

# Symbolic Music Features and Musical Patterns

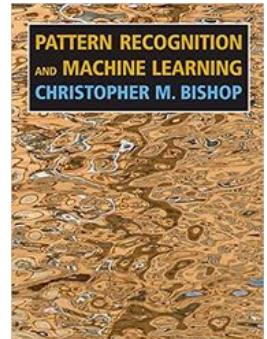
Iris Yuping Ren



# I. Pattern Recognition

# What is pattern recognition?

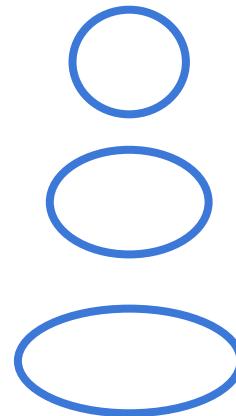
"...the **automatic discovery of regularities** in **data** through the use of computer algorithms and with the use of these regularities to **take actions** such as **classifying** the data into different categories" -- Bishop



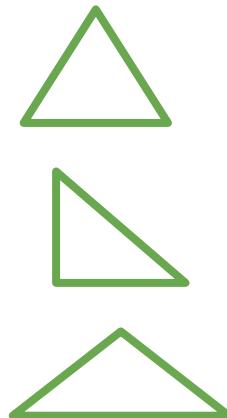
# Example: Regularities and classes



**Pattern set 1**

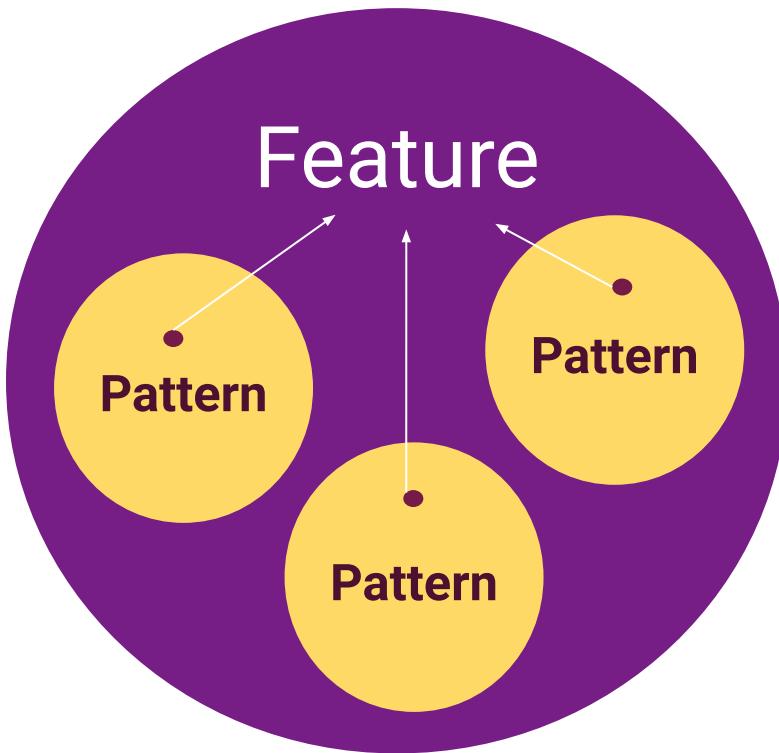


**Pattern set 2**

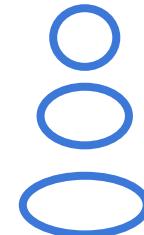


**Pattern set 3**

# Example: What describes the regularities?



Pattern  
set 1



Pattern  
set 2



Pattern  
set 3

Feature?  
#edges

# Patterns - Interdisciplinarily

- Mathematics: geometric pattern, visual motif, symmetry, fractal, ...
- Programming: pattern matching, design pattern, subexpression, ...
- In nature: pattern formation, trees, dunes, waves, ...
- ...
- Music!



Dirce beauty butterfly,  
*Coleura dirce*

Grevy's zebra, *Equus  
griseyl*

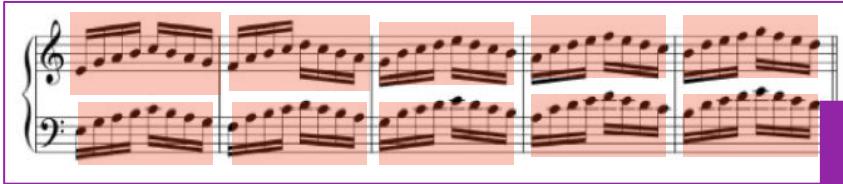
Royal angelfish,  
*Pygoplites diacanthus*

Leopard, *Panthera  
pardus pardus*

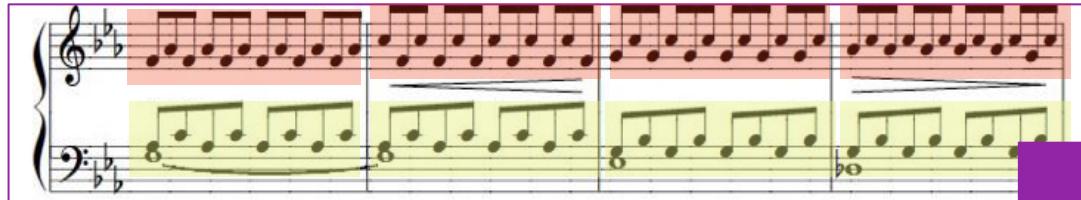
Array of ladybirds by  
G.G. Jacobson

Breeding pattern of  
cuttlefish, *Sepia  
officinalis*

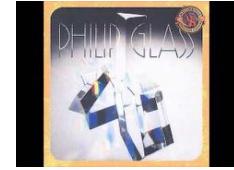
## II. Musical Patterns



Etudes



Minimal



Folk music



Fugues

# Described in different ways

- The **smallest independent** particle in a musical idea (Webern)
- Structural unit possessing **thematic** identity (White)
- A unit which contains one or more **features of interval and rhythm** [whose] presence is maintained in constant use throughout a piece (Schoenberg)

# Beethoven 5th: Violin I



A musical score for the Violin I part of Beethoven's Fifth Symphony. The score consists of two staves of music. The top staff starts with a rest followed by a rhythmic pattern of eighth and sixteenth notes. The number '2' is written above the second measure. The bottom staff begins with a dynamic 'f' (fortissimo) and shows a similar rhythmic pattern. Measures are numbered 14 and 15. The music is set in common time with a key signature of one flat.

Features of

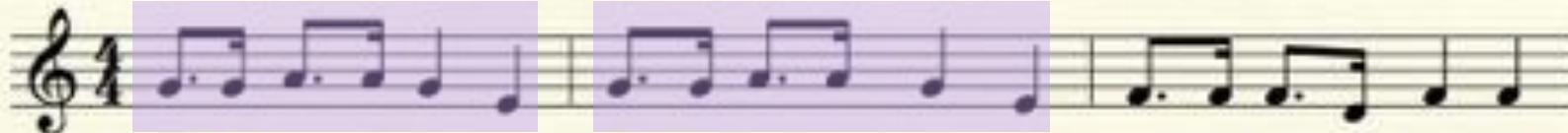


- Rhythmic pattern
- U, u, -3 intervallic pattern

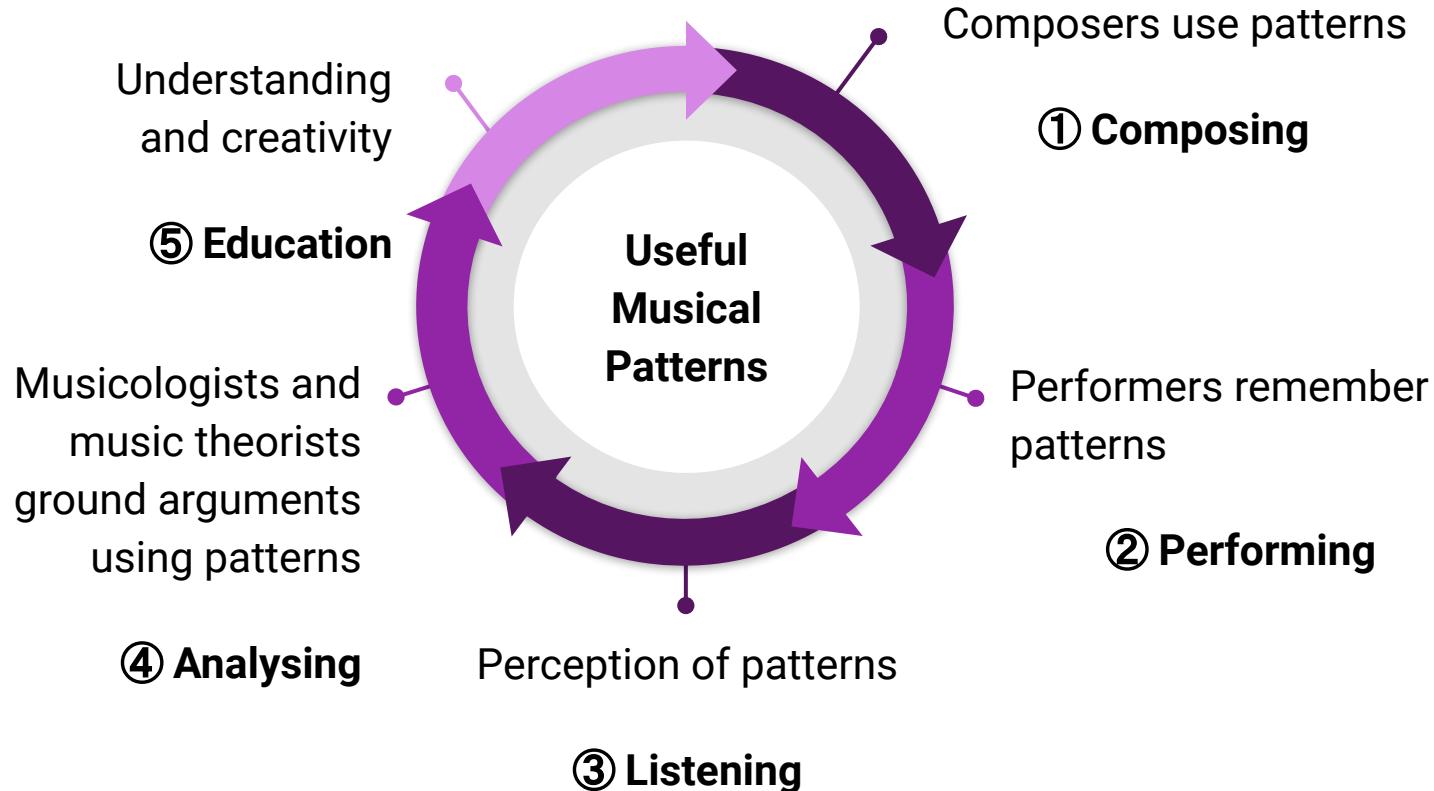
# Sinterklaas kapoentje

[kinderliedjes.overtuin.net](http://kinderliedjes.overtuin.net)

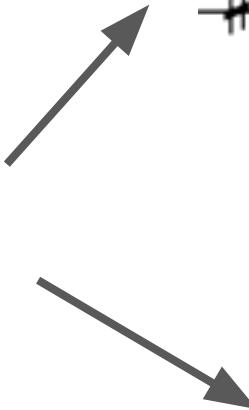
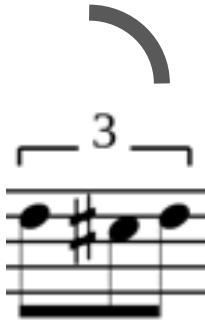
Voice



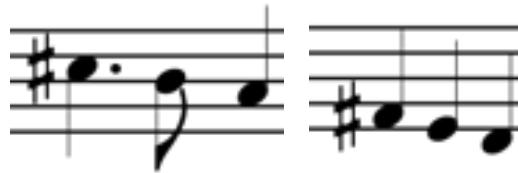
# Applications: Interaction



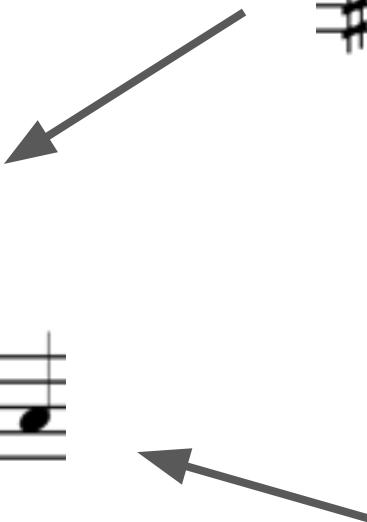
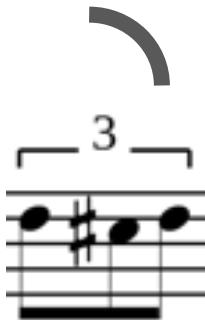
# Interaction: Creativity



A complex musical score. It features multiple staves with various note heads and stems. Grouping brackets labeled '3' indicate measures. Above the music, there are several abstract icons: a light grey triangle, a dark grey curved arrow, another light grey triangle, and another dark grey curved arrow. The score includes a treble clef, a key signature of one sharp, and a time signature of three over three.



# Retrieval: Pattern discovery



### III. Automatic Pattern Discovery

# Musical Pattern Discovery: The ideal algorithm



## 24. ER REED EEN JONKHEER, HIJ WAS WELLEGEMOED



Er reed een jonk-heer, hij was wel - le - go - moed,

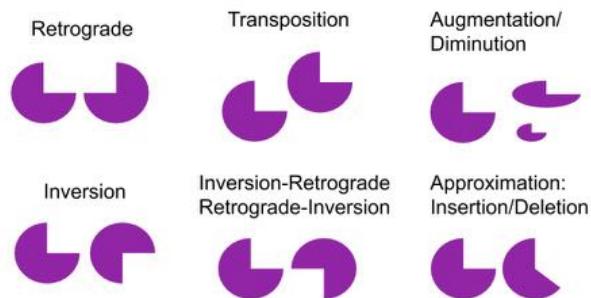
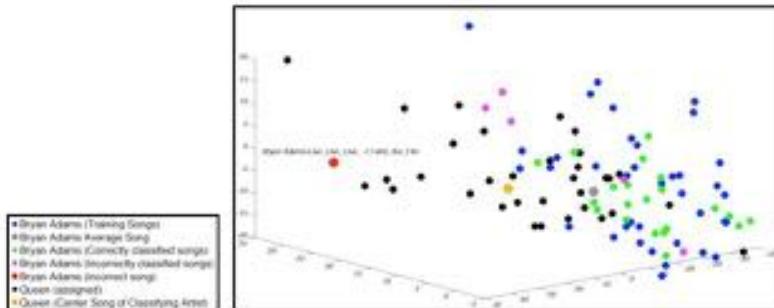
Er reed een jonk-heer, hij was wel - le - ge - moed,

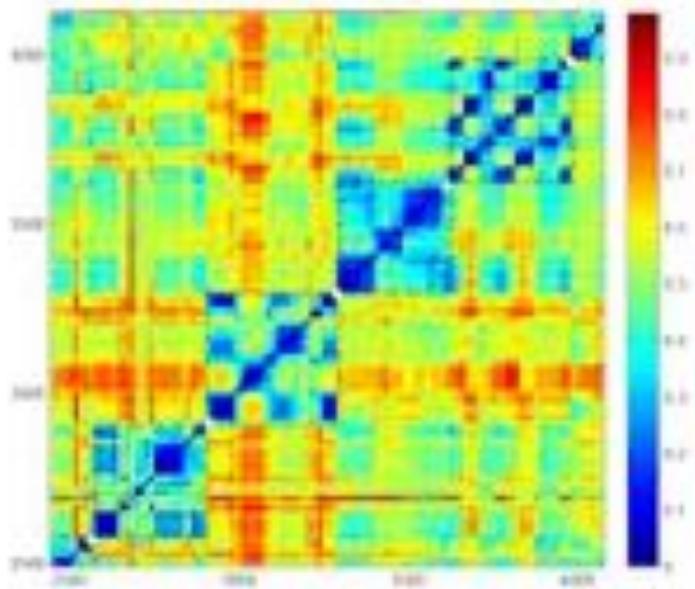
En hij droeg er een ro-zenkrana om - me zijn hoed

En hij droeg er een ro-zen-krans om - me zijn hoed.

