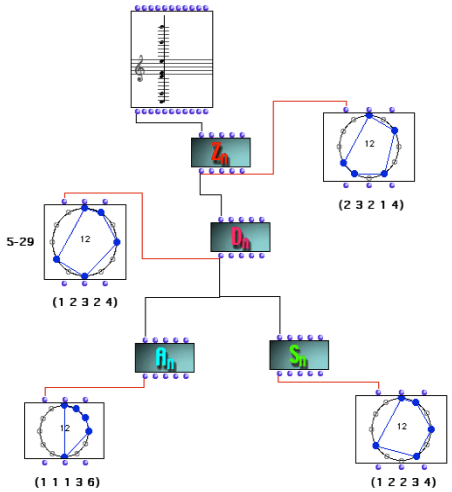
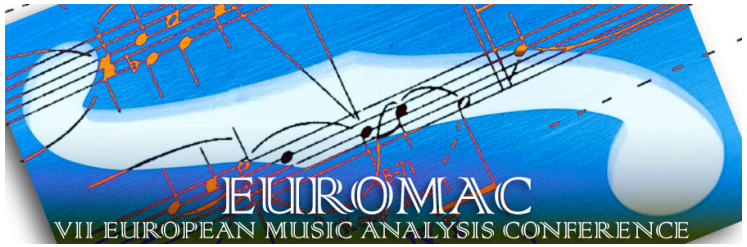
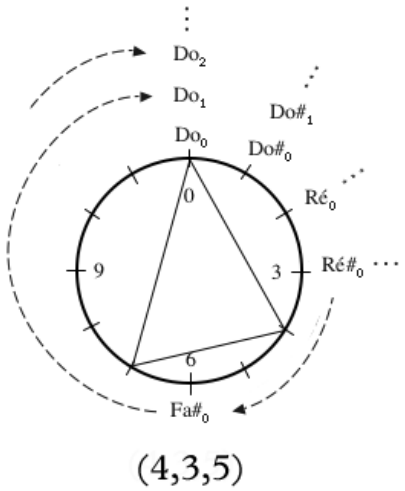






Some OpenMusic-based Computational Models in Computer-Aided Music Theory and Analysis

Carlos Agon – Moreno Andreatta
Equipe Représentations Musicales
IRCAM/CNRS

ircam Centre Pompidou

cnrs

UPMC SORBONNE UNIVERSITÉS

"MathTools": an algebraic environment within OpenMusic visual programming language

OM=♬+∑

Computational Music Theory:

- Classification and Enumeration of musical structures
  - Chords/scales, motifs and rhythms:
    - ♬ Catalogues (Costère, Zalewski, Vieru, Forte, Carter, Morris, Mazzola, Estrada, …)
    - ∑ Combinatorial algebra, Polya Enumeration Theory, Burnside Lemma, Discrete Fourier Transform
  - Rhythmic Tiling Canons (by translation, inversion and augmentation)
    - ♬ Messiaen, Vieru, Levy, Johnson, Bloch, Wild, Lanza, …
    - ∑ Group factorization theory

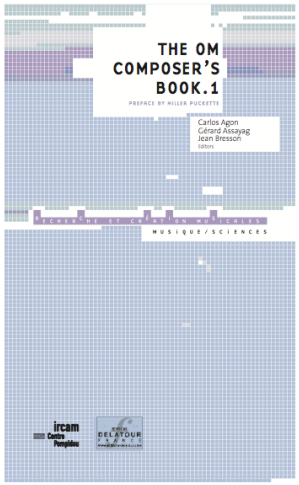
Computational Music Analysis:

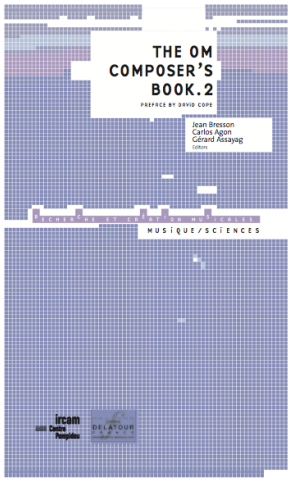
- *Set Theory,* Transformational Analysis and Sieve Theory
  - Pitch-class sets, interval vectors and IFUNC, Z-relations:
    - ♬ Carter, Vieru, Xenakis
    - ∑ Group Actions, Homometry, TFD
  - Transformational progression/network, *K-nets*
    - ♬ Generalized Interval Systems (David Lewin)
    - ∑ Group action and category theory

Computer Aided-Composition:

- Cf. *The OM Composer's Book (2 volumes).*

  Edited by C. Agon, G. Assayag and J. Bresson

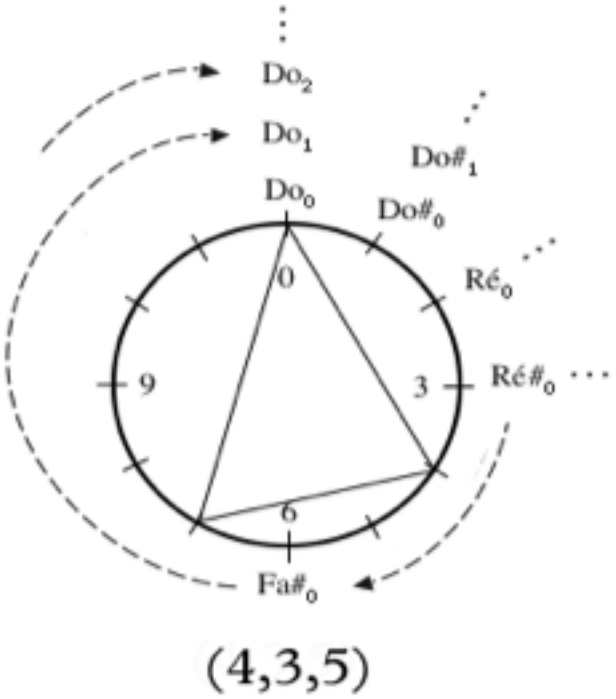




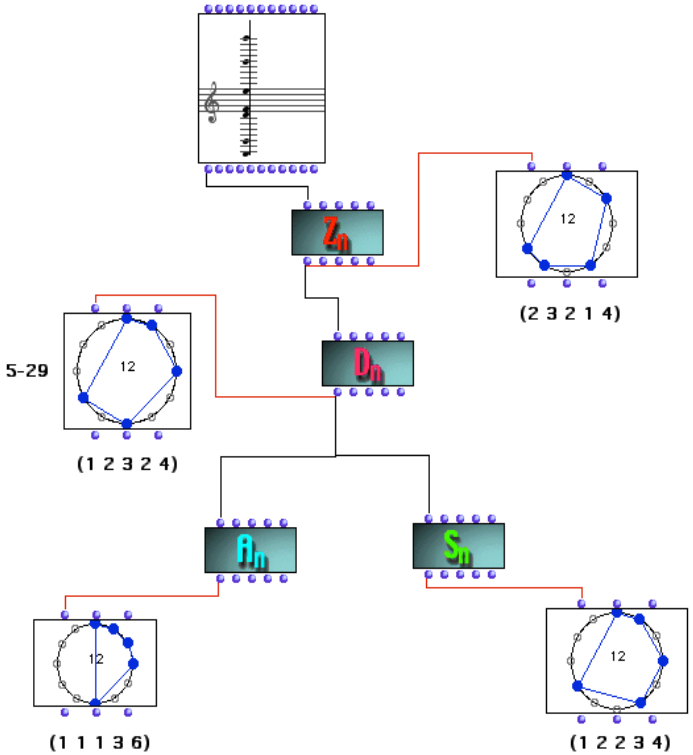
http://recherche.ircam.fr/equipes/repmus/OpenMusic/

Computational Music Theory

Classification and Enumeration of Musical Structures

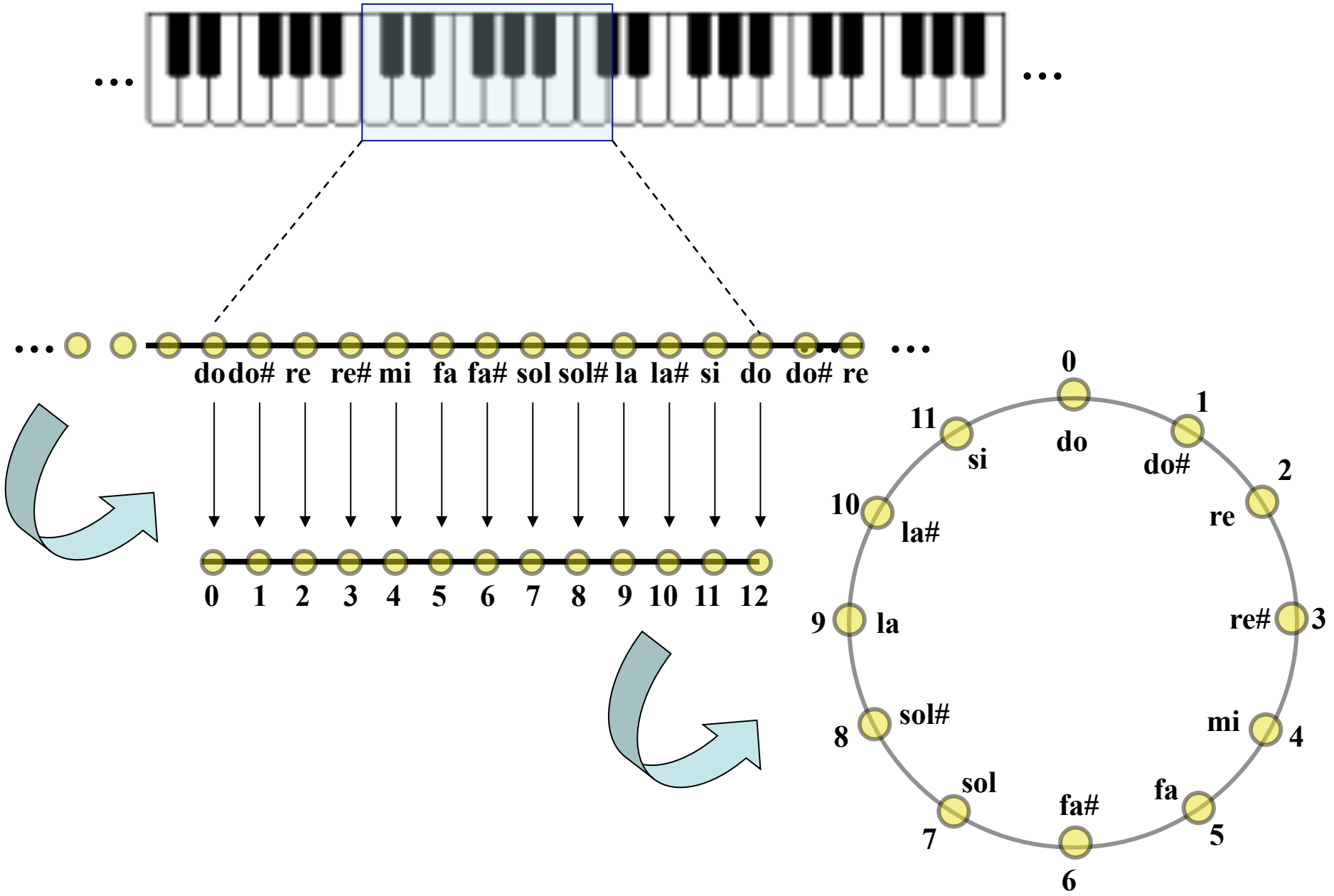


Circular representation

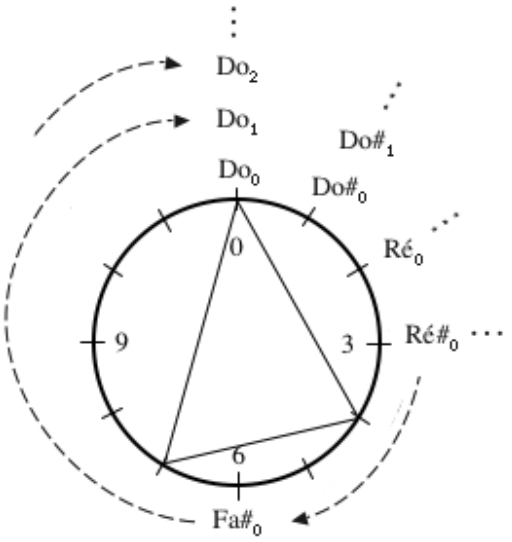


Paradigmatic architecture

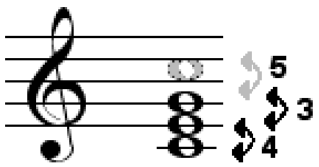
Octave equivalence and mod 12 congruence



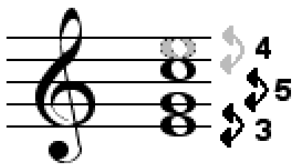
Circular representation and intervallic structure



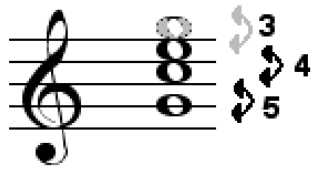
(4,3,5)



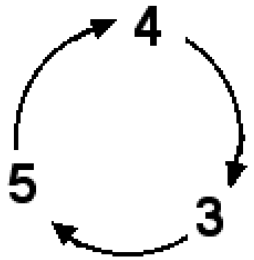
(4 3 5)

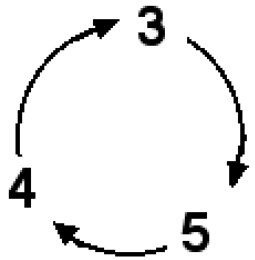


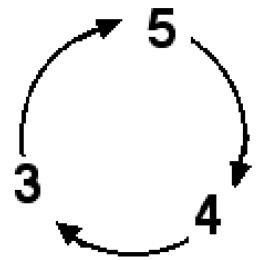
(3 5 4)



