Symbolic music features: Melody and Harmony

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Sound and Music Technology,
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Announcement

- Project Proposal discussion next Tuesday, December 10th
  - Location: BBG 4.47 – Hence NOT Bolognalaan!!
- I will make a schedule on the Google drive, document "Schedule for discussion of project proposals" and send around an email

Project Option C: Automatic Generation

- Dataset of 200 songs from previous rounds of the Eurovision Song Contest
- Use it for analysis and/or generation
- Skype meeting with VPRO planned on December 12, 15:00

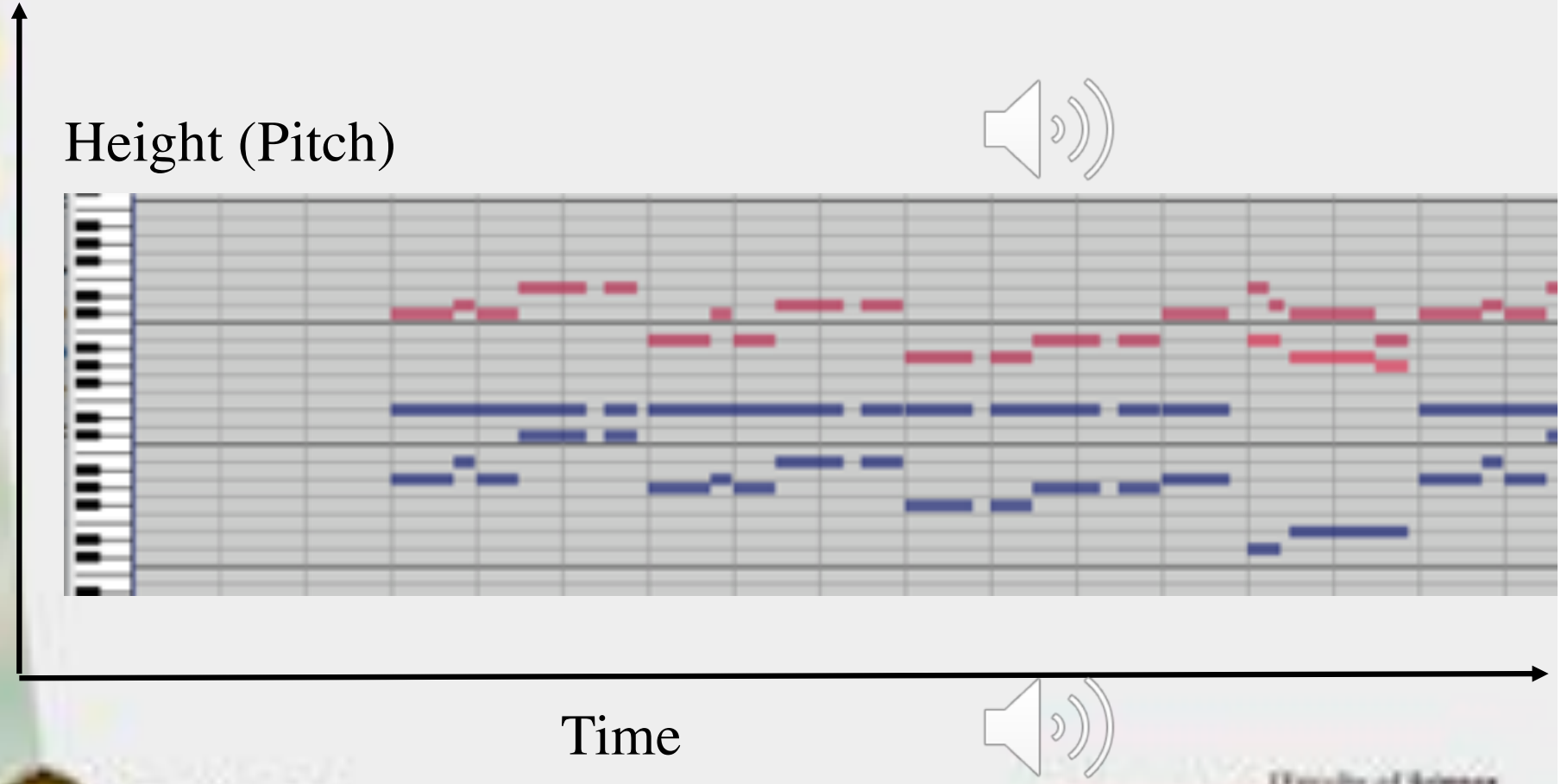
Recap MIR

- What are the two basic types of digital formats for music?
  - Audio: digitized wave form
  - Symbolic: event-based representation

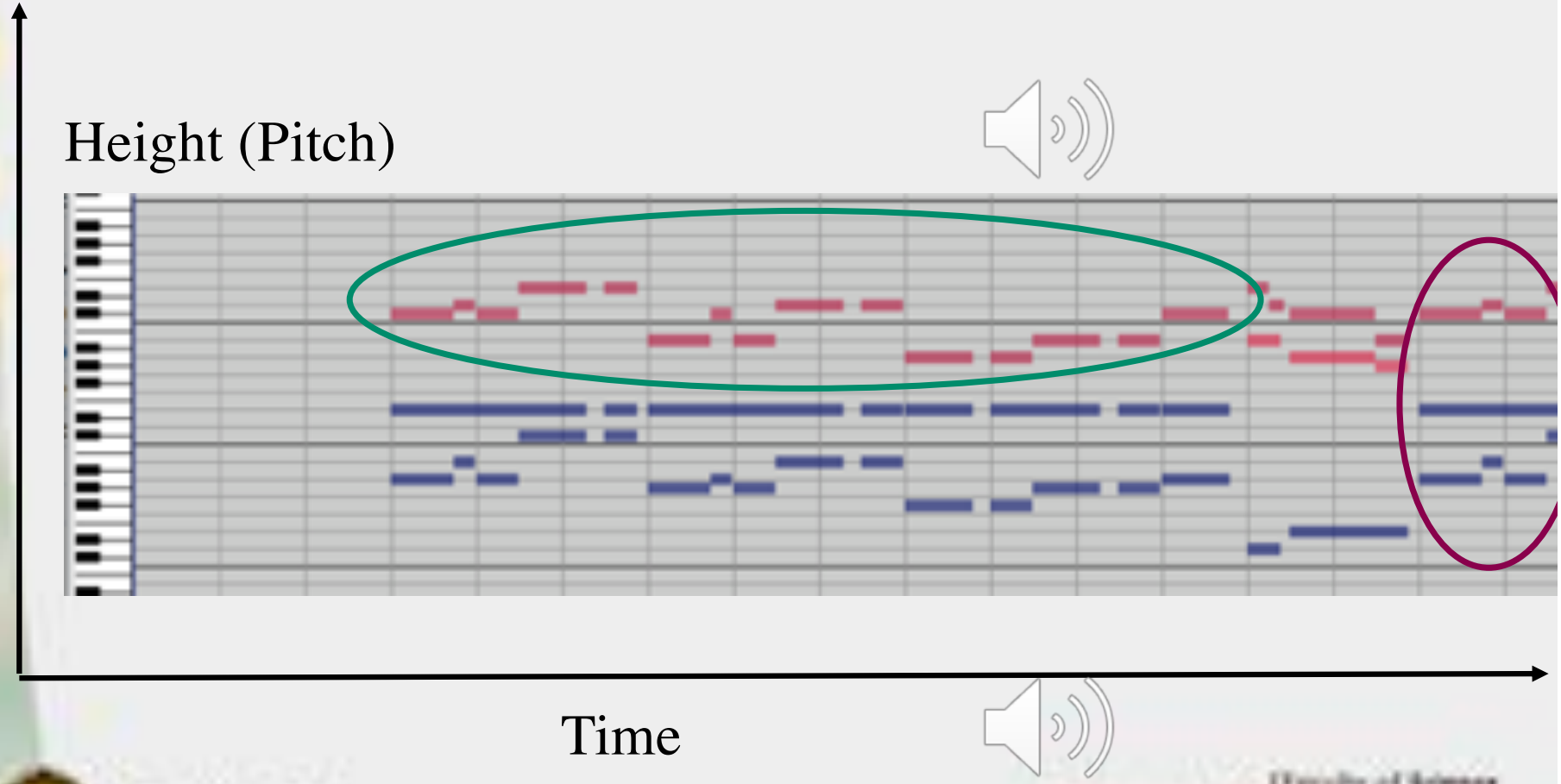
Recap rhythm

- What is rhythmic information?
  - Musical events as structured in time
  - E.g. duration of sound events, starting points of sound events
- What is metric information?
  - Re-occuring patterns of accents
  - E.g. beat, bars
- How do we extract metric information from symbolically encoded music? What are the steps involved?
- In what application areas(s) do we need rhythmic/metric information?
  - (Dance music) classification
  - Games: metric information important for horizonal re-sequencing

Symbolic music feature extraction: Melody and harmony



Symbolic music feature extraction: Melody and harmony



Outline

- Pitch perception
- Computational modelling of melody
  - Themefinder
  - EMD
  - Sequence alignment
- Polyphony
- Chords and tonality
- Computational modelling of harmony
  - Grammar of harmony
  - Krumhansl profiles

Perceived musical features (lecture 1)

- Sound events
  - pitched, unpitched
- Basic parameters of a pitched sound event
  - pitch: how high or low the sound is: perceptual analog of frequency
  - duration: how long the note lasts
  - loudness: perceptual analog of amplitude
  - timbre or tone quality

Pitch: continuous or discrete?

George Gershwin, Rhapsody in blue

Pitch: continuous or discrete?

