

Musique et mathématiques en musique savante et dans la chanson

Conservatoire Darius Milhaud d'Antony

4 Mai 2017

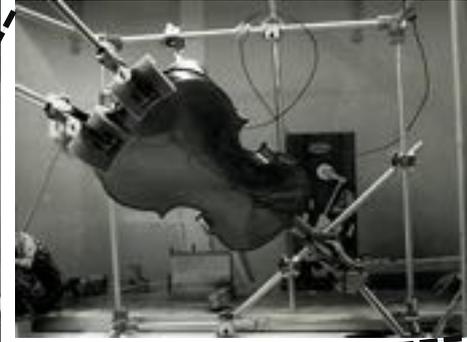
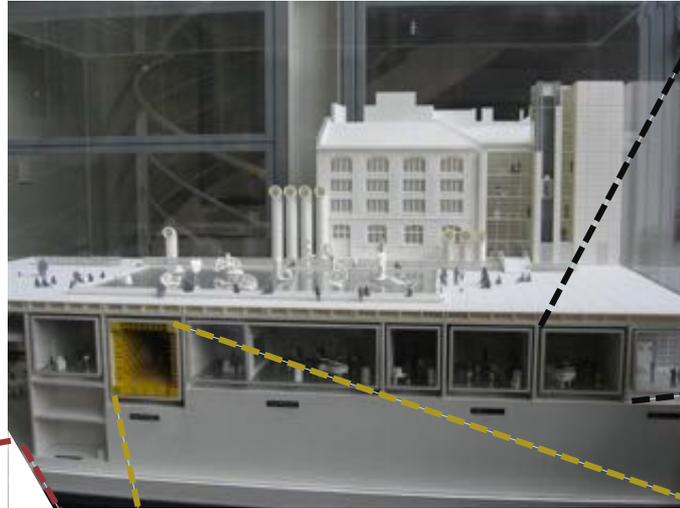
Moreno Andreatta

Music Representations Team

IRCAM / CNRS UMR 9912 / UPMC, Paris

IRMA & GREAM, University of Strasbourg

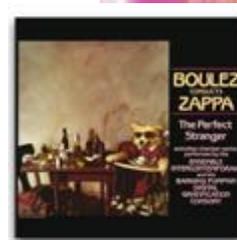
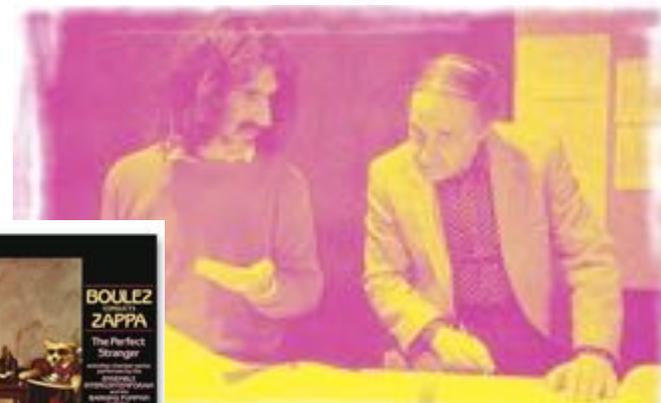
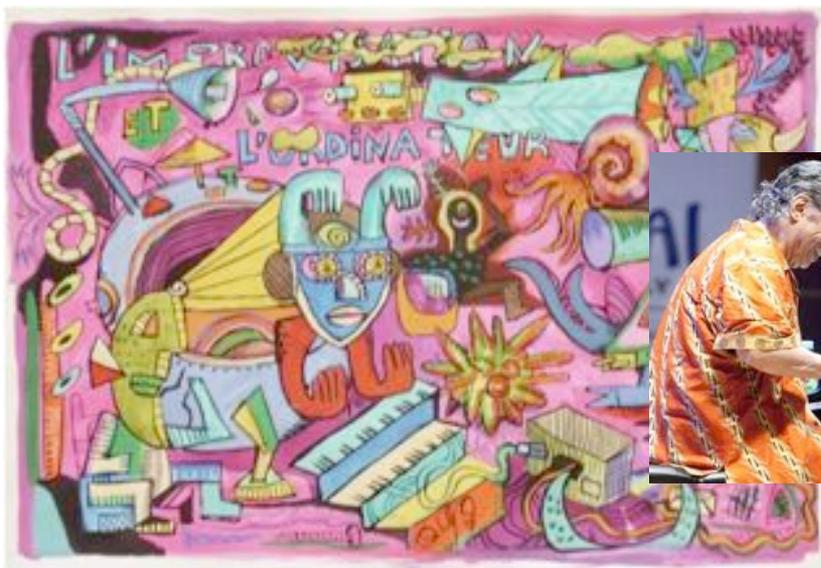
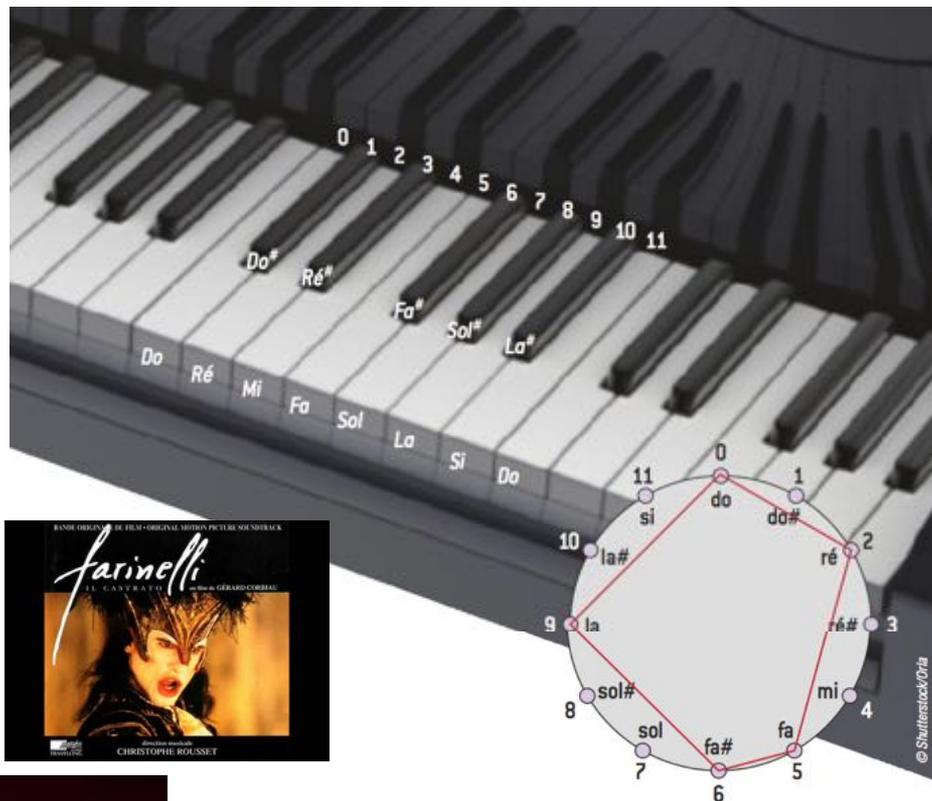
La recherche musicale et scientifique à l'IRCAM...



... entre musique savante et *popular music*

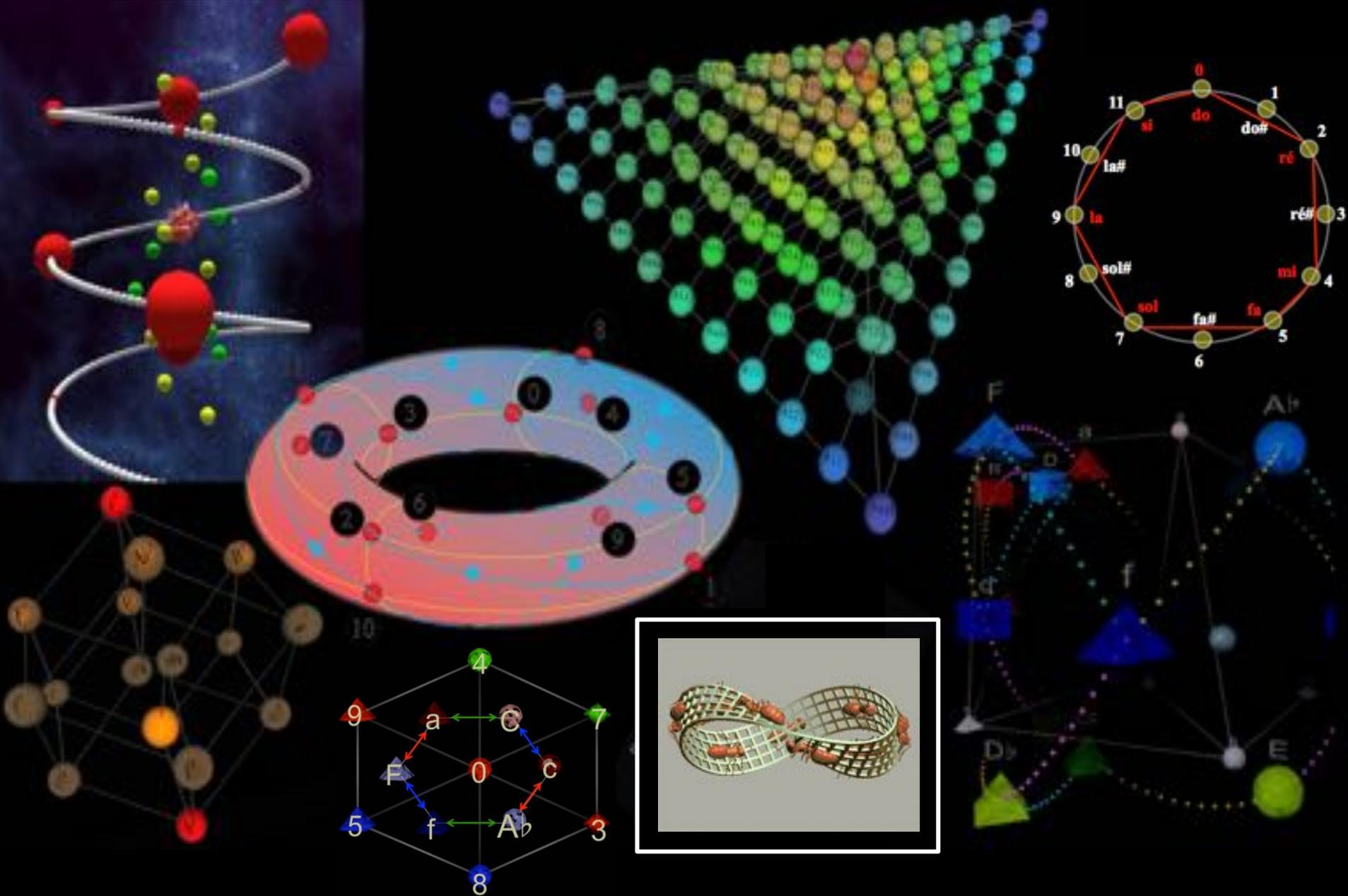


MusiqueLab 2

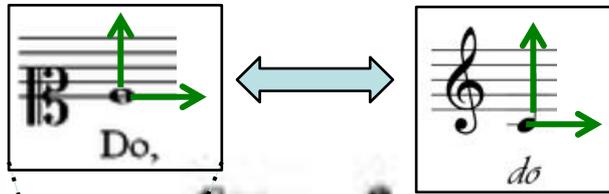
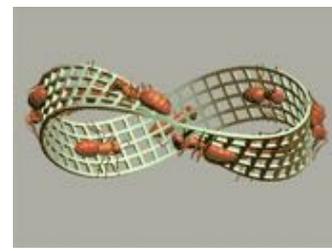


OMAX (logiciel d'improvisation)

La galaxie des modèles géométriques au service de la musique

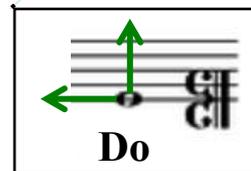


Canons énigmatiques chez Bach et géométrie

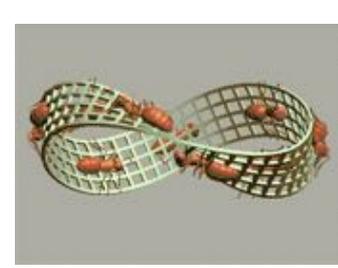


Canones diversi
super thema regium

1. Canon a 2



Ma fin est mon début (renversé !)

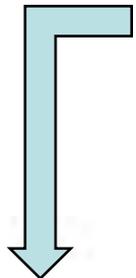


Canones diversi super thema regium:

1. Canon a 2

Canones diversi super thema regium:

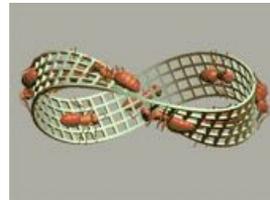
1. Canon a 2



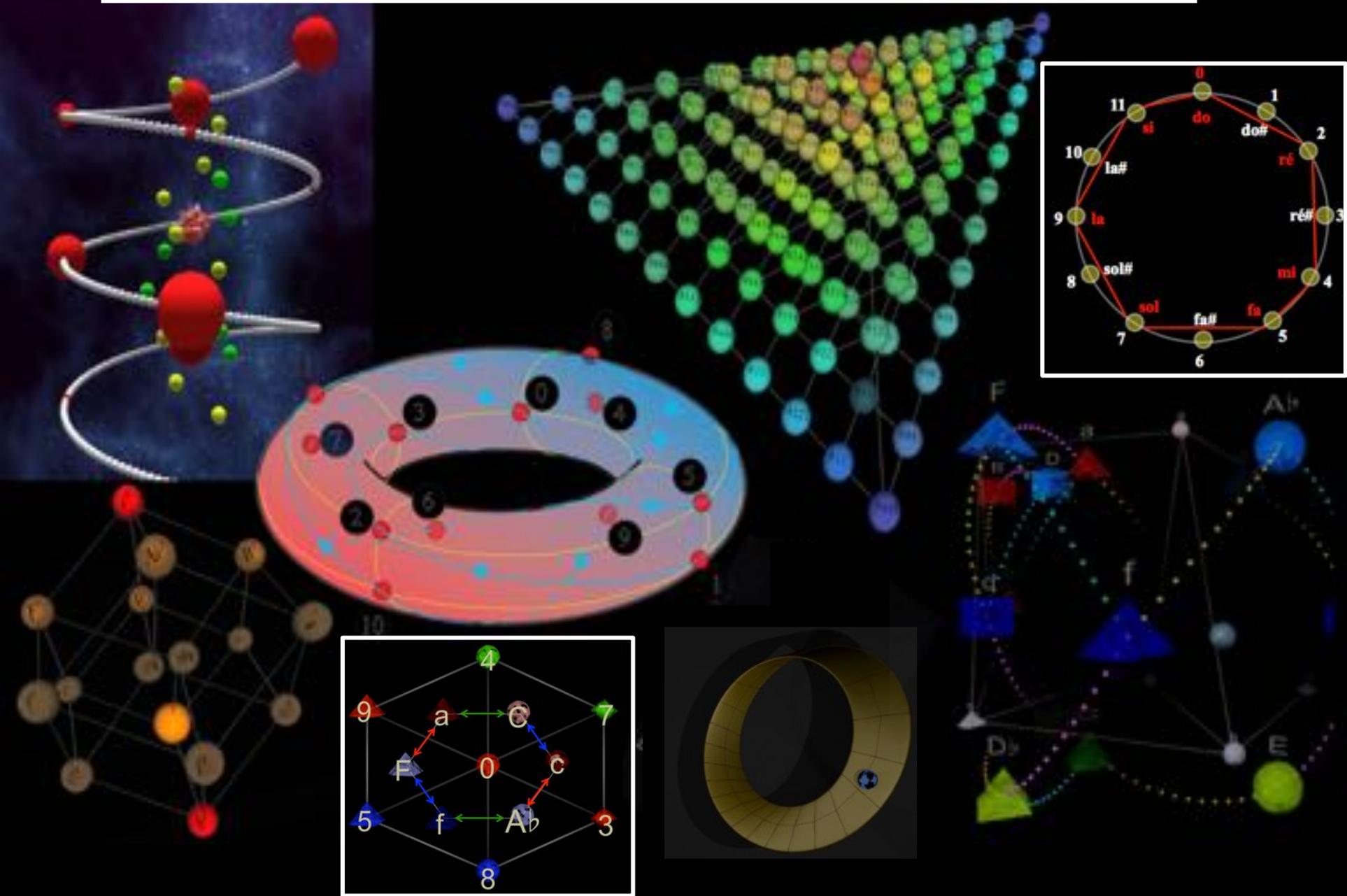


<http://www.josleys.com/Canon/Canon.html>

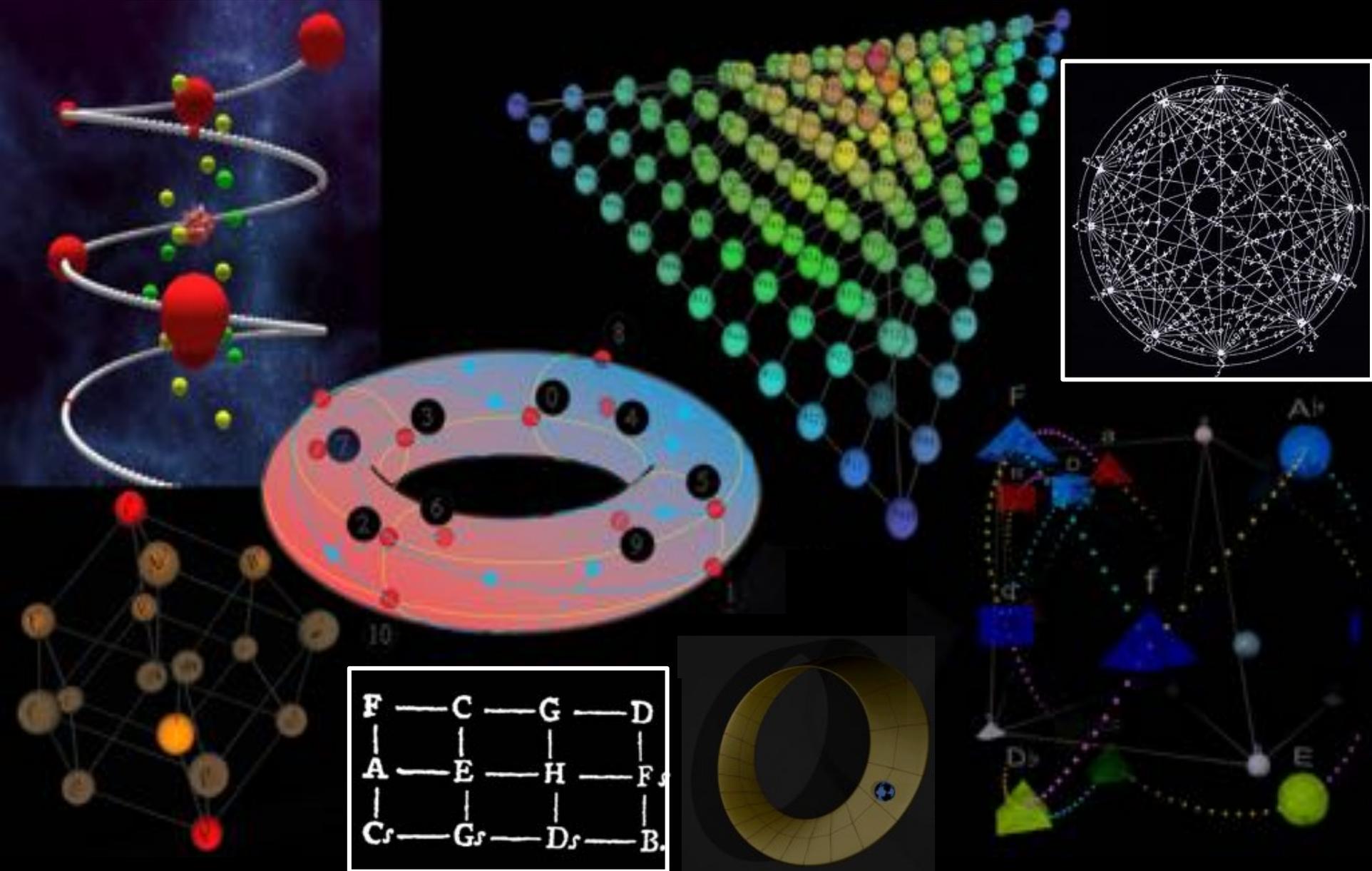
[min. 1'14"]



La galaxie des modèles géométriques au service de la musique



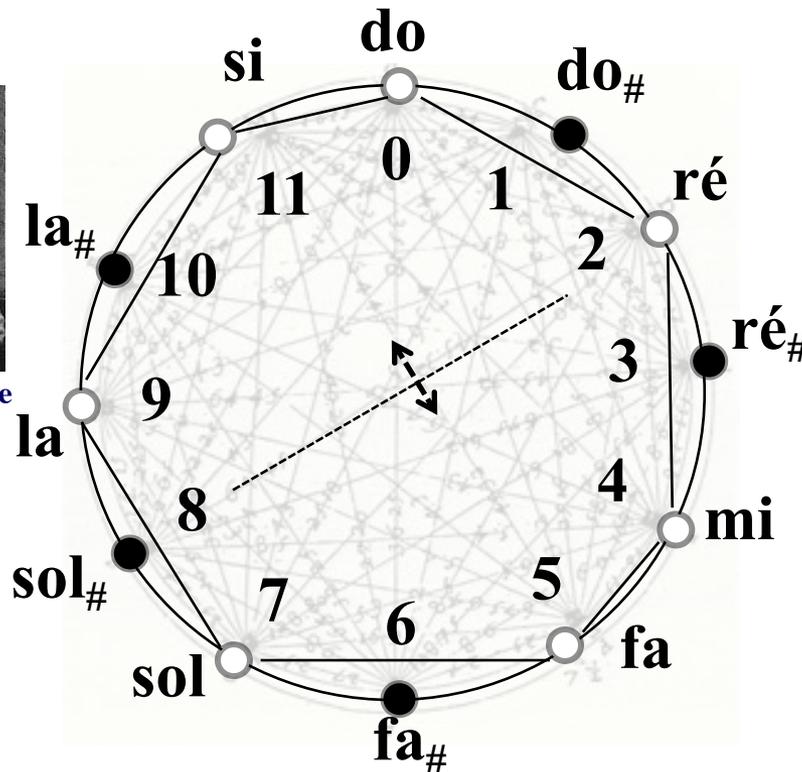
La galaxie des modèles géométriques au service de la musique



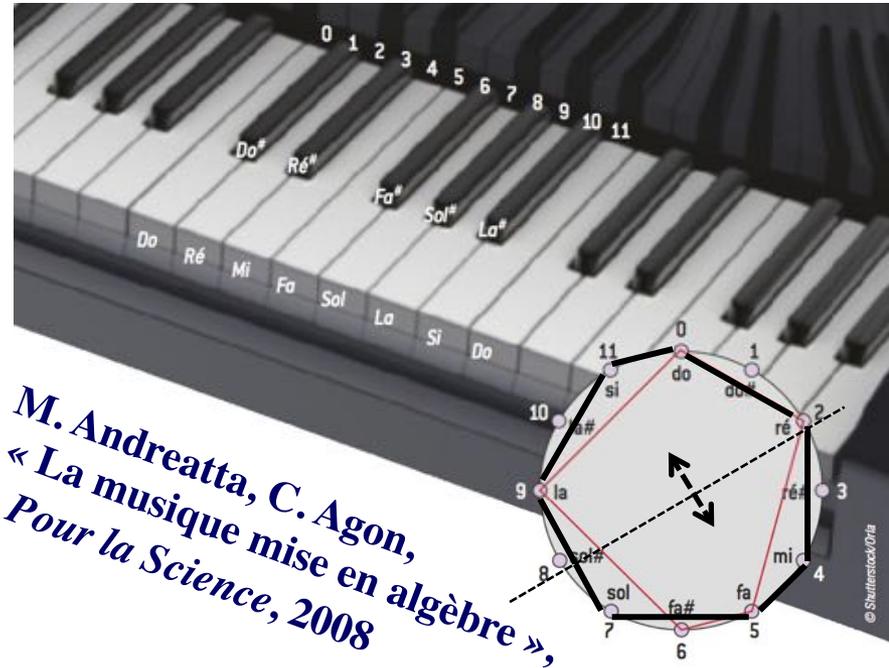
La représentation circulaire des notes de musique



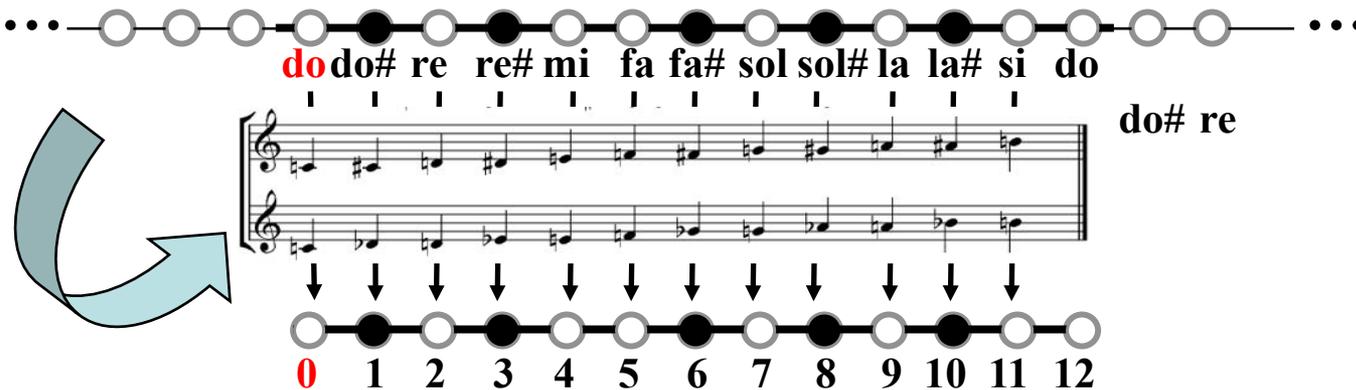
Marin Mersenne



Harmonicorum Libri XII, 1648



M. Andreatta, C. Agon, « La musique mise en algèbre », Pour la Science, 2008



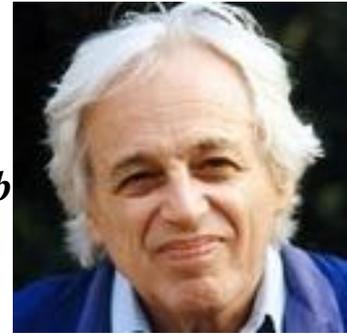
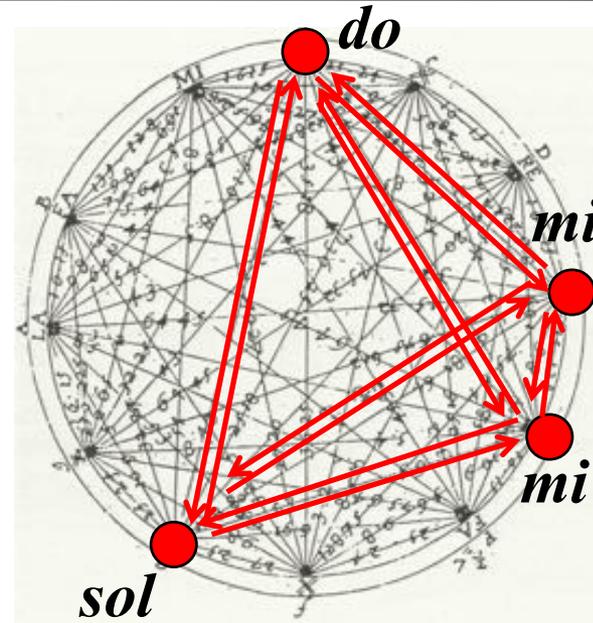
Mersenne et la naissance de la combinatoire

114. Marin Mersenne, *Harmonicorum Libri XII*, 1648

LIBER SEPTIMVS. DE CANTIBVS, SEV CANTILENIS, EARVMQ; NVMERO, PARTIBVS, ET SPECIEBVS.

Tabula Combinationis ab 1 ad 22.

I	1
II	2
III	6
IV	24
V	110
VI	710
VII	3040
VIII	40310
IX	361880
X	3618800
XI	39916800
XII	479001600
XIII	6127016800
XIV	87178291200
XV	1307674368000
XVI	20912789888000
XVII	315687418096000
XVIII	6401373705718000
XIX	121648100408811000
XX	2431301008176640000
XXI	5090941171709440000
XXII	111400071777607480000



Six Bagatelles
(G. Ligeti, 1953)



Varietas, seu Combinatio quatuor notarum.

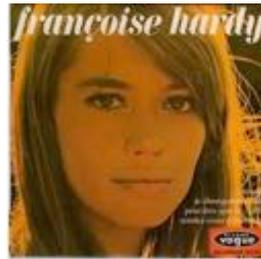
Musical score for "Varietas, seu Combinatio quatuor notarum" showing 24 numbered combinations of four notes across six staves.

Une chanson permutationnelle

Se telefonando, 1966 (Maurizio Costanzo/Ennio Morricone) / Mina



(min. 0'53'')

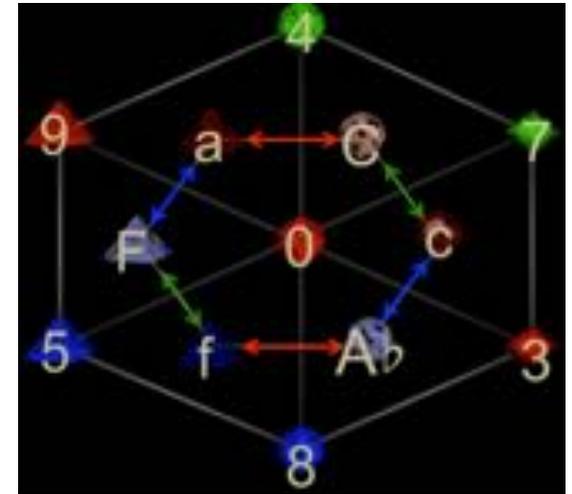


Je changerais d'avis,
(Françoise Hardy)



Ennio Morricone

L'espace harmonique



C	c	C#	c#	D	d
E_b	e_b	E	e	F	f
F#	f#	G	g	G#	g#
A	a	B_b	b_b	B	b

Chord enumeration

→ demo

Les transpositions sont des additions...

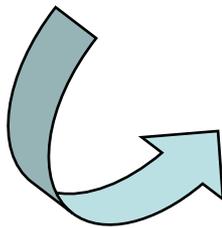
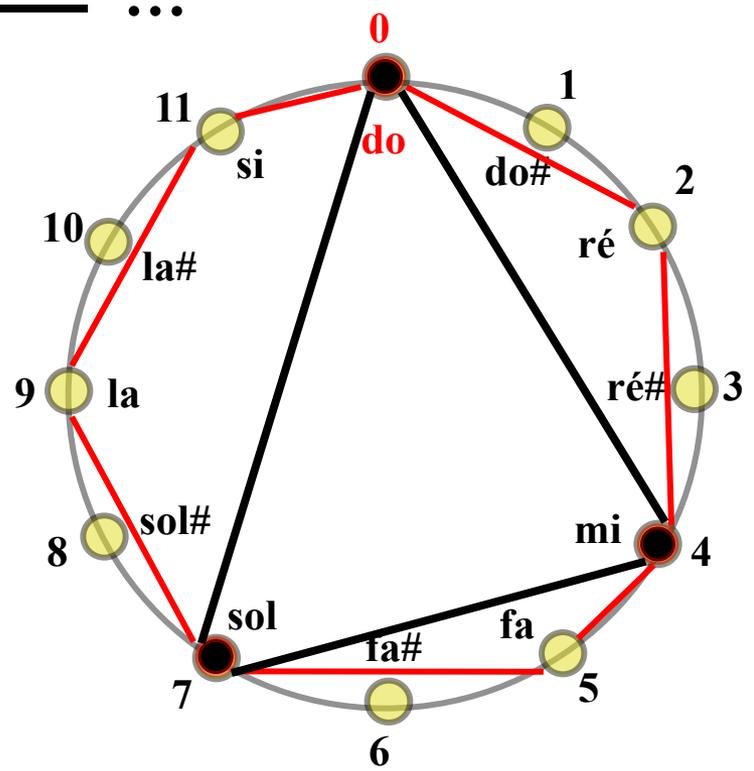


$$\text{Do maj} = \{0, 2, 4, 5, 7, 9, 11\} + 1$$

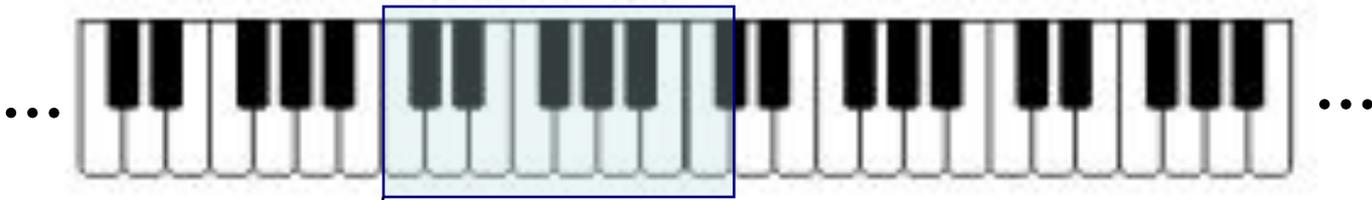
... do do# ré ré# mi fa fa# sol sol# la la# si do ...