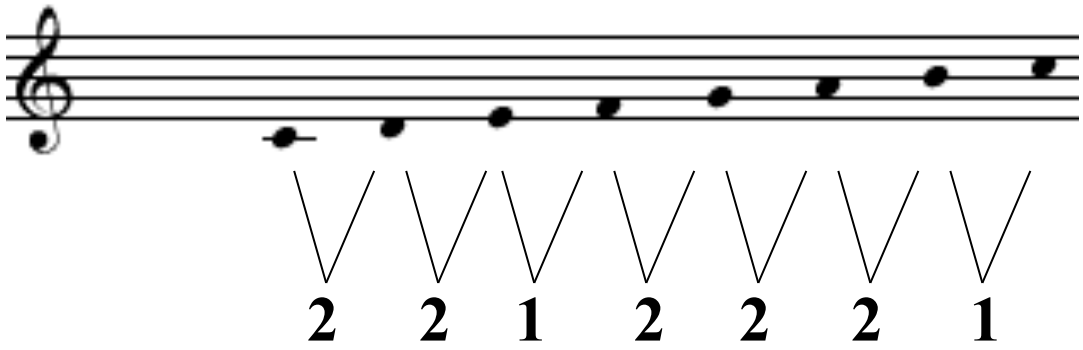
(5 4 3)

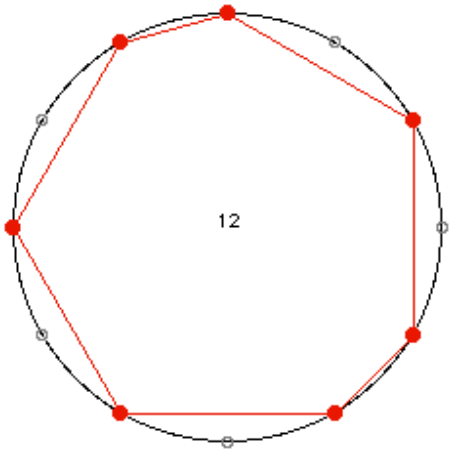






The « inversions » of a chord are all circular permutations on an intervallic structure

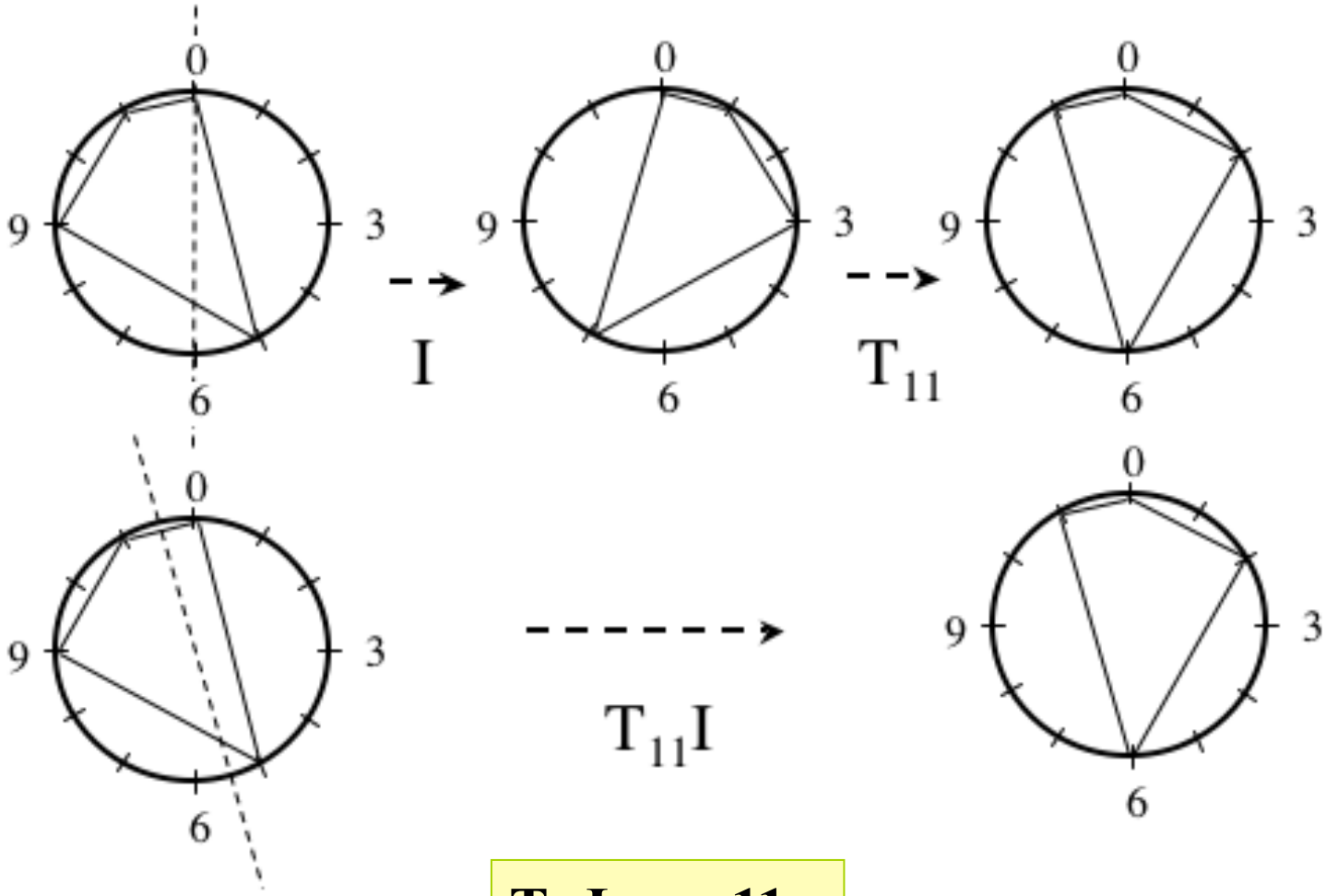




01-circular-representation

Transposition and Inversion

I: $x \rightarrow 12-x$ **T_k: $x \rightarrow k+x$**



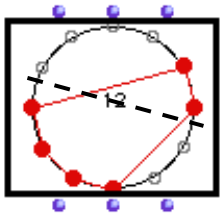
$T_{11}I$: $x \rightarrow 11-x$

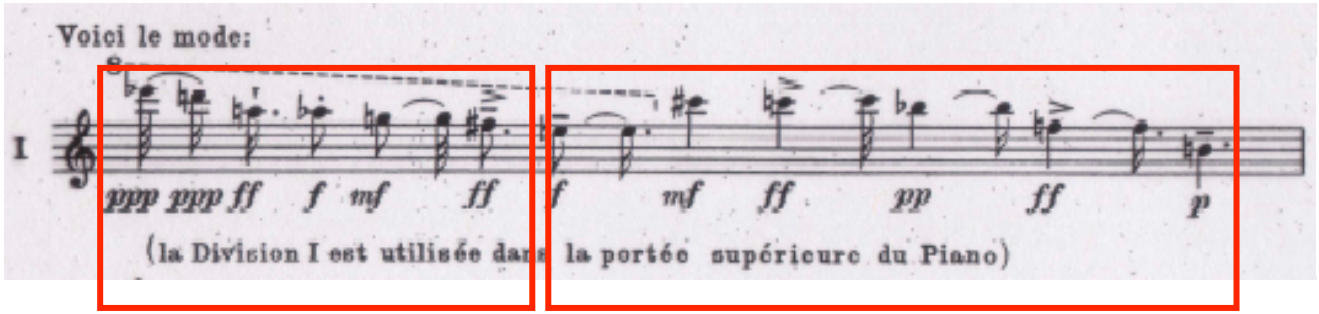
{0, 5, 9, 11} → **{11, 6, 3, 0}**

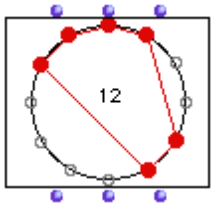
02-transp-inv

Hexachordal Combinatoriality in Messiaen

- Mode de valeurs et d'intensités (1950)







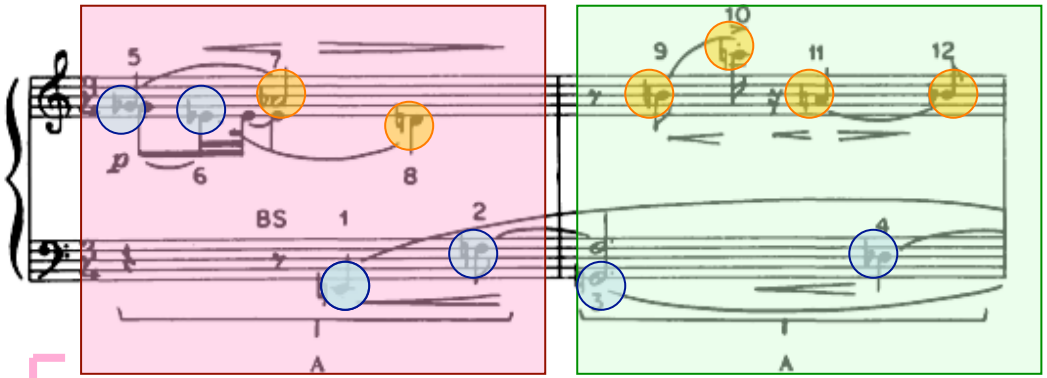
$\{3,2,9,8,7,6\} \longrightarrow \{4,5,10,11,0,1\}$

$T_7I : x \rightarrow 7\text{-}x$

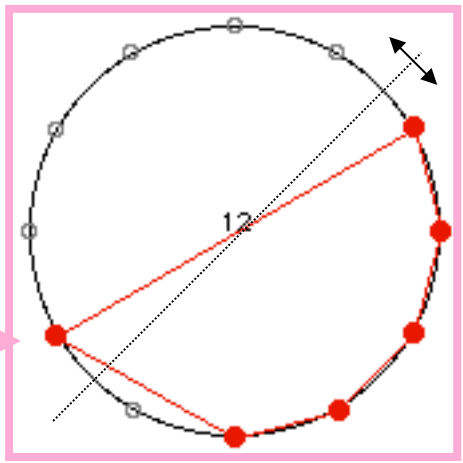
03-messiaen

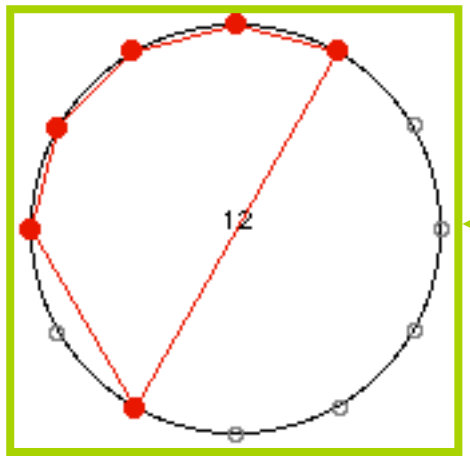
Serialisme and hexachordal combinatoriality

