Hochschule für Musik Karlsruhe

Blockvorlesung

Advanced Audio-Based Music Processing

5. Harmonic Feature Design

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Dissertation: Tonality-Based Style Analysis

Christof Weiß
Computational Methods for Tonality-Based Style Analysis of Classical Music Audio Recordings
PhD thesis, Ilmenau University of Technology, 2017
https://www.db-thueringen.de/receive/dbt_mods_00032890

Chapter 6: Design of Tonal Features

Harmonic Feature Design

Motivation

- Harmony analysis:
  - Recognition of **specific** chords, keys, …
  - Resulting features / analyses characterize a **specific** piece
  - Allows for playing / accompaniment
  - Sensitive to transpositions, **key-dependent**
- Harmonic features:
  - Describe more **general** properties of a piece
  - Characterize musical „language“ or **style**
  - Allow for historical analysis / style classification
  - Independent of key, **transposition-invariant**
  - Quantification of chord **types**, **relative** chord transitions, …

Harmonic Feature Design

Overview

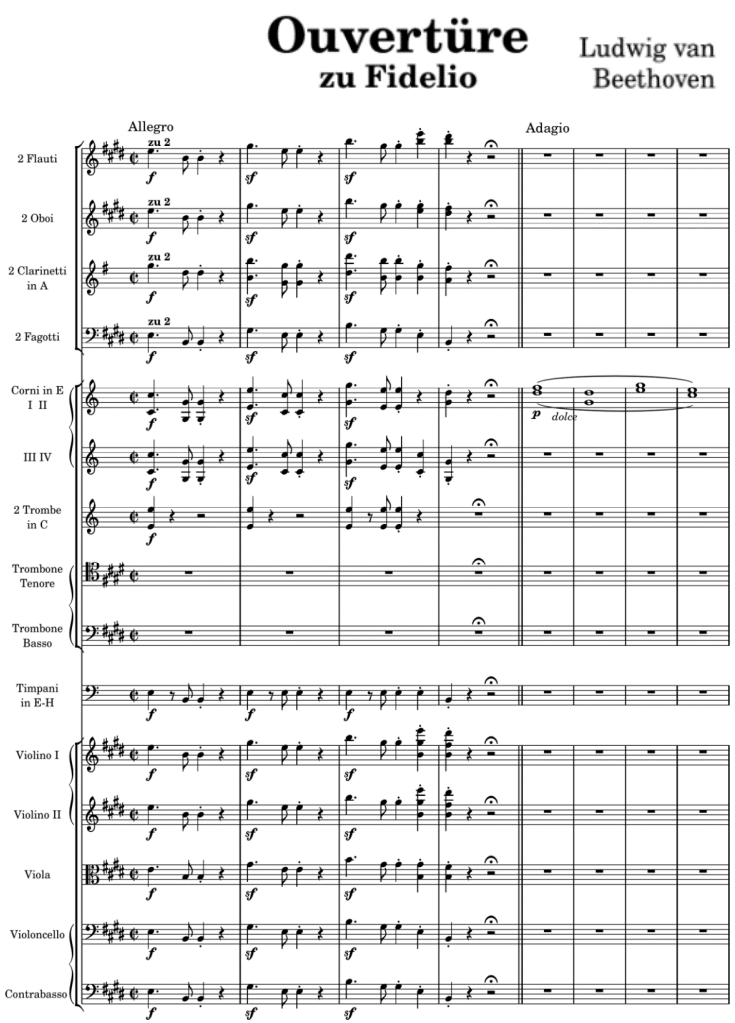
- Measuring Interval and Chord Categories
- Measuring Tonal Complexity

Harmonic Feature Design

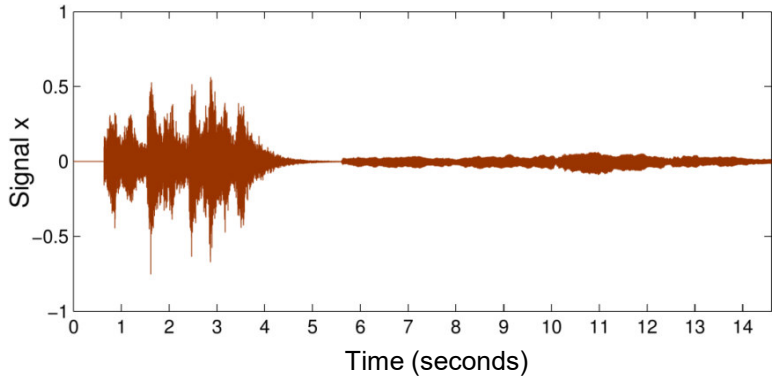
Overview

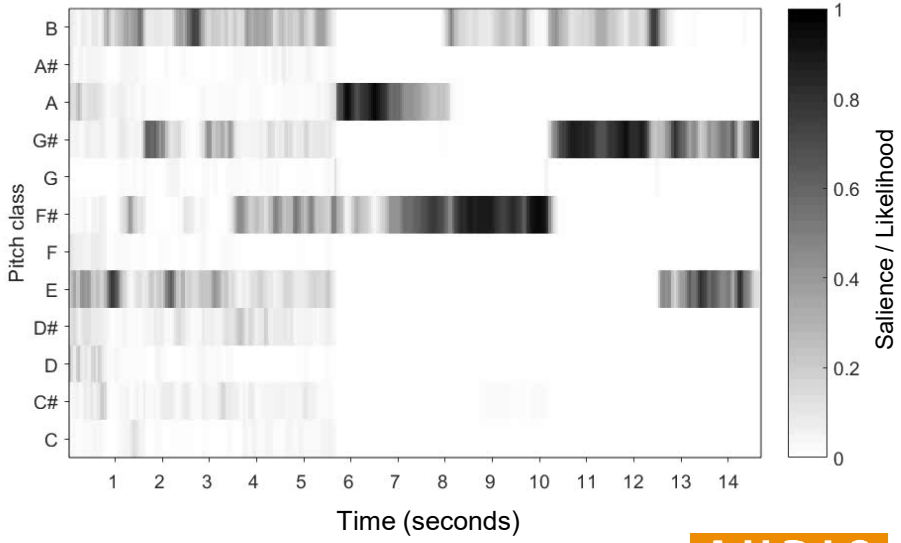
- Measuring Interval and Chord Categories
- Measuring Tonal Complexity

Signal Processing: Chroma Features



L. van Beethoven,
Fidelio, Overture,
Slovak Philharmonic





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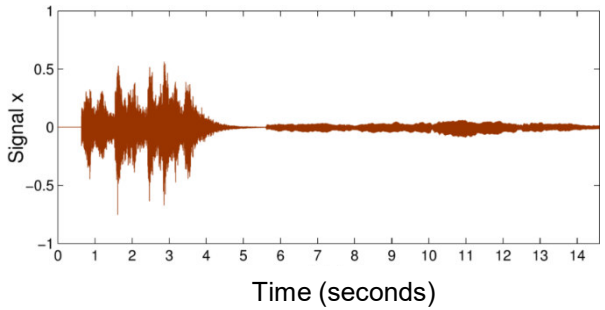

L. van Beethoven,
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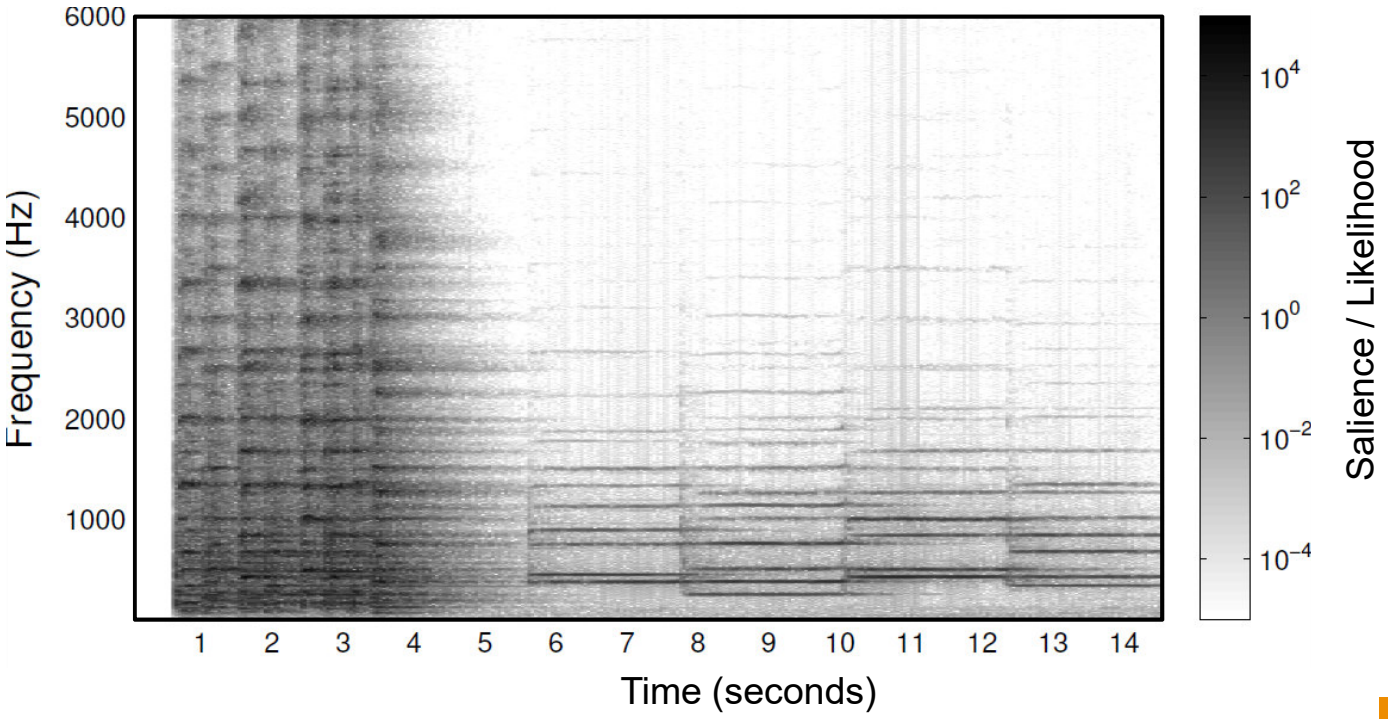
Spectrogram: Time – Frequency



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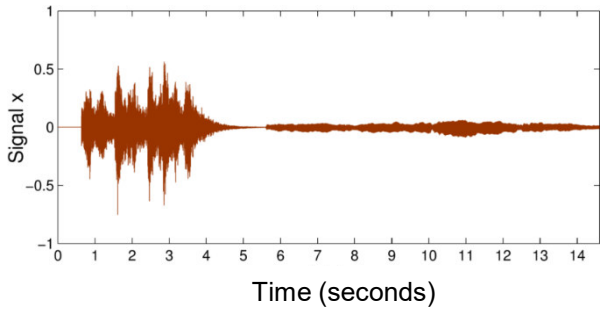

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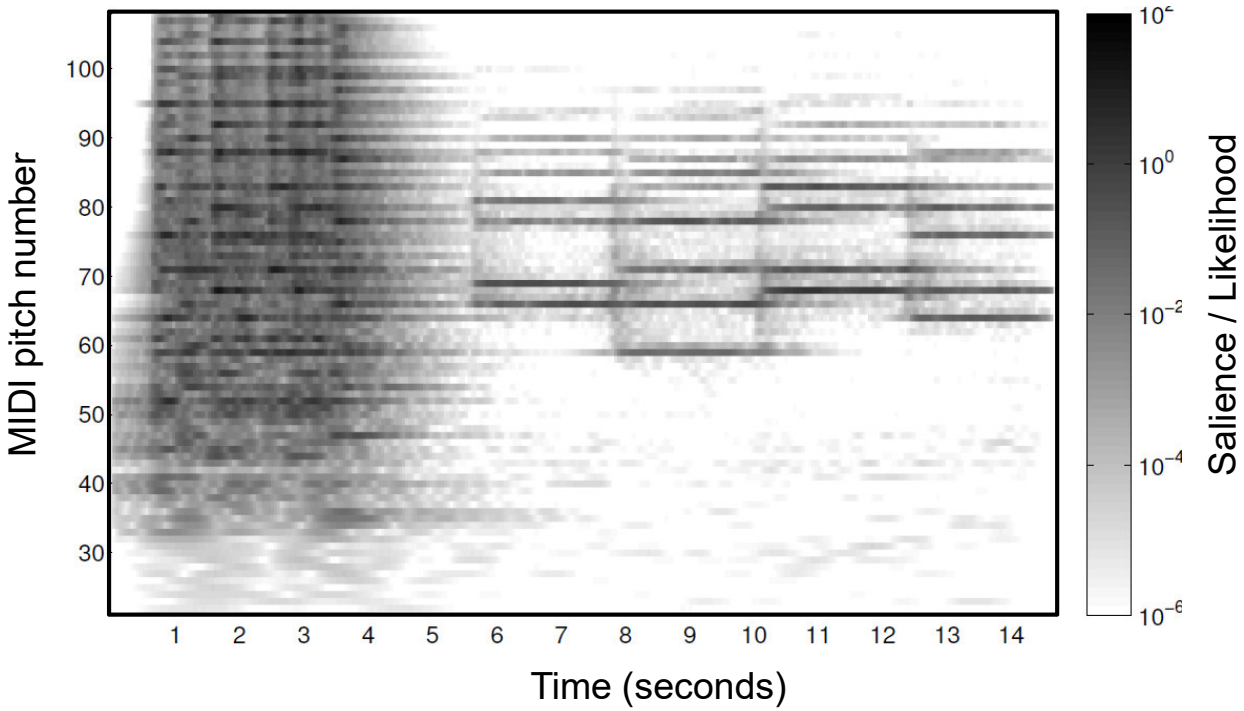
Log-Frequency-Spectrogram: Time – Pitch



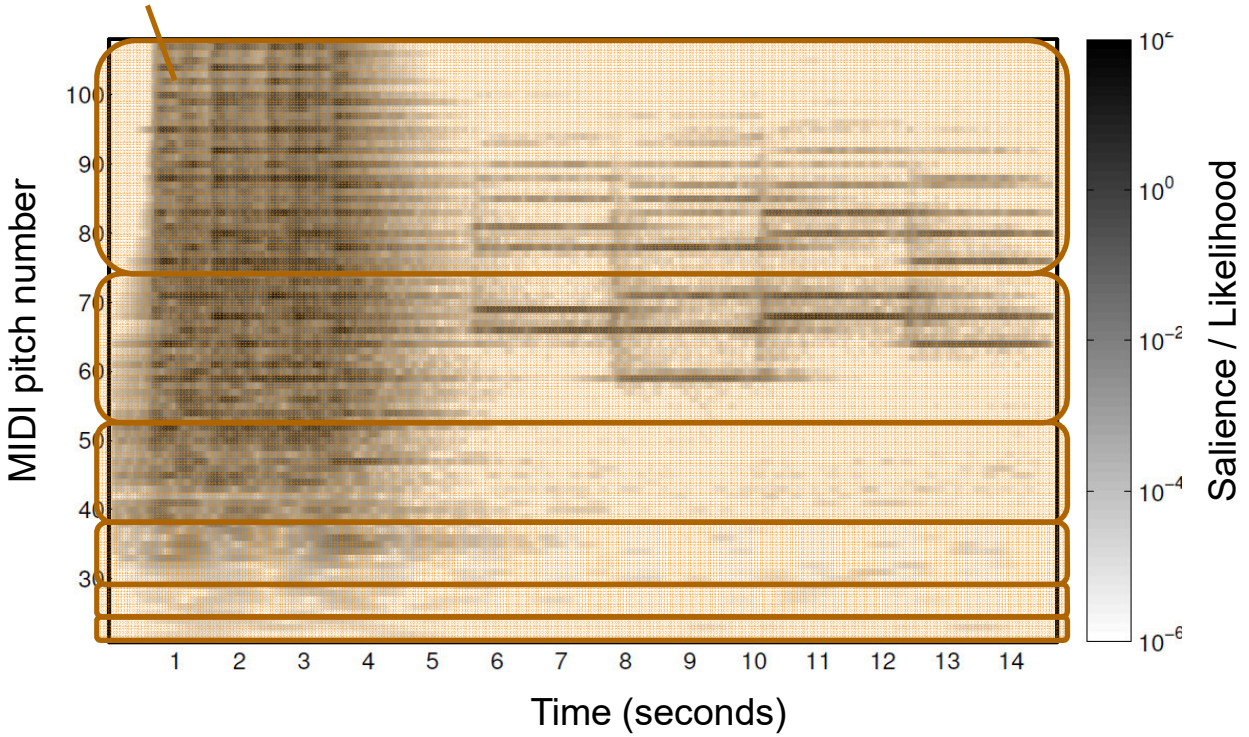
Signal Processing: Spectral Features

→ independent of exact pitches

→ describe **timbral** properties (sound color)

