

Musical Notation & Representation

Music 253/CS 275a

Stanford University

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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://www.schoyencollection.com/music_files/ms5105.jpg
<http://www.schoyencollection.com/music.html>

Music Notation in Ancient Greece

Oldest complete notated song (~1st century AD)

Seikilos epitaph



ΩΣΟΕΖΗΣΦΑΙΝΟΥ
ΜΗΔΕΝΟΛΩΣΣΥ
ΛΥΠΤΟΥΠΡΟΣΟΛΙ
ΓΟΝΕΣΤΓΟΖΗΝ
ΤΟΤΕΛΟΣΦΟΧΡΟ
ΝΟΣΑΤΠΑΙΤΕΙ

C Z Z KIZ I
"Ο σον ζῆς φαί νου

K I Z IK O C OΦ
μη δὲν ὅ λως σù λυ ποῦ

C K Z I KIK C OΦ
πρὸς ὁ λί γον ἐσ τὶ τὸ ζῆν

C K O I Z K C C X I
τὸ τέ λος ὁ χρό νος ἀπ αι τεῖ.

Music Notation in Ancient Greece

C Z Z KIZ I

Ο σον ζῆς φαί vou
While you live, shine

K I Z IK O C OΦ

μη δὲν ὅ λως σὺ λυ ποῦ
Have no grief at all

C K Z I KIK C OΦ

πρὸς ὁ λί γον ἐσ τὶ τὸ ζῆν

Life exists only for a short while

C K O I Z K C C CX

τὸ τέ λος ὁ χρό νος ἀπ αι τεῖ.

And time demands its toll

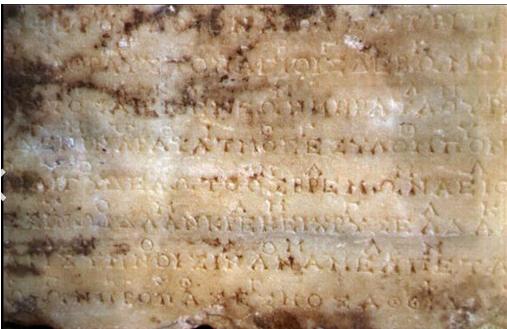
http://en.wikipedia.org/wiki/Seikilos_epitaph

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

The image shows four staves of ancient Greek music notation. Each staff consists of a G clef, a 6/8 time signature, and a sharp key signature. The notation uses black dots for pitch and vertical strokes for rhythm. Below each staff is a line of Greek text with blue underlined words indicating the lyrics:

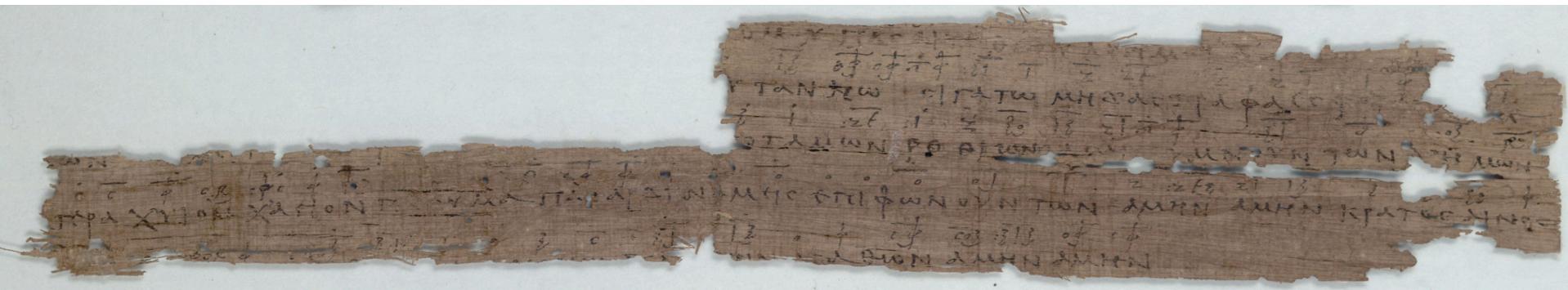
- Top staff: Ο-σον ζης φαι - vou
- Second staff: μη - δεν ο-λως συ λυ - που
- Third staff: προς ο - λι - γον εσ - τι το ζην
- Bottom staff: το τε - λος ο χρο - νος απ αι - τει

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



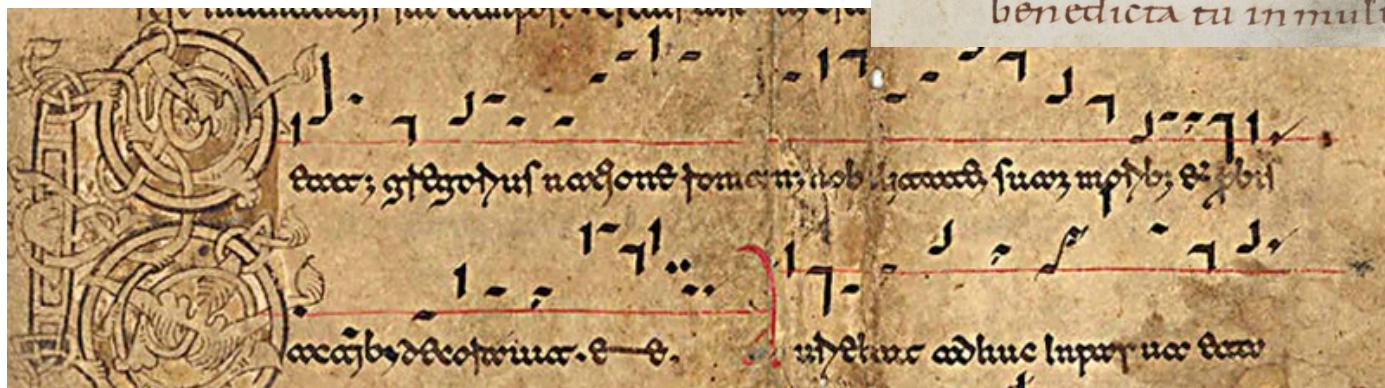
Romania, 1823

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

A comparison of Byzantine musical notation with modern Western musical notation. The top part shows a series of stylized Greek characters representing musical intervals, followed by their phonetic transcription in Greek: Δεῦ - τε πό - μα πί - ω - μεν καὶ νόν οὐκ ἐκ πέ - τρας. Below this, a staff of Western musical notation is shown with corresponding note heads and rests. The bottom part shows the same text in Greek: Δεῦ - τε πό - μα πί - ω - μεν καὶ νόν οὐκ ἐκ πέ - τρας, with the Western musical notation below it.

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

Gregorian Chant



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

Messine notation

Modern chant notation

St. Gall notation

Comm.

I.

E.

vot

c-ce virgo concipi- et, et pá- ri- et fi- li-

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

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



Shape Notes



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,
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 - zon a - dorming, 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.

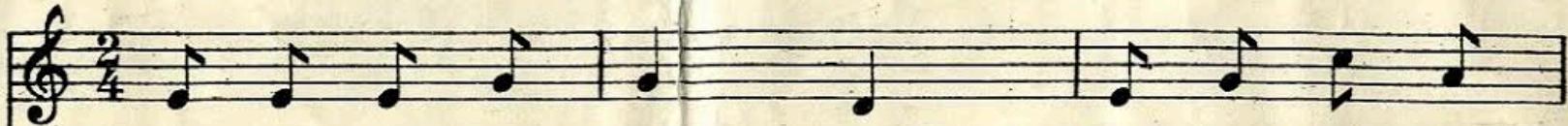
Tonic Sol-Fa

The Lamb.

WILLIAM BLAKE.

GEORGE HENSCHEL.

VOICE.



KEY C. { | m .m :m .s | s :r | m .s :d' .l | }

PIANO.



Tablature

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



P B P BP B P B P B

3 r b a b | a b b a | r b a b a | a a a a a a | a

TAB 1 0 4 1 3 1 3 5 3 4 4 4 2 2 2 0

5

G# A A# B C C# D D# E F F# G G# A A# B

T 1 2 3 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

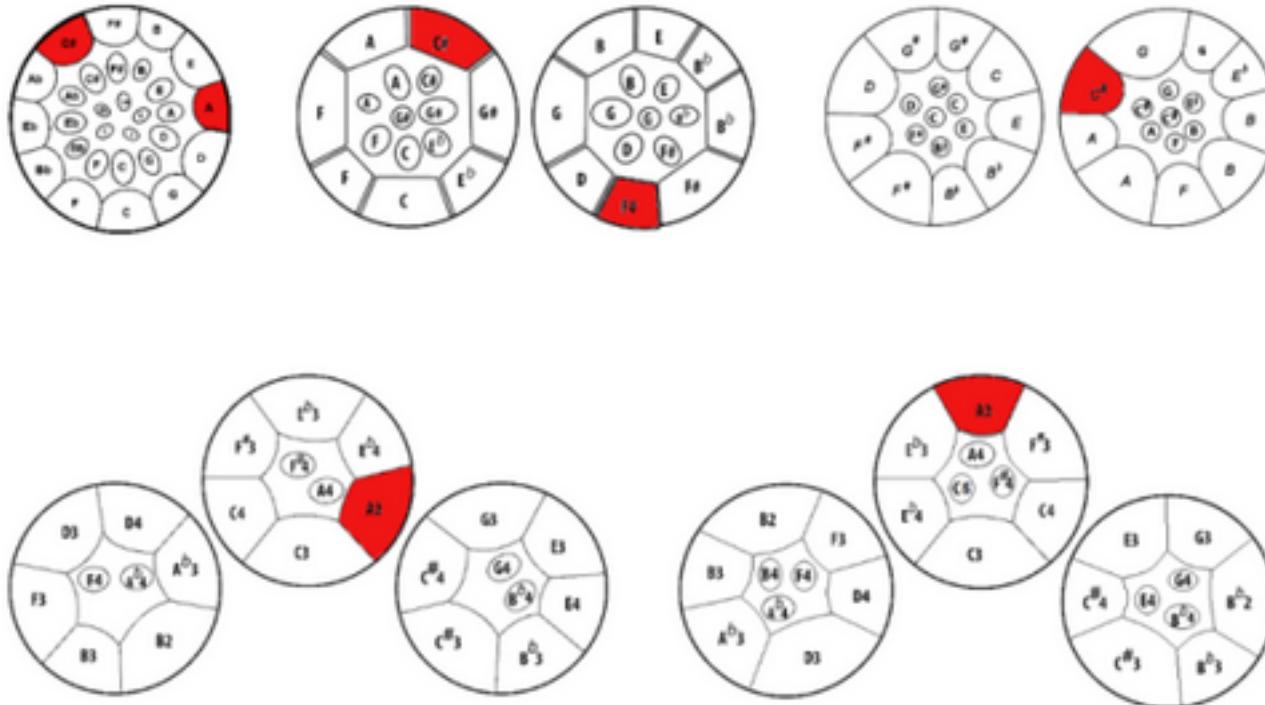
A 6 7 8 9 10 11 12 13 14 15 16 17 18

B 11 12 13 14 15 16 17 18

16 17 18

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

Steel Drum Tablature



Position:

Tempo:

PLAY STOP

lead tenors seconds triples new_triples metronome sound

Choose File No file chosen Submit MIDI File

allica.mid Load MIDI File

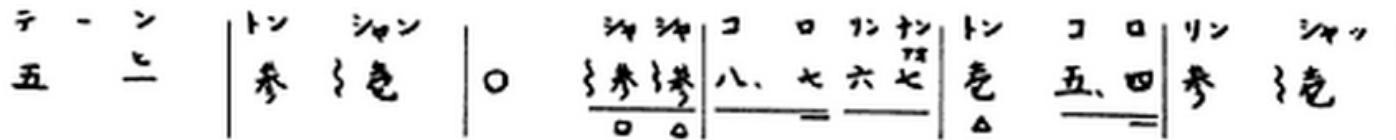
— Jonathan Potter, Cardinal Calypso

Koto Tablature

Ikuta school notation (Kyoto)

五
二
三
四
五
六
七
一
二
三
四
五
六
七
一
二
三
四
五

Yamada school notation (Tokyo)



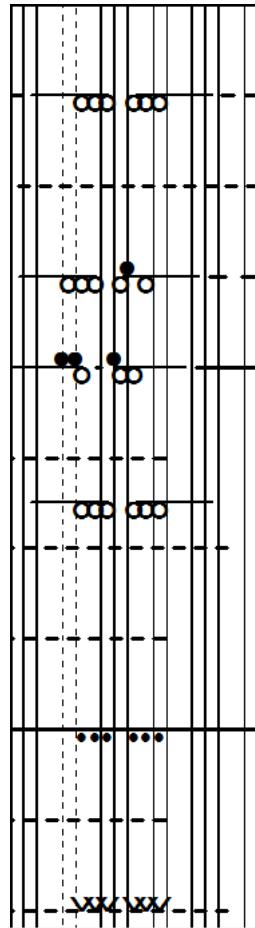
“Rokudan no shirabe”

by Kengyō Yatsuhashi (1614–1685)



Digital representation:

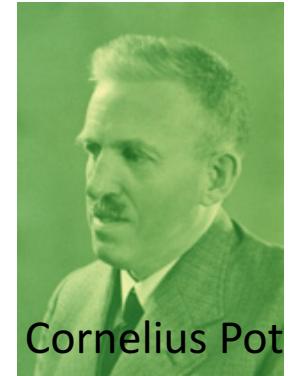
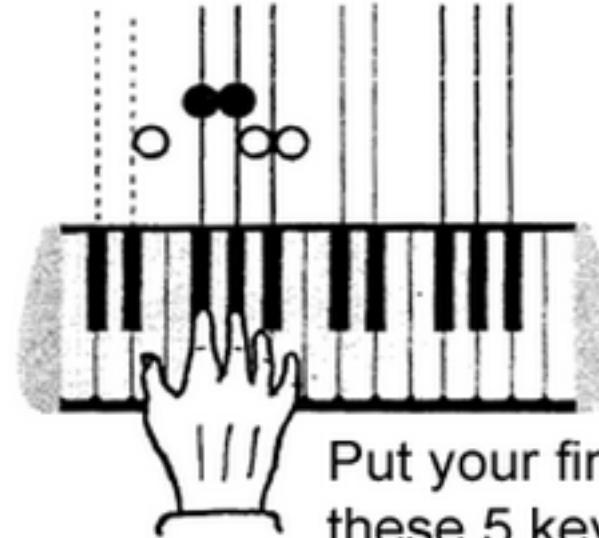
**koto	**kuchi	**kern
*M4/4	*M4/4	*M4/4
=1-	=1-	=1-
{5+i	te	{2d
-	n	.
3	ton	4A
1s	shan	4d: 4G:
=2	=2	=2
0}	.	4r}
{3 sb	sha	{8A: 8A#:
3 sc	sha	8A: 8A#:
8 .	koo	8.a
7	ro	16g
6	rin	8d#
7 o	chin	16gH
.	.	16ah
=3	=3	=3
1c	ton	4d
5 .	koo	8.d
4	ro	16A#
3}	rin	4A}
{1s	shan	{4d: 4G:
=4	=4	=4



Piano Tablature

Klavarskribo

“Keyboard script” in Esperanto



Cornelius Pot

<https://www.youtube.com/watch?v=MlolvxunihA&t=659>

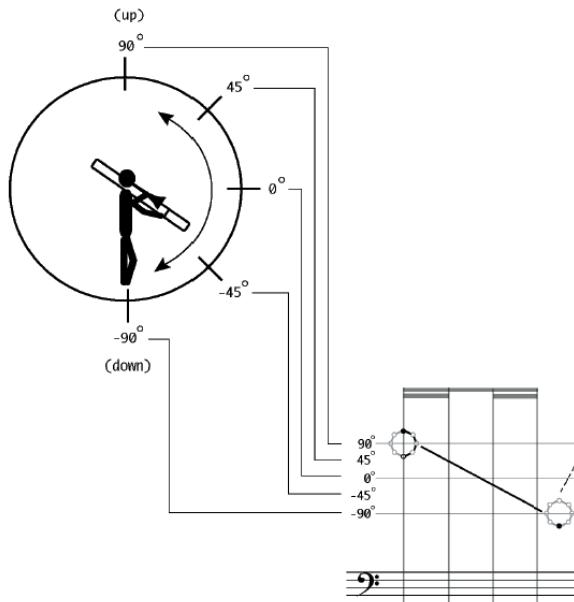
<http://evanlenz.net/blog/2007/11/02/re-discovering-klavarscribo/>

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

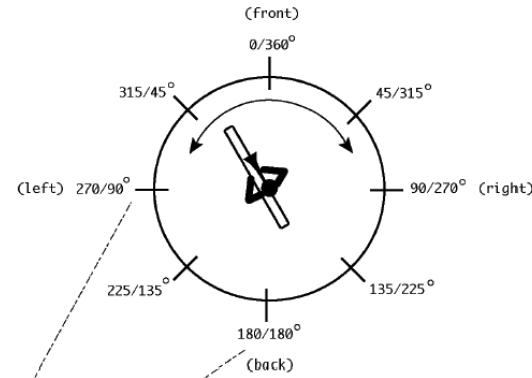
<http://www.klavarskribo.nl/en>

Prescriptive Notation

lateral view



aerial view

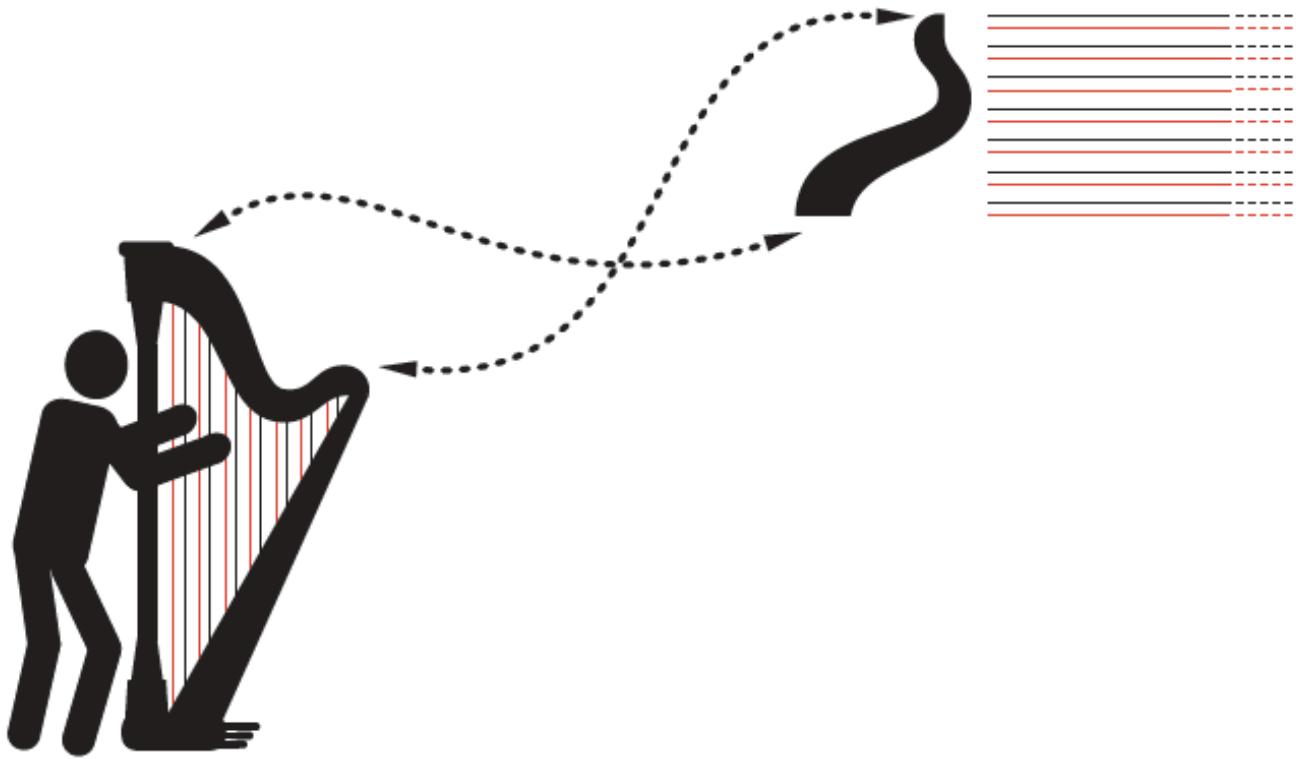


in this example, the player should locate the instrument bell 90 degrees above his vertical body axis and then reaching 90 degrees under that axis while turning his body right side (following the bold lines inside the circle) until reaching his back side (180 degrees on the horizontal axis), all this happens approximately in $\frac{1}{4}$ of the beat.

