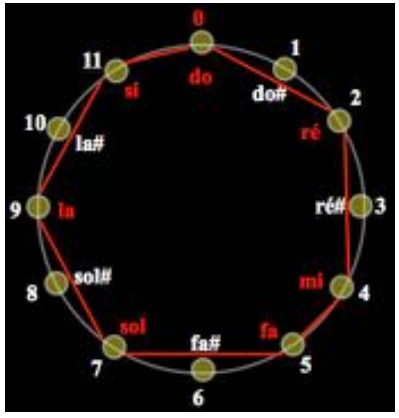
Neo-Riemannian tools for compositional adventures and empirical research

GMTH 2023
Hochschüle für Musik Freiburg
22-24 September 2023

gmth
GESELLSCHAFT FÜR MUSIKTHEORIE



José L. Besada & Moreno Andreatta

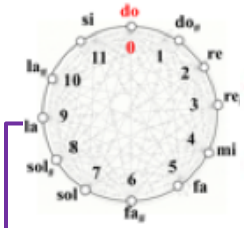
Universidad Complutense Madrid
CREAA Université de Strasbourg

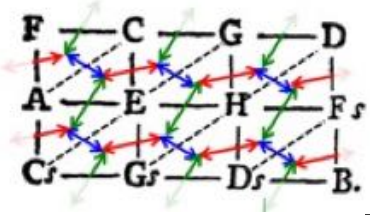
CNRS / IRMA / CREAA Université de Strasbourg
IRCAM / Sorbonne Université

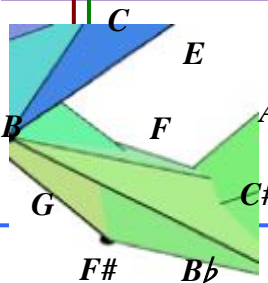
Theory, analysis & composition in Music Infomation Research

Signal-based Music Information Retrieval

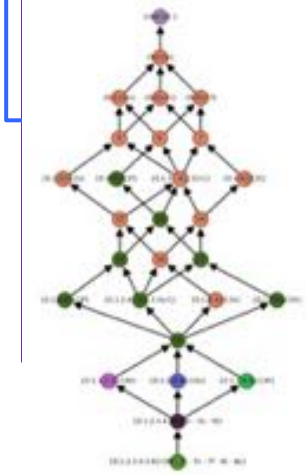
Algebraic models

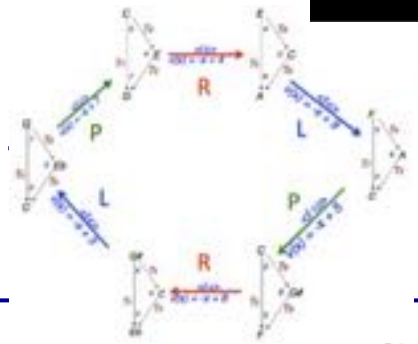


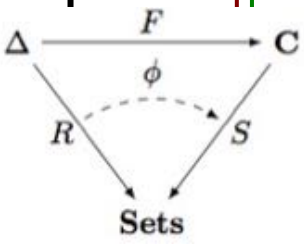




Geometric topological models

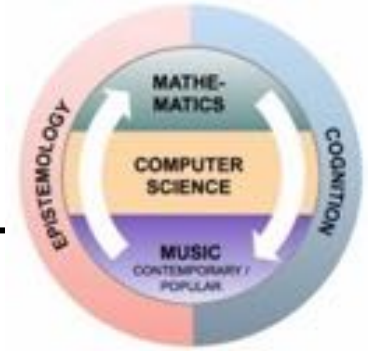






Categorical models

Computational models

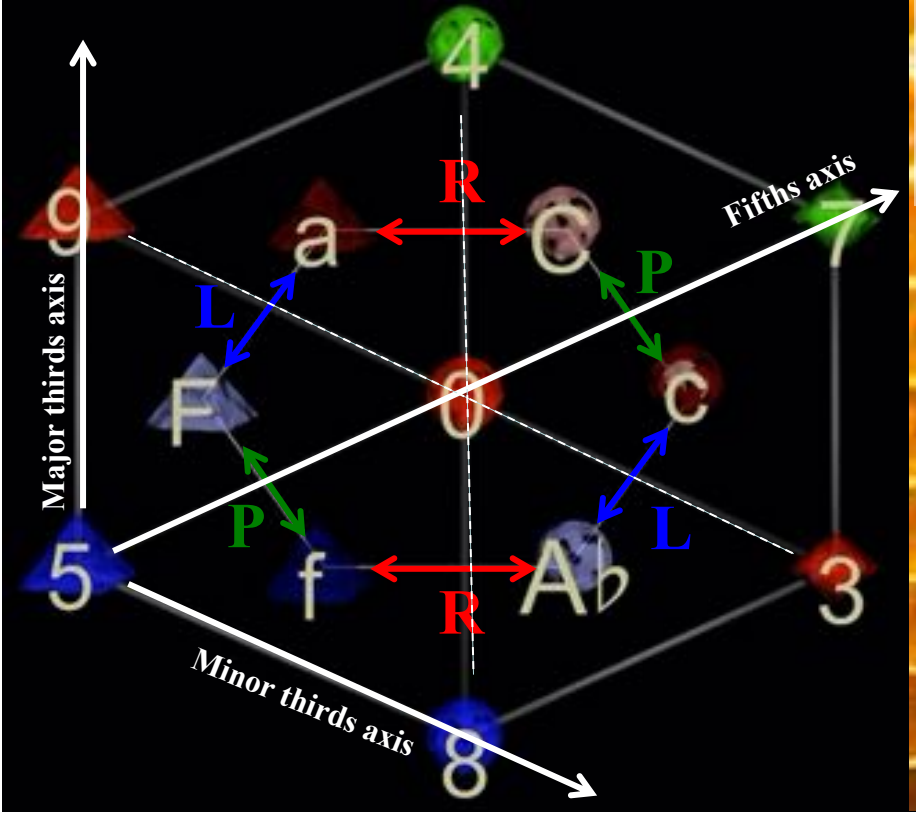


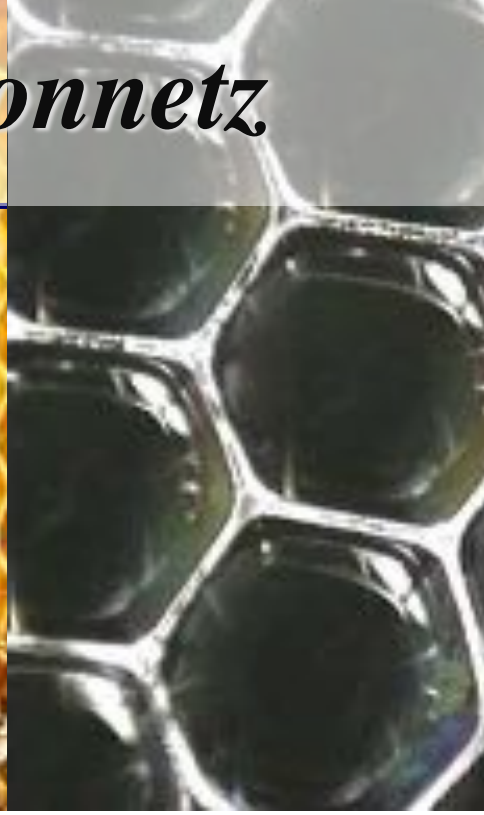
Cognitive models

Structural Symbolic Music Information Research

(SMIR Project)

The *Tonnetz*





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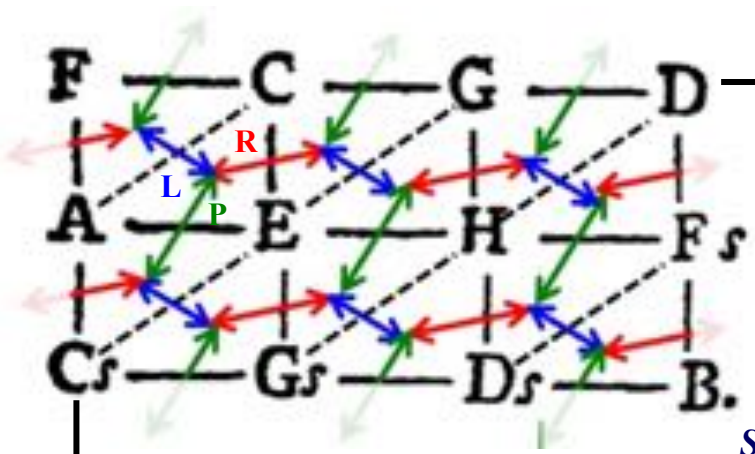
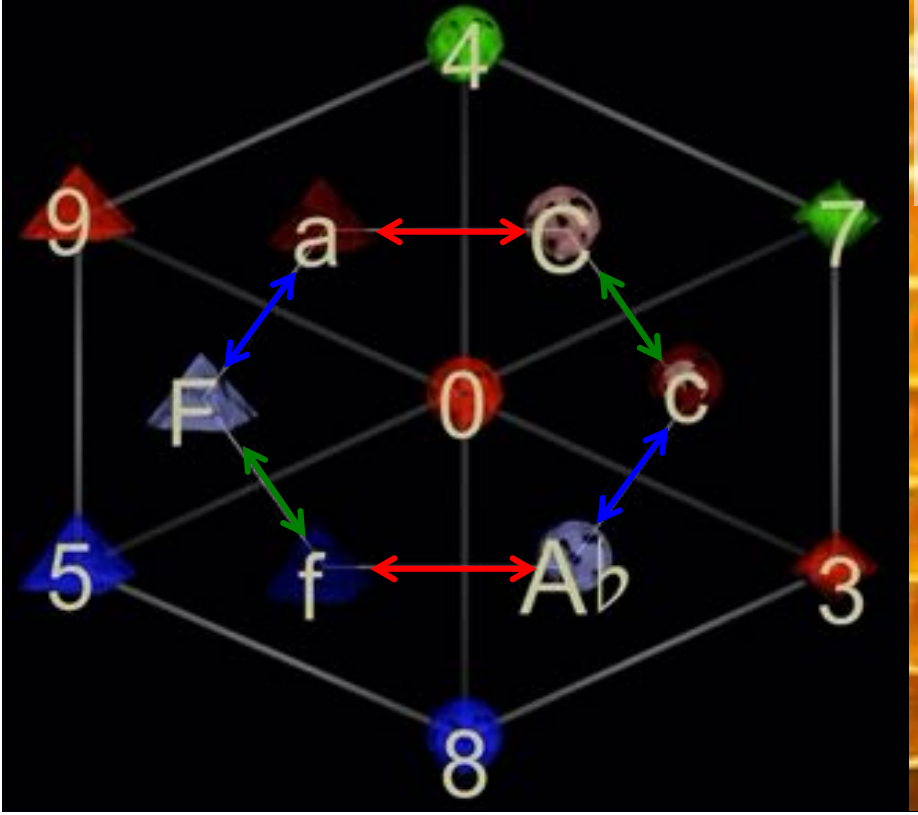
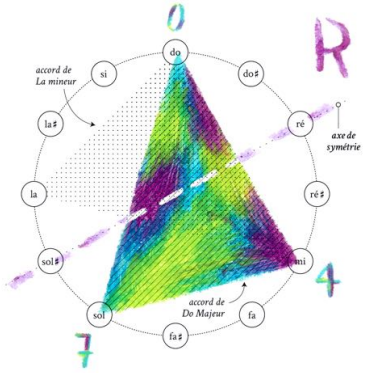
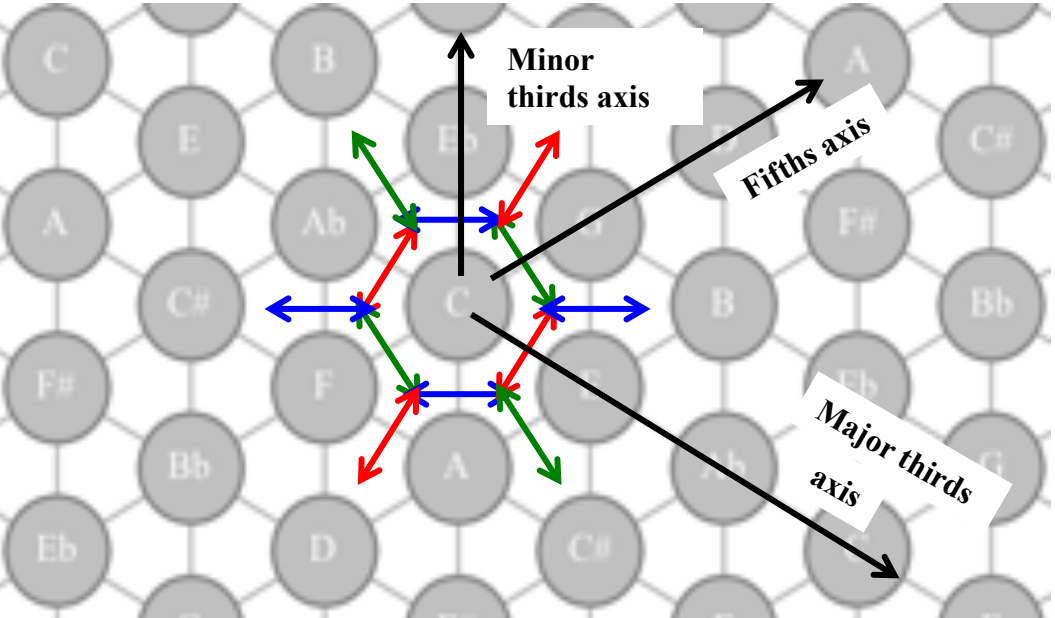


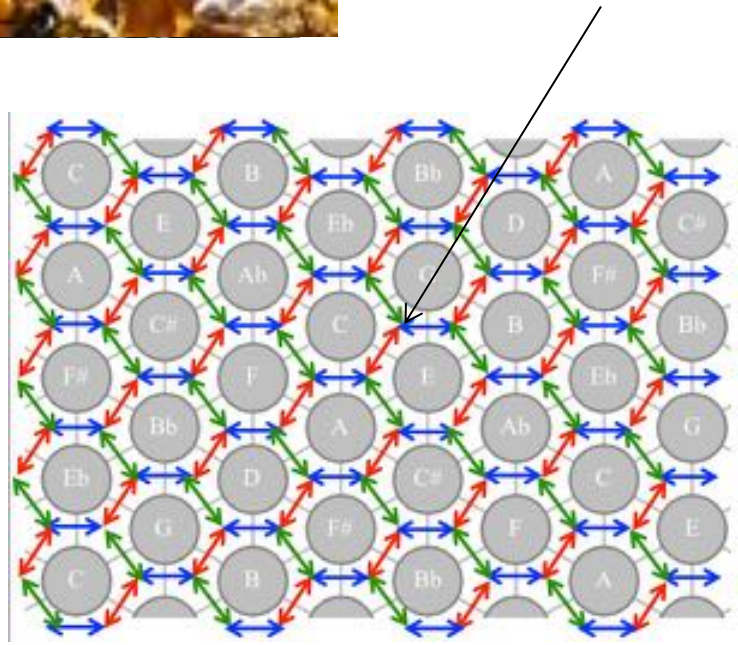
Speculum Musicum (Euler, 1773)

The *Tonnetz*
(triangular vs hexagonal tiling)