- pitch space is continuous
- division in discrete steps is a property of our cognition
- usually, the absolute pitch (like 440 Hz) is not what matters most
- distances between pitches (intervals) seem to be the most important cognitive categories

Western pitch

- octave divided in 12 equal intervals
  - semitones, ratio = $1:\sqrt[12]{2}$
- Western pitch system consists of over 7 octaves divided into semitones
  - grand piano has 88 keys
  - MIDI represents pitch by number between 0 and 127

Western pitch

- octave divided in 12 equal intervals
  - semitones, ratio = $1:\sqrt[12]{2}$

https://www.youtube.com/watch?v=6uqo8x-iERE

http://virtualpiano.net/

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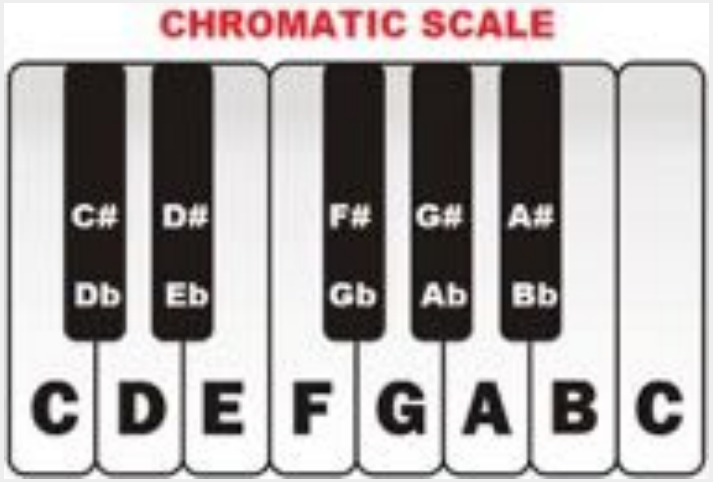


http://virtualpiano.net/

Tonality

- pitch is generally not equally distributed within a piece of music
- if it is, you get 'atonal' music
  - e.g. Webern's piano variations

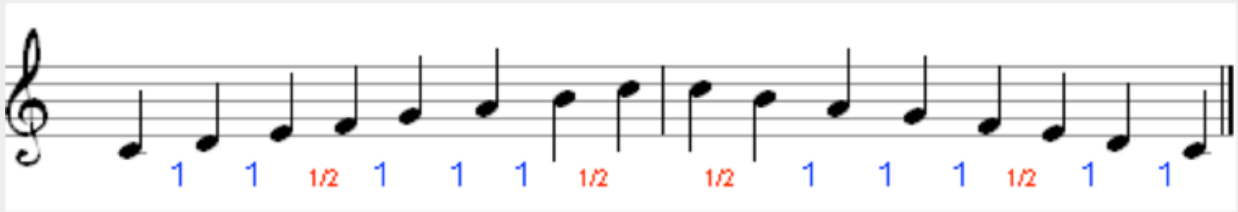
- when we use only a subset, music generally sounds much more structured

Tonality

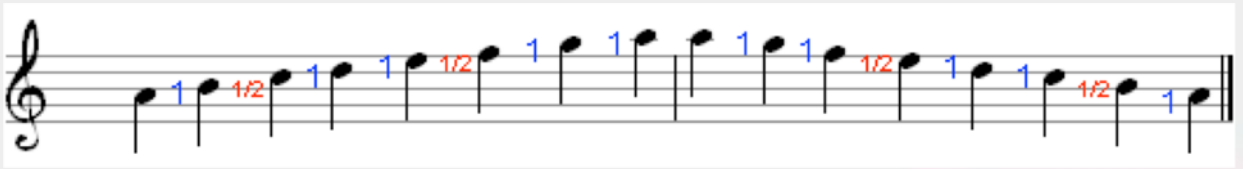
- subsets are often visualised as musical scales
  - perceptually, they help us identify 'tonality'
  - music hovers around certain pitch, the 'final' or 'tonic'
- most common scales: major and minor
  - 7 different pitches within octave
  - most audible difference: third note of scale
  - change can be quite dramatic

http://virtualpiano.net/

major



minor



ex. Gustav Mahler, 1st symphony, 3rd mvt

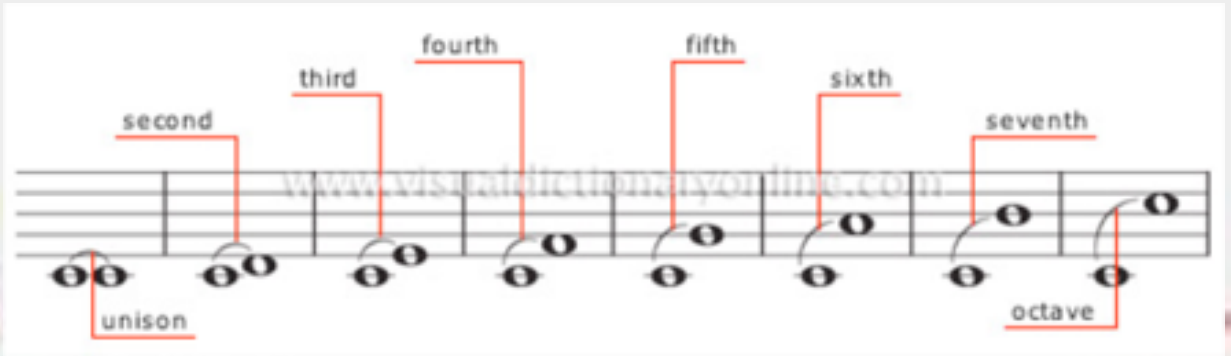
C major scale in notation

http://virtualpiano.net/

Intervals

- music notation optimised for 7 different pitches
  - use of sharps and flats for black keys

- interval names based on 7 notes within octave
  - qualified by labels such as ‘major’, ‘minor’, ‘diminished’



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Melody

- melody, defined as pitched sounds arranged in musical time in accordance with given cultural conventions and constraints, represents a universal human phenomenon traceable to prehistoric times (Oxford Music Online)

- This lecture
  - how do we model melody as a succession of pitched sounds?
  - retrieval by melody

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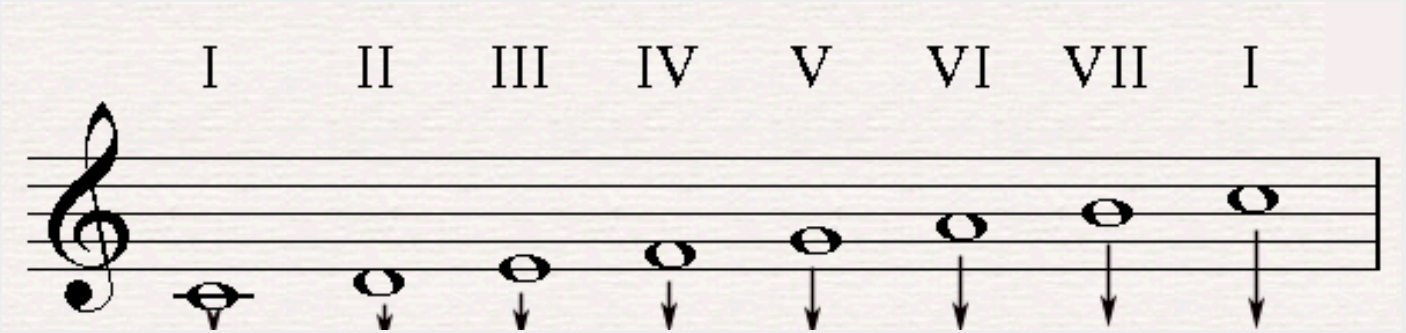
How to represent characteristics of melody?

- Exact pitch sequence
- Series of intervals
- Scale degrees



How to model characteristics of melody?

- Exact pitch sequence
- Series of intervals
- Scale degrees
- Contour
- …

http://virtualpiano.net/

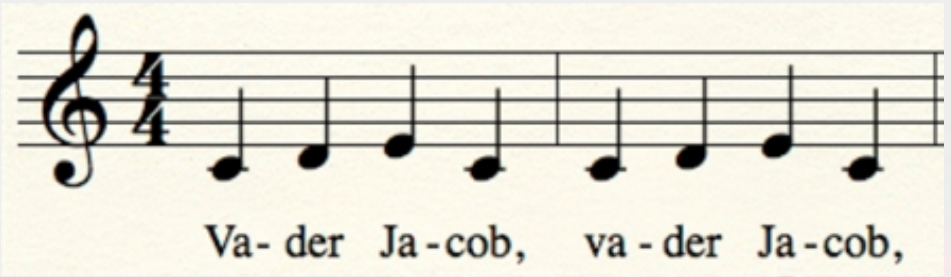
themefinder.org

- CCARH service, 1999
- ca. 40.000 themes, initially from Barlow & Morgenstern (1948)
- melody search based on Humdrum toolkit
- regular-expression based string matching

Representing a melody

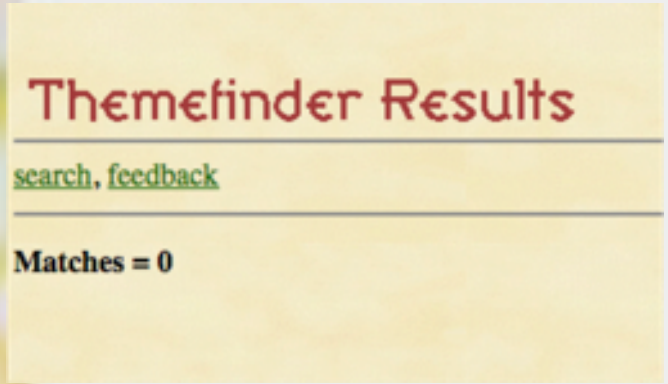
Pitch		A-G, *sharp*=♯, *flat*=– *e.g.* C E– G F♯
Interval		*maj*=M, *min*=m, *aug*=A, *dim*=d *per*=P, *fifth*=5, *up*=+, *down*=–. *e.g.* +m9 –P8 +M3 P1
Scale Degree		*do*=1, *re*=2, *mi*=3, *fa*=4, *so*=5, *la*=6, *ti*=7 (mode insensitive). *e.g.* 34554321
Gross Contour		*up*=/, *down*=\, *unison*=–. *e.g.* //\–/ or uudsu
Refined Contour		*up step*=u, *up leap*=U, *down step*=d, *down leap*=D, *same*=s. *e.g.* uUDsdu

- different string representations (1D, just pitch)
  - pitch: C D E C C D E C
  - interval: +M2 +M2 –M3 P1 +M2 +M2 –M3
  - scale degree: 12311231
  - gross contour: //\-//\
  - refined contour: su, sd



