A decorative graphic on the left side of the slide, consisting of a grid of squares in various shades of blue and purple, arranged in a pattern that tapers to the right.

Using Statistical Feature Extraction to Distinguish the Styles of Different Composers

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Topics

- Introduction to “features” (from a machine learning perspective)
 - And how they can be useful for musicologists and music theorists
- jSymbolic2
 - And how it can be useful to music theorists and musicologists
- Composer attribution study

Personal context

- I was originally trained as a physicist and as a jazz guitarist before changing careers and focusing on music information retrieval
- As a former physicist, I am deeply attached to:
 - Overarching **abstract theoretical models**
 - **Empirical validation** of those models
- I think we do a great job at the first of these in music theory and musicology
 - But there is still room for improvement with respect to the second

Empiricism, software & statistics

- Empiricism, automated software tools and statistical analysis techniques allow us to:
 - Study huge quantities of music very quickly
 - More than any human could reasonably look at
 - Empirically validate (or repudiate) our theoretical suspicions
 - Do purely exploratory studies of music
 - See music from fresh perspectives
 - Can inspire new ways of looking at music

Human involvement is crucial

- Of course, computers certainly **cannot replace** the expertise and insight of musicologists and theorists
 - Computers instead serve as powerful **tools** and **assistants** that allow us to greatly expand the scope and reliability of our work
- Computers do not understand musical experience
 - We must **pose the research questions** for them to investigate
 - We must **interpret the results** they present us with
- Music is, after all, defined by human experience, not some “objective” externality

What are “features”?

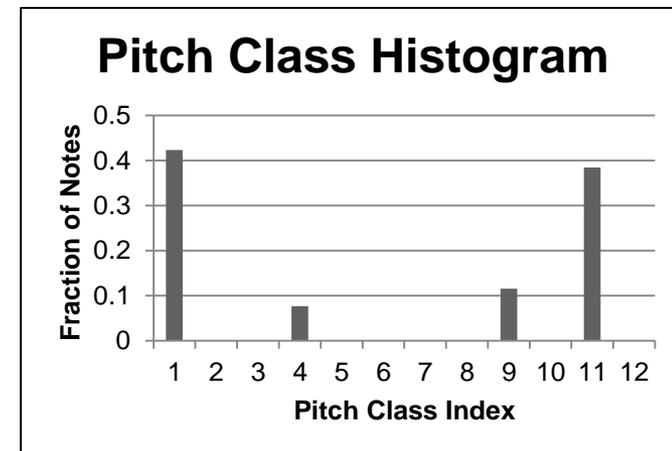
- Pieces of information that can **characterize something** (e.g. a piece of music) in a **simple way**
- Usually **numerical values**
 - A feature can be a **single value**, or it can be a **set of related values** (e.g. a histogram)
- Can be extracted from pieces **as a whole**, or from **segments** of pieces

Example: Two basic features

- **Range (1-D)**: Difference in semitones between the highest and lowest pitches.
- **Pitch Class Histogram (12-D)**: Each of its 12 values represents the fraction of notes with a particular pitch class. The first value corresponds to the most common pitch class, and each following value to a pitch class a semitone higher than the previous.



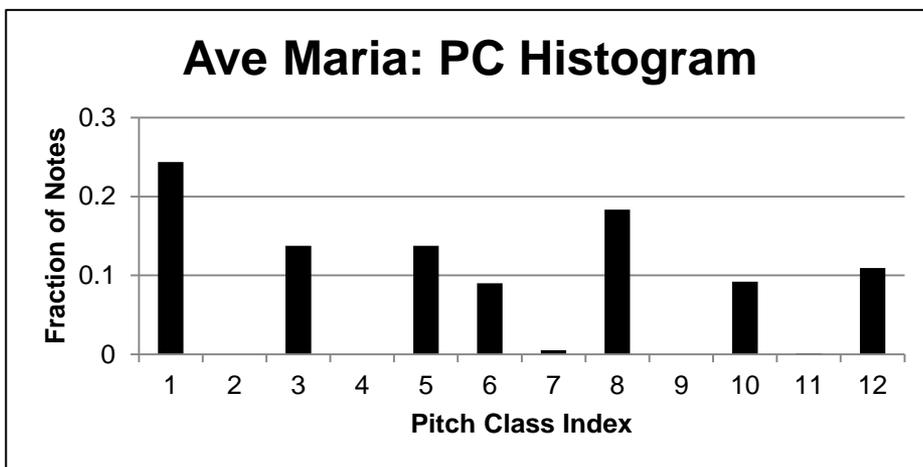
- **Range** = G - C = 7 semitones
- **Pitch Class Histogram**: see graph ->
 - Note counts: C: 3, D: 10, E: 11, G: 2
 - Most common note: E (11/26 notes)
 - Corresponding to 0.423 of the notes
 - E is thus pitch class 1, G is pitch class 4, C is pitch class 9, D is pitch class 11