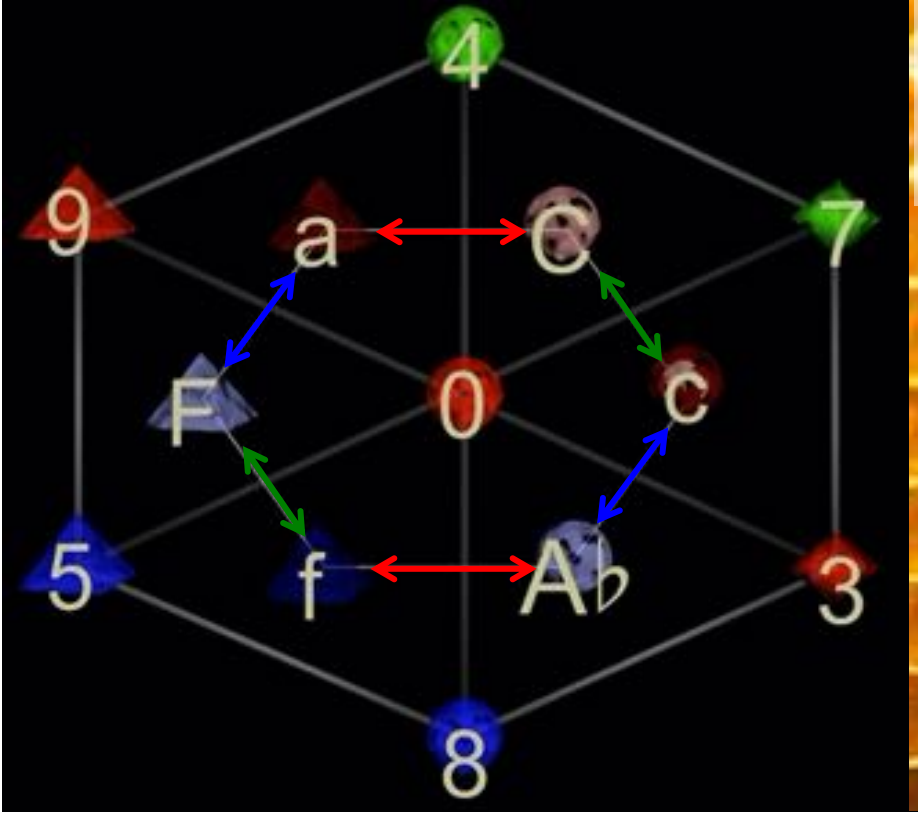


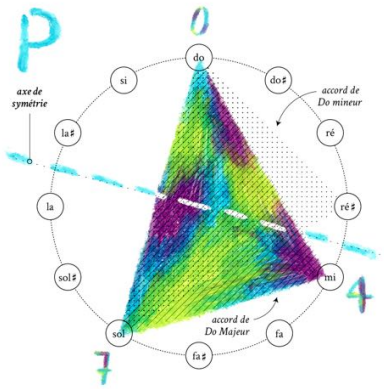


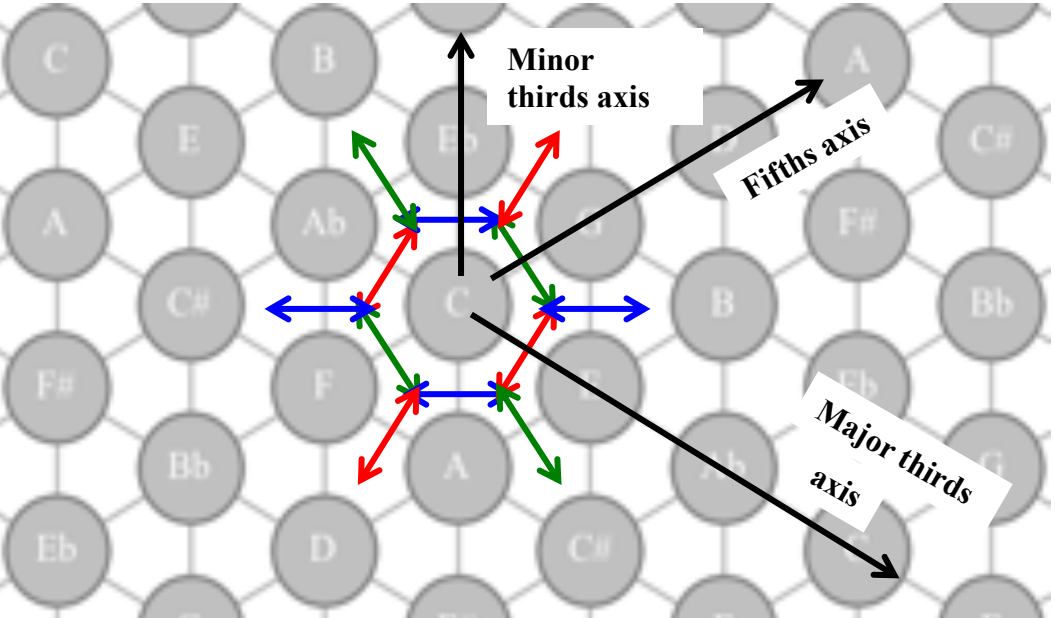


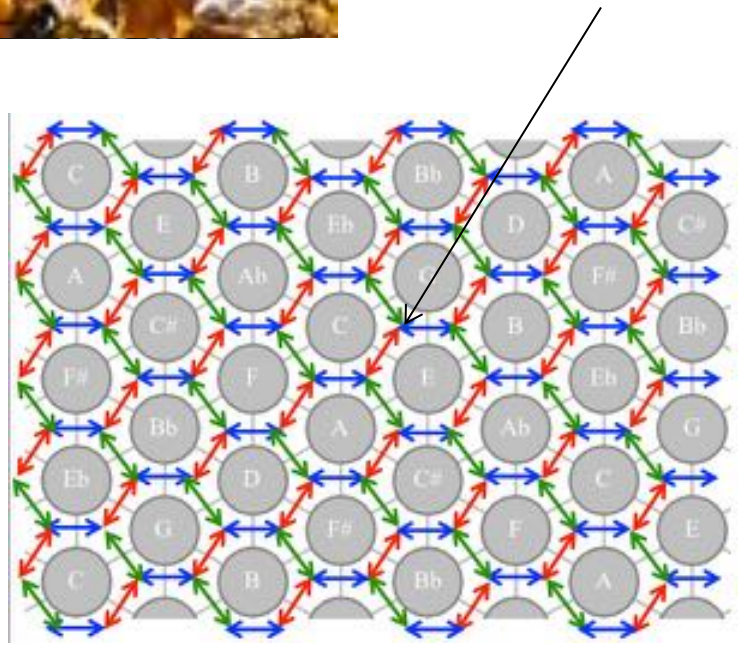


The *Tonnetz*
(triangular vs hexagonal tiling)

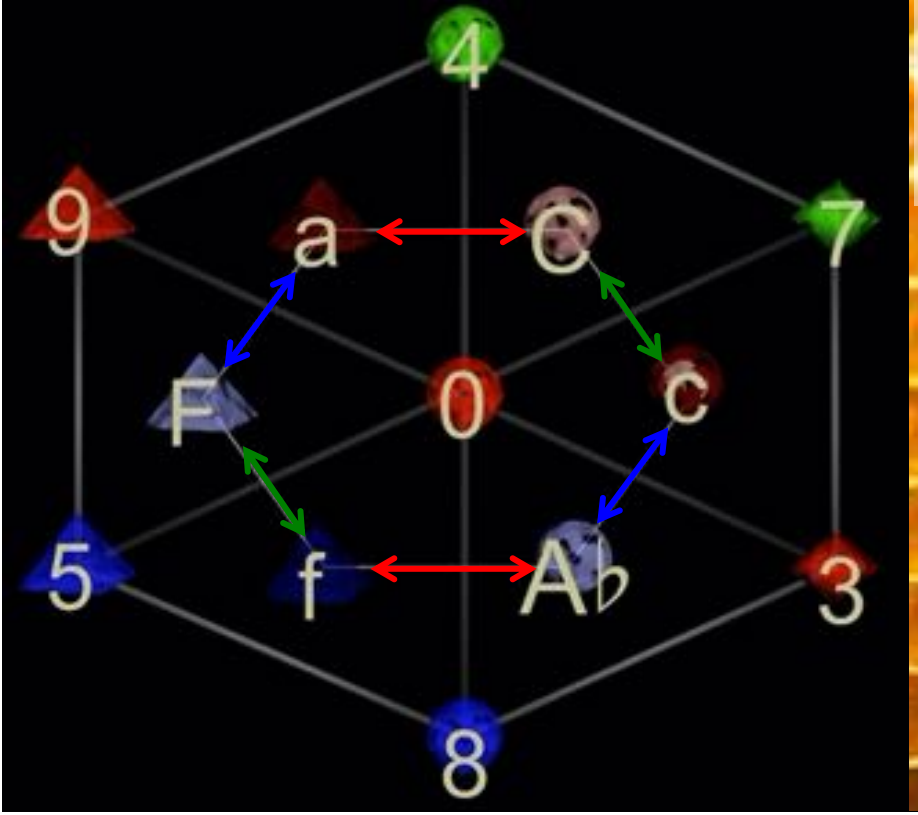


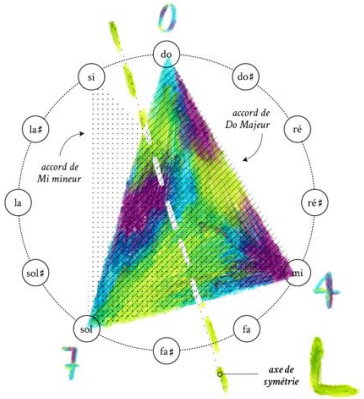


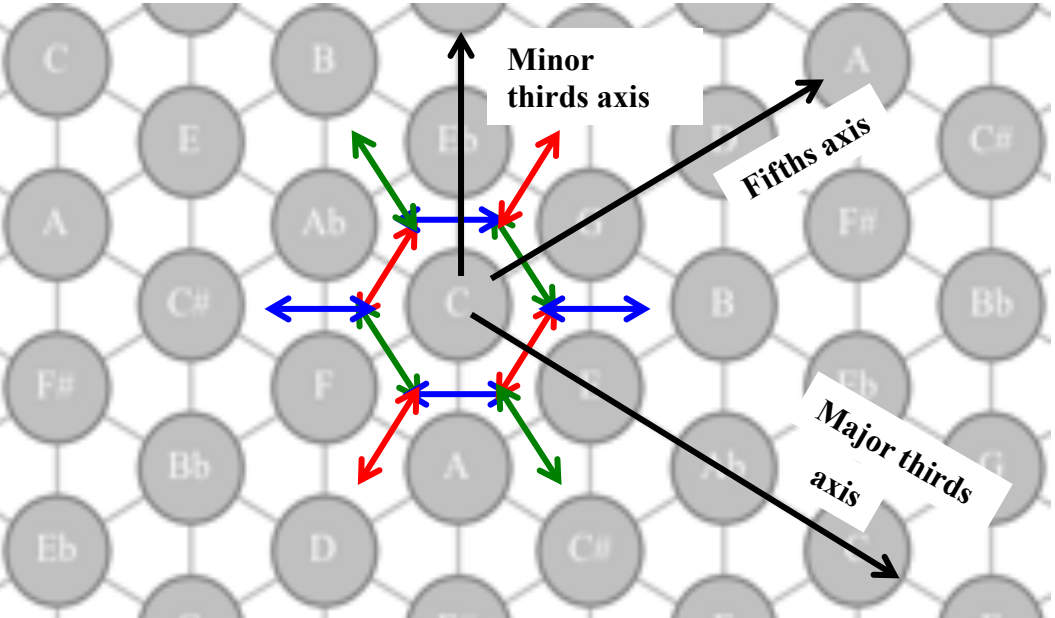


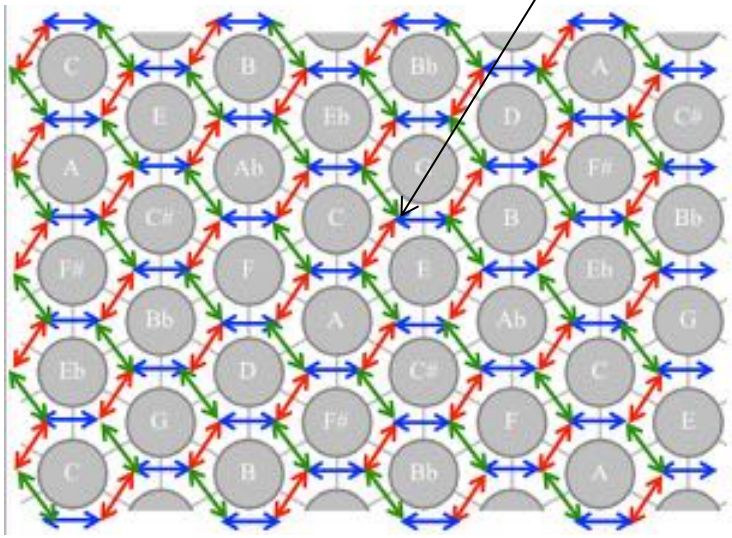


The *Tonnetz*
(triangular vs hexagonal tiling)