$\text{♩} = \sim 40$

A musical score for Tuba (Tbn.) featuring prescriptive notation. The score includes a tempo marking of $\text{♩} = \sim 40$. The top staff shows a continuous line with circular arrows indicating movement paths. The middle staff shows a grid with degree markings (90°, 45°, 0°, -45°, -90°) corresponding to the performer's body axes. The bottom staff is a standard musical staff with notes and dynamics like $f\text{--}fff$, $m\text{--}ff$, and $f\text{--}fff$. Measure numbers 6 and 7 are indicated on the staff.

Prescriptive Notation



1 ~48

⊕ ⊕ ⊕ 3

⊕ 5

⊕ 3

5

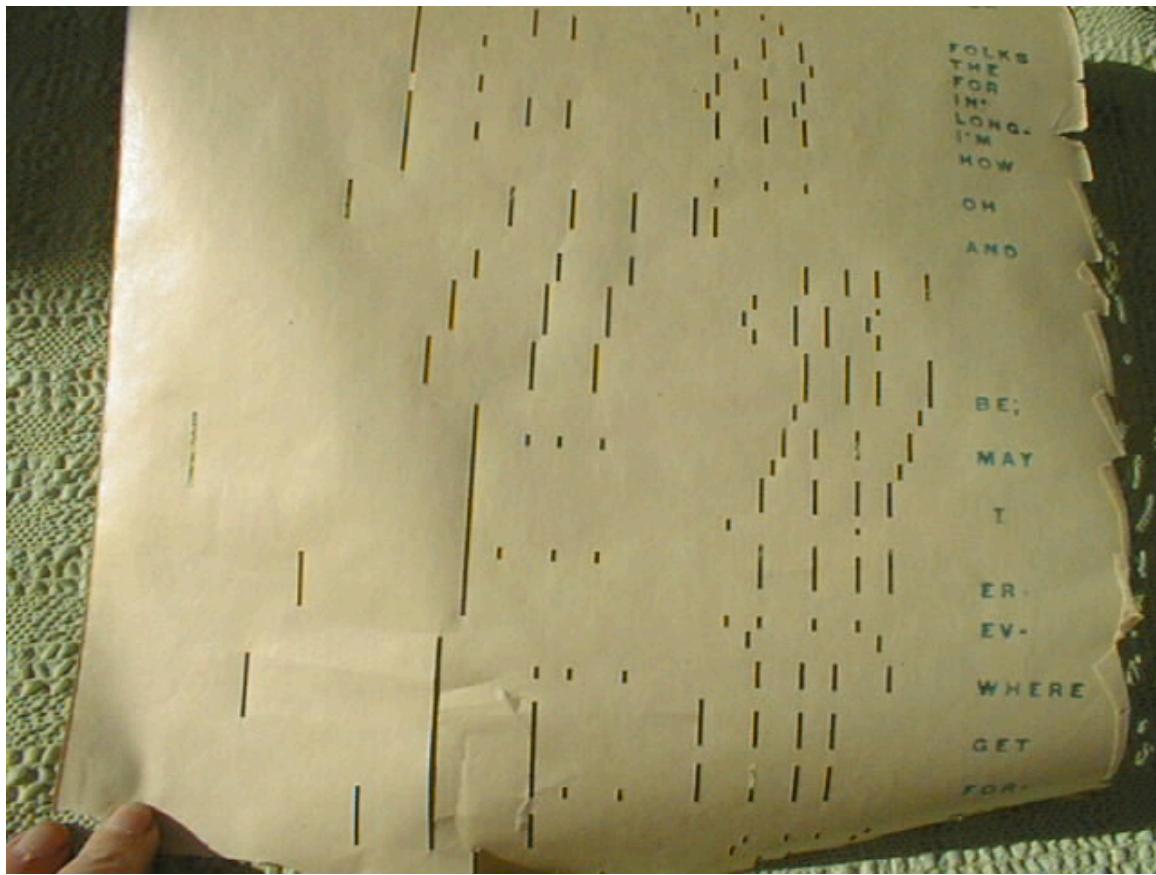
3 5

⊕ ⊕ 3

(m)

Piano Rolls

Mechanical Representation of music



Performance Data Visualization

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

Anderszewski 1996

Musical score for Webern Piano Variations, mvmt. 2, Op. 27, Anderszewski 1996 edition. The score consists of five staves of music. Staff 1 starts at measure 0 and ends at measure 1. Staff 2 starts at measure 2 and ends at measure 11. Staff 3 starts at measure 14 and ends at measure 21. Staff 4 starts at measure 15 and ends at measure 31. The music features complex rhythmic patterns and harmonic structures typical of Webern's style.

Gould 1954

Musical score for Webern Piano Variations, mvmt. 2, Op. 27, Gould 1954 edition. The score consists of five staves of music. Staff 1 starts at measure 0 and ends at measure 1. Staff 2 starts at measure 4 and ends at measure 11. Staff 3 starts at measure 19 and ends at measure 21. The music features complex rhythmic patterns and harmonic structures typical of Webern's style.

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

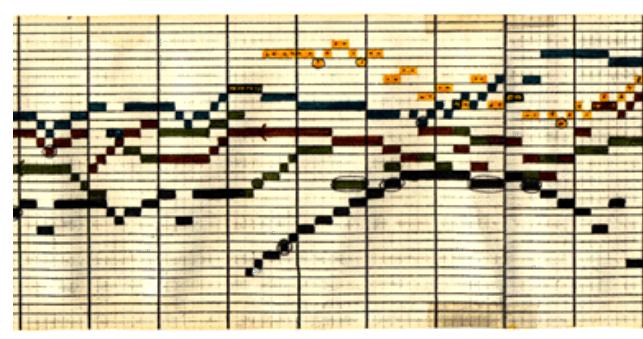
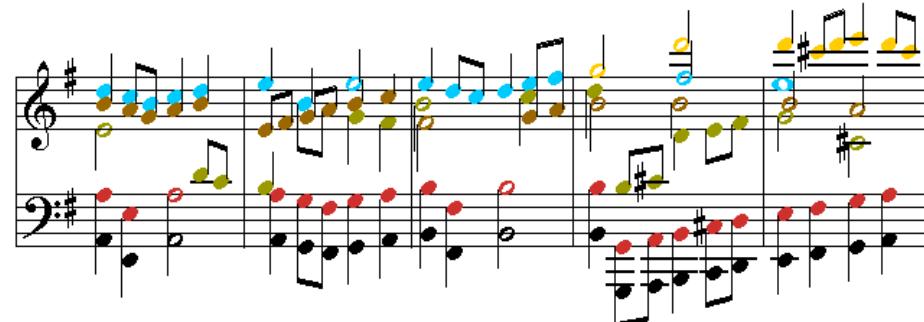
<http://mazurka.org.uk/webern/notation/Anderszewski1996>

<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

How are musical
Dimensions mapped
In each visualization?

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)

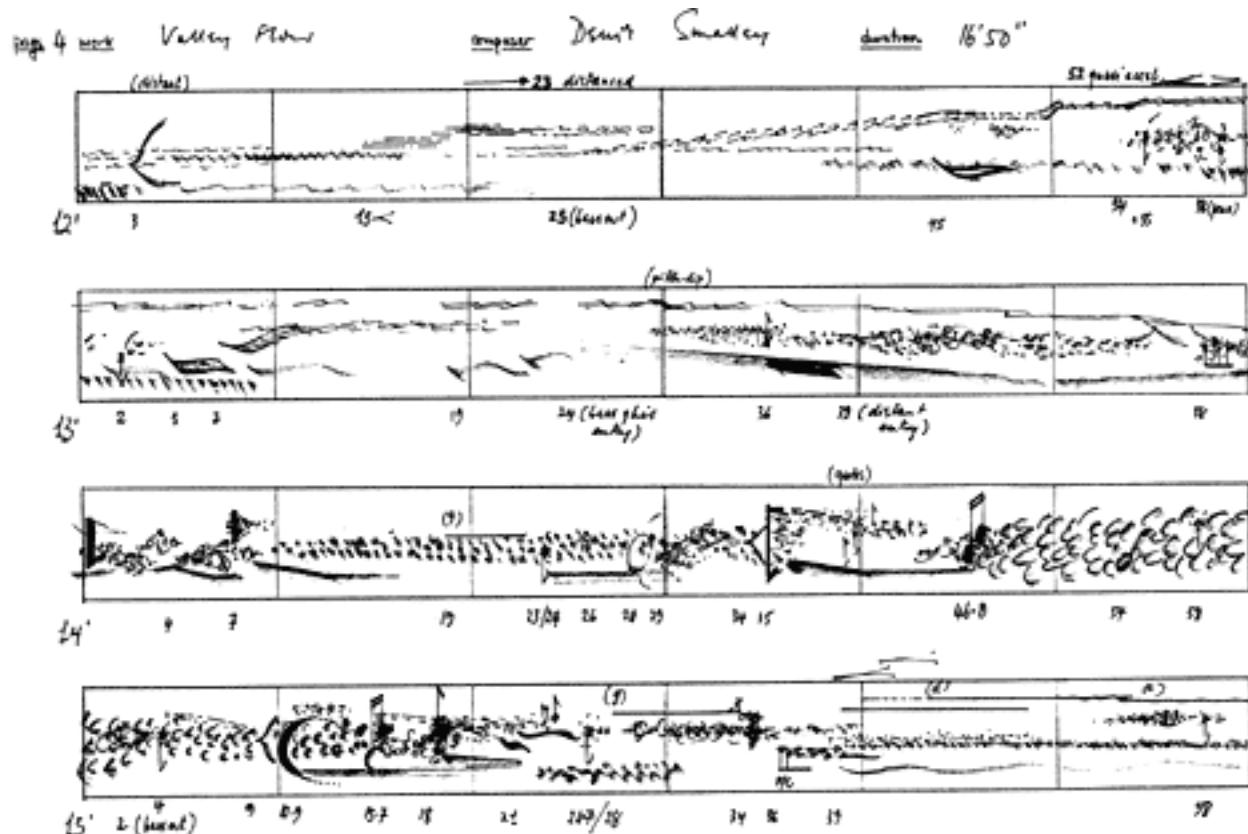
<https://www.youtube.com/watch?v=xhc1PsokFOw>