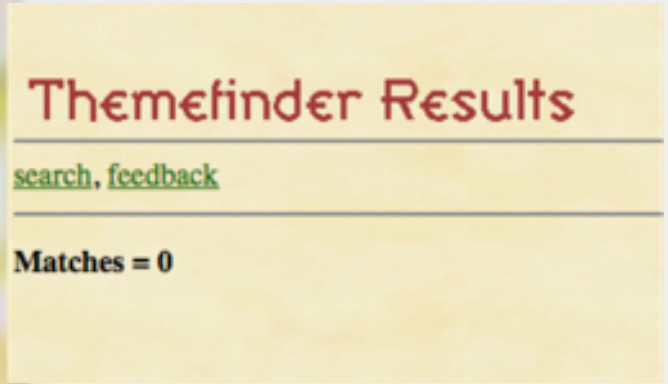
Search results (1)

pitch

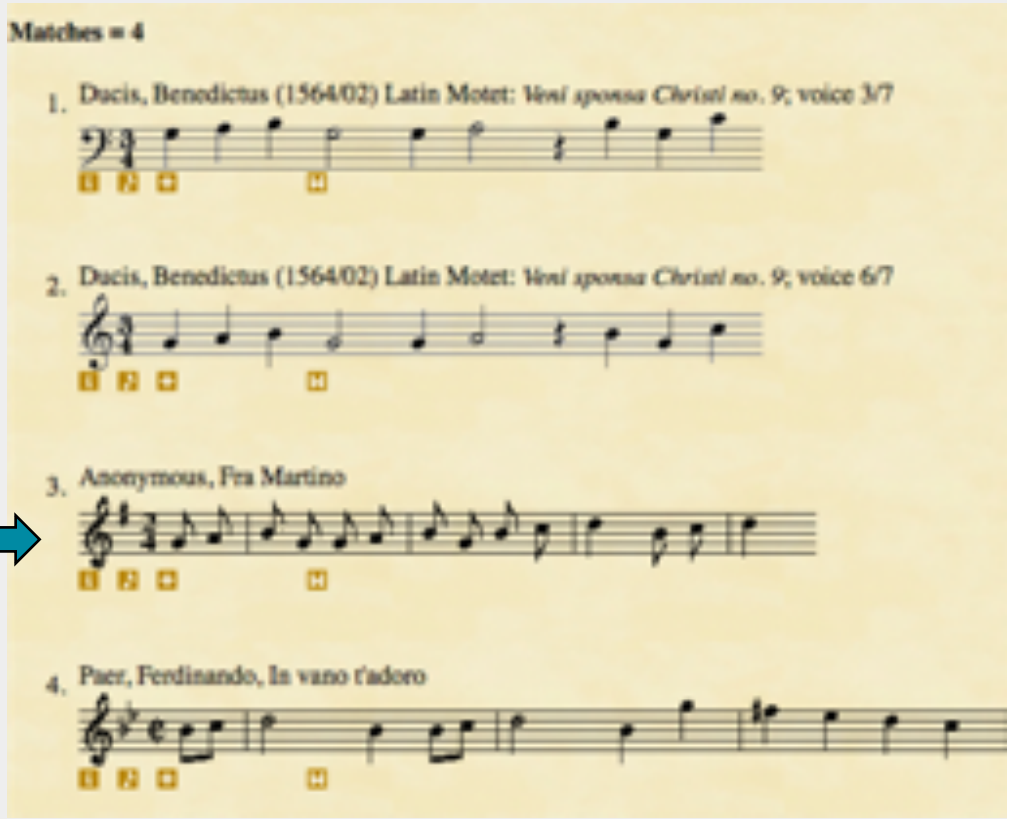


Search results (1)

pitch



interval



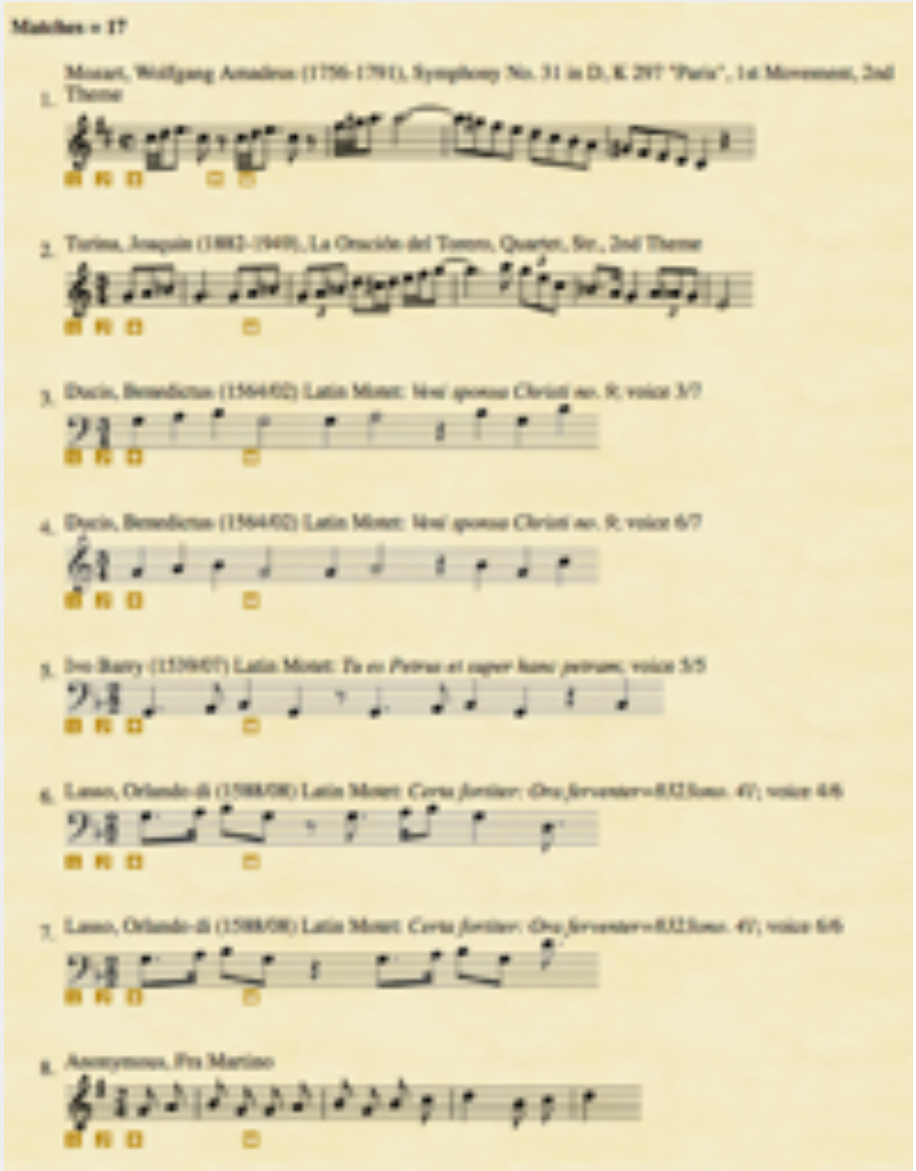
- pitch not really helpful
- interval representation is invariant against transposition (desirable property)

Search results (2)

- gross contour //\-//\ rank 25/61
- refined contour: rank 8/17
- ranking erratic

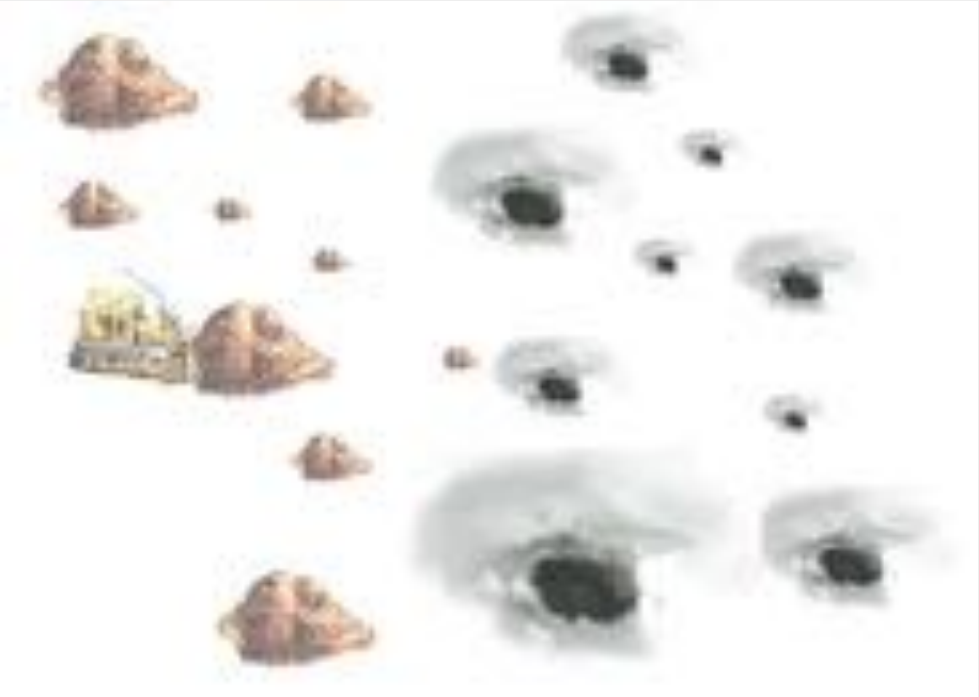
- observations
  - yes/no answer, rank depends on database order
  - number of hits varies a lot
  - other matches musically very different
  - how to deal with melodic variation?

- might adding duration information help?
  - need different representation



Melodic similarity: Earth Mover's Distance

- The Earth Mover's Distance (EMD) calculates the minimum flow that would match two set of weighted points. One set emits weight, the other one receives weight
- constraints:
  - no negative flow
  - no point emits or receives more than its weight
  - the lighter pointset is completely matched



Melodic similarity: Earth Mover's Distance

Point sets:

$P=\{(p_1,w_{p1}) \ldots, (p_m,w_{pm})\}$

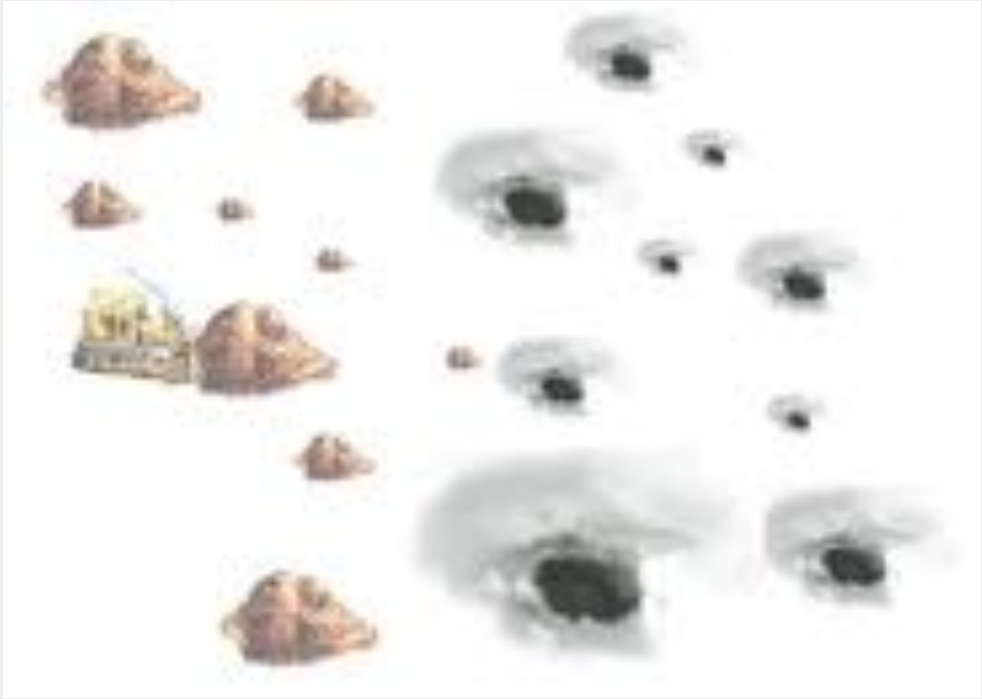
$Q=\{(q_1,w_{p1}) \ldots, (q_n,w_{pn})\}$

