



Universiteit Utrecht

(Faculty of Science
Information and Computing Sciences)

Symbolic music features: Rhythm and meter

Anja Volk

Sound and Music Technology,
Nov 28, 2019

Today

■ Main modules

- A. Sound and music for games
- B. **Analysis, classification, and retrieval of sound and music for media**
- C. Generation and manipulation of sound and music for games and media

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- A. Sound and music for games
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 - Today: **Symbolic music feature**: Rhythm and meter
 - What is rhythmic and metric information in music?
 - Computational models for rhythm and meter extraction
 - Inner Metric Analysis
 - Application in Music Analysis, Music Cognition and Music Information Retrieval
- C. Generation and manipulation of sound and music for games and media

Recap

■ Last lecture: serious games

- Games with a purpose involving music: collecting data for MIR
- Education and health: role of serious games involving music

■ Recap Module A

- Different functions of sound and music for games
- Audio typologies (IEZA) supporting immersion and interactivity
- Different techniques to support immersion and interactivity in a game with audio

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 - Short Recapitulation: Music Information Retrieval
 - Representation of musical data: symbolic vs. audio data
 - Main topic: Symbolic music feature extraction: Rhythm and meter
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Module B: Analysis, classification, and retrieval of sound and music for media

- Music Information Retrieval
- Downie 2004:

- a multidisciplinary research endeavor that strives to develop innovative content-based searching schemes, novel interfaces, and evolving networked delivery mechanisms in an effort to make the world's vast store of music accessible to all

- Emerged in 1960s, maturing since late 1990s
- Research communities (Futrelle and Downie 2002)
 - computer science, information retrieval
 - audio engineering, digital sound processing
 - musicology, music theory
 - library science
 - cognitive science, psychology, philosophy
 - law



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Module B: Analysis, classification, and retrieval of sound and music for media

- Music Information Retrieval
- Symbolic vs. audio data



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Module B: Analysis, classification, and retrieval of sound and music for media

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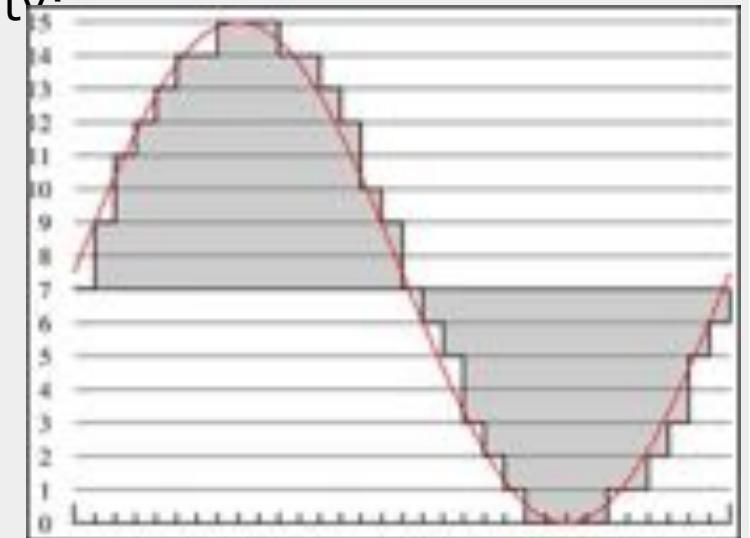
Module B: Analysis, classification, and retrieval of sound and music for media

- Music Information Retrieval
- Symbolic vs. **audio** data

Representation of musical data: symbolic vs. audio data

- Audio is most natural representation of music
 - ideally, this is what the MIR user works with
 - audio waveform provides detailed encoding of a specific performance of a piece, including any temporal, dynamic, and tonal micro-deviations present

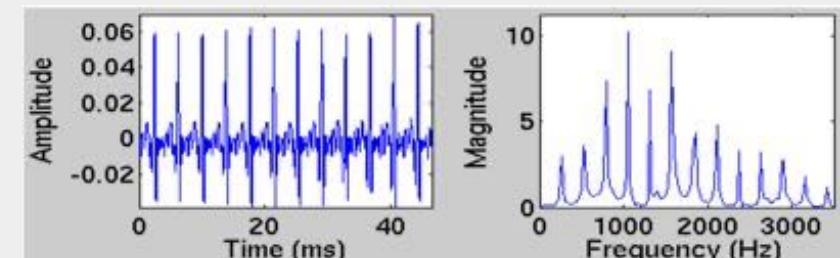
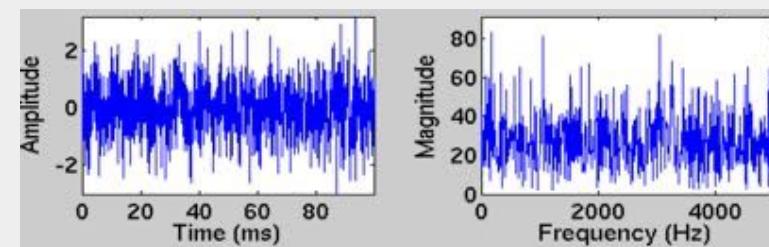
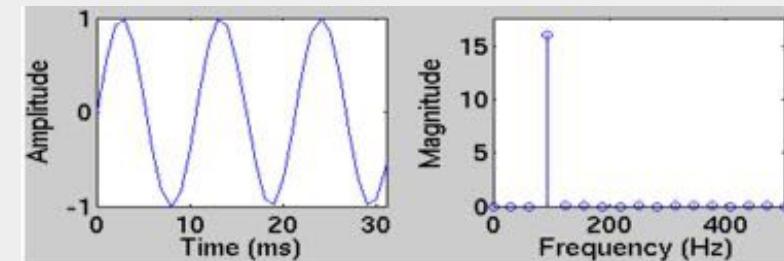
- Important digital audio formats
 - PCM (Pulse Code Modulation), CD quality:
 - sample rate 44.100 Hz
 - amplitude resolution 16 bits
 - 2 channels
 - MP3
 - lossy, perceptual compression
 - perceptual masking
 - suppresses inaudible components
 - ‘bit rate’ can be set by creator
 - many different MP3s from one recording



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Representation of musical data: symbolic vs. audio data

- Musical audio is analysed in 2 domains:
 - time domain
 - change of amplitude over time
 - frequency domain
 - within certain time interval
 - Fast Fourier Transform
 - magnitude of frequency components
- Musical tones have a periodic spectrum ($f_0, 2f_0, 3f_0, 4f_0, \dots$)
 - harmonics



trumpet

Representation of musical data: symbolic vs. audio data

■ Sample audio features

- frequencies
- fundamental frequency
- spectral energy
- Cepstral coefficients, MFCC
- amplitude envelope
- attack
- decay
- zero crossing rate
- spectral centroid
- standard deviations of the above
- etc. etc.

■ Low-level features: most of these not directly observable by listener



Representation of musical data: symbolic vs. audio data

- Music Information Retrieval
- Symbolic vs. audio data



Representation of musical data: symbolic vs. audio data

■ MIDI: Musical Instrument Digital Interface

- Event messages: sound events
- Standardized in 1983
- Protocol for communicating with electronic instruments

	Sound event perception	MIDI
pitch	low-high: c. 90 categories octave equivalence	pitch number
duration	long-short: multiples of 2 and 3	Onset and offset times
loudness	soft-loud: continuous	Velocity number
timbre	tone quality sound source	MIDI Instrument

Representation of musical data: symbolic vs. audio data

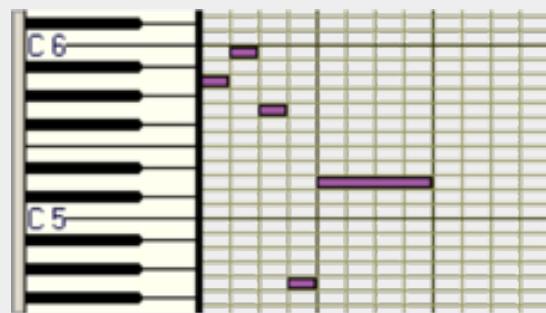
- MIDI:
 - Event messages: sound events

```
MFile 1 2 1024
MTrk
0 TimeSig 2/4 24 8
0 KeySig 0 major
0 Tempo 500000
16385 Meta TrkEnd
TrkEnd
MTrk
0 Meta TrkName "Acoustic Grand
Piano"
0 PrCh ch=1 p=0
0 On ch=1 n=72 v=64
0 On ch=1 n=48 v=64
1024 Off ch=1 n=72 v=0
1024 On ch=1 n=72 v=64
1024 Off ch=1 n=48 v=0
1024 On ch=1 n=60 v=64
2048 Off ch=1 n=72 v=0
2048 Off ch=1 n=60 v=0
2048 On ch=1 n=79 v=64
2048 On ch=1 n=64 v=64
3072 Off ch=1 n=79 v=0
3072 On ch=1 n=79 v=64
3072 Off ch=1 n=64 v=0
3072 On ch=1 n=60 v=64
4096 Off ch=1 n=79 v=0
```

Representation of musical data: symbolic vs. audio data

- MIDI: Musical Instrument Digital Interface
 - Event messages: sound events
 - Standardized in 1983

piano roll notation



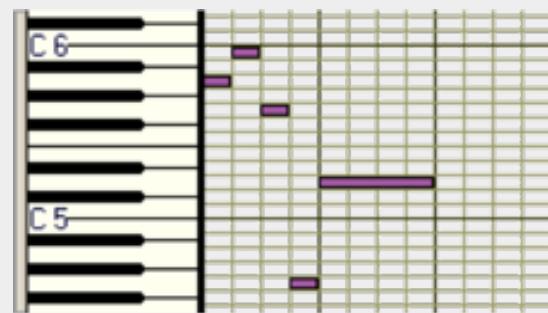
MIDI in action:

<https://www.youtube.com/watch?v=8w57c3f9GrI>

Representation of musical data: symbolic vs. audio data

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piano roll notation



Origin: piano roll

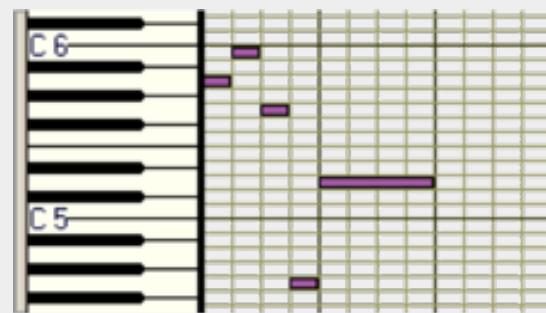
Representation of musical data: symbolic vs. audio data



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Origin: piano roll



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Representation of musical data: symbolic vs. audio data

■ Symbolic data

- MIDI
- Kern
- MusicXML
- ...

■ *Beyond MIDI. The Handbook of Musical Codes.* ed. Eleanor Selfridge-Field (1997)

- c. 27 music encoding systems, detailed descriptions
- non-proprietary formats only

Representation of musical data: symbolic vs. audio data

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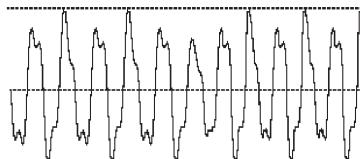
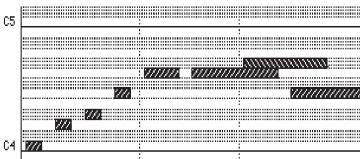
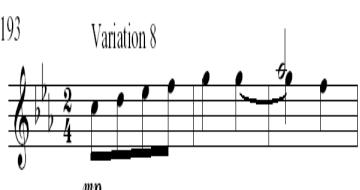
Representation of musical data: symbolic vs. audio data



- KERN
- David Huron, c. 1990
- <http://csml.som.ohio-state.edu/Humdrum/>
- syntax for developing (light-weight) encoding systems
 - data organised in parallel ‘spines’
 - humdrum representation for CMN: kern
- humdrum tools (UNIX)

**kern	**kern	
*staff2	*staff1	
=1-	=1-	
*cleff4	*clefG2	
*k[]	*k[]	
*M2/4	*M2/4	
*^ *		
2ryy	4C	4cc
.	4c	4cc
=2	=2	=2
2ryy	4e	4gg
.	4c	4gg
=3	=3	=3
2ryy	4f	4aa
.	4c	4aa
=4	=4	=4
2ryy	4e	4gg
.	4c	4gg
=5	=5	=5
2ryy	4d	4ff
.	4B	4ff
=6	=6	=6
2ryy	4c	4ee
.	4A	4ee
=7	=7	=7

Basic representations of musical content

musical content	example	compare image	compare text	structure	convert to above	convert to below
Digital audio (MP3, Wav)		level 1: primitive features	speech	none	-	hard
Time-stamped events (MIDI)		level 2: objects	text	little	easy	fairly hard (OK job)
Music notation (Finale, Sibelius, MusicXML)		level 2: compound objects	text + markup	much	easy (OK job)	-

MIDI and AUDIO in Games

- Greater level of interactivity requires more flexibility of music; a more granular (note) level control over the music necessary
- Composers work with MIDI sequencers and a sampling engine; by rendering out to a wav file, we are essentially creating the “one-track-orchestra” (every possible variation requires to render out a separate file).