Josquin's *Ave Maria... Virgo serena*

- Range: 34
- Repeated notes: 0.181
- Vertical perfect 4^{ths}: 0.070
- Rhythmic variability: 0.032
- Parallel motion: 0.039

Ave Maria... Virgo serena
Motet
Josquin Des Prez
(1440 - 1521)

Ockeghem's *Missa Mi-mi* (Kyrie)

Kyrie



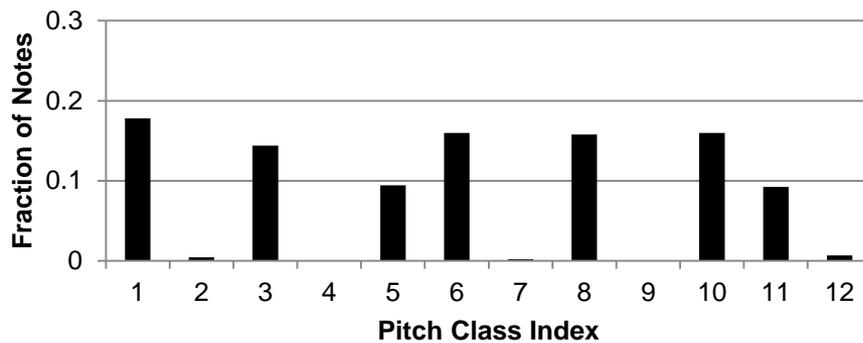
- Range: 26
- Repeated notes: 0.084
- Vertical perfect 4^{ths}: 0.109
- Rhythmic variability: 0.042
- Parallel motion: 0.076

Johannes Ockeghem



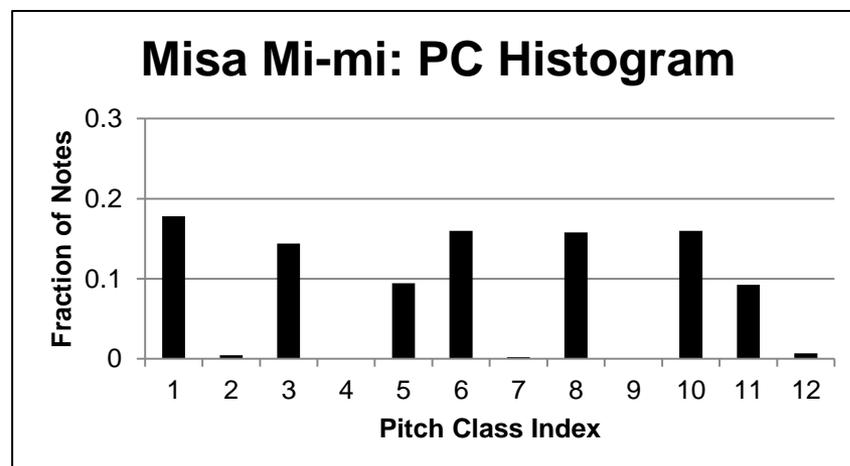
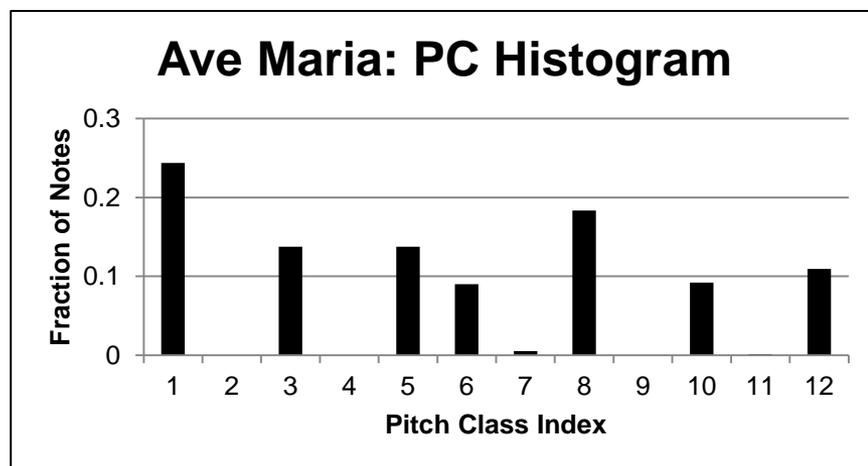