# Two parts of the problem:

- Querying: Find exact repetition
- Fuzzy matching (discovery): Find variations
  - Similarity measure of features + thresholding
  - Parsing + define transformation and their combinations

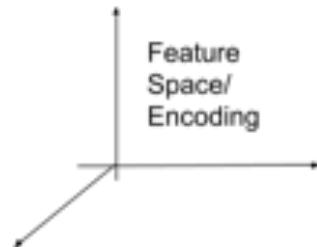


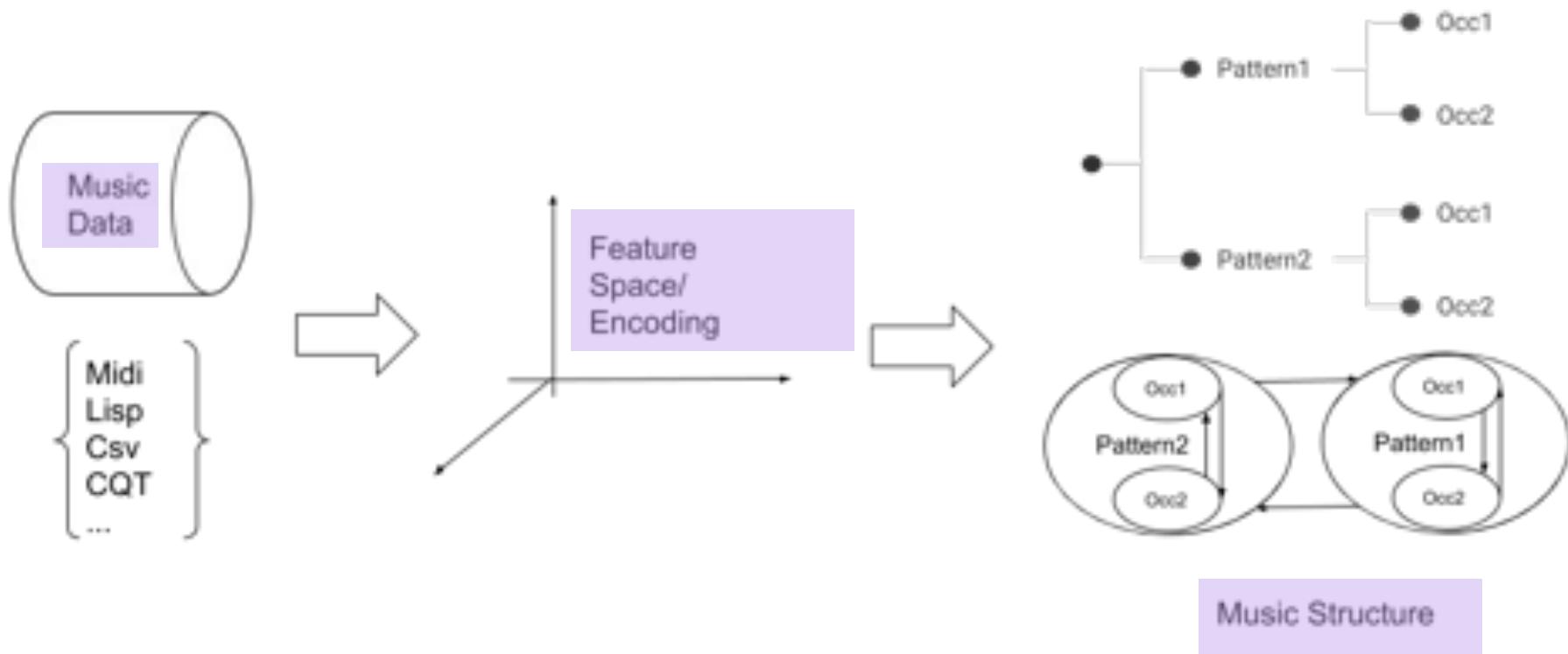


```
data Note = Note
{ ontime :: Time
, midi :: MIDI
}
type Pattern = [Note]
```

```
data PatternGroup = PatternGroup
{ prototype :: Pattern
, occurences :: [Pattern]
}
```