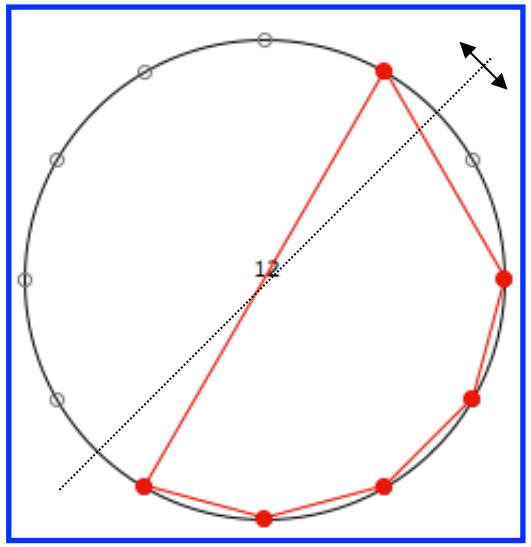
Schoenberg: Suite Op.25, Minuetto

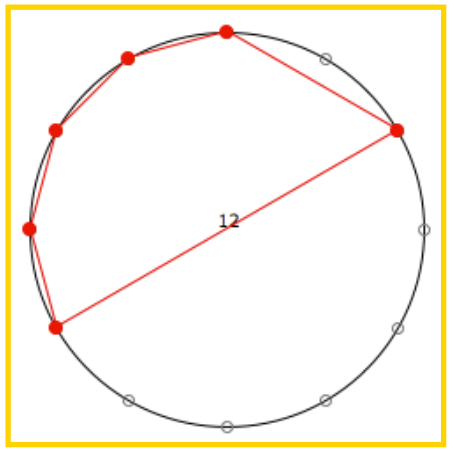


Double combinatoriality





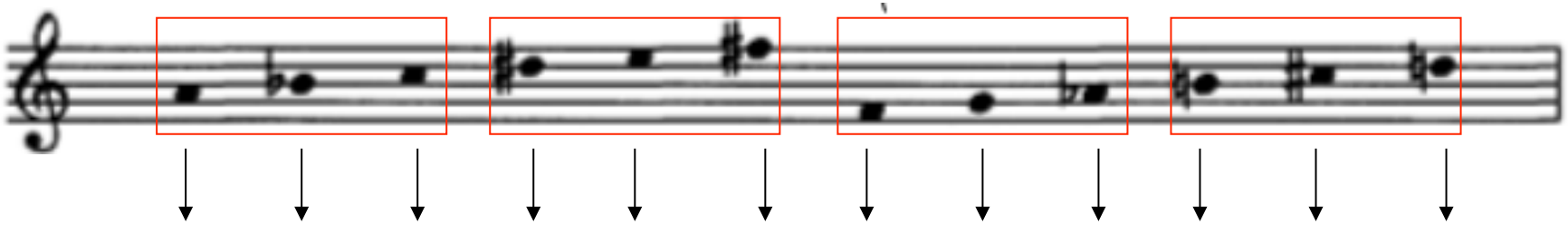




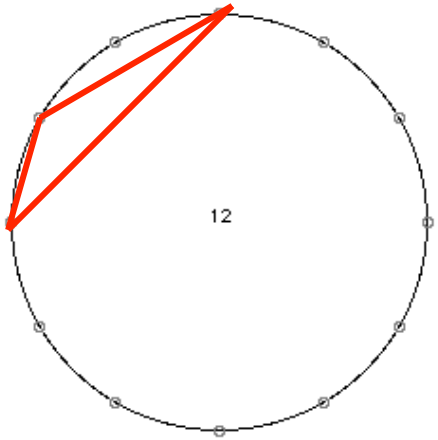
04-schoenberg-op25

Symmetries in a Twelve-Tone Row : partitioning trichords

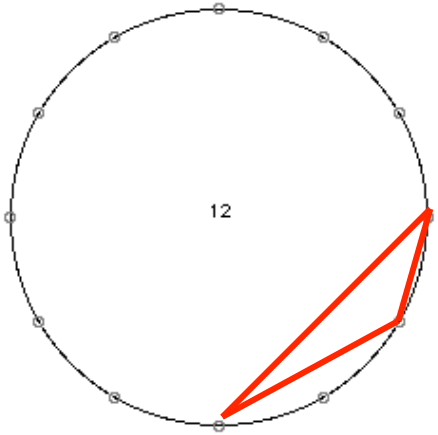
Schoenberg: Serenade Op.24, Mouvement 5



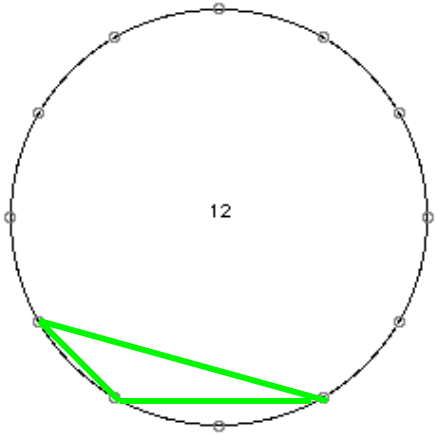
{9 , 10 , 0} {3 , 4 , 6} {5 , 7 , 8} {11 , 1 , 2}



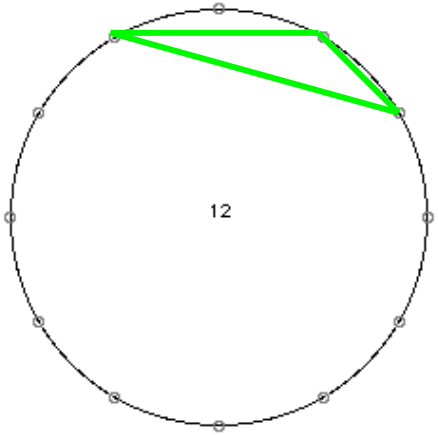
(1 , 2 , 9)



(1 , 2 , 9)



(2 , 1 , 9)



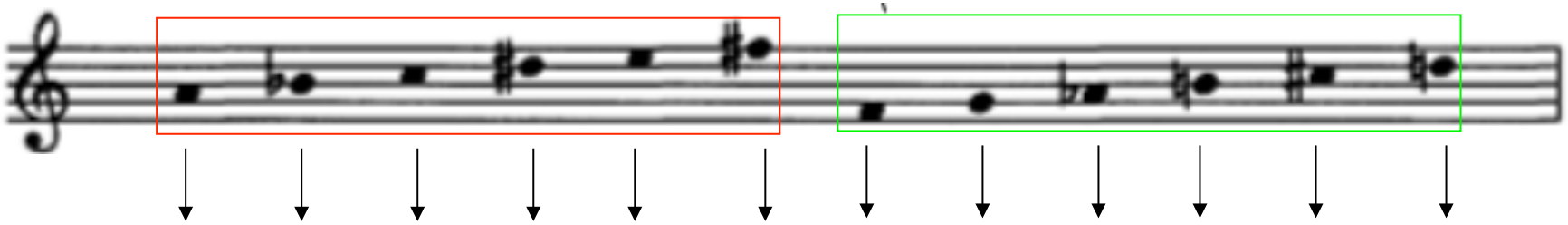
(2 , 1 , 9)

➔

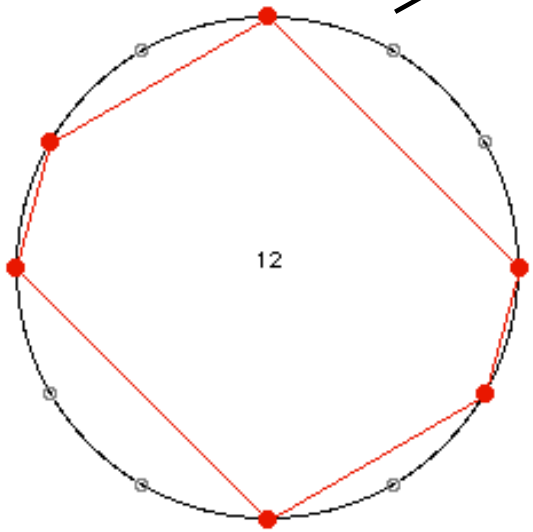
05-schoenberg-op24

Transpositional Symmetry (Messiaen's Modes)

Schoenberg: Serenade Op.24, Mouvement 5



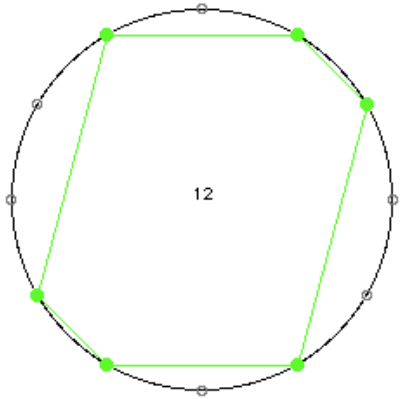
A = {9 , 10 , 0 , 3, 4 , 6} {5 , 7, 8, 11, 1, 2}



(3, 1, 2, 3, 1, 2)

T6{9,10,0,3,4,6}=
={6+9,6+10,6,6+3,6+4,6+6}=
={3,4,6,9,10,0}

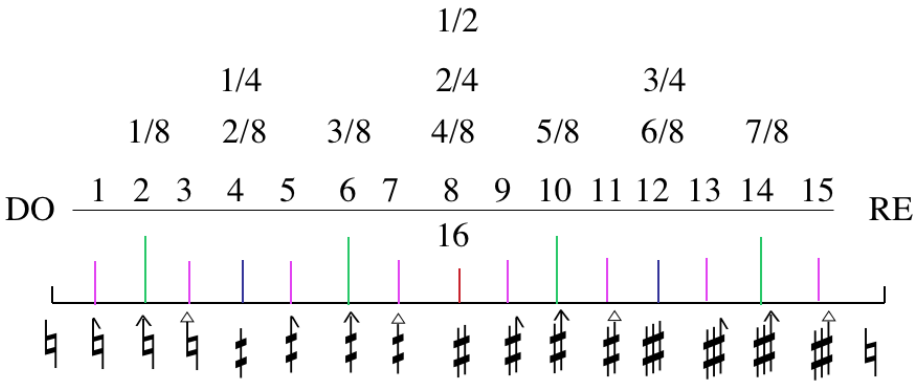
T6(A)=A

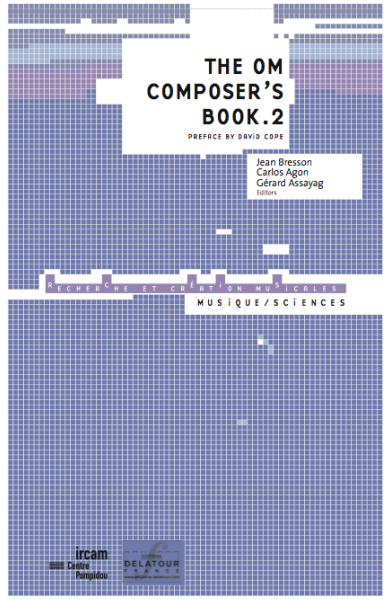


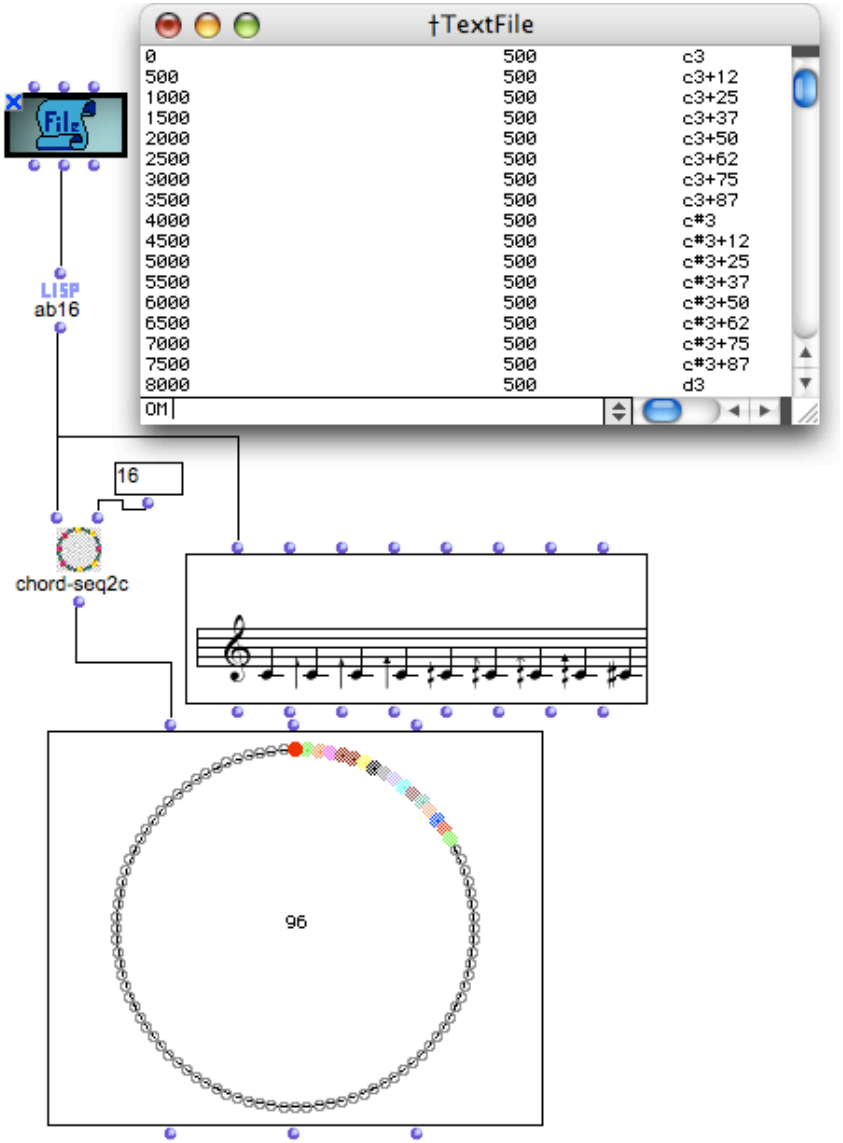
(2, 1, 3, 2, 1, 3)

06-ttl-catalogue

Microtonal composition (Alain Bancquart)

