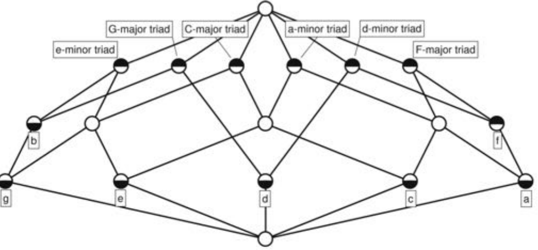
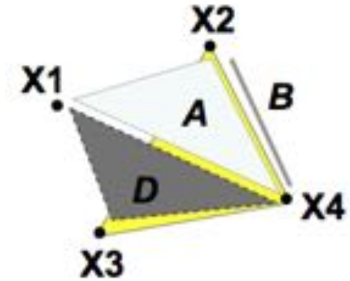
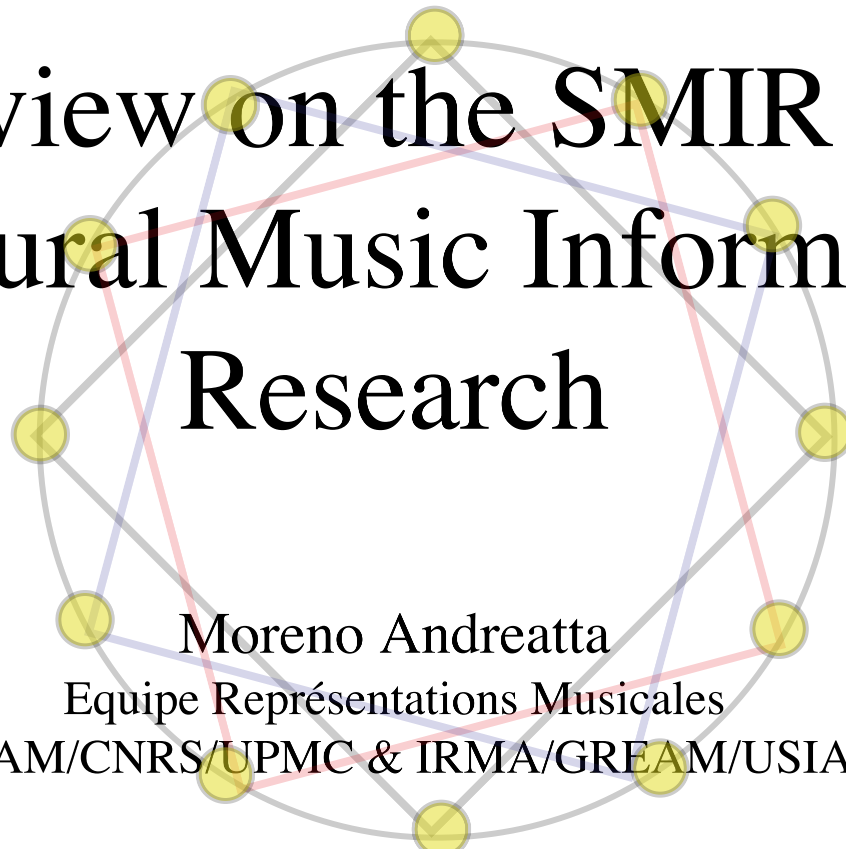




An overview on the SMIR Project: Structural Music Information Research



Moreno Andreatta
Equipe Représentations Musicales
IRCAM/CNRS/UPMC & IRMA/GREAM/USIAS

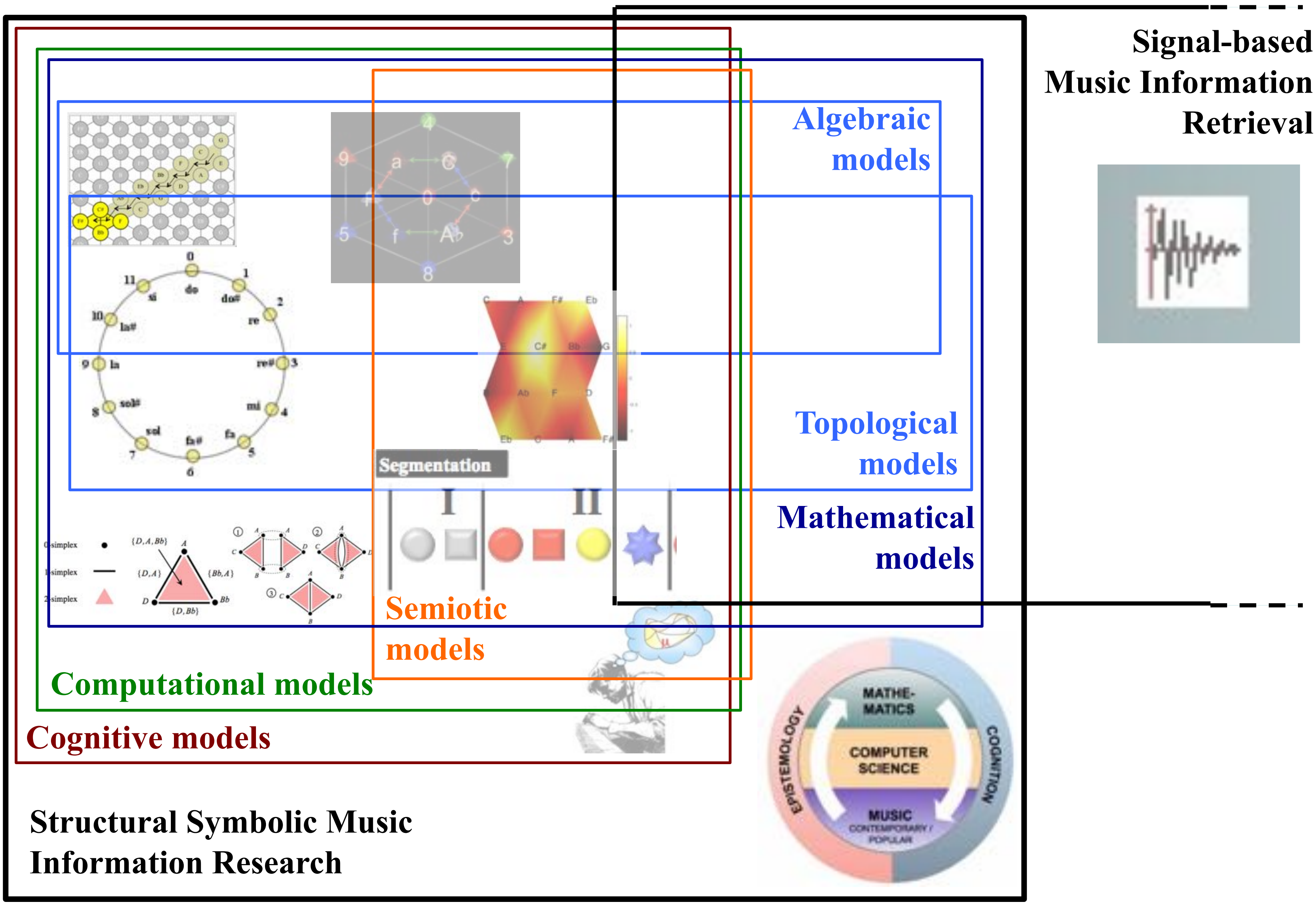
http://repmus.ircam.fr/moreno/smir

Programme

- **Mardi 10 octobre**
- 9h30-10h30 accueil avec présentation du projet SMIR (Moreno)
- 10h30-11h45 techniques d'homologie persistante pour l'analyse musicale (Davide Stefani et Pierre Guillot)
- Discussion
- Après-midi : rencontre avec Sonia Cannas (Tonnetz 3D et cycles hamiltoniens) et Pierre Relano (treillis et morphologie mathématique en analyse musicale)

- **Mercredi 11 octobre matin**
- 9h30-11h00 Rencontre avec Jose-Louis Besada (post-doc GREAM/IRMA) et Nathalie Herold (post-doc GREAM) - conceptual blending et processus compositionnels (aspects épistémologiques et cognitives), systèmes complexes et musique, …
- 11h00-12h00 Théorie des catégories en analyse musicale (K-nets et théories transformationnelles) - Moreno
- Petite Discussion

The SMIR Project: Structural Music Information Research



The 3+1 main research axes

- **Generalized Tonnetze, Persistent Homology and automatic classification of musical styles**
  - **Sonia Cannas (PhD candidate)**
  - **Davide Stefani (PhD candidate)**
  - **Pierre Guillot (Researcher, IRMA)**
- **Mathematical Morphology, Formal Concept Analysis and computational musicology**
  - **Pierre Relaño (former Master student & composer)**
  - **Isabelle Bloch (Télécom ParisTech)**
  - **Jamal Atif (University of Dauphine)**
- **Category theory and transformational (computer-aided) music analysis**
  - **Andrée Ehresmann (mathematician)**
  - **Alexandre Popoff (mathematical music theorist)**
  - **Tom Fiore (University of Michigan, editor or JMM)**
  - **Thomas Noll (ESMuC, Barcelona)**
- **Epistemology and cognitive musicology**
  - **José-Luis Besada (post-doc GREAM/IRMA)**
  - **Nathalie Herold (post-doc GREAM)**

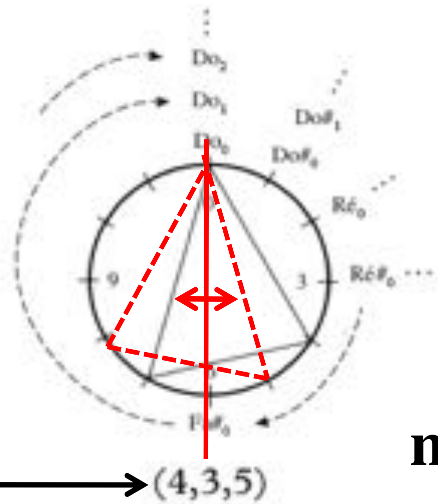
The *Tonnetz* as a simplicial complex

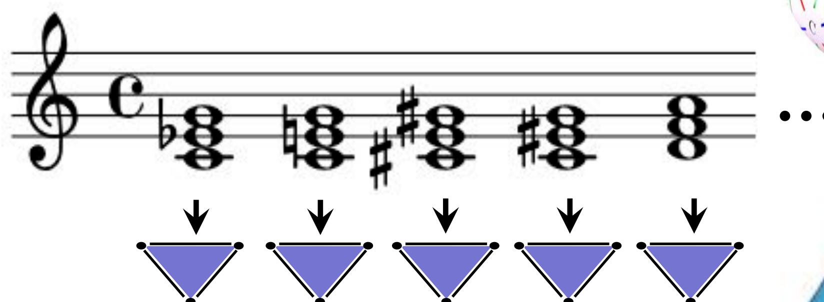
L. Bigo, *Représentation symboliques musicales et calcul spatial*, PhD, Ircam / LACL, 2013

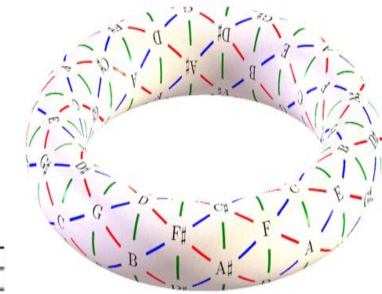
Louis Bigo

- Assembling chords related by some equivalence relation
  - Equivalence up to transposition/inversion:

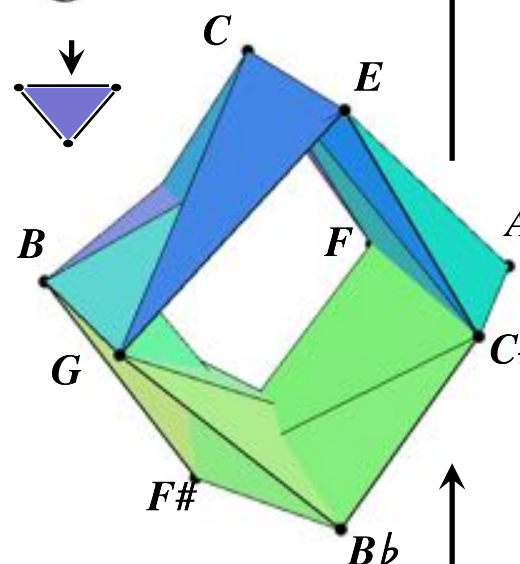
Intervallic structure

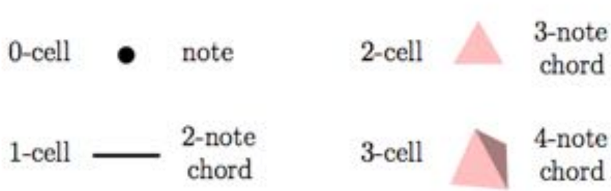


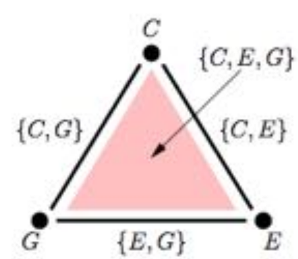


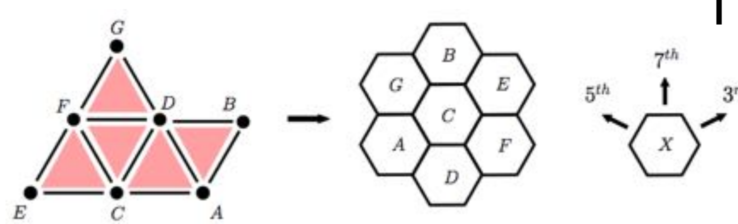


major/minor triads

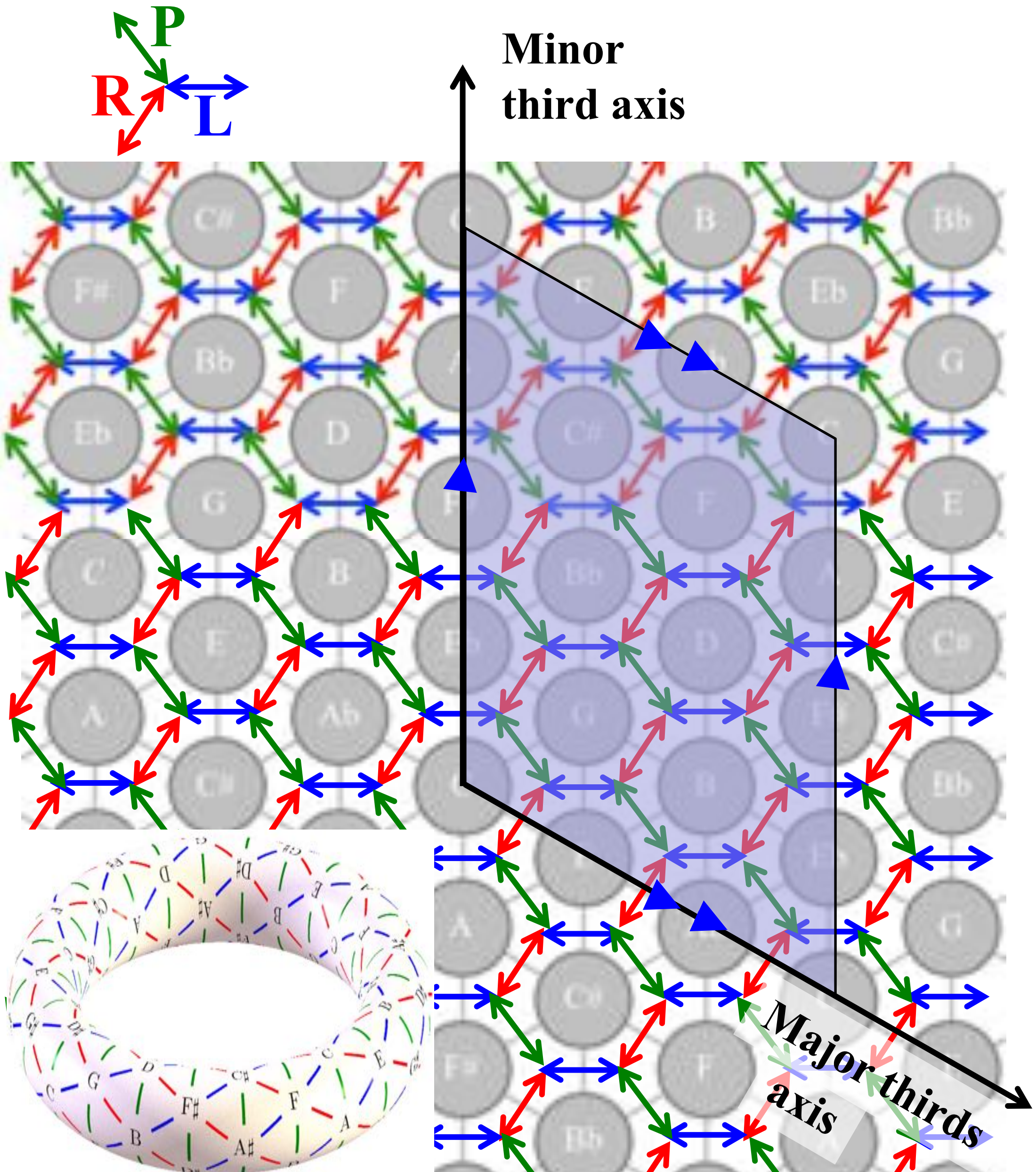


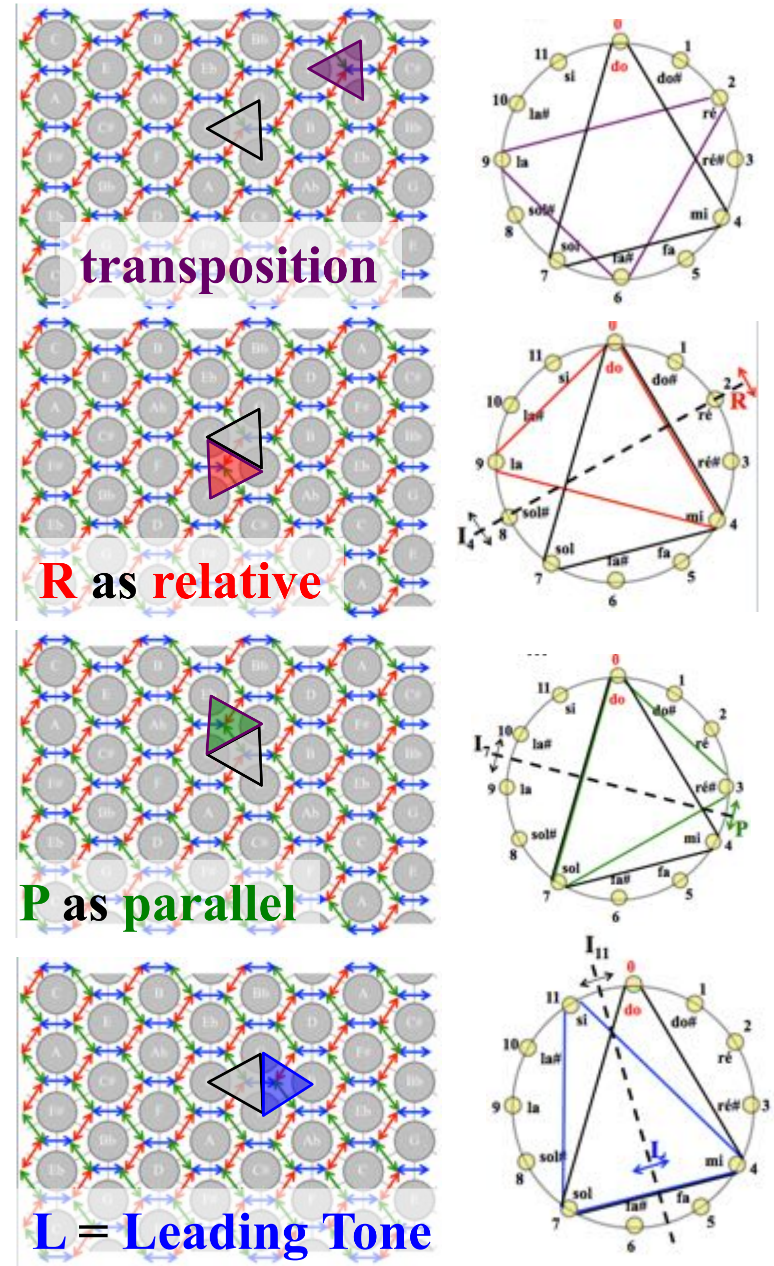






The *Tonnetz*, its symmetries and its topological structure





➔ Source: Wikipedia

The collection of 28 « redundant » Hamiltonian Cycles

1. 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
2. C-Cm-Ab-Fm-C#-C#m-A-Am-F-Dm-Bb-Bbm-F#-F#m-D-Bm-G-Gm-Eb-Ebm-B-Abm-E-Em--PLRLPL
3. 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
4. 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
5. 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
6. C-Cm-Eb-Gm-Bb-Bbm-C#-C#m-E-Em-G-Bm-D-Dm-F-Fm-Ab-Abm-B-Ebm-F#-F#m-A-Am--PRLRPRPR
7. 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
8. 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
9. 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
10. 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
11. C-Em-G-Gm-Bb-Bbm-C#-C#m-E-Abm-B-Bm-D-Dm-F-Fm-Ab-Cm-Eb-Ebm-F#-F#m-A-Am--LRPRPRPR
12. C-Em-G-Gm-Bb-Bbm-C#-Fm-Ab-Cm-Eb-Ebm-F#-F#m-A-C#m-E-Abm-B-Bm-D-Dm-F-Am--LRPRPRLR
13. C-Em-G-Gm-Bb-Dm-F-Fm-Ab-Cm-Eb-Ebm-F#-Bbm-C#-C#m-E-Abm-B-Bm-D-F#m-A-Am--LRPR
14. C-Em-G-Bm-B-Ebm-Eb-Gm-Bb-Dm-D-F#m-F#-Bbm-C#-Fm-F-Am-A-C#m-E-Abm-Ab-Cm--LRLPLP
15. C-Em-G-Bm-D-Dm-F-Fm-Ab-Cm-Eb-Gm-Bb-Bbm-C#-C#m-E-Abm-B-Ebm-F#-F#m-A-Am--LRLRPRPR
16. C-Em-G-Bm-D-F#m-A-C#m-E-Abm-B-Ebm-F#-Bbm-C#-Fm-Ab-Cm-Eb-Gm-Bb-Dm-F-Am--LR
17. C-Am-A-F#m-F#-Ebm-Eb-Cm-Ab-Fm-F-Dm-D-Bm-B-Abm-E-C#m-C#-Bbm-Bb-Gm-G-Em--RPRPRPRL
18. C-Am-A-F#m-F#-Ebm-B-Abm-Ab-Fm-F-Dm-D-Bm-G-Em-E-C#m-C#-Bbm-Bb-Gm-Eb-Cm--RPRPRLRP
19. C-Am-A-F#m-F#-Ebm-B-Abm-E-C#m-C#-Bbm-Bb-Gm-Eb-Cm-Ab-Fm-F-Dm-D-Bm-G-Em--RPRPRLRL
20. C-Am-A-F#m-D-Bm-B-Abm-Ab-Fm-F-Dm-Bb-Gm-G-Em-E-C#m-C#-Bbm-F#-Ebm-Eb-Cm--RPRLRPRP
21. C-Am-A-F#m-D-Bm-B-Abm-E-C#m-C#-Bbm-F#-Ebm-Eb-Cm-Ab-Fm-F-Dm-Bb-Gm-G-Em--RPRL
22. C-Am-A-F#m-D-Bm-G-Em-E-C#m-C#-Bbm-F#-Ebm-B-Abm-Ab-Fm-F-Dm-Bb-Gm-Eb-Cm--RPRLRLRP
23. C-Am-F-Fm-C#-C#m-A-F#m-D-Dm-Bb-Bbm-F#-Ebm-B-Bm-G-Gm-Eb-Cm-Ab-Abm-E-Em--RLPLPL
24. 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--RLRPRPRP
25. 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
26. C-Am-F-Dm-D-Bm-G-Em-E-C#m-A-F#m-F#-Ebm-B-Abm-Ab-Fm-C#-Bbm-Bb-Gm-Eb-Cm--RLRP
27. C-Am-F-Dm-Bb-Gm-G-Em-E-C#m-A-F#m-D-Bm-B-Abm-Ab-Fm-C#-Bbm-F#-Ebm-Eb-Cm--RLRLRPRP
28. C-Am-F-Dm-Bb-Gm-Eb-Cm-Ab-Fm-C#-Bbm-F#-Ebm-B-Abm-E-C#m-A-F#m-D-Bm-G-Em--RL

Hamiltonian Cycles and the « thirds circle »