Debussy, First Arabesque

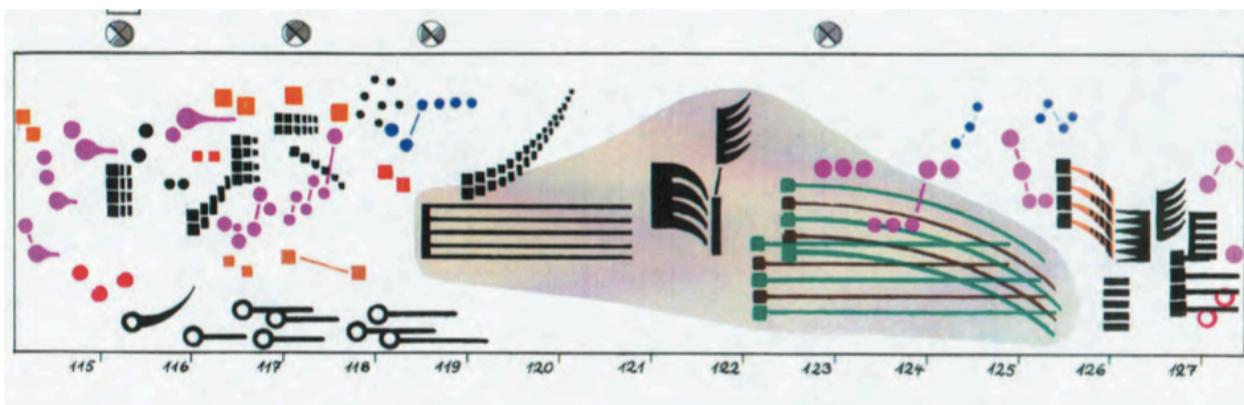
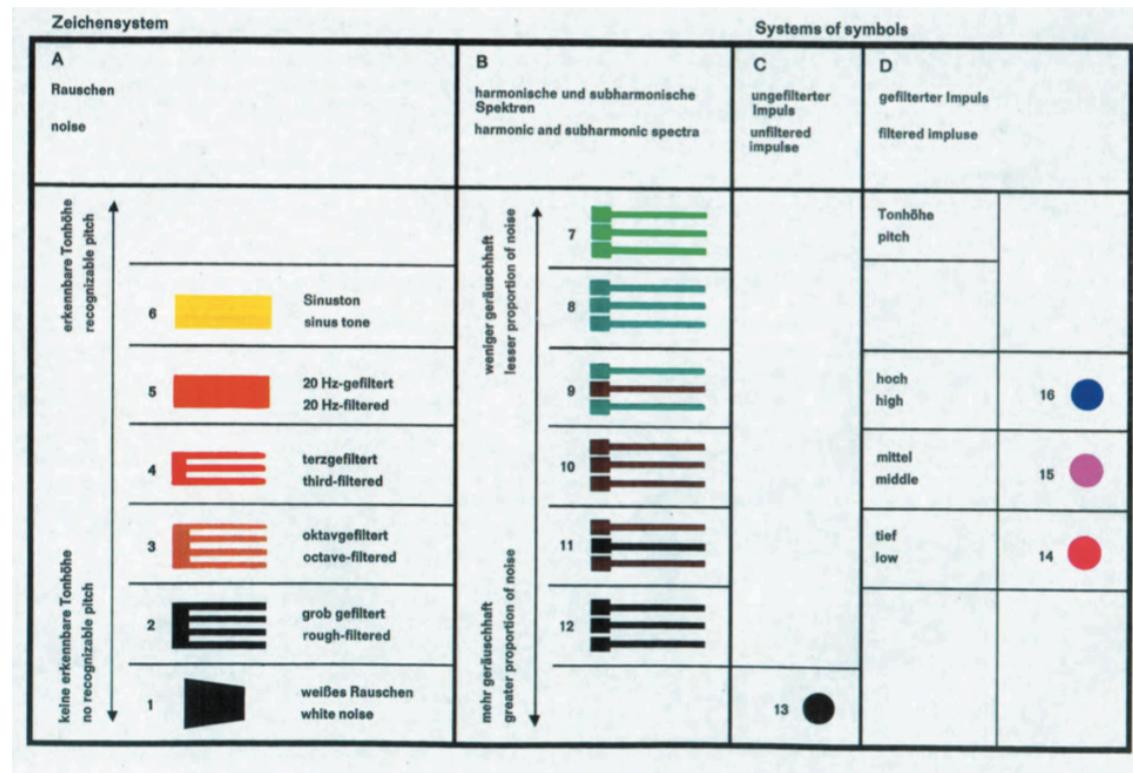
<https://www.youtube.com/watch?v=Yt1jfX5C1u0>

Textural Notation

Analytic notation of electro-acoustic music

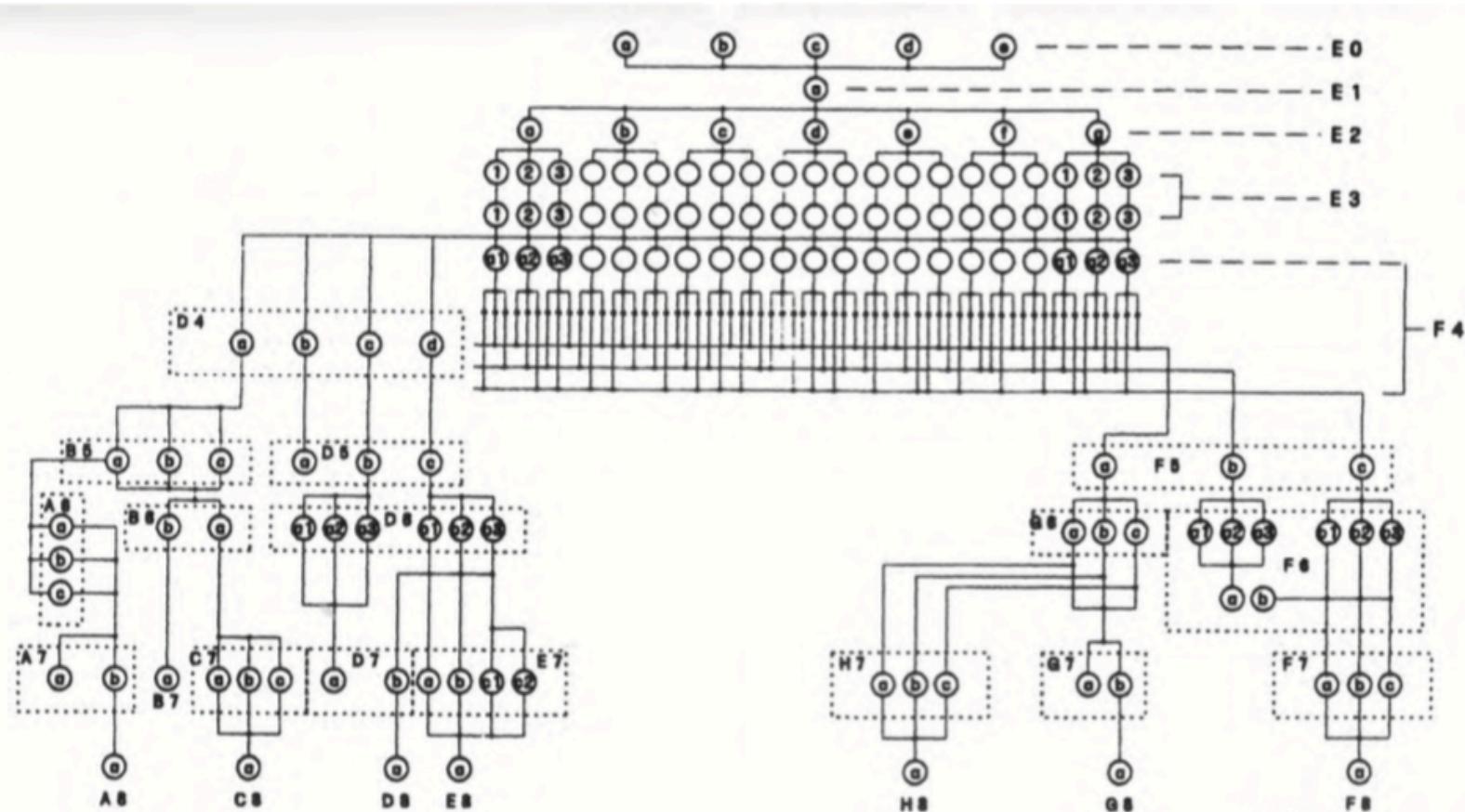


Listening Scores



Music Notation & Music Process

Terminus (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   COUNT
        DIV2,-
        CNT2
        DIV2,-;
    CALCULATE
        MASTER:MASTER+1
        MAX:5-MASTER;
        ZERO?
        YES:END;;
    SWITCH
        MASTER
        PART1,PART2,PART3,PART4;;
&
&-----&
&                               PART1
&
&-----&
PART1  INITIALIZE
        CNTRL1:-15
        PEAK:40
        CNT1:-
        A:0;;
CREATE LIST
        NAME:MODAMP
        SIZE:80;
    CHECK
        CNT
        A3,-;
    INITIALIZE
        SKIP:-2;;
A1     SAMPLE LIST
        NAME:ENV2
        SIZE:8
        INCREMENT:1;;
    CHECK
```

Language description

```
FILE2  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;

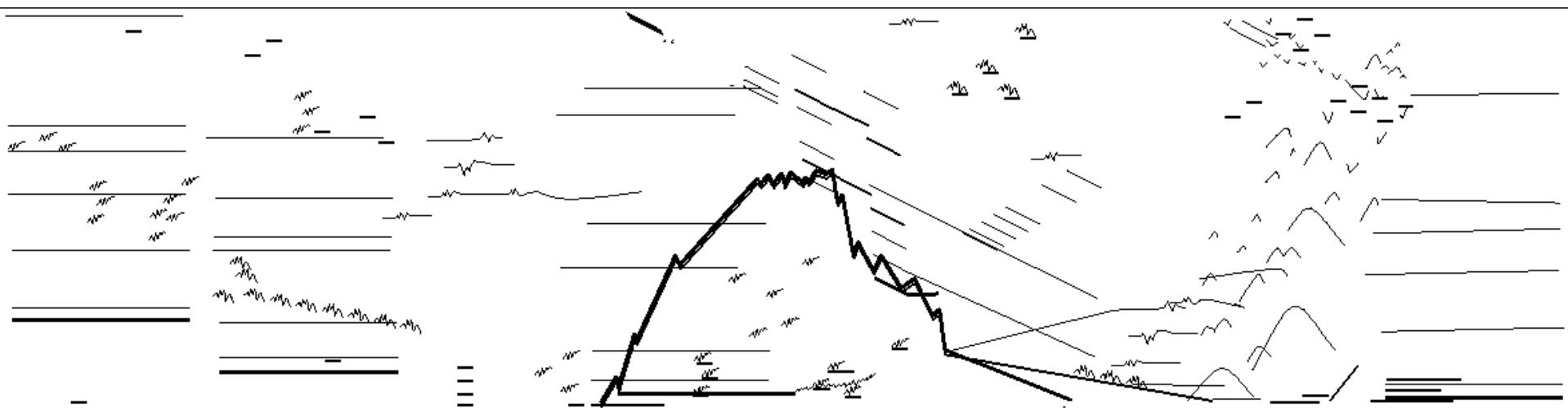
5. label: an address name given to an instruction. The name is from
1-6 symbols. The first symbol must be a letter. The remaining
symbols may be either letters or numbers. A label may occur only
in the first line of an instruction (the line which contains the
operation). A label (if it is to be used)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