Feature encoding: matrices and data types





Pattern Discovery Pipeline

# Features: Musicological and music theoretical sources

Pitch Statistics

Melodic Intervals

Chords and Vertical Intervals

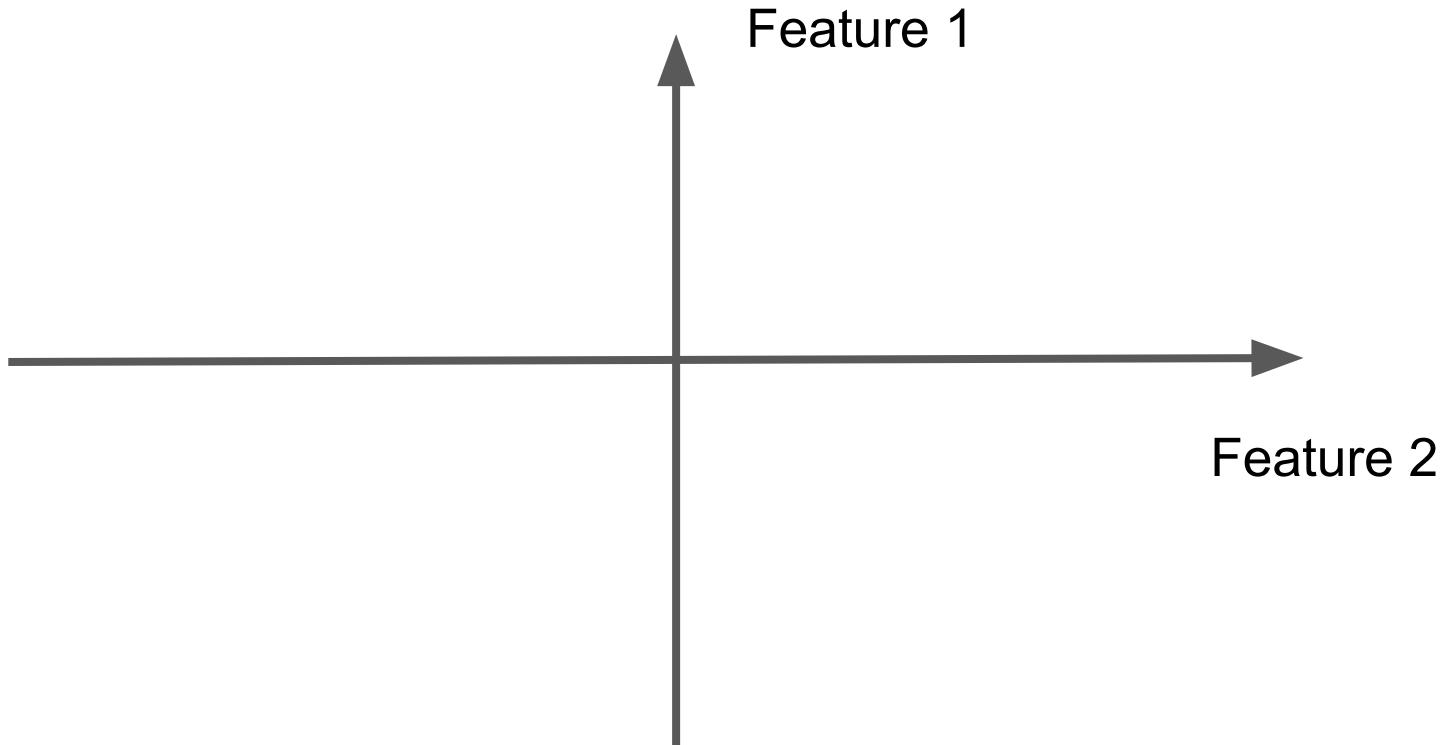
Rhythm

Instrumentation

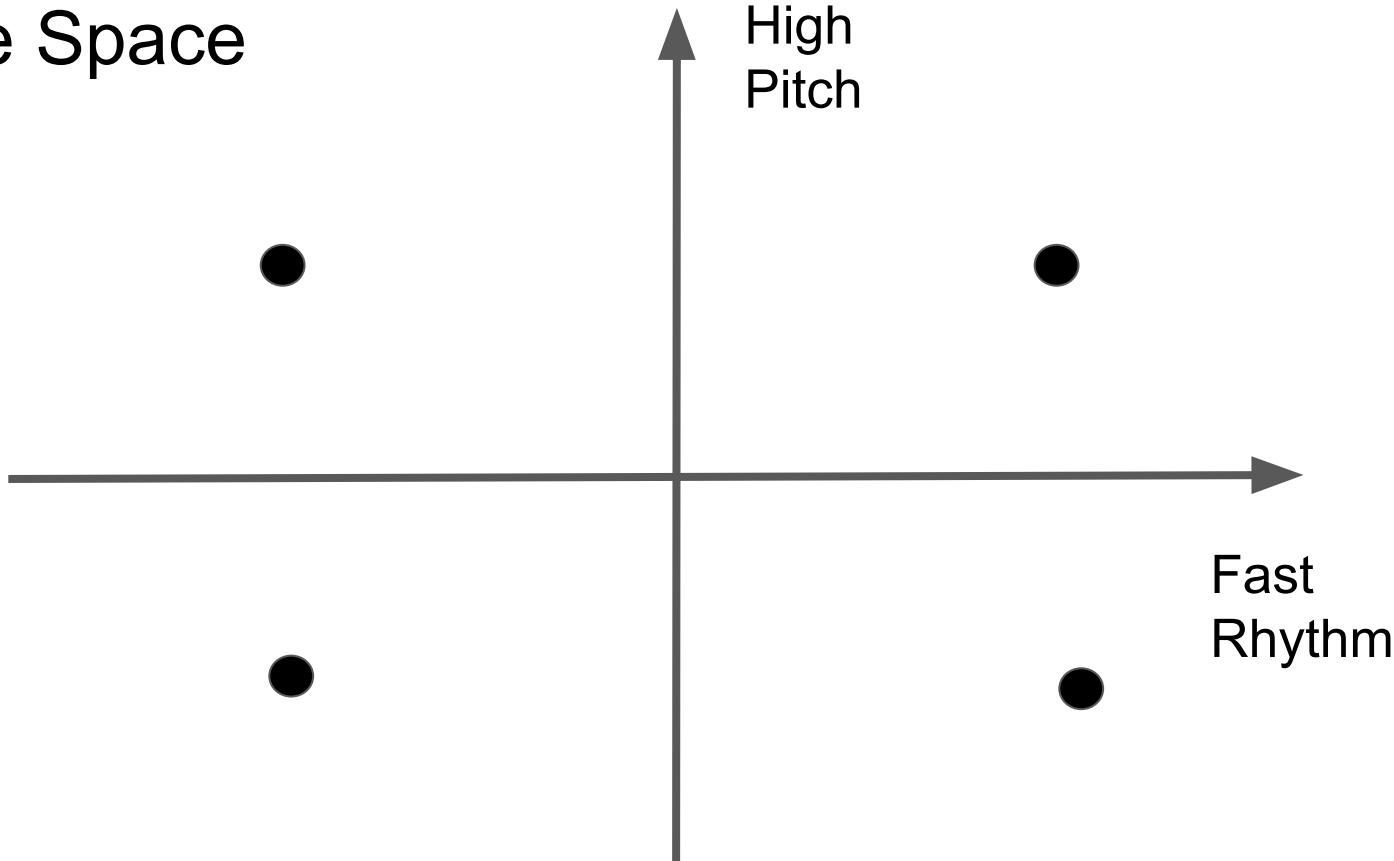
Texture

Dynamics

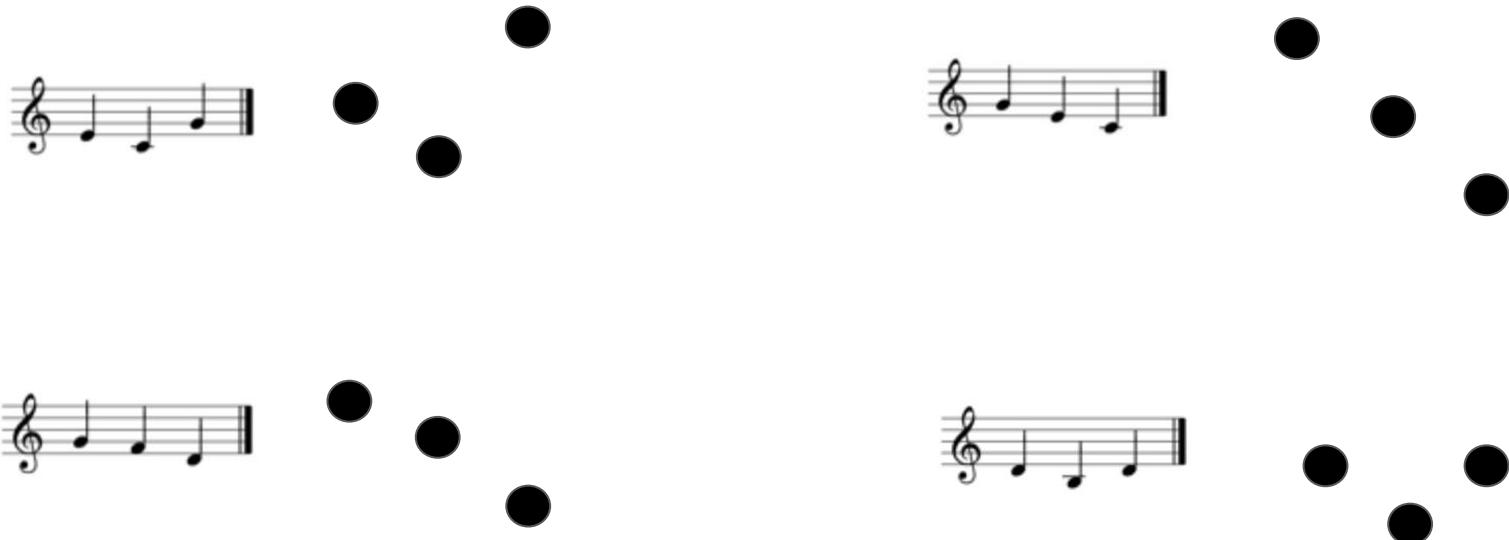
# Feature Space



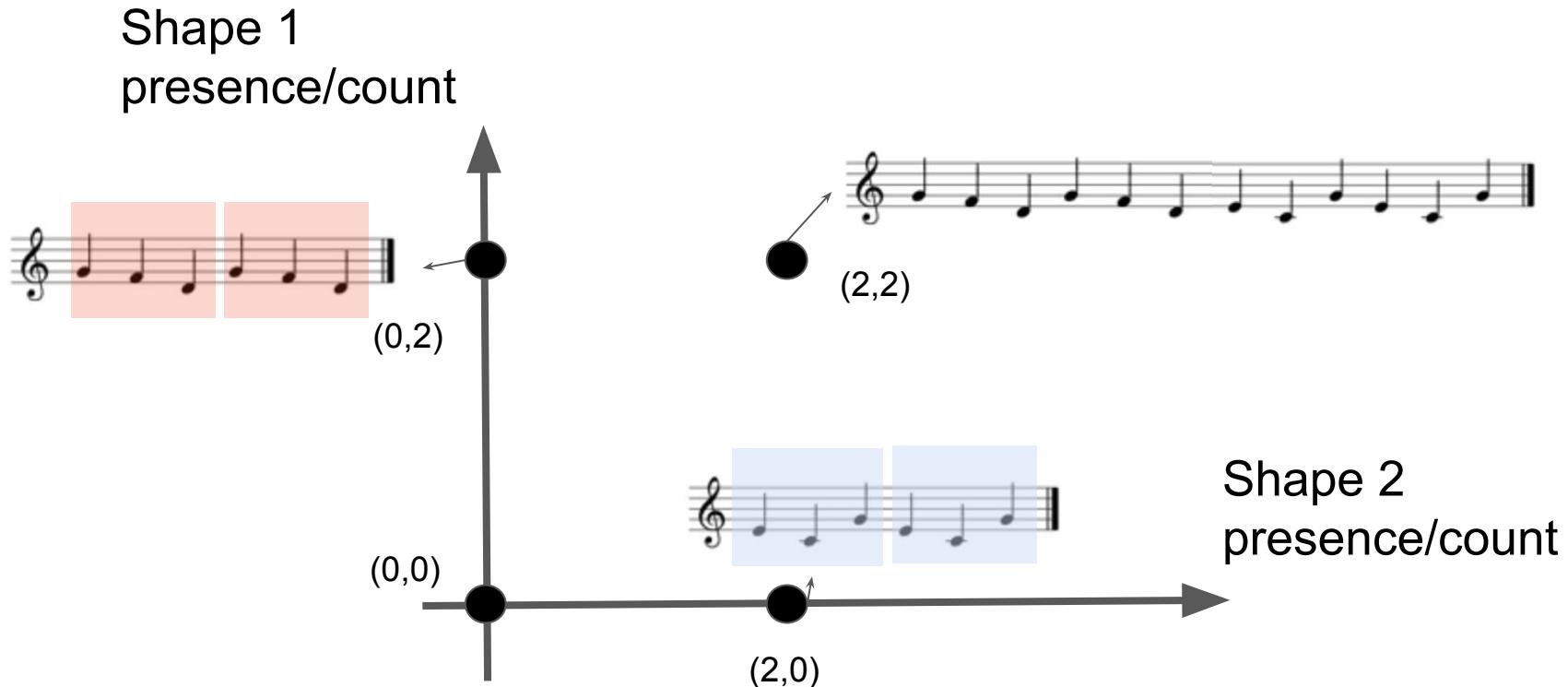
# Feature Space



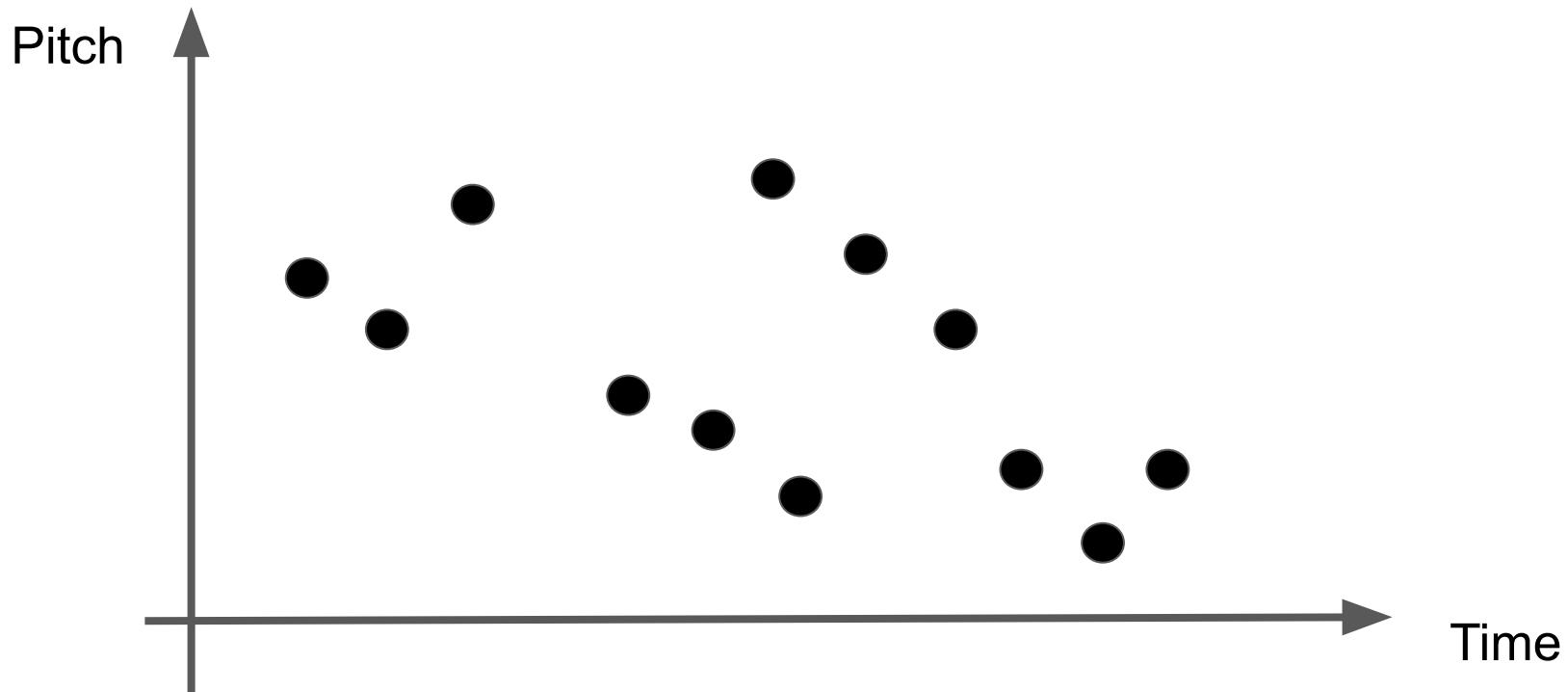
# Another possibility: Shapes as features



# Feature Space



Input: (onset, pitch)

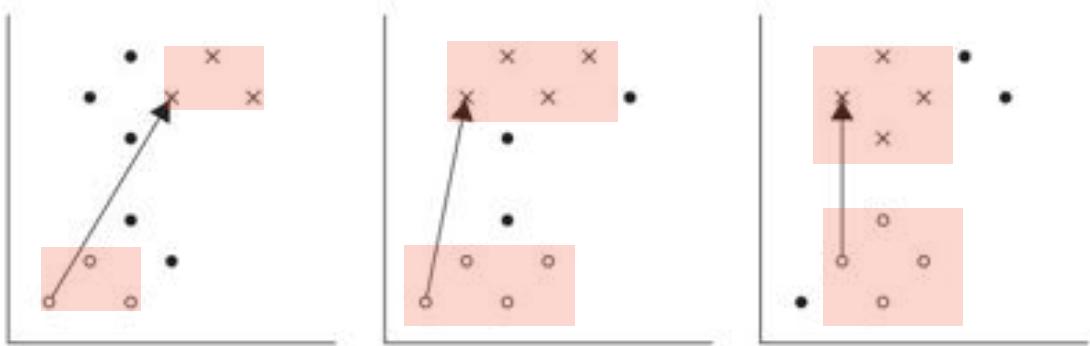


# Geometric pattern discovery

Maximal Translatable Patterns (MTPs).

$$\text{MTP}(v, D) = \{p \mid p \in D \wedge p + v \in D\},$$

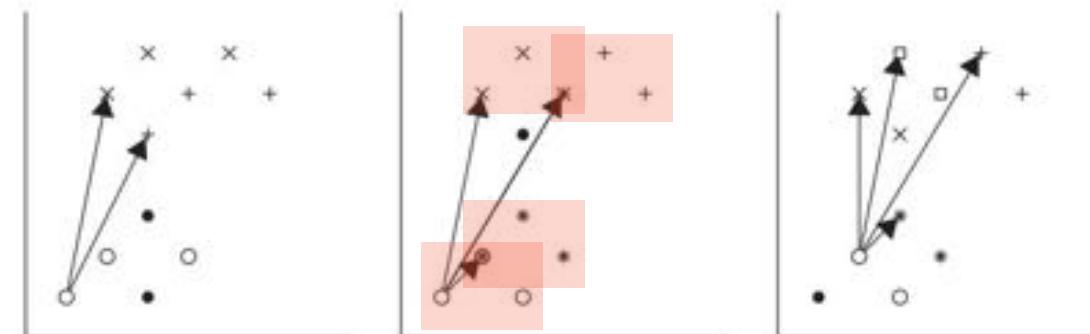
 pitch shift  
 (Onset, Pitch)  
 the pattern set



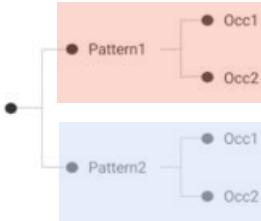
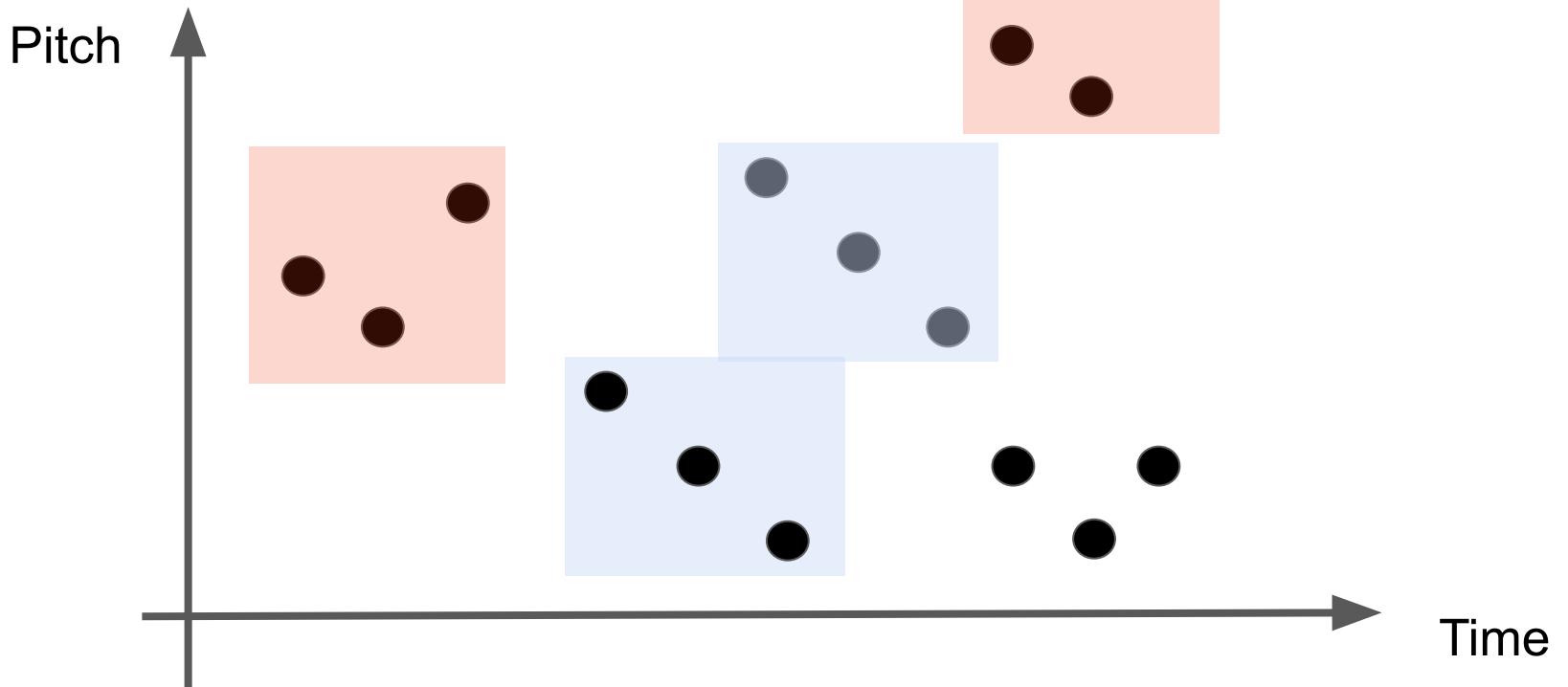
Translational Equivalence Classes (TECs)

$$\text{TEC}(P, D) = \{Q \mid Q \equiv_T P \wedge Q \subseteq D\}.$$

 the query pattern  
 the pattern set  
 Translational eqv



# Output: (onset, pitch)



# Another possibility: Repetitions as features

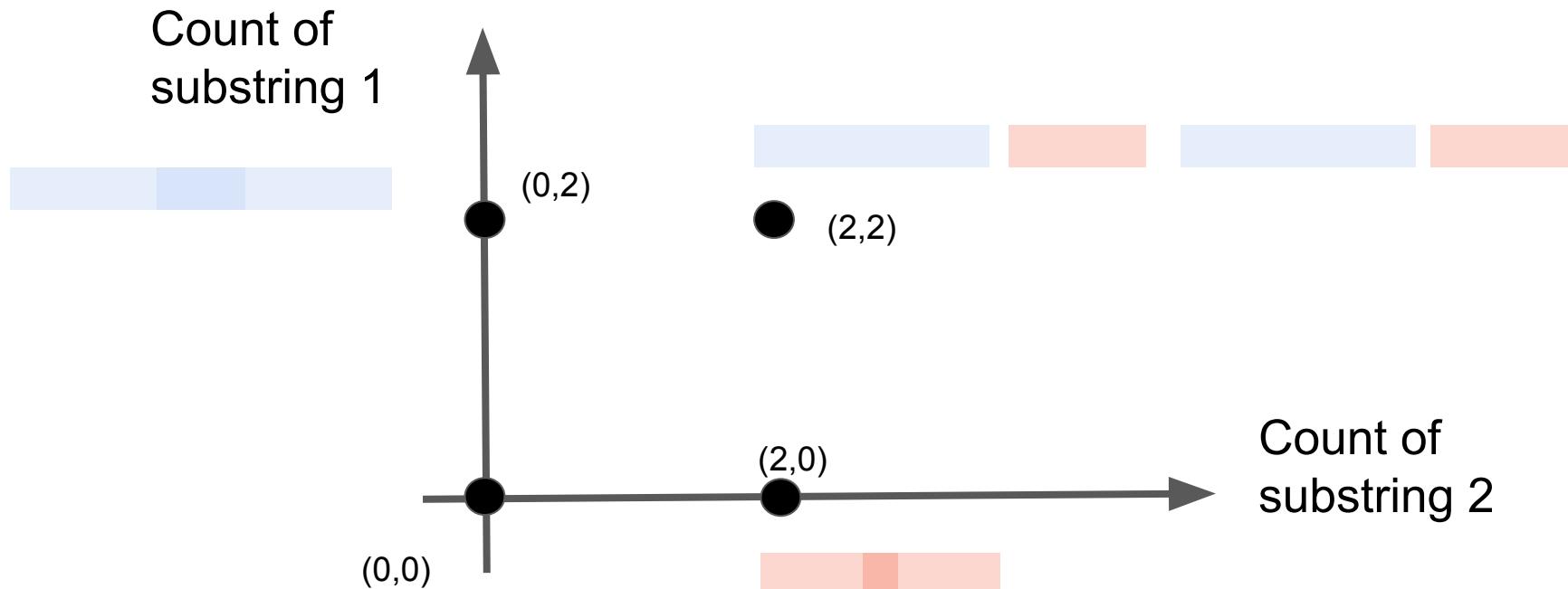


Substring1



Substring2

# Feature Space

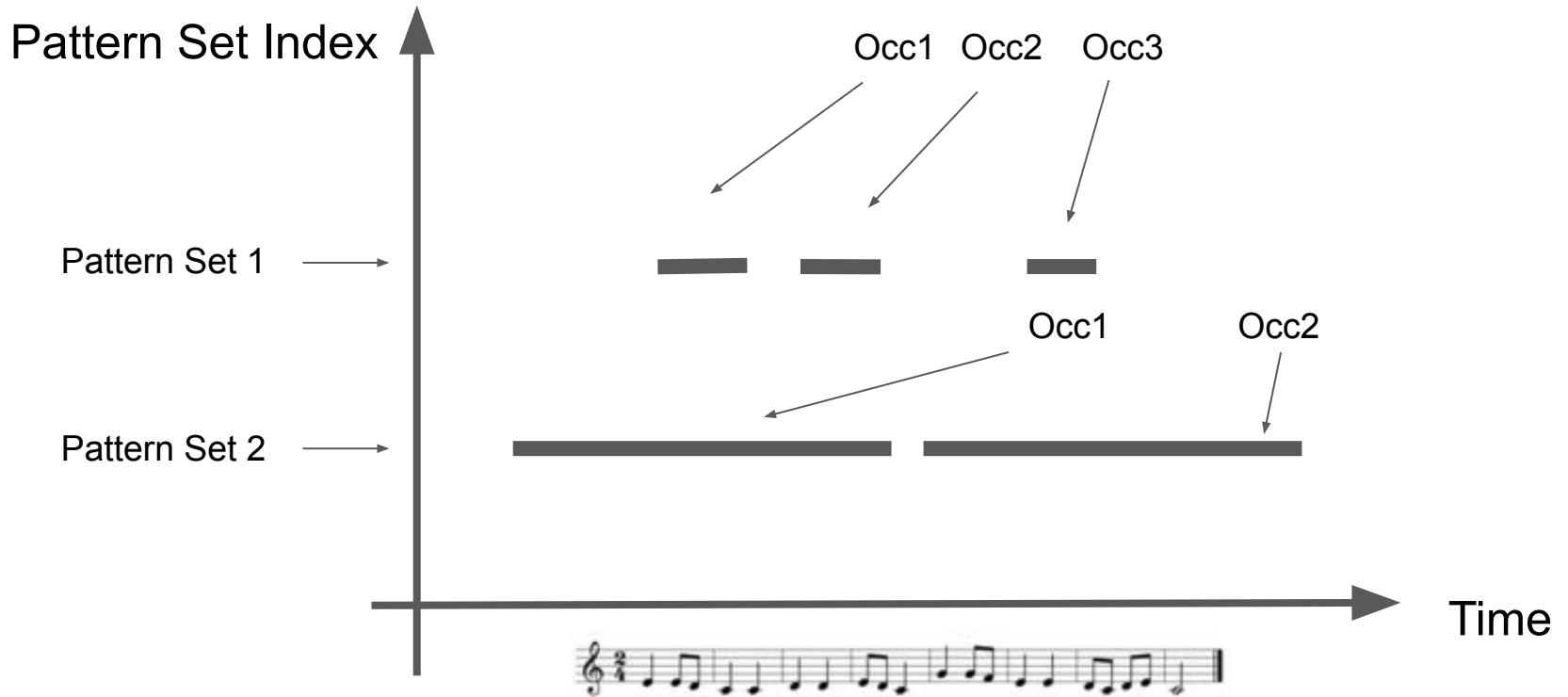
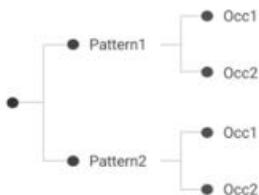


