

Automatic Harmonic Analysis of Classical String Quartets From Symbolic Score

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Music
Technology
Group



Summary

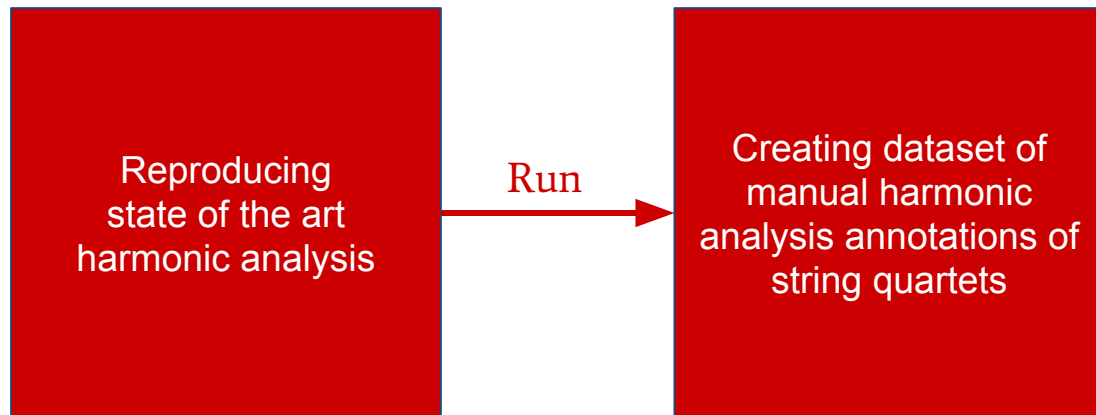
Reproducing
state of the art
harmonic analysis

Summary

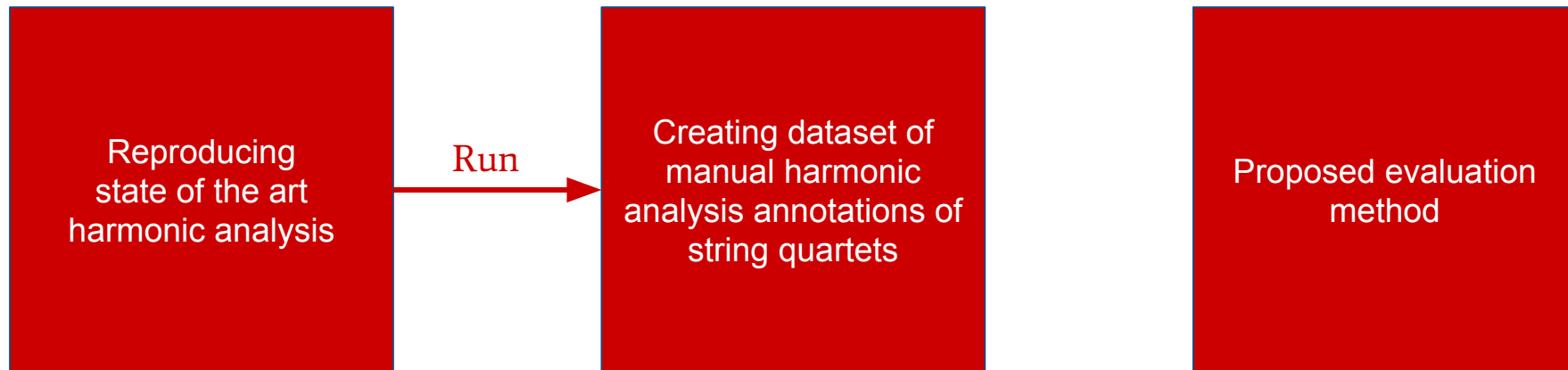
Reproducing
state of the art
harmonic analysis

Creating dataset of
manual harmonic
analysis annotations of
string quartets

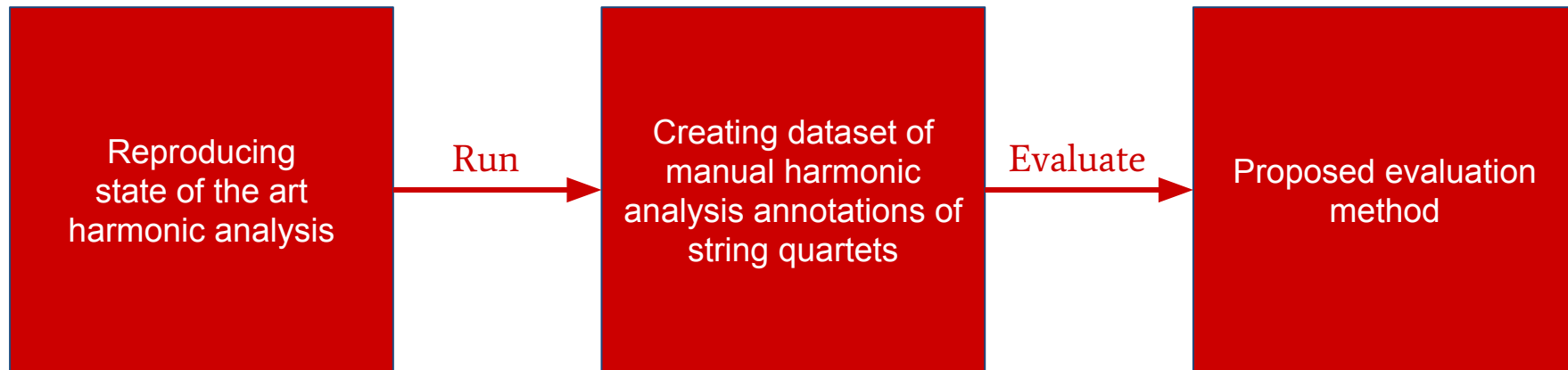
Summary



Summary



Summary



Structure of the presentation

1. Automatic Harmonic Analysis
2. The dataset: Six string quartets Op.20, Joseph Haydn
3. Running the analysis
4. Evaluation
5. Results
6. Contributions

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1. Automatic Harmonic Analysis
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Automatic Harmonic Analysis

Analysis

Interpreting the structures in music,
resolving into relatively simpler elements,
investigating the relevant functions of those elements.

Automatic Harmonic Analysis

Harmony

The simultaneous sounding of notes.

"Harmony." The Oxford Dictionary of Music, 2nd ed. rev. Ed. Michael Kennedy. Oxford Music Online. Oxford University Press. Web. 28 Jun. 2017. <<http://www.oxfordmusiconline.com/subscriber/article/opr/t237/e4724>>.

Automatic Harmonic Analysis

Harmonic analysis

Interpreting the **harmonic** structures in music,
resolving into relatively simpler elements, **i.e., labels**,
investigating the relevant functions of those elements.

Automatic Harmonic Analysis

Harmonic analysis

Interpreting the **harmonic structures** in music,
resolving into relatively simpler elements, i.e., labels,
investigating the relevant functions of those elements.

Automatic Harmonic Analysis

The image displays a musical score for four instruments: Violin I, Violin II, Viola, and Violoncello. The score is written in 3/4 time and B-flat major (two flats). The key signature is B-flat major, and the time signature is 3/4. The score consists of six measures. The Violin I part begins with a whole rest in the first measure, followed by a half note G4 in the second measure, and then a series of eighth notes: A4, B4, C5, B4, A4, G4, F#4, E4, D4, C4. The Violin II part begins with a whole rest in the first measure, followed by a half note G4 in the second measure, and then a series of eighth notes: A4, B4, C5, B4, A4, G4, F#4, E4, D4, C4. The Viola part begins with a whole rest in the first measure, followed by a half note G4 in the second measure, and then a series of eighth notes: A4, B4, C5, B4, A4, G4, F#4, E4, D4, C4. The Violoncello part begins with a whole rest in the first measure, followed by a half note G3 in the second measure, and then a series of eighth notes: A3, B3, C4, B3, A3, G3, F#3, E3, D3, C3. The score is written in a standard musical notation style with a grand staff for each instrument.

Excerpt from Joseph Haydn's Op.20 No.3 - II. Menuetto: Allegretto, mm. 1-6

Automatic Harmonic Analysis

The image displays a musical score for four instruments: Violin I, Violin II, Viola, and Violoncello. The score is written in 3/4 time and the key of B-flat major (two flats). The first system consists of two measures. The second measure of the first system is highlighted with a red box, indicating the focus of the automatic harmonic analysis. The instruments are arranged in a standard orchestral format, with Violin I and Violin II on the top staves, Viola in the middle, and Violoncello on the bottom staff. The notation includes various musical symbols such as notes, rests, and bar lines.

Instrument	Measure 1 (First System)	Measure 2 (First System)
Violin I	Rest	Quarter note G4
Violin II	Rest	Quarter note G4
Viola	Rest	Quarter note G4
Violoncello	Rest	Quarter note G4

Harmony

Automatic Harmonic Analysis

The image displays a musical score for four instruments: Violin I, Violin II, Viola, and Violoncello. The key signature is B-flat major (two flats) and the time signature is 3/4. The score is divided into measures by vertical bar lines. Red vertical rectangles are drawn around specific notes in each measure, highlighting the harmonic structure. The instruments are arranged vertically, with Violin I at the top, followed by Violin II, Viola, and Violoncello at the bottom. The Viola and Violoncello staves are joined by a brace on the left. The score begins with a rest in the first measure, followed by a series of notes in the subsequent measures. The red boxes highlight the notes that form the harmonic structure of each measure.