Ground distance matrix:

$D=[d_{ij}]$

Flow: $F=[f_{ij}]$

$$\text{WORK}(P, Q, \mathbf{F}) = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij} f_{ij},$$



Melodic similarity: Earth Mover's Distance

$$\mathrm{WORK}(P, Q, \mathbf{F}) = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij} f_{ij},$$

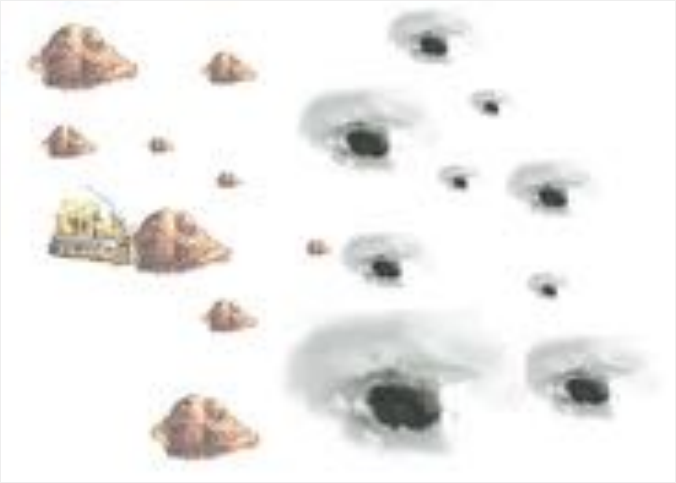
$$f_{ij} \geq 0 \qquad 1 \leq i \leq m,\ 1 \leq j \leq n \qquad (1)$$

$$\sum_{j=1}^{n} f_{ij} \leq w_{\mathbf{p}_i} \qquad 1 \leq i \leq m \qquad (2)$$

$$\sum_{i=1}^{m} f_{ij} \leq w_{\mathbf{q}_j} \qquad 1 \leq j \leq n \qquad (3)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} f_{ij} = \min\left(\sum_{i=1}^{m} w_{\mathbf{p}_i}, \sum_{j=1}^{n} w_{\mathbf{q}_j}\right), \qquad (4)$$

$$\mathrm{EMD}(P, Q) = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij} f_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n} f_{ij}}$$

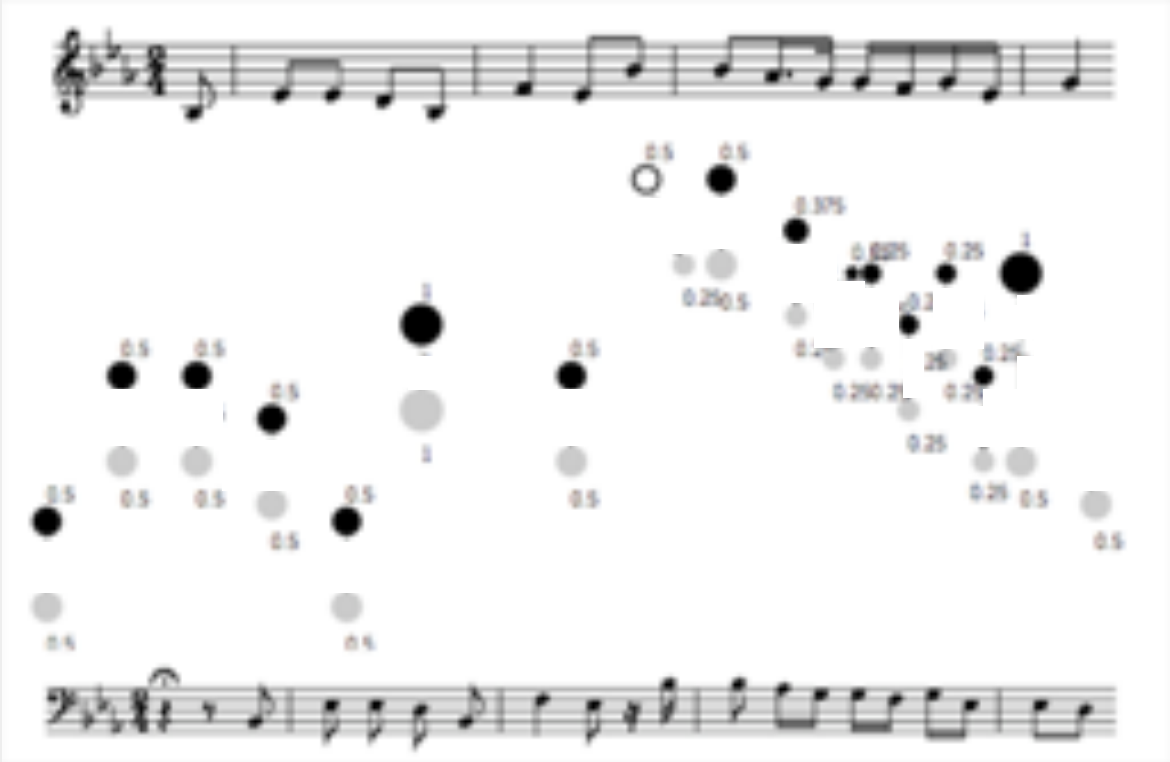


2) and 3): no point emits or receives more than its weight

4) the lighter point set is completely matched

Application to music

- represent notes as weighted point sets in 2-dimensional space (pitch, time)
- weight represents duration

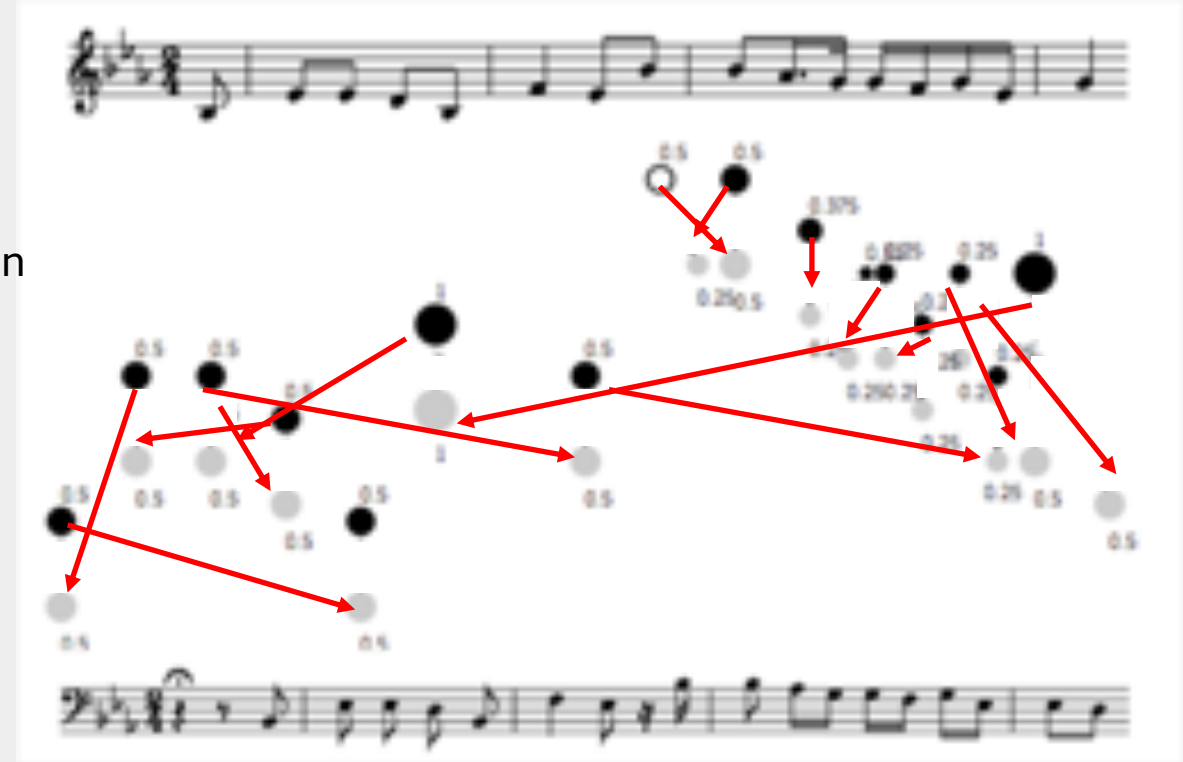


after alignment, the ‘earth’ is moved both along the temporal axis and along the pitch axis

Application to music

Minimize!

