Ornament as Data Structure: An Algorithmic Model based on Micro-Rhythms of Csángó Laments and Funeral Music

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Abstract

This study presents an algorithmic method for creating ornaments linked to skeletal base-notes. In developing this model, a data structure for encoding ornament-types is presented. This data structure employs contour theory, variable harmonic scaling, temporal/iterative parameters, and stochastic noise. In order to tune these parameters, the laments and funeral music of the Csángó, a music rich with ornamentation and dense heterophony, is used both as a textural model and as a source of quantitative data. This model is implemented in the Python programming language and is integrated into the athenaCL composition system, an open-source, cross-platform program for algorithmic composition in Csound. It is shown that convincing heterophonic textures can result by the combination of algorithmic ornamentations of a single line.

1 Introduction

This study presents an algorithmic method for creating ornaments linked to skeletal base-notes. In developing this model, a data structure for encoding ornament-types is presented. This data structure employs contour theory, variable harmonic scaling, temporal/iterative parameters, and stochastic noise

This model is implemented in the Python programming language and is integrated into the athenaCL composition system, an open-source, cross-platform program for algorithmic composition in Csound. It is shown that convincing heterophonic textures can result by the combination of algorithmic ornamentations of a single line.

The laments and funeral music of the Csángó are used as a point of departure for this study, providing a musical model of sophisticated heterophony and dramatic ornamentation. Ornament-types, as well as actual temporal measurements from ornaments in recorded Csángó music are employed in this model. The use of this music is as a textural model and as a source of performative data. This not an attempt to model a style or a performance practice.

2 Music of the Csángó

The Csángó, in some cases a Szekler ethnic group, are found in eastern Transylvania (Kalotaszeg), the Gyimes valley, and Moldavia. The folk music of these people is renowned for its preservation of the most archaic forms of Hungarian folk culture. Intermingled with this population are many Roma (Gypsy); most musicians in these regions are Roma and have contributed significantly to the development of this music.

Amongst various Csángó groups is a tradition of violin duets performed as laments or in association with rites of the dead. This music has regional differences and goes under various names: Keserves (lament), Hajnali (dawn songs), or simply as funeral music. In most situations, two violins perform a descending melodic line in a heterophonic fashion. Each performer provides ornamentation consisting of turns, trills, and detailed passage work. Often trills are combined with other trills or wide vibrato to create a dense, strident spectrum. The harmonic materials are usually diatonic or pentatonic. The rhapsodic, free rhythm often used for this music is often referred to as *parlando rubato*.

Two recordings are analyzed for this study. The first is a stereo recording titled "Dawn Songs And Gypsy Couple Dances" from the album *Transylvanian Folk Music From Kalotaszeg*, recorded in 1999. The second is a mono recording titled "Lamenting music at the side of the dead with two violins" from the album *Hungarian Instrumental Folk Music*. For simplicity these recordings will be referred to as A and B respectively.

To observe the rapid and detailed ornaments of this music, computer-rendered pitch-tracking graphs were created with the open-source digital audio editor Audacity. These graphs were captured at a resolution of 6.28 milliseconds per pixel (a duration roughly equivalent to a 256th note at quarter equals 120 BPM), providing detailed temporal information. To measure durations, the number of pixels between note-attacks is then counted and converted to seconds. Both the quality of the recordings and the register of the violin contribute to the precision of these graphs. Stereophonic recording additionally contributes to this analysis. As each violin is recorded in a sperate channel with a minimum of bleed, an isolated transcription of each part is created.

3 Ornamentation & Heterophony

Heterophony, as demonstrated in the music of the Csángó, is the simultaneous presentation of a single skeletal melody by two or more performers, each musician providing unique elaborations to the melody. The use of ornaments is a frequent and functionally important feature. Often improvised, the combination of ornaments adds a micro-polyphony to a line. Ornaments do not have a prescribed duration or rhythm, and thus by their very nature are gestural. With each instance, an ornament-type produces a unique set of pitches and durations. These attributes are amplified when two players perform the same ornament, or two different ornaments, in a heterophonic context. Small variations in timings, tuning, and phrasing result in a complex and conterpuntal result.

