Statistical learning and the history of music perception

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15th-Century example
Okeghem: *Missa Ecce ancilla domini*

Aim

Explore history of music perception

- "history" = Medieval, Renaissance
  - origins of major-minor tonality
- "music" = Western polyphonic
  - statistical analysis of electronic scores
- "perception" = expectation
  - tonal-harmonic syntax

Specific objectives

Explore changing relative prevalence of music-structural elements such as:

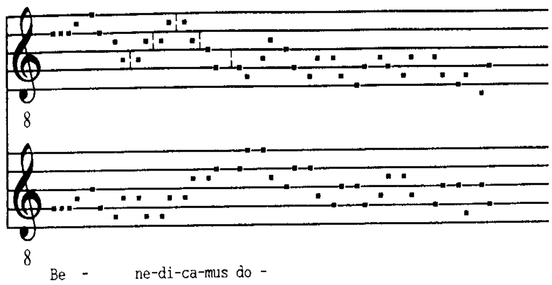
- melodic fragments
  - e.g. cadential formulae
- sonorities expressed as Tn-sets
  - e.g. 047, 037
- specific polyphonic cadential formulae
  - e.g. double leading-tone cadence

The approach ignores:

- Enharmonics and microtonality
  - Chromatic scale steps as categories
- Musically interesting "abnormalities"
  - First identify the main trends
- Rhythm
  - Main focus is pitch

Example: Early polyphony

Ex.1
Anonymous two-part setting of 'Benedicamus domino'.
The vertical lines in the upper voice represent short slanting lines in the manuscript; they have been interpreted as reflecting the position of the syllables '[Be]nedicamus do[mino]'



From H. van der Werf (1992): Early Western polyphony. In Knighton & Fallows (Eds.)

Spinoffs

- Music history
  - document musical heritage
  - revive interest in syntax
- Music theory and analysis
  - history of syntax versus history of theory
  - test claims about history of syntax
  - "explain" major–minor tonality
- Music performance and education
  - improve performing editions
  - develop computer tools

Domain of research

- Notation (symbolic data)
- Polyphonic (no chant)
- Medieval – Renaissance
- Pitch-time patterns
- Chromatic scale

Example of corpus analysis

Eberlein's (1994) sample (1700-1850):

- J. S. Bach: 7 Chorales
- Händel: Trio sonata Op. 5 No. 5
- Mozart: *Missa brevis* KV 65
- Beethoven: Mass in C
- Mendelssohn: Motets Op. 78

Prevalence of individual sonorities

(Eberlein, 1994)

Ranking:

- major triad
- minor triad
- major-minor (dominant) seventh
- diminished seventh
- minor added sixth chord
- triad with suspended fourth
- minor seventh
- diminished triad

Prevalence of two-chord progressions

Intervals between bass tones of root-position chords (Eberlein, 1994)

	rising P4	falling P4	rising 3rd	falling 3rd	rising M2	falling M2	total
maj-maj	64	19	0	0	6	2	**91**
maj-min	60	1	2	9	5	0	**77**
min-maj	5	20	1	15	5	3	**49**
min-min	21	5	0	0	1	0	**27**
total	**150**	**45**	**3**	**24**	**17**	**5**	**244**

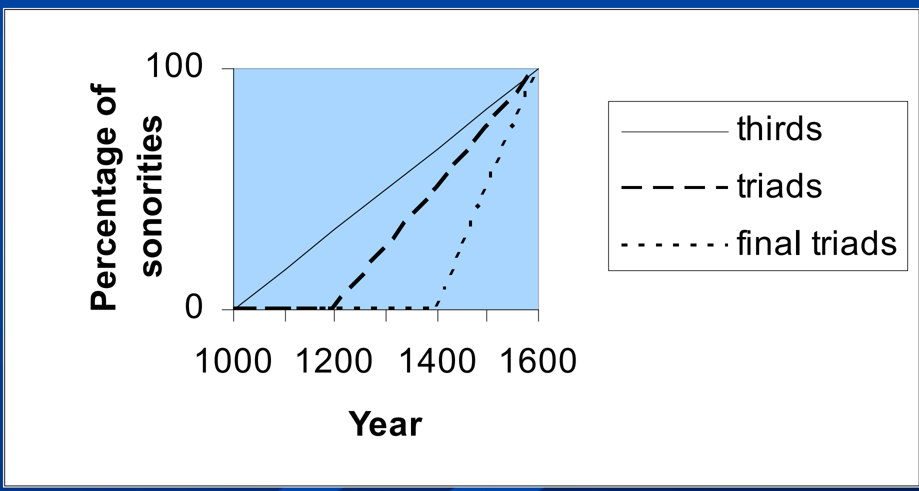
Stylistic differences

- cf. Mozart, Schubert, Brahms:
  - Mozart: more maj & dim triads, maj 7ths
  - Schubert: more dom 7ths
  - Brahms: more min triads, half-dim 7ths

Ferkova, E., Zdimal, M., & Sidlik, P. (2007). Statistical harmonic analysis in the piano music of Mozart and Schubert. IMS Zürich.