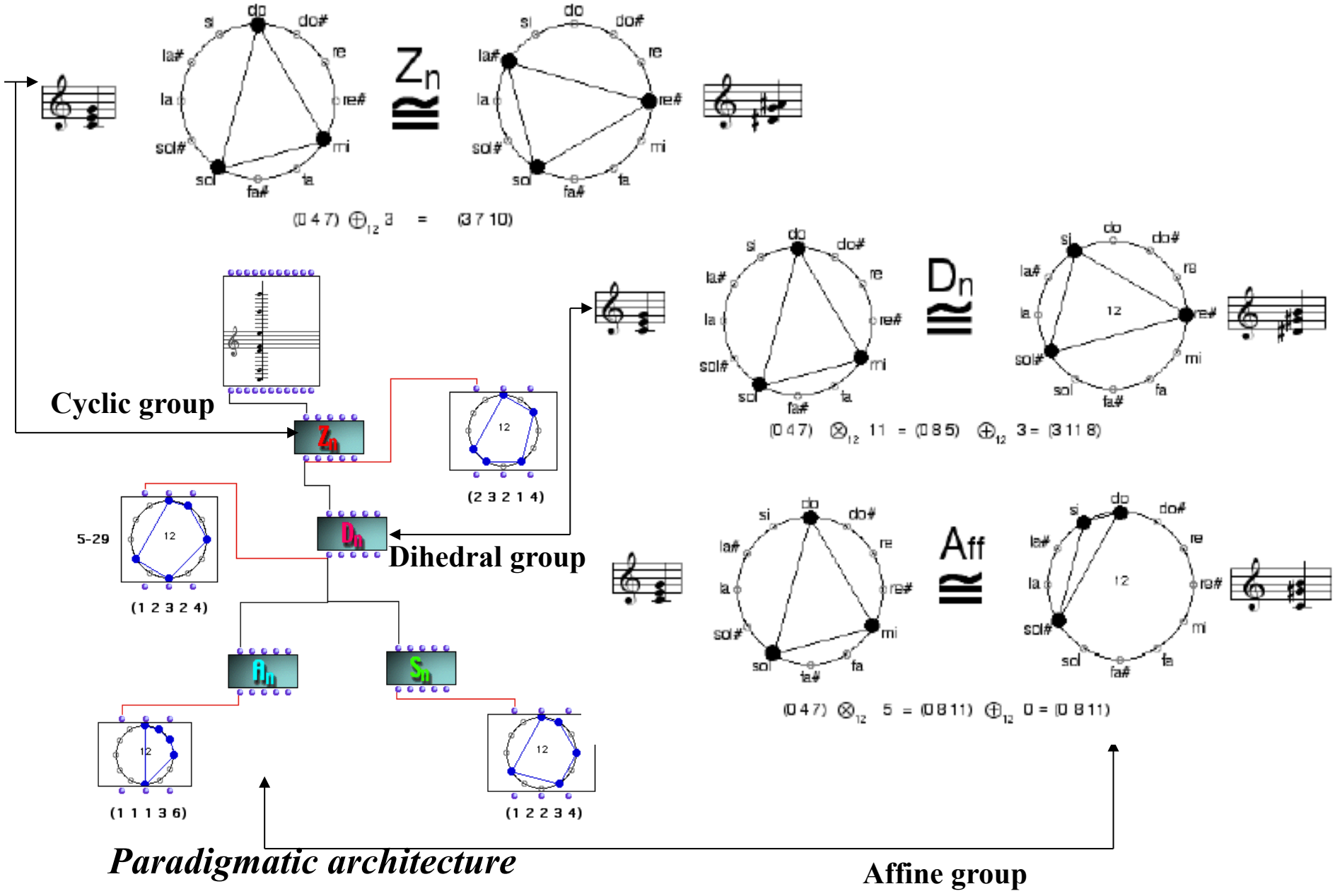






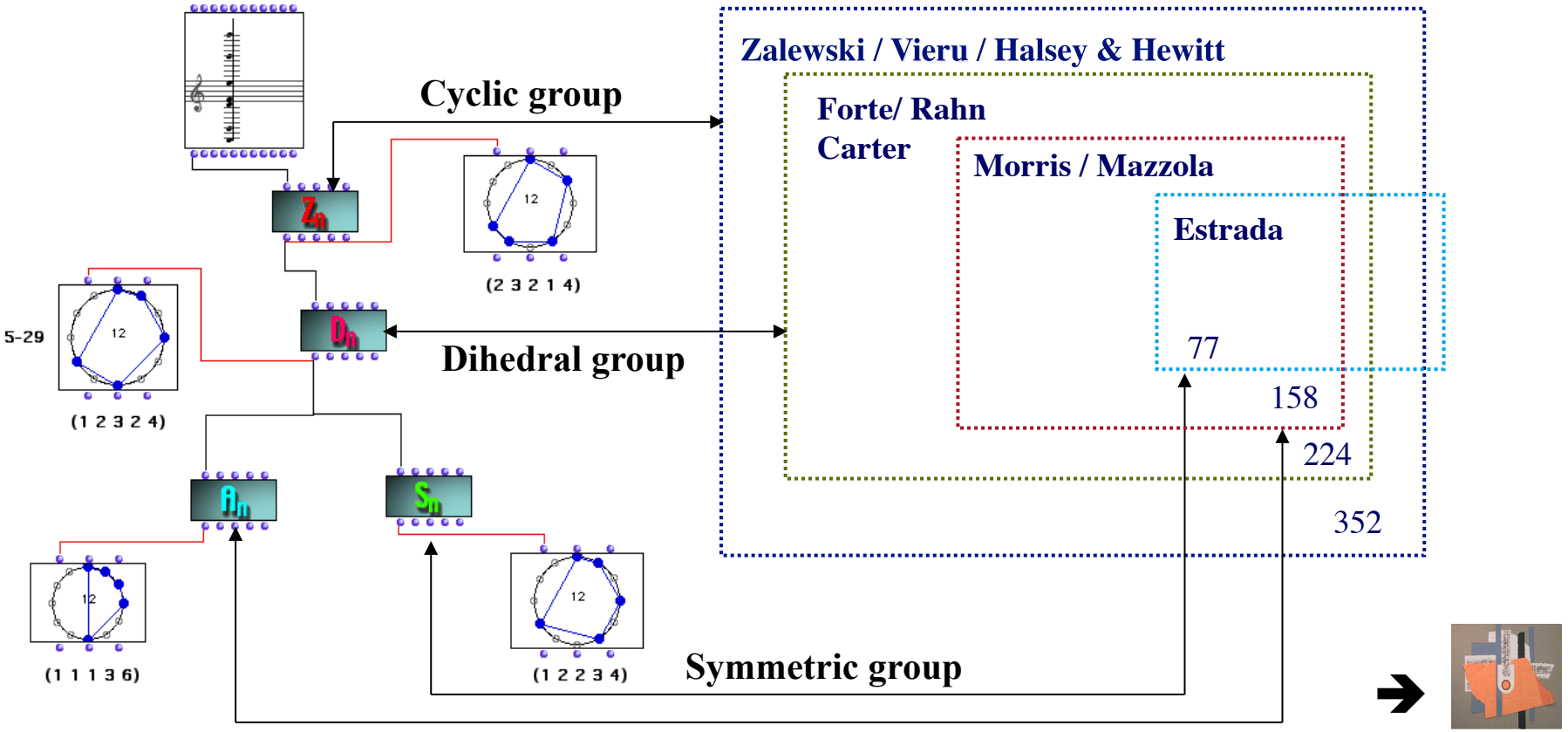
A. Bancquart, M. Andreatta, et C. Agon, « Microtonal Composition », The OM Composer's Book 2, éd. Jean Bresson, Carlos Agon, Gérard Assayag (Ircam/Delatour France, Sampzon), 2008, p. 279-302.

Equivalence relation between musical structures



Enumeration of musical structures

$G\backslash k$	1	2	3	4	5	6	7	8	9	10	11	12	
C_{12}	1	6	19	43	66	80	66	43	19	6	1	1	
D_{12}	1	6	12	29	38	50	38	29	12	6	1	1	**Set Theory**
$\mathrm{Aff}_1(Z_{12})$	1	5	9	21	25	34	25	21	9	5	1	1	

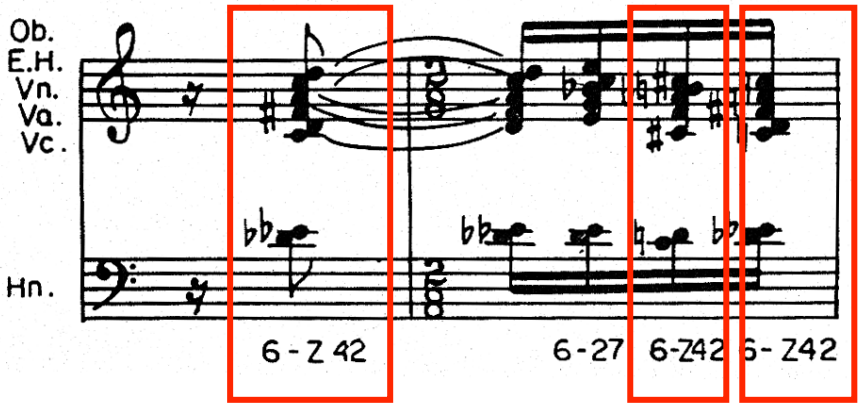


Paradigmatic architecture

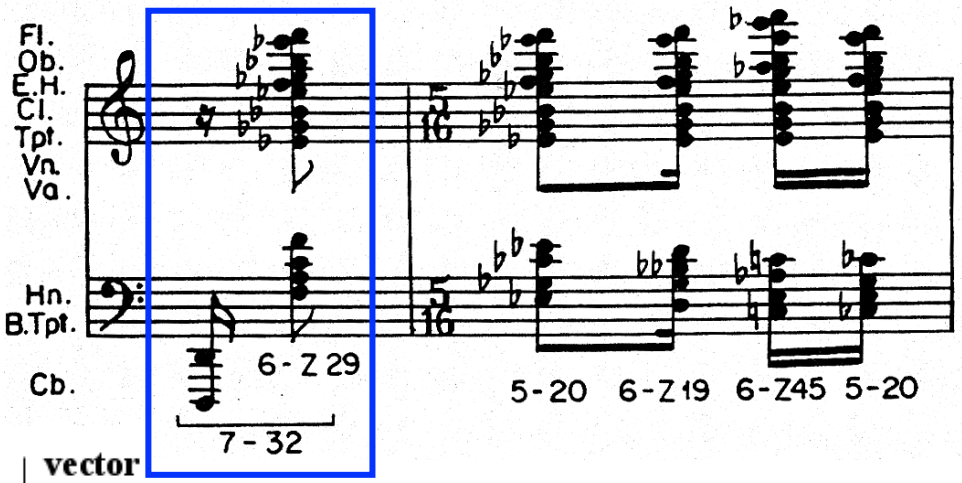
07-paradigms

Set Theory Analysis (Allen Forte)

Ex. 89. *Sacrificial Dance:* R142+3



Ex. 90. *Sacrificial Dance:* R144



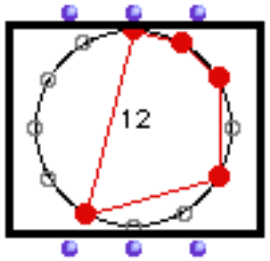
name	pcs	vector
5-30	0,1,4,6,8	121321
5-31	0,1,3,6,9	114112
5-32	0,1,4,6,9	113221
5-33(12)	0,2,4,6,8	040402
5-34(12)	0,2,4,6,9	032221
5-35(12)	0,2,4,7,9	032140
5-Z36	0,1,2,4,7	222121
5-Z37(12)	0,3,4,5,8	212320
5-Z38	0,1,2,5,8	212221
6-1(12)	0,1,2,3,4,5	543210
6-2	0,1,2,3,4,6	443211
6-Z3	0,1,2,3,5,6	433221
6-Z4(12)	0,1,2,4,5,6	432321
6-5	0,1,2,3,6,7	422232
6-Z6(12)	0,1,2,5,6,7	421242
6-7(6)	0,1,2,6,7,8	420243
6-8(12)	0,2,3,4,5,7	343230
6-9	0,1,2,3,5,7	342231
6-Z10	0,1,3,4,5,7	333321
6-Z11	0,1,2,4,5,7	333231
6-Z12	0,1,2,4,6,7	332232
6-Z13(12)	0,1,3,4,6,7	324222

name	pcs	vector
7-30	0,1,2,4,6,8,9	343542
7-31	0,1,3,4,6,7,9	336333
7-32	0,1,3,4,6,8,9	335442
7-33	0,1,2,4,6,8,10	262623
7-34	0,1,3,4,6,8,10	254442
7-35	0,1,3,5,6,8,10	254361
7-Z36	0,1,2,3,5,6,8	444342
7-Z37	0,1,3,4,5,7,8	434541
7-Z38	0,1,2,4,5,7,8	434442
6-Z36	0,1,2,3,4,7	
6-Z37(12)	0,1,2,3,4,8	
6-Z38(12)	0,1,2,3,7,8	
6-Z39	0,2,3,4,5,8	
6-Z40	0,1,2,3,5,8	
6-Z41	0,1,2,3,6,8	
6-Z42(12)	0,1,2,3,6,9	

5-16
5-31 ⊂ **6-27** ⊂ **7-16**, **7-31**, **7-32**
5-32

5-31 ⊂ **6-z42**, **6-27**, **6-z28**

PCS Theory: interval vector and Z-relation

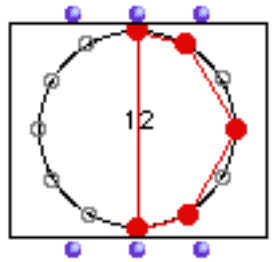


5-30	0,1,4,6,8	121321
5-31	0,1,3,6,9	114112
5-32	0,1,4,6,9	113221
5-33(12)	0,2,4,6,8	040402
5-34(12)	0,2,4,6,9	032221
5-35(12)	0,2,4,7,9	032140
5-Z36	0,1,2,4,7	222121
5-Z37(12)	0,3,4,5,8	212320
5-Z38	0,1,2,5,8	212221
6-1(12)	0,1,2,3,4,5	543210
6-2	0,1,2,3,4,6	443211
6-Z4(12)	0,1,2,4,5,6	432321
6-5	0,1,2,3,6,7	422232
6-Z6(12)	0,1,2,5,6,7	421242
6-7(6)	0,1,2,6,7,8	420243
6-8(12)	0,2,3,4,5,7	343230
6-9	0,1,2,3,5,7	342231
6-Z10	0,1,3,4,5,7	333321
6-Z11	0,1,2,4,5,7	333231
6-Z12	0,1,2,4,6,7	332232
6-Z13(12)	0,1,3,4,6,7	324222

5-Z36 0,1,2,4,7 222121

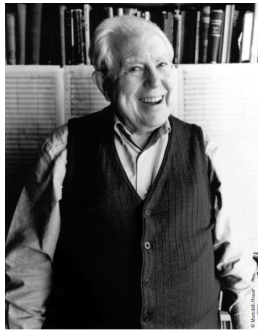
7-30	0,1,2,4,6,8,9	343542
7-31	0,1,3,4,6,7,9	336333
7-32	0,1,3,4,6,8,9	335442
7-33	0,1,2,4,6,8,10	262623
7-34	0,1,3,4,6,8,10	254442
7-35	0,1,3,5,6,8,10	254361
7-Z36	0,1,2,3,5,6,8	444342
7-Z37	0,1,3,4,5,7,8	434541
7-Z38	0,1,2,4,5,7,8	434442

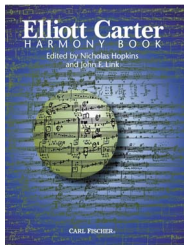
6-Z36	0,1,2,3,4,7
6-Z37(12)	0,1,2,3,4,8
6-Z38(12)	0,1,2,3,7,8
6-Z39	0,2,3,4,5,8
6-Z40	0,1,2,3,5,8
6-Z41	0,1,2,3,6,8
6-Z42(12)	0,1,2,3,6,9