„standard features“ for genre classification

Frequency bands: Loudness, Spectral Flatness, Spectral Centroid



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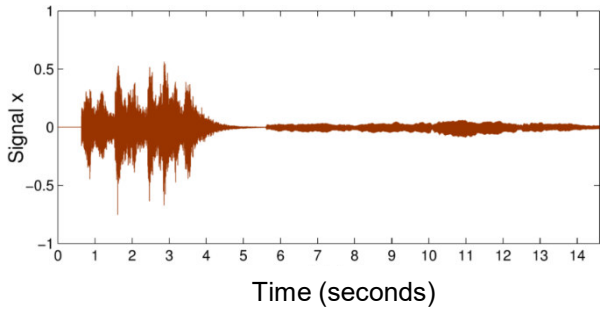
Signal Processing: Chroma Features



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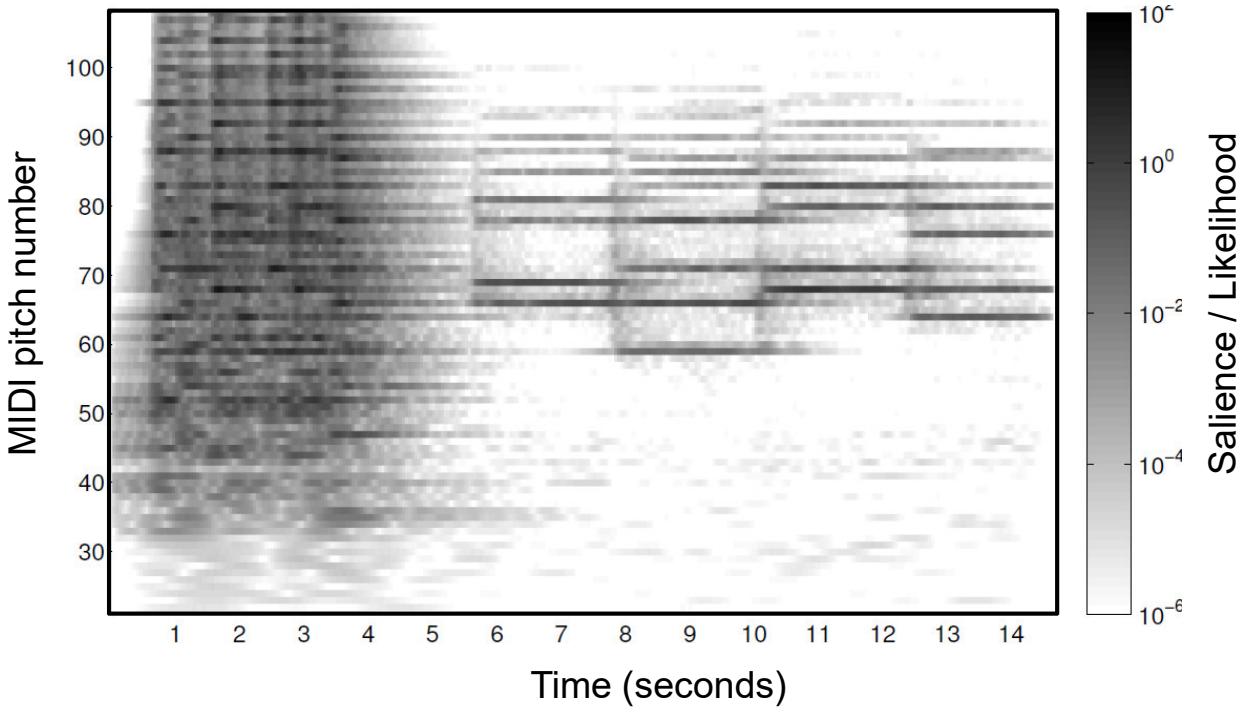

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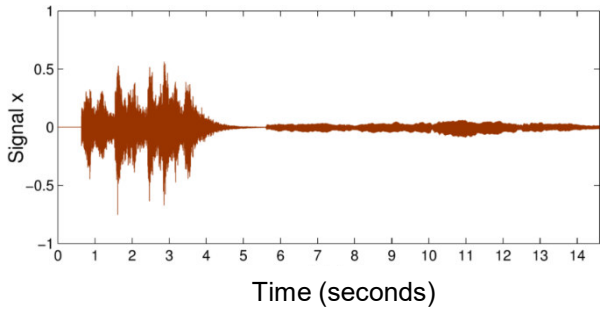

L. van Beethoven,
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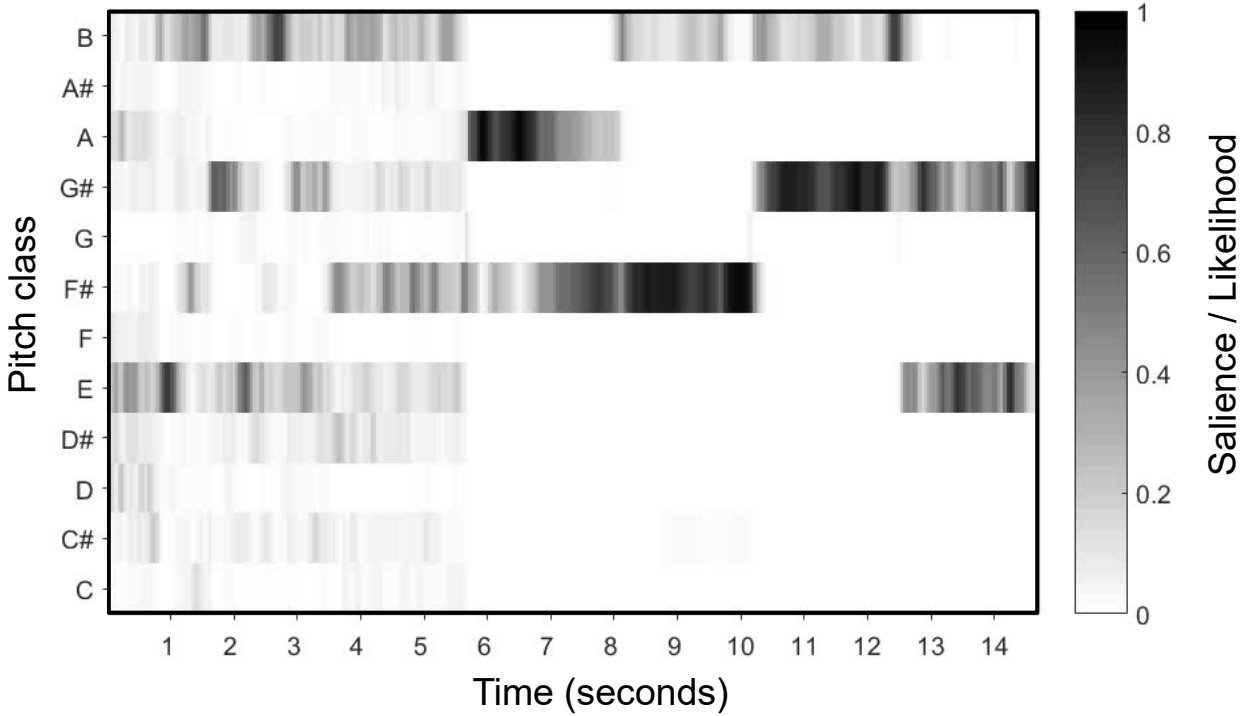
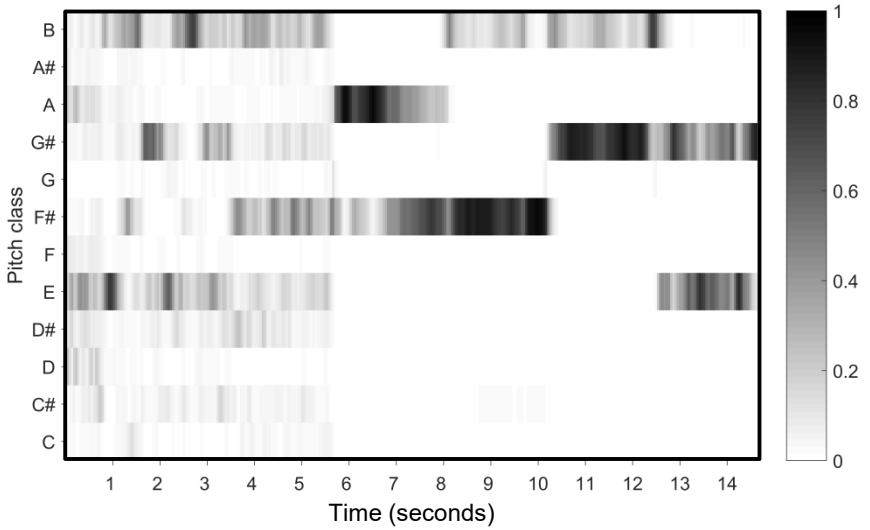
Chromagram: Time – Pitch class



Signal Processing: Chroma Features

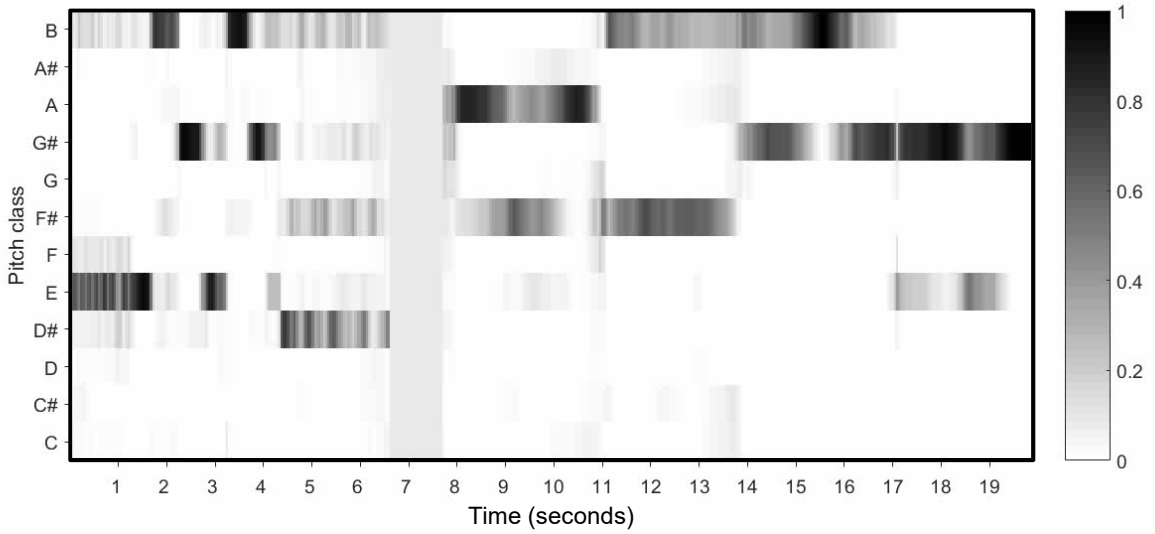
- Orchestra

L. van Beethoven,
Fidelio, Overture,
Slovak Philharmonic



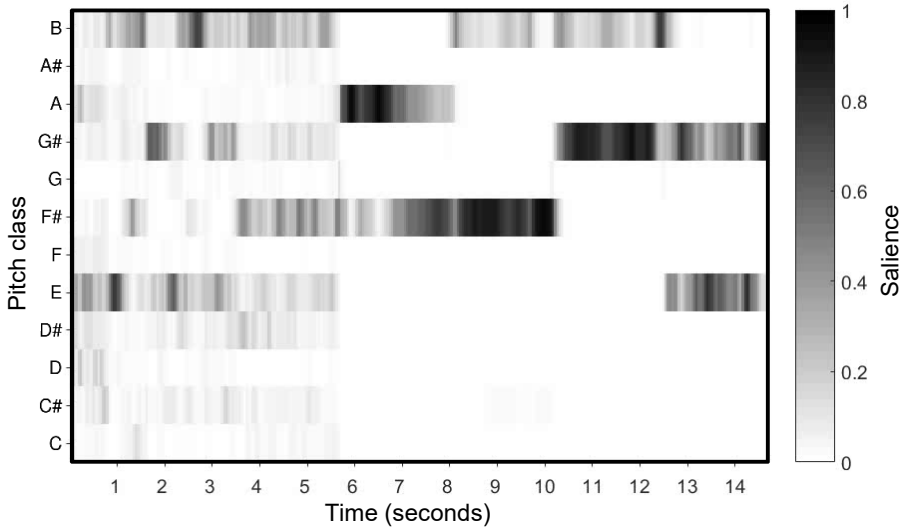
- Piano

Fidelio, Overture,
arr. Alexander Zemlinsky
M. Namekawa, D.R. Davies,
piano four hands