1. 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
2. C-Cm-Ab-Fm-C#-C#m-A-Am-F-Dm-Bb-Bbm-F#-F#m-D-Bm-G-Gm-Eb-Ebm-B-Abm-E-Em--PLRLPL
3. 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
4. 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
5. 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
6. C-Cm-Eb-Gm-Bb-Bbm-C#-C#m-E-Em-G-Bm-D-Dm-F-Fm-Ab-Abm-B-Ebm-F#-F#m-A-Am--PRLRPRPR
7. 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
8. 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
9. 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
10. 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
11. C-Em-G-Gm-Bb-Bbm-C#-C#m-E-Abm-B-Bm-D-Dm-F-Fm-Ab-Cm-Eb-Ebm-F#-F#m-A-Am--LRPRPRPR
12. C-Em-G-Gm-Bb-Bbm-C#-Fm-Ab-Cm-Eb-Ebm-F#-F#m-A-C#m-E-Abm-B-Bm-D-Dm-F-Am--LRPRPRLR
13. C-Em-G-Gm-Bb-Dm-F-Fm-Ab-Cm-Eb-Ebm-F#-Bbm-C#-C#m-E-Abm-B-Bm-D-F#m-A-Am--LRPR
14. C-Em-G-Bm-B-Ebm-Eb-Gm-Bb-Dm-D-F#m-F#-Bbm-C#-Fm-F-Am-A-C#m-E-Abm-Ab-Cm--LRLPLP
15. C-Em-G-Bm-D-Dm-F-Fm-Ab-Cm-Eb-Gm-Bb-Bbm-C#-C#m-E-Abm-B-Ebm-F#-F#m-A-Am--LRLRPRPR
16. C-Em-G-Bm-D-F#m-A-C#m-E-Abm-B-Ebm-F#-Bbm-C#-Fm-Ab-Cm-Eb-Gm-Bb-Dm-F-Am--LR
17. C-Am-A-F#m-F#-Ebm-Eb-Cm-Ab-Fm-F-Dm-D-Bm-B-Abm-E-C#m-C#-Bbm-Bb-Gm-G-Em--RPRPRPRL
18. C-Am-A-F#m-F#-Ebm-B-Abm-Ab-Fm-F-Dm-D-Bm-G-Em-E-C#m-C#-Bbm-Bb-Gm-Eb-Cm--RPRPRLRP
19. C-Am-A-F#m-F#-Ebm-B-Abm-E-C#m-C#-Bbm-Bb-Gm-Eb-Cm-Ab-Fm-F-Dm-D-Bm-G-Em--RPRPRLRL
20. C-Am-A-F#m-D-Bm-B-Abm-Ab-Fm-F-Dm-Bb-Gm-G-Em-E-C#m-C#-Bbm-F#-Ebm-Eb-Cm--RPRLRPRP
21. C-Am-A-F#m-D-Bm-B-Abm-E-C#m-C#-Bbm-F#-Ebm-Eb-Cm-Ab-Fm-F-Dm-Bb-Gm-G-Em--RPRL
22. C-Am-A-F#m-D-Bm-G-Em-E-C#m-C#-Bbm-F#-Ebm-B-Abm-Ab-Fm-F-Dm-Bb-Gm-Eb-Cm--RPRLRLRP
23. C-Am-F-Fm-C#-C#m-A-F#m-D-Dm-Bb-Bbm-F#-Ebm-B-Bm-G-Gm-Eb-Cm-Ab-Abm-E-Em--RLPLPL
24. 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--RLRPRPRP
25. 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
26. C-Am-F-Dm-D-Bm-G-Em-E-C#m-A-F#m-F#-Ebm-B-Abm-Ab-Fm-C#-Bbm-Bb-Gm-Eb-Cm--RLRP
27. C-Am-F-Dm-Bb-Gm-G-Em-E-C#m-A-F#m-D-Bm-B-Abm-Ab-Fm-C#-Bbm-F#-Ebm-Eb-Cm--RLRLRPRP
28. C-Am-F-Dm-Bb-Gm-Eb-Cm-Ab-Fm-C#-Bbm-F#-Ebm-B-Abm-E-C#m-A-F#m-D-Bm-G-Em--RL


UNIVERSITÉ DE RENNES 1

UNIVERSITE BRETAGNE LOIRE

THÈSE / UNIVERSITÉ DE RENNES 1
sous le sceau de l'Université Bretagne Loire

pour le grade de
DOCTEUR DE L'UNIVERSITÉ DE RENNES 1
Mention : Informatique
École doctorale MATISSE
présentée par
Corentin Guichaoua
préparée à l'unité de recherche 6074 (IRISA)
Institut de Recherche en Informatique et Systèmes Aléatoires
(Composante universitaire)

Modèles de compression et critères de complexité pour la description et l'inférence de structure musicale

Soutenance prévue à Rennes le 19 septembre 2017
devant le jury composé de :
Moreno ANDREATTA
DR2 CNRS, IRCAM / rapporteur
Myriam DESAINTE-CATHERINE
PR CSI, Bordeaux INP / rapporteur
Matthew DAVIES
Senior Researcher, INESC TEC / examinateur
Mathieu GIRAUD
CR CNRS, CRISTAL / examinateur
François PACHET
Directeur de laboratoire de recherche, Sony CSL Paris / examinateur
Frédéric BIMBOT
DR CNRS, IRISA / directeur de thèse

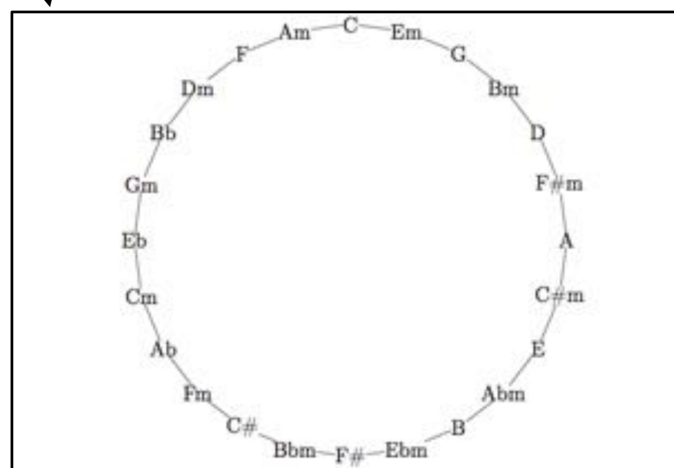
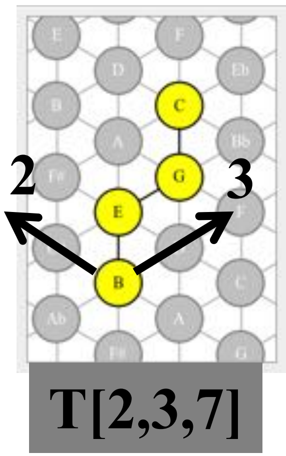
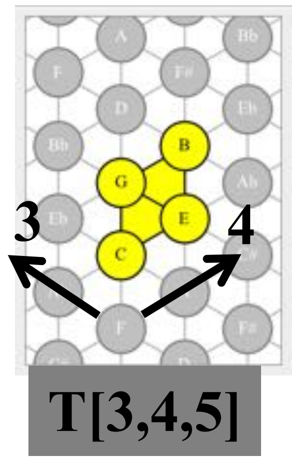
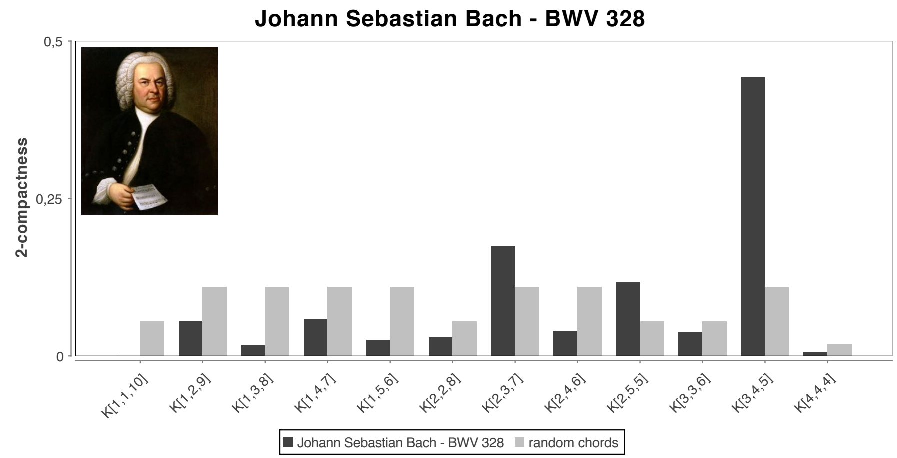


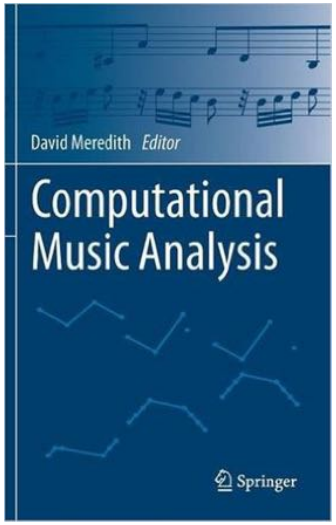
FIGURE 6.15 – Le cercle utilisé pour représenter l'espace des accords

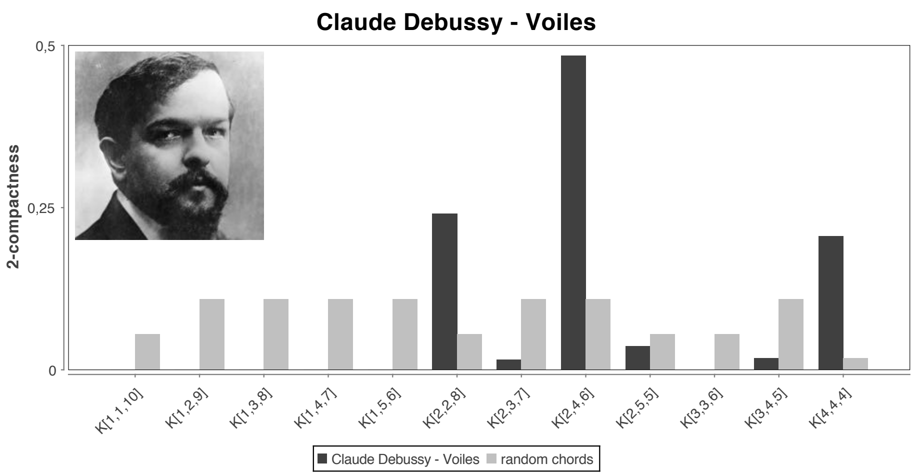
The spatial character of the « musical style »

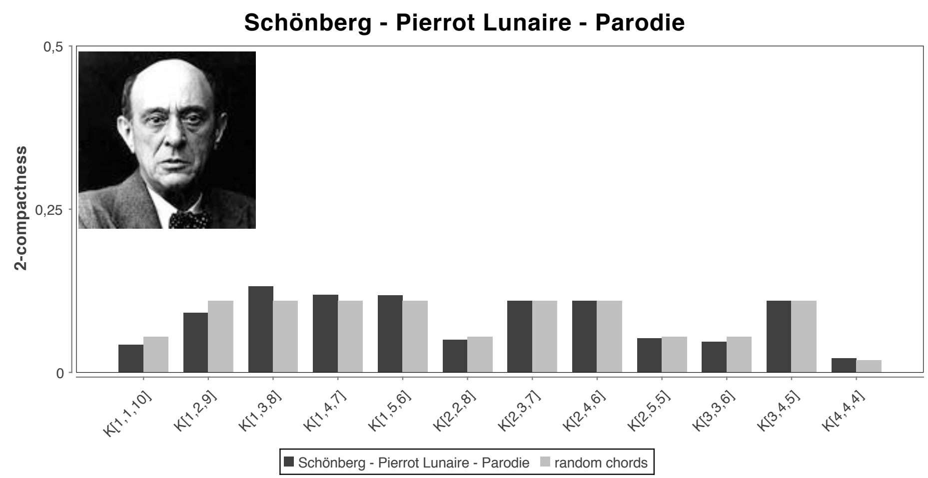






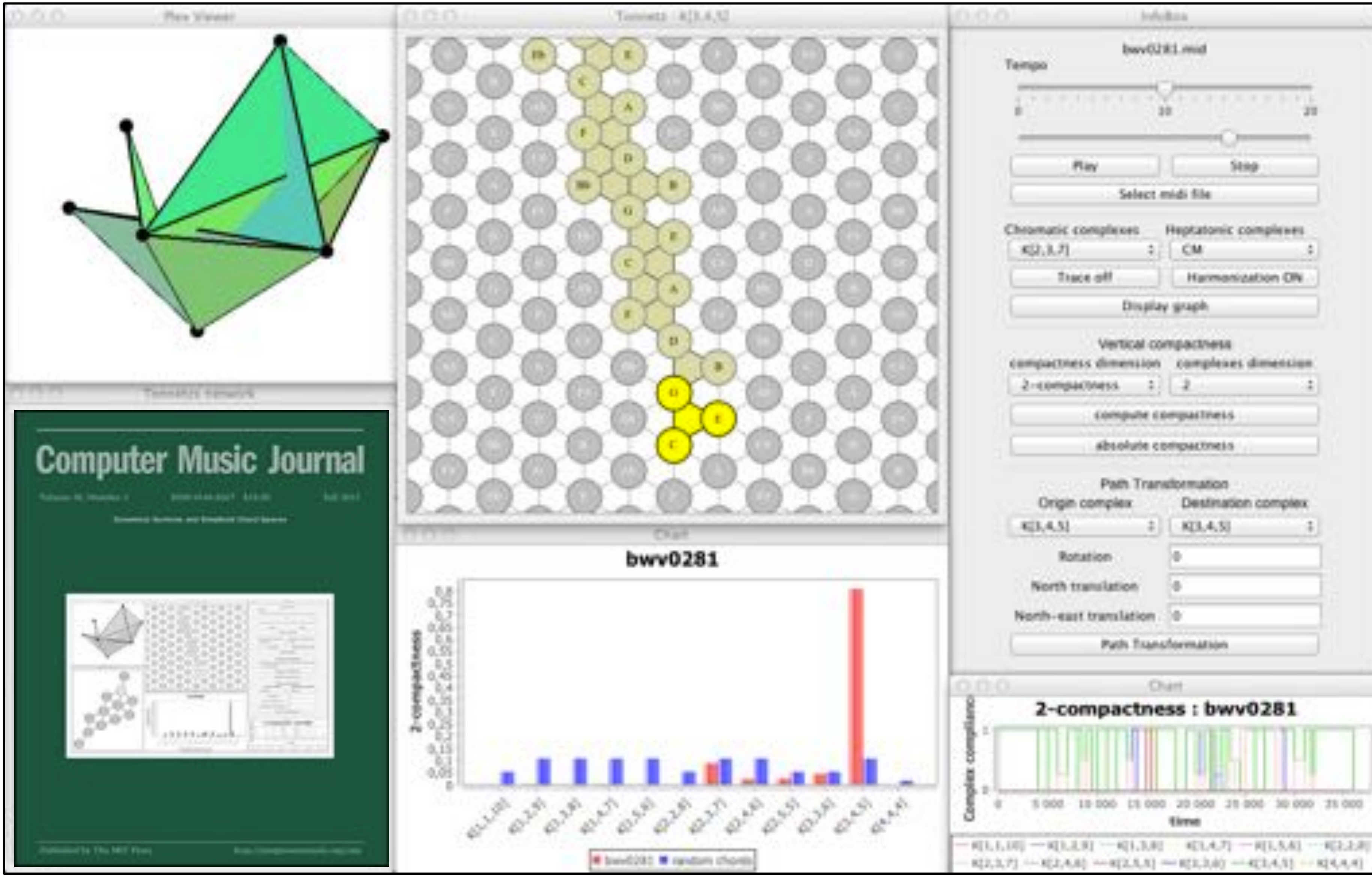






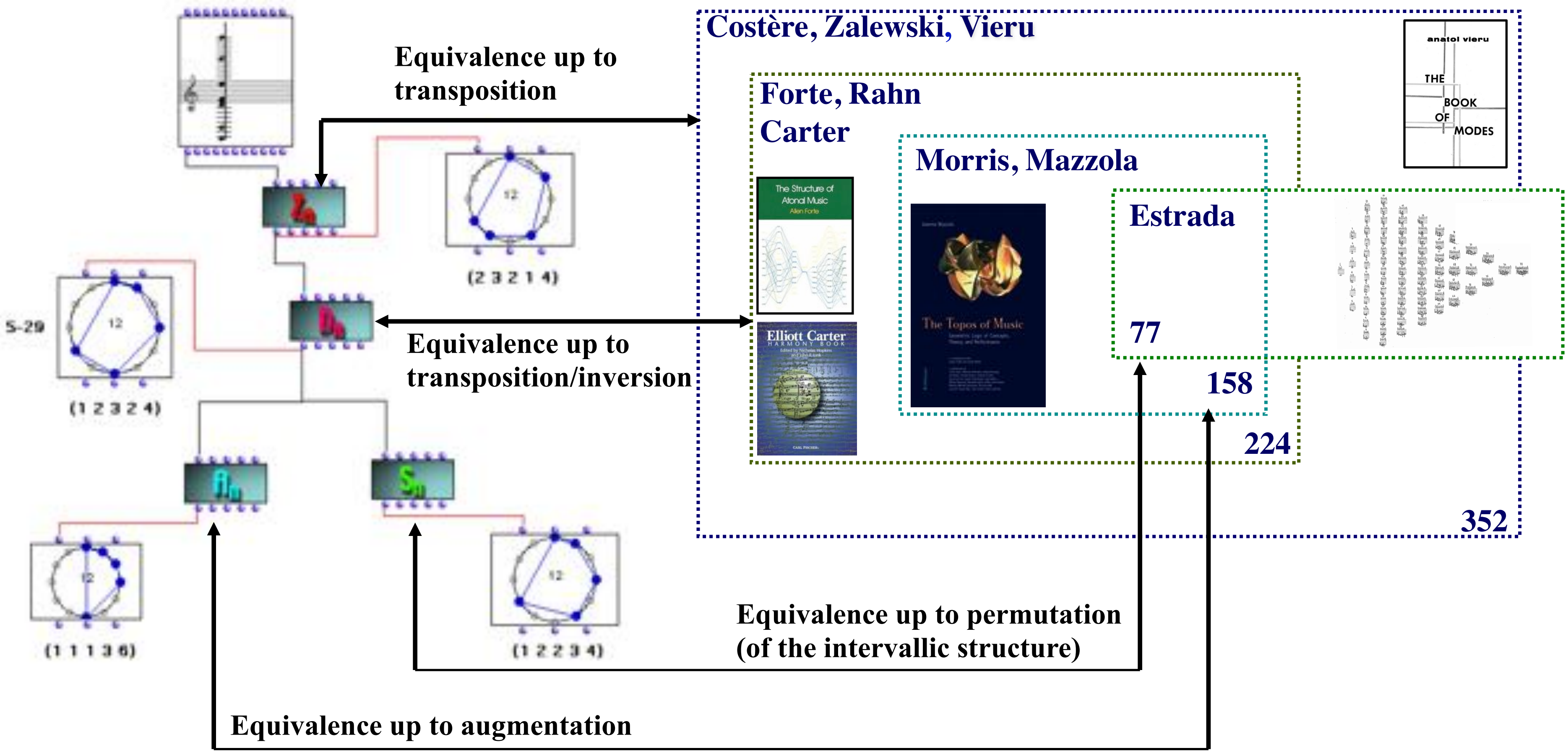
Bigo L., M. Andreatta, « Musical analysis with simplicial chord spaces », in D. Meredith (ed.), *Computational Music Analysis*, Springer, 2016

Spatial music analysis via *Hexachord*



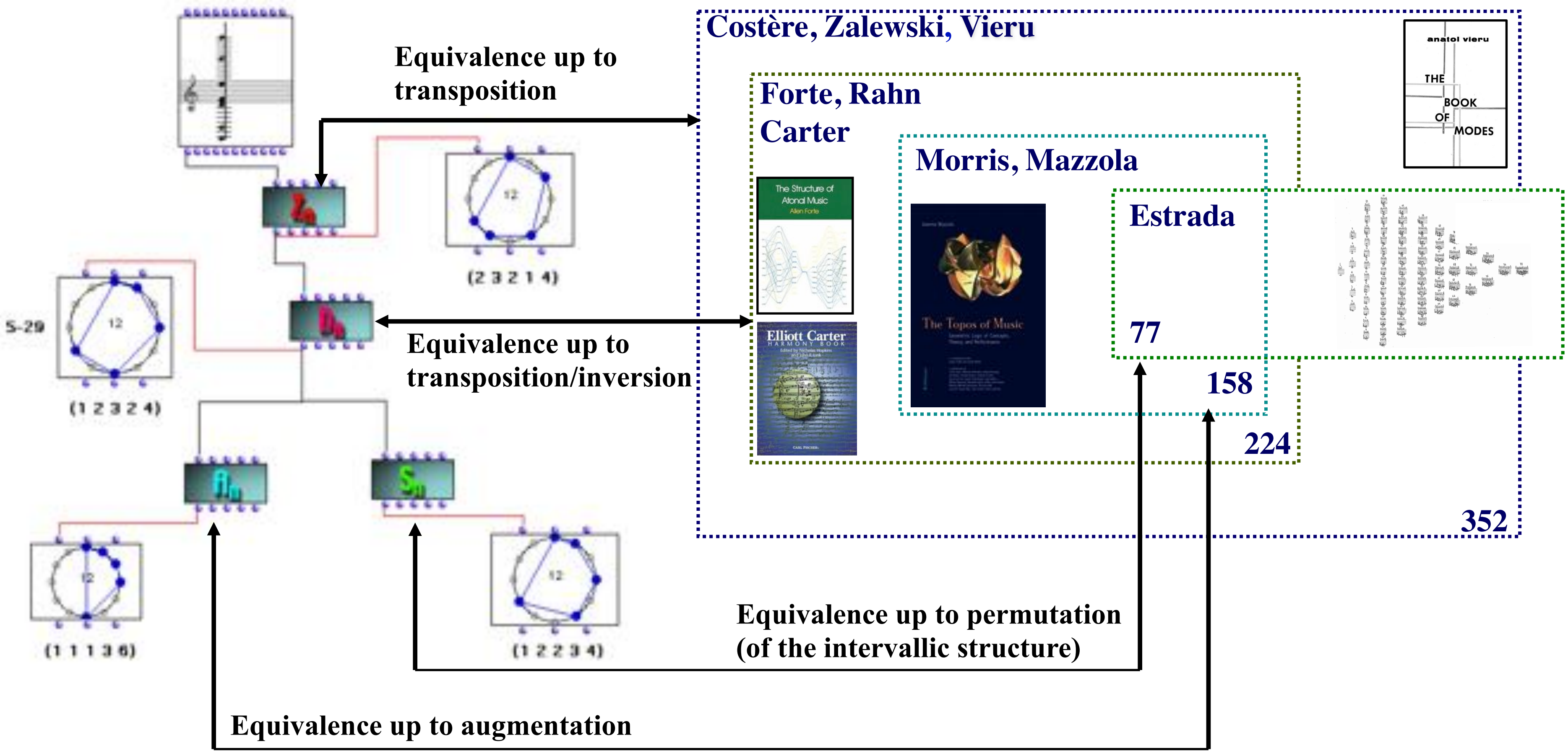
➔**`http://www.lacl.fr/~lbigo/hexachord`**

The catalogues of musical structures (from Costere to Estrada)



	1	2	3	4	5	6	7	8	9	10	11	12
Z_n →	1	6	19	43	66	80	66	43	19	6	1	1
D_n →	1	6	**12**	29	38	50	38	29	12	6	1	1
A_n →	1	5	9	21	25	34	25	21	9	5	1	1
S_n →	*1*	*6*	*12*	*15*	*12*	*11*	*7*	*5*	*3*	*2*	*1*	*1*

Epistemological aspects of a group-theoretical approach



« [C'est la **notion de groupe** qui] donne un sens précis à l'idée de **structure** d'un ensemble [et] permet de déterminer les éléments efficaces des transformations en réduisant en quelque sorte à son **schéma opératoire** le domaine envisagé. […]L'objet véritable de la science est le **système des relations** et non pas les termes supposés qu'il relie. […] Intégrer les résultats - symbolisés - d'une expérience nouvelle revient […] à créer un canevas nouveau, un **groupe de transformations** plus complexe et plus compréhensif » **(G.-G. Granger : « Pygmalion. Réflexions sur la pensée formelle », 1947)**

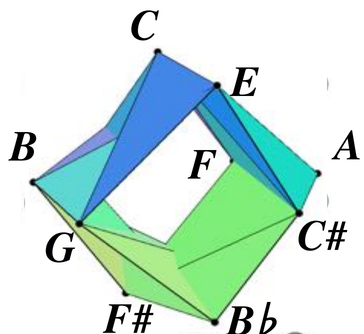
G.-G. Granger

Classifying Chord Complexes

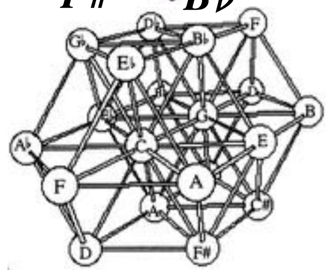
L. Bigo, *Représentation symboliques musicales et calcul spatial*, PhD, Ircam / LACL, 2013

- Complexes enumeration in the chromatic system

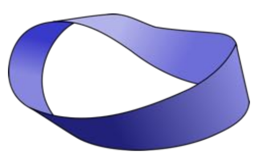
$K_{TI}[3,4,5]$
[Cohn – 1997]

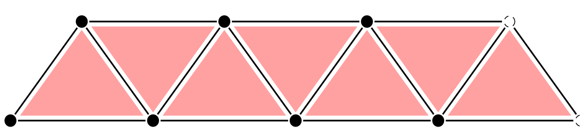


$K_{TI}[2,3,3,4]$
[Gollin - 1998]



$K_{T}[2,2,3]$
[Mazzola – 2002]