5-Z12

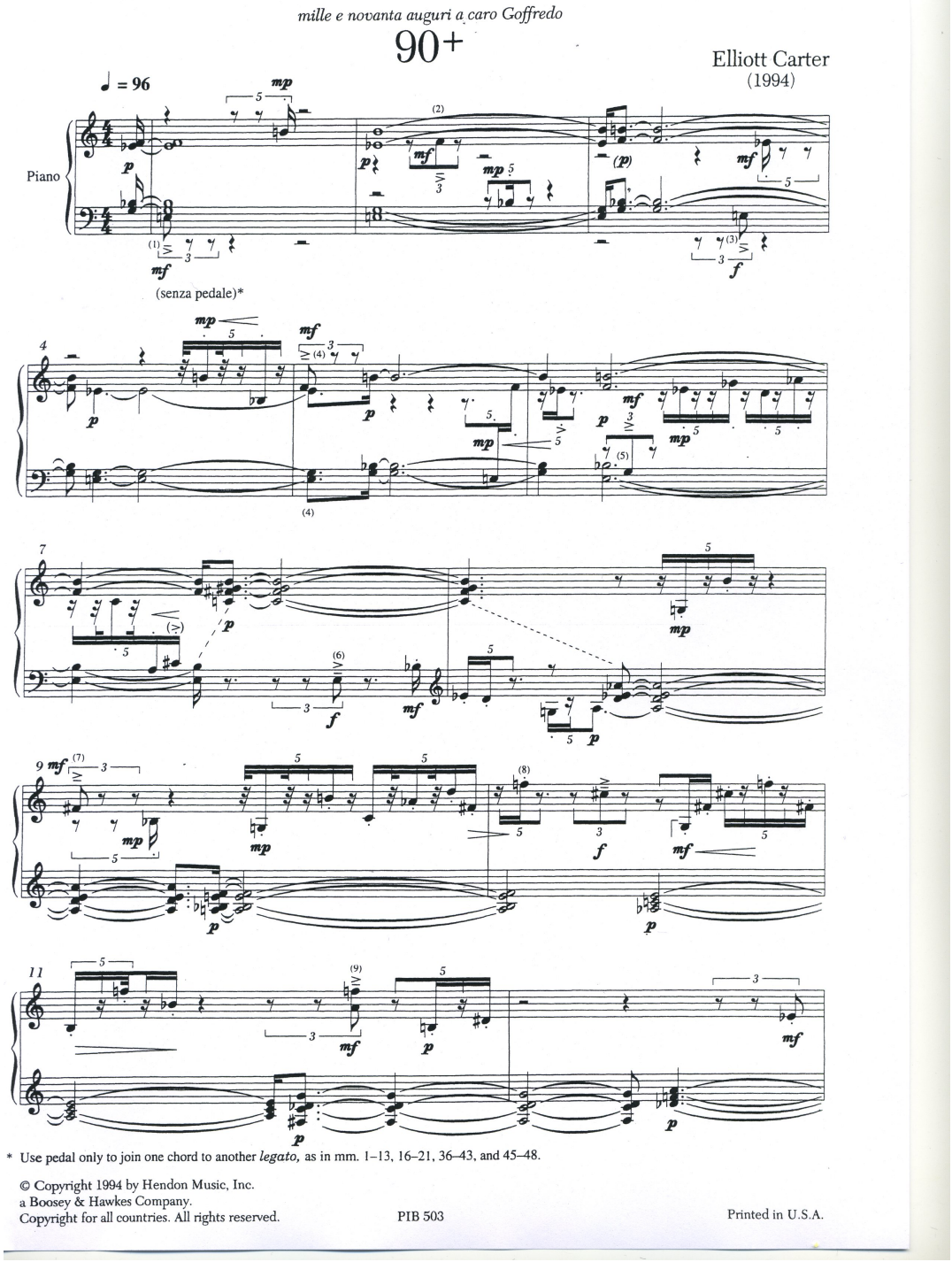
Elliott Carter : 90+ (1994)



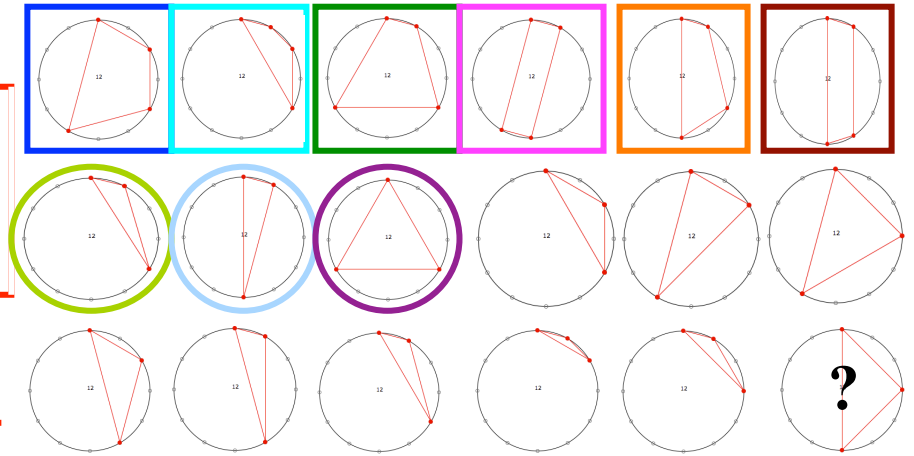


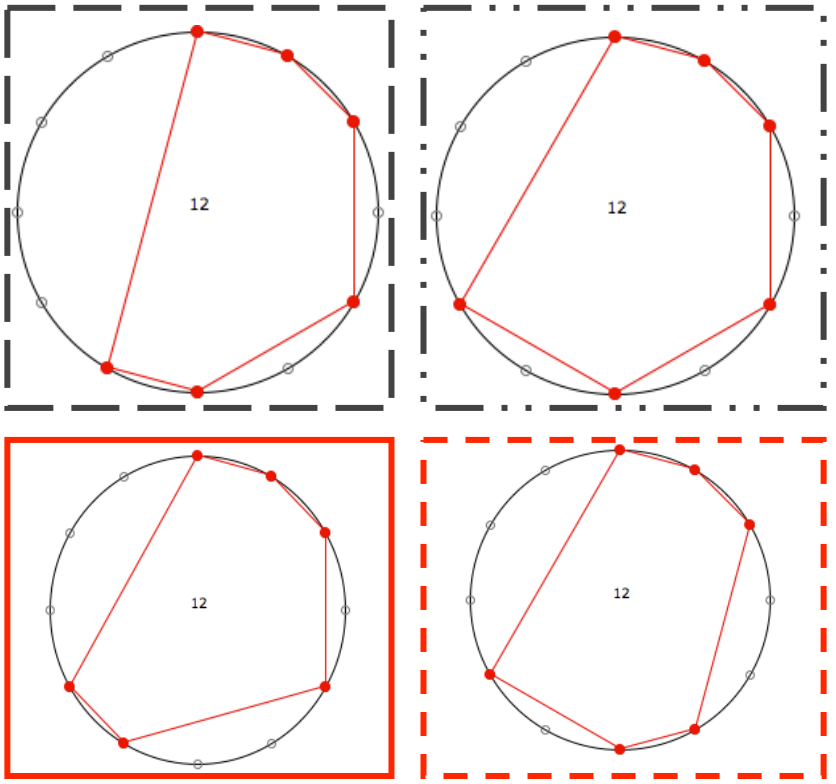
- **Chord combinatorics**
  - **Hexacords**
  - **Tetrachords**
  - **Triads**
  - **Z-relation**
- **all-interval series**
  - ***Link–chords***

(piano: John Snijders)

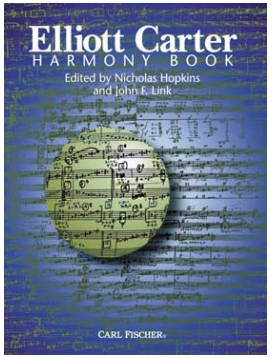


Elliott Carter : 90+ (1994) : tetra/trichordal combinatorics

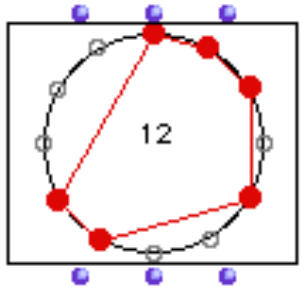
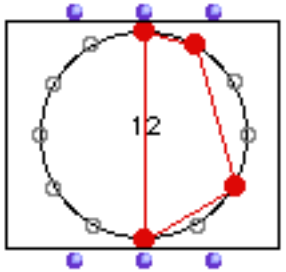
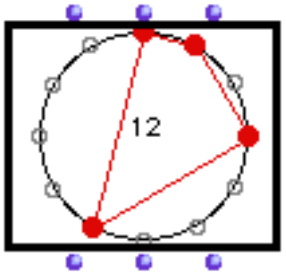




Elliott Carter: 90+ (1994)



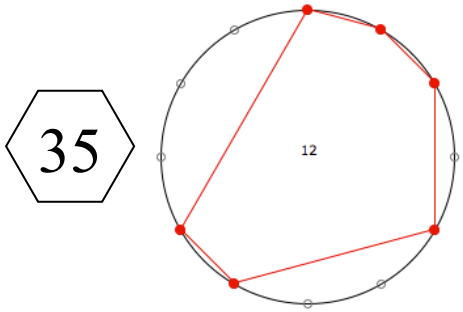
« *From about 1990, I have reduced my vocabulary of chords more and more to the six note chord n° 35 and the four note chords n° 18 and 23, which encompass all the intervals* » (*Harmony Book*, 2002, p. ix)

		pcset	*vector*	*name*
35		(0 1 2 4 7 8)	[322332]	6-Z17
18		(0 1 4 6)	[111111]	4-Z15
23		(0 1 3 7)	[111111]	4-Z29

All-triad hexachord

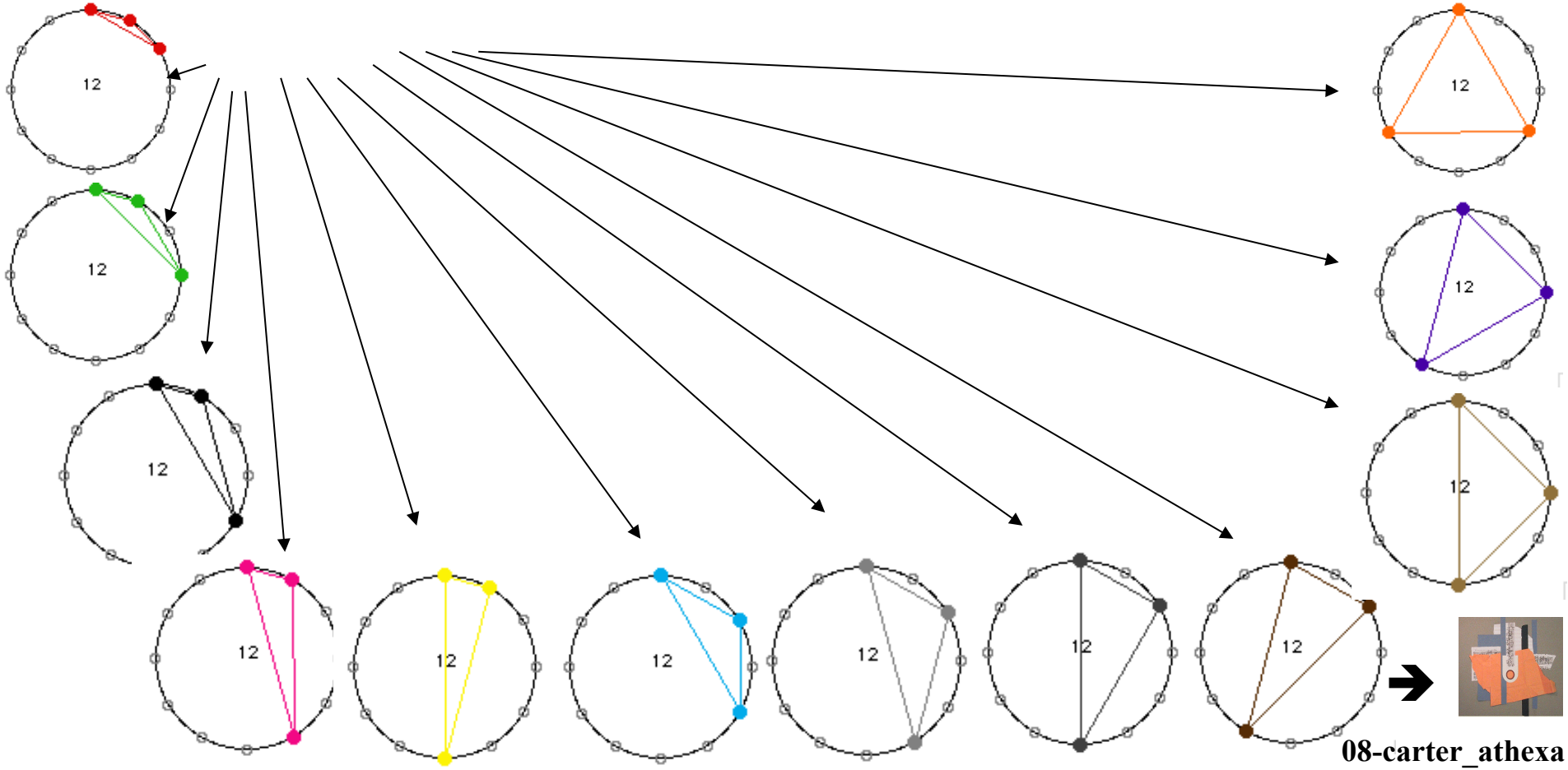
Elliott Carter: 90+ (1994)