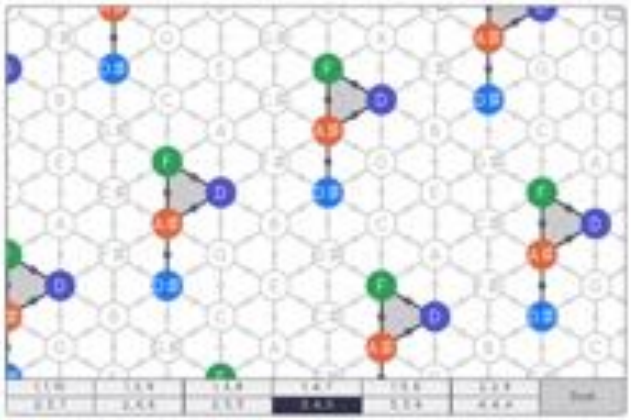




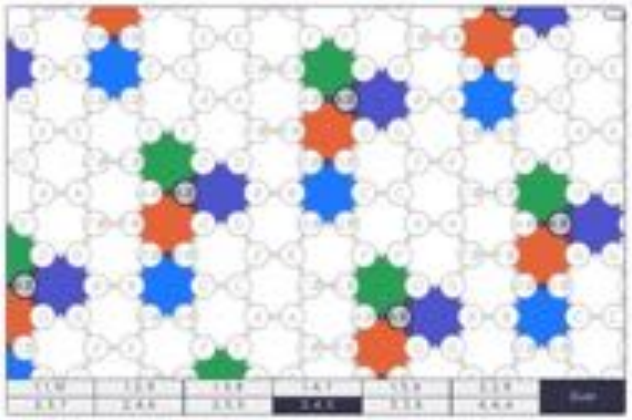


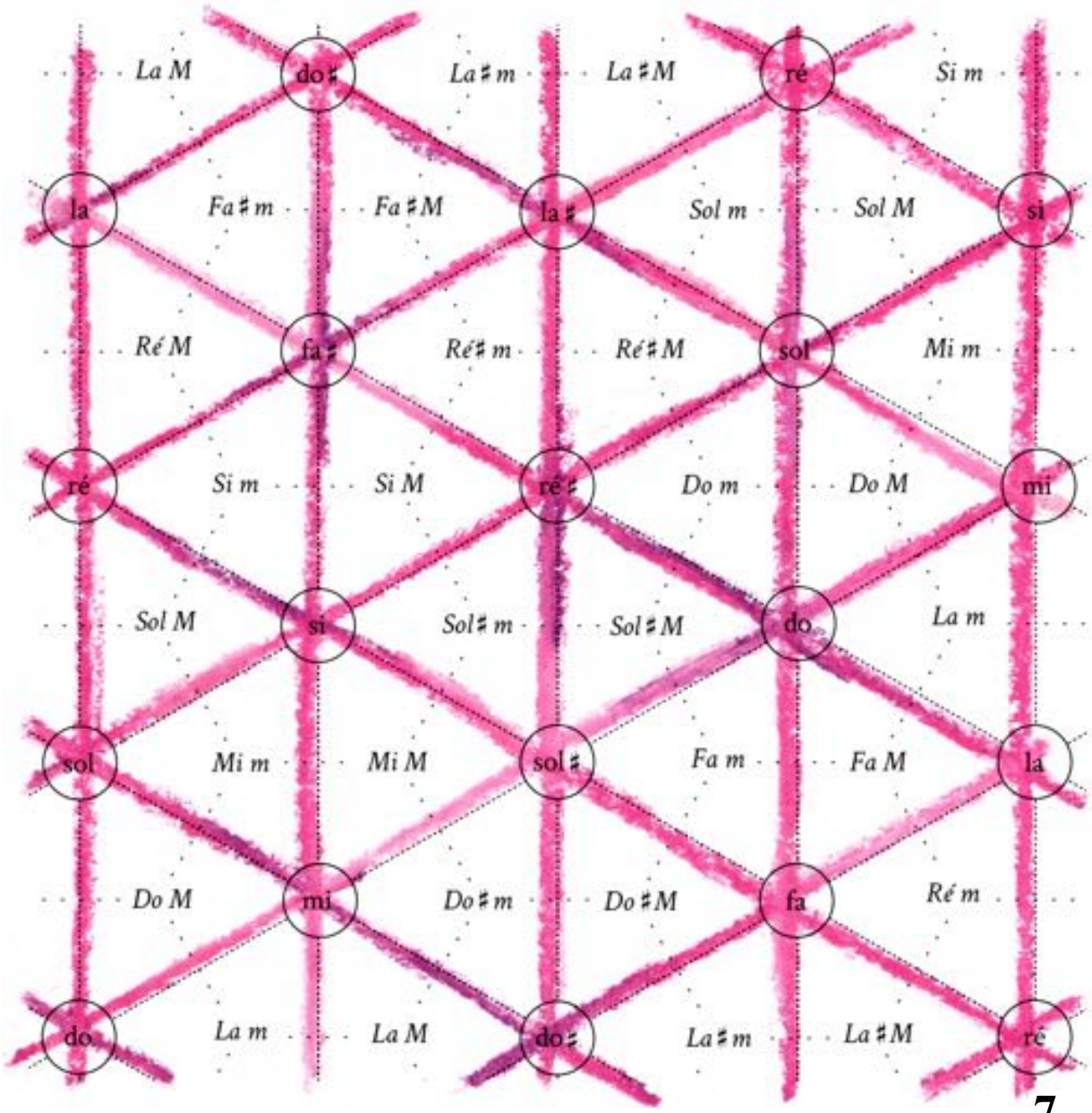


From the *Tonnetz* to the dual one

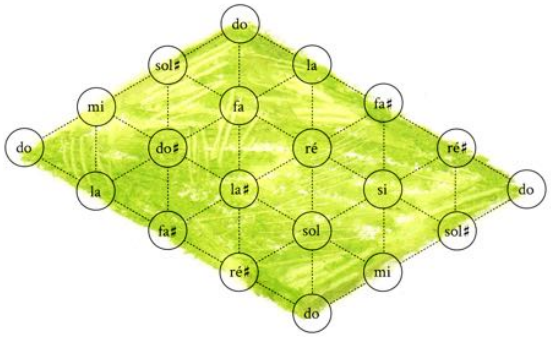


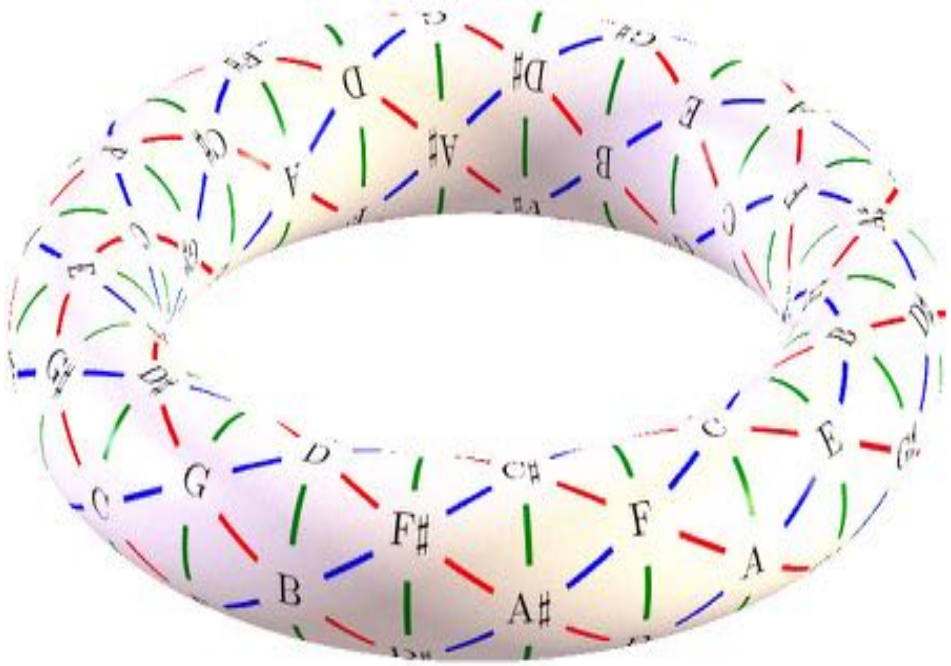
duality





The topological structure of the *Tonnetz*





(Source: www.wikimedia.org/)

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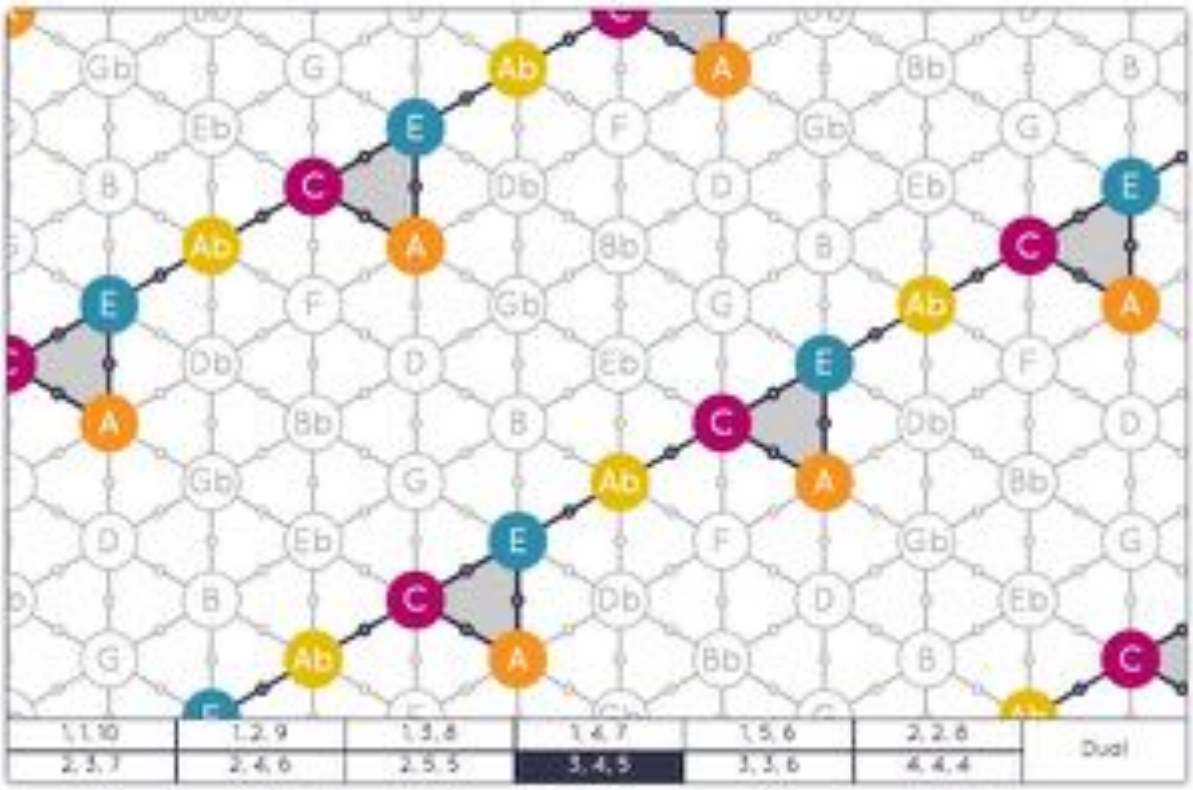
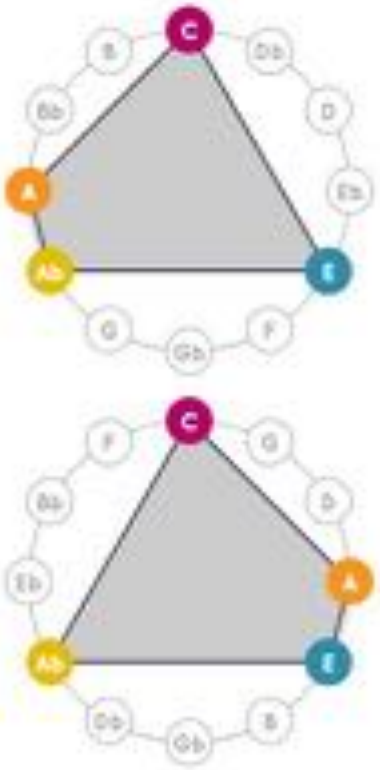
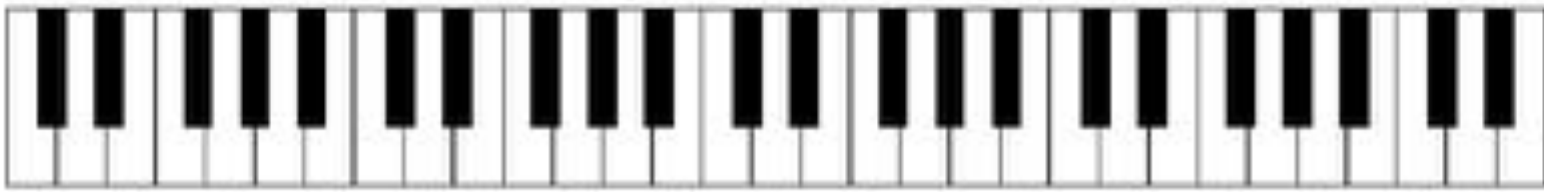
THE TONNETZ

ONE KEY – MANY REPRESENTATIONS

➔ DEMO







C. Guichaoua

➔ https://morenoandreatta.com/software/

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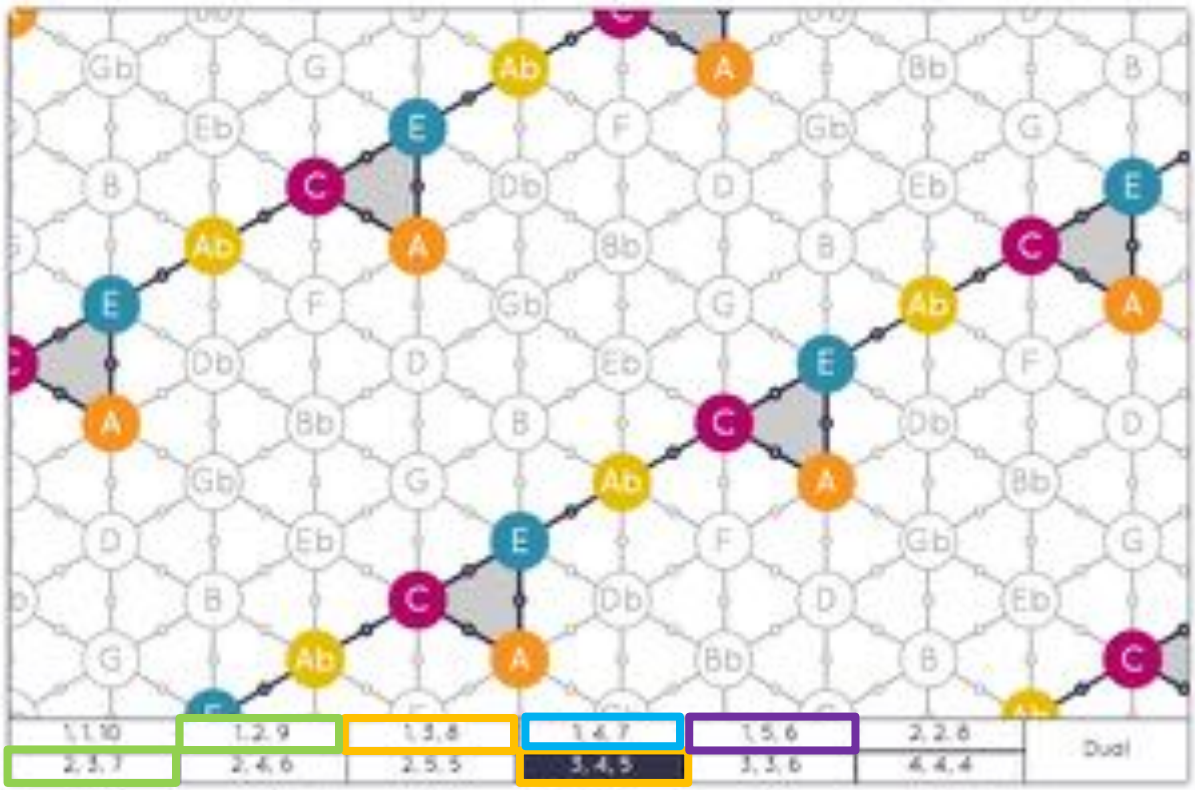
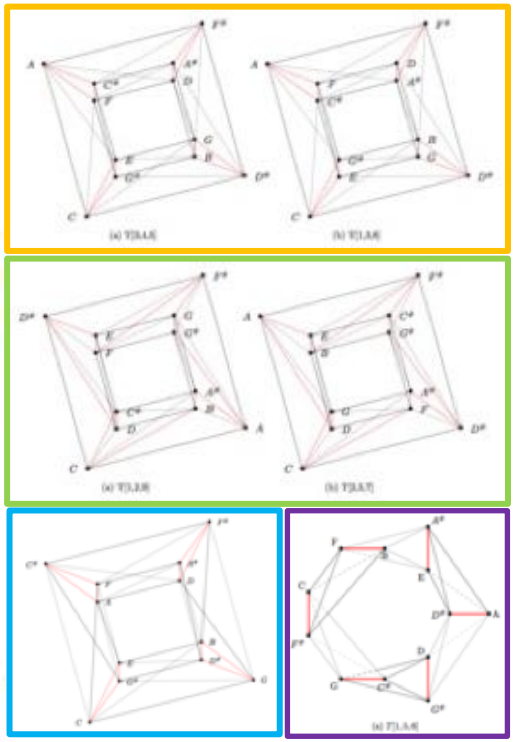
THE TONNETZ

ONE KEY – MANY REPRESENTATIONS

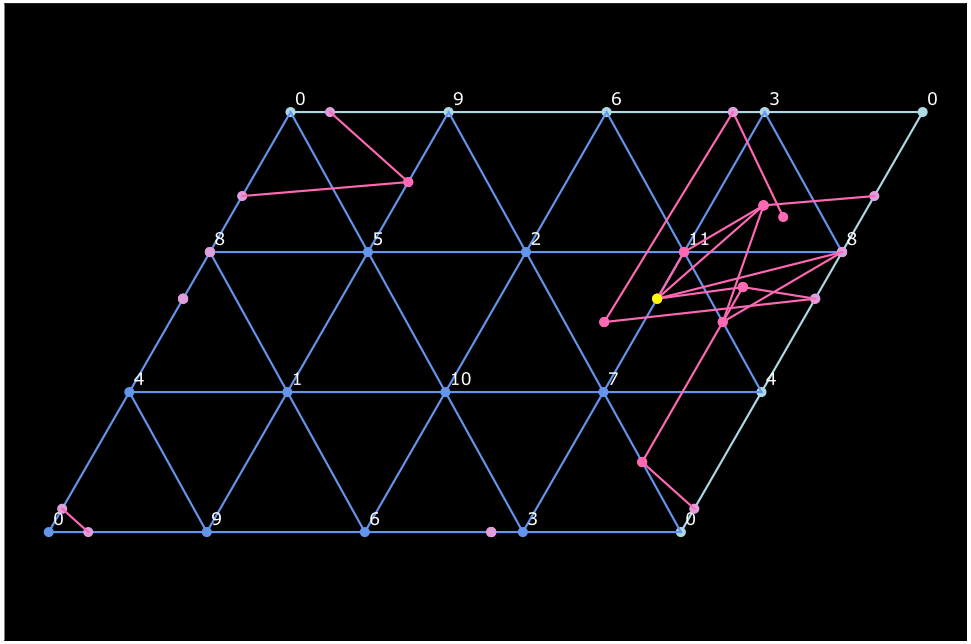




Paul Lascabettes
(PhD student)

The study of the trajectories in the Tonnetz

Cristophe Weis
(PhD student HfMK)



La trajectoire spatiale dans le Tonnetz
comme outil de classification stylistique automatique
et de génération

Mémoire de stage

Christophe WEIS

Encadrants :
Isabelle BLOCH, Carlos AGON, Moreno ANDREATTA

Structures d'accueil :
LIP6 (Sorbonne Université), IRCAM (Équipe Représentations musicales)

1er mars - 31 août 2022

Geometric Models of Harmony as Tools for
Computer Assisted Composition and Improvisation

➔

Bewerber: Christophe Weis

Erstbetreuer: Prof. Dr. Marlon Schumacher
Zweitbetreuer: Moreno Andreatta (Université de Strasbourg)

Hamiltonian Cycles = progressions with 24 different chords

List of 124 Hamiltonian Cycles (Bigo/Andreatta, February 2014)

