

DECODING THE SENSUALITY IN MUSIC

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Why care about music experience

- Explosion in digital music information
- Rise of music information research/retrieval

IFPI Global Music Report: Key figures

- **Global recorded music revenue: US\$15.7b (2016)**
- Global revenue growth: 5.9%
- Digital share of global revenues: 50%
- Digital revenue growth: 17.7%
- **Growth in streaming revenues: 60.4%**
- Physical revenues: -7.6%
- Download revenues: -20.5%

2017

International Federation
of the Phonographic Industry



Industry-scale digital music applications

- Last.fm (www.last.fm)
- Pandora (www.pandora.com)
- Shazam (www.shazam.com)
 - 120M monthly active users (2016)
 - 30B song identification requests, +20M per day
- Spotify (www.spotify.com)
 - 60M subscribers, >140M active users



Why care about music experience

- Explosion in digital music information
- Rise of music information research/retrieval
- Understand how humans process music
- Appreciate how humans experience music

Agenda

- A moving experience
 - Strong emotions: frisson, laughter, awe
- Expectation
 - Fulfillment: Reward
 - Violation: Surprise, laughter
- Tension, anticipation
 - Delayed resolution
 - Density of activity

Agenda

- A moving experience
 - Strong emotions: frisson, laughter, awe
- Expectation
 - Fulfillment: Reward
 - Violation: Surprise, laughter
- Tension, anticipation
 - Delayed resolution
 - Density of activity
- Prominence
 - Note-level variations
 - Vibrato and portamento
- Contrast
 - Section-level variations
 - Key change
- Time
 - Phrase-level variations
 - Tipping points
- Tension

Op. 52, No. 4

Edvard Grieg
Arr. for Piano by the Author

Poco andante

12

The image shows a page of sheet music for piano. The top staff is in treble clef and consists of two measures. The first measure starts with a three-note chord (A, C, E) followed by a descending eighth-note line (A, G, F#). The second measure begins with a single eighth note (E) followed by a descending eighth-note line (E, D, C). The bottom staff is in bass clef and consists of six measures. The first measure has a bass note (D) with a 'Ped.' instruction below it. The second measure has a bass note (C) with a 'Ped.' instruction below it. The third measure starts with a bass note (B) with a 'non arpeggiando' instruction above it, followed by a sixteenth-note arpeggio (B, A, G, F#) with a wavy line underneath. The fourth measure has a bass note (A) with a 'Ped.' instruction below it. The fifth measure has a bass note (G) with a 'Ped.' instruction below it. The sixth measure has a bass note (F#) with a 'Ped.' instruction below it.

non arpeggiando

cresc.

p

molto

f

dim.

p

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Prominence

Op. 52, No. 4

Edvard Grieg
Arr. for Piano by the Author

Poco andante

2 4 4 2 2

p

f

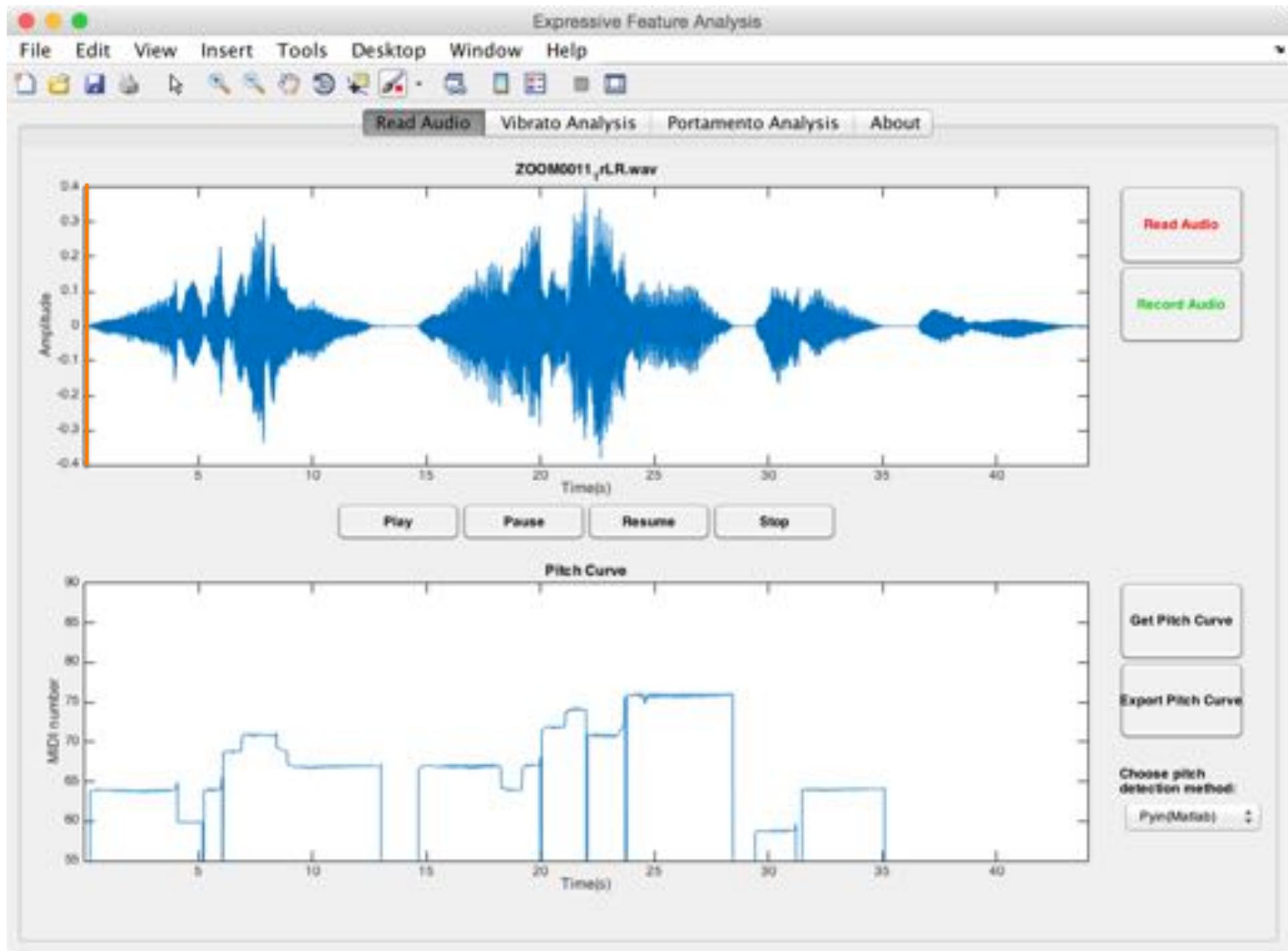
dim.

p

12

This image shows the first page of a musical score for piano, page 12. The score consists of two staves. The top staff is in common time (C) and treble clef (G), with dynamic markings 'p' (piano) and 'f' (forte). The bottom staff is in common time (C) and bass clef (F). Measure 2 starts with a half note followed by a sixteenth-note pattern. Measure 3 begins with a half note, followed by a sixteenth-note pattern, and ends with a forte dynamic 'f'. Measure 4 starts with a half note, followed by a sixteenth-note pattern, and ends with a dynamic 'dim.'. Measure 5 starts with a half note, followed by a sixteenth-note pattern, and ends with a forte dynamic 'p' over a bass note. Measures 2 through 5 are highlighted with a light orange background.

A musical score for piano featuring two staves. The top staff uses a treble clef and shows a melodic line with various note heads and stems. The bottom staff uses a bass clef and shows a harmonic bass line with sustained notes and bass clef changes. The score includes dynamic markings like 'Ped.' and 'non arpeggiando', fingerings (e.g., 1, 2, 3, 4, 5), and a key signature of one sharp. A section of sixteenth-note chords is preceded by a bracket and a star symbol (*).

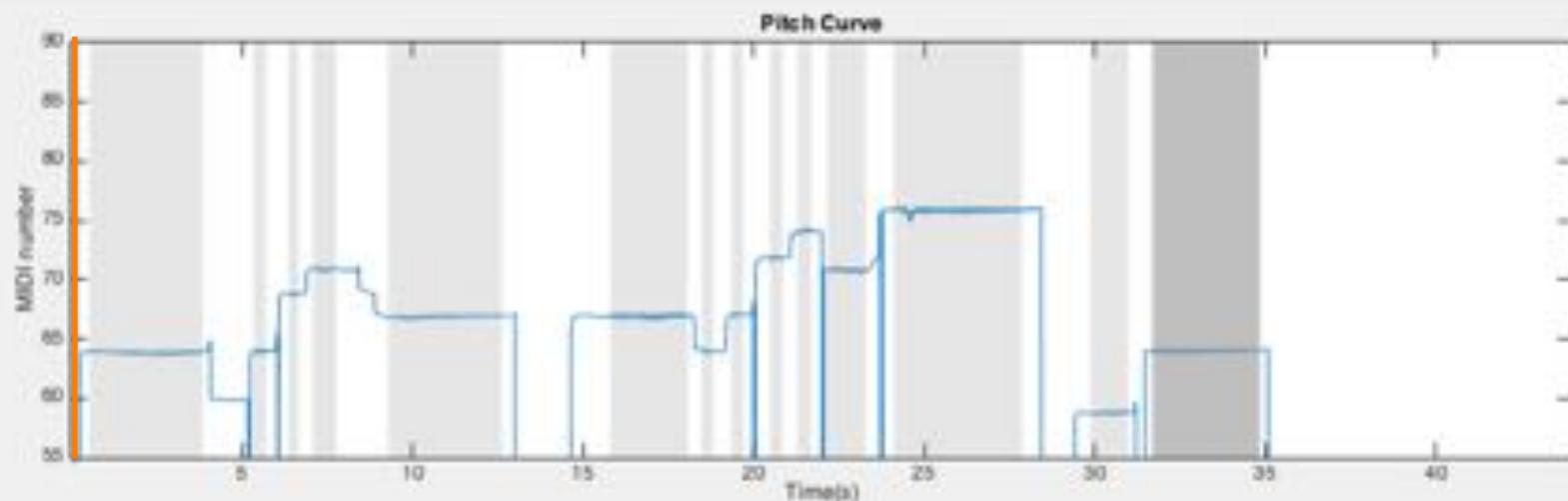


Expressive Feature Analysis

File Edit View Insert Tools Desktop Window Help



Read Audio Vibrato Analysis Portamento Analysis About



Get Vibrato:

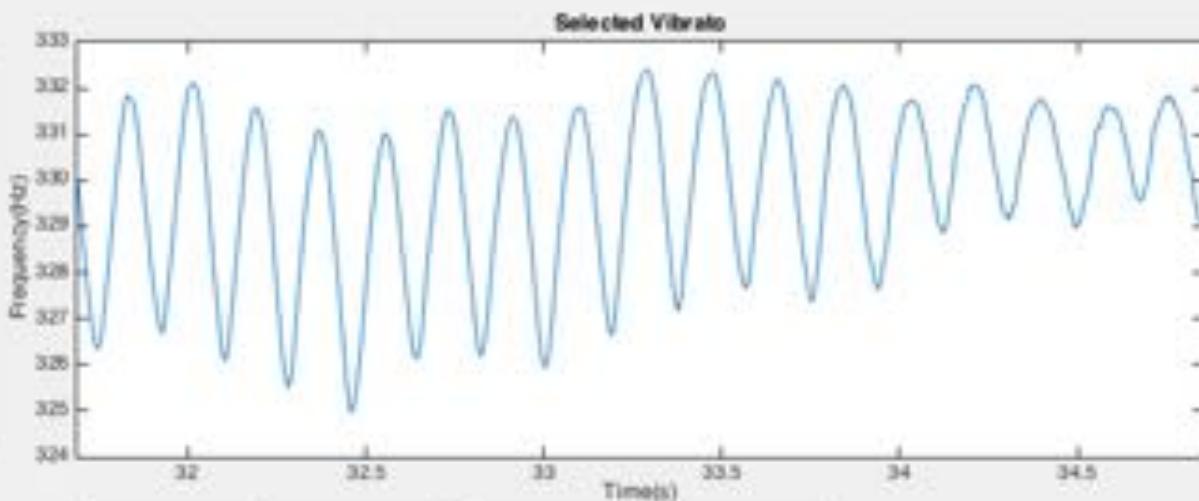
Frequency Range(Hz): 4-9

Amplitude Range: 0.1-Na

Vibratos

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14

X axis:
Original Time



Statistics

Rate (Hz): 6.41052

Extent (Semitone): 0.0924299

Sinusoid Similarity: 0.901292

Method: FDM

Portamento

Prominence

Vibrato



Le Grand Tango by Astor Piazzolla – Ian Pressland & EC

119 *Rosa (up)*
A Tempo

mf *f*

127

base first down

The image shows two staves of handwritten musical notation for bass. The top staff begins with a dynamic marking 'mf' followed by a forte dynamic 'f'. Above the staff, there is a box containing the number '119' and the handwritten instruction 'Rosa (up)' above 'A Tempo'. The bottom staff begins with a dynamic marking '127'. To the right of the bottom staff, there is a circled area with the handwritten instruction 'base first down'.



Le Grand Tango by Astor Piazzolla

- Ian Pressland & EC
- Susanne Beer & EC

The image shows a handwritten musical score for 'Le Grand Tango' by Astor Piazzolla. The score consists of two staves of music. The top staff is for piano (treble clef) and the bottom staff is for cello/bass (bass clef). The score includes various musical markings such as dynamics (mf, f), tempo changes (A Tempo), and performance instructions (e.g., 'less (up)'), written in blue ink. A speaker icon is positioned above the piano staff, indicating that the score is intended to be listened to. There is also a circled section of the cello/bass staff with handwritten notes: 'back first down' and a circular arrow.

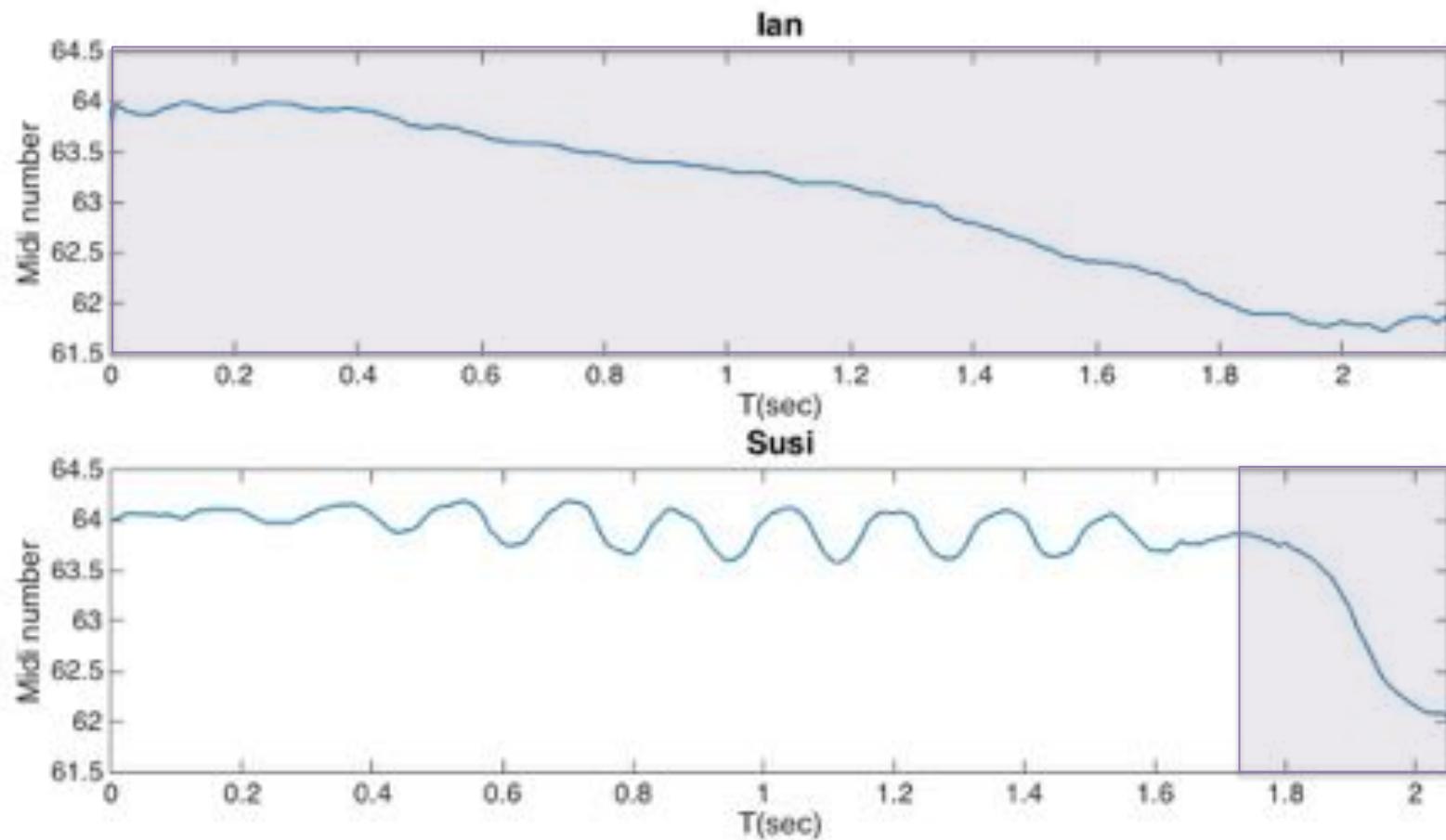
119 *A Tempo*
less (up)

