UNIVERSITY OF CALIFORNIA – SANTA CRUZ

Refraction Frequency, for Orchestra
A Discussion of Related Elements

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by

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Abstract

Vedran Mehinovic

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The following discussion addresses *Refraction Frequency*, an orchestral work that draws material from distinct disciplines and utilizes extremely contrasting compositional approaches. The textural complexity contains elements akin to some found in Korean traditional music, where vibrato is an integral expressive device, and spectral noise naturally present within sound is brought out. The emphasis on slower progression of events, particularly evident in rich, gradually-shifting formations is an essential structural characteristic of the work. The produced effect offsets the later usage of quasi-melodies, rooted in a Balkan aesthetic. The notion of vibration unites the piece, originating in Nikola Tesla's polyphase motor and continuing through related ideas in M-theory. The general result is a duality of rest and motion, imbued with vibrancy, on an organic kinetic course.

Orthography

I italicized titles, most performance techniques, direct translations, and words receiving emphasis. I did not italicize foreign words because that enhances the impression of "foreignness," contrary to my intent of bringing Korean and Balkan musical elements closer to the reader. Vibrato is an integral component of my work, and I did not italicize that word either, as it occurs often and it would have been cumbersome otherwise.

The Revised Romanization of Korean, implemented in 2000, improves upon certain aspects of the previous McCune-Reischauer system, but also contains misleading oversimplifications. I am including an English pronunciation guide, which for the sake of convenience does not address certain nuances, but comes close to actual sounds. I am also listing the words I chose to spell differently from the current system, due to strong feelings about some aspects of pronunciation. The apostrophes indicate aspiration. While I explain the meanings in the pages ahead, the translations can also be found in the glossary (p. 62).

My Spelling	Revised Romanization	Close English Pronunciation
	ajaeng	ahjehng
	Baekje	Pekche
	Bitgarak Jeongeup	Pitkarak Chongoop
	haegeum	hehgoom
	Hyang piri	Hyang piri
	jang	chang
	janggu	changoo
	jeongganbo	chonganbo
	Jeongeupsa	Chongoopsa
	jwago	chwago
kayageum	gayageum	kayagoom
Koryeo	Goryeo	Koryo
p'ansori	pansori	p'ansori
Shilla	Silla	Shilla
	sogeum	sohgoom
	Sujecheon	Soojechun
	daegeum	dehgoom
	yoneum	yohnoom

Balkan pronunciation is more straightforward. I analyzed music from the territories of Bosnia and Serbia, whose languages are nearly identical (even if Bosnian uses a Latin and Serbian a Cyrillic alphabet). The guide below addresses a few letters of interest.

Written	English Pronunciation
C	*ts*
Ć	a lighter *ch* sound.
G	*gh*
J	*y*, as in *Yugoslavia*.
R	a flipped *r* sound, close to the palate front.
Š	a harder *sh* sound.
U	*oo*

Acknowledgements

I am grateful to my adviser, Hi Kyung Kim, for tirelessly working with me on this complex and consuming endeavor. Her input has shaped and fortified important aspects of the dissertation. Committee members Paul Nauert and Karlton Hester were generous with their time and ideas, and demonstrated both precise insight and open mind regarding my diverse choice of topics.

Consultation with the daegeum virtuoso and scholar Kim Jeong Seung was invaluable for clarifying a wide array of practices in Korean music, from performance techniques to structural features. Colleagues Kim Hyelim and Kevin Parks provided further advice.

I received information on aspects of Balkan music from Enisa Hajdarević-Šojko and Ružica Ivić. I am thankful to Mrs. Hajdarević-Šojko and a score of people in Sarajevo and Zagreb, too humble to be named here, for donating their time in various ways following one of the worst Balkan snowstorms on record. The accordion virtuoso Edo Krilić possesses a vast knowledge of the repertoire, and gave crucial bibliographical input.

My family has offered tremendous support throughout my schooling. This milestone is dedicated to Vesna, Senad, and Dinko Mehinović.

Part One: Structural Characteristics

Refraction Frequency is an ambitious work, in its scale and techniques. It stems from an essential thought of relatively simple contrapuntal movement, obscured by dense, massive groupings. The instrumentation is that of a large orchestra, with each wind instrument (this includes the brass) on an independent staff. The winds are fortified with a contrabass clarinet. The first and second percussionists are placed in the back left corner of the stage, and the third in the back right, enabling spatial effects. The percussive forces are basic, with two bass drums, a tam-tam, tubular bells, a vibraphone, and a marimba. Each player is responsible for one non-pitched and one pitched instrument. Aside from the percussion spatialization, the rest of the orchestral placement is standard. The strings are greatly divided, with five first violin groups (A, B, C, D and E, ideally about three per division), five second violin groups (same arrangement), four viola groups (about three per division), five cello groups (about two per division), and four bass groups (about two per division). The resulting distribution creates 50 possible independent lines, unless one percussionist plays both instruments at the same time, which is never the case.

INITIAL PITCH ARRANGEMENT

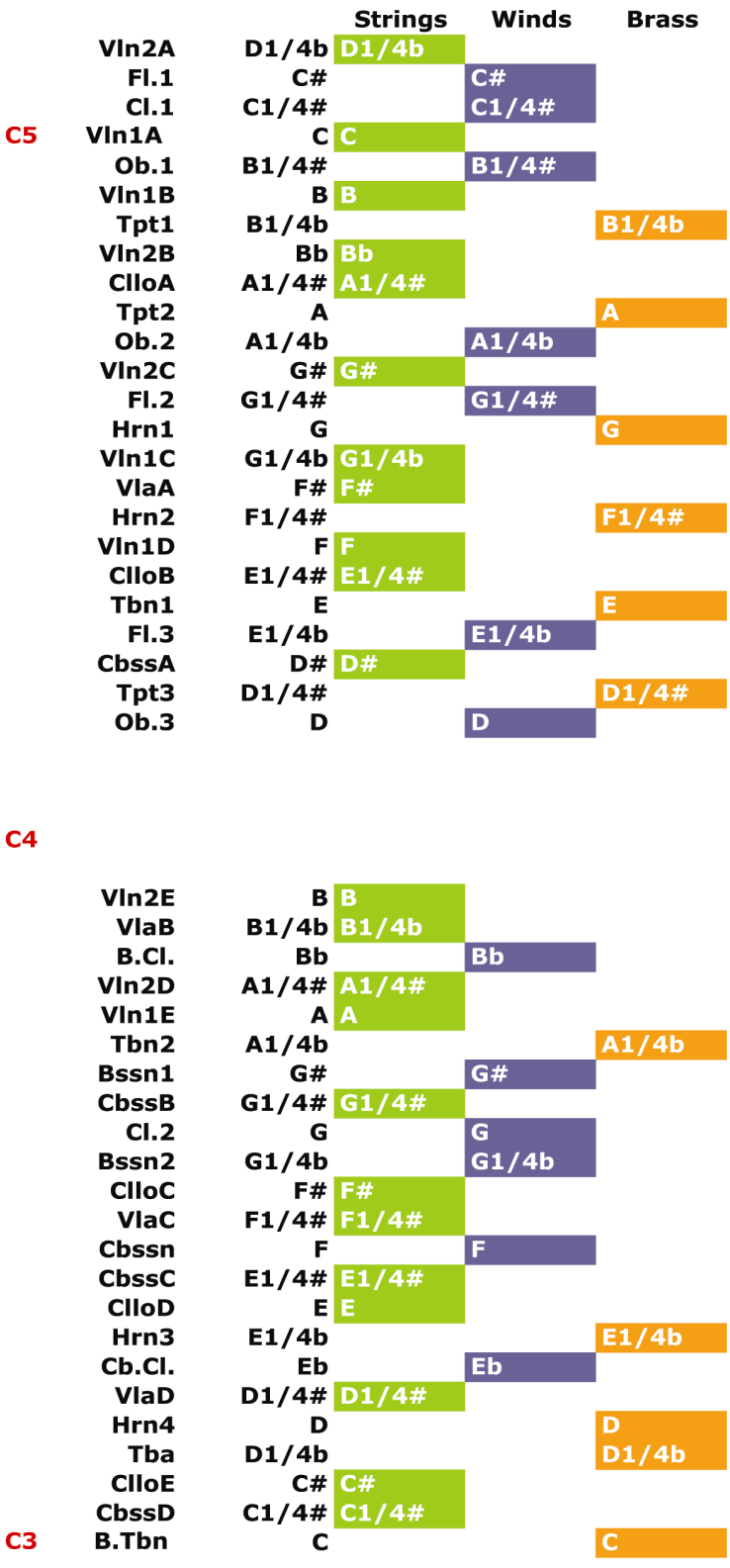
The duration is close to 13.5 minutes. The tempo of quarter note at 65 and the meter of four quarters remain throughout. While a convenient way of organizing time, the meter does not reflect on the generally seamless progressions in the music. The piece opens with an extremely dense, deafening

cluster, spanning C3 (in the bass trombone) to D¼b5 (in the violin 2A[1]). All winds play multiphonics and all strings *sul ponticello*, with extra bow pressure. Most pitches, down to the quartertone level are represented, except for the cluster spanning B¼#3 to D¼b4. I left this space empty since I wanted a particular overall span, and the C - D¼b sonority between the extreme notes, but did not possess enough instrumental forces to fill everything. I also wished to reduce octave doublings with the highest subcluster. There is however a kinetic value in this initial choice, and the middle space becomes quite saturated later on.

The area of approximately two octaves at the very beginning signifies a dense core, which acts as a hyperenergetic place of origin for later developments. The instrumental distribution is not equivalent in terms of ascending microchromatic layering (such as wind-string-wind-string etc.). I wanted to avoid the two instrumental groups (again, the winds also refer to the brass, as will be the case throughout the analysis) creating two chromatic collections. The layering is somewhat more complicated, as illustrated in the following diagram. There is one wind line at the bottom, followed by two string lines. The latter are topped by two wind lines, followed by a single string line. What succeeds is two wind lines, and so on. This arrangement creates a greater variety of collections within the cluster. The only place I abandoned such ordering is near the top, since I was running out of instruments and wanted a particular sonority in both the winds and the strings.

[1] Even though there are a few per line, I will refer to the string names in singular, for the sake of simplicity.

Fig. 1. *Refraction Frequency*: Initial pitch arrangement.