$G\backslash k$	1	2	3	4	5	6	7	8	9	10	11	12
C_{12}	1	6	19	43	66	80	66	43	19	6	1	1
D_{12}	1	6	12	29	38	50	38	29	12	6	1	1
$\mathrm{Aff}_1(Z_{12})$	1	5	9	21	25	34	25	21	9	5	1	1



pcset	*vector*	*name*
(0 1 2 4 7 8)	[322332]	6-Z17

All-triad hexachord

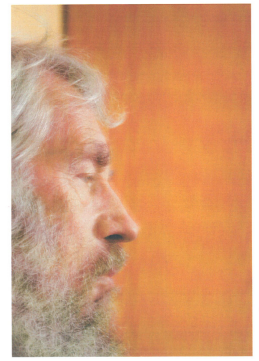


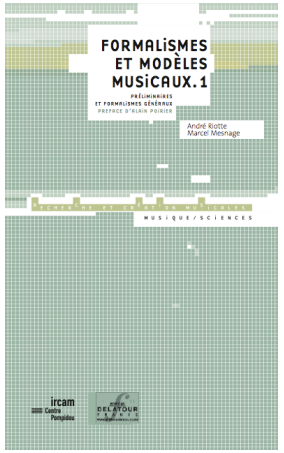
08-carter_athexa

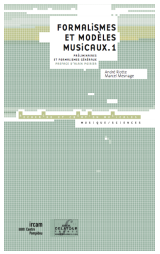
Computational Music Analysis: neutral level

1.) *Formalismes et modèles musicaux* (André Riotte & Marcel Mesnage)

- « Anamorphoses » d'André Riotte
- « La terrasse des audiences du clair de lune » de Claude Debussy : esquisse d'analyse modélisée
- La mise en évidence de régularités locales : le « Mode de valeurs et d'intensités » de Messiaen
- Un exemple d'invention structurelle : le « Mikrokosmos » de Béla Bartok
- Un modèle informatique de la « Pièce pour quatuor à cordes » n°1 de Stravinsky
- Les « Variations pour piano », op. 27, d'Anton Werbern
- L'« Invention à deux voix » n°1 de J.-S. Bach
- Un modèle informatique du « Troisième Regard sur l'Enfant Jésus » d'Olivier Messiaen
- Un modèle de la « Valse sentimentale », Op. 50, n°13, de Franz Schubert
- Un automate musical construit à partir d'une courte pièce de Béla Bartok (Mikrokosmos n°39)



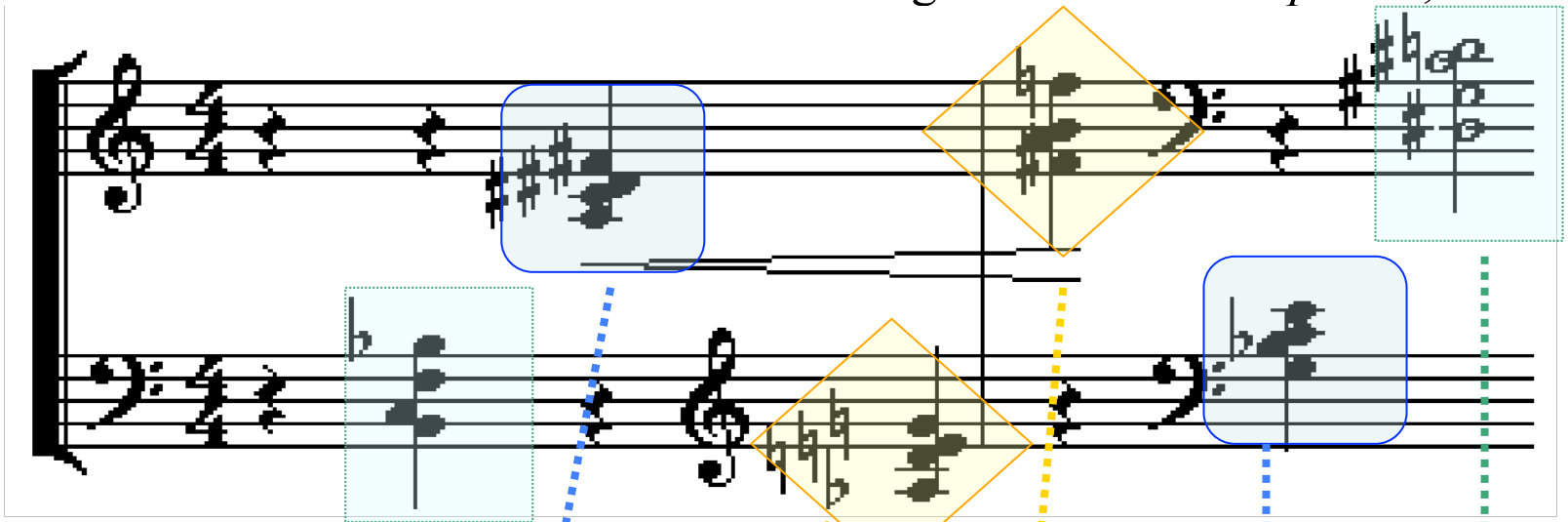


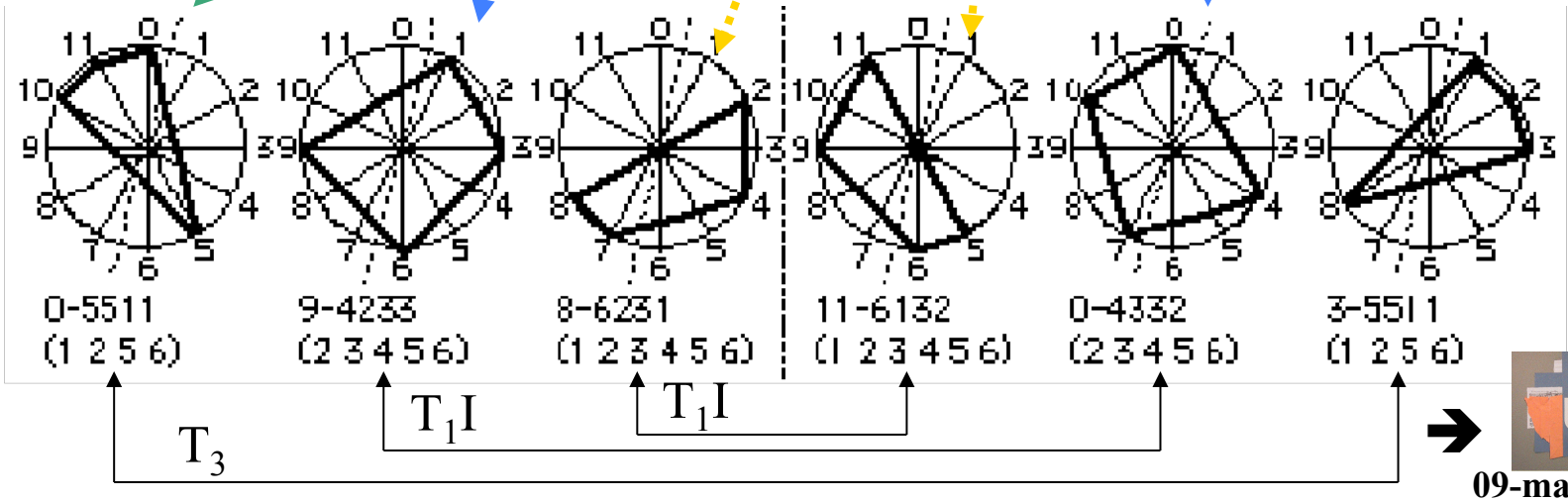


« Entités formelles pour l'analyse musicale »

Marcel Mesnage (1998)

A. Schoenberg : *Klavierstück Op. 33a*, 1929

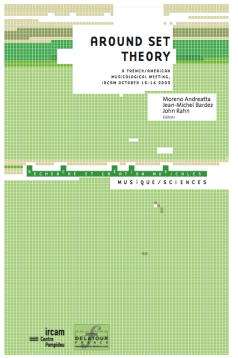


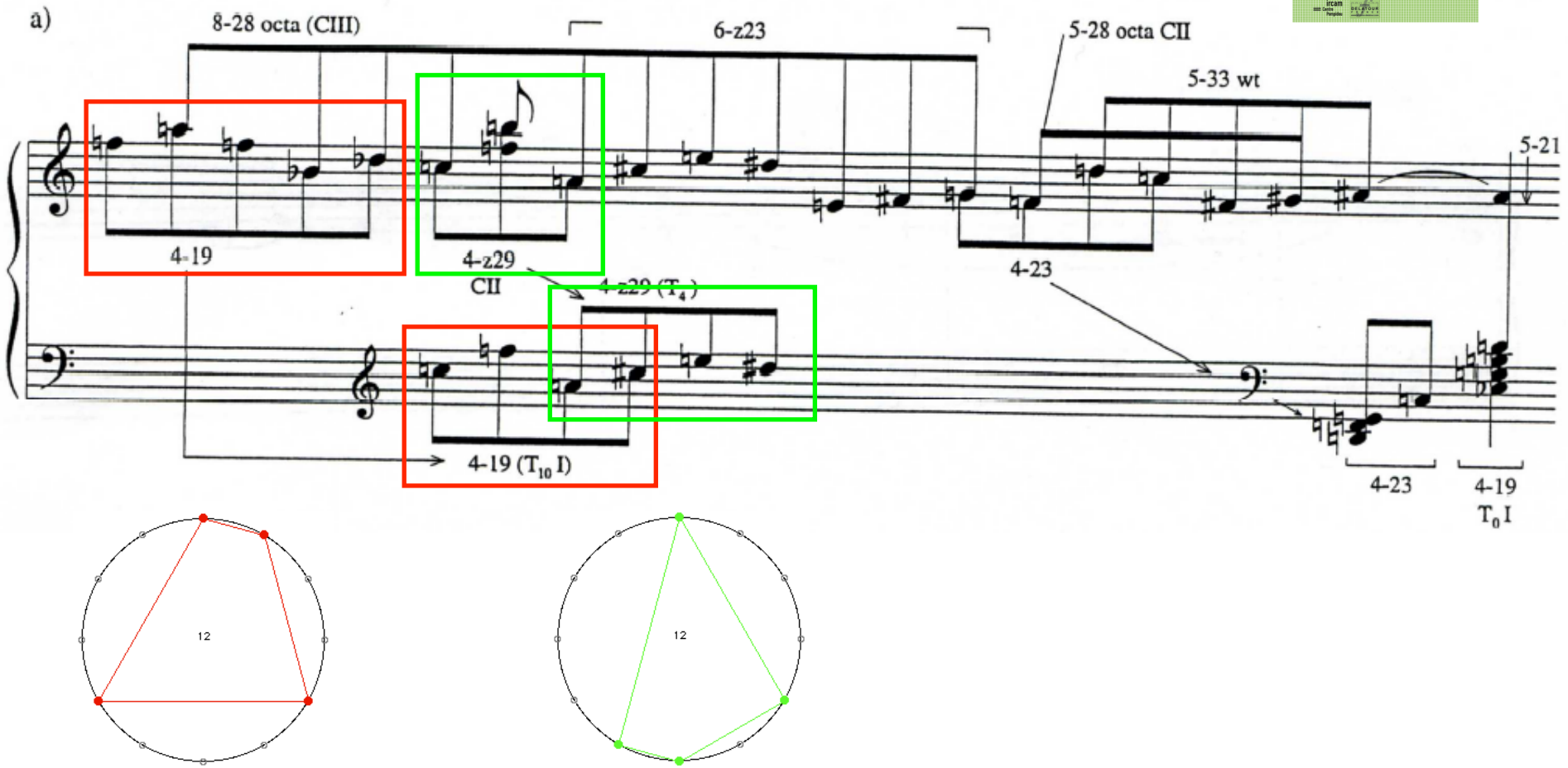


Analysis by Allen Forte: visualisation

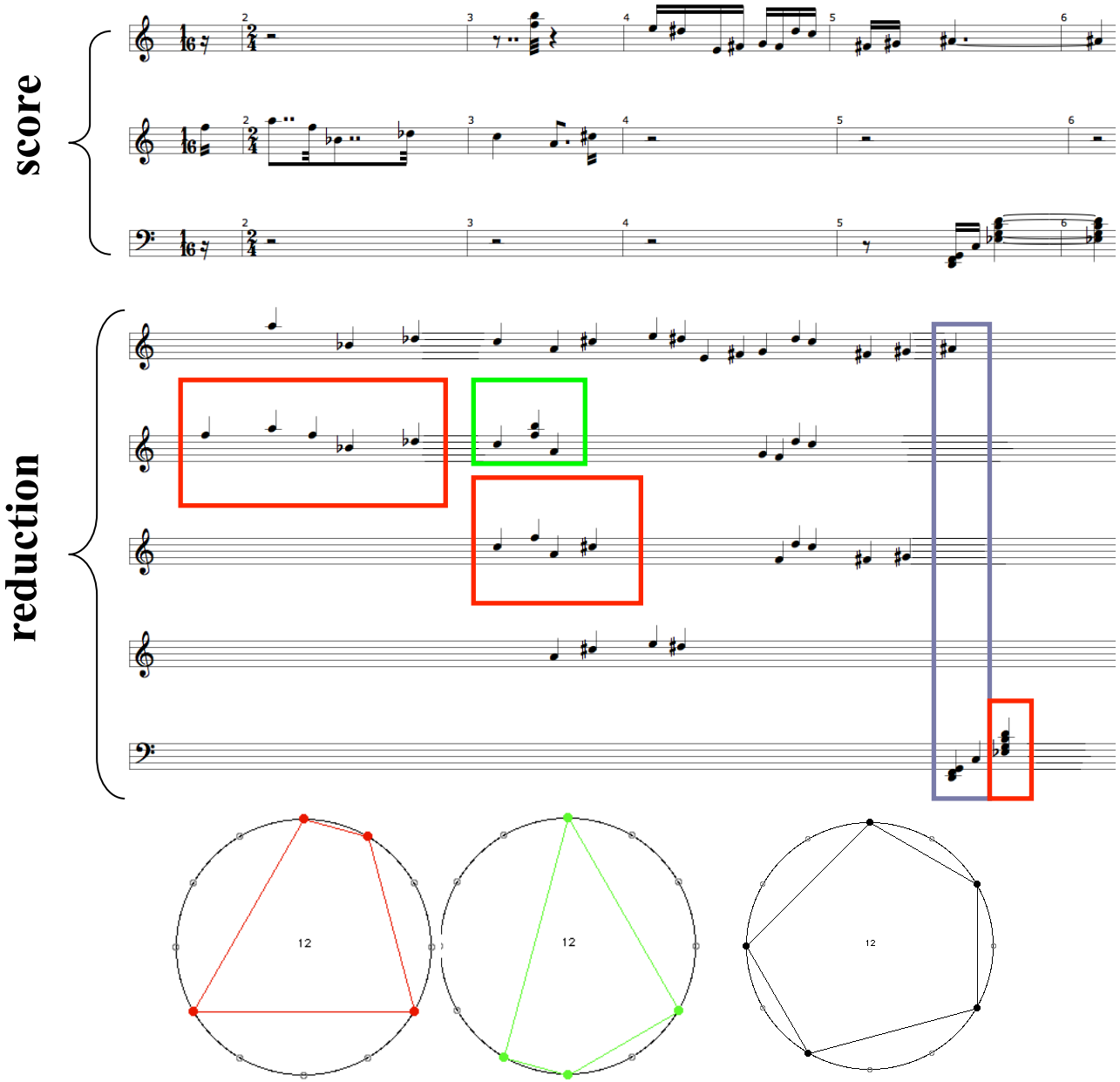
Arnold Schoenberg: *Klavierstück* op. 19 n° 4

reduction





Towards an assisted analysis of the *Klavierstück* op. 19 n° 4



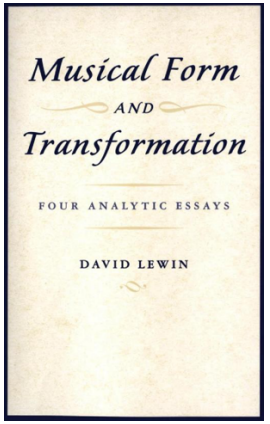
« *Making* and *Using* a Pcset Network for Stockhausen's Klavierstück III »