mf f

127

back first down

Portamenti models



Logistic modeling of portamentos

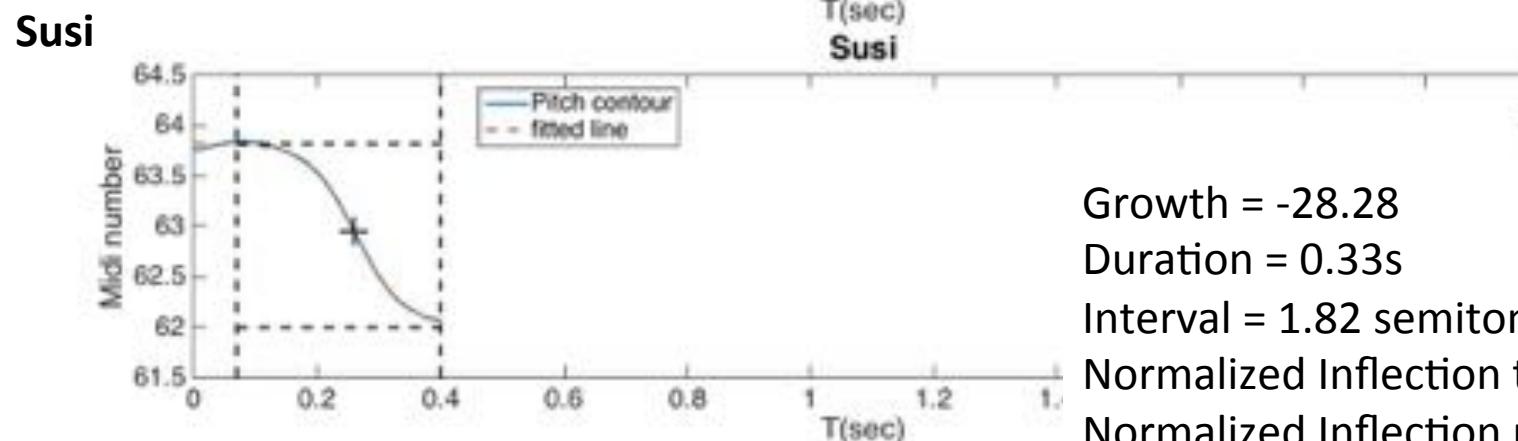
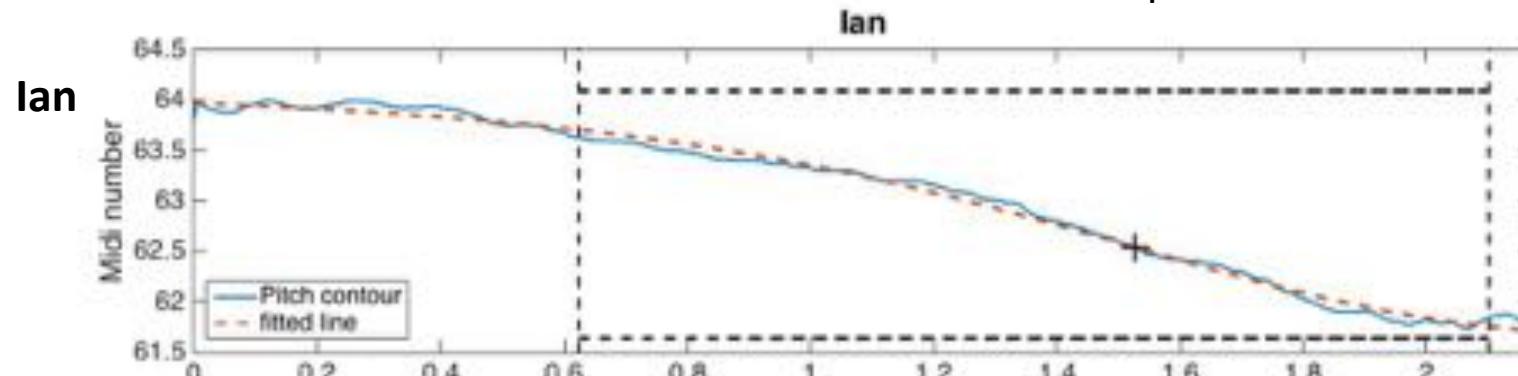
Growth = -1.952

Duration = 1.48s

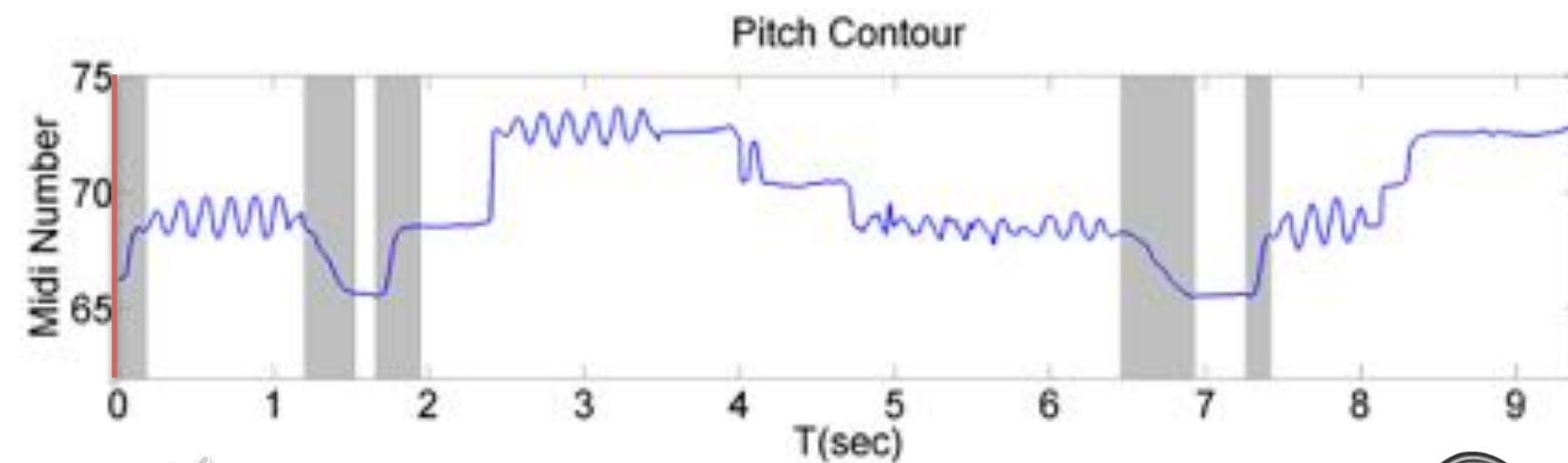
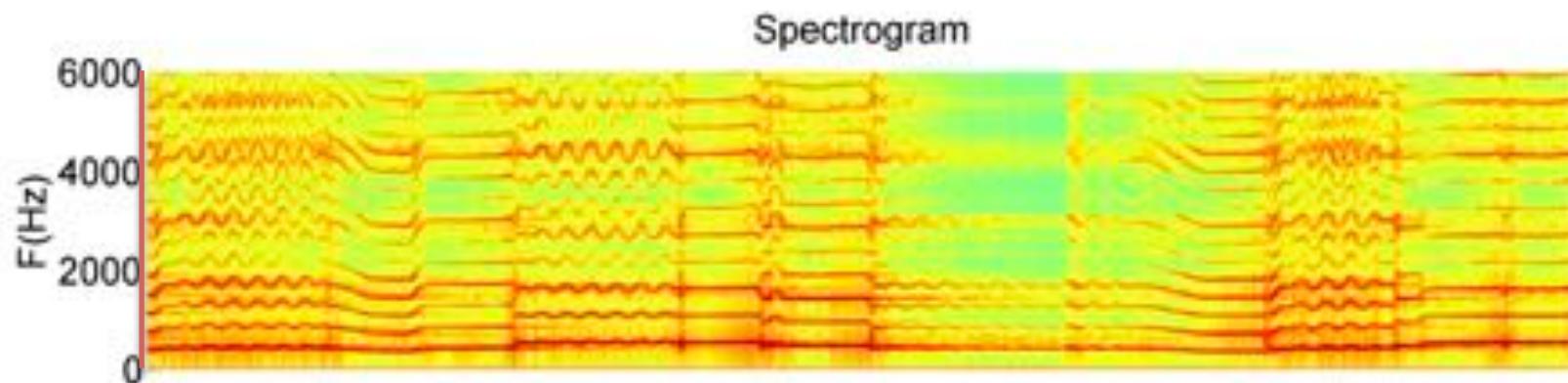
Interval = 2.45 semitones

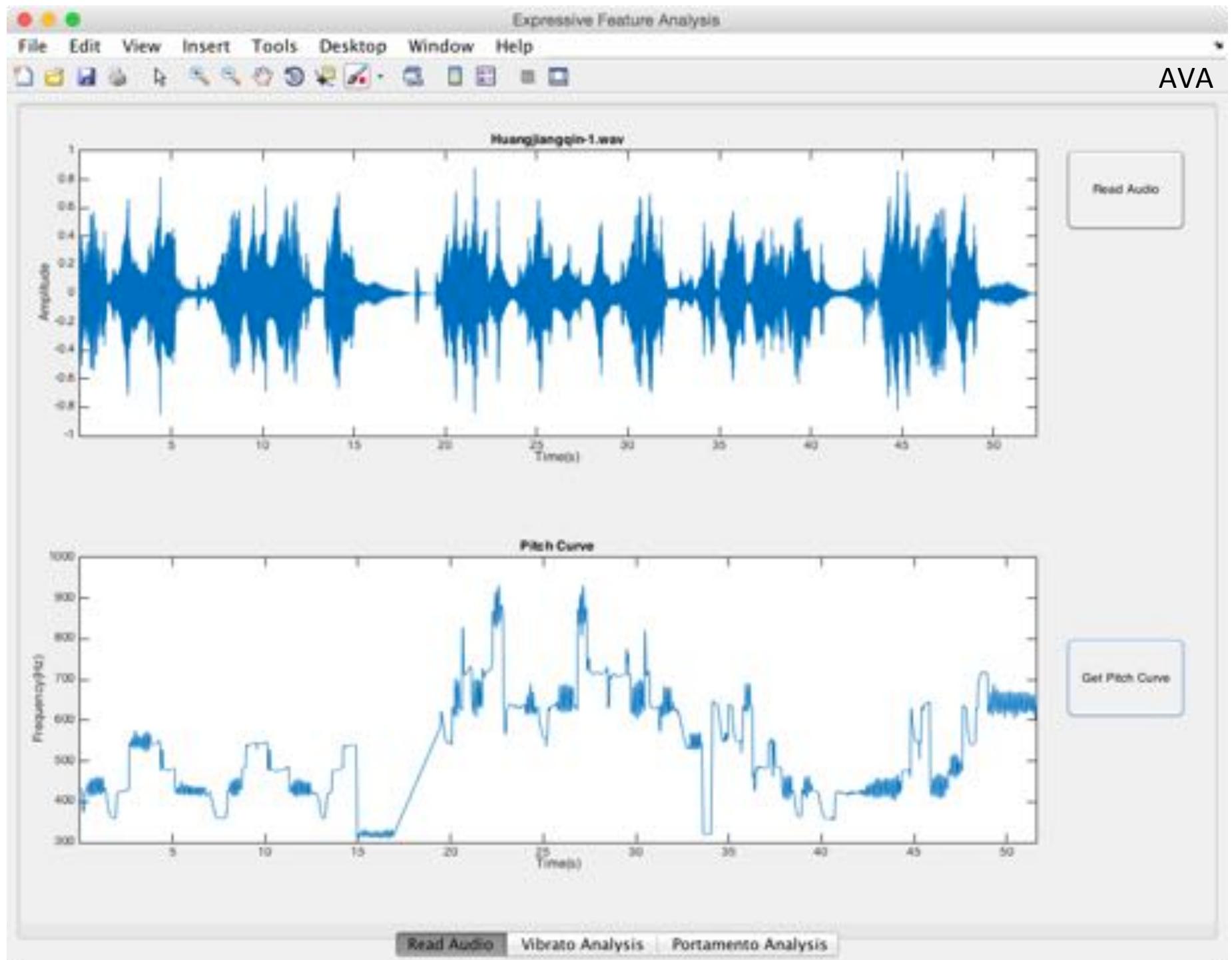
Normalized Inflection time: 0.6105

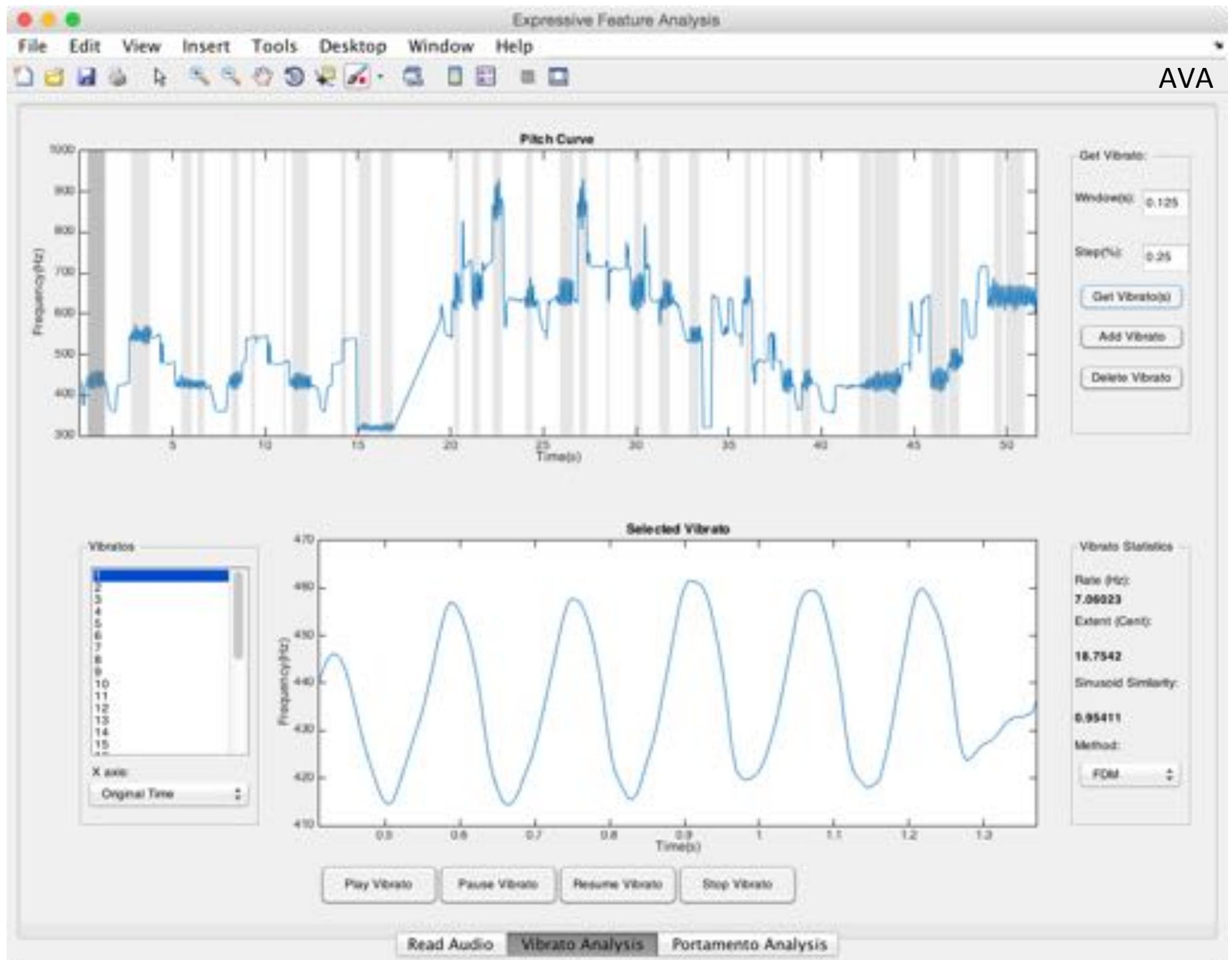
Normalized Inflection pitch: 0.3687



Portamenti in an erhu performance





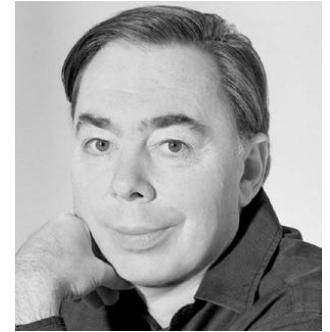




Luwei Yang, Khalid Rajab, Elaine Chew
luweiyang.com/research/ava-project

Contrast

Think of Me



Andrew Lloyd Webber



Allegretto

On that day, that not so distant day, when you are far a-way and

Clef: Treble clef
Key Signature: F major (no sharps or flats)
Time Signature: Common time (indicated by 'C')
Instrumentation: Vocal line with piano accompaniment.
Text: Think of me.



On that day, that not so distant day, when you are far a-way and

Clef: Treble clef
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Time Signature: Common time (indicated by 'C')
Instrumentation: Vocal line with piano accompaniment.
Text: Think of me.