…

d	complexe	taille	b_n	p-v	χ
-	$\mathcal{K}_\emptyset$	0	0		0
0	$\mathcal{K}_{TI}[0]$	0	[0]		0
1	$\mathcal{K}_{TI}[1,11]$	12	[1, 1]	x	0
	$\mathcal{K}_{TI}[2,10]$	12	[2, 2]		0
	$\mathcal{K}_{TI}[3,9]$	12	[3, 3]		0
	$\mathcal{K}_{TI}[4,8]$	12	[4, 4]		0
	$\mathcal{K}_{TI}[5,7]$	12	[1, 1]	x	0
	$\mathcal{K}_{TI}[6,6]$	6	[6, 0]		6
2	$\mathcal{K}_{TI}[1,1,10]$	12	[1, 1, 0]	x	0
	$\mathcal{K}_{TI}[1,2,9]$	24	[1, 2, 1]	x	0
	$\mathcal{K}_{TI}[1,3,8]$	24	[1, 2, 1]	x	0
	$\mathcal{K}_{TI}[1,4,7]$	24	[1, 2, 1]	x	0
	$\mathcal{K}_{TI}[1,5,6]$	24	[1, 1, 6]		6
	$\mathcal{K}_{TI}[2,2,8]$	12	[2, 2, 0]		0
	$\mathcal{K}_{TI}[2,3,7]$	24	[1, 2, 1]	x	0
	$\mathcal{K}_{TI}[2,4,6]$	24	[2, 2, 6]		6
	$\mathcal{K}_{TI}[2,5,5]$	12	[1, 1, 0]	x	0
	$\mathcal{K}_{TI}[3,3,6]$	12	[3, 0, 3]		6
	$\mathcal{K}_{TI}[3,4,5]$	24	[1, 2, 1]	x	0
	$\mathcal{K}_{TI}[4,4,4]$	4	[4, 0, 0]		4
	$\mathcal{K}_{TI}[1,1,1,9]$	12	[1, 1, 0, 0]	x	0
	$\mathcal{K}_{TI}[1,1,2,8]$	24	[1, 1, 12, 0]		12
	$\mathcal{K}_{TI}[1,1,3,7]$	24	[1, 2, 13, 0]		12
	$\mathcal{K}_{TI}[1,1,4,6]$	24	[1, 1, 18, 0]		18
	$\mathcal{K}_{TI}[1,1,5,5]$	12	[1, 1, 6, 0]		6

On the group of transformations of classical types of seventh chords

Sonia Cannas[1,2], Samuele Antonini[1], and Ludovico Pernazza[1]

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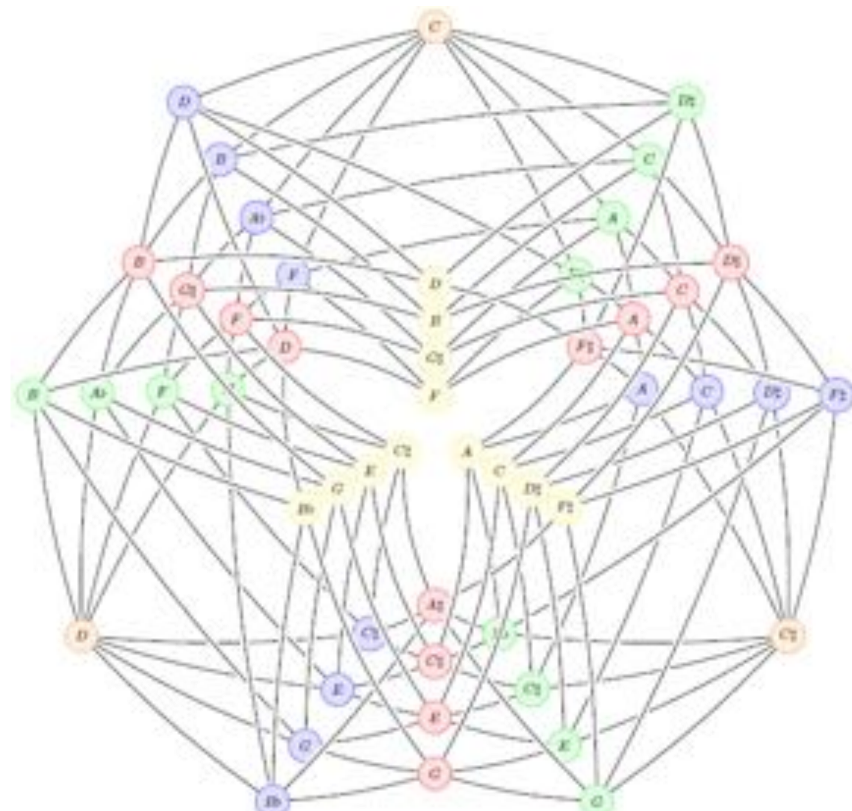
Abstract. This paper presents a generalization of the well-known neo-Riemannian group PLR to the classical five types of seventh chord (dominant, minor, half-diminished, major, diminished) considered as tetrachords with a marked root and proving that it is isomorphic to the abstract group $S_5 \ltimes \mathbb{Z}_{12}^4$. This group includes as subgroups the PLR group and several other groups already appeared in the literature.

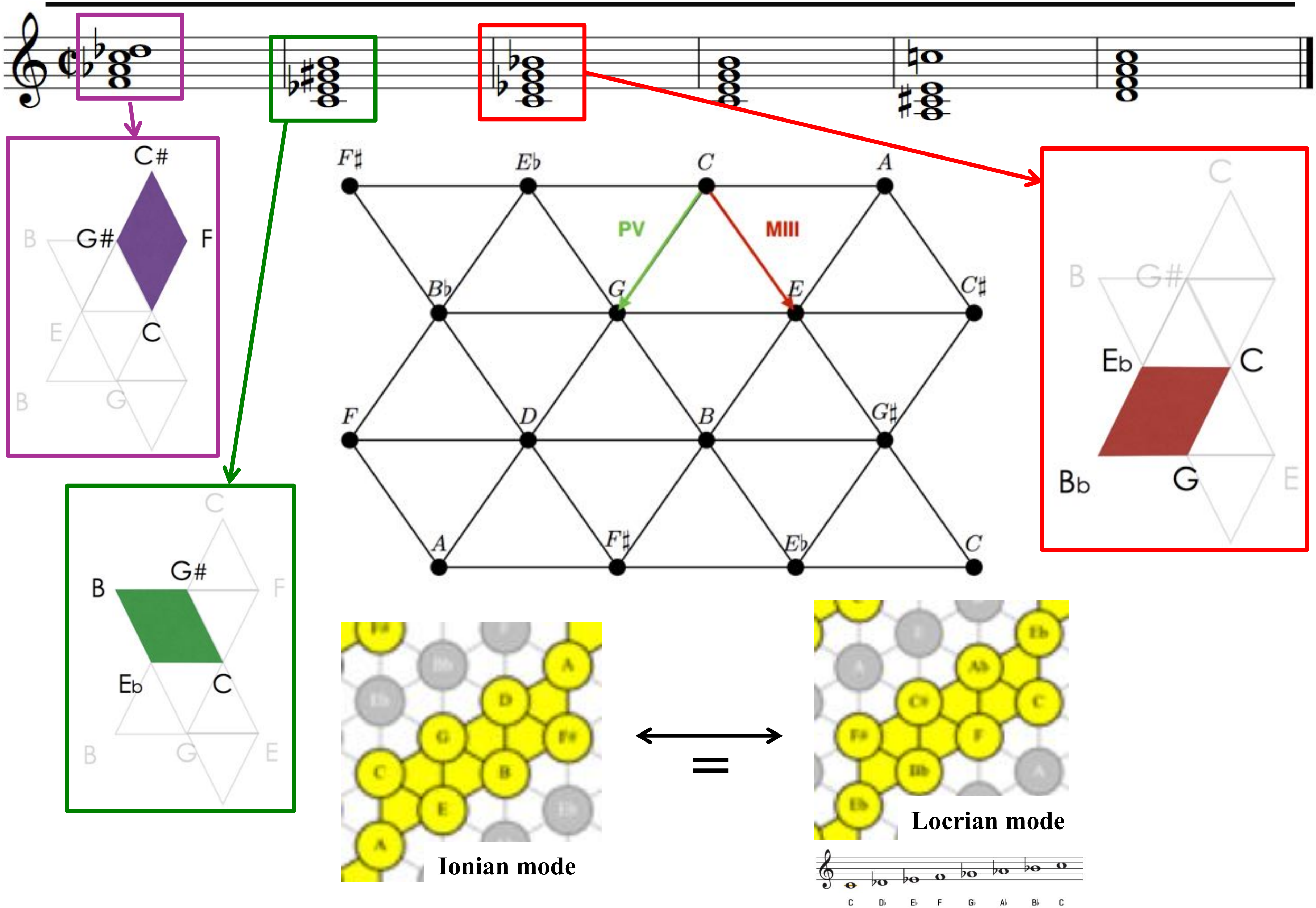
Keywords: Transformational theory; neo-Riemannian group; semi-direct product; seventh chord



Hamiltonian paths/cycles?

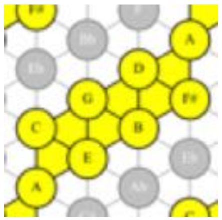
➔ **Après-midi**

Chordal limitations of an isotropic Tonnetz model

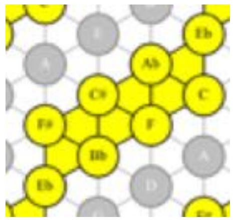


Towards a ‘morphological’ anisotropic *Tonnetz*

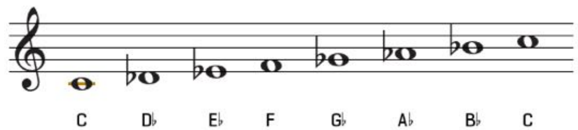
- **M. Bergomi,** ***Dynamical and topological tools for (modern) music analysis*****, UPMC-Ircam/LIM Milan, 2015**.

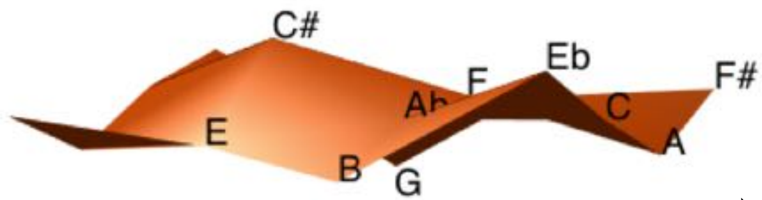


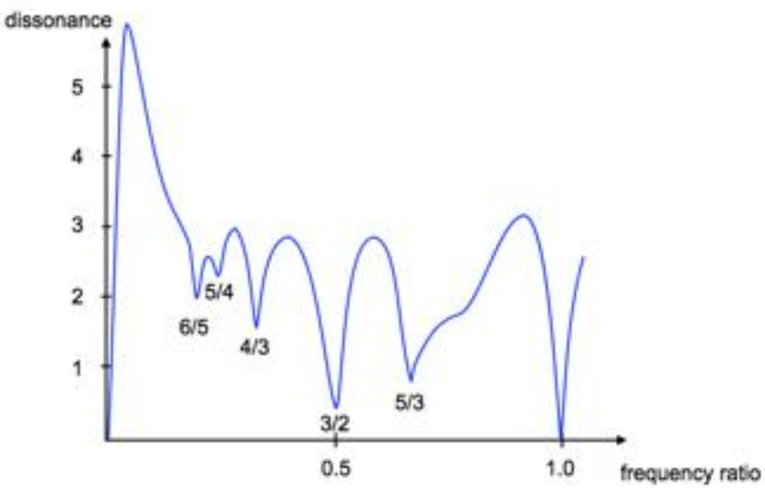
Ionian mode

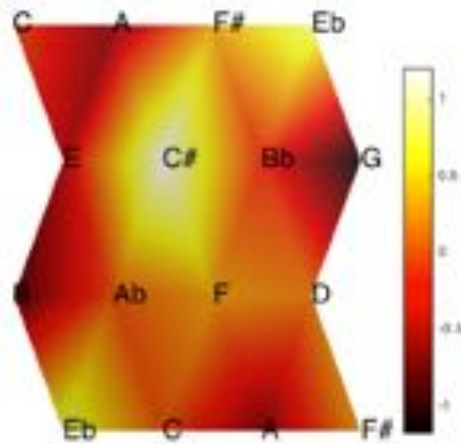


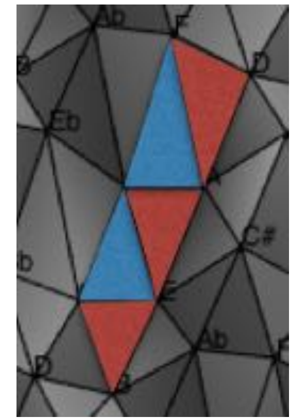
Locrian mode



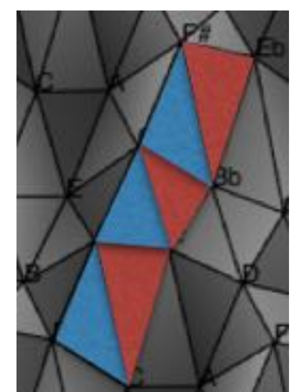








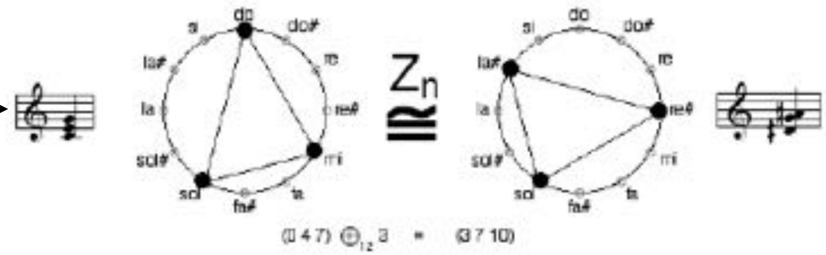
Ionian mode



Locrian mode

➔ **Persistent homology (Davide)**

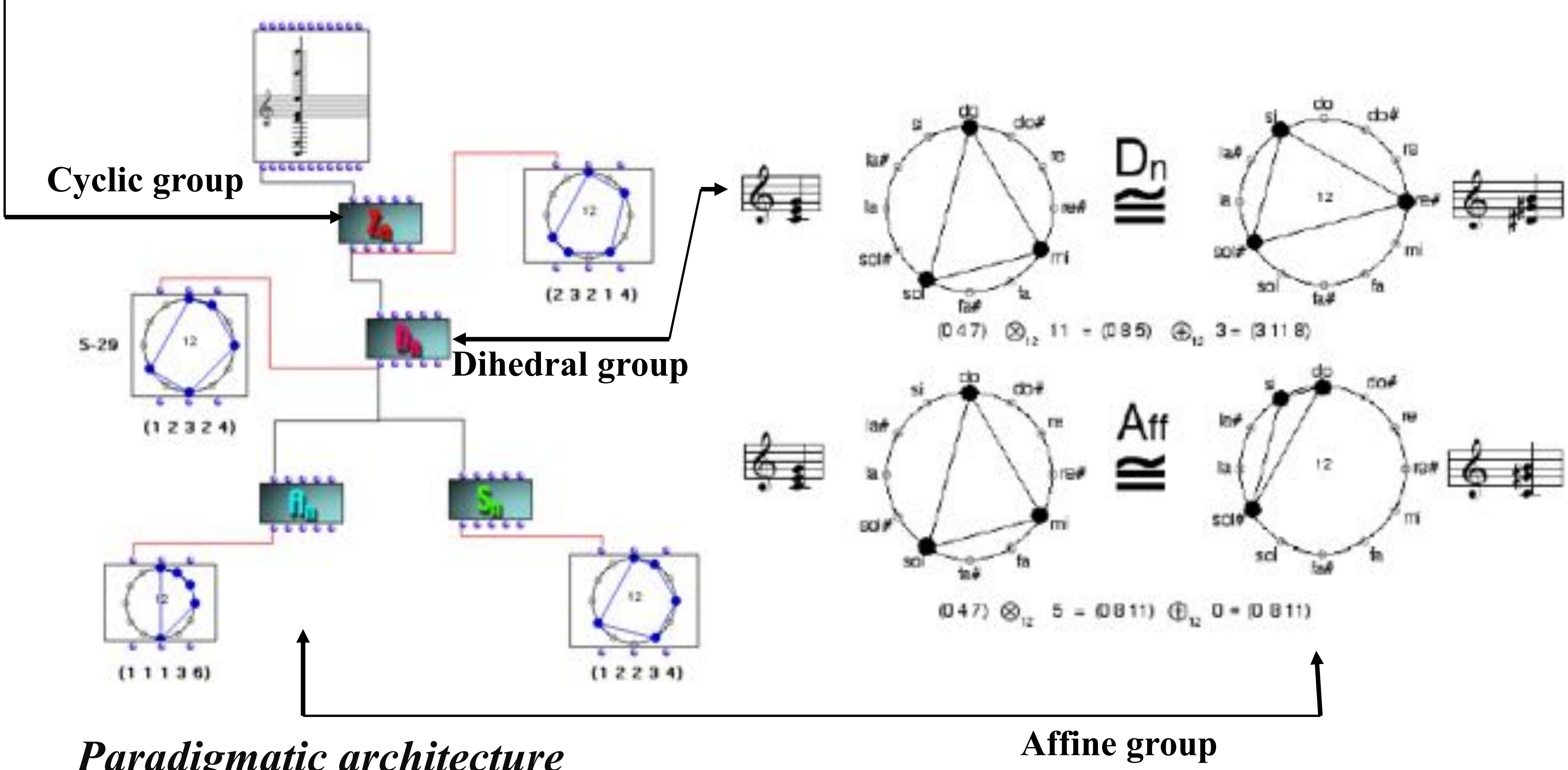
Equivalence classes of chords (up to a group action)



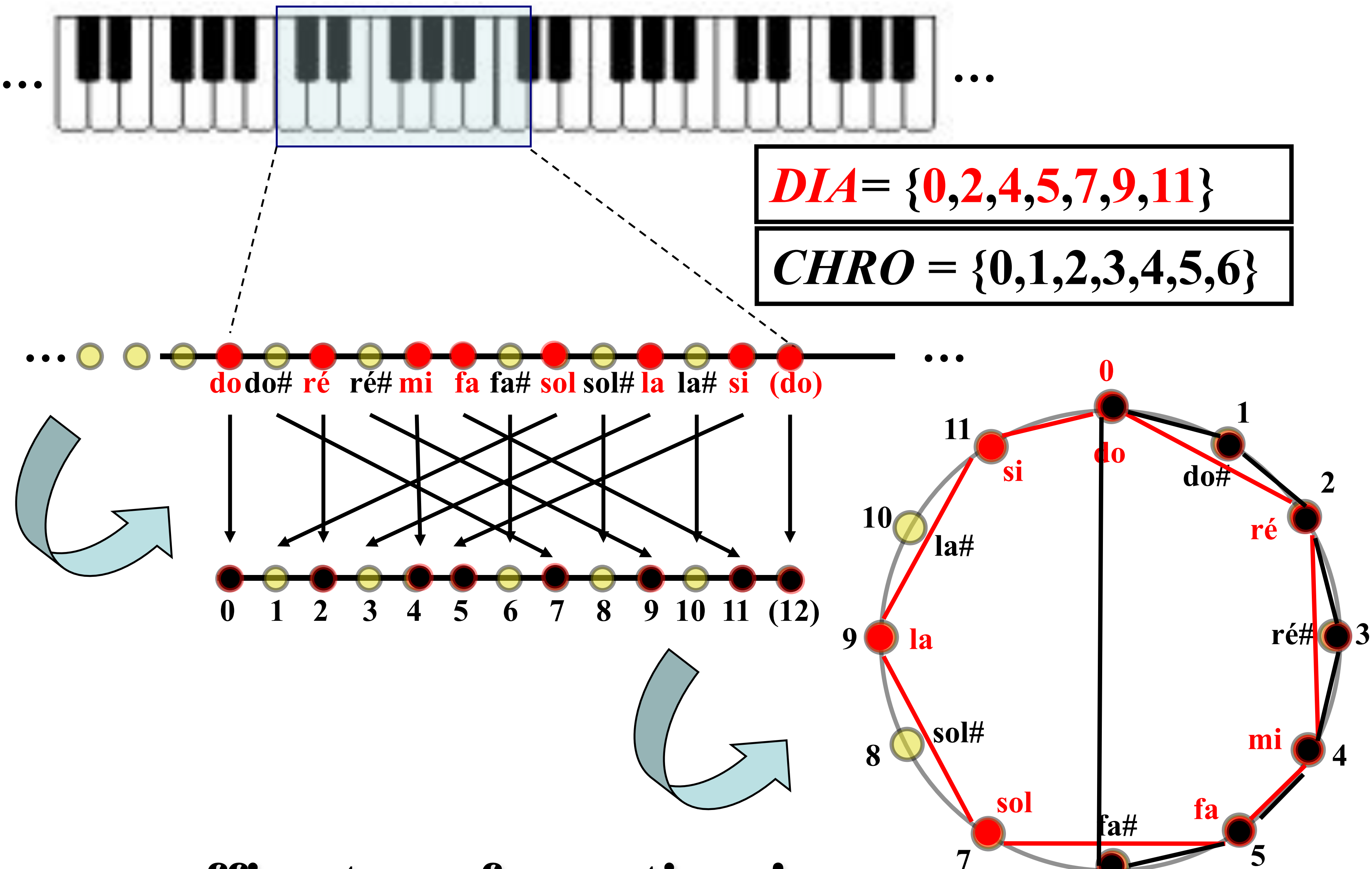
$$\mathbf{Z_{12}} = \langle T_k \mid (T_k)^{12} = T_0 \rangle$$

$$\mathbf{D_{12}} = \langle T_k , I \mid (T_k)^{12} = I^2 = T_0 , ITI = I(IT)^{-1} \rangle$$

$$\mathbf{Aff} = \{ f \mid f(x) = ax + b,\ a \in (\mathbf{Z_{12}})^*,\ b \in \mathbf{Z_{12}} \}$$

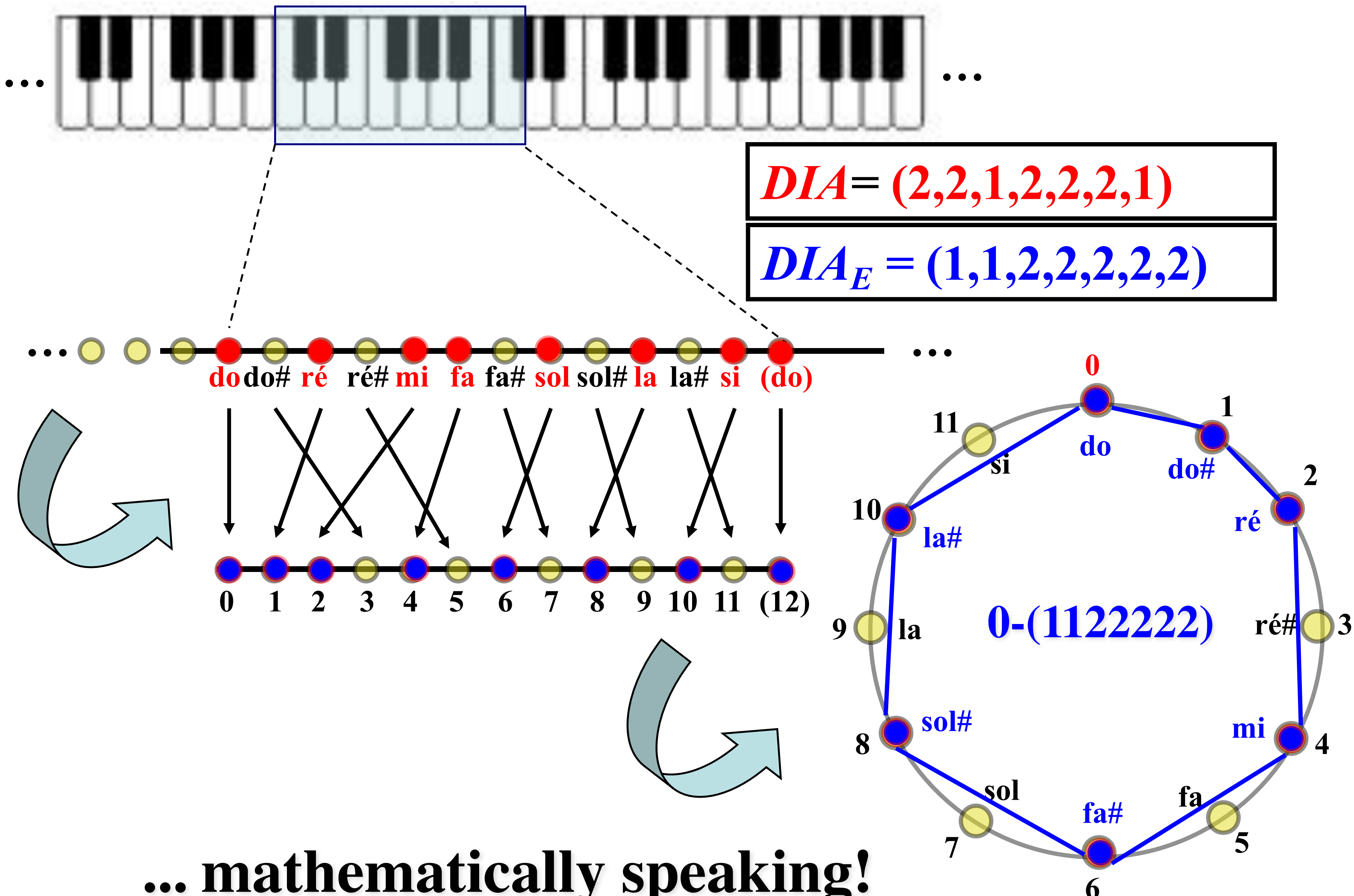


Augmentations are multiplications...



... or affine transformations!