- represent notes as weighted point sets in 2-dimensional space (pitch, time)
- weight represents duration



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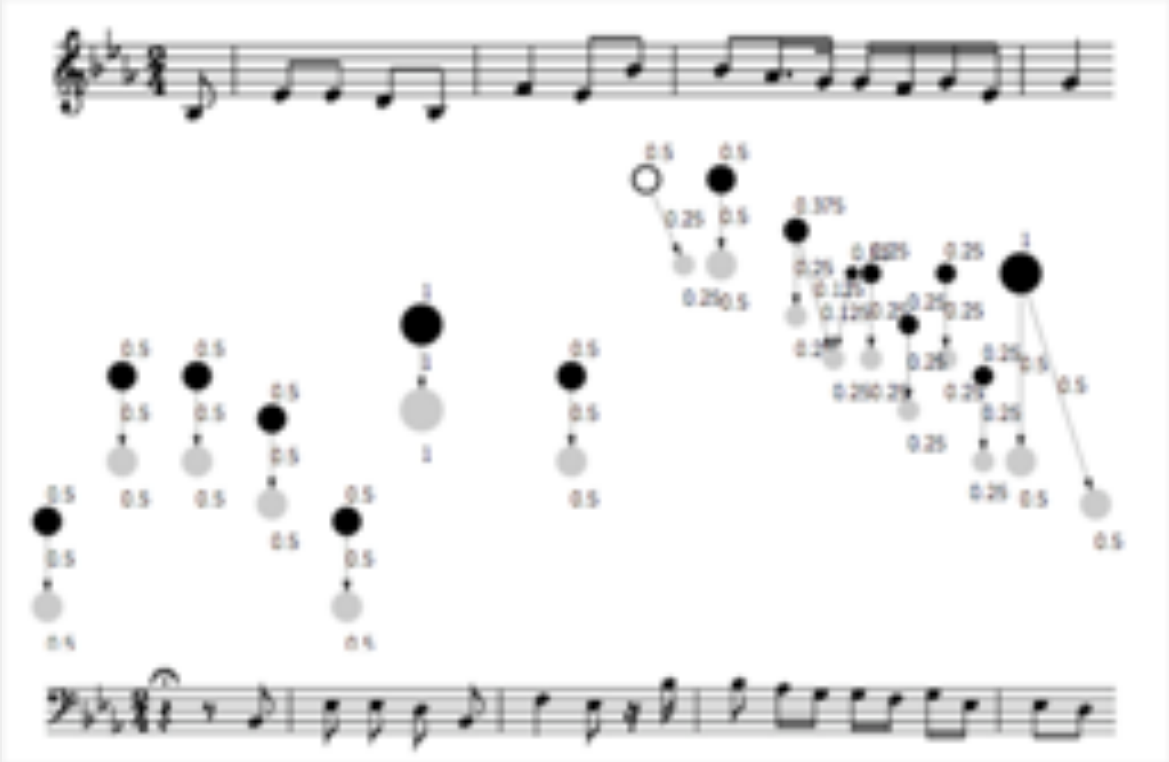
Application to music

- represent notes as weighted point sets in 2-dimensional space (pitch, time)
- weight represents duration
- interesting properties
  - tolerant against melodic confounds
  - suitable for polyphony
  - partial matching



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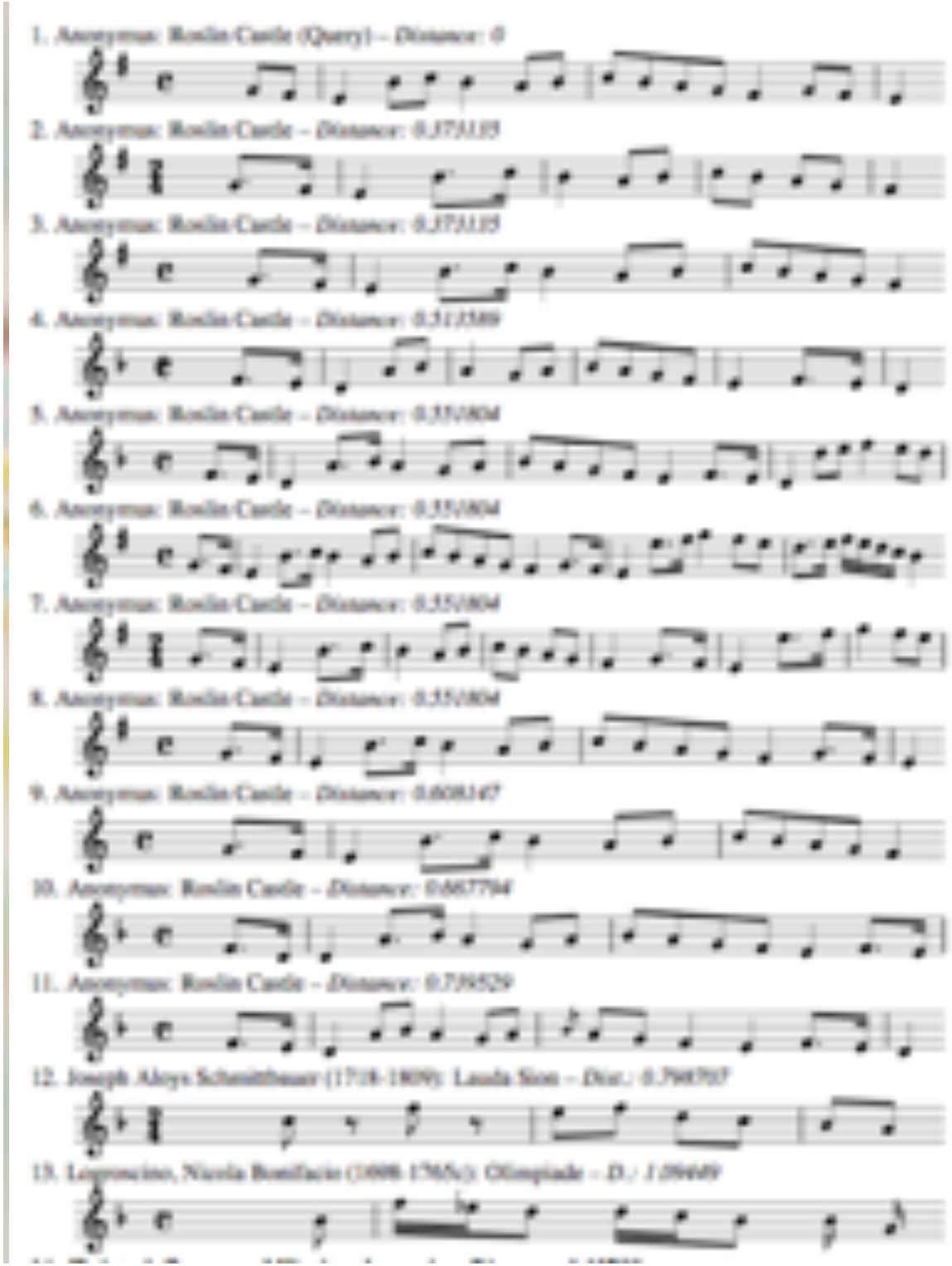

Results

- tested on RISM A/II incipits
  - around 400.000 items
- example
  - item 1 = query
  - 12 / 16 in top 17 matches
- further experiments
  - reasonably tolerant against variation
  - insertions and deletions are problematic
  - Treating music two-dimensional can be problematic (time different than pitch)

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- Chords and tonality
- Harmony modelling
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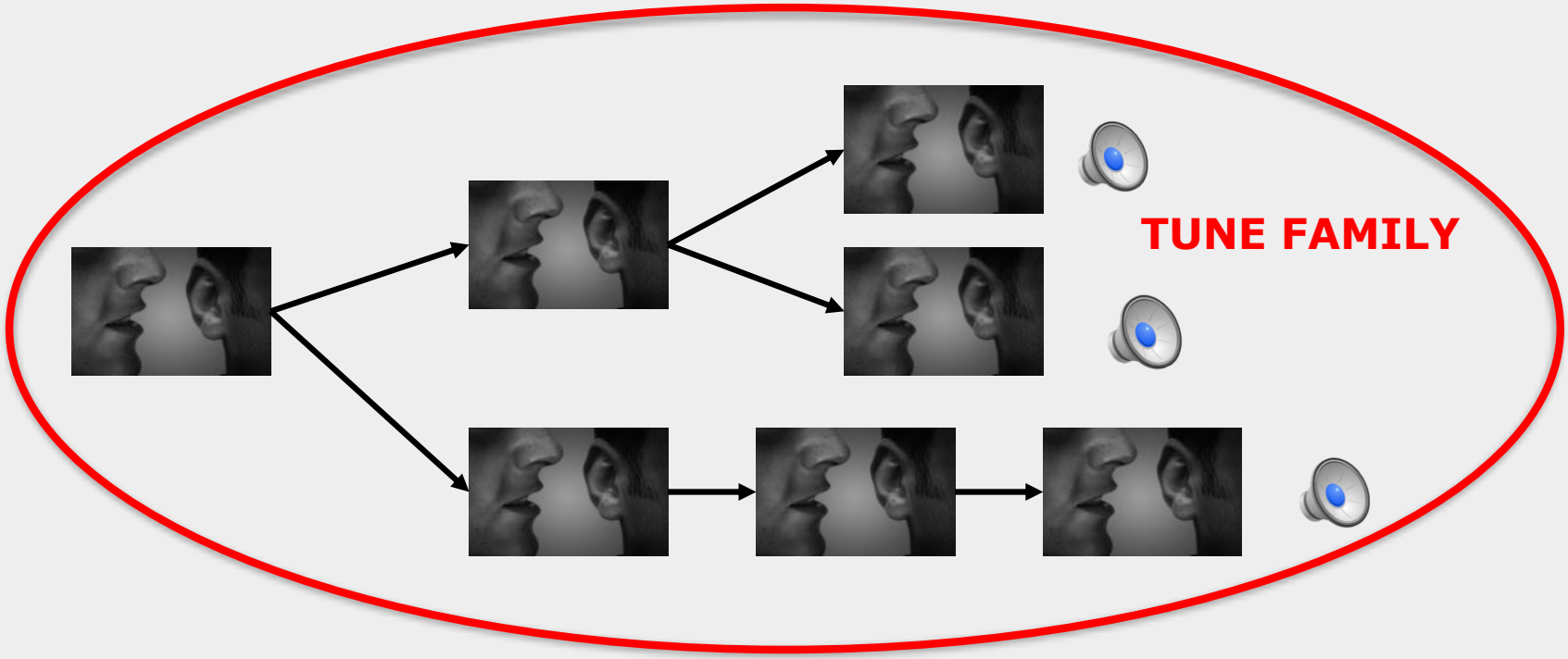
  - Krumhansl profiles

Sequence alignment

Meertens Institute (Amsterdam):
Onder de groene linde: c. 7000 recordings.
Recorded 1950s – 1980s