Recording A provides frequent examples of the same ornament being performed simultaneously by two players. At 0:07 both instruments perform a downward then ascending arc. These ornaments, nearly identical in contour, nonetheless have greatly divergent rhythms and pitch content. This combination of similar ornament-types produces micro-polyphonies between points of melodic unison.

In other circumstances, contrasting ornament-types are performed simultaneously. For example, in recording A, from 0:03 to 0:04, violin L performs a three-note turn, while violin R performs a two-note trill (figure 5, below). The combination of the two ornaments produces complex timbral and rhythmic interactions. This technique of combining different ornament-types is found throughout recording A. Notice at 0:19 to 0:20, where again a three-note turn is combined with a two-note trill (figure 7 below).

With this observed context, heterophony may be seen as a texture which results largely from independent uses of ornamentation. Quntatative temporal data supports this claim: ornaments and heterophony often operate within a similar time scale. In recording A ornament-note durations are often between 30 and 130 ms, while heterophonic note-articulations are often separated by a duration between 40 and 450 ms.

4 An Abstraction of Ornament

There are many classification systems for ornaments designed for particular musical styles or performance practices. Labels such as "trill" and "turn" for example are generally understood in Western classical traditions, whereas a wide variety of other ornamental gestures have multiple names, redundant names, or no names at all.

In developing an algorithmic system to create ornaments linked to skeletal base-notes, common names and context-specific classifications systems are of little use. Rather, a sophisticated and practical data-structure model of an ornament is required, allowing a wide variety of ornaments to be encoded and generated. The data structure presented here employs contour theory, variable harmonic scaling, temporal/iterative parameters, and stochastic noise. This system categorizes and stores reusable ornament-types that can then be applied to any note in various contexts. This system defines ornament-types with three main parameters: *position, shape,* and *style*.

This model assumes that ornaments operate in relation to a base-note. This relation need not be functional. This paper makes no claim that this is actually how musicians think of ornaments; rather, it claims only that in hearing ornaments, one note may be considered the source, base, or goal of a gesture. Ornaments are thus 'attached' to a base-note by either appearing before or after the base-note, or the base-note being a prominent member of the ornament gesture itself. It is irrelevant that in many instances it is difficult to decide contextually which note is the base-note, for here the base-note functions solely as a point of reference.

4.1 Ornament Position

Three terms are used to identify the position of an ornament in relation to the base-note. An "attack" ornament appears at the start of the base-note, a "release" ornament appears at the end of the base-note. An "anticipate" ornament appears before the base-note, but starts before the note's expected (or contextually determined) start-time, beginning in negative time in relation to a base-note starting at time equal to zero.

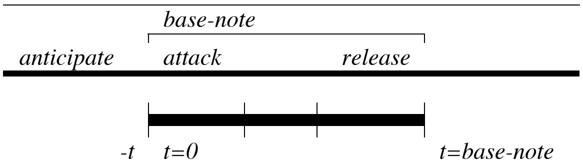

Figure 1. Ornament position in relation to base-note.

4.2 Ornament Shape

The shape of an ornament is given by a contour space segment (cseg). Contrary to traditional contour theory (Morris 1987), and for the sake of algorithmic implementation, the base-note pitch of an ornament-type is assigned the integer 0. Positive and negative integers can thus be used to represent distances above and below the base-note in contour space. This contour, when contextually realized, is scaled by a controlling harmonic language to produce a pitch-space realization.

For example, a cseg of <0 1 0 -1> could be scaled by a chromatic harmonic language. With a chromatic scaling, each integer represents a half-step. As shown in figure 2, if the base-note is D, the cseg is scaled to the pitches D, D♯, D, C♯.

Alternatively, the same cseg could be scaled by a diatonic harmonic language. This means that each integer represents a diatonic scale step. If the base-note is D, and the local diatonic system as C Major, the cseg is scaled to D, E, D, C. Diatonic, as used here, does not necessarily refer to major/minor collections, but rather any collection less then the aggregate that is used as a local controlling harmony.