Missa Mi-mi: PC Histogram



Feature value comparison

Feature	Ave Maria	Misa Mi-mi
Range	34	26
Repeated notes	0.181	0.084
Vertical perfect 4 ^{ths}	0.070	0.109
Rhythmic variability	0.032	0.042
Parallel motion	0.039	0.076



How can we use features?

- Perform sophisticated **searches** of large musical databases
 - e.g. find all pieces with less than X amount of chromaticism and more than Y amount of contrary motion
- Use **machine learning** to classify or cluster music
 - e.g. identify the composers of unattributed musical pieces
- Apply **statistical analysis** and **visualization tools** to features extracted from large collections of music
 - Look for **patterns**
 - Study the relative musical **importance of various features**

jSymbolic2: Introduction

- **jSymbolic2** is a software platform we have implemented for extracting features from symbolic music
 - Part of our much larger **jMIR** package
- Compatible with **Macs**, **PCs** and **Linux** computers

What does jSymbolic2 do?

- Extracts **172 unique features**
- Some of these are **multi-dimensional histograms**, including:
 - Pitch and pitch class histograms
 - Melodic interval histograms
 - Vertical interval histograms
 - Chord types histograms
 - Beat histograms
 - Instrument histograms
- In all, extracts a total of **1230 separate values**

jSymbolic2: Feature types (1/2)

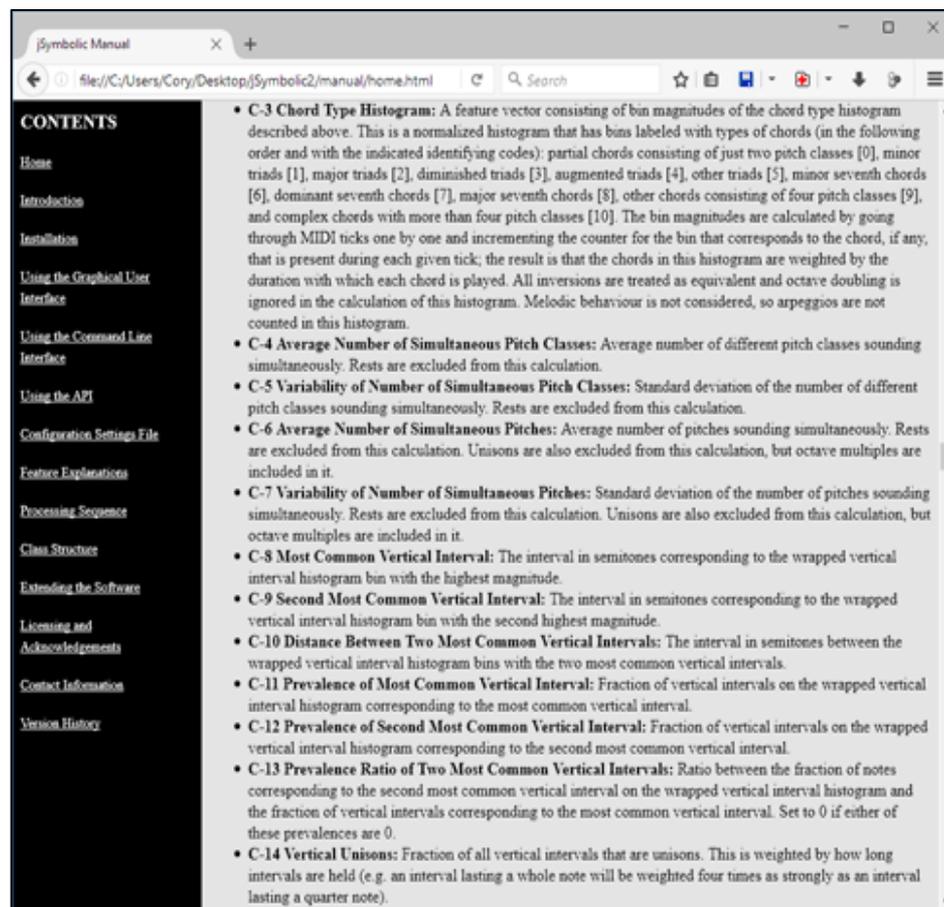
- Pitch Statistics:
 - What are the occurrence rates of different pitches and pitch classes?
 - How tonal is the piece?
 - How much variety in pitch is there?
- Melody / horizontal intervals:
 - What kinds of melodic intervals are present?
 - How much melodic variation is there?
 - What kinds of melodic contours are used?
 - What types of phrases are used?
- Chords / vertical intervals:
 - What vertical intervals are present?
 - What types of chords do they represent?
 - How much harmonic movement is there?