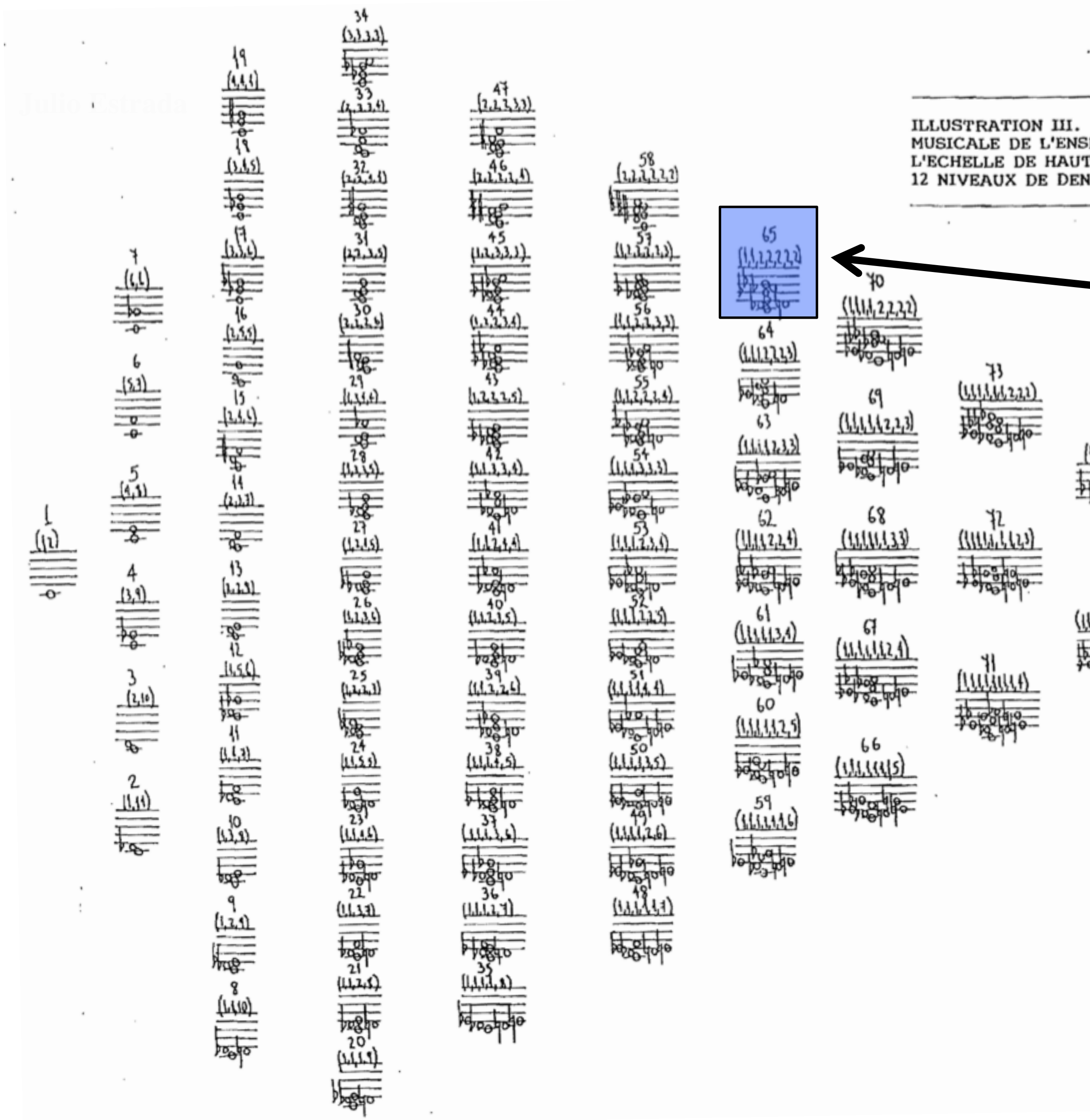
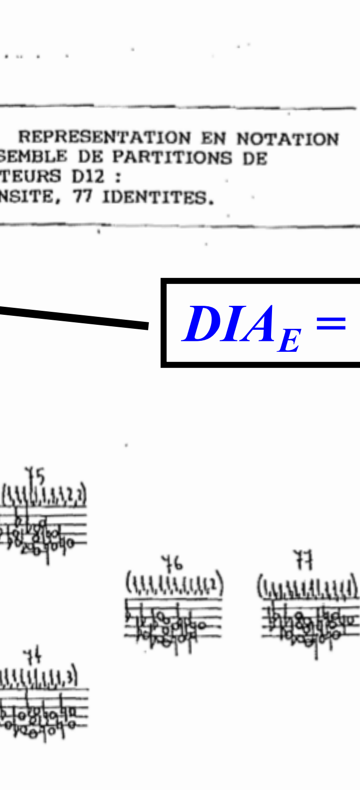
Permutations are 'partitions'...



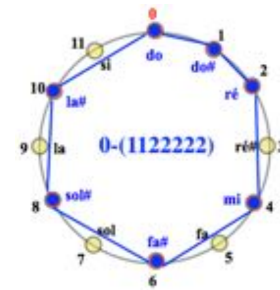
... mathematically speaking!

The permutohedron as a combinatorial space

Julio Estrada, *Théorie de la composition : discontinuum – continuum,* université de Strasbourg II, 1994

$DIA_E = (1,1,2,2,2,2,2)$




THEORIE DE LA COMPOSITION :

DISCONTINUUM - CONTINUUM

Julio ESTRADA

Thèse en Musicologie

Nouveau Doctorat

Département de Musicologie

Université de Strasbourg II

Sciences Humaines

Directeur de thèse :
François-Bernard Mâche

Membres du Jury :

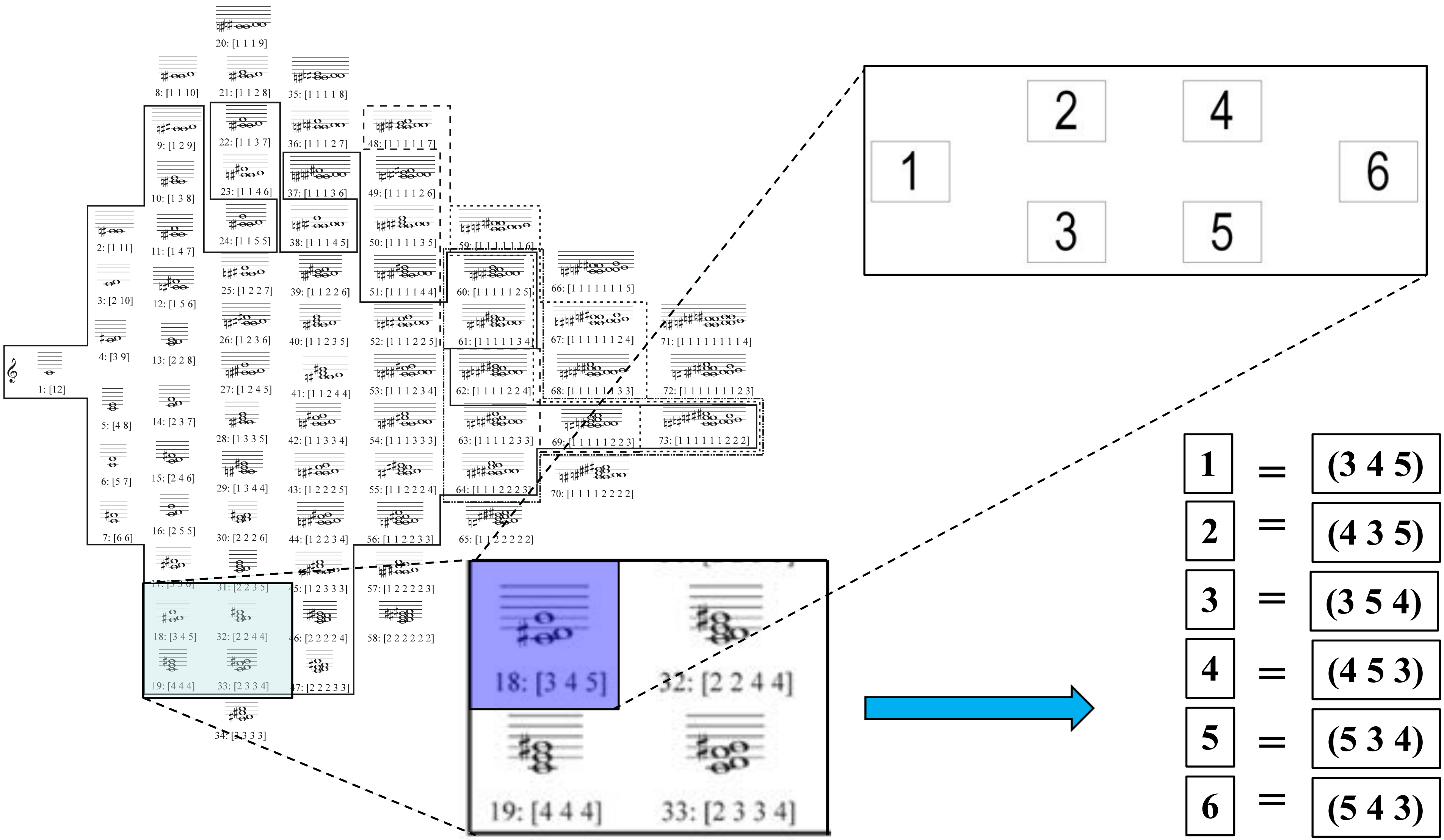
M. François-Bernard Mâche, Ecole d'Hautes Etudes
Mme. Marta Grabòtz, Université de Strasbourg
M. Hartmut Möller, Université de Rostock

Rapports de thèse :

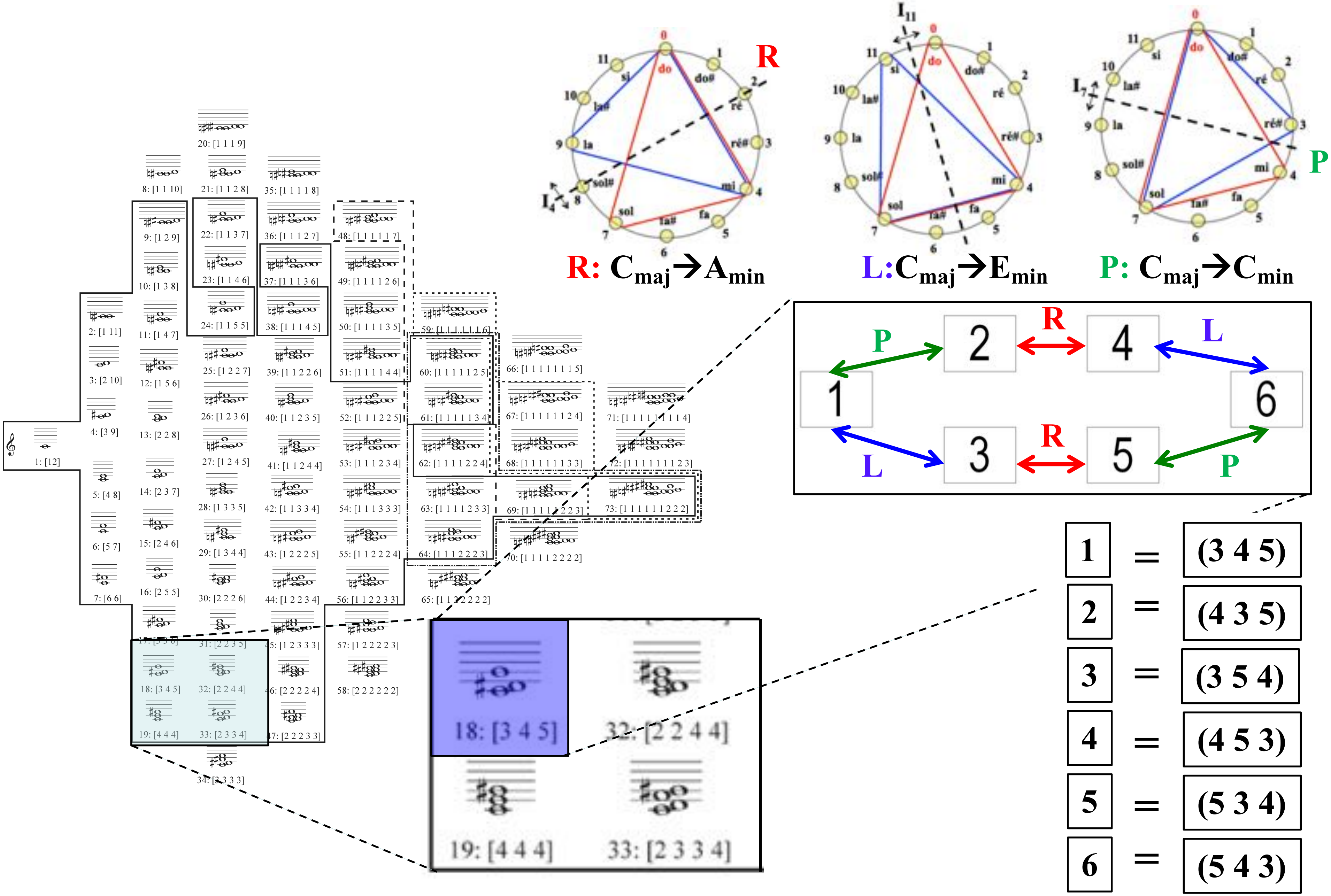
Mme. Evélyne Andreani, Université de Paris VIII
M. Daniel Charles, Université de Nice


J. Estrada

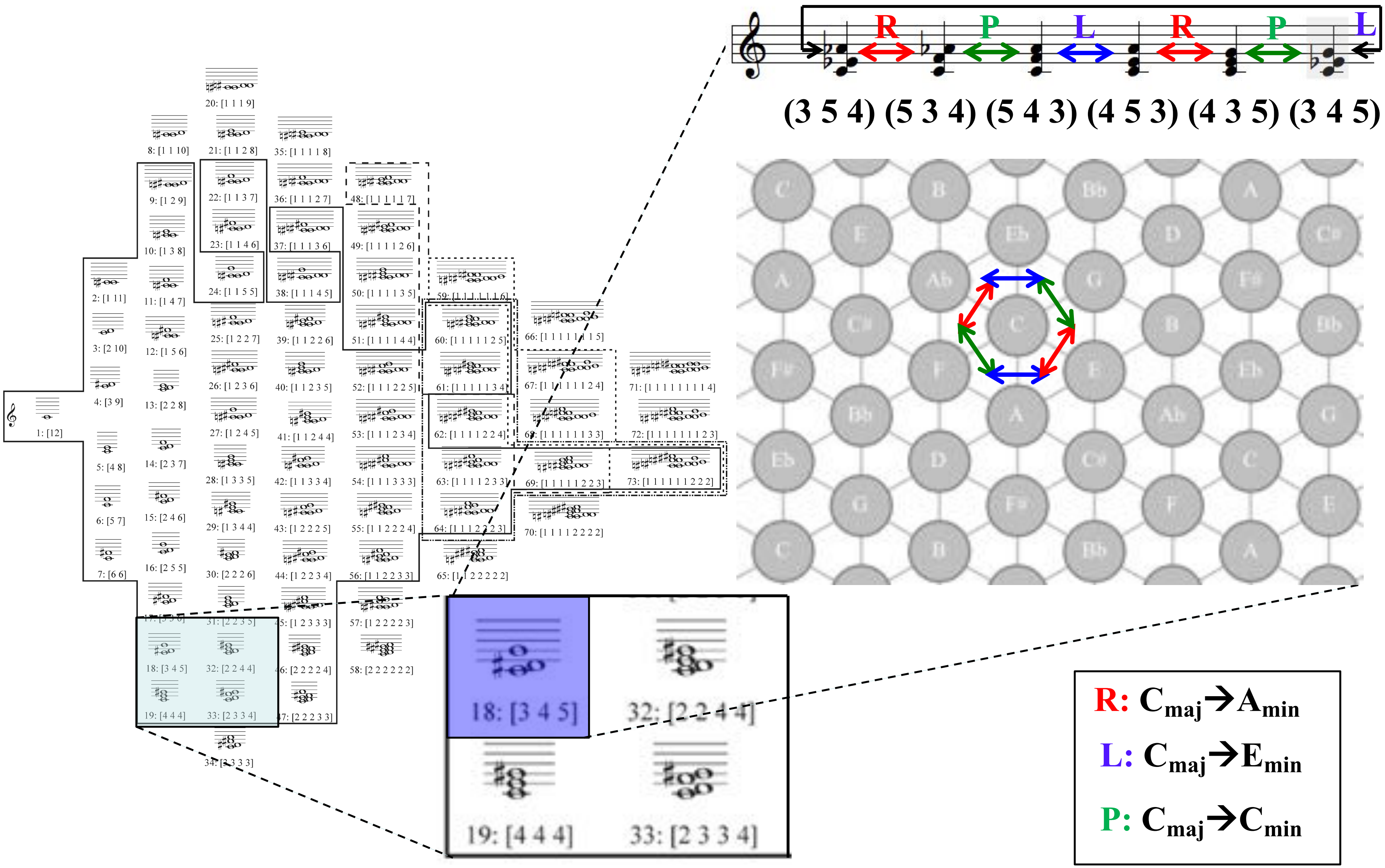
Permutohedron and *Tonnetz*: a structural inclusion



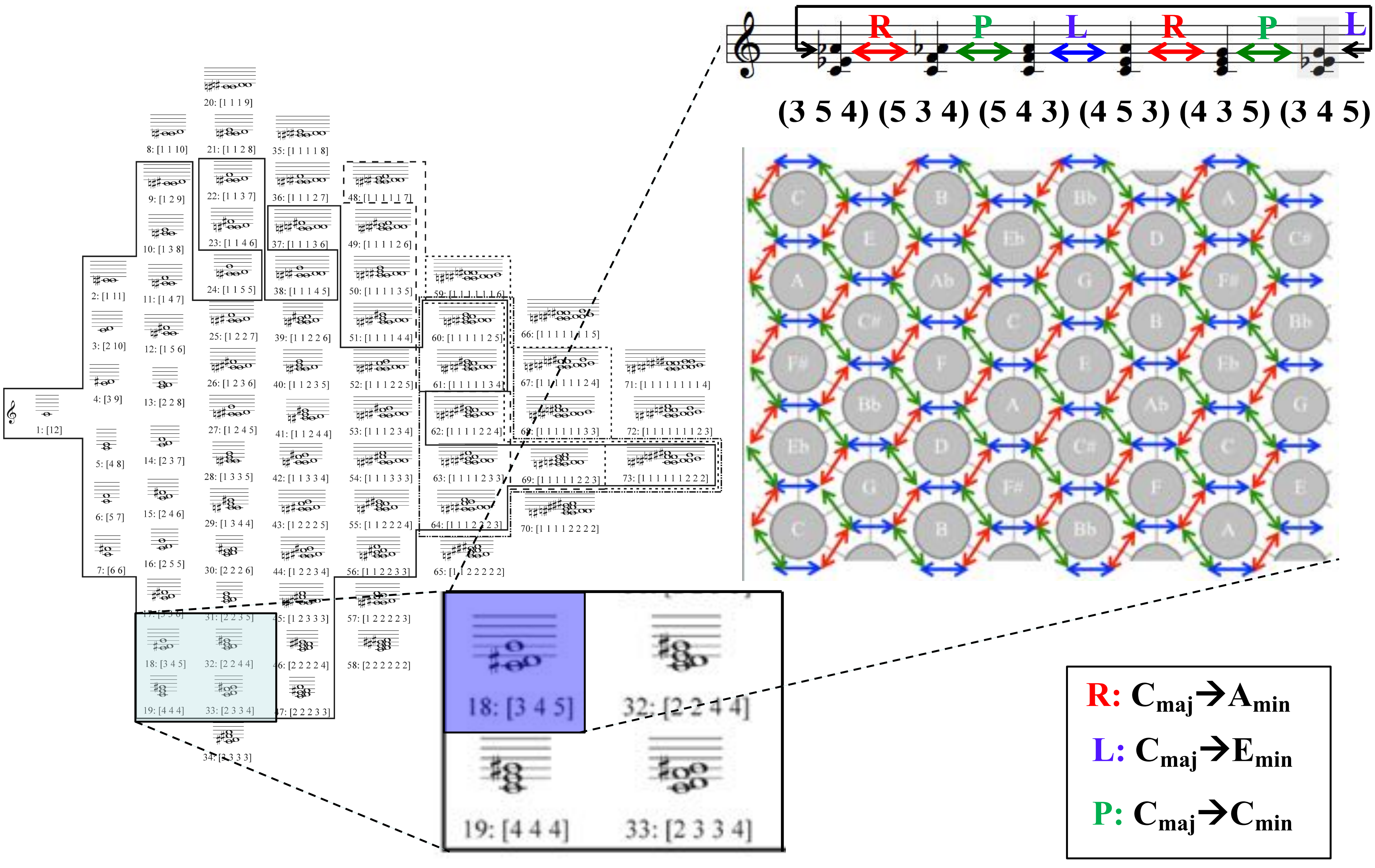
Permutohedron and *Tonnetz*: a structural inclusion



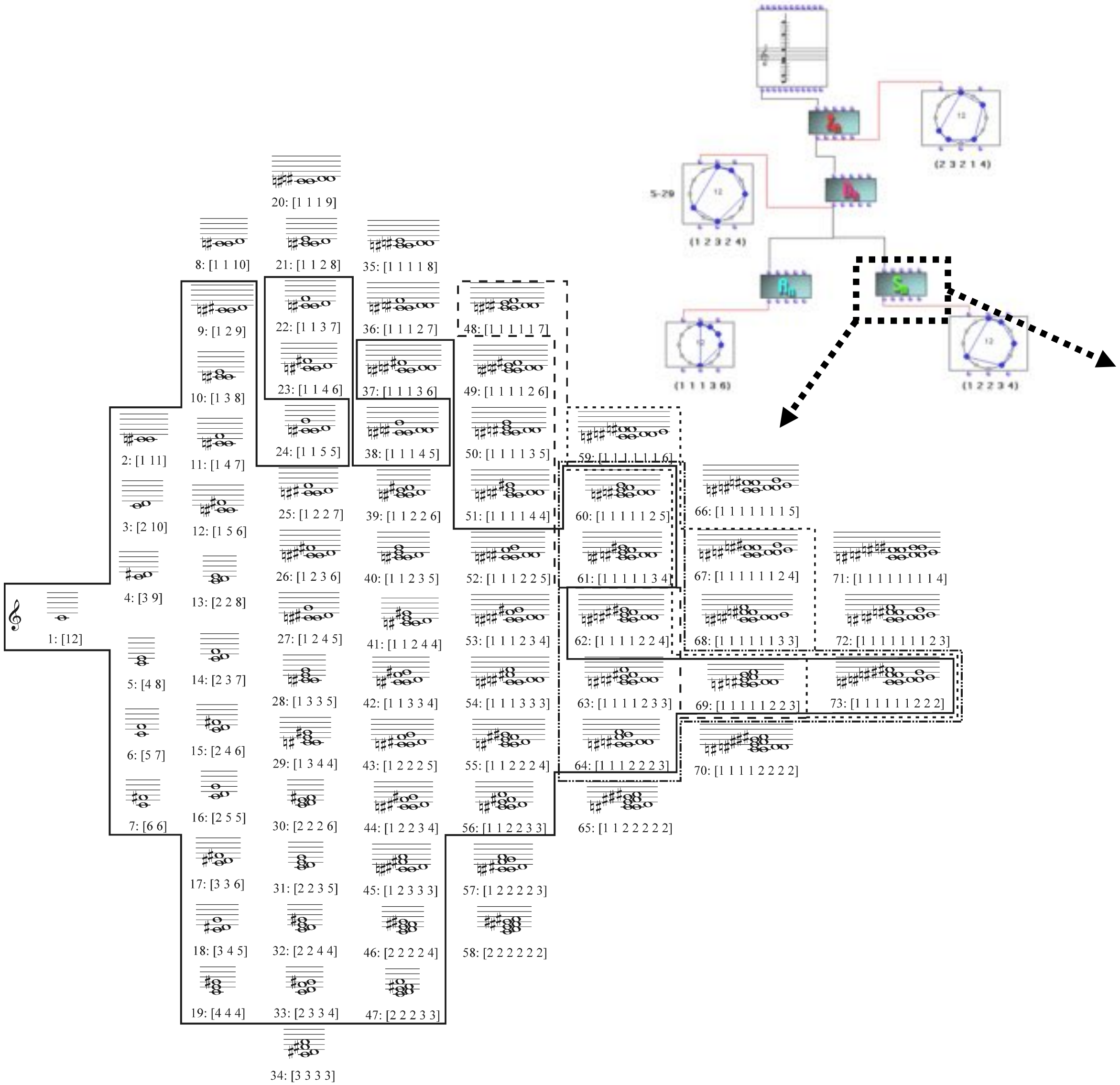
Permutohedron and *Tonnetz*: a structural inclusion

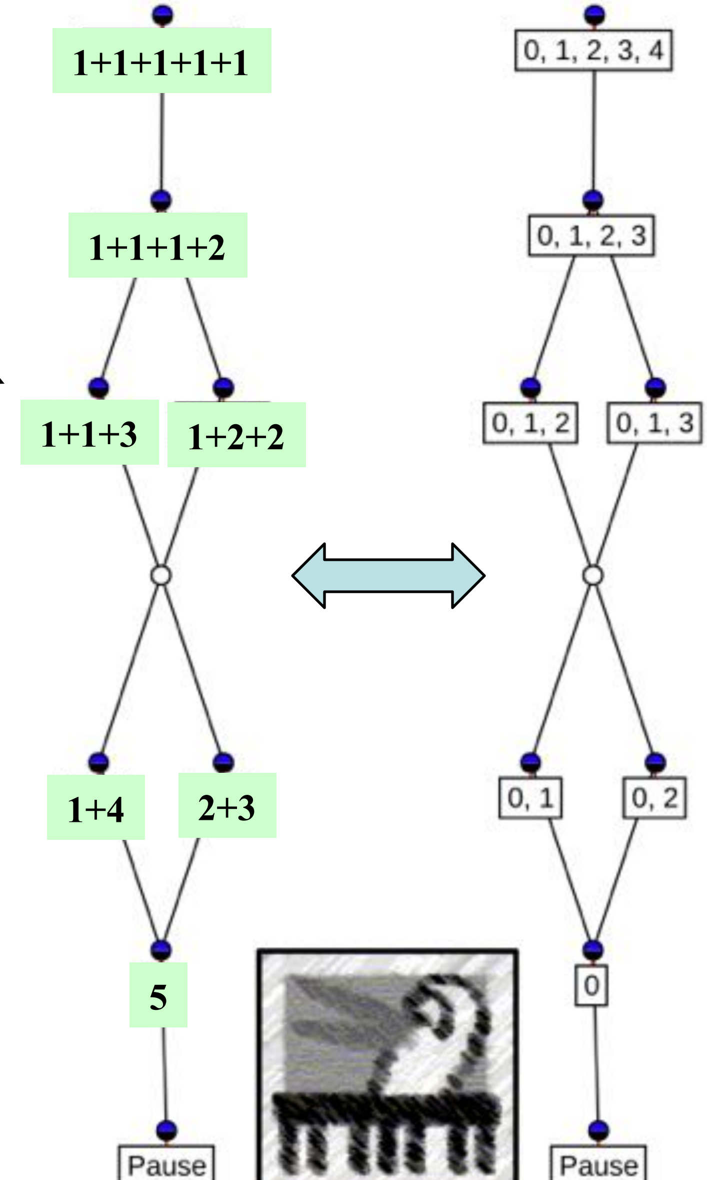


Permutohedron and *Tonnetz*: a structural inclusion



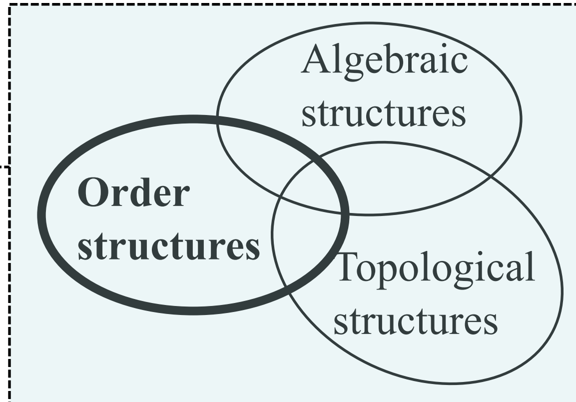
The permutohedron as a lattice of formal concepts





- T. Schlemmer, M. Andreatta, « Using Formal Concept Analysis to represent Chroma Systems », MCM 2013, McGill Univ., Springer, LNCS.