1. C-Cm-Ab-Abm-E-Em-G-Gm-Eb-Ebm-B-Bm-D-Dm-Bb-Bbm-F#-F#m-A-C#m-C#-F#m-F-Am-PLPLPRPLPLPRPLPLPRLPLPLR
2. C-Cm-Ab-Abm-E-Em-G-Gm-Eb-Ebm-B-Bm-D-F#m-F#-Bbm-Bb-Gm-F-Fm-C#-C#m-A-Am-PLPLPRPLPLPRLPLPLRPLPLPR
3. C-Cm-Ab-Abm-E-Em-G-Bm-B-Ebm-Eb-Gm-Bb-Bbm-F#-F#m-D-Dm-F-Fm-C#-C#m-A-Am-PLPLPRLPLPLRPLPLPRPLPLPR
4. C-Cm-Ab-Abm-E-C#m-C#-Fm-F-Am-A-F#m-F#-Bbm-Bb-Dm-D-Bm-B-Ebm-Eb-Gm-G-Em-PLPLRPLPLPRPLPLPRPLPLPR
5. C-Cm-Ab-Abm-E-C#m-A-Am-F-Fm-C#-Bbm-F#-F#m-D-Dm-Bb-Gm-Eb-Ebm-B-Bm-G-Em-PLPLRL
6. C-Cm-Ab-Abm-B-Bm-G-Gm-Eb-Ebm-F#-F#m-D-Dm-Bb-Bbm-C#-Fm-F-Am-A-C#m-E-Em-PLPRPLPLPRPLPLPRLPLPLRPL
7. C-Cm-Ab-Abm-B-Bm-G-Gm-Eb-Ebm-F#-Bbm-Bb-Dm-D-F#m-A-Am-F-Fm-C#-C#m-E-Em-PLPRPLPLPRLPLPLRPLPLPRPL
8. C-Cm-Ab-Abm-B-Bm-G-Em-E-C#m-A-F#m-D-Dm-Bb-Gm-Eb-Ebm-F#-Bbm-C#-Fm-F-Am-PLPRPLRPRLRLPLRLPRLRLPLR
9. C-Cm-Ab-Abm-B-Ebm-Eb-Gm-G-Bm-D-Dm-Bb-Bbm-F#-F#m-A-Am-F-Fm-C#-C#m-E-Em-PLPRLPLPLRPLPLPRPLPLPRPL
10. C-Cm-Ab-Abm-B-Ebm-Eb-Gm-Bb-Dm-D-Bm-G-Em-E-C#m-A-F#m-F#-Bbm-C#-Fm-F-Am-PLPRLPLRLPRLRPLRLPLRLPLR
11. C-Cm-Ab-Abm-B-Ebm-Eb-Gm-Bb-Dm-F-Fm-C#-Bbm-F#-F#m-D-Bm-G-Em-E-C#m-A-Am-PLPRLPLRLRPLRLPLRLRPRLPR
12. C-Cm-Ab-Fm-F-Am-A-C#m-C#-Bbm-Bb-Dm-D-F#m-F#-Ebm-Eb-Gm-G-Bm-B-Abm-E-Em-PLRPLPLPRPLPLPRPLPLPRLPL
13. C-Cm-Ab-Fm-F-Am-A-F#m-F#-Bbm-C#-C#m-E-Abm-B-Ebm-Eb-Gm-Bb-Dm-D-Bm-G-Em-PLRPLPRPLRPRLRLPLRLPRLRL
14. C-Cm-Ab-Fm-F-Am-A-F#m-D-Dm-Bb-Gm-Eb-Ebm-F#-Bbm-C#-C#m-E-Abm-B-Bm-G-Em-PLRPLPRLPLRLPRLRPRLRPLRL
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20. C-Cm-Ab-Fm-C#-C#m-E-Abm-B-Ebm-Eb-Gm-Bb-Bbm-F#-F#m-A-Am-F-Dm-D-Bm-G-Em-PLRLPRLRLPLRPLPRPLRPRLRL
21. C-Cm-Ab-Fm-C#-Bbm-Bb-Dm-F-Am-A-C#m-E-Abm-B-Bm-D-F#m-F#-Ebm-Eb-Gm-G-Em-PLRLRPLRLPLRLRPRLPRPLPRL
22. C-Cm-Ab-Fm-C#-Bbm-Bb-Gm-Eb-Ebm-F#-F#m-D-Dm-F-Am-A-C#m-E-Abm-B-Bm-G-Em-PLRLRPRLPRPLPRLPLRLRPLRL
23. C-Cm-Eb-Ebm-B-Bm-G-Gm-Bb-Bbm-F#-F#m-D-Dm-F-Am-A-C#m-C#-Fm-Ab-Abm-E-Em-PRPLPLPRPLPLPRLPLPLRPLPL
24. C-Cm-Eb-Ebm-B-Bm-G-Gm-Bb-Dm-D-F#m-F#-Bbm-C#-C#m-A-Am-F-Fm-Ab-Abm-E-Em-PRPLPLPRLPLPLRPLPLPRPLPL
25. C-Cm-Eb-Ebm-B-Bm-D-F#m-F#-Bbm-C#-Fm-Ab-Abm-E-C#m-A-Am-F-Dm-Bb-Gm-G-Em-PRPLPRLPLRLRPLRLPLRRLRPRL
26. C-Cm-Eb-Ebm-B-Abm-Ab-Fm-C#-Bbm-F#-F#m-D-Bm-G-Gm-Bb-Dm-F-Am-A-C#m-E-Em-PRPLRPRLRLPLRLPRLRLPLRPL

27. C-Cm-Eb-Ebm-F#-F#m-A-C#m-E-Em-G-Gm-Bb-Bbm-C#-Fm-Ab-Abm-B-Bm-D-Dm-F-Am-PRPRPRLR
28. C-Cm-Eb-Ebm-F#-Bbm-C#-C#m-E-Em-G-Gm-Bb-Dm-F-Fm-Ab-Abm-B-Bm-D-F#m-A-Am-PRPRLRPR
29. C-Cm-Eb-Ebm-F#-Bbm-C#-Fm-Ab-Abm-B-Bm-D-F#m-A-C#m-E-Em-G-Gm-Bb-Dm-F-Am-PRPRLRLR
30. C-Cm-Eb-Gm-G-Bm-B-Ebm-F#-F#m-D-Dm-Bb-Bbm-C#-C#m-A-Am-F-Fm-Ab-Abm-E-Em-PRLPLPLRPLPLPRPLPLPRLPL
31. C-Cm-Eb-Gm-G-Bm-D-F#m-F#-Ebm-B-Abm-Ab-Fm-C#-Bbm-Bb-Dm-F-Am-A-C#m-E-Em-PRLPLRLPRLRPRLRPLRLPLRPL
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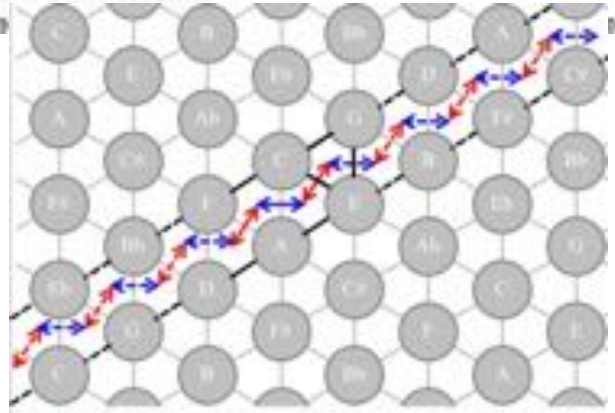
36. C-Cm-Eb-Gm-Bb-Bbm-C#-Fm-Ab-Abm-E-C#m-A-Am-F-Dm-D-F#m-F#-Ebm-B-Bm-G-Em-PRLRPRLRPLRLPLRPLPRLPLRL
37. C-Cm-Eb-Gm-Bb-Bbm-C#-Fm-Ab-Abm-B-Ebm-F#-F#m-A-C#m-E-Em-G-Bm-D-Dm-F-Am-PRLR
38. C-Cm-Eb-Gm-Bb-Dm-D-F#m-A-Am-F-Fm-Ab-Abm-E-C#m-C#-Bbm-F#-Ebm-B-Bm-G-Em-PRLRLPLRPLPRPLRPRLRPLRL
39. C-Cm-Eb-Gm-Bb-Dm-D-F#m-A-C#m-C#-Bbm-F#-Ebm-B-Bm-G-Em-E-Abm-Ab-Fm-F-Am-PRLRLPLRLPRLRLPLRLPRLPLR
40. C-Cm-Eb-Gm-Bb-Dm-F-Fm-Ab-Abm-B-Ebm-F#-Bbm-C#-C#m-E-Em-G-Bm-D-F#m-A-Am-PRLRLRPR
41. C-Em-E-Abm-Ab-Cm-Eb-Ebm-B-Bm-G-Gm-Bb-Bbm-F#-F#m-D-Dm-F-Fm-C#-C#m-A-Am-LPLPLRPLPLPRPLPLPRPLPLPR
42. C-Em-E-Abm-Ab-Cm-Eb-Gm-G-Bm-B-Ebm-F#-Bbm-Bb-Dm-D-F#m-A-C#m-C#-Fm-F-Am-LPLPLR
43. C-Em-E-Abm-Ab-Fm-F-Am-A-C#m-C#-Bbm-Bb-Dm-D-F#m-F#-Ebm-B-Bm-G-Gm-Eb-Cm-LPLPRPLPLPRPLPLPRLPLPLRP
44. C-Em-E-Abm-Ab-Fm-F-Am-A-C#m-C#-Bbm-F#-F#m-D-Dm-Bb-Gm-G-Bm-B-Ebm-Eb-Cm-LPLPRPLPLPRLPLPLRPLPLPRP
45. C-Em-E-Abm-Ab-Fm-C#-C#m-A-Am-F-Dm-D-F#m-F#-Bbm-Bb-Gm-G-Bm-B-Ebm-Eb-Cm-LPLPRLPLPLRPLPLPRPLPLPRP
46. C-Em-E-Abm-B-Bm-G-Gm-Eb-Ebm-F#-F#m-D-Dm-Bb-Bbm-C#-C#m-A-Am-F-Fm-Ab-Cm-LPLRPLPLPRPLPLPRPLPLPRLP
47. C-Em-E-Abm-B-Bm-G-Gm-Bb-Bbm-F#-Ebm-Eb-Cm-Ab-Fm-C#-C#m-A-F#m-D-Dm-F-Am-LPLRPLPRPLRPRLRLPLRLPRLR
48. C-Em-E-Abm-B-Bm-G-Gm-Bb-Dm-D-F#m-A-C#m-C#-Bbm-F#-Ebm-Eb-Cm-Ab-Fm-F-Am-LPLRPLPRLPLRLPRLRPRLRPLR
49. C-Em-E-Abm-B-Ebm-Eb-Gm-G-Bm-D-F#m-F#-Bbm-Bb-Dm-F-Am-A-C#m-C#-Fm-Ab-Cm-LPLRLP
50. C-Em-E-Abm-B-Ebm-Eb-Cm-Ab-Fm-F-Dm-Bb-Gm-G-Bm-D-F#m-F#-Bbm-C#-C#m-A-Am-LPLRLPRLRPRLRPLRLPLRPLPR
51. C-Em-E-Abm-B-Ebm-Eb-Cm-Ab-Fm-C#-C#m-A-F#m-F#-Bbm-Bb-Gm-G-Bm-D-Dm-F-Am-LPLRLPRLRLPLRPLPRPLRPRLR
52. C-Em-E-Abm-B-Ebm-F#-F#m-D-Bm-G-Gm-Eb-Cm-Ab-Fm-F-Dm-Bb-Bbm-C#-C#m-A-Am-LPLRLRPLRLPLRLRPRLPRPLPR
53. C-Em-E-Abm-B-Ebm-F#-F#m-A-C#m-C#-Bbm-Bb-Dm-D-Bm-G-Gm-Eb-Cm-Ab-Fm-F-Am-LPLRLRPRLPRPLPRLPLRLRPLR

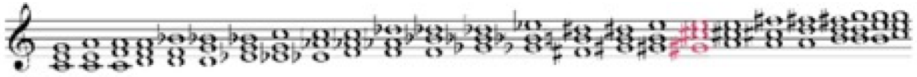
Hamiltonian Cycles = progressions with 24 different chords

Hamiltonian Cycles = progressions with 24 different chords

108. C-Am-F-Fm-C#-Bbm-F#-F#m-A-C#m-E-Abm-Ab-Cm-Eb-Ebm-B-Bm-D-Dm-Bb-Gm-G-Em-
-RLPLRLPRLRLPLRPLPRPLRPRL
109. C-Am-F-Fm-C#-Bbm-F#-Ebm-Eb-Gm-Bb-Dm-D-F#m-A-C#m-E-Em-G-Bm-B-Abm-Ab-Cm-
-RLPLRLRPLRLPLRLRPRLPRPLP
110. C-Am-F-Fm-C#-Bbm-F#-Ebm-Eb-Cm-Ab-Abm-B-Bm-G-Gm-Bb-Dm-D-F#m-A-C#m-E-Em-
-RLPLRLRPRLPRPLPRLPLRLRPL
111. C-Am-F-Fm-Ab-Abm-E-Em-G-Bm-B-Ebm-F#-Bbm-C#-C#m-A-F#m-D-Dm-Bb-Gm-Eb-Cm-
-RLPRPLPRLPLRLRPLRLPLRLRP
112. C-Am-F-Fm-Ab-Cm-Eb-Ebm-F#-Bbm-C#-C#m-A-F#m-D-Dm-Bb-Gm-G-Bm-B-Abm-E-Em-
-RLPRLRPRLRPLRLPLRPLPRLPL
113. C-Am-F-Fm-Ab-Cm-Eb-Gm-G-Bm-D-Dm-Bb-Bbm-C#-C#m-A-F#m-F#-Ebm-B-Abm-E-Em-
-RLPRLRLPLRPLPRPLRPRLRLPL
114. C-Am-F-Dm-D-F#m-A-C#m-C#-Fm-Ab-Abm-E-Em-G-Bm-B-Ebm-F#-Bbm-Bb-Gm-Eb-Cm-
-RLRPLRLPLRPLPRLPLRLPRLRP
115. C-Am-F-Dm-D-F#m-A-C#m-C#-Fm-Ab-Cm-Eb-Ebm-F#-Bbm-Bb-Gm-G-Bm-B-Abm-E-Em-
-RLRPLRLPLRLRPRLPRPLPRLPL
116. C-Am-F-Dm-D-Bm-B-Abm-Ab-Fm-C#-Bbm-Bb-Gm-G-Em-E-C#m-A-F#m-F#-Ebm-Eb-Cm-
-RLRPRLPRP
117. C-Am-F-Dm-D-Bm-B-Abm-E-C#m-A-F#m-F#-Ebm-Eb-Cm-Ab-Fm-C#-Bbm-Bb-Gm-G-Em-
-RLRPRPRL
118. C-Am-F-Dm-D-Bm-G-Gm-Bb-Bbm-F#-F#m-A-C#m-C#-Fm-Ab-Cm-Eb-Ebm-B-Abm-E-Em-

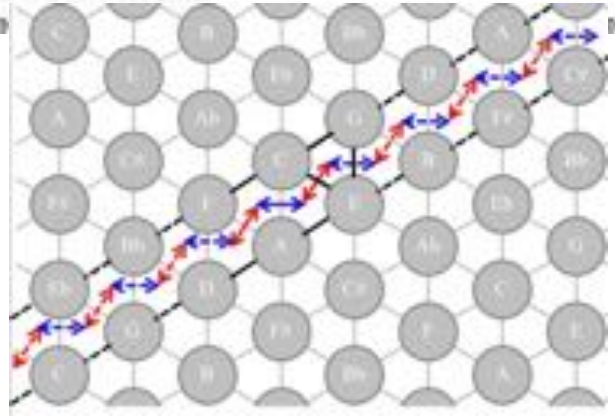
119. C-Am ... -Ab-Cm-

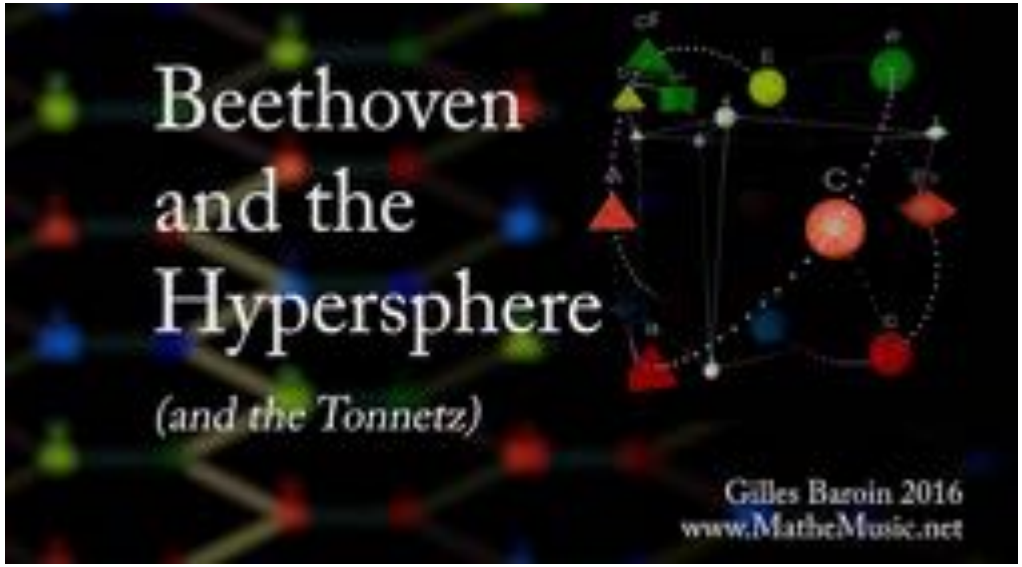




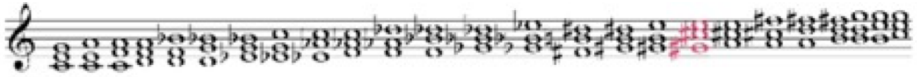
Hamiltonian Cycles = progressions with 24 different chords