0 1 2 3 4 5 6 7 8 9 10 11 12



Les transpositions sont des additions...

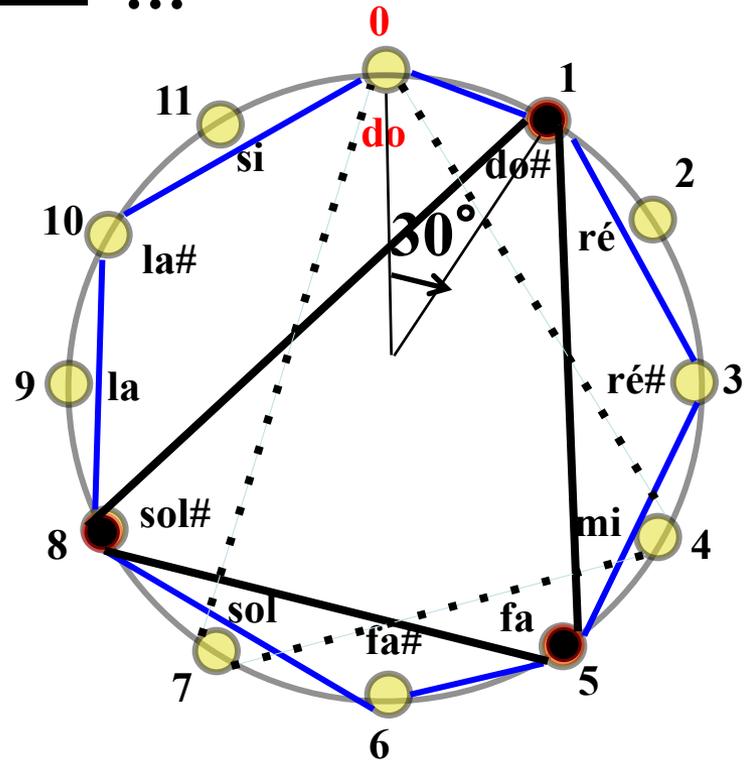


$$Do\# \text{ maj} = \{1, 3, 5, 6, 8, 10, 0\}$$

... do do# ré ré# mi fa fa# sol sol# la la# si do ...

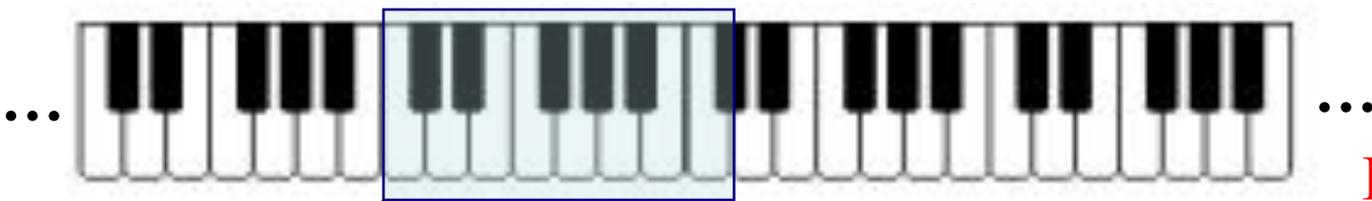


0 1 2 3 4 5 6 7 8 9 10 11 12



... ou des rotations !

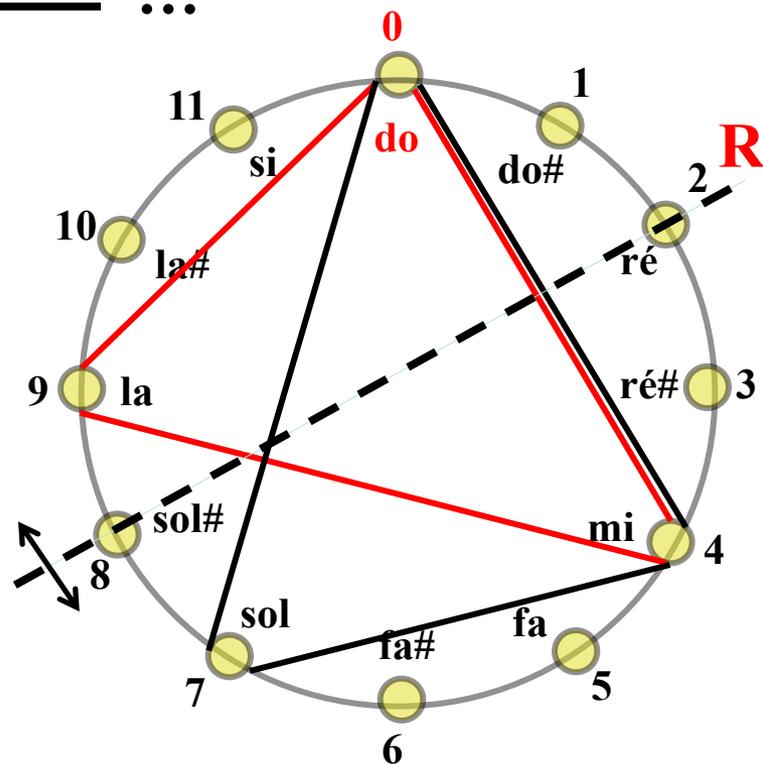
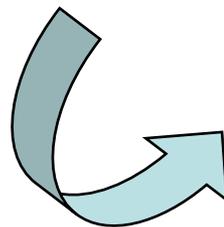
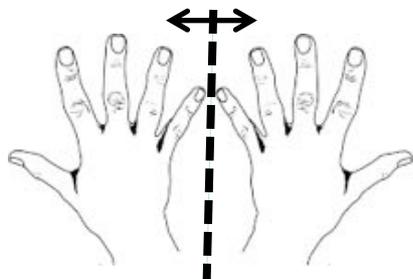
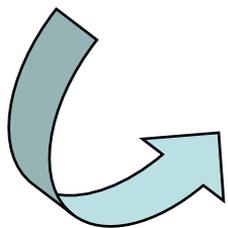
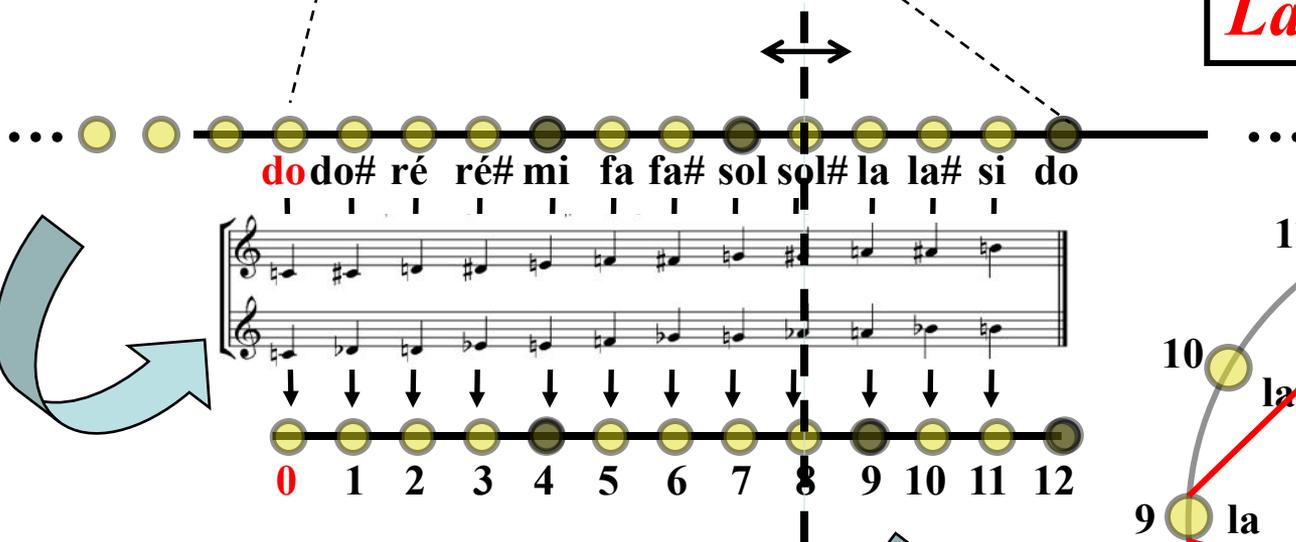
Les inversions sont des symétries axiales



R comme **relatif**

Do maj = {0,4,7}

La min = {0,4,9}

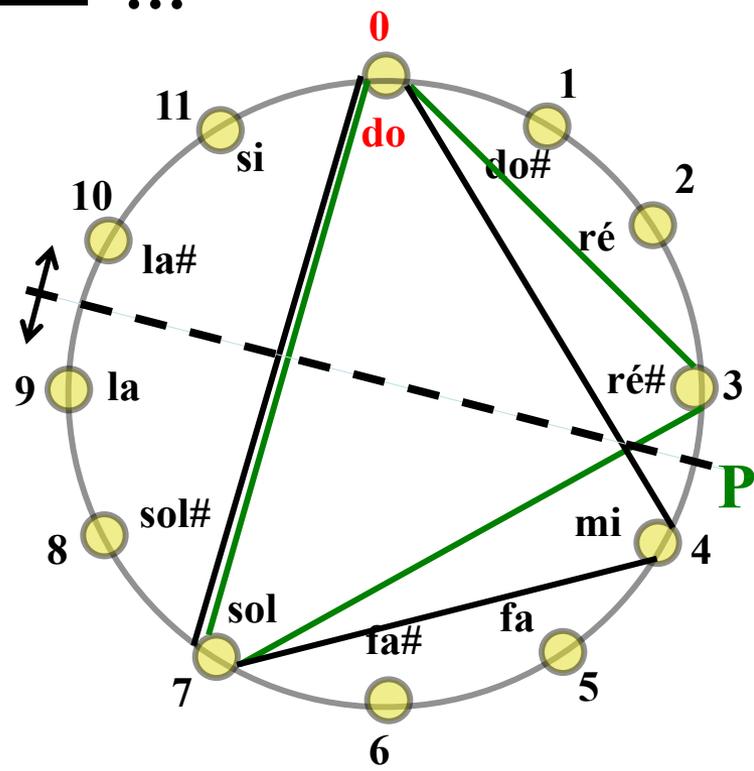
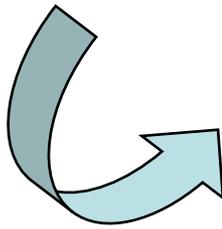
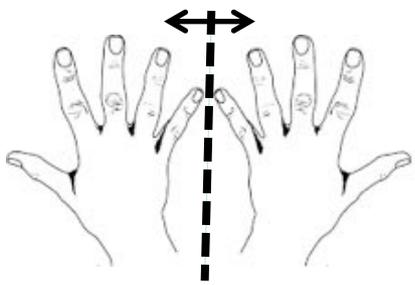
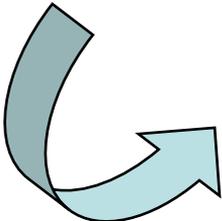
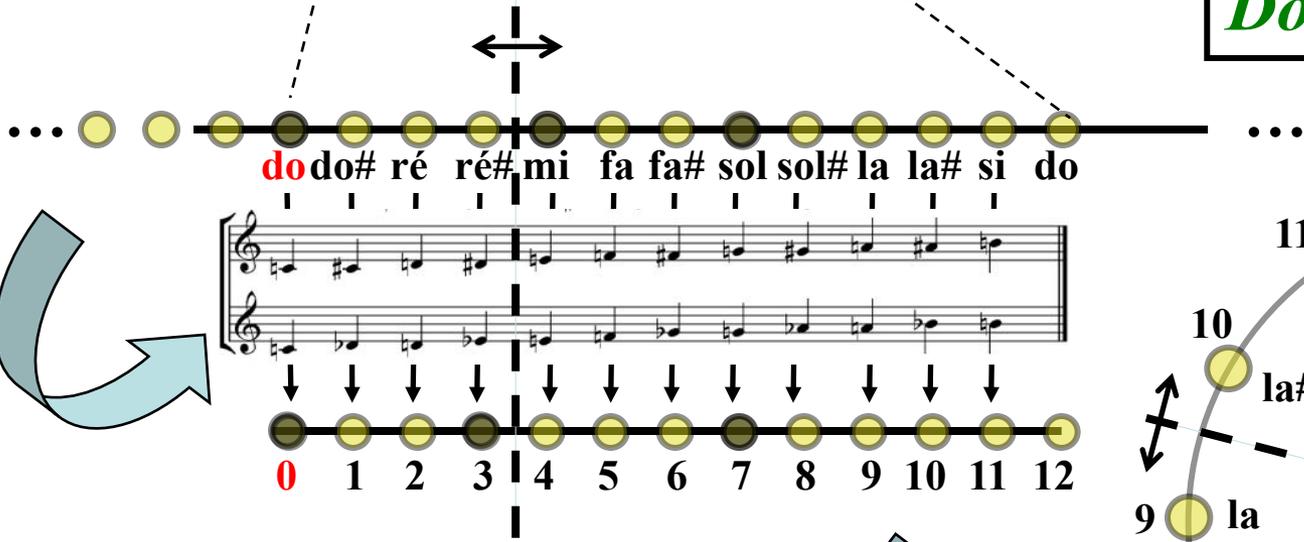