Stevens and Reybold (2013): Game audio tutorial

Historically in games, we moved away from MIDI to immersive sounds and great audio quality, but at the expensive interactivity

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Symbolic music feature extraction: Rhythm and meter

- What is rhythm and meter?
 - Fundamental to human perception and cognition of music



Example: Steve Reich's Clapping music app

■ Serious game: training of rhythm skills

- Steve Reich: "Clapping music (1972)"
<https://www.youtube.com/watch?v=FcFyl8amoEE>
- What is this? <https://www.youtube.com/watch?v=lzkOFJMI5i8>
- Steve Reich on the app: <https://www.youtube.com/watch?v=7Z23EmPsoto>
- Collaboration: LondonSinfonietta, Queen Mary University of London, Touchpress, started in 2015

Symbolic music feature extraction: Rhythm and meter

- What is rhythm and meter?
 - Fundamental to human perception and cognition of music
- "Rhythm and pitch are the two primary parameters of musical structure (Meyer, E 1973). ... If pitch is concerned with the disposition of the frequencies of musical notes, then rhythm is concerned with the description and understanding of their duration and durational patterning. These durations may be more or less regular, may or may not give rise to a sense of beat or tempo, and may be more or less continuous, but as all music involves duration(s), all music necessarily has some manner of rhythm.

Grove Music Online

The image shows two musical staves side-by-side. Both staves begin with a clef (F clef for bass, C clef for treble), a key signature of one sharp (F#), and a common time signature (indicated by a 'C').
CLAP 1 staff: The first measure consists of four eighth notes (two vertical stems with 'x' heads). The second measure consists of two eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head). The third measure consists of three eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head, one vertical stem with 'z' head). The fourth measure consists of two eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head). The fifth measure consists of three eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head, one vertical stem with 'z' head). The sixth measure consists of two eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head). The staff ends with a double bar line and repeat dots.
CLAP 2 staff: The first measure consists of four eighth notes (two vertical stems with 'x' heads). The second measure consists of two eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head). The third measure consists of three eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head, one vertical stem with 'z' head). The fourth measure consists of two eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head). The fifth measure consists of three eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head, one vertical stem with 'z' head). The sixth measure consists of two eighth notes (one vertical stem with 'x' head, one vertical stem with 'y' head). The staff ends with a double bar line and repeat dots.

Symbolic music feature extraction: Rhythm and meter

- What is rhythm and meter?
 - Fundamental to human perception and cognition of music

Height (Pitch)



Time



Yannick Jannink

Faculty of Science

Informatics and Computing Sciences

Symbolic music feature extraction: Rhythm and meter

- What is rhythm and meter?
 - Fundamental to human perception and cognition of music
- Listening experiment: How difficult is it to tap along?



Dancing



Picture from hcs.harvard.edu/~hma-bdc

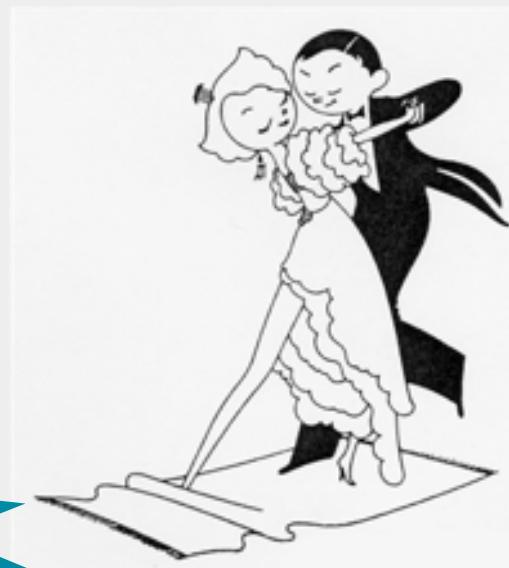


Yannick Groulx

Dancing



Mambo !



Picture from hcs.harvard.edu/~hma-bdc



Merengue !

... even 7 months old babies are experts



Phillips-Silver/Trainor: Feeling the Beat: Movement Influences Infant Rhythm Perception, 2005



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Rhythm and games

- ... lots of rhythm games out there
- ... very addictive
- ... has to do with events in time

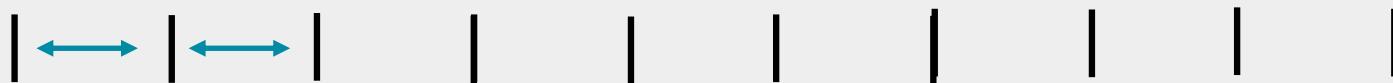
"Would a hierarchy of time structures help my game? That is, several short rounds that together comprise a larger round? **Timing can be very difficult to get right, but it can make or break a game.**"

Schell, J. The Art of Game Design: A book of lenses (2008).

Rhythm



Spontaneous reaction: tapping along the beat



Rhythm: Meter



Spontaneous reaction: tapping along the beat



Rhythm: Meter



Spontaneous reaction: tapping along the beat



Rhythm: Meter



Accent Pattern

A musical score is shown with two staves. The top staff is in treble clef and the bottom staff is in bass clef. Blue arrows point from the text 'Accent Pattern' to specific notes on the treble staff. Red vertical lines mark the beginning of measures. Blue '<' symbols above the staff indicate the start of a new measure or a change in rhythm.

<https://www.youtube.com/watch?v=O2jpnkEOH3A>

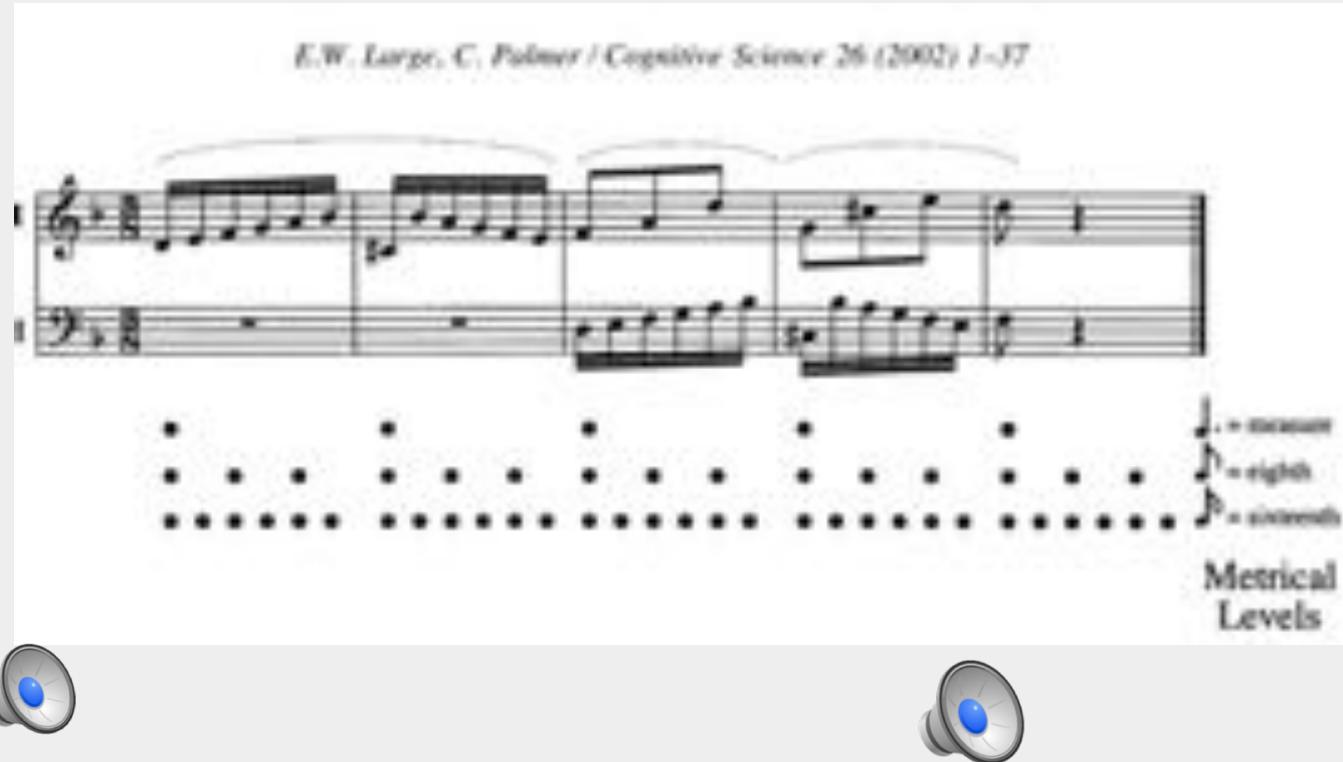


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Theories of rhythm and meter

Yeston, Lerdahl/Jackendoff, Hasty



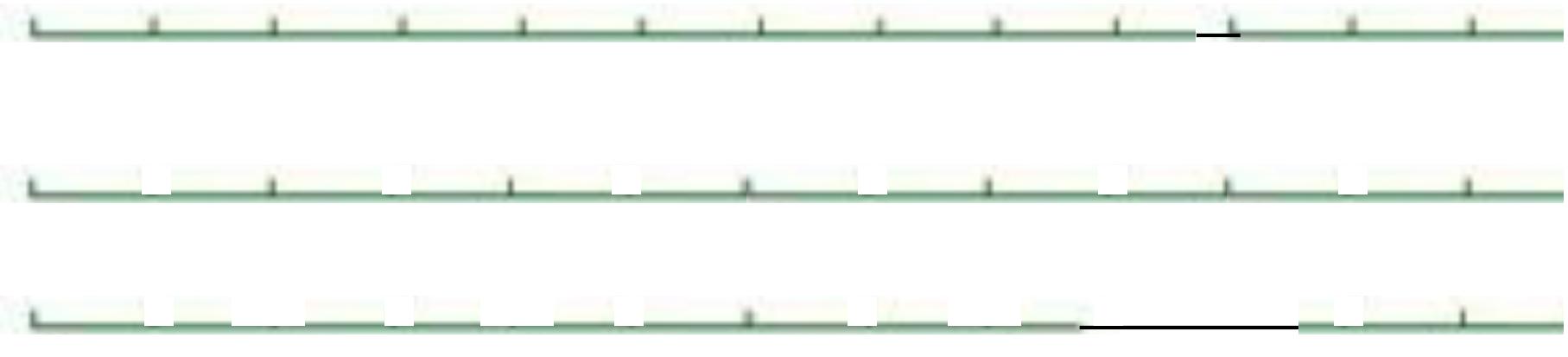
I define the meter of a work as the union of all layers of motion (i.e., series of regularly recurring pulses) **active** within it.

Harald Krebs



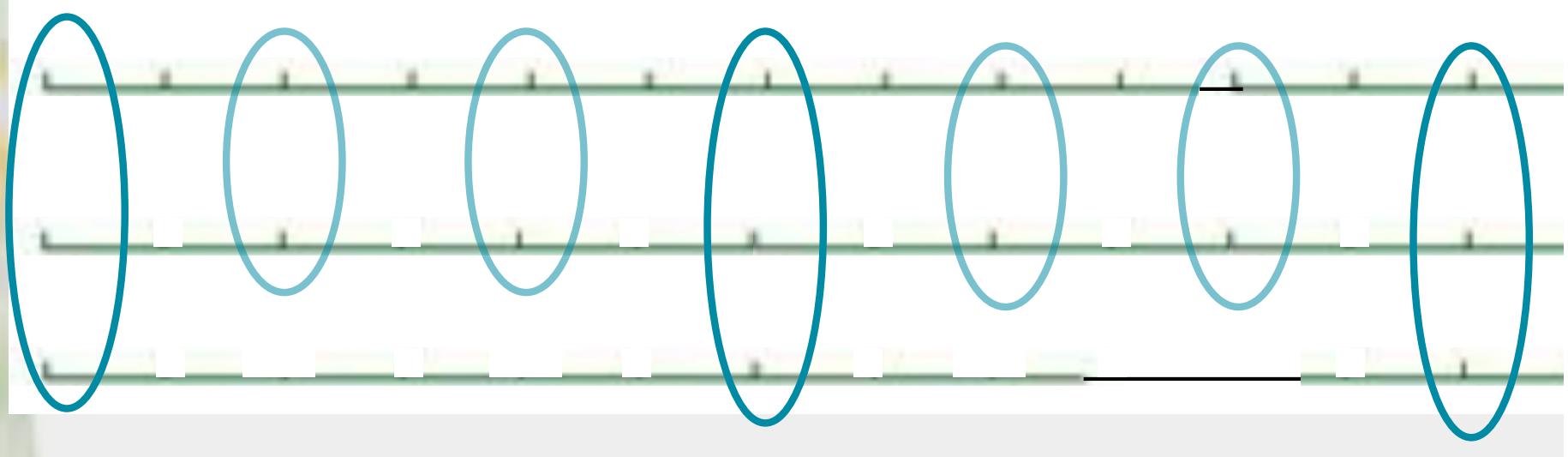
Theories of rhythm and meter

nested pulses



Theories of rhythm and meter

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Inner Metric Analysis

Inner metric analysis: motivation



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Inner Metric Analysis



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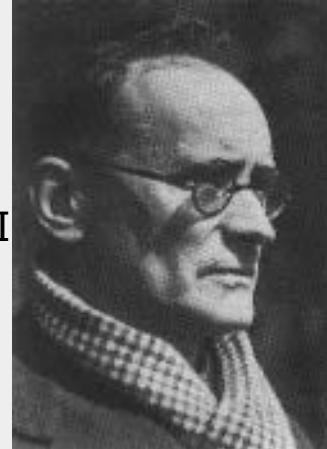
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Inner Metric Analysis