Harmonic structures

Automatic Harmonic Analysis

Harmonic analysis

Interpreting the **harmonic structures** in music,
resolving into relatively simpler elements, i.e., **labels**,
investigating the relevant functions of those elements.

Automatic Harmonic Analysis

The image displays a musical score for four instruments: Violin I, Violin II, Viola, and Violoncello. The music is in 3/4 time and features a key signature of two flats (B-flat and E-flat). The score is divided into six measures. The first measure contains a whole rest for all instruments. The second measure begins with a G minor triad (G2, Bb2, D3) in the Violoncello, which is sustained through the third measure. The Violin I and Violin II enter in the second measure with a G4 and A4 respectively, moving in parallel motion. The Viola enters in the second measure with a Bb3. The fourth measure introduces a C minor triad (C3, Eb3, F3) in the Violoncello, sustained through the fifth measure. The Violin I and Violin II continue their melodic lines. The fifth measure features a complex chordal texture with a F# diminished triad (F#3, Ab3, Bb3) in the Violoncello, a F# diminished seventh chord (F#3, Ab3, Bb3, Db3) in the Viola, and a D minor triad (D3, F3, Ab3) in the Violoncello. The sixth measure concludes with a D minor triad (D3, F3, Ab3) in the Violoncello. Below the score, a blue box labeled "Chord labels" provides the harmonic analysis for each measure: Gm, Adim, Gm/Bb, Cm, Gm/Bb, F#dim/A, F#dim7/A, and Dm/A.

Violin I

Violin II

Viola

Violoncello

Chord labels

Gm	Adim	Gm/Bb	Cm	Gm/Bb	F#dim/A	F#dim7/A	Dm/A
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Automatic Harmonic Analysis

Violin I

Violin II

Viola

Violoncello

Chord labels

Gm	Adim	Gm/Bb	Cm	Gm/Bb	F#dim/A	F#dim7/A	Dm/A
----	------	-------	----	-------	---------	----------	------

Figured bass

b5	6	5	6	#6	#6	#6
					5	4
					3	3

Automatic Harmonic Analysis

Violin I

Violin II

Viola

Violoncello

Chord labels

Gm Adim Gm/Bb Cm Gm/Bb F#dim/A F#dim7/A Dm/A

Figured bass

b5 6 5 6 #6 #6 5 3 #6 4 3

Roman numerals

i ii° i6 iv i6 vii°6 vii°6 V4

Automatic Harmonic Analysis

Harmonic analysis

Interpreting the **harmonic structures** in music,
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Automatic Harmonic Analysis

Violin I

Violin II

Viola

Violoncello

Chord labels

Gm Adim Gm/Bb Cm Gm/Bb F#dim/A F#dim7/A Dm/A

Figured bass

b5 6 5 6 #6 #6 5 3 #6 4 3

Roman numerals

i ii° i6 iv i6 vii°6 vii°6 V4

Automatic Harmonic Analysis

Violin I

Violin II

Viola

Violoncello

Chord labels

Gm Adim Gm/Bb Cm Gm/Bb F#dim/A F#dim7/A Dm/A

Figured bass

b5 6 5 6 #6 #6 5 3 #6 4 3

Roman numerals

i ii° i6 iv i6 vii°6 vii°6 V4

Automatic Harmonic Analysis

Harmonic analysis

Interpreting the **harmonic structures** in music,
resolving into relatively simpler elements, i.e., **labels**,
~~investigating the relevant functions of those elements.~~

Automatic Harmonic Analysis

Violin I

Violin II

Viola

Violoncello

Roman numerals

i	ii°	i6	iv	i6	vii°6	vii°6	V ₄
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Automatic Harmonic Analysis

Harmonic analysis

Interpreting the **harmonic structures** in music,
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investigating the relevant **functions** of those elements.

Automatic Harmonic Analysis



Automatic
Harmonic
Analysis



i ii° i6 iv i6 vii°6

Automatic Harmonic Analysis



Automatic
Harmonic
Analysis



i ii° i6 iv i6 vii°6

Structure of the presentation

1. Automatic Harmonic Analysis
2. The dataset: Six string quartets Op.20, Joseph Haydn
3. Running the analysis
4. Evaluation
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Dataset

**Six string quartets
from Joseph Haydn**

Op.20 No.1

Op.20 No.2

Op.20 No.3

Op.20 No.4

Op.20 No.5

Op.20 No.6

Dataset

Six string quartets from Joseph Haydn

Op.20 No.1

Op.20 No.2

Op.20 No.3

Op.20 No.4

Op.20 No.5

Op.20 No.6

Dataset

Six string quartets
from **Joseph Haydn**

Op.20 No.1

Op.20 No.2

Op.20 No.3

Op.20 No.4

Op.20 No.5

Op.20 No.6

Dataset

Six string quartets
from Joseph Haydn

Op.20 No.1

Op.20 No.2

Op.20 No.3

Op.20 No.4

Op.20 No.5

Op.20 No.6

Dataset

The String Quartet

- Require a broad knowledge of harmony
- One of the most prominent genres developed during the Classical period
- Four voices (almost) all the time
- Explicit stream segregation
 - Each voice is separated explicitly in the symbolic score
 - Its own midi channel, spine, node, etc.

Dataset

The image displays a musical score excerpt from Ludwig van Beethoven's Sonata Op.10 No.1 - I. Molto Allegro e con brio, measures 1-5. The score is written for piano in 3/4 time, featuring a treble and bass staff. The key signature has two flats (B-flat and E-flat). The excerpt is divided into five measures. The first measure is highlighted with a green box and labeled '7 voices'. The second measure is highlighted with a blue box and labeled '1 voice'. The third measure is highlighted with a red box and labeled '4 voices'. The fourth measure is highlighted with a red box and labeled '4 voices'. The fifth measure is highlighted with a yellow box and labeled '8 voices'.

7 voices

1 voice

4 voices

4 voices

8 voices

Excerpt from Ludwig van Beethoven's Sonata Op.10 No.1 - I. Molto Allegro e con brio, mm. 1-5

Dataset

The image displays a musical score for four instruments: Violin I, Violin II, Viola, and Violoncello, in 3/4 time. The score is divided into two sections: a green section labeled "3 voices" and a red section labeled "4 voices".

Violin I: Treble clef, key of B-flat major. The green section contains four measures of quarter notes. The red section contains four measures of quarter notes, with the first measure being a dotted quarter note.

Violin II: Treble clef, key of B-flat major. The green section contains four measures of quarter notes. The red section contains four measures of quarter notes, with the first measure being a dotted quarter note.

Viola: Alto clef, key of B-flat major. The green section contains four measures of quarter notes. The red section contains four measures of quarter notes, with the first measure being a dotted quarter note.

Violoncello: Bass clef, key of B-flat major. The green section contains four measures of quarter notes. The red section contains four measures of quarter notes, with the first measure being a dotted quarter note.

The "3 voices" section is highlighted with green vertical rectangles, and the "4 voices" section is highlighted with red vertical rectangles. The labels "3 voices" and "4 voices" are positioned below the corresponding sections.

Dataset

Joseph Haydn

- Colloquially named “*The father of the string quartet*”
- Major figure of the classical period of western art music
 - Exemplifies many of the characteristic features of the style
- Mentor of Wolfgang Amadeus Mozart and Ludwig van Beethoven
 - The two other major figures of the classical period

Dataset

Six string quartets Op.20

- They provided innovations to the compositional technique of string quartets
- Good distribution of musical forms and structure
 - Sonata movements, fugues, theme and variations, minuets, etc.
- Mastery in the use of musical elements
 - Syncopation, imitation, counterpoint
- Representative style, less experimental than later works, e.g., Op.33

Dataset

KernScores

<http://kern.ccarh.org/>

Virtual library of musical scores in Humdrum **kern syntax

Allocates musical scores for 19 out of 24 pieces of the String quartets Op.20

Dataset

Humdrum **kern syntax

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4Λ	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.Λ	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.Λ_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4Λ]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d