Formal Concept Analysis: the double history



CAMS
Centre d'analyse et de mathématique sociales

TECHNISCHE UNIVERSITÄT DARMSTADT

- M. Barbut, « Note sur l'algèbre des techniques d'analyse hiérarchique », in B. Matalon (éd.), L'analyse hiérarchique, Paris, Gauthier-Villars, 1965.
- M. Barbut, B. Monjardet, *Ordre et Classification. Algèbre et Combinatoire*, en deux tomes, 1970
- M. Barbut, L. Frey, « Techniques ordinales en analyse des données », Tome I, *Algèbre et Combinatoire des Méthodes Mathématiques en Sciences de l'Homme*, Paris, Hachette, 1971.
- B. Leclerc, B. Monjardet, « Structures d'ordres et sciences sociales », *Mathématiques et sciences humaines,* 193, 2011, 77-97

- R. Wille, « Mathematische Sprache in der Musiktheorie », in B. Fuchssteiner, U. Kulisch, D. Laugwitz, R. Liedl (Hrsg.): Jahrbuch Überblicke Mathematik. B.I.-Wissenschaftsverlag, Mannheim, 1980, p. 167-184.
- R. Wille, « Restructuring Lattice Theory: An approach based on Hierarchies of Concepts », I. Rival (ed.), *Ordered Sets,* 1982
- R. Wille, « Sur la fusion des contextes individuals », Mathématiques et sciences humaines, tome 85, 1984.
- B. Ganter & R. Wille, *Formal Concept Analysis: Mathematical Foundations*, Springer, Berlin, 1998

Formal Concept Analysis: the common root

Garrett Birkhoff
(1911-1996)

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- M. Barbut, « Note sur l'algèbre des techniques d'analyse hiérarchique », in B. Matalon (éd.), L'analyse hiérarchique, Paris, Gauthier-Villars, 1965.
- M. Barbut, B. Monjardet, *Ordre et Classification. Algèbre et Combinatoire*, en deux tomes, 1970
- M. Barbut, L. Frey, « Techniques ordinales en analyse des données », Tome I, *Algèbre et Combinatoire des Méthodes Mathématiques en Sciences de l'Homme*, Paris, Hachette, 1971.
- B. Leclerc, B. Monjardet, « Structures d'ordres et sciences sociales », *Mathématiques et sciences humaines,* 193, 2011, 77-97

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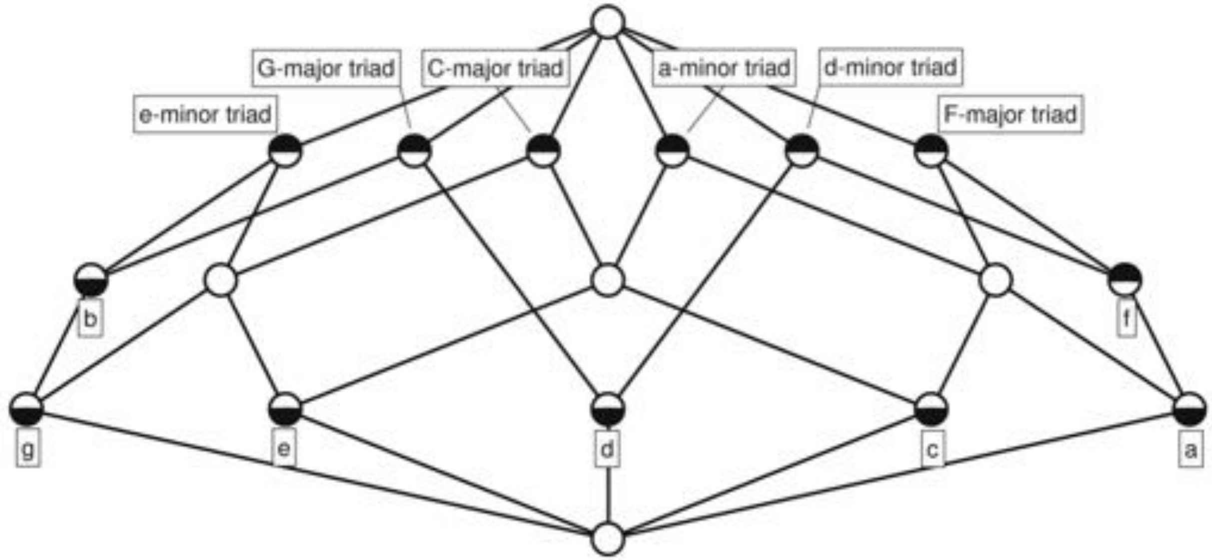
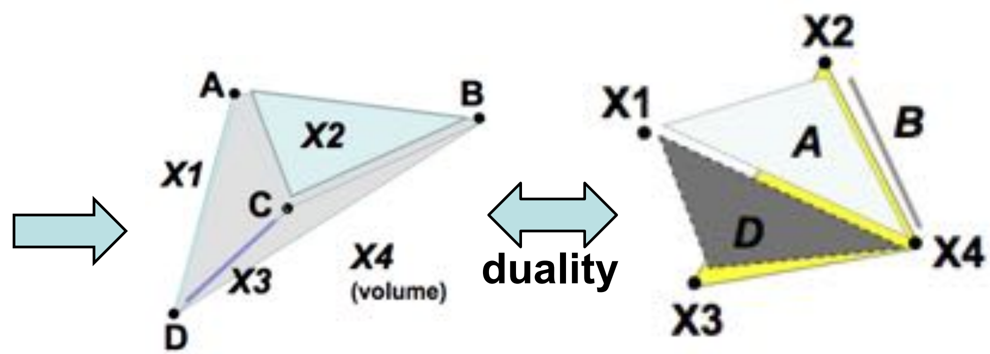
- B. Ganter & R. Wille, *Formal Concept Analysis: Mathematical Foundations*, Springer, Berlin, 1998

Formal Concept Analysis and topology: the Q-analysis

	C-major triad	d-minor triad	e-minor triad	F-major triad	G-major triad	a-minor triad
c	X			X		X
d		X			X	
e	X		X			X
f		X		X		
g	X		X		X	
a		X		X		X
b			X		X	

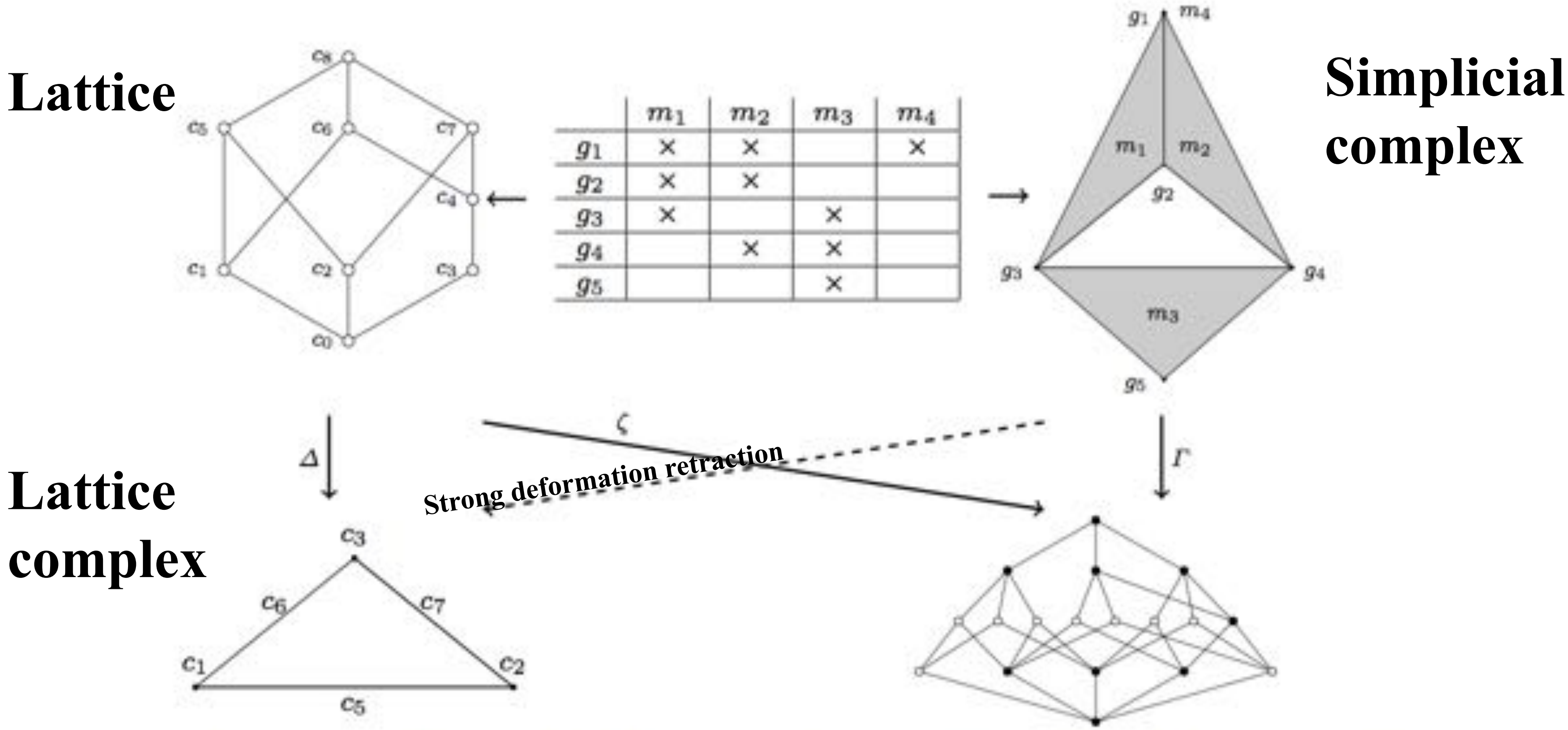


	A	B	C	D
X1	1	0	0	1
X2	1	1	1	0
X3	0	0	1	1
X4	1	1	1	1



Concept lattice *vs* simplicial complex

Freund A., M. Andreatta, J.-L. Giavitto (2015), « Lattice-based and Topological Representations of Binary Relations with an Application to Music », *Annals of Mathematics and Artificial Intelligence*, 2015.



Conclusions:

- The concept lattice alone cannot be fully reconstructed from the simplicial complex
- The simplicial complex cannot be fully determined from the concept lattice alone
- The concept lattice alone allows to determine the homotopy type of the simplicial complex

Concept lattice & mathematical morphology


RAPPORT DE STAGE RECHERCHE - M2 INFORMATIQUE FONDAMENTALE

ENS DE LYON

Morphologie Mathématique, Analyse des Concepts Formels et Musicologie Computationnelle

Effectué au sein des structures :

ircam Centre Pompidou — TELECOM ParisTech — DAUPHINE UNIVERSITÉ PARIS

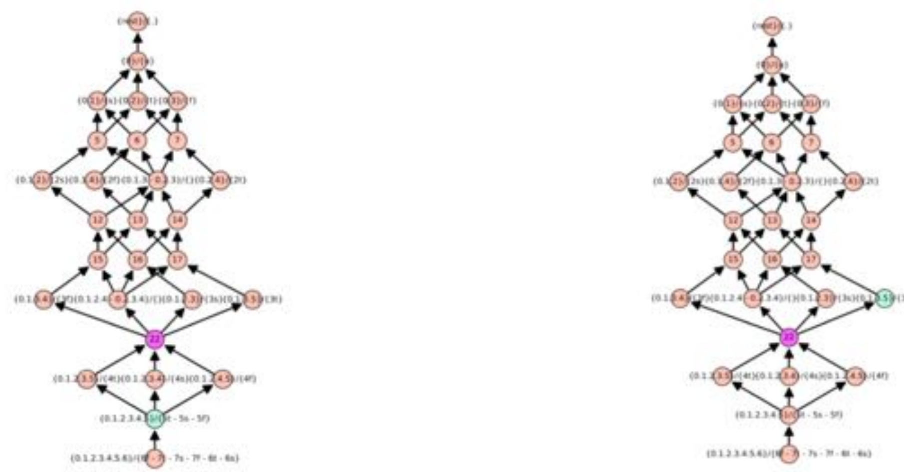
Présenté par :
Pierre Mascarade
ENS Lyon
M2 Informatique Fondamentale

Sous la direction de :
Moreno Andreatta,
IRCAM - RepMus
Musicologie Computationnelle
Jamal Atif,
Paris Dauphine
Morphologie Mathématique - FCA
Isabelle Bloch,
Télécom ParisTech
Morphologie Mathématique - FCA

Sous le tutorat de :
Márton Karsai,
ENS Lyon
Computer Science / Complex Systems

Effectué durant la période
Février 2017 - Juin 2017

?

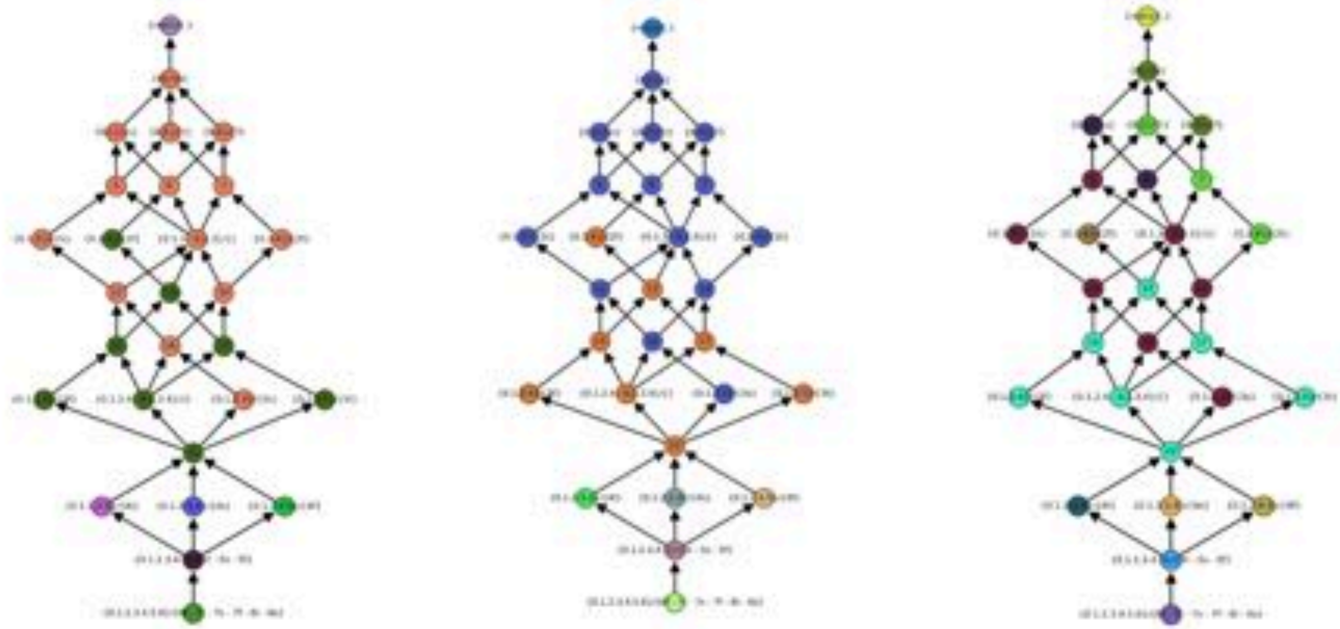


➔ **Après-midi**

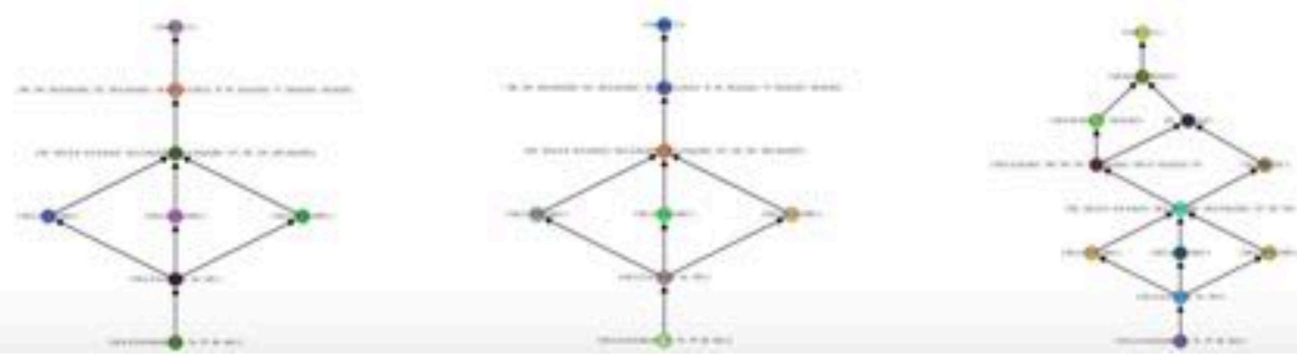
Concept lattice & mathematical morphology

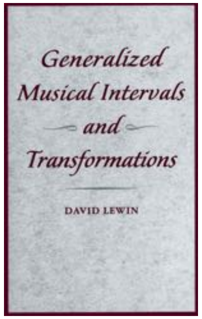
Exemple de descripteurs harmonico-morphologiques chez Ligeti

Congruence θ - θ_δ - θ_ε sur $\mathbb{C}$(7-tet) engendrées par: $H_{\mathbb{C}}^{\mathfrak{M}}$ - $\delta(H_{\mathbb{C}}^{\mathfrak{M}})$ - $\varepsilon(H_{\mathbb{C}}^{\mathfrak{M}})$

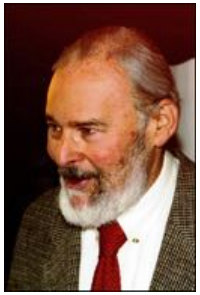


Treillis-quotients: neutre $\mathbb{C}(\mathfrak{M})/\theta$ - dilatation $\mathbb{C}(\mathfrak{M})/\theta_\delta$ - érosion $\mathbb{C}(\mathfrak{M})/\theta_\varepsilon$.





Système d'Intervalles Généralisés - Système Généralisé d'Intervalles
David Lewin's *Generalized Interval System* [GMIT, 1987]



D. Lewin

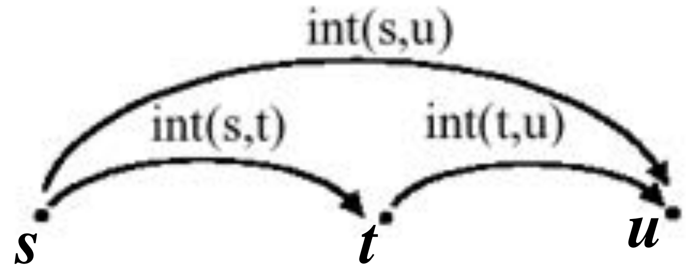
GIS = (S, G, int)

S = ensemble

(G,•) = groupe d'intervalles

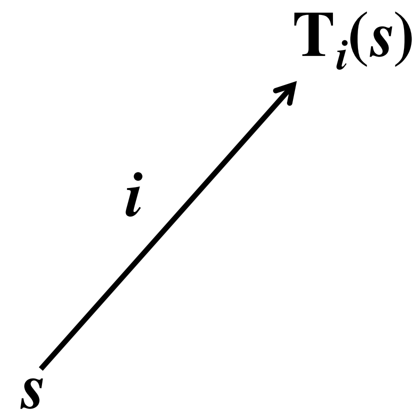
int = fonction intervallique

$$S \times S \xrightarrow{\text{int}} G$$



Action simplément transitive

1. Pour tous objets s, t, u dans S :
   int(s, t)•int(t, u) = int(s, u)
2. Pour tout objet s dans S et tout intervalle i dans G il y a un seul objet t dans S tel que int(s, t) = i

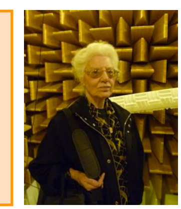


Soit τ ={T_i ; $i \in G$} le groupe des transpositions

GIS = (S, G, int) ⇔ $\tau \times S \to S$ telle que $(T_i, s) \to T_i(s)$ où int(s, $T_i(s)$) = i

➔ Extension de la théorie transformationnelle aux groupoïdes et aux actions générales de groupoïdes (thèse J. Mandereau, 2011-2013)

➔ Liens avec les Systèmes Evolutifs à Mémoire (thèse G. Genuys, 2014-2017)



K-nets as a transformational construction

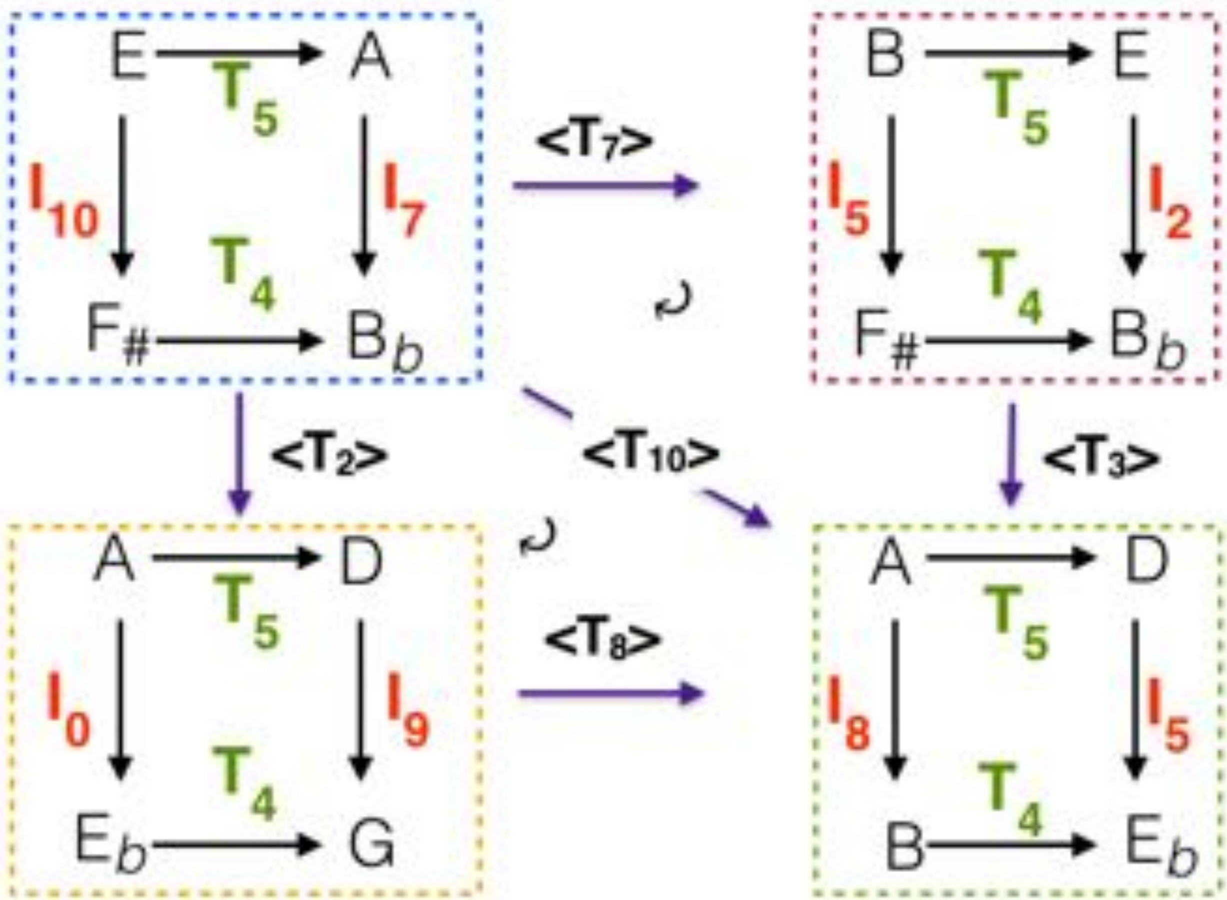
D. Lewin, "A Tutorial on K-nets using the Chorale in Schoenberg's Op.11, N°2 », *JMT*, 1994