Anton Webern

Piano Variations Op. 27, II



Scott Joplin

Nonpareil Rag

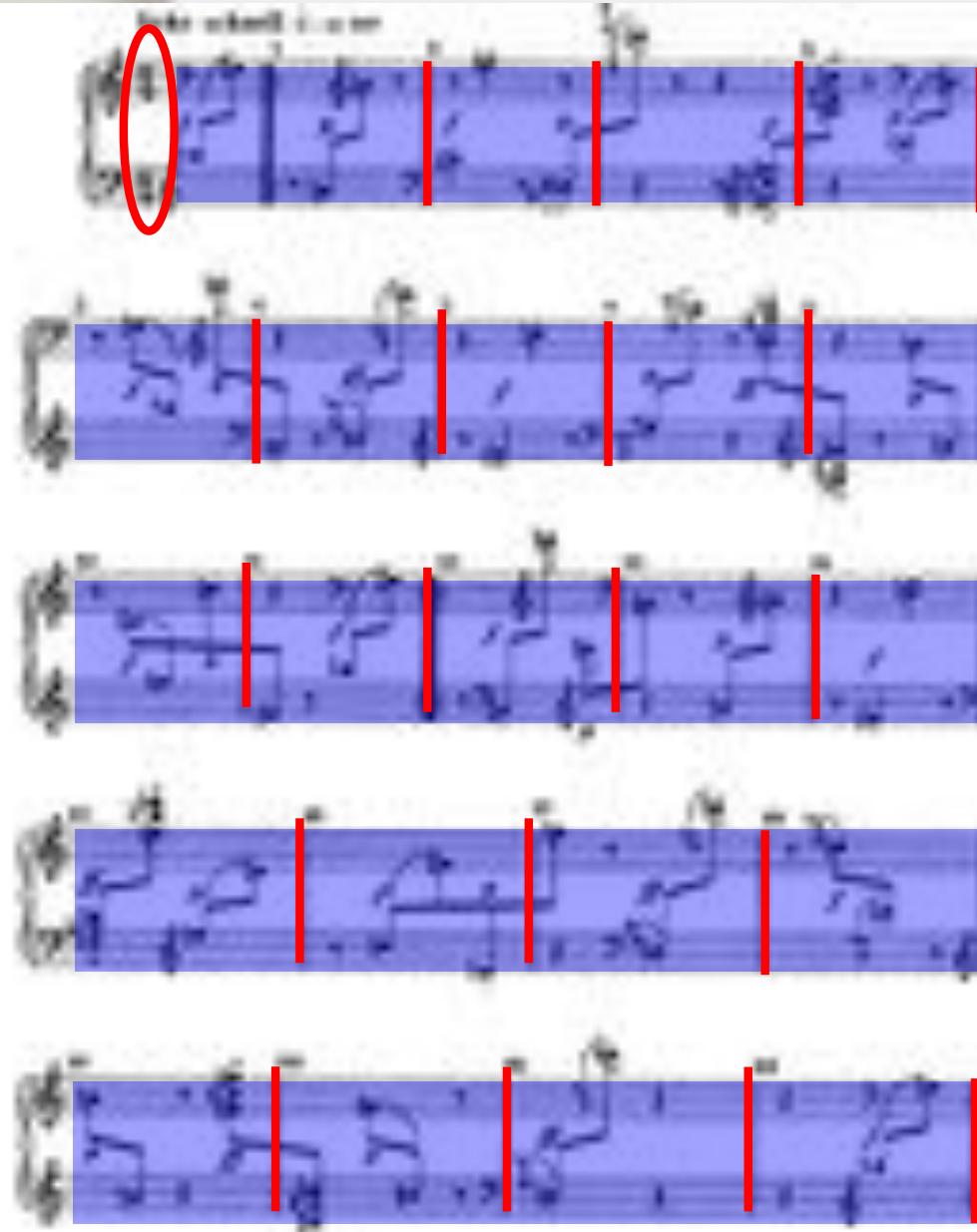


Inner Metric Analysis

A musical score page featuring five staves of music. The first staff is circled in red, drawing attention to its unique metric structure. The music consists of various note heads and stems, with some notes having vertical dashes through them.

A continuation of the musical score from the previous page, consisting of five more staves of music. Similar to the first page, the first staff is circled in red, indicating it is the focus of the inner metric analysis.

Inner Metric Analysis



Outer Metric Structure

Inner Metric Structure

Inner Metric Analysis

Metric Weight



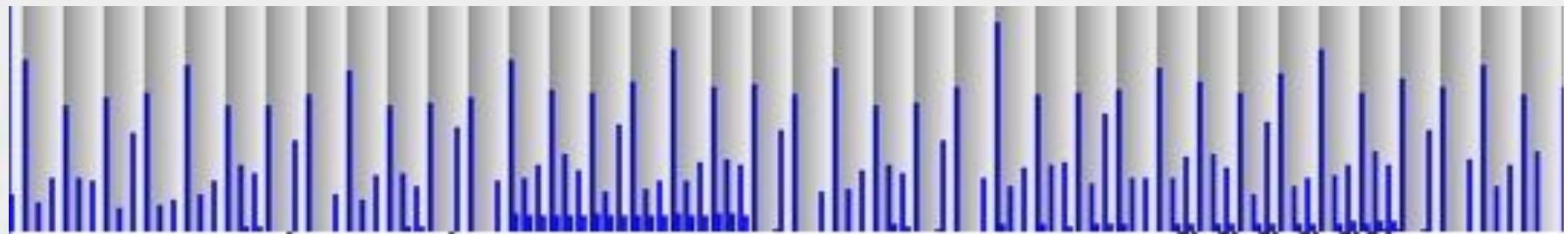
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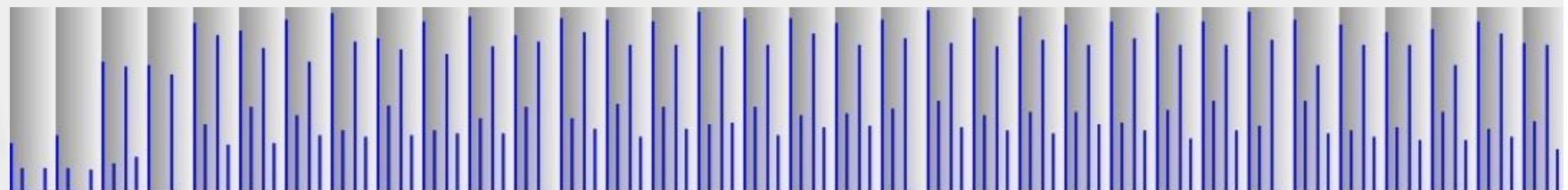
Inner Metric Analysis