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C30, D30, E30, F30, G30, A30, B30, C31, D31, E31, F31, G31, A31, B31, C32, D32, E32, F32, G32, A32, B32, C33, D33, E33, F33, G33, A33, B33, C34, D34, E34, F34, G34, A34, B34, C35, D35, E35, F35, G35, A35, B35, C36, D36, E36, F36, G36, A36, B36, C37, D37, E37, F37, G37, A37, B37, C38, D38, E38, F38, G38, A38, B38, C39, D39, E39, F39, G39, A39, B39, C40, D40, E40, F40, G40, A40, B40, C41, D41, E41, F41, G41, A41, B41, C42, D42, E42, F42, G42, A42, B42, C43, D43, E43, F43, G43, A43, B43, C44, D44, E44, F44, G44, A44, B44, C45, D45, E45, F45, G45, A45, B45, C46, D46, E46, F46, G46, A46, B46, C47, D47, E47, F47, G47, A47, B47, C48, D48, E48, F48, G48, A48, B48, C49, D49, E49, F49, G49, A49, B49, C50, D50, E50, F50, G50, A50, B50, C51, D51, E51, F51, G51, A51, B51, C52, D52, E52, F52, G52, A52, B52, C53, D53, E53, F53, G53, A53, B53, C54, D54, E54, F54, G54, A54, B54, C55, D55, E55, F55, G55, A55, B55, C56, D56, E56, F56, G56, A56, B56, C57, D57, E57, F57, G57, A57, B57, C58, D58, E58, F58, G58, A58, B58, C59, D59, E59, F59, G59, A59, B59, C60, D60, E60, F60, G60, A60, B60, C61, D61, E61, F61, G61, A61, B61, C62, D62, E62, F62, G62, A62, B62, C63, D63, E63, F63, G63, A63, B63, C64, D64, E64, F64, G64, A64, B64, C65, D65, E65, F65, G65, A65, B65, C66, D66, E66, F66, G66, A66, B66, C67, D67, E67, F67, G67, A67, B67, C68, D68, E68, F68, G68, A68, B68, C69, D69, E69, F69, G69, A69, B69, C70, D70, E70, F70, G70, A70, B70, C71, D71, E71, F71, G71, A71, B71, C72, D72, E72, F72, G72, A72, B72, C73, D73, E73, F73, G73, A73, B73, C74, D74, E74, F74, G74, A74, B74, C75, D75, E75, F75, G75, A75, B75, C76, D76, E76, F76, G76, A76, B76, C77, D77, E77, F77, G77, A77, B77, C78, D78, E78, F78, G78, A78, B78, C79, D79, E79, F79, G79, A79, B79, C80, D80, E80, F80, G80, A80, B80, C81, D81, E81, F81, G81, A81, B81, C82, D82, E82, F82, G82, A82, B82, C83, D83, E83, F83, G83, A83, B83, C84, D84, E84, F84, G84, A84, B84, C85, D85, E85, F85, G85, A85, B85, C86, D86, E86, F86, G86, A86, B86, C87, 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A136, B136, C137, D137, E137, F137, G137, A137, B137, C138, D138, E138, F138, G138, A138, B138, C139, D139, E139, F139, G139, A139, B139, C140, D140, E140, F140, G140, A140, B140, C141, D141, E141, F141, G141, A141, B141, C142, D142, E142, F142, G142, A142, B142, C143, D143, E143, F143, G143, A143, B143, C144, D144, E144, F144, G144, A144, B144, C145, D145, E145, F145, G145, A145, B145, C146, D146, E146, F146, G146, A146, B146, C147, D147, E147, F147, G147, A147, B147, C148, D148, E148, F148, G148, A148, B148, C149, D149, E149, F149, G149, A149, B149, C150, D150, E150, F150, G150, A150, B150, C151, D151, E151, F151, G151, A151, B151, C152, D152, E152, F152, G152, A152, B152, C153, D153, E153, F153, G153, A153, B153, C154, D154, E154, F154, G154, A154, B154, C155, D155, E155, F155, G155, A155, B155, C156, D156, E156, F156, G156, A156, B156, C157, D157, E157, F157, G157, A157, B157, C158, D158, E158, F158, G158, A158, B158, C159, D159, E159, F159, G159, A159, B159, C160, D160, E160, F160, G160, A160, B160, C161, D161, E161, F161, G161, A161, B161, C162, D162, E162, F162, G162, A162, B162, C163, D163, E163, F163, G163, A163, B163, C164, D164, E164, F164, G164, A164, B164, C165, D165, E165, F165, G165, A165, B165, C166, D166, E166, F166, G166, A166, B166, C167, D167, E167, F167, G167, A167, B167, C168, D168, E168, F168, G168, A168, B168, C169, D169, E169, F169, G169, A169, B169, C170, D170, E170, F170, G170, A170, B170, C171, D171, E171, F171, G171, A171, B171, C172, D172, E172, F172, G172, A172, B172, C173, D173, E173, F173, G173, A173, B173, C174, D174, E174, F174, G174, A174, B174, C175, D175, E175, F175, G175, A175, B175, C176, D176, E176, F176, G176, A176, B176, C177, D177, E177, F177, G177, A177, B177, C178, D178, E178, F178, G178, A178, B178, C179, D179, E179, F179, G179, A179, B179, C180, D180, E180, F180, G180, A180, B180, C181, D181, E181, F181, G181, A181, B181, C182, D182, E182, F182, G182, A182, B182, C183, D183, E183, F183, G183, A183, B183, C184, D184, E184, F184, G184, A184, B184, C185, D185, E185, F185, G185, A185, B185, C186, D186, E186, F186, G186, A186, B186, C187, D187, E187, F187, G187, A187, B187, C188, D188, E188, F188, G188, A188, B188, C189, D189, E189, F189, G189, A189, B189, C190, D190, E190, F190, G190, A190, B190, C191, D191, E191, F191, G191, A191, B191, C192, D192, E192, F192, G192, A192, B192, C193, D193, E193, F193, G193, A193, B193, C194, D194, E194, F194, G194, A194, B194, C195, D195, E195, F195, G195, A195, B195, C196, D196, E196, F196, G196, A196, B196, C197, D197, E197, F197, G197, A197, B197, C198, D198, E198, F198, G198, A198, B198, C199, D199, E199, F199, G199, A199, B199, C200, D200, E200, F200, G200, A200, B200, C201, D201, E201, F201, G201, A201, B201, C202, D202, E202, F202, G202, A202, B202, C203, D203, E203, F203, G203, A203, B203, C204, D204, E204, F204, G204, A204, B204, C205, D205, E205, F205, G205, A205, B205, C206, D206, E206, F206, G206, A206, B206, C207, D207, E207, F207, G207, A207, B207, C208, D208, E208, F208, G208, A208, B208, C209, D209, E209, F209, G209, A209, B209, C210, D210, E210, F210, G210, A210, B210, C211, D211, E211, F211, G211, A211, B211, C212, D212, E212, F212, G212, A212, B212, C213, D213, E213, F213, G213, A213, B213, C214, D214, E214, F214, G214, A214, B214, C215, D215, E215, F215, G215, A215, B215, C216, D216, E216, F216, G216, A216, B216, C217, D217, E217, F217, G217, A217, B217, C218, D218, E218, F218, G218, A218, B218, C219, D219, E219, F219, G219, A219, B219, C220, D220, E220, F220, G220, A220, B220, C221, D221, E221, F221, G221, A221, B221, C222, D222, E222, F222, G222, A222, B222, C223, D223, E223, F223, G223, A223, B223, C224, D224, E224, F224, G224, A224, B224, C225, D225, E225, F225, G225, A225, B225, C226, D226, E226, F226, G226, A226, B226, C227, D227, E227, F227, G227, A227, B227, C228, D228, E228, F228, G228, A228, B228, C229, D229, E229, F229, G229, A229, B229, C230, D230, E230, F230, G230, A230, B230, C231, D231, E231, F231, G231, A231, B231, C232, D232, E232, F232, G232, A232, B232, C233, D233, E233, F233, G233, A233, B233, C234, D234, E234, F234, G234, A234, B234, C235, D235, E235, F235, G235, A235, B235, C236, D236, E236, F236, G236, A236, B236, C237, D237, E237, F237, G237, A237, B237, C238, D238, E238, F238, G238, A238, B238, C239, D239, E239, F239, G239, A239, B239, C240, D240, E240, F240, G240, A240, B240, C241, D241, E241, F241, G241, A241, B241, C242, D242, E242, F242, G242, A242, B242, C243, D243, E243, F243, G243, A243, B243, C244, D244, E244, F244, G244, A244, B244, C245, D245, E245, F245, G245, A245, B245, C246, D246, E246, F246, G246, A246, B246, C247, D247, E247, F247, G247, A247, B247, C248, D248, E248, F248, G248, A248, B248, C249, D249, E249, F249, G249, A249, B249, C250, D250, E250, F250, G250, A250, B250, C251, D251, E251, F251, G251, A251, B251, C252, D252, E252, F252, G252, A252, B252, C253, D253, E253, F253, G253, A253, B253, C254, D254, E254, F254, G254, A254, B254, C255, D255, E255, F255, G255, A255, B255, C256, D256, E256, F256, G256, A256, B256, C257, D257, E257, F257, G257, A257, B257, C258, D258, E258, F258, G258, A258, B258, C259, D259, E259, F259, G259, A259, B259, C260, D260, E260, F260, G260, A260, B260, C261, D261, E261, F261, G261, A261, B261, C262, D262, E262, F262, G262, A262, B262, C263, D263, E263, F263, G263, A263, B263, C264, D264, E264, F264, G264, A264, B264, C265, D265, E265, F265, G265, A265, B265, C266, D266, E266, F266, G266, A266, B266, C267, D267, E267, F267, G267, A267, B267, C268, D268, E268, F268, G268, A268, B268, C269, D269, E269, F269, G269, A269, B269, C270, D270, E270, F270, G270, A270, B270, C271, D271, E271, F271, G271, A271, B271, C272, D272, E272, F272, G272, A272, B272, C273, D273, E273, F273, G273, A273, B273, C274, D274, E274, F274, G274, A274, B274, C275, D275, E275, F275, G275, A275, B275, C276, D276, E276, F276, G276, A276, B276, C277, D277, E277, F277, G277, A277, B277, C278, D278, E278, F278, G278, A278, B278, 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A302, B302, C303, D303, E303, F303, G303, A303, B303, C304, D304, E304, F304, G304, A304, B304, C305, D305, E305, F305, G305, A305, B305, C306, D306, E306, F306, G306, A306, B306, C307, D307, E307, F307, G307, A307, B307, C308, D308, E308, F308, G308, A308, B308, C309, D309, E309, F309, G309, A309, B309, C310, D310, E310, F310, G310, A310, B310, C311, D311, E311, F311, G311, A311, B311, C312, D312, E312, F312, G312, A312, B312, C313, D313, E313, F313, G313, A313, B313, C314, D314, E314, F314, G314, A314, B314, C315, D315, E315, F315, G315, A315, B315, C316, D316, E316, F316, G316, A316, B316, C317, D317, E317, F317, G317, A317, B317, C318, D318, E318, F318, G318, A318, B318, C319, D319, E319, F319, G319, A319, B319, C320, D320, E320, F320, G320, A320, B320, C321, D321, E321, F321, G321, A321, B321, C322, D322, E322, F322, G322, A322, B322, C323, D323, E323, F323, G323, A323, B323, C324, D324, E324, F324, G324, A324, B324, C325, D325, E325, F325, G325, A325, B325, C326, D326, E326, F326, G326, A326, B326, C327, D327, E327, F327, G327, A327, B327, C328, D328, E328, F328, G328, A328, B328, C329, D329, E329, F329, G329, A329, B329, C330, D330, E330, F330, G330, A330, B330, C331, D331, E331, F331, G331, A331, B331, C332, D332, E332, F332, G332, A332, B332, C333, D333, E333, F333, G333, A333, B333, C334, D334, E334, F334, G334, A334, B334, C335, D335, E335, F335, G335, A335, B335, C336, D336, E336, F336, G336, A336, B336, C337, D337, E337, F337, G337, A337, B337, C338, D338, E338, F338, G338, A338, B338, C339, D339, E339, F339, G339, A339, B339, C340, D340, E340, F340, G340, A340, B340, C341, D341, E341, F341, G341, A341, B341, C342, D342, E342, F342, G342, A342, B342, C343, D343, E343, F343, G343, A343, B343, C344, D344, E344, F344, G344, A344, B344, C345, D345, E345, F345, G345, A345, B345, C346, D346, E346, F346, G346, A346, B346, C347, D347, E347, F347, G347, A347, B347, C348, D348, E348, F348, G348, A348, B348, C349, D349, E349, F349, G349, A349, B349, C350, D350, E350, F350, G350, A350, B350, C351, D351, E351, F351, G351, A351, B351, C352, D352, E352, F352, G352, A352, B352, C353, D353, E353, F353, G353, A353, B353, C354, D354, E354, F354, G354, A354, B354, C355, D355, E355, F355, G355, A355, B355, C356, D356, E356, F356, G356, A356, B356, C357, D357, E357, F357, G357, A357, B357, C358, D358, E358, F358, G358, A358, B358, C359, D359, E359, F359, G359, A359, B359, C360, D360, E360, F360, G360, A360, B360, C361, D361, E361, F361, G361, A361, B361, C362, D362, E362, F362, G362, A362, B362, C363, D363, E363, F363, G363, A363, B363, C364, D364, E364, F364, G364, A364, B364, C365, D365, E365, F365, G365, A365, B365, C366, D366, E366, F366, G366, A366, B366, C367, D367, E367, F367, G367, A367, B367, C368, D368, E368, F368, G368, A368, B368, C369, D369, E369, F369, G369, A369, B369, C370, D370, E370, F370, G370, A370, B370, C371, D371, E371, F371