jSymbolic2: Feature types (2/2)

- Instrumentation:
 - What types of instruments are present and which are given particular importance relative to others?
- Texture:
 - How many independent voices are there and how do they interact (e.g., polyphonic, homophonic, etc.)?
- Rhythm:
 - Time intervals between the attacks of different notes
 - Duration of notes
 - What kinds of meters and rhythmic patterns are present?
 - Rubato?
- Dynamics:
 - How loud are notes and what kinds of dynamic variations occur?

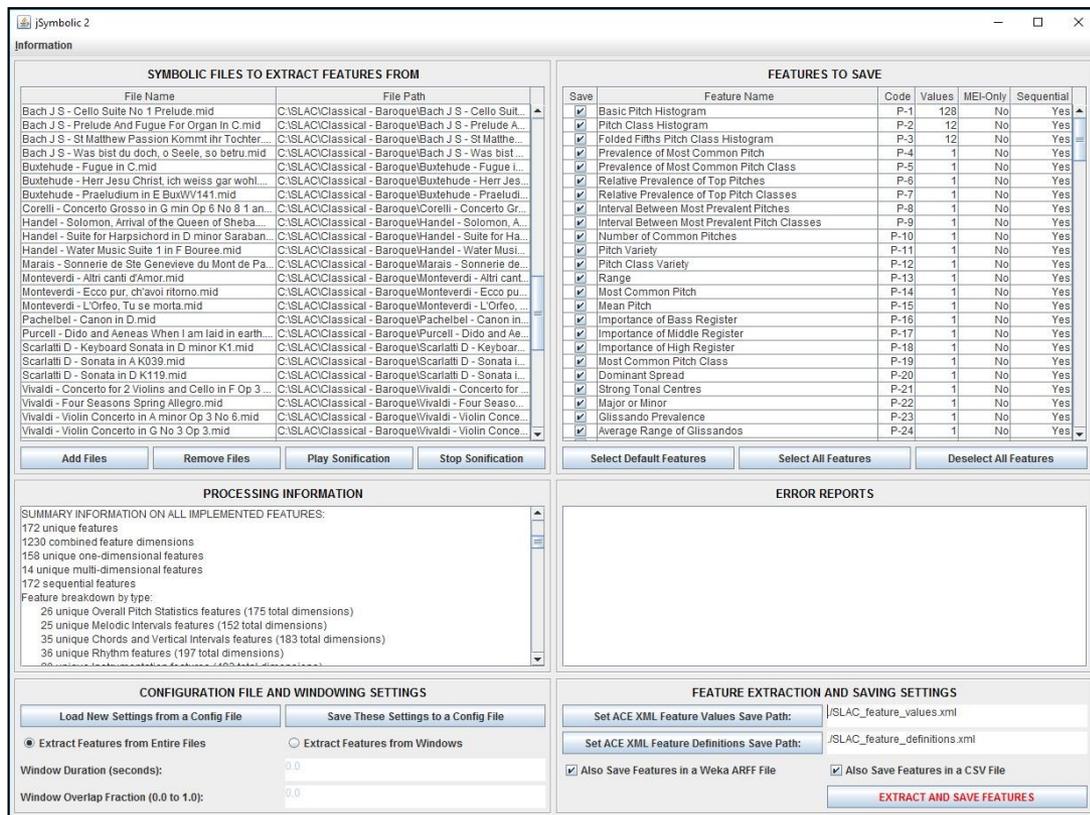
jSymbolic2: Manual

- Extensive manual includes:
 - Detailed **feature descriptions**
 - Detailed instructions on **installation and use**



jSymbolic2: User interfaces

- Graphical user interface
- Command line interface
- Java API
- Rodan workflow



The screenshot displays the jSymbolic 2 GUI with the following sections:

- SYMBOLIC FILES TO EXTRACT FEATURES FROM:** A table listing files and their paths.