# String-based pattern discovery: features = repetition



- A maximal itemset is an itemset that has no superset that is frequent.
- A closed itemset is an itemset that has no superset that has the same support.

# Output: Representing the structure

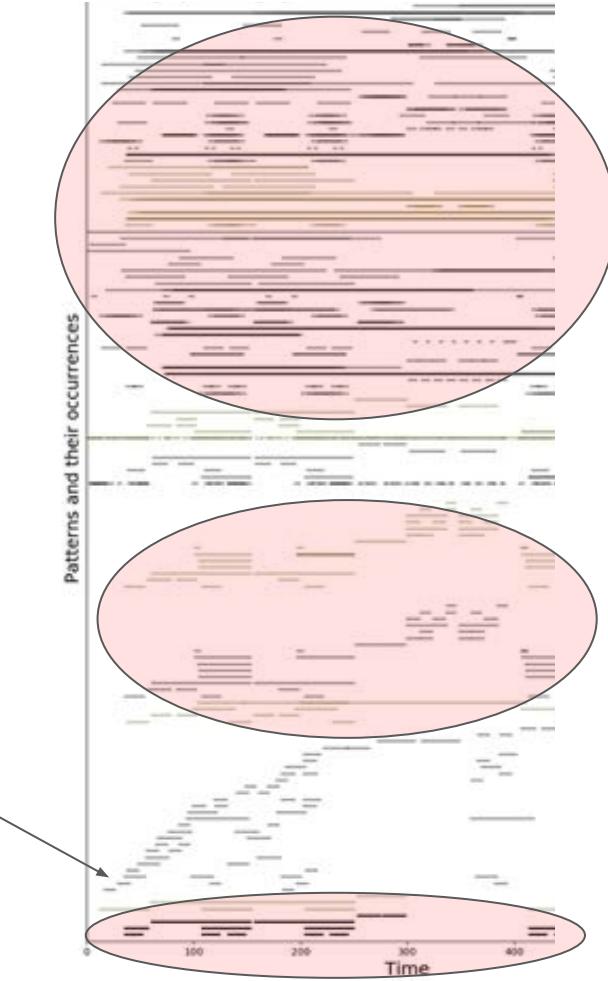


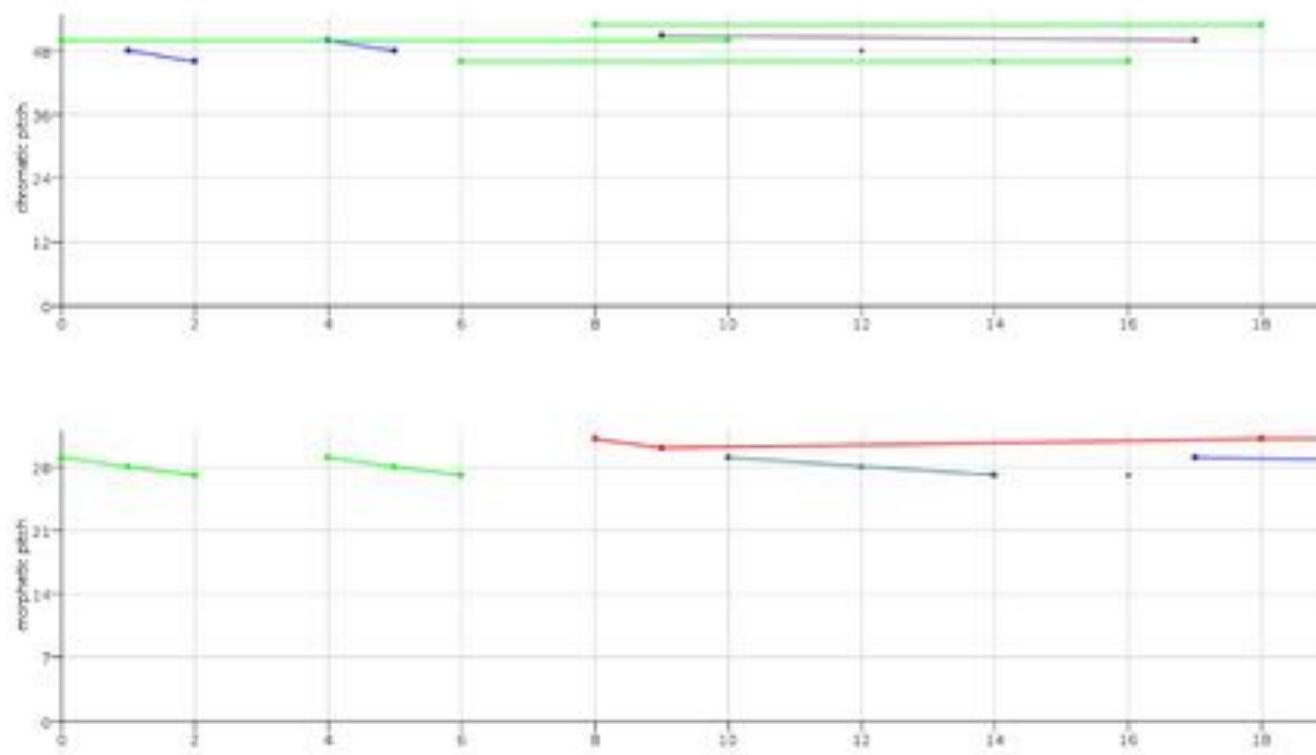
Geometric

String-based

Human/  
Ground  
truth

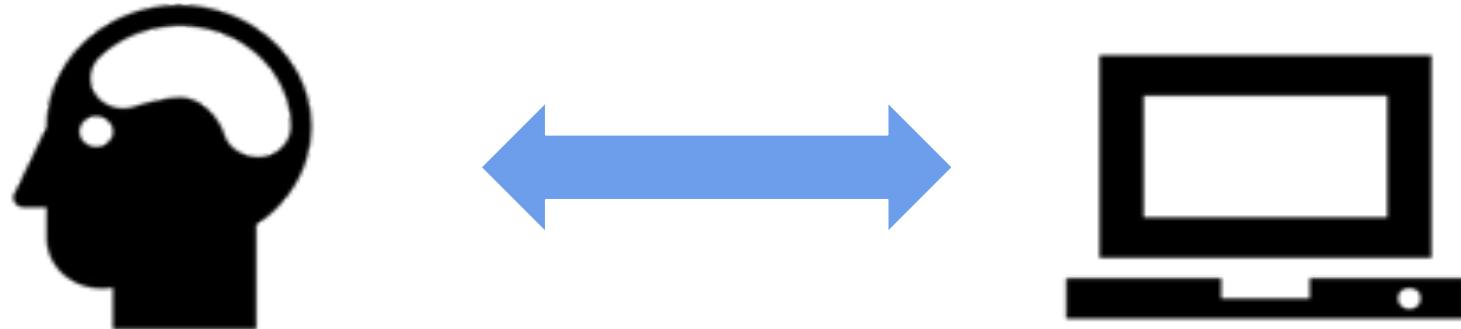
State-of-the-art algorithms:  
(Too) many & disagreeing output





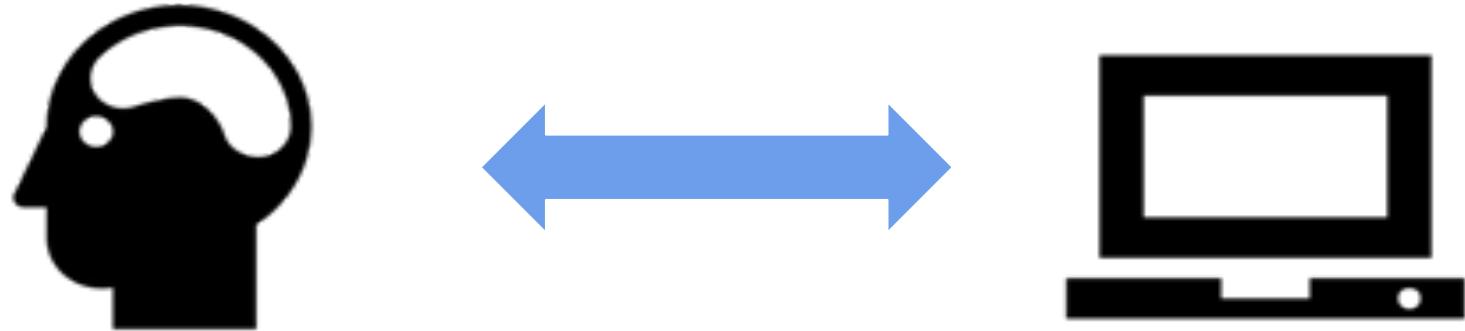
Patterns discovered at very different locations

## MIREX JKU-PDD: Discovery of Repeated Themes & Sections



How to compare and evaluate? With compiled patterns from books.

# MTC-ANN: The Meertens Tune Collections Annotated



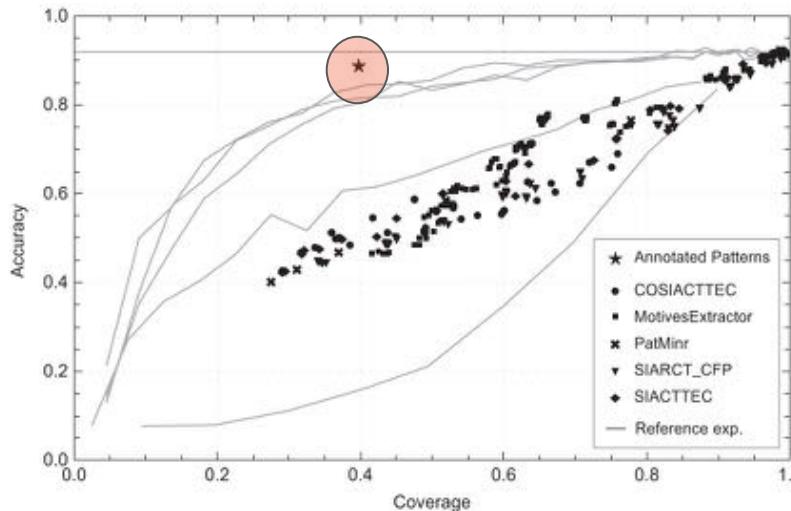
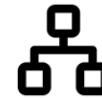
How to compare and evaluate? With experts' annotation.

"...the **automatic discovery** of regularities in data ... take actions ... "

## Discovery



## Classification

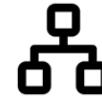


"...the **automatic discovery** of regularities in data ... take actions ... "

Discovery



Classification



...

Error Detection



Segmentation



Prediction

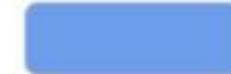




Annotations



Algorithms



Alternatively: Direct Comparison

# Transformations

Retrograde



Transposition



Augmentation/  
Diminution



Inversion



Inversion-Retrograde  
Retrograde-Inversion



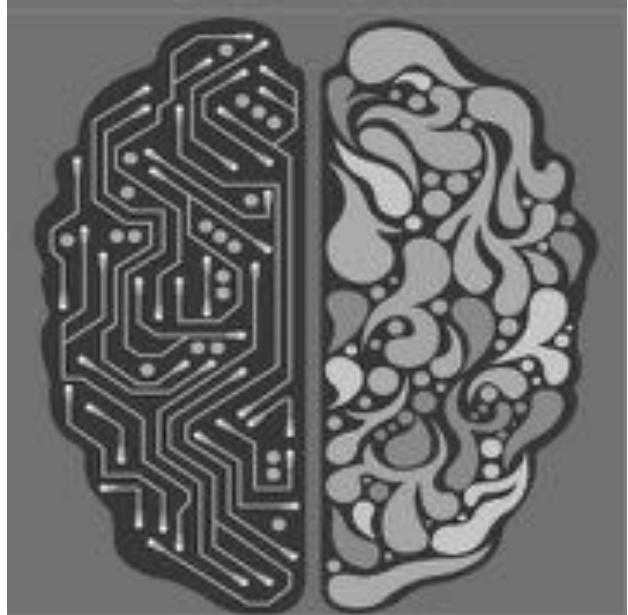
Approximation:  
Insertion/Deletion



Comparison based on occurrence relations: Occurrence 1  $\Leftrightarrow$  Occurrence 2

# Advantages

- Explainability
- Feedback and customisability
- Supported by nice mathematical properties
- Supported by domain knowledge



```
type Check a b = a -> b -> Bool
```

```
type HomCheck a = Check a a
```

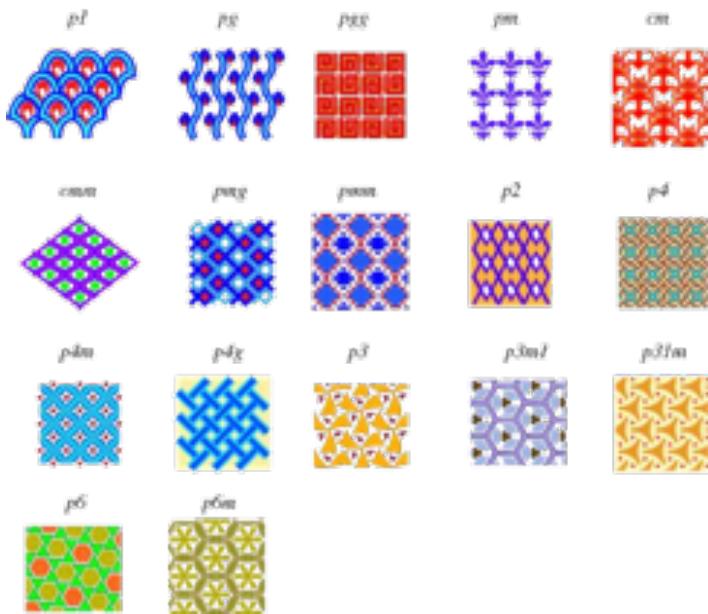


```
checkBasedOnTime :: (Pattern -> Time) -> HomCheck Time -> HomCheck Pattern
```

Checking transformations in patterns based on features: contravariant functors!