Dataset

Each column
represents a voice

Humdrum ****kern** syntax

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d

Dataset

KernScores

<http://kern.ccarh.org/>

Virtual library of musical scores in Humdrum **kern format

Allocates musical scores for **19 out of 24 pieces** of the String quartets Op.20

Dataset

KernScores

<http://kern.ccarh.org/>

Virtual library of musical scores in Humdrum **kern format

Allocates musical scores for 19 out of 24 pieces of the String quartets Op.20

Transcribing 5 remaining scores

Dataset

The Humdrum ****harm** syntax

<http://www.music-cog.ohio-state.edu/Humdrum/representations/harm.rep.html>

Very detailed syntax for roman numerals

Allows to annotate roman numerals in a machine-friendly

and (sort of) human-friendly format

Dataset

Humdrum ****kern**, ****harm** syntax

**harm	**commentary	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g;	*g;	*g;	*g;	*g;	*g;
*	*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	.	2r	2r	2r	2r
.	.	4r	4r	4r	4d
=1	=1	=1	=1	=1	=1
i	.	4G	2.r	4B-	4b-
iio	Not really diminished, missing the fifth	4A	.	4c	4a
ib	.	4B-	.	4d	4g
=2	=2	=2	=2	=2	=2
iv	.	2c	2r	2e-	4g
.	.	.	.	.	4g
ib	.	4B-	4d	4d	4g
=3	=3	=3	=3	=3	=3
viiob	.	[2.A	[2.c	[2.f#	4cc
.	.	.	.	.	4cc
V7c	.	.	.	.	4dd
=4	=4	=4	=4	=4	=4
viiioD7b	.	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	.	4ee-
=5	=5	=5	=5	=5	=5
V7c	.	4A]	4c]	4f#]	4dd
.	.	2r	2r	2r	4r
.	.	.	.	.	4d

Dataset

Humdrum ****kern, **harm** syntax

Manual
annotation of
harmony

**harm	**commentary	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g;	*g;	*g;	*g;	*g;	*g;
*	*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	.	2r	2r	2r	2r
.	.	4r	4r	4r	4d
=1	=1	=1	=1	=1	=1
i	.	4G	2.r	4B-	4b-
iio	Not really diminished, missing the fifth	4A	.	4c	4a
ib	.	4B-	.	4d	4g
=2	=2	=2	=2	=2	=2
iv	.	2c	2r	2e-	4g
.	.	.	.	.	4g
ib	.	4B-	4d	4d	4g
=3	=3	=3	=3	=3	=3
viiob	.	[2.A	[2.c	[2.f#	4cc
.	.	.	.	.	4cc
V7c	.	.	.	.	4dd
=4	=4	=4	=4	=4	=4
viiOD7b	.	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	.	4ee-
=5	=5	=5	=5	=5	=5
V7c	.	4A]	4c]	4f#]	4dd
.	.	2r	2r	2r	4r
.	.	.	.	.	4d

Dataset

Summary of the dataset

Six string quartets

24 pieces of music

146 pages of music notation (Altmann Edition)

4961 roman numerals annotations

Commentaries (ambiguous sections, structural analysis, etc.)

https://github.com/napulen/haydn_op20_harm

Structure of the presentation

1. Automatic Harmonic Analysis
2. The dataset: Six string quartets Op.20, Joseph Haydn
3. Running the analysis
4. Evaluation
5. Results
6. Contributions

Running the analysis



Automatic
Harmonic
Analysis



i ii° i6 iv i6 vii°6

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d



Automatic Harmonic Analysis



**harm	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:	*g:
*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	2r	2r	2r	2r
.	4r	4r	4r	4d
=1	=1	=1	=1	=1
i	4G	2.r	4B-	4b-
iio	4A	.	4c	4a
ib	4B-	.	4d	4g
=2	=2	=2	=2	=2
iv	2c	2r	2e-	4g
.	.	.	.	4g
ib	4B-	4d	4d	4g
=3	=3	=3	=3	=3
viiob	[2.A	[2.c	[2.f#	4cc
.	.	.	.	4cc
V7c	.	.	.	4dd
=4	=4	=4	=4	=4
viiOD7b	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	4ee-
=5	=5	=5	=5	=5
V7c	4A]	4c]	4f#]	4dd
.	2r	2r	2r	4r
.	.	.	.	4d

Running the analysis

Approach	Type of Model	Year	Implementation	Available
Terry Winograd	Grammar-based	1968	LISP	No
John Maxwell	Rule-based	1992*	LISP	No
David Temperley	Rule-based	1997**	C	Yes
Christopher Raphael	Probabilistic	2003	C	Partially
Plácido Illescas	Rule-based	2008	Java	Partially

** Maxwell presented this work at his PhD dissertation in 1984. However, most researchers cite the publication from 1992 in the book “Understanding music with AI”.*