Les inversions sont des symétries axiales



P comme **parallèle**

Do maj = {0,4,7}
Do min = {0,3,7}

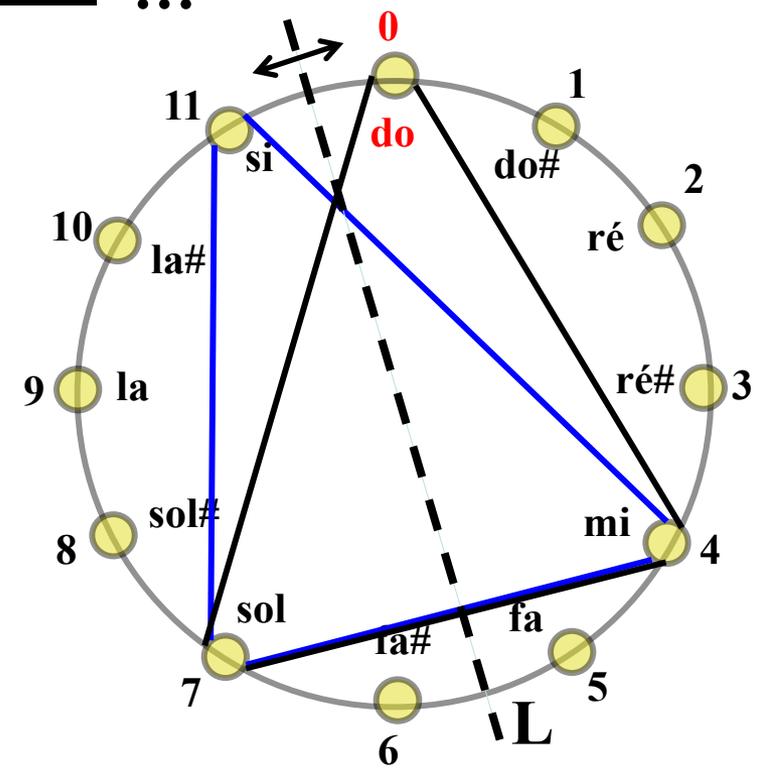
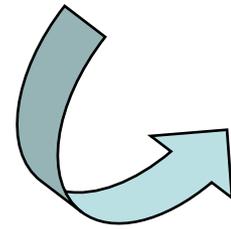
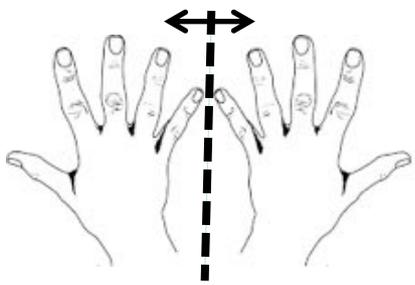
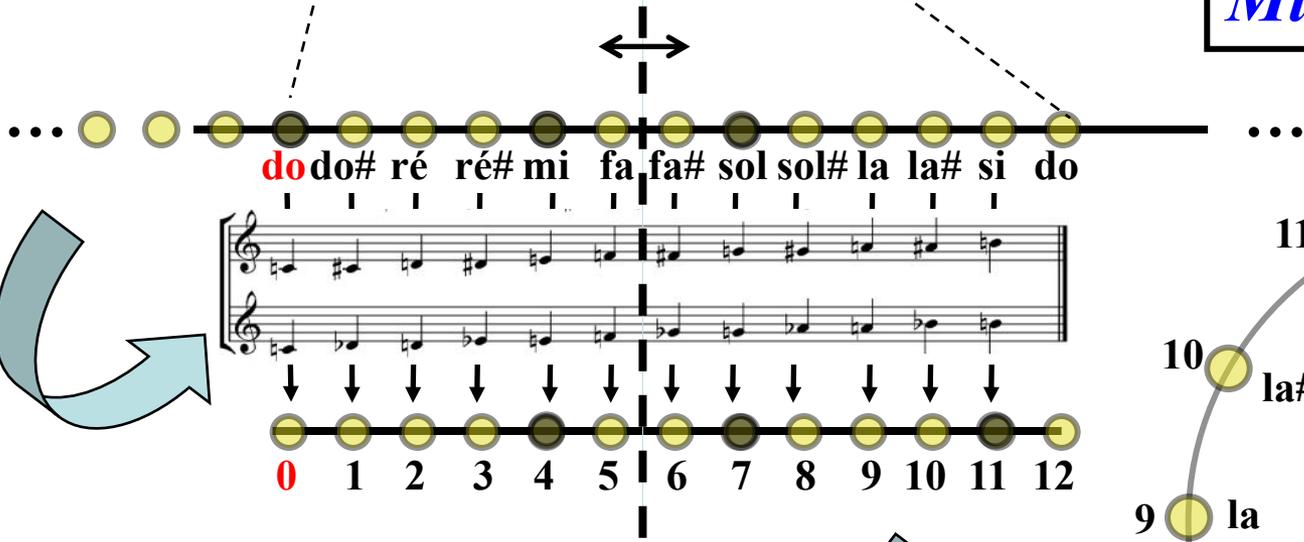


Les inversions sont des symétries axiales

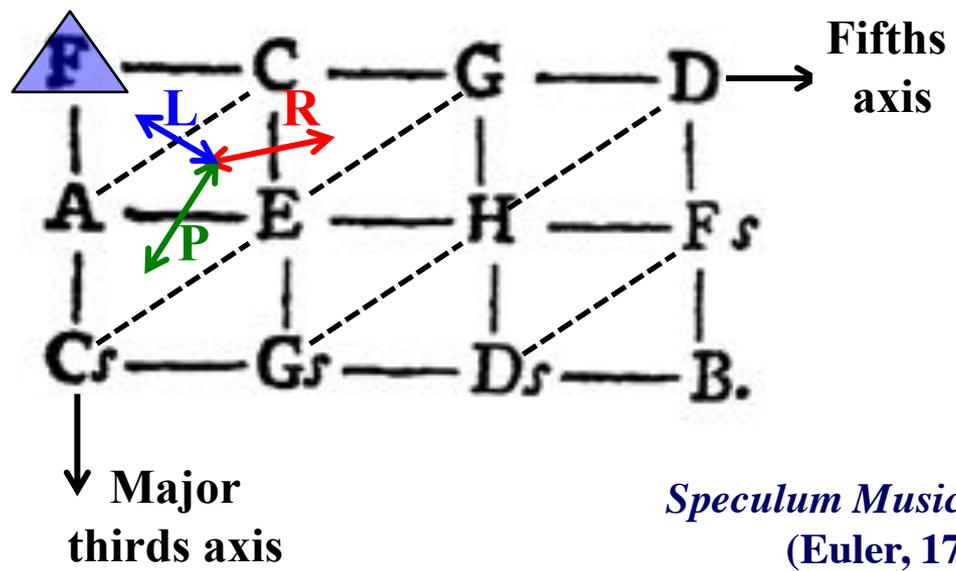
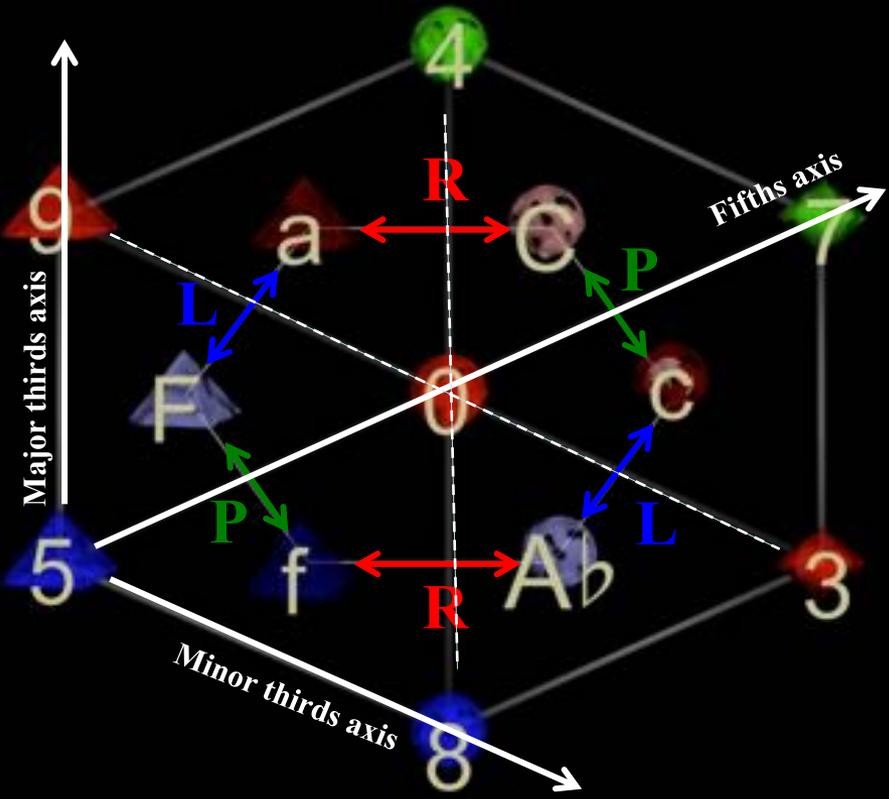


L = Leading Tone

Do maj = {0,4,7}
Mi min = {4,7,11}

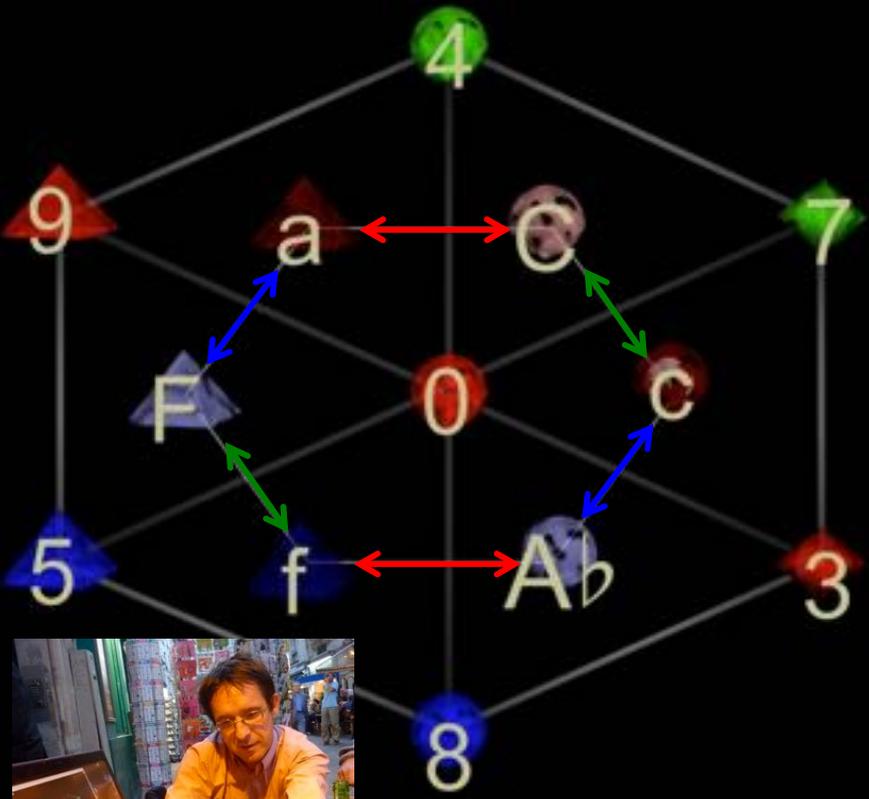


Le Tonnetz (ou nid musical d'abeilles)



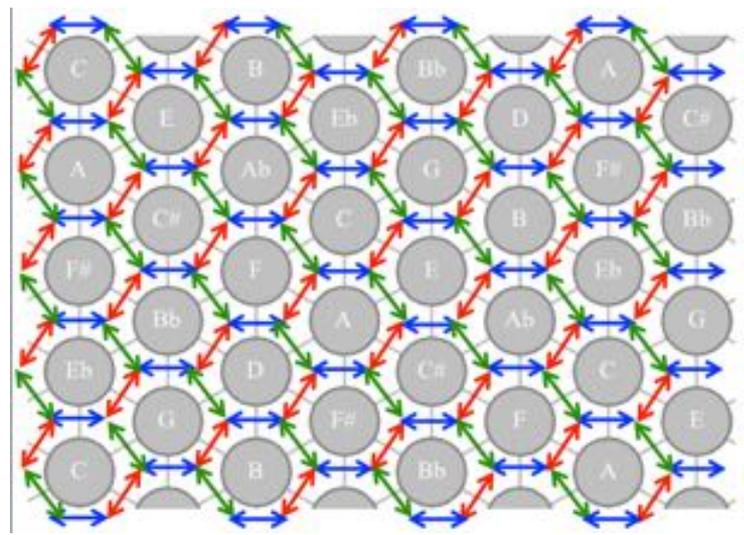
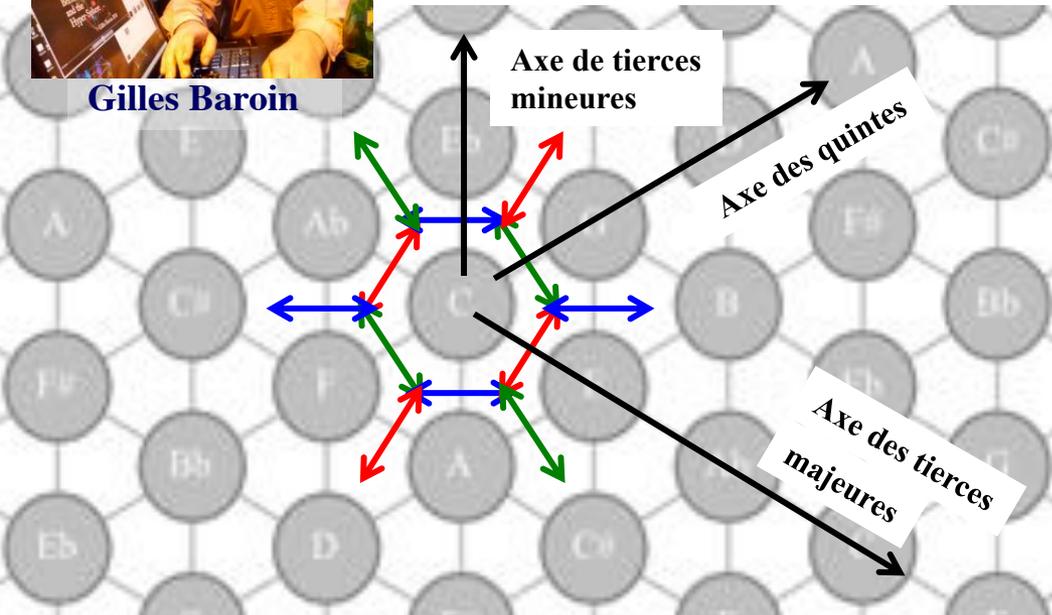
Speculum Musicum
(Euler, 1773)

Le Tonnetz (ou nid musical d'abeilles)

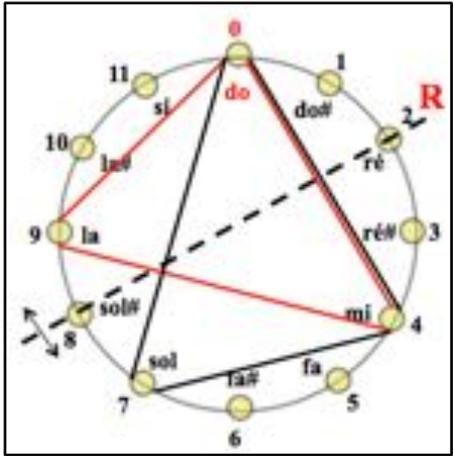
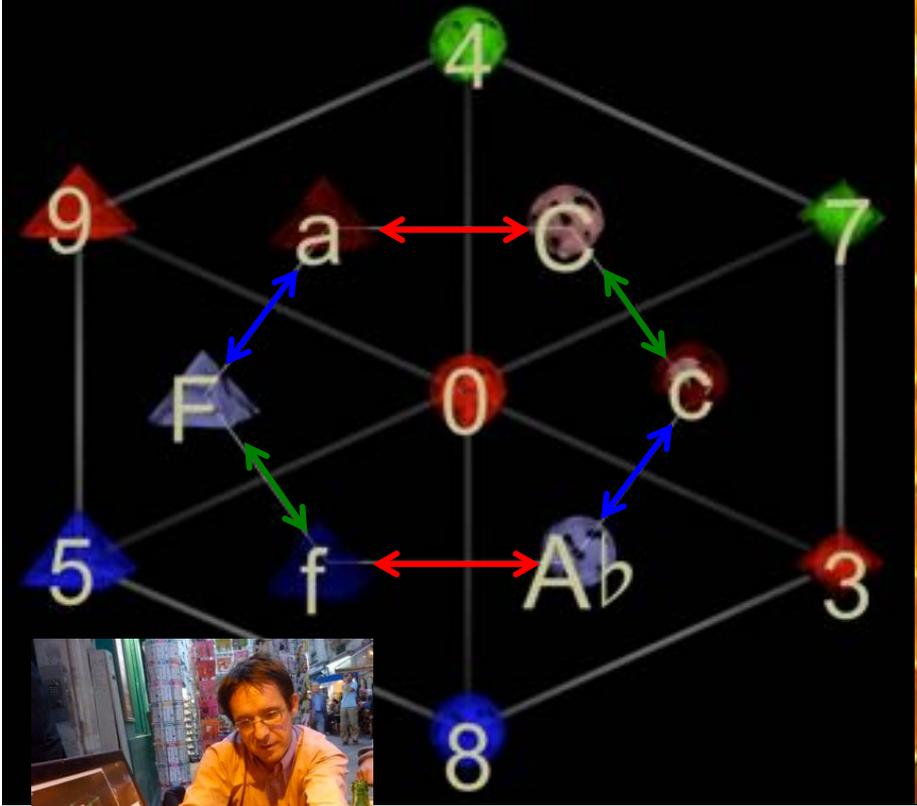


