Aspects of Computational musicology

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Guest lecture in Logic, Language and Computation

Music at the ILLC

- Henkjan Honing – music cognition
- Rens Bod – computational musicology
- Aline Honingh – mathematical/computational musicology

- Monthly seminar/discussion group on music cognition and computation

What is mathematical about music?

- Mathematical character of intervals: Temperament and intonation studies
- Musical Set theory
- Scale theory
- In general: organizing musical objects (notes, scales, chords, voiceleadings, counterpoint, etc.) and describing their relationship, in order to gain better understanding

What is computational about music?

Music Information Retrieval

- Automatic analysis
- Segmentation
- Score following
- Pitch spelling
- Classification (on basis of genre/composer/..)
- Similarity metrics
- Key finding

Goal of these applications is both practical (automatic accompaniment, notation software, etc.) and interesting from cognitive point of view.

Sequential association rules in atonal music

Tonal/atonal music

- Tonal music: tonal centre, hierarchies between notes and scale degrees causing expectations
- Atonal music: every note is equally important as every other note

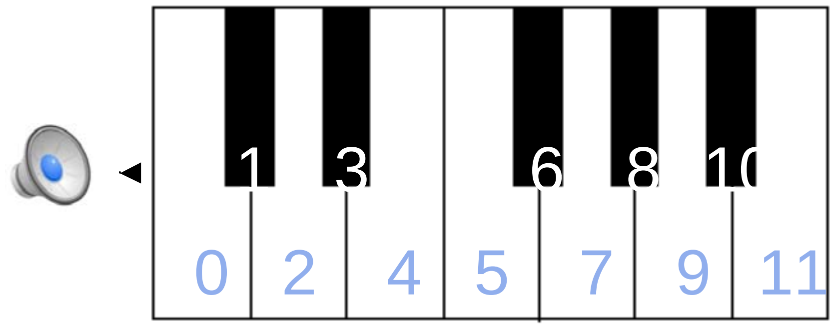
Harmonic analysis of tonal music

- When tonal music is analyzed harmonically, a typical structure can be revealed
- We are interested to find an analogue structure in atonal music

Chord	is followed by	sometimes by	less often by
I	IV, V	VI	II, III
II	V	IV, VI	I,III
III	VI	IV	I, II, V
IV	V	I, II	III, VI
V	I	VI, IV	III, II
VI	II, V	III, IV	I
VII	III	I	

Table of chord progressions taken from Piston and DeVoto (1989)

Pitch classes



Pitch class:

- number between 0 and 11
- Choose a reference note, e.g. C=0, then C#/Db=1, D=2, etc.
- abstraction of a note:
  - octave equivalence
  - enharmonic equivalence

Pitch class sets

- Permutation equivalence: (1,0) = (0,1)
- Cardinality equivalence (0,0,3,3,3)=(0,3)

  therefore: no difference between chord and melody

  e.g. set (0,5,7,8): chord melody

- Transpositional equivalence (1,2,3)=(2,3,4)
- Inversional equivalence (1,2,3)=(11,10,9)

Pitch class set theory to analyze atonal music

- Pitch class set theory has been described in 1973 by Alan Forte
- List of abstractions used:
  - Octave equivalence
  - Enharmonic equivalence
  - Permutation equivalence
  - Cardinality equivalence
  - Transpositional equivalence
  - Inversional equivalence
- With these abstraction, the list of all possible melodies/chords is reduced to 351 pitch class sets.

Comparison analysis of tonal and atonal music

Tonal music

- Harmonic analysis based on chord progressions
- General progression rules can be found:
- vb: I => IV,V

  II => ...

Atonal music

- Analysis based on pitch class set theory using 351 different pitch class sets
- Would it be possible to reduce this number and to group the pitch class set into larger categories, and to use these categories to find general progression rules?

Pitch Class Set Categories

- Attempts to group the pitch class sets into larger categories have been made among others by Ericksson (1986), Quinn (2003) and Honingh et al (2009).
- Quinn used a cluster analysis to group pitch class sets into 6 different categories according to several similarity measures
- Each category corresponds to a cycle of one of the six interval classes.
  - cycle of interval 1: 0,1,2,3,4, ...
  - cycle of interval 2: 0,2,4,6,8, ...
  - etc.

- For each category, a prototype can be identified
- If a pc set is grouped into a certain category, this pc set is similar to the prototype of that category, according to the similarity measure used.
- The cycles of IC's that have periodicities that are less than the cardinality of their class are extended as follows: the cycle is shifted to pitch class 1 and continued from there (Hanson, 1960).

	prototypes (pc sets)
IC1	$\{0,1\}$, $\{0,1,2\}$, $\{0,1,2,3\}$, etc.
IC2	$\{0,2\}$, $\{0,2,4\}$, $\{0,2,4,6\}$, etc.
IC3	$\{0,3\}$, $\{0,3,6\}$, $\{0,3,6,9\}$, etc.
IC4	$\{0,4\}$, $\{0,4,8\}$, $\{0,1,4,8\}$, etc.
IC5	$\{0,7\}$, $\{0,2,7\}$, $\{0,2,5,7\}$, etc.
IC6	$\{0,6\}$, $\{0,1,6\}$, $\{0,1,6,7\}$, etc.