***A lot of work has been done after Temperley in 1997, traceable to as recent as 2017. This reference is just the starting point for this approach.*

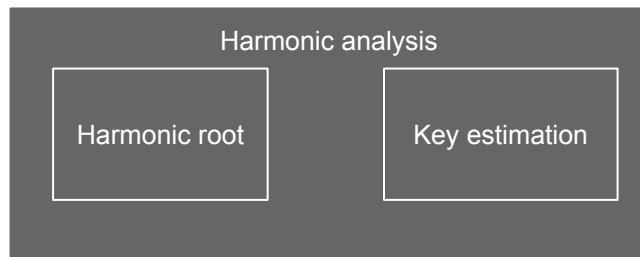
Running the analysis

Approach	Type of Model	Year	Implementation	Available
Terry Winograd	Grammar-based	1968	LISP	No
John Maxwell	Rule-based	1992*	LISP	No
David Temperley	Rule-based	1997**	C	Yes
Christopher Raphael	Probabilistic	2003	C	Partially
Plácido Illescas	Rule-based	2008	Java	Partially

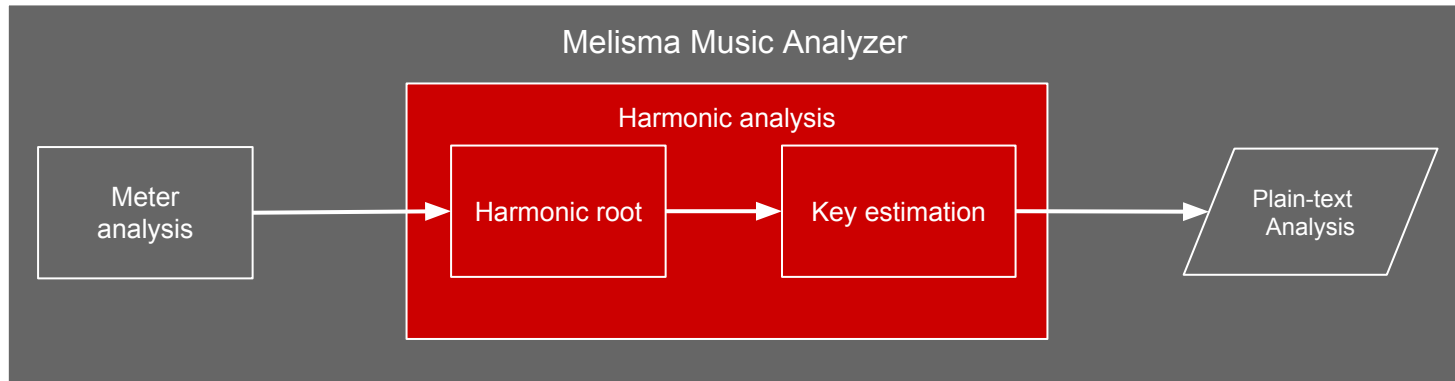
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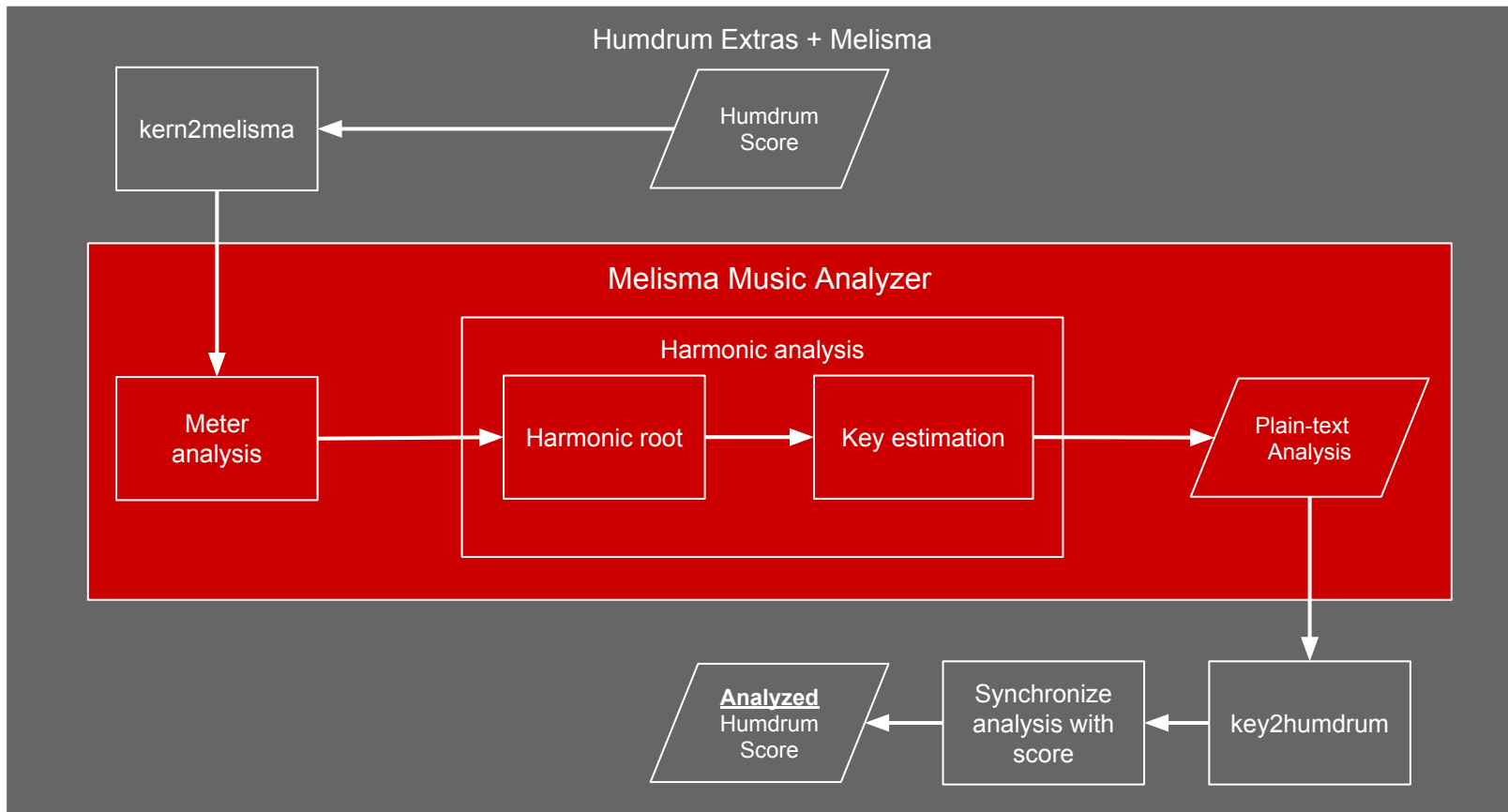
Running the analysis