Strings
Winds
Brass
Vln2A D1/4b D1/4b
Fl.1 C#
Cl.1 C1/4#
C#
C1/4#
C5
Vln1A C
Ob.1 B1/4#
Vln1B B
Tpt1 B1/4b
Vln2B Bb
ClloA A1/4#
Tpt2 A
Ob.2 A1/4b
Vln2C G#
Fl.2 G1/4#
Hrn1 G
Vln1C G1/4b
VlaA F#
Hrn2 F1/4#
Vln1D F
ClloB E1/4#
Tbn1 E
Fl.3 E1/4b
CbssA D#
Tpt3 D1/4#
Ob.3 D
C
B1/4#
B
B1/4b
A
A1/4b
G#
G1/4#
G
F1/4#
F
E1/4#
E
E1/4b
D#
D1/4#
D
C4
Vln2E B
VlaB B1/4b
B.Cl. Bb
Vln2D A1/4#
Vln1E A
Tbn2 A1/4b
Bssn1 G#
CbssB G1/4#
Cl.2 G
Bssn2 G1/4b
ClloC F#
VlaC F1/4#
Cbssn F
CbssC E1/4#
ClloD E
Hrn3 E1/4b
Cb.Cl. Eb
VlaD D1/4#
Hrn4 D
Tba D1/4b
ClloE C#
CbssD C1/4#
C3
B.Tbn C
B
B1/4b
Bb
A1/4#
A
A1/4b
G#
G1/4#
G
G1/4b
F#
F1/4#
F
E1/4#
E
E1/4b
Eb
D1/4#
D
D1/4b
C#
C1/4#
C

Most of the instruments proceed to take linear routes shortly into the initial segment (50 bars). The goal is bar 51, where the dense two-octave cluster is compressed into an even denser major seventh (also including quartertones). The process of getting there is gradual, and takes slightly over three minutes. The volume is very loud throughout (triple *forte*), and becomes even louder as the progression completes because multiphonics slowly dissipate (the sung portion in the brass generally impedes volume). The strings play *ordinario* by then, without the previous hindering raspiness, and multiple instruments are assigned same pitches. The transfer from extended techniques to normal playing is rather seamless, and the effect is that of a slow color shift. The simplification combined with reduction in range forces the initial diversity into a focal center, with tremendous power to further propel the piece. The impression at the beginning might be that of overwhelming density and weight, possibly setting up expectations of amelioration, but the following developments contradict this and take the listener onto a yet higher plane of intensity.

			Strings	Winds	Brass
	VlaA, Fl.1, Ob.2	F#	F#	F#.2	
	Vln2C, Fl.3, Cl.1	F1/4#	F1/4#	F1/4#.2	
	Vln1C, Ob.3	F	F	F	
	Vln2A, Fl.2	E1/4#	E1/4#	E1/4#	
	ClloA, Tpt2, Tbn1	E	E		E.2
	ClloB, Hrn1	E1/4b	E1/4b		E1/4b
	Hrn3	Eb			Eb
	Vln1D, Tpt1	D1/4#	D1/4#		D1/4#
	Vln2B, Ob.1	D	D	D	
	Vln1B, Hrn2	D1/4b	D1/4b		D1/4b
	Vln1A, Hrn4, B.Tbn	C#	C#		C#.2
	Vln2E, Tpt3, Tbn2	C1/4#	C1/4#		C1/4#.2
C4	CbssB, Tba	C	C		C
	VlaD, Cl.2	B1/4#	B1/4#	B1/4#	
	CbssA	B	B		
	ClloD	B1/4b	B1/4b		
	VlaB	Bb	Bb		
	Vln2D	A1/4#	A1/4#		
	ClloE, Cb.Cl.	A	A	A	
	Vln1E, Bssn1, Bssn2	A1/4b	A1/4b	A1/4b	
	ClloC, Cbssn	Ab	Ab	Ab	
	VlaC, CbssC	G1/4#	G1/4#.2		
	CbssD, B.Cl.	G	G	G	

Fig. 2. Measure 51 pitch distribution. The initial central empty space has been filled. More than one instrument of same type on same pitch is marked with *.2*.

FORMATION OF GROUPS

There is a very gradual decrease in the low brass volume beginning in m. 67. Bars 68-120 are of special interest, however, since most of the orchestra (not including the low brass) becomes divided into six formations of five lines, with coordinated attacks as the main unifying force of each group. The entrances thus far have been purely individual, with each instrumental line for itself. Reorganizing most of the ensemble as described changes the overall sound, since silence while one or more groups are resting will give prominence to other sonorities. Each group diminishes towards *pianissimo* very slowly, then drops out, as some of the individual players across formations begin other developments. The percussion makes its first appearance in this section as well. I am addressing

the area spanning mm. 68-120 because of prominent group activity, but multiple processes are in fact taking place, making delineation otherwise impossible.

The following diagram illustrates group developments. The dynamic changes are indicated only in the highest member of a group. The occasional slight attack differences (due to factors such as vibrato speed, to be addressed later) are not represented, since they will mostly go unnoticed. The spaces indicate full measures of rest; while there certainly are more pauses, allowing the winds to breathe, this diagram manifests general activity and indicating the smallest details is not essential. The groups are numbered according to their entrances.

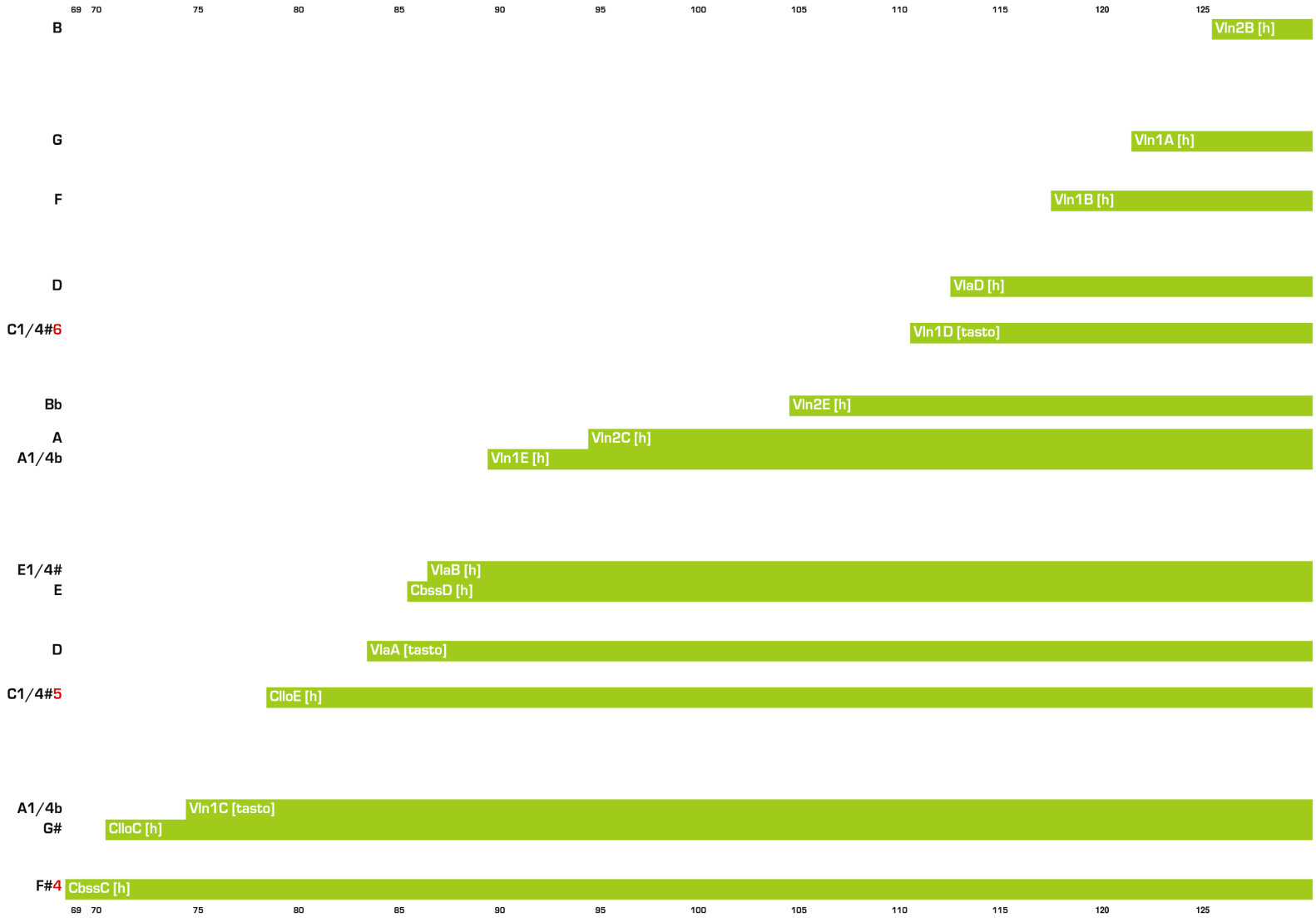
Fig. 3. Dynamic group pitch distribution.


Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
68 70 75 80 85 90 95 100 105 110 115 120
F# Fl.1 [fff] [f] [mf] [p] [pp]
Ob.2 [fff] [f] [mp] [p] [pp]
F1/4# Fl.3 [fff] [f] [mf] [p] [pp]
Cl.1
F Ob.3
E1/4# Fl.2 [fff] [f] [mf] [p] [pp]
Vln2A
E ClloA
Tpt2
E1/4b ClloB
D#
D1/4# Vln1D [fff] [f] [mf] [p] [pp]
Tpt1
D Vln2B [fff] [f] [mf] [p] [pp]
Ob.1
D1/4b Vln1B
C# Vln1A
C1/4# Vln2E
Tpt3
C 4 CbssB
B1/4# Cl.2
VlaD
B CbssA
B1/4b ClloD
Bb
A1/4# Vln2D
A Cb.Cl.
A1/4b Bssn1
Bssn2
G# Cbssn
G1/4# VlaC
G B.Cl.
68 70 75 80 85 90 95 100 105 110 115 120

STRING ACCUMULATION

The next development that needs to be addressed is the string accumulation beginning in bar 69. The process is long and lasts, in part, until the very end of the piece. We will look at the area spanning mm. 69-126, since this is where the most important development takes place. While the resultant collection does not change until bar 141, it is sufficient to examine the structuring up to about m. 126. There are 15 string lines involved, comprising (in descending orchestral order) all violins 1, violins 2B, 2C, 2E, violas A, B, D, cellos C and E, and basses C and D. Most of the lines play harmonics, starting with the sounding F#4, or the top of the major 7th cluster. Violins 1C and 1D, and viola A play regular pitches *sul tasto*, in order to diversify the sound. This period brings gradual range expansion, and these strings are taking us up. The diagram illustrates the accumulation. Courtesy pauses, so the players can rest their hands, are not represented.

