Musical Notation & Representation

Music 253/CS 275a
Stanford University
Craig Stuart Sapp & Mauricio Rodriguez
January 2017

Representing Music

Two main categories:

- For **Performance** (used as memory aid and for non-aural transmission)

  Usually not a complete representation (some discretion left to performer)
  - Usually written, but also Guidonian hand is a spatial representation of music for education and memorization.

- For **Analysis**

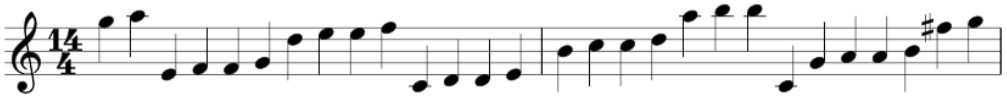
  Usually highlights a specific aspect of the music (reductive)
  - Graphical representations (visualizations)
  - Digital representations (computational analysis)
  - Audio-based analysis (such as spectrograms)

Also:

- Sonification: reverse process on converting data into sound.

Oldest Known Music Notation

Old Babylonian cuneiform musical notation. 2000-1700 BC



2 double columns, each of 7 ruled lines with numbers in Old Babylonian cuneiform tablature notation, with headings, "intonation" and "incantation", respectively.

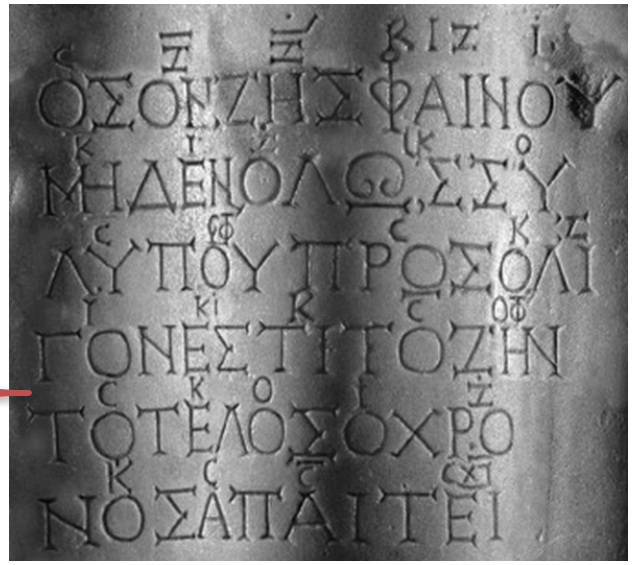
Two ascending 7-note scales to be played on a 4-stringed lute tuned in ascending fifths.

http://ww.schoyencollection.com/music_files/ms5105.jpg
http://ww.schoyencollection.com/music.html

Music Notation in Ancient Greece

Oldest complete notated song (~1st century AD)

Seikilos epitaph



C Z Ż K I Z Ī

Ὅ σον ζῇς φαί νου

Κ I Ż Ī Κ O C ΟΦ

μη δὲν ὅ λως σὺ λυ ποῦ

C K Z İ K̇İ K C ΟΦ

πρὸς ὀ λί γον ἐσ τὶ τὸ ζῆν

C K O İ Ż K̇ C C ΧΓ

τὸ τέ λος ὁ χρό νος ἀπ αι τεῖ.

http://en.wikipedia.org/wiki/Seikilos_epitaph

Music Notation in Ancient Greece

C Z Ż K I Z Ī

Ὅ σον ζῇς φαί νου

While you live, shine

K I Ż Ī K O C OΦ

μη δὲν ὅ λως σὺ λυ ποῦ

Have no grief at all

C K Z I K̇I K C OΦ

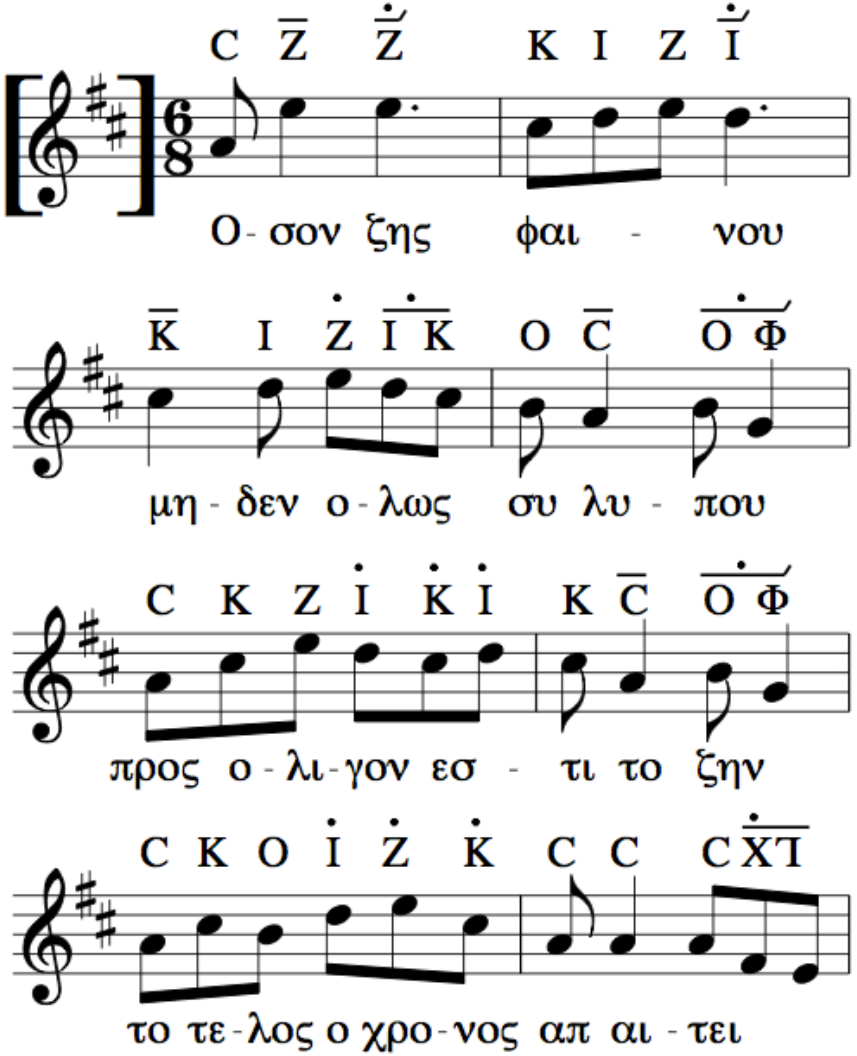
πρὸς ὀ λί γον ἐσ τὶ τὸ ζῆν

Life exists only for a short while

C K O I Ż K C C CX̄T

τὸ τέ λος ὁ χρό νος ἀπ αι τεῖ.

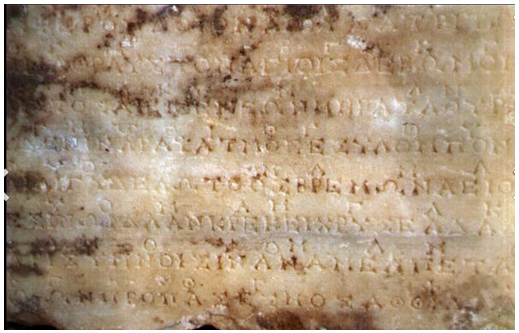
And time demands its toll



http://en.wikipedia.org/wiki/Seikilos_epitaph

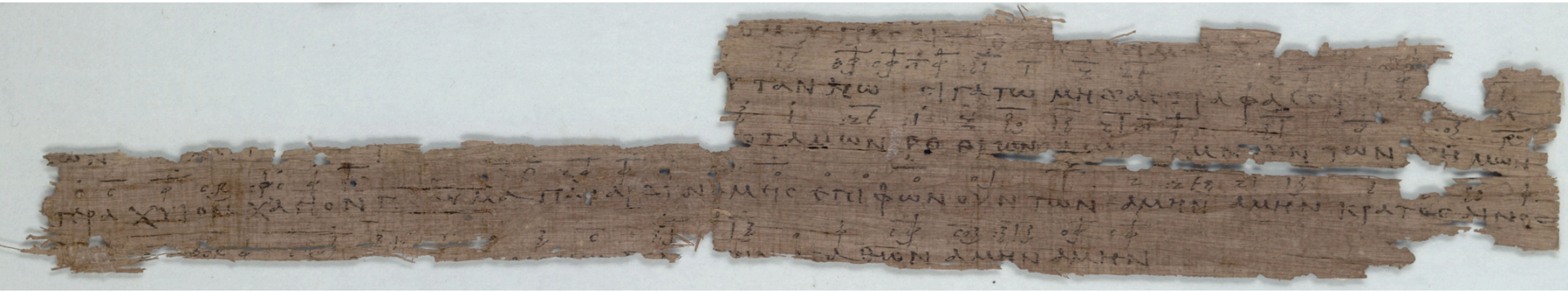
Performed on a hydraulis: https://www.youtube.com/watch?v=P4_iWkP24Ww#t=7

Music Notation in Ancient Greece



2nd century BC
Earliest surviving composition with a known composer (Athenios son of Athenios)

http://en.wikipedia.org/wiki/Delphic_Hymns



http://en.wikipedia.org/wiki/Oxyrhynchus_hymn

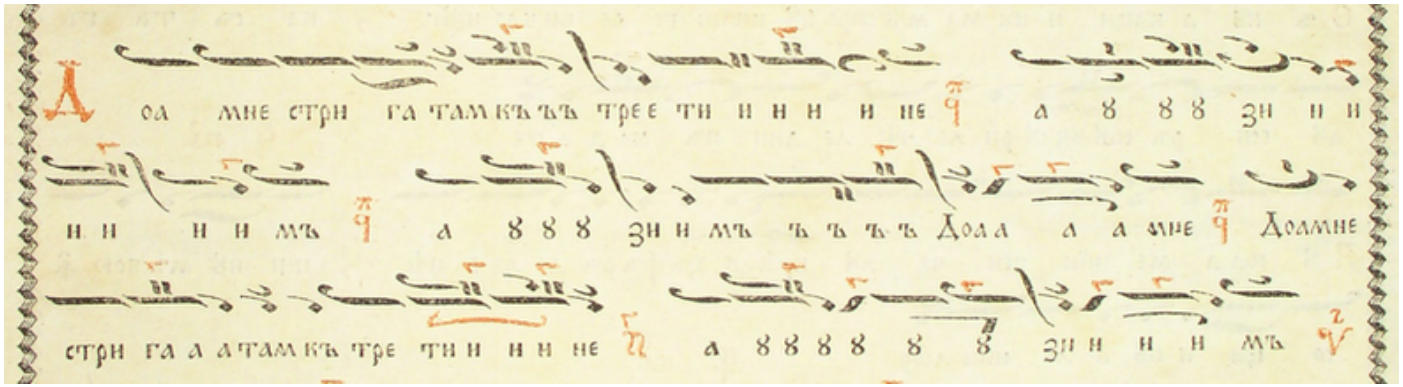
3rd century AD

http://en.wikipedia.org/wiki/Music_of_ancient_Greece

Byzantine Music Notation

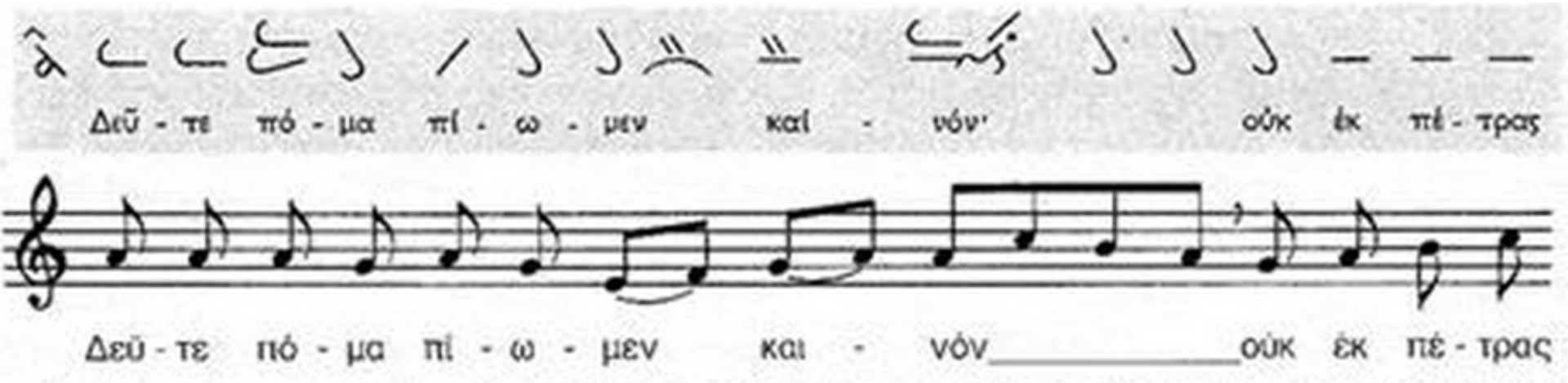
(10th – 15th centuries)

interval notation



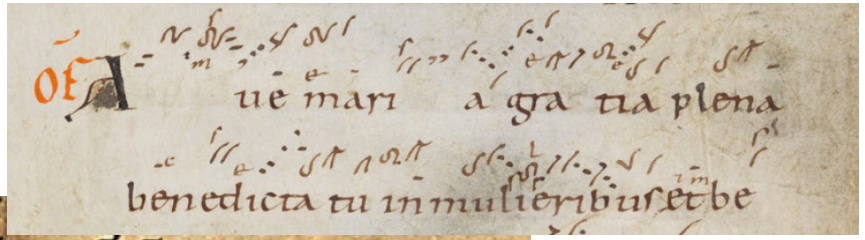
Romania, 1823

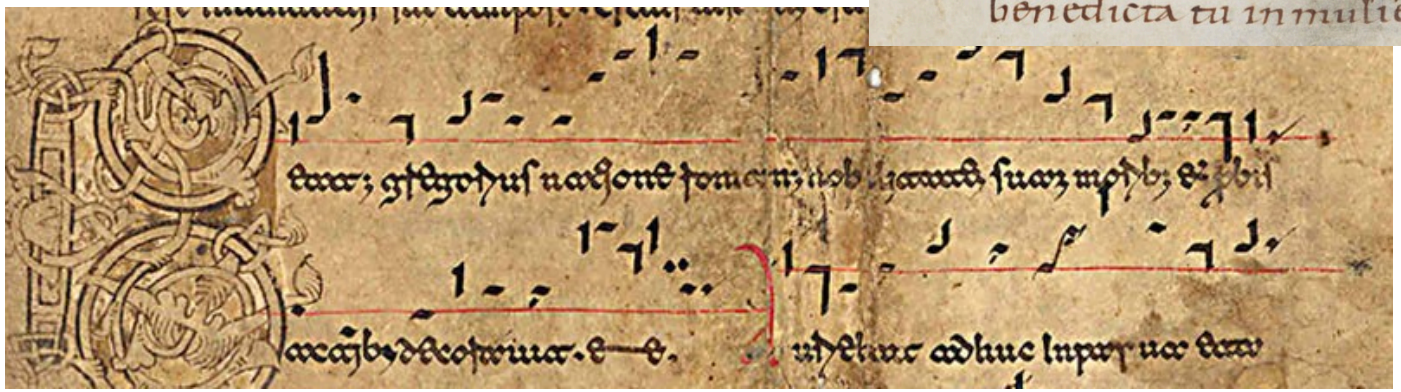
http://en.wikipedia.org/wiki/Musical_notation#Byzantine_Empire



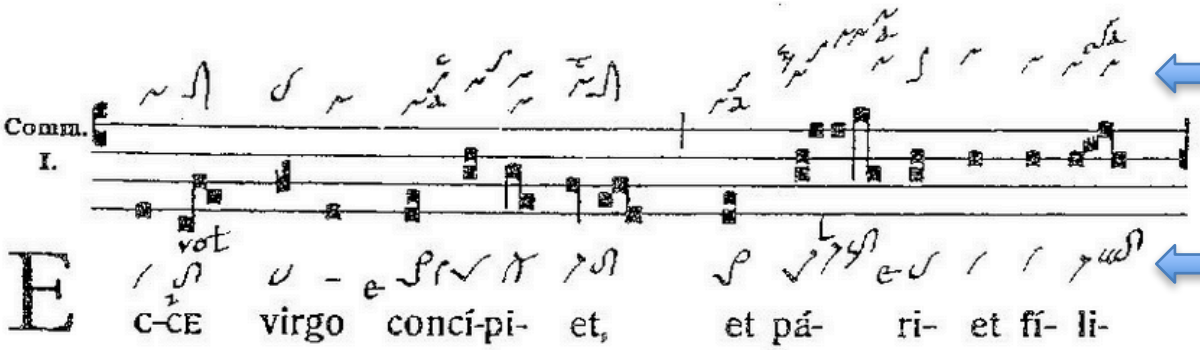
http://www.musicportal.gr/byzantine_music_system/?lang=en

