SOUND OBJECTS:
APPROACHES TO COMPOSITION IN AN OBJECT-ORIENTED PARADIGM

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A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN
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I recommend that the thesis prepared
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Sound Objects: Approaches to Composition
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requirements for the degree of
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ABSTRACT

This thesis presents compositions that demonstrate two distinct object-oriented approaches to the representation of sound. Object-oriented refers to the computational paradigm where structures are represented as classes of objects. The acoustic pieces employ a computer-assisted method that uses an object-oriented representation of harmonic rhythm through the creation of a series of tetrachords. The tuning of the tetrachords is based on the partials of the harmonic series and these works are written for ensembles of instruments with flexible intonation. The electronic pieces were created with software based on an object-oriented methodology, which visually represent synthesis and digital signal processing procedures. This software allows flexible intonation through the specification of pitch in terms of frequency. The context paper examines these compositional methodologies, including the approaches to tuning and intonation, in relation to historical and contemporary composers and theorists.

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I would like to express my appreciation for the support provided by my family. To my mother and aunt for their meticulous corrections of the final drafts, to my father for years of vocabulary-expanding crossword puzzles and to my sister Julie for providing solidarity during our years of piano lessons.

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for string quartet

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The harmonic rhythm of the piece was determined though an object-oriented system that consists of class definitions for both the chords and rhythmic durations. The methods of interaction thus generate the sequence of instances of these classes.

The source pitch material for the piece was derived from the first fifteen partials of the harmonic series above C, resulting in eight different pitches – C, D, E F sharp, G, A, B flat, and B. All possible four note combinations of these pitches were available as instances of the chord class. The available rhythmic durations were derived by multiplying the prime numbers between one and thirty-two by a sixteenth note. Thus the twelve available rhythmic durations are the equivalents of one, two, three, five, seven, eleven, thirteen, seventeen, nineteen, twenty-three, twenty-nine, and thirty-one sixteenth notes. Available combinations of durations were determined by applying variations on the series of primes to the set of durations. Then, according to the methods of the classes, a sequence of chords, duration, and tuning was determined.

Thus a slow moving homophonic harmonic sequence was established. The melodic material of the piece was then composed using the same source pitches however the durations of the pitches in their melodic context were not governed by any overriding methodology.

Movement II:

This freely composed movement consists of a series of solos and a single duet. The lengths of the sections were determined from numbers occurring in the Fibonacci series (1, 3, 5, 8, 13, 21, 34, 55, 89, 144).

It is the intention of the composer that the piece be realized in a way that facilitates the pure tuning possibilities created by the choice of the harmonic series for the source pitches. The players are made aware of these occurrences through the notational device of the asterisk (*) and are requested to retune these pitches accordingly. A list of the pure intervals, in cents, is appended to the score. In order to achieve maximum homogeneity of the ensemble the performers are required to play from score. In the second movement the players should concentrate on picking up the melody line from the previous solo as seamlessly as possible rather than counting rests.

Partial Objects

I. Adagio

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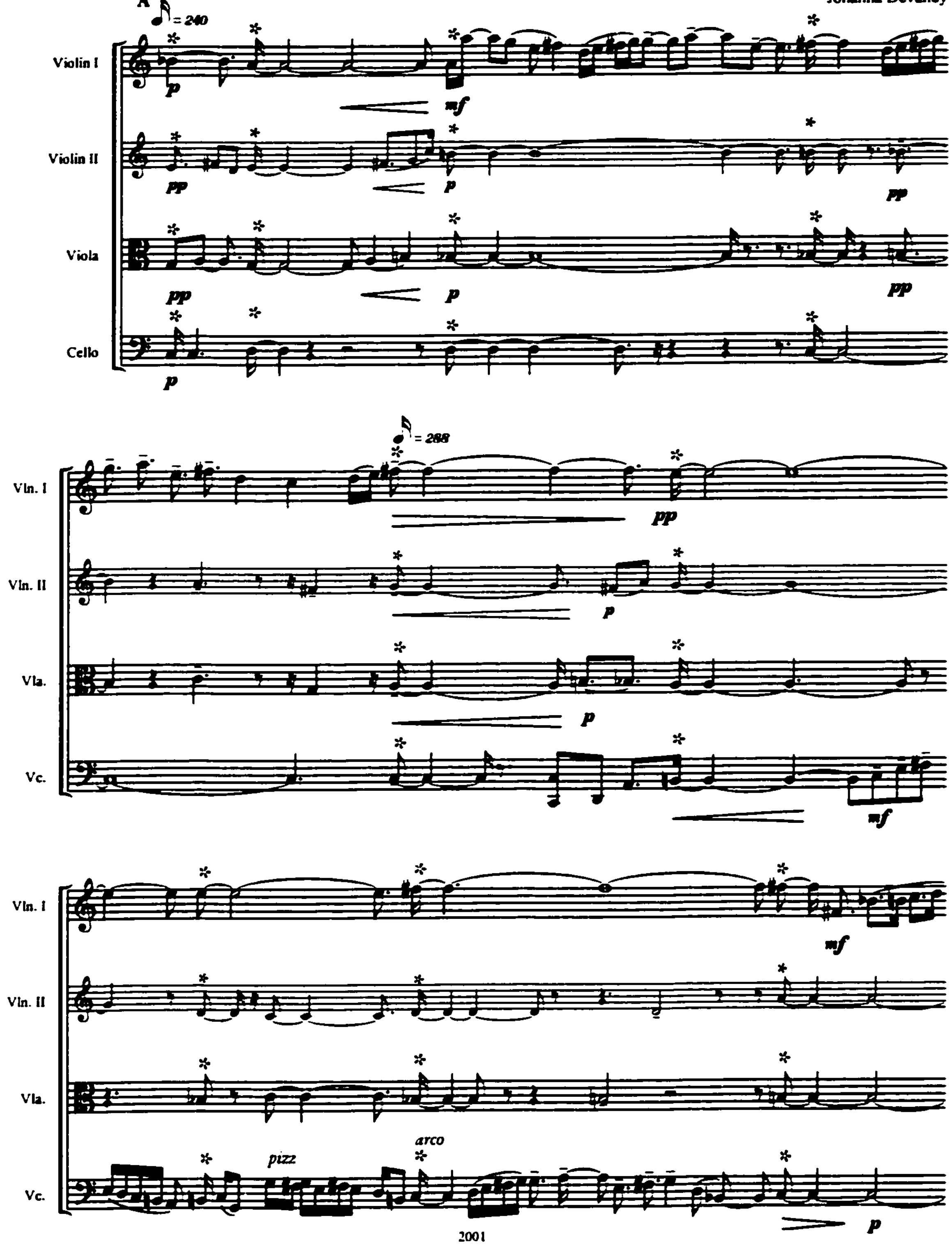


Vln. I
Vln. II
Vla.
Vc.
B
= 96 (= 378)
p
mf
pp
mp


Vln. I
Vln. II
Vla.
Vc.
= 288
p
pp
mp
mf


Vln. I
Vln. II
Vla.
Vc.


C
Vln. I
Vln. II
Vla.
Vc.
mp
mf
p

D
= 96
= 378
Vln. I
Vln. II
Vla.
Vc.
pp
p
mp
mf


Vln. I
Vln. II
Vla.
Vc.
77
82
= 288

Partial Objects

II. Ad Lib.

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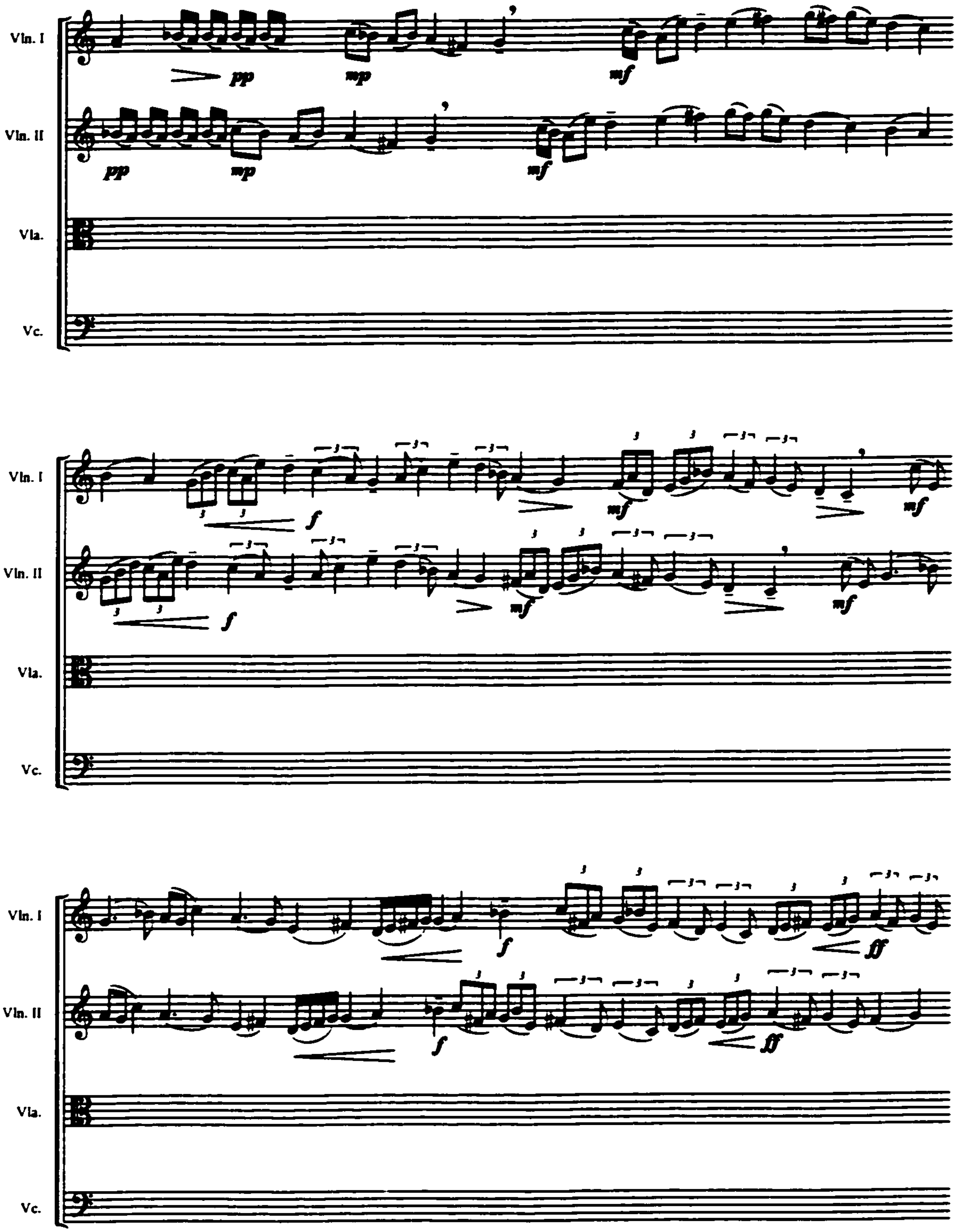
2002


16
Vln. I
Vln. II
Vla.
Vc.
3
f
21
Vln. I
Vln. II
Vla.
Vc.
mf
f
mf
Vln. I
Vln. II
Vla.
Vc.
mp
mp
mp
mf


Vln. I
Vln. II
Vla.
Vc.


Vln. I
Vln. II
Vla.
Vc.
f
mf
51
Vln. I
Vln. II
Vla.
Vc.
mp
f
56
Vln. I
Vln. II
Vla.
Vc.
mf
3


Vln. I
Vln. II
Vla.
Vc.

Partial Objects

III. Allegro

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Vln. I
Vln. II
Vla.
Vc.
mp
mf
p
pp


Vln. I
Vln. II
Vla.
Vc.
Vln. I
Vln. II
Vla.
Vc.
Vln. I
Vln. II
Vla.
Vc.


Vln. I
Vln. II
Vla.
Vc.


Vln. I
Vln. II
Vla.
Vc.
Glissando


Vln. I
Vln. II
Vla.
Vc.

Pure Interval Tunings

Interval	Deviations from EQ (in Cents)
Unison	0
Minor Second	+12
Major Second	+4
Minor Third	+16
Major Third	-14
Perfect Fourth	-2
Tritone	-17
Perfect Fifth	+2
Minor Sixth	+14
Major Sixth	+6
Minor Seventh	-4
Major Seventh	-12
Perfect Octave	0

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deMusica

for twelve-part choir

Program Notes:

The harmonic rhythm of the piece was determined though an object-oriented system that consists of class definitions for both the chords and rhythmic durations. The methods of interaction, thus generate the sequence of instances of these classes. The source pitch material for the piece was derived from the first fifteen partials of the harmonic series above C, resulting in eight different pitches - C, D, E F sharp, G, A, B flat, and B. All possible four note combinations of these pitches were available as instances of the chord class. The available rhythmic durations were derived by multiplying the prime numbers between one and thirty-two by a sixteenth note. Thus the twelve available rhythmic durations are the equivalents of one, two, three, five, seven, eleven, thirteen, seventeen, nineteen, twenty-three, twenty-nine, and thirty-one sixteenth notes. Available combinations of durations were determined by applying variations on the series of primes to the set of durations. Then, according to the methods of the classes, a sequence of chords, their duration, and tuning was determined.

Each of the tetrachord pitches was assigned to a group of voices (Soprano, Alto, Tenor, Bass). For each tetrachord occurrence the assigned pitches were sounded by all voices with varying offsets, one voice with no offset, a second with an eighth note offset, and a third with a quarter note offset. Thus a slow moving harmonic sequence was established. The melodic material of the piece was then composed using the same source pitches however the durations of the pitches in their melodic context were not governed by any overriding methodology.

During sustained sonorities the singers are requested to use the pitch in the bass as the reference point for intonation.

de Musica

Johanna Devaney

2002

Text taken from:
Anicius Manlius Severinus Boethius


3
S 1
no - bis es - se co - ni - unc - tam et mor -
S 2
no - bis es - se co - ni - unc - tam et mor -
S 3
no - bis es - se co - ni - unc - tam et mor -
A 1
cam et mor -
A 2
cam et mor - es
A 3
cam et mor -
T 1
se et mor -
T 2
se et mor - - -
T 3
se et mor -
B 1
ter no - - - - - - - - - - bis et
B 2
no - - - - - - - - - - bis et
B 3
no - - - - - - - - - bis et


6
S 1
p mp
es vel Tres
S 2
p mp
es vel Tres
S 3
p mp
es vel Tres
A 1
p mp
es vel Tres
A 2
p mp
vel vel Tres
A 3
p mp
es vel Tres
T 1
p mf
es vel Tres
T 2
p mf
es vel Tres
T 3
p mf
es vel Tres
B 1
mp mf p
vel ev - er - te - re Tres
B 2
mp mf p
vel ev - er - te - re Tres
B 3
mp mf p
vel ev - er - te - re Tres


10
S 1
es - - - - - - - - - - - se De
S 2
es - - - - - - - - - - - se De
S 3
es - - - - - - - - - - se
A 1
es - se quo De
A 2
es - se quo De
A 3
es - se quo
T 1
es - se mu - si - cas. de vi mu - si - cae
T 2
es - se mu - si - cas. de vi mu - si - cae De
T 3
es - se mu - si - cas. in quo de vi mu - si - cae. De
B 1
mu - si - cas. in quo de vi mu - si - cae.
B 2
mu - si - cas. in quo de vi mu - - - si - - - cas. De
B 3
mu - si - cas. in quo de vi mu - - - si - - - cae De


14
S 1
vo-ci-bus ac de mu - si - cae mu - - - - - - - - - - - si - cae De
S 2
mu - - - - - - - - - - si - cae De
S 3
De mu - - - - - - si - cae De
A 1
mu - - - - - - - - - - - - - - si -
A 2
mu - - - - - - - - - - - - - - si -
A 3
De mu - - - - - - - - - - - - - - si -
T 1
De vo - ci - bus ac de mu - - - si - cae el -
T 2
vo - ci - bus ac de mu - si - - - - - - cae el -
T 3
vo - ci - bus ac de mu - si - cae el -
B 1
De mu - - - - - - - - - - - - - si -
B 2
mu - - - - - - - - - - - - - - si -
B 3
mu - - - - - - - - - - - - - - si -


18
S 1
in - ae - qual - - - i - ta - tis Quae
S 2
spe - cie - bus
Quae
S 3
spe - cie - bus
Quae
A 1
cae
in - ae - qual - i -
A 2
cae
Quae
A 3
cas.
in - ae -
T 1
e - men - tis De
spe - - -
T 2
e - men - tis De
spe - - - -
T 3
e - men - tis De
spe - - - - -
B 1
cae
De spe -
B 2
cae
De spe -
B 3
cae
De spe - - -


22
S 1
Quae spe-cies con - so - nan - tiis
S 2
con-so - nan - tiis
S 3
Quae con-so-nan - tiis
A 1
ta - tis Quae in - ae-qual - i - ta - tis spe
A 2
Quae in - ae - qual - i - ta - tis spe
A 3
qual - i - ta - tis Quae in - ae-qual - i - ta - tis spe
T 1
cie bus
T 2
cie bus
T 3
cie bus
B 1
cie - bus Quae Quae
B 2
cie - bus Quae Quae
B 3
cie - bus Quae Quae


26
S 1
de - pu
S 2
de - pu
S 3
de - pu
A 1
cies Quae de
A 2
cies de
A 3
cies Quae de
T 1
in - ae - qual - i - ta - tis de - pu
T 2
in - ae - qual - i - ta - tis de - pu -
T 3
in - ae - qual - i - ta - tis de - pu -
B 1
in - ae - qual - i - ta - tis spe - cies de - pu - ten -
B 2
Quae con - so - nan -
B 3
Quae con - so - nan -


30
S 1
ten - - - - - - - - - - tur
S 2
ten - - - - - - - - - - - - - tur
S 3
ten - - - - - - - - - - - - - - tur
A 1
pu - - - - ten - - - - - - - - - - - - - tur
A 2
pu - ten - - - - - - - - - - - - - - tur
A 3
pu - ten - - - - - - - - - - - - - - - tur
T 1
ten - - - - - - - - - - - - - - - - tur
T 2
ten - - - - - - - - - - - - - - tur
T 3
ten - - - - - - - - - - - - - tur
B 1
tur de - pu - ten - - - - - - - - - tur
B 2
tiis de - - - - - - pu - ten - - - - - tur pu - ten - tur
B 3
tiis de - - - - - - - pu - ten - - - - - tur


34
S 1
Cur et et
S 2
Cur mul - ti - pli - ci - tas et
S 3
Cur et
A 1
Cur et
A 2
Cur et et
A 3
Cur et
T 1
Cur et
T 2
Cur et et
T 3
Cur et
B 1
Cur mul - ti - pli - ci - tas et
B 2
Cur et
B 3
Cur mul - ti - pli - ci - tas et et


37
S 1
con - so - - - - - nan - tiis
S 2
pp
et
con - so - - - - nan - tiis
S 3
pp
et
con - so - nan - tiis
A 1
mp
su - per - par - tic - u - la - ri - tas
con - - - - so - - - - - -
A 2
con - so - - - - -
A 3
mp
su - per - par - tic - u - la - ri - tas
con - - - so - - - - - - - -
T 1
et
con - - - - - - - - - - - -
T 2
con - - - - - - - - -
T 3
et
con - - - - - - - - - - - -
B 1
et
con - so - - - - - - - -
B 2
et
con - so - - - - - - - - -
B 3
con - so - - - - - - - - -


41
S 1
de - - - pu - - - - ten - - - - - - - - - tur
S 2
de - - - pu - - - - - ten - - - - - - - - - tur
S 3
de - - - pu - - - - - ten - - - - - - - - tur
A 1
nan - - - - - - - tiis
mp
Cur
A 2
nan - - - - - - - - - tiis
mp
Cur mul - ti - pli - ci -
A 3
nan - - - - - - - - - - - tiis
mp
Cur
T 1
so - - - nan - - - - - - - tiis
p
Cur
T 2
so - nan - - - - - tiis
p
Cur
T 3
so - nan - - - tiis
p
Cur
B 1
nan - - - - - - - - - - tiis
p
Cur
B 2
nan - - - - - - - - tiis
p
Cur
B 3
nan - - - - - - - - tiis
p
Cur


45
S 1
S 2
S 3
A 1
A 2
A 3
T 1
T 2
T 3
B 1
B 2
B 3
mp
p
mf
et
con
tas
su - per - par - tic - u - la - ri - tas
su - per - par - tic - u - la - ri -


49
S 1
mp
so - - - - - - - - - - - - - - nan - - - - - - - - - - - -
S 2
mp
so - - - - - - - - - - - - - nan - - - - - - - - - - - -
S 3
mp
so - - - - - - - - - - - nan - - - - - - - - - - - -
A 1
mp
so - - - - - - - - - - - - - - nan - - - - - - - - - - - -
A 2
mp
so - - - - - - - - - - - nan - - - - - - - - - - - -
A 3
mp
so - - - - - - - - - - - - - - nan - - - - - - - - - - - -
T 1
mp
de - - - - - - - - - - - - - - pu - - - - - - - - - - ten -
T 2
mp
de - - - - - - - - - - - pu - - - - - - - - - ten -
T 3
mp
de - - - - - - - - - - - - - - pu - - - - - - - - - ten -
B 1
mp
so - - - - - nan - - - - - - tiis
mf
de - pu - ten -
B 2
mp
so - - - - - - nan - - - - - tiis
mf
de - pu - ten -
B 3
mp
tas
con - - - - - so - - - - - - nan - - - - - -


53
S 1
tiis
Quae
qui - - - - bus
S 2
tiis
Quae
qui - - - - bus
S 3
tiis
Quae
qui - - - - bus
A 1
tiis
Quae
Quae pro - por - tion - es
A 2
tiis
Quae
Quae pro - por - tion - es
A 3
tiis
Quae
Quae pro - por -
T 1
tur
Quae
qui - - - -
T 2
tur
Quae
qui - - - - - -
T 3
tur
Quae
qui - - - - -
B 1
tur
Quae
qui - bus
B 2
tur
Quae pro - por - tion - es
qui - bus
B 3
tiis
Quae
qui - - - - bus


57
S 1
mf
qui - - - - bus qui - bus con - so - nan - tiis
S 2
mf
qui - - - - - - - bus con - so - nan - tiis
S 3
mf
qui - - - - - - - - bus con - so - nan - tiis
A 1
mf
qui - bus con - - - - so - nan - - - -
A 2
mp
mf
qui - bus con - so - nan - - - -
A 3
mf
tion - es qui - bus con - - - so - nan - - - - - -
T 1
mf
mp
bus qui - bus con - - - - - - - so - nan -
T 2
mf
mp
bus qui - bus con - - - - - - so - nan -
T 3
mf
mp
bus qui - bus con - - - - - - - so - nan -
B 1
con - - - - - - - - - - - so - - - - - - - -
B 2
con - - - - - - - - - - so - - - - - - - - -
B 3
con - - - - - - - - - - - so - - - - - - - - -