D. Lewin


H. Klumpenhouwer

$\langle T_k \rangle : T_m \rightarrow T_m$
$\qquad\qquad I_m \rightarrow I_{k+m}$

$\langle T_k \rangle \cdot \langle T_m \rangle = \langle T_{k+m} \rangle$



K-nets as a transformational construction

D. Lewin, "A Tutorial on K-nets using the Chorale in Schoenberg's Op.11, N°2 », *JMT*, 1994

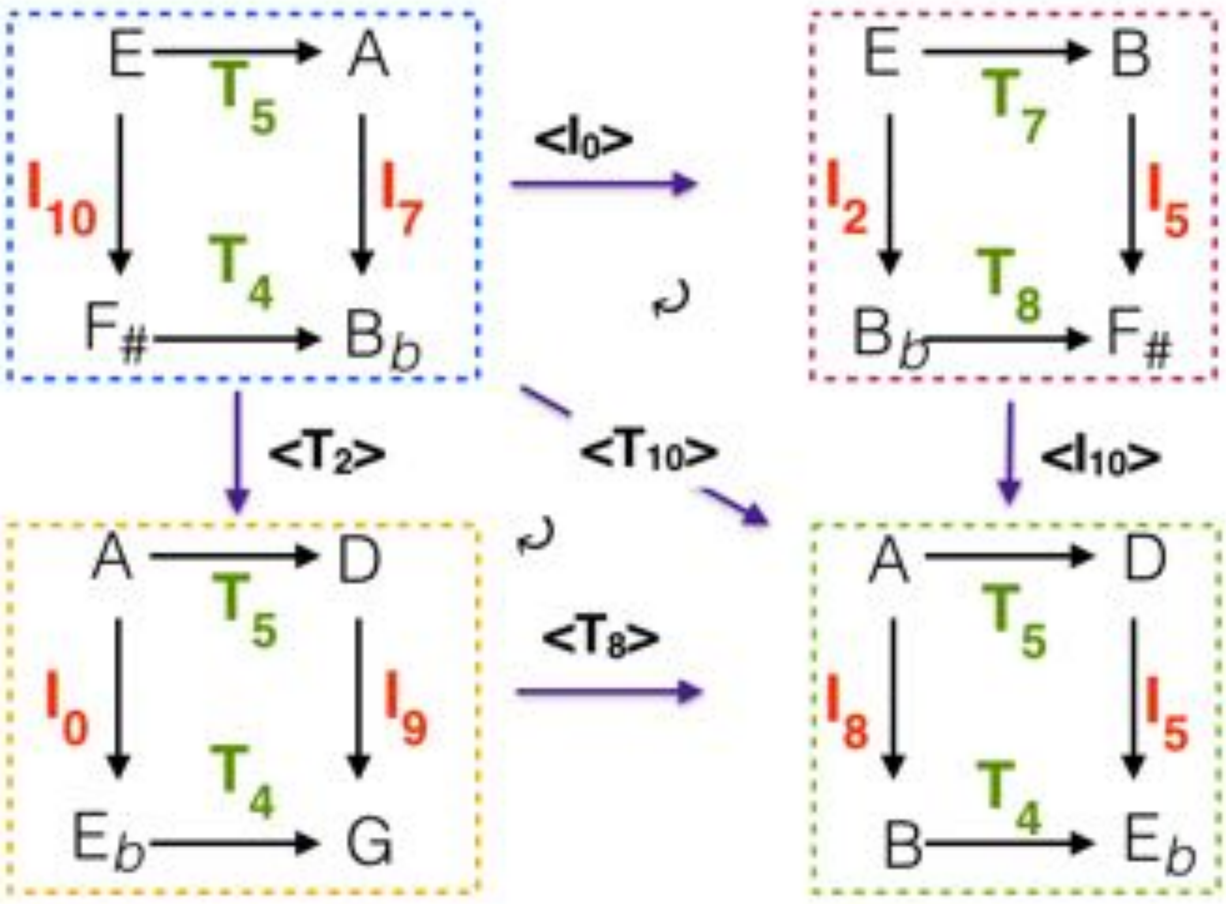
D. Lewin

H. Klumpenhouwer

$$\langle T_k\rangle : T_m \to T_m \qquad I_m \to I_{k+m}$$

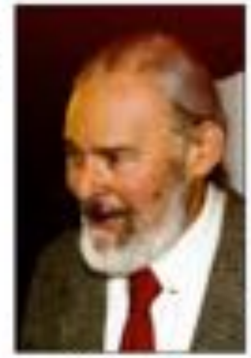
$$\langle I_k\rangle : T_m \to T_{-m} \qquad I_m \to I_{k-m}$$

$$\langle T_k\rangle \cdot \langle T_m\rangle = \langle T_{k+m}\rangle$$
$$\langle I_k\rangle \cdot \langle I_m\rangle = \langle T_{m-k}\rangle$$



K-nets as a transformational construction

D. Lewin, "A Tutorial on K-nets using the Chorale in Schoenberg's Op.11, N°2 », *JMT*, 1994



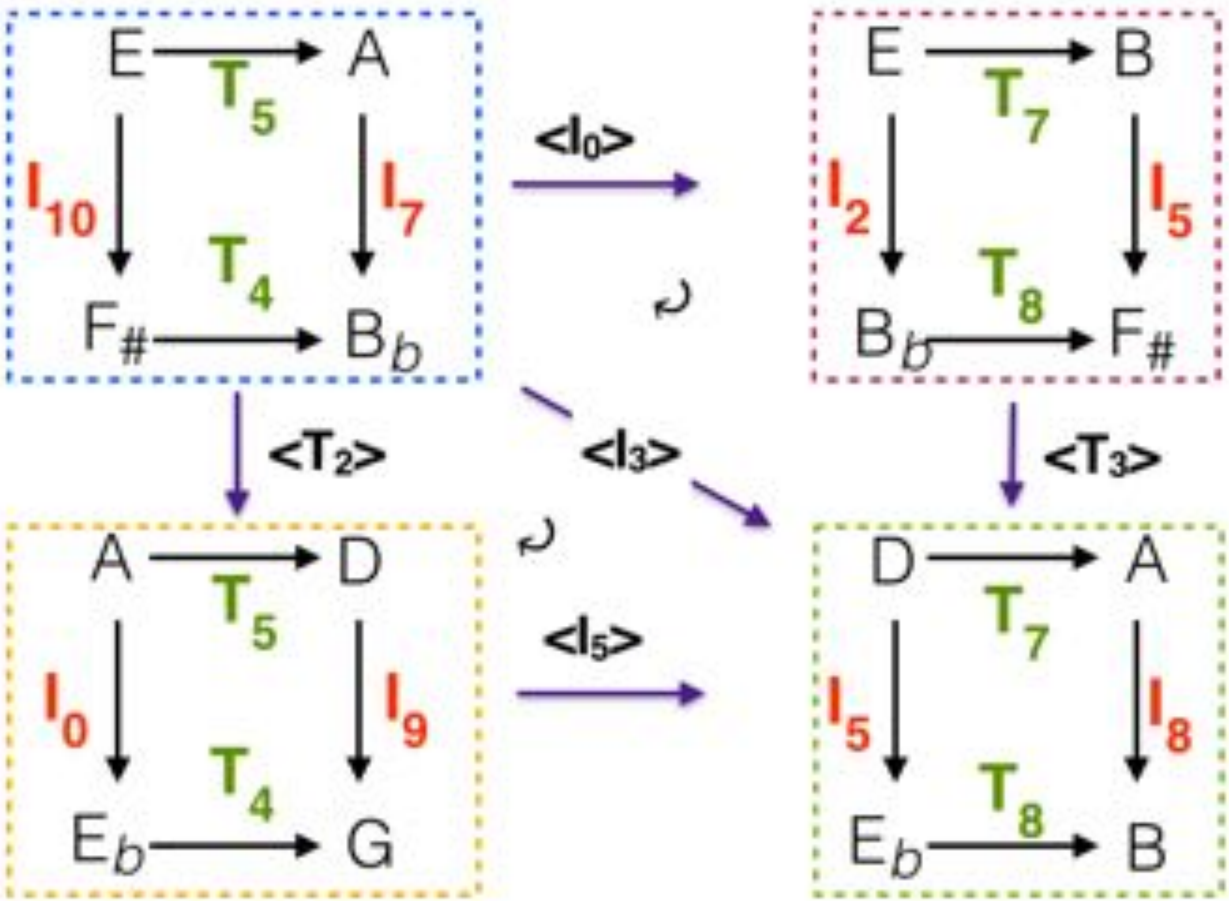
D. Lewin

H. Klumpenhouwer

$\langle T_k \rangle : T_m \to T_m$
$\qquad\quad I_m \to I_{k+m}$

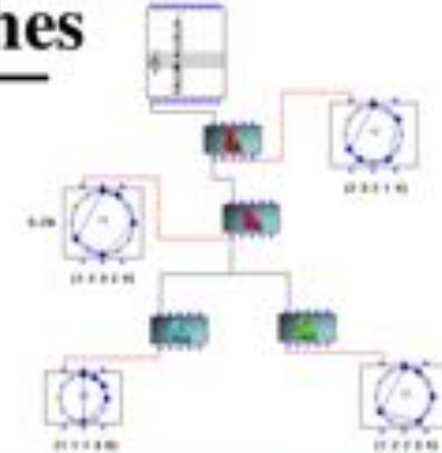
$\langle I_k \rangle : T_m \to T_{-m}$
$\qquad\quad I_m \to I_{k-m}$

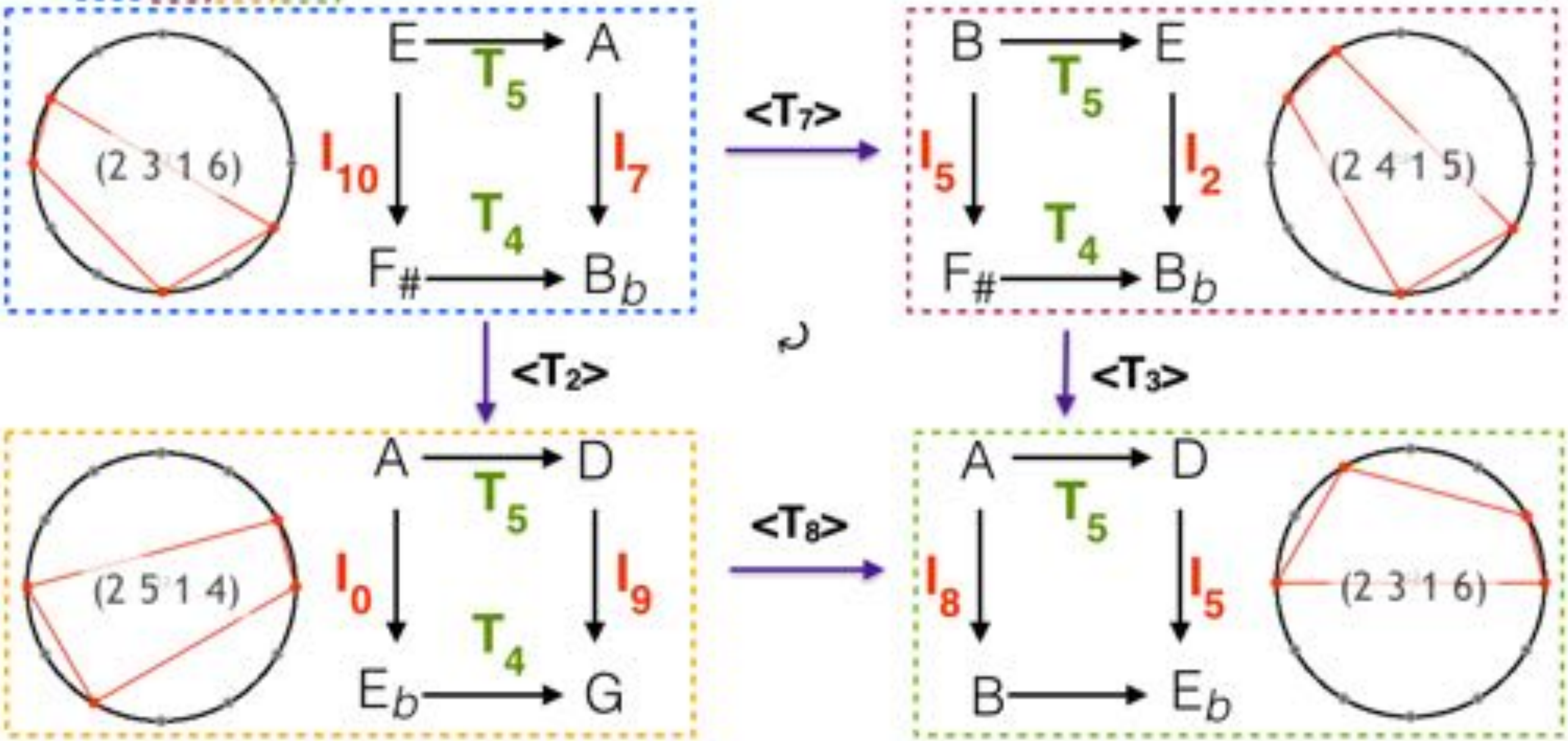
$\langle T_k \rangle \cdot \langle T_m \rangle = \langle T_{k+m} \rangle$
$\langle T_k \rangle \cdot \langle I_m \rangle = \langle I_{m-k} \rangle$
$\langle I_m \rangle \cdot \langle T_k \rangle = \langle I_{k+m} \rangle$
$\langle I_k \rangle \cdot \langle I_m \rangle = \langle T_{m-k} \rangle$



Transformational *vs* set-theoretical approaches

D. Lewin, "A Tutorial on K-nets using the Chorale in Schoenberg's Op.11, N°2 », *JMT*, 1994

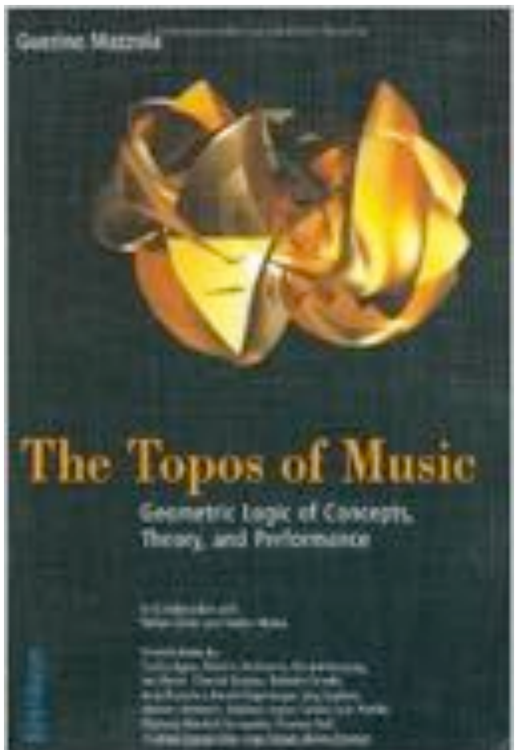


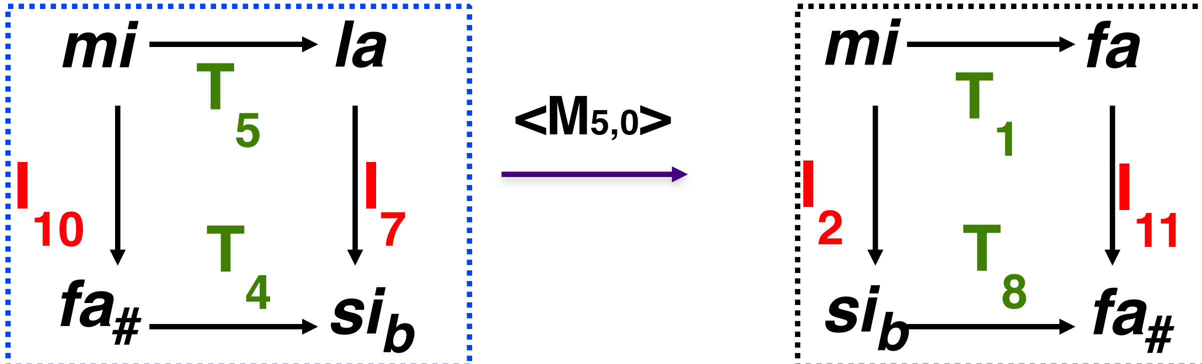


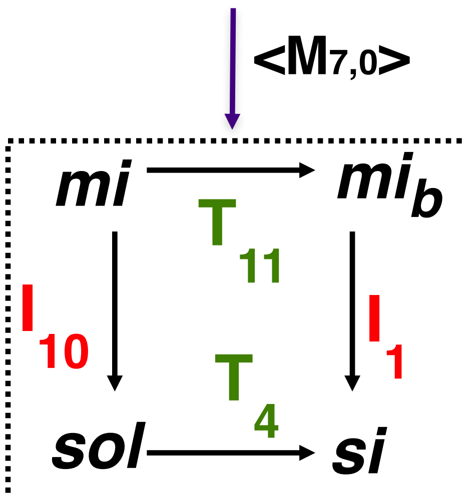
Affine isographies

$\langle M_{5,k}\rangle : T_m \rightarrow T_{5m}$
$I_m \rightarrow I_{k+5m}$

$\langle M_{7,k}\rangle : T_m \rightarrow T_{7m}$
$I_m \rightarrow I_{k+5m}$





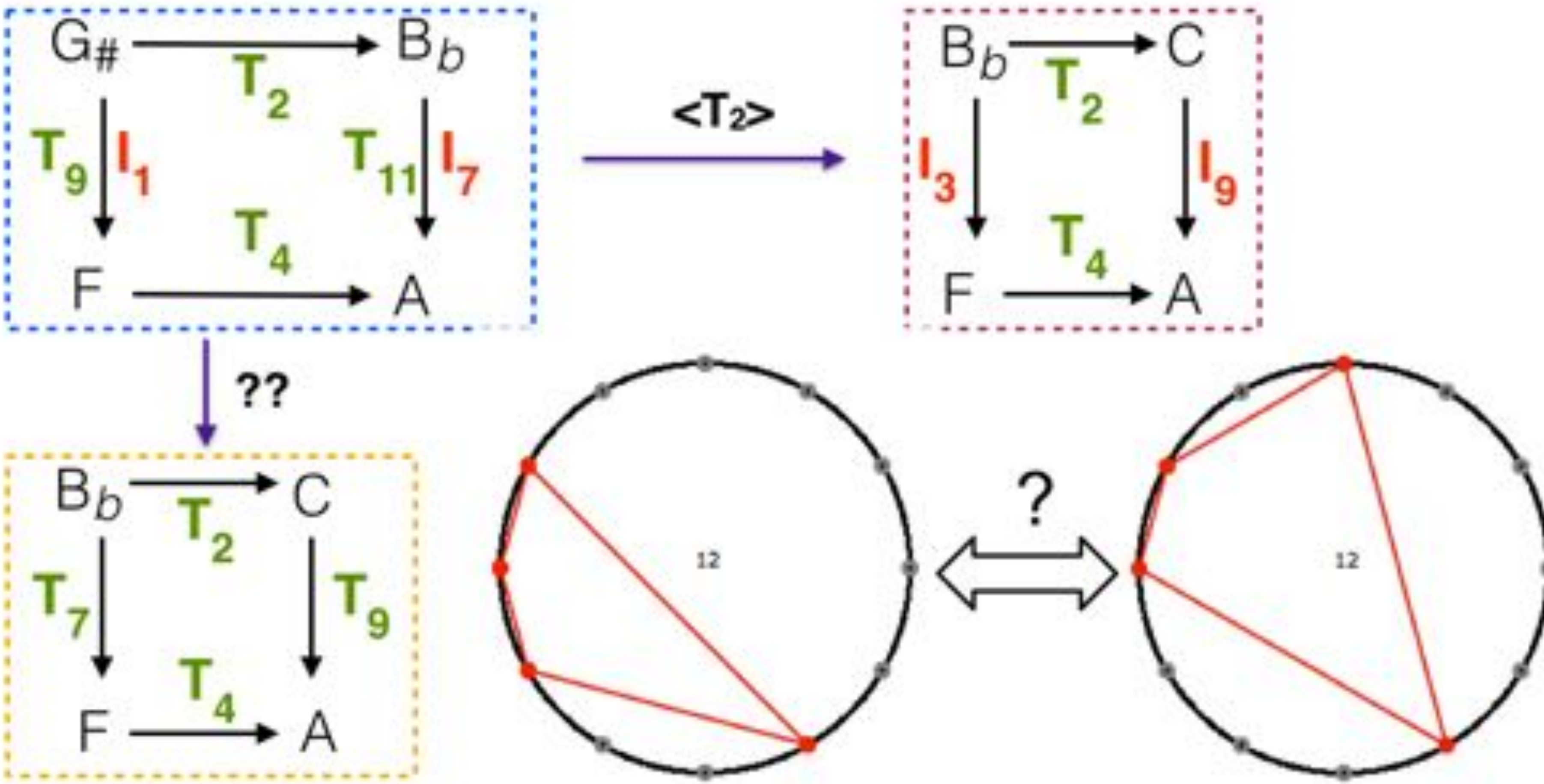


D. Lewin

H. Klumpenhouwer

G. Mazzola

Some theoretical difficulties with the isographic relations

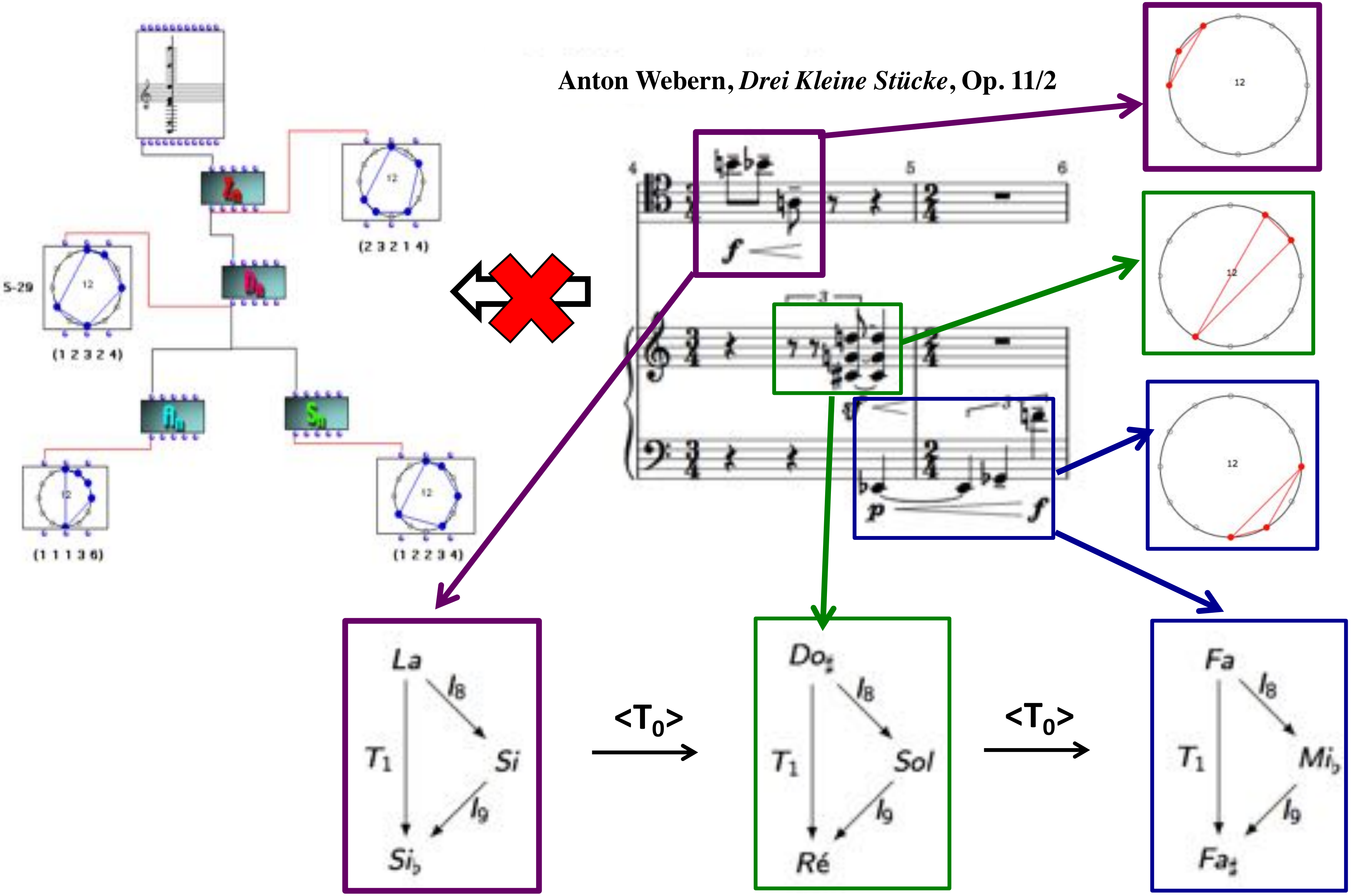


CONCLUSION

There are K-Nets which are not always isographic to a given one, i.e. the isographic relations are highly sensitives to the transformations used to label the arrows.