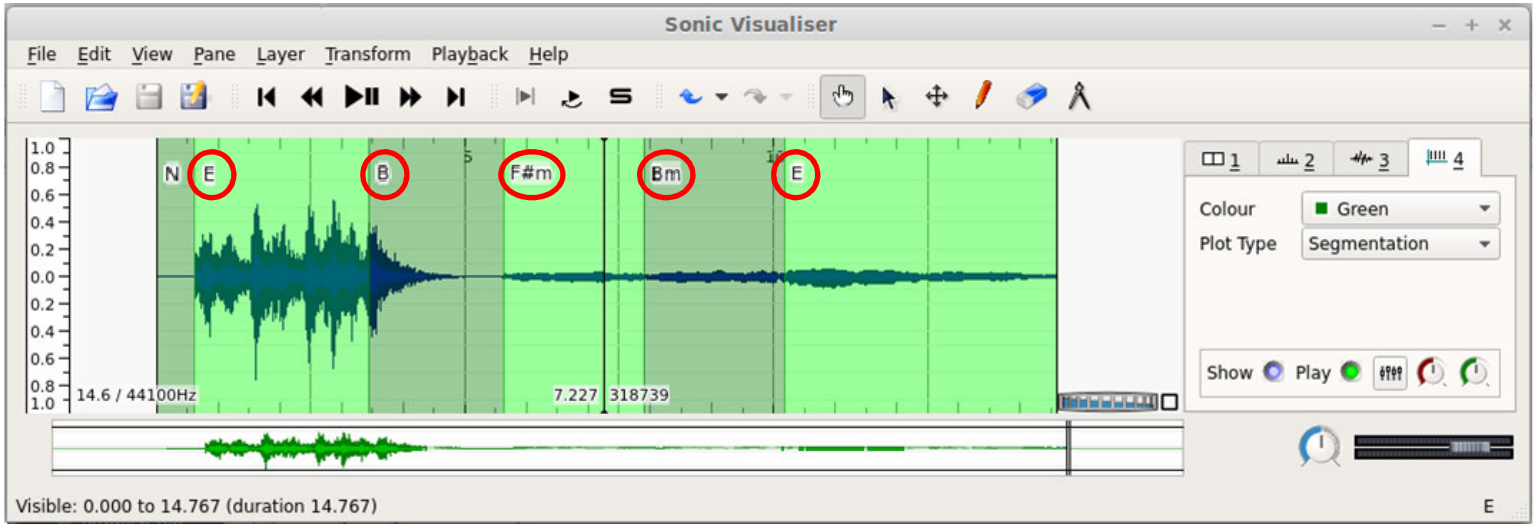


Design of Harmonic Features

- Chromagram



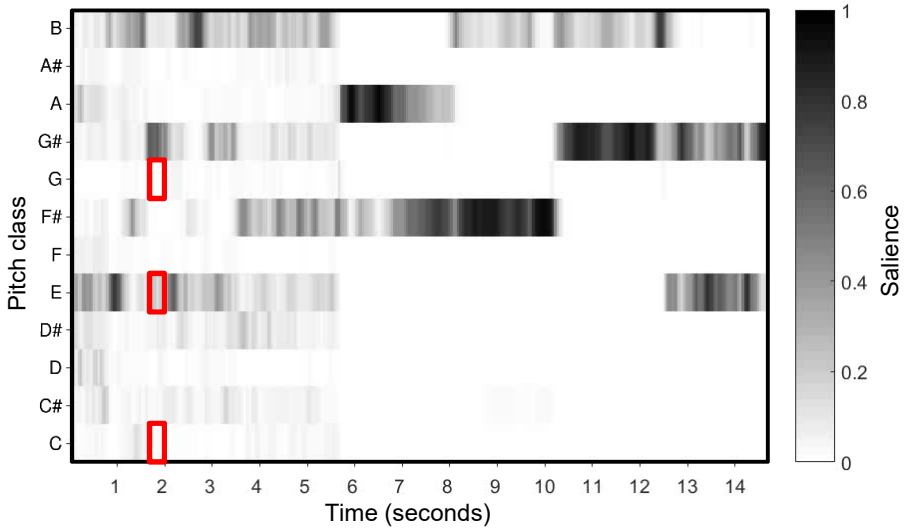
- Chord Recognition (HMM-based)



Sonic Visualizer, Chordino Plugin (Queen Mary Univ., London)

Design of Harmonic Features

- Chromagram

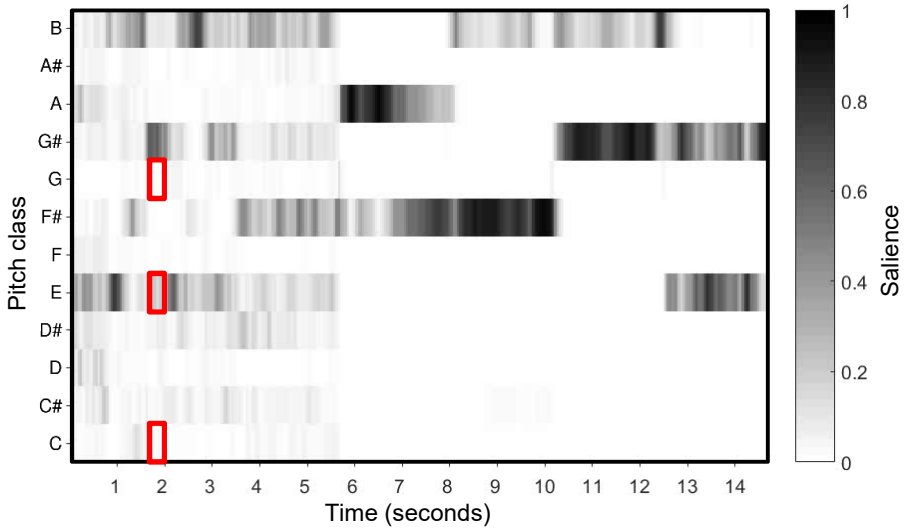


- Chord types
  - Major / minor / diminished / augmented?
  - Probabilities / likelihoods (*continuous*) instead of recognition (*discrete*)
  - Multiply chroma values that form a certain chord

AUDIO LABS

Design of Harmonic Features

- Chromagram



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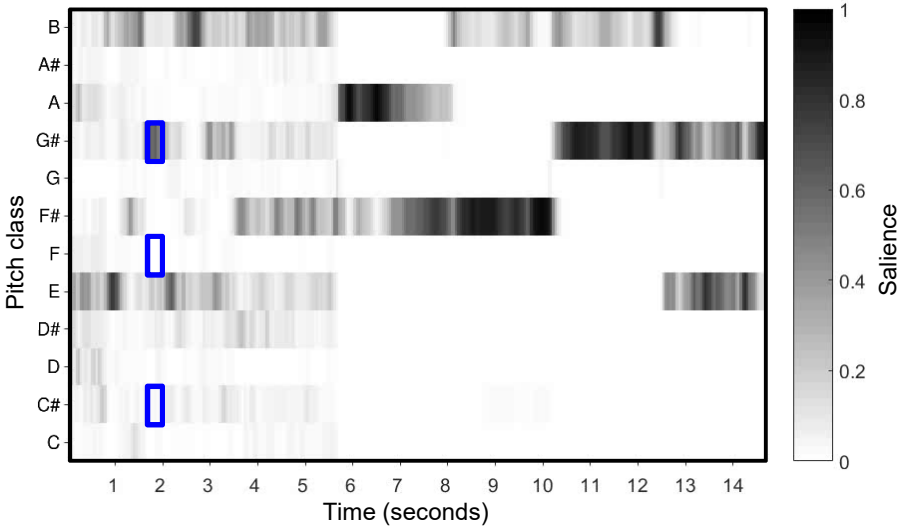

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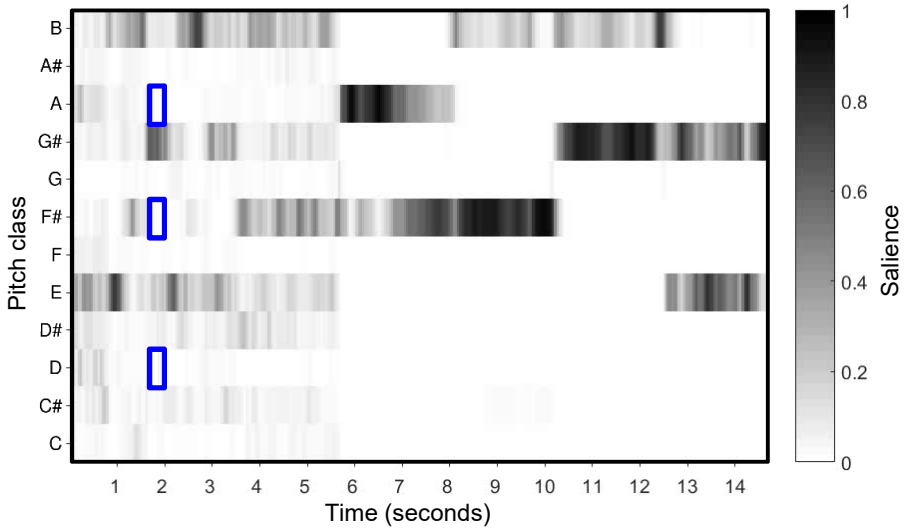

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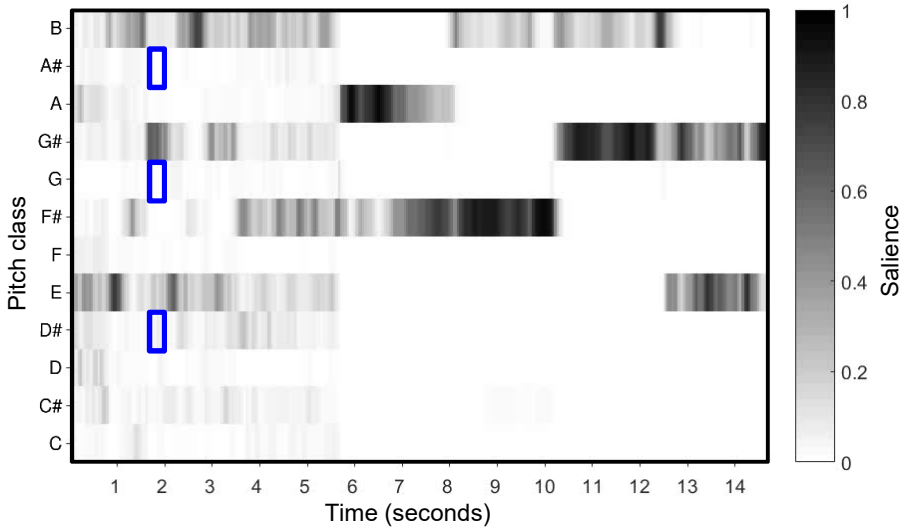

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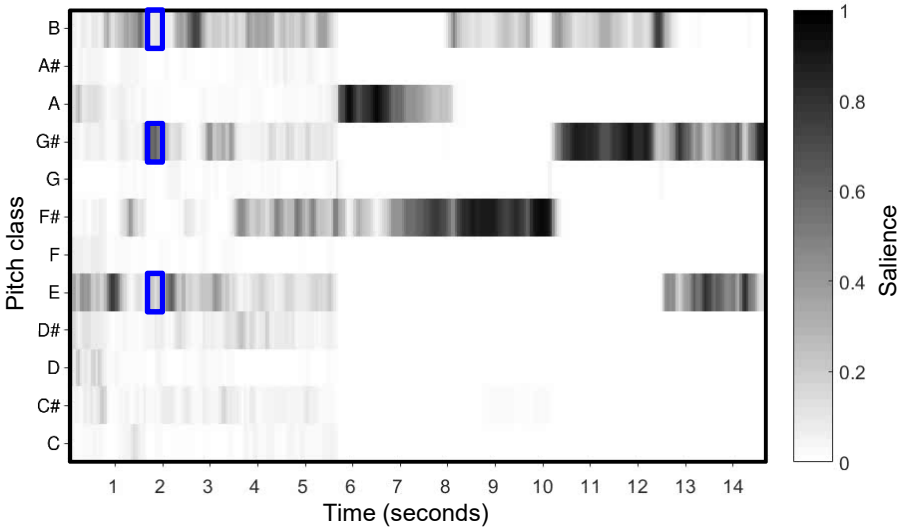

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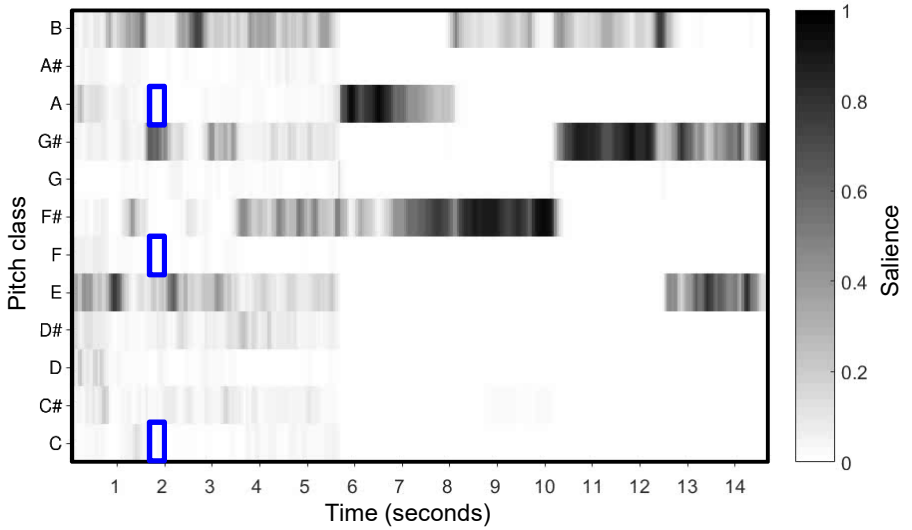

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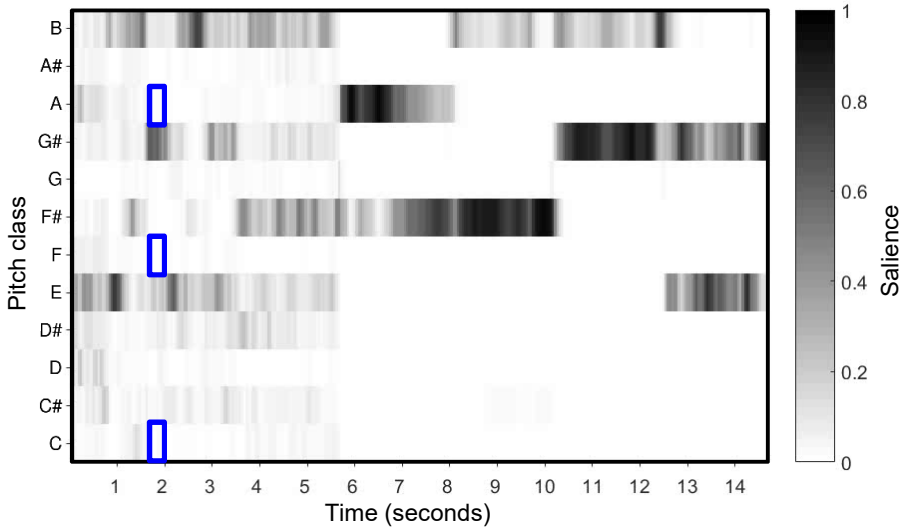

- Chord types
  - Major / minor / diminished / augmented?
  - Probabilities / likelihoods (*continuous*) instead of recognition (*discrete*)
  - Multiply chroma values that form a certain chord
  - Repeat this for all cyclic shifts
  - Sum up all similarity values (products) → transposition-invariance

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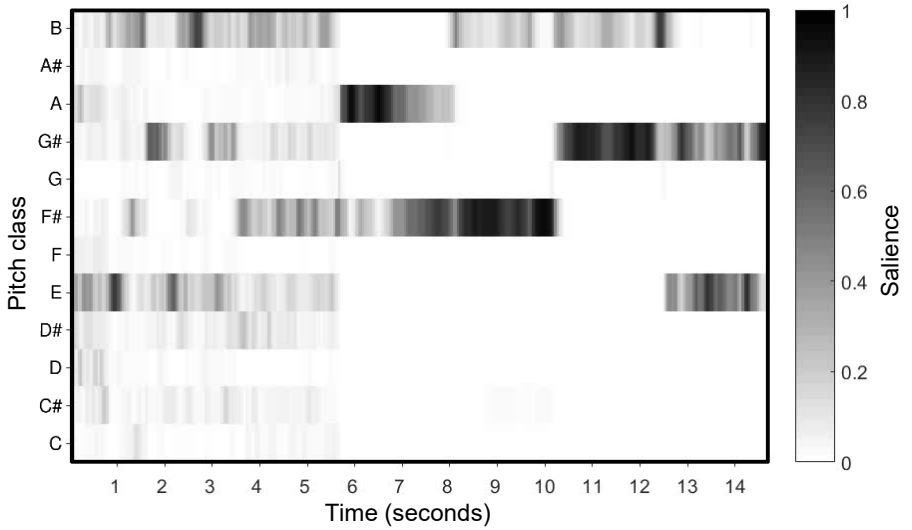
Design of Harmonic Features