Finally, the same cseg could be scaled by a microtonal interval of any size. This means that each integer represents an exact interval, given as a fraction of a half-step. If the base-note is D, and the microtonal interval is specified as a quarter tone (.5 half-steps, or 50 cents), the contour-form translates to D, D𝄲, D, C𝄰. The following figure summarizes these relationships:

cseg	*base-note*	*harmonic language*	*resultant pitches*
<0 1 0 -1>	D	chromatic	D D♯ D C♯
<0 1 0 -1>	D	diatonic (C-major)	D E D C
<0 1 0 -1>	D	microtone (50 cents)	D D𝄲 D C𝄰

Figure 2. Cseg *shapes* scaled to three harmonic languages.

As should be clear, the combination of csegs and harmonic languages provides a wide variety of ways to specify an ornament-type. Ornament-types can be redundant when complete information is known. That is to say, with knowledge of the local diatonic system, a diatonic ornament can be constructed by specifying a chromatically scaled cseg with the appropriate number of half-steps for each interval. This redundancy contributes to the flexibility of this system.

4.3 Ornament Style

The temporal/iterative structure, or *style*, of an ornament can be specified in a variety of ways. To account for these temporal/iterative deployments, each ornament-type has parameters for both note-duration and total-gesture duration. Note durations are given as a list of values in seconds; if a cseg demands more durations than provided in the list, the list of durations simply loops. The total-gesture duration is given as a percentage of the base-note's duration.

In the case where ornament note-durations are used, information about total-gesture duration is not needed, as the total-gesture duration is calculated from the ornament note durations. Contrarily, in the case where total-gesture duration is used, note durations are scaled to fit within the total-gesture duration.

These *styles* provide a way to classify temporal/iterative relationships. Three *styles* are used in this algorithmic model: "single", "scale", and "loop". (1) If a duration for each note of the ornament is known, the ornament can be presented once, as a single iteration of the cseg. A "single" ornament derives its total-gesture duration from one iteration of the cseg. A mordent is a common "single" ornament, as each instance often uses absoulte durations for each ornamental note. (2) Alternatively, if the total-gesture duration of the ornament passage is known, a "scale" ornament can scale the prescribed ornament durations to fit within the total-gesture duration. In this case, the absolute duration of the ornament notes are secondary to the proportional relationship between the ornament's durations. An appogiatura may act as such an ornament, its duration functioning as a percentage of the base-note. (3) Finally, if both the ornament note-duration and the total-gesture duration are known, a "loop" ornament can repeatedly iterate its cseg as a cycle. This is a hybrid of a "single" and a "scale" ornament. Trills, tremolos, and various vibratos are common "loop" ornaments. The dependence of these styles to durational information is presented in figure 3:

temporal information	*ornament style*		
	single	*scale*	*loop*
ornament note-durations	•		•
total-gesture duration		•	•

Figure 3. Available ornament styles based on available temporal information.

4.4 Combining Ornament Position, Shape, and Style

Combining these three primary parameters provides a way of encoding a wide variety of ornaments. More importantly, similarities between ornaments become readily apparent. For insance, the only formal difference between a trill and a wide vibrato is the choice of harmonic language. Both ornaments may have an "attack" or "release" *position*, a cseg <0 1> *shape*, and a "loop" *style*. A trill, however, uses a chromatic or diatonic harmonic language, while a wide vibrato uses a microtonal harmonic laguage. The same cseg *shape*, <0 1> can also be conceived of as a turn. In this case the ornament has an "attack" *position* and a "*single*" *style*. The same cseg *shape* might also be used to create a passing tone gesture to a following note on contour-step 3. In this case the ornament could use a diatonic harmonic language, a "release" *position*, and a "scale" *style*.

4.5 Proportional and Stochastic Parameters

In addition to the parameters described above, ornaments have parameters to control stochastic noise. This noise is applied to both the amplitude and duration of each ornament-note. The amplitude of ornamental notes is determined as a percentage of the base-note plus stochastic noise, producing the unpredictable fluctuations common to any gesture. Durations, after determination based on *style* (described above), are likewise altered with stochastic noise. Normal, exponential, or other continuous distributions may be used. The amount of noise applied to an ornament-note is given as a maximum percentage of variation. For example, if a duration of 100 ms is selected and the ornament-type has a maximum percent offset of .08, or 8%, the distribution is scaled between an offset of -8 and 8 ms. The same procedure is applied to amplitude.