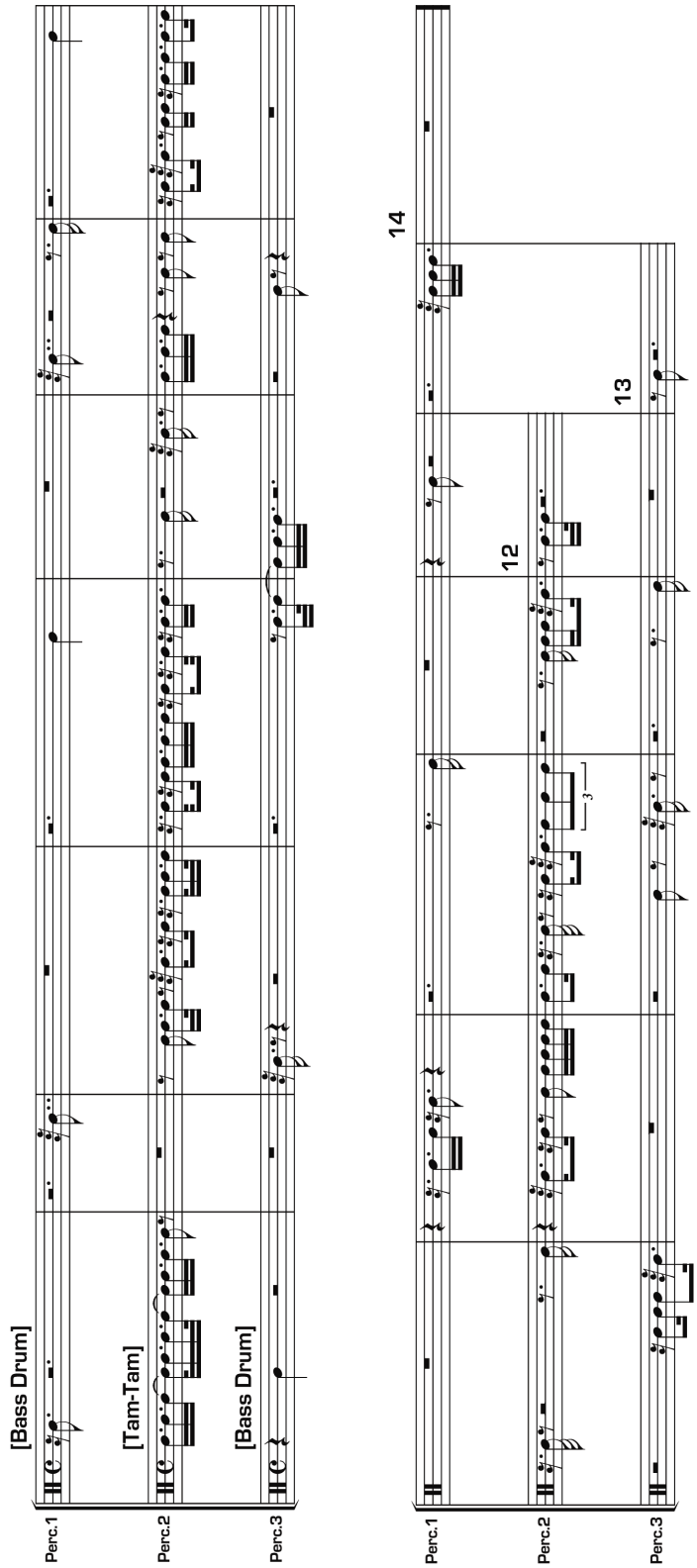
Fig. 4. String accumulation mm. 69-126.


69 70 75 80 85 90 95 100 105 110 115 120 125
B
Vln2B [h]
G
Vln1A [h]
F
Vln1B [h]
D
VlaD [h]
C1/4#6
Vln1D [tasto]
Bb
Vln2E [h]
A
Vln2C [h]
A1/4b
Vln1E [h]
E1/4#
VlaB [h]
E
CbssD [h]
D
VlaA [tasto]
C1/4#5
CllоE [h]
A1/4b
Vln1C [tasto]
G#
CllоC [h]
F#4
CbssC [h]
69 70 75 80 85 90 95 100 105 110 115 120 125

PERCUSSION

The treatment of percussion in this piece is cautious, since I wanted to avoid the cliché of interrupting a complex orchestral texture with heavy-handed hits and bangs. The tam-tam (Perc. 2) is the first on the scene, entering as late as bar 81. While most of the surrounding orchestra is still very loud, the tam-tam plays a quiet and relatively dense 12-bar pattern of beats. The desired effect is not that of individual attacks, but of soft white noise swells, emerging from and aiding the general cluster. A bass drum (Perc. 3), placed in the opposite stage corner from the tam-tam, enters quietly in m. 87. Its 13-bar pattern is sparser, but nonetheless lightly delineates the orchestral mass. There is simultaneously plenty of time for the unmuted decays to add to the texture. While the bass drum might seem to be engaging in a conversation with the tam-tam, the former's real counterpart is another bass drum. Played by Perc. 1, it stands next to Perc. 2 and enters quietly in m. 101 with a sparse pattern of 14 bars. A spatial counterpoint ensues, further delineating the surrounding sound mass and giving an impression of bigger events in the distance. The three rhythmic cycles are overlaid and presented in the following diagram; such arrangement mostly never appears in the score.

Fig. 5. Unpitched percussion patterns.


[Bass Drum]
[Tam-Tam]
[Bass Drum]
Perc.1
Perc.2
Perc.3
12
13
14
3
Perc.1
Perc.2
Perc.3

LOW RANGE EXPANSION

As the six groups from a few pages back fade out, their members either tacit or begin other developments. In the case of cello A from group 1, it drops to G#2 in m. 106, after the collective group stop two bars earlier. Some of the strings have begun expanding the range upward in m. 69, and ten instrumental lines, starting with cello A, will do the same in the opposite direction. G#2 is the lowest pitch in the piece thus far, to be followed in descending order by G (CllоD), E (Bssn1), D (B.Cl.), D¼b (Bssn2), B1 (CbssB), A (B.Tbn), F# (Cb.Cl.), E¼# (CbssA), and D# (Cbssn). The gradual expansion happens during mm. 106-140. The ten instrumental systems eventually become divided into two groups of five lines and last, in reduced form, until the end of the piece. Courtesy rests are not represented in the diagram.

Fig. 6. Low range expansion, mm. 106-140.


106
110
115
120
125
130
135
140
G#2
G1/4#
G
G1/4b
F#
F1/4#
F
E1/4#
E
E1/4b
D#
D1/4#
D
D1/4b
C#
C1/4#
C2
B1/4#
B
B1/4b
Bb
A1/4#
A
A1/4b
Ab
G1/4#
G
G1/4b
F#
F1/4#
F
E1/4#
E
E1/4b
D#1
CIloA [G#]
CIloD [G]
Bssn1 [E]
B.Cl. [D]
Bssn2 [D1/4b]
CbssB [B]
B.Tbn [A]
Cb.Cl. [F#]
CbssA [E1/4#]
Cbssn [D#]

MELODIC PATTERNS

There is a new process starting in m. 136, which will define the rest of the work. Its nature is gradually accumulative, to a point where the general volume rises almost just by the sheer number of players, ending in relatively quick dissipation. The intent is not to create a climax, but to introduce a yet unheard paradigm. The loudest sections have already happened, and nothing will exceed the initial blast. The final segment leads the listener into believing something even bigger is on the horizon, only to quiet down and disappear like a sudden gust of wind. The new material is based on melodic patterns of 10, 11, and 12 bars. There hasn't been anything even resembling a melody thus far, just held pitches of varying attributes. While I use the term "melodic," the three patterns will always be layered to various extents, more closely resembling Ligeti's micropolyphony. The fact that there is melody-like movement is nonetheless important, since it introduces a fresh element which propels the piece until the end. The pitch choice is derived from close intervals in Balkan (and generally Eastern European) music, emphasizing minor and major seconds. There are very chromatic parts, where one small collection displaces another. There are also major thirds, which complicate the narrow impression. The whole tone sound suggested at places further disrupts the chromaticism, while the combination of the two creates a kind of extended octatonicism. The constantly shifting, ambiguous nature of these "melodies" suits their cyclical usage, where there is no real end. The ties before the first notes in the following music indicate connection to the last notes of the patterns. No line attempts to draw attention to itself, and the widest melodic interval is a perfect fourth. The depiction I am presenting corresponds to the initial arrangement in three winds, starting in m.

136. There will be numerous combinations and transpositions as the piece progresses. The three lines will also accelerate, resulting in medium-velocity and fast versions, respectively marked with “A” and “B.” This is achieved through decreasing the note values from the first pattern and adding new material. The cycles in the fast group are also shorter, from eight to ten bars, enhancing the compression effect. All patterns are played *legato*, unless indicated otherwise.

Fig. 7.1. Melodic Patterns 1-3.


1
2
3
10
1
11
2
12
3

Fig. 7.2. Melodic Patterns 1A-3A.