- Chromagram

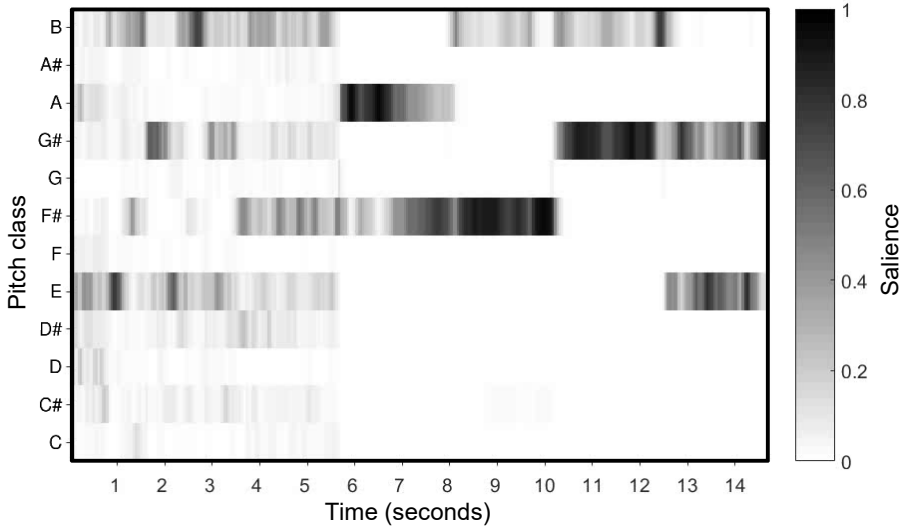


- Chord types
  - Major: $\mathbf{T}^{\mathrm{CM}} = (1,0,0,0,1,0,0,1,0,0,0,0)^{\mathrm{T}}$
  - Minor: $\mathbf{T}^{\mathrm{Cm}} = (1,0,0,1,0,0,0,1,0,0,0,0)^{\mathrm{T}}$
  - Diminished: $\mathbf{T}^{\mathrm{C}\circ} = (1,0,0,1,0,0,1,0,0,0,0,0)^{\mathrm{T}}$
  - Augmented: $\mathbf{T}^{\mathrm{C}+} = (1,0,0,0,1,0,0,0,1,0,0,0)^{\mathrm{T}}$

AUDIO LABS

Design of Harmonic Features

- Chromagram



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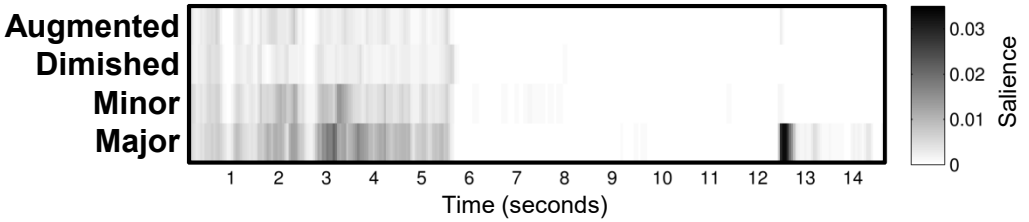

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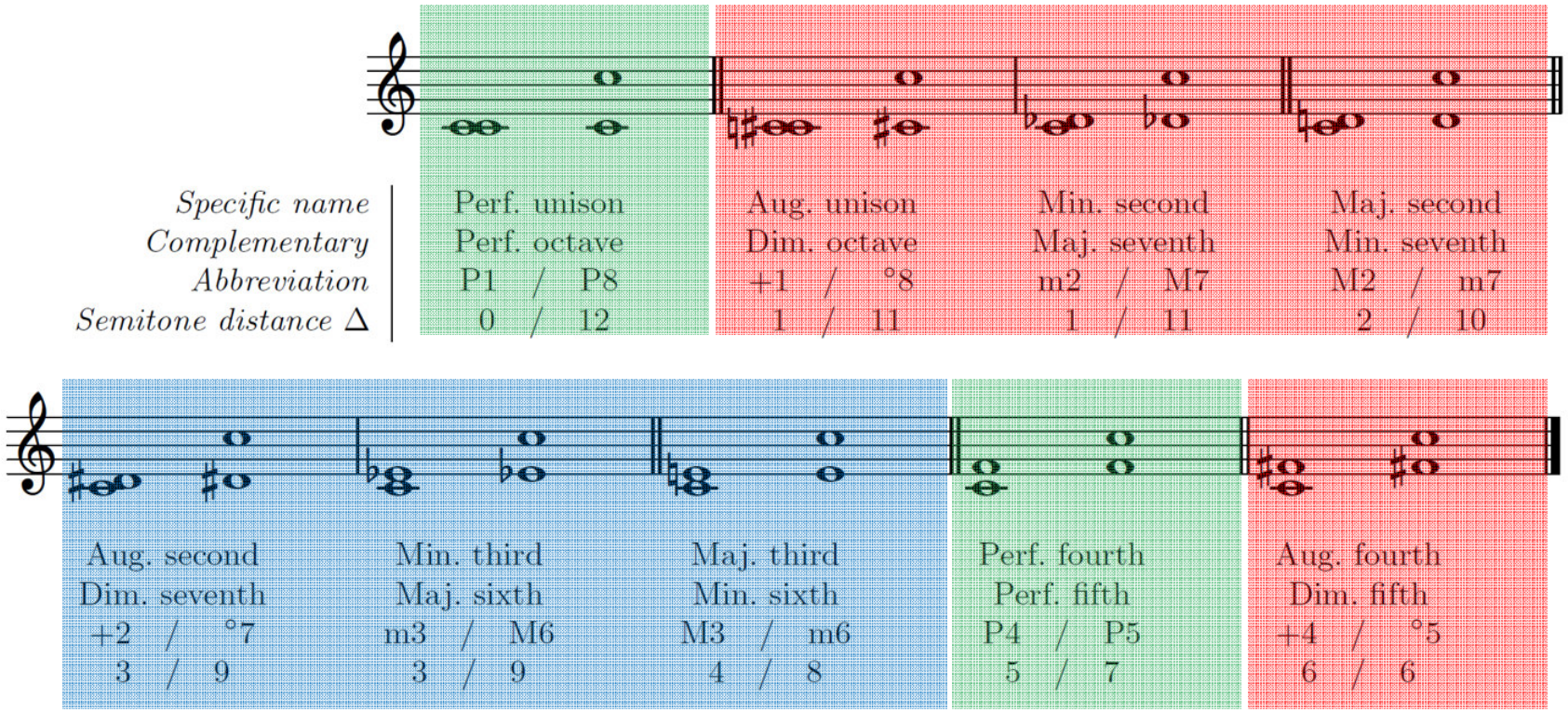
Design of Harmonic Features

Consonant & Dissonant Intervals



- Perfect consonances
- Imperfect consonances
- Dissonances

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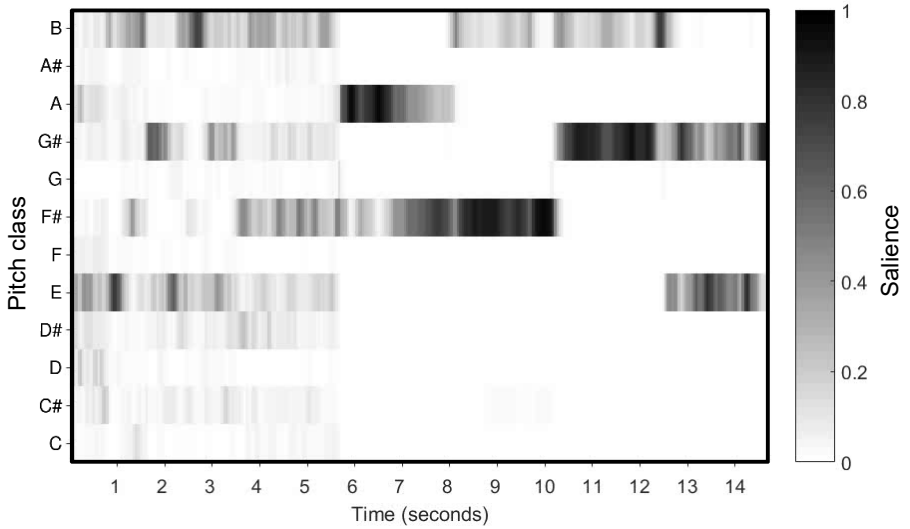
Design of Harmonic Features

- Chromagram



- Interval categories
  - Δ = 1 / 11: $\mathbf{T}^{\mathrm{IC1}} = (1,1,0,0,0,0,0,0,0,0,0,0)^{\mathrm{T}}$
  - Δ = 2 / 10: $\mathbf{T}^{\mathrm{IC2}} = (1,0,1,0,0,0,0,0,0,0,0,0)^{\mathrm{T}}$
  - Δ = 3 / 9: $\mathbf{T}^{\mathrm{IC3}} = (1,0,0,1,0,0,0,0,0,0,0,0)^{\mathrm{T}}$
  - Δ = 4 / 8: $\mathbf{T}^{\mathrm{IC4}} = (1,0,0,0,1,0,0,0,0,0,0,0)^{\mathrm{T}}$
  - Δ = 5 / 7: $\mathbf{T}^{\mathrm{IC5}} = (1,0,0,0,0,1,0,0,0,0,0,0)^{\mathrm{T}}$
  - Δ = 6 / 6: $\mathbf{T}^{\mathrm{IC6}} = (1,0,0,0,0,0,1,0,0,0,0,0)^{\mathrm{T}}$

AUDIO LABS

Design of Harmonic Features

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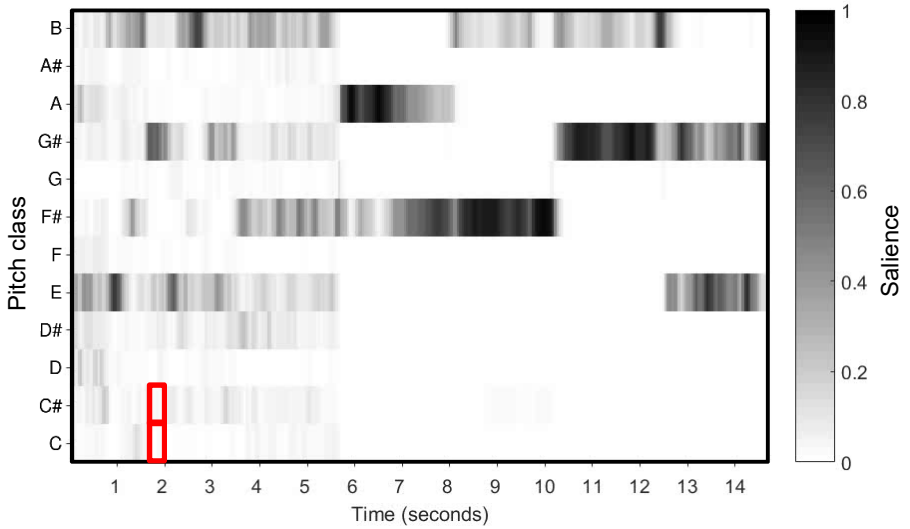

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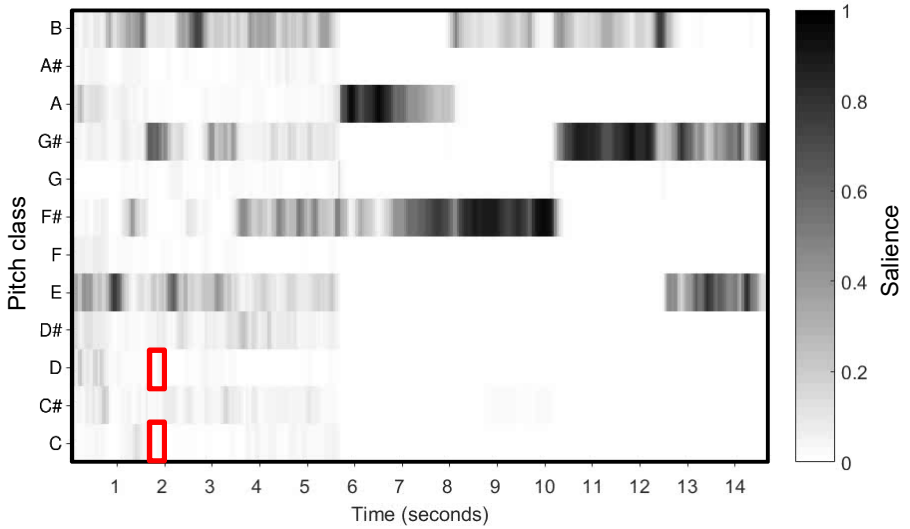

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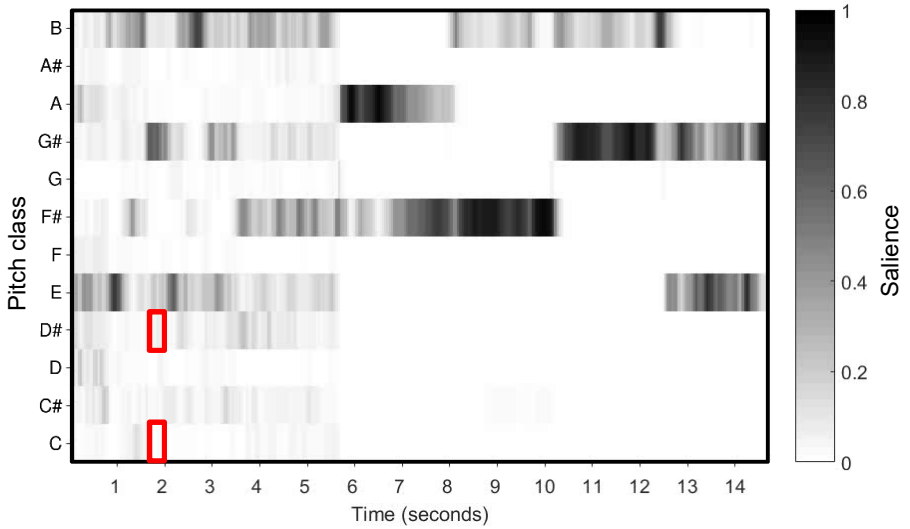

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AUDIO LABS

Design of Harmonic Features

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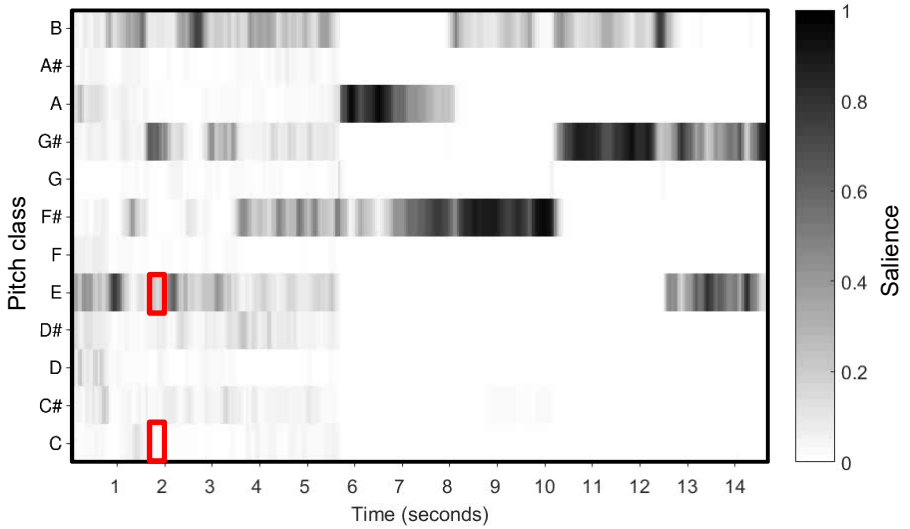