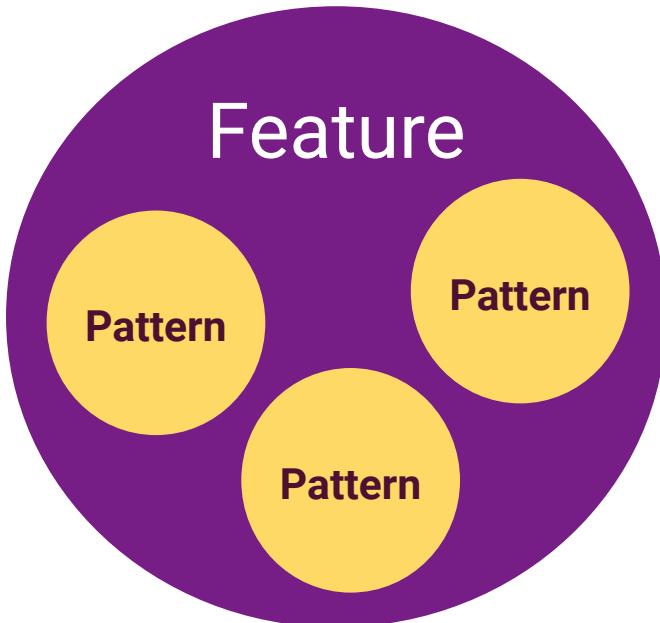


## More complicated transformations for generation and classification!



- Symmetry and Transformations in the Musical Plane (Vi Hart, 2009)
- Spiegel, Laurie (1981). "Manipulations of musical patterns". Proceedings of the Symposium on Small Computers and the Arts.
- Lewin, D. (1987). Generalized musical intervals and transformations. New Haven: Yale University Press.

# Summary



A musical score in G major with a 2/4 time signature. The lyrics are:

Er reed een jonk - heer, hij was wel - le - ge - moed,  
Er reed een jonk - heer, hij was wel - le - ge - moed,  
En hij droeg er een ro - zen-kraan om - me zijn hoed  
En hij droeg er een ro - zen-kraan om - me zijn hoed.

The first two lines of lyrics are highlighted with a red box, the third line with a green box, and the fourth line with a blue box, corresponding to the three pattern sets identified in the Venn diagram.

NLB141251\_01 - <http://www.liederbank.nl/liedpresentatie.php?roek=141251>

Pattern  
set 1



Pattern  
set 2



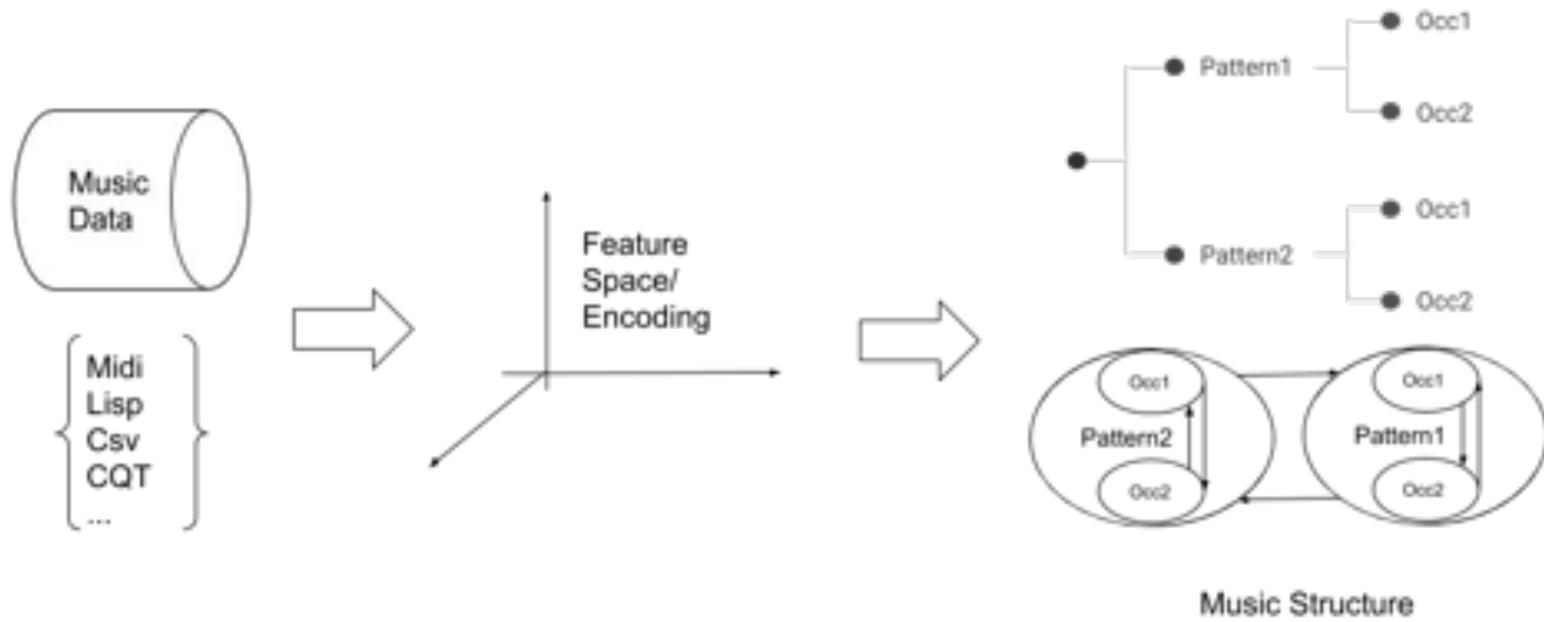
Pattern  
set 3



Feature: music, shape, repetition...

# Concepts & Challenges

- Features: design and application
- Geometric / String-based methods
  - TEC, MTP
  - Closed patterns, Maximal patterns
- Transformation
  - Exact repetition
  - Symmetry
  - Approximation
- Disagreement and Evaluation
  - Comparison based on applications
  - Direct comparison



## Musical Pattern Discovery Summary:

**Input - Music data**

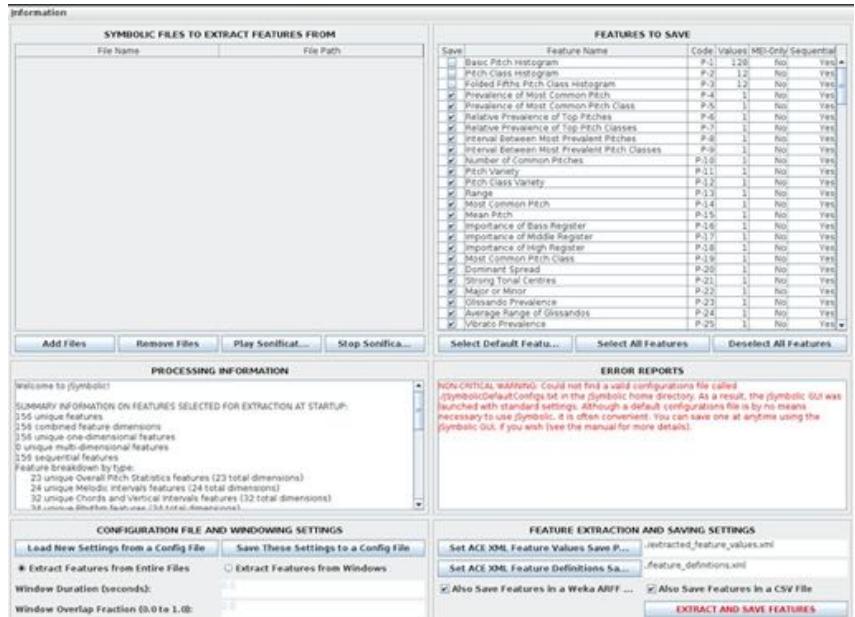
**Algorithm - Pattern recognition (extract based on features &/or transformation)**

**Output - Pattern occurrences (examine based on features &/or transformation)**

## IV. Feature Extraction and Analysis

# A general idea of the UI

CONTINU



## Available tool: JSymbolic 2.2

[http://jmir.sourceforge.net/manuals/jSymbolic\\_manual/home.html](http://jmir.sourceforge.net/manuals/jSymbolic_manual/home.html)

## Example features from JSymbolic:

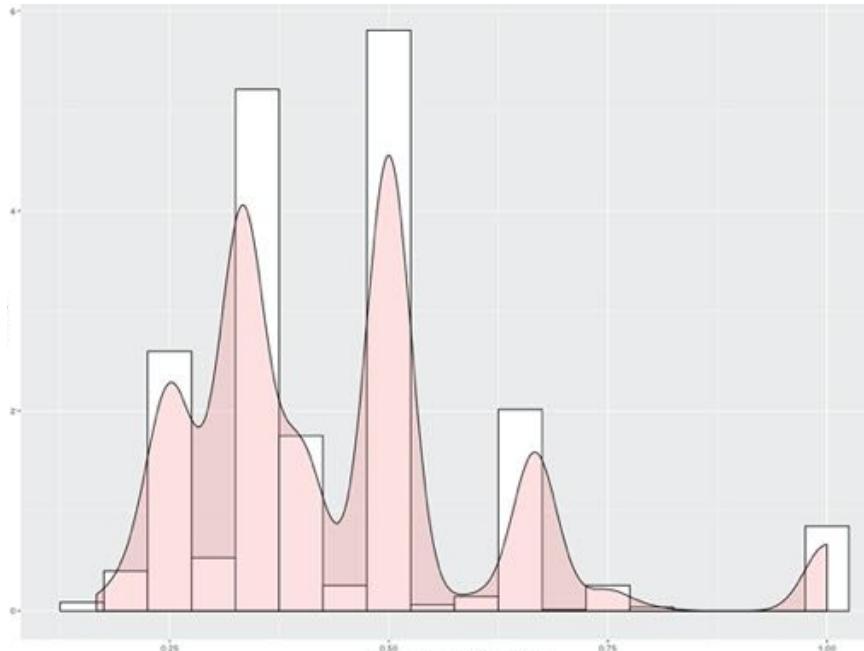
- **P-16 Most Common Pitch:** MIDI pitch value of the most frequently occurring pitch.
- **P-17 Most Common Pitch Class:** The pitch class that occurs most frequently compared to other pitch classes.
- **P-18 Prevalence of Most Common Pitch:** Fraction of notes that correspond to the most common pitch.
- **P-19 Prevalence of Most Common Pitch Class:** Fraction of notes that correspond to the most common pitch class.
- **RT-5 Note Density:** Average number of notes per second. Takes into account all notes in all voices, including both pitched and unpitched notes.

## Feature Matrix:

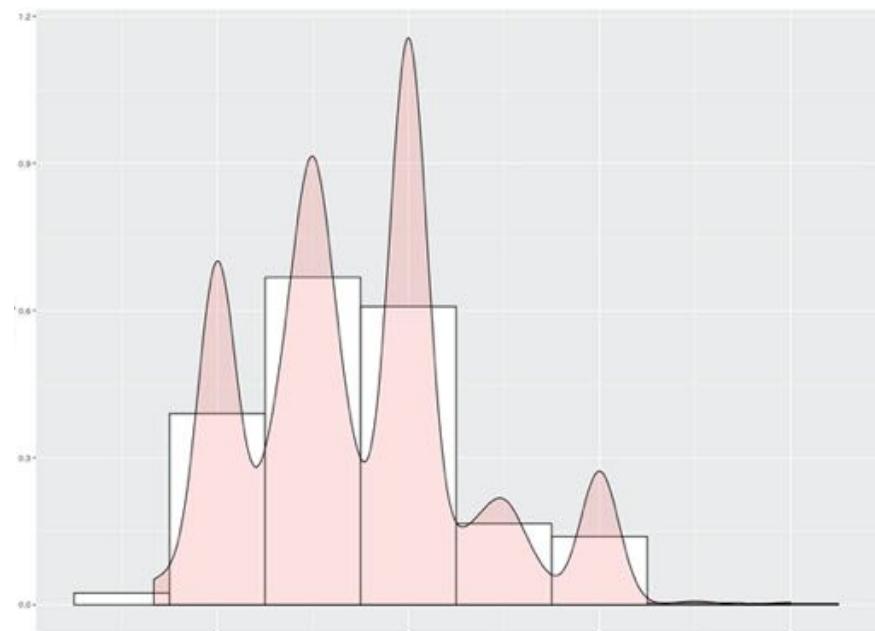
	Feature1	Feature2	...	Feature n
Music 1				
Music 2				
...				
Music m				