108. C-Am-F-Fm-C#-Bbm-F#-F#m-A-C#m-E-Abm-Ab-Cm-Eb-Ebm-B-Bm-D-Dm-Bb-Gm-G-Em-
-R1PL1R1PR1R1L1P1R1PL1PR1L1RPR1
109. C-Am-F-Fm-C#-Bbm-F#-Ebm-Eb-Gm-Bb-Dm-D-F#m-A-C#m-E-Em-G-Bm-B-Abm-Ab-Cm-
-R1PL1R1PL1R1L1R1PR1L1PR1PL1P
110. C-Am-F-Fm-C#-Bbm-F#-Ebm-Eb-Cm-Ab-Abm-B-Bm-G-Gm-Bb-Dm-D-F#m-A-C#m-E-Em-
-R1PL1R1L1PR1PL1PR1L1R1L1RPL
111. C-Am-F-Fm-Ab-Abm-E-Em-G-Bm-B-Ebm-F#-Bbm-C#-C#m-A-F#m-D-Dm-Bb-Gm-Eb-Cm-
-R1PR1PL1PR1L1R1PL1R1L1R1L1RP
112. C-Am-F-Fm-Ab-Cm-Eb-Ebm-F#-Bbm-C#-C#m-A-F#m-D-Dm-Bb-Cm-G-Bm-B-Abm-E-Em-
-R1PR1L1PR1PL1R1PL1R1L1PR1PL
113. C-Am-F-Fm-Ab-Cm-Eb-Gm-G-Bm-D-Dm-Bb-Bbm-C#-C#m-A-F#m-F#-Ebm-B-Abm-E-Em-
-R1PR1L1R1PL1PR1PL1R1PR1L1PL
114. C-Am-F-Dm-D-F#m-A-C#m-C#-Fm-Ab-Abm-E-Em-G-Bm-B-Ebm-F#-Bbm-Bb-Gm-Eb-Cm-
-R1R1PL1R1PL1PR1L1R1L1PR1L1RP
115. C-Am-F-Dm-D-F#m-A-C#m-C#-Fm-Ab-Cm-Eb-Ebm-F#-Bbm-Bb-Cm-G-Bm-B-Abm-E-Em-
-R1R1PL1R1L1R1PR1L1PR1L1PR1PL
116. C-Am-F-Dm-D-Bm-B-Abm-Ab-Fm-C#-Bbm-Bb-Cm-G-Em-E-C#m-A-F#m-F#-Ebm-Eb-Cm-
-R1L1R1PR1P
117. C-Am-F-Dm-D-Bm-B-Abm-E-C#m-A-F#m-F#-Ebm-Eb-Cm-Ab-Fm-C#-Bbm-Bb-Cm-G-Em-
-R1L1R1PR1PL
118. C-Am-F-Dm-D-Bm-G-Gm-Bb-Bbm-F#-F#m-A-C#m-C#-Fm-Ab-Cm-Eb-Ebm-B-Abm-E-Em-
119. C-Am ... Ab-Cm-

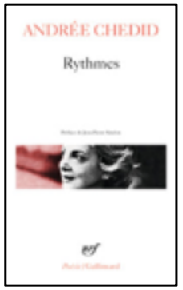




Gilles Baroin



From poetry to song writing: hamiltonian compositional strategies



A part (Andrée Chedid, poème tiré du recueil *Rhymes* Collection Poésie/Gallimard (n. 527), Gallimard, 2018)

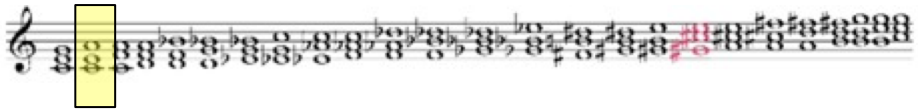
➔ http://repmus.ircam.fr/_media/moreno/prix_chedid_2018_moreno.mp3

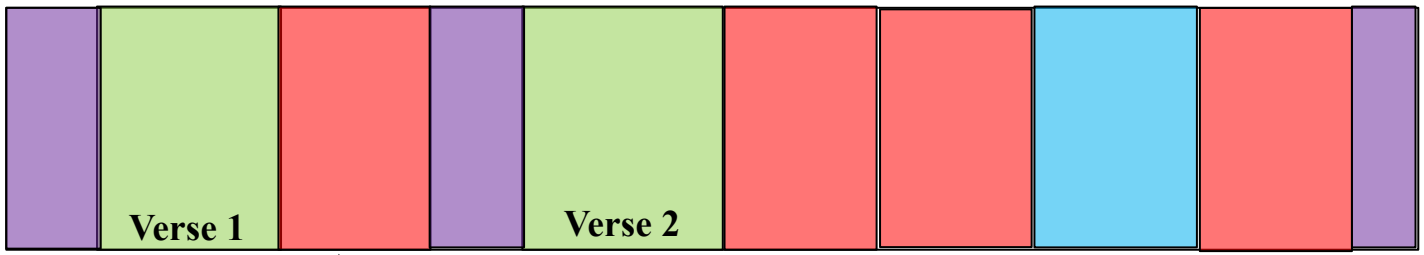
À part le temps
Et ses rouages
À part la terre
En éruptions
À part le ciel
Pétrisseur de nuages
À part l'ennemi
Qui génère l'ennemi

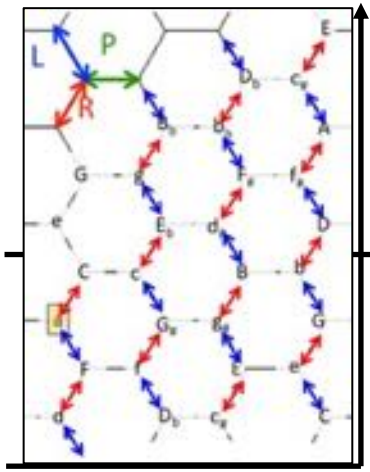
À part le désamour
Qui ronge l'illusion
À part la durée
Qui moisit nos visages

À part les fléaux
À part la tyrannie
À part l'ombre et le crime
Nos batailles nos outrages

Je te célèbre ô Vie
Entre cavités et songes
Intervalle convoité
Entre le vide et le rien







Less trivial Hamiltonian Cycles

41. C-Em-E-Abm-Ab-Cm-Eb-Ebm-B-Bm-G-Gm-Bb-Bbm-F#-F#m-D-Dm-F-Fm-C#-C#m-A-Am--
LPLPLRPLPLPRPLPLPRPLPLPR

42. C-Em-E-Abm-Ab-Cm-Eb-Gm-G-Bm-B-Ebm-F#-Bbm-Bb-Dm-D-F#m-A-C#m-C#-Fm-F-Am--
LPLPLR

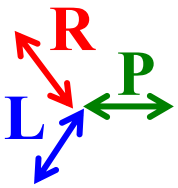
43. C-Em-E-Abm-Ab-Fm-F-Am-A-C#m-C#-Bbm-Bb-Dm-D-F#m-F#-Ebm-B-Bm-G-Gm-Eb-Cm--
LPLPRPLPLPRPLPLPRLPLPLRP

→

L P L P L R …
P L P L R L …
L P L R L P …
P L R L P L …
L R L P L P …
R L P L P L …

min. 1'02"

Music: M. Andreatta
Arrangement and mix: M. Bergomi & S. Geravini (*Perfect Music Production*)
Mastering: A. Cutolo (Massive Arts Studio, Milan)



➔ http://repmus.ircam.fr/_media/moreno/la_sera_mario-luzi_moreno-andreatta.mp3

La sera non è più la tua canzone
(Mario Luzi, 1945, in *Poesie sparse*)

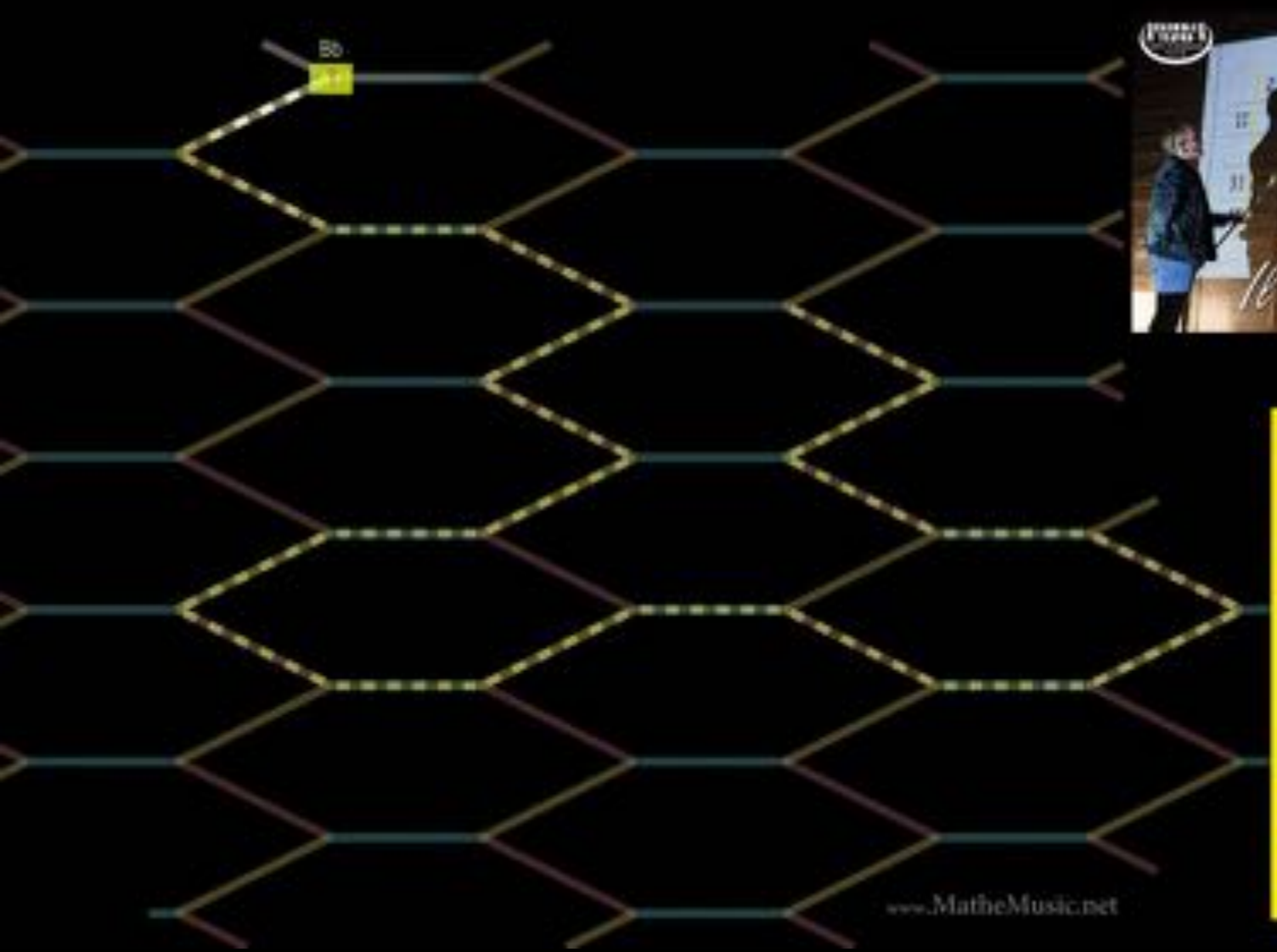
La sera non è più la tua canzone,
è questa roccia d'ombra traforata
dai lumi e dalle voci senza fine,
la quiete d'una cosa già pensata.

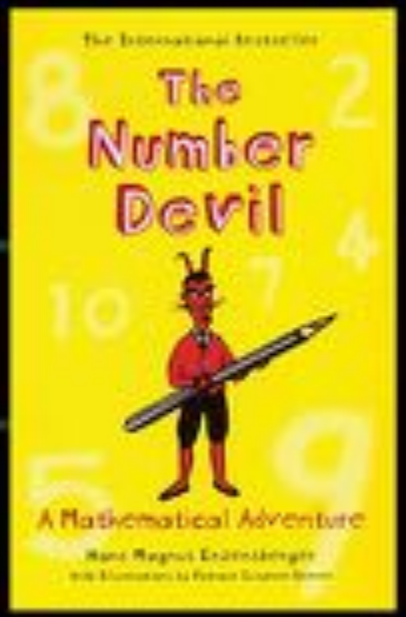
Ah questa luce viva e chiara viene
solo da te, sei tu così vicina
al vero d'una cosa conosciuta,
per nome hai una parola ch'è passata
nell'intimo del cuore e s'è perduta.

Caduto è più che un segno della vita,
riposi, dal viaggio sei tornata
dentro di te, sei scesa in questa pura
sostanza così tua, così romita
nel silenzio dell'essere, (compiuta).

L'aria tace ed il tempo dietro a te
si leva come un'arida montagna
dove vaga il tuo spirito e si perde,
un vento raro scivola e ristagna.

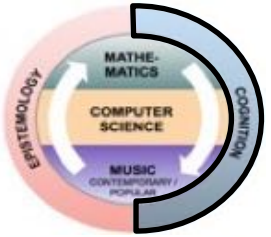
Hamiltonian Cycles of maximal complexity

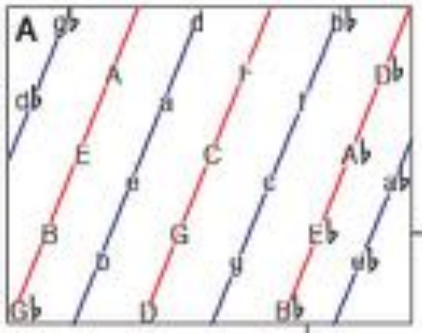




The same cycles have been used in the song *Aprile* (after a poem by Gabriele D'Annunzio):
➔ **https://www.youtube.com/watch?v=AB8By7ghTkU&ab_channel=MatheMusic4D**

Neo-riemannian analysis and perception

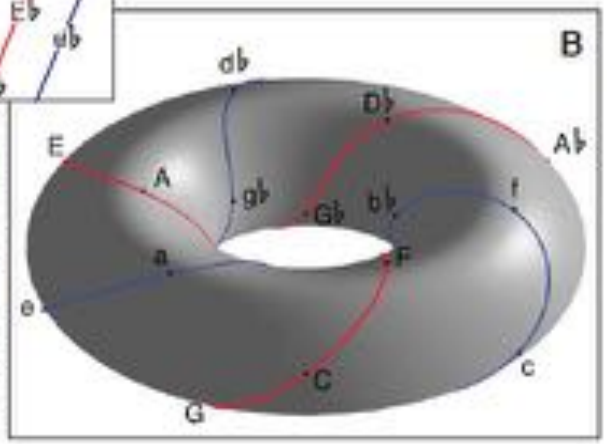




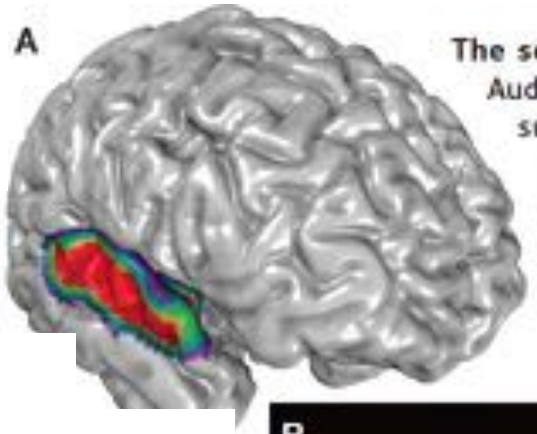
PERSPECTIVES: NEUROSCIENCE

Mental Models and Musical Minds

(Zatorre et Krumhansl, 2002)

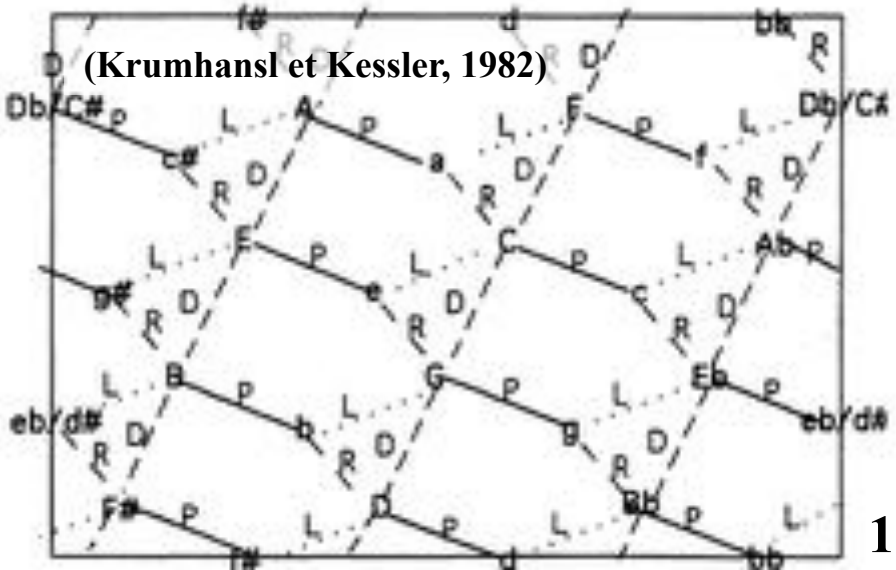


Mental key maps. (A) Unfolded version of the key map, with opposite edges to be considered matched. There is one circle of fifths for major keys (red) and one for minor keys (blue), each wrapping the torus three times. In this way, every major key is flanked by its relative minor on one side (for example, C major and a minor) and its parallel minor on the other (for example, C major and c minor). **(B)** Musical keys as points on the surface of a torus.