A/D G/D A/D

think of me fond - ly while we've said good - bye But remember me

Clef: Treble clef
Key Signature: F major (no sharps or flats)
Time Signature: Common time (indicated by 'C')
Instrumentation: Vocal line with piano accompaniment.
Text: think of me fond - ly while we've said good - bye But remember me



E/I D/A Bm7 Am7 Em Fm G A

free, if you ev - er find a man - ager, spare a thought for

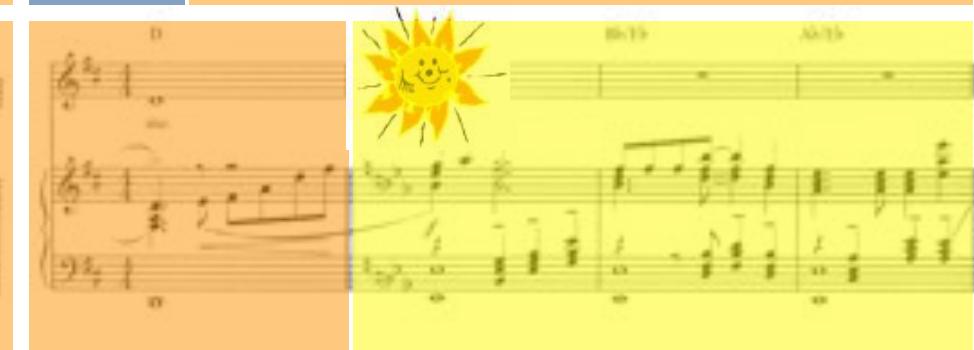
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A/D G/D A/D

in - 'ry' on of - ly, pre - cisely you'll try

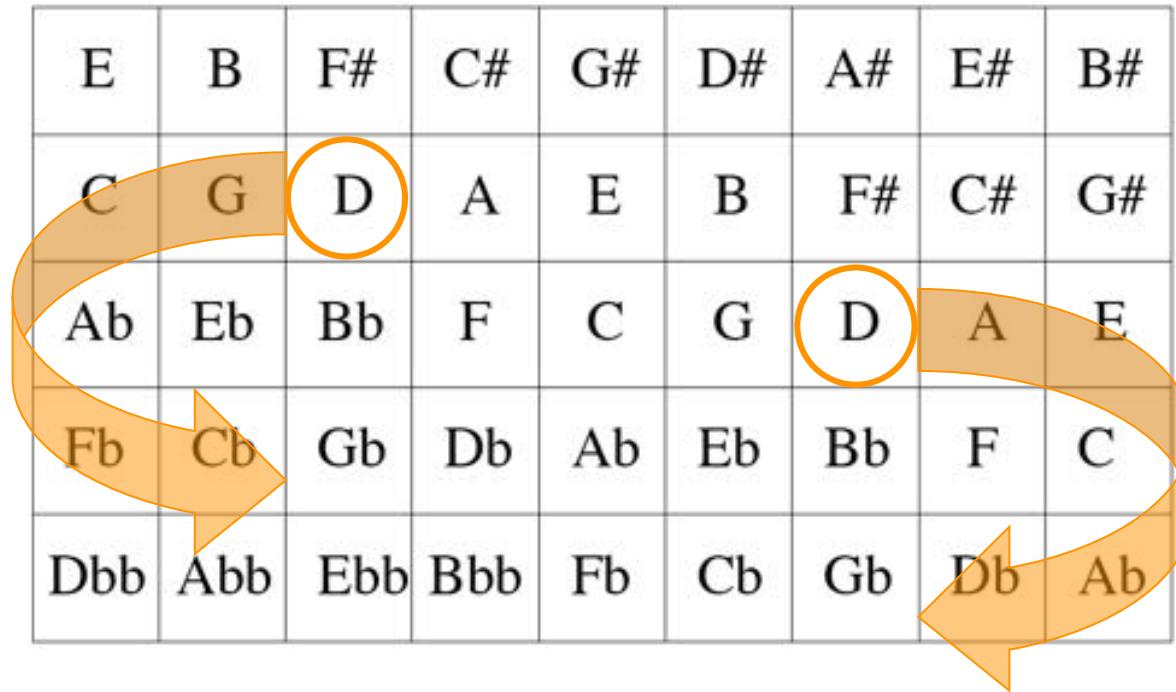
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Instrumentation: Vocal line with piano accompaniment.
Text: in - 'ry' on of - ly, pre - cisely you'll try



D Bm7 A/D

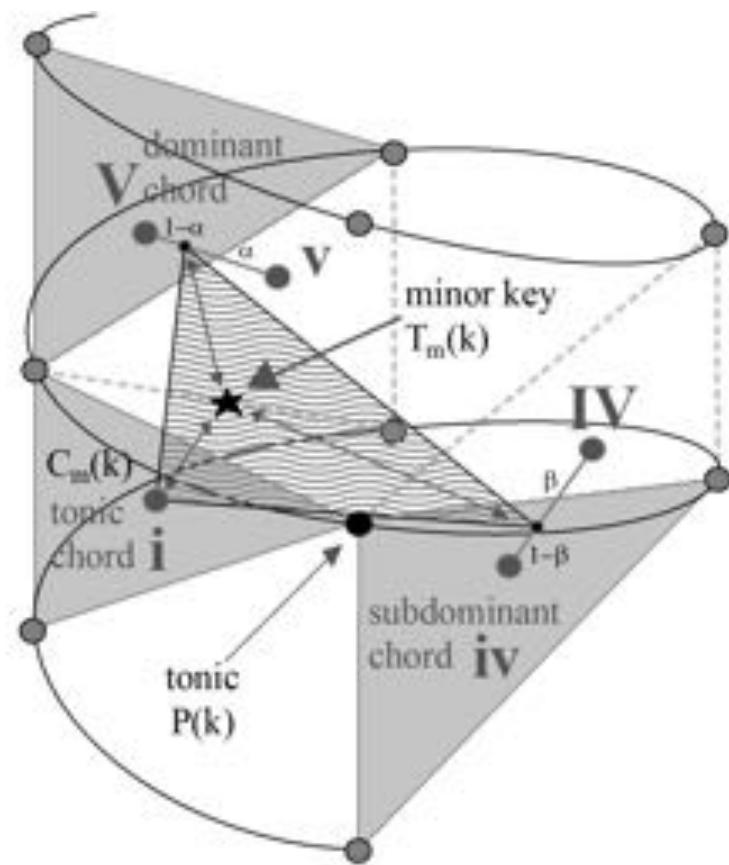
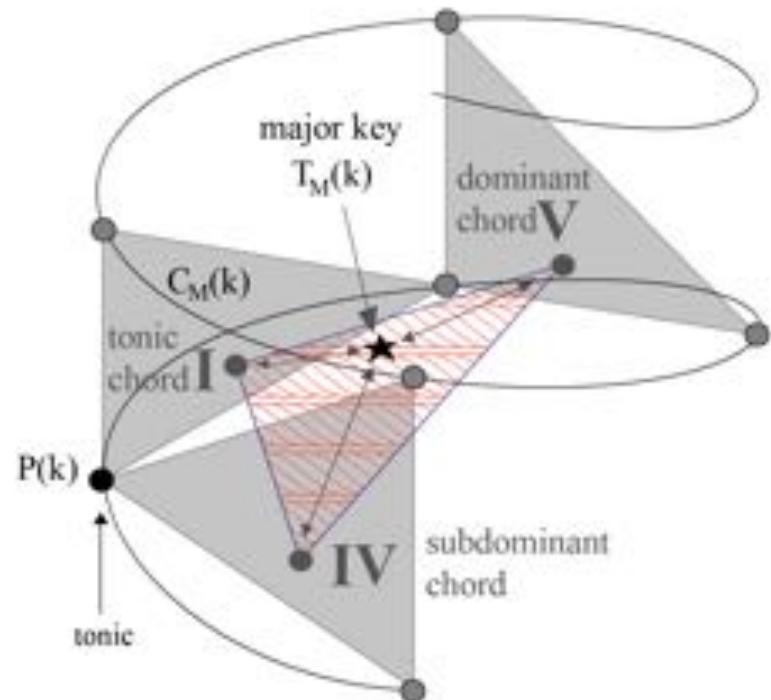
Clef: Treble clef
Key Signature: F major (no sharps or flats)
Time Signature: Common time (indicated by 'C')
Instrumentation: Vocal line with piano accompaniment.
Text: Sun

Spiral Array



Chew, E. (2000). Towards a Mathematical Model of Tonality.
Ph.D. dissertation. Operations Research Center, MIT. Cambridge, Massachusetts

Spiral Array



Chew, E. (2000). Towards a Mathematical Model of Tonality.
Ph.D. dissertation. Operations Research Center, MIT. Cambridge, Massachusetts

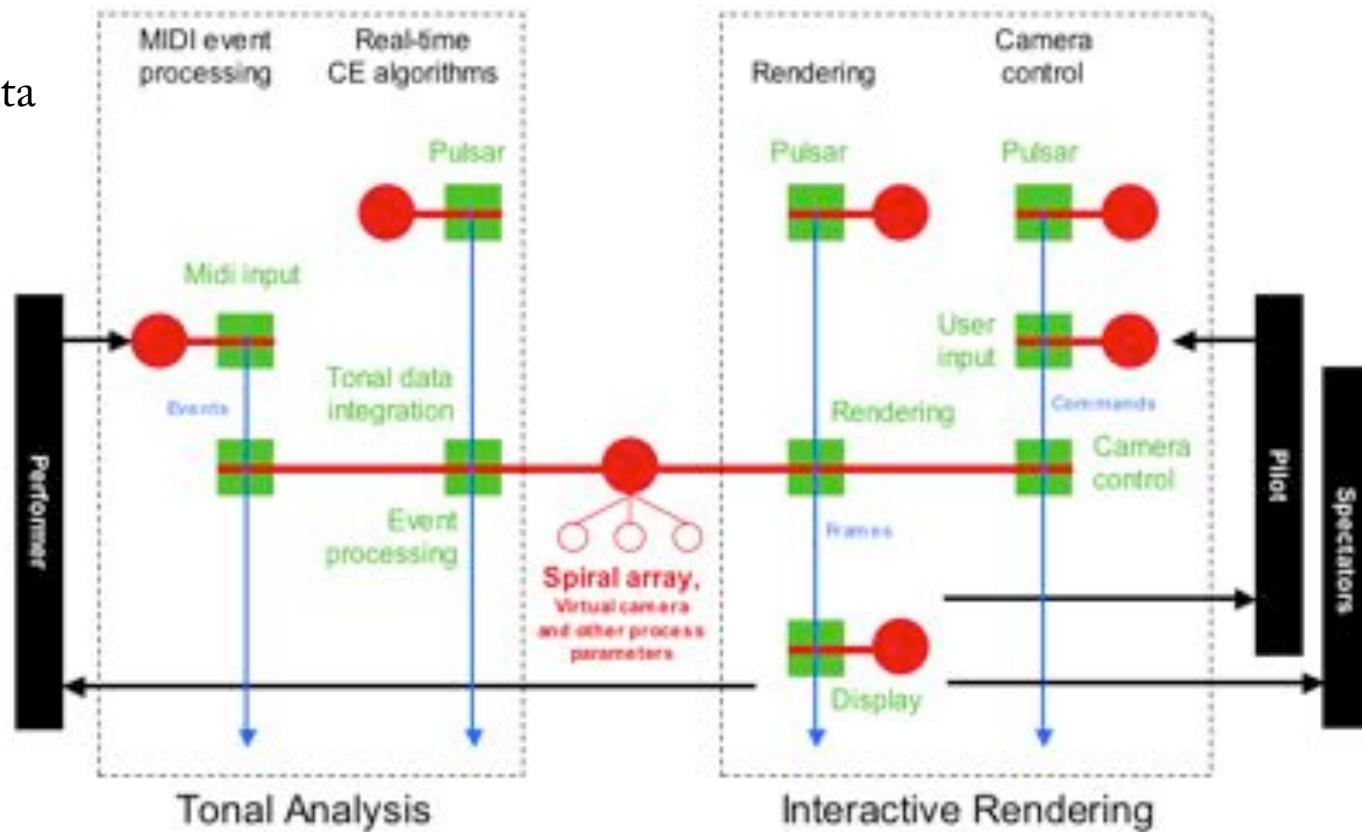
Engineer-Pianist Elaine Chew Talks About Using Mathematical and Software Tools to Analy...



USC Video Channel - youtu.be/4GPwVNPyKuA

MuSA.RT: Software architecture

volatile vs.
persistent data



François, Alexandre R. J. (2009). Time and Perception in Music and Computation. In G. Assayag and A. Gerzso (eds.): New Computational Paradigms for Computer Music, Editions Delatour France / IRCAM, pp. 125-146.



Huron, D. (2006). *Sweet Anticipation: Music and the psychology of expectation*, Cambridge, MA: MIT Press.

PDQ Bach's Prelude No. 1 in C major

Expectations Violated: Jazz Ending



[♩ = c. 112]

mf

[sim.]



b

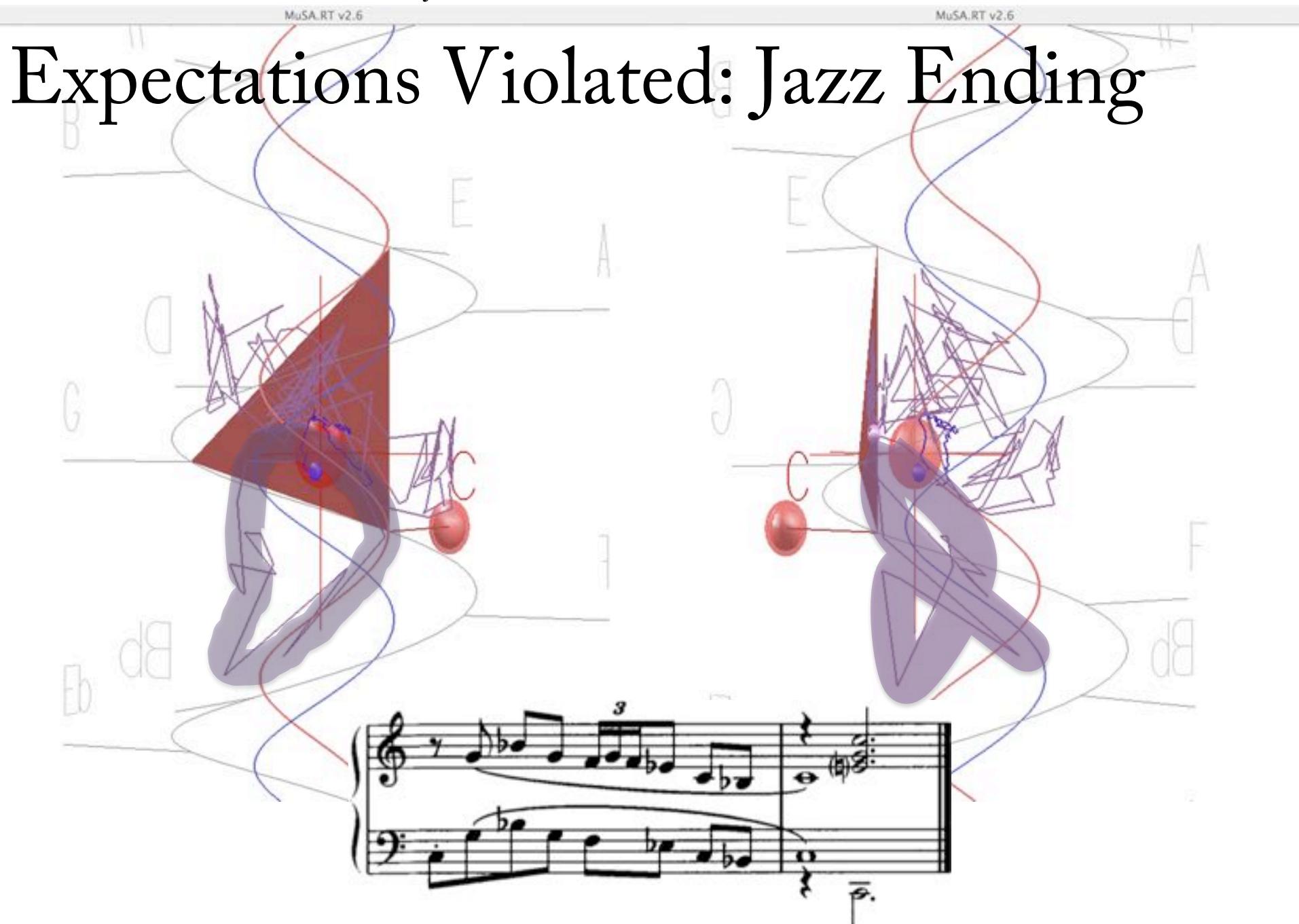
Cheat, E. and A. R. J. François (2009). Visible Humour – Seeing P.D.Q. Bach's Musical Humour Devices in The Short-Tempered Clavier on the Spiral Array Space. In T. Klouche, T. Noll (eds.): Mathematics and Computation in Music, CCIS 37: 11-18, Berlin/Heidelberg: Springer