Pitch reductions for *Hyperprism*

(Kronengold)

mm. ① ⑤ ⑫ ⑯ ⑰ ⑲ ⑳ ㉗ ㉙ ㉚ ㉛ ㉔ ㉖ ㉗ ㉘ ㉙
 ㉔ ㉖ ㉗ ㉘ ㉙ ㉔ ㉖ ㉗ ㉘ ㉙ ㉔ ㉖ ㉗ ㉘ ㉙

<0-2> ————— 3 ————— <2—0> ————— 1 ————— 3>

Ia { MOTIVIC DYADS
 MOTIVIC P.C.s

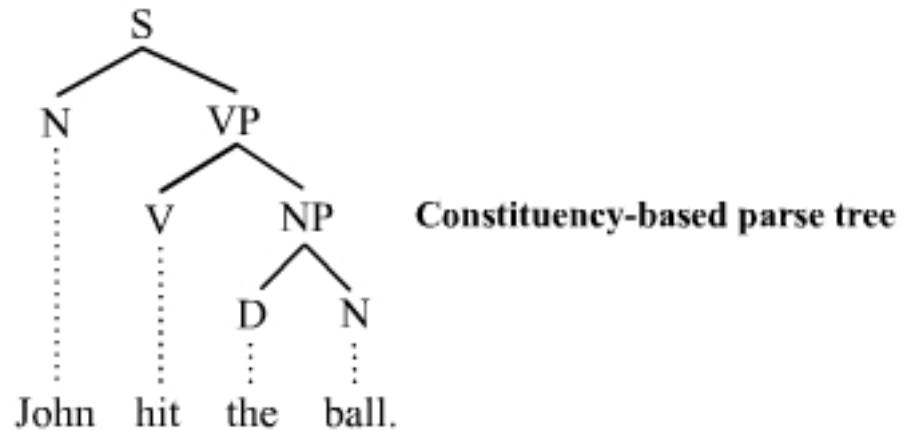
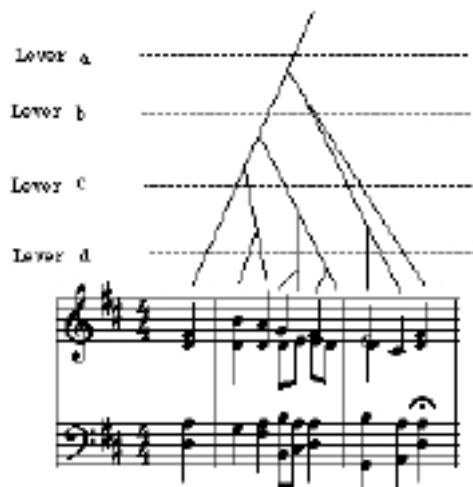
Ib {

II { MELODIC CONTOURS*

see ex. 2 for detail of mm. 40-43

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

GTTM

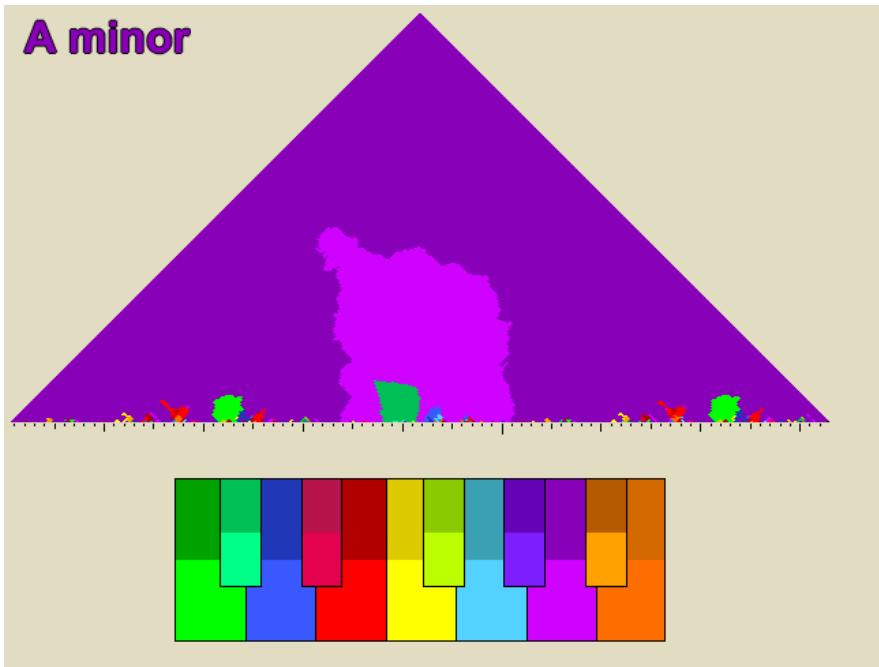


http://en.wikipedia.org/wiki/Parse_tree

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

Keyscapes

Graphical display of harmonic structure



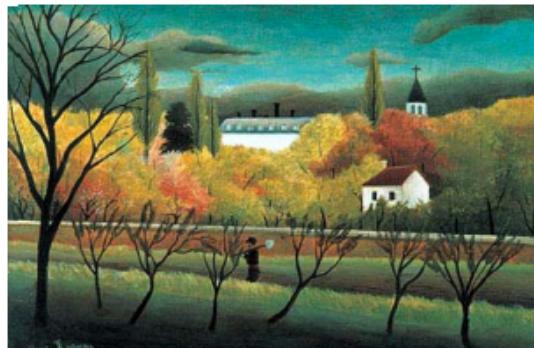
Chopin mazurka in A minor Op. 67, No. 4

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

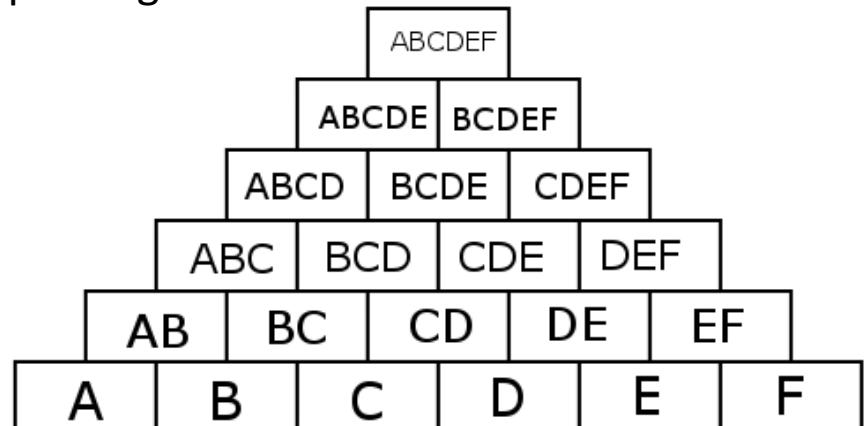
A major: 1:18

A minor: 2:10

Landscape:



Scape plotting domain:



background

large-scale structures

middleground

small-scale structures

foreground
surface features

An Orchard c1896 Henri Rousseau

Computational Key Identification



Computational Key Identification



Pearson correlation:

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

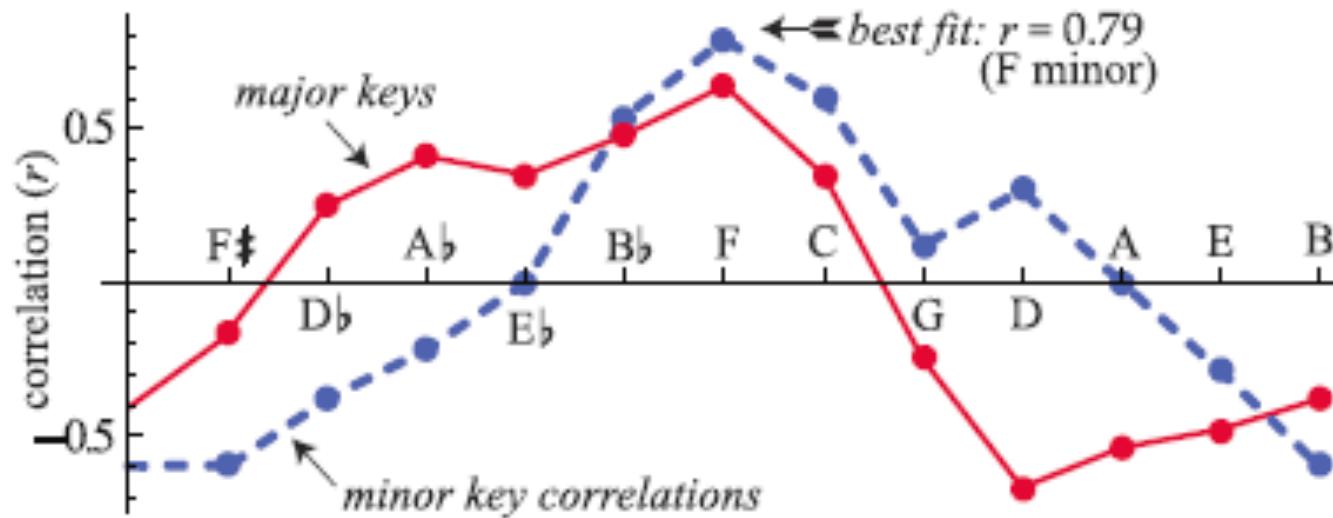
Krumhansl-Schmuckler
key-finding algorithm:

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

Computational Key Identification

A musical score excerpt consisting of two staves. The top staff is in treble clef and the bottom staff is in bass clef. Both staves are in 2/4 time. The key signature consists of two flats. The music includes various note values such as eighth and sixteenth notes.

pitch-class counts
(duration weighted): C: 8♪ D#/E♭: 0 F#: 0 A: 0
C♯/D♭: 0 E: 2♪ G: 5♪ A♯/B♭: 5♪
D: 0 F: 11♪ G♯/A♭: 7♪ B: 2♪