The following table presents all attributes of the ornament data structure and their relevant values and units:

	values/ units	*example*
ornament position	*anticipate* *attack* *release*	
ornament shape (cseg)	*scale steps*	<-3 -2 -1>
pitch language	*chromatic* *path* *set* *microtone*	
ornament style	*single* *scale* *loop*	
ornament note duration list	*seconds*	.110, .096, .101
ornament duration as percent of base-note	unit interval	.50
duration variance percent offset	unit interval	.08
ornament amplitude as percent of base-note	unit interval	.92
amplitude variance percent offset	unit interval	.10
microtone size	semitones	.500

Figure 4. Ornament data structure parameters.

5 Real-Value Temporal Data Extracted from Pitch-Tracking Analysis

This model, based on a contour surrounding a referential pitch, provides a framework with which to apply ornaments in a wide variety of contexts. Rather than arbitrarily setting these parameers, this project uses real-values found in recordings of ornamented Csángó laments and funeral music. Again, the goal of this project is not to imitate a particular performance practice, but rather to use real-values to inform an algorithmic model. The real-value attributes considered here are the duration and micro-rhythms of individual ornament notes.

Two representative musical segments will be presented. Examining seconds 3 to 4.5 in recording A, we see the simultaneous presentation of a turn (in violin L) and a trill (in violin R). Duration measurements for succesive notes along with statistical information is presented in the following table:

violin L, recording A, 0:03—0:04.5, turn

time	*note length in pixels*		*pixels*	*s*
3-4.5	16	average	11.4	0.0717
	17	minimum	7	0.04396
	9	maximum	17	0.10676
	16	median	11	0.06908
	10			
	12			
	8			
	14			
	9			
	9			
	7			
	10			

violin R, recording A, 0:03—0:04.5, trill

time	*note length in pixels*		*pixels*	*s*
3-4.5	10	average	12.6	0.07913
	13	minimum	5	0.0314
	5	maximum	22	0.13816
	8	median	12	0.07536
	15			
	10			
	10			
	17			
	10			
	16			
	12			
	15			
	11			
	15			
	22			

Figure 5. Ornament durations. 6.28 ms per pixel.

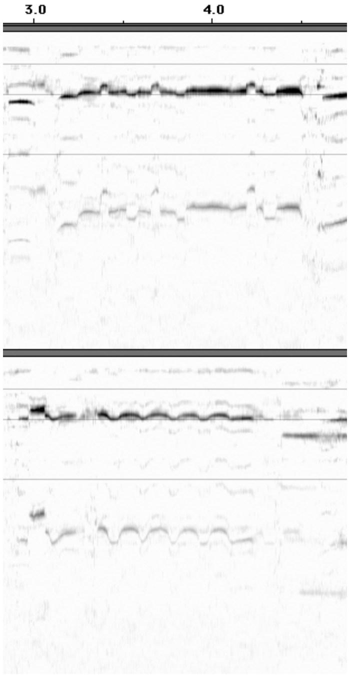

Figure 6. Pitch tracking analysis of recording A, seconds 3 to 4.5.

Notice that in the case of the turn the durations alternate between larger (12-17 pixel) and smaller (8-10 pixel) durations. The longer durations align with the base-note, while the shorter durations align with the surrounding scale steps 1, -1. In the case of the turn, there appears a micro-rhythm emphasizing the base-note. The trill in violin R, on the contrary, shows no similar organization, moving unpredictably from values between 5 and 22 pixels. In the case of the trill, there appears no directed durational change.

Seconds 19-20 again demonstrate the combination of a turn (in violin L) and a trill (in violin R):

violin L, recording A, 0:19—0:20, turn

time	*note length in pixels*		*pixels*	*s*
19-20	7	average	12.3	0.07745
	18	minimum	7	0.04396
	11	maximum	18	0.11304
	17	median	11	0.06908
	11			
	17			
	8			
	13			
	10			
	9			
	10			
	17			

violin R, recording A, 0:19—0:20, trill

time	*note length in pixels*		*pixels*	*s*
19-20	10	average	12.5	0.07874
	10	minimum	8	0.05024
	12	maximum	17	0.10676
	13	median	12	0.07536
	14			
	11			
	17			
	10			
	14			
	8			
	12			
	17			
	15			

Figure 7. Ornament durations. 6.28 ms per pixel.