Humor

Contrast

Surprise

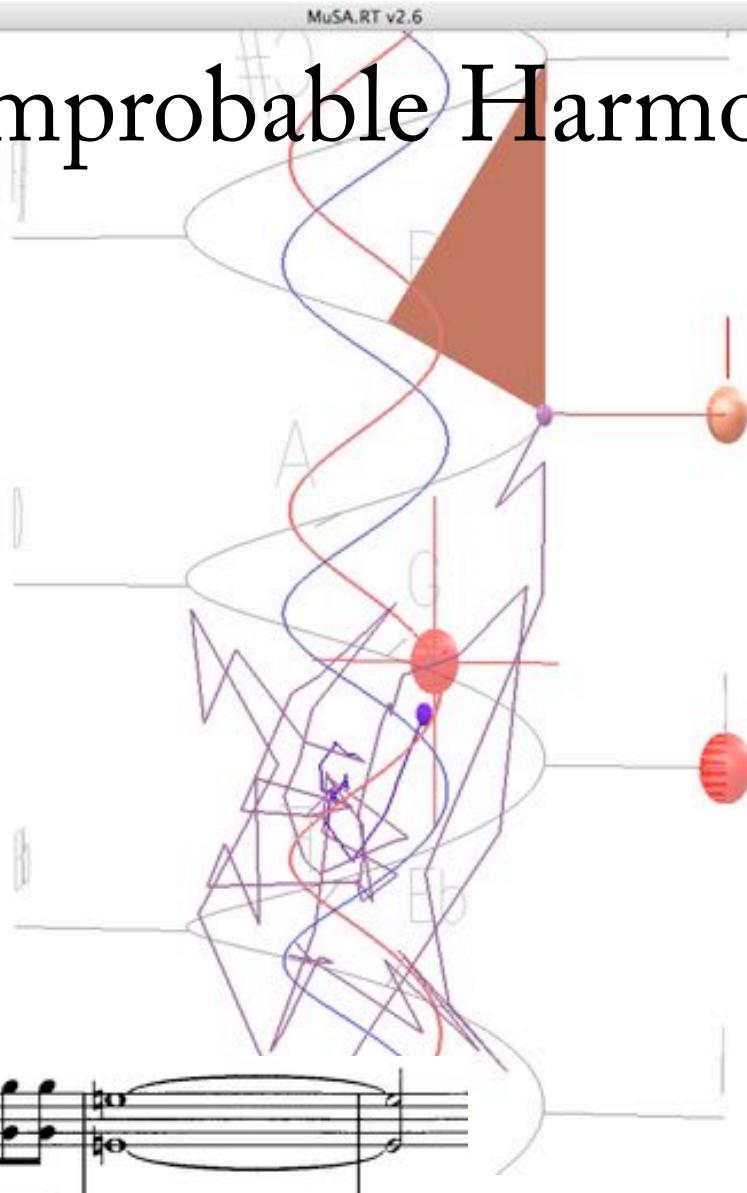
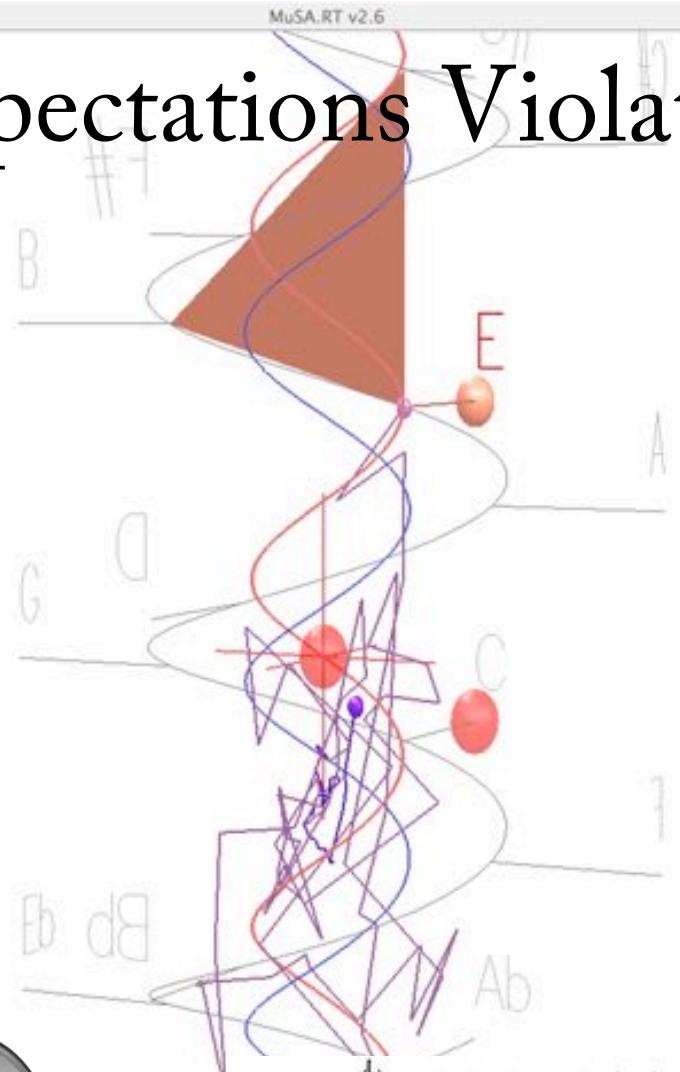
Expectations Violated: Jazz Ending



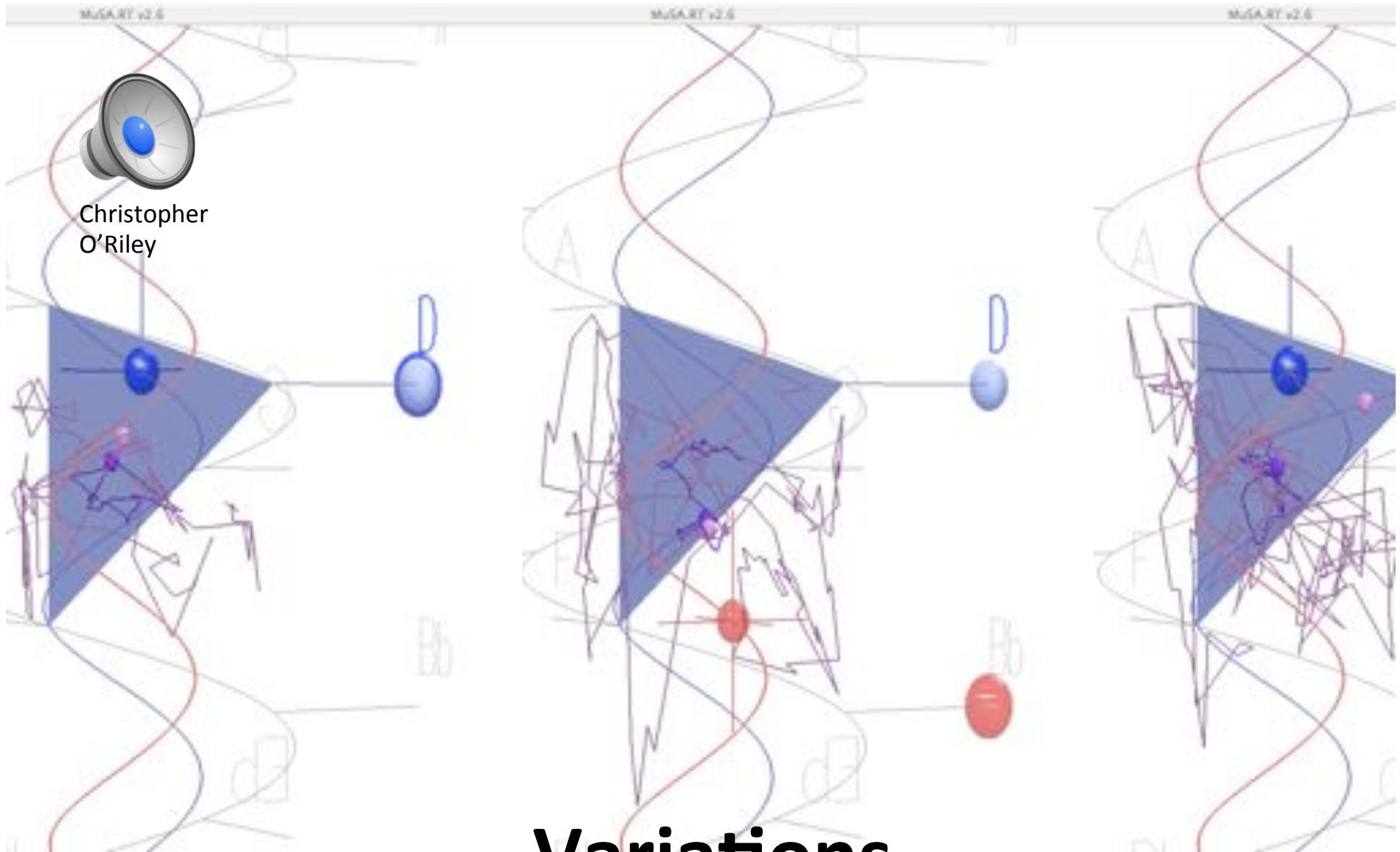
Expectations Violated: Improbable Harmonies



Christopher
O'Riley



Variations on a Theme: Prelude No. 5 in D minor: Theme (simple)



Variations



Alexandre François and Elaine Chew
itunes.apple.com/us/app/musa-rt/id506866959?mt=12

International Series in Operations Research & Management Science ISOR 204

Elaine Chew

Mathematical and Computational Modeling of Tonality

Theory and Applications

I have watched with interest and appreciation as Elaine Chew's Spiral Array model has developed over the last 15 years. It is unique in representing pitches, intervals, chords, and keys in the same elegant geometric representation. In this way, the model addresses the fundamental problem of how to represent the hierarchical nature of tonal listening. The monograph presents in-depth analyses of a wide variety of interesting musical examples as well as large-scale, quantitative tests of algorithms for key-finding, pitch spelling, and musical segmentation. The reader will be amply rewarded with mathematical and musical insights – and intrigued by the power of mathematics to reveal the inner workings of music cognition.

– Carol Lynne Krumhansl, Professor of Psychology Cornell University

“What do you mean by key?” The seemingly innocent question asked once to the author by a student initiates a fascinating scientific journey into the concept of tonality addressed through its cognitive, mathematical and computational ramifications. This essential yet accessible and entertaining book results from years of research and experimentation by one of today’s prominent minds in music science, with the right balance of formal modelling, experimentation and musical knowledge, always situated in the history of ideas. The student and the professional in computation and music related domains will benefit greatly from reading this book, as well as the music lover interested in reflecting on the way we apprehend tonality.

– Gerard Assayag, Research Director, Sciences and Technologies for Music and Sound Laboratory (IRCAM, CNRS, and Pierre et Marie Curie University)

From its imaginative opening pages to its rigorous appendices, Chew’s book takes the reader on an engrossing tour through the theory and applications of her ingenious multiple-helix model of musical tonality. She approaches music theory and cognition from a fresh perspective inspired by operations research, to great advantage. One comes away with the clear sense that this approach will continue to bear fruit, whether through elaboration of the underlying model or through discovery of its applicability to new practical problems. No one interested in pitch representation, computational music analysis, or music visualization should miss this important volume.

– Douglas Keislar, Editor, Computer Music Journal (MIT Press)

Business/Economics

ISBN 978-1-4614-9474-4



► springer.com

Chew



Mathematical and Computational
Modeling of Tonality

International Series in
Operations Research & Management Science

Elaine Chew

Mathematical and Computational Modeling of Tonality

Theory and Applications



Springer

Andante. ♩ = 72.

2 Flauti gr.

2 Clarinetti in A.

2 Corni in E.

Arpa.

**Violini I.
(con sordini)**

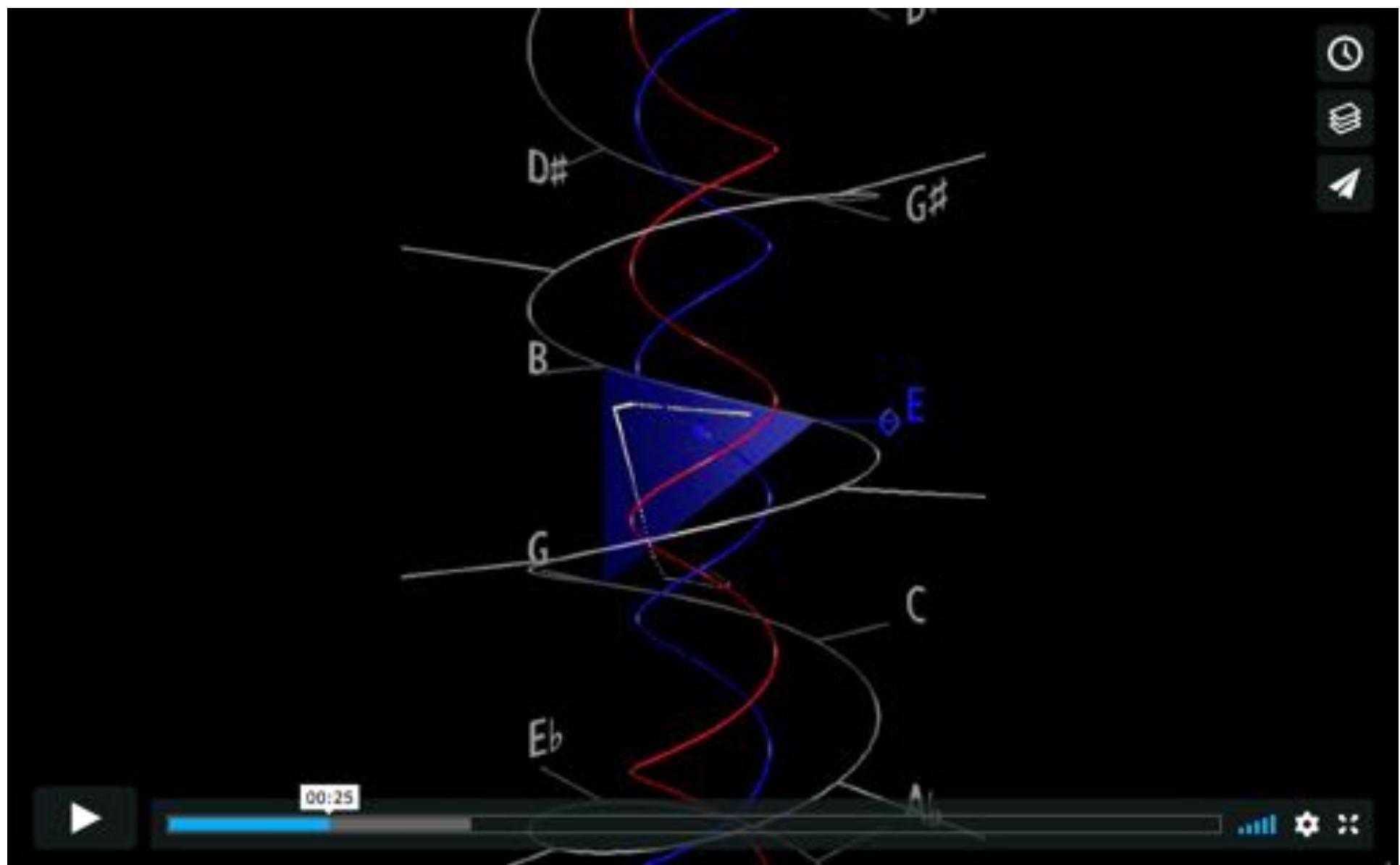
**Violini II.
(con sordini)**

**Viole.
(con sordini)**

Violoncelli.

Bassi.

E/e a G G C e e/E e/E E



<https://vimeo.com/195047764>

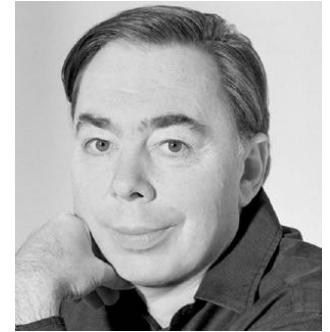
Humor

Tonal contrast

Contrast

Surprise

Think of Me



Andrew Lloyd Webber



Allegretto

On that day, that not so distant day, when you are far a-way and

Clef: Treble clef
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A/D G/D A/D

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Clef: Treble clef
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Time Signature: Common time (indicated by 'C')
Instrumentation: Vocal line with piano accompaniment.
Text: think of me fond - ly while we've said good - bye But remember me



E/I D/A Bm7 Am7 Em Fm G A

free, if you ev - er find a man - ager, spare a thought for

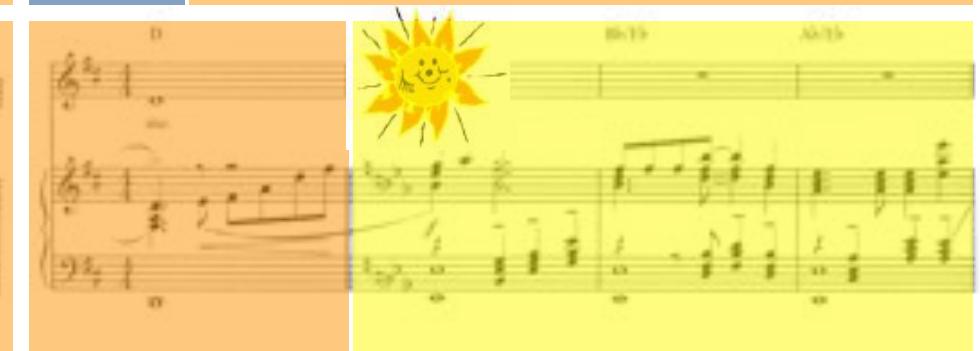
Clef: Treble clef
Key Signature: F major (no sharps or flats)
Time Signature: Common time (indicated by 'C')
Instrumentation: Vocal line with piano accompaniment.
Text: free, if you ev - er find a man - ager, spare a thought for