61
S 1
con - so - nan - tiis mu - si - - - - - - - - cis
S 2
con - so - nan - tiis mu - - - si - - - - - - - cis
S 3
con - so - nan - tiis mu - si - - - - - - cis
A 1
tiis ap - - - - - - - - - - - - -
A 2
tiis ap - - - - - - - - - - -
A 3
tiis ap - - - - - - - - -
T 1
tiis qui - bus con - so - nan - tiis mu - si - cis
T 2
tiis qui - bus
T 3
tiis qui - bus
B 1
nan - - - - - - - tiis ap - - - - - - - - - - - -
B 2
nan - - - - - - - tiis ap - - - - - - - - - - - - -
B 3
nan - - - - - - - tiis ap - - - - - - - - - - - - - -


65
S 1
mp
ap - - - - - - ten - tur
mf
Quid
S 2
mp
ap - - - - - - ten - tur
mf
Quid
S 3
mp
ap - - - - - - ten - tur
mf
Quid
A 1
ten - - - - - - - - - tur
mf
Quid
A 2
ten - - - - - - - tur.
mf
Quid
A 3
ten - - - - - - - - - - - tur
mf
Quid
T 1
mp
ap - - - - - - ten - - - - - - tur
mf
Quid
T 2
mp
ap - - - - - ten - tur
mf
Quid
T 3
mp
ap - - - - - ten - - - - - - tur
mf
Quid
B 1
ten - - - - - - - - - tur.
f
Quid
B 2
ten - - - - - - - - tur
f
Quid sit
B 3
ten - - - - - - - - - tur
f
Quid sit


69
S 1
mp mf
sit so - nus, quid
S 2
mp mf
sit so - nus, quid
S 3
mp mf
sit so - nus, quid
A 1
sit so - - - - - - - - - - nus,
A 2
sit so - - - - - - - - nus,
A 3
sit so - - - - - - - - - - nus,
T 1
sit so - - - - - - - - nus,
T 2
sit so - - - - - - - - - nus,
T 3
sit so - - - - - - - - - - nus,
B 1
mf f mf
sit so - nus, quid sit so - nus, quid in -
B 2
mf mf
so - nus, quid sit so - nus, quid in - ter -
B 3
mf f mf
so - nus, quid sit so - nus, quid in - ter -


73
S 1
in - - - - - - - - - - - - - - ter - - - - -
S 2
in - - - - - - - - - - - - - ter - - - - -
S 3
in - - - - - - - - - - - - - - ter - - - -
A 1
quid
sit
A 2
quid
sit
A 3
quid
sit
T 1
so - nus,
Non iu - di - ci - um
T 2
so - nus, in - ter - val - lum, quid
om - ne
T 3
so - nus,
quid con - so - nan - ti - a. Non om - ne
B 1
ter - val - lum, in - - - - ter - - - - - - - val - -
B 2
val - lum, in - - - - - - - ter - - - - - - - val - - - - -
B 3
val - lum, in - - - - - - - - - ter - - - - - - - val - - - - -


77
S 1
val - - - lum, quid con -
S 2
val - - - lum, quid con -
S 3
val - lum, quid
A 1
so - nus, sit so - nus, quid
A 2
so - nus, sit so - nus, quid
A 3
so - nus, sit so - nus, quid
T 1
quid quid
T 2
quid quid
T 3
quid quid
B 1
lum, quid in -
B 2
lum, quid in -
B 3
lum, quid in -


81
S 1
so - - - - - - - - - - - - - nan - - - - - -
S 2
so - - - - - - - - - - - - - nan - - - - - -
S 3
con - - - - - - - so - - - - - - - - - - - - - - - nan - - - -
A 1
in - - - - - - - - - - - ter - val - - - - lum,
A 2
in - - - - - - - - - ter - val - lum,
A 3
in - - - - - - - - - - - ter - val - lum,
T 1
so - - - - - - - - - nus, quid
T 2
so - - - - - - - - nus, quid
T 3
so - - - - - - - - nus, quid in -
B 1
ter - val - lum, quid con - - - - - - - - - - -
B 2
ter - val - lum, quid con - - - - - - - - - - - - -
B 3
ter - val - lum, quid con - - - - - - - - - - - - - -


85
S 1
ti - - - - - - - - - a.
S 2
ti - - - - - - - - - a.
S 3
ti - - - - - - - - - a
A 1
mf
con - - - - - so - - - nan - - - - - - - -
A 2
mf
con - - - - - so - - - nan - ti - - - - - -
A 3
mf
con - - - - - so - - - nan - - - - - - - -
T 1
f
in - ter - val - lum,
mf
quid
T 2
mf
quid
T 3
ter - val - lum,
mf
quid
B 1
mf
f
so - - - - - - - - - - - - - - nan - ti - a.
B 2
mf
f
so - - - - - - - - - - - - - - nan - ti - a.
B 3
mf
f
so - - - - - - - - - - - - - - nan - - ti - a.


90
S 1
Non
dan - - - - - - dum
S 2
Non
dan - - - - - esse - - -
S 3
Non
dan - - - - dum
A 1
ti - - - a.
Non
A 2
a.
Non
A 3
ti - a.
Non
T 1
Non
om - - - - - - - - -
T 2
Non
om - - - - - - - - -
T 3
Non
om - - - - - - -
B 1
Non om - ne iu - di - ci-um dan - dum esse sen - si -
B 2
Non om - - - - ne esse sen - si -
B 3
Non om - - - - ne esse sen - si -


94
S 1
mp
esse sen - - - - - - - - - - si - - -
S 2
mp
esse sen - - - - - - - - - - - si -
S 3
mp
esse sen - - - - - - - - - - - - - si -
A 1
mp
om - - - - - - - - - - - sen - - - - - - - - - si - - - -
A 2
mp
om - - - - - - - - sen - - - - - - - - - - - - si -
A 3
mp
om - - - - - - - - - - sen - - - - - - - - - - - - - - - - - si -
T 1
mp
ne iu - - - - di - - - - - - - - - - - - ci -
T 2
mp
ne iu - - - - di - - - - - - - - - - - ci -
T 3
mp
ne iu - - - - di - - - - - - - - - - - ci - um
B 1
mp
bus, sed am - - - - pli - - - us ra - ti -
B 2
mp
bus, sed am - - - - - pli - - - us ra - ti -
B 3
mp
bus, sed am - - - - - pli - - - - us ra - ti -


99
S 1
bus, sed am - pli-us ra - ti-on - i cre-den-dum; fal -
mp rit. p
S 2
bus, sed
mp rit.
S 3
bus, sed
mp rit.
A 1
bus, sed
rit.
A 2
bus, sed sen -
rit. mp
A 3
bus, sed
rit.
T 1
um dan - - - - - dum sed
rit.
T 2
um dan - - - - - dum sed esse
rit. mp
T 3
dan - - - - - dum sed
rit.
B 1
on - i esse sen - - - - - - - - -
mp rit.
B 2
on - i esse sen - - - - - - - - - - -
mp rit.
B 3
on - i esse sen - - - - - - - - - - - - su -
mp rit. p


103
S 1
la - - ci - - - - - a
S 2
p
fal - - - la - - - ci - - - - - - a
S 3
p
fal - la - ci - - - - - - - - a.
A 1
mp
sen - - - - - - - su - - - - - - um
A 2
su - - - - - - - - - um
A 3
mp
sen - - - - - su - - - - - - - - um
T 1
mp
esse cre - - - - - - den - - - - - dum.
T 2
cre - - - - - - den - - - - - - - - dum.
T 3
mp
esse cre - - - - - - den - - - - - - - dum.
B 1
p
su - - - - - - - - - - - - - - um
B 2
p
su - - - - - - - - - - - - - um
B 3
um


107
S 1
a tempo
Mu - - - - si - cam no-bis es-se
S 2
a tempo
Mu - - - - - si - cam no-bis es - se
S 3
a tempo
Mu - - - - si - cam no-bis es-se
A 1
a tempo
Mu - si - - - - cam mu - - - - - - - si - - - - - cam
A 2
a tempo
Mu - si - - cam mu - - - - - - si - cam
A 3
a tempo
Mu - si - - - - cam mu - - - - - - si - - - - - cam
T 1
a tempo
Mu - si - cam no - - - - bis es - - - - - se
T 2
a tempo
Mu - si - cam no - - - - bis es - - - - - - se
T 3
a tempo
Mu-si - cam no - - - - - bis es - - - - se
B 1
a tempo
Mu - si-cam na - tu-ra-li - - - - ter
B 2
a tempo
Mu - si-cam na - tu-ra-li - ter no - - - - - -
B 3
a tempo
Mu - si-cam na - - - - tu-ra-li - ter no - - - - - - -


110
S 1
co - ni - unc - tam et mor - - - - es vel
S 2
co - ni - unc - tam et mor - - - - es vel
S 3
co - ni - unc - tam et mor - - - - es vel
A 1
et mor - - - - - es vel
A 2
et mor - - - - - es vel
A 3
et mor - - - - es vel
T 1
et mor - - - - es ev - - -
T 2
et mor - - - - - es ev -
T 3
et mor - - - - - es ev - - -
B 1
et vel
B 2
bis et vel ev -
B 3
bis et vel ev - er -


114
S 1
es - - - - - - - - - - - se
S 2
es - - - - - - - - - - - - - se
S 3
es - - - - - - - - - - - - - se
A 1
es - - - - - - - - - - - se
A 2
es - - - - - - - - - - - - - se
A 3
es - - - - - - - - - - - - - - - se
T 1
er - - - - - - - - - te - - - - - - re.
T 2
er - - - - - - - - te - - - - - re
T 3
er - - - - - - - - - - te - - re
B 1
ev - er - te - re es - - - - - - - - - - - - - se
B 2
er - te - re es - - - - - - - - - - - - se
B 3
te - re es - - - - - - - - - - - - - se

Translation of Texts from *Boethius De institutione musica, liber I*

The texts are taken from the chapter headings of Boethius' treatise.
Below are the original texts and an English translation by Claude V. Palisca. [1]

Original Latin:

(i) Musicam naturaliter nobis esse coniunctam et mores vel honestare vel evertere.
(ii) Tres esse musicas; in quo de vi musicae.
(iii) De vocibus ac de musicae elementis.
(iv) De speciebus inaequalitatis.
(v) Quae inaequalitatis species consonantiis deputentur.
(vi) Cur multiplicitas et superparticularitas consonantiis deputentur.
(vii) Quae proportiones quibus consonantiis musicis aptentur.
(viii) Quid sit sonus, quid intervallum, quid consonantia.
(ix) Non omne iudicium dandum esse sensibus, sed amplius rationi esse credendum; in quo de sensuum fallacia.

English Translation:

(i) Music forms a part of us through nature, and can ennoble or debase character.
(ii) There are three kinds of music, and concerning the influence of music.
(iii) Concerning pitches and concerning the basic principles of music.
(iv) Concerning the specifies of inequality.
(v) What species of inequality pertain to consonance.
(vi) What multiplicity and superparticularity are assigned to consonances.
(vii) What ratios should be fitted to which musical consonances
(viii) Definitions of sound, interval, and consonance.
(ix) Not all judgment ought to be given to the senses, but reason ought more to be trusted.
Concerning the decoction of the sense in this matter.

---

[1] Anicius Manlius Serverinus Boethius, *Fundamental of Music* Translated into English by Claude V. Palisca (New Haven, Conn.: Yale University Press, 1989) p. vii-viii.

Johanna Devaney

:GONGNOG:

for piano and tape

Program Notes:

The tape component of this piece was generated through the modification of a single gong sample triggered forward and backwards through a metronome function in *Pd*. Modifications implemented in the *Pd* patch include transposition, delay and ring modulation.

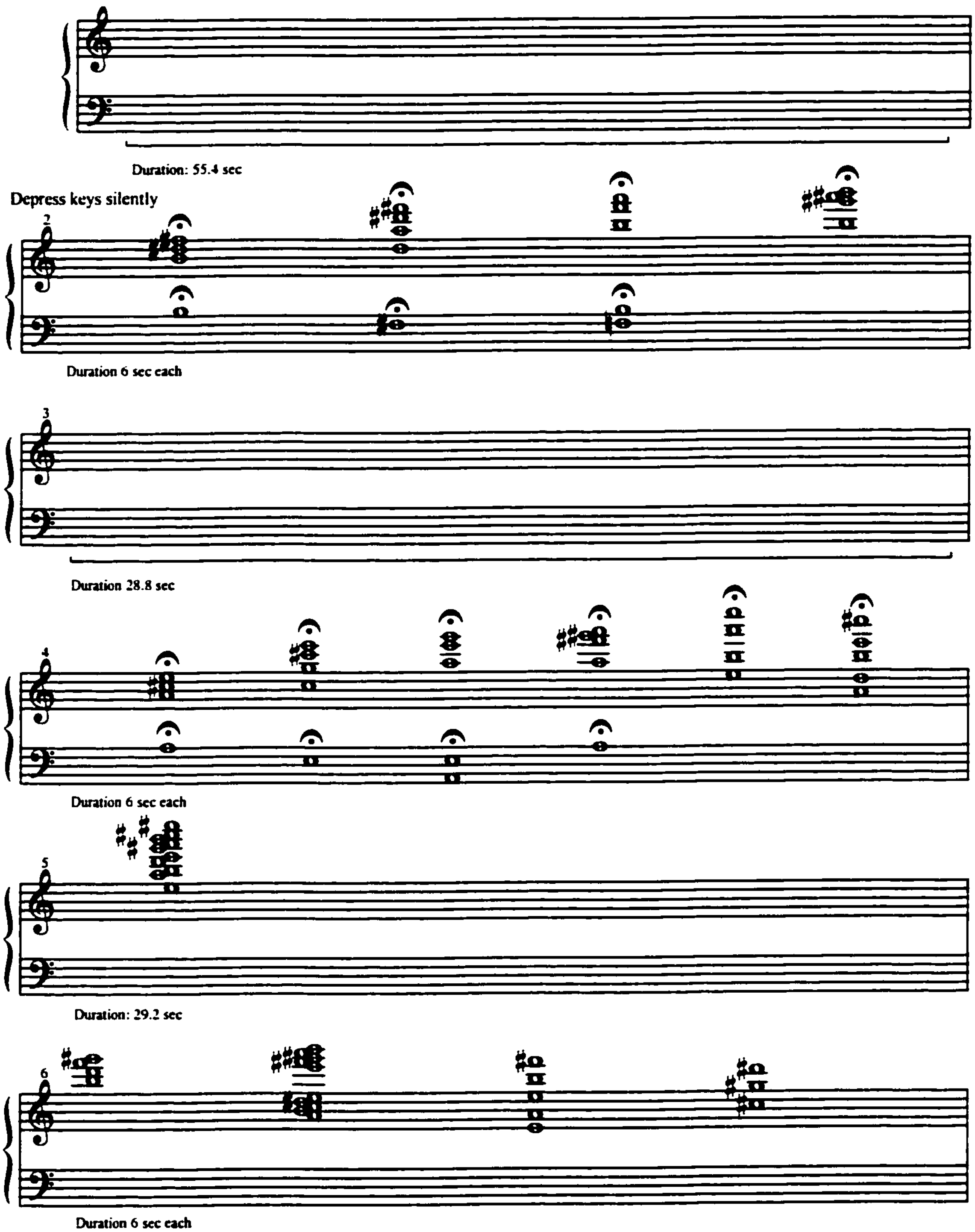
For the performance of the piece a speaker playing the taped component is to be placed directly over the strings of a grand piano. The piano score instructs the pianist to either silently play certain notes or depress the damper pedal. This action releases the dampers of some or all of the strings thus allowing them to vibrate in sympathy with various pitches found in the tape component.

The tape component should only be broadcast through the speakers over the piano strings. The piano board should be closely miked, so as to pick up both the tape component and the piano strings, and amplified through the concert hall.

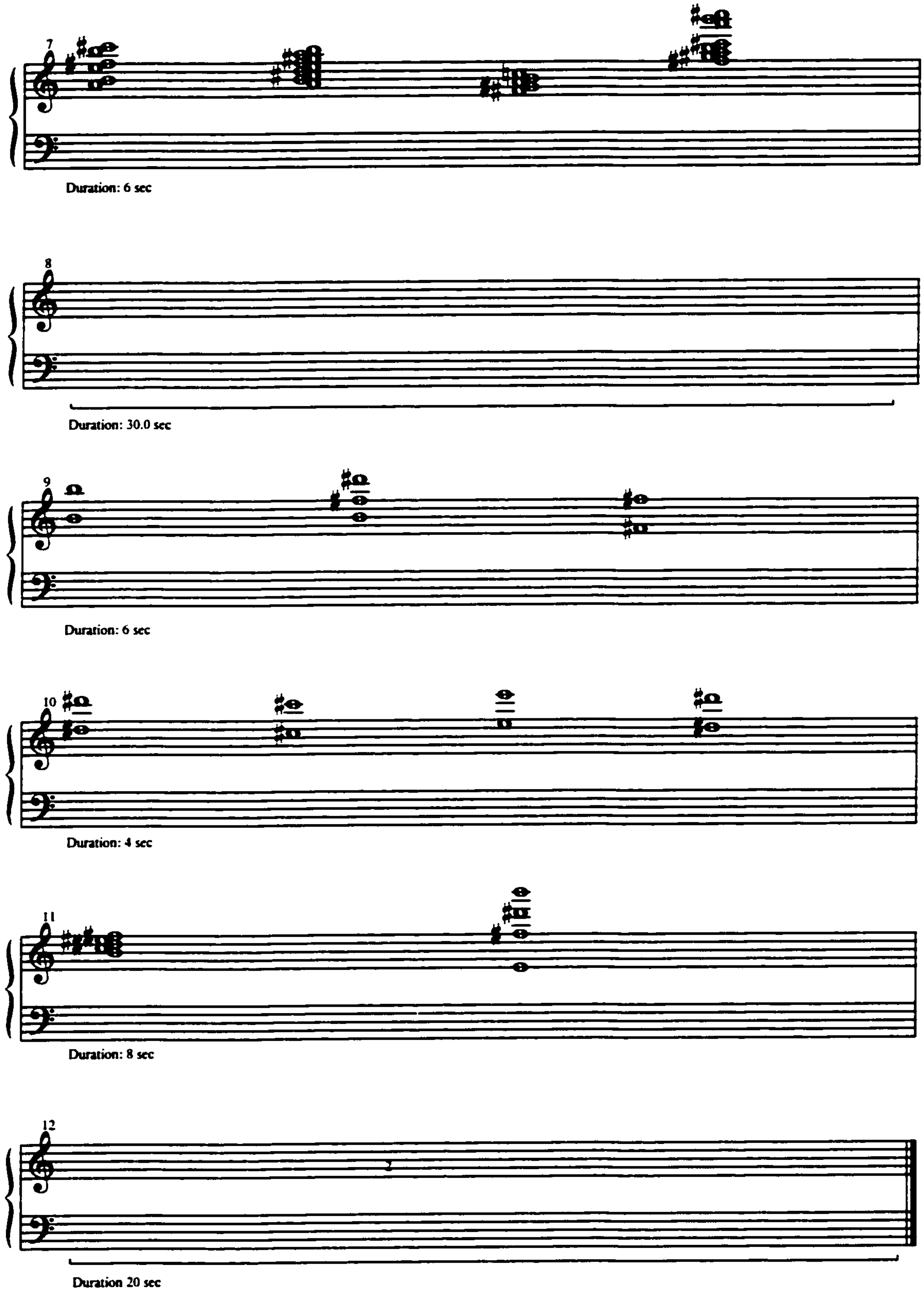
:GONGNOG:

Piano Score

Johanna Devaney



2001


7
Duration: 6 sec
8
Duration: 30.0 sec
9
Duration: 6 sec
10
Duration: 4 sec
11
Duration: 8 sec
12
Duration 20 sec

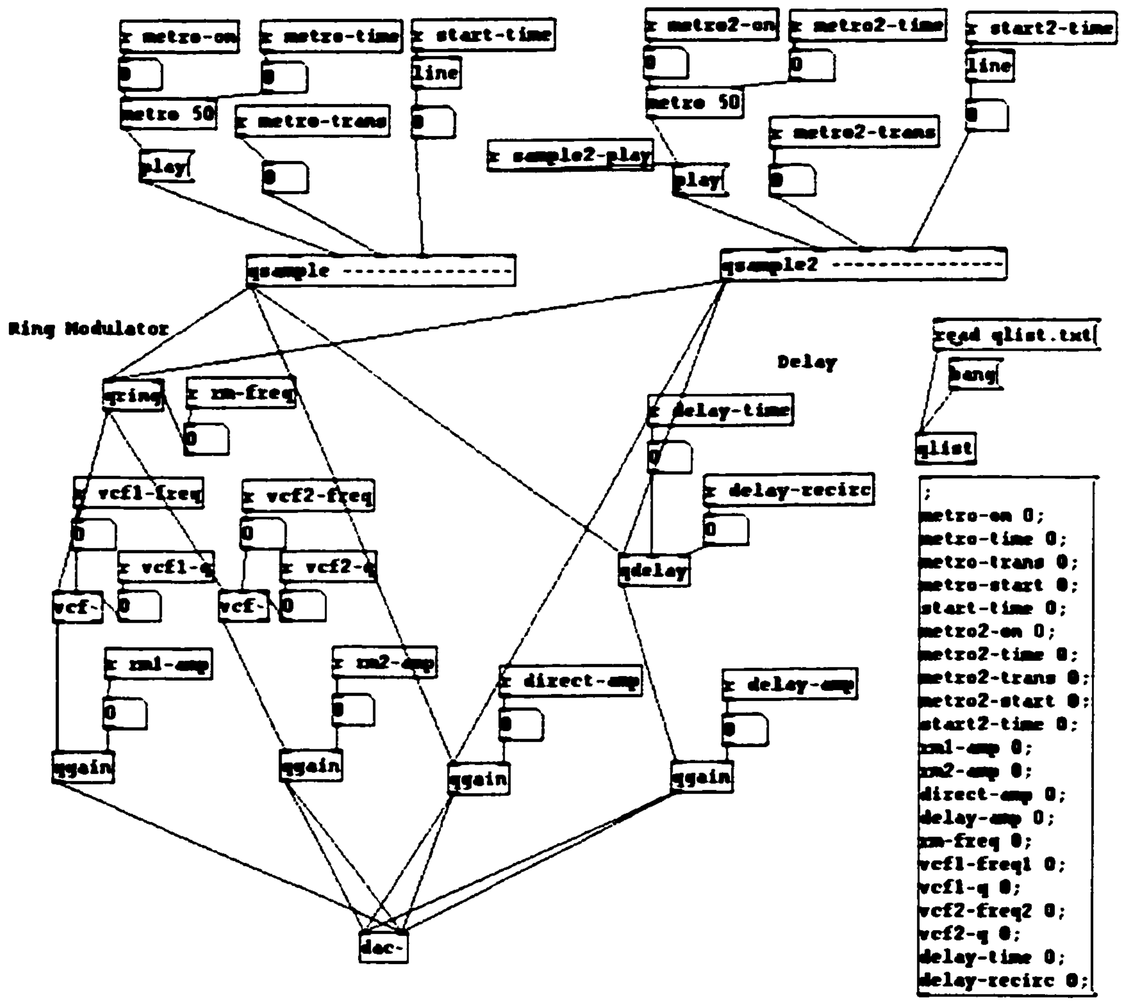
:GONGNOG:
PD qlist

```
direct-amp 90;
sample2-play 1;
800 metro-on 1;
metro-time 1600;
2400 sample2-play 1;
3200 sample2-play 1;
6400 sample2-play 1;
1000 metro-time 1800;
800 sample2-play 1;
1600 start-time 800 1600;
800 sample2-play 1;
1600 metro-time 1600;
1600 start-time 0 1600;
800 metro-time 1800;
800 start-time 800 1600;
800 metro-time 1600;
6400 delay-amp 90;
delay-time 128;
3200 metro-time 1800;
delay-recirc 32;
2400 start-time 800 1600;
1600 metro-time 1600;
1600 start-time 0 1600;
800 metro-time 1800;
3200 start-time 800 1600;
800 metro-time 1600;
3200 start-time 0 1600;
9600 metro-time 1200;
delay-time 112 800;
start-time 800 1600;
4800 delay-time 96 800;
4800 delay-time 80 800;
4800 metro-time 800;
9600 metro2-on 1;
metro2-time 800;
9600 metro-trans -4;
9600 metro2-trans -4;
9600 rm-freq 440;
vcf1-freq 660;
vcf2-freq 990;
vcf1-q 7;
vcf2-q 7;
rm1-amp 40;
rm2-amp 40;
4800 rm1-amp 80 4800;
rm2-amp 80 4800;
4800 rm2-amp 100 1600;
```

```
2400 rm2-amp 80 1600;
2400 rm2-amp 100 1600;
2400 rm2-amp 80 1600;
1200 rm1-amp 100 1600;
1200 rm2-amp 100 1600;
1200 rm1-amp 80 1600;
1200 rm2-amp 80 1600;
1200 rm1-amp 100 1600;
1200 rm2-amp 100 1600;
1200 rm1-amp 80 1600;
1200 rm2-amp 80 1600;
1200 rm1-amp 100 1600;
1200 rm2-amp 100 1600;
1200 rm1-amp 80 1600;
1200 rm2-amp 80 1600;
1200 rm1-amp 100 1600;
1200 rm2-amp 100 1600;
1200 rm1-amp 80 1600;
1200 rm2-amp 80 1600;
direct-amp 70;
19200 direct-amp 0 4800;
3200 delay-recirc 96 1000;
1800 delay-recirc 32 1000;
3200 delay-recirc 96 1000;
1800 delay-recirc 32 1000;
4800 vcf1-q -7;
4800 delay-amp 60 800;
4800 delay-amp 0 3600;
rm1-amp 90 1200;
rm2-amp 90 1200;
9600 vcf2-q -7;
19200 direct-amp 80 3600;
4800 rm1-amp 80 2400;
rm2-amp 80 2400;
20000 metro-trans 0;
9600 vcf1-q 7;
vcf2-q 7;
9200 metro2-trans 0;
9200 delay-amp 80;
4800 rm1-amp 40;
rm2-amp 40;
6400 rm1-amp 0;
rm2-amp 0;
4800 direct-amp 0;
7200 metro-time 1600;
800 metro2-time 1600;
4800 delay-recirc 0;
3200 direct-amp 80;
4800 delay-amp 0;
6400 metro2-on 0;
3200 metro-on 0;
```