Gilles Baroin

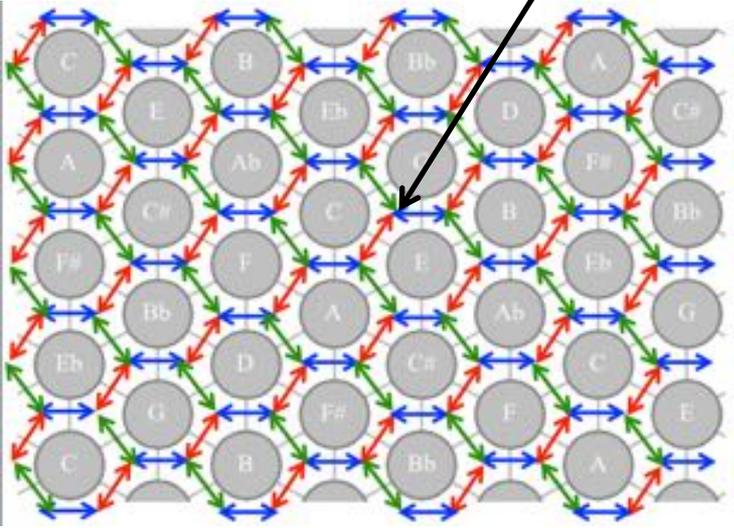
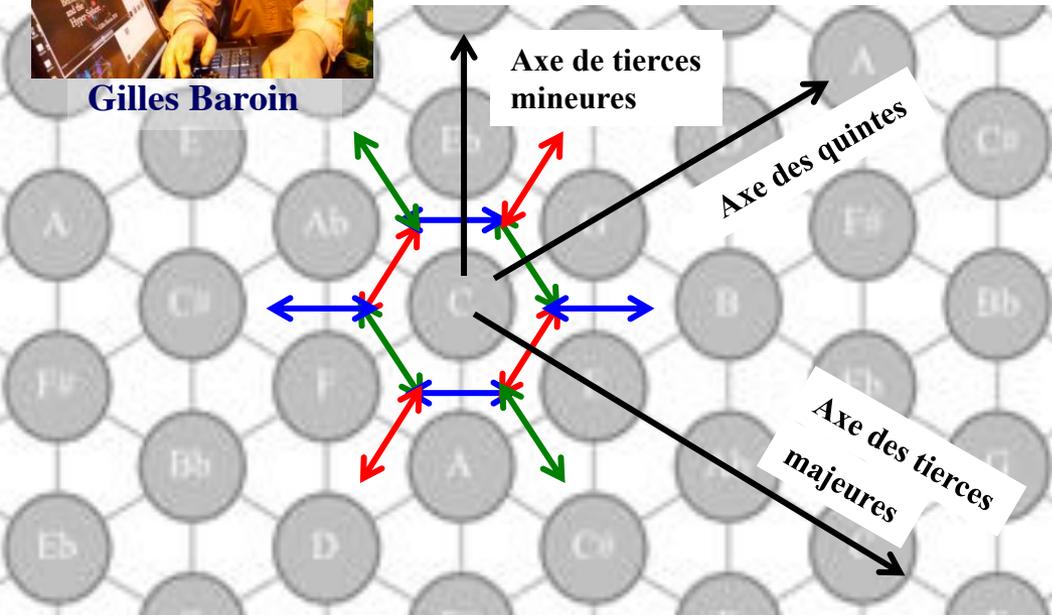
Speculum Musicum (Euler, 1773)



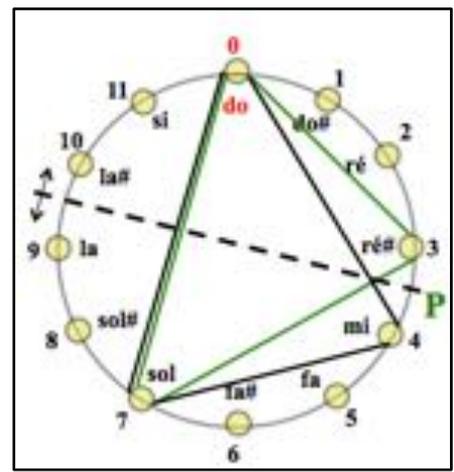
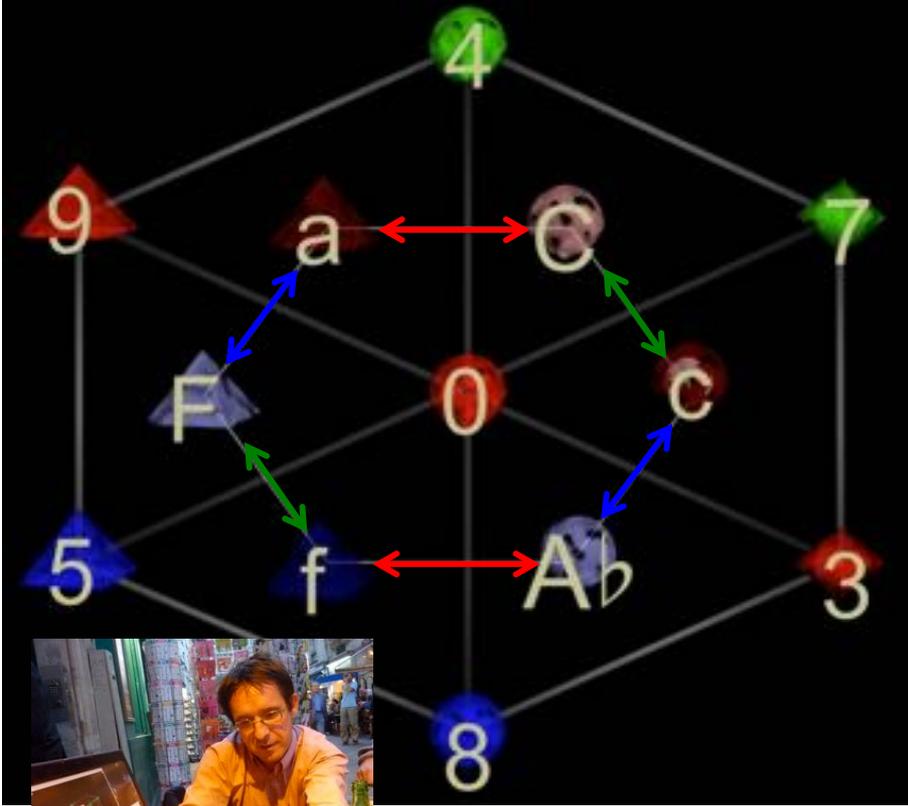
Le Tonnetz (ou nid musical d'abeilles)



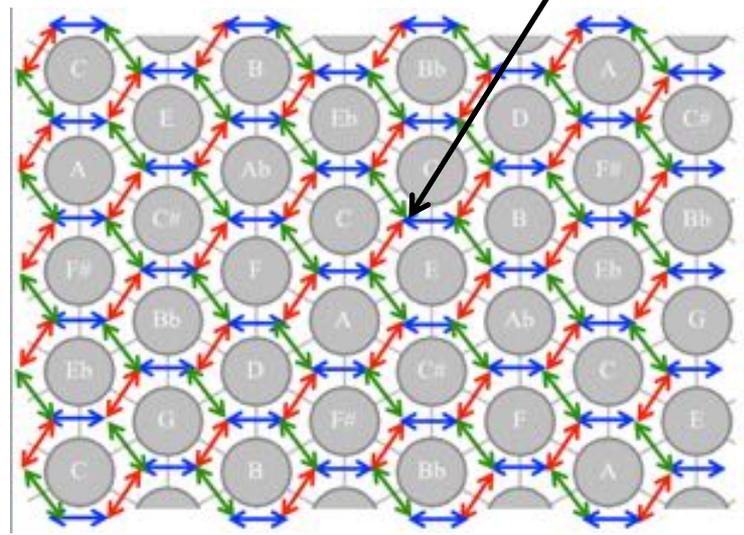
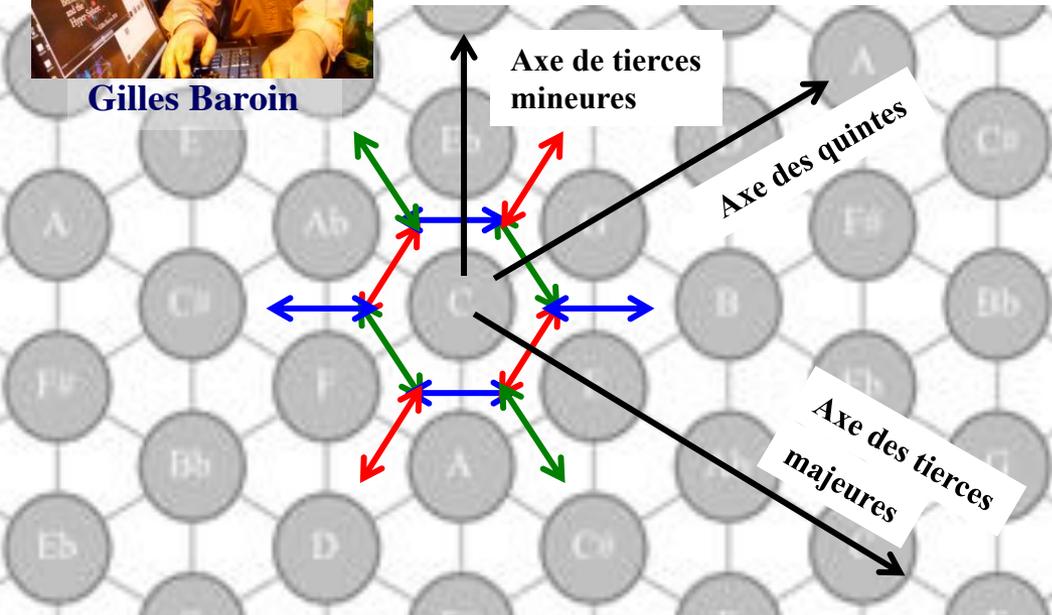
Gilles Baroin



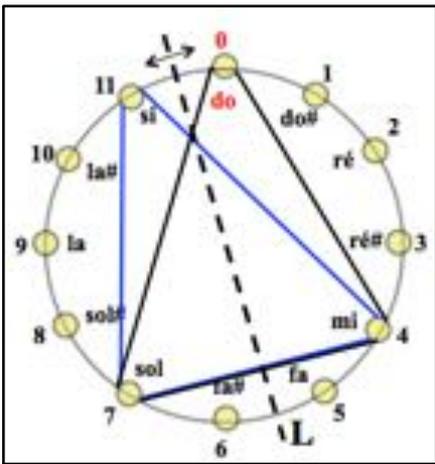
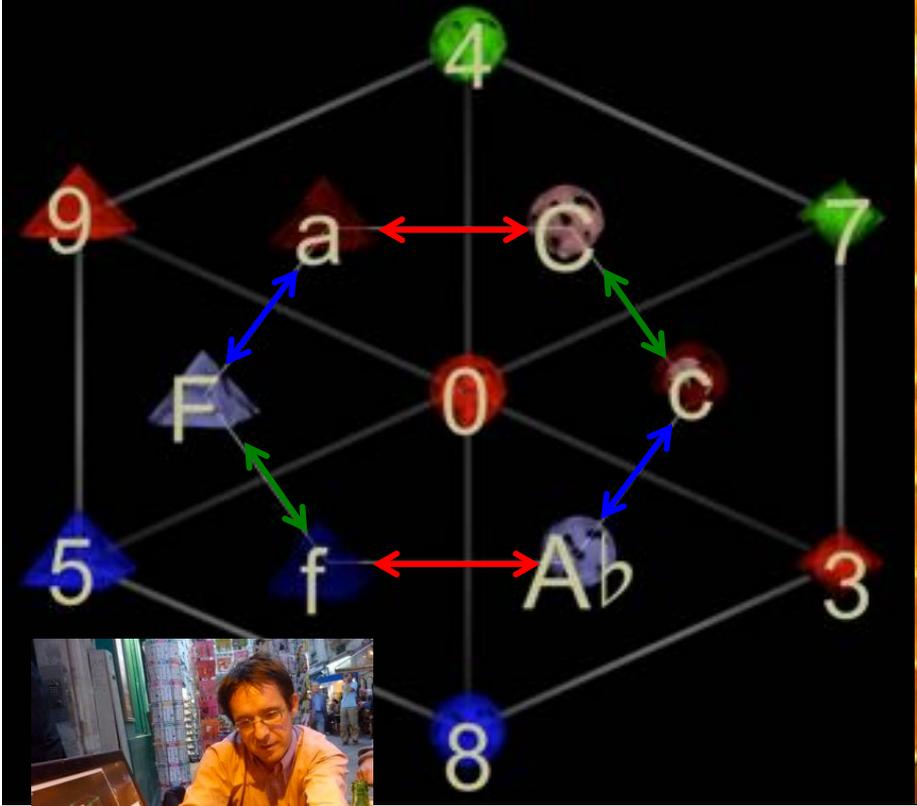
Le Tonnetz (ou nid musical d'abeilles)



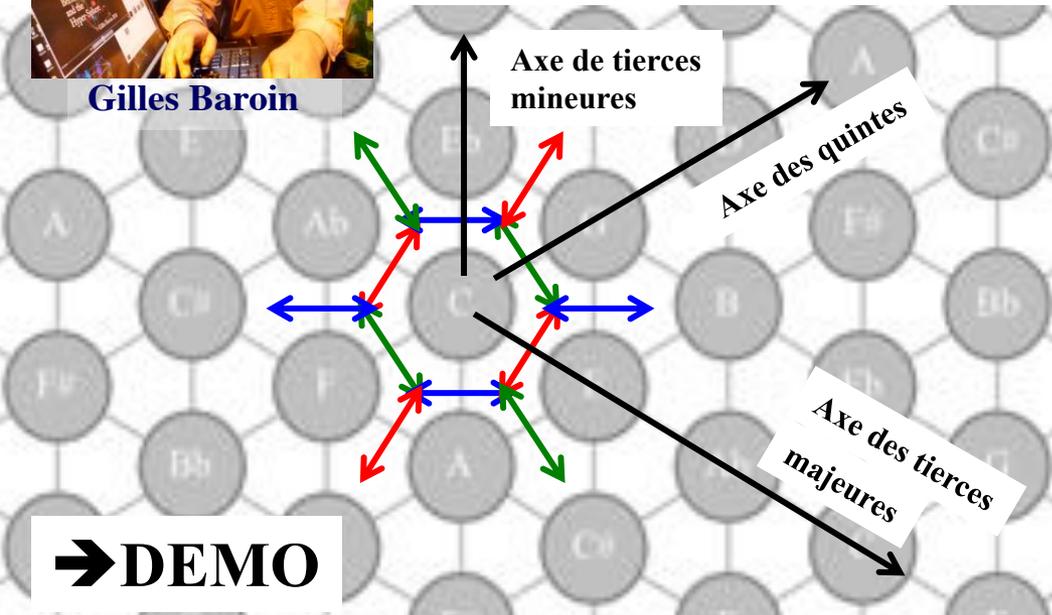
Gilles Baroin



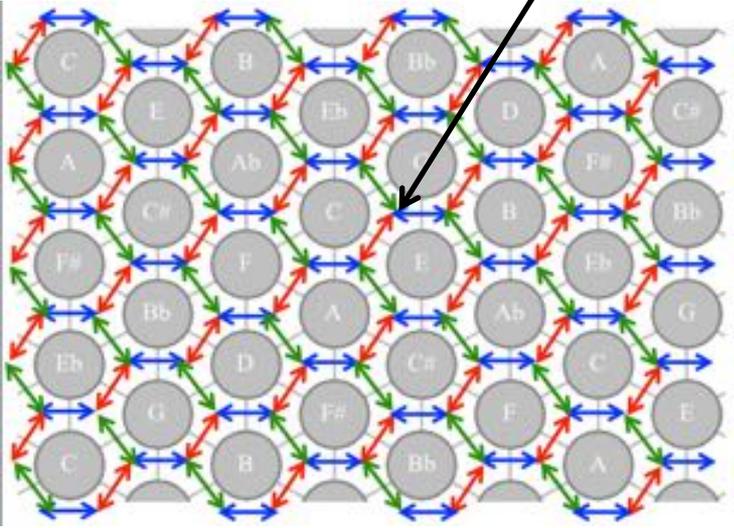
Le Tonnetz (ou nid musical d'abeilles)