A/D G/D A/D

in - 'ry' on of - ly, pre - cisely you'll try

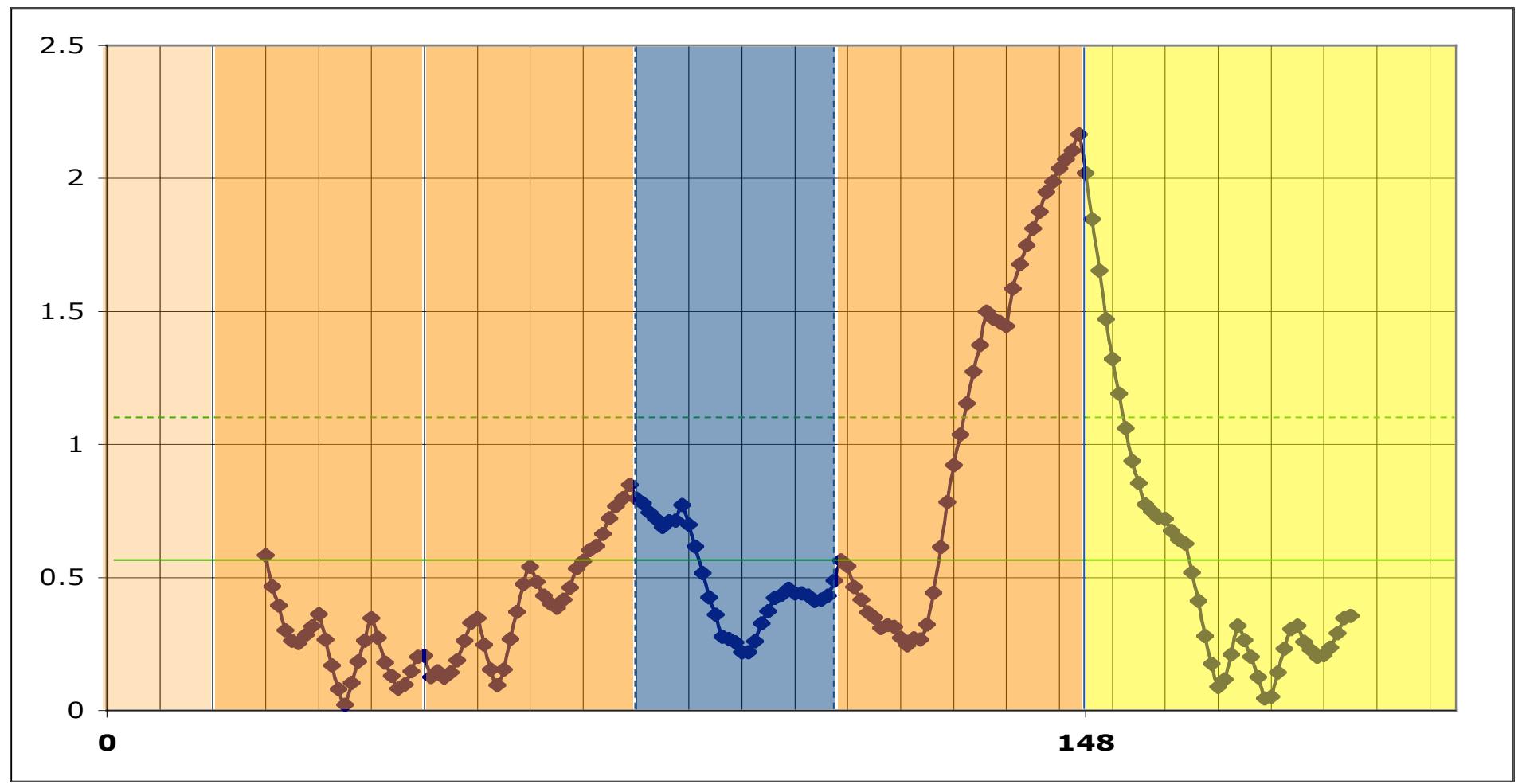
Clef: Treble clef
Key Signature: F major (no sharps or flats)
Time Signature: Common time (indicated by 'C')
Instrumentation: Vocal line with piano accompaniment.
Text: in - 'ry' on of - ly, pre - cisely you'll try



D Bm7 A/D

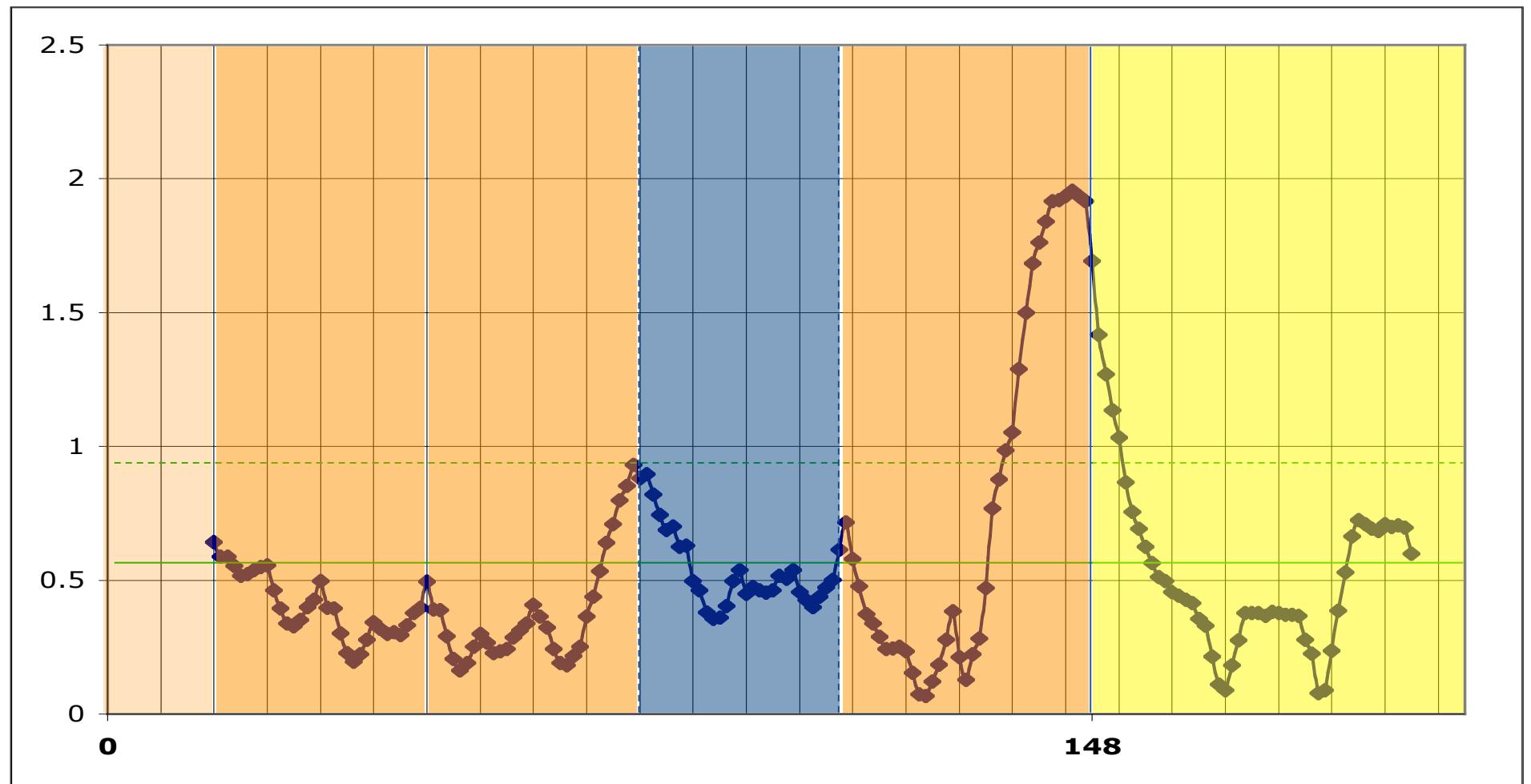
Clef: Treble clef
Key Signature: F major (no sharps or flats)
Time Signature: Common time (indicated by 'C')
Instrumentation: Vocal line with piano accompaniment.
Text: Sun

Tonal Contrast

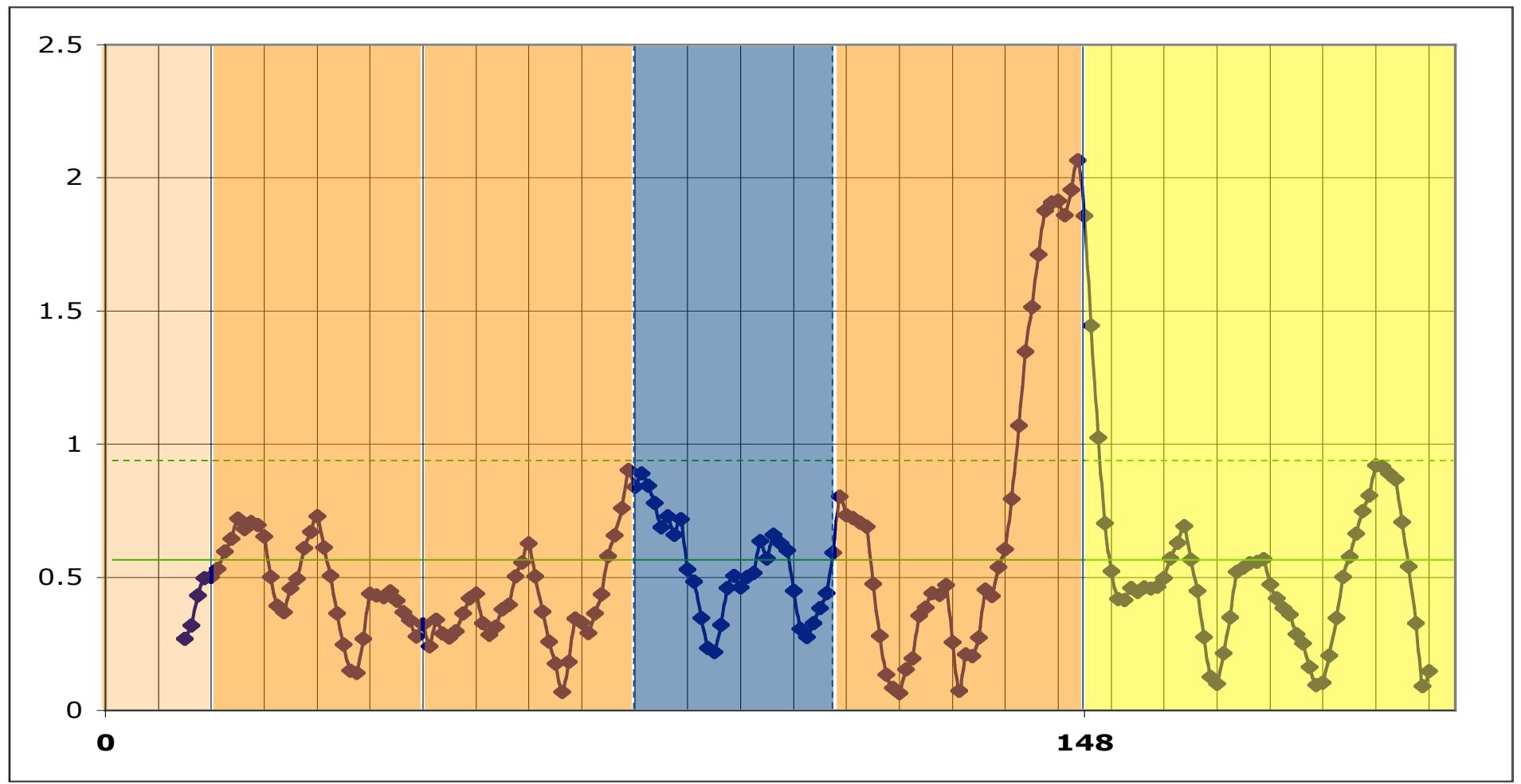


w=24 eighth notes (3 bars)

Tonal Contrast



Tonal Contrast



w=12 eighth notes (1-1/2 bars)

Time

<https://vimeo.com/151142022>

Schoenfeld Trio mvt 2 theme

00:41

Cheung, E. (2016). Motion and Gravitation in the Musical Spheres. In J. B. L. Smith, E. Cheung, G. Assayag (eds.): *Mathemusical Conversations: Mathematics and Computation in Music Performance and Composition*. London: Imperial College Press / NUS Institute for Mathematical Sciences Lecture Notes, World Scientific



Allegretto con moto

pp

3 4

2 5 4 1 2 4 5

Red. Red. Red. Red. Red.

4 1 2 4 5

5

Red. Red. Red. Red.

dolciss.

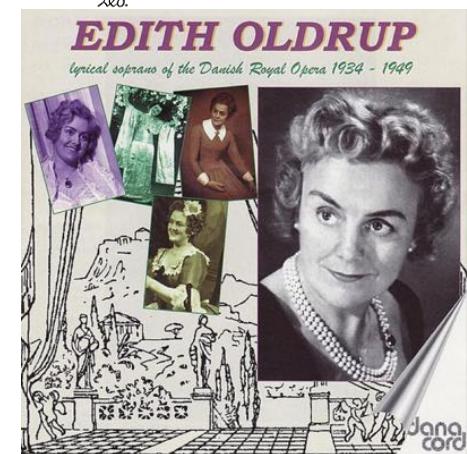
4 5 3 2

poco rit.

Tempo 1

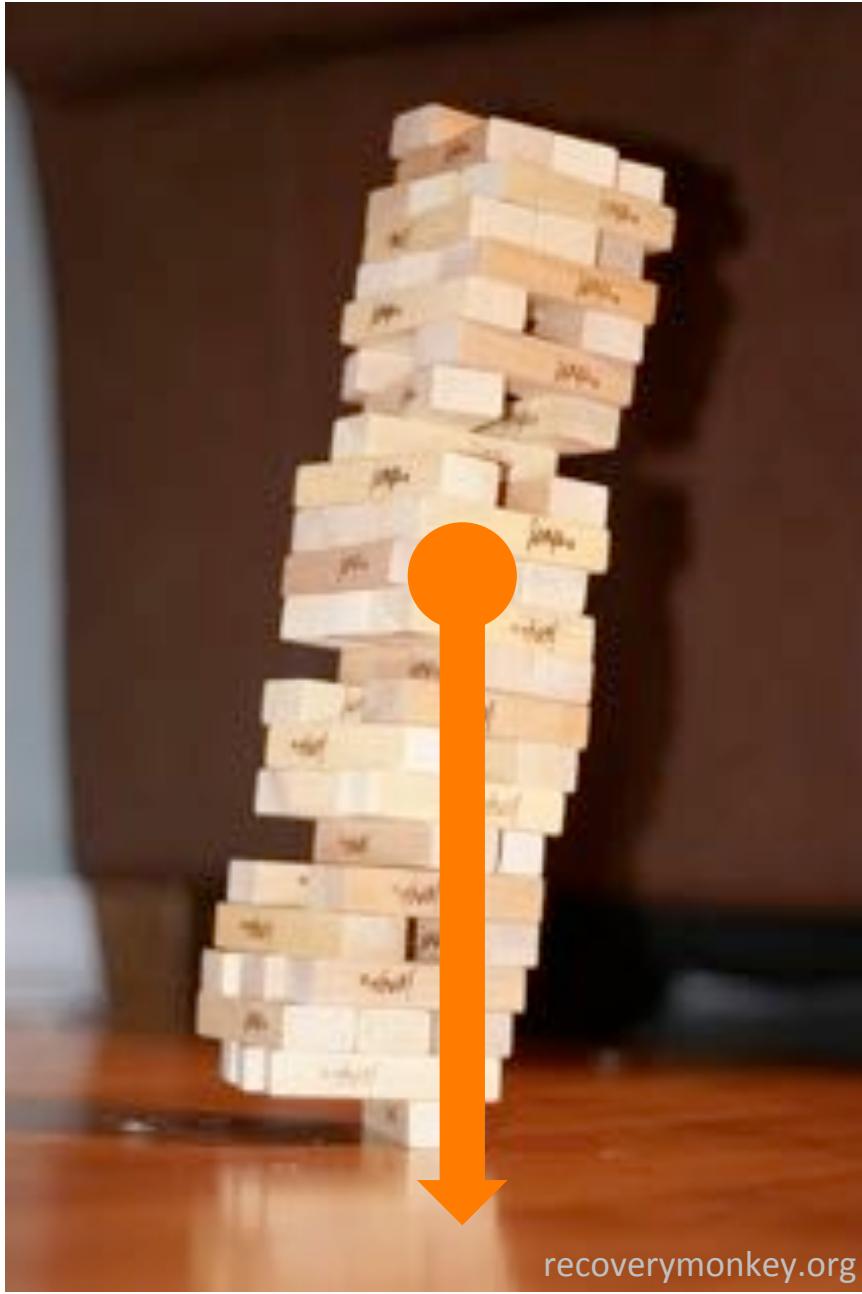
pp

Red. *



Time

Tipping points



Physics: The point beyond which the line through the centre of gravity lies outside the base of the object.