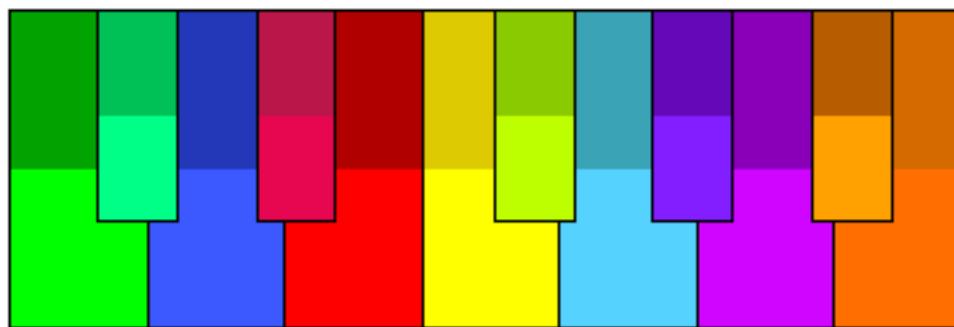
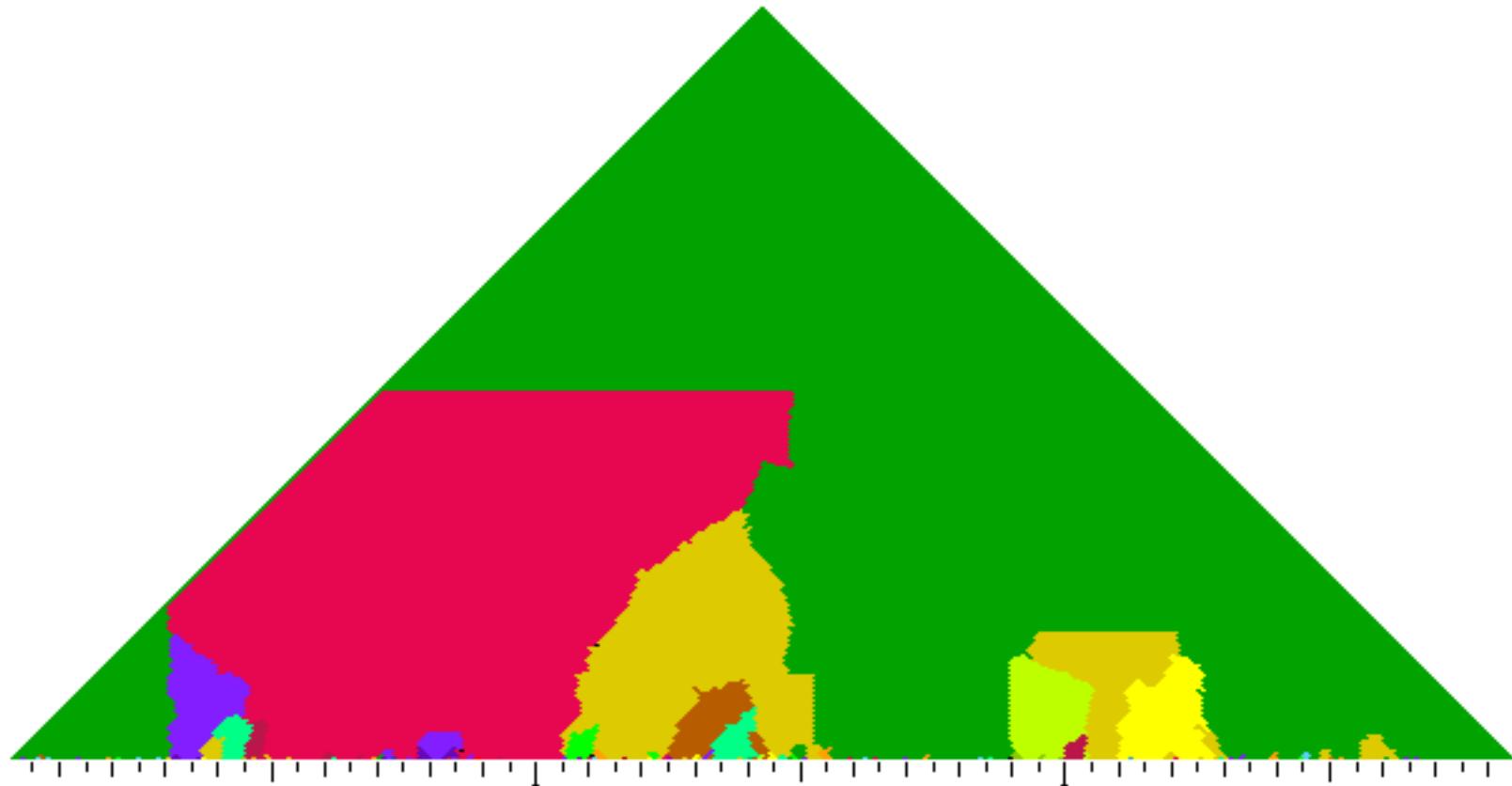


pitch-class histogram: $x = (8, 0, 0, 0, 2, 11, 0, 5, 7, 0, 5, 2)$

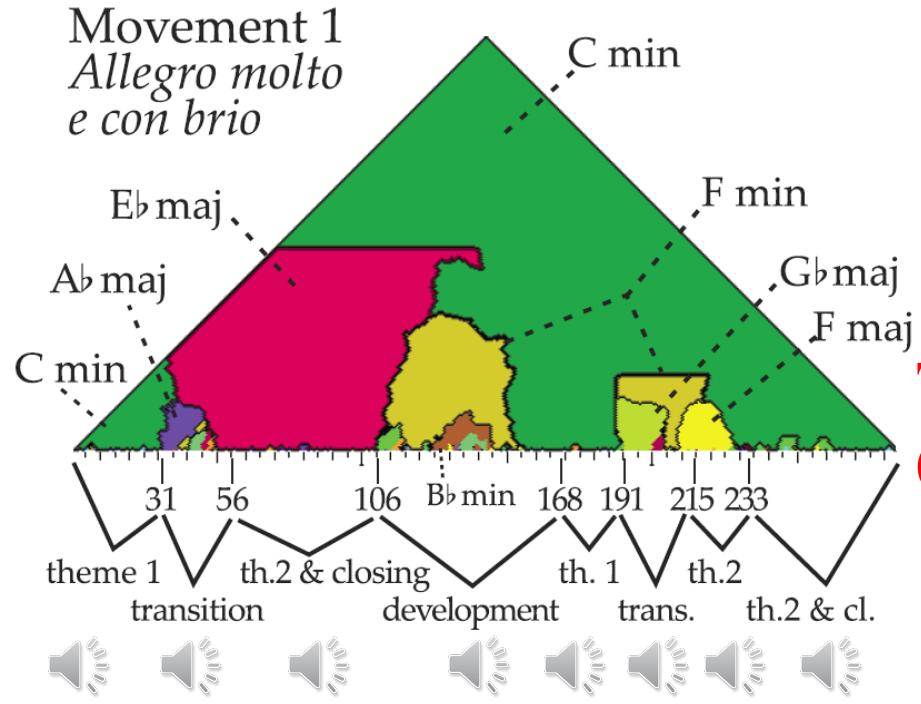
major key prototype: $y_M = (2, 0, 1, 0, 1, 1, 0, 2, 0, 1, 0, 1)$

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
(E♭ major):**



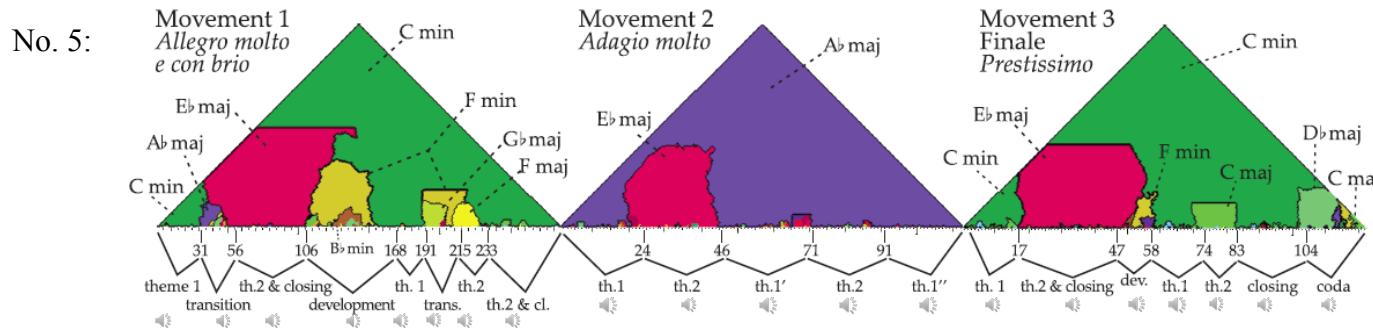
Theme 2 (F major):



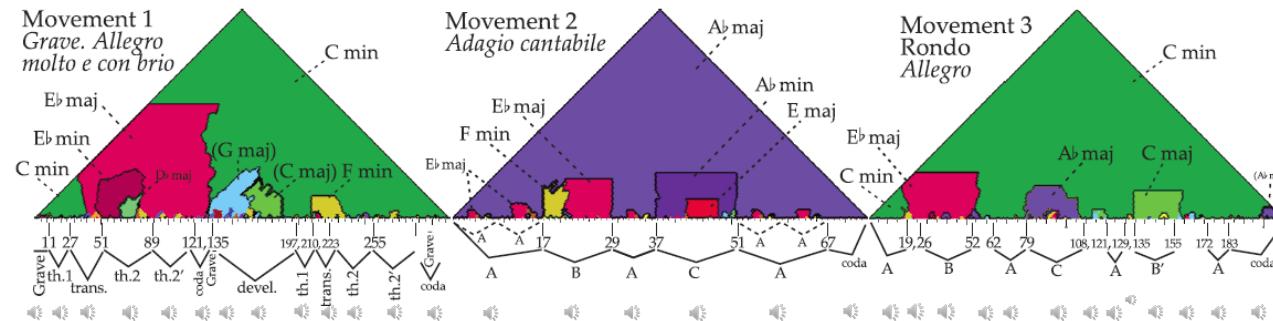
Theme 2 (C minor):