File Name	File Path
Bach J S - Cello Suite No 1 Prelude.mid	C:\SLAC\Classical - Baroque\Bach J S - Cello Suit...
Bach J S - Prelude And Fugue For Organ In C.mid	C:\SLAC\Classical - Baroque\Bach J S - Prelude A...
Bach J S - St Matthew Passion Kommt ihr Tochter...	C:\SLAC\Classical - Baroque\Bach J S - St Matthe...
Bach J S - Was bist du doch, o Seele, so betru.mid	C:\SLAC\Classical - Baroque\Bach J S - Was bist...
Buxtehude - Fugue in C.mid	C:\SLAC\Classical - Baroque\Buxtehude - Fugue I...
Buxtehude - Herr Jesu Christ, ich weiss gar wohl...	C:\SLAC\Classical - Baroque\Buxtehude - Herr Jes...
Buxtehude - Praeludium in E BWV1141.mid	C:\SLAC\Classical - Baroque\Buxtehude - Praeludi...
Corelli - Concerto Grosso in G min Op 6 No 8 1 an...	C:\SLAC\Classical - Baroque\Corelli - Concerto Gr...
Handel - Solomon, Arrival of the Queen of Sheba...	C:\SLAC\Classical - Baroque\Handel - Solomon, A...
Handel - Suite for Harpsichord in D minor Saraban...	C:\SLAC\Classical - Baroque\Handel - Suite for Ha...
Handel - Water Music Suite 1 in F Bouree.mid	C:\SLAC\Classical - Baroque\Handel - Water Musi...
Marais - Sonnerie de Ste Genevieve du Mont de Pa...	C:\SLAC\Classical - Baroque\Marais - Sonnerie de...
Monteverdi - Altri canti d'Amor.mid	C:\SLAC\Classical - Baroque\Monteverdi - Altri cant...
Monteverdi - Ecco pur, ch'avoil ritorno.mid	C:\SLAC\Classical - Baroque\Monteverdi - Ecco pu...
Monteverdi - L'Orfeo, Tu se morta.mid	C:\SLAC\Classical - Baroque\Monteverdi - L'Orfeo, ...
Pachelbel - Canon in D.mid	C:\SLAC\Classical - Baroque\Pachelbel - Canon in...
Purcell - Dido and Aeneas When I am laid in earth...	C:\SLAC\Classical - Baroque\Purcell - Dido and Ae...
Scarlatti D - Keyboard Sonata in D minor K1.mid	C:\SLAC\Classical - Baroque\Scarlatti D - Keyboar...
Scarlatti D - Sonata in A K039.mid	C:\SLAC\Classical - Baroque\Scarlatti D - Sonata i...
Scarlatti D - Sonata in D K119.mid	C:\SLAC\Classical - Baroque\Scarlatti D - Sonata i...
Vivaldi - Concerto for 2 Violins and Cello in F Op 3...	C:\SLAC\Classical - Baroque\Vivaldi - Concerto for ...
Vivaldi - Four Seasons Spring Allegro.mid	C:\SLAC\Classical - Baroque\Vivaldi - Four Seaso...
Vivaldi - Violin Concerto in A minor Op 3 No 6.mid	C:\SLAC\Classical - Baroque\Vivaldi - Violin Conce...
Vivaldi - Violin Concerto in G No 3 Op 3.mid	C:\SLAC\Classical - Baroque\Vivaldi - Violin Conce...
- FEATURES TO SAVE:** A table of features with checkboxes for selection.