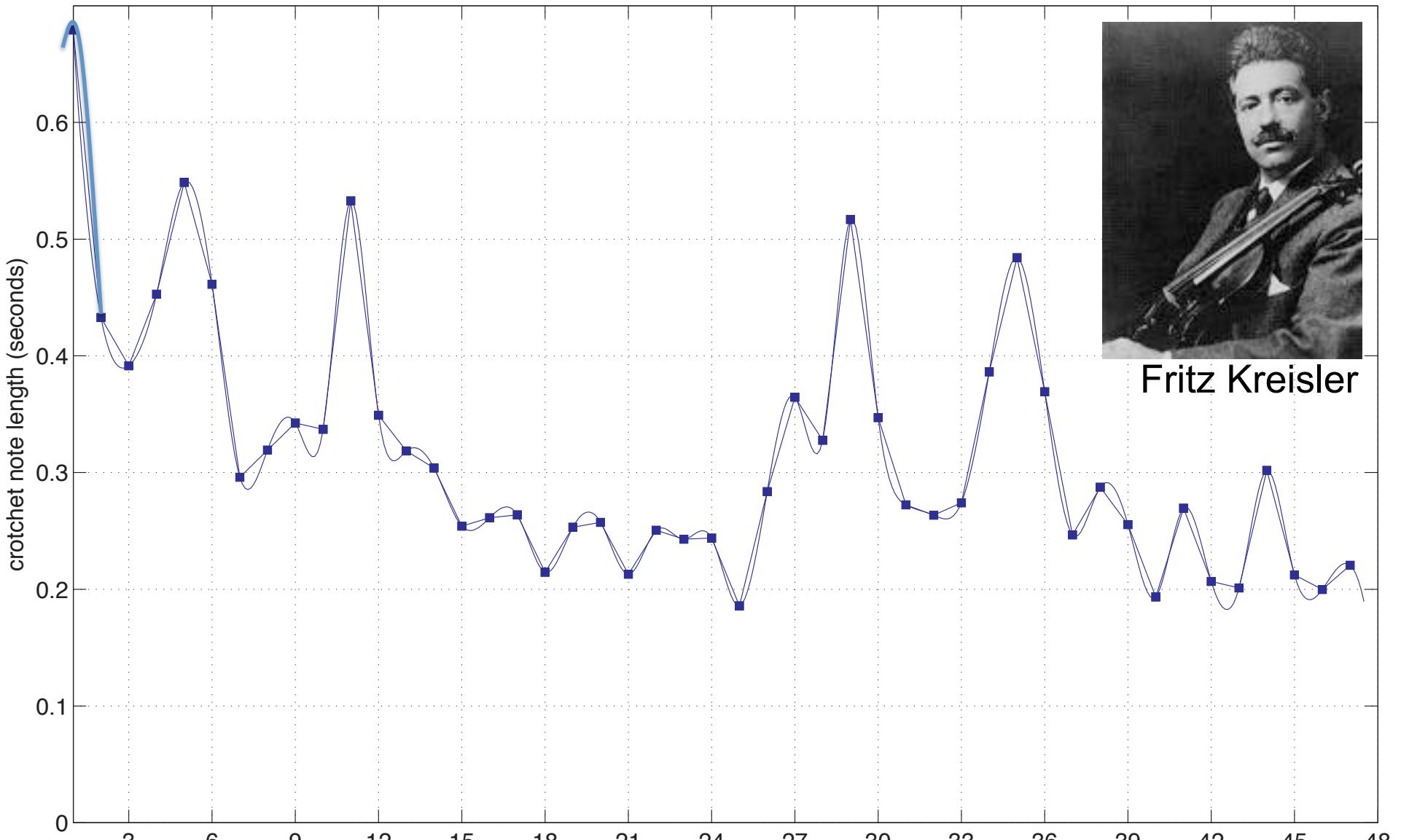
Schon Rosmarin

by Kreisler

1936 version, with pianist
Franz Rupp

youtu.be/RTNeHzzF8i8

Kreisler plays Schon Rosmarin: Graph of crotchet note length vs. crotchet note number



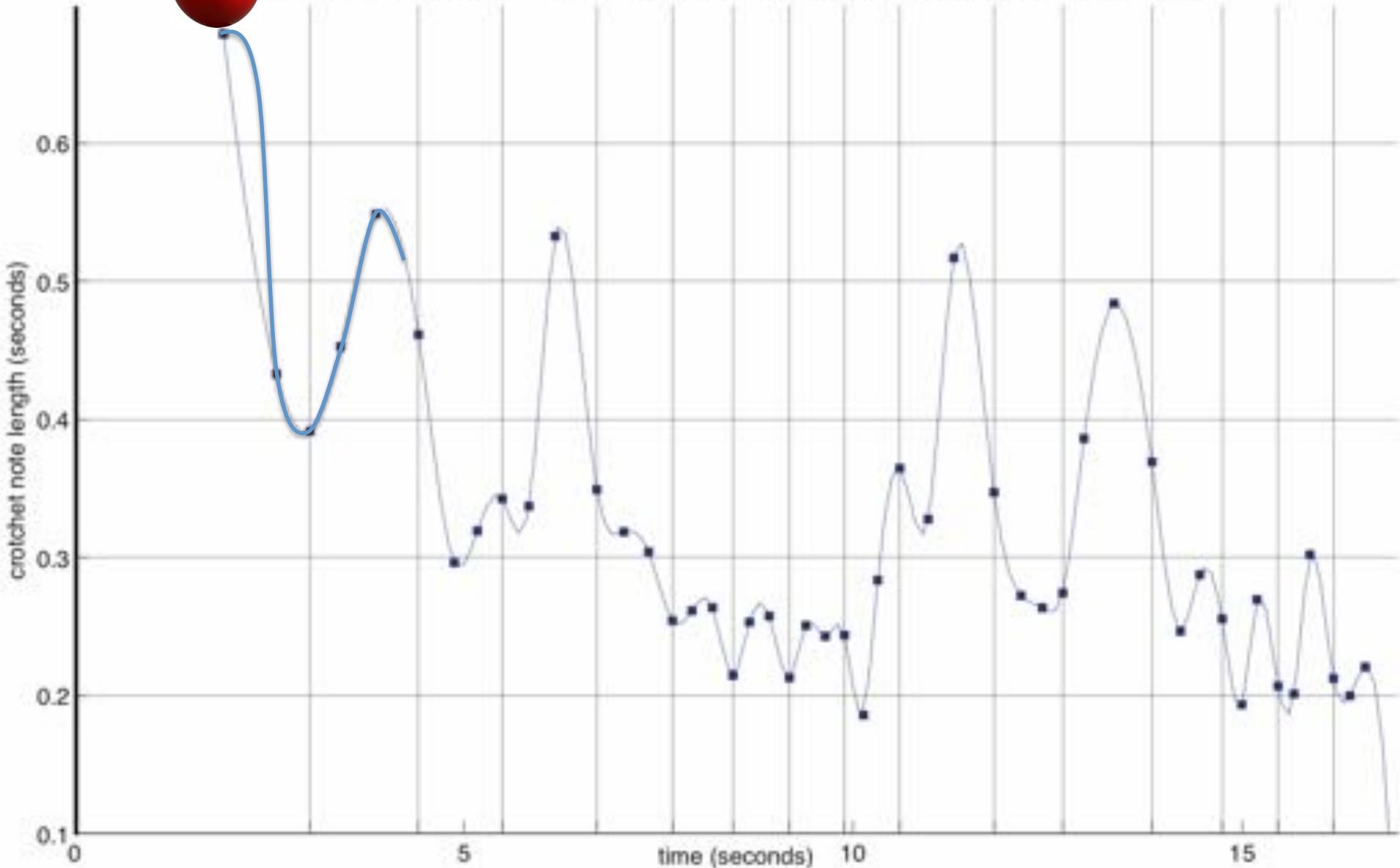
Musical score for the 'Grazioso' section of Schon Rosmarin. The score consists of two staves: a treble clef staff and a bass clef staff. The key signature is A major (no sharps or flats). The time signature is common time (indicated by '4'). The score features a series of eighth-note patterns and rests, with dynamic markings like 'p' (piano) and 'f' (forte). The music is divided into measures numbered 1 through 48.



Fritz Kreisler



Kreisler plays Schon Rosmarin: Graph of crotchet note length vs. crotchet note onset time





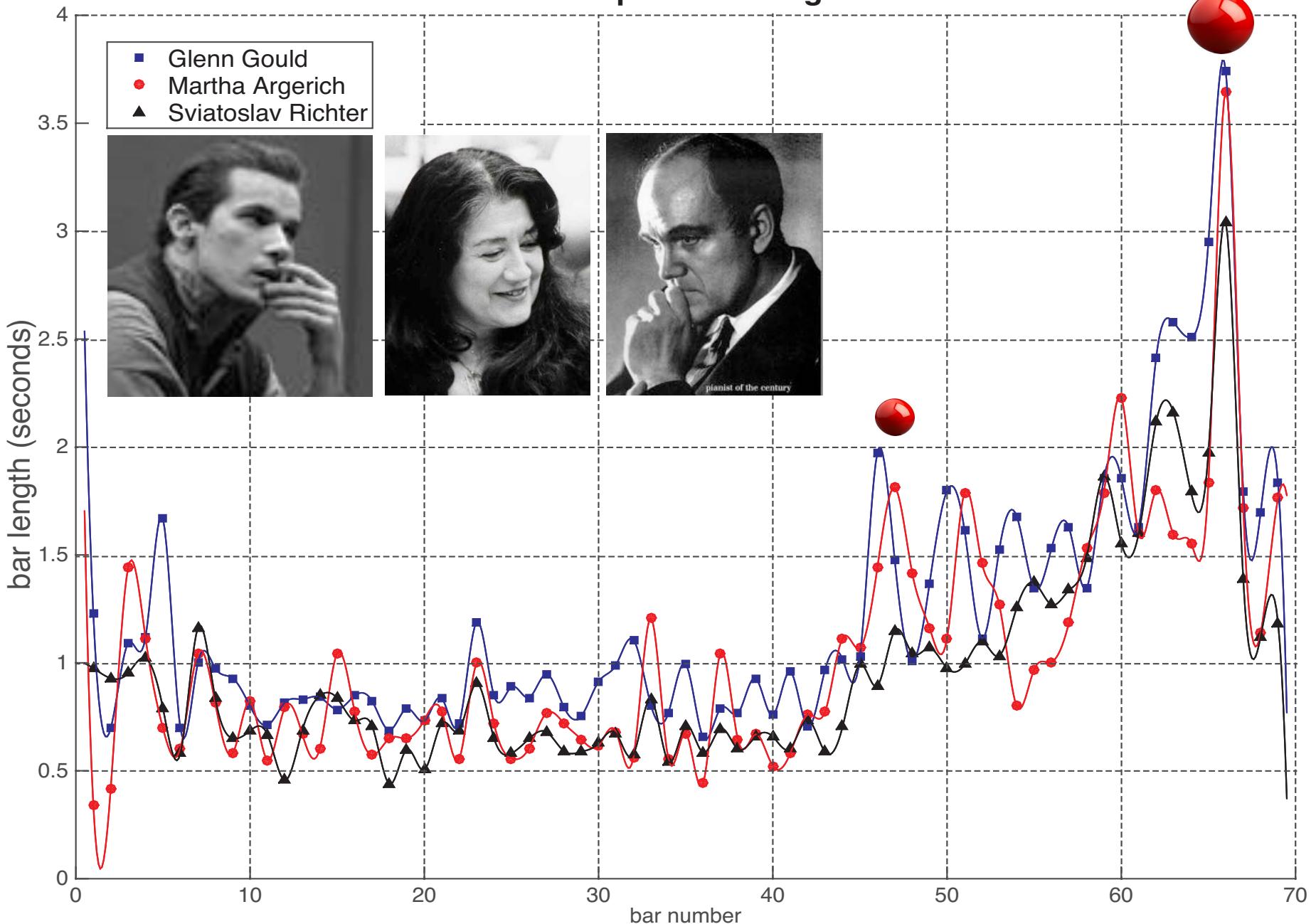
butchbellah.com

15:20

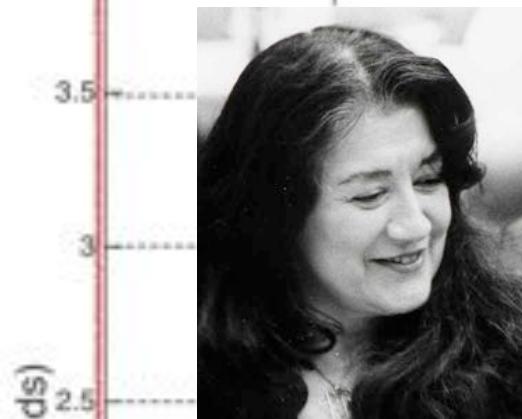


https://youtu.be/4q_zSvns0QY

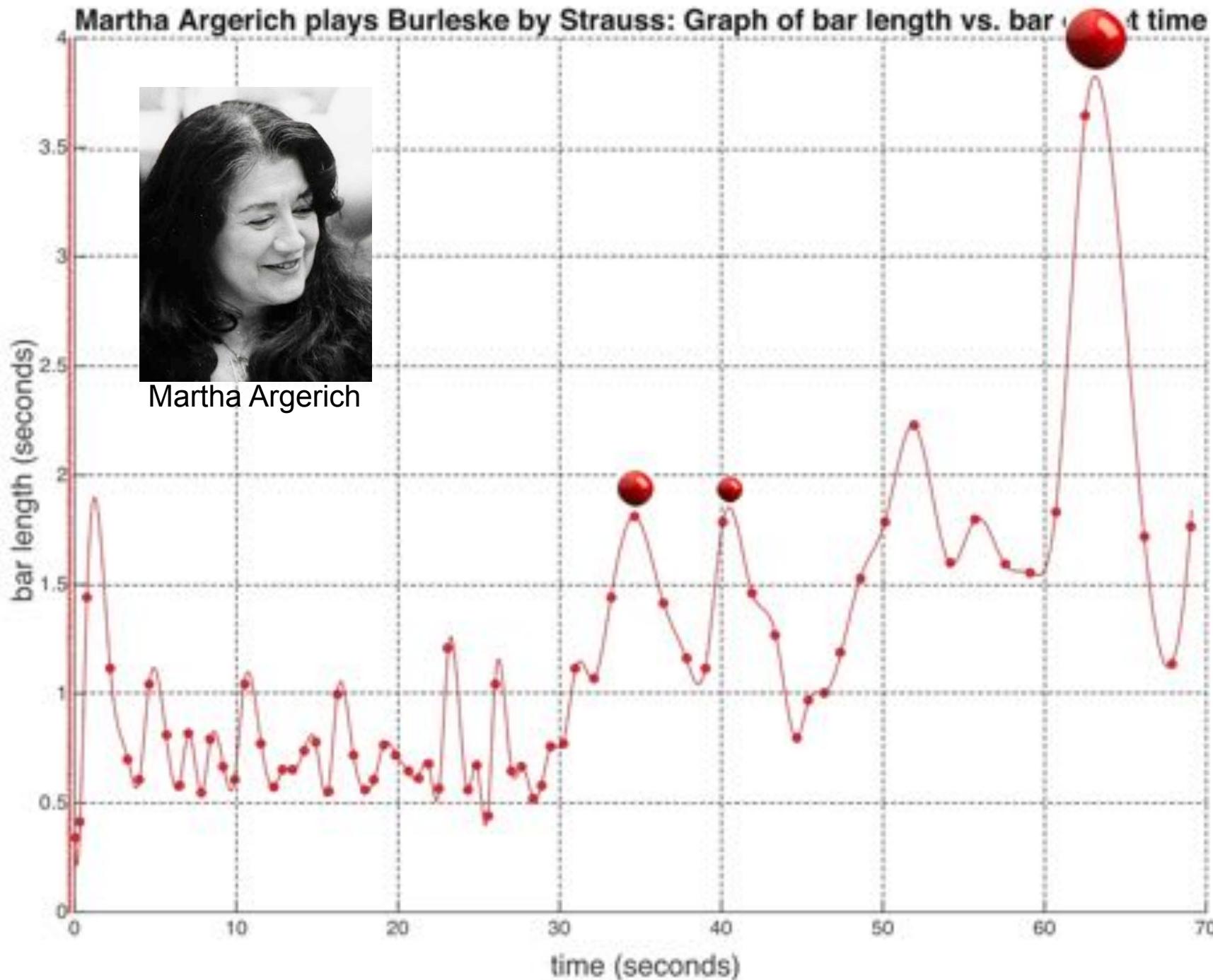
Strauss: Burleske: Graph of bar length vs. bar number



Martha Argerich plays Burleske by Strauss: Graph of bar length vs. bar count time



Martha Argerich



music
perception

FEBRUARY 2016

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VOLUME 33 NUMBER 3

FEBRUARY 2016

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music
perception

music perception

AN INTERDISCIPLINARY JOURNAL

EDITOR: LOLA L. CUDDY

PUBLISHED BY UNIVERSITY OF CALIFORNIA PRESS



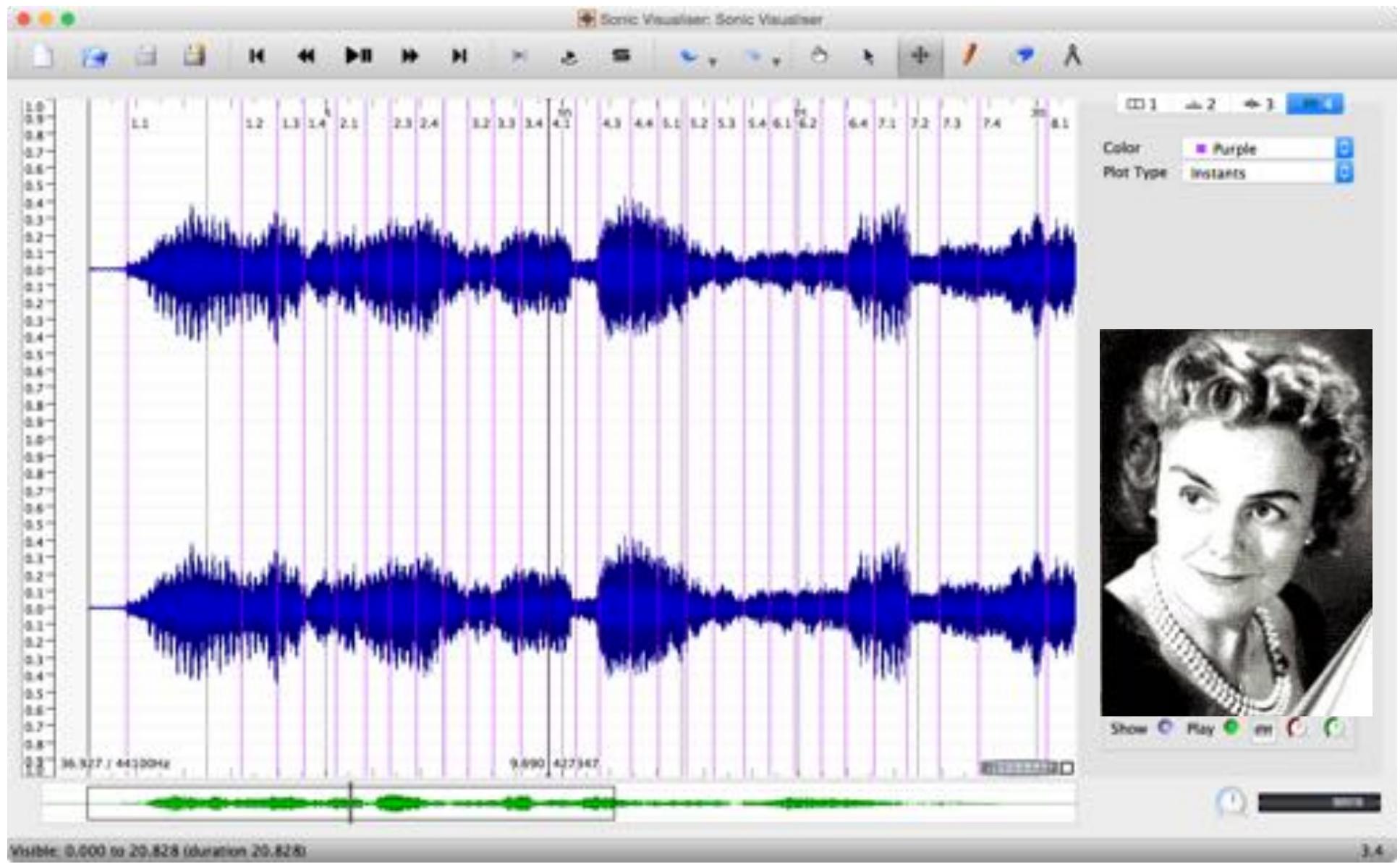
Chew, E. (2016). Playing with the edge: Tipping points and the role of tonality. In Stephen McAdams, David Temperley, Alexander Rozin (eds.): Milestones in Music Cognition Special Issue, *Music Perception*, 33(3):344-366.