Gregorian Chant





http://ww.schoyencollection.com/music_files/ms1681.jpg



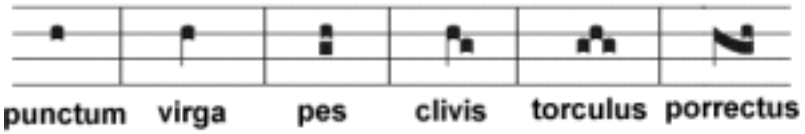
Messine notation

Modern chant notation

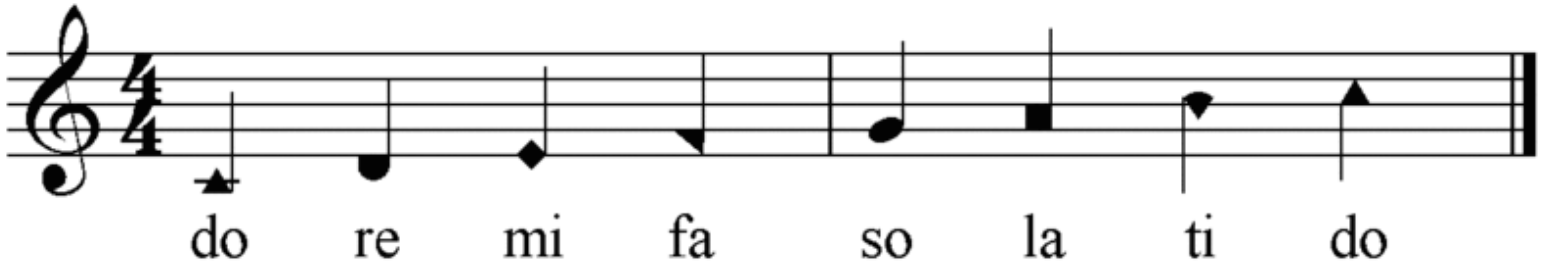
St. Gall notation

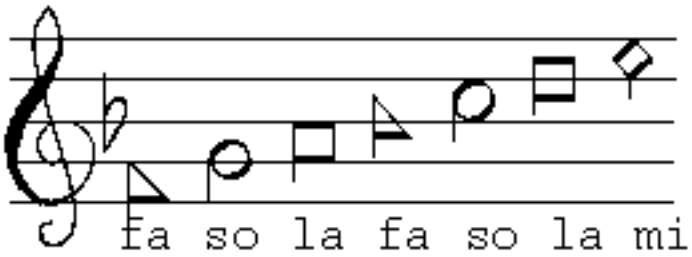
http://euouae.com/category/transcription/

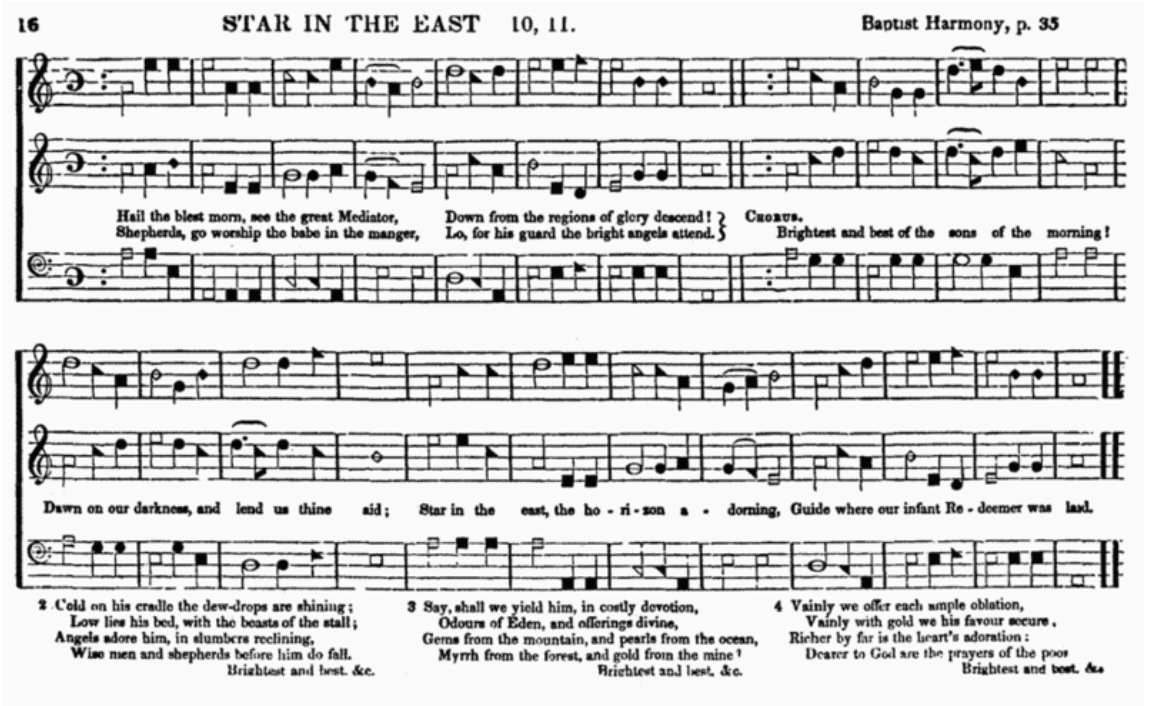
http://en.wikipedia.org/wiki/Gregorian_chant
http://en.wikipedia.org/wiki/Neume



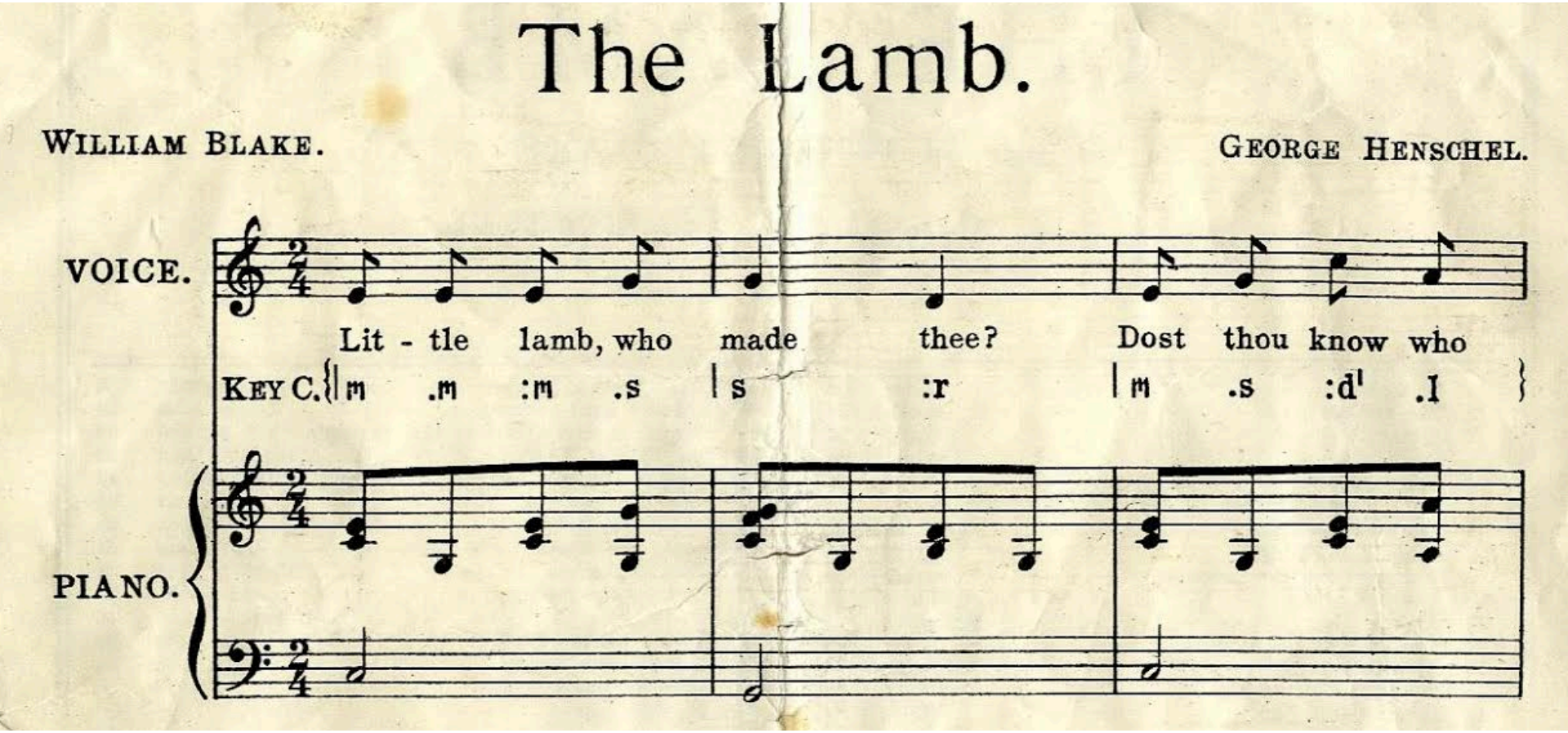
Shape Notes


do re mi fa so la ti do


fa so la fa so la mi


16
STAR IN THE EAST 10, 11.
Baptist Harmony, p. 35
Hail the blest morn, see the great Mediator,
Shepherds, go worship the babe in the manger,
Down from the regions of glory descend!
Lo, for his guard the bright angels attend.
Chorus.
Brightest and best of the sons of the morning!
Dawn on our darkness, and lend us thine aid;
Star in the east, the ho - ri - son a - dorning,
Guide where our infant Re - deemer was laid.
2 Cold on his cradle the dew-drops are shining;
Low lies his bed, with the beasts of the stall;
Angels adore him, in slumbers reclining,
Wise men and shepherds before him do fall.
Brightest and best. &c.
3 Say, shall we yield him, in costly devotion,
Odours of Eden, and offerings divine,
Gems from the mountain, and pearls from the ocean,
Myrrh from the forest, and gold from the mine?
Brightest and best. &c.
4 Vainly we offer each ample oblation,
Vainly with gold we his favour secure;
Richer by far is the heart's adoration:
Dearer to God are the prayers of the poor
Brightest and best. &c.

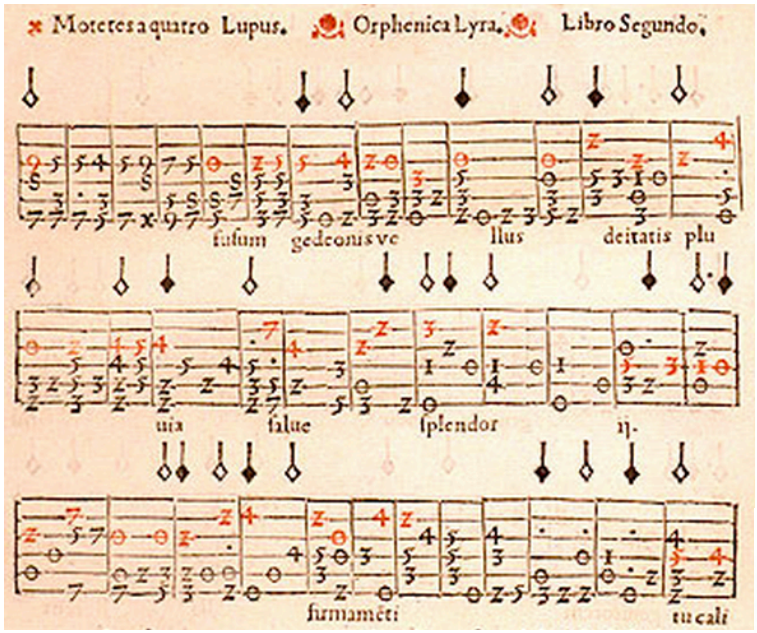
Tonic Sol-Fa



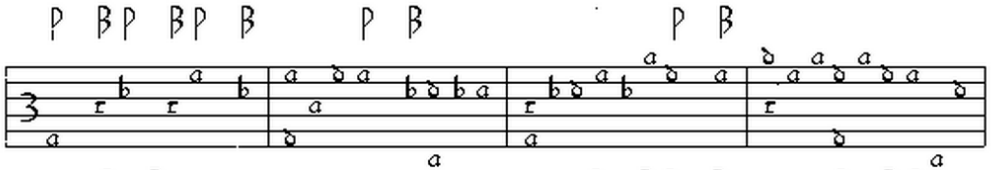
http://en.wikipedia.org/wiki/Tonic_sol-fa

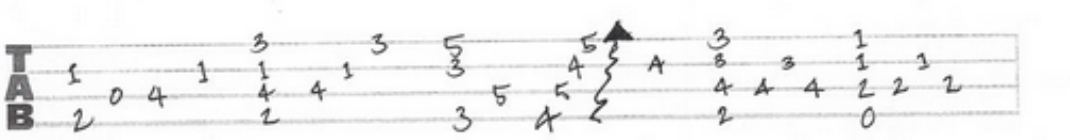
Tablature

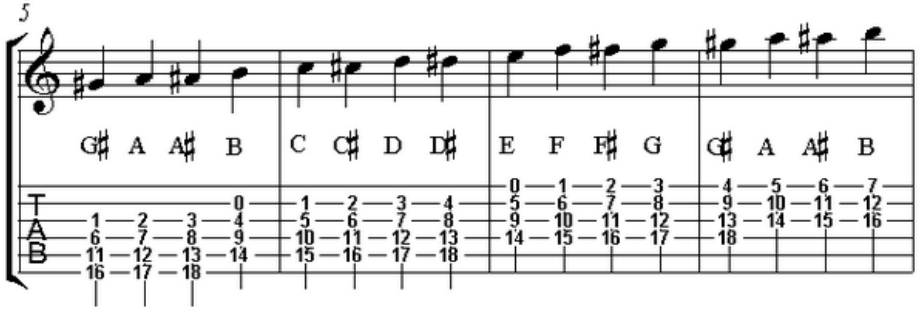
Indicates *how* to play the pitches, not an abstracted/neutral concept of pitch.