:GONGNOG:

PD patch



Johanna Devaney

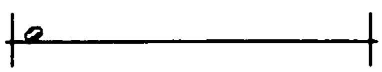
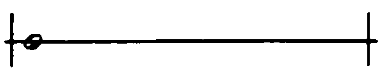
LiveGong

for gong and live electronics

Program Notes:

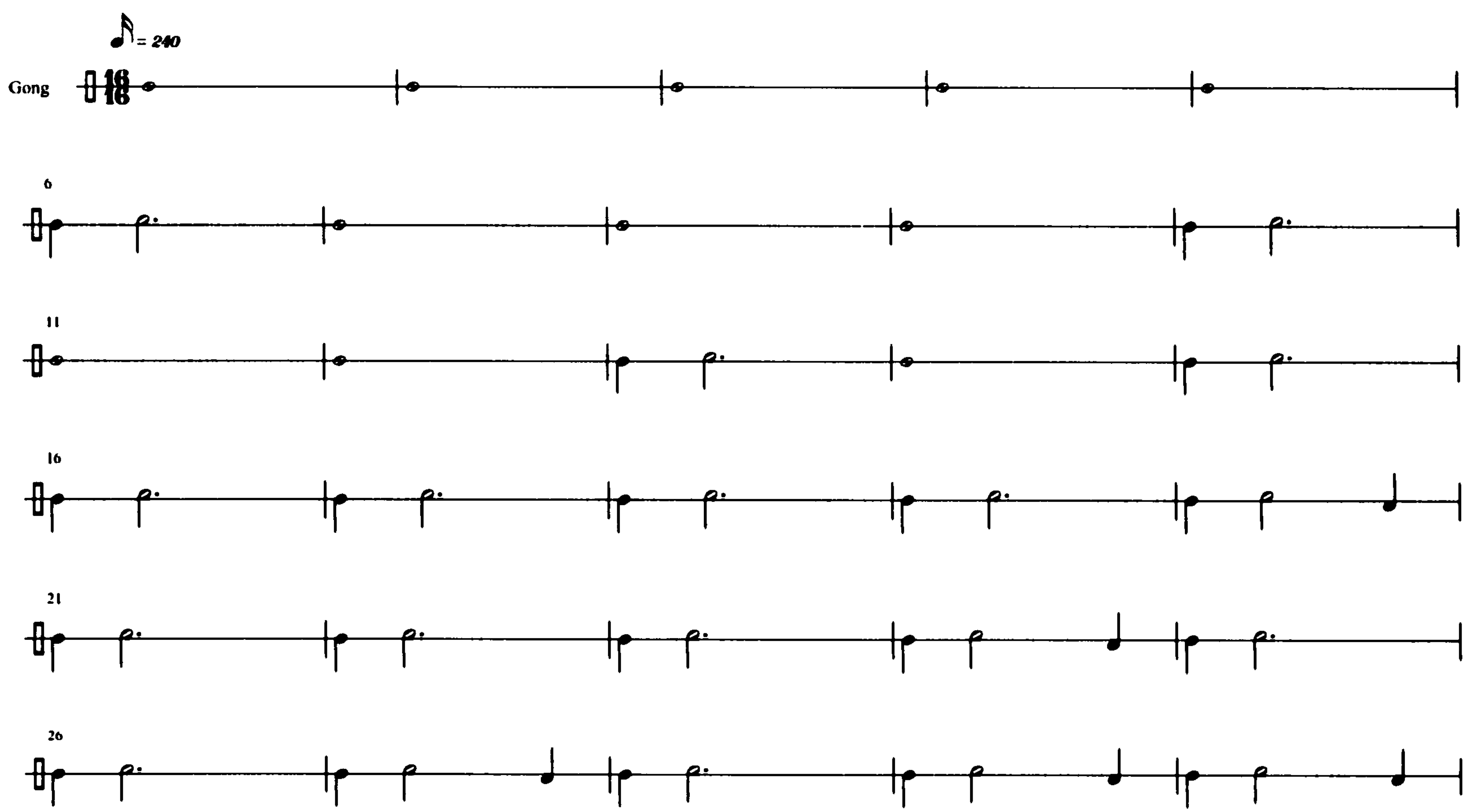
The gong is to be performed live, as per the score, and miked with the signal going into the computer for processing with the *Pd* patch. Modifications, implemented in the *Pd* patch, include transposition, delay and ring modulation. The output of the *Pd* patch is to be broadcast through speakers to the room, where it mixes with the acoustic resonance of the gong.

Notation Legend:

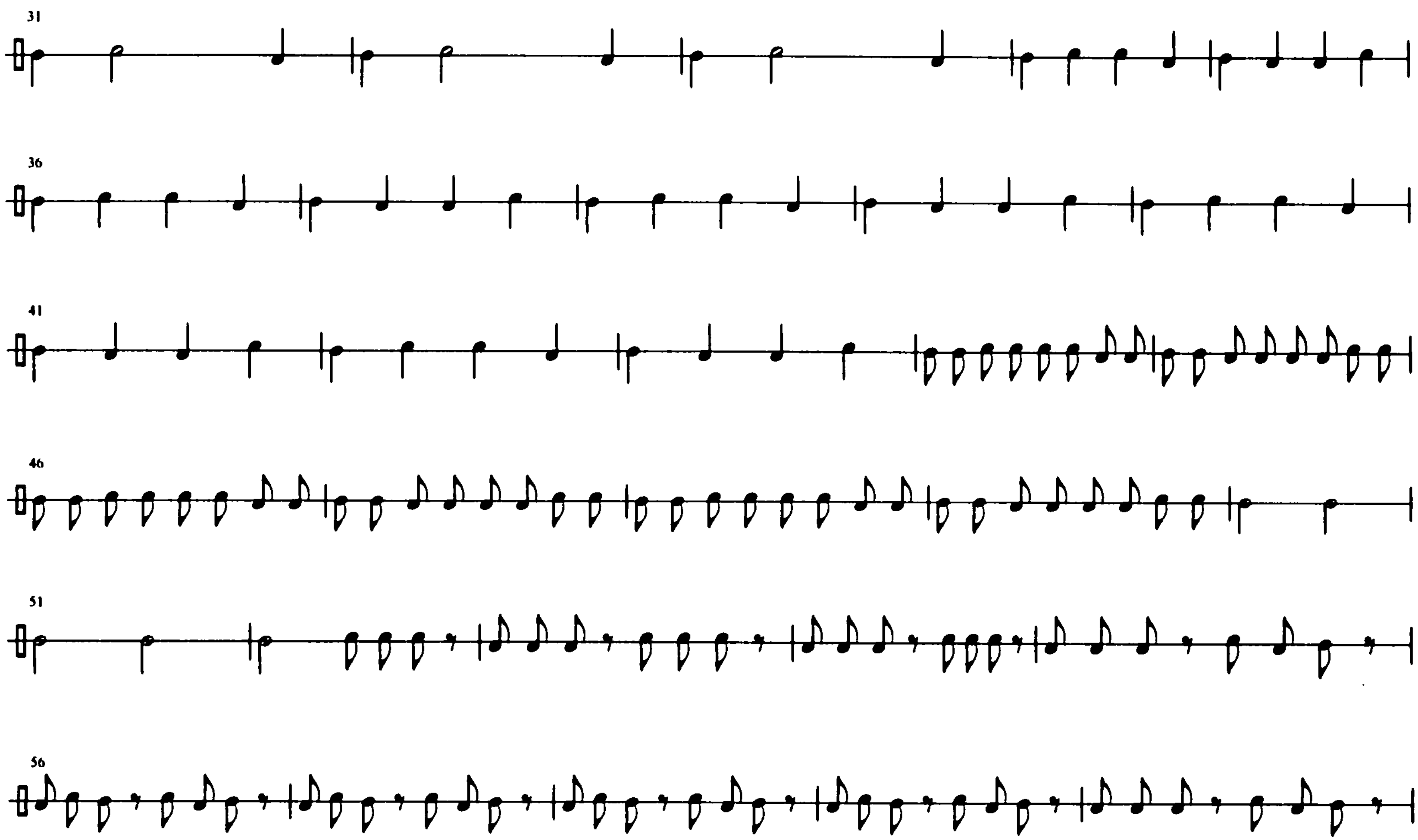
Notation	**Position on Gong**
 Note above the line	Above Centre
 Note on the line	Centre
 Note below the line	Below Centre

LiveGong

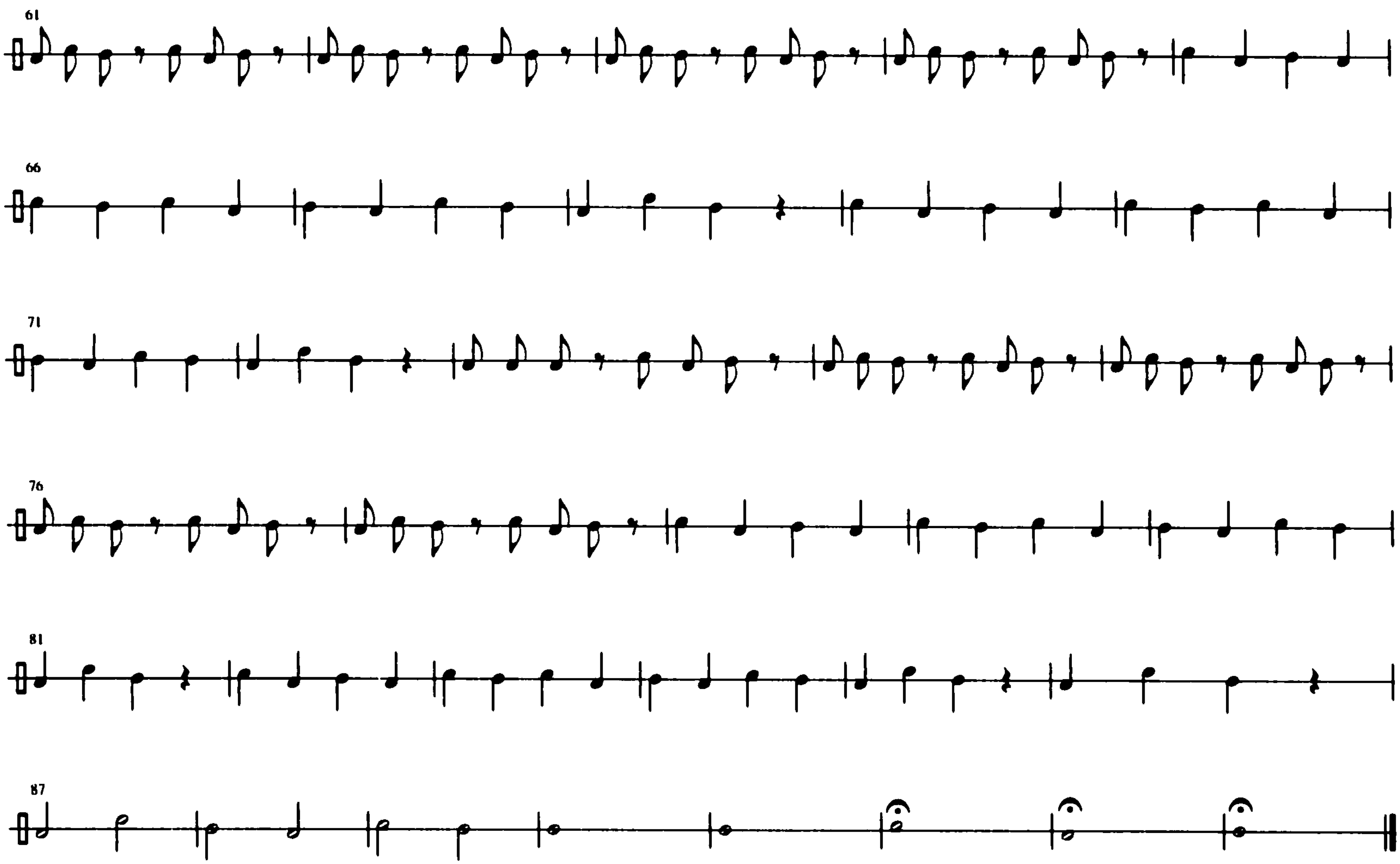
Johanna Devaney



2002



31
36
41
46
51
56


61
66
71
76
81
87

LiveGong

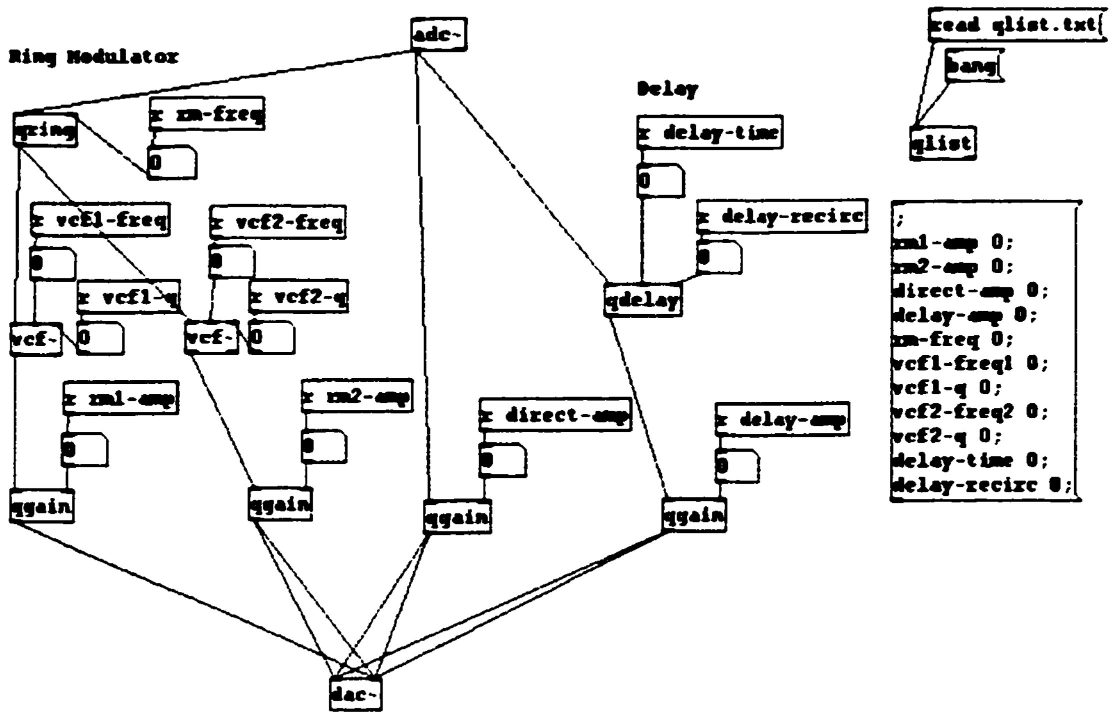
PD qlist

```
direct-amp 80;
metro-on 1;
metro-time 1600;
4000 delay-time 64;
delay-recirc 32;
delay-amp 40;
8000 delay-amp 80;
8000 direct-amp 60;
delay-time 128;
delay-recirc 64;
12000
rm1-amp 80;
rm-freq 110;
vcf1-freq 220;
vcf1-q 1;
4000 rm1-amp 80;
16000 direct-amp 80;
delay-amp 60;
rm1-amp 60;
12000 rm-freq 440;
rm1-amp 80;
vcf2-freq 110;
vcf2-q 4;
rm2-amp 80;
20000 rm1-amp 80;
rm2-amp 80;
12000 delay-amp 60;
rm1-amp 60;
rm2-amp 60;
delay-time 192;
4000 rm1-amp 80;
rm2-amp 80;
delay-time 254;
8000 delay-amp 80;
rm1-amp 60;
rm2-amp 60;
16000 delay-amp 60;
8000 rm1-amp 60;
rm2-amp 60;
rm-freq 0;
vcf1-freq 660;
vcf1-q -7;
vcf2-freq 990;
```

```
vcf2-q -7;
40000 rm-freq 220;
44000 delay-recirc 128;
delay-time 128;
delay-amp 80;
20000 rm1-amp 70;
rm2-amp 70;
direct-amp 70;
10000 rm1-amp 60;
rm2-amp 60;
direct-amp 60;
delay-amp 60;
10000 rm1-amp 70;
rm2-amp 70;
direct-amp 70;
delay-amp 70;
20000 rm1-amp 80;
rm2-amp 80;
direct-amp 80;
delay-amp 80;
20000 delay-amp 0;
20000 rm1-amp 60;
rm2-amp 60;
delay-amp 80;
rm-freq 0;
20000 rm1-amp 0;
rm2-amp 0;
16000 delay-time 20;
delay-recirc 80;
```

LiveGong

PD patch



Johanna Devaney

Reajet

for tape

Movements:

I - 0001
II - 0010
III - 0011
IV - 0100
V - 0101
VI - 0110
VII - 0111
VIII - 1000
IX - 1001
X - 1010
XI - 1011
XII - 1100
XIII - 1101
XIV - 1110
XV - 1111

Program Notes:

This piece is comprised of four basic objects (0001, 0010, 0100, and 1000), the movements are created from the sixteen possible combinations of these objects.

1. INTRODUCTION

1.1 OVERVIEW

This paper provides a context for my compositions by examining my compositional methods and concerns; specifically, how these methods are linked through their representation of sound-related constructs as computational abstractions known as objects. In other words, how these compositional methods operate in an *object-oriented*[1] paradigm.

My acoustic approach is based on the representation of tetrachords as objects that are sequenced to create a homophonic sub-structure, or harmonic rhythm, for the piece. The context of this acoustic object-oriented method is considered historically in regards to *algorithmic* and *numerological* compositional trends. My electronic approach is object-oriented through the use of commercial software that represents sound creation and processing as visual objects able to interact with one another.

In terms of aesthetic concerns this paper examines the flexible intonation potential facilitated by the acoustic ensembles and computer music software used for the performance/realization of these pieces, and explores this approach in the context of historical and contemporary tuning theory.

My definition and use of the term 'paradigm' in this context is equivalent to Gareth Loy's term 'compositional formalism', which he defines as

> any systematic ordering, or way of organizing, creating or analyzing compositional systems (or processes or designs). Other terms, such as

[1] Definitions of italicized words can be found in the glossary on page 123.

> procedure, method, game, and algorithm, are all formalisms in this way of thinking.[2]

Though the primary focus of Loy's discussion is computer music his concept of compositional formalism directly relates to both my acoustic and electronic compositional operations as all the included works were created from a set of prescribed and calculated conditions, namely the representation of musical structures as objects.

An object is a computational structure. Objects are grouped in abstractions known as *classes*. An object consists of three types of information: its name, which indicates the class to which it belongs, data, and sets of logical procedures. The specifics of an object's data and logic are determined by its class. An object-oriented approach analyzes and represents structures as classes of objects, each with *member variables* and *functions*. In my acoustic works, the tetrachords are represented as objects, while in my electronic works the processes of sound creation and manipulation are so represented.

The member variables hold the object's data and the functions are its logical procedures. Functions serve both as the methods by which the object's data can be accessed and adjusted and as the facilitators for interaction with other classes of objects. In terms of my compositional operations the application of this object-oriented paradigm is two-fold as it applies differently to my acoustic and electronic pieces.

The acoustic pieces, *Partial Objects* and *deMusica*, are based on an object-oriented representation of tetrachords, thus the object-oriented paradigm is implemented for the purpose of tonal organization. This object-oriented representation was realised in the

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[2] Gareth Loy, "Composing with Computers – a Survey of Some Compositional Formalisms and Music Programming Languages." in M. Matthews and J. Pierce (eds.) *Current Directions in Computer Music Research* (Cambridge: Mass.: MIT Press, 1989) p. 293.

program *SoundObjects*. *SoundObjects* generates a sequence of tetrachords through the implementation of the Tetrachord class, an object-oriented representation of a tetrachord. The member variables of the objects store the information that governs the construction of the tetrachord by defining the pitch-class set, fine-tuning, and rhythmic durations. The pitch-class set of the tetrachord structure adheres to traditional twelve-tone pitch-classes. The fine-tuning variable holds the amount of the deviation in *cents* between the *equal-tempered* version of each interval and the tuning of the ratios found in the *harmonic series*.