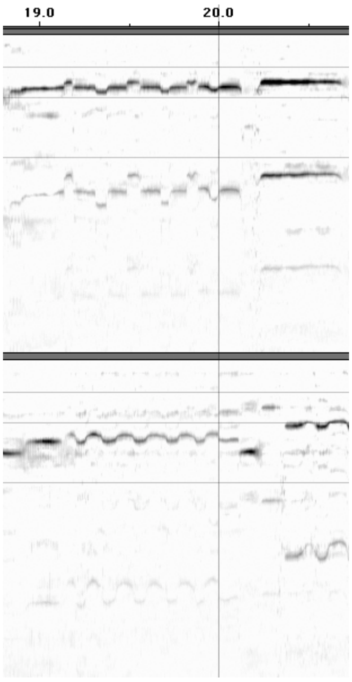

Figure 8. Pitch tracking analysis of recording A, seconds 19-20.

Notice that violin L again presents a turn in a distinct micro-rhythm, alternating between long and short durations in order to provide greater durational weight to the base-note. The trill in violin R is likewise consistent: there appears an average duration of around 80ms, no ordered use of durations, and no directed change in tempo.

The particular contstruction of ornaments described above is part of larger collection of real-value data obtained from recordings A and B for this study. In addition to the measurement of ornament note-durations and micro-rhythms within ornaments, pitch movement of specific ornaments is translated to the appropriate csegs and harmonic laguages. The collection of this data enables the creation of a repertory of ornament-types and parameters. The table below gives the names and parameters of threesample ornaments in this repertory.

parameter	*values*		
common name	trill	turn	appog-giatura
ornament position	release	anticipate	anticipate
cseg	<1 0>	<0 1 0 -1>	<-1>
pitch language	diatonic	diatonic	diatonic
ornament style	loop	single	single
ornament note duration list (s)	.090, .096, .094, .092,	.110, .070, .105, .076	.088
ornament duration as percent of base-note (%)	.6	n/a	n/a
duration noise maximum percent offset (%)	.10	.06	.08
ornament amplitude as percent of base-note (%)	.910	.940	.960
amplitude noise maximum offset (%)	.010	.025	.022

Figure 9. Example parameters for common ornaments

Notice that the trill has a distributed list of durations and high value of durational noise, promoting the generation of durations similar to those seen above. The turn, likewise, has weighted durations to produce the observed alternating rhythm.

6 Implementation in athenaCL

This model of ornament-types is integrated within the athenaCL algorithmic composition system, allowing the easy deployment and sonic realization of these ornaments. This software has three features that support the use of this ornament model.

First, in athenaCL a musical part is conceived of as a texture. A texture is any way of organizing musical parameters into a single musical part. Textures are implemented as object instances created from a TextureModule. Any number of texture instances can be combined within athenaCL, each functioning as an independent part.

Second, textures take as a primary organizing parameter a "path". A path is an ordered collection of pitch sets. These sets can be of any size, can contain redundancies, and can simultaneously be interpreted as ordered or un-ordered and as operating in pitch-space, pitch class space, or set-class space. The use of paths allows athenaCL to determine two types of diatonicism for any given pitch: a local diatonicism based on the total pitch collection in a pitch's set, and a global diatonicism based on the total pitch collection of the entire path. When using ornaments within athenaCL, the user can choose between either of these two diatonicisms for each ornament-type.

Third, textures within athenaCL can be assigned a variety of temperaments, unique tunings for each of the twelve tones. Some temperaments model historical temperaments such as mean-tone and Pythagorean tunings. Other temperaments provide varying degrees of noise upon twelve-tone equal temperament, simulating humanistic deviations.