lute





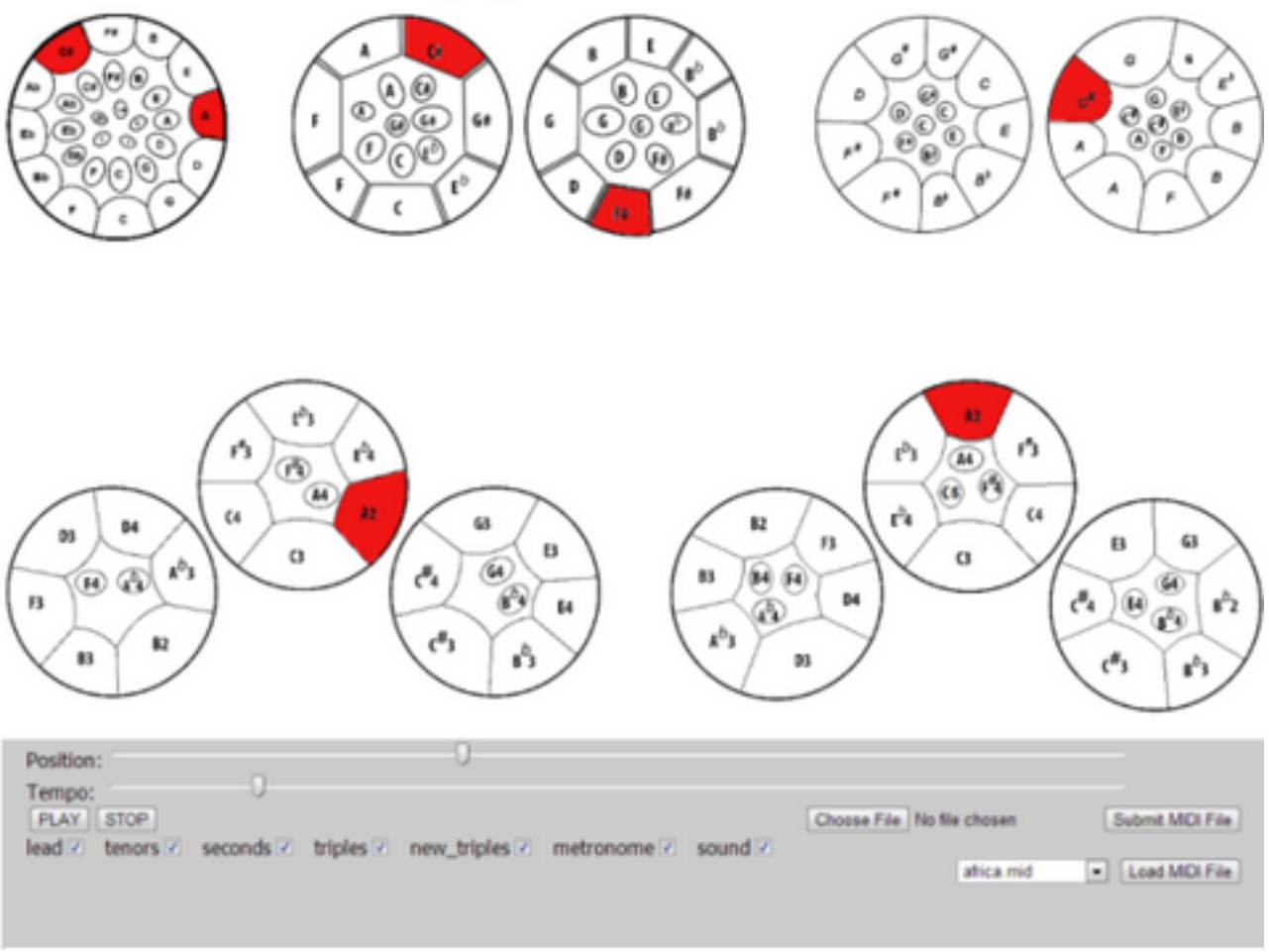



```
E - - 5 - - 3 - - - - - - 5 - - 3/5 - - - - |
B - - - 7 - - - 7 - - - - - - 7 - - - - 7 - - |
G - - - - - - 7 - 7 - 0 - - - 0 - - 7 - 7 - |
D - 0 - - 0 - - - - - - - - - - - - - - - - |
A 0 - - - - - - - - - - - - - - - - - - - - |
E - - - - - - - - - - - - - - - - - - - - - |
```

http://en.wikipedia.org/wiki/Tablature

http://www.wikihow.com/Read-Guitar-Tabs

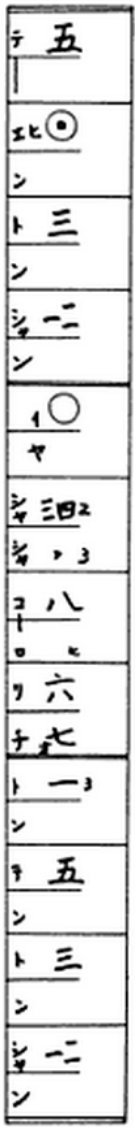
Steel Drum Tablature



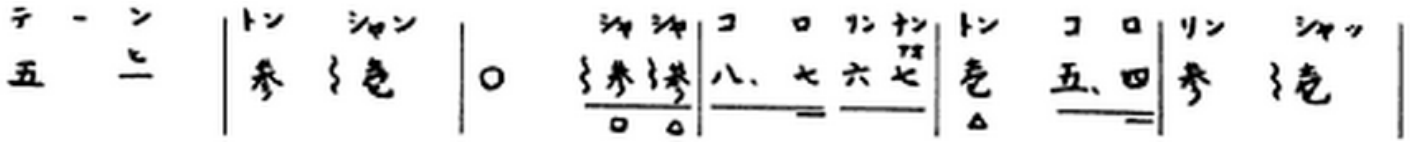
— Jonathan Potter, Cardinal Calypso

Koto Tablature

Ikuta school notation (Kyoto)



Yamada school notation (Tokyo)

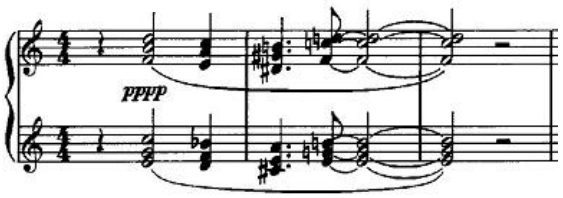


"Rokudan no shirabe"
by Kengyō Yatsuhashi (1614–1685)

Digital representation:

**koto	**kuchi	**kern
*M4/4	*M4/4	*M4/4
=1-	=1-	=1-
{5+i	te	{2d
-	n	.
3	ton	4A
1s	shan	4d: 4G:
=2	=2	=2
0}	.	4r}
{3|sb	sha	{8A: 8A#:
3|sc	sha	8A: 8A#:
8|.	koo	8.a
7||	ro	16g
6|	rin	8d#
7|o	chin	16gH
.	.	16ah
=3	=3	=3
1c	ton	4d
5|.	koo	8.d
4||	ro	16A#
3}	rin	4A}
{1s	shan	{4d: 4G:
=4	=4	=4

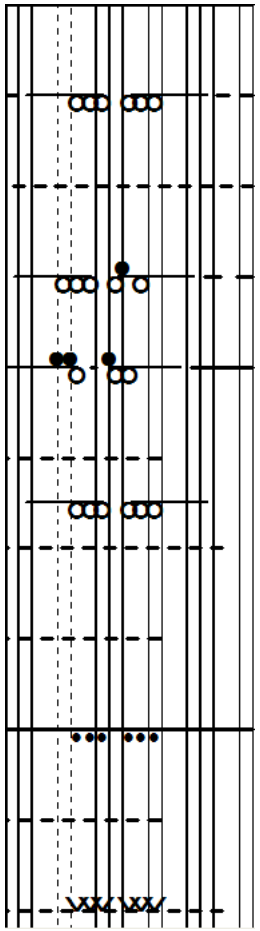
http://en.wikipedia.org/wiki/Koto_%28instrument%29

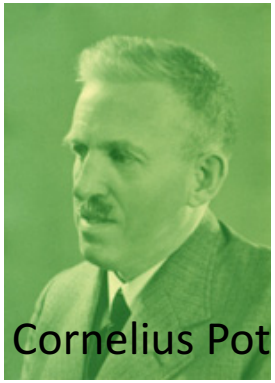


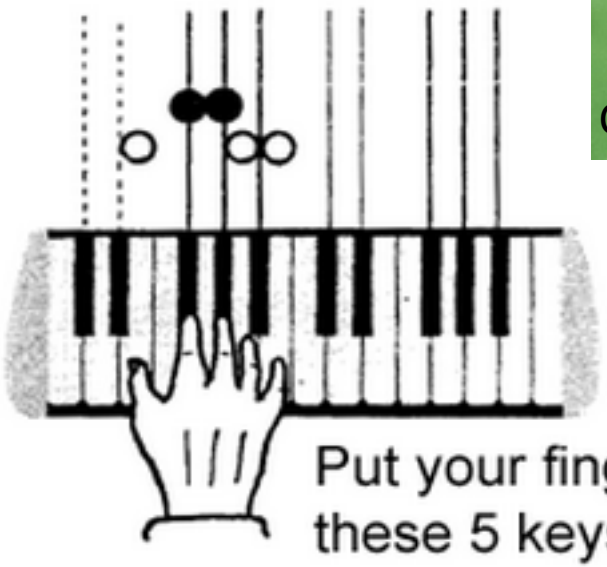
Piano Tablature

Klavarskribo

"Keyboard script" in Esperanto







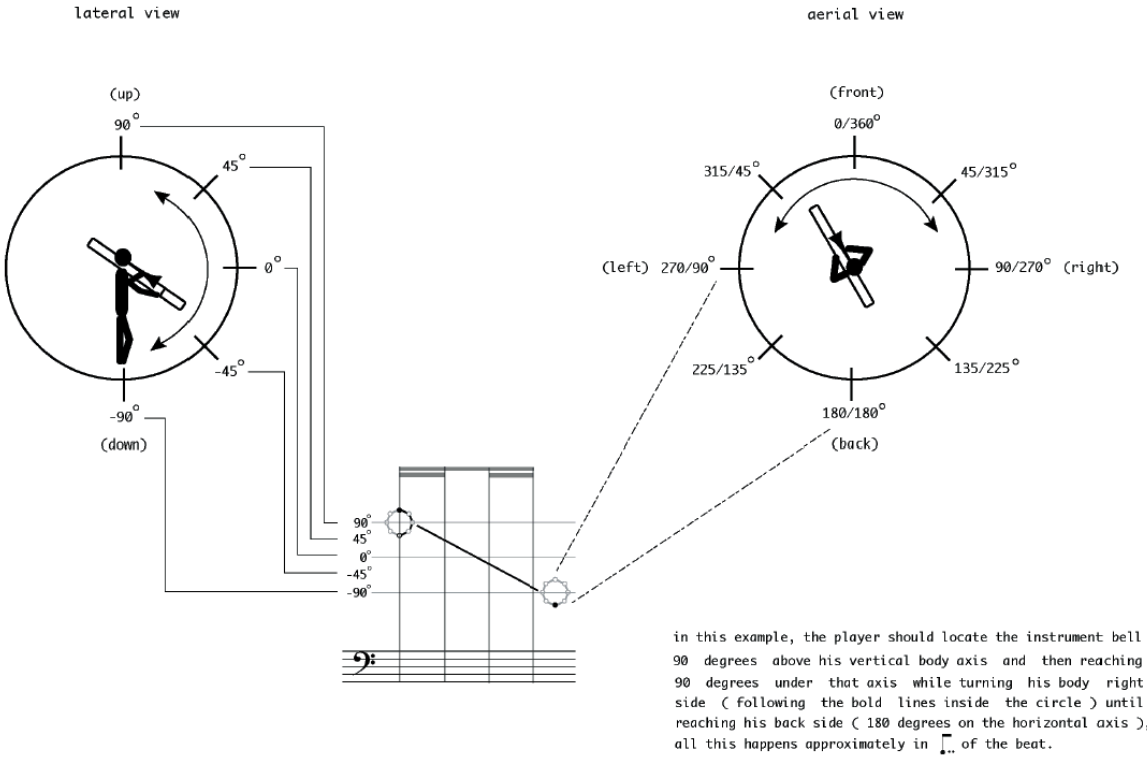
https://www.youtube.com/watch?v=MIoIvxunihA&t=659

http://evanlenz.net/blog/2007/11/02/re-discovering-klavarscribo/

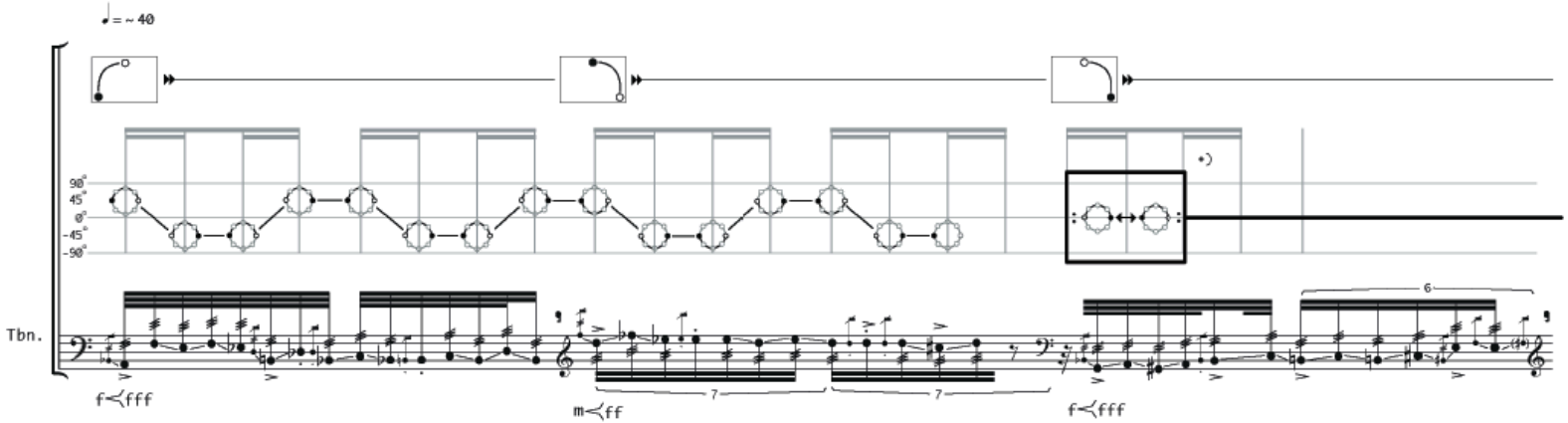
http://en.wikipedia.org/wiki/Klavarskribo

http://www.klavarskribo.nl/en

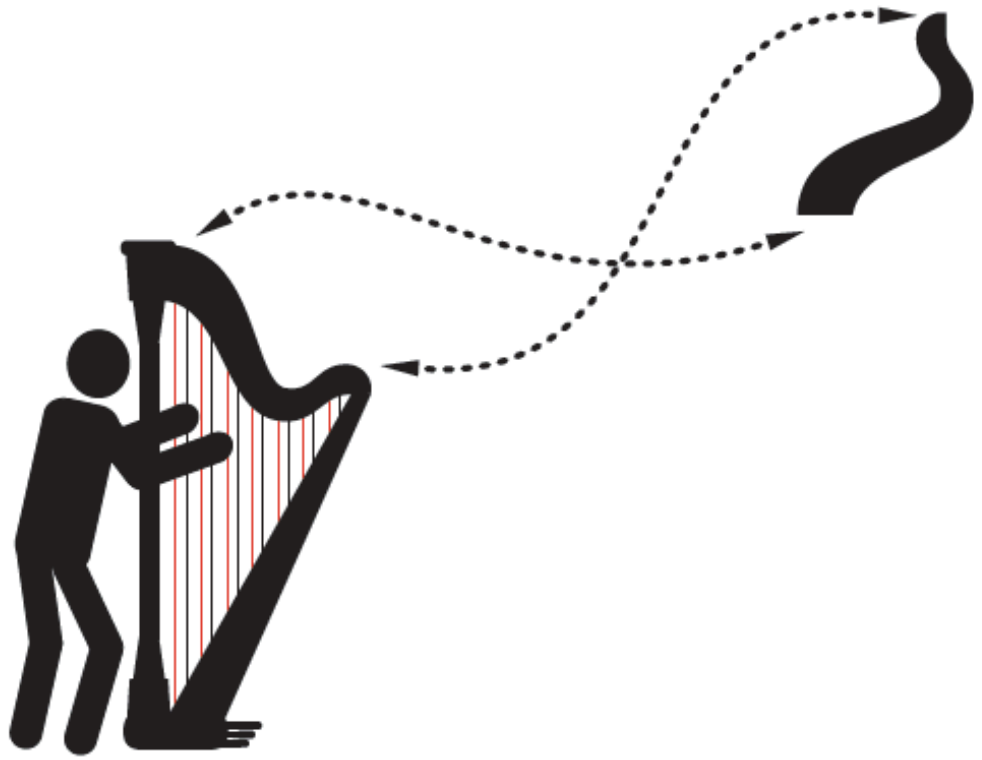
Prescriptive Notation

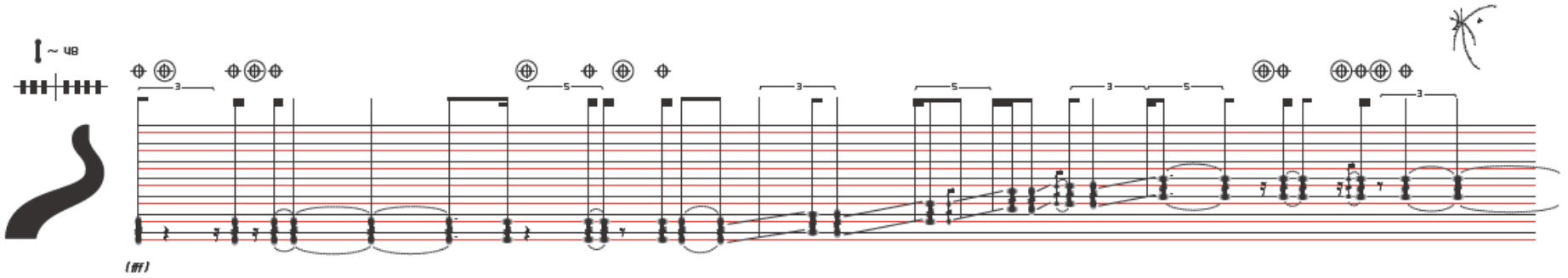


in this example, the player should locate the instrument bell 90 degrees above his vertical body axis and then reaching 90 degrees under that axis while turning his body right side (following the bold lines inside the circle) until reaching his back side (180 degrees on the horizontal axis), all this happens approximately in of the beat.