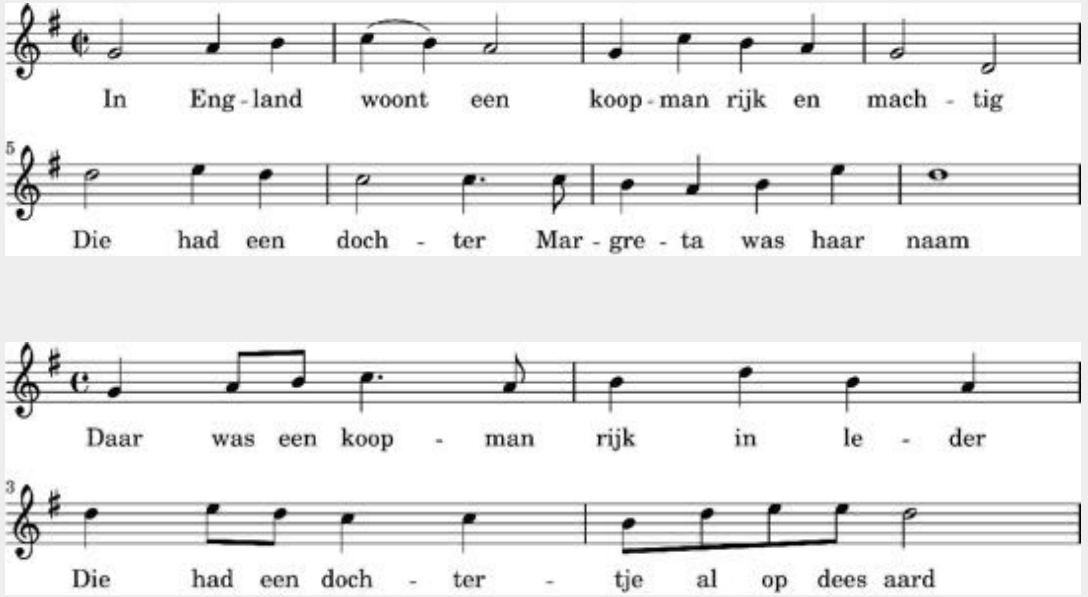
Sequence alignment

- Oral transmission



Sequence alignment

- Oral transmission

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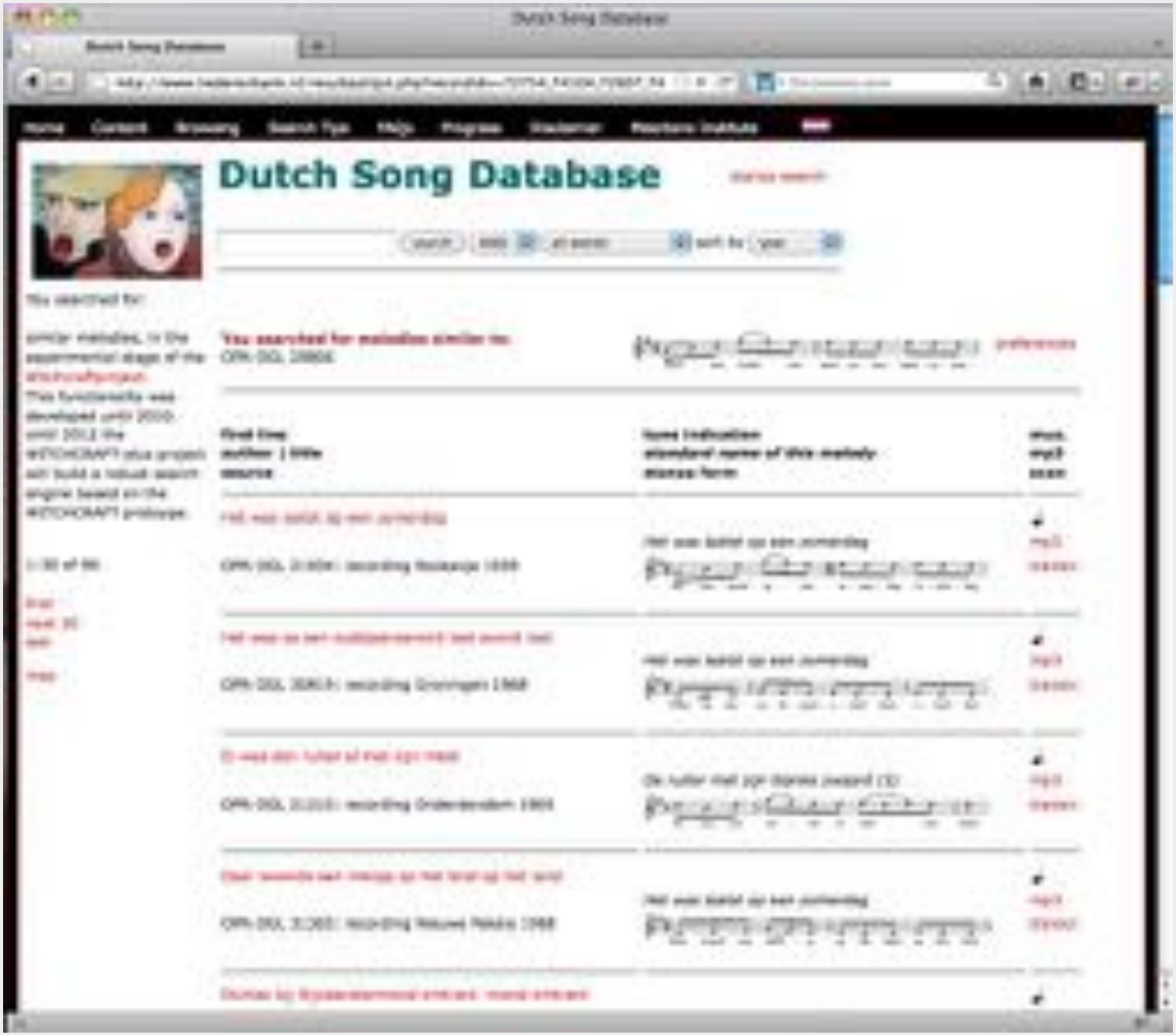
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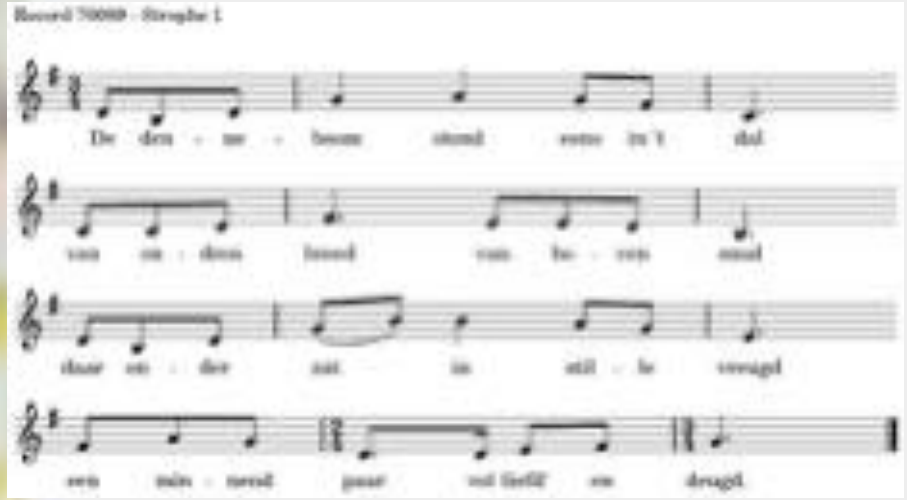
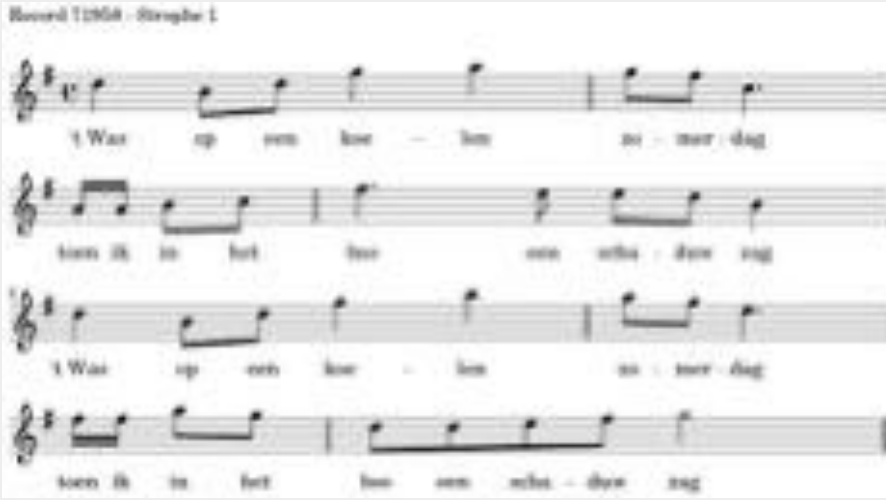
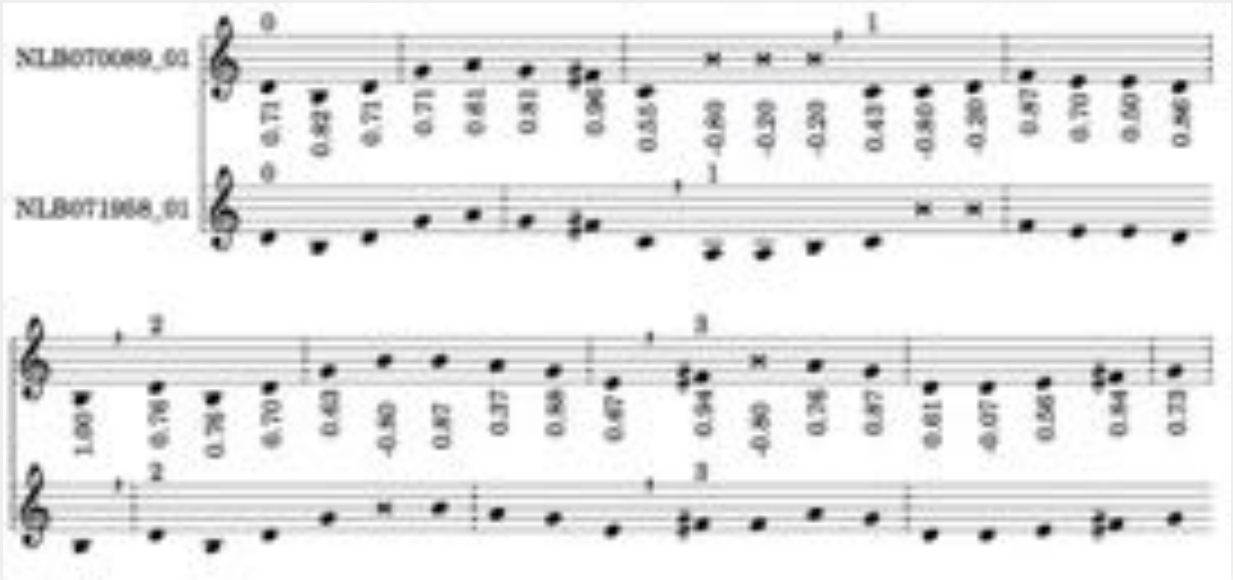
Alignment