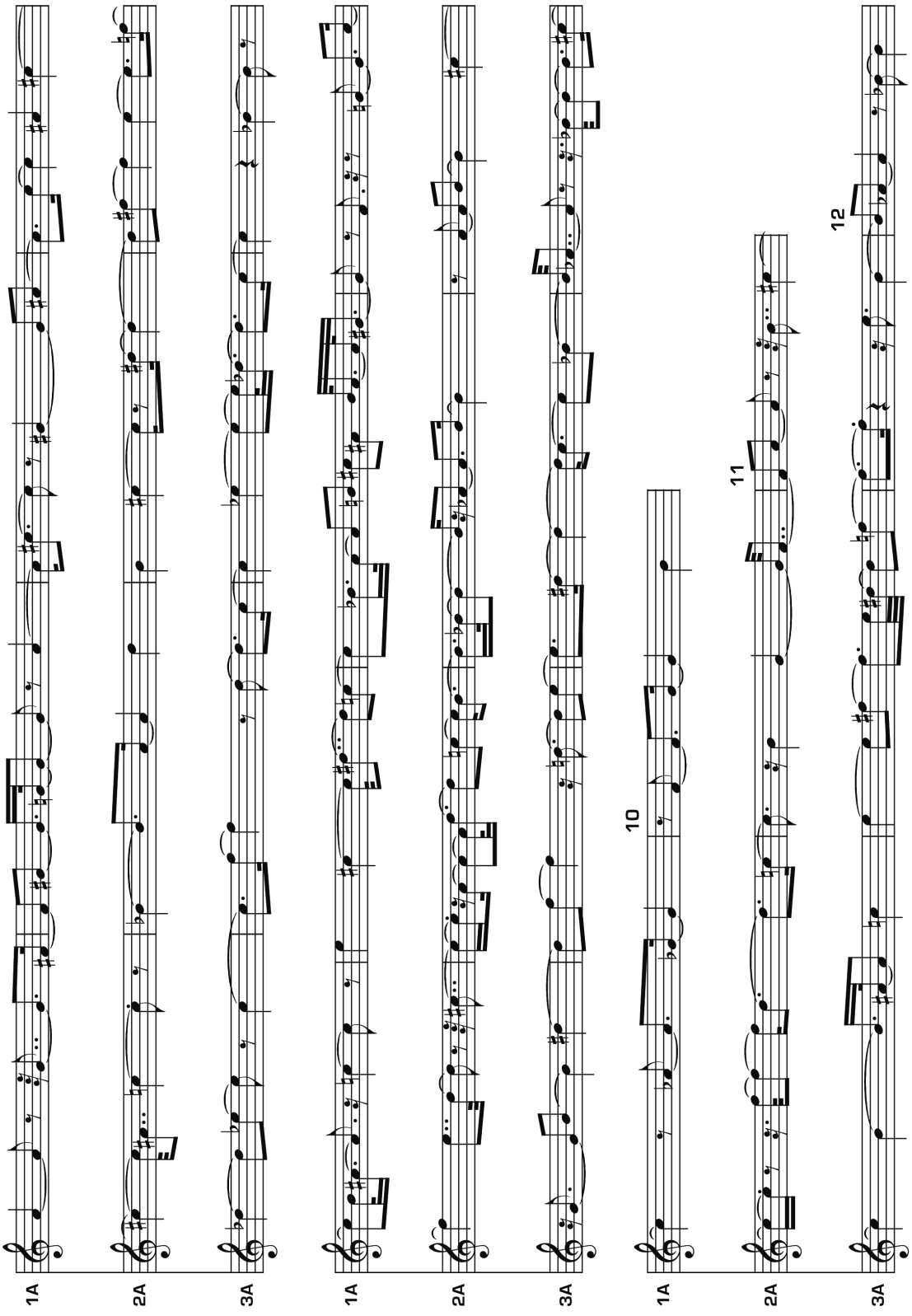

1A
2A
3A
1A
2A
3A
10
1A
11
2A
12
3A

Fig. 7.3. Melodic Patterns 1B-3B.


1B
2B
3B
1B
2B
3B
7
1B
8
2B
9
3B
10

FINAL DEVELOPMENTS

The ten lines which have performed the initial low expansion in mm. 106-140 have quietly remained on their pitches. Towards the end of the piece, they become theoretically divided into two groups of five. The top collection gradually dissipates during bars 187-207, leaving no higher pitch in that area than the B1 in contrabass B. As the fast melodic cycles draw to a close, the remaining low group begins slowly pulsating, to anticipate a further juxtaposition with the non-vibrated high strings. The bottom note has thus far been D#1, in the contrabassoon. The lowest point in the range is achieved in m. 209 when the tuba, having left its medium-velocity cycle (3A), drops down to the equivalent of the lowest Bb on the piano (let us call it Bb0). The group now contains six lines of even instrumental distribution: two strings (contrabasses A and B), two woodwinds (contrabass clarinet and contrabassoon), and two brass (bass trombone and tuba). The pitches are, in descending order: B(1) – A – F# - E¼# - D# - Bb(0). When violin 2B reaches its F#7, the final and greatest interval in the piece is six octaves and an augmented 5^{th}. The end is quiet (*pianissimo* in all instruments), both a reverberation of and a vast backdrop to the previous developments.

SUMMARY

Refraction Frequency is characterized by seemingly uncoordinated processes, which create a structure of depth and multidimensionality. The seminal events are often guided by simple directional movement, but the amount of material and the level of detail might cloud the transparency. The beginning is a dense cluster of about two octaves, which by bar 51 becomes compressed into

the space of a major 7th. Various groupings begin to branch out at distinct stages thereafter, either fading out gradually or expanding the range towards both extremes. Unpitched percussion, which enters in m. 81, softly contributes to the timbral atmosphere while delineating the surrounding sound masses. Slow melodic patterns emerge in bar 136, accelerating steadily and accumulating more instruments. The process becomes loud, but briefly and not as forcefully as the first part of the piece. The melodic cycles drop out in quick succession near the end, where the initial two octave cluster hovers quietly dissipated at over three times its range. The entire piece is one pulsation, essentially expanding from the nucleus.

Part Two: Korean Influence

Refraction Frequency contains abstracted expressive elements found in Korean traditional music. It was in 1997 that I heard my first p'ansori recording (narrative singing), and have been interested in Korean music ever since. While the said elements in my orchestral work do not solely stem from the Korean ones, the connection is there and deserves elaboration. The areas of interest are the use of vibrato and timbral treatment. I will look at *Sujecheon*, an ancient piece of court music, as it is also for large ensemble and demonstrates the relevant techniques. Before examining the details, let us address the general characteristics of the work.

The historical and cultural significance of *Sujecheon* does not have many equivalents. The title could be translated in a number of ways, all essentially meaning *Life as Endless as Heaven*[2]. The name is possibly of broader nature, referring to various pieces dedicated to the longevity of the ruler, and has only been considered the main title of the work since the early 20th century (Chang 85). A name which has lasted much longer, and is still associated with the piece, is *Bitgarak Jeongeup* (Cho Chae-son 123). The first word refers to the fingering position of the wind instrument daegeum which produces the note C, central in the piece. *Jeongeup* carries an association with the only surviving song (musically speaking) from the Baekje kingdom (18 BCE – 660 CE), *Jeongeupsa*, dating to about the 7th century. The song itself possibly underwent structural changes during the later Koryeo period (918 – 1392), since having compared it to the

[2] My own interpretation based on consultation with Kim Jeong Seung. The characters are 壽 濟 天

music in *Sujecheon*, I did not notice similarities save for the initial ascending motion of a perfect fourth. The scholarly view is that there is indeed a connection (for instance, when *Sujecheon* was still performed with lyrics they were those of *Jeongeupsa*) (Chang 322), and I will focus on the court piece while leaving the song's incredibly intricate history to other researchers.

Sujecheon was created during the period of the unified Shilla (668 – 935), approximately in the 8th century (Chang 323). The matter of comparison between the current version of *Sujecheon* and that performed during Shilla is complex (as music notation likely did not exist then), and for our current purposes best left for another time. Suffice to say, the original instrumentation had to differ in certain aspects since some of the instruments used today, such as haegeum and ajaeng, were not introduced until a few centuries later (e.g. Howard 215). The piece has historically been performed during royal banquet ceremonies, in a processional function.

The instrumentation is wind, string and percussion, comprising Hyang piri (a double-reed wind, "Hyang" indicating Korean properties), daegeum (transverse flute), sogeum (smaller transverse flute), haegeum (two-stringed spike fiddle), ajaeng (bowed zither), janggu (hourglass-shaped drum), and jwago (big barrel drum). Aside from the drums, contemporary performance involves multiples of all the other instruments; I will refer to them in singular, for the sake of simplicity. The piri plays the main melody throughout most of the piece, while the rest of the pitched instruments follow heterophonically. The octave displacements depend on instrumental range, and the degrees of virtuosity differ (e.g. the small sogeum is more likely to perform elaborate ornaments than the less flexible ajaeng). *Sujecheon* has been played along with the procession of the

crown prince, and Cho Chae-son believes that the slow drum strokes might relate to the ceremonial walking pace (124).

VIBRATO

One of the main characteristics distinguishing Korean from Chinese court music (according to how the latter has been preserved in Korea), and subsequently the Korean and Japanese forms, is the prominence of vibrato. There are long, straight tones in *Sujecheon*, but they are commonly ended with vibrato (often heavy) or ornamentation. In the rare instance that the melody leader, piri, stops the straight tone as is, other instruments (especially the winds) tend to be there to elaborate the ending. The name of the final marking in both drum cycles used in the piece means *shaking tone* (搖音), or *shake* for short (Cho Chae-son 133), where even the janggu performs what can be likened to a vibrato (repeated, decaying strokes). The slow melody leaves plenty of time for timbral manipulation, and when a larger collection of instrumental groups is vibrating together the energy is tremendous, and the patterns dense and complex. The piri vibrato is especially powerful, as the instruments are very loud and often already create rich bands of sound due to microtonal differences. Cho Chae-son associates a straight tone with tension and accumulated energy, while a vibrated one signifies relaxation and release (131). To expand on this, the overall loudness and register of the piece are contributing factors (a low, quiet straight tone might not be considered as intense), as the high frequency of a loud straight pitch in generally high range easily evokes tension. The vibrato at the end of a pitch therefore creates an effect of decelerating the inherent periodicity,

an intuitive and natural approach. The duality of straight and vibrant propels the music on a very local level, and enriches the timbral palette of the piece.

Some markings dealing with pitch fluctuation are displayed below. The top portion is taken from the kayageum section of *Korean Musical Instruments*, by Keith Howard. That plucked zither is not found in *Sujecheon*, but many of the markings are nonetheless used with other instruments. The bottom portion is from daegeum notation, also in Howard's book, applicable to winds in general. The intrinsic tendency of Korean musicians to vibrate a pitch is evident from the existence of the kayageum non-vibrato marking, found in the middle.