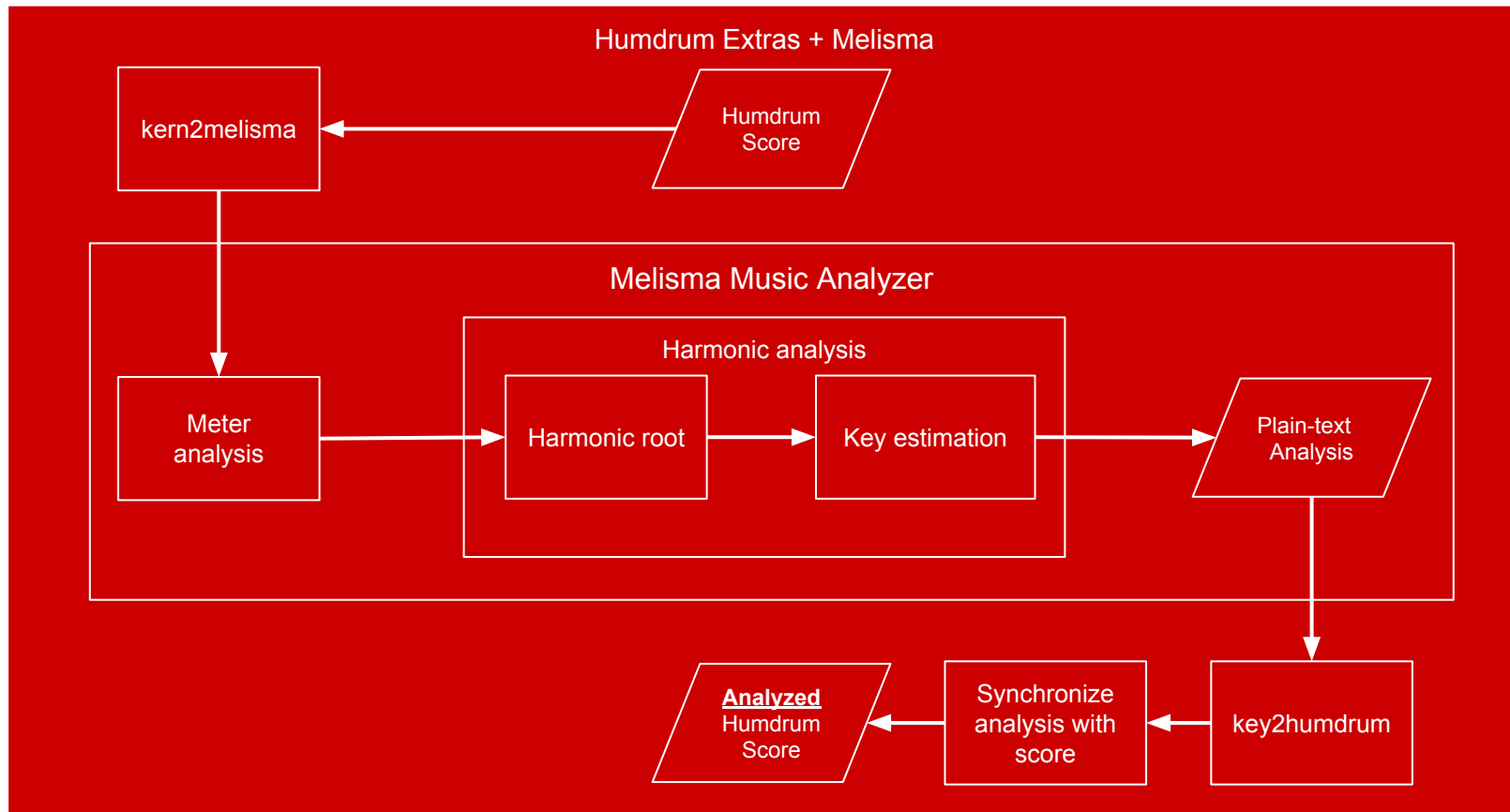
Running the analysis



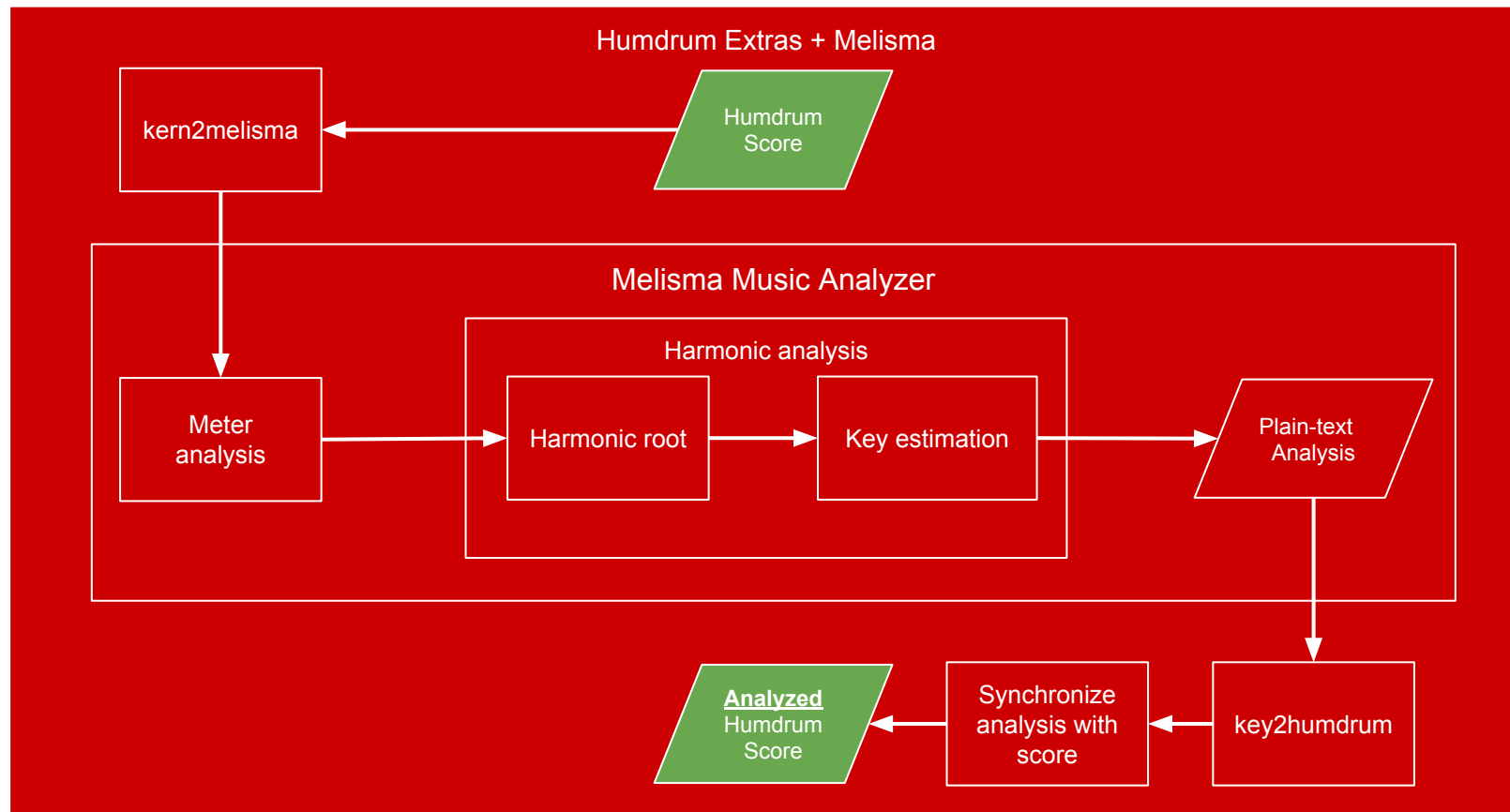
Running the analysis



Running the analysis



Running the analysis



Running the analysis

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d



Automatic
Harmonic
Analysis



**harm	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:	*g:
*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	2r	2r	2r	2r
.	4r	4r	4r	4d
=1	=1	=1	=1	=1
i	4G	2.r	4B-	4b-
iiio	4A	.	4c	4a
ib	4B-	.	4d	4g
=2	=2	=2	=2	=2
iv	2c	2r	2e-	4g
.	.	.	.	4g
ib	4B-	4d	4d	4g
=3	=3	=3	=3	=3
viiob	[2.A	[2.c	[2.f#	4cc
.	.	.	.	4cc
V7c	.	.	.	4dd
=4	=4	=4	=4	=4
viiOD7b	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	4ee-
=5	=5	=5	=5	=5
V7c	4A]	4c]	4f#]	4dd
.	2r	2r	2r	4r
.	.	.	.	4d