Save	Feature Name	Code	Values	MEI-Only	Sequential
<input checked="" type="checkbox"/>	Basic Pitch Histogram	P-1	128	No	Yes
<input checked="" type="checkbox"/>	Pitch Class Histogram	P-2	12	No	Yes
<input checked="" type="checkbox"/>	Folded Fifths Pitch Class Histogram	P-3	12	No	Yes
<input checked="" type="checkbox"/>	Prevalence of Most Common Pitch	P-4	1	No	Yes
<input checked="" type="checkbox"/>	Prevalence of Most Common Pitch Class	P-5	1	No	Yes
<input checked="" type="checkbox"/>	Relative Prevalence of Top Pitches	P-6	1	No	Yes
<input checked="" type="checkbox"/>	Relative Prevalence of Top Pitch Classes	P-7	1	No	Yes
<input checked="" type="checkbox"/>	Interval Between Most Prevalent Pitches	P-8	1	No	Yes
<input checked="" type="checkbox"/>	Interval Between Most Prevalent Pitch Classes	P-9	1	No	Yes
<input checked="" type="checkbox"/>	Number of Common Pitches	P-10	1	No	Yes
<input checked="" type="checkbox"/>	Pitch Variety	P-11	1	No	Yes
<input checked="" type="checkbox"/>	Pitch Class Variety	P-12	1	No	Yes
<input checked="" type="checkbox"/>	Range	P-13	1	No	Yes
<input checked="" type="checkbox"/>	Most Common Pitch	P-14	1	No	Yes
<input checked="" type="checkbox"/>	Mean Pitch	P-15	1	No	Yes
<input checked="" type="checkbox"/>	Importance of Bass Register	P-16	1	No	Yes
<input checked="" type="checkbox"/>	Importance of Middle Register	P-17	1	No	Yes
<input checked="" type="checkbox"/>	Importance of High Register	P-18	1	No	Yes
<input checked="" type="checkbox"/>	Most Common Pitch Class	P-19	1	No	Yes
<input checked="" type="checkbox"/>	Dominant Spread	P-20	1	No	Yes
<input checked="" type="checkbox"/>	Strong Tonal Centres	P-21	1	No	Yes
<input checked="" type="checkbox"/>	Major or Minor	P-22	1	No	Yes
<input checked="" type="checkbox"/>	Glissando Prevalence	P-23	1	No	Yes
<input checked="" type="checkbox"/>	Average Range of Glissandos	P-24	1	No	Yes
- PROCESSING INFORMATION:** SUMMARY INFORMATION ON ALL IMPLEMENTED FEATURES:
 - 172 unique features
 - 1230 combined feature dimensions
 - 158 unique one-dimensional features
 - 14 unique multi-dimensional features
 - 172 sequential features
 - Feature breakdown by type:
 - 26 unique Overall Pitch Statistics features (175 total dimensions)
 - 25 unique Melodic Intervals features (152 total dimensions)
 - 35 unique Chords and Vertical Intervals features (193 total dimensions)
 - 36 unique Rhythm features (197 total dimensions)
- CONFIGURATION FILE AND WINDOWING SETTINGS:**
 - Buttons: Load New Settings from a Config File, Save These Settings to a Config File
 - Radio buttons: Extract Features from Entire Files (selected), Extract Features from Windows
 - Window Duration (seconds): 0.0
 - Window Overlap Fraction (0.0 to 1.0): 0.0
- FEATURE EXTRACTION AND SAVING SETTINGS:**
 - Set ACE XML Feature Values Save Path: JSLAC_feature_values.xml
 - Set ACE XML Feature Definitions Save Path: JSLAC_feature_definitions.xml
 - Also Save Features in a Weka ARFF File
 - Also Save Features in a CSV File
 - EXTRACT AND SAVE FEATURES

What can you do with jSymbolic2's features?

- Empirically study huge collections of music in new ways
 - Search music databases based on feature values
 - Use machine learning
 - Analyze and visualize music based on feature values

Composer attribution study

- We used jSymbolic2 features to automatically classify pieces of Renaissance music by composer
 - As an example of the kinds of things that can be done with jSymbolic2
 - As a meaningful research project in its own right

RenComp7 dataset

- Began by constructing our “**RenComp7**” dataset:
 - 1584 MIDI pieces
 - By 7 Renaissance composers
- Combines:
 - **Top right**: Music drawn from the Josquin Research Project (Rodin, Sapp and Bokulich)
 - **Bottom right**: Music by Palestrina (Miller 2004) and Victoria (Sigler, Wild and Handelman 2015)

Composer	Pieces
Busnoys	69
Josquin (<i>only includes the 2 most secure Jesse Rodin groups</i>)	131
La Rue	197
Martini	123
Ockeghem	98