Alignment

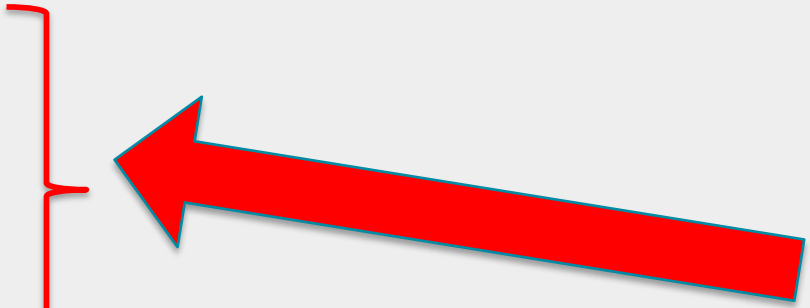
- Note-to-Note-Alignment
- General idea
  - Align two sequences of notes (songs)
  - Find the optimal alignment, allowing gaps.
  - Each gap/mismatch adds to a penalty score
- Example with text: align the words BEAR and BARS
  - B E A R
  - B - A R S

Distance: 2 (one gap, one addition)

Alignment Algorithm

There is an algorithm that given

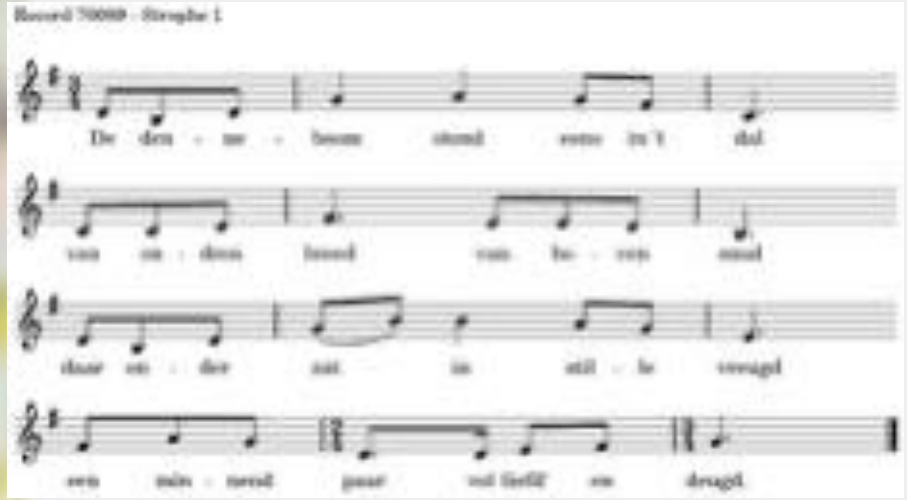
- two sequences of symbols
- an association scoring function
- a gap scoring function

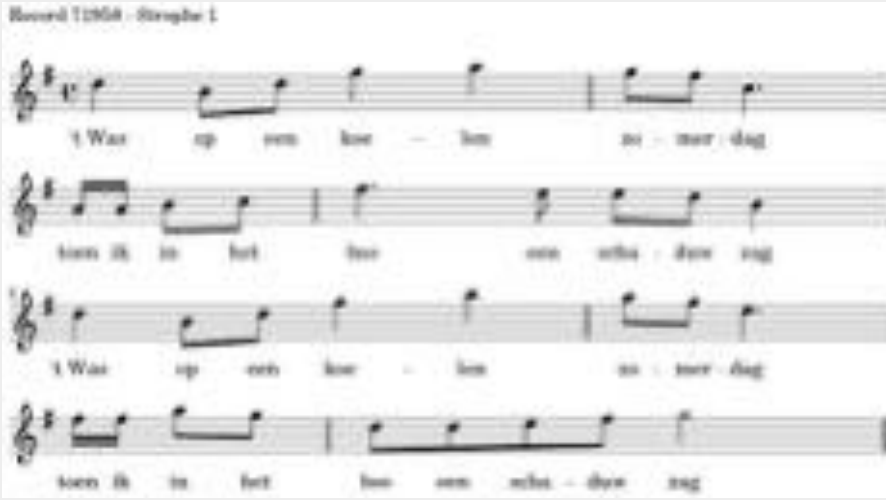


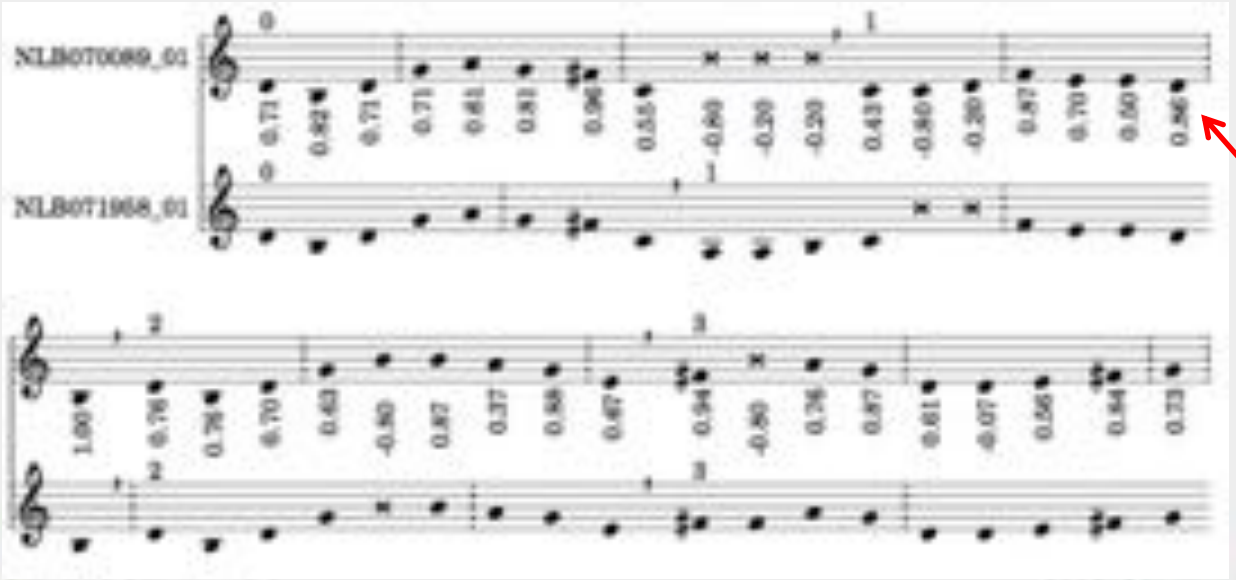
finds the optimal alignment efficiently.

Smith, T. F. & Waterman, M. S. (1981). “Identification of Common Molecular Subsequences”. *Journal of Molecular Biology*, 147(1), 195–197.

Alignment







Pitch band
Metric weight (IMA)
Phrase position

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Polyphony

- A term used to designate various important categories in music: namely, music in more than one part, music in many parts, and the style in which all or several of the musical parts move to some extent independently. (Oxford Music Online)

- polyphony exploits consonance and dissonance of intervals sounding together
  - consonance: sensation of relaxation
  - dissonance: sensation of tension or roughness
- dull Youtube video: http://www.youtube.com/watch?v=uKXxa9P1Bug

Counterpoint

- rules about how to move from one interval combination to another
  - dissonance creates expectation, resolved by consonance (or not)
  - maximise independence and/or interestingness of each voice
  - share common melodic material
  - e.g. J.S. Bach's fugues
- highly formalised part of music theory
  - attempts at automatisation go back to at least to 17th century
- example of modern counterpoint
  - Dmitri Shostakovich (1906-1975)
  - String Quartet 8, 1st mvt
  - autobiographical Leitmotiv
  - note tension and relaxation

Counterpoint

- Challenge: given a MIDI file containing a polyphonic piece with different voices, how do we automatically determine these voices?
- Automatic composition of counterpoint is typical task in music generation research

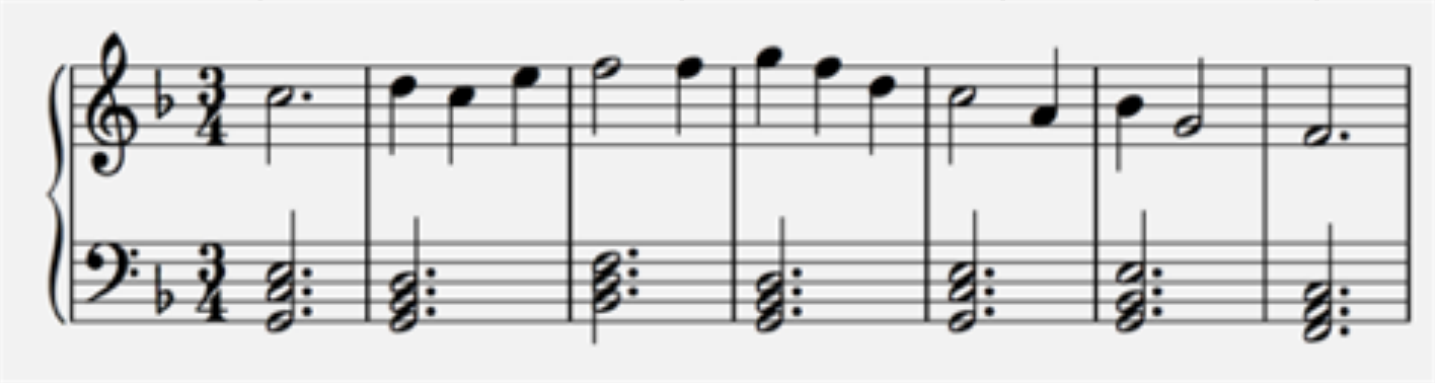
Harmony

- another way of looking at polyphony is as a combination of melody and accompaniment
  - e.g. beginning of *Rhapsody in blue*

- accompaniment consists of sequence of chords
- a chord is a number of simultaneous pitch events
  - certain level of perceptual fusion
- both chord structure and chord progressions are rather stereotypical and can be formalised (to a certain extent)

Chords

- theoretically, chords are stacks of thirds
  - triads: 2 thirds, like C-E-G
  - seventh chords: 3 thirds, like C-E-G-B
  - single chord can be ‘spaced’ in many different ways



- some chords are consonant (Major and Minor triad)
- all the others are dissonant