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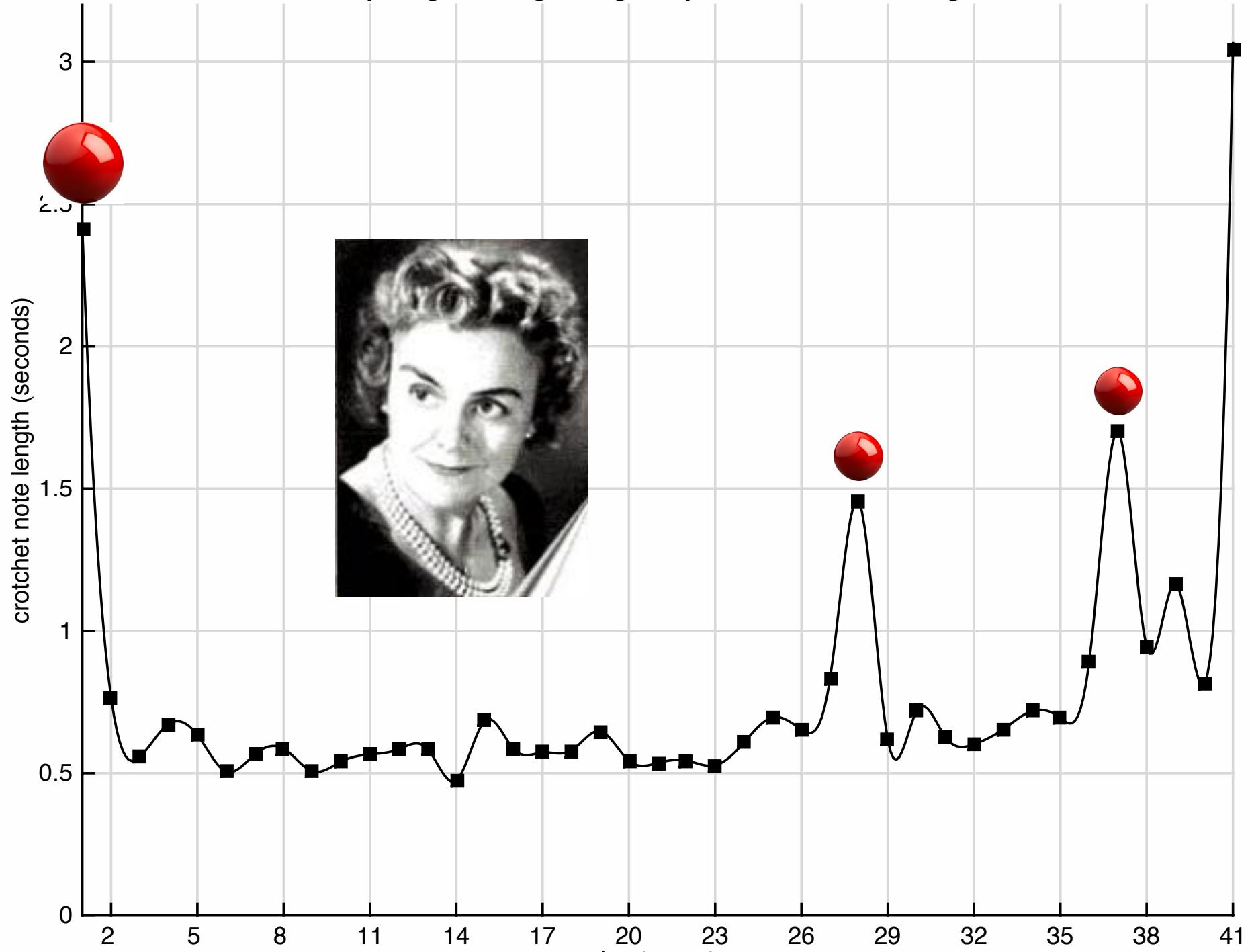
Creator: Chris Cannam et al.



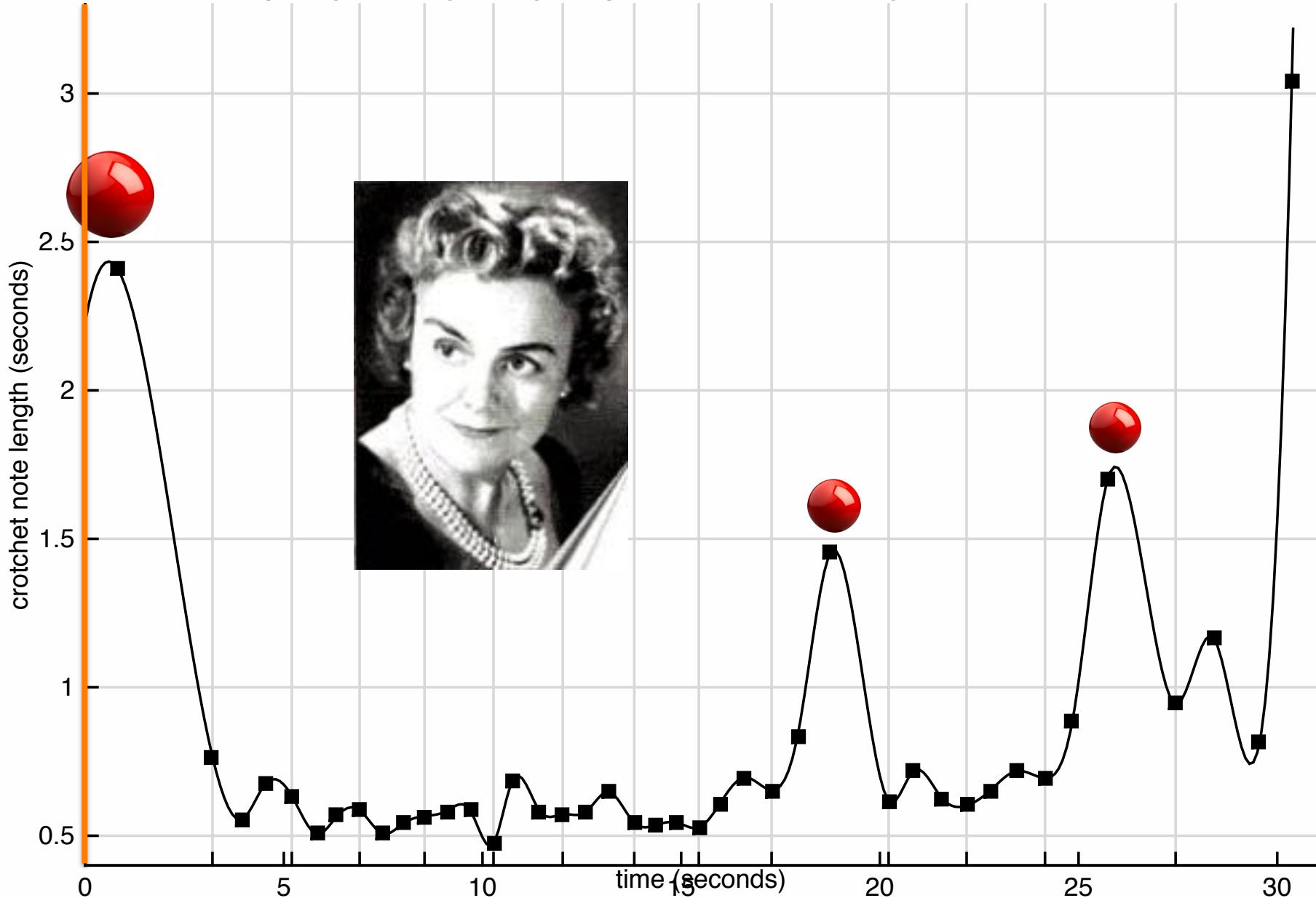


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Eduard Gurny Simys Sovtsevs Song. Graph of crotchet note length vs. beat

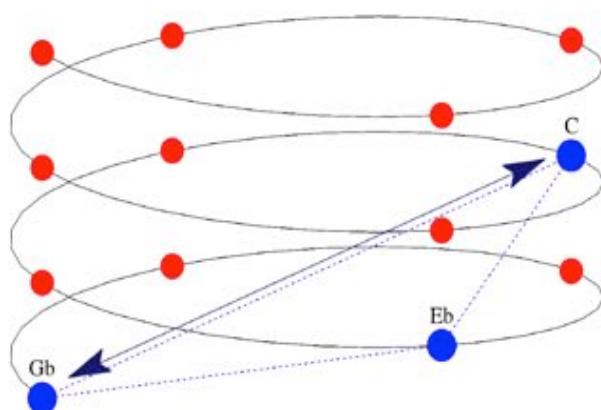


Edith Oldrup Sings Solveigs Song: Graph of crotchet note length vs. crotchet note onset time

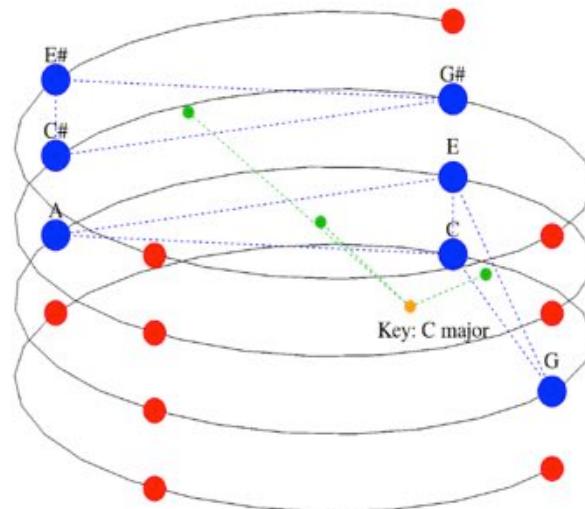


Tension

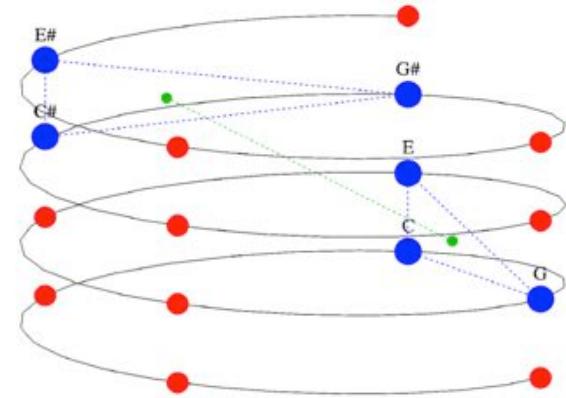
Modelling Tension



Cloud diameter



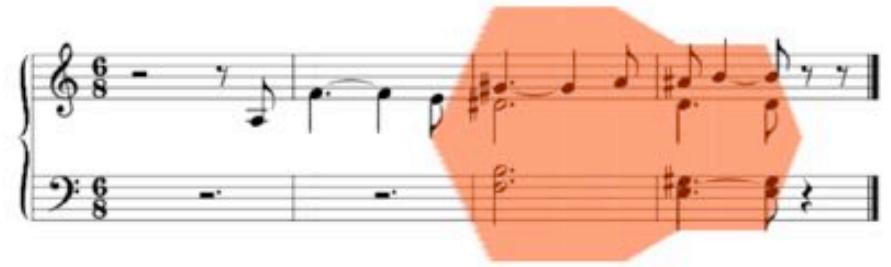
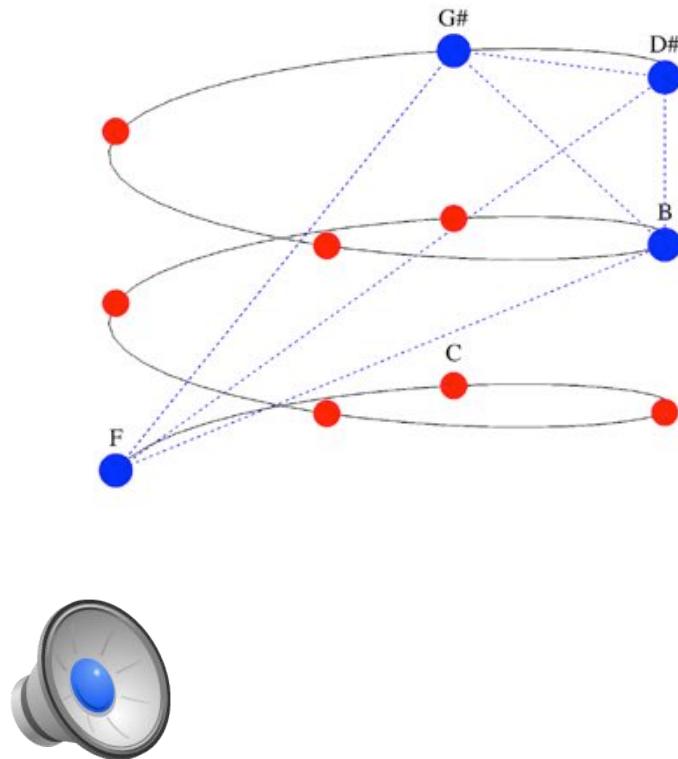
Tensile strain (distance to key)



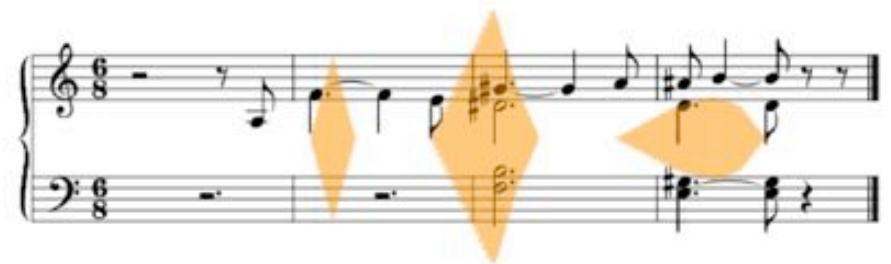
Cloud momentum

Herremans, D., E. Chew (2016). Tension Ribbons: Quantifying and visualising tonal tension. In Proceedings of the Second International Conference on Technologies for Music Notation and Representation (TENOR), Anglia Ruskin University, Cambridge, May 27-29, 2016.