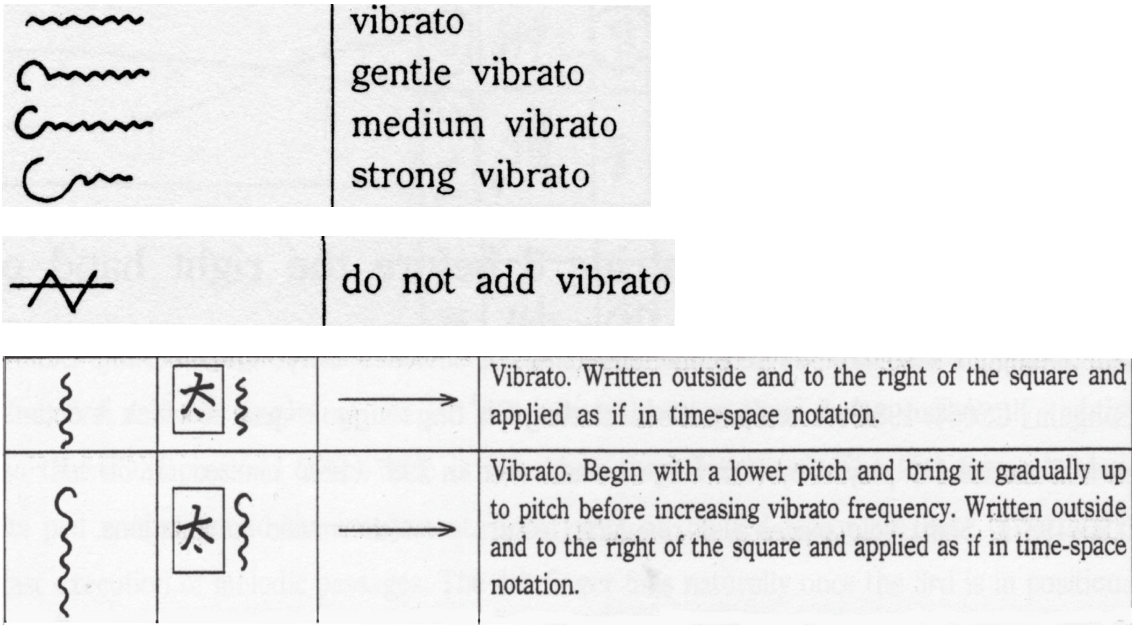


Fig. 8. Various Korean vibrato markings (not a complete collection). Kim Jeong Seung points out that in practice, Korean musicians are more likely to rely on aesthetic sense than markings when determining vibrato intensity (personal email).

The reader can get a sense of ornamental placement from the initial page of the traditional *Sujecheon* score. The notational system (one of many) is called jeongganbo, the first mensural notation in Asia, with which the first large ensemble scores were written anywhere in the world (Kwon 12). While close to representing the way the piece should be understood, jeongganbo was still developed in the 15th century, a long time after *Sujecheon* was composed. The exact metric translation of the written material is subject of debate, but it is generally known that one beat is marked with one square. This matter becomes complicated in *Sujecheon* (unlike some other pieces of court music), where the leader, Hyang piri, determines its phrase (breath) lengths, and the ensemble follows accordingly. The instruments are arranged in columns, reading from left to right: ajaeng, haegeum, piri, daegeum, sogeum, and janggu. There is no jwago column, perhaps a matter of economy as its material is simple, coordinated with the low strokes in the janggu. The vibrato symbols are placed to the right of columns, or at ends of phrases, and the piri tends to receive the most.

Fig. 9. *Sujecheon* opening in jeongganbo notation.


장중하게
수 제 천 (壽 齊 天)
빗가락정읍(橫指井邑)
합 보(合 譜)
장구
一章소금
대금
피리
해금
아쟁
1
(준박)
(원박)
(준박)

My own experimentation with sound pulsation began in 2008, upon reading about Nikola Tesla's polyphase motor. This device uses evenly-spaced waves of current to create a rotating magnetic field, and operates a lot more efficiently than the single-phase concept developed by others. What drew my attention was the idea of phase displacement, which can be viewed as vibrato in musical terms, and which I expanded into diverse, layered pulsations. For a while I wrote patterns that would not change for the duration of a tone. Closer examination of the Korean techniques was partly responsible for an introduction of more organic, breathable formulations, which are currently still developing and branching out.

In *Refraction Frequency*, vibrato speeds are not specified during the first 50 measures. While the strings will employ their standard vibrato, all winds and brass are playing multiphonics, and there is usually no tendency to vibrate those due to difficulty of performance. There is a sudden change in bar 51, where the entire orchestra uniformly starts precisely notated speeds of pulsation, generally faster than regular vibrato and featuring quite a few *molto vib.* markings as well. The effect is comparable to a sudden boiling point. I aimed to prevent any particular pattern from dominating, so there is much variety in rhythm. I also avoided assigning the same types to players sitting close together. The slowest pulse, and not very common, is a quarter note; the fastest is 16^{th} note sextuplets. The *molto vib.* indications will produce further diversity since different players will have different interpretations, while likely resulting in wider vibrati than at slower paces. This vibration will probably not be more dense than the sextuplets, but will be asymmetrically distributed over the beats and make the general sound thick and irregular. Otherwise, there are very few vibrato types

that extend over the beats since I wanted simplicity of execution and a fair amount of activity on the smallest level. Individual pulse transforms often, eradicating a sense of pattern and constantly shifting attention to the faster (and wider) groupings. These devices are very effective in an orchestral setting; no pitches change from bars 51 to 66, a period of close to a minute, yet the sound space is continuously brimming with activity.

There are other strategic ways I use vibrato (or lack thereof) in the piece. While the technique brings an already hectic situation to an even more chaotic level in m. 51, I pair gradually decelerating pulsations with diminishing dynamics in order to eventually change the character of the central brass cluster. The main volume shift happens during measures 67-105, accompanied with only slight decrease in vibrato speed (the initial power does not merit from a hasty decay). A more prominent pulse deceleration happens during bars 115 – 145, emphasized through coupling with range descent. The high strings accumulating from m. 68 and lasting until the very end are not vibrated at all. The sporadic individual entrances, following short breaks meant for the players to rest their hands might be considered a very slow pulse, but the otherwise frozen, stratospheric strings greatly contrast the flux below. The quiet ending of the piece is a juxtaposition of five high, non-pulsed string lines with six low lines of relaxed vibration, some so slow they extend over the beats. While wind and brass multiphonics are normally straight, the beginning of the piece will feature a surface teeming with sonic beats due to dissonant partials, as well as the condensed pitch space within the two-octave cluster. Vibrato, in its many forms, and even when not specifically indicated, is a crucial device in the work.

TIMBRE

While the initial multiphonics create incidental beats, they also greatly intensify the sonic texture. The sonorities are dense and clashing, and will constitute a different overall color at each new performance because the wind fingerings are not set. All strings play *sul pont.*, along with increased bow pressure, activating high spectral noise bands. Instruments gradually switch to normal modes of playing on approach to bar 51, smoothing out the sound in preparation for a new type of distortion (layered pulsation). Noise is therefore a very important element in the piece, offset against clean sound either over the course of such a long shift, or simultaneously (e.g. quiet brass, with fewer audible high partials vs. the tam-tam white noise washes, in an area around m. 100). The high string accumulation from m. 68 possesses timbral contrasts of its own, as some lines play harmonics, brighter in sound, and some regular, duller pitches *sul tasto*. The fast, high melodic cells towards the end are spatially close, causing friction, while the longer tones in the brass below, as well as the muted tubular bells, present yet another example of offsetting smoothness.

Spectral noise is an integral aspect in Korean music as well, and a large part of the traditional musical identity would be unimaginable without an array of techniques that enrich instrumental and vocal sound. The court ajaeng is played with a stick instead of a bow, activating the upper, buzzing partials which both enhance the tone and enable the instrument to project alongside ensemble members better equipped for loudness. There is a husky, nasal quality to the haegeum, which becomes especially prominent in comparison with its cleaner Chinese relative, the erhu. The most repeated example in the realm of voice is that of certain p'ansori apprentices, training by a loud waterfall until their vocal

chords bleed, scar tissue develops and grants their sung stories a hoarse, textured shading.

There are dualities present on many levels in *Sujecheon*, and one of them is the interaction between the piri and the daegeum. The double reed is a raspy sonic powerhouse, while the transverse flute is generally used for its smoother properties. The aesthetic of noise does somewhat alter the daegeum, with an attached buzz membrane, which the player activates according to taste. The textural duality is nonetheless significant, and carries an architectural importance in the work. While the piri plays the main melody during the jang, or longer sections where the drum is present, the daegeum becomes the leader during the contrasting yoneum, shorter segments where both the piri and the janggu drop out. These shifts in sound help propel the piece, a dichotomy somewhat akin to the structural contrast of vibrated and straight tones. Brief spectral analysis of the two winds, to be found in the appendix (p. 54), will add further awareness and appreciation of their characters.

Part Three: Balkan Background

The last main region of *Refraction Frequency*, starting in m. 136, contrasts the initial held sonorities with gradually accelerating melodic patterns. These are not melodies, since they are made from smaller cells which could be rearranged in a number of ways and still produce a similar result. If the same were done to a typical melody, breaks in continuity would be noticed more often. Another quality of the patterns is that their ends were composed to fit their beginnings, producing seamless cycles. There are melody-like traits present, but a perceptive listener will notice that the loops are agglomerations of smaller, independent components, which create an illusion of more traditional motion.

The basis for such additive construction lies in a type of Balkan aesthetic, found in instrumental dance music. I heard a lot of Bosnian folk while growing up in Sarajevo, as well as that of other former Yugoslavian states. Back then I was a pianist in the classical European tradition, and did not pay closer attention to the musical heritage around me, until I gradually realized both the unbridled and sophisticated qualities of some Balkan music after coming to the US. I began using abstracted forms of those qualities in my composition, manifesting them with pitch collections, phrasing, and a liberal stance towards dissonance. While I appreciate the subtleness and emotional range in the folk language of urban areas, I am especially drawn towards a particular type of energetic village music, which sometimes features a clashing coexistence of meter and lack thereof. The two styles are certainly different, but do share a similar approach to melody and a great amount of ornamental detail.

Gocino kolo

The music for this kolo (circle dance) was composed and performed by the accordion virtuoso from the Belgrade area, Budimir Jovanović Buca (1933-1987), with the addition of some members from his ensemble. Accordion is the primary instrument, and the tempo is fast, with quarter note at 140. If one were to listen while dancing or for enjoyment, as would usually be the case, the melody and a certain amount of ornamentation would be apparent. More attention to the recording brings out incredibly fast, dense ornamentation, to a point where transcription at normal speed is nearly impossible. Precisely notating every sonic filigree was not crucial for the grasp of the general melodic construct, and would have greatly cluttered parts of the score. I decided to include a reasonable amount of detail, to do justice to the aesthetic. For those who do not know what to make of the amount of notes on the page, or cannot clearly follow the melody at places of less scalar motion, I recommend to look for the repeated pitches as those of prominence. Viewing the score should also not substitute listening to the recording.