Metric Weight

Cycles in 3



Cycles in 2



Inner Metric Analysis

Metric Weight



Picture from www.ritzenhoff.de



Ritzenhoff

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Inner Metric Analysis

Metric Weight



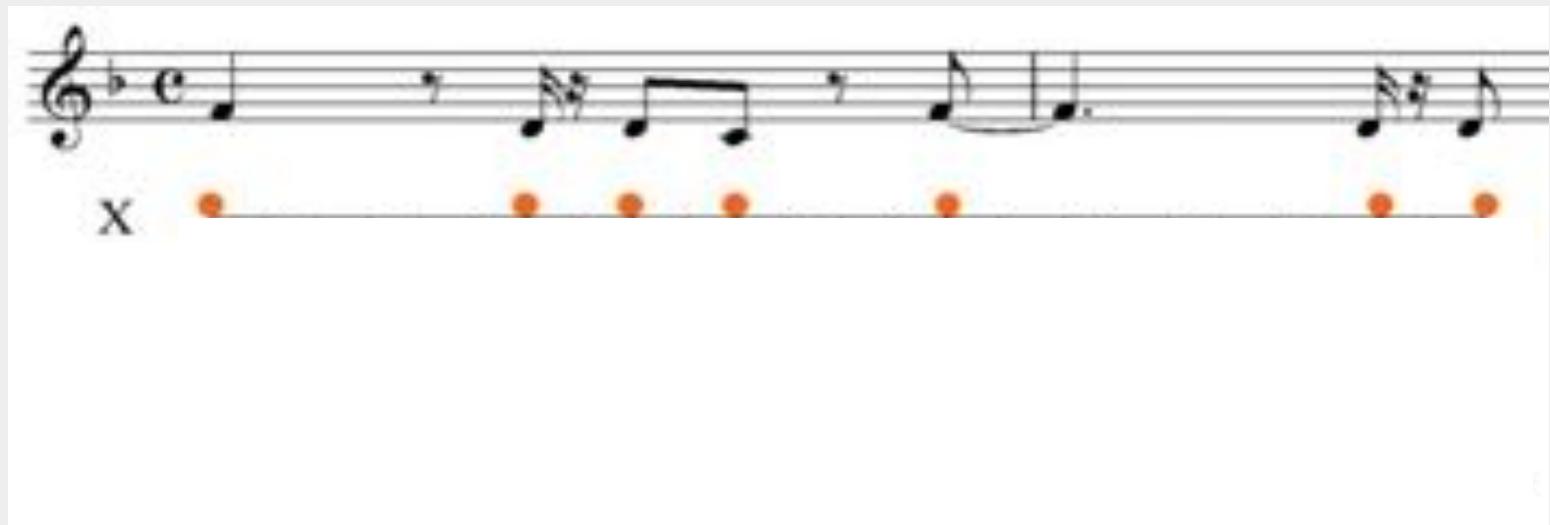
Picture from www.ritzenhoff.de



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Inner Metric Analysis

Metric Weight



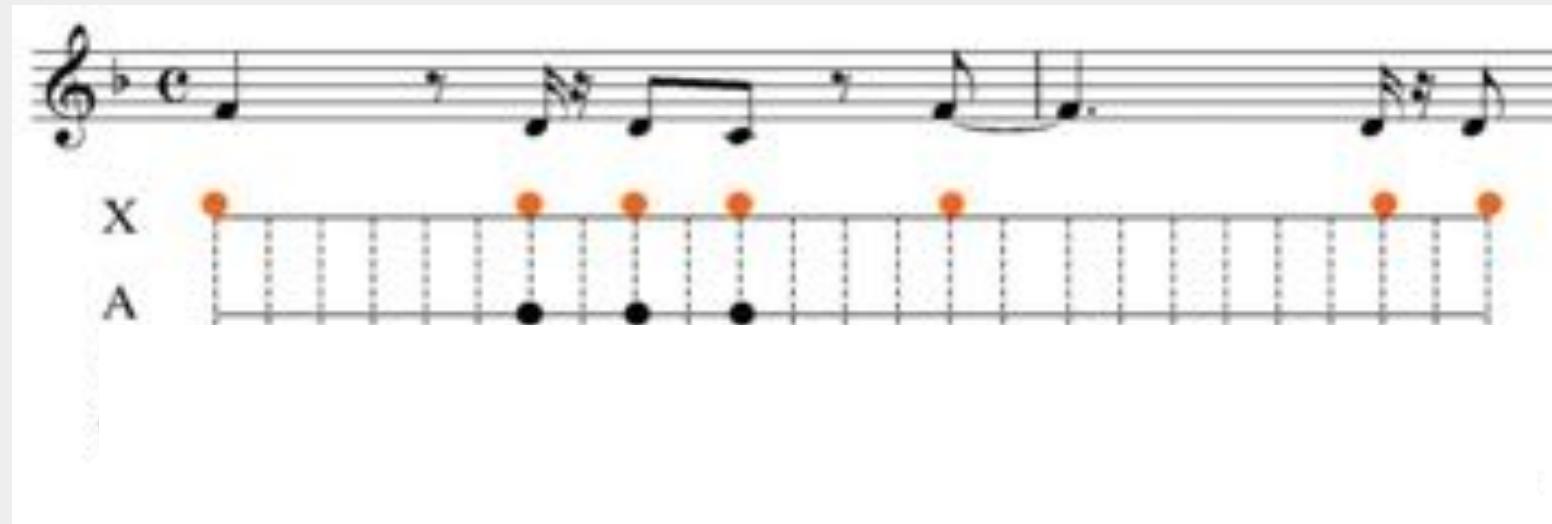
Picture from www.ritzenhoff.de



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Inner Metric Analysis

Metric Weight



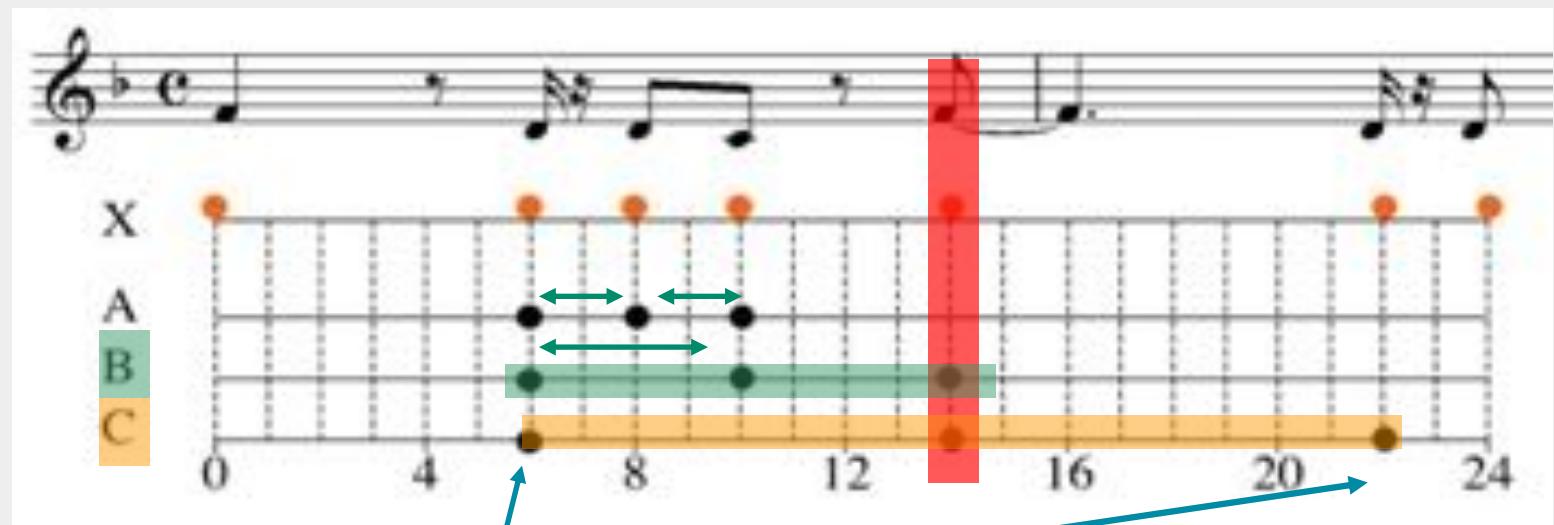
Picture from www.ritzenhoff.de



Wissenschaftsverlag

Inner Metric Analysis

Metric Weight



$$m(s, d, k) = \{s + id, i = 0, \dots, k\} \subset X$$

$$M(\ell) = \{m(s, d, k) : k \geq \ell\}$$

$$W_{\ell, p}(o) = \sum_{\{m \in M(\ell) : o \in m\}} k^p$$

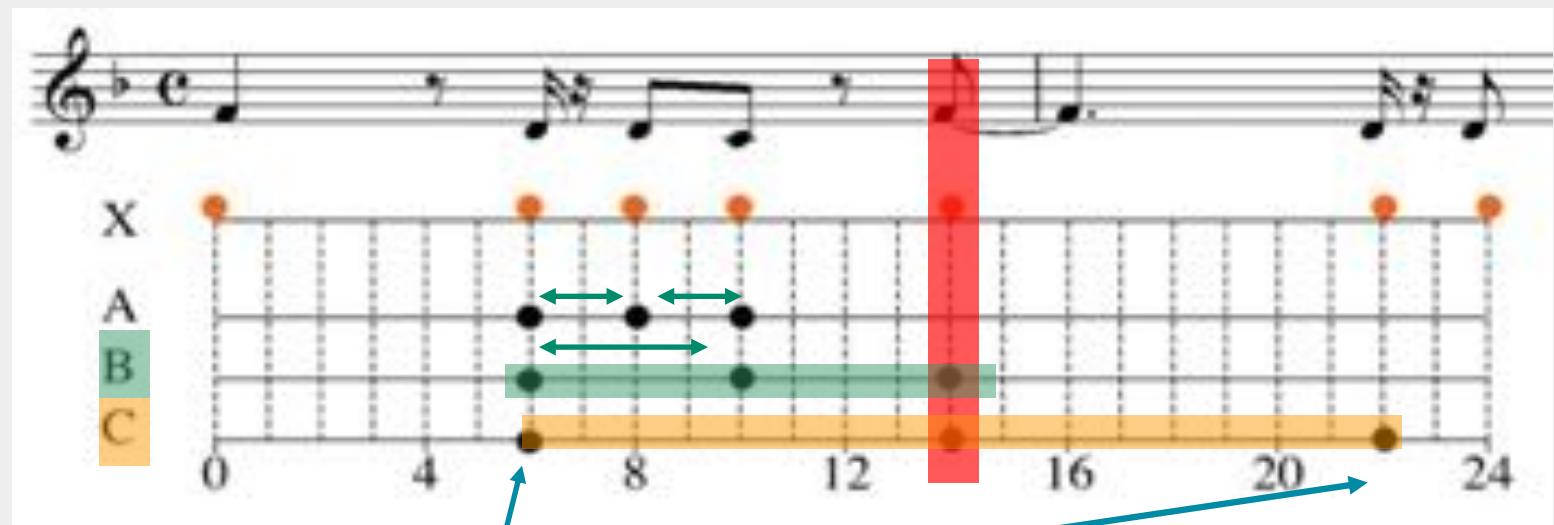
Picture from www.ritzenhoff.de



ritzenhoff

Inner Metric Analysis

Metric Weight



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$$W_{\ell, p}(o) = \sum_{\{m \in M(\ell) : o \in m\}} k^p$$

m : local meter

M: set of all local meters with minimal length l

W: metric weight of onset o



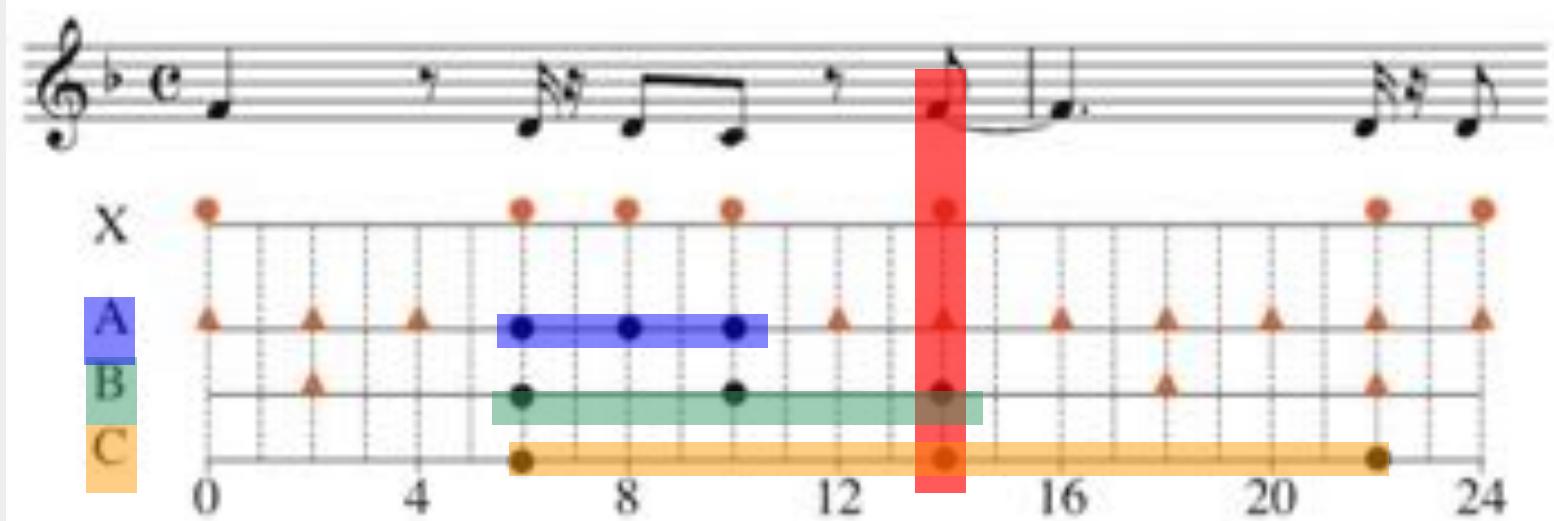
Picture from www.ritzenhoff.de

Inner Metric Analysis

Spectral Weight



Picture from www.ritzenhoff.de



$$m(s, d, k) = \{s + id, i = 0, \dots, k\} \subset X$$

$$\text{ext}(m(s, d, k)) = \{s + id, \forall i\}$$

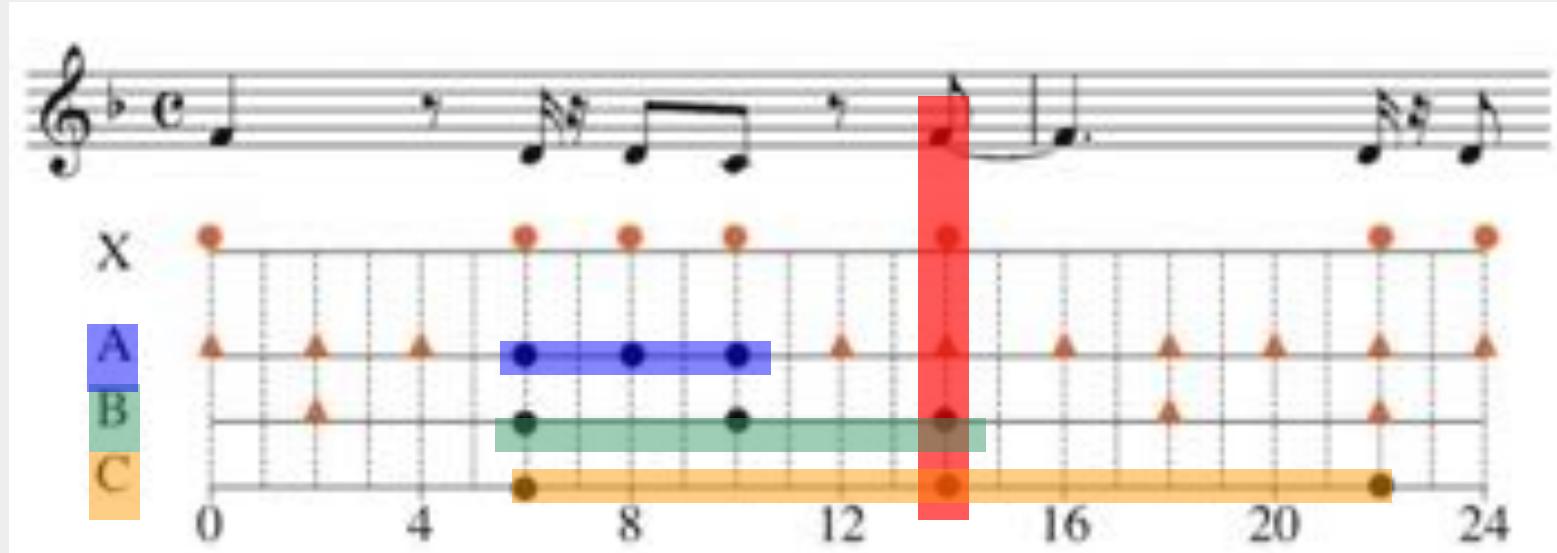
$$SW_{\ell,p}(t) = \sum_{\{m \in M(\ell) : t \in \text{ext}(m)\}} k^p$$