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AUDIO LABS

Design of Harmonic Features

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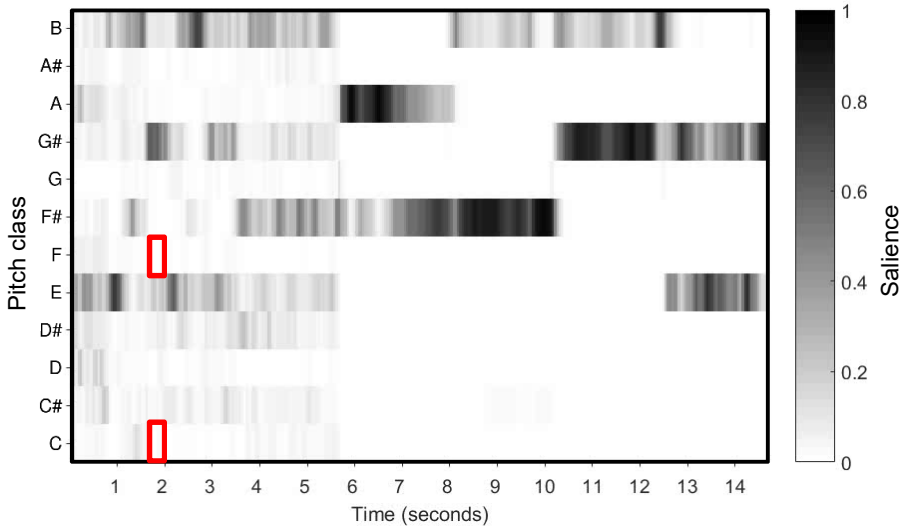

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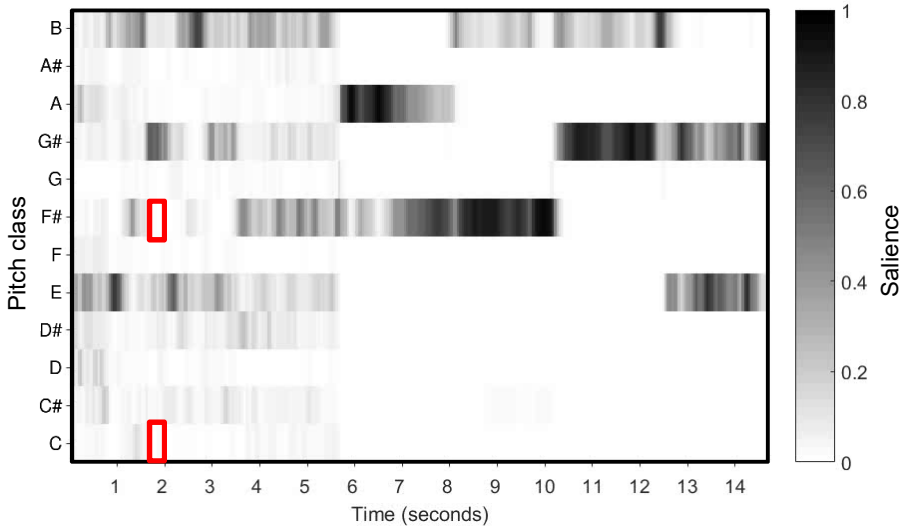
AUDIO LABS

Design of Harmonic Features

- Chromagram



- Interval categories
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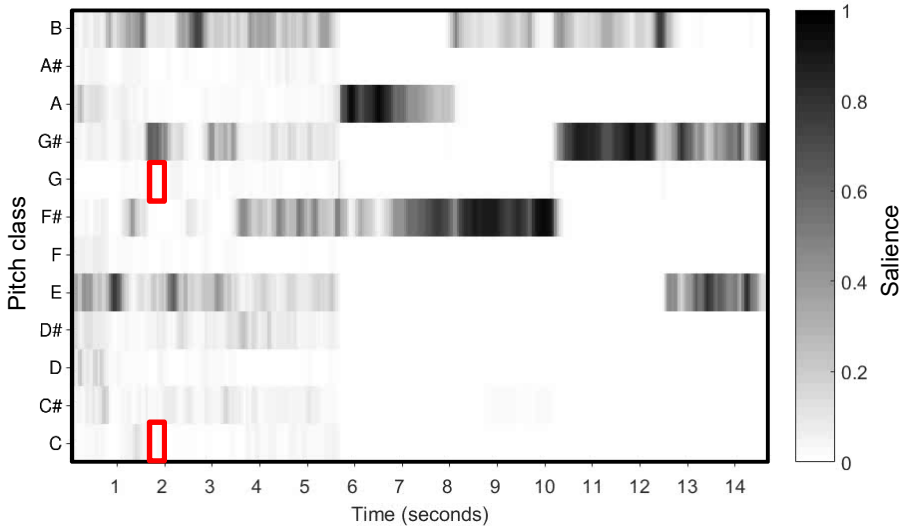
AUDIO LABS

Design of Harmonic Features

- Chromagram



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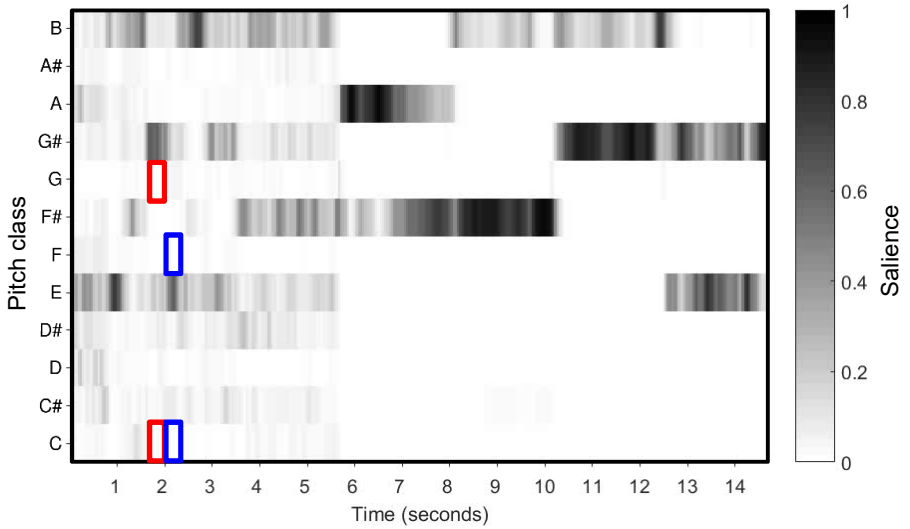
AUDIO LABS

Design of Harmonic Features

- Chromagram



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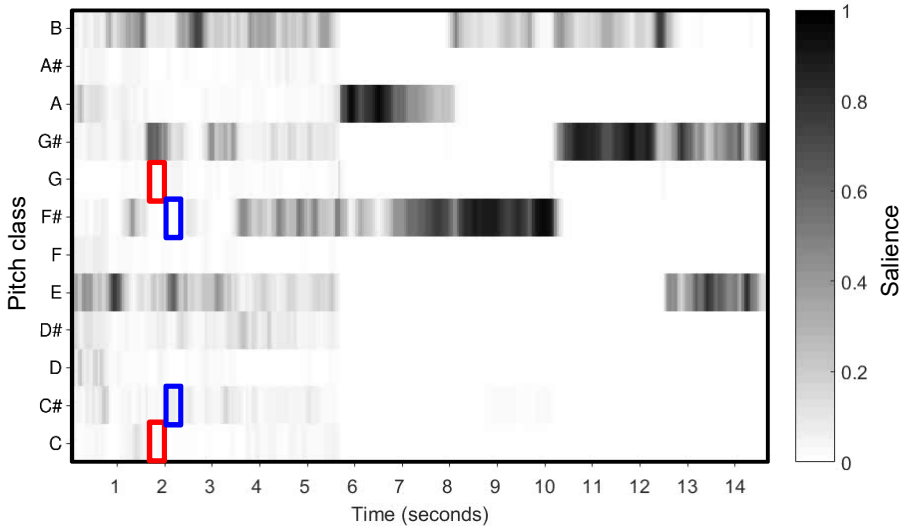
AUDIO LABS

Design of Harmonic Features

- Chromagram



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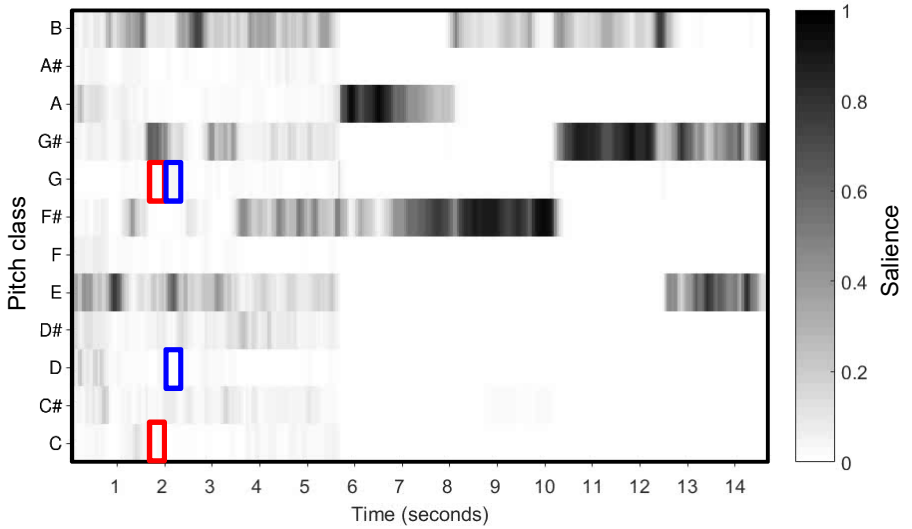
AUDIO LABS

Design of Harmonic Features

- Chromagram



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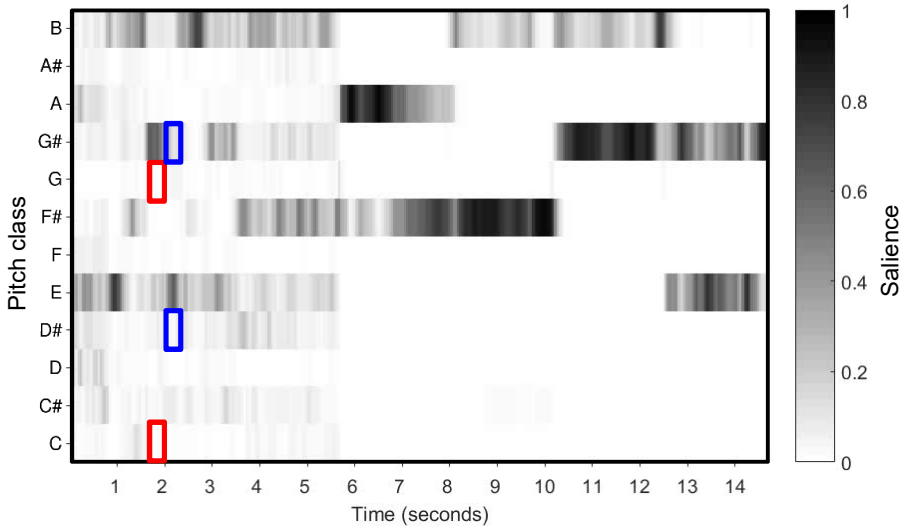
AUDIO LABS

Design of Harmonic Features

- Chromagram



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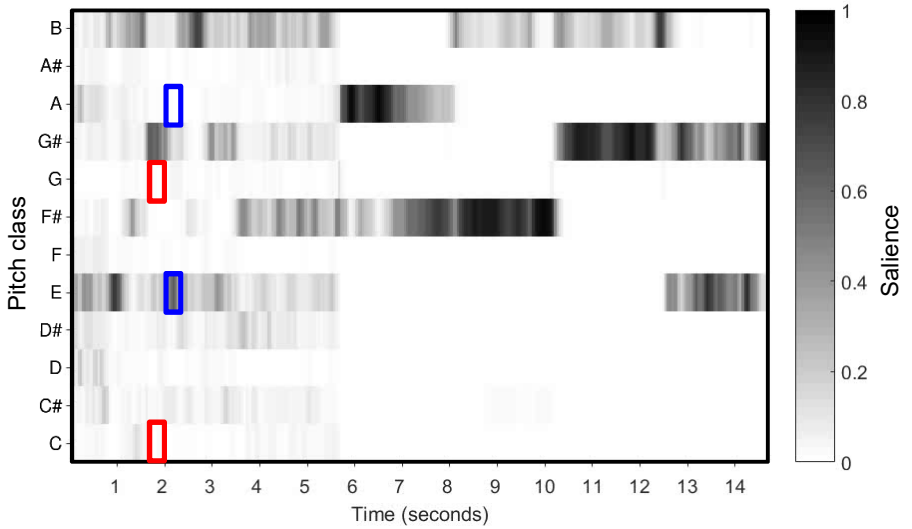
AUDIO LABS

Design of Harmonic Features

- Chromagram



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AUDIO LABS

Design of Harmonic Features

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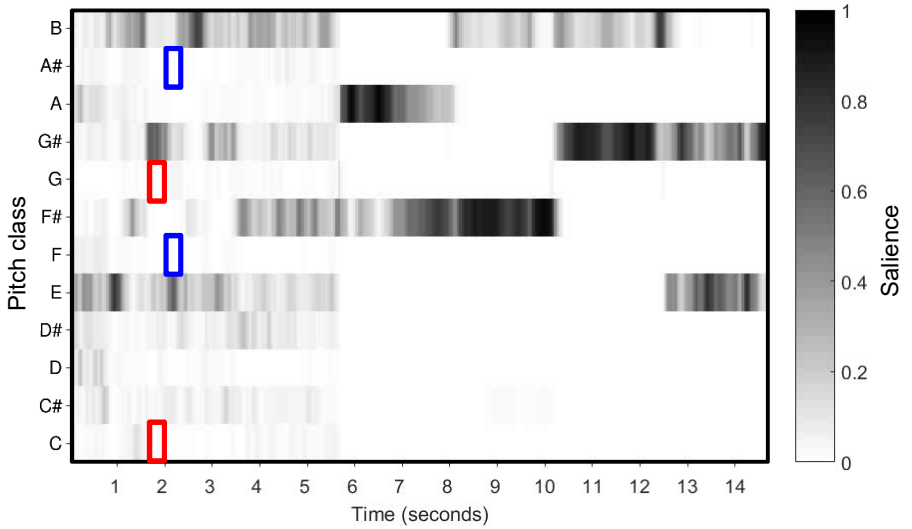

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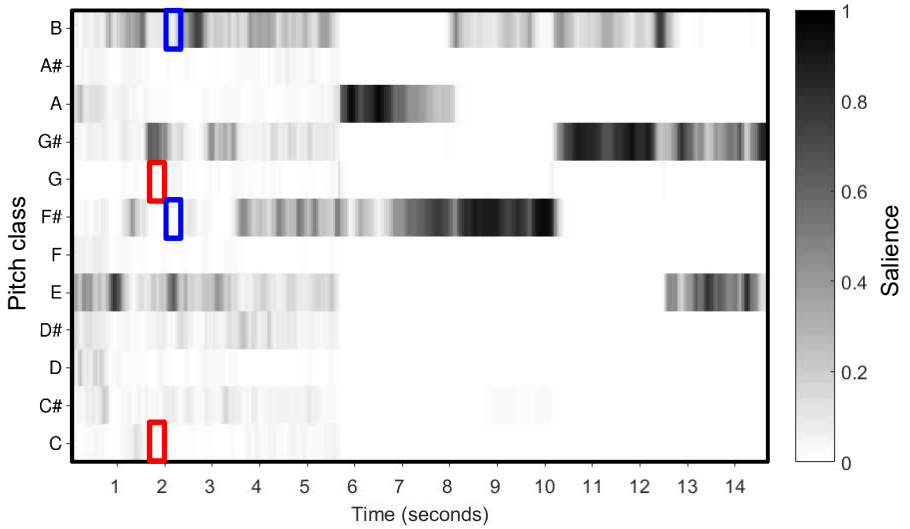
AUDIO LABS