The sensation of music. (A) Auditory cortical areas in the superior temporal gyrus that respond to musical stimuli. Regions that are most strongly activated are shown in red. **(B)** Metabolic activity in the ventromedial region of the frontal lobe increases as a tonal stimulus becomes more consonant.

(Krumhansl et Kessler, 1982)



E. Bisesi

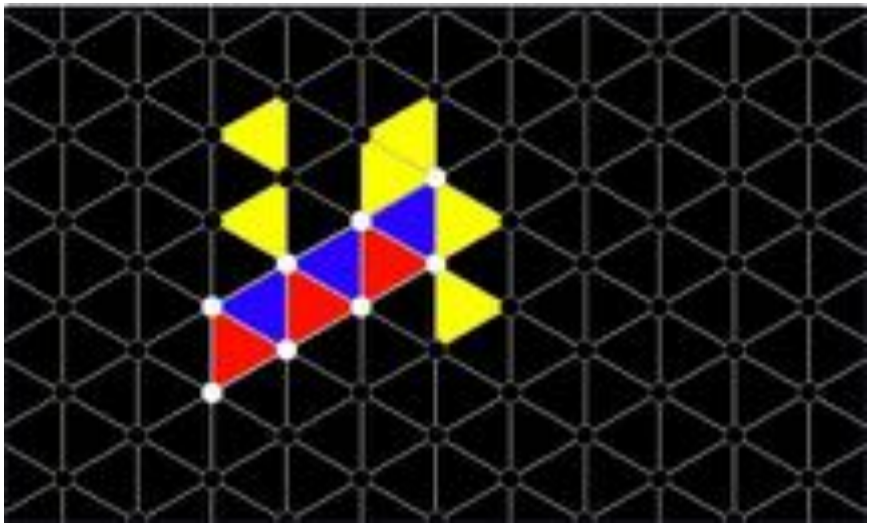
J. L. Besada

C. Guichaoua

M. Andreatta

Multimodal interaction and perceptual processes

LaLaLab Exhibition, Heidelberg May 2019 – Dec 2020



Research hypotheses

- Despite the apparent geometrical simplicity of the *Tonnetz*, its deep structural implications are very complex. Only people with high skills in music theory are able, at least, to partially grasp its overall structure at first sight.

- The geometry of the *Tonnetz* is not consistent with the widely spread vertical schema for pitches; nor does it provide self-evident patterned representations of tonal functionality. Both facts may bias the apprehension of the *Tonnetz*, particularly in non-functional harmonic contexts.

Method:
Participants

88 participants (44.32% female, 55.68% male) took part in the study, split into 4 balanced groups:

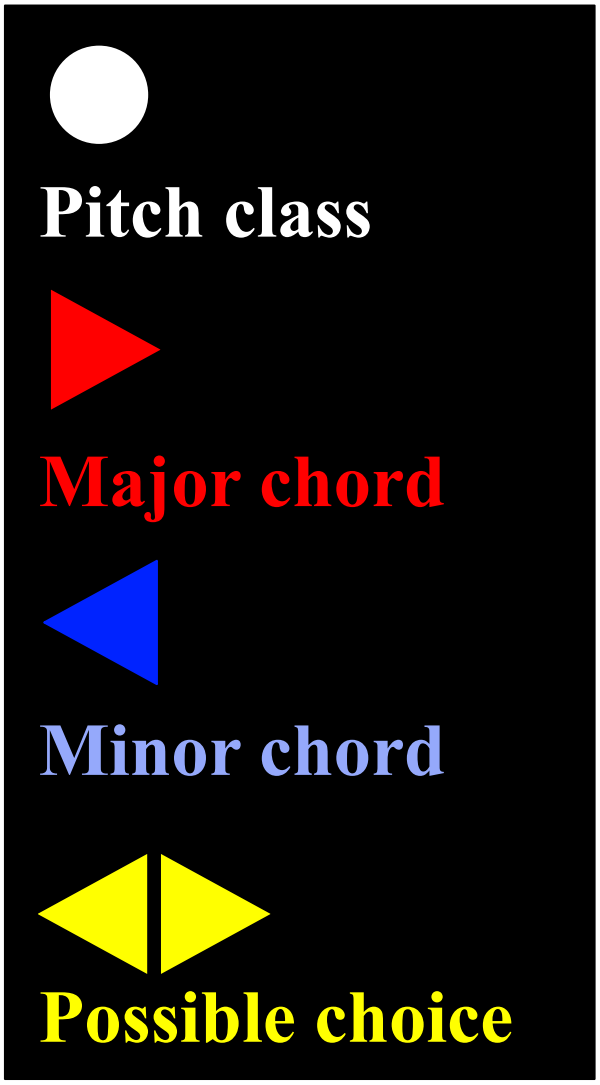
1) Music professionals [MusPro] (age: M=38.32, SD=8.07)

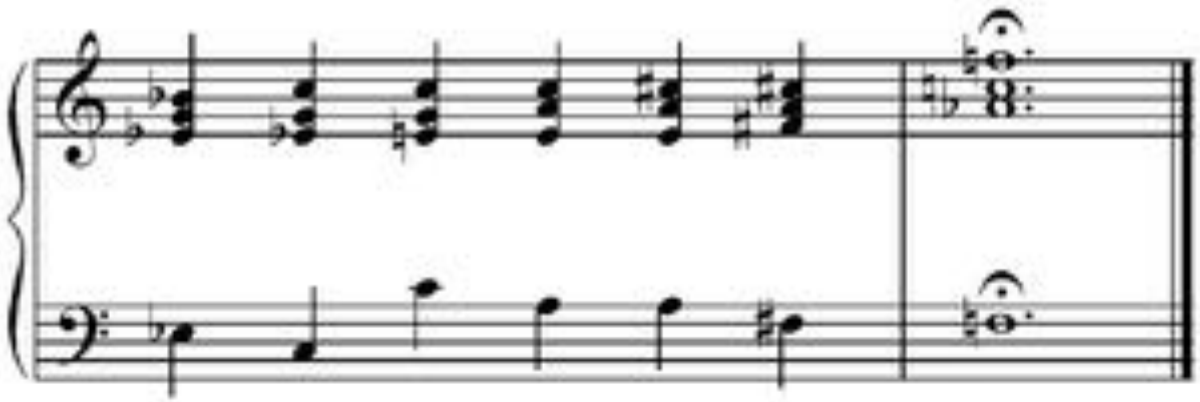
2) Science professionals [SciPro] (age: M=43.68, SD=12.10)

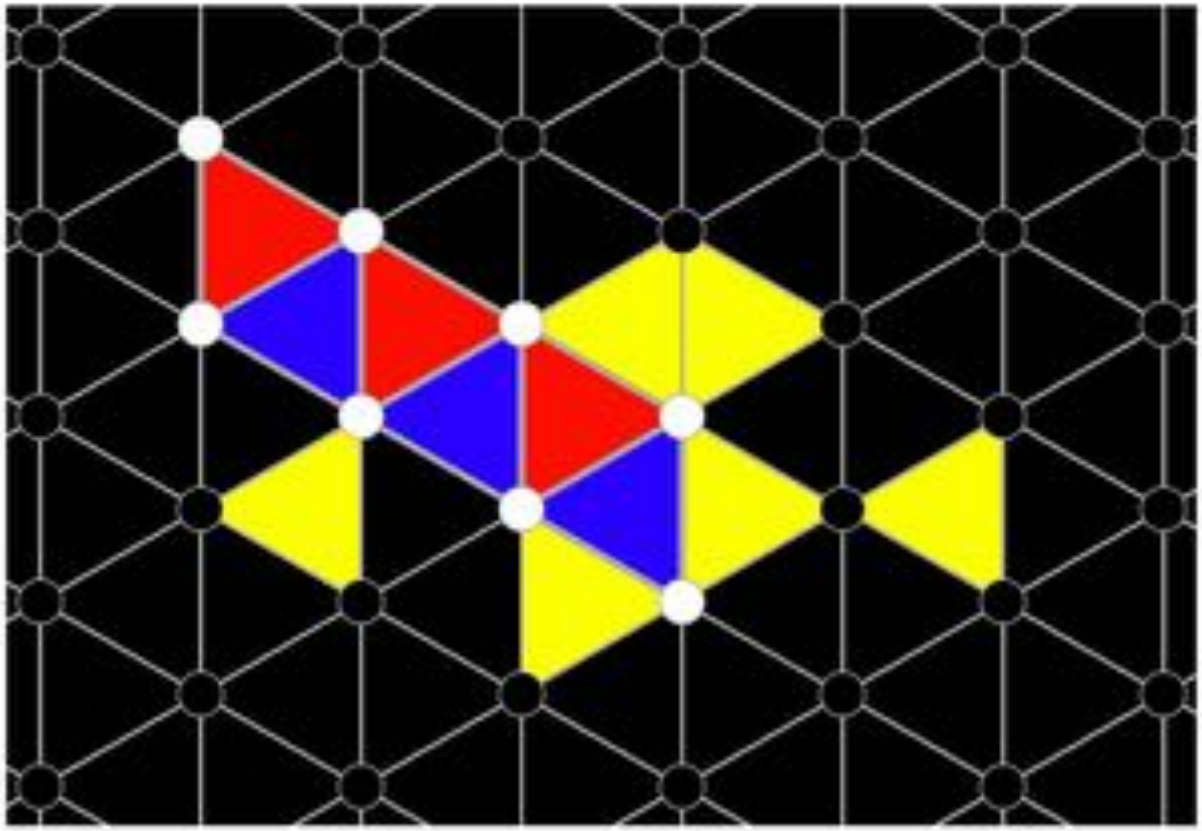
3) Music students [MusStu] (age: M=22.82, SD=2.89)

4) Science students [SciStu] (age: M=20.31, SD=1.77)

Method:
Materials

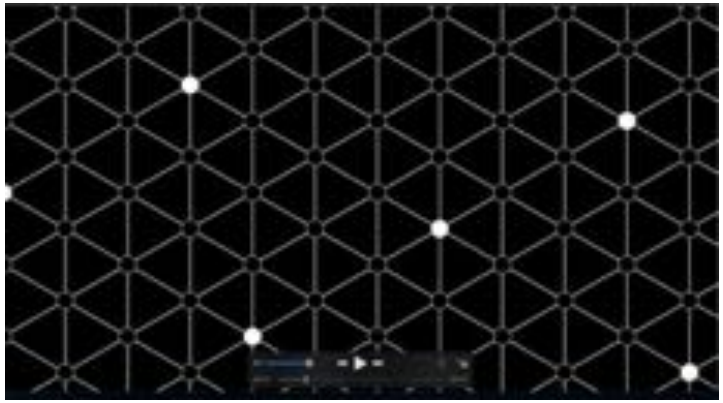




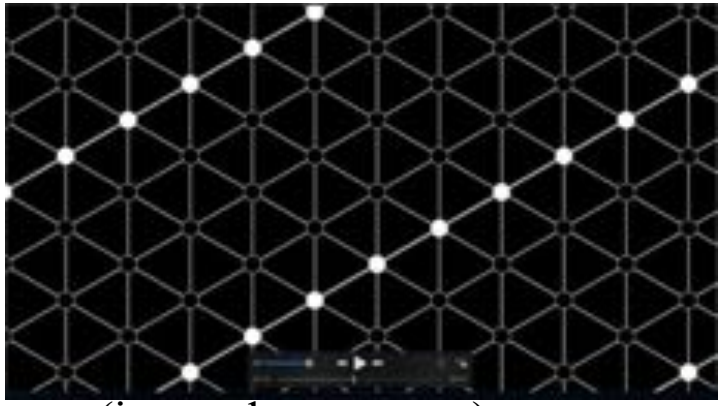


Method:
Procedure

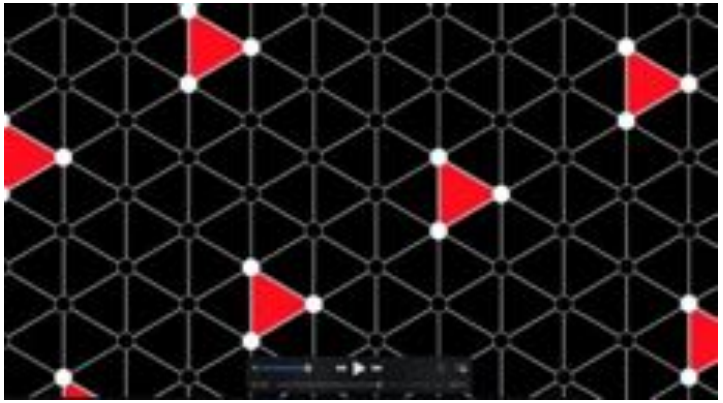
Task performed twice
Video tutorial



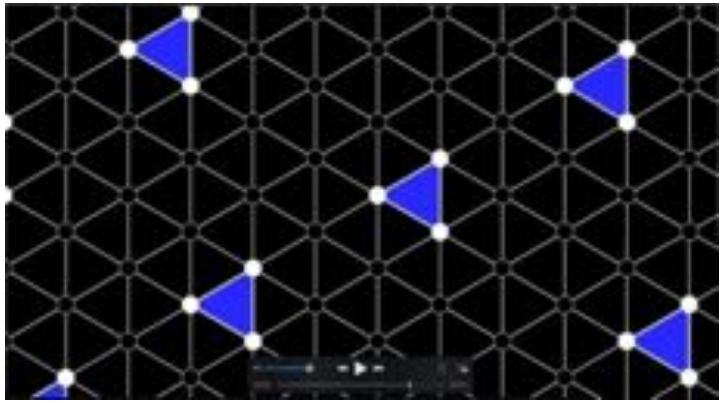
pitch classes



axes (interval generators)



major chords



minor chords

Questionnaire

Results

	Attempt 1				Attempt 2			
Group	Total	0 s.pc.	1 s.pc.	2 s.pc.	Total	0 s.pc.	1 s.pc.	2 s.pc.
MusPro	3.32 ± 1.46	0.64 ± 0.66	0.73 ± 0.88	1.95 ± 1.09	3.50 ± 2.06	0.68 ± 0.84	1.32 ± 1.09	1.50 ± 1.06
SciPro	2.23 ± 1.02	0.32 ± 0.65	0.41 ± 0.73	1.50 ± 1.14	2.55 ± 1.26	0.23 ± 0.43	0.82 ± 0.96	1.50 ± 0.74
MusStu	2.09 ± 1.27	0.36 ± 0.58	0.50 ± 0.60	1.23 ± 1.07	2.32 ± 1.70	0.59 ± 0.80	0.82 ± 0.85	0.91 ± 0.68
SciStu	1.95 ± 1.40	0.41 ± 0.59	0.50 ± 0.80	1.05 ± 1.05	2.27 ± 1.12	0.23 ± 0.53	0.68 ± 0.72	1.36 ± 0.90
Mus	2.70 ± 1.49	0.50 ± 0.63	0.61 ± 0.75	1.59 ± 1.13	2.91 ± 1.96	0.64 ± 0.81	1.07 ± 1.00	1.20 ± 0.93
Sci	2.09 ± 1.22	0.36 ± 0.61	0.45 ± 0.76	1.27 ± 1.11	2.41 ± 1.19	0.23 ± 0.48	0.75 ± 0.84	1.43 ± 0.82

Accuracy:

MusPro was significantly different ($p < .050$) for both attempts when compared with both Sci groups

Results

	Quality		Visual bias	
Group	Attempt 1	Attempt 2	Attempt 1	Attempt 2
MusPro	7.05 ± 1.79	8.32 ± 2.44	4.68 ± 2.88	3.77 ± 1.54
SciPro	5.91 ± 1.15	6.68 ± 1.21	6.55 ± 3.63	5.82 ± 3.70
MusStu	6.18 ± 1.50	7.45 ± 2.42	4.00 ± 3.51	4.00 ± 2.09
SciStu	6.41 ± 1.53	6.32 ± 1.25	4.50 ± 3.07	4.00 ± 2.02
Mus	6.61 ± 1.69	7.89 ± 2.44	4.34 ± 3.19	3.89 ± 1.82
Sci	6.16 ± 1.36	6.50 ± 1.23	5.52 ± 3.48	4.91 ± 3.09

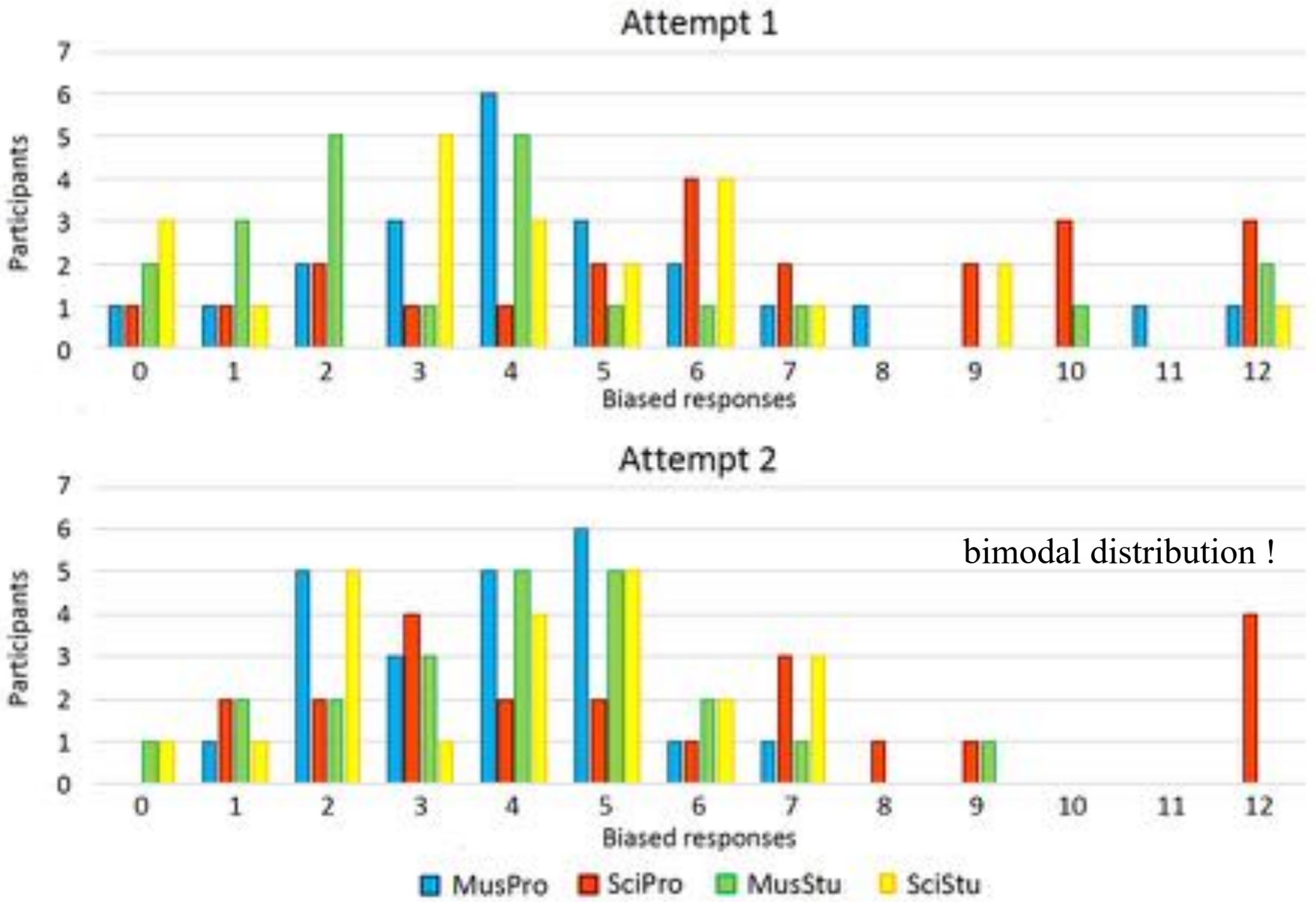
Quality:

MusPro was significantly different for both attempts when compared with both Sci groups
The difference between both attempts per group was slightly significant (except SciStu)

Visual bias:

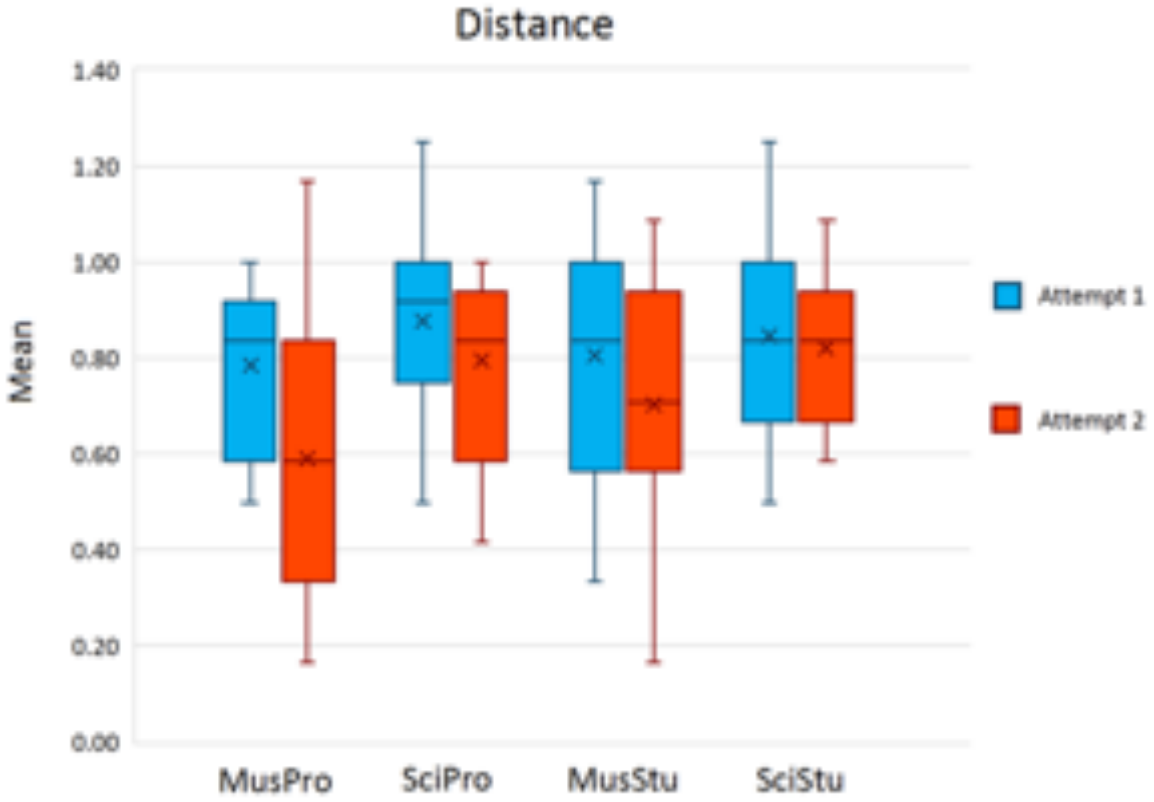
SciPro stands as a signifiatively different group

Results



bimodal distribution !

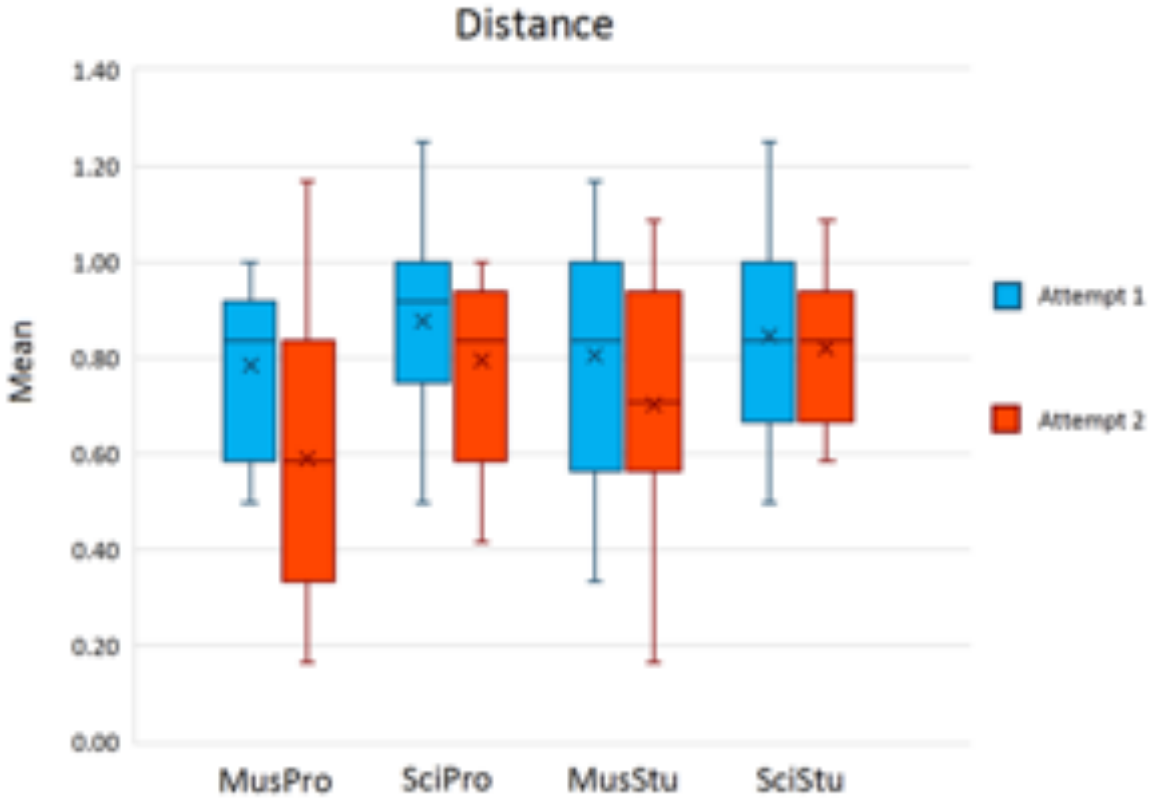
Results



Distance:

$$d = |s_p - s_r|$$

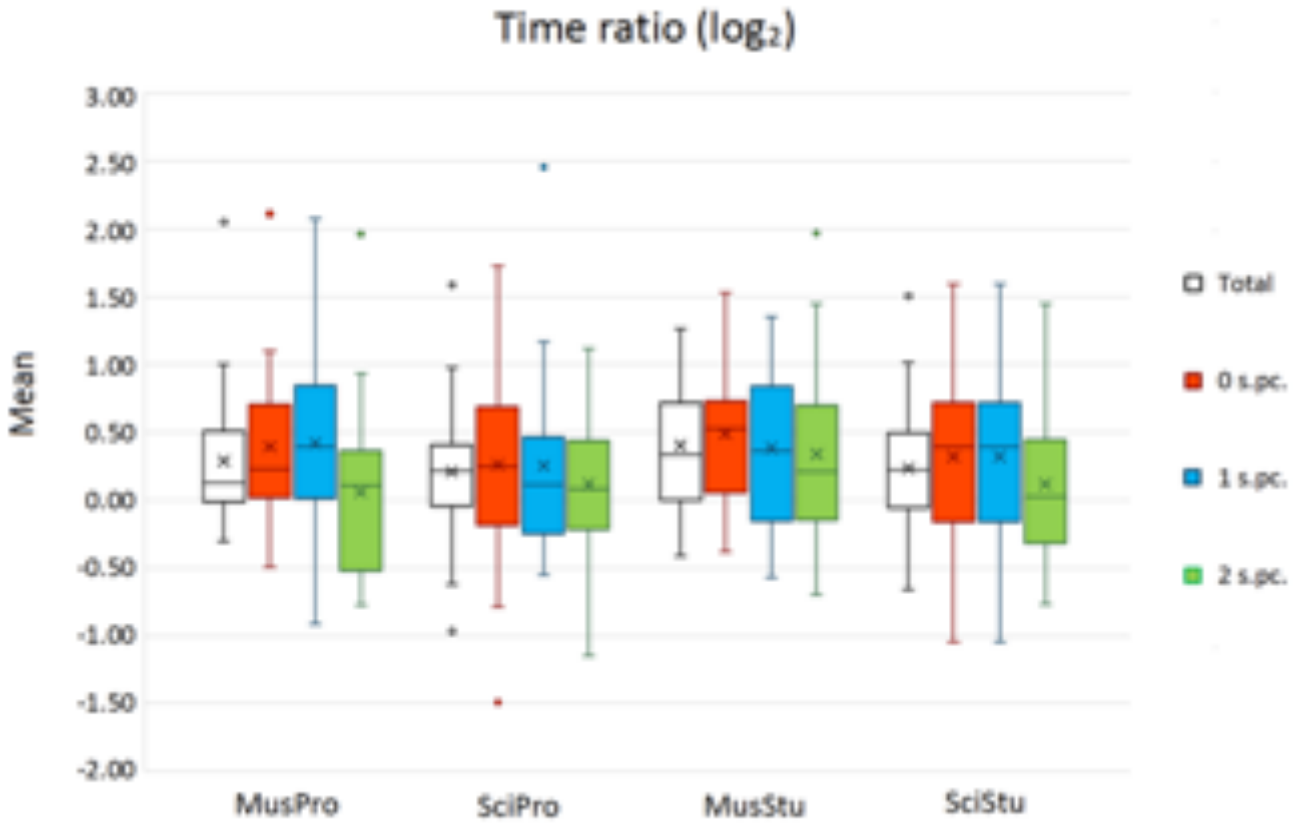
Results



Distance:

MusPro is significantly different for the second attempt when compared with both Sci groups. In addition, MusPro performed significantly different in their second attempt.