The rules governing the sequencing of the tetrachords are determined, in part, in the methods of these objects. These methods, or functions, combine with additional logic in the *SoundObjects* program to determine how the tetrachord objects interact to produce a series of pitches and their durations, which in turn provides the harmonic rhythm, the basic homophonic sub-structure of the piece. While the character and pacing of the harmonic rhythm is determined, the rules for the realisation of the tetrachord sequence into a piece are not stipulated, the pitch and rhythmic material remains freely composed. Thus this is a semi-algorithmic approach that falls into the genre of computer assisted composition.[3]

My electronic pieces were created with *digital signal processing (DSP)/sound synthesis* software that uses an object-oriented approach to graphical user-interface (GUI) design. In the GUI the individual components of the DSP/synthesis constructs are represented by visual objects that are able to interact with each other. These electronic works are

---

[3] In computer-assisted composition rather than creating or editing sound the computer acts as a tool to generate structures or rules for acoustic compositions. For a discussion on the history of computer-assisted composition see "Chapter Ten: Automated Music" in David Cope, *New Music Compositions* (New York, N.Y.: Schirmer Books, 1977) p. 287-330, for an overview of the various uses of computers in composition see Stephen Travis Pope, "Music Composition and Editing by Computer" in M. Matthews and J. Pierce (eds.) *Current Dictions in Computer Music Research* (San Francisco, CA: Computer Music Association, 1999) p. 25-72.

algorithmic in that a *score file* must be produced in order to control the *patches*. The *score file* contains the data concerning which pitches are played, when, and for how long, while the *patches* are data structures within the program where the instructions that determine the type of the signal processing or the timbral information of the synthesized sound are compiled. Unlike my acoustic approach this algorithmic process does not provide the underlying structure for the piece nor does it directly influence the rhythmic or harmonic decisions.

Stylistically the works are linked through their exploration of the harmonic series and the *'natural' intonation* possibilities available in each medium. The decision to use voice and stringed instruments for the acoustic pieces was made because of their flexible intonation capabilities. The commercial software used for the computer music pieces provides two different ways of interacting with pitch. *Pd* allows the specification of pitch in terms of *hertz*, rather than relying on standard scales, thereby allowing pure ratios to be easily and accurately generated. *Reaktor* is less precise: while the frequency range of the filter is determined in hertz, the frequency associated with the oscillator generator is determined by a seven-bit MIDI control, thus limited to a range of one hundred and twenty seven gradients.

1.2 Explanation of Object-Oriented Theory/Terminology

Object-oriented programming has been the dominant paradigm of the computer-programming field for the past two decades. Prior to object-oriented programming the paradigm of choice was *structured* programming, a paradigm that allowed those logic sequences that were accessed a number of times in the running of the program to be coded into functions. These functions existed outside of the *main* function, or sequence of logic, in the program and could be called by the program's main function as many times as necessary. Good structured programming practice stipulated that all data be *local* to only one function as the use of *global data* accessible by all functions in a program was potentially insecure. As the need emerged for data to be available beyond a single function, the object-oriented paradigm provided a way to bind the logic to the data, thus allowing the data to become globally accessible, through the use of entities with their own set of data and logic called classes.[4] The data remains secure, as it is only available to *instances* of other classes through the functions of the primary class.

The key difference between structured and object-oriented programming is philosophical. The impetus behind structured programming was the desire to create a logical process while the aim of object-oriented programming is a design process that attempts to model real world objects and the methods by which the objects interact. This philosophy of software design has been used to model musical sounds and processes since the mid-eighties. It was a combination of the current proliferation of music software using object-oriented interfaces and the potential of the approach for organizing tonal material[5] that drew me to working within this paradigm.

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[4] This is referred to as *encapsulation*, the concept that in the design of an object its data and logic are bound together and that the object's data is not directly accessible by other objects. The goal of encapsulation is to create an object where the data can only be accessed or adjusted by the logic, or functions, within the object, and where all outside interactions with the object's data take place through the object's functions.

[5] My implementation of object-oriented methodology for tonal organization is limited, as it not does fully exploit the potential of polymorphism or inheritance, two of the key strengths of the object-oriented paradigm. Polymorphism is the process by which the names given to processes can be overloaded so that they do relatively the same thing when called by different objects, thus providing a global link between the objects of the same class. Inheritance is the ability to derive new classes from existing ones, these *child* classes are inherited from the *parent* class and, unless explicitly stated otherwise, contain all the data and logic of the parent.

1.3 TUNING THEORY

The harmonic series is a naturally occurring acoustic phenomenon that is an intrinsic part of any sound. This normally audible series of *partials* above the fundamental frequency is made up of frequencies that are whole number multiples of the fundamental and the relative strength (amplitude) of those individual partials contributes to the timbre of the sound. The intervals traditionally considered consonant are found near the beginning of the series, since these lower partials have the greatest amplitude they are the ones the human ear hears most readily. The ratios found in the harmonic series have been considered pure ratios for tuning intervals from the early Greek and Chinese tuning theorists through to the contemporary proponents of Just Intonation. For over two thousand years theorists have used the harmonic series as the basis for studies of temperament. However the creation of a cohesive tuning system based on the harmonic series is inhibited by a number of problems inherent in the harmonic series. The primary problem, as shown in Figure 1.1b, is that there are a number of occurrences of each interval in the harmonic series; thus, in order to create a cohesive system it is necessary to place some limits on which partials can be used.

This approach to intonation utilises the twelve-tone chromatic scale as its reference point. The division of the octave into twelve parallels equal temperament, however in this tuning system the twelve tones have variable intonation. The use of the twelve-tone chromatic scale sets this approach apart from temperaments that employ other divisions of the octave; both those that divide the octave equally and those that determine the subdivisions of the octave through various restrictions on the partials used.

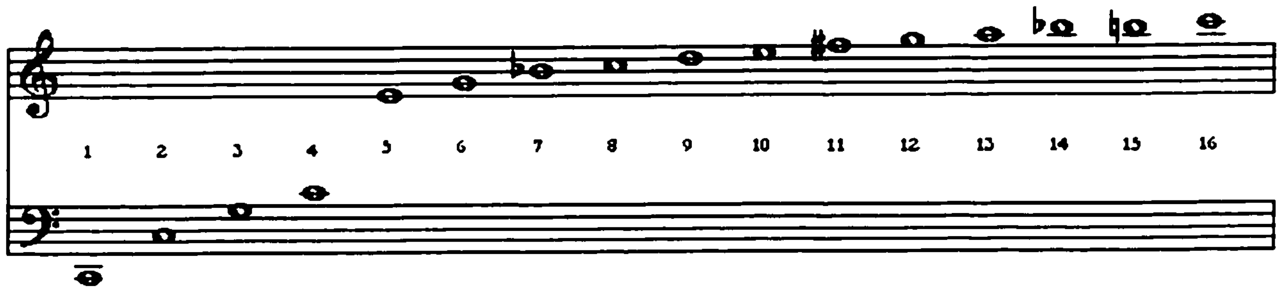

Figure 1.1a Harmonic Series.[6]
The first sixteen partials of the harmonic series.

P8	**2/1 (4/2, 6/3, 8/4, 10/5, 12/6, 14/7, 16/8)**	**TT**	**7/5 (14/10) 10/7, 11/8, 15/11, 16/11**
M7	**13/7, 15/8**	**P4**	**4/3 (8/6, 16/12) 13/10**
m7	**7/4 (14/8) 16/9**	**M3**	**5/4 (10/8, 15/12) 11/9, 14/11**
M6	**5/3 (10/6, 15/9) 11/6, 12/7, 13/8, 14/9**	**m3**	**6/5 (12/10) 7/6 (14/12) 13/11, 16/13**
m6	**8/5 (16/10) 11/7**	**M2**	**8/7 (16/14) 9/8, 10/9, 11/10, 12/11, 13/12, 15/13**
P5	**3/2 (6/4, 9/6, 12/8, 15/12) 13/9**	**m2**	**14/13, 15/14, 16/15**

Figure 1.1b Harmonic Series.
This chart lists all the occurrences of intervals less than or equal to an octave occurring in the first sixteen partials of the harmonic series.

The first exploration of the harmonic series is credited to Pythagoras and his experiments with a monochord,[7] an instrument with a single piece of string stretched across three frets (two stationary and one movable), where he divided the string with the movable fret into various ratios. He determined that the ratio for the octave is 2:1; when the string is half the length of the whole it sounds a frequency double the frequency produced by the

[6] For the sake of clarity pitches and tonal intervals are used in this and the proceeding examples to provide a familiar reference point, rather than with the intention to imply a direct correlation between these pitches or tonal intervals and the partials in the harmonic series.

[7] For a detailed discussion of Pythagoras' experiments with the monochord see: Hugh Boyle and LL S. Lloyd, *Intervals, Scales & Temperament* (London: Macdonal Press, 1963) and the English translations of Bartolmé Ramos, "From the *Musica Practica.*" in O. Strunk's (ed.) *Source Readings in Music History: The Renaissance* (New York, N.Y.: W. W. Norton & Company, 1965) p. 11-14.

whole. Likewise the perfect fifth is produced when the string is divided by a ratio of 3:2; the perfect fourth when the string is divided by a ratio of 4:3; and the major second or whole tone when the string is divided by a ratio of 9:8. The cohesiveness of these observations is demonstrated by the fact that the multiplication of 3:2 and 4:3 results in 2:1, just as the addition of a perfect fifth and a perfect fourth result in a perfect octave, likewise the division of 3:2 by 4:3 results in 9:8, just as the distance between a perfect fourth and perfect fifth is a major second. The system however is not cohesive as a whole, as the comparison of seven purely tuned octaves and twelve purely tuned fifths demonstrates.

27.5	55	110	220	440	880	1760	3520
A	A	A	A	A	A	A	A

Figure 1.2a Seven Pure Octaves.
From A (27.5Hz) multiplied by a 2:1 ratio.

27.5	41.25	61.88	92.81	139.22	208.83	313.24
A	E	B	F#	C#	G#	D#

469.86	704.79	1057.19	1585.78	2378.68	3568.02
A#	E# (F)	B# (C)	Fx (G)	Cx (D)	Gx (A)

Figure 1.2b Twelve Pure Fifths.
From A (27.5Hz) multiplied by a 3:2 ratio.

This discrepancy is referred to as the Pythagorean comma and it is essentially the difference between a G double sharp and an A in a Pythagorean system. The above calculations demonstrate that when calculated from A (27.5Hz) the comma is equal to 48 Hz. However due to the fact that hertz is an exponential unit of measurement the size of the comma changes with each unique starting pitch. It is easier to work with cents, an arithmetic unit of measurement used for calculating the distance between pitches. The formula for converting a ratio to cents is:

$$\text{Cents} = (1200/\log_2) * \log_{\text{ratio}}.$$

The octave ((1200/ $\log_2$) * $\log_2$) is equal to 1200 cents and the perfect fifth ((1200/ $\log_2$) * $\log_{1.5}$) is equal to 702 cents,[8]

0	1200	2400	3600	4800	6000	7200	8400
A	A	A	A	A	A	A	A

Figure 1.3a Seven Pure Octaves in cents.

0	702	1404	2106	2808	3510	4212
A	E	B	$F_\#$	$C_\#$	$G_\#$	$D_\#$
4914	5616	6318	7020	7722	8424	
$A_\#$	$E_\#$ (F)	$B_\#$ (C)	F_x (G)	C_x (D)	G_x (A)	

Figure 1.3b Twelve Pure Fifths in cents.

thus the Pythagorean comma equals 24 cents, which is roughly a quarter of a semitone.

A complete Pythagorean system where all usable intervals are derived from the pure fifth and octave is essentially a three-limit system, that is the system is limited to ratios made up of multiples of three or less. In order to create a complete system additional calculations were required. First, the division of the whole tone into two differently sized semitones: one with a ratio of 254:243 and another with a ratio of 2187:2048. Second, the calculation of the major third through the addition of two whole tones, 9/8 * 9/8 = 81/64.[9] Aristoxenus, a later Greek theorist, argued that the unequal division of the whole tone, while mathematically correct, was musically incorrect and proposed an exact semitone unit which

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[8] 702 is a rounded figure, the exact size of the Pythagorean fifth is 701.96, likewise the 24 cent Pythagorean comma is rounded from its exact value of 23.52. These numbers have been rounded for the sake of clarity in the included calculations. The difference between the original and rounded numbers can be viewed as negligible as variations of less than half of a cent are well below the difference perceivable by the human ear (see discussion on the 'just noticeable difference' below).

[9] For more detail on Pythagoras and Pythagorean Intonation see André Barbera, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Pythagoras" Vol. 20, p. 642-3; J. Murray Barbour, "The Persistence of the Pythagorean Tuning System" *Scripta Mathematica* 1 (1933): p. 286-304, Andrew Barker (ed.), *Greek Musical Writings, Vol II: Harmonic and Acoustic Theory* (New York: Cambridge University Press, 1989) p. 28-52, and Mark Lindley, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Pythagorean Intonation" Vol. 20, p. 643-5 and "Pythagorean Intonation and the Rise of the Triad" in *Royal Musical Association Research Chronicle* 16 (1980): p. 4-61.

he later used as the basis for the construction of the enharmonic, chromatic, and diatonic genera or tetrachords. Aristoxenus is considered the first tuning theorist to prioritize the musical implications of temperament.[10]

The systems by Pythagoras and Aristoxenus used the 81/64 major third, an interval which is nearly a quarter of a semitone sharper than the 5/4 major third. Didymus, another Greek theorist, proposed a five-limit system, thus allowing the inclusion of the fifth partial and new ratios for the major third, 5/4, and minor third, 6/5, into the study of temperament. These ratios convert to intervals of 384 cents and 316 cents versus the Pythagorean equivalents of 408 cents and 294 cents.[11] The difference between both the Pythagorean major third and the Just major third and the Pythagorean minor third and the Just minor third is 22 cents. This is also the difference between the 9/8 whole tone and the 10/9 whole tone (available in a five-limit system)[12]and is known both as the comma of Didymus and the syntonic comma.[13] The syntonic comma became significant in the development of Meantone[14] temperaments in the late Renaissance while the Pythagorean comma was significant in the development of Equal Temperament during the early Baroque era.

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10 For more on Aristoxenus see the translation of a section of Aristoxenus's text "*Harmonic Elements*" in O. Strunk (ed.) *Source Readings in Music History: Antiquity and the Middle Ages* (New York, N.Y.: W. W. Norton & Company, 1965) p. 25-33; Andrew Barker's (ed.), *Ibid.* p. 119-89; Annie Bélis, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Aristoxenus" Vol. 2, p. 1-2; Edward A. Lipperman, *Musical Thought in Ancient Greece* (New York, N.Y.: Columbia University Press, 1975) p. 144-53; and Henry Macran, *The Harmonics of Aristoxenus* (Oxford: Clarendon Press, 1902) p. 25-33.

11 A minor third is equal to a major second and minor second (9/8 * 256/243) or a ratio of 32/27, or 294 cents. For details on these calculations sees "Chapter Eight: Intervals, Scales, Tuning and temperament" in John Backus, *Acoustical Foundations of Music* (New York, N.Y.: W.W. Norton & Company Inc., 1969) p. 113-40.

12 The 10/9 semitone can be calculated by subtracting the 3/2 perfect fifth from the 5/3 major sixth the major sixth can be calculated though the addition of the major third and perfect fourth (5/4 * 4/3 = 5/3)).

13 For more detail on the life and writings of Didymus see Lukas Richter, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Didymus" Vol. 7, p. 326-7.

Ptolemy, a Greek theorist in the first century AD, developed modes from the ancient Greek tetrachords. He expanded the theories of Pythagoras and genera of Aristoxenus with the modifications proposed by Didymus. Ptolemy was the first to define the five-limit Just Intonation system – a complete system using the lowest occurring instances of intervals with ratios containing primes of five or less.[15] Gioseffe Zarlino later codified this system in greater detail in his treatise *Istitutione Harmoniche.*[16]

	P1	m2	M2	m3	M3	P4	TT	P5	m6	M6	m7	M7	P8
JI ratio	1/1	16/15	9/8	6/5	5/4	4/3	45/32 64/45	3/2	8/5	5/3	16/9	15/8	2/1
JI cents	0	112	204	316	384	498	590 610	702	814	884	996	1088	1200
ET cents	0	100	200	300	400	500	600	700	800	900	1000	1100	1200

Figure 1.4 Five-limit Just vs. Equal Tempered Intervals.
This chart details the discrepancies between the Just Intonation system and Equal Temperament.

Just Intonation and Meantone, the dominant temperaments in the Renaissance and early Baroque eras, were supplanted in the late Baroque era by the comma-tuning[17] systems from which *Equal Temperament* developed. Equal Temperament provided a solution for the main problem that arises when using the harmonic series as a basis for temperament: that

[14] Meantone is a precursor to comma tunings; it utilizes the first two major seconds which occur in the harmonic series (9/8 and 10/9) and works with the difference between the two to generate a cohesive twelve tone temperament.
[15] For more detail on the life and writings of Ptolemy see Lukas Richter, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Ptolemy" Vol. 20, p. 562-4.
[16] Gioseffe Zarlino was a late Renaissance theorist in Venice Italy, who Oliver Strunk called "easily the most influential personality in the history of musical theory from Aristoxenus to Rameau" (Strunk, *Renaissance* p. 38). A student of Adrian Willaert, Zarlino was well versed in Greek and Medieval music theory, he subscribed to the theory that music was a reflection of nature. In addition to his position as *maestro di capella* at San Marco in Venice he is noted for being the first theorist to discuss a triadic harmonic language.
[17] Comma tunings, developed in the early Baroque era by Werkmeister, Niedhart, Kimberger, and others, were temperaments devised through the distribution of the Pythagorean or syntonic commas. Comma tuning developed from the comma distribution techniques employed in Meantone systems and differed from later equal-tempered systems in their uneven distribution of these commas. Werkmeister, for example, developed a system where the first five fifths were detuned by a third of a Pythagorean comma while the remaining eight fifths remained pure. For a detailed discussion see George J. Burelow, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Andreas Werkmeister" Vol. 20, p. 343-5.

intervals in different keys have different sizes. In an Equal Tempered system all of the intervals except the octave are slightly detuned so that the tuning of a piece will be the same no matter which key it is played in. On the strength of this consistency Equal Temperament has remained the mainstream temperament of choice from circa 1750 to the present. Equal Temperament can be viewed as the even distribution of the Pythagorean comma. Each fifth is tempered by two cents, one twelfth of the 24-cent comma, so that twelve fifths are equal to seven octaves or by the simpler mathematical explanation that each semitone is equal to the twelfth-root of two ($\sqrt[12]{2}$).

These theoretical concepts become an aesthetic consideration once the deviation of an equal tempered interval from its pure equivalent is large enough to be perceived by the ear. The degree of deviation necessary for someone to be able to discriminate between pitches is known as 'just noticeable difference'. As a general rule, the higher the pitch the larger the deviation needed to detect variations in frequency due to the exponential nature of frequency in relation to pitch. Amplitude is another factor. Variations in frequency are harder to distinguish when a sound is very soft or very loud. A limited range of frequencies is normally used for music (from 27.5 Hz to 4186 Hz on the standard piano). The 'just noticeable difference' is generally considered to be three to four cents over this range when the pitch is sounded at a moderate amplitude.[18]

Once Equal Temperament began to become established as the tuning system of choice there were relatively few new temperaments developed until the early twentieth century. The major works of the period were primarily surveys of existing temperaments,

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[18] For a more detailed discussion on pitch discrimination and other tuning issues as they relate to acoustics see "Chapter Seven: Frequency and Pitch" in Backus, *Ibid.* p. 110-4.

such as eighteenth century theorist Jean-Phillipe Rameau's *Treatise on Harmony* (1722).[19] But it was an earlier survey, Christiaan Huygens' translation of Nicola Vicentino's *Antica musica ridotta alla moderna prattica*[20] into Danish in c1691, that would have a profound influence on twentieth century tuning theory.

Vicentino was a late Renaissance theorist noted for his development of a modified Just Intonation/Meantone 31-tone system. The Vicentino translation did not have any great implications in Huygen's time, but the use of it by early-twentieth century tuning theorist Adriaan Fokker was characteristic of the growing movement towards divisions of the octave into discrete intervals smaller than a semitone (microtonality).

The resurgence of Just and Meantone theory, often combined with investigations into tuning systems developed in non-western cultures, represented one approach to twentieth-century microtonality. The key theorists in these areas were Colin McPhee, Harry Partch, Ben Johnston, and John Chalmers. Harry Partch, the most pre-eminent and original tuning theorist of the past century, has been credited with resurrecting Just Intonation theory through his compositional practices. Using an eleven-limit system he developed a forty-three-tone scale for which he developed his own notation systems and built his own instruments. Partch's *Genesis of Music*[21] stands not only as an explanation of his own system but as one of the key works in twentieth century tuning theory. Ben Johnston, a student of Partch for a brief period during the fifties, has continued to be a key proponent of his

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[19] See Jean-Philippe Rameau, *Treatise on Harmony* Translated from the English by Philip Gossett (New York, N.Y.: Dover Publications, 1971).

[20] Nicola Vicentino was a sixteenth century northern Italian theorist and composer. His treatise Antica musica ridotta alla moderna prattica (Ancient music adapted to modern practice) described his 31-tone tuning system and 36-tone keyboard, the archicembalo. Vicentino was concerned with observing the natural tendencies of singers to adjust their intonation depending on the function of the note. From these studies and his knowledge of ancient Greek genera he developed his 31-tone system.

theories and of Just Intonation. Colin McPhee was exposed to gamelan tunings during his residence in Bali in the 1930s and later incorporated these tunings into his compositions.

The rise of twelve-tone theory inspired investigations into equal microtonal divisions of the octave by theorists such as Julián Carrillo, Ivan Wyschengradsky, Alois Haba, Ferruccio Busoni, Gyorgy Ligeti, Krzysztof Penderecki, and Iannis Xenakis. Julián Carrillo began his investigations with quarter-tones (24 divisions of the octave) and culminated in 1924 with sixty-fourth tones (384 divisions of the octave). Ferruccio Busoni worked primarily with third tones, while Ivan Wyschengradsky worked extensively with third, sixth, and twelfth tones. Alois Haba saw quartertones as the natural expansion of Schoenberg's twelve-tone serial technique. Quartertones continued to be popular in altered tempered compositional practices during the mid-twentieth century.

The exploration of temperament was facilitated in the second half of the century by the rise of synthesizers and computers; Wendy Carlos, Easley Blackwood, John Eaton, Ivor Darreg, La Monte Young, Lou Harrison, and Terry Riley are noted for their pioneering and extensive inroads into the potential of the electronic medium. Though restricted to Equal Temperament with her ground breaking synthesizer realizations, *Switched on Bach (1968)* and *The Well Tempered Synthesizer (1969)*, on early Moog synthesizers, Wendy Carlos later recreated Bach era temperaments digitally on her album *Switched on Bach 2000.* Here Carlos exploited the greater tuning flexibility allowed when pitches are specified in frequency.[22] In the 1980s, Easley Blackwood conducted an extensive study of equal-tempered divisions of the octave, summarized in his book *The Structure of Recognizable Diatonic Tunings*, and used a computer to

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[21] See Harry Partch, *Genesis of a Music* (New York: Da Cape Press, 1974).

realize these systems through a set of compositions entitled *Twelve Microtonal Etudes*. John Chalmers has also made extensive use of synthesizers, particularly the Yamaha FB-01,[23] for gamelan-based tuning systems.