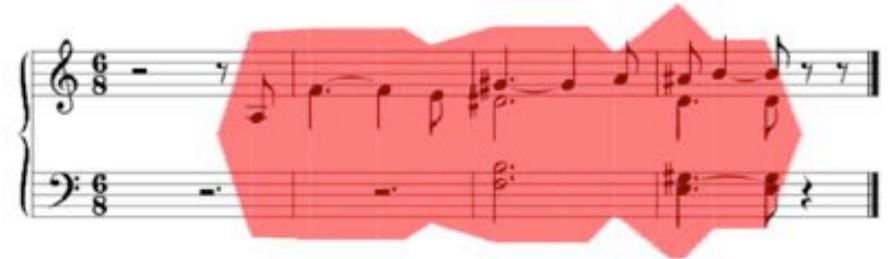
Tension ribbons (Tristan chord)



(a) Cloud diameter



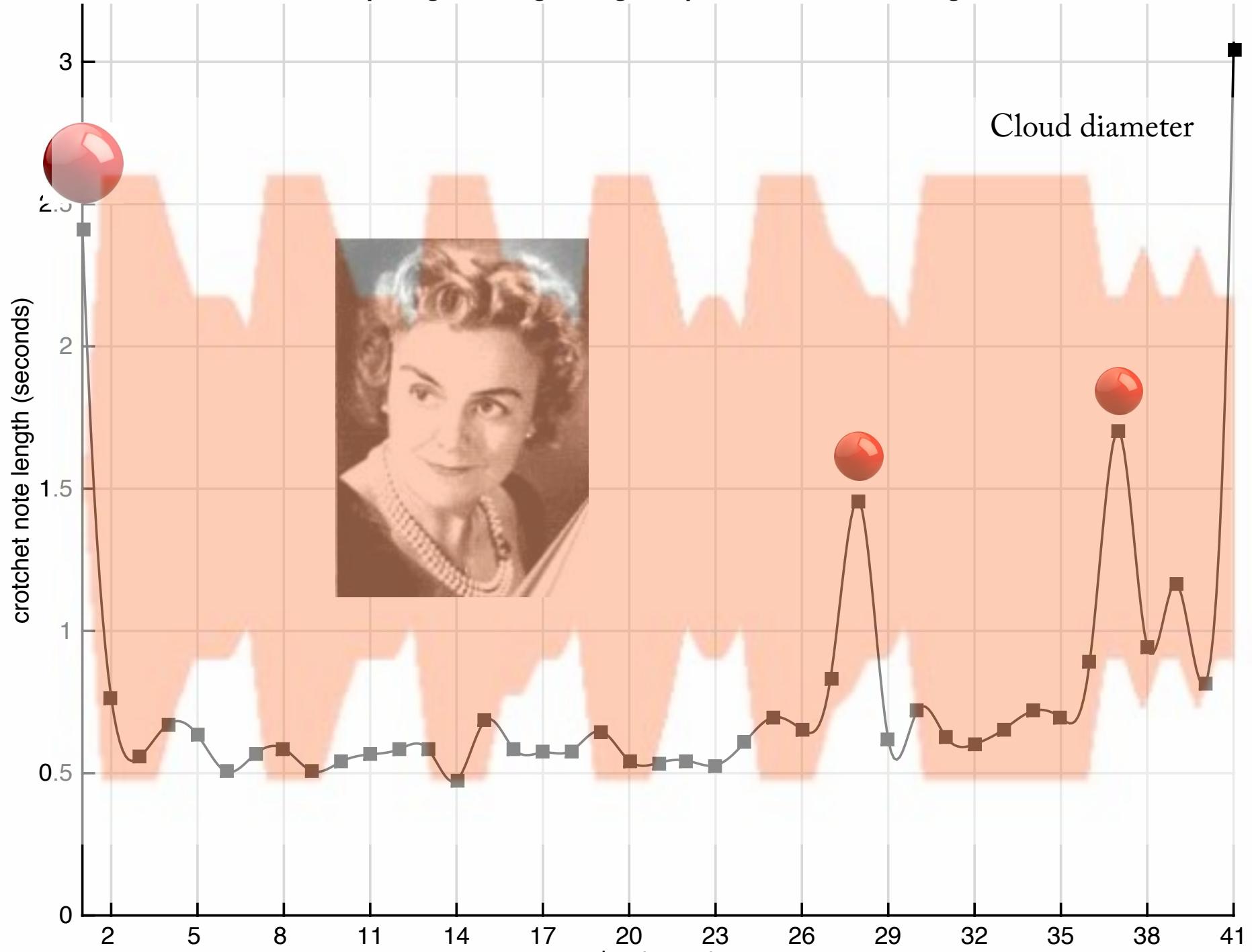
(b) Cloud momentum

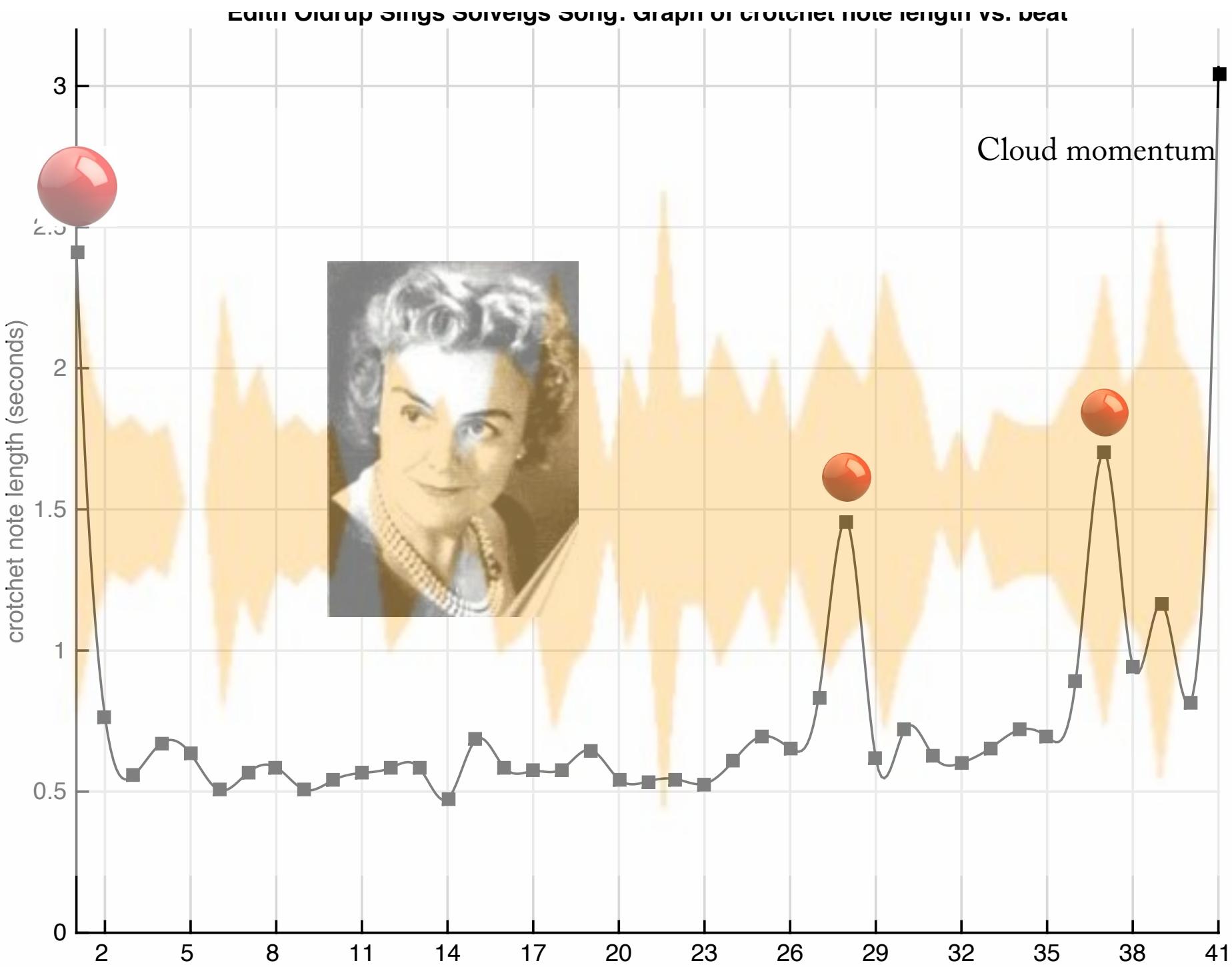


(c) Tensile strain

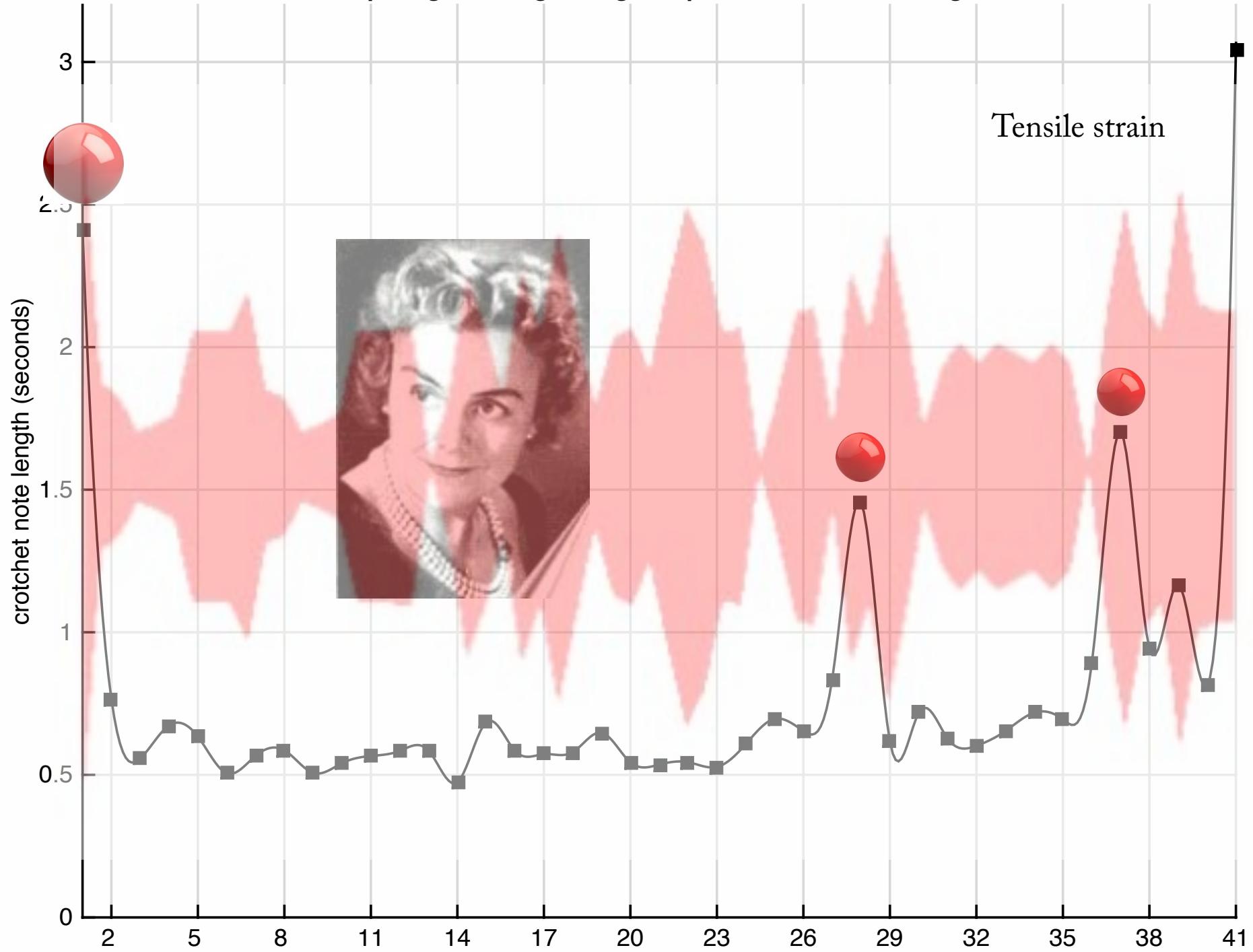
Herremans, D., E. Chew (2016). Tension Ribbons: Quantifying and visualising tonal tension. In Proceedings of the Second International Conference on Technologies for Music Notation and Representation (TENOR), Anglia Ruskin University, Cambridge, May 27-29, 2016.

Eduard Gruber-Schoebergs Song. Graph of crotchet note length vs. beat



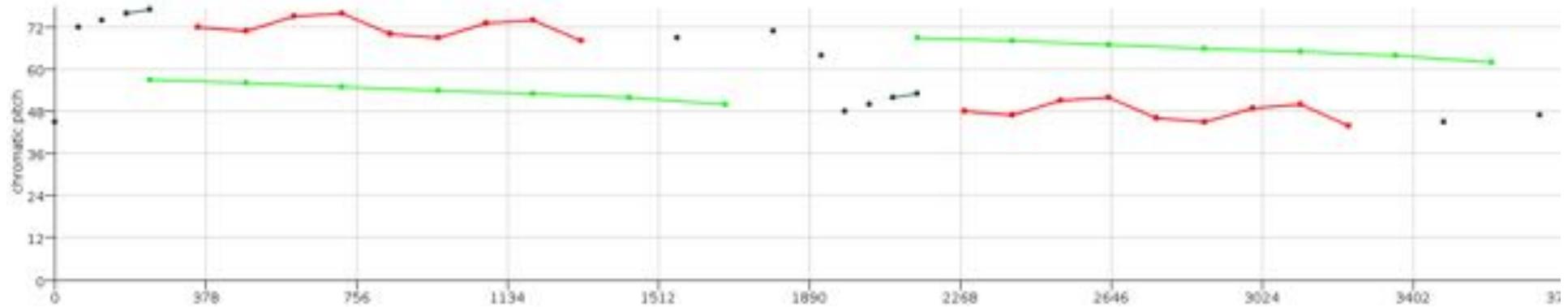


Eduard Gurny Simys Suvileig's Song. Graph of crotchet note length vs. beat



Repeated Pattern Constraints

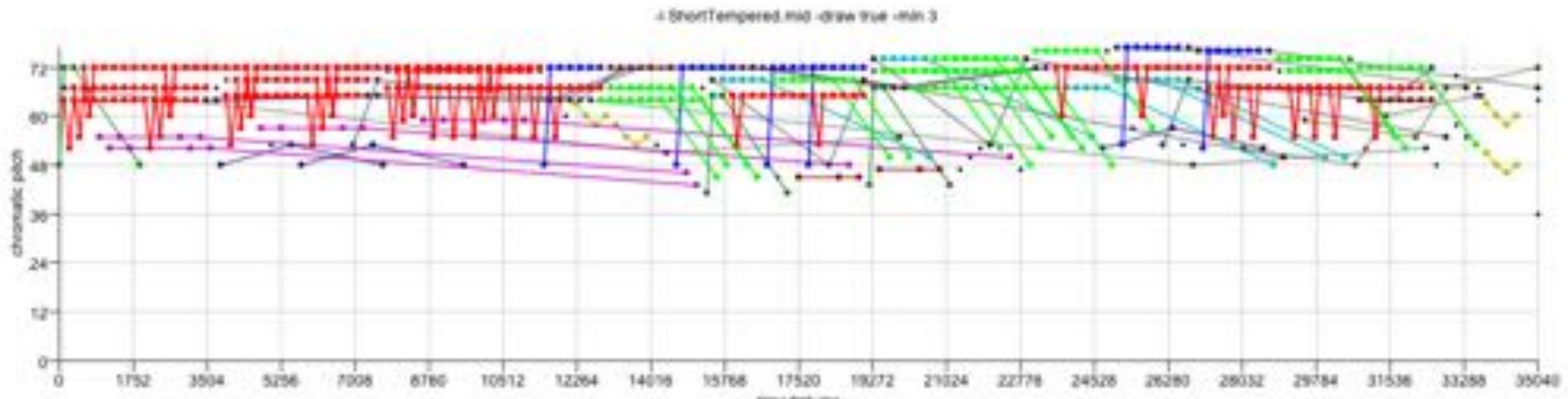
SIATECCompress / COSIATEC by David Meredith



COSIATEC output for Bach WTC II Prelude XX

Repeated Pattern Constraints

SIATECCompress / COSIATEC by David Meredith



COSIATEC output for PDQ Bach STC Prelude I

+ Variable Neighborhood Search

Herremans, D., E. Chew (2017). MorpheuS: generating structured music with constrained patterns and tension. *IEEE Transactions on Affective Computing*.

Prelude in C from the Short-tempered Clavier (start)



MorpheuS-PDQ Bach

Music score for measure 1, treble clef, 4/4 time. The melody consists of eighth-note pairs and sixteenth-note pairs. The bass line provides harmonic support.

Continuation of the musical score for measure 1, showing the end of the measure and the beginning of measure 2.

Music score for measure 2, treble clef, 4/4 time. The melody continues with eighth-note pairs and sixteenth-note pairs. The bass line provides harmonic support.

Continuation of the musical score for measure 2, showing the end of the measure and the beginning of measure 3.

Prelude in C from the Short-tempered Clavier (iter 1)



MorpheuS-PDQ Bach

1

2

Measures 1 and 2 of the musical score. The top staff is in treble clef and 4/4 time, showing a continuous eighth-note pattern of quarter note pairs. The bottom staff is in bass clef and 4/4 time, showing a bass line consisting of eighth-note pairs.

3

4

Measures 3 and 4 of the musical score. The top staff continues the eighth-note pattern of quarter note pairs. The bottom staff shows a bass line with eighth-note pairs, starting with a half note on measure 3.

5

6

Measures 5 and 6 of the musical score. The top staff continues the eighth-note pattern of quarter note pairs. The bottom staff shows a bass line with eighth-note pairs.

Prelude in C from the Short-tempered Clavier (iter 3)



MorpheuS-PDQ Bach

4/4 time signature. Treble clef. Bass clef. The treble staff shows eighth-note chords. The bass staff shows eighth-note patterns: quarter note, eighth note, eighth note, eighth note.

3 4/4 time signature. Treble clef. Bass clef. The treble staff shows eighth-note chords. The bass staff shows eighth-note patterns: eighth note, eighth note, eighth note, eighth note.

5 4/4 time signature. Treble clef. Bass clef. The treble staff shows eighth-note chords. The bass staff shows eighth-note patterns: eighth note, eighth note, eighth note, eighth note.



March in D Major (BWV Anh. 122)

from the Notebook for Anna Magdalena Bach

Johann Sebastian Bach

Animato

Piano

1 4
f
mp
2 1
3
6
3 2
2 1
4 1 3
Pno.
5
10
4
4
cresc.
Pno.
16
2 1 3
1 3 4
dim.
p
3 cresc.
Pno.
20
3 1
1
3 2 3
f
3 2 1 3 2 1
5



March in D Major (BWV Anh. 122)

from A Little Notebook for Anna Magdalena Bach

MorpheuS-Bach

Animato

5
10
p
15
cresc.
dim.
p
19
cresc.
f

MorpheuS

Dorien Herremans and Elaine Chew
dorienherremans.com/MorpheuS

Music Generation

- Google Magenta Project
- Jukedeck
- MeloDrive

melodrive
adaptive music generation



Agenda

- A moving experience
 - Strong emotions: frisson, laughter, awe
- Expectation
 - Fulfillment: Reward
 - Violation: Surprise, laughter
- Tension, anticipation
 - Delayed resolution
 - Density of activity
- Prominence
 - Note-level variations
 - Vibrato and portamento
- Contrast
 - Section-level variations
 - Key change
- Time
 - Phrase-level variations
 - Tipping points
- Tension

THANK YOU

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Research Team – mupae.blogspot.com

Piano Blog – elainechew-piano.blogspot.com