Running the analysis

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d

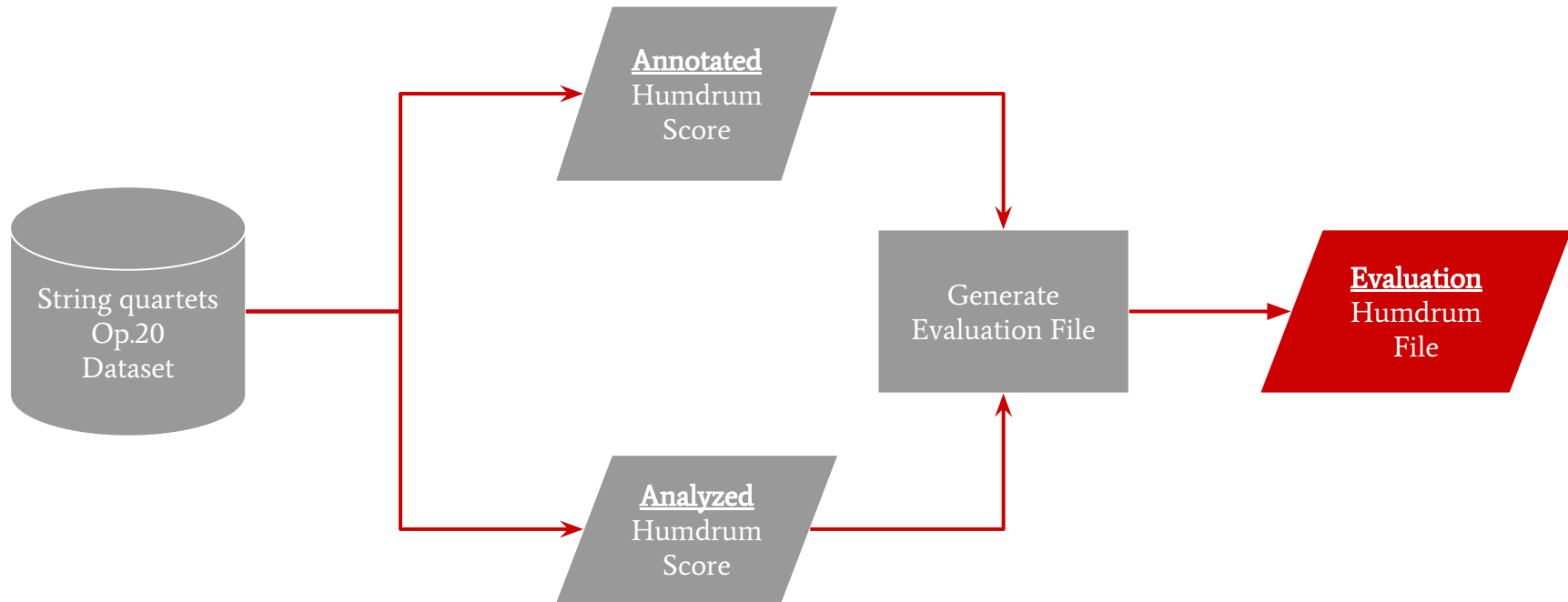


Humdrum
Extras
+
Melisma
Music
Analyzer



**harm	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:	*g:
*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	2r	2r	2r	2r
.	4r	4r	4r	4d
=1	=1	=1	=1	=1
i	4G	2.r	4B-	4b-
iio	4A	.	4c	4a
ib	4B-	.	4d	4g
=2	=2	=2	=2	=2
iv	2c	2r	2e-	4g
.	.	.	.	4g
ib	4B-	4d	4d	4g
=3	=3	=3	=3	=3
viiob	[2.A	[2.c	[2.f#	4cc
.	.	.	.	4cc
V7c	.	.	.	4dd
=4	=4	=4	=4	=4
viiOD7b	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	4ee-
=5	=5	=5	=5	=5
V7c	4A]	4c]	4f#]	4dd
.	2r	2r	2r	4r
.	.	.	.	4d

Running the analysis



Structure of the presentation

1. Automatic Harmonic Analysis
2. The dataset: Six string quartets Op.20, Joseph Haydn
3. Running the analysis
4. Evaluation
5. Results
6. Contributions

Evaluation

Evaluation file

It is a valid Humdrum file. However, it is no longer a musical score

Contains two pairs of ****harm **root** spines

Evaluation

**harm	**root	**harm	**root
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
=1	=1	=1	=1
i	g	.	.
.	.	.	.
iiio	a	iv	f
.	.	.	.
ib	g	.	.
.	.	.	.
=2	=2	=2	=2
iv	c	ib	c
.	.	.	.
.	.	V7c	g
.	.	.	.
ib	g	.	.
.	.	.	.

Evaluation

Manual annotations

**harm	**root
.	.
.	.
.	.
.	.
.	.
.	.
=1	=1
i	g
.	.
iiio	a
.	.
ib	g
.	.
=2	=2
iv	c
.	.
.	.
.	.
ib	g
.	.

Automatic analysis

**harm	**root
.	.
.	.
.	.
.	.
.	.
.	.
=1	=1
.	.
.	.
iv	f
.	.
.	.
.	.
=2	=2
ib	c
.	.
V7c	g
.	.
.	.
.	.
.	.

Evaluation

Summary of evaluation

Normalization of time units,

resolution of harmonic roots,

string comparison of harmonic roots per time unit

output the percentage of matches over the time units

Evaluation

Normalization of time units

Shortest note of the musical score

Evaluation

Resolution of harmonic roots

Cmajor: I == Gmajor: IV

Cmajor: V/V == Gmajor: V

Cmajor: V7/vi == Dminor: V7/V

Evaluation

Resolution of harmonic roots

Developed a parser for the `**harm` syntax

<https://github.com/napulen/harmparser>

Input a `**harm` expression and output its characteristics

Using this to resolve the harmonic roots of different labels,
even if they are relative to different keys

Structure of the presentation

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Results

	Matching time units	Total time units	Score
Op.20 No.1			
I	2261	3489	64.80%
II	221	805	27.45%
III	1319	1730	76.24%
IV	332	1289	25.76%
Op.20 No.2			
I	1254	5137	24.41%
II	1119	2017	55.48%
III	713	1033	69.02%
IV	309	1945	15.89%
Op.20 No.3			
I	2426	4322	56.13%
II	121	535	22.62%
III	3386	4069	83.21%
IV	535	1681	31.83%
Op.20 No.4			
I	2464	3663	67.27%
II	1992	3922	50.79%
III	65	223	29.15%
IV	1651	6289	26.25%
Op.20 No.5			
I	4950	7729	64.04%
II	793	1201	66.03%
III	2617	3061	85.49%
IV	798	1473	54.18%
Op.20 No.6			
I	1808	3985	45.37%
II	6217	7585	81.96%
III	405	505	80.20%
IV	1361	3041	44.76%

Structure of the presentation

1. Automatic Harmonic Analysis
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3. Running the analysis
4. Evaluation
5. Results
6. Contributions

Contributions

1. Reproducing the harmonic analysis done in the backend of KernScores
2. Finding, and in some cases, fixing issues
3. The Op.20 dataset of manual annotations
 - a. With help of Rafael Caro for the first movement of each quartet
4. A basic evaluation process
5. A parser for the `**harm` syntax