My approach to the realization of non-tempered intervals in my compositions tends more towards the Greek/Medieval/Renaissance lineage than the contemporary one. As detailed below I focus on facilitating a performance environment where the 'natural' tendencies of the performers are realized, whereas the overriding twentieth century approach is to create a prescribed system for the performers to follow.

1.4 LIMITATIONS/POTENTIAL OF CHOSEN MEDIA

Despite the current dominance of Equal Temperament, vocalists and instrumentalists on instruments with flexible intonation revert to playing in some form of 'natural' intonation when not playing with fixed intonation instruments. The acoustic ensembles for my submitted pieces were chosen because they consist only of instruments with flexible intonation capabilities. In an attempt to avoid the undue complications that would arise from writing the precise tunings into the score other methods of notation were explored, in *Partial Objects* asterisks indicate when the performers should concentrate on attaining these pure sonorities whereas in *deMusica* the intonation adjustments are left entirely to the performers. The asterisks in *Partial Objects* occur, without exception, on the

[22] For a description on her approach to recreation on Circular and Meantone temperaments in *Switched on Bach 2000* see http://www.wendycarlos.com/+sob2k.html.
[23] Kristine H. Burns, *The History and Development of Algorithms in Music Composition* (Miami FL.: Florida International University, 1994) p. 82.

algorithmically generated tetrachords. Although this is not an exact implementation of Pythagorean or five-limit Just Intonation the resulting tunings do adhere quite closely to a non-tempered system on account of the tendency of instrumentalists to replicate the version of the interval with 'natural' intonation. Due to the fast paced change of reference points the success of a realisation of this system is dependent on the players' abilities and experience in intonation adjustment.

Which form of 'natural' intonation the players revert to is subject to some debate. The theory that instrumentalists gravitate towards Just thirds was first purported by Helmholtz in his treatise *On the Sensation of Tone*[24] however acoustic analysis done during the 1960s[25] indicated that instrumentalists tend towards Pythagorean thirds. Ultimately this is something of a non-issue as the intended aim is to create a piece in which the instrumentalists tend towards a 'natural' tuning, whichever one that may be.

The computer provides a medium for working with non-fixed temperaments comfortably and effectively, though in terms of analysis, my computer music pieces are slightly outside the realm of cohesive temperaments. In this medium it is sufficient, and indeed necessary, to use the relevant ratio to adjust the frequency of the signal in order to

[24] "But it is clear that if individual players feel themselves obliged to distinguish the different values of the notes in the different consonances, there is no reason why the bad thirds of the Pythagorean series of Fifths should be retained in quartett playing. Chords of several parts, executed by several performers in a quartett, often sound very ill, even when each single one of these performers can perform solo pieces very well and pleasantly; and, on the other hand, when quartetts are played by finely-cultivated artists, it is impossible to detect any false consonances. To my mind the only assignable reason for these results is that practiced violinists with a delicate sense of harmony, know how to stop the tones they want to hear, and hence do not submit to the rules of an imperfect school. That performers of the highest rank do really play in Just Intonation, has been directly proved by the very interesting and exact results of Delezenne." Hermann Helmholtz, *On the Sensation of Tone* (New York, N.Y.: Dover Publications, 1954) p. 324-5.

[25] "With modern acoustical equipment it is possible to measure the intervals actually played by violinists. This has been done, and it found that string players, both in solo performance and in ensemble tend toward the Pythagorean rather than the just thirds." Backus, *Ibid.* p. 131-2.

change the pitch. By restricting the choice to five-limit ratios I am to a certain extent working in Just Intonation, but from an unstructured structured angle.

2. ACOUSTIC WORKS

2.1 GENERAL METHODOLOGY

The compositional method employed in the acoustic pieces is only semi-algorithmic as the melodic material between the prescribed tetrachords is freely composed. The freely composed material attempts to explore and emphasize the tonality implied by the previous tetrachord. Thus each tetrachord and the material immediately after it can be heard and examined as micro key or tonal centres. In these small sections the harmonic language is relatively conventional but due to the quick shifting of key centres it does not produce an entirely conventional sound.

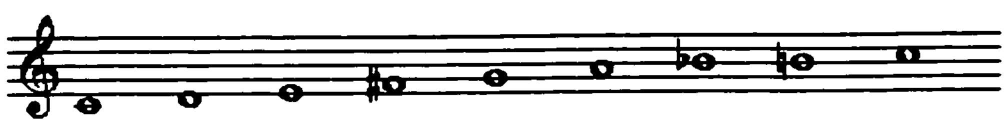

Figure 2.1 Eight-note scale used for acoustic compositions.

Both *Partial Objects* and *deMusica* are based on the pitch-classes contained in the eight-note scale in Figure 2.1; this scale contains all the pitch-classes that occur in the first sixteen partials of the harmonic series. Were the B flat omitted, the resulting seven note scale would be a Lydian mode. Likewise the omission of the B natural would result in the 'acoustic' scale. The inclusion of both the B and B flat provides a choice between the leading note in C and the flat seventh. This further obscures any overall sense of a traditional tonal centre that could potentially be implied through the use of only those partials above C. The eight-note scale also provides more tetrachord possibilities and offers greater freedom through an increased number of included intervals. The tetrachords were derived from an order of pitch-classes different from the order portrayed in Figure 2.1. Rather than use the compressed scale version, the order that the pitch-classes occur in the harmonic series were used, i.e. instead of C-D-E-F sharp-G-A-B flat-B the order of the pitch-classes was C-G-E-B flat-D-F sharp-A-B.[26]

This object-oriented approach produces compositions without an overriding identifiable tonal centre. The decision to use the partials above C often allows the impression of a C tonal centre, but this impression is transient, often fleeting. Rather the pieces shift, at times quite rapidly, through implications of numerous tonal centres. The aesthetic effect of the compositions is further defined by the two additional factors: the available pitch-class material in the combination of the Lydian and 'acoustic' modal scales, and combined effect of the homophonic texture created by the occurrences of the tetrachords and the melodic, often contrapuntal, nature of the freely composed material.

Without the cohesiveness that a tonal centre provides the aesthetic effect in these works is different from that created by pieces of the Baroque, Classical and Romantic eras. Nor does this aesthetic effect sit comfortably with either the highly structured or seemingly random approaches found in twentieth composition. Rather, the lack of tonal cohesiveness and contrapuntal treatment of the melodic material echoes a Renaissance lineage.

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[26] In relation to **Appendix A - Available Tetrachords**: C = 0; G = 1; E = 2; B flat = 3; D = 4; F sharp = 5; A = 6; and B = 7.

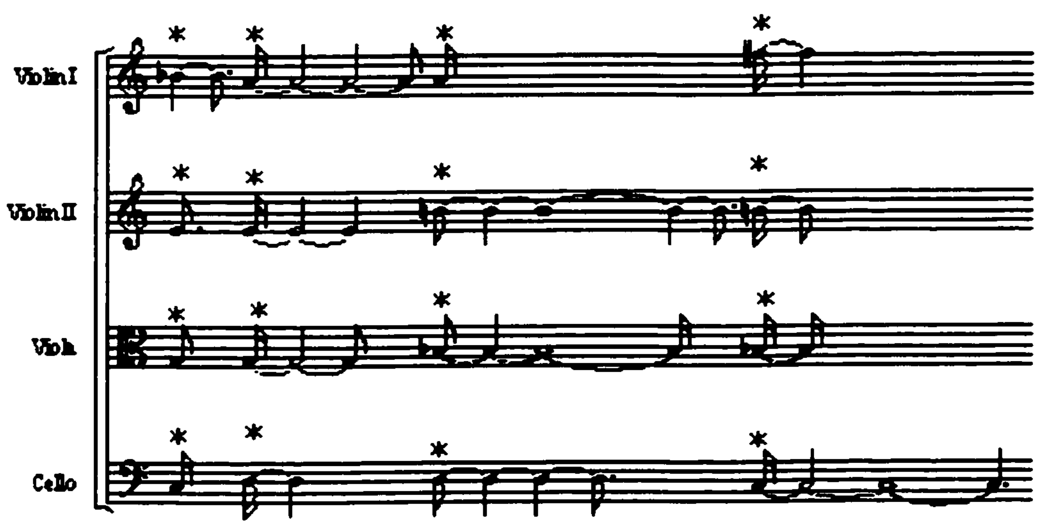
2.2 OBJECT-ORIENTED METHODOLOGY

```
class Tetrachord{
private:
  int notes[4];
  int retune[4];
  char rhythmic_dur[4];
public:
  bool used = FALSE;
public:
  Tetrachord(int num);
  populate_notes(int num);
  populate_retune(int num);
  populate_rhythm(int num);
  ret_values(int *note);
  mark_used();
}
```

Figure 2.2 Tetrachord Class Definition[27]

Each instance of the Tetrachord class represents a potential tetrachord for use in the composition through the specification of its pitch-classes, durations, and fine-tuning properties. All possible tetrachords containing only those pitch-classes found in the eight-note scale were identified;[28] each of these tetrachords was then represented by one and only one instance of the Tetrachord class. The Tetrachord class member variables include the 'notes' array, the values in which are determined by the included pitch-classes of the tetrachord while the order of the elements is determined by the order in which the included pitch-classes occur in the tetrachord, e.g. the first, and lowest, pitch-class is 'notes[0]', the second pitch-class is 'notes[1]', etc. To the extent that the instrument to which the pitch-class is assigned limits it, the order of the elements assigns the registral order of the pitch-classes in the first tetrachord of the piece, the order in the remaining tetrachords is determined by either the continuation of a common pitches or by movement to the closest available pitch. The fine-tuning[29] is determined in relation to the bass-note of the tetrachord ('notes[0]') using five-limit ratios.

Figure 2.3a and 2.3b use the first four tetrachords of the first movement of *Parital Objects* to demonstrate how the tuning of each instance of a pitch-class is dependant on the bass-note of the tetrachord in which it occurs. The tuning of a pitch-class is only consistent when it occurs in tetrachords with the same bass-note or when the intervallic difference between the pitch-class and bass-note is one which maintains a level of consistency between ratios (see the consistency between the G a perfect fifth above C and the G a perfect fourth above D in Figure 2.3b, this consistency can be explained by nature of the fact that all of these ratios (3:2 between G and C, 4:3 between G and D, and 9:8 between D and C) are three-limit).



[27] The development of the *SoundObjects* program encountered a number of problems during the pre-compositional planning stages for *Partial Objects* and *deMusica* so the series of tetrachords were derived by manually 'walking-through' the logic of the program.
[28] See **Appendix A - Available Tetrachords.**
[29] This fine-tuning array was not actually used in the creation of the acoustic pieces, rather, as discussed below, the exact intonation was left to the player.

Figure 2.3a First four tetrachords in *Partial Object: I-Adagio*.

	Tetrachord 1	Tetrachord 2	Tetrachord 3	Tetrachord 4
Violin I	B flat (996)	A (906)	A (906)	C (1166)
Violin II	E (384)	E (408)	B flat (1018)	B flat (967)
Viola	G (702)	G (702)	B (1110)	B (1081)
Cello	C (0)	D (204)	D (204)	F sharp (583)

Figure 2.3b Chart demonstrating variations in pitch-class tuning among the first four tetrachords of *Partial Object: I-Adagio*.

The values are in cents with a reference point of C = 0 cents, for the sake of clarity all values have been reduced to less than an octave (i.e. < 1200 cents).

Taking the pitch-class E as an example from Figure 2.3b we see that when it is calculated as a 5/4 above C rather than as a 9/8 ratio above D the latter is twenty-two cents sharper. (Comparing both resulting Es to C we see that the two types of thirds are in fact Pythagorean and 5-limit Just, and the difference between the two is equivalent to the syntonic comma. Thus we see that much like the consistency found between some of Gs, as discussed above, there is also a consistency in some of the tuning 'discrepancies'.)

The deviations, in cents, from the equal-tempered tuning of the note[30] are stored in the 'retune' array. Ultimately, the 'retune' array became superfluous as it was decided during the compositional process that the specification of tunings in terms of cents for each tetrachord pitch-class was likely to cause the players undue confusion. Instead the players are instructed tune on the fly to the bass-note, with the hope that the 'natural' tendencies of the players to gravitate towards pure ratio tunings will prevail. Figure 2.3a shows the wide range of tetrachord pitch-class durations. While some tetrachords allow players a great deal of time to achieve the correct intonation other tetrachords, such as the first tetrachord in

[30] Above a C the equal tempered tunings (in cents)of the pitches in the eight-note scale are:

C	D	E	F sharp	G	A	B flat	B
0	200	400	600	700	900	1000	1100

Figure 2.3a, allow very little time. It will likely be a challenge for even the most experienced players to shift intonation quickly and seamlessly for these shorter tetrachords.

The rhythmic durations were selected, in order, from a numerological sequence containing sets of numbers representing the length in sixteenth notes of each note in the tetrachord. In this process, sets of four durations[31] were determined by selecting those occurring in prime number locations from a series of the first twelve primes (1, 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31).[32] This data is stored in the 'rhythmic_dur' array. The rhythmic durations are based on prime numbers in order to obscure any sense of regular meter. The length of each tetrachord section is determined by the longest duration, a process that subverts any uniform bar divisions the ear may try to impose.

The freely composed material between instances of the tetrachords was composed and notated in Finale with no preconceived rules governing its creation. The only consistent overriding consideration was the function of the material to move from the starting pitch-class given by the previous tetrachord to the pitch-class prescribed by the next one. Figure 2.4 demonstrates the general approach to the freely composed material between instances of the Tetrachord class. The instrument assigned the tetrachord pitch-class with the shortest duration carries a melody line through to the next tetrachord. The other two instruments play either counter-melodies or rests, depending on the amount of time between the end of their tetrachord pitch-classes and the beginning of the next tetrachord.

[31] See **Appendix B – Available Rhythmic Durations.**
[32] See **Appendix C – Possible Rhythmic Duration Combinations.**

Figure 2.4 An instance of a tetrachord with freely composed material.
From *Partial Objects: I-Adagio*

At times a series of tetrachords imply a tonal centre, when this occurs the movement of the melodic line was not just to the next tetrachord but also through it and the proceeding ones to the beginning of the next implied tonal centre.

Figure 2.5 Two tetrachord instances with a shared melodic line.
From *Partial Objects: I-Adagio*

A *Boolean* member variable, 'used', was included in the class to flag whether the particular instance had been used or not. The rules for the sequence require two common pitch-classes between instances, but a pitch-class cannot occur in more than two instances in a row. In an implementation of this sequence the piece ends when there are no unused instances of the class left to progress to.[33]

2.3 General Musical Context

My approach to acoustic composition owes much to past and present trends in algorithmic composition. The practice of using algorithms or structures as a compositional tool is at least a thousand years old. Guido d'Arezzo, a Medieval theorist,[34] employed mnemonics for solmization, while Renaissance composers made extensive use of techniques such as isorhythms and rounds,[35] and many of these algorithmic methods also made use of numbers with numerological significance.

2.3.1 Algorithmic Composition

The serial and the stochastic methods provide a contemporary context for my acoustic pieces. The serial technique was applied with varying degrees of strictness and to various musical elements by a number of the century's preeminent composers, including Arnold Schoenberg, Anton Webern, Alban Berg, Pierre Boulez, Milton Babbitt, and Karlheinz Stockhausen. Serialism is defined by Paul Griffiths in the *New Grove Dictionary* as

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[33] See **Appendix D - C++ Code for Sound Objects Algorithm.**
[34] Guido d'Arezzo, a tenth century Benedictine monk well versed in Greek music theory, wrote numerous treatises on musical techniques and practices.
[35] The oeuvres of Guilliame de Machaut and John Dunstable provide ample examples of these Renaissance algorithmic compositional practices. Of particular note are Machaut's *Ma fin est mon commencement* (a canon with retrograde canonic imitation) and *Nostrum est impletum gaudium* (a motet with an isorhythmic tenor) and Dunstable's isorhythmic mass *Rex Seculorum).* For more detailed examples see Loy, *Ibid.* p. 297-310 and Ernest

> a method of composition in which a fixed permutation, or series, of elements is referential (i.e. the handling of these elements in the composition is governed, to some extent and in some manner, by the series)[36]

Schoenberg, the originator of the serial technique, employed a relatively flexible approach to the serialisation of pitch. His pupils Berg and Webern took different approaches in further developing Schoenberg's ideas. Berg adopted an even more flexible approach while Webern adhered strictly to the use of a single twelve-tone row per movement or composition.

Berg's *Lyric Suite*, which exhibits the characteristic balance between structuralism and spontaneity in his serialist technique,[37] has a complex numerological element; the program for the piece, discovered after Berg's death, is the description of his secret love affair with a married woman. Though not always emotionally significant all six movements of the *Lyric Suite* were subject to some degree of number based pre-compositional organization, such as the overall structure of the fifth movement where the duration of the five parts are in the series 5:4:3:2:1.[38] The numerlogical implications are extended to the serialist technique through Berg's choice of a tone row that begins with his and his lover's initials interlaced and

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H. Sander, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 1980) S.v. "Isorhythm" Vol. 9, p. 351-4.

[36] Paul Griffiths, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Serialism" Vol. 23, p. 116-23.

[37] Douglas Jarman compares Berg's technique to those of Schoenberg and Webern:
"More than either of his colleagues, Berg's music belongs emotionally to the world of late nineteenth-century romanticism and its melodic and harmonic language is more reminiscent of that of earlier tonal music than is the music of Schoenberg and Webern... during the course of his development, from earlier songs to Lulu, Berg moved from romanticism to structuralism without ever abandoning his emotional intensity and apparently spontaneity which are the most striking features of his music."
Douglas Jarman, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Alban Berg" Vol. 3, p. 318.

[38] For more detailed discussion on the numerological basis of *Lyrical Suite* see Douglas Jarmen, *Ibid.* and *The Music of Alban Berg* (London: Faber & Faber, 1979) p. 159-61.

the selection of only those treatments of the row that do not interrupt the consecutive order of these pitches.[39]

The serial technique was extended by later composers to apply to other compositional parameters, including: duration and rhythm by Boulez and Babbitt, dynamics by Boulez, and timbre by Stockhausen in his electronic works. Thus the prevailing view is that "serialism cannot be described as constituting by itself a system of composition, still less a style"[40] rather it is a set of parameters in which the composer works.

The most direct link between my acoustic compositional practices and the serialist system is the combined systemization of pitch and rhythmic material first practiced by Boulez. Inspired by Oliver Messiaen's creation of rhythmic, as well as dynamic and articulatory, scales for his piece *Mode de baleurs et d'intensities*, Boulez began serialising rhythmic durations in his *Second Piano Sonata*, ultimately moving to his total serialist technique with *Structures*. In his book *Modern Music: A Concise History*, Griffiths' discussion of this work speculates on the appeal of total serialism to Boulez, arguing that the

> submission to the almost automatic system of control, such as occurs in *Structures Ia*, offered Boulez the means to eradicate all that had been learned from the past, all traces of other styles[41]

Rather than the specific details of serialist method,[42] it is the combination of the idea of creating a system that facilitates exploration of new musical styles with the flexible

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[39] This set of pitch classes is prioritized so that "the choice of note row, row forms and transposition in the outer 12-note sections is limited to those forms that keep the four notes" (Jarman, Douglas *Ibid.* p320), A-B flat-B-F representing Alban Berg/Hanna Fuchs, together and in sequence.
[40] Griffiths, *Ibid.* p. 116.
[41] Paul Griffiths, *Modern Music: A Concise History* (New York, N.Y.: Thames and Hudson, 1994) p. 138.
[42] For a more detailed overview of Serial method see Griffiths *Ibid.* and Leibowitz, René *Schoenberg and his School: the Contemporary Stage of the Language of Music* Translated from the French by Nika Newlin (New York, N.Y.: Philosophical Library, 1949).

philosophy behind its various implementations that is most relevant to my compositional method.

The stochastic approach as implemented in the music of Iannis Xenakis provides a second context in twentieth century acoustic compositions. Xenakis was critical of the serialist approach, preferring probabilistic stochastic techniques to generate pitch material. In his book *Formalised Music*, Xenakis explains how his seemingly random 'free stochastic' approach is in fact governed by logic, based from the law of large numbers as "this law implies an asymptotic evolution towards a state, towards a kind of goal, of *stochos*, when comes the adjective 'stochastic'."[43]

Xenakis' stochastic games can be seen as a sophistication of the tradition of the eighteenth century dice music, *Würfelspiel*, where the result of a dice toss determined which musical motives were chosen from a prepared table, these motives were then arranged according to the compositional rules of the era.[44] In *Achorripsis*, one of his first stochastic pieces, Xenakis used a matrix created with a number of mathematical formulas as the source of all the elements in the piece.[45]

Xenakis' early algorithms, including the one for *Achorripsis*, were calculated by hand but as the field developed Xenakis engaged extensively in computer-assisted composition practices. This field, pioneered in the sixties at the University of Illinois through experiments by Lejaren Hiller and Lemand Issacson,[46] attempted to create software

[43] Iannis Xenakis, *Formalised Music thought and mathematics in composition* (Bloomington: Indiana University Press, 1971) p. 4.
[44] For more detail see Loy, *Ibid.* p. 302-5.
[45] For a detailed analysis of this piece see Linda M. Arsenault, "Iannis Xenakis's Achorripsis: The Matrix Game" in *Computer Music Journal* 26:1 (2002) p. 58-72.
[46] Robert Baker and Lejaren Hiller, "Computer Cantata: A Study in Compositional Method" *Perspective of New Music* 3 (1964) p. 68.

algorithms to generate musical compositions from a set of rules. In addition to the early rule-based systems, computer-assisted composition systems have been developed that employ Markov chains, fractal theory, composing grammars, and artificial intelligence constructs such as neural networks, as the basis for composition generating algorithms.[47]

2.3.2 Numerological Composition

The numerological basis of my acoustic works provides a second musical context. Numerology has long been a characteristic of musical practice, dating back through the tuning theories of the Greeks, the medieval concept of the 'Music of the Spheres' and the incorporation of numbers with biblical significance into Renaissance and Baroque compositions.

In the twentieth century a number of musicologists attempted to retrofit numerological intentions on some Renaissance and Baroque composers. Two of the most notable discussions have covered Guilliame Dufay and Johann Sebastian Bach. There have been heated debates between the proponents and detractors of the theories; however, the fact that this has been a topic of controversy has brought the issue of numerological significance in musical compositions into the general parlance of twentieth century musical culture.

Dufay's *Nuper Rosarum Flores* was written for the opening ceremony at the Florentine Cathedral, it has been proposed that the 6:4:2:3: ratio formed by the relative duration of each of the four sections was imposed intentionally so as to reflect the dimensions of

[47] For a more detailed overview of rule sources of computer-assisted composition see Burns, *Ibid.*

Brunelleschi's Dome in the cathedral.[48] In the case of Bach there have been numerous theories on his pre-compositional practices, including a particularly heated debate around his alleged use of number alphabets.[49] However, Bach's knowledge and practice of fairly sophisticated pre-compositional planning techniques is generally accepted, including the ideal purported by some of his contemporaries, most notably Johann Mattheson, that the pre-compositional process should be similar to the preparatory practices of an architect.[50] The examination of the compositional practices of Dufay and Bach in relation to architecture provides an interesting context for and parallel to the works and theories of Iannis Xenakis.