# Feature Distributions



Prevalence of Common Pitch



Note Density

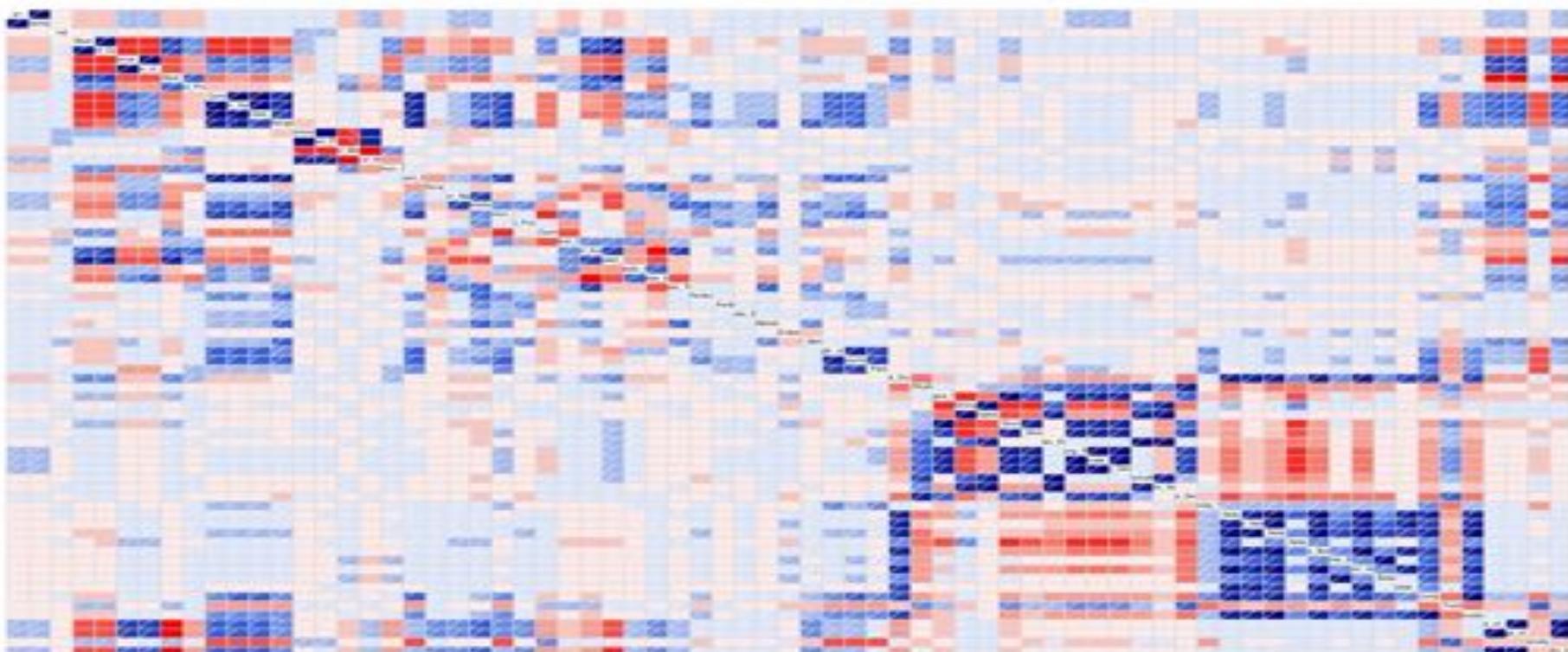
# Feature Correlation



Positive Correlation

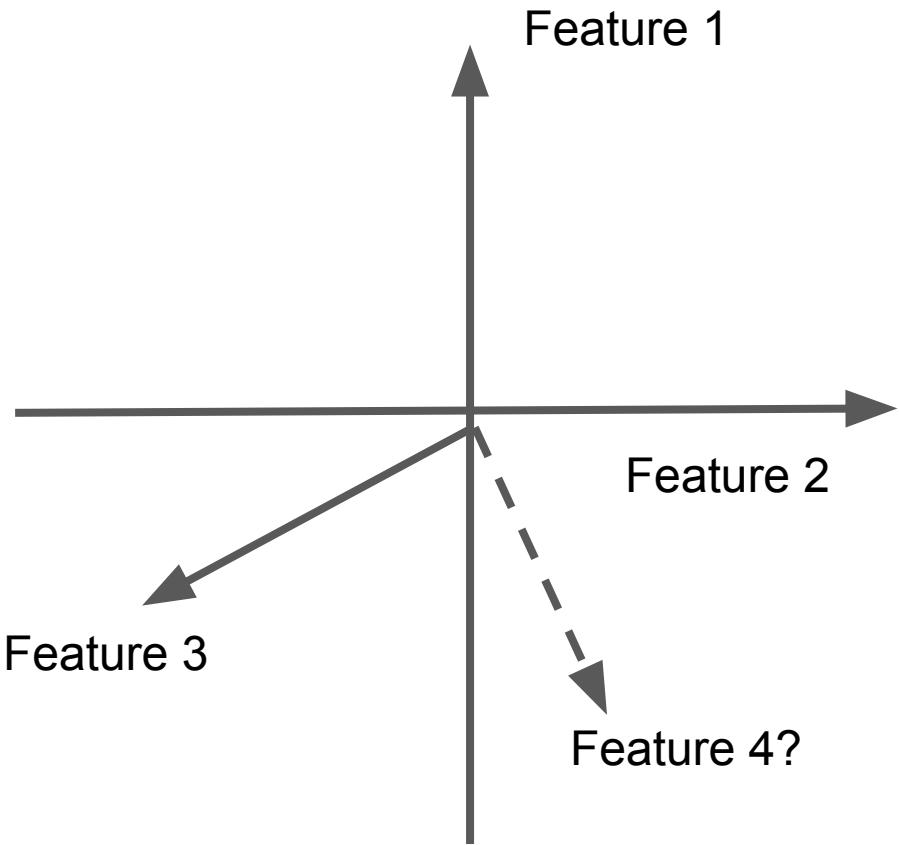


Negative Correlation



# Feature Space again

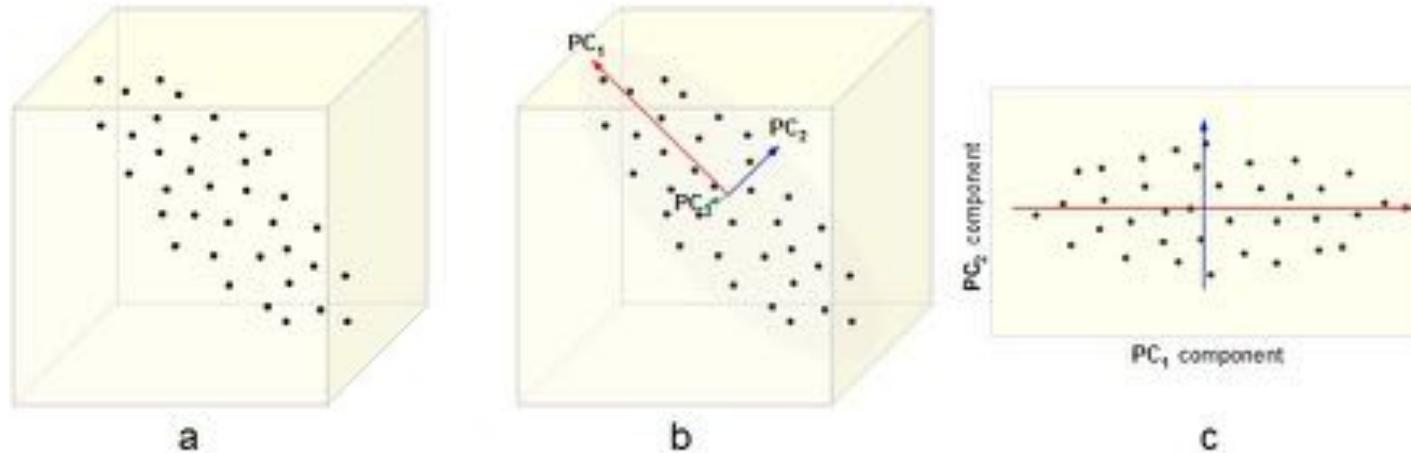
How to represent so many features?



# Principal Component Analysis (PCA)

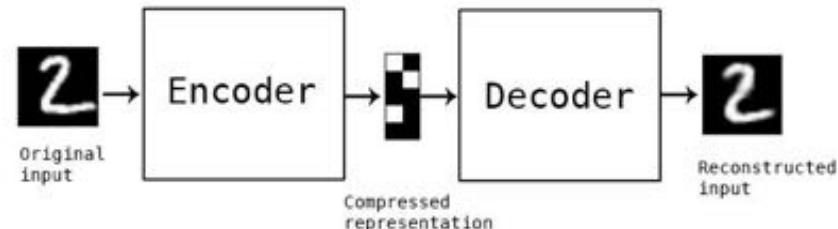
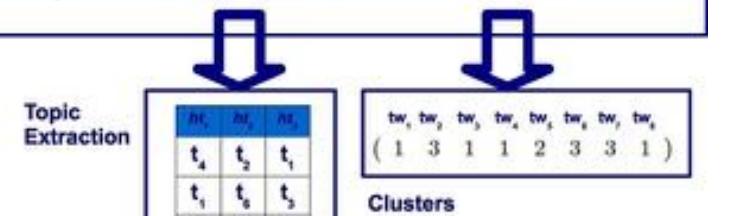
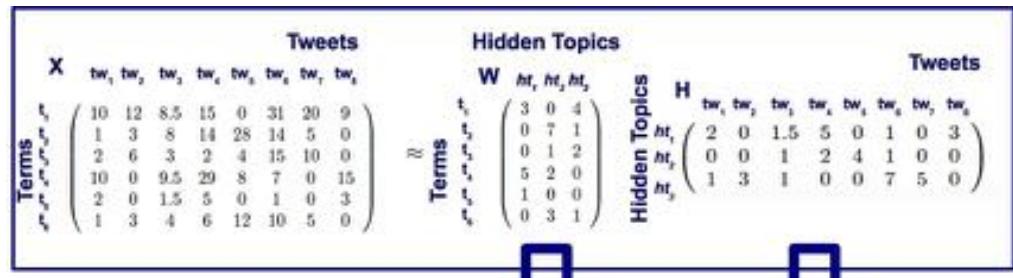
Intuition: Capture the **variance** in data by using a **combination** of features as **new axis** in the feature space

## Dimensionality Reduction

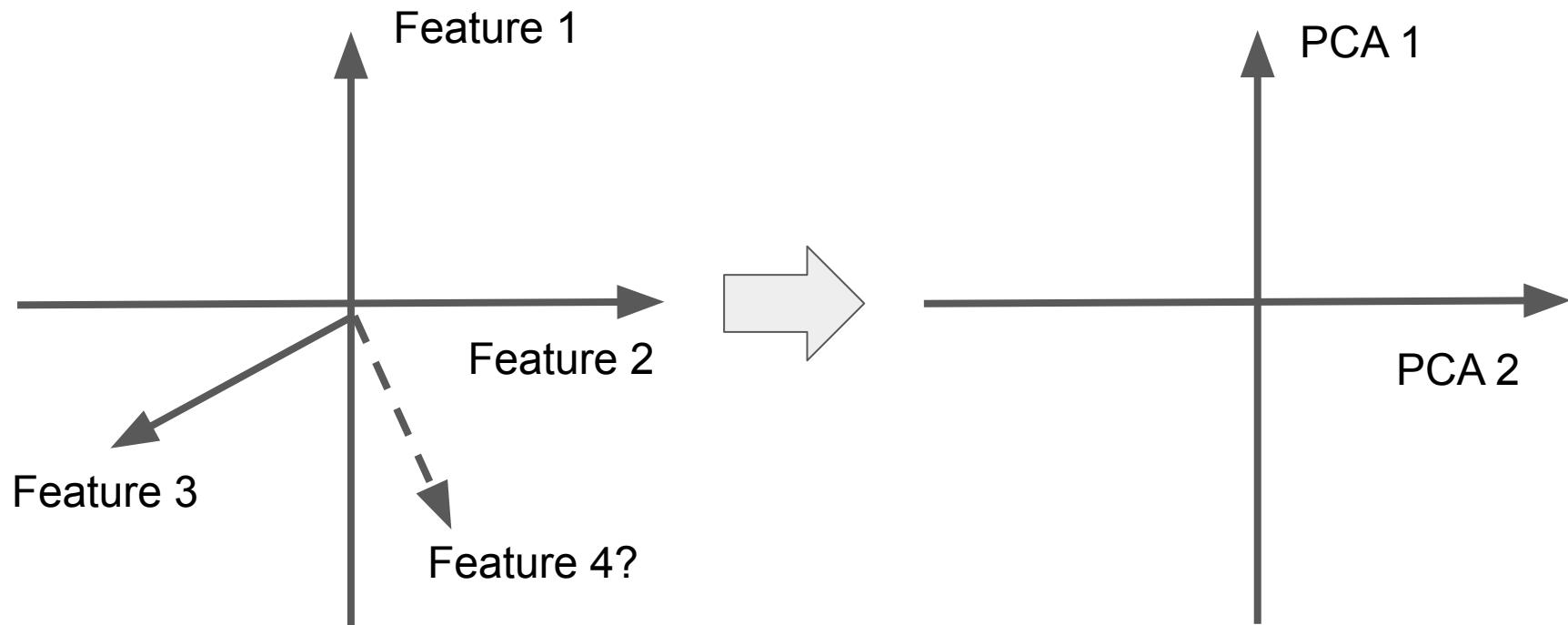


# Other Dimensionality Reduction Methods

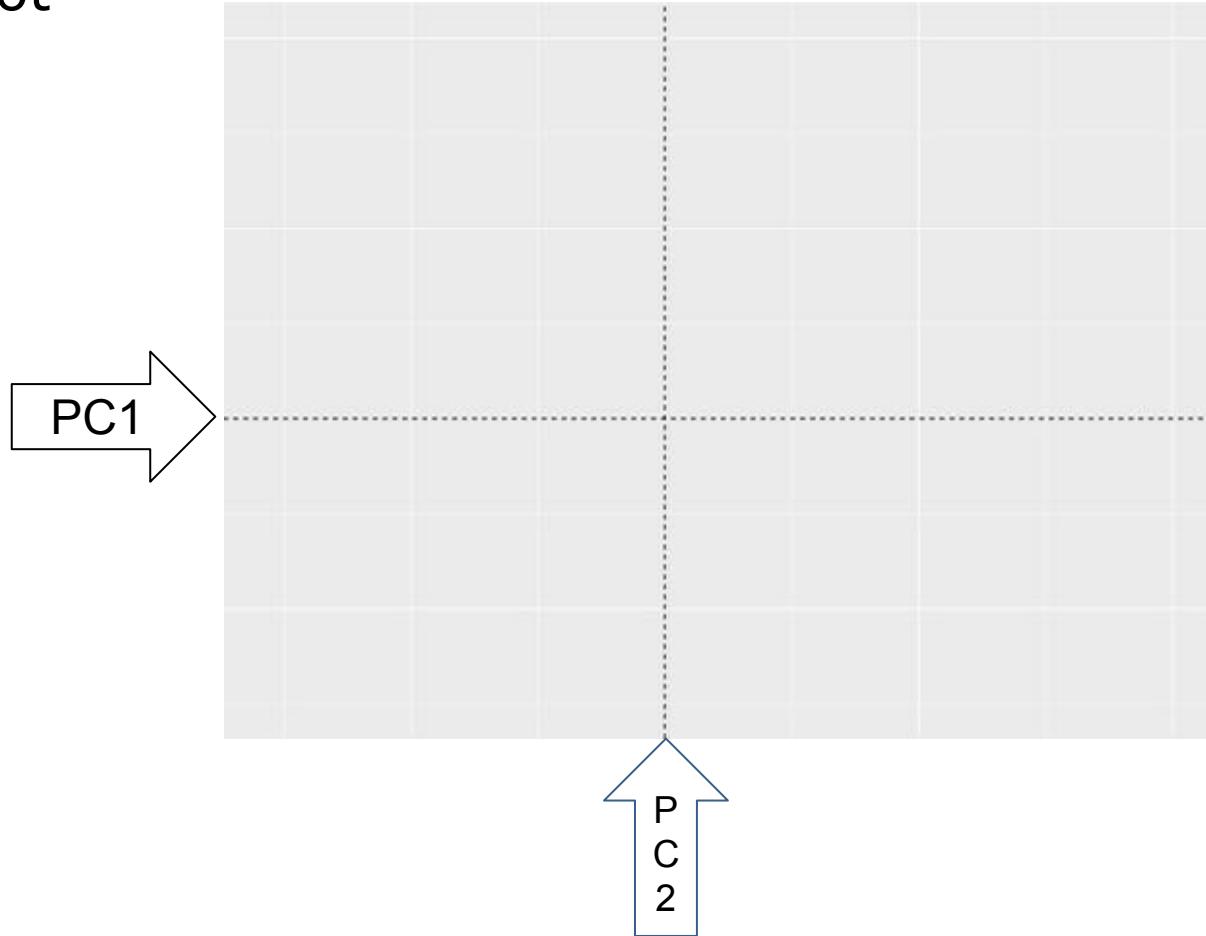
- NMF
- T-SNE
- Autoencoder
- ...



# How to represent so many features?



# PCA biplot



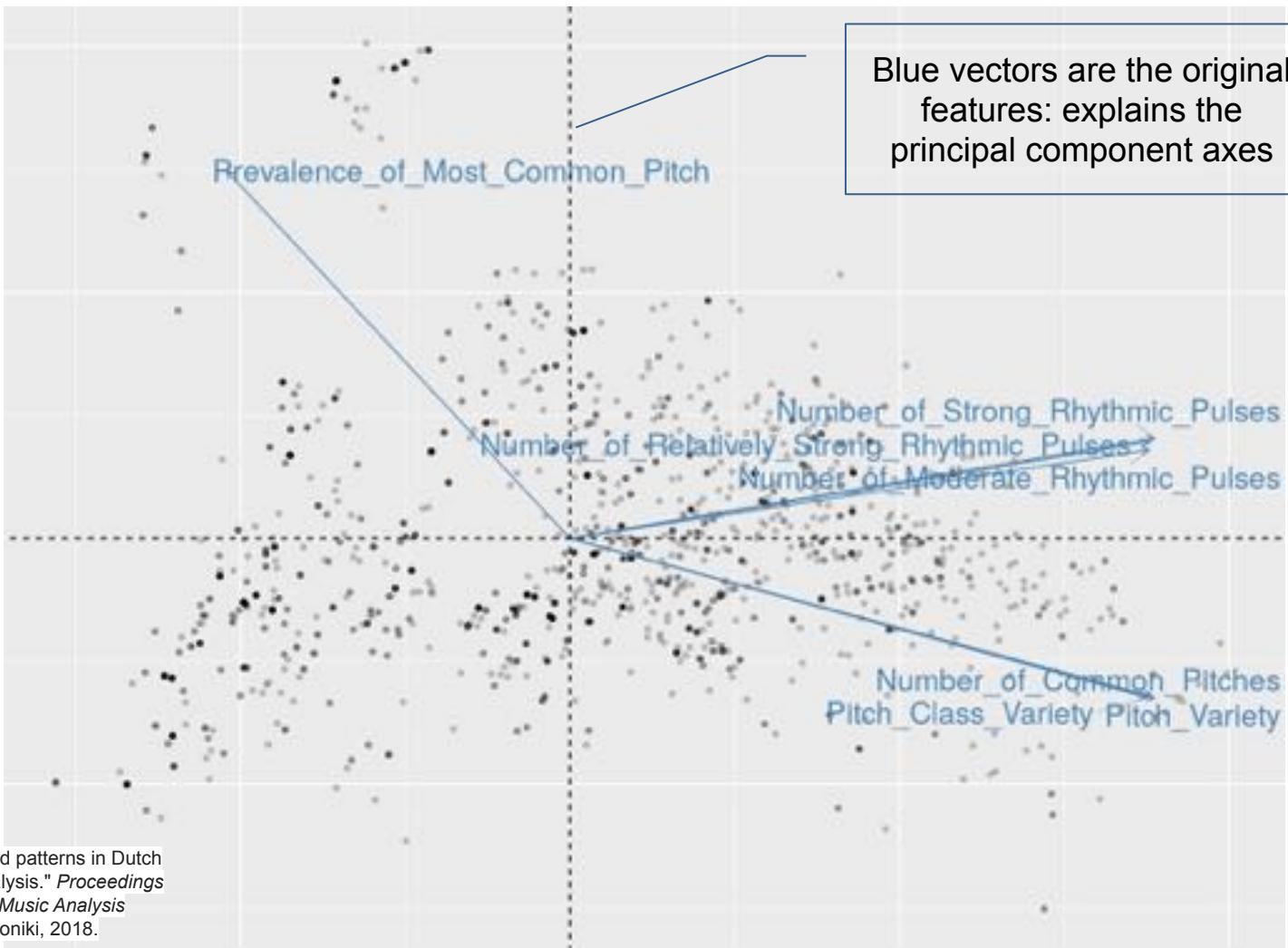
# PCA biplot

PC1

PC2

Black dots are  
projection of the feature  
vectors: representing  
music

# PCA biplot



Ren, Y., et al. "Feature analysis of repeated patterns in Dutch folk songs using Principal Component Analysis." *Proceedings of the 8th International Workshop on Folk Music Analysis (FMA2018)*. Aristotle University of Thessaloniki, 2018.