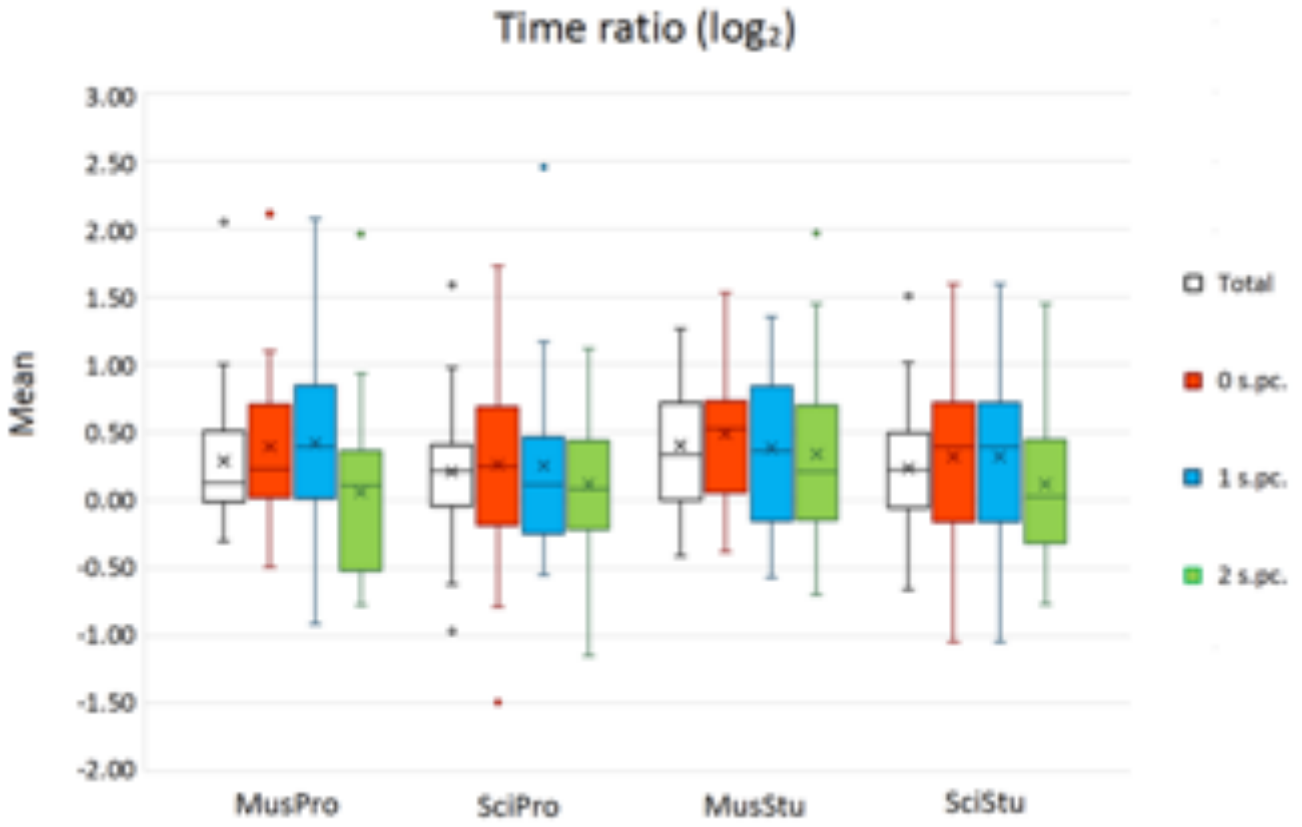
Results



Time ratio:

$$T = \log_2(t_2/t_1)$$

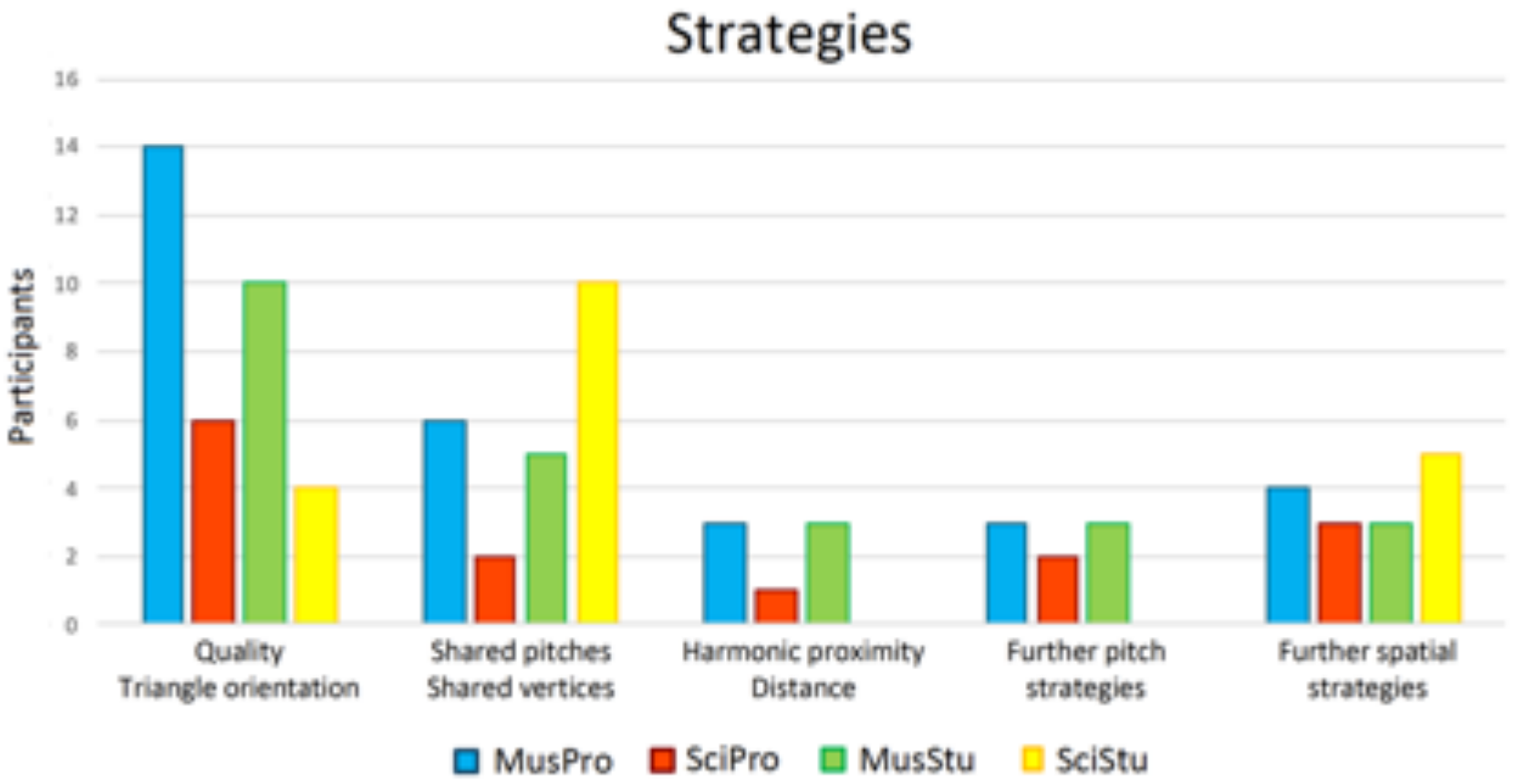
Results



Time ratio:

Positive on average, lower for 2 shared pitch class sets. Particular and significant behavior for MusPro.

Results



One SciPro participant:

"Although I am aware that I am wrong, the only logical answer for me is to follow the alignment of the triangles "

Results

Mus group	Attempt 1				Attempt 2			
Strategy	mean A	mean Q	mean D	mean B	mean A	mean Q	mean D	mean B
Quality	*0.31*	0.23	-0.13	0.19	*0.36*	*0.32*	-0.22	0.02
Shared pitches	0.19	0.20	-0.08	0.02	***0.45***	*0.44*	***-0.43***	-0.14
Visual distance	0.08	0.17	-0.06	0.15	0.02	0.10	-0.13	-0.05
Alt. pitches	-0.01	-0.14	0.19	0.02	-0.19	-0.12	0.01	-0.19
Alt. visual	0.13	0.07	-0.23	-0.05	**-0.13**	**-0.31**	**0.25**	**0.23**
Sci group	Attempt 1				Attempt 2			
Strategy	mean A	mean Q	mean D	mean B	mean A	mean Q	mean D	mean B
Quality	0.01	0.10	-0.10	-0.02	0.22	***0.36***	***-0.37***	-0.13
Shared pitches	-0.21	-0.03	-0.21	-0.23	-0.22	-0.17	-0.00	-0.15
Visual distance	-0.14	-0.24	0.12	-0.02	-0.05	-0.06	**-0.22**	-0.10
Alt. pitches	0.08	-0.26	-0.07	0.06	0.11	**0.18**	-0.24	0.12
Alt. visual	0.11	-0.05	0.23	0.12	-0.11	-0.05	0.06	-0.03

Correlations over |0.30| in italics, variations greater than |0.25| in bold.

Discussion

- Despite the apparent geometrical simplicity of the *Tonnetz*, its deep structural implications are very complex. Only people with high skills in music theory are able, at least, to partially grasp its overall structure at first sight. 

Quality and distance have proven more useful variables for checking this fact than accuracy. However, participants have behaved quite different according to them.

Hypotheses for quality recognition:

MusPro: detection of the feature prior to the video tutorial ?

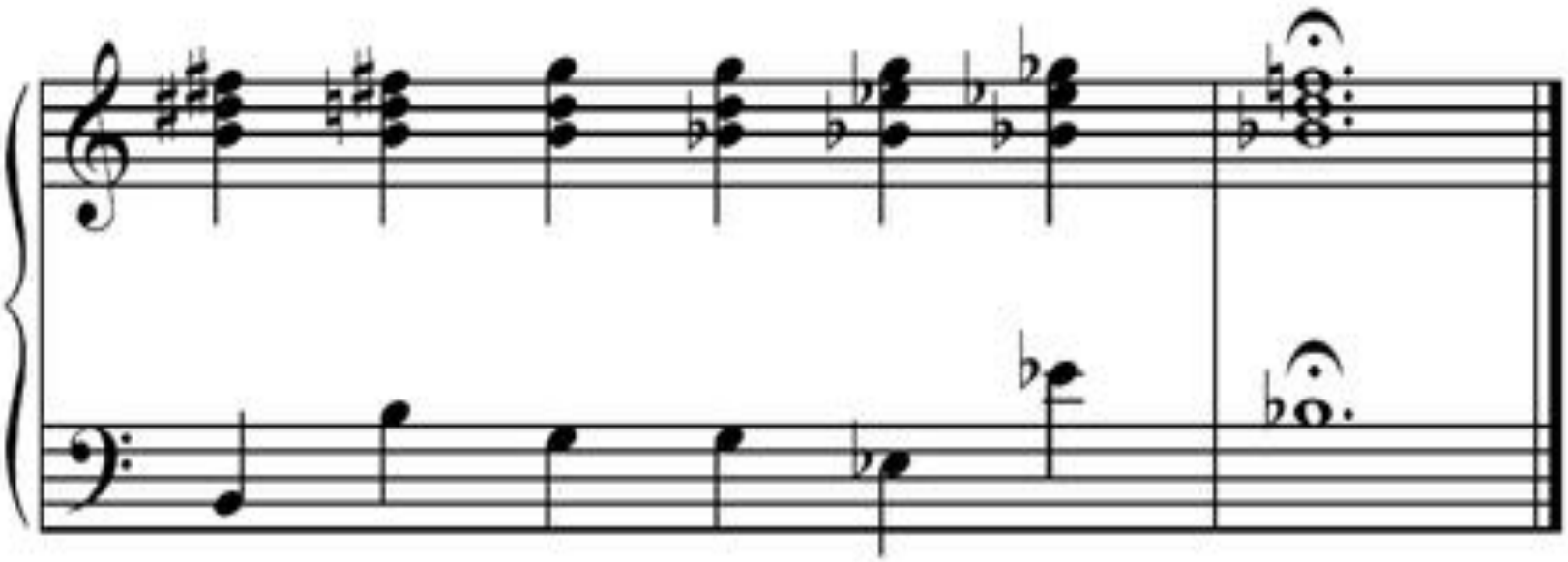
Sci: Rather intuitive than rationalized

Discussion

- The geometry of the *Tonnetz* is not consistent with the widely spread vertical schema for pitches; nor does it provide self-evident patterned representations of tonal functionality. Both facts may bias the apprehension of the *Tonnetz*, particularly in non-functional harmonic contexts.

Induced visual bias depends on previous skills with music theory and systematic geometrical thinking.

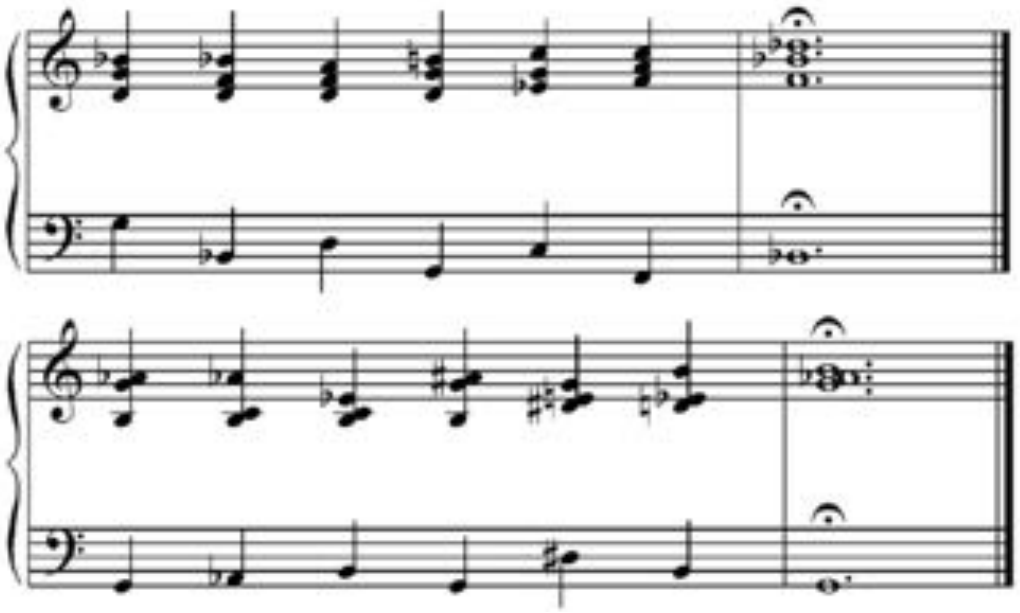
Proximity (in terms of parsimony) related to response time after the video tutorial. Particular behavior of MusPro when tonal functionality and non-functionality clashes.



vi IV iv I

Plagal cadence!

From the Tonnetz to the generalized (*a,b,c*)-*Tonnetze*



ICMPC International Conference on Music Perception and Cognition

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Cognitive Inspections of the *Tonnetz*: A Multimodal Approach

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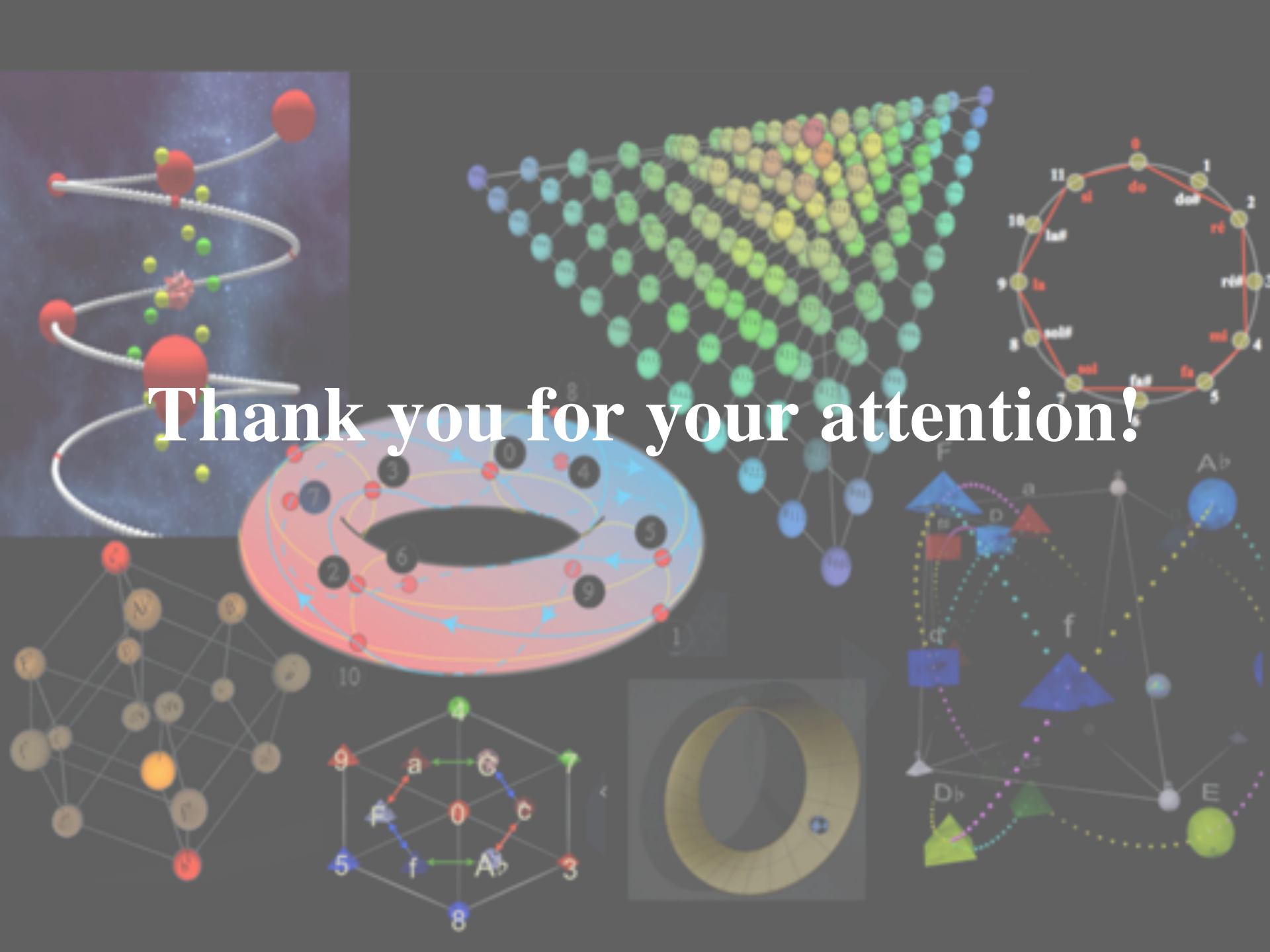
Thank you for your attention!