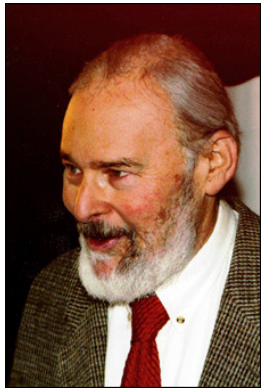
Trois interprétations :

Henck

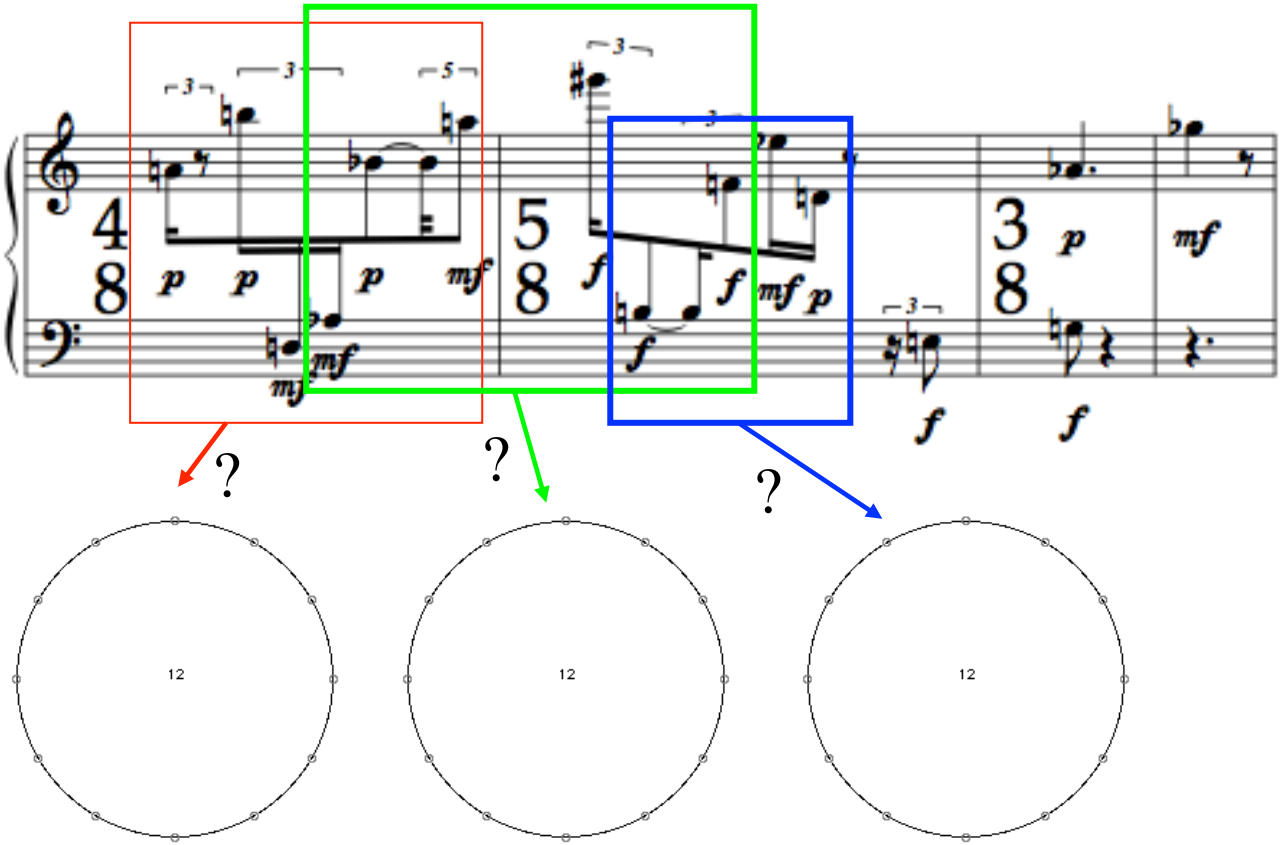
Kontarsky

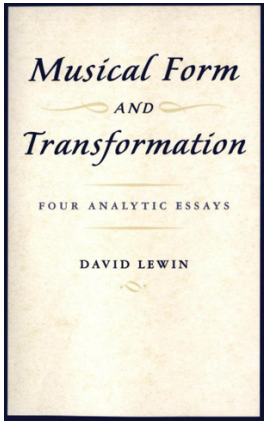
Tudor

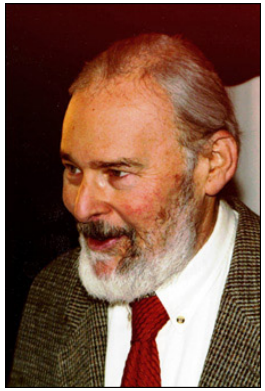




« *Making* and *Using* a Pcset Network for Stockhausen's Klavierstück III »





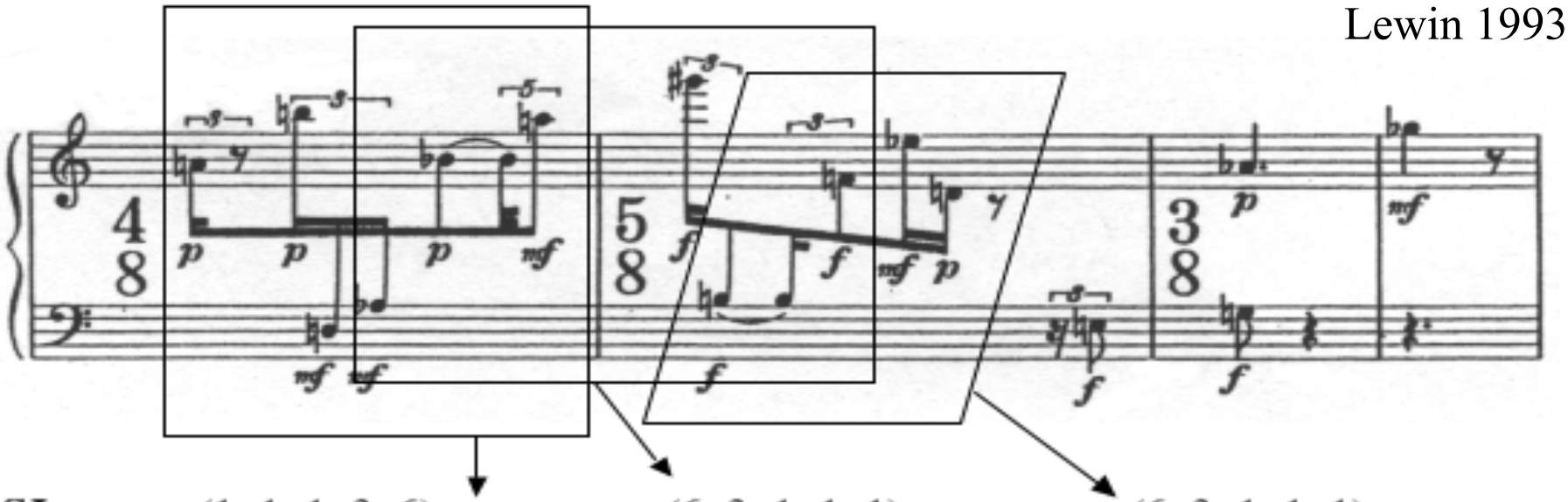


« The most 'theoretical' of the four essays, it focuses on the forms of one pentachord reasonably ubiquitous in the piece. A special **group of transformations** is developed, one suggested by the musical interrelations of the pentachord forms. Using that group, the essay arranges **all pentachord forms** of the music into a **spatial configuration** that illustrates network structure, for this particular phenomenon, over the entire piece. »

David Lewin, *Musical Form and Transformation,* YUP 1993

« *Making* and *Using* a Pcset Network for Stockhausen's Klavierstück III »

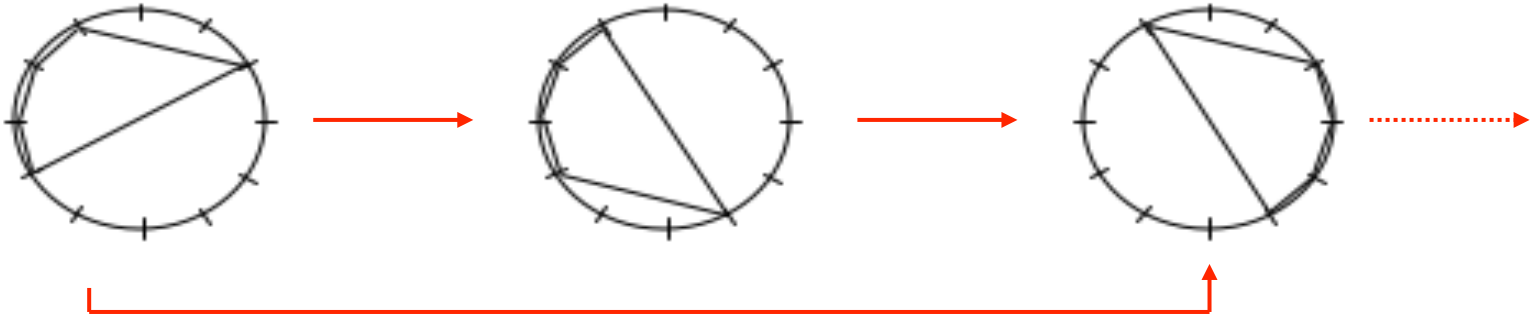
Lewin 1993



SI: (1, 1, 1, 3, 6) (6, 3, 1, 1, 1) (6, 3, 1, 1, 1)

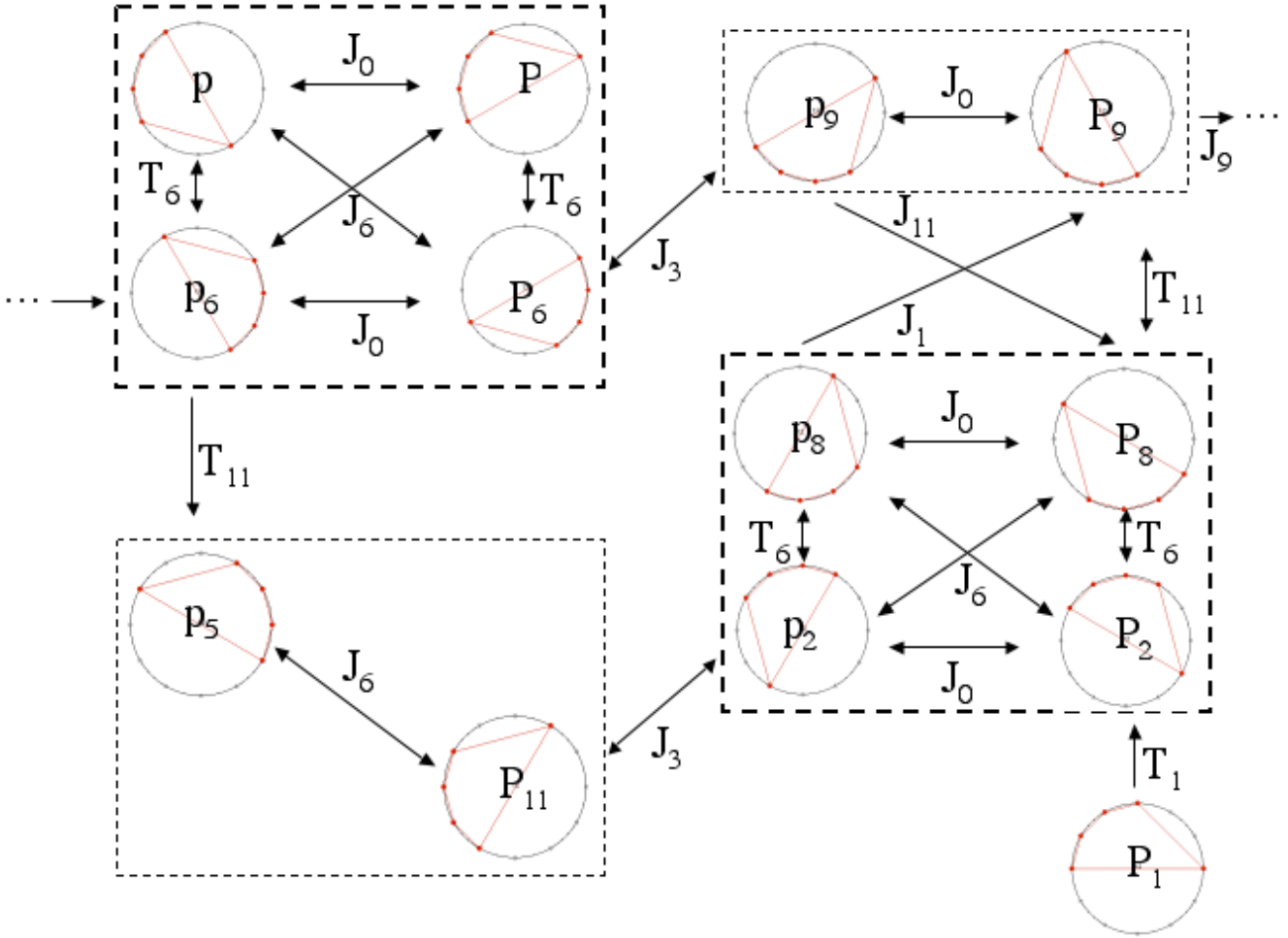
IFUNC: [5 3 2 2 1 1 1 1 1 2 2 3] [5 3 2 2 1 1 1 1 1 2 2 3] [5 3 2 2 1 1 1 1 1 2 2 3]