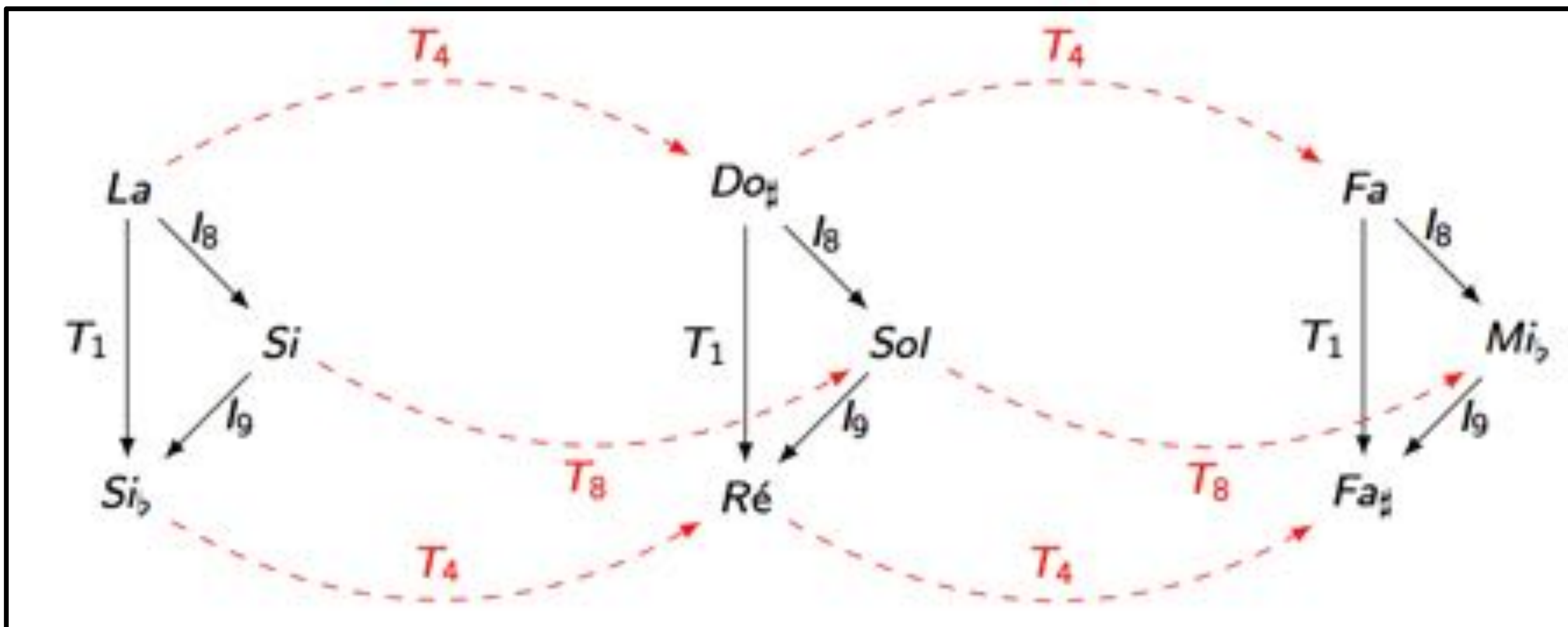
Is it possible to overstep this theoretical limitation? Which new definition of K-nets allows one to do that?

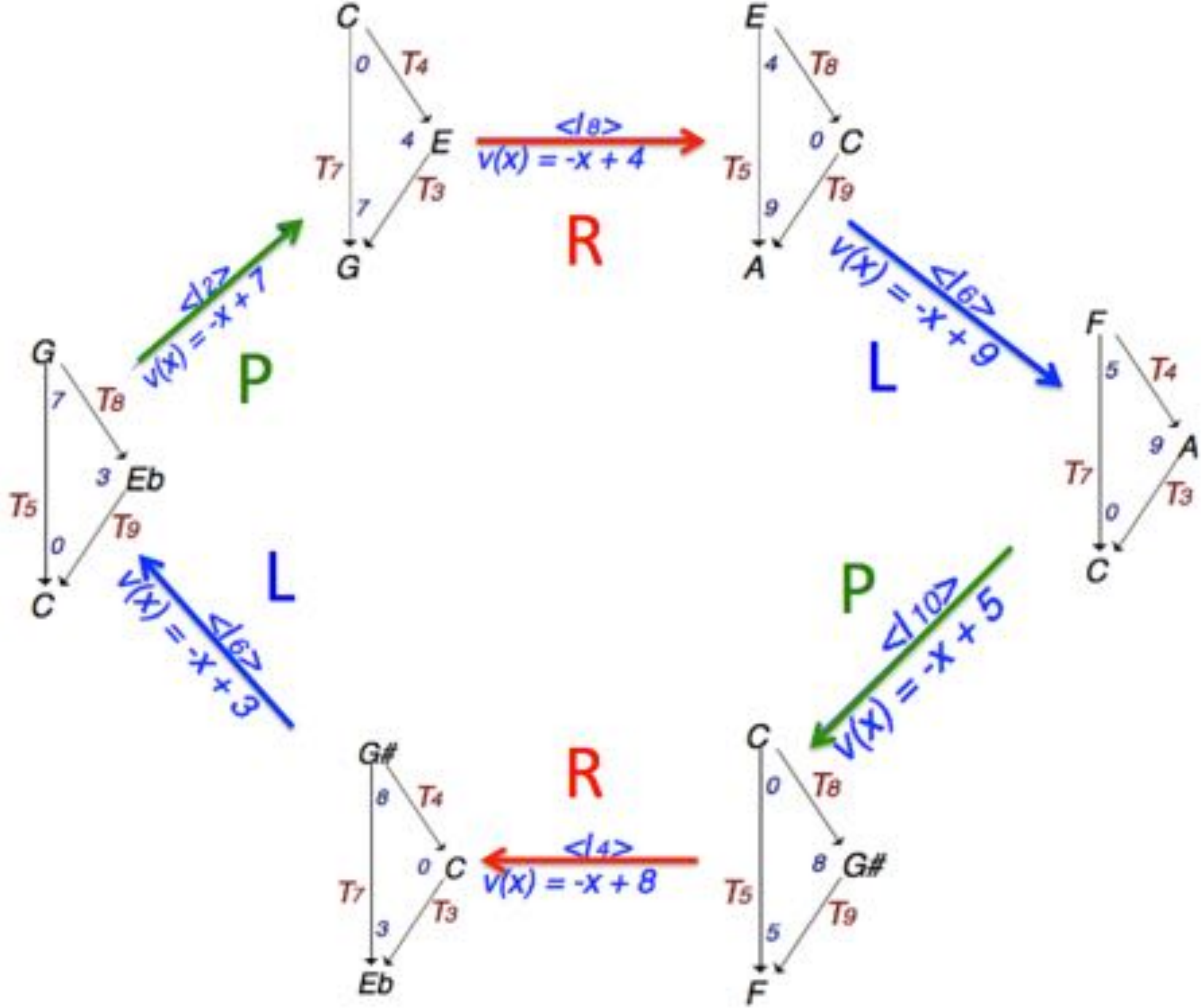
K-Nets and the paradigmatic approach

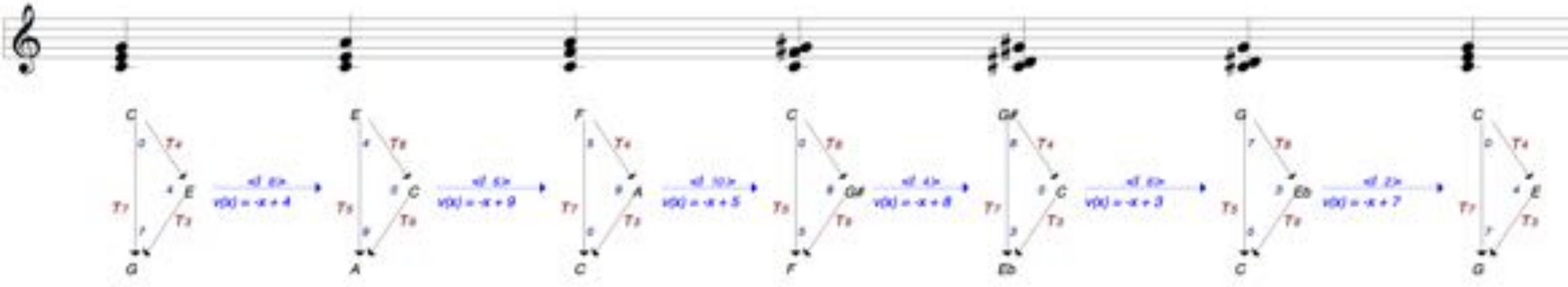


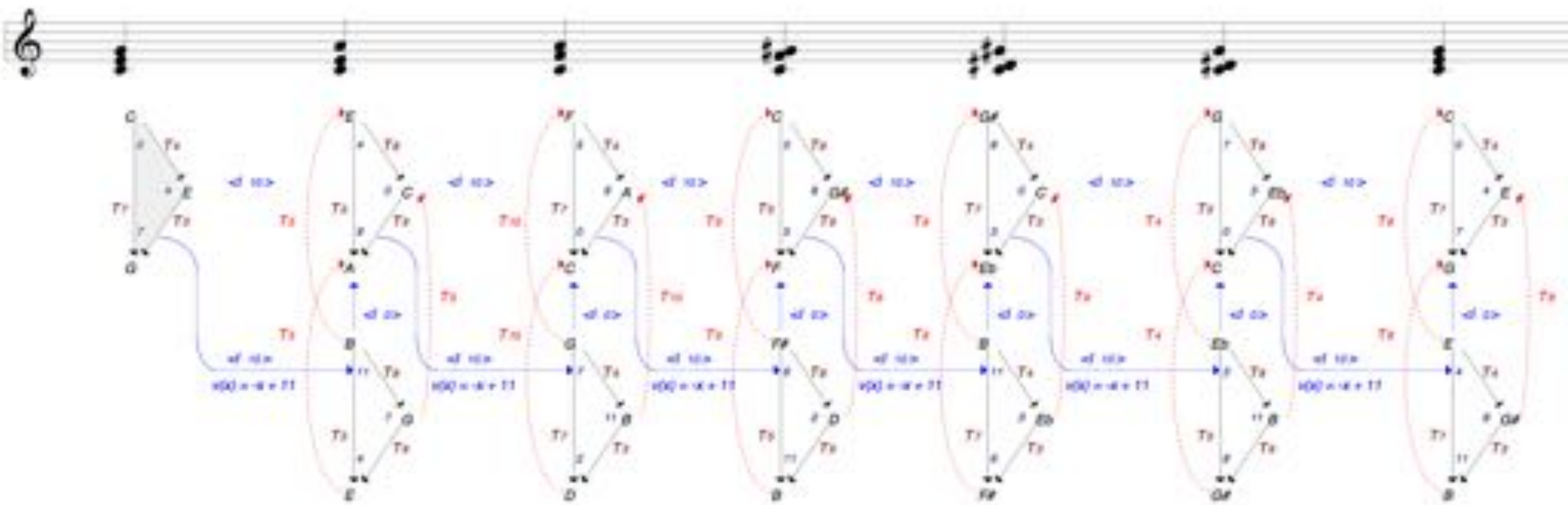
Local isographies: node-to-node applications

Webern, *Drei Kleine Stücke*, Op. 11/2




C
0
T4
4 E
T7
7
T3
G
<I8>
v(x) = -x + 4
R
E
4
T8
0 C
T5
9
T9
A
v(x) = -x + 9
<I6>
L
F
5
T4
9 A
T7
0
T3
C
P
<I10>
v(x) = -x + 5
C
0
T8
8 G#
T5
5
T9
F
R
<I4>
v(x) = -x + 8
G#
8
T4
0 C
T7
3
T3
Eb
L
<I6>
v(x) = -x + 3
G
7
T8
3 Eb
T5
0
T9
C
P
<I2>
v(x) = -x + 7


v(x) = -x + 4
v(x) = -x + 9
v(x) = -x + 5
v(x) = -x + 8
v(x) = -x + 3
v(x) = -x + 7


v(x) = -x + 11
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v(x) = -x + 11
v(x) = -x + 11
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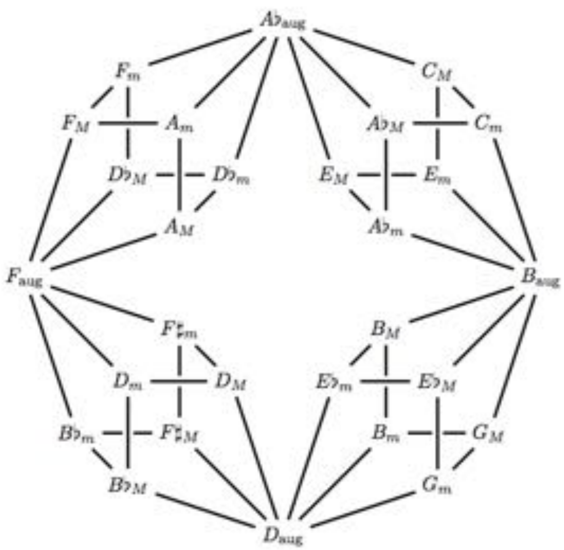
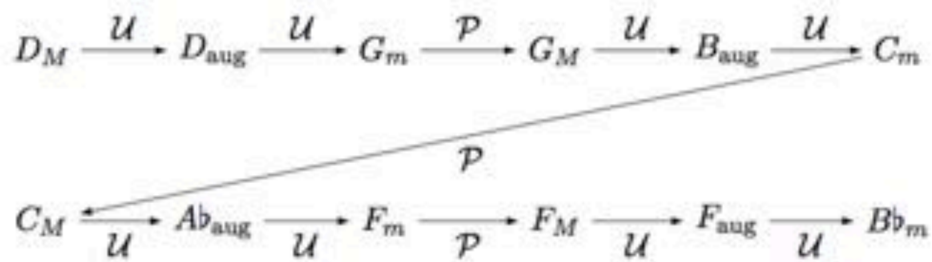
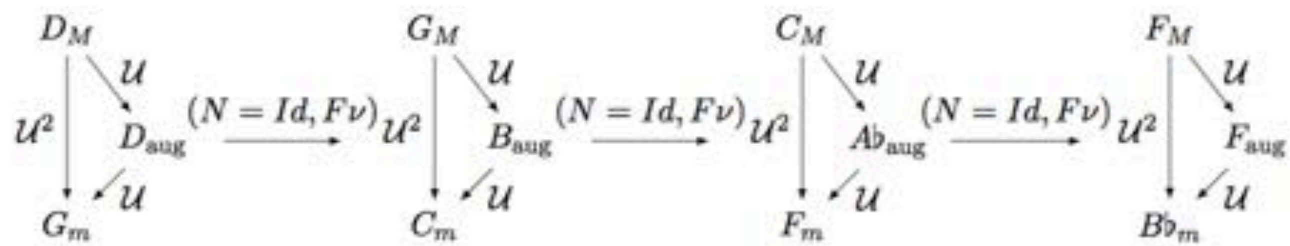


(a)



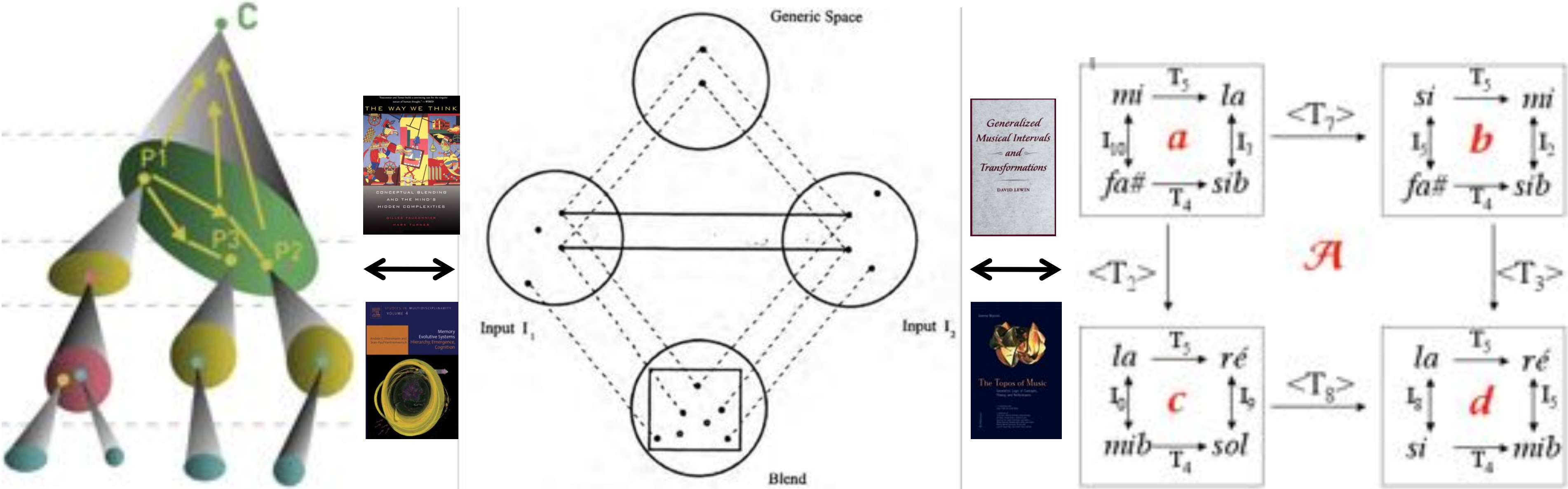
(b)



(c)

Figure 11. (a) Reduction of the opening progression of *Take A Bow* from Muse (the first twelve chords are represented here). (b) First transformational analysis in the $M_{\mathcal{UPL}}$ monoid showing the sequential regularity of the progression. (c) Second transformational analysis in the $M_{\mathcal{UPL}}$ monoid showing the successive transformations of the initial three-chord cell by the homography $(N = Id, F\nu)$ with $\nu(n_M) = (n+5)_M$, $\nu(n_m) = (n+5)_m$, and $\nu(n_{\text{aug}}) = (n + 1 \pmod 4)_{\text{aug}}$.

Towards a categorical explanation of music perception?



(a) **(b)** **(c)**

(a) Processus de « colimite » à la base des systèmes évolutifs à mémoire (Ehresmann et Vanbremeersch, 2007) ; (b) réseau minimal pour le « blending conceptuel » (Fauconnier & Turner, 2002) et exemple de Klumpenhouwer Network (ou *K-net*).

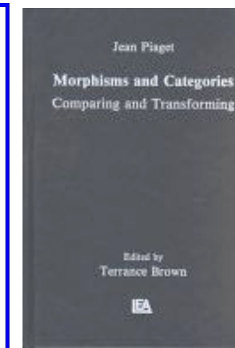
« La **théorie des catégories** est une théorie des constructions mathématiques, qui est macroscopique, et procède d'étage en étage. Elle est un bel exemple d'**abstraction réfléchissante**, cette dernière reprenant elle-même un principe constructeur présent dès le stade sensori-moteur. Le **style catégoriel** qui est ainsi à l'image d'un aspect important de la **genèse des facultés cognitives**, est un style adéquat à la description de cette genèse »

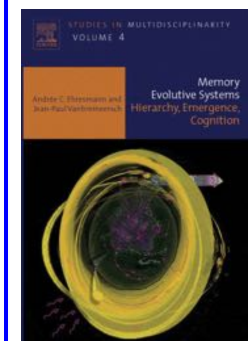
J. Piaget

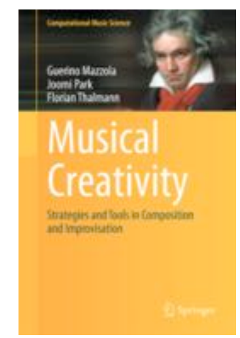
Jean Piaget, Gil Henriques et Edgar Ascher, *Morphismes et Catégories. Comparer et transformer*, 1990

Category Theory and Cognition

- G. S. Halford & W. H. Wilson, "A Category Theory Approach to Cognitive Development", *Cognitive Psychology*, 12, 1980
- **J. Piaget, Gil Henriques et Edgar Ascher, *Morphisms and Categories: Comparing and Transforming* (orig. French, 1990)**
- J. Macnamara & G. E. Reyes, *The Logical Foundation of Cognition*, OUP, 1994
- A. Ehresmann, J.-P Vanbremeerch, *Memory Evolutive Systems, Hierarchy, Emergence, Cognition*, 2007
- **A. Ehresmann, J.-P. Vanbremeerch, "MENS, a mathematical model for cognitive systems", *Journal of Mind Theory*, 2009**
- S. Phillips, W. H. Wilson, "Categorial Compositionality: A Category Theory Explanation for the Systematicity of Human Cognition", PLoS Comp. Biology, 6(7), July 2010
- S. Phillips, W. H. Wilson, "Categorial Compositionality II: Universal Constructions and a General Theory of (Quasi-)Systematicity in Human Cognition, PLoS Comp. Biology, 7(8), August 2011
- A. Ehresmann, "MENS, an Info-Computational Model for (Neuro-)cognitive Systems Capable of Creativity", *Entropy*, 2012
- **G. Mazzola, *Musical Creativity*, Springer, 2012**
- M. Andreatta, Andreatta M., A. Ehresmann, R. Guitart, G. Mazzola, "Towards a categorical theory of creativity", Fourth International Conference, MCM 2013, McGill University, Montreal, June 12-14, 2013, Springer, 2013.



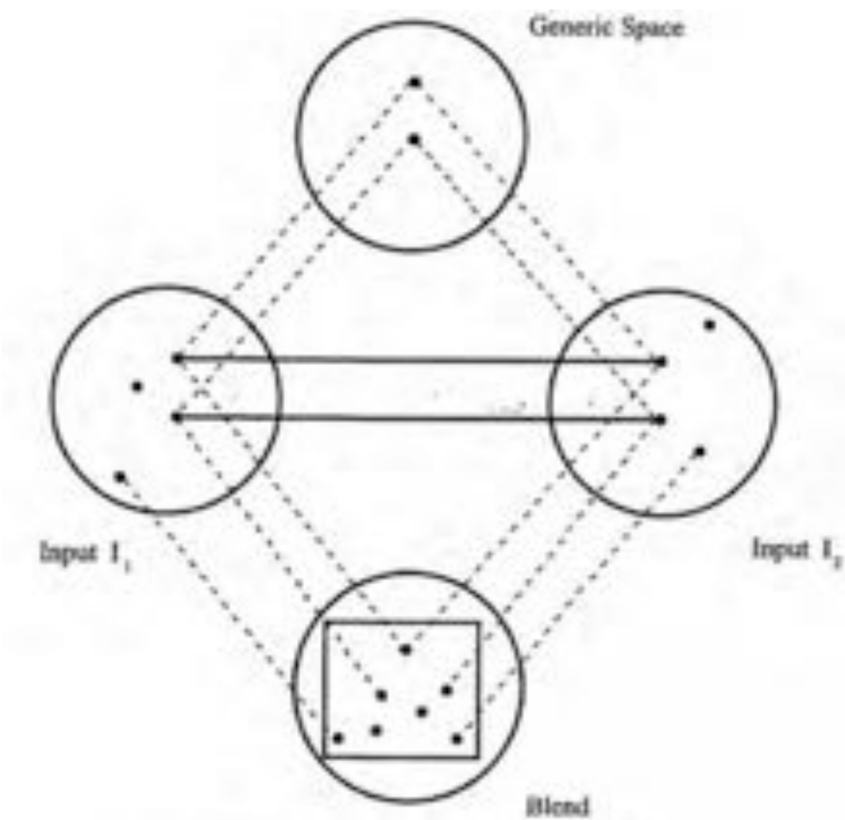




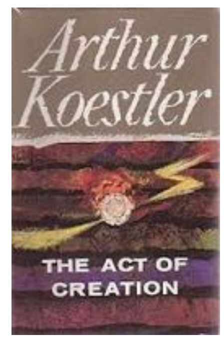
Category theory offers a re-conceptualization for cognitive science, analogous to the one that Copernicus provided for astronomy, where representational states are no longer the center of the cognitive universe —replaced by the relationships between the maps that transform them [S. Phillips, W. H. Wilson, 2010].

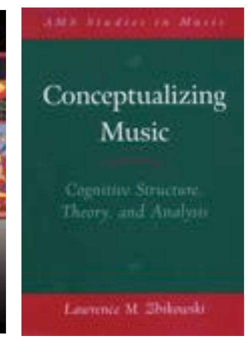
Creative processes and conceptual blending

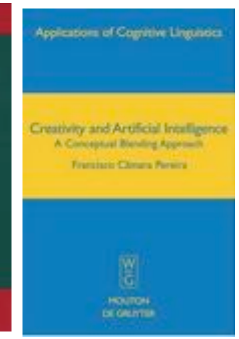
- A. Koestler, *The act of creation,* 1964
- **L. Zbikowski, « Seeger's Unitary Field Theory Reconsidered ». In: Yung, Bell & Helen Rees (eds). *Understanding Charles Seeger, Pioneer in American Musicology*. Illinois: University of Illinois Press. 1999: 130-149.**
- G. Fauconnier & M. Turner, *The Way We Think*, 2002
- L. Zbikowski, *Conceptualizing Music: Cognitive Structure, Theory, and Analysis*, 2002
- F. C. Pereira, *Creativity and Artificial Intelligence - A Conceptual Blending Approach*, 2007



Minimal network for the *conceptual blending* [Fauconnier & Turner, 2002]







[…] Conceptual Blending is as an elaboration of other works related to creativity, namely Bisociation, Metaphor and Conceptual Combination. As such, it attracts the attention of computational creativity modelers and, regardless of how Fauconnier and Turner describe its processes and principles, it is unquestionable that there is some kind of blending happening in the creative mind.