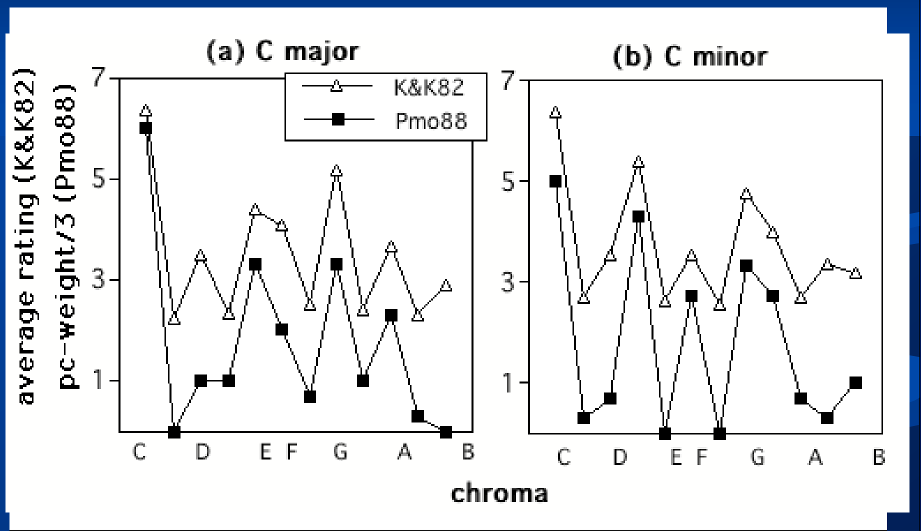
A testable prediction

- Quantify „evolving consciousness of sonority" in 14th cent. (Fuller, 1986)
- Understand „emergence of tonality"
- Compare prevalence of harmonic thirds and triads in different periods



Another testable prediction

Does scale step prevalence correlate with K&K82 and Pmo88?



K&K82 = Krumhansl & Kessler, *Psychological Review*, 1982; Pmo88 = Parncutt, *Music Perception*, 1988

Procedure

- Choice and coding of scores
- Chromatic pitch categorisation
- Manual mark-up
- Transition probabilities of notes
- Chunking (segmentation)
- Transition probabilities of chunks

Choice and coding of scores

- Representative repertoire of each period
  - convert existing electronic scores
  - code new scores
- Common coding format
  - Include non-score parameters
    - note saliences, stream assignments…
  - define and count "patterns"
    - pattern definition: specificity versus generality
  - → Humdrum?
- Copyright issues
  - different degrees of accessibility (internet)

Editorial information

- "Urtext", copy or edition?
  - editorial aims? practice? criteria?
  - include this info in electronic scores
  - create historically reputable source
  - maintain distinction in statistical analyses?

Chromatic pitch categorisation

Chromatic scale as pitch categories

- Ficta problem
  - avoid tritones…
  - raise leading tones…
- Different versions of each piece
  - existing performance editions
  - subjective vs. objective formulation and application of ficta rules
- Expert evaluations
  - weighting of diff. versions in calculations

Tablature - no problem

From F. Wiering (1997), „DARMS extensions for lute tablatures“. In E. Selfridge-Field (Ed.), *Beyond MIDI*

Rhythm

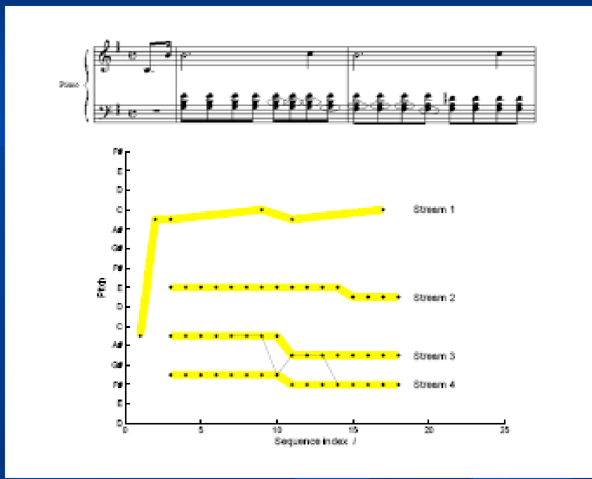
Not a focus of the planned study

- Minimum requirement
  - encode temporal order only
- Maximum requirement
  - temporal categories of standard notation