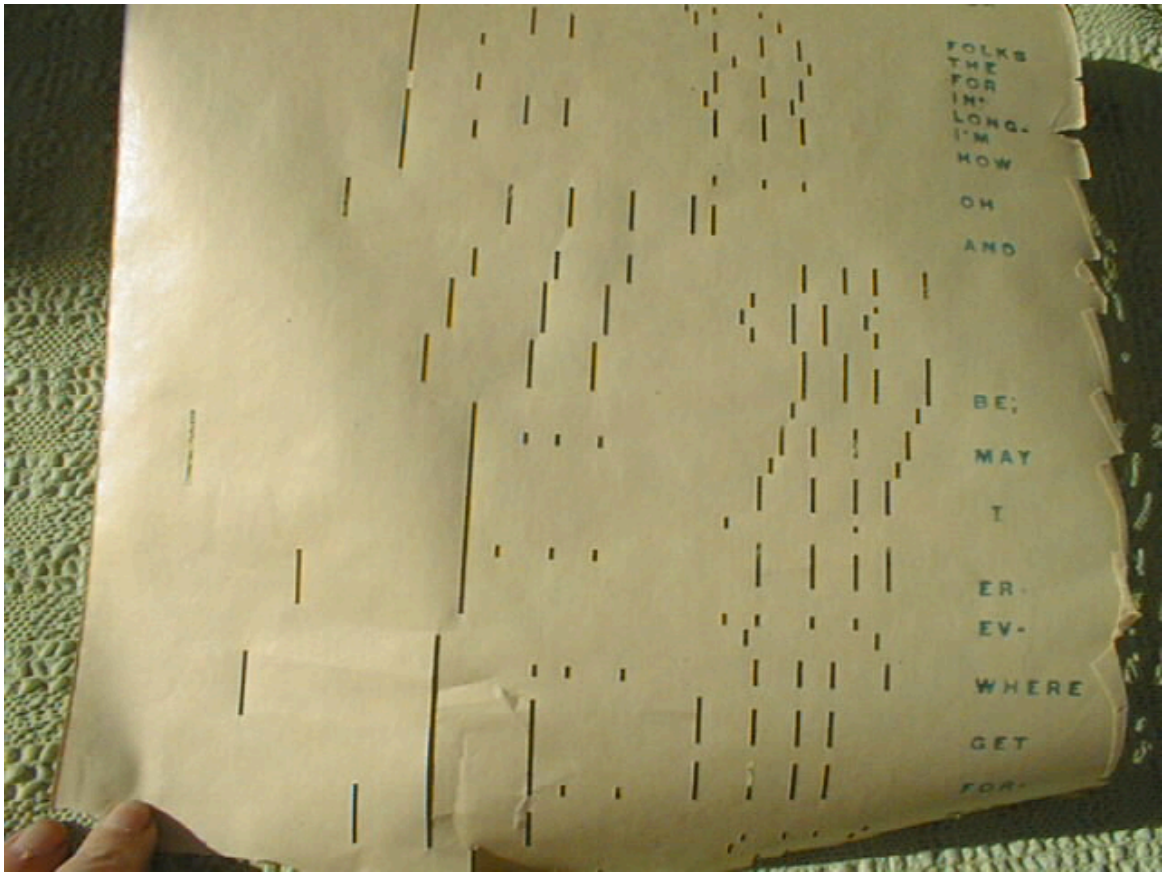
Prescriptive Notation





Piano Rolls

Mechanical Representation of music



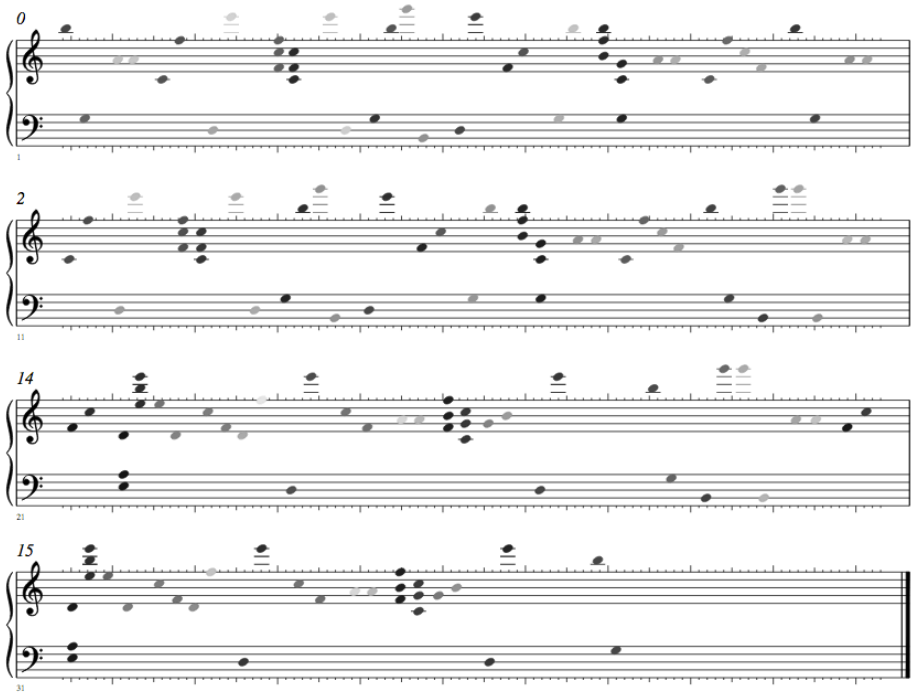
http://en.wikipedia.org/wiki/Piano_roll

https://www.youtube.com/watch?v=GjpPesy7kIA

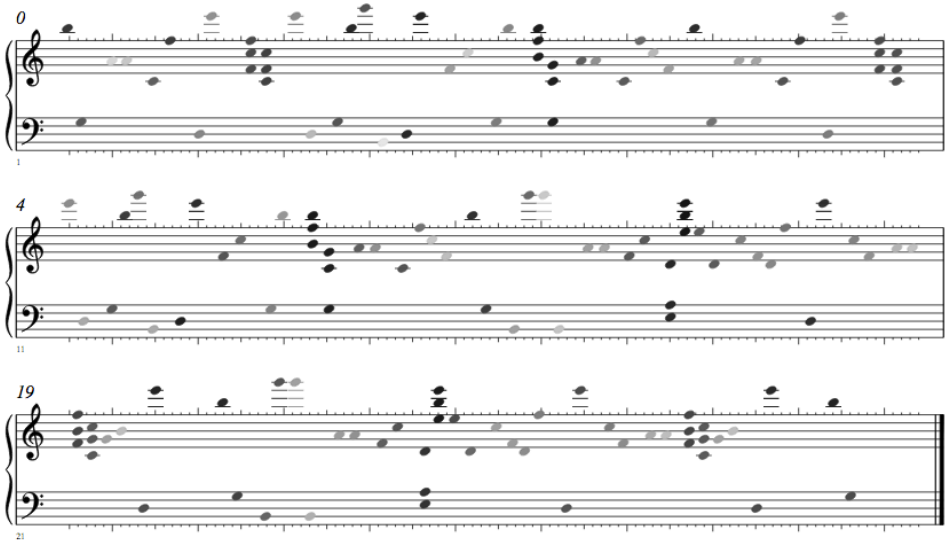
Performance Data Visualization

Webern Piano Variations, mvmt. 2, (Op. 27)

Anderszewski 1996



Gould 1954



http://dl.acm.org/citation.cfm?id=2597179

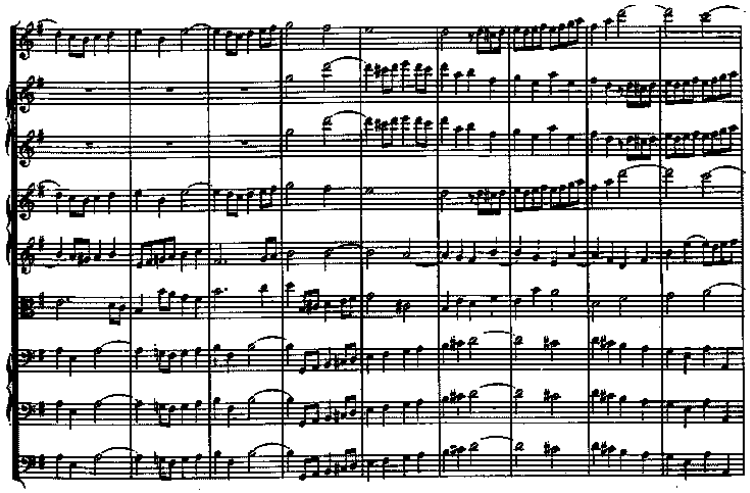
http://mazurka.org.uk/webern/notation/Anderszewski1996

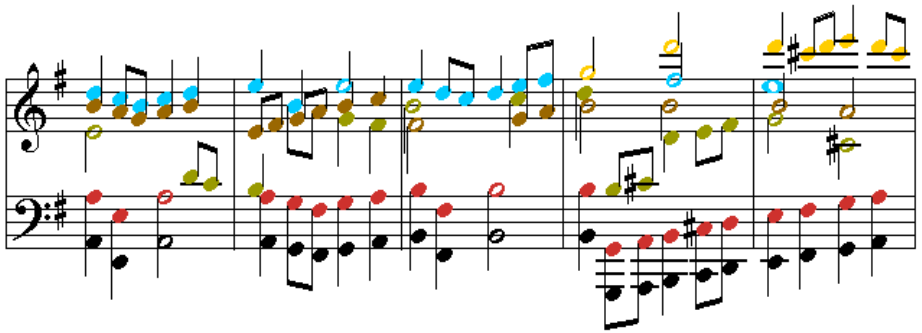
http://mazurka.org.uk/webern/notation/Gould1954

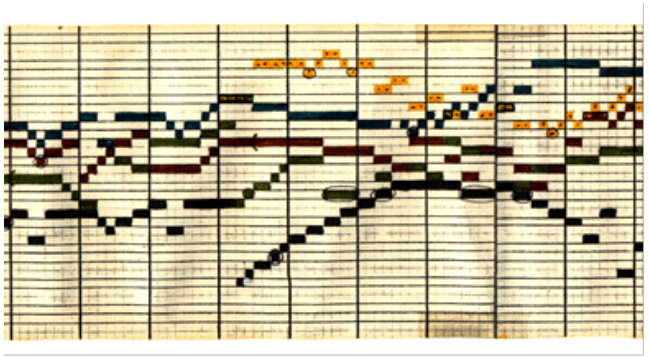
Music Animation Machine

http://www.musanim.com

Stephen Malinowski







https://www.youtube.com/channel/UC2zb5cQbLabj3U9l3tke1pg

https://www.youtube.com/playlist?list=PLMOarqHv8B7P1BuvL2iGqkjS1xNrvTiuX

Music Animation Machine

Bach, Toccata and Fugue in D minor, organ
https://www.youtube.com/watch?v=ipzR9bhei_o

Mozart, Symphony No. 40 in G minor
https://www.youtube.com/watch?v=xvtoqE33iZg

Beethoven, Fur Elise
https://www.youtube.com/watch?v=o0VwTw1eZ1k

Beethoven, String Quartet No. 16, 1st mvt. (opus 135)
https://www.youtube.com/watch?v=Lj4kLPgX5QM

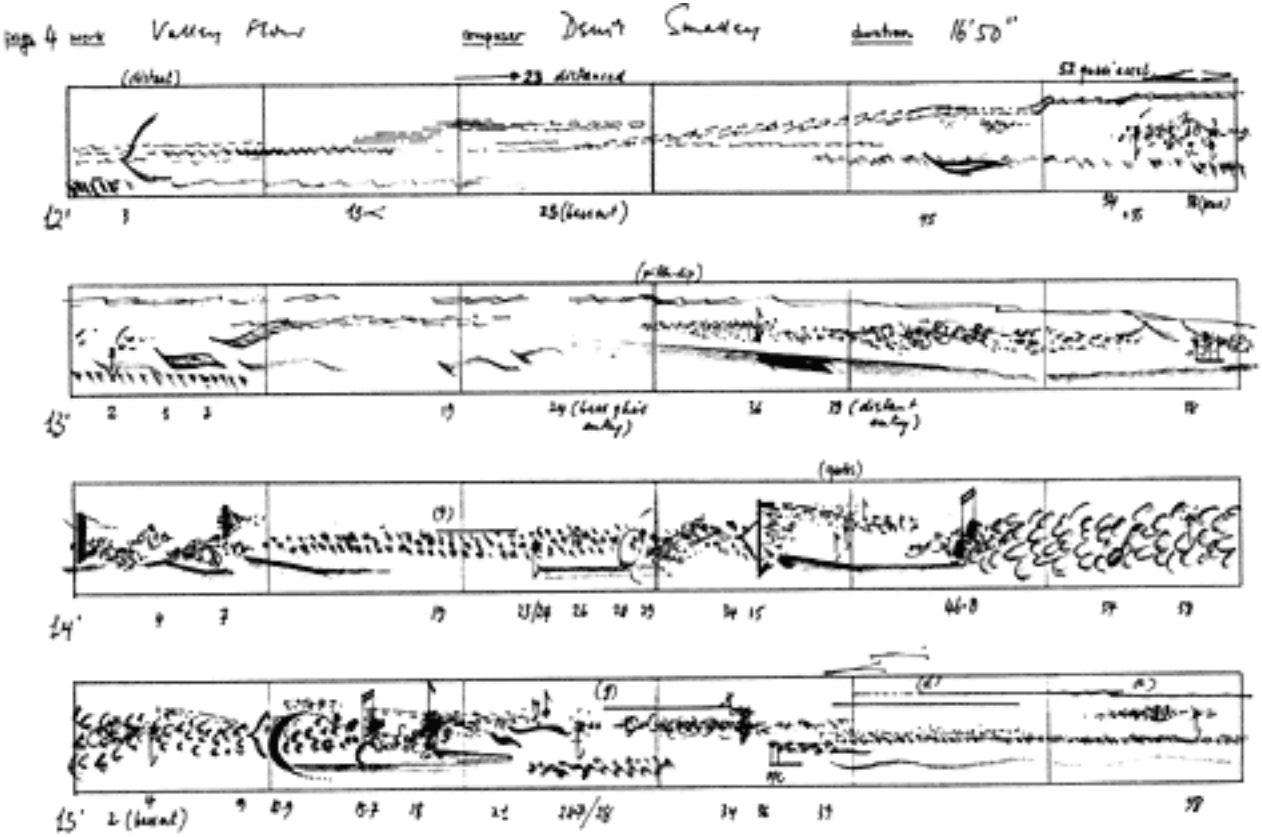
Paganini, Caprice No. 5 (solo violin)
https://www.youtube.com/watch?v=xhc1PsokFOw

Debussy, First Arabesque
https://www.youtube.com/watch?v=Yt1jfX5C1u0

How are musical
Dimensions mapped
In each visualization?