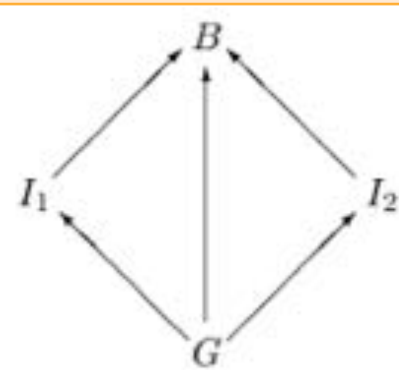
F. C. Pereira, *Creativity and Artificial Intelligence - A Conceptual Blending Approach*, 2007

From conceptual to structural blending

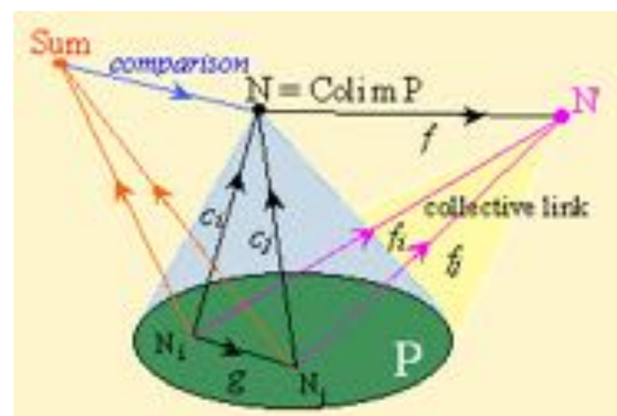
- J. Goguen, « A Categorical Manifesto », *Math. Structures in Computer Science*, 1991.
- J. Goguen, « An Introduction to Algebraic Semiotics, with Applications to User Interface Design », 1999
- **J. Goguen, « Musical Qualia, Context, Time, and Emotion », in *Journal of Consciousness Studies* 11, 3/4, 117-147, 2004**
- J. Goguen, « What is a Concept? », *International Conference on Comp. Science*, 2005
- A. Ehresmann, J.-P Vanbremeerch, Memory Evolutive Systems, Hierarchy, Emergence, Cognition, 2007

The **category of sign systems** with **semiotic morphisms** has some additional structure over that of a category: it is an *ordered category*, because of the orderings by quality of representation that can be put on its morphisms. This extra structure gives a richer framework for considering blends; I believe this approach captures what Fauconnier and Turner have called « emergent » structure, without needing any other machinery. [Goguen, 1999, p. 32]

Algebraic/structural semiotics

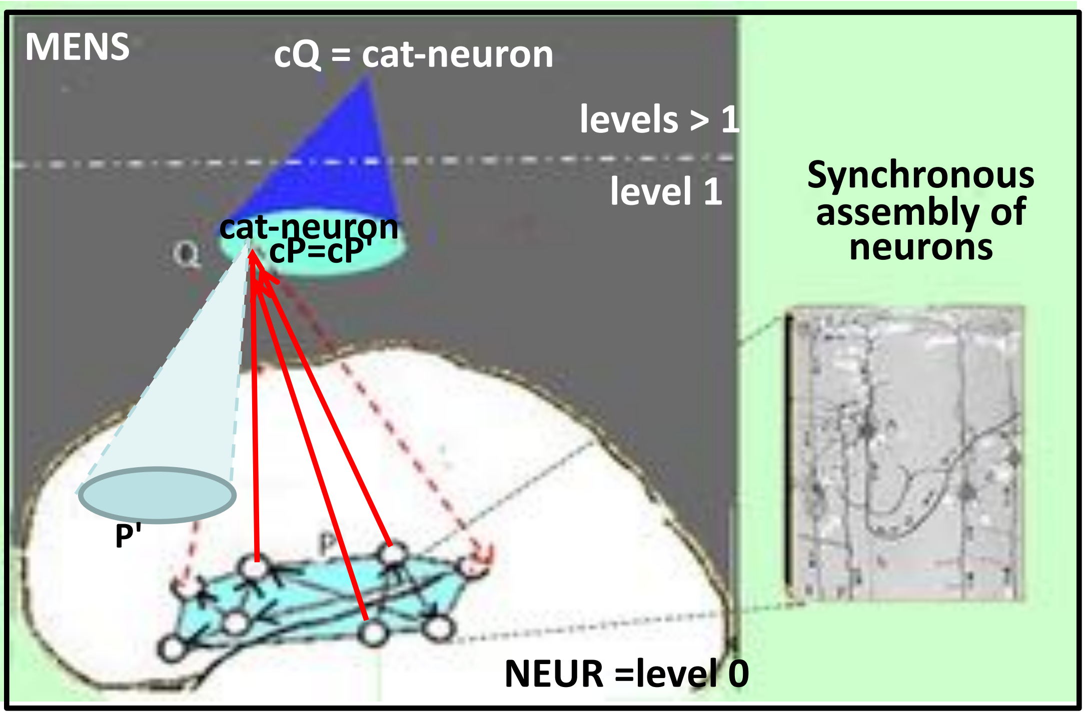


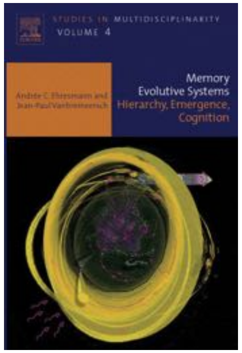
structural blending



Colimit of a diagram

The structure of Memory Evolutive Neural Systems

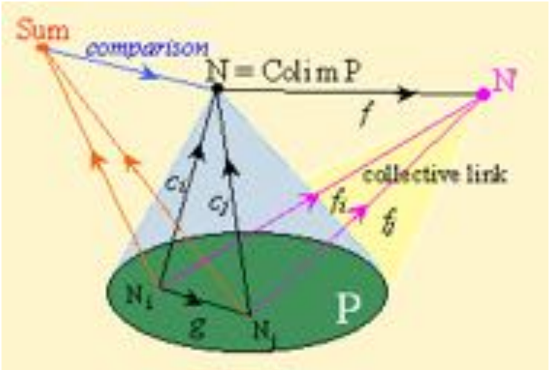




Donald Hebb

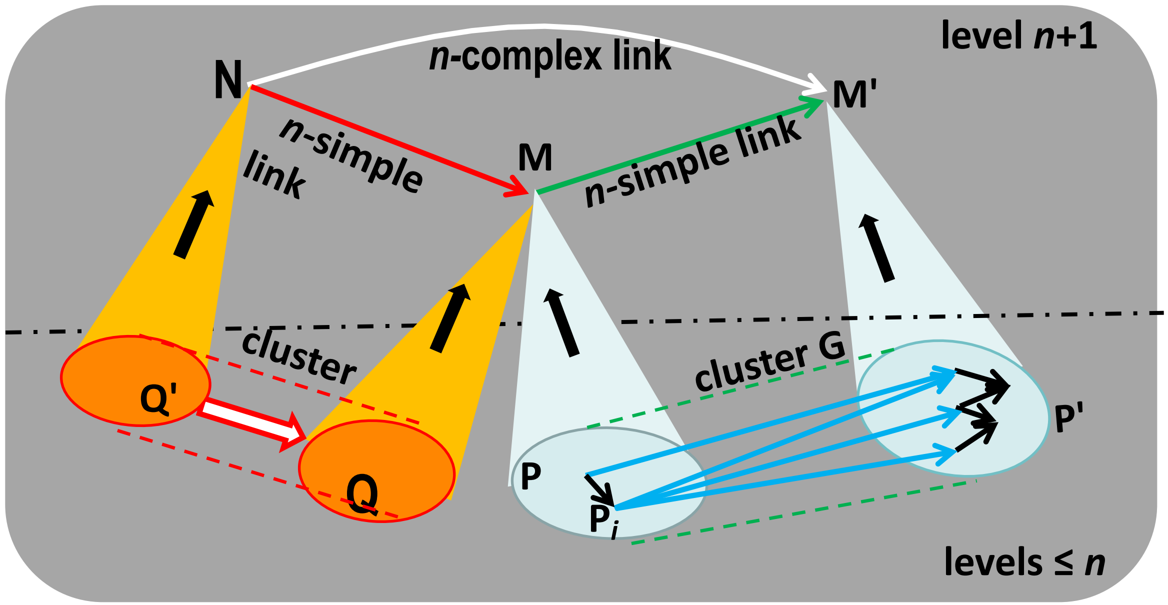
It is a MES whose level 0 is the Evolutive System of neurons NEUR. The components represent the neurons and their links are the synaptic paths.

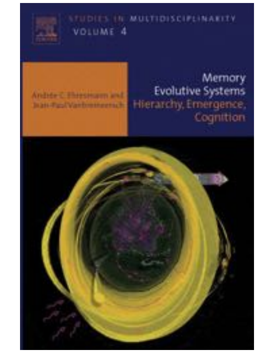
At higher levels: there are more and more complex 'conceptual' objects, called *cat(egory)-neurons*, modeling a mental object as the colimit cP = cP' of the synchronous assemblies of (cat-)neurons P , P' which activate them.



➔ **Why colimits for the study of creativity?**

Hierarchical categories and Emergence





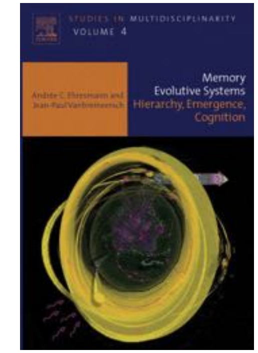
G. Edelman

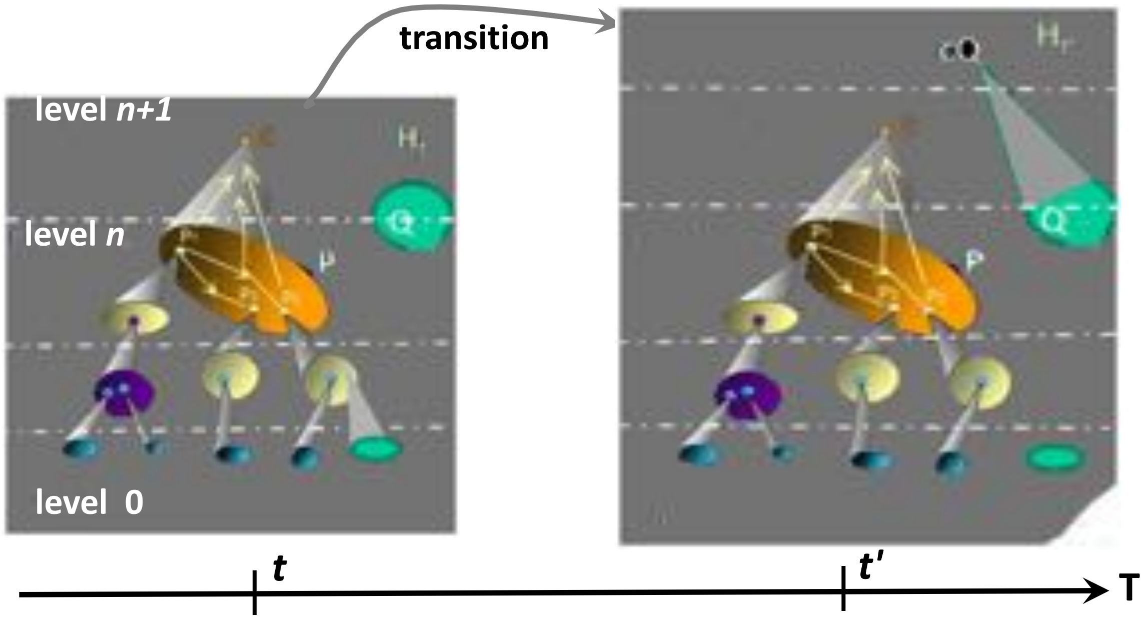
A category is *hierarchical* if its objects are partitioned into levels, so that M of level n+1 is the colimit of at least one pattern (= diagram) P of levels ≤ n.
A morphism M → M' is a (P, P')-*simple link* (or *n-simple link*) if it binds a cluster of links between decompositions P and P' of M and M' (of levels ≤ n).

Multiplicity Principle (or degeneracy principle by Edelman/Gally) = existence of *multiform objects* M which are the colimit of 2 patterns P and Q non isomorphic nor connected by a cluster; then M can switch between them. This 'flexible redundancy' gives flexibility to the system.

➔ Existence of *n-complex links* composites of n-simple links representing properties 'emerging' at level n+1.

Memory Evolutive Systems (MES)





A *MES* H consists of:

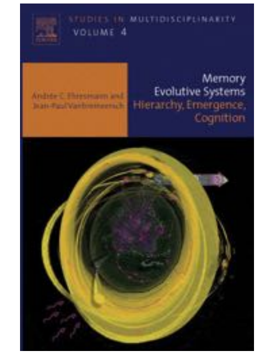
(i) a timescale T (included in R);

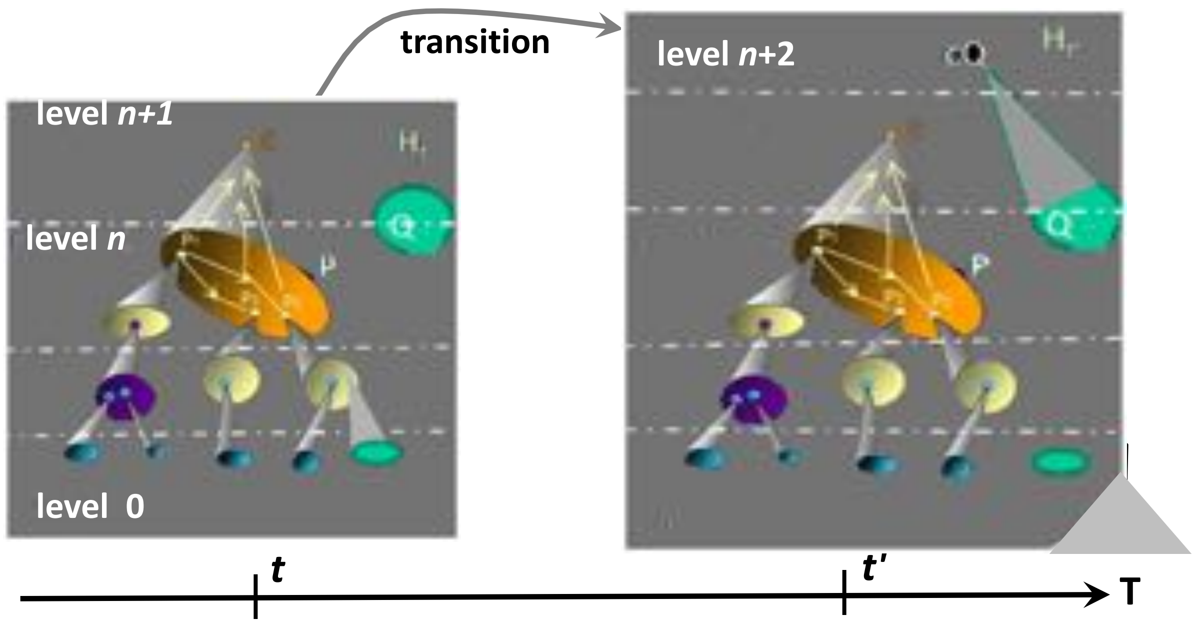
(ii) a family $(H_t)_{t \in T}$ of hierarchical categories whose objects are the states C_t at t and its morphisms represent channels transmitting information or actions;

(iii) for $t < t'$, *a transition* functor from a subcategory of H_t to $H_{t'}$. A component C is a maximal set of successive states C_t linked by transitions. Such a component C has at least one *ramification* down to level 0, and its *complexity order* is the shortest length of a ramification

The dynamic is modulated by the interactions between a net of specialized subsystems called *co-regulators* which develop a subsystem Mem acting as a long-term memory.

Complexification and Emergence Theorem





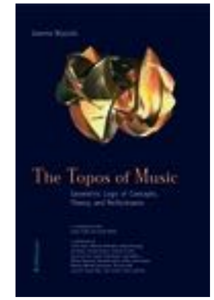
In a MES the transition from *t* to *t'* results from changes of the following types: 'adding' external elements, 'suppressing' or 'decomposing' some components, adding a colimit to some given patterns. Modeled by the *complexification process*: given a procedure Pr on H_t with objectives of the above kinds, the *complexification of* H_t for Pr is the category $H_{t'}$ in which these objectives are optimally satisfied. It is explicitly constructed in MES (2007).

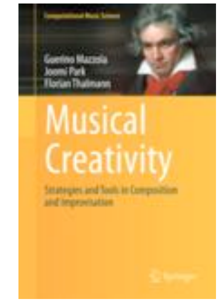
EMERGENCE THEOREM. *The Multiplicity Principle is necessary for the existence of components of complexity order > 1 and it is preserved by complexification. Two successive complexifications do not reduce to a unique one. Iterated complexifications lead to the emergence of components of increasing orders.*

Towards a categorical theory of creativity (in music, cognition and discourse)

Abstract

This article presents a first attempt at establishing a **category-theoretical model of creative processes**. The model, which is applied to musical creativity, discourse theory, and cognition, suggests the relevance of the notion of "colimit" as a unifying construction in the three domains as well as the central role played by the Yoneda Lemma in the categorical formalization of creative processes.





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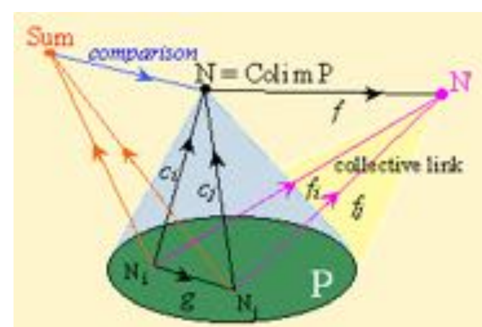
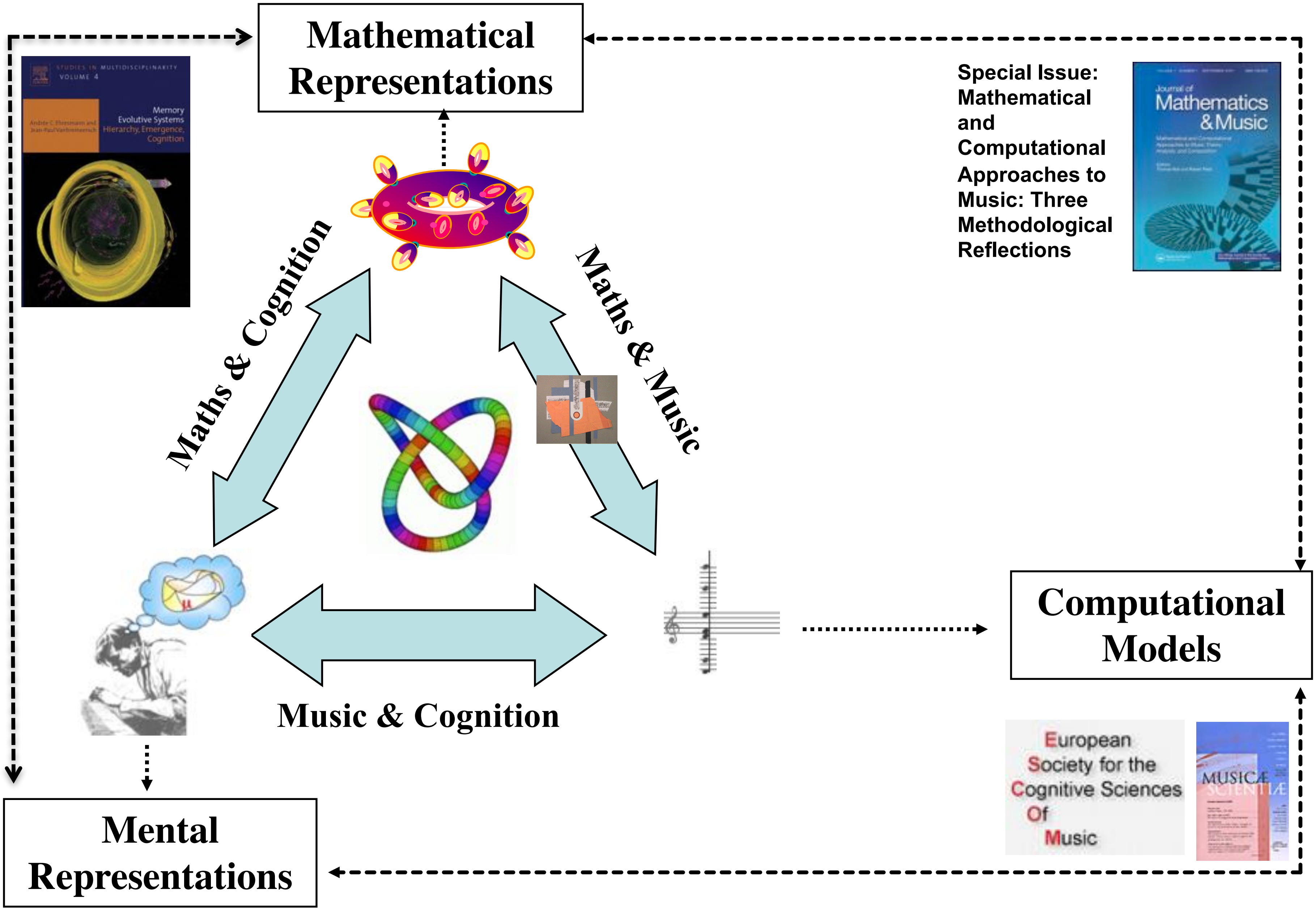
MATHEMATICS AND COMPUTATION IN MUSIC



Andreatta M., A. Ehresmann, R. Guitart, G. Mazzola, « Towards a categorical theory of creativity », Fourth International Conference, MCM 2013, McGill University, Montreal, June 12-14, 2013, Springer, 2013.

Bridging the gap: mathematical and cognitive approaches

http://recherche.ircam.fr/equipes/repmus/mamux/Cognition.html

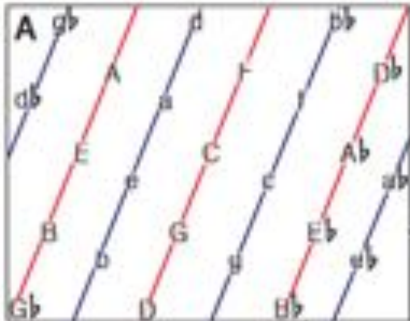


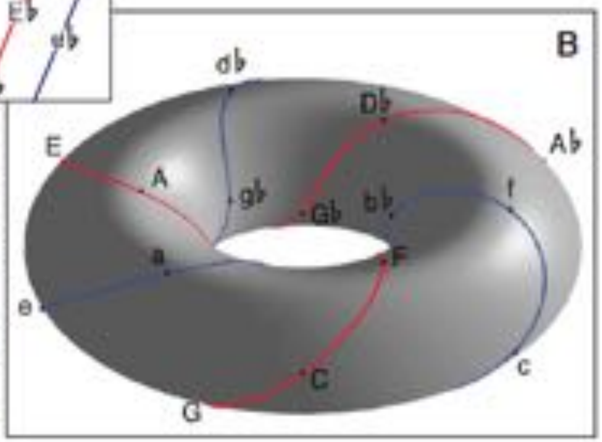
The neuronal foundation of the *Tonnetz*

PERSPECTIVES: NEUROSCIENCE

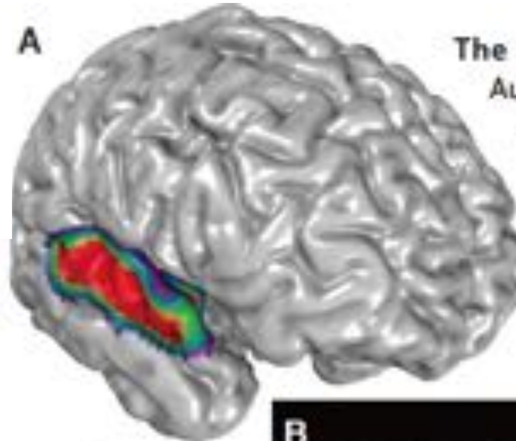
Mental Models and Musical Minds

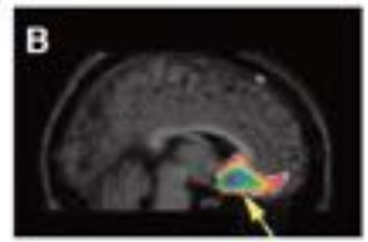
Robert J. Zatorre and Carol L. Krumhansl



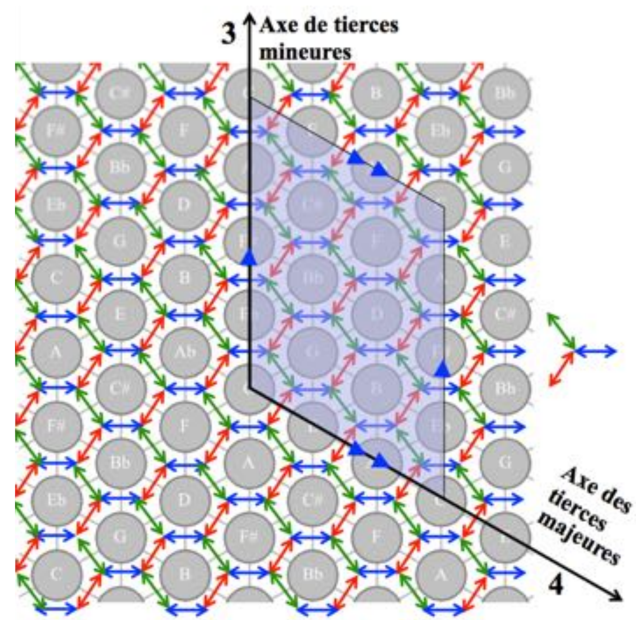


Mental key maps. (A) Unfolded version of the key map, with opposite edges to be considered matched. There is one circle of fifths for major keys (red) and one for minor keys (blue), each wrapping the torus three times. In this way, every major key is flanked by its relative minor on one side (for example,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

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