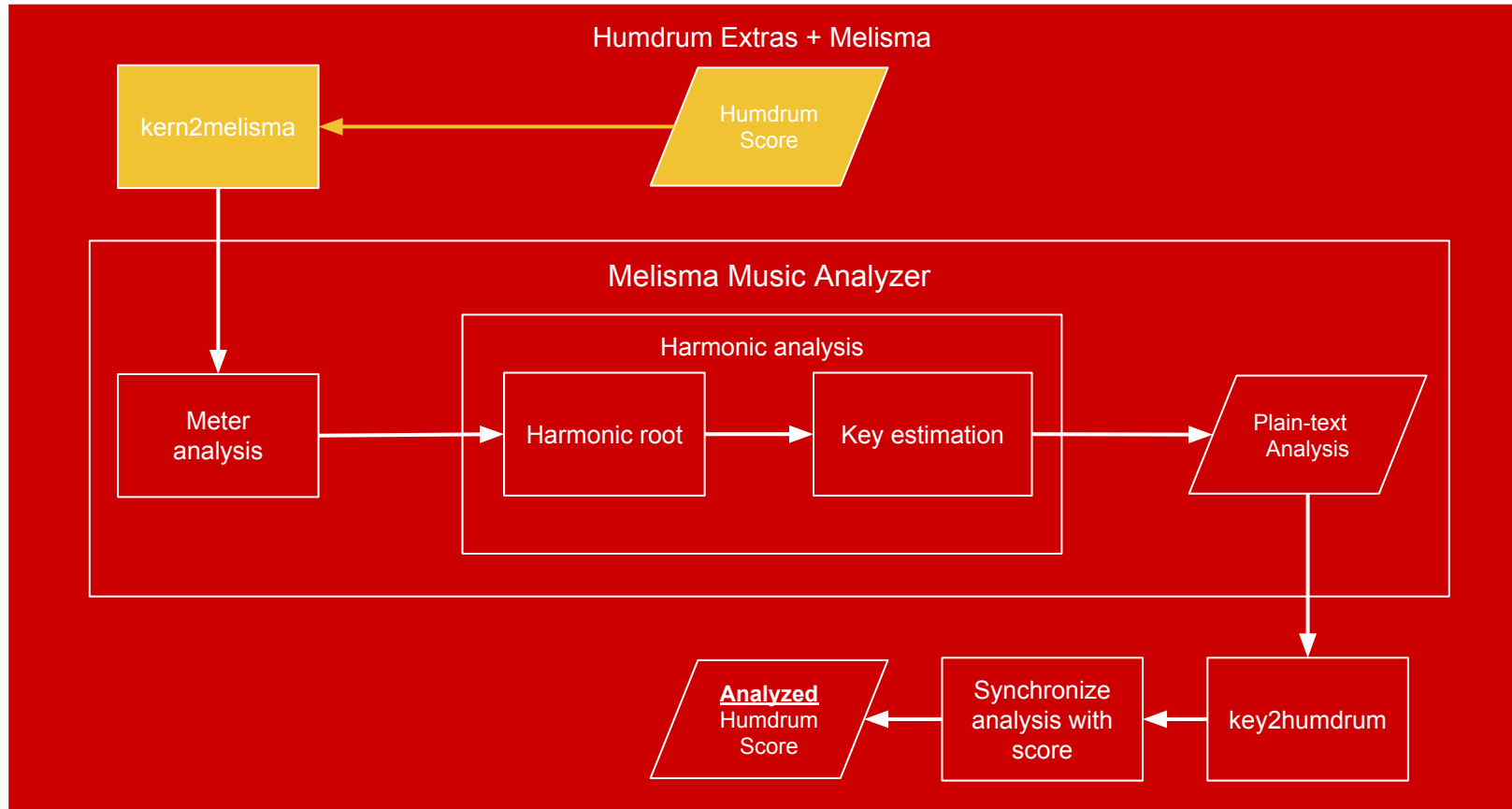
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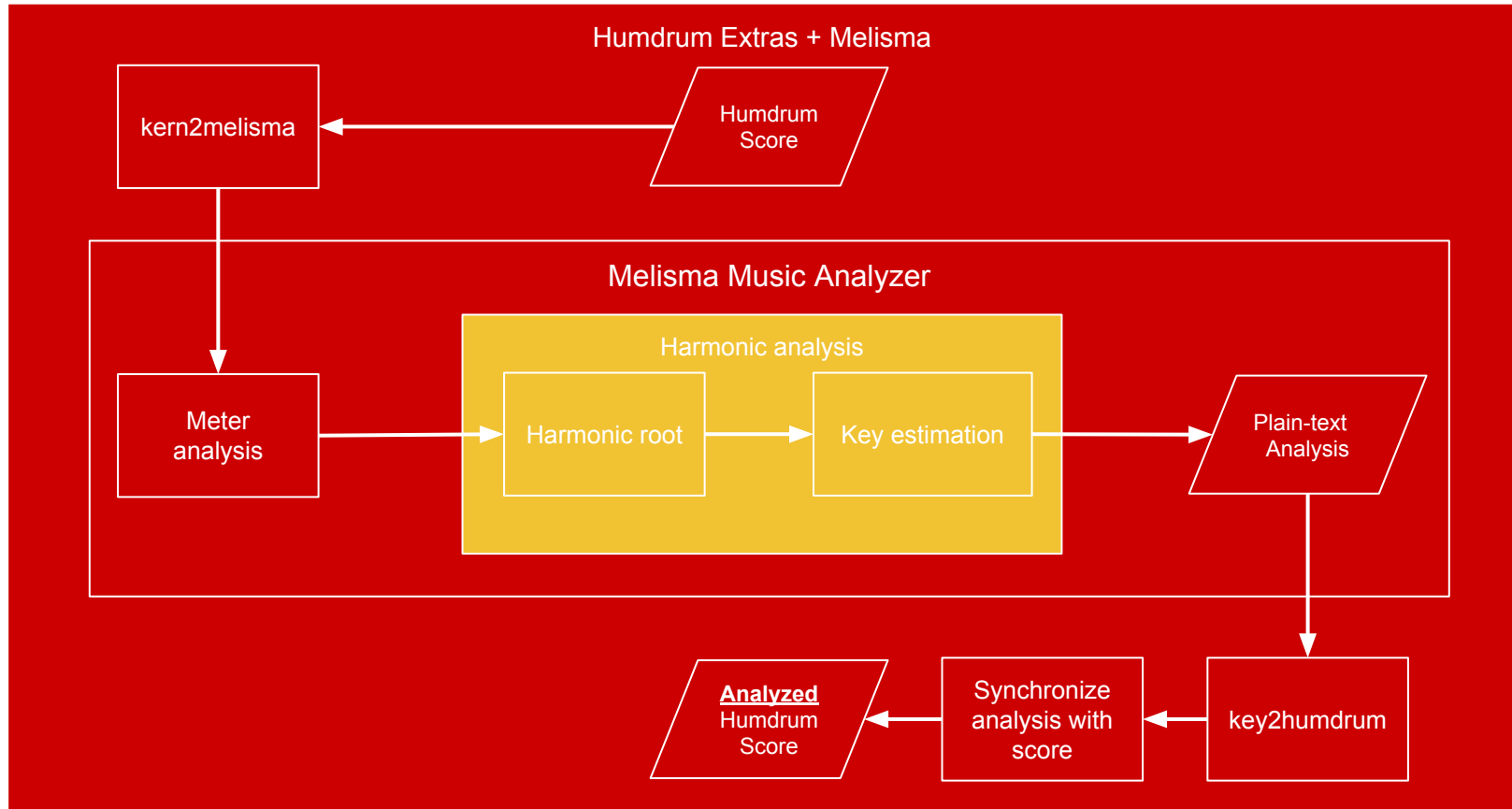
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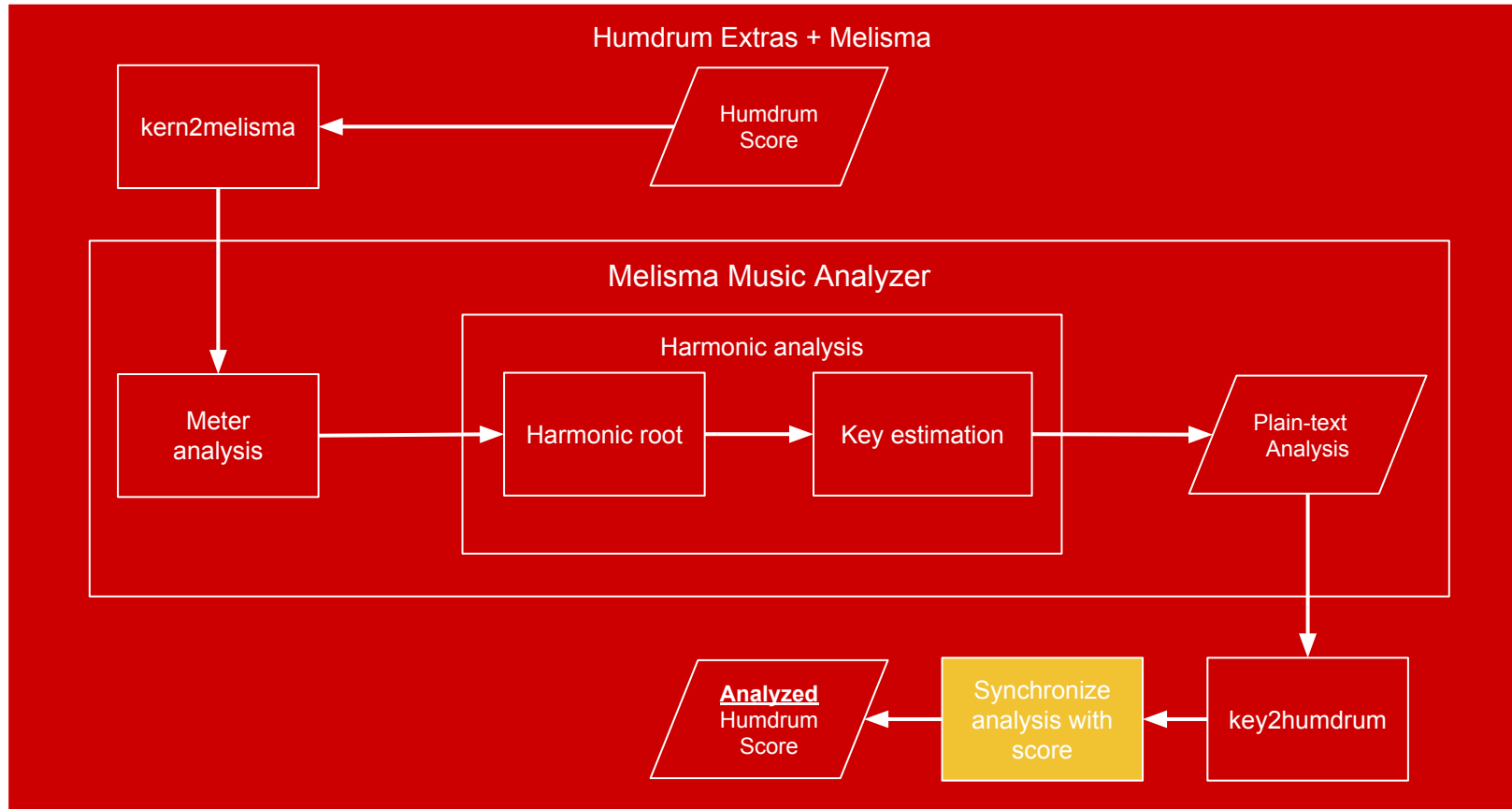
Running the analysis



Running the analysis



Running the analysis



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Thank you

Backup Slides

Isn't there any more recent research than that?

Isn't there any more recent research than that?

Sort of, but not entirely.

They are considering a pre-processed music score,
especially ignoring the difficult problem of non-harmonic tones

They output a different kind of label notation

**harm parser

```

^(
  (?P<accidental>          # Named group _accidental
  [#-]{0,2})

  (?P<root>                # Named group _root_
  i|ii|iii|iv|v|vi|vii|   # Minor mode degrees
  I|II|III|IV|V|VI|VII|   # Major mode degrees
  N|Gn|Lt|Fr|Tr)          # Special chords

  (?P<attribute>           # Named group _attribute_
  [o+]?)

  ((?P<intervals>          # Named group _intervals
  \d+|[mMPAD]\d+|         # Detect minor, Major, Augmented or Diminished intervals
  AA\d+|                  # Double-augmented intervals
  DD\d+|                  # Double-diminished intervals
  *)                       # Not a limit on how many intervals can be added

  (?P<inversion>           # Named group _inversions_
  [b-d]?)                 # Only third inversions possible so far

  ([
  (?P<alternative>         # Named group _alternative_
  ([^\\[\\]])+)           # Match at least one time for any expression inside brackets
  \\                       # Close brackets
  ]?)                     # If no alternative expression, then no brackets should appear at all

  (/                       # Slash implies a secondary function
  (?P<secondary>          # Named group _secondary_
  ([\\s\\S])+)            # Get all the expression after the slash symbol
  )?                      # If no secondary function, then the slash symbol should not appear
)$

```