Design of Harmonic Features

- Chromagram



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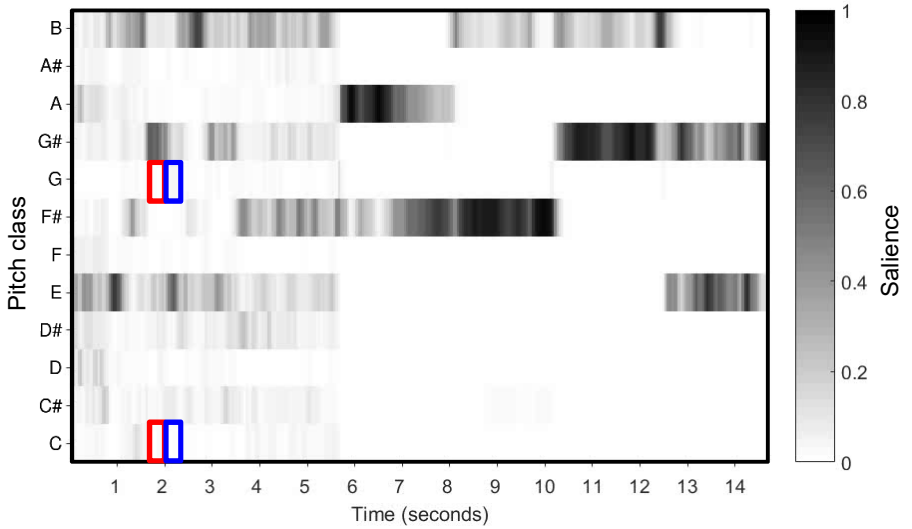
AUDIO LABS

Design of Harmonic Features

- Chromagram



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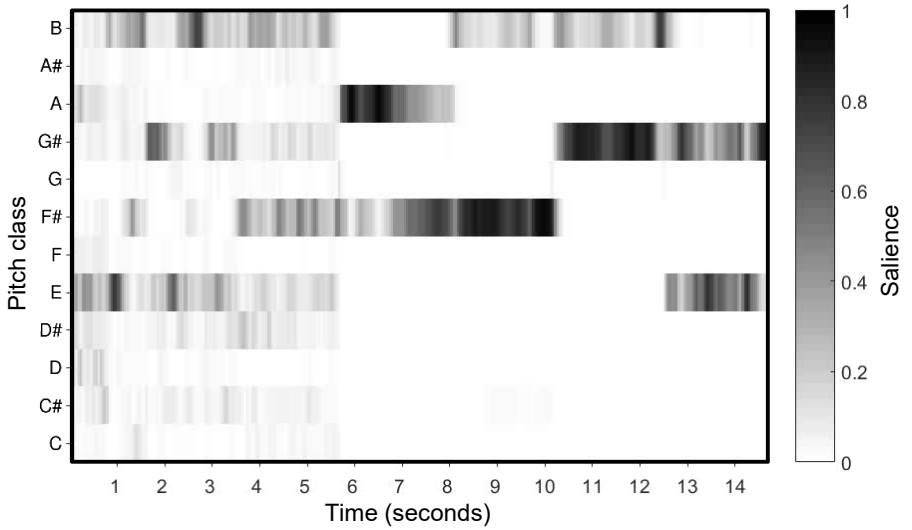
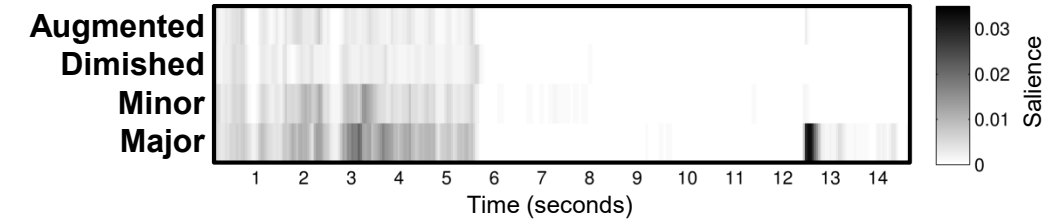
AUDIO LABS

Design of Harmonic Features

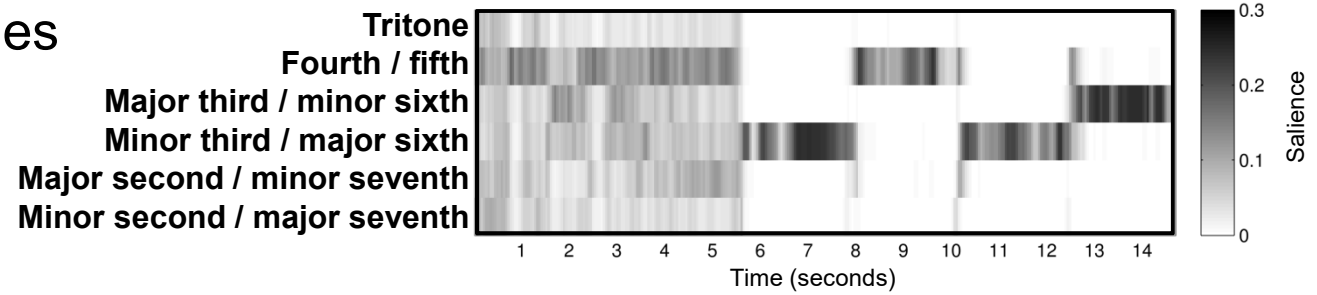
- Chromagram



- Chord types



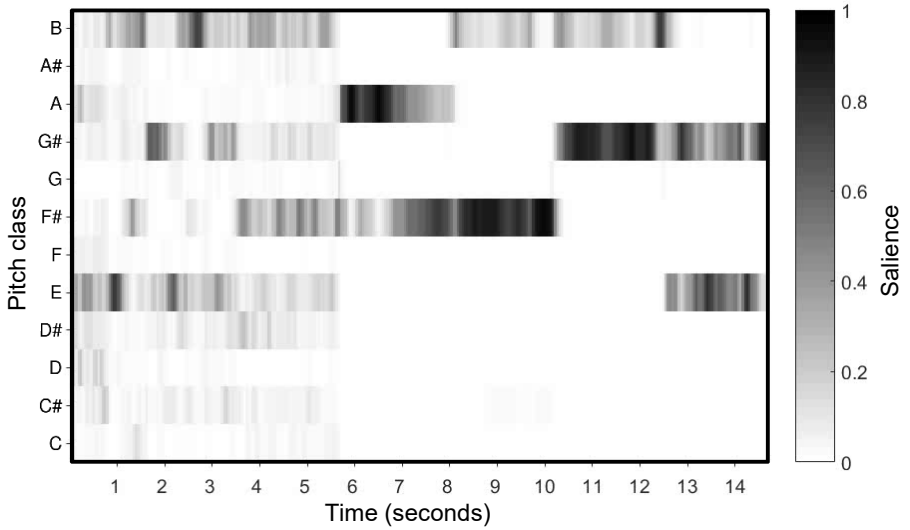
- Interval categories



→ transposition-invariant features!

Design of Harmonic Features

- Chromagram



- Feature computation

$$\Psi^{\mathbf{T}}(\mathbf{c}) = \sum_{q=0}^{11} \left(\prod_{k=0}^{11} \left(c_{(q+k) \mod 12} \right)^{T_k} \right)$$

chroma vector entry

binary template entry

sum

product

shift

AUDIO LABS

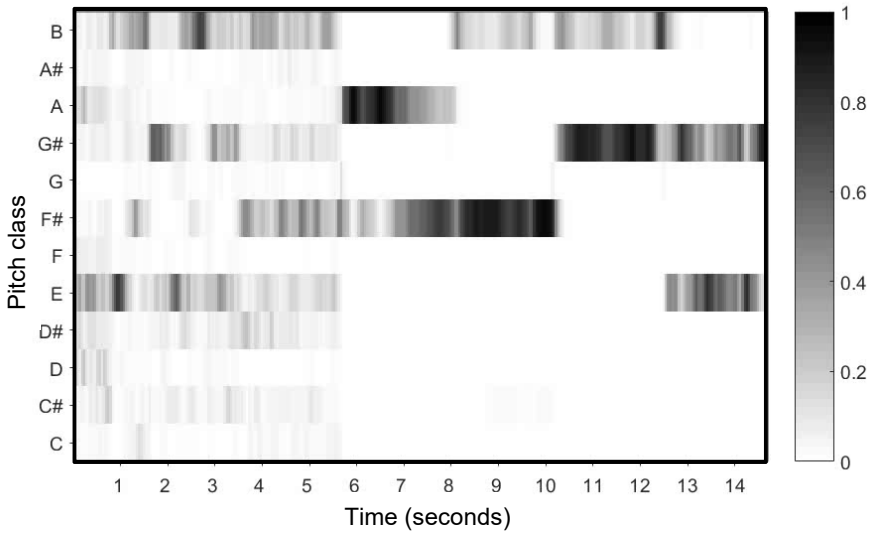
Harmonic Feature Design

Overview

- Measuring Interval and Chord Categories
- Measuring Tonal Complexity

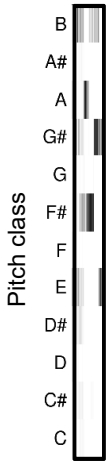
Design of Harmonic Features

- Chromagram:



Design of Harmonic Features

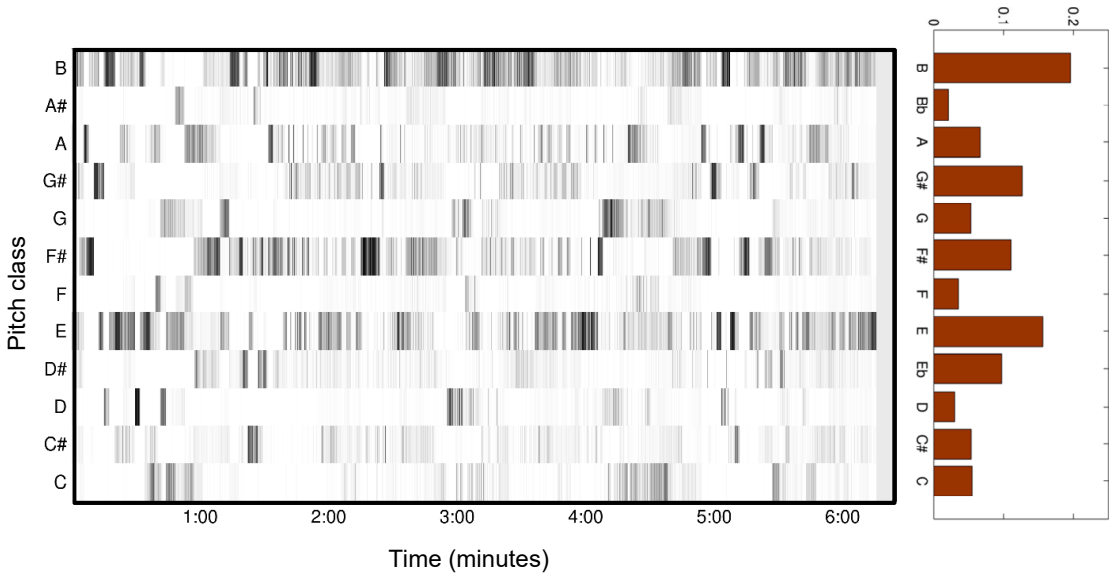
- Chromagram: Full piece



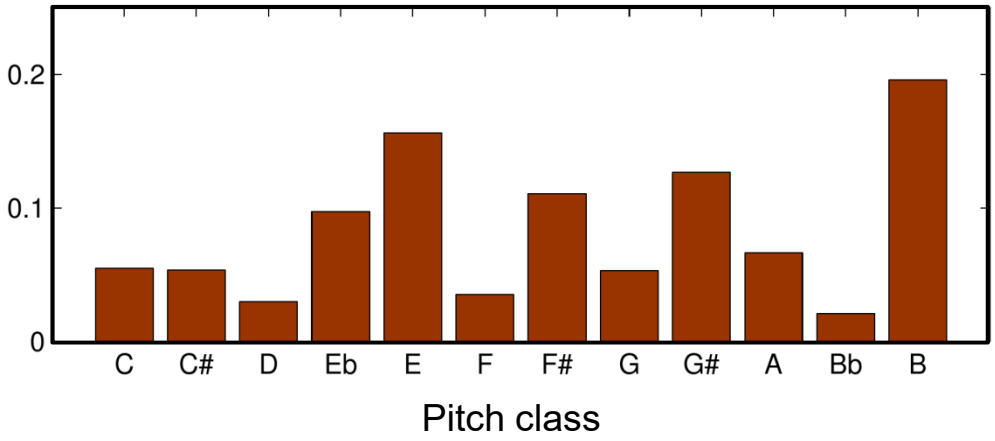
AUDIO LABS

Design of Harmonic Features

- Chromagram: Full piece



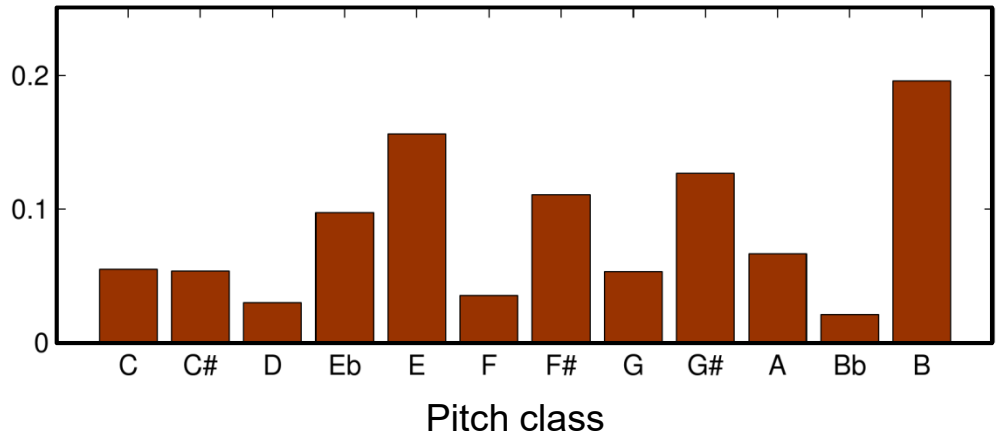
- Chroma statistics:



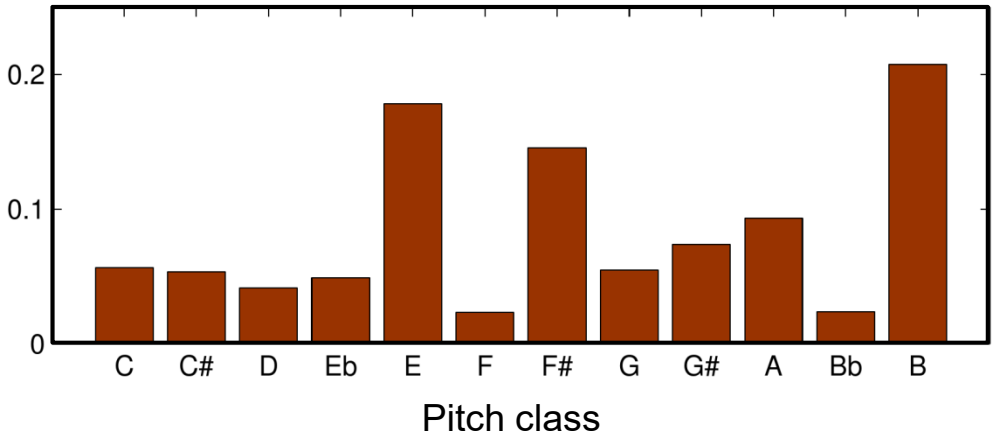
AUDIO LABS

Design of Harmonic Features

- Orchestra:



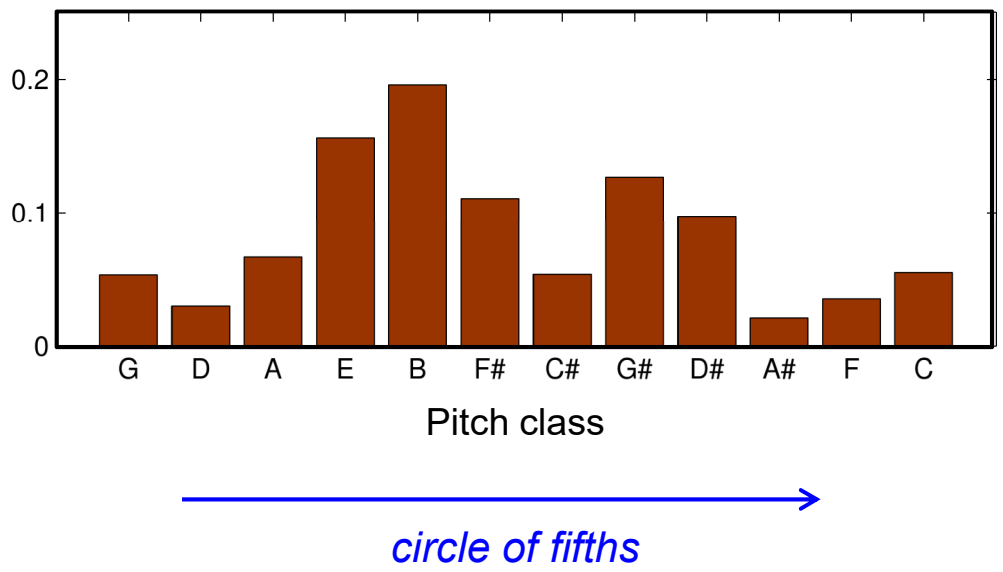
- Piano:



AUDIO LABS

Design of Harmonic Features

- Orchestra:



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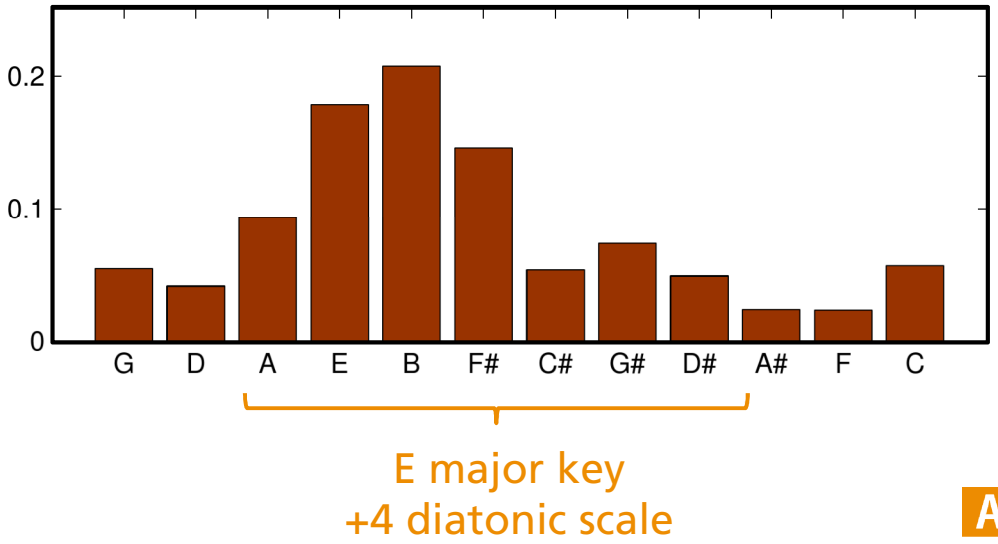
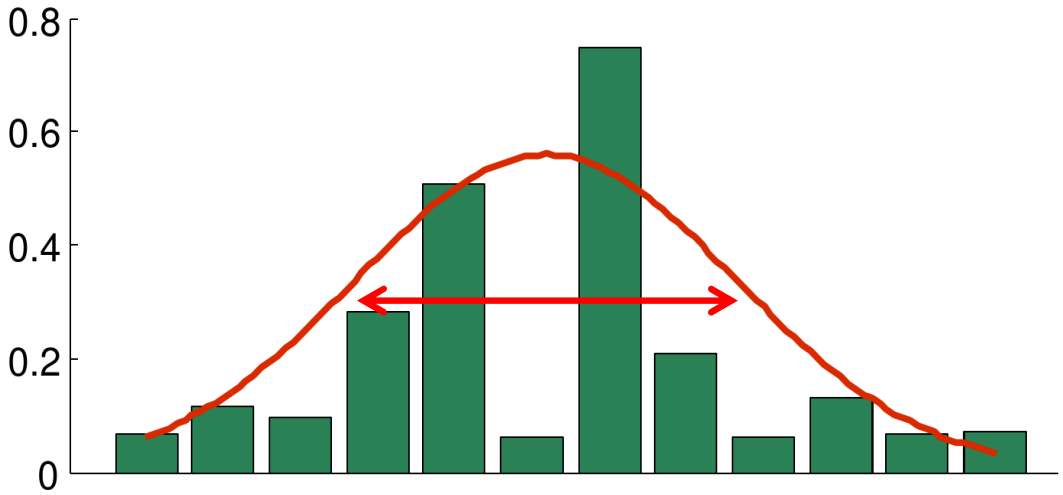


AUDIO LABS

Design of Harmonic Features

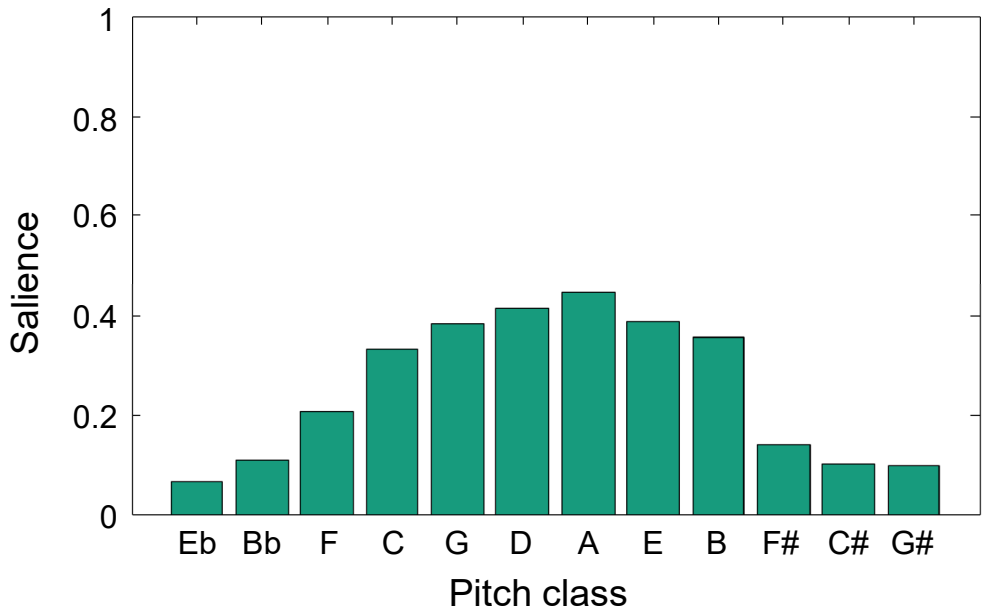
- What does a global chroma statistics tell us about a piece of music?
- Measure spread / flatness / centricity on the circle of fifths:



AUDIO LABS

Tonal Complexity

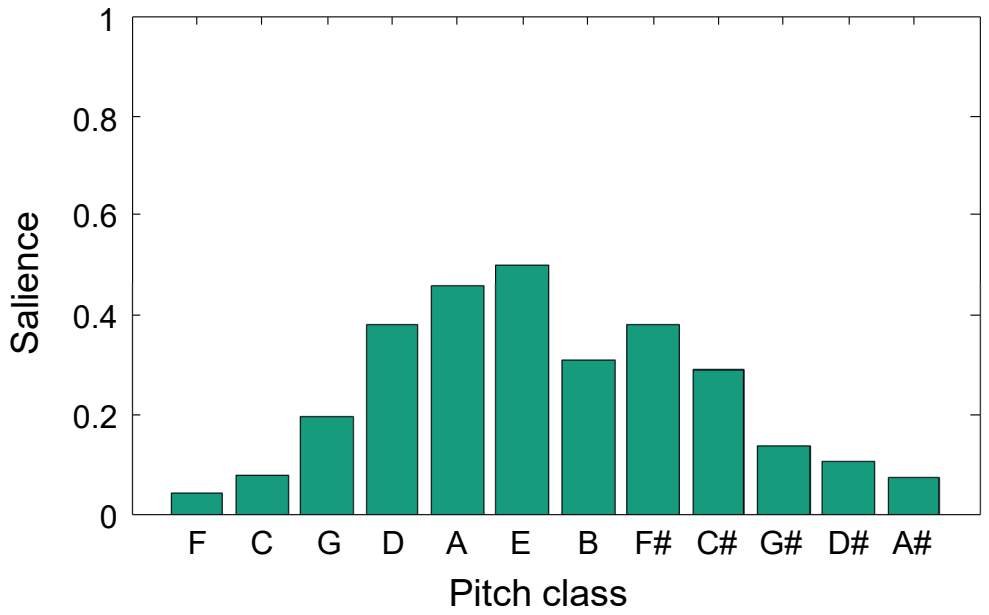
- Global chroma statistics (audio)
- **1567** – G. P. da Palestrina, Missa de Beata Virgine, Credo



Circle of fifths →

Tonal Complexity

- Global chroma statistics (audio)
- **1725** – J. S. Bach, Suite No. 4 BWV 1069, 1. Overture (D major)

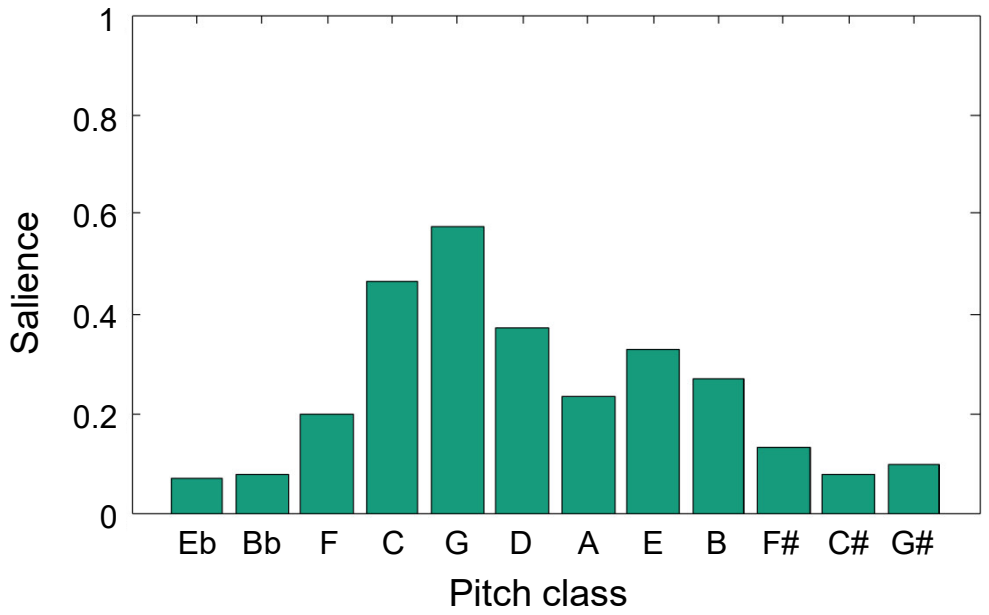


Circle of fifths →

AUDIO LABS

Tonal Complexity

- Global chroma statistics (audio)
- **1783** – W. A. Mozart, „Linz“ symphony KV 425, 1. Adagio / Allegro

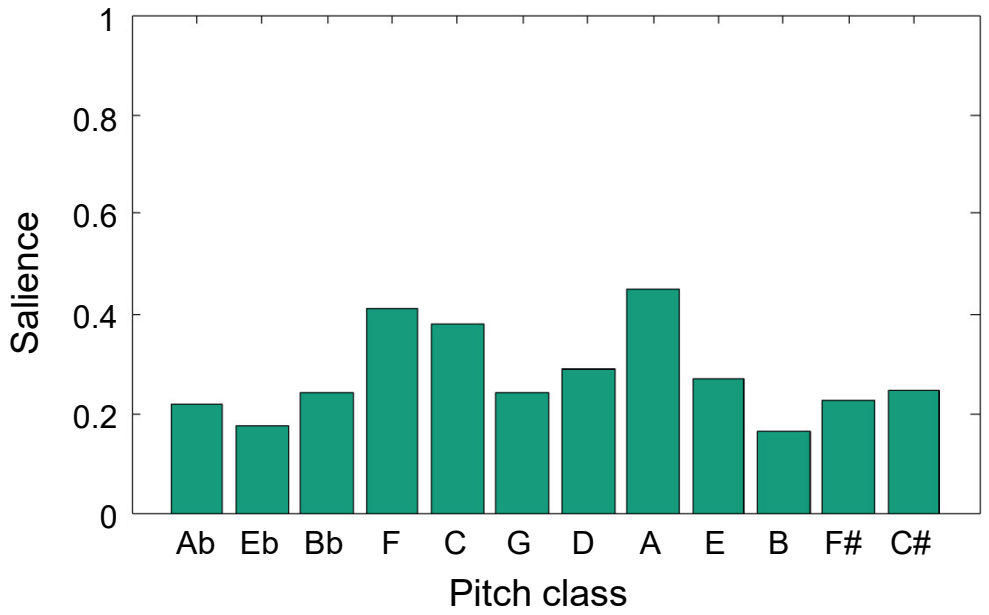


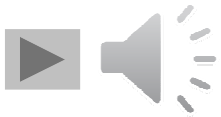
Circle of fifths →

AUDIO LABS

Tonal Complexity

- Global chroma statistics (audio)
- **1883** – J. Brahms, Symphony No. 3, 1. Allegro con brio (F major)