Finding sequential association rules

- Using a corpus of atonal music, we are hoping to find some sequential association rules based on the categorization described before.

- A sequential association rule is a progression $a \rightarrow b$, where the probability $p(b|a)$ is higher than chance level, meaning that category *b* tends to follow category *a* more often than expected (Conklin 2006).

Method

- The MIDI file is segmented on the bar level.
- The notes in each bar form a pc set and of each pc set can be calculated to which category it belongs to.
- The number of occurrences of all categories are counted
- The instances of each progression from one category to another are counted.

Corpus

composer	piece
Schoenberg	Pierrot Lunaire part 1, 5, 8, 10, 12, 14, 17, 21
Schoenberg	Piece for piano opus 33
Schoenberg	Six little piano pieces opus 19 part 2, 3, 4, 5, 6
Webern	Symphony opus 21 part 1
Webern	String Quartet opus 28
Boulez	Notations part 1
Boulez	Piano sonata no 3, part 2: "Texte"
Boulez	Piano sonata no 3, part 3: "Parenthese"
Stravinsky	in memoriam Dylan Thomas Dirge canons (prelude)

The instances of each progression from one category to another are counted

category		To 1	2	3	4	5	6
From	1	109	23	49	36	28	62
	2	27	21	12	15	18	22
	3	49	18	30	21	24	22
	4	44	17	29	39	15	32
	5	33	17	15	29	27	16
	6	47	20	28	34	22	38

Transition matrix

category		To 1	2	3	4	5	6
From	1	1.23	0.70	1.04	0.71	0.72	1.13
	2	0.82	1.70	0.68	0.79	1.24	1.07
	3	1.04	1.03	1.21	0.78	1.16	0.75
	4	0.87	0.90	1.08	1.35	0.67	1.02
	5	0.85	1.17	0.73	1.30	1.57	0.66
	6	0.85	0.97	0.96	1.08	0.91	1.11

Lift matrix

The lift is a measure for the over-representation of a progression $a \rightarrow b$

$$\text{lift}(a \rightarrow b) = \frac{p(b|a)}{p(b)}$$

category		To					
		1	2	3	4	5	6
	1	109	23	49	36	28	62
	2	27	21	12	15	18	22
From	3	49	18	30	21	24	22
	4	44	17	29	39	15	32
	5	33	17	15	29	27	16
	6	47	20	28	34	22	38

Transition matrix

category		To					
		1	2	3	4	5	6
	1	1.23	0.70	1.04	0.71	0.72	1.13
	2	0.82	1.70	0.68	0.79	1.24	1.07
From	3	1.04	1.03	1.21	0.78	1.16	0.75
	4	0.87	0.90	1.08	1.35	0.67	1.02
	5	0.85	1.17	0.73	1.30	1.57	0.66
	6	0.85	0.97	0.96	1.08	0.91	1.11

Lift matrix

category		To					
		1	2	3	4	5	6
	1	**0.001**	**0.020**	>0.5	**0.009**	**0.026**	0.111
	2	0.150	**0.003**	0.097	0.288	0.179	>0.5
From	3	>0.5	>0.5	0.135	0.159	0.252	0.079
	4	0.201	>0.5	>0.5	**0.008**	0.059	>0.5
	5	0.163	0.438	0.104	**0.047**	**0.003**	**0.030**
	6	0.167	>0.5	>0.5	0.345	1.222	0.254

Significance matrix using a Chi-Square test

Sequential association rules

Category	is followed by	sometimes by	less often by
1	1	3,6	2,4,5
2	2	1,3,4,5,6	
3		1,2,3,4,5,6	
4	4	1,2,3,5,6	
5	4,5	1,2,3	6
6		1,2,3,4,5,6	

Possible other applications

- Tonal/atonal classification

Category	Percentage of occurrence for tonal music	Percentage of occurrence for atonal music
1	3.22 %	28.25 %
2	4.96 %	10.56 %
3	19.16 %	10.98 %
4	14.96 %	16.16 %
5	53.13 %	12.45 %
6	4.78 %	16.60 %

	Number of correctly classified atonal pieces	Number of correctly classified tonal pieces
Our algorithm	19	53
Baseline algorithm	14	53
Total number of pieces	20 atonal pieces	56 tonal pieces

Possible other applications (2)

- Major/minor classification

Category	Percentage of occurrence for music in major	Percentage of occurrence for music in minor
1	**2.30 %**	**4.48 %**
2	**1.86 %**	**5.16 %**
3	**11.06 %**	**23.87 %**
4	**3.49 %**	**10.48 %**
5	**79.81 %**	**53.58 %**
6	**1.48 %**	**2.42 %**

- Similarity judgements
- Coversong identification
- Composer recognition
- ...

Thank you