminuendo lastNotes: 3) at0,
  (mode subtonic mf ninth arpeggiate diminuendo
        diminuendo reverse firstNotes: 2).
phrase followCanvas: rcanvas.
phrase staccato: 0.4; removeSolidDuration.
```

Of course it is also possible to mix Smalltalk code and string representation:

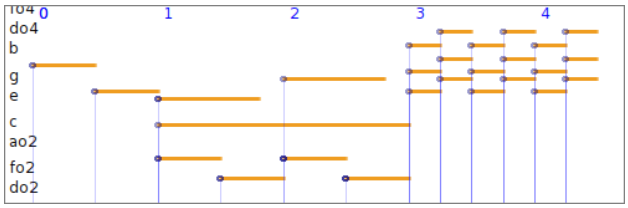
```
phrase := Mode E harmonicMinor readPhrase:
            '4|ninth;ap;dim;dim|,1|+rev|,4,7|+rev|'.
phrase followCanvas:
        (#(M 1 (1 8) 1 (1 16) 1 (2 14)) sig
                bpm: 130) asCanvas.
phrase staccato: 0.4; removeSolidDuration.
```

17.2. Nested phrases

Here we use three simultaneous nested phrases for a complex chord structure (including dynamics variations), followed by another nested phrase repeating two chords

three times:

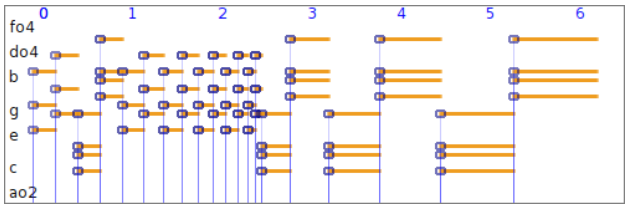
```
a,f,{c"&&}{go2^,e,g^,e}{/nonleg/ e^&,g""},
{/r3/ f!":min,g}
```



17.3. hi & ho

This example demonstrates how nested phrases can be bound to an symbol and recalled later.

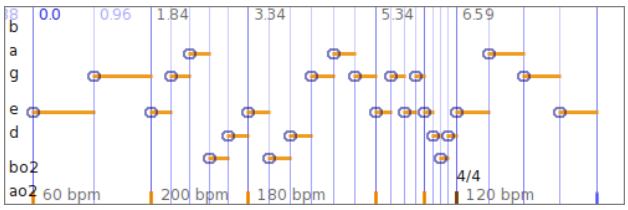
```
{f!:min,g}@hi,{c!^:min2,a}@ho,
{/mf;r5;acc4;cresc/ @hi}, {/mf;r3;rit4;dim/ @ho}
```



17.4. Rhythmic variations

In this example we start with a plain 4/4 signature and play with it via rhythmic cell modifiers:

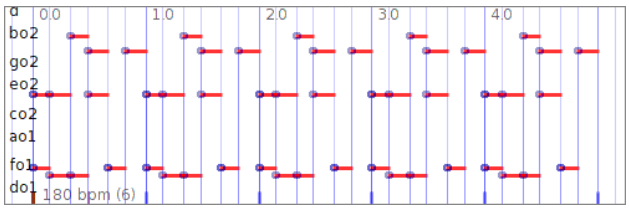
```
[4/4] [:tup2:4;acc] e,g, [.:tup5:3] e,g,a,c,d,
 [.:tup6:4] e,c,d,g,a,g, [.:tup4:2;acc2] e,g,e,g,
 [.:tup4:1] e,d,c,d, [.:rit] e,a,g,e
```



17.5. Drumming

6/6 drumming with swing and dynamics:

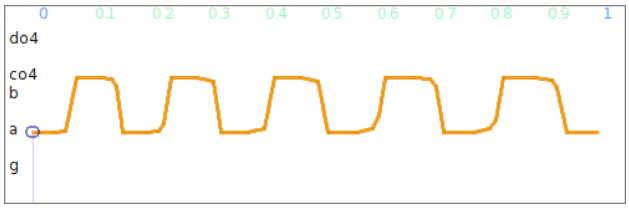
```
/r5/ [3/6][;dsw0.45] +(loFTom)^ +(riCy1), +(riCy1)"
 +(eSnare), +(eSnare) +(riCy2), +(riCy1) +(crshCy2),
 +(loFTom)^, +(crshCy2)"
```



17.6. A vibrato

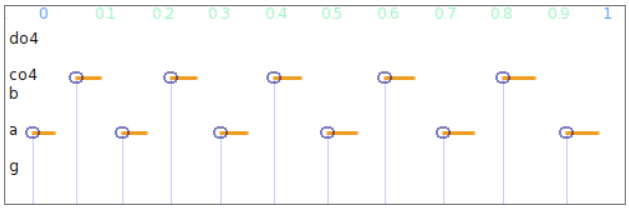
Pitch inflexion can be sculpted in very precise way; in this example we define all details of a vibrato:

```
{/d1.0/ {/r5.5;stacc;rit1.5/ a,c}}~slur
```



The vibrato skeleton is the part within brackets:

```
/d1.0/ {/r5.5;stacc;rit1.5/ a,c}
```



Over the course of 1 second we repeat 5.5 times the sequence A C with a slight ritardando. The staccato articulation defines which proportion of the notes will have a stable pitch in the eventual vibrato,

See for example with a much shorter staccato:

```
{/d1.0/ {/r5.5;dots;rit1.5/ a,c}}~slur
```