# VI. Applications: Error Detection, Classification, Explanation

# AI music: Folk RNN

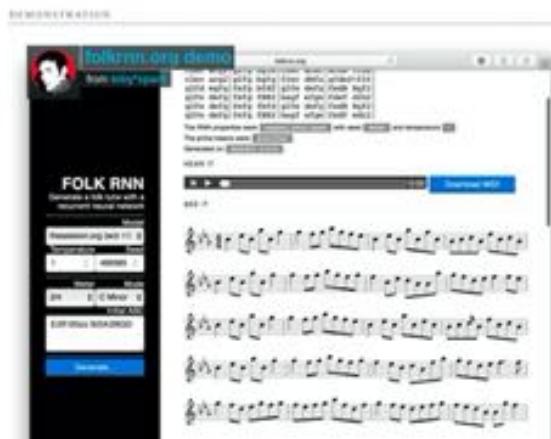


ABOUT FOLK MINN

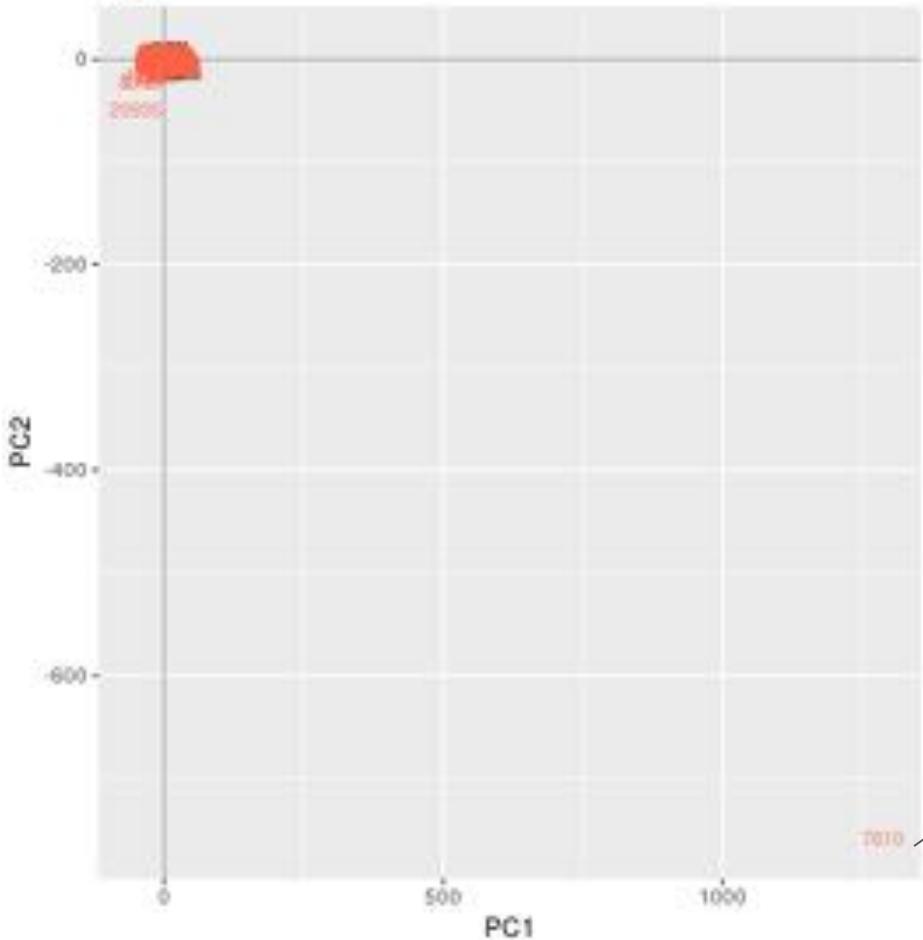
This website lets you generate music using an artificial intelligence called a "recurrent neural network" (RNN). It's called "folk-rnn" because the RNN is trained on transcriptions of folk music. Each press of the "compose" button will create a new tune, shaped by your initial input. For example, raising "temperatur" will make the algorithm more adventurous. Or if a generated tune has a feature you like, you can copy that back into the "Initial ABC" field and generate new tunes led by that feature.

<sup>10</sup> Machine-folk music, curated by Alphaville media, [www.alphavillemedia.com](http://www.alphavillemedia.com), The Conversation, March 2012.

Why do I care? As that article goes on to say, the original folkster was developed, and its developers composed music using its successes and failures. This website aims to make that possible for everyone. It's a tool for anyone.



PCA



## Error Detection: Folk RNN



# Classification:

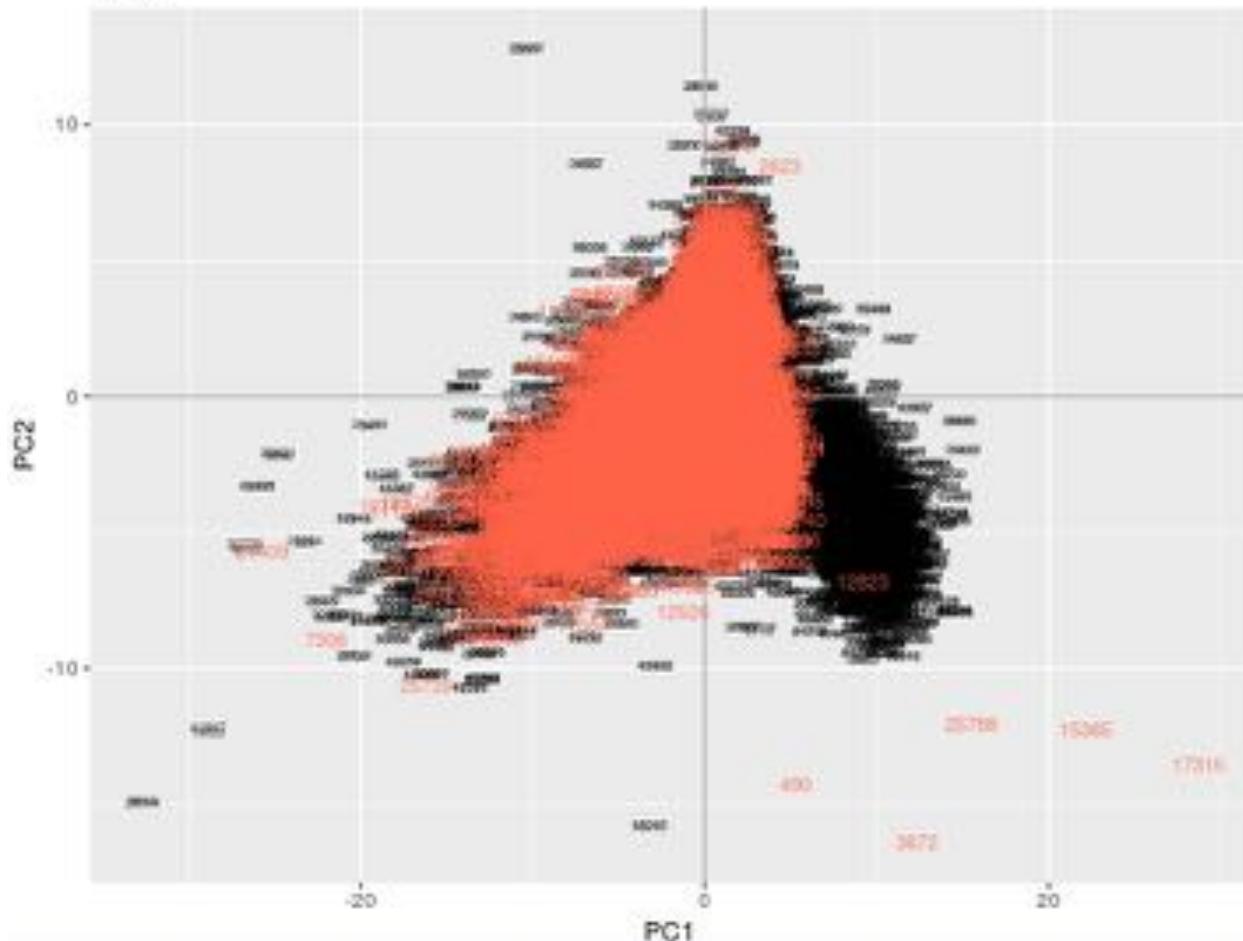
## Algorithmically composed music

### Vs

## Human music

## Session.org pieces

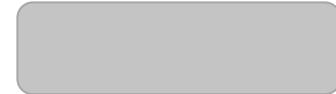
## Folk-RNN pieces



# Pattern Classification:

## Comparing algorithmically extracted patterns vs human annotations

# Random baseline



**32. Daar zou 'er een magetje vroeg opstaan. C.**  
Record 1549 - Strophe I

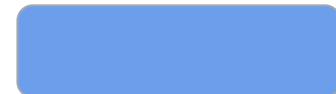
A musical score for 'Daar zou 'er een magetje vroeg opstaan' in common time (indicated by 'C'). The score consists of four staves of music. Annotations are shown as colored boxes (blue, purple, and gray) highlighting specific musical patterns or notes across the staves. The lyrics are written below each staff.

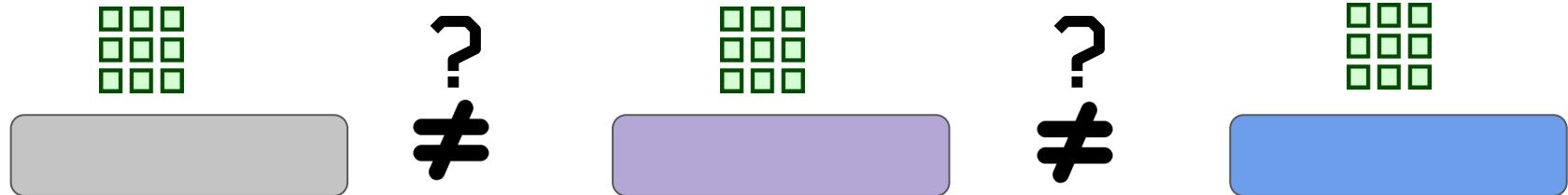
Daar zou 'er een magetje vroeg opstaan  
Om haar lieve kleine kooi gaan  
En zij mocht 't niet meer derde deel van den  
Maar ik daar haar lief - jo niet? vin - den.

# Annotation

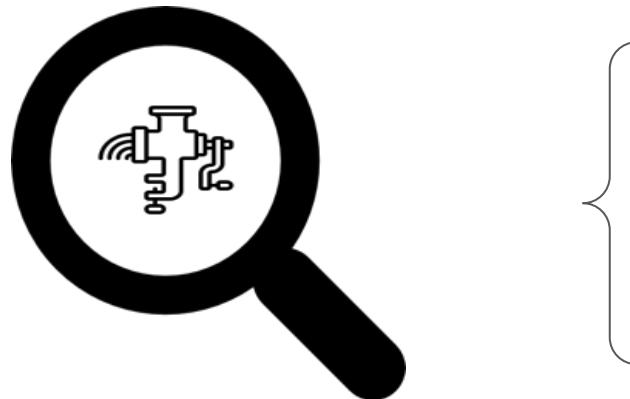


# Algorithm



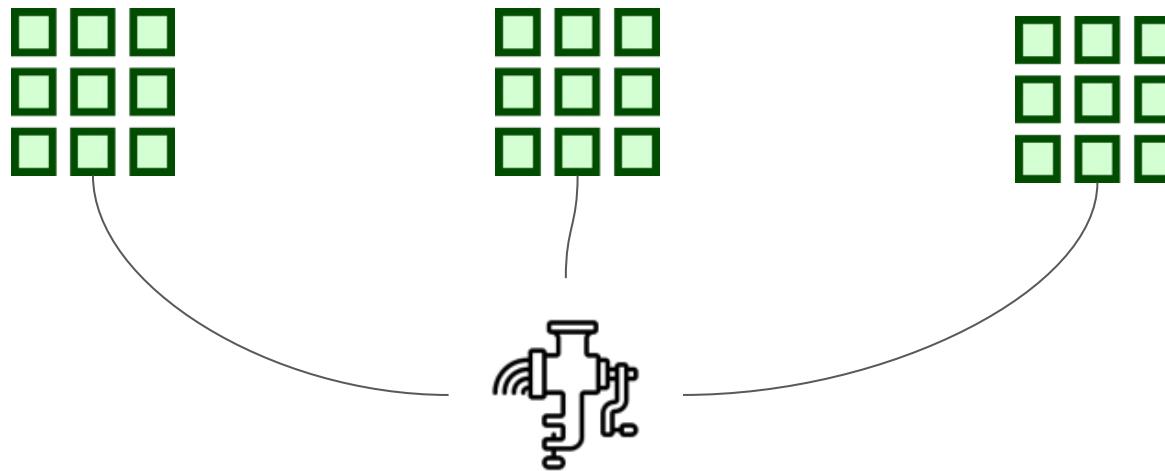


Compare the features: Identifying the differences

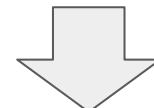


Note Density  
Average Note Duration  
Most Common Pitch Class  
Range  
Repeated Notes  
Amount of Arpeggiation  
...