Inner Metric Analysis

Spectral Weight



Picture from www.ritzenhoff.de



$$m(s, d, k) = \{s + id, i = 0, \dots, k\} \subset X$$

$$\text{ext}(m(s, d, k)) = \{s + id, \forall i\}$$

$$SW_{\ell,p}(t) = \sum_{\{m \in M(\ell) : t \in \text{ext}(m)\}} k^p$$

m : local meter

ext: extension of local meter m

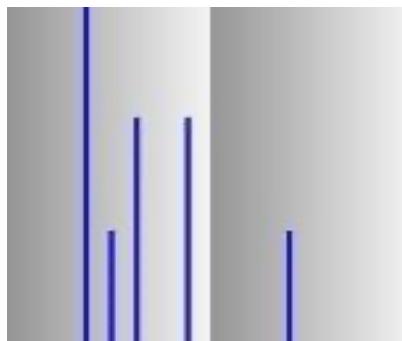
SW: spectral weight of timepoint t

Inner Metric Analysis

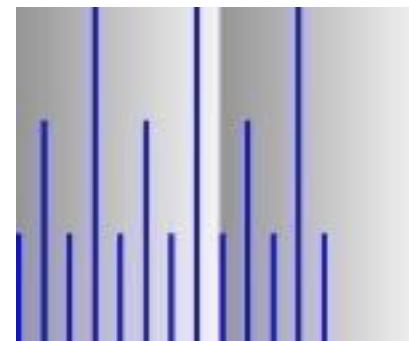
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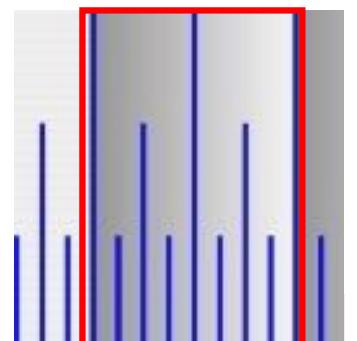
Picture from www.ritzenhoff.de



Metric Weight



Spectral Weight



University of Salzburg

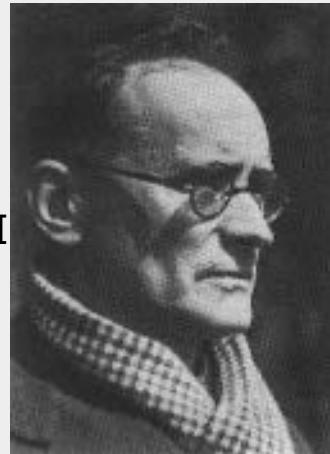
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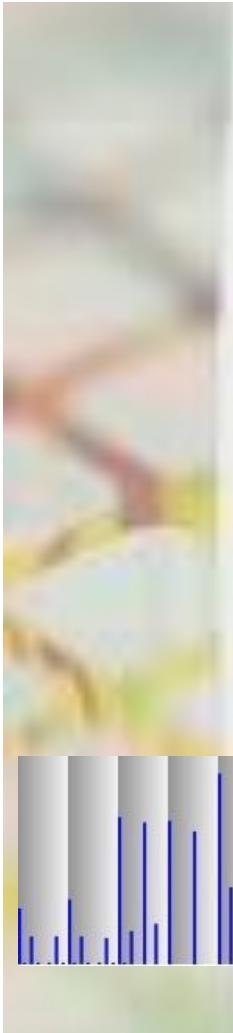
Inner Metric Analysis

A collage of musical notation and portraits related to inner metric analysis. The background consists of several staves of musical notation, some with small portraits of musicians placed on them. A large, prominent question mark is centered in the middle of the page. The portraits include one of Arnold Schoenberg and one of W. E. B. DuBois.

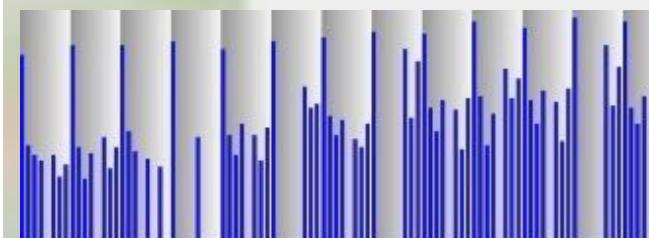
Webern vs. Joplin

A five-line musical staff is shown, divided into two distinct halves. The upper half consists of six measures of dense, short, eighth-note-like strokes, creating a complex, atonal texture. The lower half consists of six measures of longer, sustained notes, primarily quarter and eighth notes, creating a more rhythmic and melodic pattern.

Webern vs. Joplin



left hand

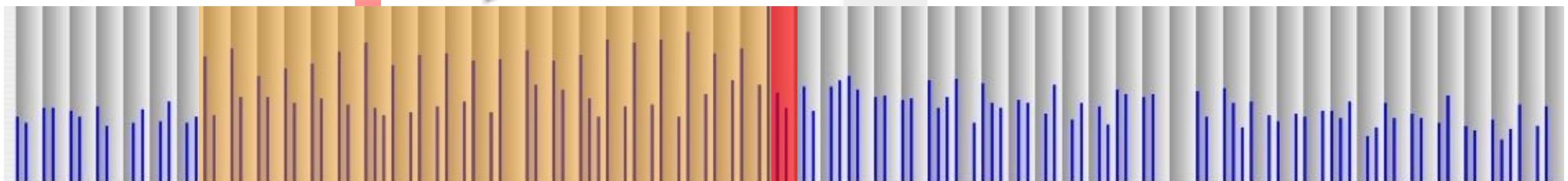
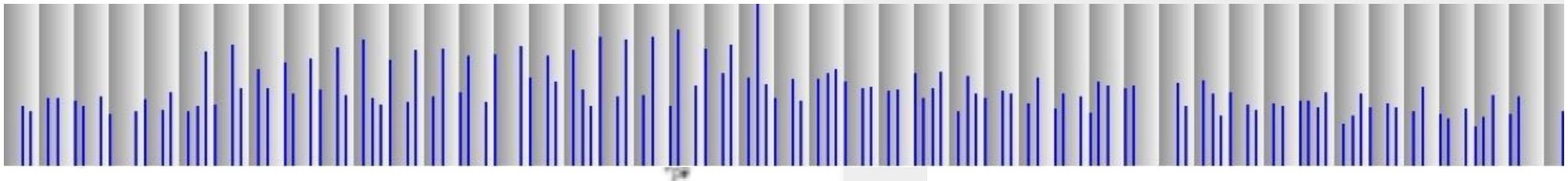


right hand



A musical score consisting of two staves. The top staff is in common time and features a treble clef, a key signature of one sharp, and a bass clef. It contains a series of eighth-note patterns and rests. The bottom staff is also in common time with a treble clef, a key signature of one sharp, and a bass clef. It contains a series of eighth-note patterns and rests, mirroring the top staff's rhythm.

Webern vs. Joplin



Today

■ Main modules

- A. Sound and music for games
- B. **Analysis, classification, and retrieval of sound and music for media**
 - Short Recapitulation: Music Information Retrieval
 - Representation of musical data: symbolic vs. audio data
 - Main topic: Symbolic music feature extraction: Rhythm and meter
 - What is rhythmic and metric information in music?
 - Computational models for rhythm and meter extraction
 - Inner Metric Analysis
 - **Application in Music Analysis, Music Cognition and Music Information Retrieval**

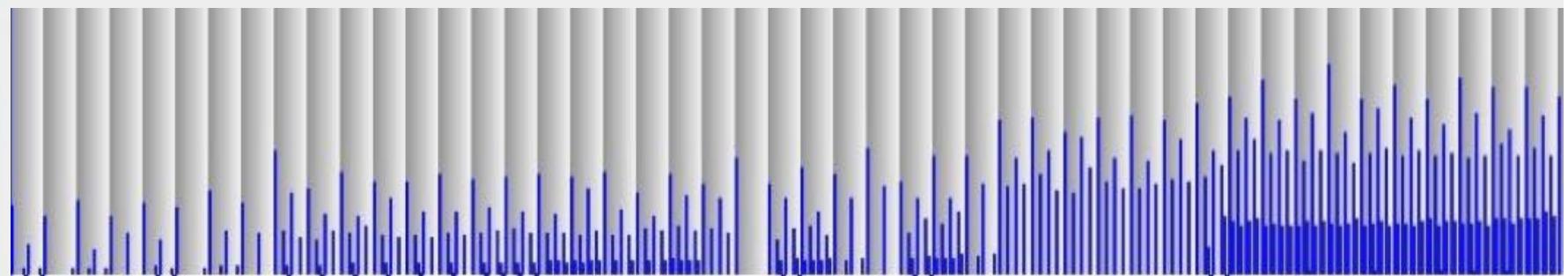


Music Analysis

Symphony C Major K. 551

1. Movement (4/4)

Wolfgang A. Mozart



Excerpt from Metric weight $W_{2,2}$ of the exposition (bars 1-55)



Music Analysis

Igor Stravinsky: The Rite of Spring

Danse Sacrale



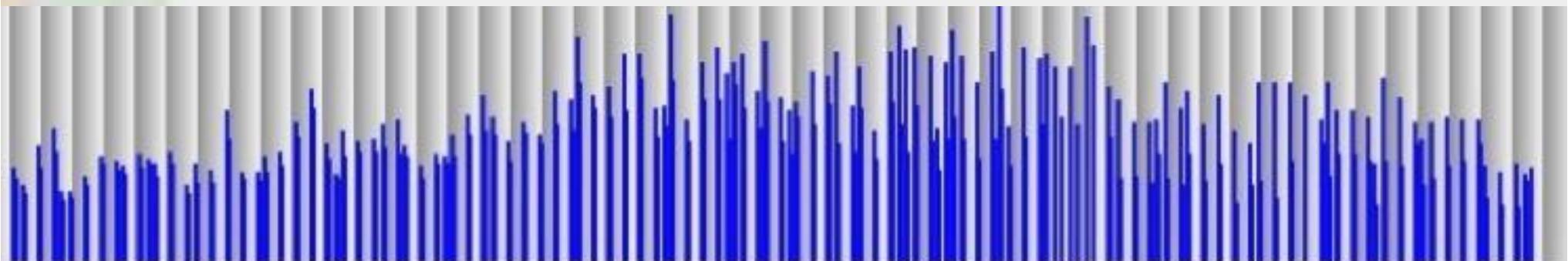
Yannick Noah

Faculty of Science
Information and Computing Sciences

Music Analysis



Music Analysis



University of Science

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Information and Computing Sciences

Music Cognition

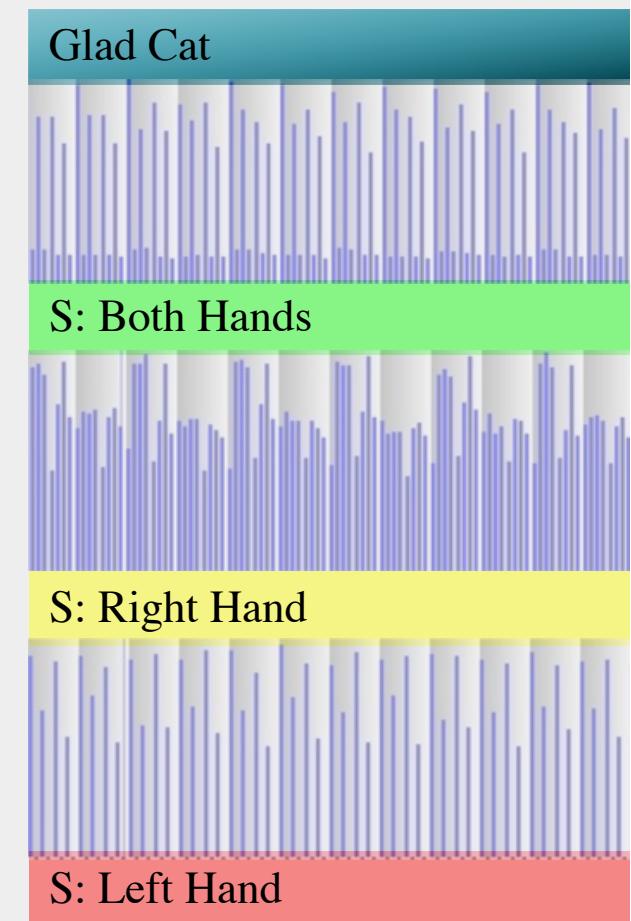
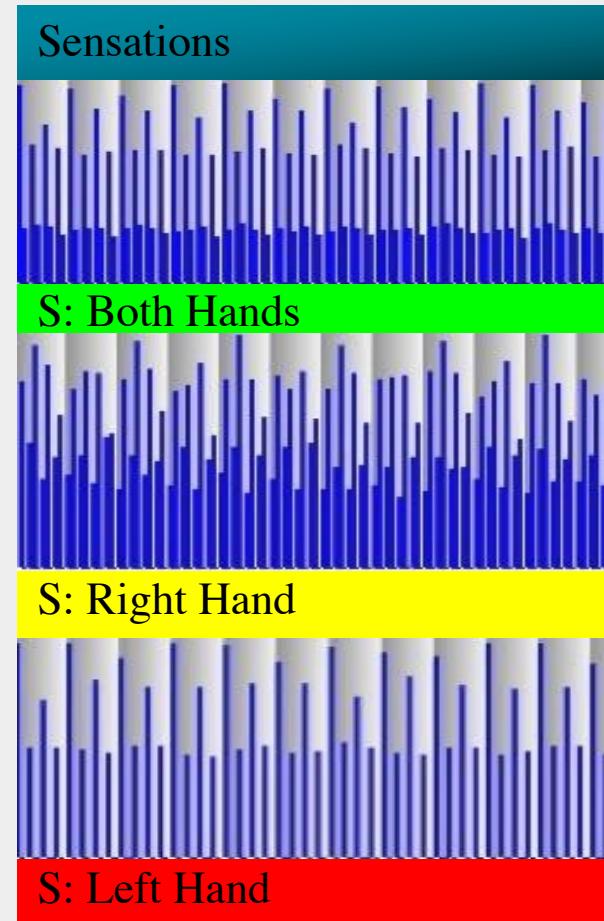
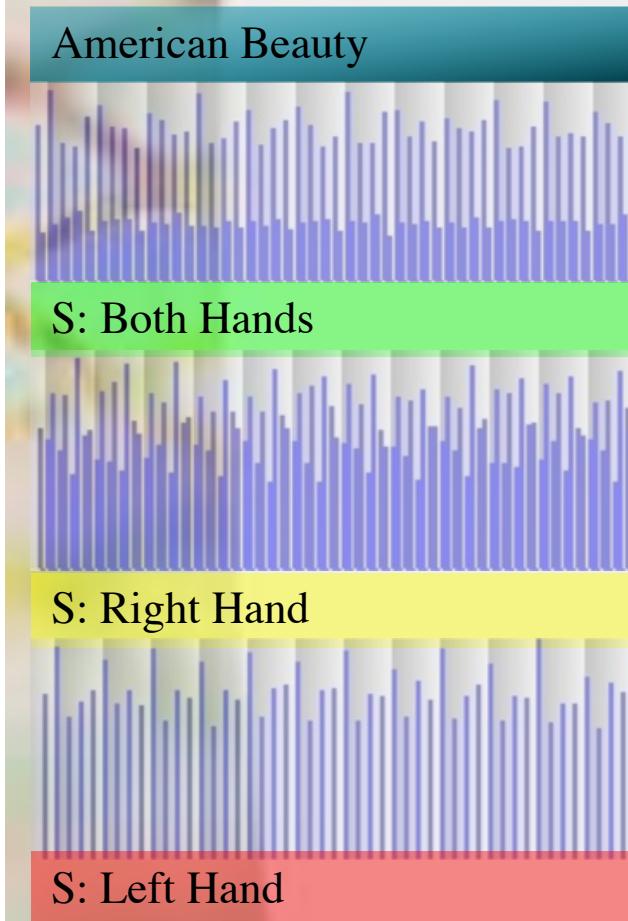
J. Snyder & C. Krumhansl: Tapping to Ragtime - Cues to Pulse Finding