Gilles Baroin



→ DEMO





Two Dimensions

Traditional Chordal Space

© Gilles Baroin 2011

➔ <https://www.youtube.com/user/MathMusic4D>

Harmonic Progressions

In Paolo Conte

Sotto le Stelle del Jazz



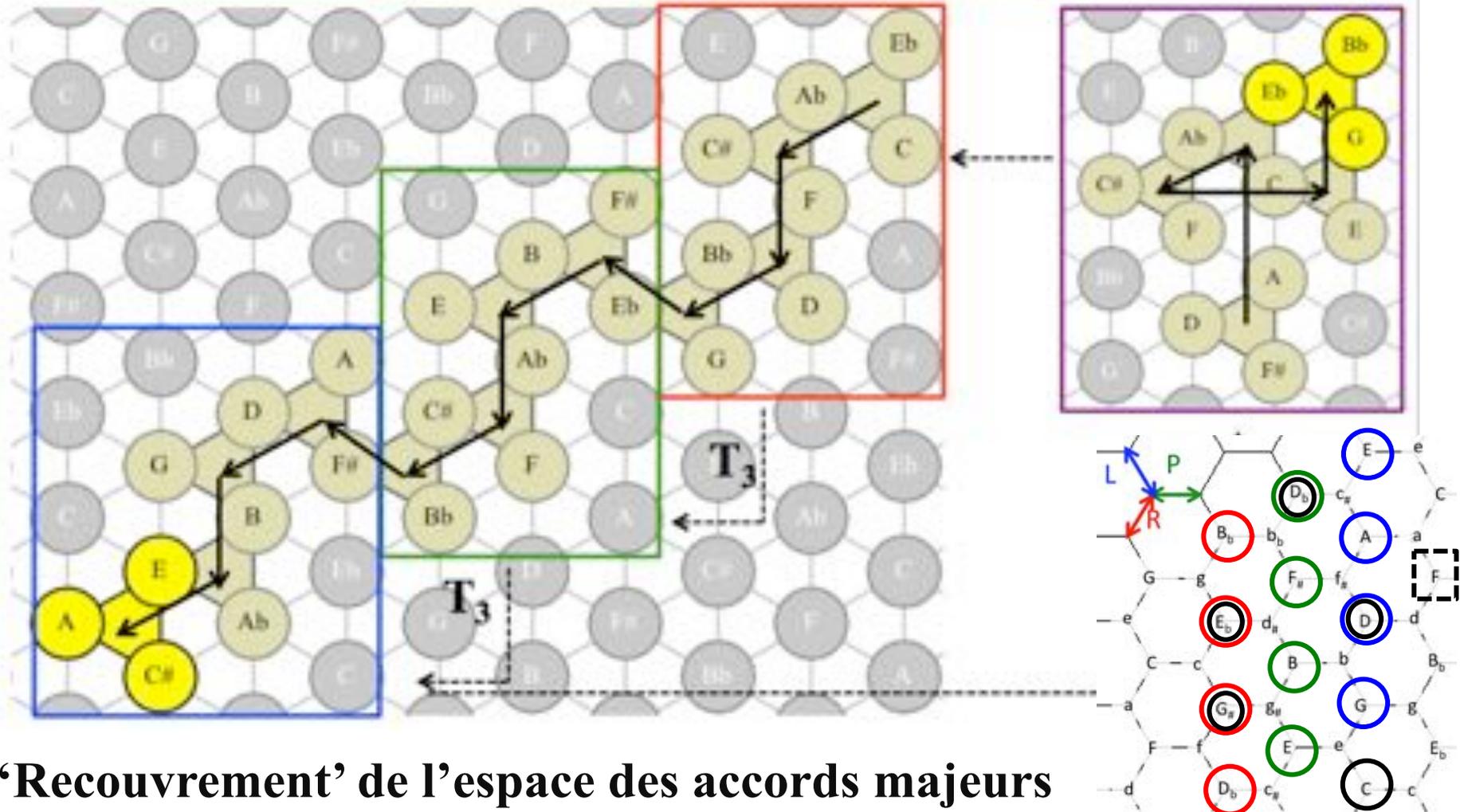
Supervision Moreno Andreatta
Modelisation Gilles Baroin 2016

➔ <https://www.youtube.com/user/MathMusic4D>



Symétries dans *Madeleine* de Paolo Conte

La_b Re_b Si_b Mi_b Si Mi Re_b Fa_# Re Sol Mi La Re La_b Re_b Do Mi_b

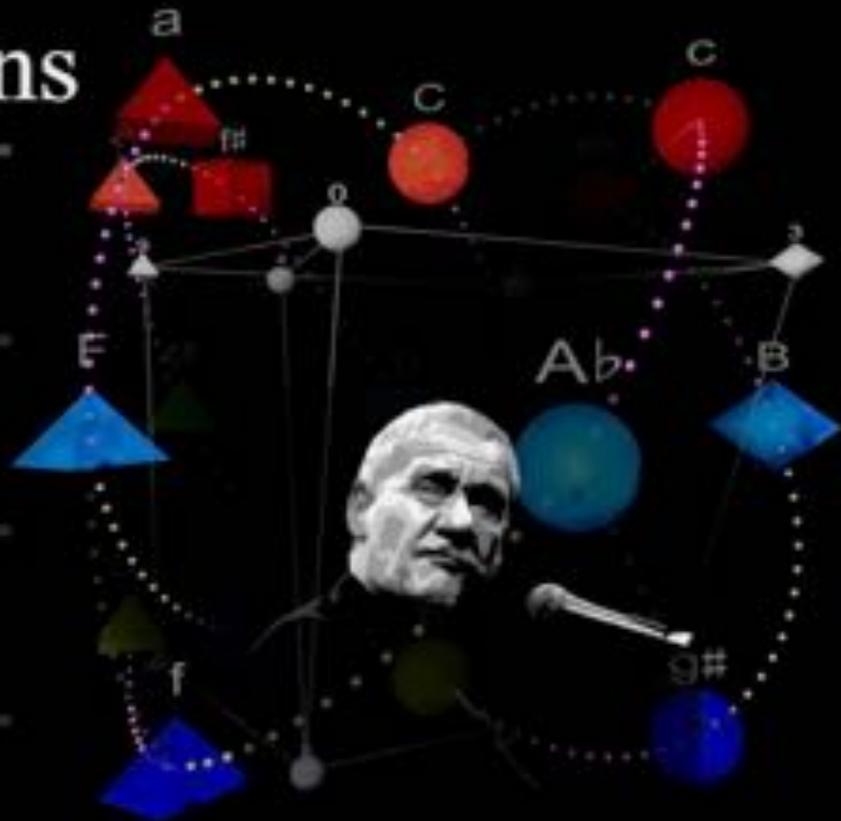


‘Recouvrement’ de l’espace des accords majeurs

Harmonic Progressions

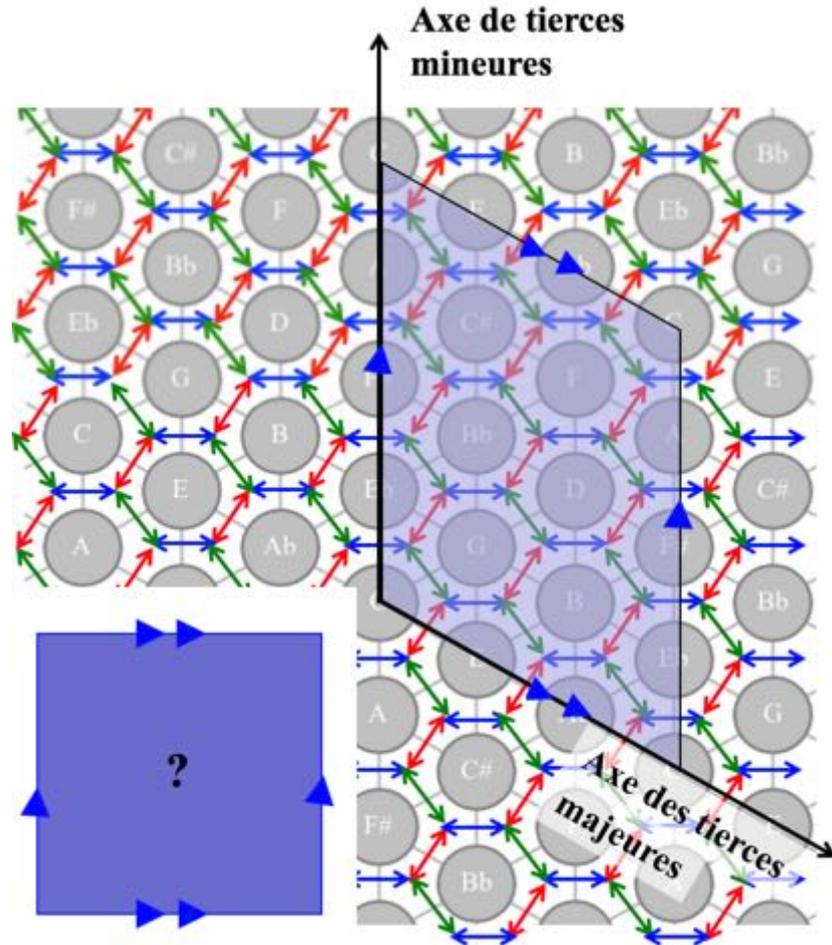
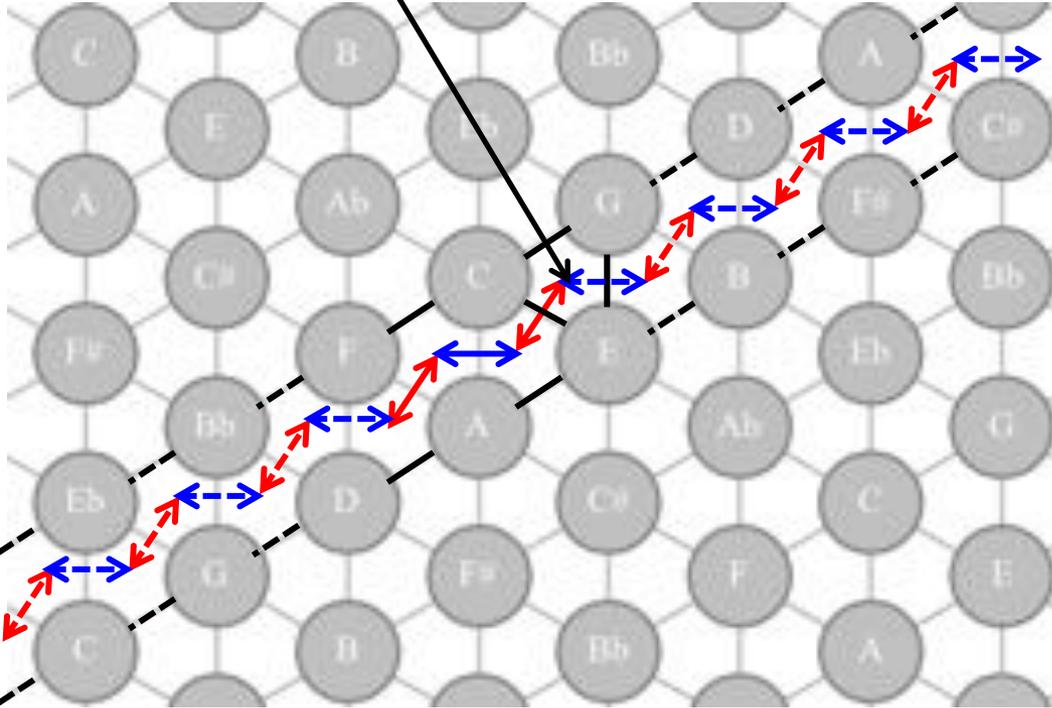
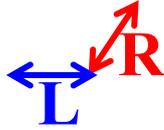
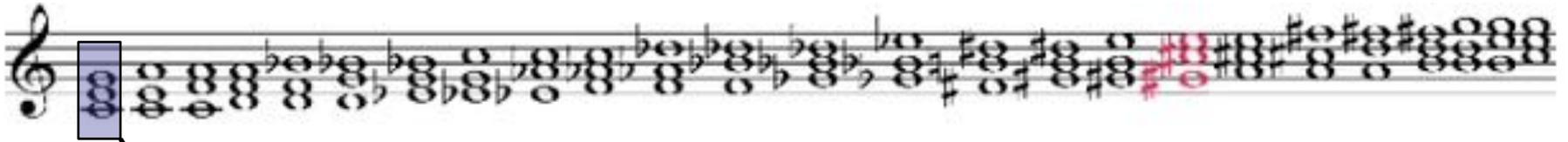
In Paolo Conte

Madeleine

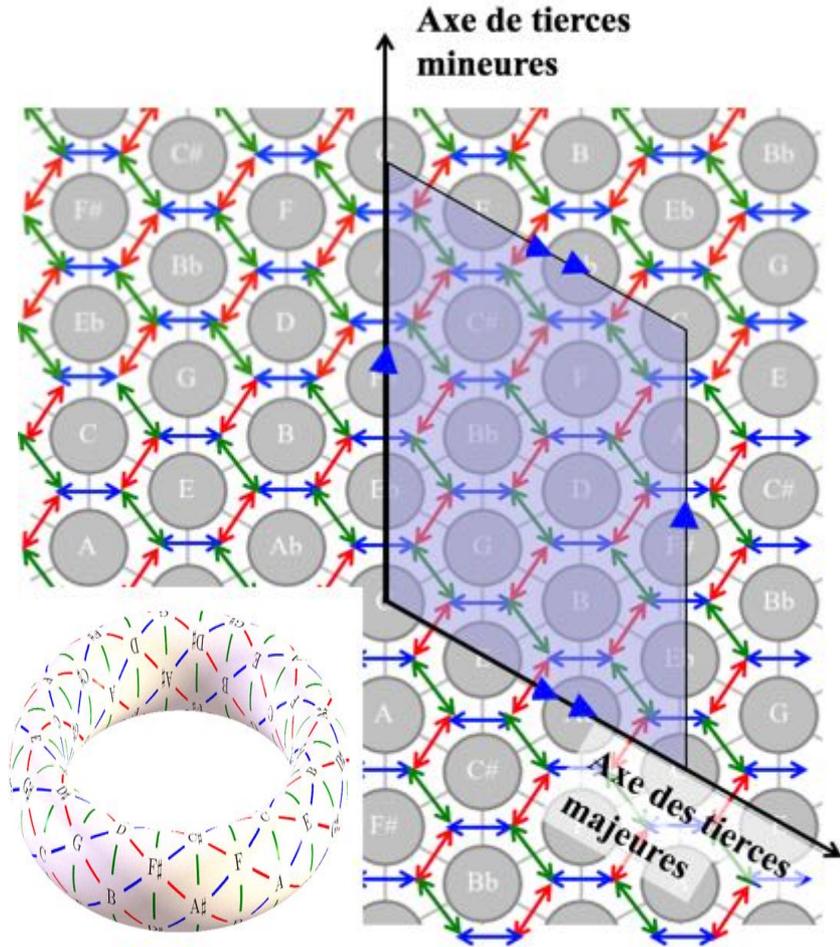
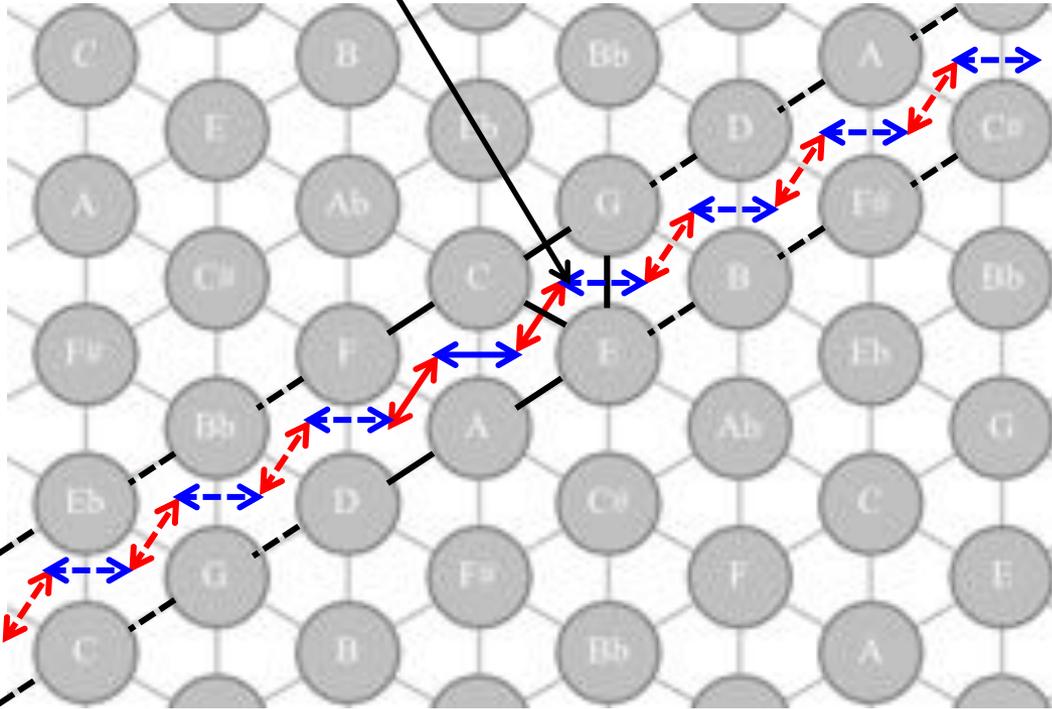
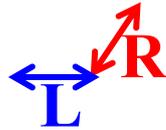
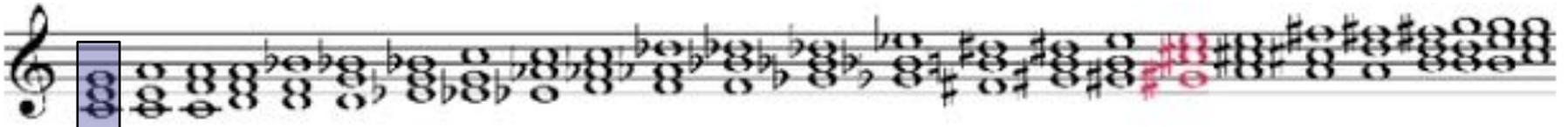