A well-substantiated numerological implication in Bach's oeuvre is that the proportions of the thematic sections of *The Art of Fugue* are the same as the Fibonacci series. The following chart from Erno Lendrai's *The Workshop of Bartok and Kodaly* lists the length of each section.

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[48] Charles W. Warren, in his article "Brunelleschi's Dome and Dufay's Motet" in *Music Quarterly* 59 (1973) p. 92-105, argues that it is not only the overall structure of the work that relates to the architecture of the dome but also "its use of two tenors with the same cantus firms, its isorhythmic and isomelic symmetries, its impressive sonorities" (*Ibid.* p. 92). The source of the ratio that was contested by Craig Wright, in his article "Dufay's *Nuper Rosarum Flores*, King Solomon's Temple, and the Veneration of the Virgin" in *Journal of the American Musicological Society* 47 (1994) p. 395-439, he argued that the source was not Brunelleschi's Dome but rather Solomon's temple as described in Kings vi 1-20. The crux of proof for both scholars is that the ratio 6:4:2:3 of the movements is unique not only in Dufay's oeuvre but also in the works of his contemporaries, had it been a commonplace feature of works of the era it would be difficult to argue any special significance.
[49] This theory was refuted by Ruth Tatlow, in her 1991 book *Bach and the Riddle of the Number Alphabet* (Cambridge: Cambridge University Press, 1991) and her contributions to the article on "Numbers and music" (*New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. Vol. 18 p. 231-4), argues that there is not conclusive evidence that Bach made use of numerological compositional techniques.
[50] In her discussion of Mattheson's theory, Tatlow examines his compositional term *Dispotio* as it was defined and applied in his treatise *Der volkommene Cappellmesiter*

> DISPOSTIO is a neat ordering of all the parts and details in the melody, or in an entire musical work, almost in the manner in which one arranges or draws a building, makes a plan or sketch, a ground, to show where e.g. an assembly room, an apartment, a bedroom etc. should be situated.
> (Tatlow "Numbers and Music" *Ibid.* p. 232).

Theme in ROOT position	13	
First interlude		21
Theme in INVERSION	8	
Second interlude		34
Theme in ROOT + INVERSION	13	

Figure 2.6 Proportions of Thematic Sections in Bach's *The Art of Fugue*[51]

First described in Leonardo Fibonacci de Pisa's 1202 treatise *Liber abaci* the Fibonacci series is defined by the characteristic that the sum of any two consecutive numbers in the series is equal to the subsequent number (1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233). Fibonacci discovered the series through his work as a natural philosopher, the sequence can be found in the leaf structures of numerous plants and the growth rates of some species, such as rabbits. In the early sixteenth century the mathematician Paciloli identified the series as being the simplest sequence that expresses Euclid's golden ratio (0.618034...),[52] the series moves closer to the ratio as the numbers increase. This relationship was further explored in the writings of the early seventeenth century astronomer Johannes Kepler.[53]

The Fibonacci series appears in numerous works by Debussy, though the fact that the series is a 'natural phenomena' makes it harder to attribute intent when it occurs. In his book *Debussy in Proportion: A musical analysis* Roy Howat details the occurrences of the Fibonacci series in the work of Debussy

> one's attention is attracted by how often well-defined sections in Debussy's music follow Fibonacci's numbers at strategic places – the 55 bars of introduction to the last movement of *La mer*, the 21 bars of introduction to 'Rondes de Printemps' from the orchestral *Images*; the 34 bars comprising the *joyeuse* (bars 186-219...) and likewise to the recapituation of *Masques* (bars

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51 Erno Lendrai, *The Workshop of Bartok and Kodaly* (Budapest: Edito Musica 1983) p. 52.
52 This ratio can be expressed by the equations $b/a = a / (a+b)$
53 For more in depth discussions see Ruth Tatlow, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Fibonacci Series" Vol. 8, p. 765, Roy Howat, *Debussy in Proportion: A musical analysis* (Cambridge: Cambridge University Press, 1983) p. 1-10 and Lendrai, *Ibid.* p. 46-52.

> 236-69); the first reprise in 'Reflects dans l'eau' after 34 bars and the beginning of its climax after 55[54]

'Reflects dans l'eau' from *Images* is a particularly interesting example as occurrences of the Fibonacci series can be observed in numerous elements of the piece. The macro organization of the piece adheres to the golden ratio, the relative placement of dynamics create a perceived climax .618 of the way through. Dynamically the piece is divided into two sections, the point of division occurs with the *ff* at bar 58, an event that occurs at the .618 point of the 94 bar piece. These two sections are further divided into 23 and 35 bar sub-sections and 22 and 14 bar sub-sections respectively through the activity of thematic material. The golden ratio emerges even in the smaller details of the piece; the opening motif (A flat, F, E flat), which is used as a building block for much of the melodic material, outlines three semitones followed by two semitones.[55]

Bela Bartok also made extensive use of the Fibonacci series, his *Sonata for Two Pianos and Percussion* is a particularly illuminating example. Erno Lendrai provides a detailed analysis of the piece in his book *The Workshop of Bartok and Kodaly* noting the dominance of the series in the melodic structure in the first movement, the relationship of the original theme to its inversion, the organization of the tonic and dominant sub-sections, and the structure of the recapitulation and development in the final section.[56]

Karlheinz Stockhausen also has a strong numerological element in some of his pieces, two of particular note are *Klavierstuck IX* and *Adieu* both of which are influenced to

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54 Howat, *Ibid.* p. 3.
55 For a more detailed discussion see Howat, "Chapter Three: Reflects dans l'eau" *Ibid.* p. 23-29.
56 Lendrai, *Ibid.* p. 36-45.

varying degrees by the Fibonacci series. In his book *The Works of Karlheinz Stockhausen*, Robin Maconie offers the following summary of *Klavierstuck IX*

> the form falls into 33 sections grouped by tempo into two episodes of 24 and 9 sections respectively, expressing a ratio of 8:3 which also coincides with tempi quaver = MM 160:60 of the first episode of 24 sections[57]

Though not strictly based on the Fibonacci series the sequence is echoed in Stockhausen's choice of values. The Fibonacci series emerges explicitly in *Adieu* in the length of the piece's subsections. The numerous fermatas deter the absolute precision of the sequence but Maconie provides the following overview of the sections using an estimated fermata length calculation.

> At 6 the missing proportion is as in brackets 8-13-21-13-[9]; at 17 the pattern is 2-3-5-(3+3)-(5+5)-(8+[8]); the 'sehr lang' after 25 connects with the succeeding group as [13]-8-5-8-13; while the fermata at 29, together with the four pauses of varying length which break into the closing cadence, may be interpreted as a descending series of silence duration (8-5-3-2-1) edited into the last section of a rising series of music duration (5-8-13-21-34)[58]

The numerological elements of my acoustic works occur in the process of determining rhythmic durations. A series of prime numbers were used to determine rhythmic durations in the choral and the first and third movements of the string quartet. The Fibonacci series was used in the second movement of the string quartet to determine the length of the phrases. The Fibonacci series was chosen as a structural element for this freely composed movement to impose a system of structure that, like the harmonic series, has its roots in the natural world.

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[57] Robin Maconie, *The Works of Karlheinz Stockhausen* (Oxford: Clarendon Press, 1996) p. 119.
[58] Maconie, *Ibid.* p. 183.

2.4 *Partial Objects*

Partial Objects, a three-movement work for string quartet, is well suited to the Tetrachord class as each pitch can be assigned its own instrument. My object-oriented technique was implemented in the first and third movements, while the second movement was freely composed with some general structural rules derived from the Fibonacci series. The absence of meter and bar lines in the piece, as well as the absence of rests in the second movement, is intended to enforce the closer interaction between the players necessary to attain the correct intonation. Without meter or bar lines the players must pay close attention to each other.

2.4.1 *I – Adagio & III – Allegro*

In these movements the elements of the 'note' member variable of the Tetrachord class are distributed from the bass-note ('note[0]') in the cello, the second note ('note[1]') in the viola, the third note ('note[2]') in the second violin and the first note ('note[3]') in the first violin. Thus the cello plays the bass-note of the chord, functioning as the reference point for the viola and violins during the sustained tetrachords.

The length of each movement was determined by the available instances of the Tetrachord class and the adherence to *SoundObjects'* rules of progress. The rules dictated that each instance could only be used once, each progression had to express exactly two common pitches, and a single pitch could not occur in three subsequent instances. The static nature of these rules partitioned the instruments into two groups, the first violin with the cello, and the second violin with the viola. The number of tetrachords in the series generated for these movements proved to be greater than the available number of duration combinations. In order to reconcile this discrepancy the last five tetrachords were notated as whole notes with fermatas.

To create a sense of unity between the first and third movements the same series of instances of the Tetrachord class was used for both, applied forward in the first movement and backwards in the third. To maximize potential association with the lower partials the C-E-G-B-flat tetrachord was chosen as the starting point for the first movement, thus also becoming the closing tetrachord for the piece.

There are a number of marked sections in the first movement, which at times coincide with changes in tempo. Section A begins with a tempo of 240 sixteenth notes per minute, it contains only duple rhythms, and its dynamic character is in the *pianissimo-mezzo piano* range. Section B has a slightly faster tempo, 378 sixteenth notes per minute, and louder dynamic range, *piano-mezzo forte*, in this section triple rhythms are introduced in combination with duple rhythms. The tempo slows to 288 sixteenth notes per minute halfway through section B and remains there for the duration of Section C, which has the same dynamic range as Section B, *piano-mezzo forte*, and the same rhythmic character as Section A, i.e. exclusively duple. The final section, D, marks the return of the 378 sixteenth notes per minute tempo and the triple rhythms, the dynamic quality of this section is quiet, *pianissimo-mezzo piano*, and it ends with a series of sustained harmonics in all instruments.

The third movement has a consistent tempo of 480 sixteenth notes per minute and a duple rhythmic character, this consistency is offset by the most extreme dynamic range of the movements, *piano pianissimo-fortissimo*, arranged so as to outline the climax of the movement in bar sixty-one. The movement builds to the final climax of the piece after which dynamic range becomes quieter until the piece finally returns to the starting tetrachord through a series of double stops dropping from *piano* to *piano pianissimo*.

2.4.2 II – Ad Lib.

The second movement is based on a completely different aesthetic approach than the first and third. It was the last movement composed and is based on the freely composed material of the other two movements. Whereas the other two movements produced a thick, at times homophonic texture, this middle movement is made up of a series of solos and a duet. The length of each section is determined, in eighth notes, by the Fibonacci series. Thus the first solo is a single eighth note long, the second a single quarter, the third a dotted quarter, the fourth a half note plus an eighth, the fifth is a whole note, the sixth a whole note plus a half note plus a quarter, and so on to the eleventh section, the violin duet, which is 121 eighth notes long. The 'solo' sections of the piece are set up as a palindrome, the first ten solos leading up to the duet are reversed to create the ten solos following the duet. The violin duet is a round, the first part played by the second violin and the second part by the first.

The rhythmic durations range from a triple sixteenth to tied notes greater than a whole note in length. In order to create the impression of different sections the rhythmic durations move between groups of duple and triple division of sixteenth, eighth and quarter notes. The tempo remains consistent so to emphasize the different subdivisions. The dynamic quality of this movement is louder than the first, ranging from *mezzo piano-fortissimo*. The dynamic markings in the solos do not adhere to the palindromic quality of the pitches and the durations so as to create a more musically interesting contrast.

2.5 *DEMUSICA*

The series of instances of the Tetrachord class for the twelve-part choir in *deMusica* was handled a little differently than the string quartet in *Partial Objects*. The twelve-part choir was divided in four groups; soprano, alto, tenor, and bass, with three voices assigned to each grouping. The division of the choir into four allowed the use of the same order of pitch assignment from the Tetrachord class as was used for *Partial Objects*. In order to exploit the greater textural potential offered through the existence of multiple voices there were, within each group, offsets of either an eighth or a quarter note. As a result the texture of this work is less consistently dense than the first and third movements of *Partial Objects*. Also, the consistency of the offset produces a regular pattern that creates a slightly different aesthetic effect than the one created by *Partial Objects*. The tempo of the piece is consistently slow and has a predominantly quiet dynamic character, only moving to the *mezzo forte-forte* range for a few bars in the middle of the piece.

The text is from the chapter titles of Anicius Manlius Severinus Boethius' *De institutione musica, liber I*, a treatise summarising Greek musical thought and philosophy, particularly the link between music and nature. The text intentionally becomes obscured through the placement of the syllables, serving only to provide syllable for the singer to articulate rather than to create a sense of meaning, the possibility of which is made more remote by the use of a Latin text, a language aurally unfamiliar to many people.

3. ELECTRONIC WORKS (COMPUTER MUSIC)

3.1 GENERAL CONTEXT

3.1.1 MUSIQUE CONCRÈTE

Musique concrète refers to "a method which Pierre Schaeffer saw as the opposite of *musique habituelle*: 'unlike the traditional procedure, which moves from the score to its execution, the process in *musique concrète* moves from the sound to the organization'."[59] The tape music composed under this umbrella term was created through the manipulation of recorded sounds. The use of real world, or 'found', sounds echoes the ideas purported by the Italian *futurists*, a group of theorists and composers who espoused the adoption of a machine aesthetic and the use of machines in the creation of art. Luigi Russolo's 1913 treatise *Art of Noise* linked the development of musical style to the creation of new machines. Russolo later founded an electronic ensemble that played on noise generating instruments and toured Italy, London and Paris in 1921. The 1933 sound collage *Futurist Radiophic Theater* by Filippo Tommaso Marinetti, which combined real world and musical sounds with sections of silence, was also wide-reaching.

The first forays into *musique concrète* were the early experiments with variable speed phonographs in the 1920s and 1930s by Darius Milhaud, Paul Hindemith, and Edgar Varèse. This was followed by the advent of magnet tape and experiments with tape splicing in Cologne, Germany. In Paris in the 1940s Pierre Schaeffer engaged in further experiments

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[59] For a detailed overview of Schaeffer's life and works see Francis Dhomont's *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Pierre Schaeffer" Vol. 22, p. 430.

with variable speed phonographs and in 1950 set up the *Studio de Musique Concrète* with Pierre Henry. Schaeffer and Henry explored the potential of the tape medium through five main types of tape manipulation:

- Change of tape speed
- Change of tape direction
- Tape loops
- Cutting and Splicing
- Tape Delay[60]

The process of creation was very long and involved, consisting of numerous stages of recording. Initially the taped sounds were 'found' or naturally occurring sounds and *musique concrète* was seen as distinct from the early experiments in synthesis. The divide between the two camps was eventually bridged and synthesis techniques were incorporated both to manipulate existing sounds and to generate new sounds to be manipulated.

Schaeffer's *Etude aux Chemins de Fer* is considered the first significant composition in the genre but it was Schaeffer's theoretical writings, principally his 1966 book *Traité des objets musicaux*, more so than his compositions that were his major contribution to the field.

3.1.2 SYNTHESIS

The history of sound synthesis can be traced back to the *Telharmonium*, a polyphonic synthesizer based on the results of acoustical inquires by Helmholtz and Fourier. The *Telharmonium*, patented by Thaddeus Cahill in 1895 and first produced in 1903, was the first electronic instrument to use oscillators for tone generation. The second major development in the history of synthesis was the *Theremin*, created by Leon Theremin in the 1920s, which

[60] Stefan Kostka, *Materials and Techniques of Twentieth Century Music* (Upper Saddle River, N.J.: Prentice Hall, 1999) p. 244.

would become the most successful and influential early electronic instrument. The *Theremin*'s sound was created by two radio-frequency oscillators and its two control parameters, frequency and volume, were modified by the movement of the performer's hands around its antenna. In the late 1920s Laurens Hammond began developing organs, notably the *Novachord* and the *Solovox*, based on the same basic principles as the *Telharmonium* but in a portable, commercially viable format. In addition to tone generation the *Hammond* organs allowed the adjustment of timbre through additive synthesis, that is the addition and subtraction of overtones.

A number of electronic studios were set up during the 1950s, the most notable being those in Paris, Cologne, Columbia-Princeton, and the University of Toronto. These studios were initially made up of custom designed synthesizers but later incorporated numerous commercial models as they became available. One commercial model that became a mainstay of many studios was the *RCA Mark II*, a modular, programmable synthesizer with an integrated sequencer. The sequencing mechanism was achieved via binary-code punched onto a roll of paper, the advantage of the system was that sequences could be both produced and read by the Mark II.[61]

In the 1960s a number of more sophisticated instruments that provided more control over timbre were introduced. In 1966 Robert Moog released the first *Moog* synthesizer, a breakthrough instrument in its use of voltage to control parameters, other contemporary synthesizers that used this technology included the *Putney VCS-3*, the *ARP 2500*, and the *Buchla*. While the *Moog* synthesizer used a keyboard controller the *Buchla*

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[61] Herbert Deutsch, *Synthesis: An Introduction to the History, Theory and Practice of Electronic Music* (New York, N.Y.: Alfred Publishing Company Inc. 1986) p. 19.

synthesizer was controlled by a touch sensitive plate and had the added feature of random voltage control. All of these early commercial synthesizers were modular, requiring external patch chords to connect the components. The first commercial synthesizer with an integrated circuit design was the *Minimoog* in the late 1960s, followed by the *ARP 2600* and the *Odyssey* in 1971. Like the *Moog*, the *Minimoog* boasted voltage controlled oscillators, filters, and voltage controlled amplifiers, unique to the *Minimoog* was the integrated keyboard and mixer. Also in the early seventies the first digital synthesizer, the *Allen*, was introduced, but the digital revolution in synthesis hardware did not take place, save for a small degree with the *Prophet-5* and its integration of digital memory with analog tone generators, until the success of Yamaha's *DX7* in 1983.[62]

3.1.3 Gesang der Jünglinge and Poème Electronique

Gesang der Jünglinge, a 1955/56 work by Karlheinz Stockhausen, was a landmark[63] in the field of early electronic music. Produced at the electronic music studio in Cologne it was one of the first pieces to combine *musique concrète* and synthesis techniques. The concrete sounds were samples of choirboys singing a Catholic Mass in German while the synthesized sounds were created with sine wave and noise generators.

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62 Hugh Davis, *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Synthesizer" Vol. 24, p. 851-2.
63 "... it was this piece, perhaps more than any other, that established electronic music as a valid art form in the minds of the public, and stimulated imaginations of generations of composers. It also established important esthetic criteria that seem to be in use even today among the electronic and computer music mainstream. It is common to hear new works, composed at the most advanced computer music facilities, that are highly reminiscent, at least superficially, of this early work."
Michael Manion, "From tape loops to MIDI: Karlheinz Stockhausen's Forty Years of Electronic Music" <http://www.stockhausen.org/tape_loops.html> 16 May, 2002.

1. Sine waves
2. Periodically frequency modulated sine waves
3. Statistically frequency modulated sine waves
4. Periodically amplitude modulated sine waves
5. Statistically amplitude modulated sine waves
6. Periodic combinations of both types of sine wave modulation simultaneously
7. Statistical combinations of both types of sine wave modulation simultaneously
8. Colored noise with unchanged density
9. Colored noise with statistically changed density
10. Filtered impulses (clicks) from periodic impulses sequences
11. Filtered impulses (clicks) from statistical impulses sequences

Figure 3.1 The continuum between sine waves and white noise in which the electronic sounds in *Gesang der Jünglinge* fall.[64]

Another original and significant feature of *Gesang der Jünglinge* was its use of a four-track tape recorder to produce a multi-channeled work with spatial movement.

Like *Gesang der Jünglinge*, *Poème Electronique*, a 1957/58 work by Edgar Varèse,[65] was also created with a combination of concrete and synthesized sounds. The concrete sounds came from both vocal and instrumental sources while the synthesized sounds were produced with sine wave and noise generators. To modify the sound Varèse made use of filtering techniques, the addition of reverb, and numerous *musique concrète* techniques, particularly the alteration of tape speed and tape splicing. However it was the performance situation that really showcased the power and innovative qualities of the piece. Varèse described the technical set-up for the original performance during the 1958 World Fair in Brussels: there were twenty amplifiers and four hundred and twenty-five loudspeakers placed around the

[64] Manion, *Ibid.*
[65] Varèse was exposed to the potential of electronic and noise based music at a concert by Rusollo's noise ensemble in 1921.

auditorium, the Phillips Pavilion which was designed in part by Iannis Xenakis,[66] grouped so as to create paths of sound as the piece was played from a three track tape.[67]

3.1.4 COMPUTER MUSIC

While the use of digital synthesis did not take hold in the synthesizer field until the 1980s, digital representation and creation of sound had been explored and expanded in the field of computer music in the late 1950s.[68] The AT&T Bell Laboratories in New Jersey were the site of the first major development in the field of computer music, it was here during the 1950s and 60s that Max Matthews developed the *Music N* series of music programming languages for digital signal processing and sound synthesis. In his 1989 article "Composing with Computers – a Survey of Some Compositional Formalisms and Music Programming Languages" Gareth Loy provides the following overview of the *Music N* languages:

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[66] Xenakis discussion about his process of designing the pavilion in *Formalized Music* demonstrates the sophistication of his compositional practices

> "Before ending this short inspection tour of events rich in the new logic which were closed to the understanding until recently, I would like to include a short parenthesis. If glissandi are long and sufficiently interlaced, we obtain sonic spaces of continuous evolution. It is possible to produce ruled surfaces by drawing the glissandi as straight lines. I performed this experiment with *Metastasis* (this work had its premiere in 1955 at Donaueschingen). Several years later, when the architect Le Corbusier, whose collaborator I was, asked me to suggest a design for the architecture of the Phillips Pavilion in Brussels, my inspiration was pin-pointed by the experiment with *Metastasis*. Thus I believe that on this occasion music and architecture found an intimate connection." (Xenakis, *Ibid.* p. 10)

[67] For a more detailed analysis of *Poème Electronique* see Robert Cogan, "Varèse: A Sonic Poetics" (Liner Notes from Neuma CD 450-74) as well as Joel Chadabe's description of the work, which including quotes from Varèse, in his book *Electric Sound: The Past and Promise of Electronic Music* Upper Saddle River: N.J: Prentice Hall, 1997 p. 60.

[68] Computer Music refers exclusively to digital signal processing and sound synthesis on the computer, a process that generates sound, whereas computer-assisted composition refers to the use of computers as a tool to facilitate part of the compositional process of acoustic works, for more detail on computer-assisted composition see footnote 2.

> 1. Synthesis algorithms are specified as combinations of unit-generators, with flexible means of configuring them into data-flow subprograms called instruments.
> 2. The activation of instruments is controlled by note statements that bind the instrument, the action times, and the acoustical parameters together. A score is a collection of note statements and instrument definitions.
> 3. Efficiency concerns are addressed by localizing the computational load into the unit-generators, and by emphasizing the use of lookup tables and simple transforms, especially for such things as generating waveforms and applying amplitude or frequency envelopes to them[69]

Matthews' *Music N* languages were written in the computer programming language Fortran. Developments in the field of general programming languages led to a number of variants written in new programming languages including *Music 11* and *Csound* in assembler, *cmusic* in C, and *clm* in Lisp. The proceeding generation of music software moved from text generated unit-generators to object-oriented graphical interfaces.