The melody is defined by very close intervals, namely minor and major seconds. Leaps greater than a minor third usually serve ornamental purposes or occur at phrase ends. The intervallic proximity creates a constricted environment, teeming with energy only heightened by speed. This effect manifests in the dancing, through small, focused movements.

The piece comprises four repetitions of the form, which in turn contains four modules. I label these A – A1 – B – B1. Each module is repeated consecutively, with a first and second ending. Aside from the ornamental differences (mark of a good player), each module group (A and B) is internally

quite similar. A1 only differs from A in its beginning, and B1 introduces two punctuated attacks on beats 3 and 4 of its second measure. In this compressed atmosphere, however, a little contrast carries great impact. I only transcribed the material up to the end of B, representing the first 40 seconds of music, as it gives a sufficient idea of smaller-scale construction, significant in my own work. The A group might seem to be in A minor harmonic, but this is due to the deceptive prevalence of minor V. One listening and attention to the bass will reveal the Balkan scale, or D Dorian with a raised fourth. Group B resides in what could be called the dominant, or A major. The beginnings of both groups emphasize the fifth degree.

There are various levels of phrasing in the piece, and deserve greater attention in another format. An immediate audible impression is that of brief melodic divisions, corresponding to individual measures, which involve a lot of rhythmic imitation. The main phrasing is dry and punctuated, at times contrasted with more connected passages. The velocity tends to create an illusion of even greater connectivity, but playback at slower speed will prove that the performer is frugal with his *legato*. The overall effect of partial separation, with an accent on each new pitch, adds to the energy and tension. The music and the dance are imitative of one another, as the dancers are constantly engaged in quick, short bounces. A single accordion tone is never held for too long, and is usually repeated very rapidly for its duration. The attacks are again separate, but seem somewhat connected due to speed and very small finger motion, creating a vibrato effect. Fast scalar passages might not be vibrated, but partial separation again makes the whole piece shimmer.

The third main section in *Refraction Frequency* features melodic patterns usually phrased under very long slurs (a substitute indication *legato* is used in the score in order to save space). The intent was to create a relatively homogeneous texture, where a sense of connectedness overwhelms individual *staccati* or rests. My guiding aesthetic still came from smaller phrases, such as those in *Gocino kolo*, and I only joined them into longer, uninterrupted passages. Aside from providing general textural uniformity, this procedure is also meant to disorient the listener by weakening a sense of graspable phrasing. As the patterns become more compressed, the number of *staccati* and breaks increases, adding more punctuation to the sound and becoming more reminiscent of the dance syntax (although still rather blurred on the orchestral level). My partial transcription is of the accordion melody line, and neglects the occasional use of diads for the sake of clarity. As the piece also features an important improvisatory ornamental aspect, it needs to be heard for full appreciation.

Fig. 10. *Gocino kolo*
Partial melodic transcription.


♩=140
some ornamental changes at repeat
A
1.
2.
some ornamental changes at repeat
A1
beat 3 4
melody same save for ornamental liberties
1.
2.
1 2
1 2
slight ornamental changes at repeat
B
1.
2.
to B1

Pjesma u kolu

There is a style of music in the central Balkans called izvorna, meaning *from the source*. It is less understated than the urban repertoire, although it carries craft and poetry of its own. The song I am addressing is called *Pjesma u kolu* (*Song in a circle dance*), sung from the viewpoint of people dancing. It is performed by the brothers Ilija and Marko Begić, from Northeast Bosnia, legends of the izvorna tradition. They are accompanied by a violin and a šargija (pronounced *shargiya*). The latter instrument is a long-necked lute featuring a number of possible metal string distributions, but normally in three courses of various double-single pairings. The šargija mainly acts as a rhythmic drone, with some, generally stepwise motion. The violin alternates between fast melodies in quadruple meter and heterophonic accompaniment to the mostly ametric vocal segments. The text in this style of music tends to be improvisatory, elaborating on a certain topic. The singing can often be described as incantation.

I have transcribed the violin melody in the instrumental introduction, spanning the first 27 seconds. The tempo is rapid, with quarter note at 170. The violinist at times plays diads, but I have mostly avoided these for the sake of directional clarity. There is much ornamentation, although not as elaborate as in the other kolo, perhaps due to speed and a more rustic aesthetic. While the singers tend to go through various modal collections, the introduction can be described as being in G Mixolydian. The use of microtones is liberal, in part stemming from the tuning (whose exact reasons deserve separate research), and adds to the atmosphere of tension and antiquity.

The phrasing consists of brief segments, even shorter than those in *Gocino kolo*. The violin further benefits from its ability to produce crisper attacks,

contributing to the dancelike punctuation. The segments are arranged into phrases, which span either one or two measures (rhythmic imitation being an important unifying factor). These in turn combine to form phrase groups, delineated by directional movement and modal emphasis, and last four measures each. The voices neutralize this through verses of mainly uneven text distribution, which the violin follows heterophonically. The quadruple meter returns every time incantation stops. The unfazed šargija maintains its steady beat throughout the song, contributing to some tremendous clashing. While the transcription might be less cluttered and easier to follow than the previous one, it should not replace the auditory experience.

Fig. 11. *Pjesma u kolu*
Violin Introduction.


♩=170
5
9
13
17
to verse

Higher Frequencies: String Vibration

The concept of Tesla's polyphase motor has increased my awareness of pulse as an integral constituent of our surroundings. Over time I began to appreciate the many levels of pulse and their influence on the human experience. The frequency range of things in vibration is astounding, tempting one to think of a hypothetical meta-instrument. On the anatomic level, the cardiac cycle is a pulsation necessary for continued existence. We would not relate to daily life if the frequency of our brainwaves were improperly modulated. Rates of pulse are observable even if all other sound is shut out, as related by John Cage after his experience in the anechoic chamber at Harvard. Amid dead silence, the low hum of his blood circulation and the high tone of his nervous system were still audible. Mr. Cage could not have held his breath for too long, and that phase might be added as well. Pulse is within us from birth.

The numerous rotational patterns within a galaxy produce a tremendously complex polyrhythm. A star pulsates slowly in a magnetic activity cycle, about 11 years in duration for our own Sun. Life on a planet would be in peril without the protection of a global magnetic field, whose frequency must be within a certain range to deflect cosmic rays. The general ordered nature of the universe is based in its current state of calibration, and depends in large part upon non-conflicting periodicities. Things are not much different on the molecular level, as a certain frequency must be maintained to avoid everything around us becoming frozen solid or melting and bursting into flames. On the other hand, increasing the oscillation just right will produce a warm meal. Exact vibrations might in fact be creating our own reality, below the subatomic level. The entire universe could be

a field of complex frequencies, in a manner far less obvious than that of sunspots or X-rays.

String theory suggests that all subatomic particles are actually specific vibrations of infinitesimally small energy strings. The theory had over a few decades branched out into five overarching superstring theories (Greene 2004: 377). In the mid-1990s, the similarities between these became apparent, and they were unified into the still incomplete M-theory (generally understood as meaning *membrane*, but the definition has been muddied by conflicting beliefs) (Greene 2004: 378-379). For the sake of simplicity, I will refer to the multitude of approaches as simply *string theory*, as the essential principles, significant in my work, still apply.

Theoretical physicists become involved with string theory because it holds potential for achieving the theory of everything, where the four physical forces (electromagnetic, strong nuclear, weak nuclear, and gravitational) would be joined through a universal law. It was in fact string theory's unique approach to explaining the graviton, the hypothetical gravity particle, that in the mid-1980s dramatically propelled the discipline out of the slump it experienced in the previous decade. Other important contributions include the theory's ability to demystify the dual particle/wave nature of light. While there is still doubt in the plausibility of some of its aspects, string theory has offered scientifically sound methods of grappling with elemental problems that have baffled physicists for over a century.

I wrote *Refraction Frequency* before I knew the intricacies of string theory, but the notion of vibration creating matter was something I was acquainted with.

Now I am aware of the idea that the subatomic particles might come into very existence by virtue of varying pulsation:

> It's just like what happens with more familiar strings like those on a violin or cello. A cello string can vibrate in many different ways, and we hear each pattern as a different musical note. In this way, one cello string can produce a range of different sounds. The strings in string theory behave similarly: they too can vibrate in different patterns. But instead of yielding different musical tones, *the different vibrational patterns in string theory correspond to different kinds of particles* (Greene 2004: 346).

Such statements welcome artistic inspiration. Vibrato in Western music has been used (or abused) in a very limited number of ways. Its more intentional speeds, whether in even or uneven patterns, can add new dimensions to a pitch. Korean musicians have throughout the centuries been using different types of vibrato for specific reasons, whether of texture, emotion or combinations thereof. *Sujecheon* would not exude such living vibrancy otherwise. Balkan dance music would not bounce and shimmer as much without the tendency to quickly repeat held tones in a semi-connected fashion. Sections of my orchestral work would not have the same effect or structural weight had I relied on unpulsed sonorities; dense, clashing vibration makes some stand out drastically, while slower, intentionally wider oscillation adds a sense of flux even to more static regions.

Sound periodicity is tremendously slow compared to that of elemental strings. One proposed frequency for the production of gravitons results in a tension of about a thousand trillion trillion trillion tons, 10^{41} times greater than that of an average piano string (Greene 2004: 356). Despite the enormous difference in the amount of energy required to initiate movement (regardless of object scale), the two concepts are connected in a very specific way:

> Calculations show that the masses of the string vibrations follow a series analogous to musical harmonics: they are all multiples of a fundamental mass, the *Planck mass*, much as overtones are all multiples of a fundamental frequency or tone (Greene 2004: 357).

This suggests that sound might be a manifestation, and the art of music perhaps continuation of the most essential inceptive processes. The plane we live on could be a mesh of frequencies, perfectly tuned from the smallest level. Composers need only consider the notion of such limitless vibrational interaction, and genuine creative paradigms will be born. The beauty and mystery of music lie in its simultaneously abstract and concrete properties; an inspired composer could use this towards realizing scenarios yet to be considered by physicists.