Supervision Moreno Andreatta
Modelisation Gilles Baroin 2016

Progressions harmoniques comme trajectoires spatiales



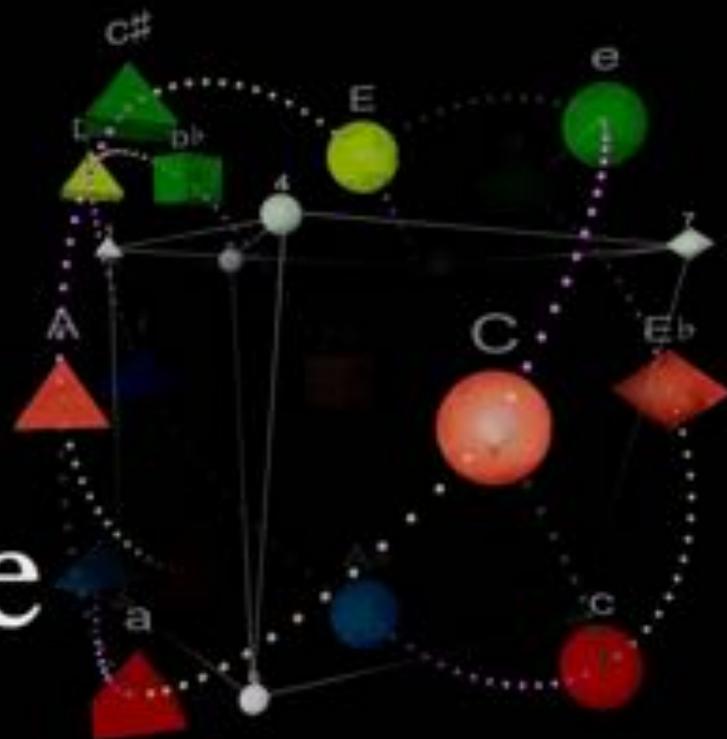
Progressions harmoniques comme trajectoires spatiales



→ Source : wikimedia.org

Beethoven and the Hypersphere

(and the Tonnetz)



Gilles Baroin 2016
www.MatheMusic.net

➔ <https://www.youtube.com/user/MatheMusic4D>

Beethoven de droite à gauche...

Le Blé en Herbe

(Polo/Moreno/Dieu)

Plonger comme un enfant, cheveux au vent

Sous l'océan du blé en herbe

Marée d'épis couleur d'amande

Qui tendent à caresser le ciel

Algues tendres de mille plages

Frôlant le ventre des nuages

Cheveux de pluie, dos de poissons

Qui frissonnent à l'unisson

Suivre le bord des continents

Dans l'océan du blé en herbe

Pêcher le corail du pavot

Dans le sang des coquelicots

Croiser matin dans l'herbe folle

Deux tourterelles qui s'envolent

Suivre les jeux des hirondelles

Sur le paysage éternel

Nager comme un enfant, cheveux au vent

Sous l'océan

Du blé en herbe

Marée de fruits au goût amer

Acide et salée comme la mer

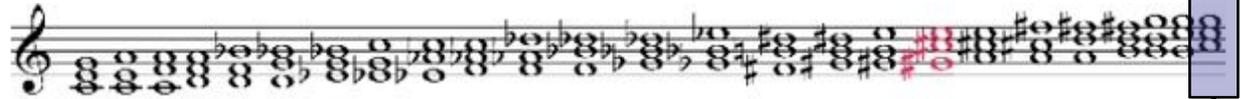
Vers l'îlot d'un petit village

Vers un château d'eau sur la plage

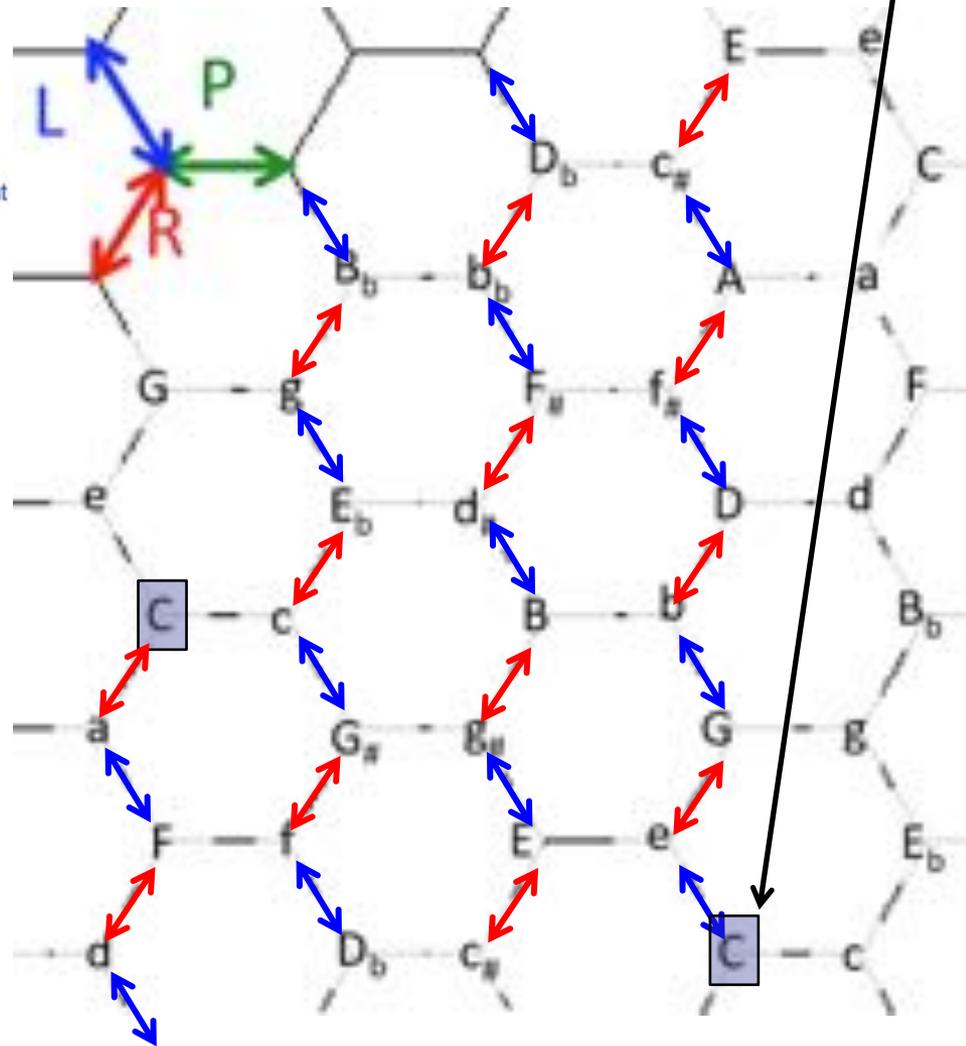
Quand tout s'éteint avant l'orage

Quand se lève le vent du large

Sur le blé vert



← time





CABARET HAMILTONIEN

FABRICE QUÉDY
Formalises dans la musique savante

MORENO ANDREATTA
Mentorises apprivoisés à la musique

POLO PIERRE LAMY
Écriture appliquée aux formes musicales

Alexis - Voix, guitare, écriture
Augustin - Voix, claviers, écriture
Eliott - Voix, guitare, écriture
Emilien - Voix, harmonica, écriture
Sélim - Voix, alto, écriture
Thomas - Voix, claviers, écriture

Écrire sous la contrainte...
TACHER DU PAPIER SOUS
L'OBLIGATION DE FAIRE
QUELQUE CHOSE...

SALIR DU BOIS CONDITIONNÉ
AVEC LE DEVOIR MORAL DE
TRANSFORMER UN OBJET
INDEFINI...

SAMEDI 27 FÉVRIER 2016 à 11h
AMPHI PARIS SCIENCE ET LETTRES
22 rue de GUGUENOT
75005 Paris

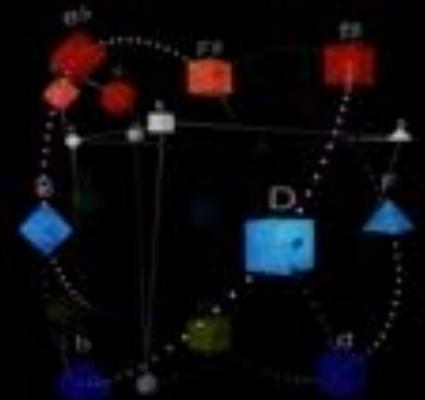
ENTRÉE LIBRE



Aprile

Hamiltonian Song

Mathemusical
2D & 4D Visualizations



Composition, Performance: Moreno Andreatta

Hyperspheres & Animations: Gilles Baroin

Spinnen-Tonnetz: Hugò Seress & G.B

Lyrics by Gabriele D'Annunzio

www.MatheMusic.net



G. D'Annunzio
(1863-1938)

➔ <https://www.youtube.com/user/MatheMusic4D>

La sera non è più la tua canzone : chanson hamiltonienne ‘redondante’

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.

*Le soir n’est plus ta chanson,
c’est ce rochet d’ombre transpercé
par les lumières et les voix sans fin,
la paix d’une chose déjà pensée.*

*Ah, cette lumière vive et claire vient
uniquement de toi, tu es si proche
du vrai d’une chose connue,
tu as pour nom une parole qui est passée
dans l’intimité du cœur où elle s’est
perdue .*

*Tombé est plus qu’un signe de la vie,
tu te reposes, du voyage tu es revenue
à l’intérieur de toi même, tu es
descendue dans cette
pure substance qui est si tienne,
si éloignée
dans le silence de l’être, achevée.*

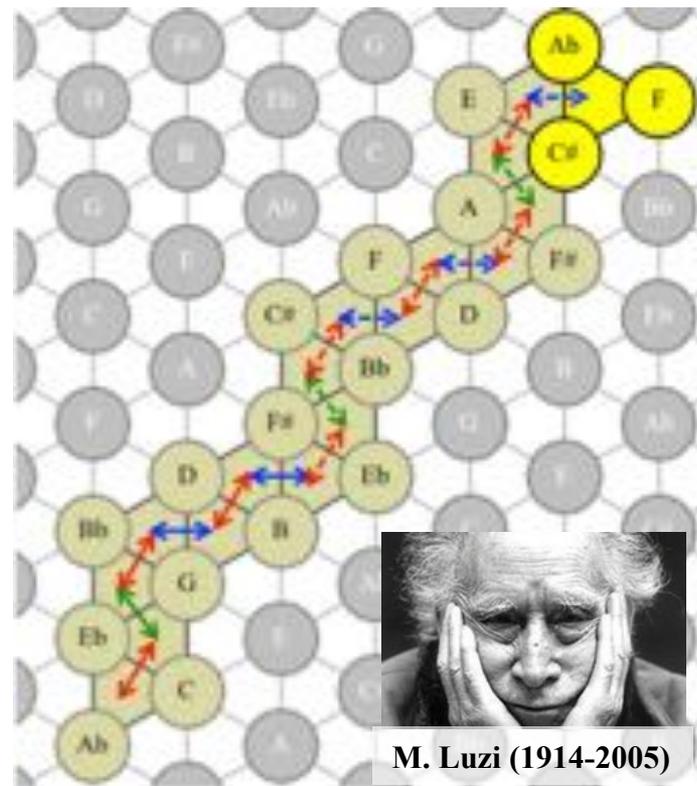
*L’air se tait et le temps derrière toi
se lève tel une montagne aride
où plane ton esprit et se perd,
un vent rare glisse et stagne.*

(tr. Antonia Soulez, philosophe et poète)

Musique : M. Andreatta
Arrangements et mixage : M. Bergomi &
S. Geravini
(Perfect Music Production)
Mastering : A. Cutolo (Massive Arts
Studio, Milan)



min. 1’19”



M. Luzi (1914-2005)



Luzi



Hamiltonian Song
on
Spinnennetz
2014

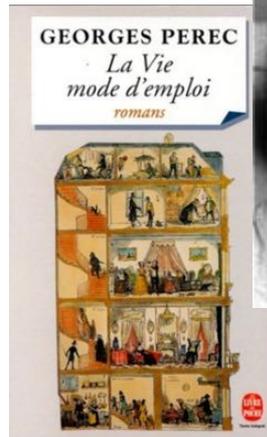
Lyrics by Mario Luzi
Music and Vocals by Moreno Andreatta
Graphics and Animation by Gilles Baroin
SpinnenNetz by Gilles Baroin, Hugò Seress
Original "Chicken Wire" graph by J.Douthett, P.Steinbach

➔ <https://www.youtube.com/user/MathMusic4D>

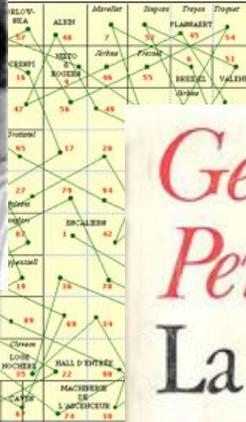
Les contraintes dans l'art : l'OuLiPo (Ouvroir de Littérature Potentielle)



Cent mille milliards de poèmes, 1961



Georges Perec



La vie mode d'emploi,

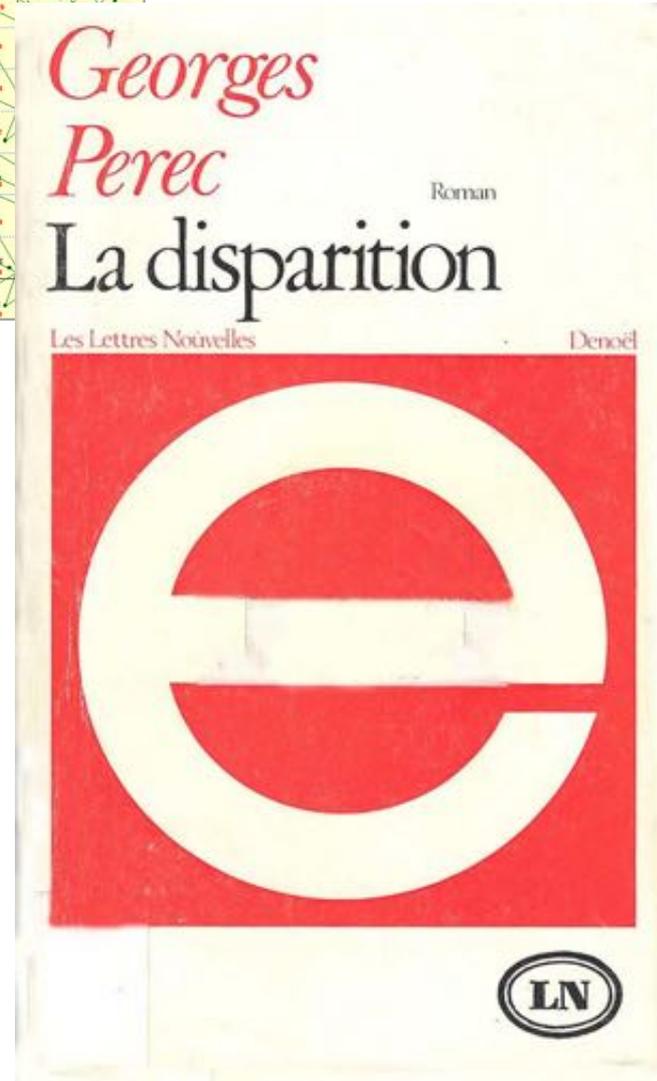


Raymond Queneau



Italo Calvino

Le Château des destins croisés, 1969



De l'OuLiPo à l'OuMuPo (ouvroir de musique potentielle)



L'Oumupo, entre musique et mathématiques

Moreno Andreatta, Martin Granger,
Tom Johnson, Valentin Villenave

*Chercheurs, musiciens, compositeurs,
membres de l'Oumupo*

18^e Salon Culture & Jeux Mathématiques 2017

Mathématiques et Langages

sous le haut parrainage de Stanislas Dehaene

Professeur au Collège de France
Directeur de l'unité de neuro-imagerie cognitive au centre NeuroSpin de Saclay.