Live performances of electronic music dated from the Russolo ensemble through the combination of tape and live instruments in the 1950s and real-time manipulation of acoustic performances with electronics, such as Stockhausen's *Microphonie I*, for tam and tam and filter, and *Mantra*, for piano and ring modulator, in the 1960s. The computer offered greater potential for human-machine interaction than the standard hardware as programs could be designed with greater ease to respond to input from the performer. In the mid-seventies Matthews developed the *GROOVE* software with F. Richard Moore that included a real time conducting element, which could be integrated with Matthew's *Radio Baton* controller. Contemporary live electronics performers use software programs, like *Max*, *Csound*, and *Pd*, that allow real time digital signal processing of performances and sophisticated gestural control of software generated sounds.

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[69] Loy, *Ibid.* p. 328.

3.2 Object-Oriented Interfaces in DSP/Synthesis Software

In the 1980s, the paradigm shift in the programming world was mirrored in the world of music software development. Object-oriented languages were of particular appeal to the music software developer because they offered flexibility, through an environment that provided "extensibility of control and data structures so that programs can evolve smoothly as understanding develops".[70] The concept of everything as an object that interacts with other objects via its methods, or, to use a common analogy, as an actor that sends and receives messages from other actors, provided a better representation of musical and DSP constructs than was available in the structured programming paradigm. The object-oriented paradigm facilitates event driven design whereas the structured paradigm is better suited for procedural designs. The object-oriented languages also facilitated the design of graphical user-interfaces better than structured languages do, thus we see the shift from the *Music N* series of music languages to event driven visual environments for sound synthesis and digital signal processing. The object-oriented paradigm moved beyond a programming language abstraction towards an actual visual representation of sound creation and manipulation. This was a significant development in the field of computer music as sound creation and manipulation could now occur interactively as well as algorithmically. The gap between the hands-on approach to synthesizers and the programmed approach to computer music was bridged.

One of the first, and more successful, visually object oriented synthesis environments was the *Kyma/Platypus* workstation. The software, written in the object-oriented programming language *Smalltalk-80*, and hardware, a workstation with dedicated digital signal processors, was developed in the mid-eighties by the CERL group at the University of Illinois. The main design goal for the system was flexibility, an attribute that its developers believe was achieved through:

1) the choice of sound objects rather than standard music notation as the representation for musical signals,
2) the choice of Smalltalk-80 rather than a compiled precompiled procedural language as the programming environment,
3) the choice of a *programmable* digital signal processor (rather than a *hardwired* synthesizer) for the production of sound[71]

Another highly successful visually object-oriented synthesis environment was *Max*, developed at *IRCAM* in the mid-eighties and written by Miller Puckette. Named after Max Matthews, the original aim of the program was to control *IRCAM*'s *4X* synthesizer but *Max* grew to become a general-purpose real-time programming environment where music and multimedia control functions could be programmed and manipulated with graphical objects. The objects, which are patched together via their inputs and outputs, are able to generate and receive MIDI data, perform calculations, and store data. The FTS and MSP extensions developed in the late eighties added digital signal processing functionality to the software.

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[70] Henry Liberman, "Machine Tongues IX: Object-Oriented Programming" in Stephen Travis Pope (ed.), *The Well-Tempered Object: Musical Applications of Object-Oriented Software Technology* (Cambridge, Mass.: MIT Press, 1991) p. 18.
[71] Carla Scarletti, "The Kyma/Platypus Computer Music Workstation" in Pope, *Ibid.* p. 121.

Interestingly *Max* was written in C, a structured programming language, however it in itself has been considered an object-oriented language for sound synthesis.[72] This seeming discrepancy highlights the fact that the implementation of the object-oriented paradigm in computer-music software goes far beyond the mere use of object-oriented languages and is an intrinsic part of software, specifically graphical user-interface, conceptualisation.

Pd, also developed by Miller Puckette, was written for the PC and Linux platforms and incorporates graphics processing with control and DSP functionality. Based on the same basic design concept as *Max*, it is intended to improve on the weaknesses of *Max*. Specific improvements include better data handling through user defined data structures, the ability to manipulate sound in the frequency domain in real time, and better interaction with gestural controllers. Puckette's main goals for *Pd* is that it possess:

- Patachable objects as in Max/FTS
- A generalized notion of array to replace unify Max/FTS... objects
- Dynamic heterogeneous lists of objects living in two-dimensional coordinate spaces[73]

3.3 *Pure Gong*

Pure Gong is a two-movement piece, the first for piano and tape, the second for gong and computer. Both movements are based on the same digital synthesis processing patch

[72] Though not without some debate, for an overview of the discussions surrounding *Max* as an object-oriented synthesis language see "Editor's Note: Putting Max in Perspective" in the *Computer Music Journal* ((1993) 12:2, available at http://mitpress2.mit.edu/e-journals/Computer-Music-Journal/Documents/EdNotes/html/m-17-2.html). The article includes comments on an earlier article by Peter Desain, Henkjan Honing, Robert Rowe, Brad Garton (*Computer Music Journal* 15:1) from Roger Dannenberg, Dean Jabobs, Cort Lippe and Zack Settel, Stephen Travis Pope, Miller Puckette, and George Lewis.

[73] Puckette, Miller "Pure Data" *Proceedings, International Computer Music Conference* San Francisco: International Computer Music Association, 1996 p. 226.

created in *Pd*. Modifications implemented in the *Pd* patch include transposition, delay and ring modulation.

The *Pure Gong* cycle was initiated in September 2001 through a series of performances which achieved various levels of success. After some early setbacks, notably with *Pure Gong 1.0 alpha* and *1.1 beta*, the current arrangements, *:GONGNOG:* and *LiveGong*, were developed.

3.3.1 :GONGNOG:

The tape component of this piece was generated through the modification of a single gong sample triggered forward and backwards through a metronome function in *Pd*, the modifications of the patch were controlled by a score file or *qlist*. For the performance of the piece a speaker playing the taped component is to be placed directly over the strings of a grand piano. The piano score instructs the pianist to either silently play certain notes or depress the damper pedal. This action releases the dampers of some or all of the strings thus allowing the strings to vibrate in sympathy with various pitches found in the tape component.

3.3.2 LIVEGONG

A live gong is miked and its signal is transposed, delayed and ring modulated with the aforementioned *Pd* patch. Unlike *:GONGNOG:* where the patch was used to create a tape component, the patch is used during the performance to modify the signal of the miked gong. Like *:GONGNOG:* modification of the patch is controlled by score file.

The output of the *Pd* patch is broadcast in the performance hall, where it mixes with the acoustic resonance of the gong. One possible variation of this piece is the real-time control of the patch instead of the use of a score file.

3.4 *REAJET*

This piece was created with *Reaktor*, a modular, object-oriented synthesis environment developed by Native Instruments. The very structure of *Reajet* is intended to exploit the concept of the 'sound object'. In addition to being created with synthesis software that implements an object-oriented interface, the piece itself is made up of four 3-minute 'objects'. Each 'object' is a movement unto itself but can also be layered onto any of the other three 'objects', resulting in fifteen different combinations (arguably sixteen, but 0000 would consist only of silence). The primary aesthetic idea behind this approach is that by presenting the 'objects' in different combinations different elements of the 'objects' are exposed and emphasized. The 'objects' or movements are designed to be both individually engaging and compatible in combination.

0001	0010	0100	1000
0011 *(0001 + 0010)*	0110 *(0010 + 0100)*	1100 *(0100 + 1000)*	
0101 *(0001 + 0100)*	1010 *(0010 + 1000)*		
1001 *(0001 + 1000)*			
0111 *(0001 + 0010 + 0100)*	1110 *(0010 + 0100 + 1000)*		
1011 *(0001 + 0010 + 1000)*			
1101 *(0001 + 0100 + 1000)*			
1111 *(0001 + 0010 + 0100 + 1000)*			

Figure 3.2 Reajet Movements

All four of the basic movements were created with a modification of the prefabricated *SineBeats* instrument in Reaktor. The instrument functions as an integrated synthesizer/step sequencer, with a single noise generator and three sine generators.

The first movement, 0001, uses only the noise generator module on the *SineBeats* synthesizer. The movement is pitched low in frequency with very subtle, gradual variation. The function of this movement is as a bedrock for the other layers. The second, 0010, third, 0100, and fourth, 1000, movements are all based on sine generator modules, each movement provides its own counterpoint line, relating to both the first movement and each other.

4. CONCLUSION

The title of this paper has not yet been explicitly addressed in terms of the historical context of the use of the term *sound object*. The first explicit reference to the term was Schaeffer's use of it in its French translation, *object sonore*, in discussion of the concrete sounds that were used by *musique concrète* composers for the basis of their tape compositions. In his book, *Modern Music: The Avant Garde since 1945*, Paul Griffiths examines Schaeffer's approach.

> It was Schaeffer's aim to use those means in such a way as to free the material from its native associations, so that an event could become not just an evocative symbol but a 'sound object' amenable to compositional treatment[74]

A second reference to the term occurs frequently in the literature concerning object-oriented music software. One such example is the article "The Kyma/Platypus Computer Music Workstation" Carla Scarletti discusses to Kyma's "choice of sound objects rather than standard music notation as the representation for musical signals."[75]

These two definitions link to my two compositional approaches, the acoustic and the electronic. My acoustic approach borrows from Schaeffer's idea of discrete objects of sound (in my case the Tetrachord class) combining it with the available organizational structures of the object-oriented programming paradigm. It breaks the tetrachord from its 'native associations' of common-practice progressions while providing a structure in which the ear

[74] Paul Griffiths, *Modern Music: the Avant Garde since 1945* (New York, N.Y.: G. Braziller, 1981) p. 31.
[75] Scarletti, *Ibid.* p. 121.

can make sense of the new rules for tetrachords progressions. My electronic implementation of the term is derived from my use of software in the object-oriented ilk, the organizational aspect is derived from the process of non-linear object-interaction. In this medium the compositional process is multidimensional: it remains linear in terms of temporal movement but the real-time manipulation of timbre and signal processing adds a new dimension of development.

These compositional approaches developed from my studies of music and computer programming. My undergraduate music degree at York University exposed me to a wide array of musical styles. My particular interest lay in digital/electro-acoustic composition and renaissance theory; I combined my study of these areas through the digital realisation of a number of altered tuning systems. After completing my BFA I pursued a computer-programming diploma, which, in addition to object-oriented programming, included courses in object-oriented analysis and design.

Concurrent to my undergraduate music degree and computer-programming diploma I studied composition privately with Larysa Kuzmenko. Through these composition lessons I learned to creatively apply my traditional music theory knowledge, acquired through courses taken both as part of my undergraduate degree and privately in preparation for the Royal Conservatory of Music theory examinations. In these lessons I was also exposed to numerous twentieth century compositional processes.

My graduate studies at York provided greater exposure to 20^{th} century composers through two years of composition seminars, an early-twentieth century music theory and analysis course, and my directed readings in the work of Elliott Carter and on the issues surrounding the notation of alternate temperaments. The early twentieth century music theory and analysis course prompted me to closely examine the folk and early music influences in the works of Vaughan Williams, Bartok, and Shostakovich. This experience influenced my compositional aesthetic in the freely composed material found in the acoustic pieces *Partial Objects* and *deMusica*. My work with Carter introduced to me to his highly complex pre-compositional planning processes. My study of alternate temperament notation demonstrated that in order to achieve accurate performances the simplicity of notational alterations is key. The opportunity to prepare and teach the first year introductory course to digital and electronic music greatly expanded my knowledge and experience of computer music history and theory.

A number of my earlier pieces were key in my development as a composer. *Octatonic* (1999), a piece for string quartet, provided my first experience working with the acoustic scale; I later continued my exploration of the possibilities of this pitch material in *For Continuum* (2001). *Ad Herennium* (2001), a piece for piano based on a number of melodic fragments that represented rhetorical devices found in Cicerco's *Rhetorica Ad Herennium*, allowed me to work out a number issues surrounding pre-compositional preparation. *Deconstruction of a String Quartet* (1999), a digital remix of a midi recording of *Octatonic*, represents one of my early forays into the creative applications of electronic noise and distortion, an aesthetic that pervades both my sample-based pieces, such as *Twelve Variations on Tone Row Conversations* (2001) and *Door Vinaigrettes* (2001), and synthesis pieces, such as *Reaject*.

GLOSSARY

algorithmic – a piece of music whose compositional process was, in some part, based on a logical sequence or set of rules.

Boolean – a variable which can only be assigned the values of 0 (traditionally assigned the macro FALSE) or 1 (traditionally assigned the macro TRUE).

cents –a unit the size of 1/100 of a semitone

child class –a class derived from another (parent) class, thus inheriting its logic and data

class *(distinct from pitch classes)* – in object-oriented programming a class is a structure where the data is secured through the encapsulation of it with the class' logic

digital signal processing (DSP) – the manipulation of a digitized audio signal

encapsulation – the binding of data and logic in class structures

equal-tempered – a temperament where all twelve fifths are detuned by 1/12 of the Pythagorean comma

function – a grouping of programming logic that is used a number of times in the running of a program

global data – data that can be accessed by any function in the program

harmonic series – a naturally occurring acoustic phenomena of frequencies in whole-number ratios above a sounded fundamental frequency

hertz – unit of measurement for frequency

instance – a run-time realization of a class definition

local data – data that can only be accessed within the function where it is declared

main - the main loop of logic in a program

member – a variable that is created within the definition of a class

numerological – the use of numbers with symbolic implications in the compositional process

object-oriented – a computer programming paradigm where logic and data is bound into objects, or classes

parent class - a class from which a child class is derived, its data and logic is passed to the child class

partials – frequencies that occur in whole-number ratios above a sounded fundamental frequency

patch – a file containing and organizing the synthesis and digital signal processing routines generated by computer music software

'natural' intonation – the production of intervals that adhere to the tunings found in the harmonic series

score file – a file containing time-specified modifications to a patch

sound synthesis - the combination of waveforms to produce new timbres

structured programming - a programming paradigm where logic sequences used a number of times in the running of a program are groups together into functions

variable – a named space reserved by a computer program to hold data

APPENDIX A – AVAILABLE TETRACHORDS

0123	0134	0145	0156	0167
0124	0135	0146	0157	
0125	0136	0147		
0126	0137			
0127				
0234	0245	0256	0267	
0235	0246	0257		
0236	0247			
0237				
0345	0356	0367		
0346	0357			
0347				
0456	0467			
0457				
0567				
1234	1245	1256	1267	
1235	1246	1257		
1236	1247			
1237				
1345	1356	1367		
1346	1357			
1347				
1456	1467			
1457				
1567				
2345	2356	2367		
2346	2357			
2347				
2456	2467			
2457				
2567				
3456	3467			
3457				
3567				
4567				

APPENDIX B - RHYTHMIC DURATIONS

Number of 16th Notes	Resultant Duration	Letter Code
1		A
2		B
3		C
5		D
9		E
11		F
13		G
17		H
19		I
23		J
29		K
31		L

Appendix C – Possible Rhythmic Duration Combinations

A	B	C	D	E	F	G	H	I	J	K	L
1	2	3	5	7	11	13	17	19	23	27	31

ABCE DFGI HJKA	ABCG DEFK HIJC	ABCK DEFC GHIF	ACEG BFIK DJAE	ACEK BFHE DILH	AEGK BHJG CLEJ
LBCD EFGH IJKL	LABF GDEJ KHIB	JLAI BKDA ECGD	HCBI LFDA GJHB	GAKL JBEK CDHE	DKHE FGLH IJKL
	CLAE FGDI JKHA	HFJB LIBJ KAEB	KCLD EFGH IJKL	FGLH IJKL	
	BCLD EFGH IJKL	CDHE FJKH IJKL		ACEK	

APPENDIX D - C++ CODE FOR SOUNDOBJECTS ALGORITHM

SOUNDOBJECTS.H

```
#include <iostream.h>

class Tetrachord{
private:
  int notes[4];
  int retune[4];
  char rhythmic_dur[4];
public:
  bool used = FALSE;
public:
  Tetrachord(int num);
  populate_notes(int num);
  populate_retune(int num);
  populate_rhythm(int num);
  ret_values(int *note);
  mark_used();
}

Tetrachord::Tetrachord(num){
  populate_notes(num);
  populate_retune(num);
  populate_rhythm(num);
}

Tetrachord::populate_notes(num){
  for (int i = 0; i < 4; i++){
    notes[i] = possibletc[num][i];
  }
}

Tetrachord::populate_retune(num){
  int diff;
  retune[0] = 0;
  for (int i = 1; i < 4; i++){
    diff = possibletc[num][i] - possibletc[num][0];
    if (diff = 1){
      retune[i] = +4;
    }
```

```
    else if (diff = 2){
      retune[i] = -16;
    }
    else if (diff = 3){
      retune[i] = -2;
    }
    else if (diff = 4){
      retune[i] = +2;
    }
    else if (diff = 5){
      retune[i] = -16;
    }
    else if (diff = 6){
      retune[i] = -4;
    }
    else if (diff = 7){
      retune[i] = -12;
    }
  }
}

Tetrachord::populate_rhythm(num){
  for (int i = 0; i < 4; i ++){
    rhythmic_dur[i] = possiblerd[num][i];
  }
}

Tetrachord::ret_values(*note){
  for (int i = 0; i < 4; i++){
    note[i] = notes[i];
  }
}

Tetrachord::mark_used(){
  used = TRUE;
}
```

SOUNDOBJECTS.CPP

```
#include "SoundObjects.h"
#def A 1
#def B 2
#def C 3
```

```
#def D 5
#def E 7
#def F 11
#def G 13
#def H 17
#def I 19
#def J 23
#def K 27
#def L 31
const int possibletc[70][4] =
  "0123","0134","0145","0156","0167","0124","0135","0146","0157","0125",
  "0136","0147","0126","0137","0127","0234","0245","0256","0267","0235",
  "0246","0257","0236","0247","0237","0345","0356","0367","0346',"0357",
  "0347","0456","0467","0457","0567","1234","1245","1256","1267","1235",
  "1246","1257","1236","1247","1237","1345","1356","1367","1346","1357',
  "1347","1456","1467","1457","1567","2345","2356",'2367","2346",'2357",
  "2347","2456","2467","2457","2567","3456",'3467","3457","3567",'4567";

const char possiblerd[54][4] =
  "ABCE","DFGI","HJKA","ABCG","DEFK","HIJC","ABCK","DEFC","GHIF",
  "ACEG","BFIK","DJAE","ACEK","BFHE","DILH","AEGK","BHJG","CLEJ",
  "LBCD","EFGH","IJKL","LABF","GDEJ","KHIB","JLAI","BKDA","ECGD",
  "HCBI","LFDA","GJHB","GAKL","JBEK","CDHE","DKHE","FGLH","IJKL",
  "CLAE","FGDI","JKHA","HFJB","LIBJ","KAEB","KCLD","EFGH","IJKL",
  "BCLD"."EFGH"."IJKL","CDHE"."FJKH"."IJKL","FGLH"."IJKL"."ACEK";

void sus_notes(Tetrachord &next_tetrachord; int &next_notes, int *sustained_notes, bool
*sustained);

void main(void){
  int i, j, k; //iteration counters
  bool done = FALSE; //flag
  bool found = FALSE; //flag
  bool more = TRUE; //flag
  bool sustained = 0; //flag
  int current_notes[4]; // holds note values in current Tetrachord
  int next_notes[4]; // holds note values in potential next Tetrachord
  int sustained_notes[2]; //holds notes to be sustained from current to next

  class tetrachords[70]; //array of available classes
  class res_tetrachords[70]; //array of resultantant classes

  //fills array of all possible tetrachords
  for (i = 0; i < 70; i++)
  {
```

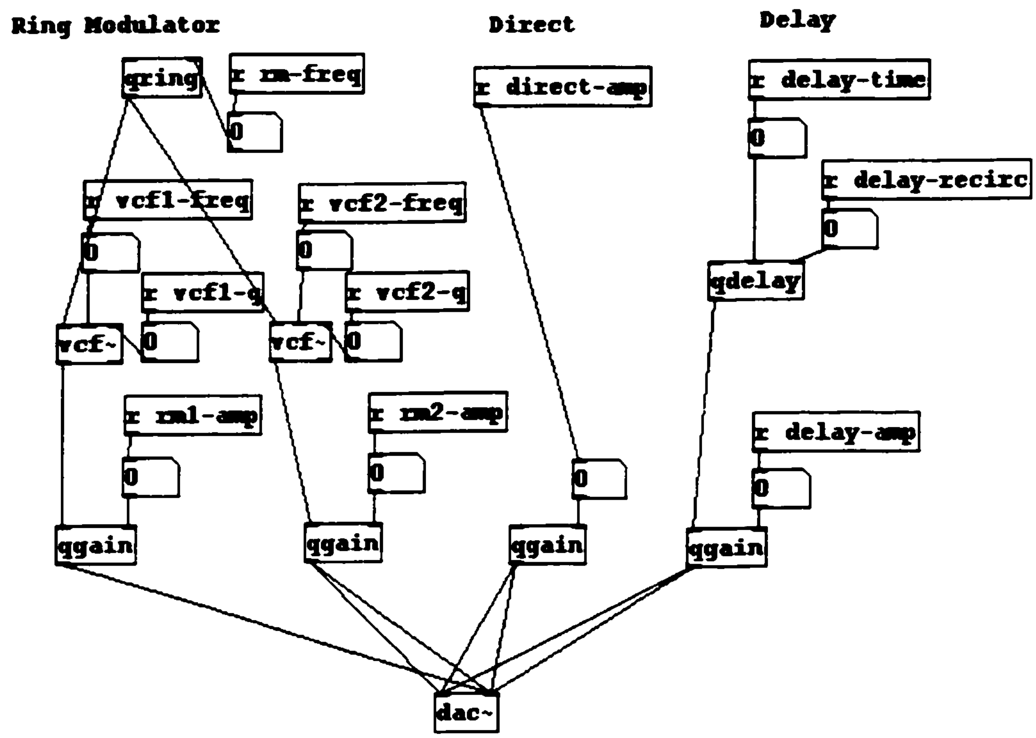
```
  tetrachords[i] = new tetrachords(i);
}
//creates an instance of the Tetrachord class called "current"
//stores a copy of the instance of the current Tetrachord
//and copies relevant information to local variables
res_tetrachords[0] = new class current = tetrachords[0];
current::ret_values(*current_notes);
sustained_notes[0] = current_notes[1];
sustained_notes[1] = current_notes[2];

//creates an instance of the Tetrachord class called "next"
//stores a copy of the instance of a potential Tetrachord
//and copies the note information to a local array
new class next_tetrachord = tetrachords[1];
next_tetrachord::ret_values(*next_notes);
  //loop to sort through and determine the sequence of
//resultant tetrachords
while (done == TRUE)
{
  //loop to input resultant tetrachords
  for (i = 1; i < 70 || more == FALSE; i++)
  {
    //loop to navigate through potential tetrachords
    for (j = 0; found == TRUE || j < 70; j++)
    {
      // checks if progression to tetrachord is allowed
      // proceeding logic sorts through tetrachords until a matching one is found
      if (((sustained_notes[0]==ret_values[0]) || (sustained_notes[0]==ret_values[1]) ||
      (sustained_notes[0]==ret_values[2]) || (sustained_notes[0]==ret_values[3])) &&
      ((sustained_notes[1]==ret_values[0]) || (sustained_notes[1]==ret_values[1]) ||
      (sustained_notes[1]==ret_values[2]) || (sustained_notes[1]==ret_values[3])))
      {
        res_tetrachords[i] = next_tetrachord;
        current = next_tetrachord;
        if (possibletc[i + 1]::used == FALSE)
        {
          next_tetrachord = possibletc[i + 1];
          get_notes(&next_tetrachord, *next_notes, *sustained_notes, *sustained);
        }
        else
        {
          for (l = 0, unused = FALSE; l < 70 || unused = TRUE; l++)
          {
            if (possibletc[l]::used == FALSE)
```

```
              {
                next_tetrachord = possibletc[l];
                get_notes(&next_tetrachord, *next_notes, *sustained_notes,
                  *sustained);
                unused = TRUE;
              }
            }
          }
          found = TRUE;
        }
        else
        {
          for (l = 0, unused = FALSE; l < 70 || unused = TRUE; l++)
          {
            if (possibletc[l]::used == FALSE)
            {
              next_tetrachord = possibletc[l];
              get_notes(&next_tetrachord, *next_notes, *sustained_notes,
                *sustained);
              unused = TRUE;
            }
          }
        }
      }
      found = FALSE;
    }
  }
}

// function copies information from new "next" Tetrachord to local variables
void sus_notes(&next_tetrachord, &next_notes, *sustained_notes, *sustained){
  next_tetrachord::ret_values(*next_notes);
  if (sustained = 0)
  {
    sustained_notes[0] = current_notes[0];
    sustained_notes[1] = current_notes[3];
    sustained = 1;
  }
  else
  {
    sustained_notes[0] = current_notes[1];
    sustained_notes[1] = current_notes[2];
    sustained = 0;
  }
}
```

APPENDIX E - *PD* DSP PATCH USED FOR *PUREGONG*



DISCOGRAPHY

CONTEMPORARY COMPOSERS

Babbitt, Milton. *Philomel.* New York, NY: New World Records, 1995. 80466-2

Bartok, Bela. *The Six String Quartets.* Germany: Philips, 1968. 442-284-2

Berg, Alban. *Streichquartett op. 3; Lyrische Suite : für Streichquartett.* Düsseldorf : Koch Schwann Musica Mundi, 1986. CD 310 005 H1

Berio, Luciano. and Maderna, Bruno. *Berio/Maderna.* Amsterdam: BV Haast, 1995. CD 9109 BV

Boulez, Pierre. *Le marteau sans maître ; Notations pour piano ; Structures pour deux pianos, livre II.* New York, N.Y.: CBS Records Masterworks, 1989. MK 42619

Ligeti, György. *Mechanical Music.* New York, N.Y.: Sony Classical, 1997. SK 62310

Norman, Katharine. *Transparent.* England: Metier, 2000.