- Ragtime: Cues for pulse finding?
 - First hypothesis: pitch
 - Tapping experiments: rhythm only!



Music Cognition

J. Snyder & C. Krumhansl: Tapping to Ragtime - Cues to Pulse Finding



Anja Volk (2008), *The Study of Syncopation using Inner Metric Analysis: Linking Theoretical and Experimental Analysis of Metre in Music*, In: Journal of New Music Research, Vol. 37:4, p. 259-273.



Music Information Retrieval



Picture from hcs.harvard.edu/~hma-bdc



University of Science
and Technology

Music Information Retrieval

I taught cha cha, waltz, foxtrot, west coast swing, tango, rumba, etc. And sure, there were music catalogues with metadata tagged in all these genres. But the songs that had those metadata tags were all ballroom dance music. Awful, awful stuff. Stuff nobody really wanted to listen to.

So what I really wanted was something that could find songs that were both good to listen to, and good to dance to at the same time.

... I don't see how this could be done without looking at the content of the music.

Jeremy Pickens, MIR-list, May 8th 2011

Music Information Retrieval

Classification

all in 4/4 !

Rumba



Tango



Picture from www.accommodationbsas.co.ar

© 2006 Microsoft Corporation. All rights reserved.

Picture from www.danceuniverse.co.kr

BossaNova



Picture from www.ritzenhoff.de

Merengue



Picture from www.mondolatino.it

March/Anthem

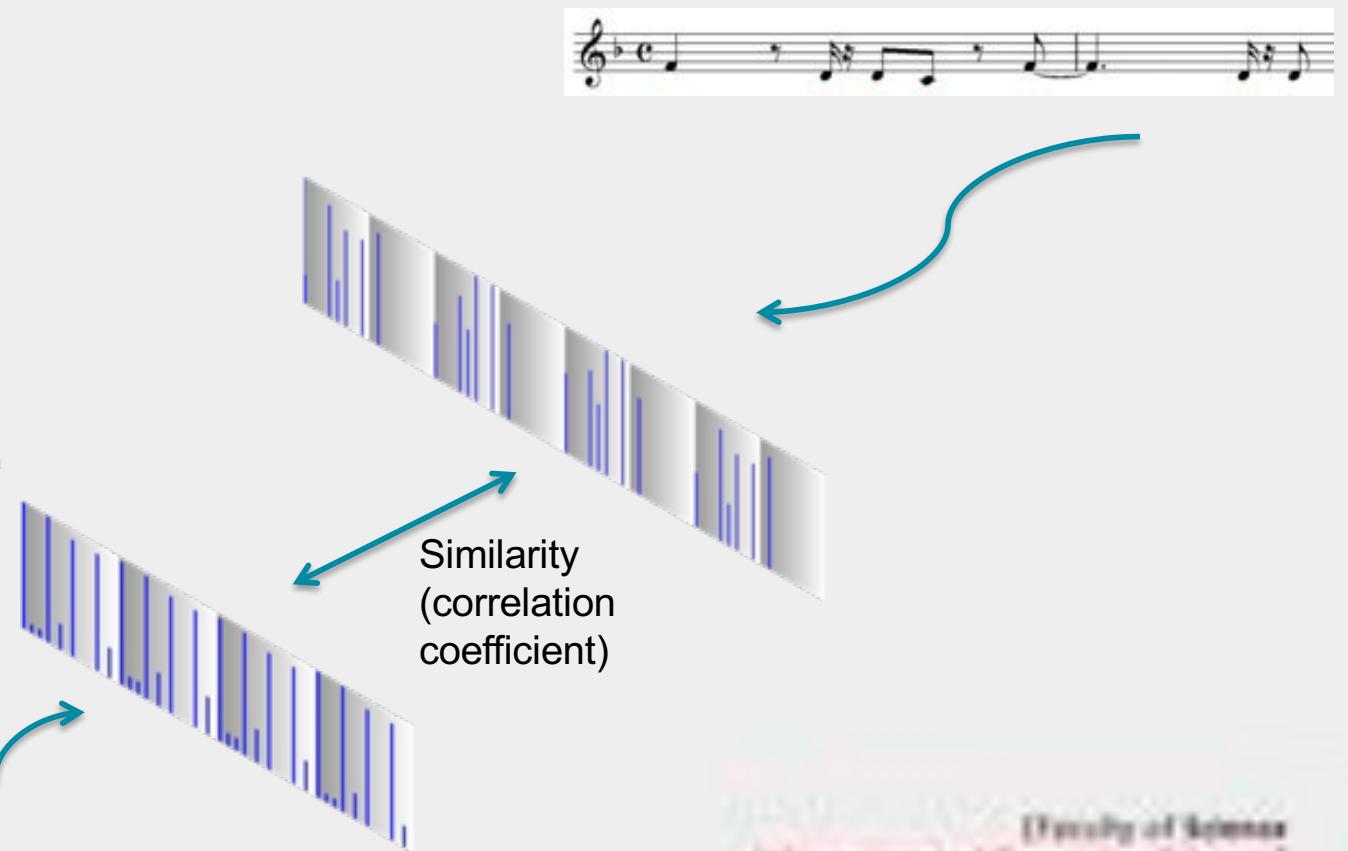
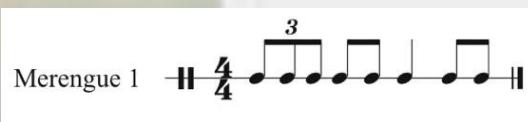
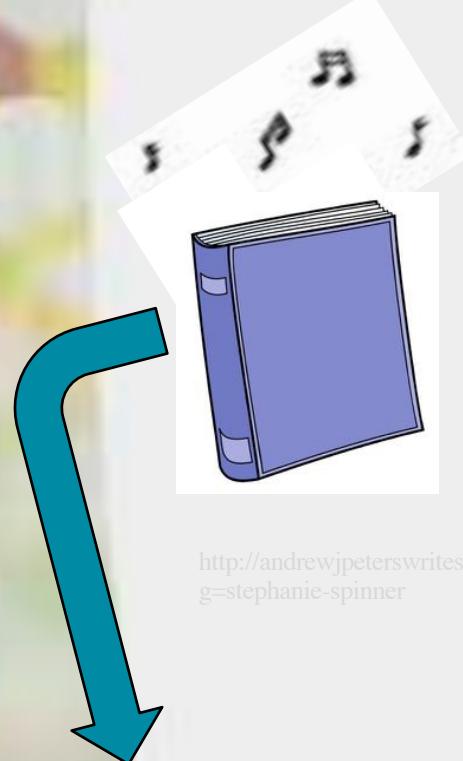


Picture from www.armygermany.com

E. Chew, A. Volk, and C.Y Lee,
Dance Music Classification Using Inner Metric Analysis, 2005

Music Information Retrieval

Complete Book of the Worlds' Dance Rhythm



Picture from www.ritzenhoff.de

Music Information Retrieval

Template Rhythms: Complete Book of the Worlds' Dance Rhythm

Corpus: 21 Marches, 17 Merengues, 25 Bossa Nova, 17 Rumbas, 22 Tangos

Stage 1: Pre-processing of template rhythms

Step 1: Repeat the template rhythm four times.

Step 2: Calculate its metric/spectral weight.

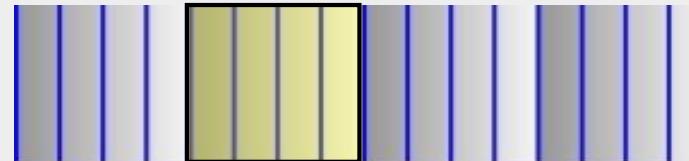
Step 3: Extract metric/spectral weight profile of 2nd repetition.

Step 4: Normalize all weights to fall between 0 and MAX (=10).

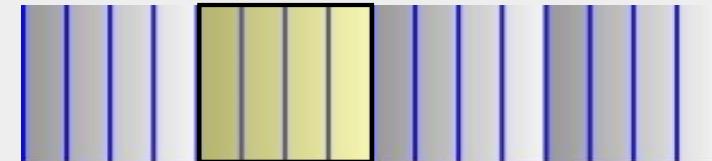


Music Information Retrieval

March

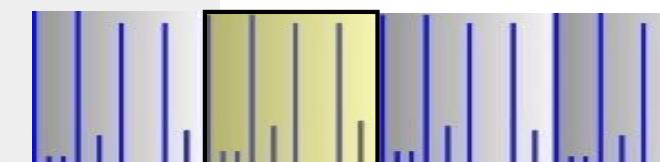


Metric Weight

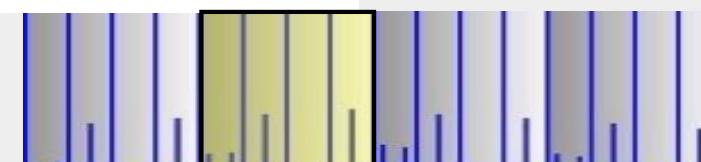


Spectral Weight

Merengue 1



Metric Weight



Spectral Weight

Music Information Retrieval

Stage 2: Classification of music sample

Step 1: Obtain melodic fragment near beginning of sample.

Step 2: Repeat the rhythm pattern four times.

Step 3: Calculate its metric/spectral weight.

Step 4: Extract metric/spectral weight profile of 2nd repetition.

Step 5: Normalize all weights to fall between 0 and MAX (=10).

Step 6: Extend (by repetition) both the sample profile and the template profile to the lowest common multiple of sample and template lengths.

Step 7: Compute the correlation coefficient between the (extended) sample and template profiles (details to follow).

Step 8: Assign piece to genre with highest correlation.



Music Information Retrieval

Classification

correct genre: 80%

Rumba



Picture from www.danceuniverse.co.kr

Tango



Picture from www.accomodationbsas.co.ar

BossaNova



Picture from www.ritzenhoff.de

Merengue



Picture from www.mondolatino.it

March/Anthem



Picture from www.armygermany.com

E. Chew, A. Volk, and C.Y Lee,
Dance Music Classification Using Inner Metric Analysis, 2005

Ragtime



University of Science

Ragtime

“A discussion on what constitutes ragtime could fill several web pages ...”



What's the problem?

1890-1920



What's the problem?

1890-1920



University of Alberta

Faculty of Science
Information and Computing Sciences

What's the problem?