Well-written pieces tend to present the listener with more than one perspective. I tried to achieve this in my orchestral work. Some inclined minds might hear its massive clusters as plasma flows within a star, others as quantum chaos at a miniscule level of space. The beginning of the piece will never sound quite the same, due to unspecified multiphonic fingerings in a fixed range, a partial reflection of the universal static flux. My interest in pulsation had in 2010 resulted in *Refraction Frequency*, and composing that piece has led me to string theory and similar research areas. As I continue drawing inspiration from the natural world and its disciplines of inquiry, I hope that the scientists in the audience will find my work an artistic refraction of their own, and other listeners a small insight into our complex, multifaceted existence.

Appendix

Hyang piri

The instrument consists of a short, narrow bamboo pipe, with a wide double reed, which acts as the main factor in sound quality. I recorded a sample with the Sony Cybershot DCS-W55 camera, equipped with a mono microphone of great quality. The segment is played by Park Chi Wan, member of the National Gugak Center in Seoul, at a UC Santa Cruz demonstration in February 2009. The Hyang piri manifests an incredibly intense spectral distribution, whose sound helps define *Sujecheon*.

The fundamental is a sharp Ab4, at 430.66 Hz (415.3 Hz would be equal temperament). It is also the loudest formant, at a little under 52 dB. The following two partials are weaker, but pronounced nonetheless, both at 40 dB, and respectively at 861.33 and 1291.99 Hz. The fourth harmonic is somewhat stronger, at a little under 43.5 dB and at 1722.66 Hz, helping reinforce the fundamental. The fifth, an approximation of two octaves and a major third above the base frequency, is weak (a little over 31.5 dB), and at 2153.32 Hz; if it were louder it might dull the pointed sonic impact (a subjective viewpoint).

The following three formants, 6-8, are of relatively equivalent loudness: a little over 43, a little under 46, and 45 dB. Although harmonic 9 seems the loudest, at a little below 48.5 dB, it peaks only briefly and does not maintain the same uniformity as the rest. The respective frequencies are 2583.98, 3014.65, 3445.31, and 3875.98 Hz. The prominence around 3000 Hz has been dubbed by researchers the "singers' formant," as trained singers (especially male) tend to produce loud harmonics in the 2800-3400 Hz range. This gives them the ability

to project over the Western orchestra, where the instruments peak at much lower frequencies. This high formant region never moves, regardless of the fundamental. The loud seventh and eighth harmonics in the piri create a similar result, ensuring the sound cuts through the rest of the ensemble, even the instruments playing in a much higher range.

Harmonic 10 is at 4306.64 Hz and somewhat weaker, at a little below 42.5 dB. It is topped by a prominent group, spanning harmonics 11–14. Here again it makes more sense to talk of frequency regions, as a slight volume increase in the sample produces small upward shifts in the higher partials. The respective regions slide up to 4737.3, 5167.87, 5598.63, and 6029.3 Hz, the last following a slightly more drastic frequency shift. The levels are a little under 48, a little over 47.5, a little over 48.5, and a little over 47.5 dB. Harmonic 11 peaks briefly and does not maintain the same intensity as the rest. Either way, the current range is quite high, yet the general formant volume is barely lower than the fundamental. The piri is an impressive spectral medium.

The upward frequency slide is even more evident in the rest of the prominent partials, 15-19. The respective areas result in 6459.96 (40 dB), 6890.62 (45.5 dB), 7321.29 (38.5 dB), 7751.95 (46 dB), and 8182.62 Hz (a little under 42.5 dB). Although somewhat below the previous region, the volume is still substantial. The entire collection is therefore 19 harmonics (counting the fundamental), 18 of significant strength and only one (the fifth) prominently weaker than the rest. The intensity found in the high formant regions of the piri is unique, not produced by any other instrument in the ensemble.

The very high range contains a lot of important noise components, the strongest one being at 11,714.1 Hz. It is worth noting the thin, vertical

interruptions in sound, starting at about the 11th harmonic. I suspect that these are partly due to the difficulty of maintaining a consistent reed vibration, as they are especially present when the volume diminishes. Other reasons might include distortion within the vibrations of the double reed, between the lips and the reed, or even the reed and the pipe, caused by feedback interference. The interruptions are likely another element in our perception of the piri sound. While the brain might distinguish a single piercing, somewhat raspy quality in the short sample, multiple processes are in fact happening simultaneously. Another detail worth mentioning is a very quick, yet gradual formant activation at the beginning of the clip, visible in the spectrogram but impossible to discern in such a way otherwise. This is evidence of the difficulty in producing sound on the instrument. The yoneum in *Sujecheon*, while providing textural contrast, also serve the important purpose of letting the piri players rest. The great diversity of spectral components, both generally static and transient, grants this instrument a forward position in the ensemble.

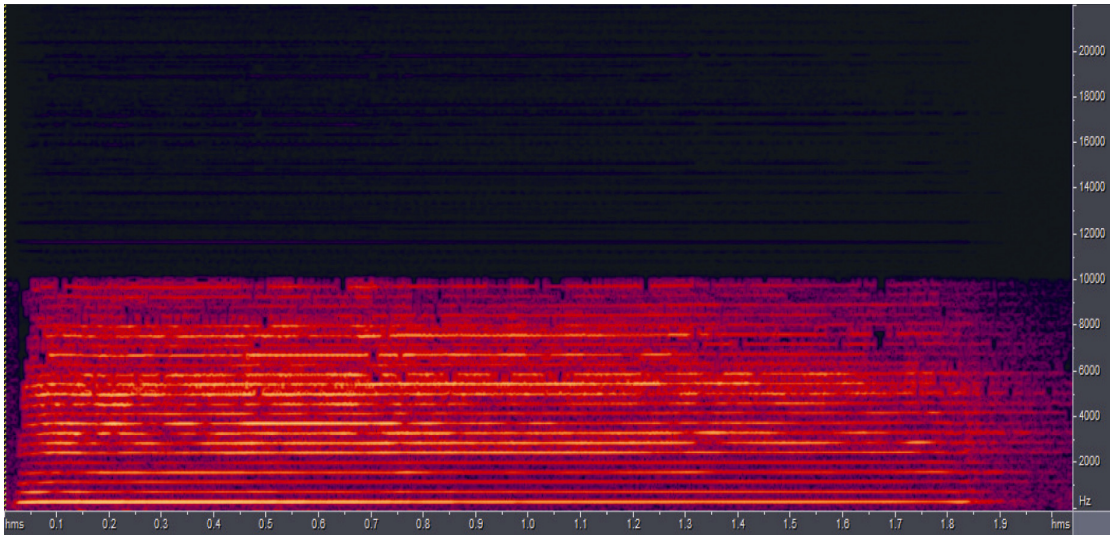


Fig. 12. Hyang piri spectrogram.

Daegeum

The smoother quality and the concise spectral distribution of this instrument are a world apart from the piri. The sample is played by Kim Jeong Seung, member of the National Gugak Center, and was taken from a stereo, professional recording he brought to UC Santa Cruz in early 2009. Along with the standard daegeum sound, I will look at the influence of the buzz membrane.

The fundamental is a very sharp F5, at 732.13 Hz. It is close to F#5 (739.99 Hz), but the mode in the source piece does not involve that pitch. The intensity is 48.5 dB, the strongest in the spectrogram. Harmonic 2 is the second loudest, at 26 dB and 1464.26 Hz. The third is 2196.39 Hz, and a little under 20.5 dB. These three components are the most important in shaping the daegeum character. Note that the third formant is less pronounced than the second, commonly a clue for rounder sound.

Harmonic 4 is much weaker, at a little under 11.5 dB. Its equivalent of two octaves above the fundamental, at 2928.52 Hz, does not emphasize harmonics 1 and 2 as do some other instruments. The following partial is stronger, at 3660.64 Hz and a little below 17.5 dB. This approximate interval of two octaves and a major third above the base does much to further smooth out the general sound. The intensity at this level is relatively prominent, but still gets obliterated by the piri arsenal in similar range. It is nonetheless worth recalling that the fifth harmonic in the piri is its weakest one of the 19, not standing in the way of the more piercing formant combinations. The same partial in the daegeum might then contribute to fill out the sonic space, especially at a louder volume, as evident from the frequency emphasis brought out by the sample *crescendo*.

Harmonics 6-8 are visible, but significantly weaker. The following frequencies are upper ends of short ascending slides, corresponding to the increase in volume: 4392.77 (slightly above 4 dB), 5124.9 (slightly below 5 dB), and 5857.03 Hz (slightly below 5.5 dB). It is important to notice that the loudness towards the end of the clip does not affect every partial the same way. Heightened intensity is observed in 5 and 7, while there is a *decrescendo* in 6 and 8. The latter two are approximations of two octaves and a fifth, and three octaves above the fundamental, evidence of diminishing influence in those, shall we say, frequency classes from a few levels below. While harmonic 5 has already been discussed, the frequency class of harmonic 7 has not occurred before, and its presence is more likely to increase the rich than the sharp timbral signature (in general terms). While barely visible, harmonic 10, the same frequency class as 5, also intensifies with the *crescendo*, pointing again to a more rounded essential quality of the instrument.