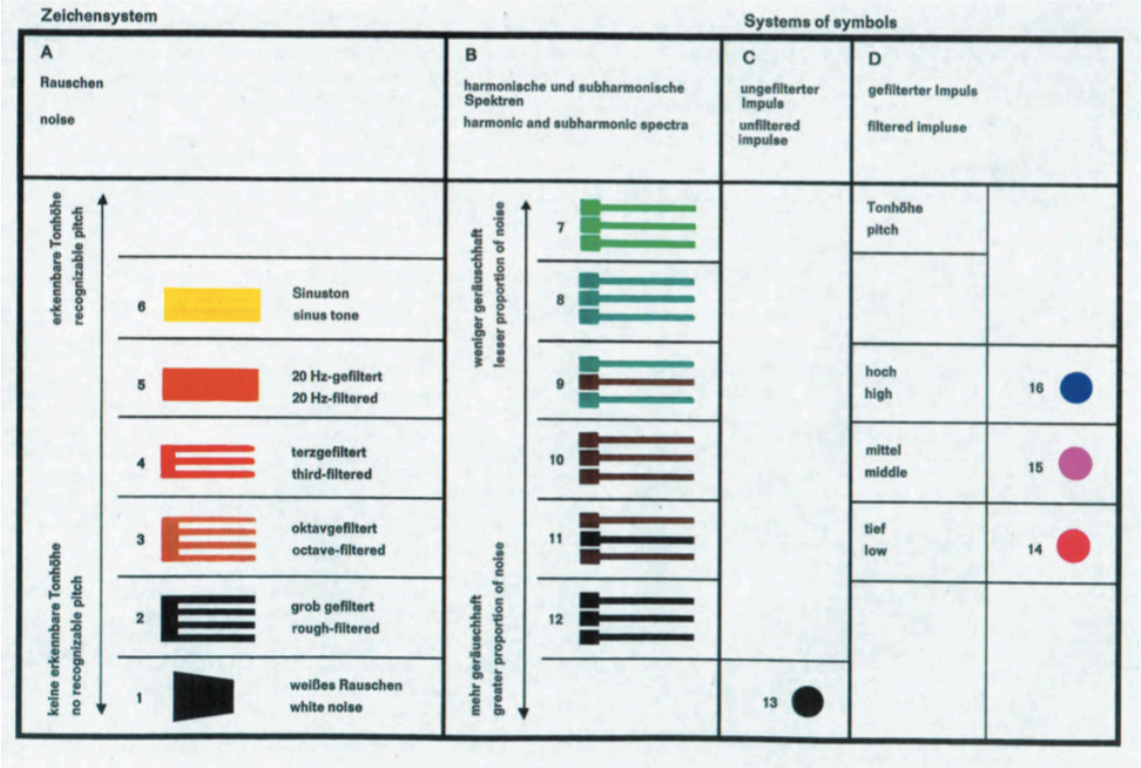
Textural Notation

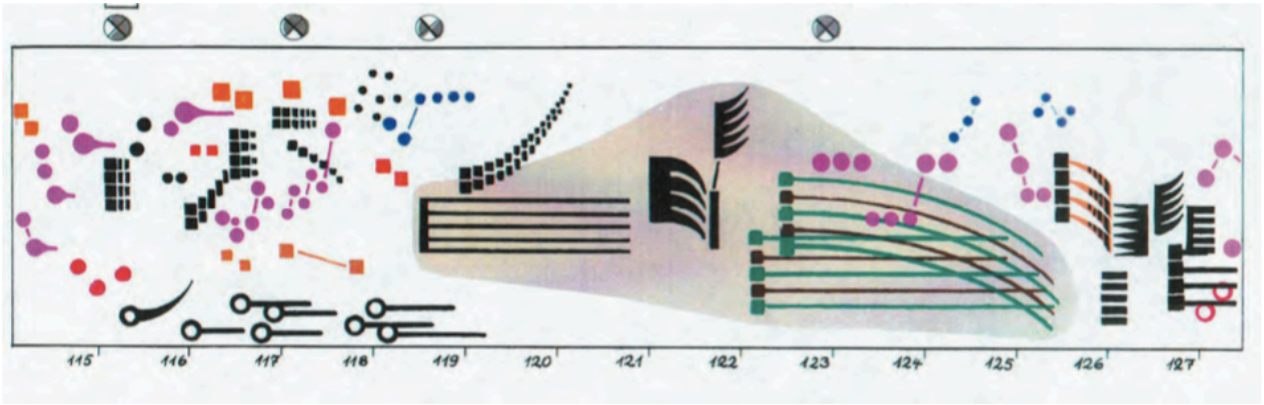
Analytic notation of electro-acoustic music



http://www.electrocd.com/en/select/photo/?id=4754

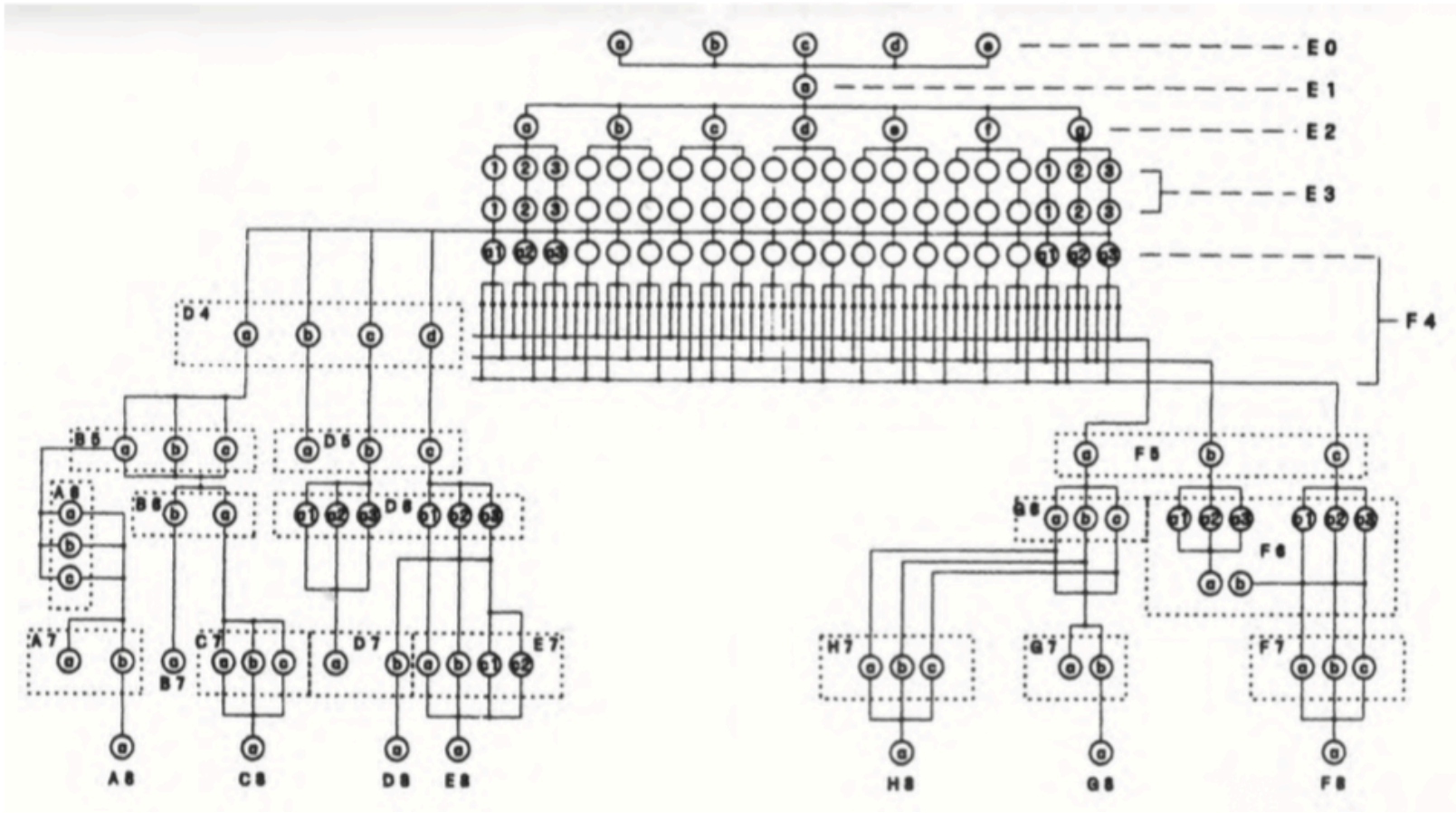
Listening Scores





Music Notation & Music Process

Teminus (I) by Gottfried Michael Koenig



Music Notation & Music Process

I never knew you cared by Paul Berg

Computer code

Score

```
&       I NEVER KNEW YOU CARED
&               PAUL BERG
&               1978
&
&       SECTION 1
&
                INITIALIZE
                        MASTER:1;
                SEED
                        147;
                BRANCH
                        TO:PART1;
DIV     INITIALIZE
                CNT2:-2;
DIV2    CONVERT
                SEND:0
                CHANNEL:0
                SEND:0
                CHANNEL:1;
        CHECK
                CNT
                DIV2,-
                CNT2
                DIV2,-;
                CALCULATE
                        MASTER:MASTER+1
                        MAX:5-MASTER;
                        ZERO?
                                YES:END;
                SWITCH
                        MASTER
                        PART1,PART2,PART3,PART4;
&
&
&----------------------------------------------------
&
&
&                                       PART1
&
&
&
PART1           INITIALIZE
                        CNTRL:-15
                        PEAK:40
                        CNT:-1
                        A:0;
        CREATE LIST
                NAME:MODAMP
                SIZE:80;
                CHECK
                        CNT
                        A3,-1
                INITIALIZE
                        SKIP:-2;
A1              SAMPLE LIST
                        NAME:ENV2
                        SIZE:8
                        INCREMENT:1;
                CHECK
```

Language description

PILE2 A DESCRIPTION OF THE LANGUAGE

paul berg

January 1978

DEFINITIONS

software

1. available characters: the letters A-Z
   the digits 0-9
   the punctuation marks .;?:&+-*/
   additional characters labelled space,tab, carriage return

2. constant: a positive or negative integer. The largest possible absolute value is 131072. E.g. 127 or -33

3. variable: the name for a storage location and the name for a quantity which is stored there. The name is from 1-6 symbols. The first symbol must be a letter, the remaining symbols may be either letters or digits. E.g. VAR3 or KOENIG or A6

4. instruction: name of an operation, and if necessary, data for that operation. The first symbol in an instruction is a tab or a space. After that any number of tabs and/or spaces may be used to align the instruction as desired. With one exception, all instructions are longer than one line. The name of the operation is on the first line. E.g. CALCULATE, CHOOSE, INITIALIZE, CREATE LIST. The following line(s) contain the information necessary or possible for a given instruction. This may involve several applications of the operation stated in the first line. The last line of an instruction should be terminated with a semicolon. E.g. INITIALIZE or CONVERT
   A:VAR; SEND:VAR
   CHANNEL:0;

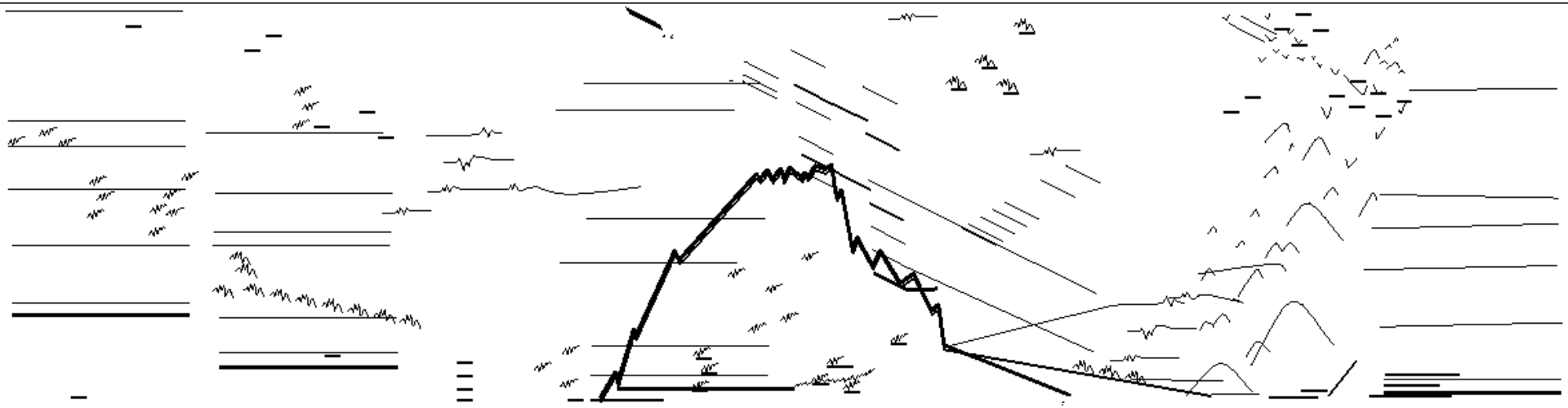
5. label: an address name given to an instruction. The name is from 1-6 symbols. The first symbol must be a letter. The remaining symbols may be either letters or numbers. A label may occur only in the first line of an instruction (the line which contains the operation). A label (if it is to be used) must be the first symbol(s)

line2sine

Sonification of vector graphics

http://sig.sapp.org/projects/all/line2sine/line2sine/examples

Example 6:

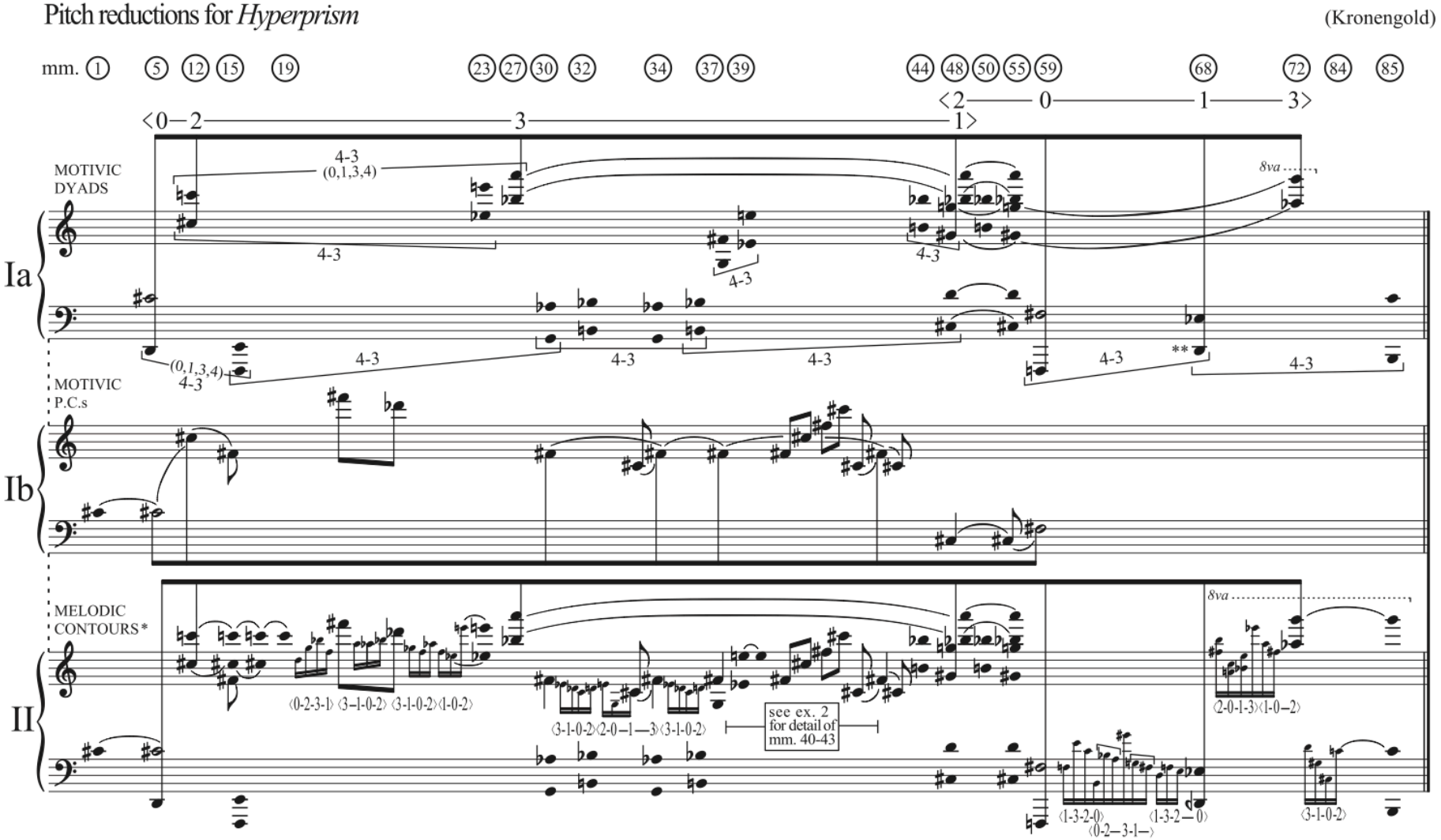


See the music of Iannis Xenakis

http://en.wikipedia.org/wiki/Iannis_Xenakis

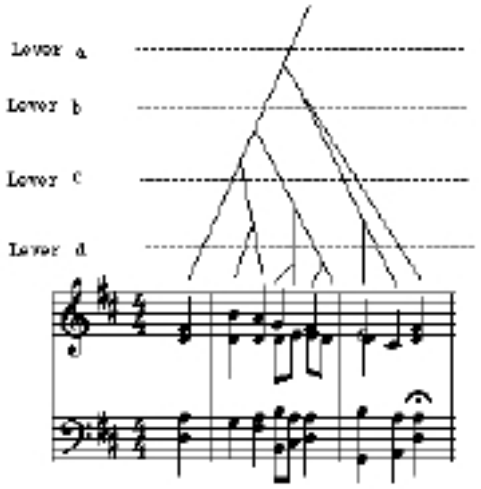
Schenkerian Graphs

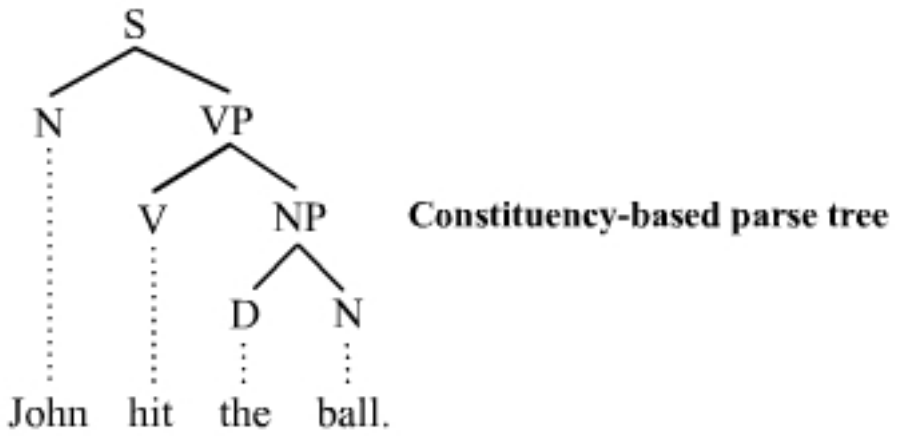
Edgard Varèse



http://en.wikipedia.org/wiki/Hyperprism_%28Var%C3%A8se%29

GTTM



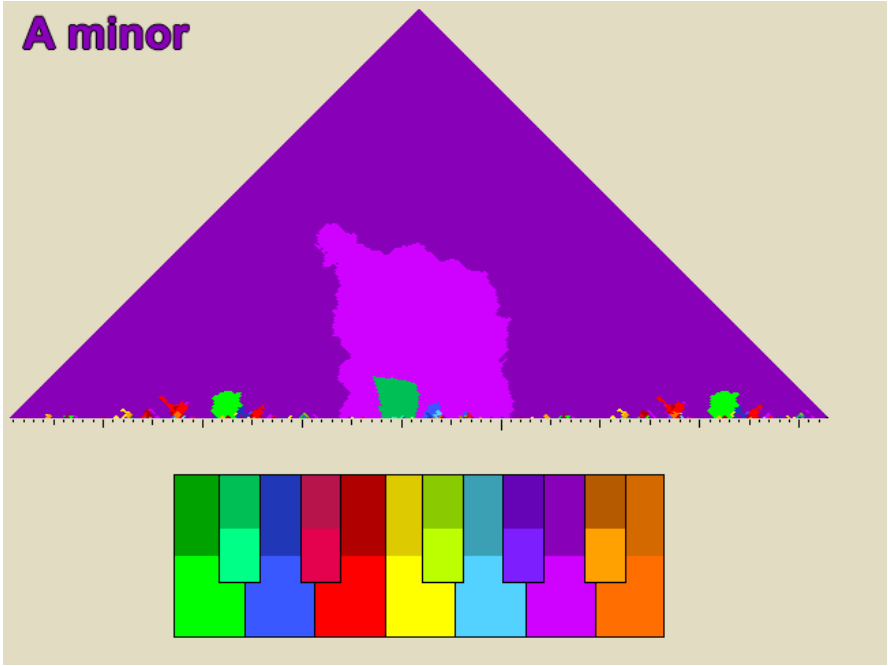


http://en.wikipedia.org/wiki/Parse_tree

h
t

Keyscapes

Graphical display of harmonic structure



Chopin mazurka in A minor Op. 67, No. 4

https://www.youtube.com/watch?v=AcxZRI6aews

A major: 1:18

A minor: 2:10

Landscape:

background

large-scale structures

middleground

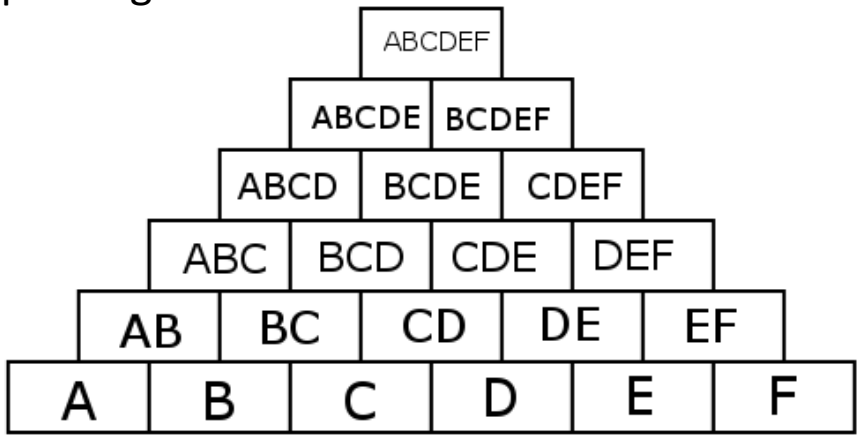
small-scale structures

foreground

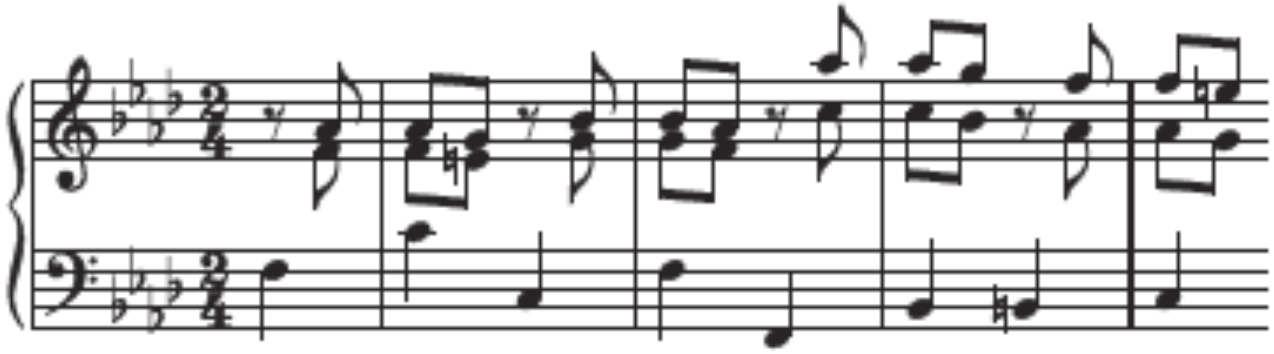
surface features

An Orchard c1896 Henri Rousseau

Scape plotting domain:

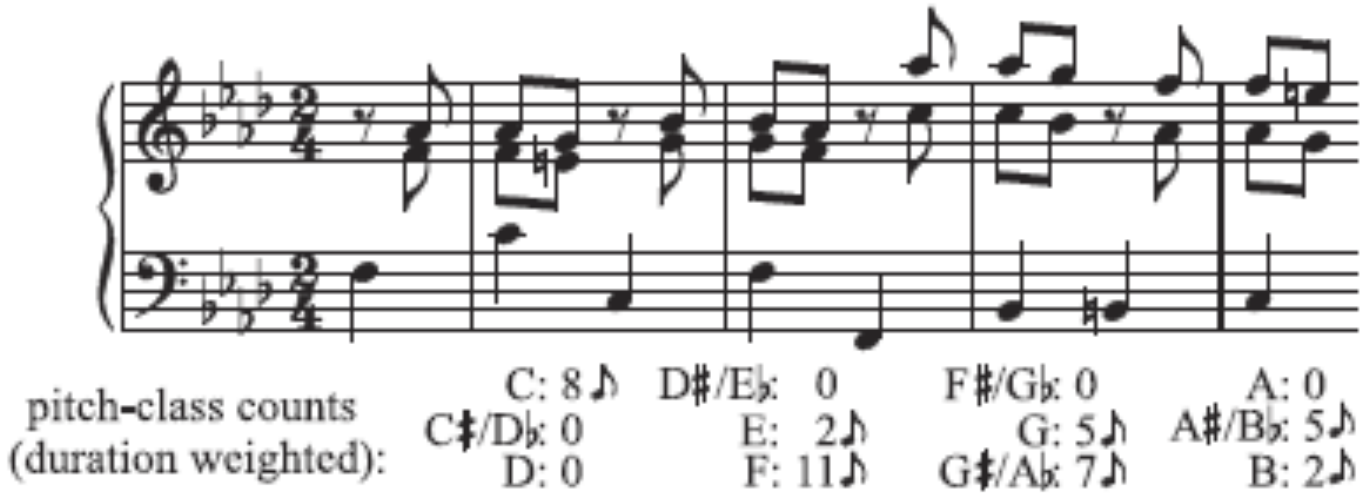


Computational Key Identification



http://extras.humdrum.org/man/keycor

Computational Key Identification



Pearson correlation:

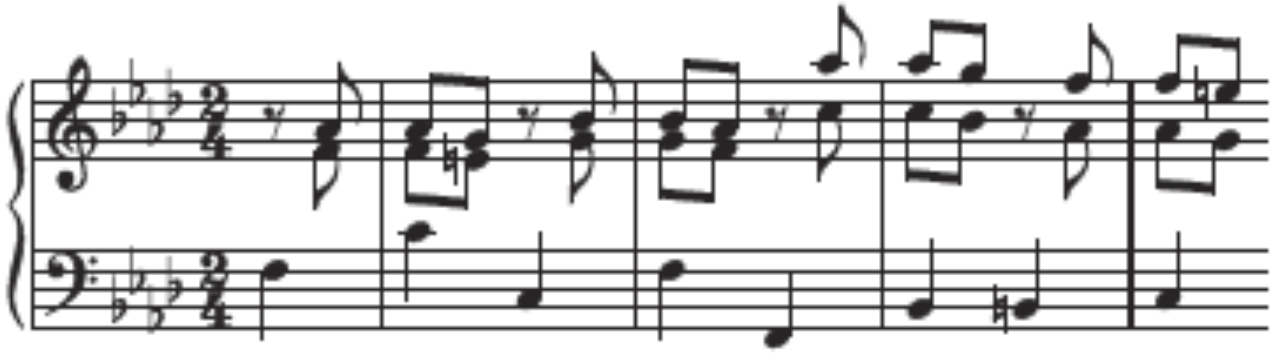
$$r(x,y) = \frac{\sum_n (x_n - \bar{x})(y_n - \bar{y})}{\sqrt{\sum_n (x_n - \bar{x})^2 \sum_n (y_n - \bar{y})^2}}$$

Krumhansl-Schmuckler key-finding algorithm:

$$\text{key}_k = \arg\max_k \; r(x, y_k)$$

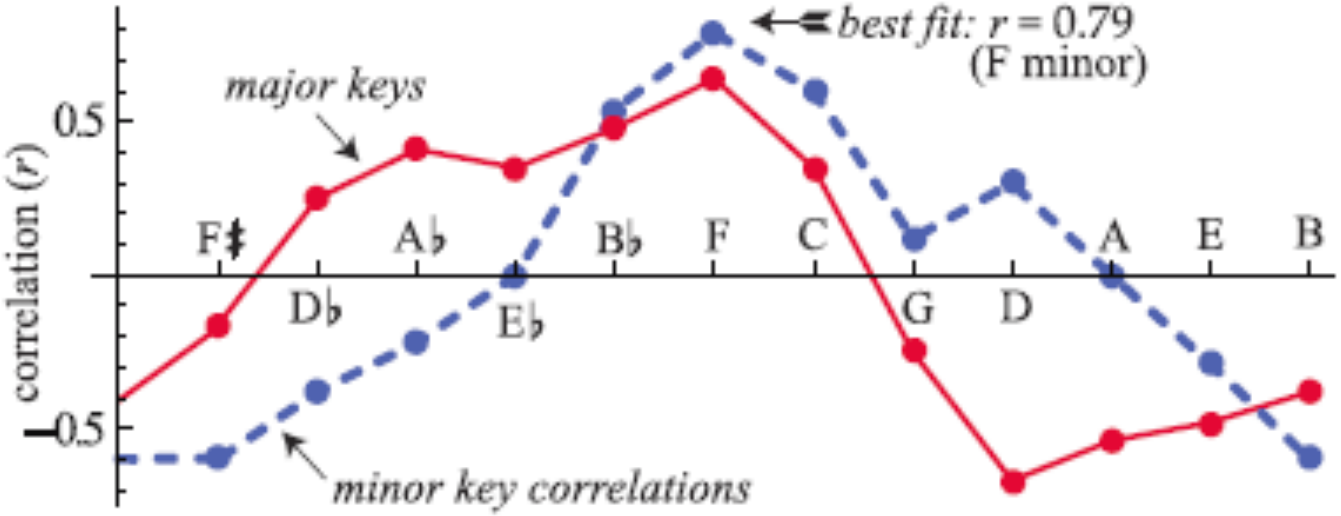
http://extras.humdrum.org/man/keycor

Computational Key Identification



pitch-class counts (duration weighted):

C: 8 ♪	C♯/D♭: 0	D: 0	D♯/E♭: 0	E: 2♪	F: 11♪	F♯/G♭: 0	G: 5♪	G♯/A♭: 7♪	A: 0	A♯/B♭: 5♪	B: 2♪

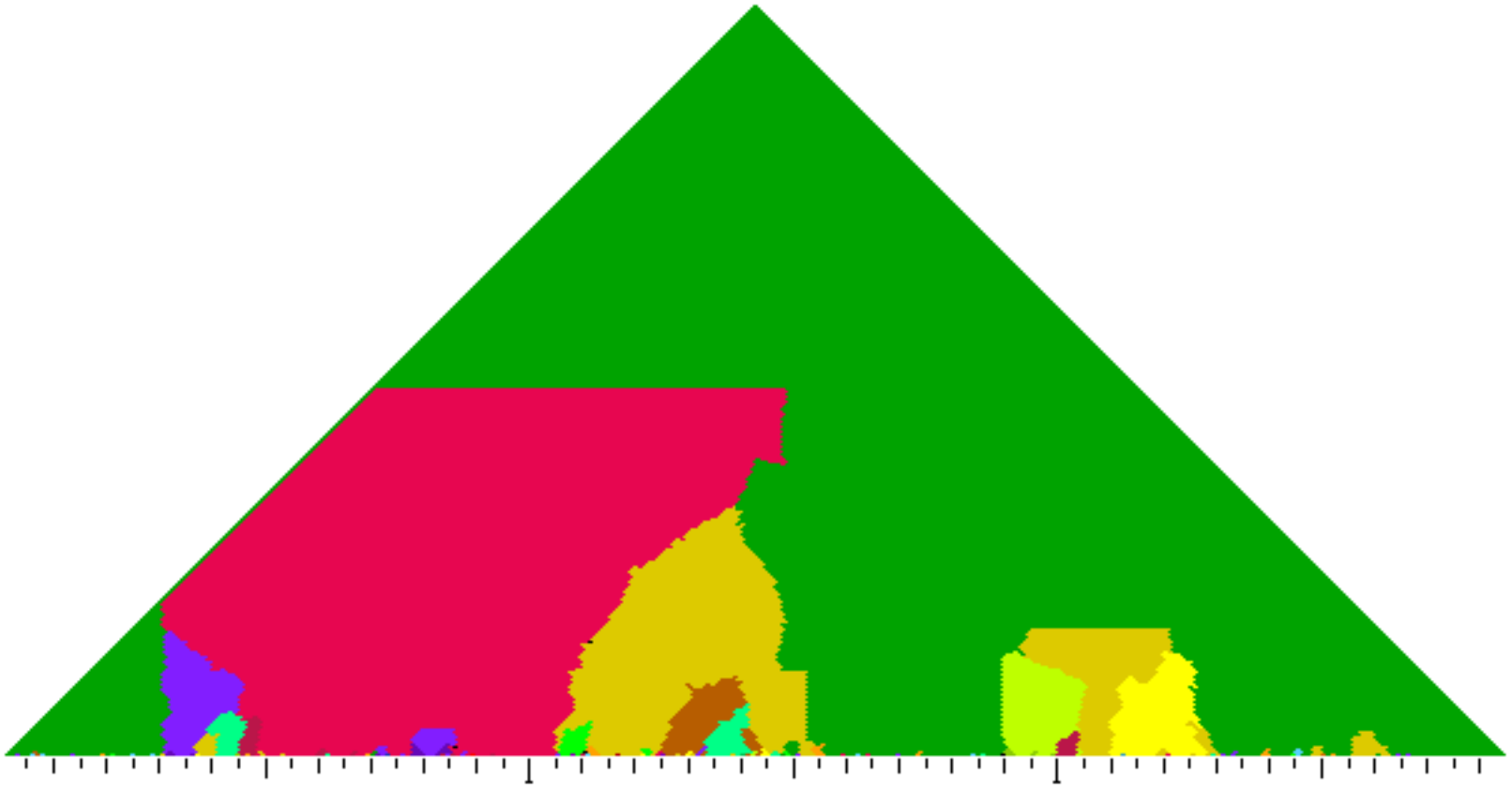


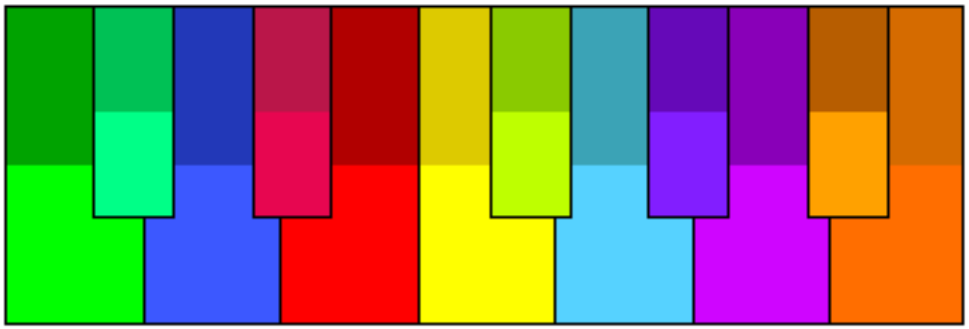
pitch-class histogram: $x = (8, 0, 0, 0, 2, 11, 0, 5, 7, 0, 5, 2)$