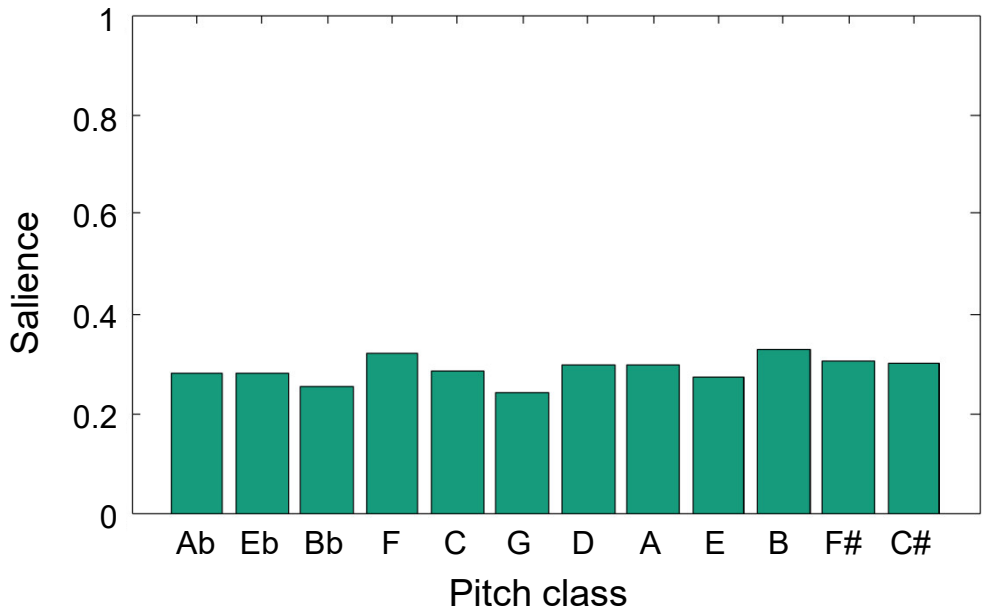


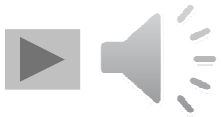
Circle of fifths →

AUDIO LABS

Tonal Complexity

- Global chroma statistics (audio)
- **1940** – A. Webern, Variations for Orchestra op. 30





Circle of fifths →

AUDIO LABS

Tonal Complexity

Requirements

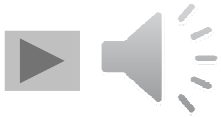
- Realization of complexity measure Γ
- Input: L1-normalized choma vector (entries sum to 1)

- Boundary conditions:
  - Sparse chroma vector: $\mathbf{c}^{\text{sparse}} := (1,0,0,0,0,0,0,0,0,0,0,0)^{\mathrm{T}}$

    $\rightarrow Complexity = 0$

    
  - Flat chroma vector: $\mathbf{c}^{\text{flat}} := \frac{1}{12} \cdot (1,1,1,1,1,1,1,1,1,1,1,1)^{\mathrm{T}}$

    $\rightarrow Complexity = 1$

    
  - All other chroma vectors:

    $\rightarrow 0 < Complexity < 1$

AUDIO LABS

Tonal Complexity

Entropy measure

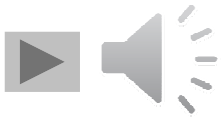
- Compute Shannon entropy of chroma vector:

$$\Gamma_{\mathrm{Entr}}(\mathbf{c}) := -\frac{1}{\log_2(12)} \left(\sum_{q=0}^{11} c_q \cdot \log_2(c_q) \right)$$

- Sparse chroma vector: $\mathbf{c}^{\mathrm{sparse}} := (1,0,0,0,0,0,0,0,0,0,0,0)^{\mathrm{T}}$

$\rightarrow Complexity = 0$

- Flat chroma vector: $\mathbf{c}^{\mathrm{flat}} := \frac{1}{12} \cdot (1,1,1,1,1,1,1,1,1,1,1,1)^{\mathrm{T}}$



$\rightarrow Complexity = 1$

- All other chroma vectors:

$\rightarrow 0 < Complexity < 1$

AUDIO LABS

Tonal Complexity

Flatness measure

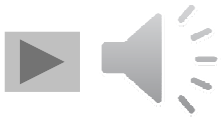
- Compute Flatness measure (ratio of geometric and arithmetic mean):

$$\Gamma_{\mathrm{Flat}}(\mathbf{c}) := \frac{\left(\prod_{q=0}^{11} c_q\right)^{1/12}}{\frac{1}{12}\sum_{q=0}^{11} c_q}$$

- Sparse chroma vector: $\mathbf{c}^{\mathrm{sparse}} := (1,0,0,0,0,0,0,0,0,0,0,0)^{\mathrm{T}}$

$\rightarrow Complexity = 0$

- Flat chroma vector: $\mathbf{c}^{\mathrm{flat}} := \frac{1}{12} \cdot (1,1,1,1,1,1,1,1,1,1,1,1)^{\mathrm{T}}$



$\rightarrow Complexity = 1$

- All other chroma vectors:

$\rightarrow 0 < Complexity < 1$

AUDIO LABS

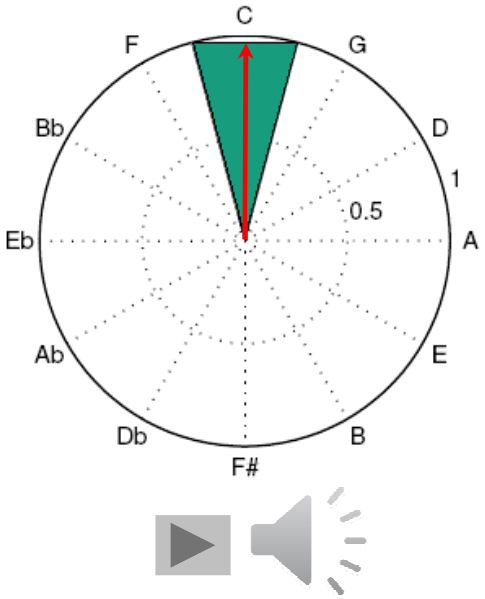
Tonal Complexity

Fifth-width measure

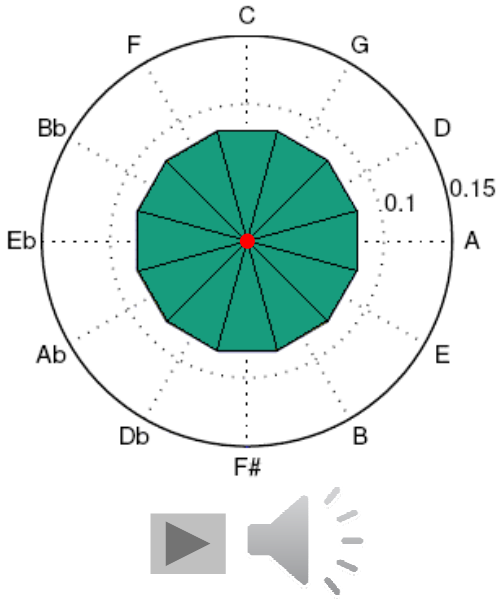
- Compute Width of Distribution over *Circle of Fifths* (angular deviation):

$$\Gamma_{\text{Fifth}}(\mathbf{c}) := \sqrt{1 - r_{\text{fifth}}(\mathbf{c})} \qquad \text{with} \qquad r_{\text{fifth}}(\mathbf{c}) = \left| \sum_{q=0}^{11} c_q^{\text{fifth}} \exp\left(\frac{2\pi \mathrm{i} q}{12}\right) \right|$$

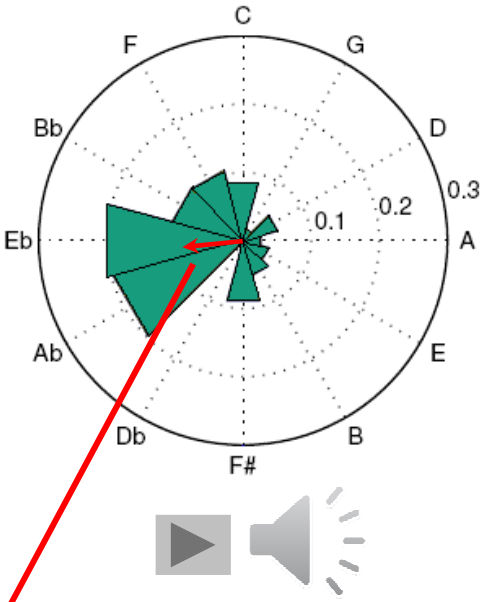
$Complexity = 0$



$Complexity = 1$



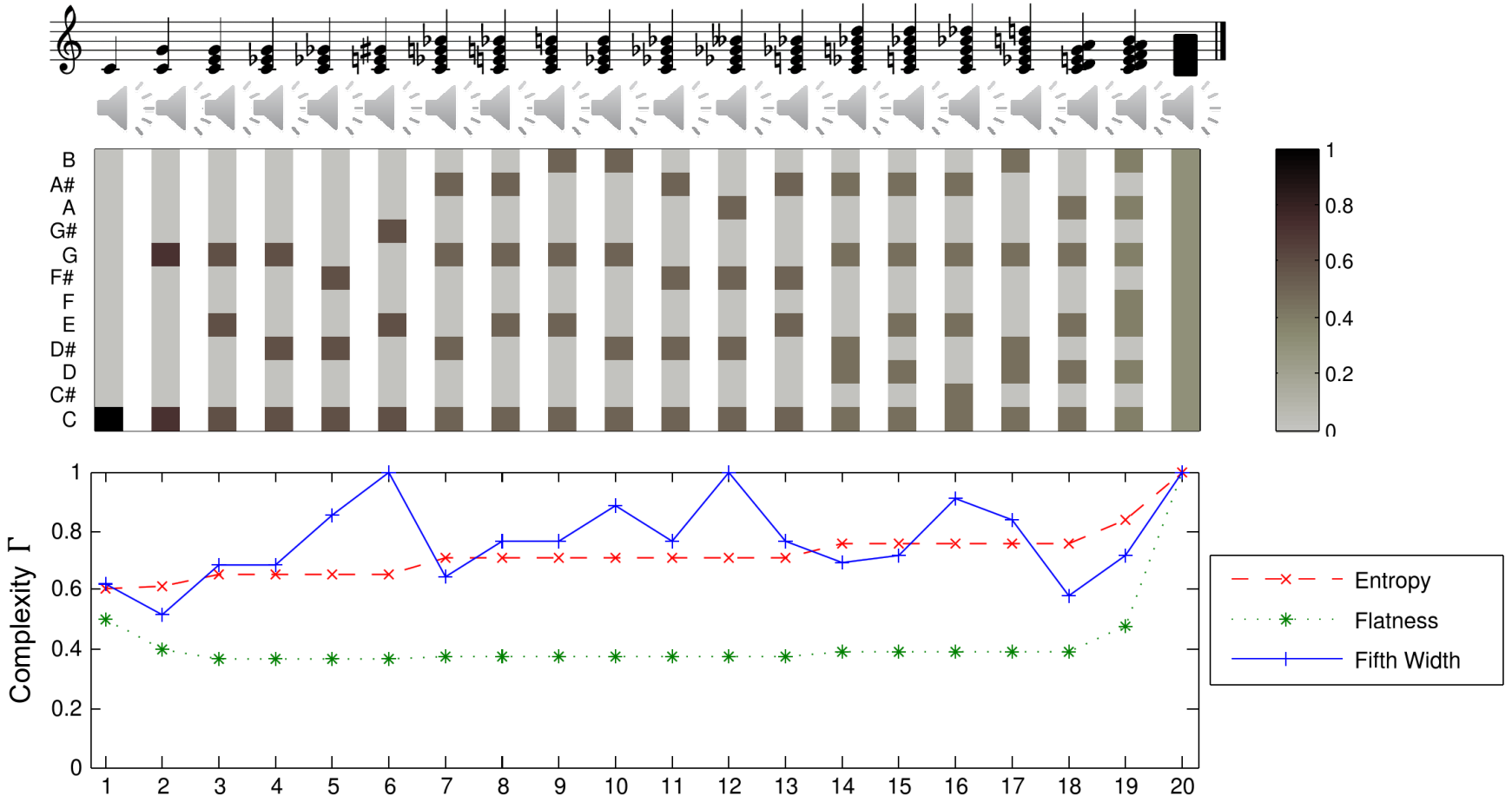
$Complexity = 0.6$



$Complexity = 1 - r_{\text{fifth}}(\mathbf{c})$

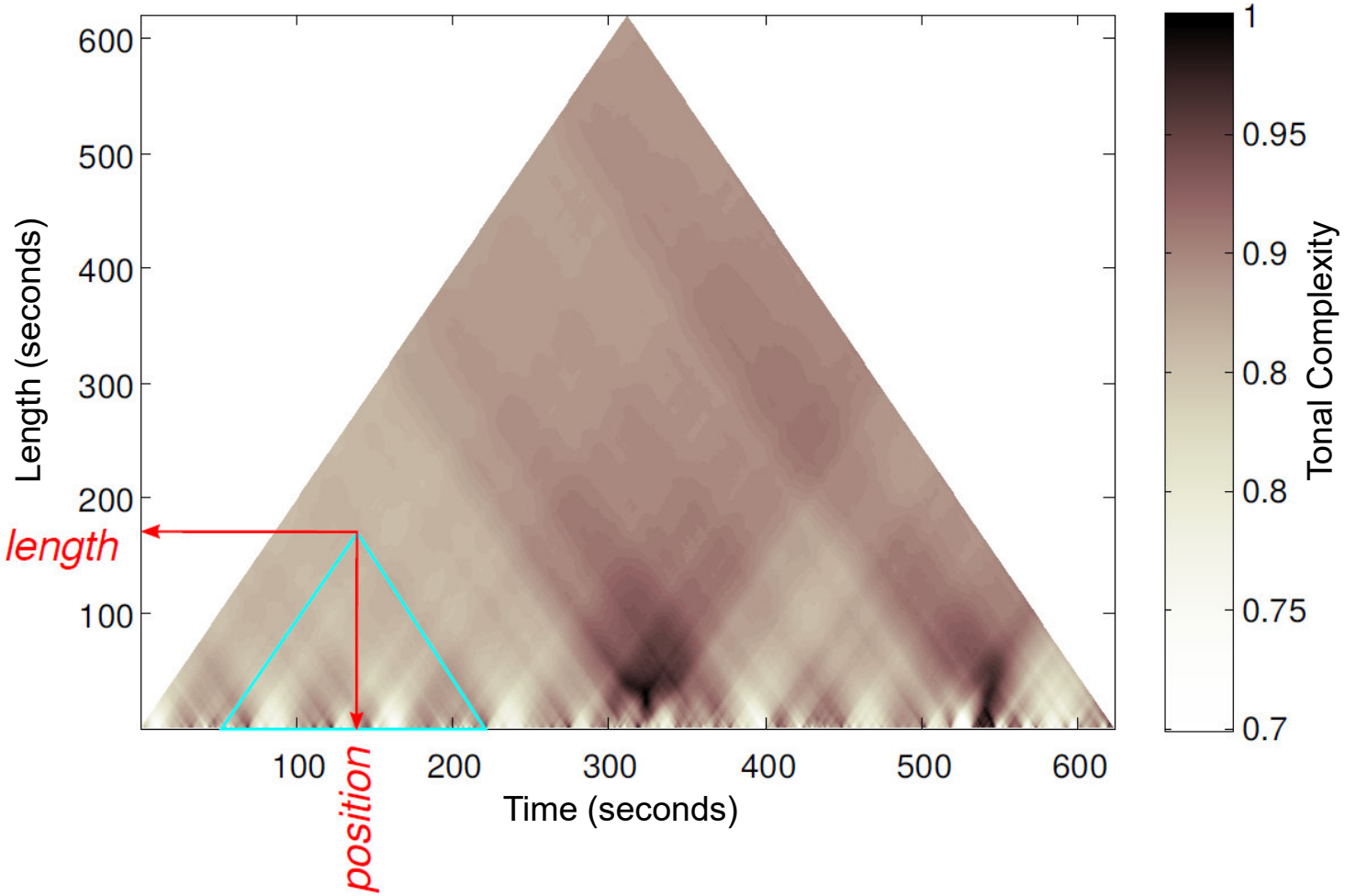
AUDIO LABS

Tonal Complexity – Chords



Tonal Complexity – Scape Plot Representations

- Complexity relates to multiple time scales
- Multi-scale visualization technique: Scape plot



Tonal Complexity – Beethoven's Sonatas