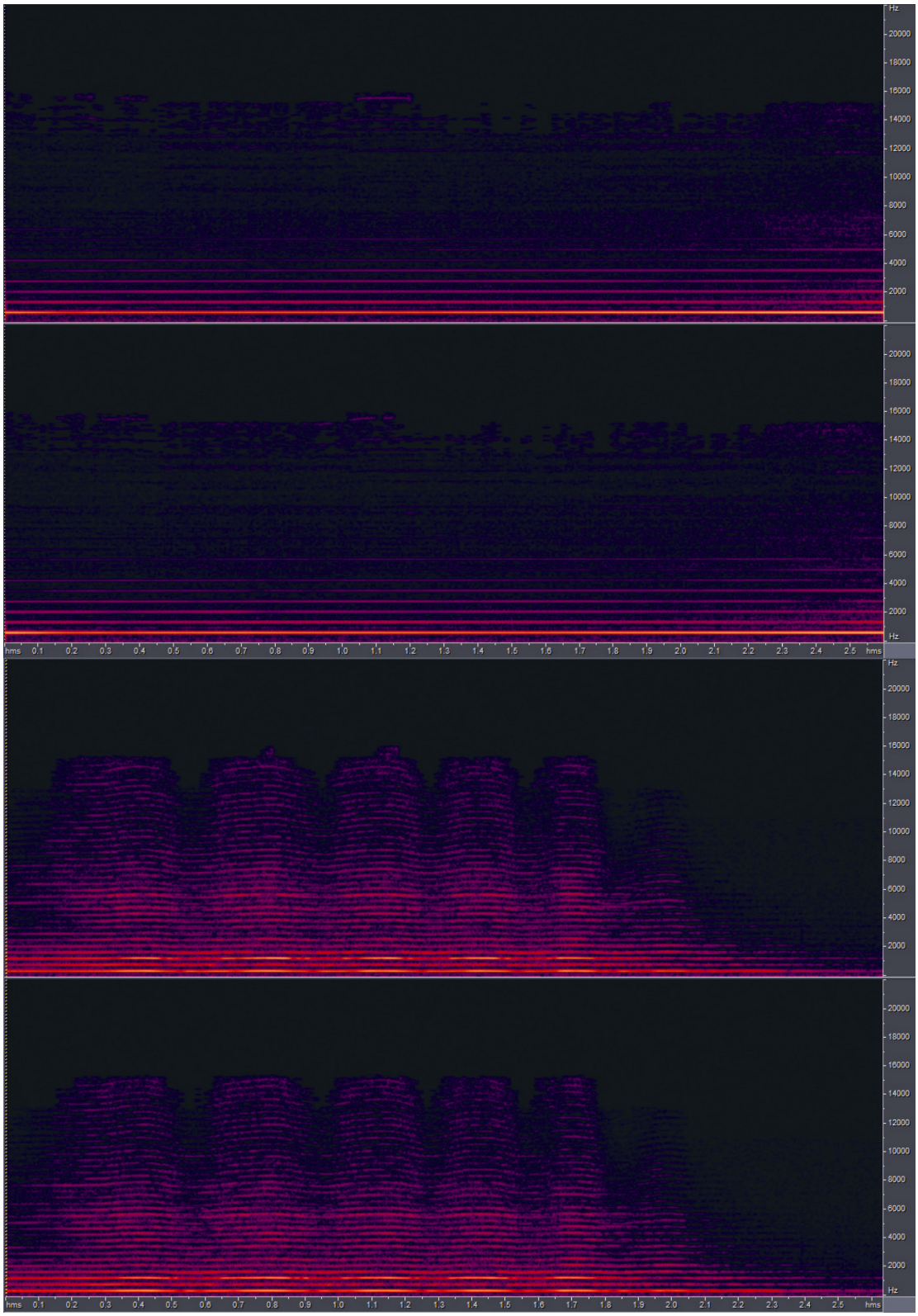
The air noise in a *crescendo* might be well-controlled on a good instrument played by a master musician, but it is nonetheless significant in competing with the basic spectral traits, and creating a more textured sound. This is particularly noticeable when the beginning and the end of the sample are played separately, and manifests as an accumulation of slightly brighter high partials at the end of the spectrogram. The element of noise becomes especially important with the activation of the daegeum membrane, to be analyzed shortly. In an essential view, however, the crucial components are harmonics 1-3, and to an extent 5; harmonics 4 and 6-8 complement the picture.

While not the principal mode of playing, the employment of the membrane gives the daegeum further timbral complexity. The effect could be compared to

sul ponticello on string instruments, with added bow pressure, activating a greater number of partials. The result is evident on the spectrogram of a sample taken from the same Kim Jeong Seung recording. For the sake of further contrast, I chose a heavily-vibrated pitch. While the more numerous partials are also the product of somewhat louder volume (peaking at about 8 dB above the previous clip), the membrane is the main factor in the noise increase.

The fundamental centers around A4. The heavy *vibrato* is wide towards the lower, and even wider into the higher frequencies (about G4 to almost C4). An element that immediately stands out is the loudness of the third harmonic, almost matching that of the fundamental. The second harmonic, on the other hand, is significantly weaker, especially compared to its prominence in the first sample. The fourth is somewhat stronger than the second, indicating that the sound in this clip carries further (especially when including all the higher partials). Waning, but prominent intensity continues until the 14^{th} harmonic, with special emphasis seen in the 13^{th}. Further noise formants continue far beyond, evidence of the membrane as a powerful envelope device. Due to the strength of the higher harmonics, this side of the daegeum could be considered a lighter version of the piri sound. It is interesting that when played without the attack noise (especially starting at the peak of an oscillation), the sample sounds closer to a haegeum; this is significant when considering the prominence of long tones in *Sujecheon* and ensemble blend, another area that deserves attention. The following figure contains the spectrograms of the two daegeum samples.

Fig. 13. Daegeum spectrograms 1 (no vibrato or membrane) and 2 (with vibrato and membrane).


Hz
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
hms
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5

Glossary

ajaeng Korean bowed zither.

Baekje Korean kingdom (18 BCE – 660 CE).

Bitgarak Jeongeup Another, older name for *Sujecheon* (see *Sujecheon*). For a more detailed explanation, see pp. 29-30.

daegeum Korean transverse bamboo flute.

haegeum Korean two-stringed spike fiddle.

Hyang piri Korean double-reed wind instrument.

izvorna A type of folk music in the central Balkans.

jang Main formal section in *Sujecheon* (see *Sujecheon*).

janggu Korean horizontal hourglass-shaped drum.

jeongganbo The first mensural musical notation in Asia, developed in the 15th century by the Korean king Sejong the Great.

Jeongeupsa A song from the Baekje kingdom, possibly from the 7th century, likely a basis for *Sujecheon* (see *Sujecheon*).

jwago Korean large barrel drum.

kayageum Korean plucked zither.

kolo Balkan circle dance.

Koryeo Korean kingdom (918 – 1392).

p'ansori Korean one-person musical drama, with barrel-drum accompaniment.

Šargija Central-Balkan long-necked lute.

Shilla Korean kingdom (57 BCE – 935 CE).

sogeum Korean short transverse bamboo flute.

Sujecheon Korean court music piece, possibly from the 8th century.

yoneum Secondary formal section in *Sujecheon* (see above); a connecting segment.

Bibliography

"A Physicist Explains Why Parallel Universes May Exist." NPR. n.p. Web. 24 January 2011.

Ansambl Budimira Jovanovića (The Budimir Jovanović Ensemble). "Gocino kolo." RTV Belgrade PGP, 1966. MP3.

Carterette, Edward C. and Roger A. Kendall. "Perceptual Scaling of Simultaneous Wind Instrument Timbres." Music Perception: An Interdisciplinary Journal 8.4 (1991): 369-404. PDF file.

Chang, Sa-hun. Gugak Cheong Neon (Korean Traditional Music Theory). Seoul: Se-Kwang Music Publishing, 1985.

Cho, Chae-son. Aspects of Melodic Formation and Structural Analysis in *Sujecheon*. Diss. Seoul: Suseowon, 1992. Print.

Cho, Seong nae. Taegum kyobon. Seoul: Do Seo Chul Pan, 1992.

Cogan, Robert. New Images of Musical Sound. Cambridge, MA and London: Harvard University Press, 1984.

Cogan, Robert. "Reconceiving Theory: The Analysis of Tone Color." College Music Symposium 15 (1975): 52-69. PDF file.

Courtney, David. "Introduction to Spectrum Analysis." Experimental Musical Instruments 8.1 (1992): 18-22. PDF file.

Demany, Laurent and Catherine Semal. "Pitch versus Brightness of Timbre: Detecting Combined Shifts in Fundamental and Formant Frequency." Music Perception: An Interdisciplinary Journal 11.1 (1993): 1-13. PDF file.

Greene, Brian. The Fabric of the Cosmos: Space, Time, and the Texture of Reality. New York: Alfred A. Knopf, 2004.

Gordon, John W. and John M. Grey. "Perception of Spectral Modifications of Orchestral Instrument Tones." Computer Music Journal 2.1 (1978): 24-31. PDF file.

Hagan, S., S. R. Hameroff, and J. A. Tuszyński. "Quantum computation in brain microtubules: Decoherence and biological feasibility." Physical Review E 65.6 (2002): 1-12. PDF file.

Howard, Keith. Korean Musical Instruments: A Practical Guide. Seoul: Se-Kwang Music Publishing, 1988.

Hwang, Jun-yon, Jin-Ah Kim, and Yong-Shik Lee, eds. Musical Notations of Korea. Seoul: Nationa Gugak Center, 2010.

Ilija and Marko Begić. "Pjesma u kolu." Jugoton, 1981. MP3.

Karača-Beljak, Tamara. "Bosnian Urban Traditional Song in Transformation: From Ludvik Kuba to Electronic Medias." Traditiones 34.1 (2005): 165-176. PDF file.

Kwon, Oh-sung. "History of Korean Notations." Musical Notations of Korea. Eds. Jun-yon Hwang, Jin-Ah Kim, Yong-Shik Lee. Seoul: National Gugak Center, 2010. 1-19. Print.

Lee, Byong Won. Styles and Esthetics in Korean Traditional Music. Seoul: National Gugak Center, 1997.

Lee, Hye-ku. Essays on Korean Traditional Music. London: Royal Asiatic Society, Korea Branch: 1981.

March, Rick. "An Internet Tour of Bosnian Music." Voices: The Journal of New York Folklore 34 (2008): n. pag. Web. 22 December 2010.

Mehinovic, Vedran. Refraction Frequency. 2010.

National Gugak Center. A Selection of Korean Traditional Music vol. 1. Seoul Records, 2002. CD.

Parks, Kevin. crow's-eye view no. x. MA thesis. Dartmouth College, 1997. PDF file.

Piszczalski, Martin. "Spectral Surfaces from Performed Music Part 1." Computer Music Journal 3.1 (1979): 18-24. PDF file.

Piszczalski, Martin. "Spectral Surfaces from Performed Music Part 2." Computer Music Journal 3.3 (1979): 25-27. PDF file.

Rossing, Thomas D., ed. The Science of String Instruments. New York, Dordrecht, Heidelberg, London: Springer, 2010.

Sandell, Gregory J. "Roles for Spectral Centroid and Other Factors in Determining 'Blended' Instrument Pairings in Orchestration." Music Perception: An Interdisciplinary Journal 13.2 (1995): 209-246. PDF file.

Slawson, Wayne. "Sound-Color Dynamics." Spec. issue of Perspectives of New Music 25.1/2 (1987): 156-181. PDF file.