major key prototype: $y_M = (2, 0, 1, 0, 1, 1, 0, 2, 0, 1, 0, 1)$

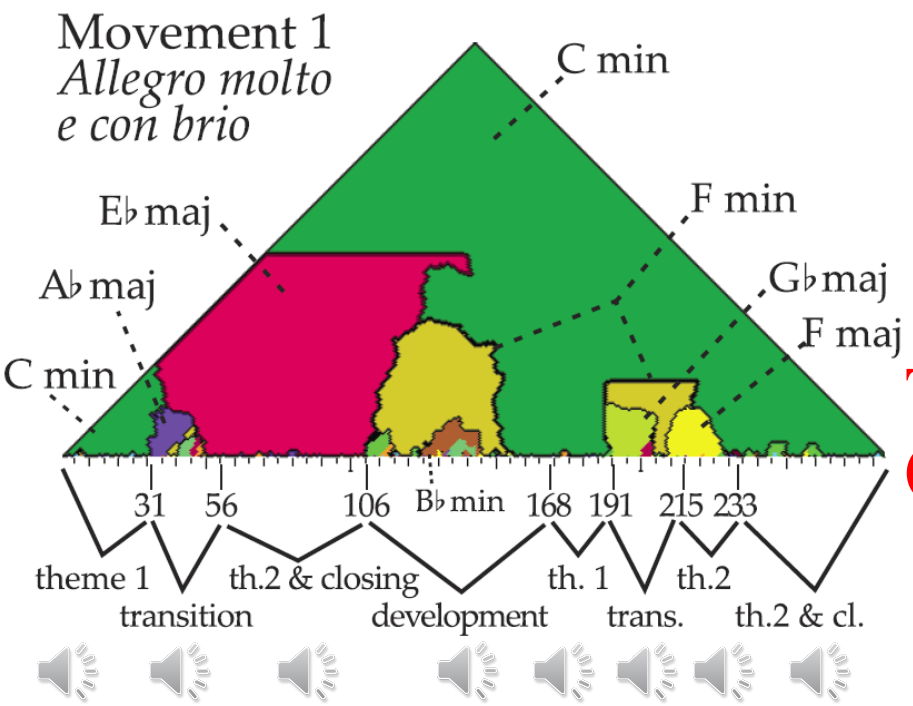
minor key prototype: $y_m = (2, 0, 1, 1, 0, 1, 0, 2, 1, 0, 1, 0)$

Beethoven Piano Sonata #5 mvmt 1

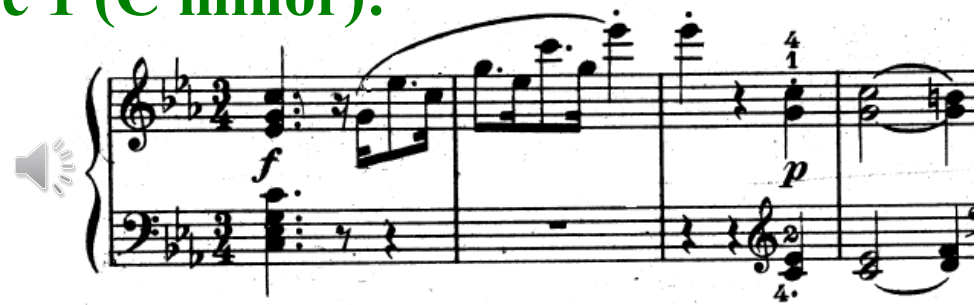




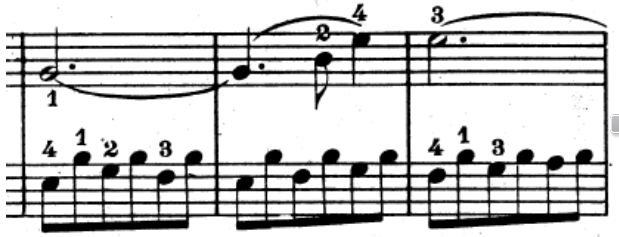
Sonata No. 5 Internal Key Structure



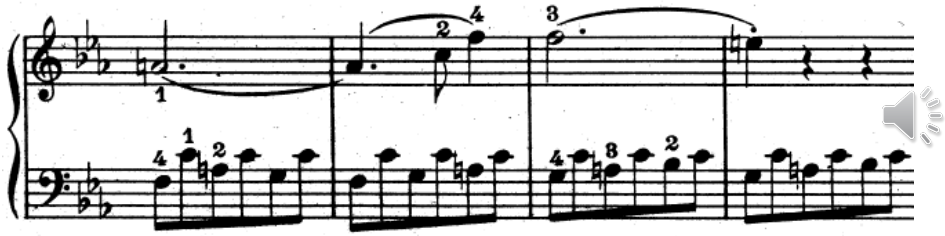
Theme 1 (C minor):



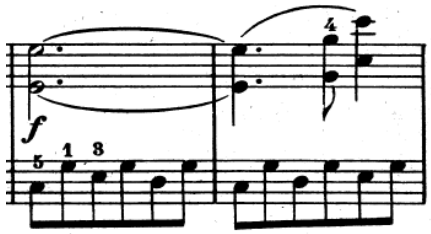
Theme 2 (Eb major):



Theme 2 (F major):

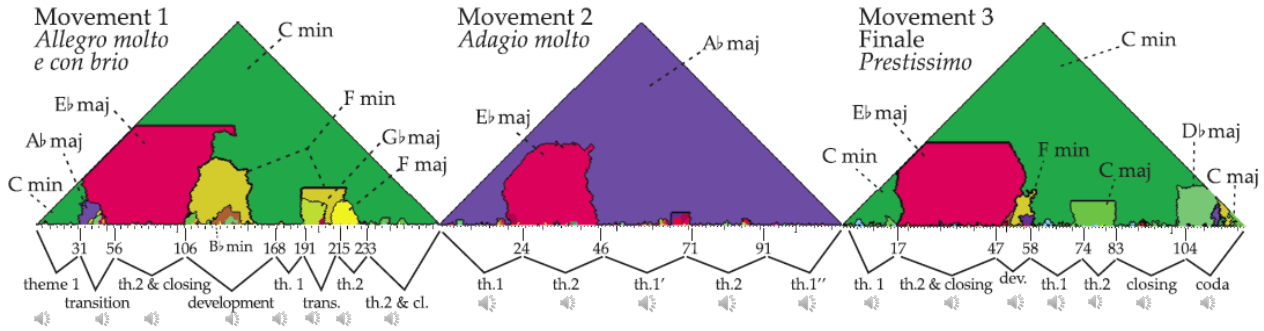


Theme 2 (C minor):

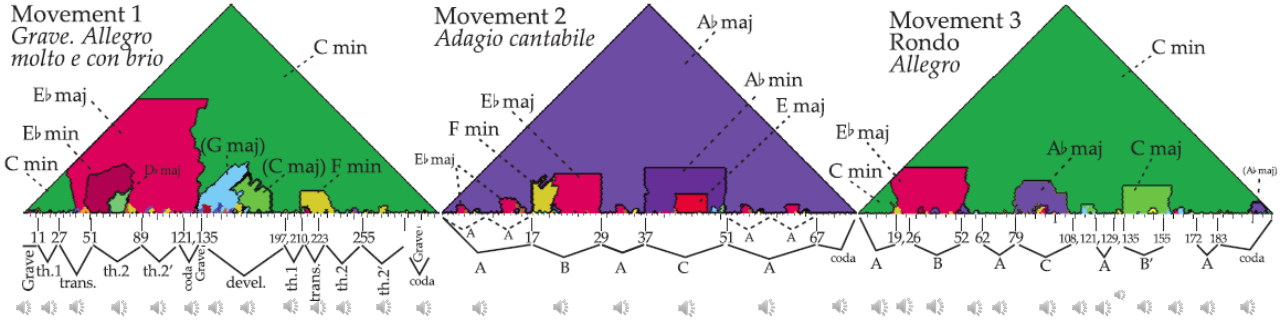


Other C-Minor Beethoven Sonatas

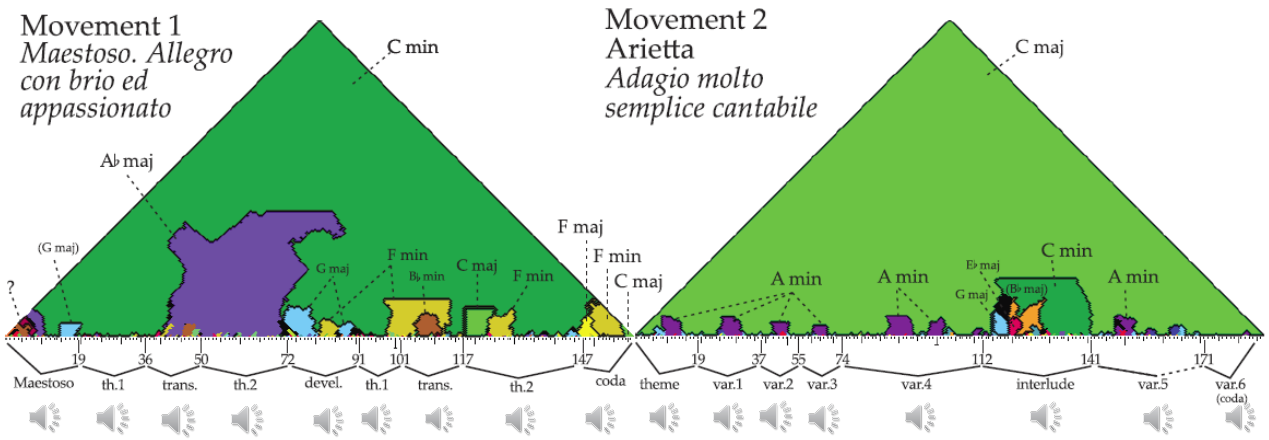
No. 5:



Piano Sonata no. 8 in C minor, op. 13 (*"Pathétique"*)



piano sonata no. 32

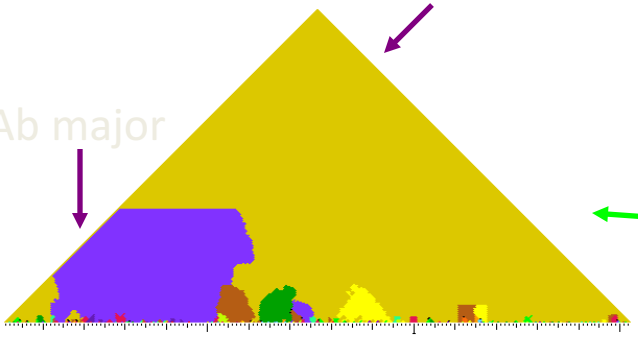


Online Keyscape Plot Generation

http://kern.ccarh.org/browse?l=beethoven/sonatas

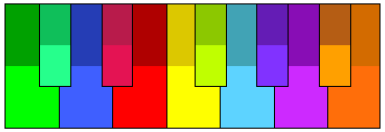
F minor

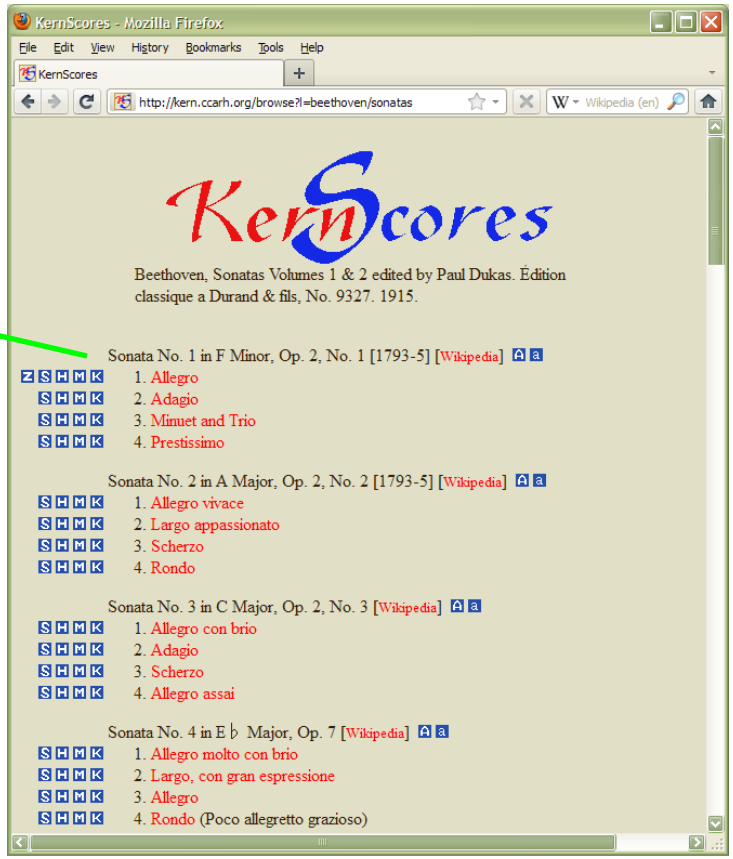
Ab major



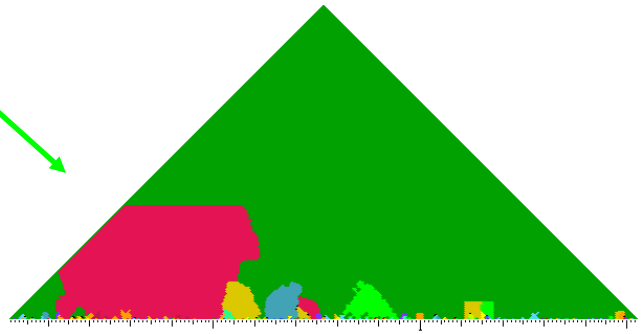
Minor keys:

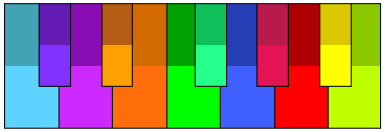
Major keys:





Transposition
(tonic on C)





→ 2nd theme in relative major which recapitulates in C minor

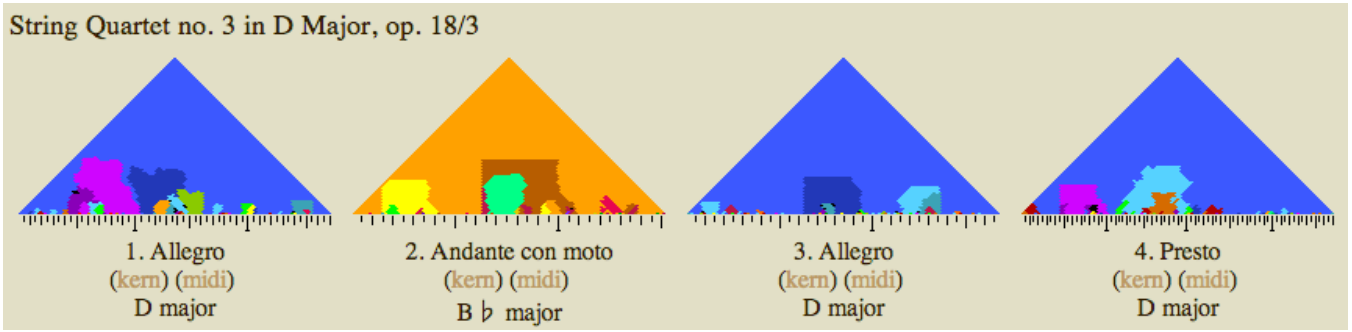
More Info

C++ implementation of KS algorithm and keyscape generator:

- http://extras.humdrum.org/man/keycor
- http://extras.humdrum.org/man/mkeyscape

See bottom of last link for latest keyscape galleries, such as Beethoven string quartets:

http://extras.humdrum.org/man/mkeyscape/beet-quartet



~5000 keyscapes of MIDI files:

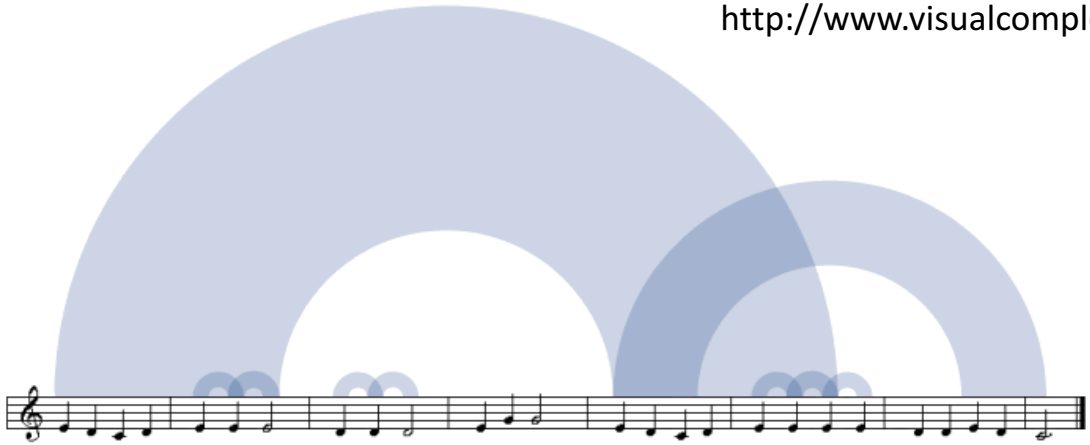
https://ccrma.stanford.edu/~craig/keyscape/class

Form Visualization/Analysis

http://www.bewitched.com/song.html
http://hint.fm/papers/arc-diagrams.pdf

Martin Wattenberg

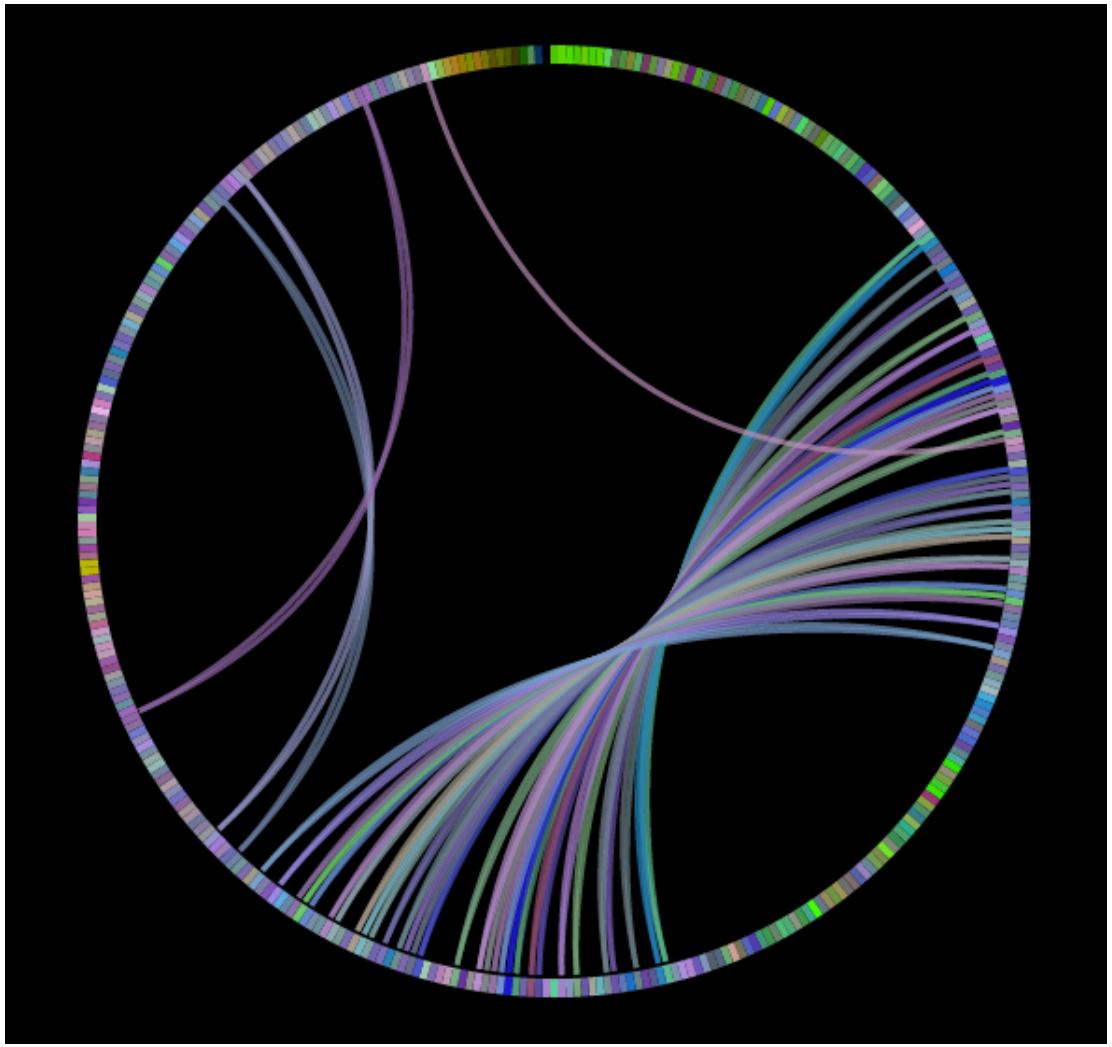
http://www.visualcomplexity.com/vc/index.cfm?method=Arc%20Diagrams



Infinite Jukebox

http://labs.echonest.com/Uploader/index.html?trid=TRORQWV13762CDDF4C

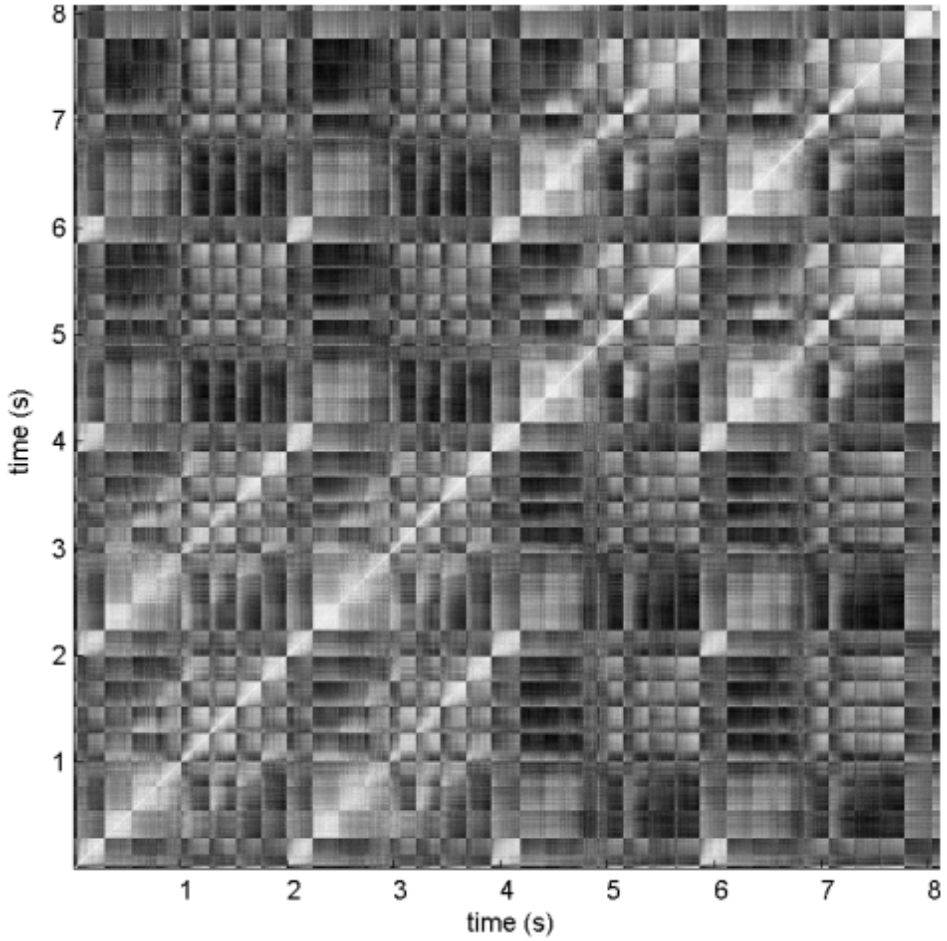
Paul Lamere

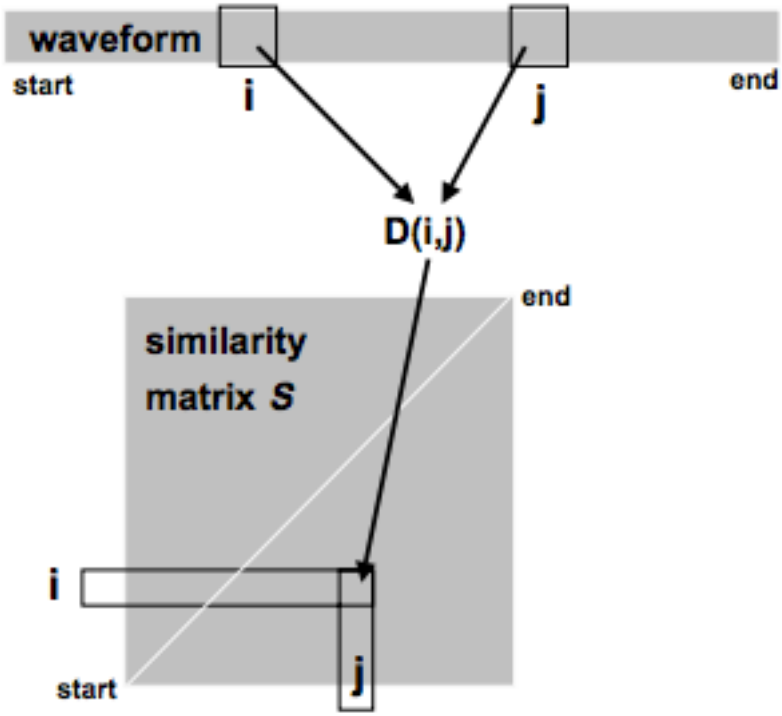


Similarity Matrix

Jonathan Foote

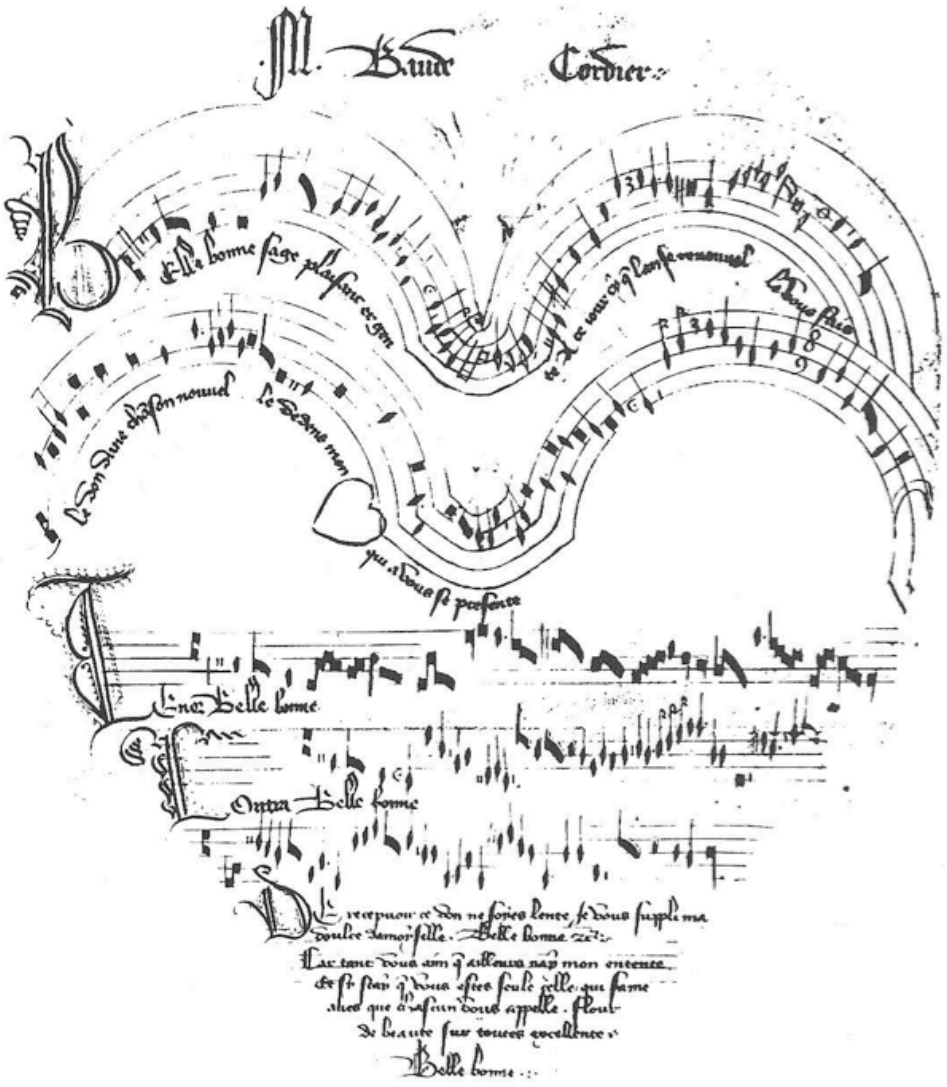
http://www.fxpal.com/publications/visualizing-musical-structure-and-rhythm-via-self-similarity.pdf





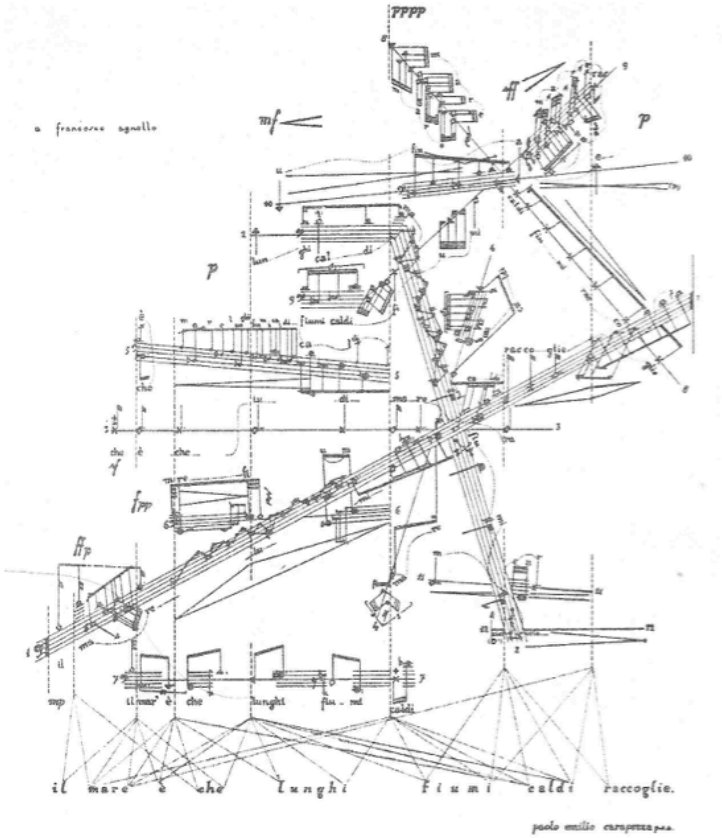
J.S. Bach WTC 1: Prelude #1 in C major

Visual Notation



Visual Notation

Visual Notation



Bussotti - Memoria

See also:

www.mauricio-rodriguez.com/visual-music-I.html

www.mauricio-rodriguez.com/visual-music-II.html