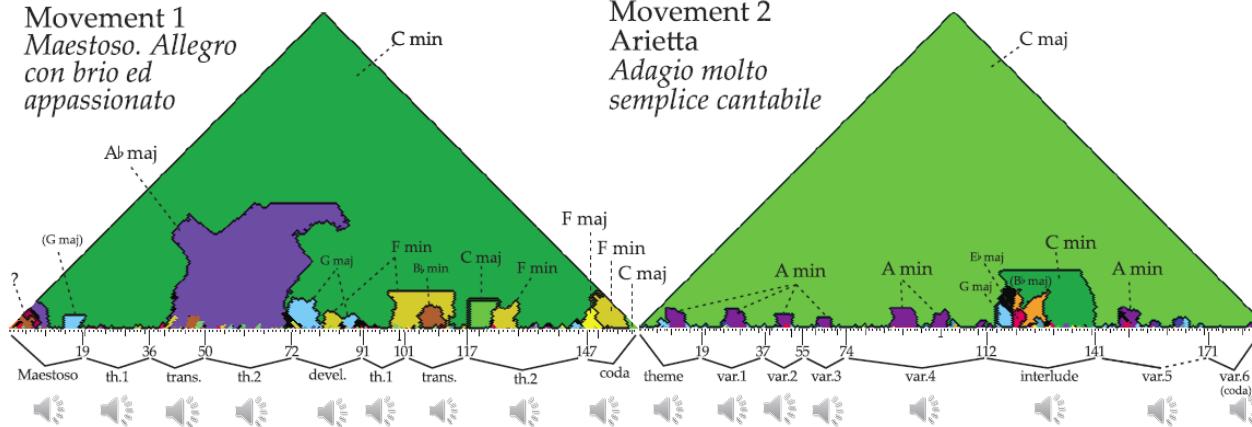
Other C-Minor Beethoven Sonatas



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

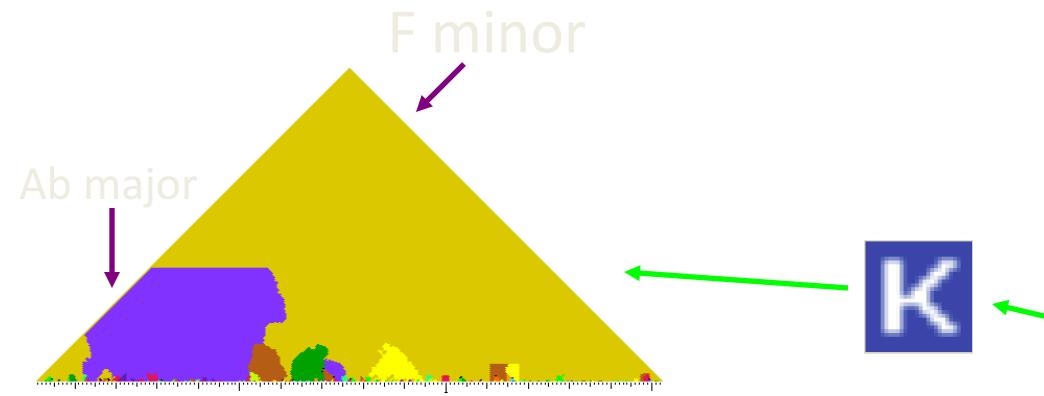


piano sonata no. 32



Online Keyscape Plot Generation

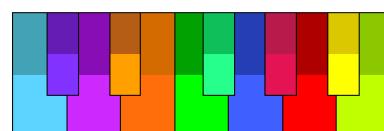
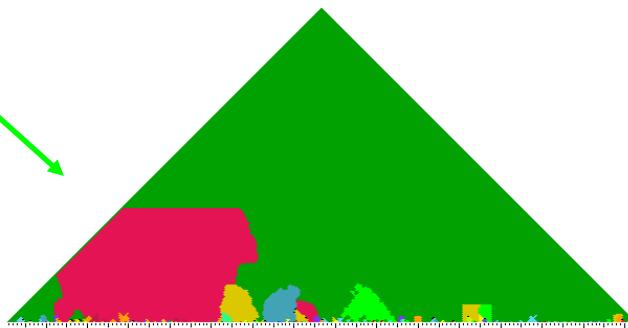
<http://kern.ccarh.org/browse?l=beethoven/sonatas>



Minor keys:

Major keys:

Transposition
(tonic on C)



KernScores - Mozilla Firefox

Beethoven, Sonatas Volumes 1 & 2 edited by Paul Dukas. Édition classique a Durand & fils, No. 9327. 1915.

S H M K 1. Allegro
S H M K 2. Adagio
S H M K 3. Minuet and Trio
S H M K 4. Prestissimo

S H M K 1. Allegro vivace
S H M K 2. Largo appassionato
S H M K 3. Scherzo
S H M K 4. Rondo

S H M K 1. Allegro con brio
S H M K 2. Adagio
S H M K 3. Scherzo
S H M K 4. Allegro assai

S H M K 1. Allegro molto con brio
S H M K 2. Largo, con gran espressione
S H M K 3. Allegro
S H M K 4. Rondo (Poco allegretto grazioso)

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

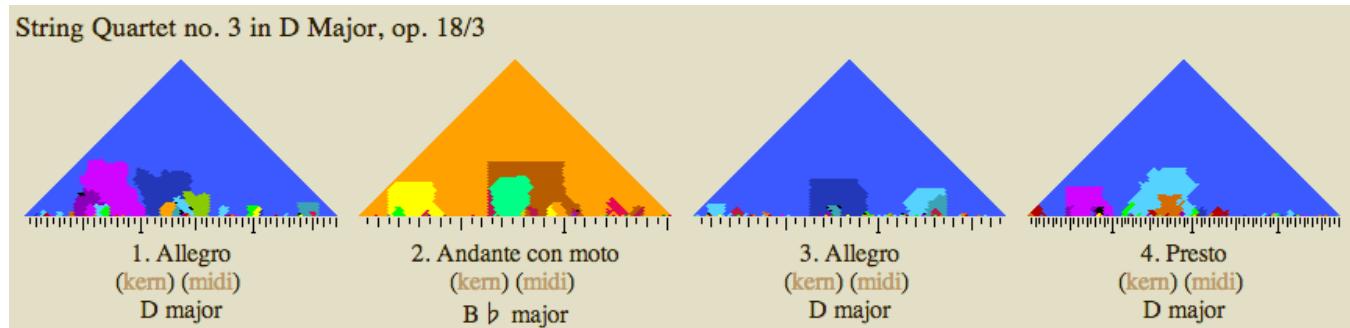
More Info

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 keyscares of MIDI files:

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

Form Visualization/Analysis

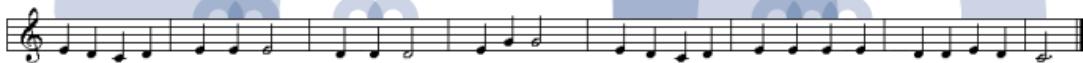
<http://www.bewitched.com/song.html>

<http://hint.fm/papers/arc-diagrams.pdf>

Martin Wattenberg



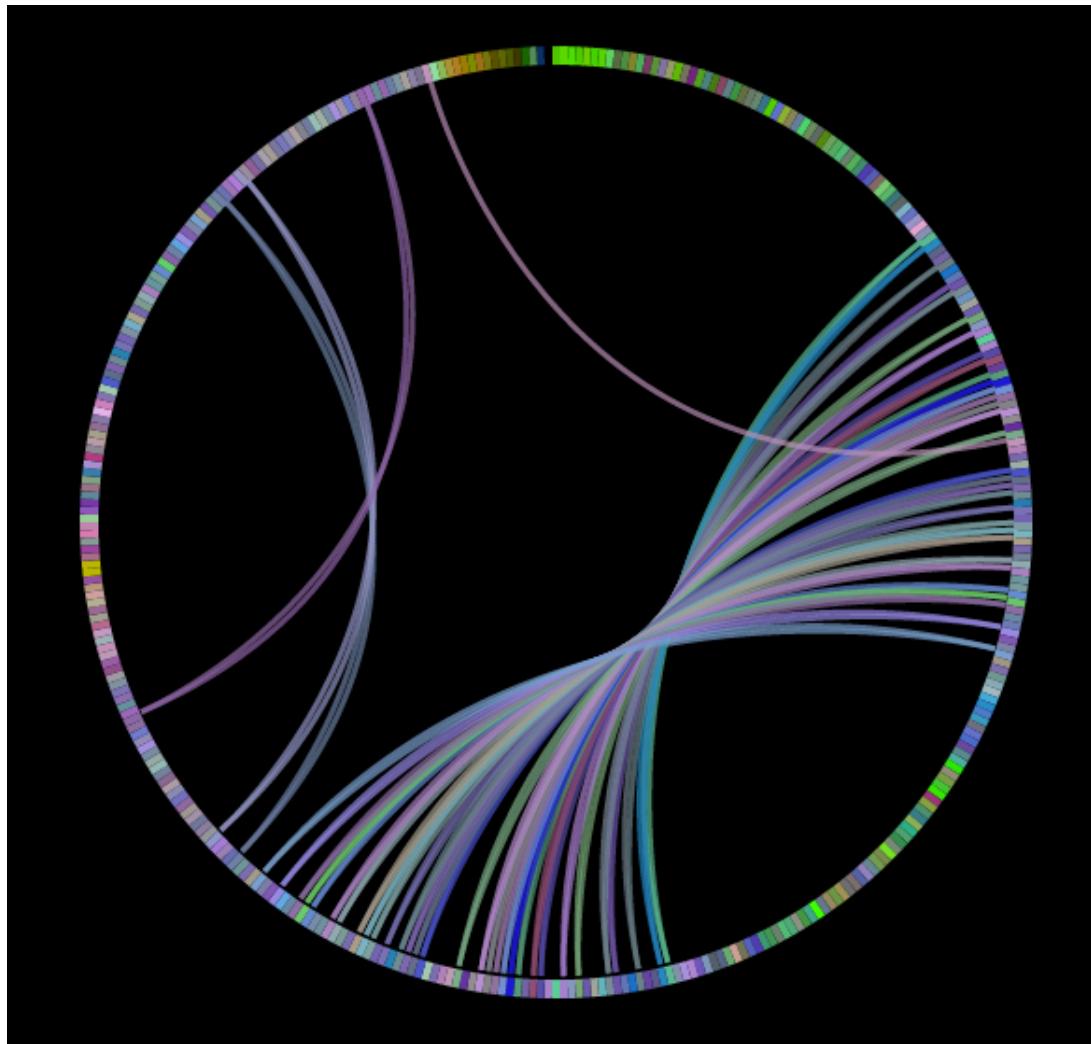
<http://www.visualcomplexity.com/vc/index.cfm?method=Arc%20Diagrams>