Manual mark-up

- Streams (voices)
  - according to score structure
  - algorithm not necessary?
- Salience
  - higher
    - main melody
    - primacy and recency (start and end of units)
    - dissonances
  - lower
    - short tones (saturation function?)

Why salience and streaming?



Source: W. M. Szeto and M. H. Wong (2006). Stream segregation algorithm for pattern matching in polyphonic music databases. *Multimedia Tools and Applications*, Volume 30, Number 1, July, 2006.

Statistical learning

Example: Preishit ("bargain")

- Segmentation depends on language
  - German:
    - known words "Preis" + "Hit" = "Preis-Hit"
    - no "sh" in German → s+h
  - English:
    - known word "shit" (tabu → emotive → salient)
    - "sh" is mostly grouped (exception: mishap)
- Transition probabilities are high in known…
  - letter combinations
  - words

Transition probabilities

Corpus containing units V, W, X, Y, Z…
What is transitional probability of XY?

n_X = total number of X's
n_{XY} = total number of XY's
$p_{XY \mid X} = n_{XY} / n_X$

cf. 1st-order Markov model
Cf. Harris structural linguistics (1950s)

Statistical learning of syllables

- Problem
  - How do babies segment language? no reliable acoustic markers!
- Participants
  - 8-month-old infants
- Exposure phase
  - nonsense syllables e.g. *bidakupadotigolabubidak*
  - transitional probabilities:
    - high (1.0) within 3-syllable "words"
    - low (0.33) between words
  - 2 minutes only!
- Test phase
  - infants attend longer to "non-words" than "words"

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274,* 1926-1928.

Statistical learning of tones

- Stimuli
  - pure tones from C4 to B4
- Exposure phase
  - e.g. 2 minutes of DFEFCF#CC#DD#EDGG#A
- Participants
  - adults and infants
- Results
  - essentially same as for syllables
  - independent of streaming by pitch proximity
- Conclusion
  - same statistical learning mechanism

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (199). Staistical learning of tone sequest by human infants and adults. *Cognition, 70,* 27-52.

Transition probabilities

- Count tones (pitches or pitch classes)
  - Distribution, probabilities
- Count local combinations of two tones
  - Successive
  - Simultaneous
- Calculate transition probabilities:
  - Given element A, probability that B will
    - follow
    - sound simultaneously

Definitions

Musical chunk

- categorically perceived pattern
  - melodic
  - harmonic
  - both

Musical syntax

- conditional probabilities of chunks

Chunking and context

- Group elements with high trans. prob.
  - E.g. cadential formulae
- Repeat previous procedure
  - Count chunks
    - Distribution, probabilities
  - Count local chunk transitions?
  - Calculate transion probabilities?
- Accounts for context

Higher-level chunking

- Repetitions of 3 or more tones
  - Invariance under transposition
- Fuzzy definition
  - intervals $\pm$ 1 semitone
  - durations reduced to short and long
- Similarity algorithms

Dealing with polyphony

- Chunk individual streams
  - Relatively easy
- Chunk harmonic progressions
  - At every note onset, identify Tn-set
  - weight of Tn-set = no. of simultaneous onsets
  - calc. transition probabilities between Tn-sets
- Study results, then attempt 2-D problem

Implications

- Music history
  - Digital history changes thinking
- Music theory
  - Pitch structures better defined and understood
- Music analysis
  - Statistical claims about syntax become testable
- Music psychology
  - Stops neglecting historical context

Problems

- Chunks have fuzzy boundaries
  - Mix objective statistical and subjective theoretical approaches?
- Getting a big picture means losing detail
  - E.g. microtonality
- Can't average dissimilar styles
  - e.g. 12th century English & European styles

Interdisciplinarity

- Historical musicology
- Music performance
- History of music theory
- Computer science
- Music psychology
- Music education

Not all in one head!
→ Interaction between experts

Core project partners:

(Music···)

- historian or theorist
- psychologist
- computer scientist
- mathematician, statistician

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