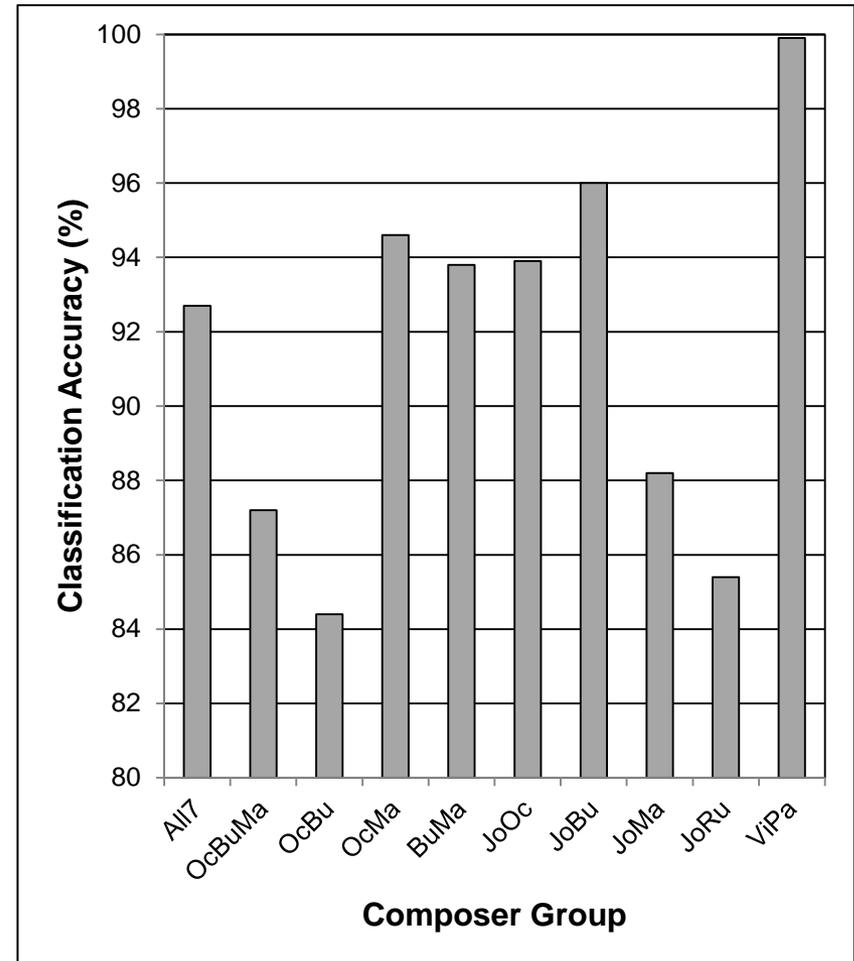
Composer	Pieces
Palestrina	705
Victoria	261

Methodology

- Extracted **721 feature values** from each of the 1584 RenComp7 pieces using jSymbolic2
- Used **machine learning** to teach a classifier to automatically distinguish the music of the composers
 - Based on the jSymbolic2 features
- Used **statistical analysis** to gain insight into relative compositional styles
- Performed **several versions** of this study
 - Classifying amongst all 7 composers
 - Focusing only on smaller subsets of composers
 - Some more similar, some less similar

Classification results

Composer Group	Classification Accuracy
All 7	92.7%
Ockeghem / Busnoys / Martini	87.2%
Ockeghem / Busnoys	84.4%
Ockeghem / Martini	94.6%
Busnoys / Martini	93.8%
Josquin / Ockeghem	93.9%
Josquin / Busnoys	96.0%
Josquin / Martini	88.2%
Josquin / La Rue	85.4%
Victoria / Palestrina	99.9%



Direct applications of such work

- Validating existing suspected but uncertain attributions
- Helping to resolve conflicting attributions
- Suggesting possible attributions of currently unattributed scores

How do the composers differ?

- Some interesting questions:
 - What musical insights can we learn from the jSymbolic2 feature data itself?
 - In particular, what can we learn about **how** the music of the various composers differ from one another?
- Chose to focus on two particular cases:
 - **Josquin vs. Ockeghem**: Relatively different
 - **Josquin vs. La Rue**: Relatively similar

A priori expectations (1/3)

- What might an expert musicologist expect to differentiate the composers?
 - Before actually examining the feature values
- Once formulating these expectations, we can then see if the feature data **confirms or repudiates** these expectations
 - **Both** are useful!
- We can also then see if the feature data reveals **unexpected insights**

A priori expectations (2/3)

- What do **you** think might distinguish the composers?
 - Josquin vs. Ockeghem?
 - Josquin vs. La Rue?
- I consulted one musicologist (Julie Cumming) and one theorist (Peter Schubert), both experts in the period . . .