Infinite Jukebox

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

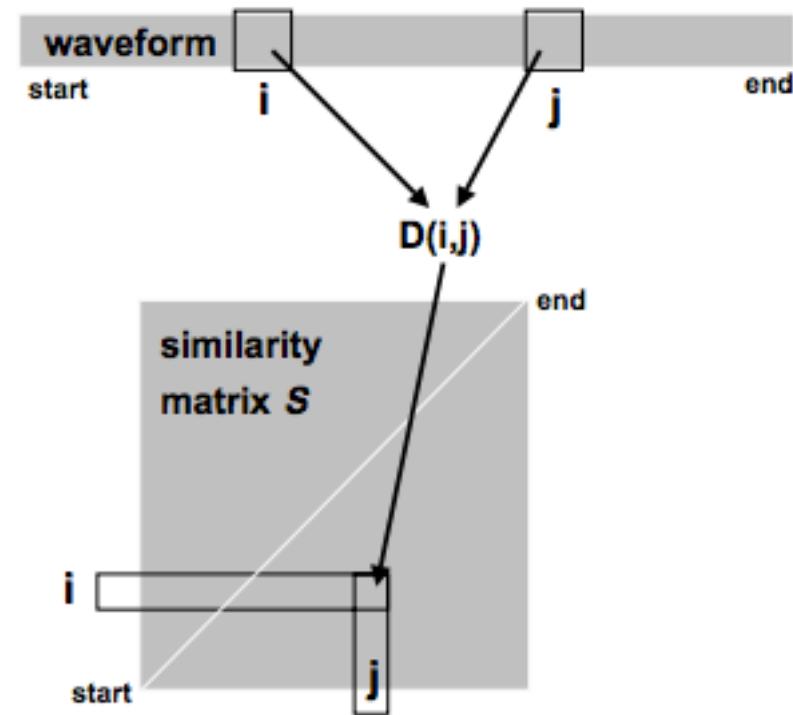
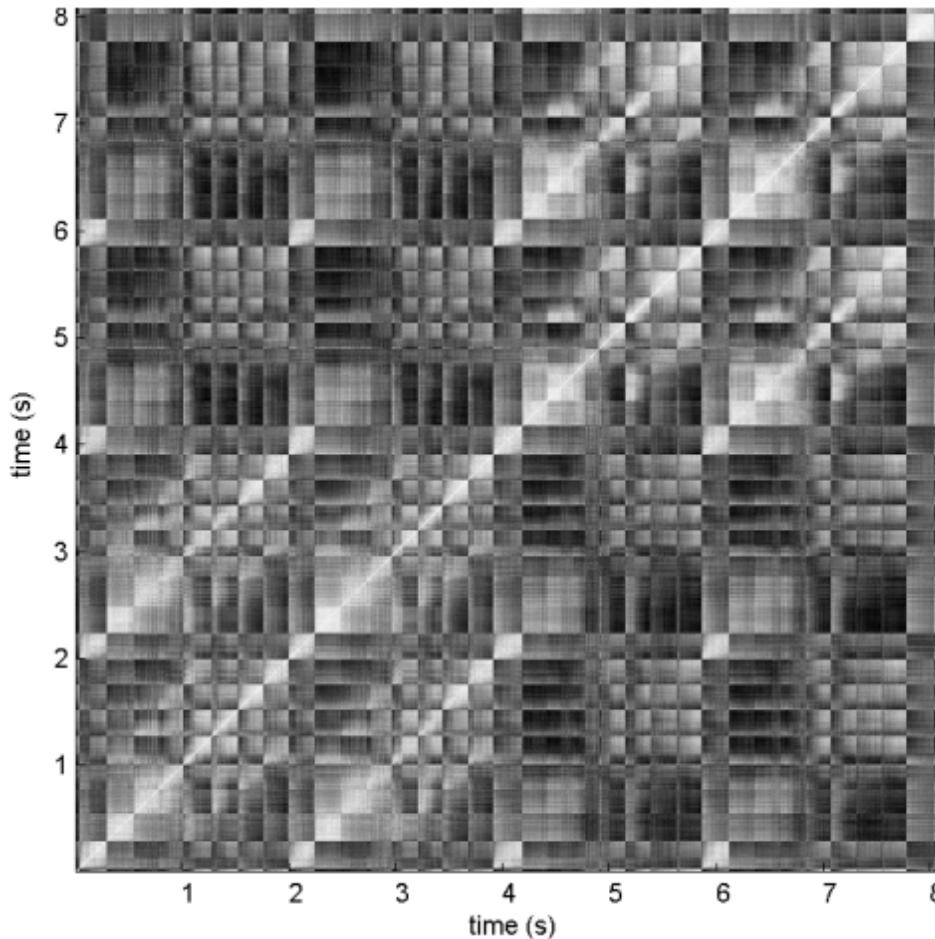
Paul Lamere



Similarity Matrix

Jonathan Foote

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

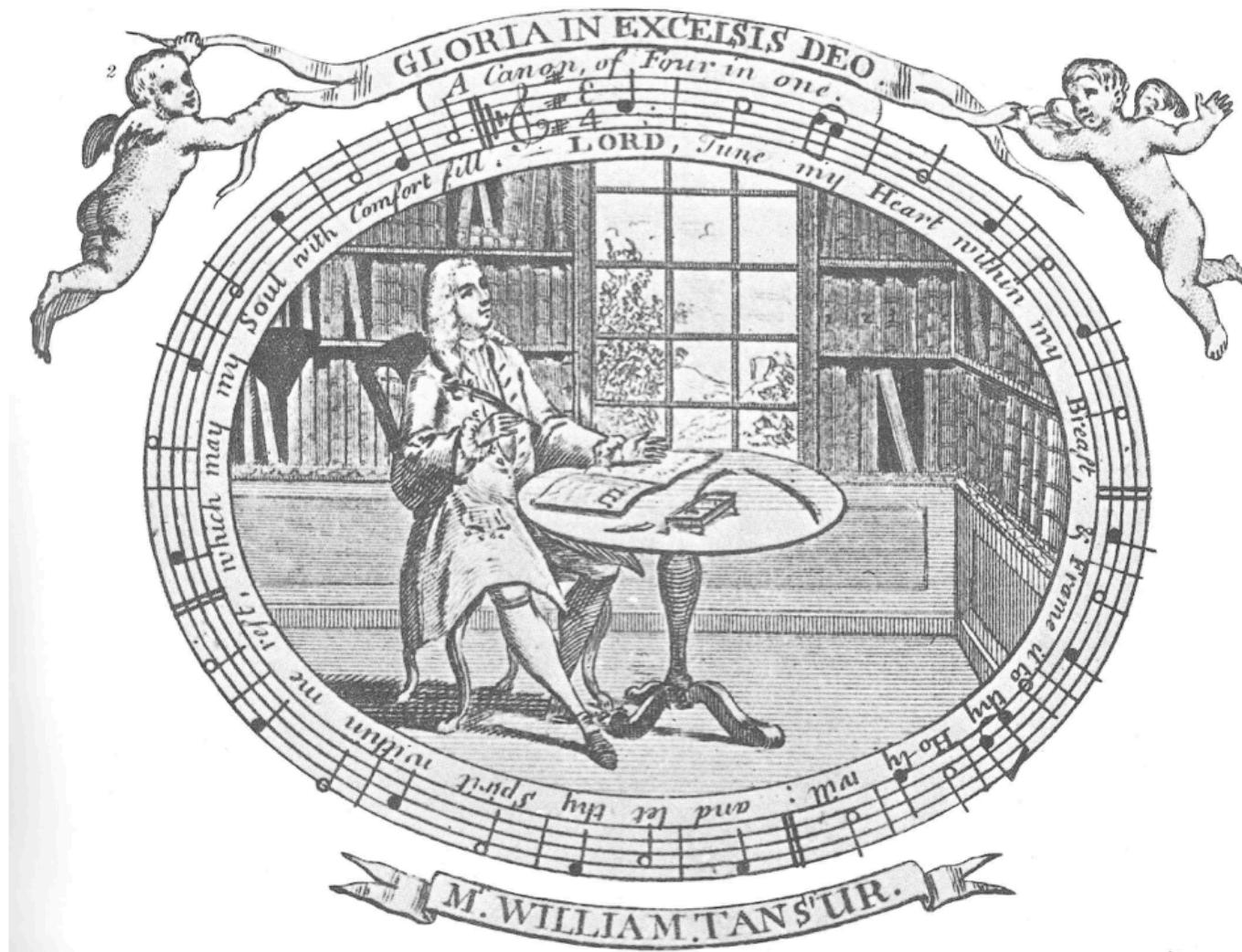


J.S. Bach WTC 1: Prelude #1 in C major

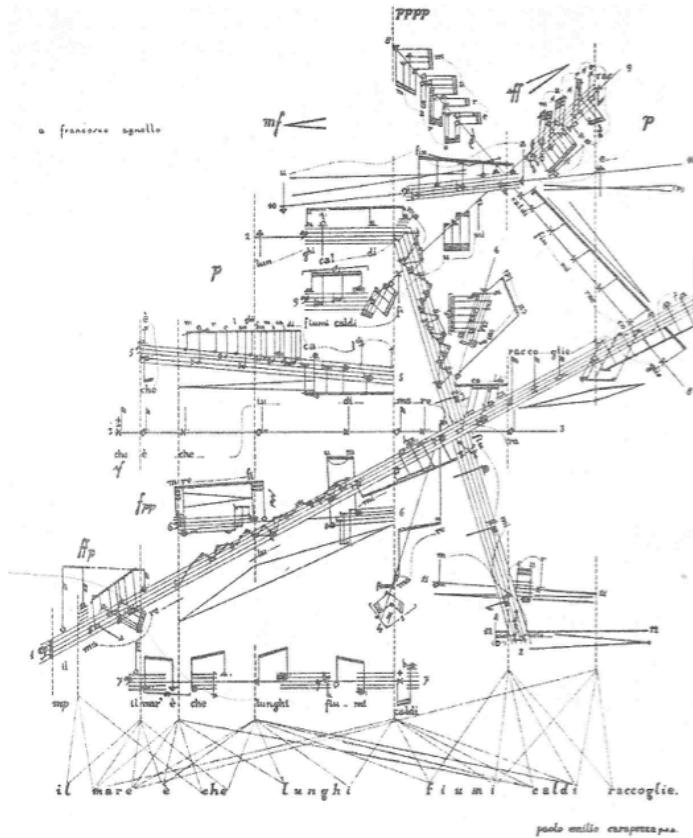
Visual Notation



Visual Notation



Visual Notation



See also:

Bussotti - Memoria

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

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