A TextureModule can be used to control the choice of when to apply an ornament and which ornament to apply. A simple method is presented here, implemented in the TextureModule "MonophonicOrnament". First, a repretory of ornaments is created as a collection of ornament data-structures. The texture, for each new note generated, then decides whether or not an ornament should be created based on a user-defined probability. If the texture chooses to create an ornament, an ornament is randomly selected from the repretory using a uniform distribution.

A future TextureModule could make ornament choices based on specialized contextual information concerning previous and next pitches, position within the set and path, or the rhythmic value of the base-note. Applications using Markov chains or formal grammars are also equally viable.

In the example provided here, base-notes are chosen in-order from a path with a single set, the set providing the skeletal melody of recording B. Base note amplitudes are kept within a narrow range. Tempo and rhythms are given so as to create a rhapsodic, *parlando rubato* pulse. The following figure shows the TextureInstance View command of a MonophonicOrnament texture from within athenaCL.

```
[PI(phraseA-nonPart6)TI(wer)] :: tiv
TI: wer, TM: MonophonicOrnament, TC: (0), TT:
TwelveEqual
   PitchMode: pitchSpaceSet, PolyMode: set
   o/+: +
(i)nstrument         50 (guitarNylonNormal)
(t)ime range         001.00--041.00
(b)pm                'staticBeat', 76.00
(r)hythm             'loop', ((4,4,+),(4,5,+),
                     (4,4,+),(4,7,+),(4,9,+),
                     (4,7,+),(4,12,+))
(p)ath               phraseA-nonPart6
   (12,11,9,12,14,11,9,11,9,9,11,9,9,11,9,
   9,9,7,7,5,2)
   40.00(s)
local (f)ield        'basketGen', 'orderedCyclic',
                     (0)
local (o)ctave       'basketGen', 'randomChoice',
                     (7)
(a)mplitude          'cyclicGen', 'linearUpDown',
                     89.00, 90.00, 0.12
pa(n)ing             'constant', 0.25
au(x) pfields        none
t(e)xture
   e0                'loopWithinSet', 'off'
   e1                'ornamentLibrary',
                     'diatonicGroupA'
```

Figure 10: athenaCL TextureInstance View display

The realized algorithmic examples demonstrate various arrangements of this texture within athenaCL, using a simple Csound instrument. Each rendering of a TextureInstance employing ornaments is unique due to both the choice of ornaments and the application of stochastic noise. These differences result in dramatic changes in the timing and character of the resultant line. When two TextureInstances are combined, both with the same rhythms and skeletal melody, the result is a thick heterophony. The timing of base-note articulations are shifted due to varying "attack" ornament durations, and "release" ornaments create varying combinations of sustained ornamental textures. Even when both textures use the same ornament-type, variations due to stochastic noise produce appropriate deviations. During moments between base-notes, thick ornamental micro-polyphony is obtained.

In order to obtain the necessary timbral distinctions between instruments, each texture can be tuned to a slightly different temperament. The resultant pitch differntiation produces a timbrally thicker sound and a greater independence between parts.

7 Conclusion

The ornament model presented here, even when employed with a simple generator, demonstrates a flexible and powerful way of algorithmically conceiving and deploying ornaments. Additionally, the results obtained suggest that in some cases heterophony may actually result as a product of choices in ornamentation alone, rather than specific considerations of timing and leader/follower relationships. Future work with this system will develop more sophisticated TextureModules designed to select ornaments based on higher levels of contextual data. This would included information such as temporally adjacent base-notes, position in the set and path, and the rhythm of the base-note. Alternatively, a TextureModule could be created that simultaneously generates both musical parts of a heterophonic texture, coordinating each part's choice in ornament and producing a more refined heterophony.

Open Source Software Resources

athenaCL <www.athenacl.org>
Python <www.python.org>
Audacity <audacity.sourceforge.net>

Recordings

"Hajnali Csárdás És Szapora A Cigányoknak / Dawn Songs And Gypsy Couple Dances" (track 1) on Kalotaszegi Népzene / Transylvanian Folk Music From Kalotaszeg. 1999. Budapest. {Recording A}

"Lamenting music at the side of the dead with two violins" (tk 41) on Hungarian Instrumental Folk Music Nos 1-2. 1977. Budapest: Hungaroton Classic. {Recording B}

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