A priori expectations (3/3)

- Josquin vs. Ockeghem: Ockeghem may have . . .
 - Slightly more large leaps (larger than a 5th)
 - Less stepwise motion in some voices
 - More notes at the bottom of the range
 - Slightly more chords (or simultaneities) without a third
 - Slightly more dissonance
 - A lot more triple meter
 - More varied rhythmic note values
 - More 3-voice music
 - Less music for more than 4 voices
- Josquin vs. La Rue: La Rue may have . . . **Hard to say!**
 - Maybe more varied repetition (melodic and contrapuntal, including rhythm)?
 - Maybe more compressed ranges?

Were our expectations correct?

- Josquin vs. Ockeghem: Ockeghem may have . . .
 - **OPPOSITE**: Slightly more large leaps (larger than a 5th)
 - **SAME**: Less stepwise motion in some voices
 - **SAME**: More notes at the bottom of the range
 - **SAME**: Slightly more chords (or simultaneities) without a third
 - **OPPOSITE**: Slightly more dissonance
 - **YES**: A lot more triple meter
 - **SAME**: More varied rhythmic note values
 - **YES**: More 3-voice music
 - **YES**: Less music for more than 4 voices
- Josquin vs. La Rue: La Rue may have . . .
 - **UNKNOWN**: Maybe more varied repetition (melodic and contrapuntal, including rhythm)?
 - **SAME**: Maybe more compressed ranges?

Diving into the feature values

- There are a variety of statistical techniques for attempting to evaluate **which features** are likely to be effective in distinguishing between types of music
- We used **seven** of these statistical techniques to find:
 - The features and feature subsets most consistently statistically predicted to be effective at distinguishing composers
- We then **manually examined** these feature subsets to find the features likely to be the most **musicologically meaningful**

Novel insights revealed (1/2)

- Josquin vs. Ockeghem (93.9%):
 - **Rhythm-related features** are particularly important
 - Josquin tends to have greater rhythmic variety
 - Especially in terms of both especially short and long notes
 - Ockeghem tends to have more triple meter
 - As expected
 - Features derived from beat histograms also have good discriminatory power
 - Ockeghem tends to have more **vertical sixths**
 - Ockeghem tends to have more **diminished triads**
 - Ockeghem tends to have longer **melodic arcs**

Novel insights revealed (2/2)

- Josquin vs. La Rue (85.4%):
 - Pitch-related features are particularly important
 - Josquin tends to have more vertical unisons and thirds
 - La Rue tends to have more vertical fourths and octaves
 - Josquin tends to have more melodic octaves

Research potential (1/2)

- The results above are the product of an initial accurate but relatively simple analysis
- There is substantial potential to expand this study
 - Apply **more sophisticated and detailed statistical analysis** techniques
 - Perform a **more detailed manual exploration** of the feature data
 - Implement **new specialized features**
 - Look at more and different **composer groups**

Research potential (2/2)

- Composer attribution is **just one small example** of the many musicological and theoretical research domains to which features and jSymbolic2 can be applied
 - e.g. genre, such as madrigals vs. motets

Research collaborations (1/2)

- We enthusiastically welcome research collaborations with other musicologists and theorists
- In particular, we are always looking for ideas for interesting for **new features** to implement
 - jSymbolic2 makes it relatively easy to add **bespoke features**
 - Can **iteratively build** increasingly complex features based on existing features

Research collaborations (2/2)

- Please do not hesitate to speak to me if you would like demos of:
 - Using jSymbolic2
 - How one can apply statistical analysis or machine learning to extracted features
 - How feature values can be visualized and explored manually
- I am also more than happy to show you any of our data or code
 - jSymbolic2 is **open-source** and **free**

Thanks for your attention!

- **jSymbolic2:** <http://jmir.sourceforge.net>
- **E-mail:** cory.mckay@mail.mcgill.ca



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SIMSSA | Single Interface for Music
| Score Searching and Analysis