Place Saint-Sulpice
PARIS VIF

Samedi 27 mai 10h - 20h
Dimanche 28 mai 10h - 20h
Lundi 29 mai 9h - 19h
Mardi 30 mai 9h - 18h

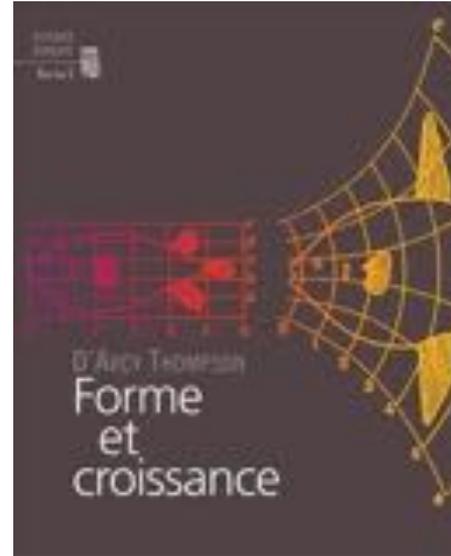
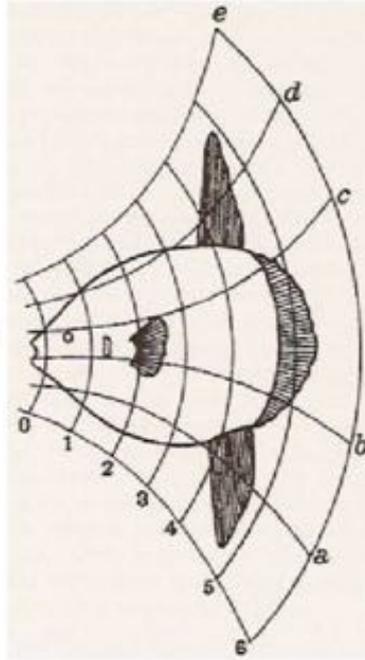
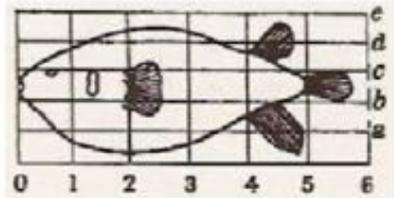


Que-ce que le style en musique ?

The diagram illustrates the transformation of musical style from $T[3,4,7]$ to $T[2,3,7]$. It features two grids of notes on a piano keyboard, with a central diagram of a piano showing the relationship between the two styles. The left grid, labeled $T[3,4,7]$, has an upward arrow labeled '3' and a downward arrow labeled '4'. The right grid, labeled $T[2,3,7]$, has an upward arrow labeled '2' and a downward arrow labeled '3'. A large blue arrow points from the left grid to the right grid. Below each grid is a musical score in treble and bass clefs, with a speaker icon indicating audio playback.

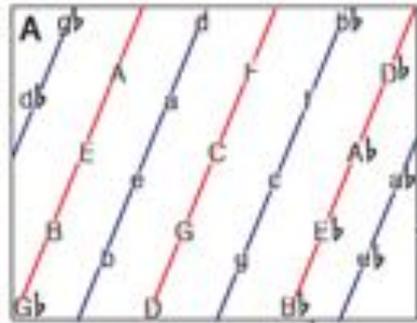


Transformations géométriques et transformations musicales



« [La notion de **transformation**] me vient d'un ouvrage qui a joué pour moi un rôle décisif et que j'ai lu pendant la guerre aux États Unis: *On Growth and Form*, en deux volumes, de D'Arcy Wentworth Thompson, paru pour la première fois en 1917. L'auteur, naturaliste écossais, (...) interprétait comme des transformations les différences visibles entre les espèces ou organes animaux ou végétaux au sein d'un même genre. Ce fut une illumination, d'autant que j'allais vite m'apercevoir que cette façon de voir s'inscrivait dans une longue tradition: derrière Thompson, il y avait la botanique de Goethe, et derrière Goethe, Albert Dürer avec son *Traité de la proportion du corps humain* » (Lévi-Strauss et Eribon, 1988).

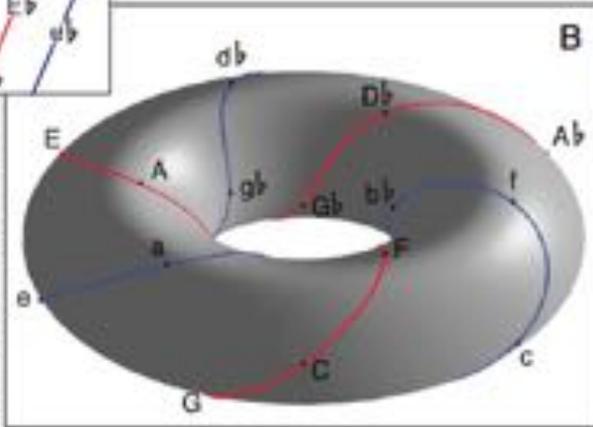
Tonnetz et neurosciences cognitives



PERSPECTIVES: NEUROSCIENCE

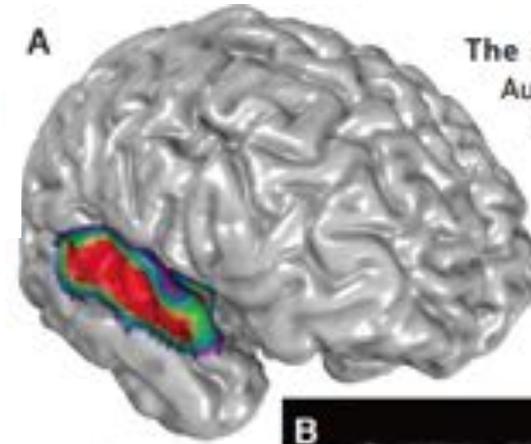
Mental Models and Musical Minds

Robert J. Zatorre and Carol L. Krumhansl

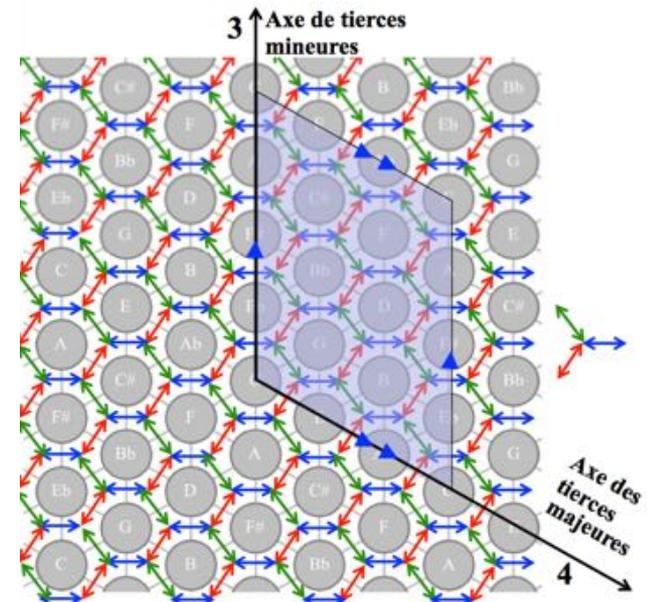
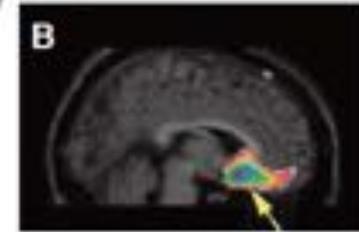


Mental key maps. (A) Unfolded version of the key map, with opposite edges to be considered matched. There is one circle of fifths for major keys (red) and one for minor keys (blue), each

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.

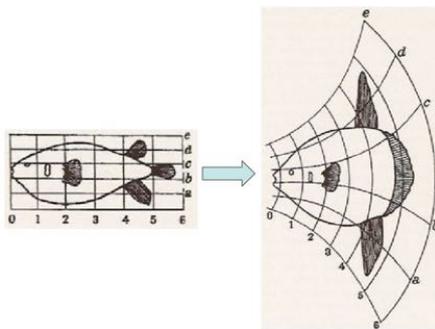


Acotto E. et M. Andreatta (2012),
 « Between Mind and Mathematics.
 Different Kinds of Computational
 Representations of Music », *Mathematics and Social Sciences*, n°
 199, 2012(3), p. 9-26.



Transformations géométriques sur les Beatles

T[3,4,7]



T[2,3,7]

Rotation
(autour du do)



T[3,4,7]

Composer et analyser la musique avec *Hexachord*

The screenshot displays the Hexachord software interface, which is used for composing and analyzing music. The interface is divided into several panels:

- File Viewer:** Shows a 3D visualization of a complex geometric shape, likely a hexachord, rendered in green and blue.
- Complexes:** A grid of circles representing musical complexes. Some are highlighted in yellow, and a path is shown connecting them. A small inset image of a man (Louis Bigo) is visible in the top right of this panel.
- Complexity Graph:** A graph showing the relationships between different complexes, with nodes and connecting lines.
- Chart:** A bar chart titled "bww0281" showing the 2-compactness of various complexes. The y-axis is labeled "2-compactness" and ranges from 0 to 10. The x-axis lists complexes from K(1,1,0) to K(4,4,1). A red bar for K(3,4,5) is significantly higher than the others.
- Control Panel:** Contains various settings and controls, including:
 - Tempo:** A slider set to 20, with "Play" and "Stop" buttons.
 - Complexes:** "Chromatic complexes" set to K(2,3,7) and "Heptatonic complexes" set to CM.
 - Vertical compactness:** "compactness dimension" set to 2 and "complexes dimension" set to 2.
 - Path Transformation:** "Origin complex" and "Destination complex" both set to K(3,4,5).
 - Rotation:** 0, "North translation": 0, "North-east translation": 0.
- Chart:** A bar chart titled "2-compactness : bww0281" showing the 2-compactness of various complexes over time. The y-axis is labeled "Complex compactness" and ranges from 0 to 1. The x-axis is labeled "time" and ranges from 0 to 25,000. The chart shows a series of vertical bars of different colors (green, blue, red) representing different complexes.

Louis Bigo

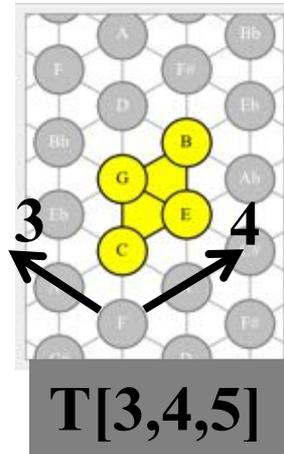
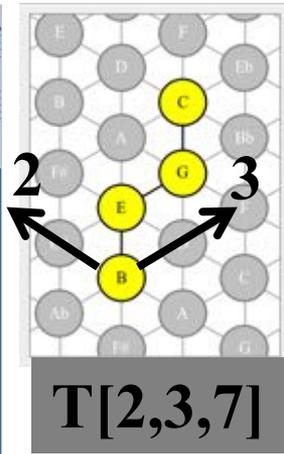
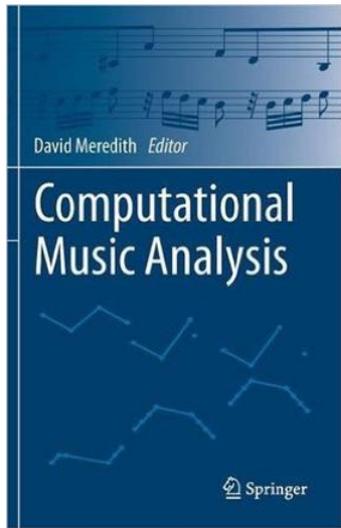
→ <http://www.lacl.fr/~lbigo/hexachord>

Le caractère spatial de la « logique musicale »

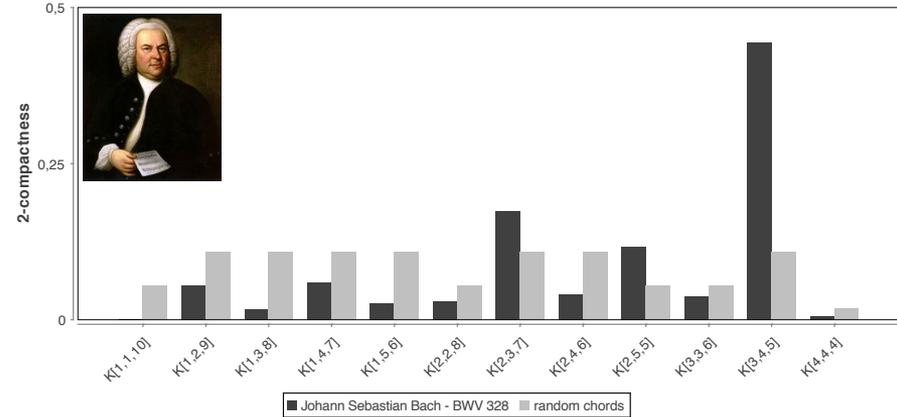
Bigo L., M. Andreatta, « Musical analysis with simplicial chord spaces », in D. Meredith (ed.), *Computational Music Analysis*, Springer, 2015



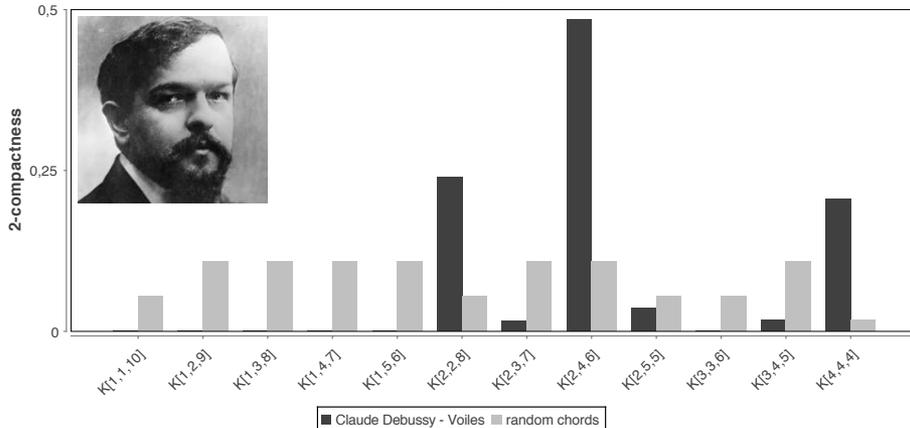
Louis Bigo



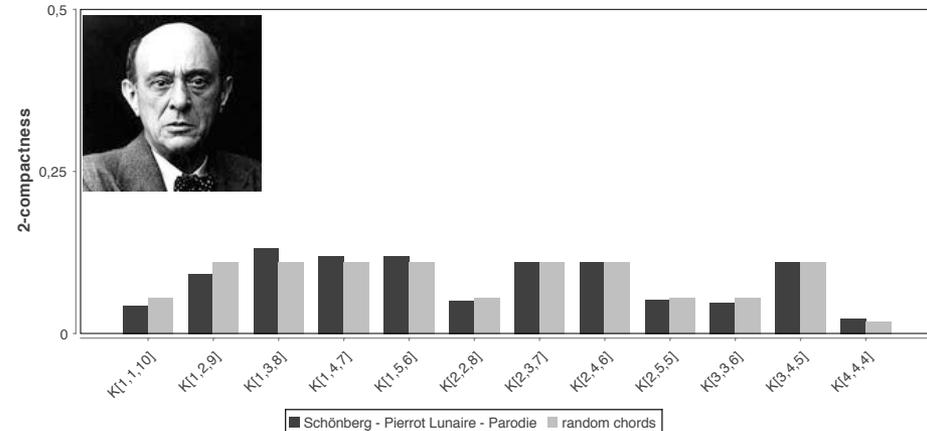
Johann Sebastian Bach - BWV 328



Claude Debussy - Voiles



Schönberg - Pierrot Lunaire - Parodie



Merci de votre attention!