VI: [3 2 2 1 1 1] [3 2 2 1 1 1] [3 2 2 1 1 1]



Transformational Network

Stockhausen: *Klavierstück III* (Analyse de D. Lewin)

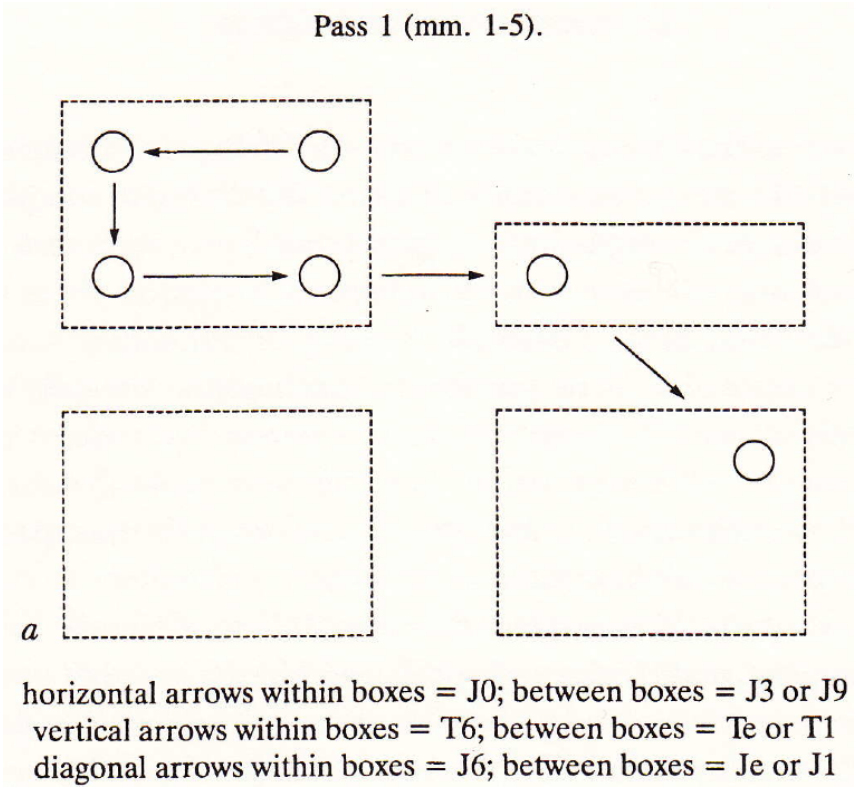


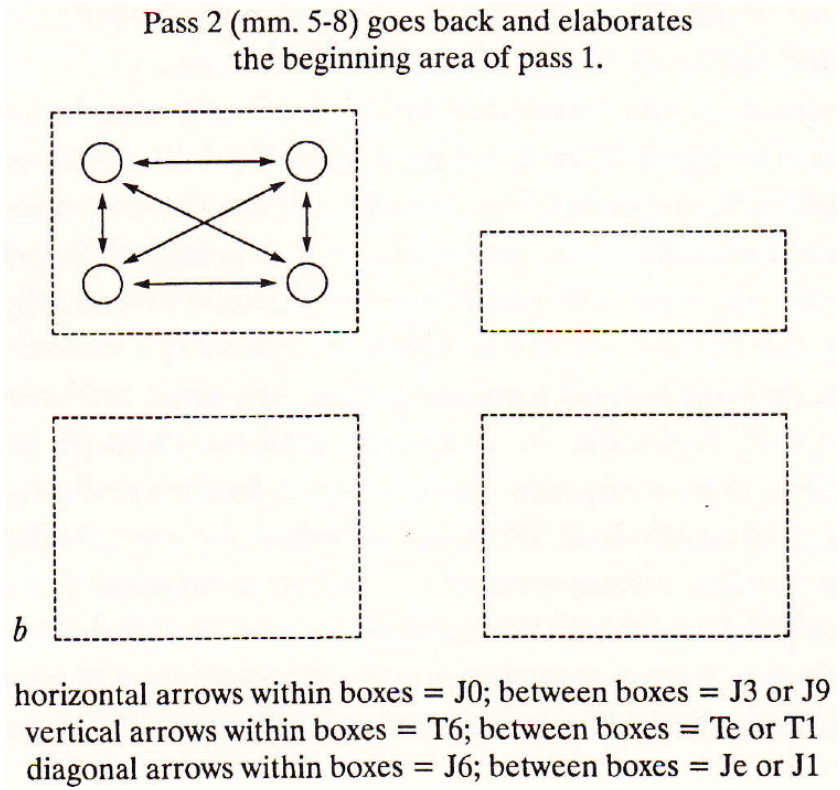
« Rather than asserting a network that follows pentachord relations one at a time, according to the chronology of the piece, I shall assert instead a network that displays all the pentachord forms used and all their **potentially functional interrelationships**, in a very compactly organized little **spatial configuration**. »

« […] the sequence of events moves within a clearly defined world of possible relationships, and because - in so moving - **it makes the abstract space of such a world accessible to our sensibilities**. That is to say that the story projects what one would traditionally call *form*. »

Listening paths within the piece

Stockhausen: *Klavierstück III* (Analyse de D. Lewin)

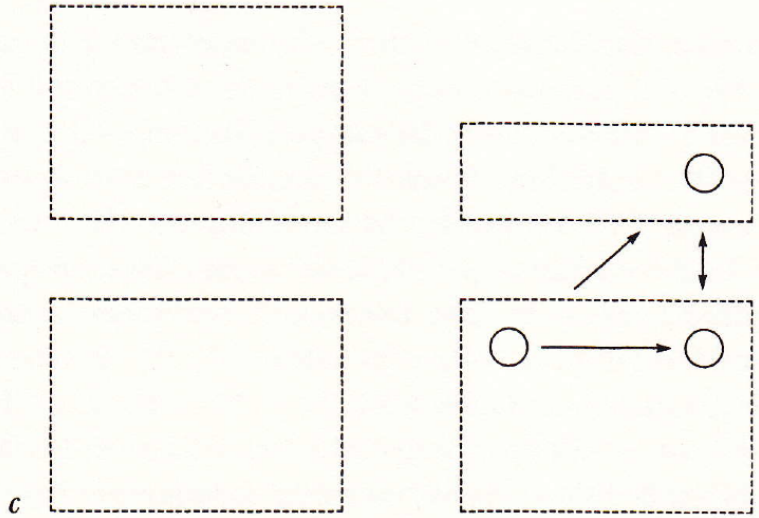




Listening paths within the piece

Stockhausen: *Klavierstück III* (Analyse de D. Lewin)

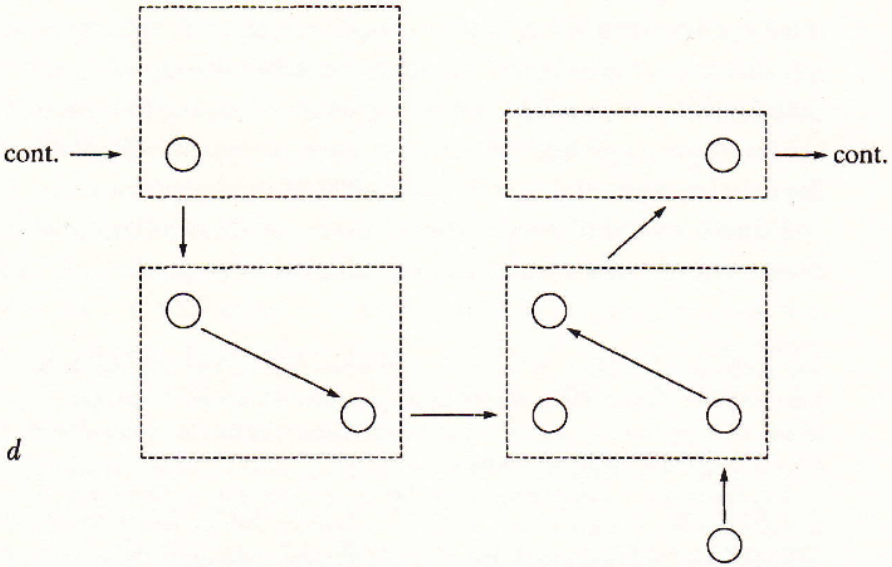
Pass 3 (mm. 8-10) picks up and elaborates
the ending area of pass 1.



c

horizontal arrows within boxes = J0; between boxes = J3 or J9
vertical arrows within boxes = T6; between boxes = Te or T1
diagonal arrows within boxes = J6; between boxes = Je or J1

Pass 4 (mm. 9-16) expands the p8 + P8 area of pass 3
to activate P2 and p2 as well. P2 is the "essential" incipit
of pass 4; p2 is the end of the pass, and of the piece.

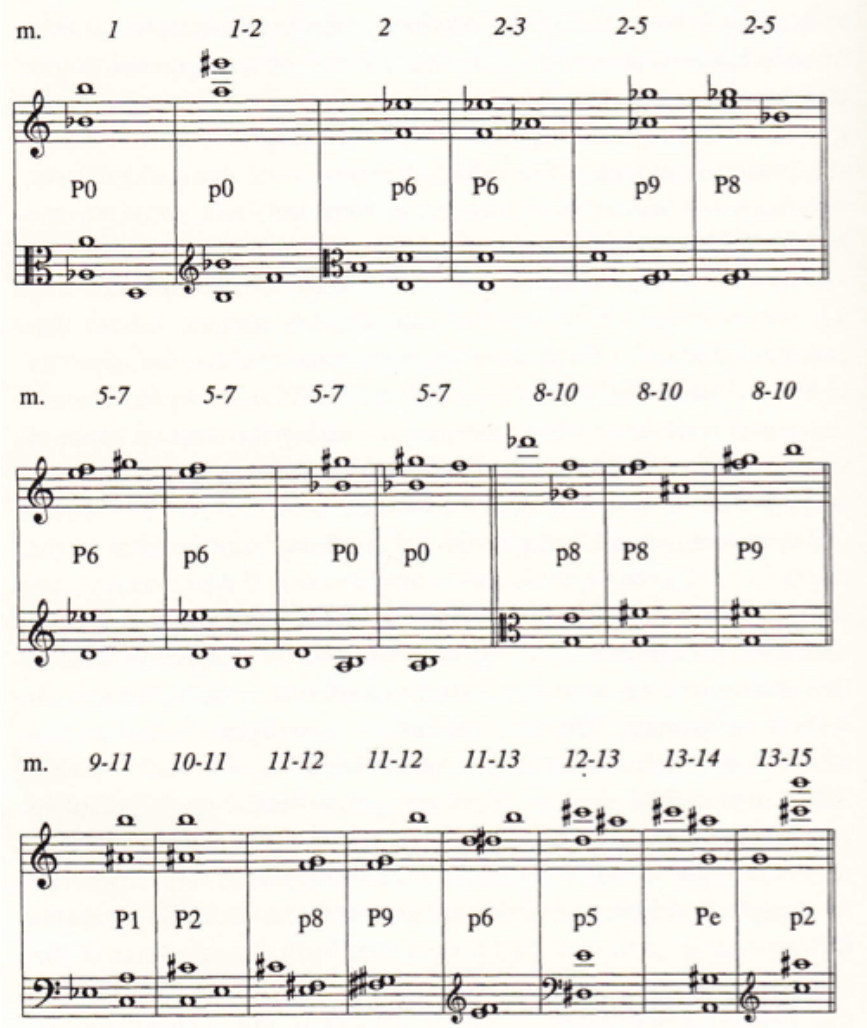


d

horizontal arrows within boxes = J0; between boxes = J3 or J9
vertical arrows within boxes = T6; between boxes = Te or T1
diagonal arrows within boxes = J6; between boxes = Je or J1

Listening exercise: « do you hear it? » *vs* « can you hear it? »

Stockhausen: *Klavierstück III* (Analyse de D. Lewin)



Example 2.7. An ear-training aid for listening to P/p forms and their interrelations.

« I take the question 'Can you hear it » to mean something like this: After studying the analysis in examples 2.5 and 2.6, do you find it possible to focus your **aural attention** upon aspects of the acoustic signal that seem to engage the signifiers of that analysis? […] For me, the interesting questions involve the extent and ways in which I am satisfied and dissatisfied when **focusing my aural attention** in that manner. It is important to ask those questions about any systematic analysis of any musical composition ».

10-lewin-stock