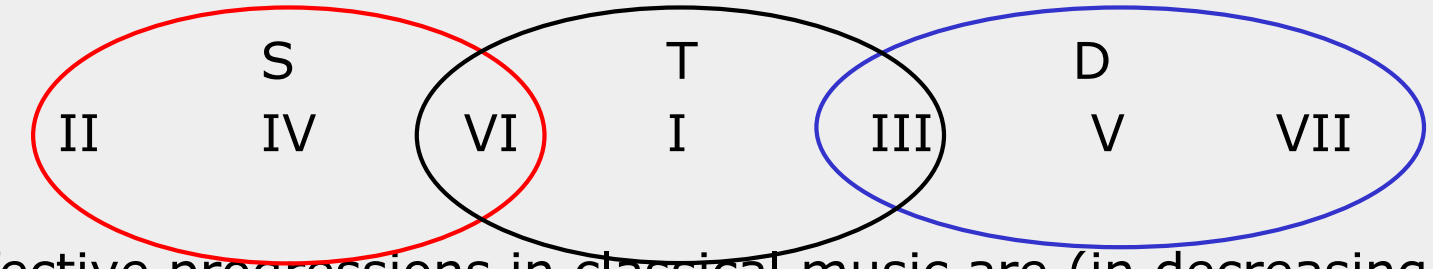
Chord progressions

- from a harmonic perspective, stereotyped chord progressions define key
  - short for 'the tonality of a piece of music'
- most important chords are those on the 1st, 4th and 5th notes of the scale
  - often indicated with Roman numerals (I-IV-V-I)
  - or Functional Harmony labels: Tonic, Subdominant, Dominant

- playing with harmonic expectancy is an important aspect of classical compositions
  - ex. J.S. Bach, BWV 90, 6th mvt (Spotify)
- Interestingly, harmony can be described by formal grammars, just like (natural and programming) languages

For reference: Harmonic functions simplified

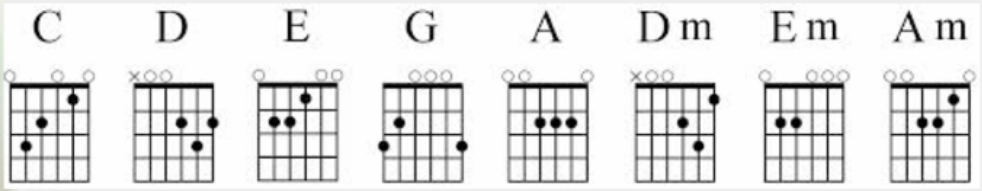
- In one key, there exist three harmonic functions:
  - Tonic: the tonal centre
  - Subdominant: moves away from tonic
  - Dominant: moves to tonic
  - All chords in one key belong to 1 or 2 of these classes



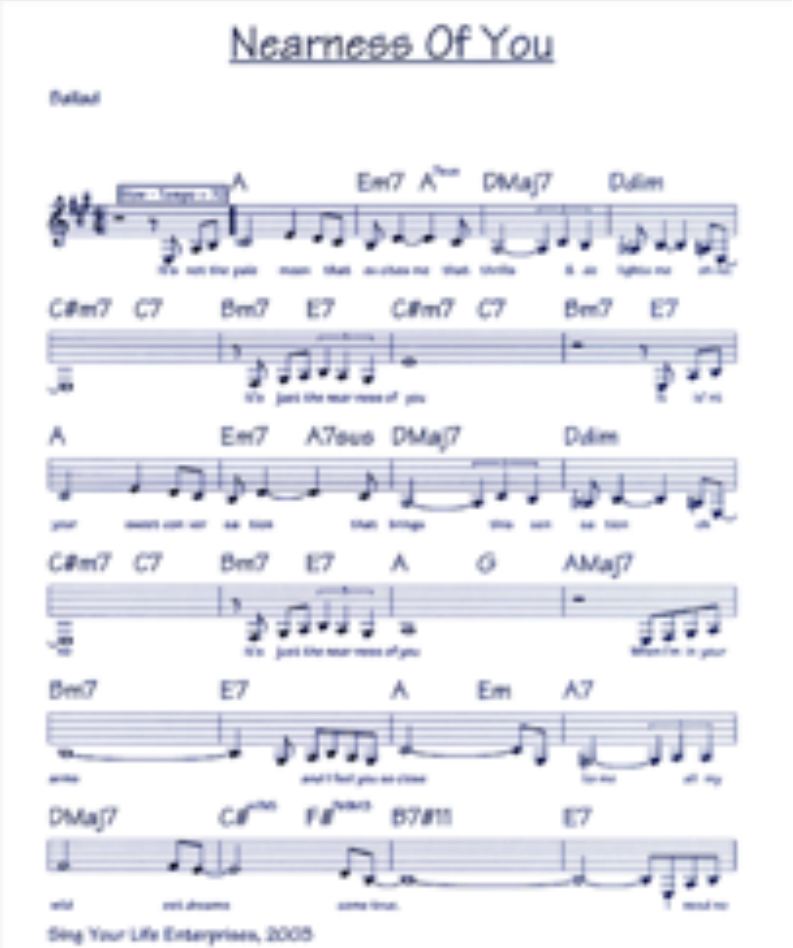
- Effective progressions in classical music are (in decreasing order) T-S-D-T, T-D-T, and T-S-T
  - tension/relaxation
  - strongest harmonic cliché: I - IV - V -I

Chord labels

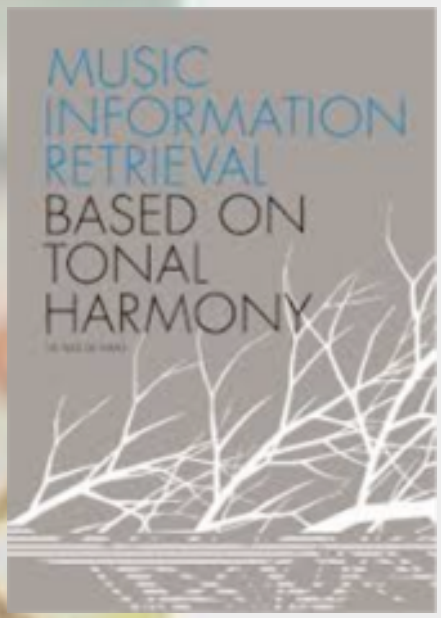
- chord labels are an important shorthand
  - widely distributed over the Internet
- formalisation of chord label syntax by Christopher Harte (PhD thesis Queen Mary U of London, 2010)
  - e.g. major triad ➔ C:(1,3,5)



closely related to guitar tabs



lead sheets



Formal grammar of harmony

$$
\begin{aligned}
4\ \ & Ton_{\text{Maj}} \rightarrow I_{\text{Maj}} \mid I_{\text{Maj}}\ IV_{\text{Maj}}\ I_{\text{Maj}} \\
5\ \ & Ton_{\text{Min}} \rightarrow I^{m}_{\text{Min}} \mid I^{m}_{\text{Min}}\ IV^{m}_{\text{Min}}\ I^{m}_{\text{Min}} \\
6\ \ & Dom_{\mathbf{m}} \rightarrow V^{7}_{\mathbf{m}} \mid V_{\mathbf{m}} \qquad \mathbf{c} \in \{\varnothing, m, 7, 0\} \\
7\ \ & Sub_{\text{Maj}} \rightarrow IV^{m}_{\text{Maj}} \mid II^{m}_{\text{Maj}} \mid \ldots \\
8\ \ & Sub_{\text{Min}} \rightarrow IV_{\text{Min}} \mid II^{m}_{\text{Min}} \mid \ldots
\end{aligned}
$$

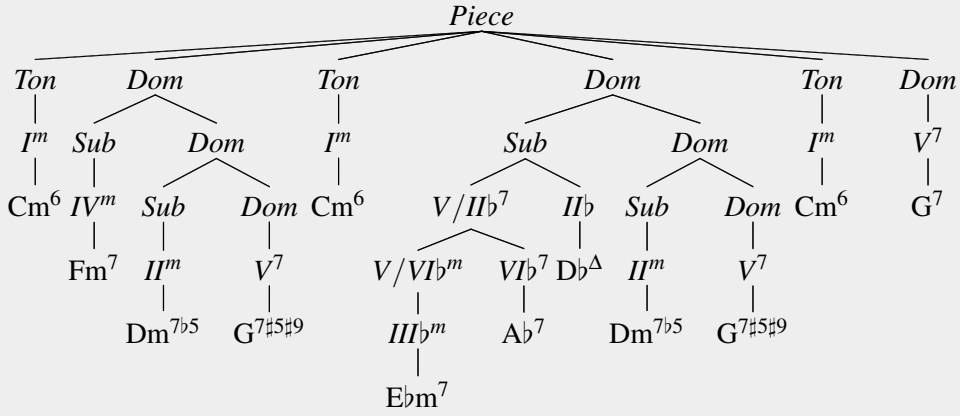


Figure 2. An analysis of the jazz standard *Blue Bossa* in C minor. Every chord belongs to a Tonic, Dominant, or Subdominant category (*Ton*, *Dom*, or *Sub*) and the V/X^7 denote chains of secondary dominants.

- PhD thesis Bas de Haas (2012)
  - uses error-correcting context free grammar
- applications
  - cover song detection
  - musicological research
  - improving chord transcription

Application in games and music generation

- Leitmotif and variation
  - Respect tonality in variation
  - Change of tonality: can create specific effect
- Create tonal sequences that are not disruptive
- Automatic composition of counterpoint (see next lectures in section C)
- Automatic accompaniment

Summary

- pitch, interval
- tonality, scale, major and minor keys
- melody representations: string, weighted point set (sequence)
- melody retrieval: string matching, EMD, expectation, patterns

- polyphony, harmony, counterpoint
- chords, chord labels, chord progressions
- harmonic grammar

Literature

- Carol L. Krumhansl, *Cognitive Foundations of Musical Pitch* (1990)
- Craig Sapp: Visual hierarchical key analysis, Computers in Entertainment 3(4):1-19, (2005)
- Van Kranenburg, P., Volk, A., Wiering, F., Veltkamp, R.C. (2009). Musical Models for Folk-Song Melody Alignment, *Proceedings of the International Society on Music Information Retrieval Conference*, Kobe, Japan, 507-512.
- De Haas, W.B., Wiering, F. & Veltkamp, R.C. (2013). A geometrical distance measure for determining the similarity of musical harmony. International Journal of Multimedia Information Retrieval, 2 (3), (pp. 189-202)