1890-1920



Yannick Granier

[Faculty of Science]
Information and Computing Sciences

What's the problem?

1890-1920

Did Johannes Brahms contemplate a Ragtime project?



What's the problem?

- historic sources vs. study of the musical material itself
- not just the three main composers (Joplin, Scott, Lamb)
- Edward Berlin: we need more balanced view on ragtime



Computational corpus-based study is the next step



Patterns in the RAG-collection

- 11.000 MIDI files
- contains Ragtimes from 1890s to 2012
- Ragtime Compendium:
 - 15.000 identified ragtime compositions
 - out of these 5600 pieces have MIDI files.
- probably the most complete listing that exists, organized by the Internet community of ragtime lovers



Some numbers from the compendium...

- 128 websites for Ragtime MIDI's
- 101 cited sources of data (Libraries, societies, individuals)
- 38 contributors for the compendium creation

Syncopation



■ 1-2-1



untied

tied



Syncopation



■ 1-2-1



untied

tied

Syncopation



■ 1-2-1



untied

tied

Syncopation



■ 1-2-1



untied



tied

Syncopation



■ 1-2-1

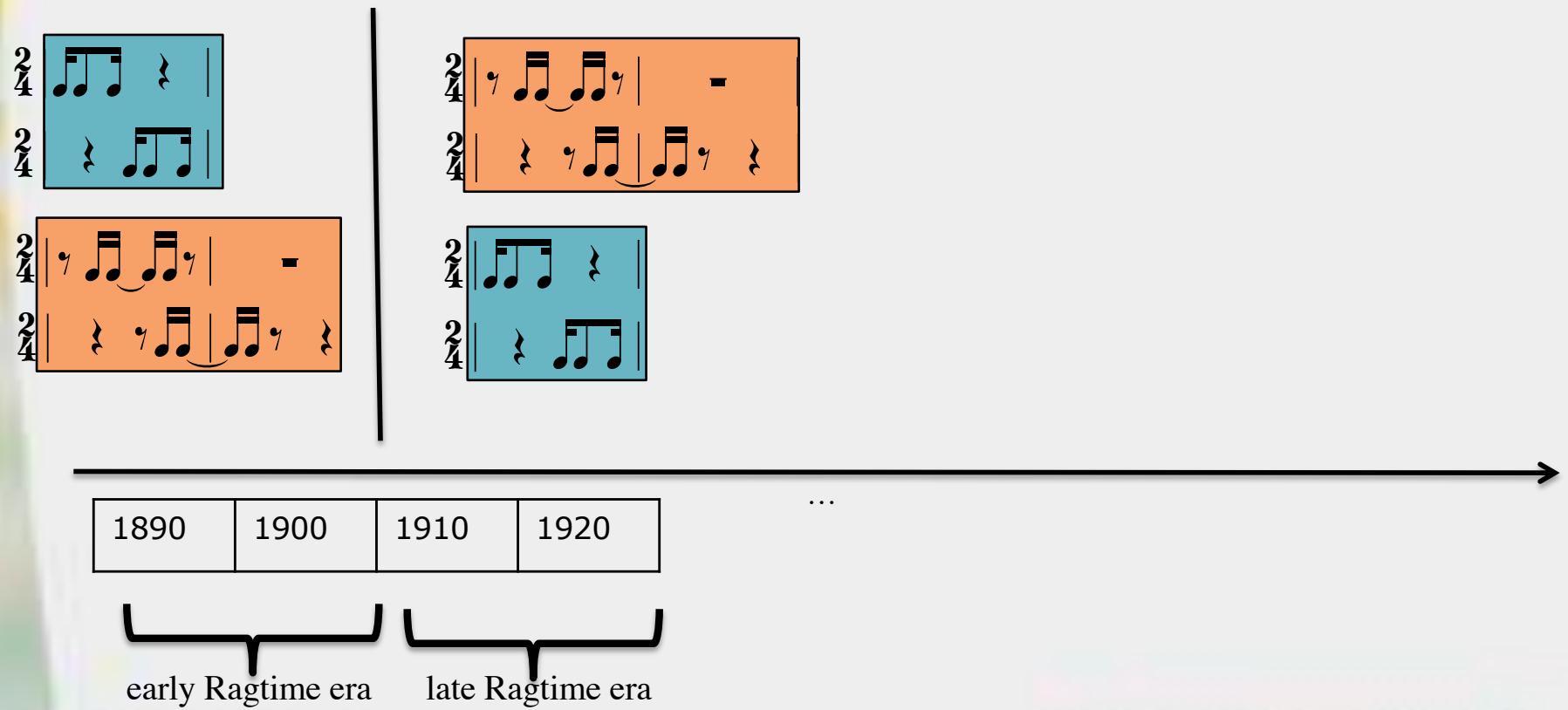


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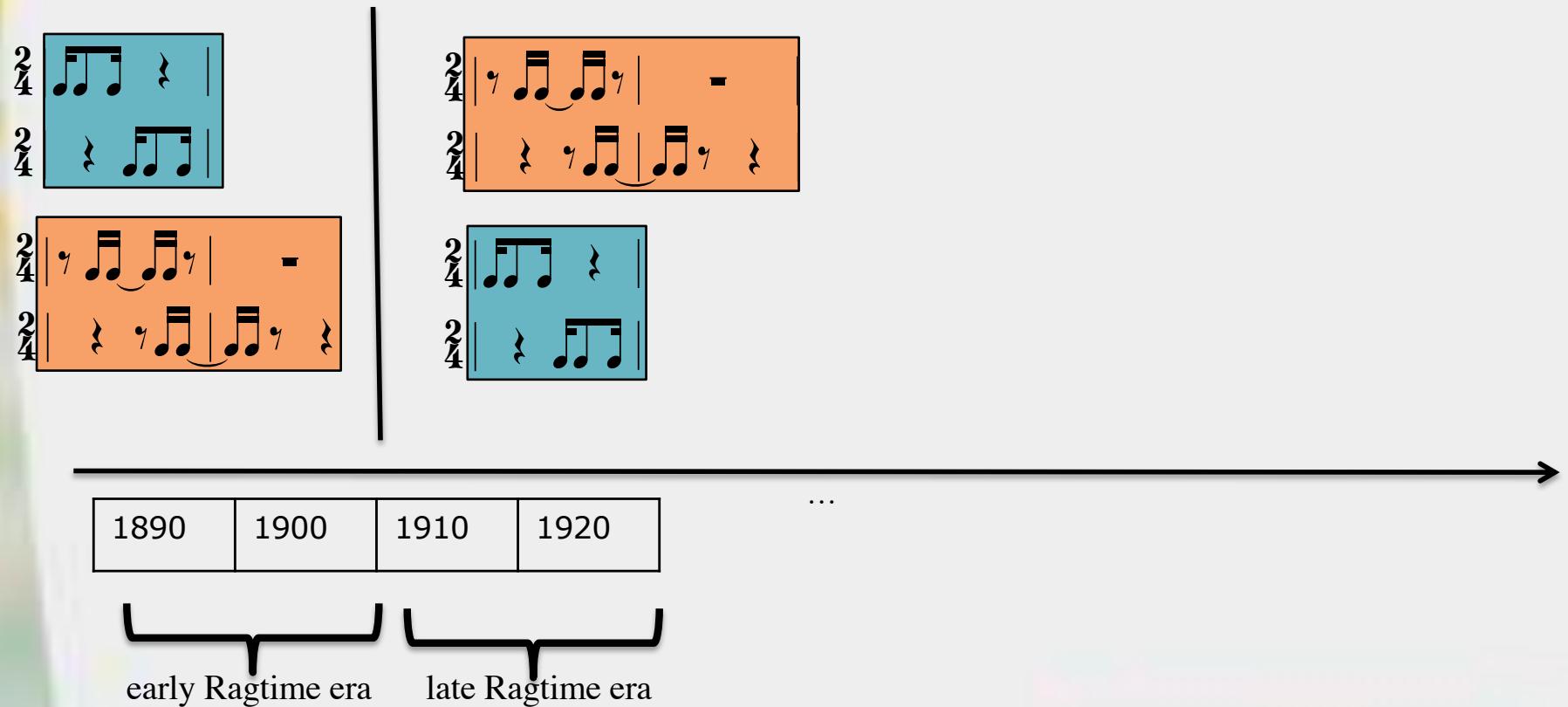


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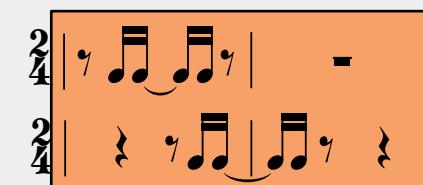
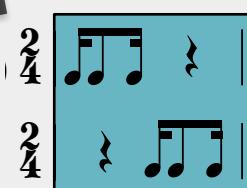
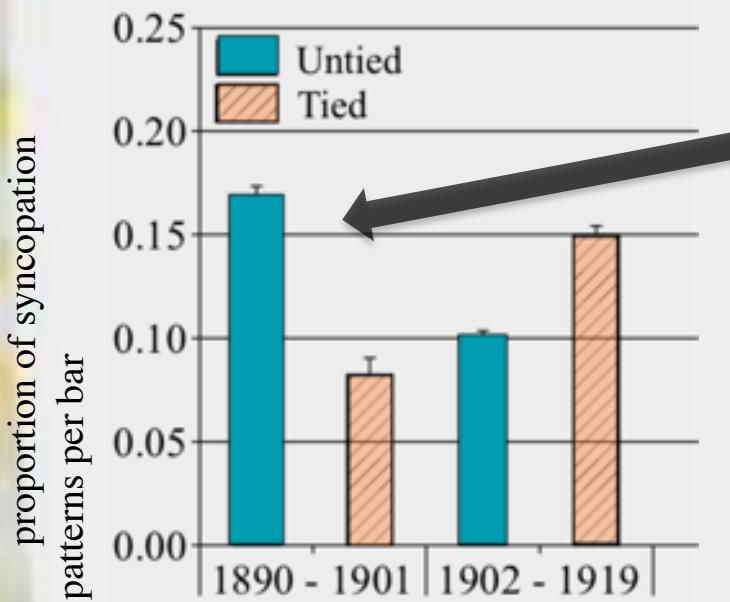
Musicological hypothesis



Result RAG-collection:



Result RAG-collection:



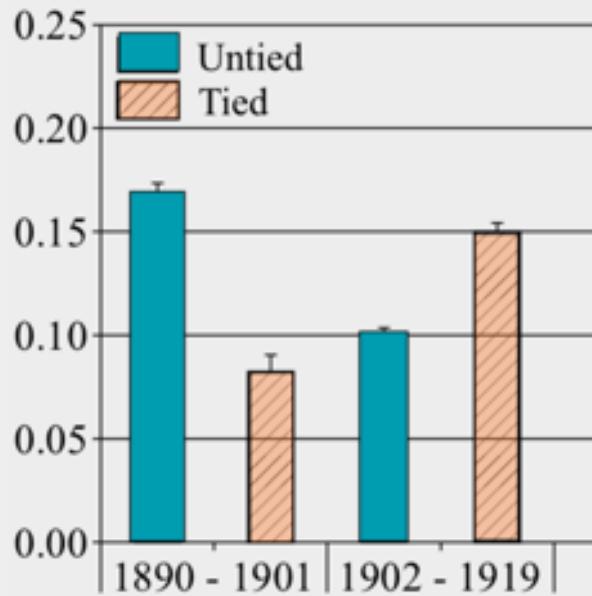
1890 1900 1910 1920

early Ragtime era late Ragtime era

...