Schaeffer, Pierre. *L'oeuvre musicale.* Paris , France: INA-GRM, 1990. INA C 1006-9

Schaeffer, Pierre. *Solfège de l'objet sonore.* Paris, France: INA-GRM, 1998. 275602

Schoenberg, Arnold. *Pierrot Lunaire, Lied der Waldtaube, Erwartung.* New York, NY: Sony, 1993. SMK 48 466

Schoenberg, Arnold. *String Quartets.* Germany: Philips, 1978. 464 046-2

Shostakovich, Dmitri. *The String Quartets.* London: London, 1975. 455 776-2

Stockhausen, Karlheinz. *Elektronische Musik 1952-1960.* Kürten, Germany: Stockhausen 1991. 3 Stockhausen

Stockhausen, Karlheinz. *Hymnen: elektronische Musik.* Kürten, Germany: Stockhausen Verlag, 1991. 10 Stockhausen

Stockhausen, Karlheinz. *Kontakte.* Mainz, Germany: Wergo, 1992. WER 6009-2

Stockhausen, Karlheinz. *Mikrophonie I Mikrophonie II* Kürten, Germany: Stockhausen, 1995. 9 Stockhausen

Varèse, Edgard. *The Complete Works.* New York, NY: London Records, 1998. 289 460 208-2

Various Composers. *The Art of the Theremin.* Performed by Clara Rockmore Santa Monica, CA: Delos, 1987. DE 1014

Various Composers. *Cocks crow, dogs bark: new compositional intentions.* Lebanon, NH: Frog Peak Music, 1998. ISAST 7

Various Composers. *V1/Computer Music @ CCRMA.* Stanford, Calif.: CCRMA, 1997. RM101

Various Composers. *V2/Computer Music @ CCRMA.* Stanford, Calif.: CCRMA, 1997. RM102

Various Composers. *Electro acoustic music: classics.* Acton, MA: Neuma, 1990. 450-74

Various Composers. *New music for electronic and recorded media: women in electronic music.* New York, NY:1750 Arch Records 1765, 1977. CRI: CD 728.

Various Composers. *Piano works of New Viennese School.* Japan: Denon, 1986. 60CO-1060-61

Various Composers. *OHM: the early gurus of electronic music: 1948-1980.* Roslyn, NY: Ellipsis Arts. 2000. CD3670 (CD3671--CD3673).

Webern, Anton. *Complete Works Opp. 1-31.* London: Sony, 1978. SM3K 45845

Xenakis, Iannis. *Palimpsest : for ensemble ; Épéi : for ensemble ; Dikhthas : for violin and piano ; Akanthos : for voice and ensemble.* Mainz, Germany: Wergo, 1990. WER 6178-2

ELECTRONIC ARTISTS

Amorphous Androgynous. *Tales of Ephidrino*. London: Virgin Records, 1993. V2 0777 7 88238 2 7

Aphex Twin. *Aphex Singles Collection.* Japan: WEA Japan. 1996

Autechre. *Amber*. Sheffield, UK: Warp Records, 1994. WARPLP25

Autechre. *Cornfield.* Sheffield, UK: Warp Records, 2001. WARPLP128

Boards of Canada. *Music has the Right to Children.* Sheffield, UK: Warp Records, 1994. WARPLP55

Future Sound of London. *Lifeforms.* London: Virgin Records, 1994. V2 7243 8 39433 2

Neotropic. *15 Levels of Magnification.* Montreal, Canada: Ninja Tunes, 2001. NTONE 44

Neotropic. *La Prochaine Foise.* London: Ninja Tunes, 1998. NTONE CD 30

Neotropic. *Mr Brubaker's Strawberry Alarm Clock.* Montreal, Canada: Ninja Tunes, 1998. NTONE CD 30

Mu-ziq. *Royal Astronomy.* London: Astralwerks. 1999. ASW 6275-1

Plaid. *333 Not for Threes.* Sheffield, UK: Warp Records, 1997. WARPLPS4

RAC. *Structures.* Sheffield, UK: Warp Records, 1996. WAP71

Seefeel. *Succour.* Sheffield, UK: Warp Records, 1995 WARPLP28

Speedy J. *A Shocking Hobby.* London: Mute Records, 2000. NOMU74LP

Squarepusher. *Hard Normal Daddy.* Sheffield, UK: Warp Records, 1997. WARP50LP

Tobim, Amon. *Permutation.* Ninja Tunes, 1997. ZENCD 36

Various Artists. *We Are Reasonable People.* Sheffield, UK: Warp Records, 1998. WAP100

BIBLIOGRAPHY

Agon, Carlos, Assyag, Gerard, Delerue, Olivier, Rueda, Camilo "Objects, Time and Constraints in Open Music" in *Proceedings: 1998 International Computer Music Conference*, p. 406-15. San Francisco, CA: Computer Music Association, 1998.

Aristoxenus "*Harmonic Elements*" in O. Strunk (ed.) *Source Readings in Music History: Antiquity and the Middle Ages.* New York, N.Y.: W. W. Norton & Company, 1965. p. 25-33.

Arsenault, Linda M. "Iannis Xenakis's Achorripsis: The Matrix Game" in *Computer Music Journal* 26:1 (2002) p. 58-72.

Backus, John. *Acoustical foundations of Music.* New York, N.Y.: W.W. Norton & Company Inc., 1969.

Baker, Robert and Hiller, Lejaren "Computer Cantata: A Study in Compositional Method" *Perspective of New Music* 3 (1964) p. 68.

Barbera, André. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001 S.v. "Pythagoras" Vol. 20, p. 642-3.

Barbour, J. Murray. "The Persistence of the Pythagorean Tuning System" *Scripta Mathematica* 1 (1933): p. 286-304.

Barker, Andrew (ed.). *Greek Musical Writings, Vol II: Harmonic and Acoustic Theory.* New York: Cambridge University Press, 1989. p. 28-52.

Basart, Ann Phillips. *Serial music: a classified bibliography of writings on twelve-tone and electronic music.* Westport, Conn.: Greenwood Press, 1976.

Bélis,Annie *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. (London: Macmillan, 2001) S.v. "Aristoxenus" Vol. 2, p. 1-2.

Blackwood, Easley. *The Structure of Recognizable Diatonic Tunings*. Princeton, N.J.: Princeton University Press, 1985.

Boethius, Anicius Manlius Serverinus *Fundamental of Music.* Translated into English by Claude V. Palisca. New Haven, Conn.: Yale University Press, 1989.

Born, Georgina. *Rationalizing Culture: IRCAM, Boulez, and the Institutionalization of the Musical Avant-Garde.* Berkeley, Calif.: University of California Press, 1995.

Boulanger, Richard ed. *The Csound Book: Perspectives in Software Synthesis, Sound Design, Signal Processing, and Programming*. Cambridge: Mass: MIT Press, 2000.

Boyle, Hugh and Lloyd, LL S. *Intervals, Scales & Temperament*. London: Macdonal Press, 1963.

Burelow, George J. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001. S.v. "Andreas Werkmeister" Vol. 20, p. 343-5.

Burns, Kristine H. *The History and Development of Algorithms in Music Composition.* Miami FL.: Florida International University, 1994 p. 82.

Chadabe, Joel. *Electric Sound: The Past and Promise of Electronic Music.* Upper Saddle River, N.J.: Prentice Hall, 1997.

Cogan, Robert. "Varèse: A Sonic Poetics" Liner Notes from Neuma CD 450-74.

Cook Perry R. *Music, Cognition, and Computerized Sound: An Introduction to Psychoacoustics.* Cambridge, Mass.: MIT Press, 1999.

Cope, David. *The Algorithmic Composer.* Madison, Wis.: A-R Editions, 2000.

Cope, David. "An Expert System for Computer-assisted Composition" *Computer Music Journal* (11:4) 1987 p. 3-47.

Cope, David. *Computer and Musical Style*. Oxford: Oxford University Press, 1991.

Cope, David. *New Directions in Music.* Prospect Heights, IL.: Waveland Press, 1998.

Cope, David. *Virtual Music: Computer Synthesis of Musical Style.* Cambridge, Mass.: MIT Press, 2000.

Davis, Hugh. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001. S.v. "Synthesizer" Vol. 24, p. 851-2.

Deutsch, Herbert. *Synthesis: An Introduction to the History, Theory and Practice of Electronic Music.* New York, N.Y.: Alfred Publishing Company Inc. 1986. p. 19.

Dhomont, Francis. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001. S.v. "Pierre Schaeffer" Vol. 22, p. 430.

Dodge, Charles. *Computer Music (2nd Ed.).* New York, N.Y.: Schirmer Books, 1997

Dorbrian, C. *Max Reference*. Opcode Systems Inc., 1995.

Dunn, David. "A History of Electonric Music Pioneers" in Richard Kostelanetz and Joseph

Darby (eds.) *Classic Essays on Twentieth-Century Music.* New York, N.Y.: Schirmer Books, 1996.

Ernest, David. *The Evolution of Electronic Music.* New York, N.Y.: Schirmer Books, 1977.

Ernst, David. *Musique Concrète*. Boston, Mass.: Crescendo Publishing Company, 1972.

Fields, Kenneth. "PostFormalism" in *Proceedings: 1999 International Computer Music Conference.* 531-4. San Francisco, CA: Computer Music Association, 1999.

Forte, Allen. *The Structure of Atonal Music.* New Haven, Conn.: Yale University Press, 1973.

Gogins, Michael "Music Graphs for Algorithmic Composition and Synthesis with an Extensible Implementation in Java" in *Proceedings: 1998 International Computer Music Conference,* p. 369.76. San Francisco, CA: Computer Music Association, 1998.

Griffiths, Paul. *Modern Music: A Concise History.* New York, N.Y.: Thames and Hudson, 1994.

Griffiths, P. *Modern Music: The Avant-Garde Since 1945.* New York, N.Y.: George Braziller, 1981.

Griffiths, Paul. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001. S.v. "Serialism" Vol. 23, p. 116-23.

Hamel, Keith and Roeder, John "A General-purpose Object-oriented System for Musical Graphics." in *Proceedings: 1989 International Computer Music Conference.* 260-263. San Francisco, CA: Computer Music Association, 1989.

Helmholtz, Hermann. *On the Sensation of Tone.* New York, N.Y.: Dover Publications, 1954 p. 324-5.

Howat, Roy. *Debussy in Proportion: A musical analysis.* Cambridge: Cambridge University Press, 1983. p. 1-10.

Howe, H.S., Jr., and Kassler, Michael. "Computers and Music " in Stanley Sadie (ed.) *New Grove Dictionary of Music and Musicians.* Washington, DC: Grove Dictions of Music Inc, 1980, p. 603-15

Jarmen, Douglas. *The Music of Alban Berg.* London: Faber & Faber, 1979. p. 159-61.

Jarman, Douglas. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001. S.v. "Alban Berg" Vol. 3, p. 318.

Jarocinski, Stefan. *Debussy: impressionism and symbolism.* Translated from the French by Rollo Myers. London: Eulenburg, 1976.

Kaper, Hans G. "Formalizing the Concept of Sound" in *Proceedings: 1998 International Computer Music Conference*, p. 387-90. San Francisco, CA: Computer Music Association, 1998.

Kostka, Stefan. *Materials and Techniques of Twentieth Century Music.* Upper Saddle River, N.J.: Prentice Hall, 1999. p. 244.

Lassfolk, Kai. "Sound Processing Kit: An Object Oriented Signal Processing Framework." in *Proceedings: 1999 International Computer Music Conference*, p. 422-4. San Francisco, CA: Computer Music Association, 1999

Leibowitz, René. *Schoenberg and his School: the Contemporary Stage of the Language of Music.* Translated from the French by Dika Newlin. New York, N.Y. : Philosophical Library, 1949.

Lendrai, Erno. *The Workshop of Bartok and Kodaly.* Budapest: Edito Musica 1983. p. 52.

Lerdahl, F and Jackendoff, R. *A Generative Theory of Tonal Music.* London: MIT Press, 1983.

Li, Tang-Chun "Creating Music in a Machine Age: the Relationships between Computer Tools, Composers, and Music making Machines" in *Proceedings: 1999 International Computer Music Conference*, p. 204-7. San Francisco, CA: Computer Music Association, 1999.

Liberman, Henry "Machine Tongues IX: Object-Oriented Programming" in Stephen Travis Pope (ed.), *The Well-Tempered Object: Musical Applications of Object-Oriented Software Technology* (Cambridge, Mass.: MIT Press, 1991).

Lindley, Mark. "Pythagorean Intonation and the Rise of the Triad" in *Royal Musical Association Research Chronicle* 16 (1980): p. 4-61.

Lindley, Mark. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001 S.v. "Pythagorean Intonation" Vol. 20, p. 643-5.

Lipperman, Edward A. *Musical Thought in Ancient Greece.* New York, N.Y.: Columbia University Press, 1975 p. 144-53.

Loy, D. Gareth "Composing with computers: A survey of some compositional formalisms and music programming languages." in Max Matthews and J Pierce (eds.) *Current Directions in Computer Music Research.* Cambridge, Mass.: MIT Press, 1989.

Maconie, Robin. T*he Works of Karlheinz Stockhausen.* Oxford: Clarendon Press, 1996. p. 119.

Macran,Henry. *The Harmonics of Aristoxenus.* Oxford: Clarendon Press, 1902 p. 25-33.

Manion, Michael. "From tape loops to MIDI: Karlheinz Stockhausen's Forty Years of Electronic Music" <http://www.stockhausen.org/tape_loops.html> 16 May, 2002.

Matthews, Max. *The Technology of Computer Music.* Cambridge, Mass.: MIT Press, 1969.

Mellinger, David K., Garnett, G. E., and Mont-Reynaud, Bernard "Virtual Digital Signal Processing in an Object-Oriented System" *Computer Music Journal* (13:2) 1989.

Moore, Richard. *Elements of Computer Music.* Englewood Cliff, N.J.: Prentice Hall, 1990.

Nattiez, Jean-Jacques. *The Boulez Cage Correspondence.* Cambridge: Cambridge University Press, 1993.

Partch, Harry. *Genesis of a Music.* New York: Da Capo Press, 1974.

Pope, Stephen Travis "Introduction to MODE: The Music Object Development Environment" in Stephen Travis Pope ed. *The Well-Tempered Object: Musical Applications of Object-Oriented Software Technology.* Cambridge Mass.: MIT Press, 1991.

Pope, Stephen Travis "Machine Tongues XI: Object-Oriented Software Design" *Computer Music Journal* (13:2) 1989.

Povall, R. "Composition in Interactive Environments" *Journal of New Music Research*, (24:2) 1995 p. 109-120

Puckette, Miller and Zicarelli, David. *MAX - An Interactive Graphic Programming Environment.* Palo Alto, Calif.: Opcode Systems, 1990.

Puckette, Miller. "Pure Data" *Proceedings, International Computer Music Conference* San Francisco: International Computer Music Association, 1996. p. 226.

Puckette, Miller "Pure Data: another integrated computer music environment." In *Proceedings: Second Intercollege Computer Music Concerts, Tachikawa, Japan*, 1996. p. 37-41.

Rameau, Jean-Philippe. *Treatise on Harmony.* Translated from the English by Philip Gossett. New York, N.Y.: Dover Publications, 1971.

Ramos, Bartolmé. "From the *Musica Practica.*" in O. Strunk's (ed.) *Source Readings in Music History: The Renaissance* New York, N.Y.: W. W. Norton & Company, 1965. p. 11-14.

Read, Gardner. *20th-Century Microtonal Notation.* New York: Greenwood Press, 1990.

Richter, Lukas. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001. S.v. "Didymus" Vol. 7, p. 326-7.

Roads, Curtis. *Composing Grammars (2nd ed.)* San Francisco, Calif.: CMA, 1978.

Roads, Curtis. *The Computer Music Tutorial.* Cambridge, Mass.: MIT Press, 1996.

Roads, Curtis. *The Music Machine.* Cambridge, Mass.: MIT Press, 1989.

Rowe, Robert. " A Self-Critical Compositional Algorithm" in *Proceedings: 1991 International Computer Music Conference*, p. 250-3. San Francisco, CA: Computer Music Association, 1991.

Rowe, Robert. *Machine Musicianship.* Cambridge Mass.: MIT Press, 2001.

Sander, Ernest H. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 1980. S.v. "Isorhythm" Vol. 9, p. 351-4.

Scarletti, Carla "Kyma: An Object Oriented Language for Music Composition" in *Proceedings: 1987 International Computer Music Conference*, p. 49-56. San Francisco, CA: Computer Music Association, 1987.

Scaletti, Carla. "The Kyma/Platypus Computer Music Workstation" *Computer Music Journal* (13:2) 1989.

Schaeffer, Pierre and A. Moles. *A la Recheroeh d'une Musique Concrète.* Paris: Edition deu Seuil, 1952.

Schaeffer, Pierre. *Traité des Object Musicaux.* Paris: Editions du Seuil, 1977.

Schaeffer, Pierre. *La Musique concrète.* Paris: Presses universitaires de France, 1967.

Simms, Bryan. *Schoenberg, Berg, and Webern: a companion to the second Viennese school.* Westport, Conn.: Greenwood Press, 1999.

Slobada, J. *The Musical Mind.* Oxford: Clarendon Press 1985.

Smith-Brindle, Reginald. *Serial Composition.* London: Oxford University Press, 1966

Stern, Colin. *Arnold Shoenberg: the Composer as Numerologist.* Lewinston, N.Y.: E. Mellen Press, 1993.

Stockhausen, Karlheinz *Stockhausen on Music.* New York, N.Y.: Marion-Boyars, 1989

Stuckenschmidt, Hans Heinz. *Twentieth Century Music.* Translated from the German by Richard Deveson. New York, N.Y.: McGraw-Hill, 1969.

Supper, Martin "A Few Remarks on Algorithmic Composition" *Computer Music Journal* (25:1) 2001 p. 48-53

Tatlow, Ruth. *Bach and the Riddle of the Number Alphabet.* Cambridge: Cambridge University Press, 1991.

Tatlow, Ruth. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001. S.v. "Fibonacci Series" Vol. 8, p. 765.

Tatlow, Ruth. *New Grove Dictionary of Music and Musicians*, Sadie, Stanley, ed. London: Macmillan, 2001. S.v. "Numbers and music" Vol. 18 p. 231-4.

Teufel, B. *Organization of Programming Languages* Wein, NY: Springer-Verlag, 1991.

Thomas, M.T. "Vivace: A Rule Based AI System for Composition." in *Proceedings: 1985 International Computer Music Conference*, p. 267-74. San Francisco, CA: Computer Music Association, 1985.

Todd, Peter M. "A connectionist approach to algorithmic composition" in Peter M. Todd and D. Gareth Loy (eds.) *Music and Connectionism* Cambridge, Mass.: MIT Press, 1991

Warren, Charles W. "Brunelleschi's Dome and Dufay's Motet" in *Music Quarterly* 59 (1973) p. 92-105.

Wright, Craig. "Dufay's *Nuper Rosarum Flores*, King Solomon's Temple, and the Veneration of the Virgin" *Journal of the American Musicological Society* 47 (1994) p. 395-439.

Vaggione, Horacio "Some Ontological Remarks about Music Composition Processes" *Computer Music Journal* (25:1) 2001 p. 54-61

Varèse, Edgard. "The Liberation of Sound" in Richard Kostelanetz and Joseph Darby (eds.) *Classic Essays on Twentieth-Century Music* New York, N.Y.: Schirmer Books, 1996.

Vicentino, Nicola, 1576. *Antica musica ridotta alla moderna prattica.* English *Ancient music adapted to modern practice* translated with introduction and notes by Maria Rika Maniates; edited by Claude V. Plasica. New Haven: Yale University Press, 1996.

Wilkinson, Scott R. *Tuning In: Microtonality in Electronic Music.* Hal Leonard Books, 1988

Winkler, Todd. *Composing Interactive Music: Techniques and Ideas Using Max.* Cambridge Mass: MIT Press, 1998.

Winsor, Phil. *Automated Music Composition.* Denton, Tex.: University of North Texas Press. 1989

Xenakis, Iannis. *Formalized Music.* Bloomington, Ind.: Indiana University Press, 1971.

Zarlino, Gioseffe, 1558 *Istitutioni harmoniche. Pt 3.* English *The art of counterpoint: Part three of Le institutioni harmoniche* translated by Guy A. Marco and Claude V. Palisca. New York: Norton, 1976.

Zarlino, Gioseffe, 1558 *Istitutione harmoniche. 4a pt.* English *On the modes: part four of Le institutioni harmoniche* translated by Vered Cohen; edited with an introduction by Claude B Palisca. New Haen: Yale University Press, 1983.