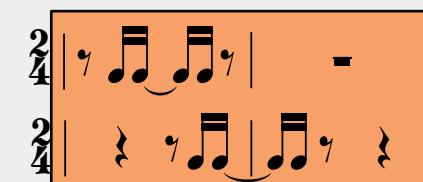
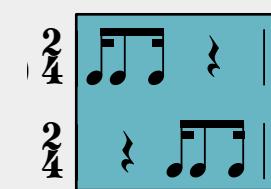
Result RAG-collection:

proportion of syncopation patterns per bar



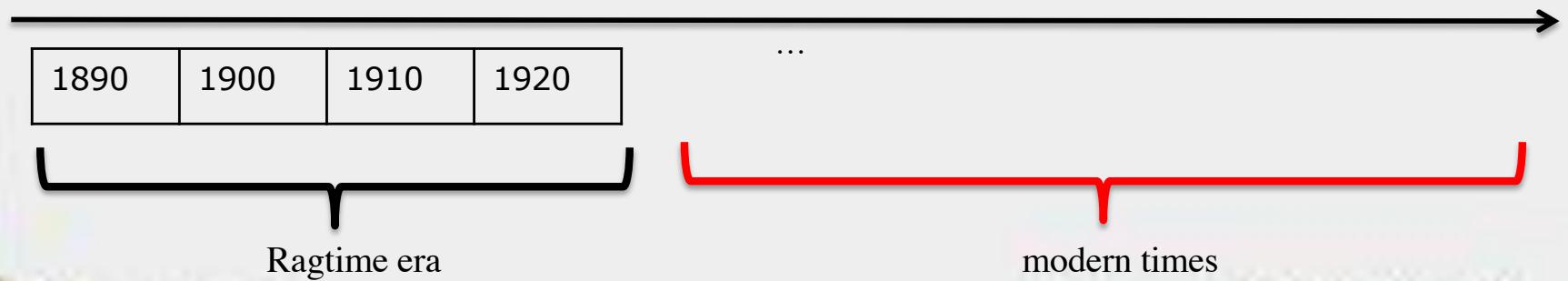
1890	1900	1910	1920
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early Ragtime era late Ragtime era

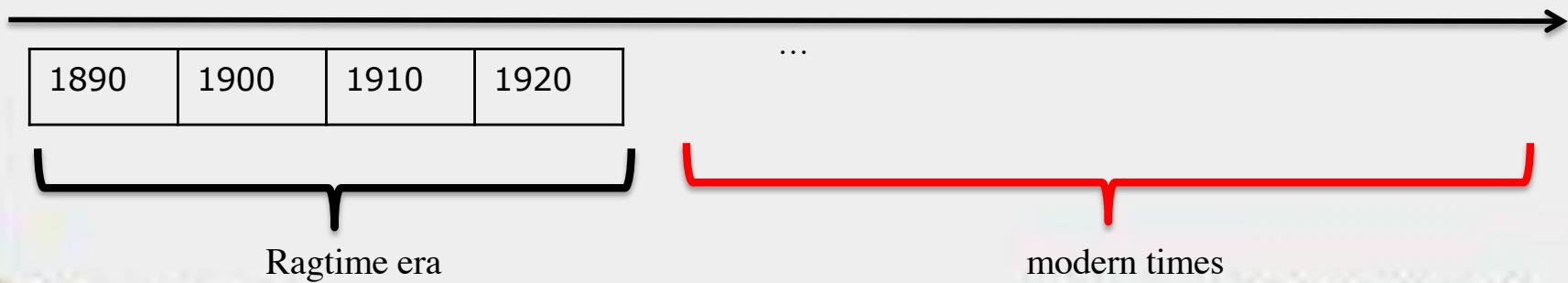
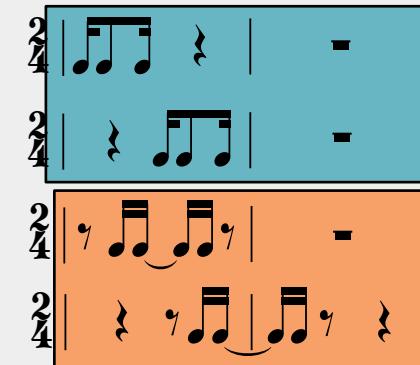
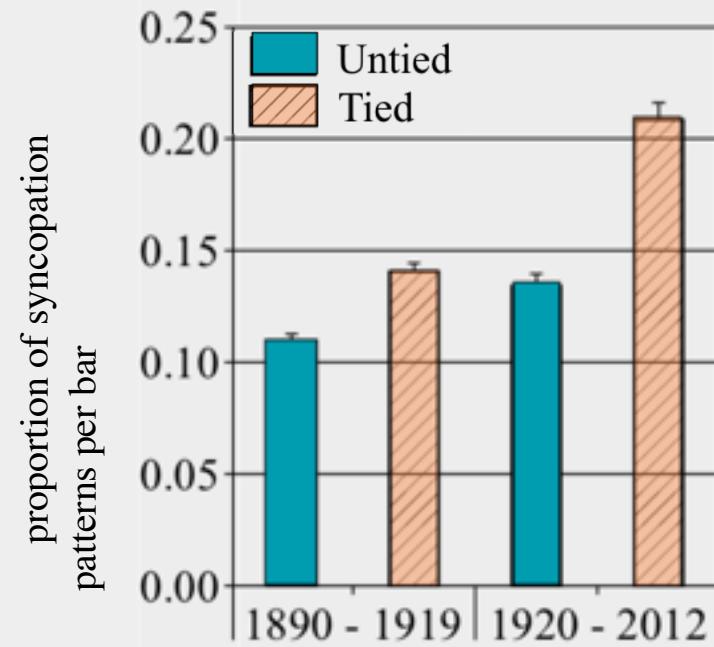


Result RAG-collection:

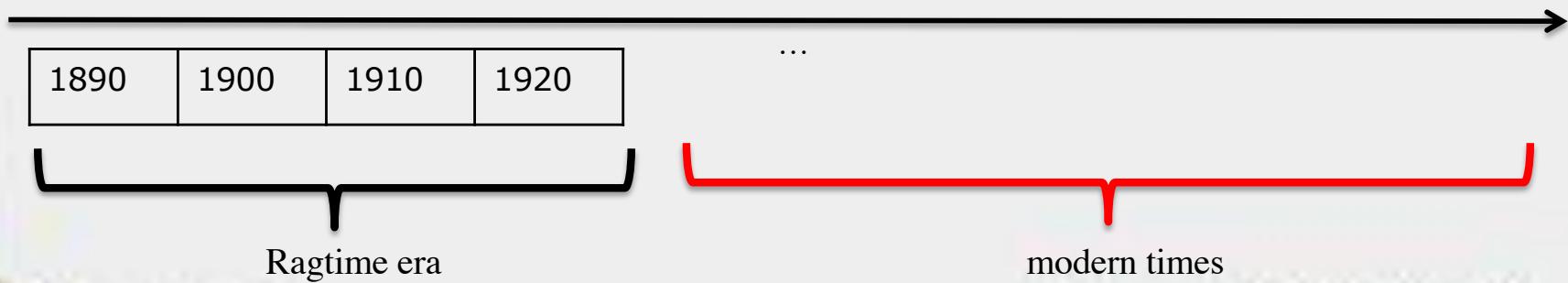
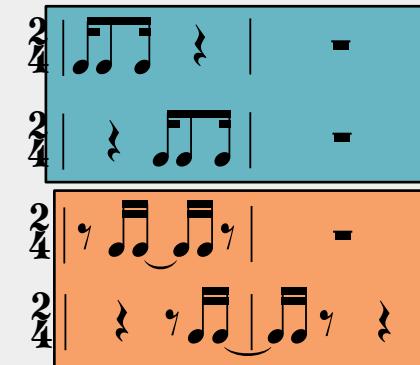
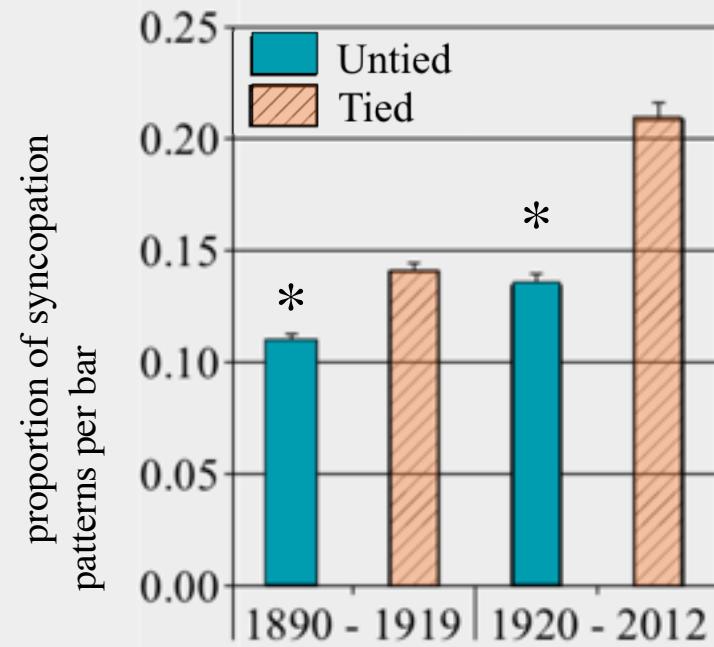
?



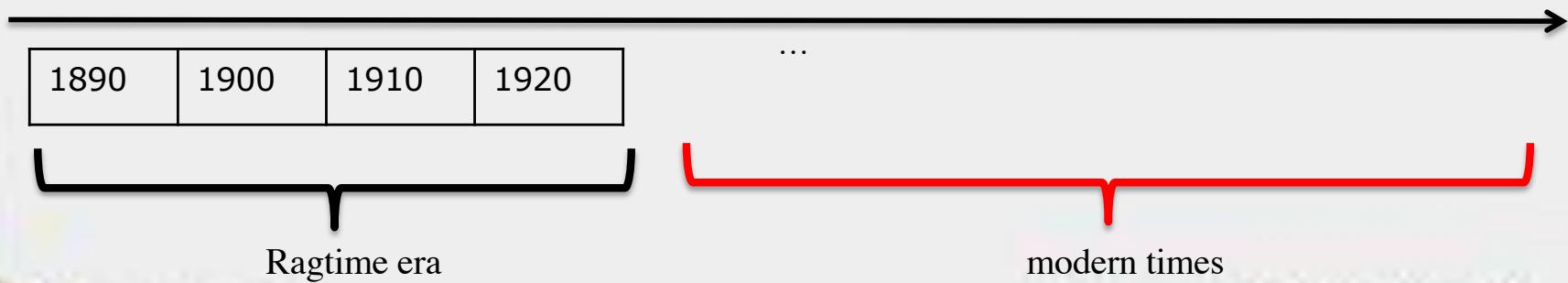
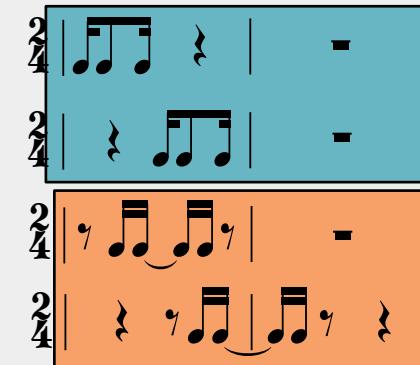
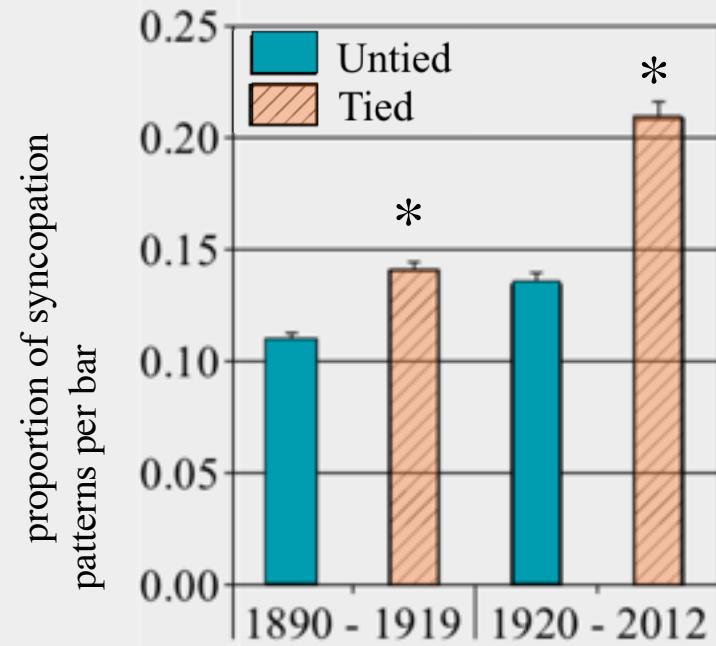
Result RAG-collection:



Result RAG-collection:



Result RAG-collection



Result RAG-collection

Hence: style is not static!



Automatic meter detection in large corpora

- W.B. de Haas & A. Volk: Meter detection in symbolic music using Inner Metric Analysis, ISMIR 2016
 - Why: meter annotation in MIDI often not reliable
 - Important for: investigating rhythms, chord annotations, ...



Summary

- What is rhythmic and metric information in music?
- Computational model for rhythm and meter extraction
- Inner Metric Analysis
 - What are the steps involved?
- Application in Music Analysis, Music Cognition and Music Information Retrieval
 - Music analysis: how does rhythm distinguish musical pieces
 - Music cognition: when is it difficult/easy to tap along?
 - How to characterize a musical style?
- Future: Application in Games
 - Humans are better in predicting time points coinciding with great metric weights

Literature

- Elaine Chew, Anja Volk (Fleischer), and Chia-Ying Lee (2005), *Dance Music Classification Using Inner Metric Analysis: a computational approach and case study using 101 Latin American Dances and National Anthems*. in The Next Wave in Computing, Optimization and Decision Technologies: Proceedings of the 9th INFORMS Computer Society Conference
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- Volk, A. & De Haas, W.B. (2013). A Corpus-based study on Ragtime syncopation. Proceedings of ISMIR 2013.