# Comparative Analysis by Classification



Classifiers: GBM, LDA, LVQ, NB, RF, SVM



# Machine Learning Classifiers & Cross-Validation

GBM: Gradient Boosting Machine

LDA: Linear Discriminant Analysis

LVQ: Learning Vector Quantisation

NB: Naive Bayes

RF: Random Forest

SVM: Support Vector Machine



Imagine in the feature space:

Overlap: Feature sharing

Anno ~ Alg 

Alg <> Random 

Anno <> Random 

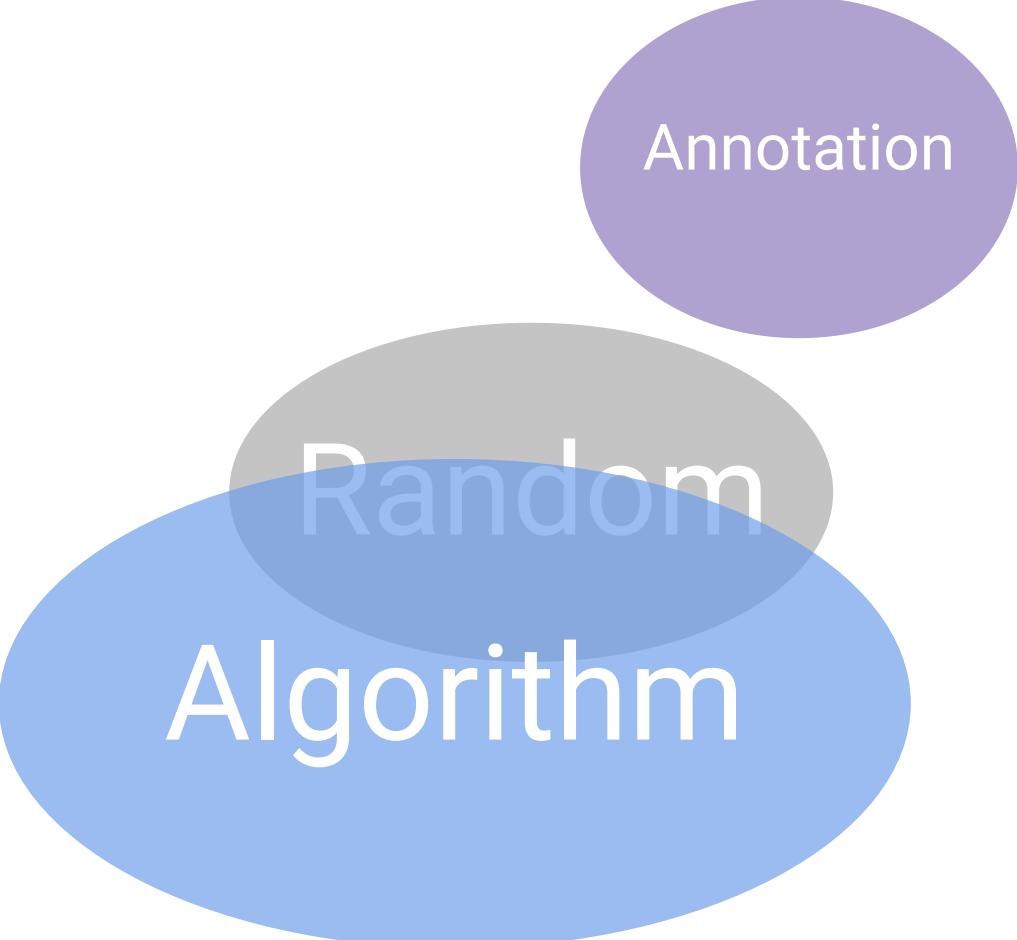
Random

Annotation  
Algorithm

Anno <> Alg 😱

Alg ~ Random 😱

Anno ~ Random 😱

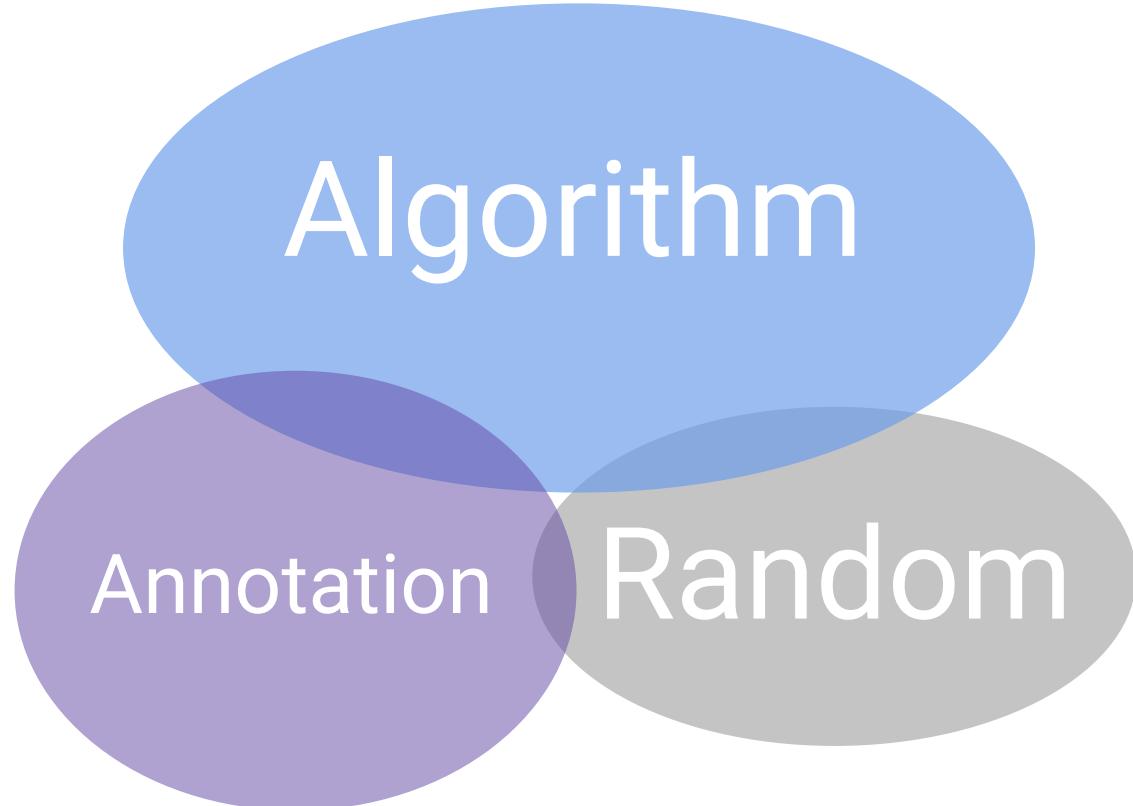


Annotation

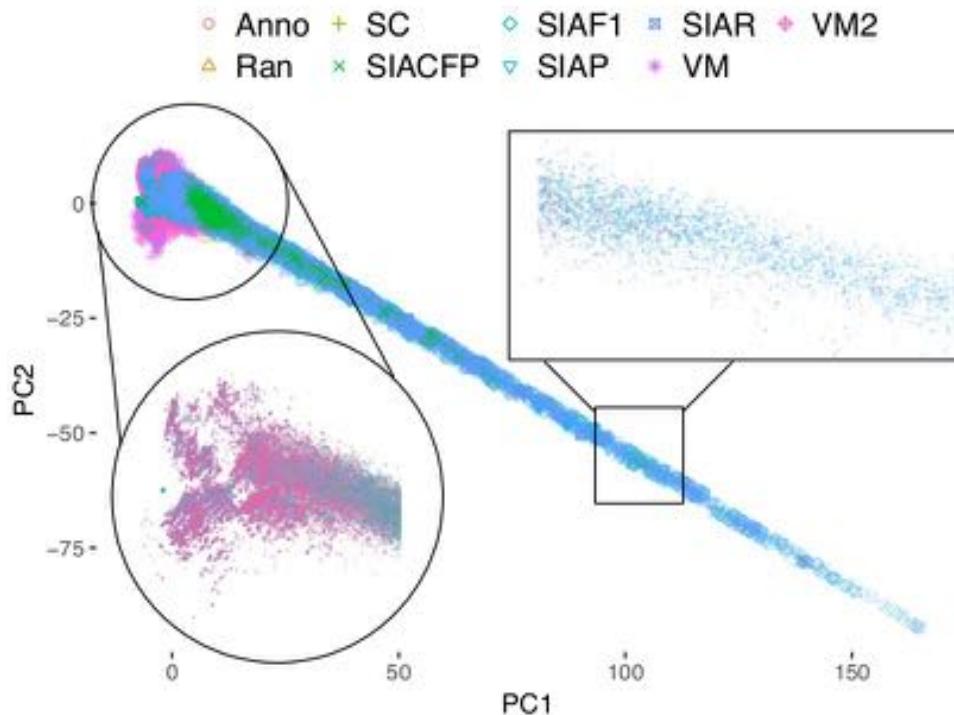
Random

Algorithm

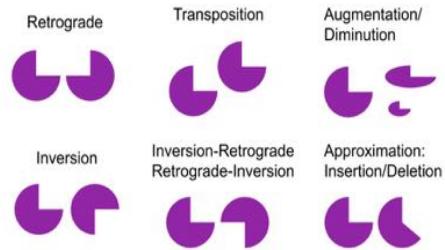
Anno <> Alg  
Alg <> Random  
Anno <> Random



# Results:

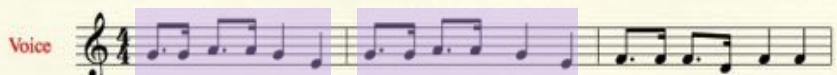


# Transformation-based Analysis



## Sinterklaas kapoentje

[kinderliedjes.overtuin.net](http://kinderliedjes.overtuin.net)

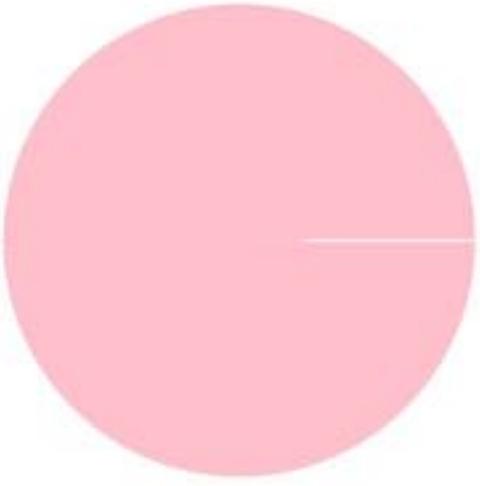


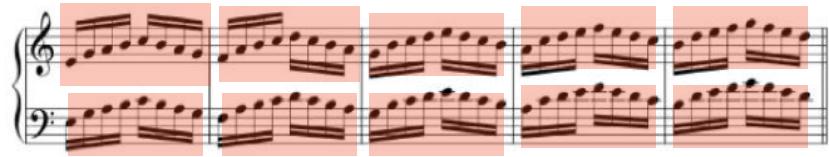
Sin- ter-klaas ka-poен - tje, gooi wat in mijn schoen - tje, gooi wat in mijn laars - je,



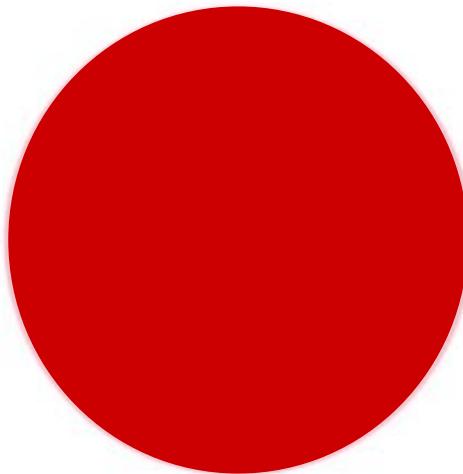
dank u Sin - - - ter - klaas - - - je!

exact

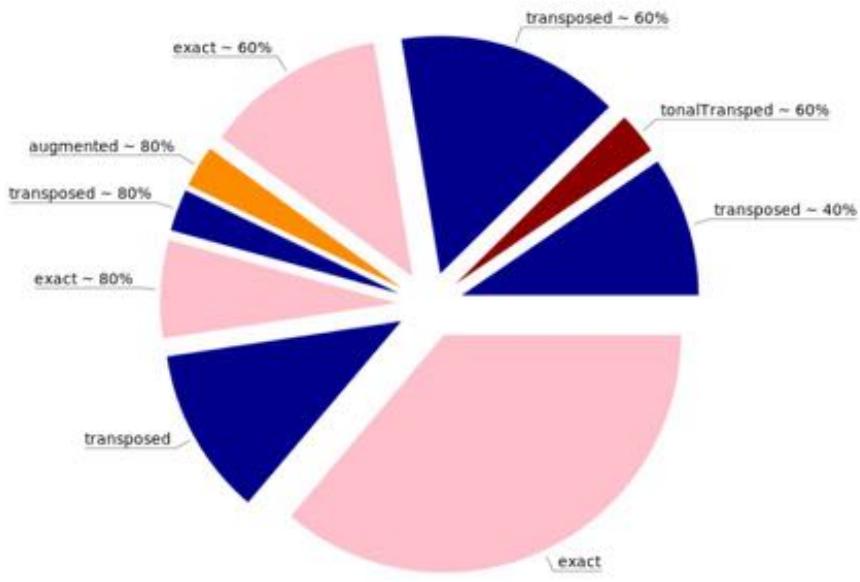




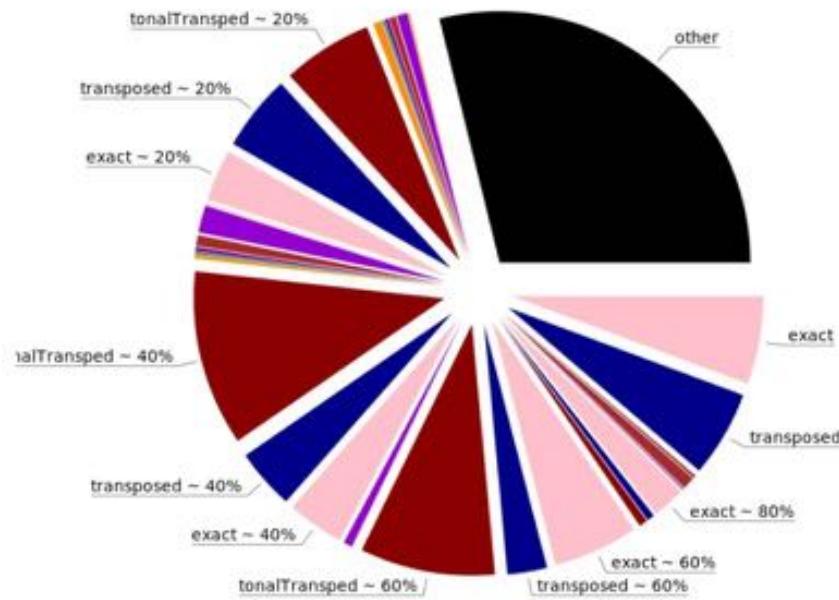
Tonal  
Transposition



# JKUPDD Expert Annotation vs Algorithmically Extracted Patterns



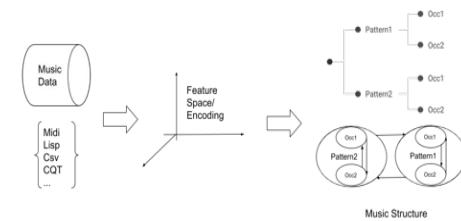
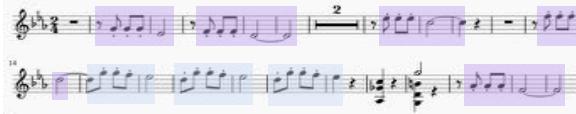
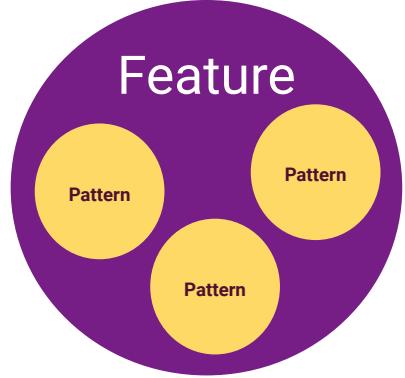
Expert



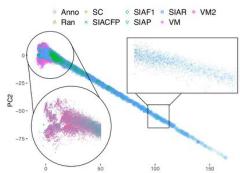
Algorithm

# Summary

- Pattern Recognition
- Musical Pattern
- Automatic Pattern Discovery
- Feature Extraction and Analysis
- Applications



	Feature1	Feature2	...	Feature n
Music 1				
Music 2				
...				
Music m				



# Creating a Tool for Facilitating and Researching Human Annotation of Musical Patterns

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## Abstract

Musical patterns (repeated segments of music) are highly widespread in all varieties of music, and annotations of such patterns are valuable in many areas of music information retrieval. Unfortunately, there is a lack of expert annotations of musical patterns, and most annotation is done by hand. In this project, we introduce a novel software, ANOMIC, designed for users to intuitively annotate repeated musical segments, and we perform a user study which yields a large database of annotations done using the tool. We find that the tool's reception was strongly positive and show that the annotations done with it reach high levels of inter-annotator agreement compared to traditional approaches.

## 1) Background

What is a **musical pattern**?

- A musical pattern is a repeated and noteworthy segment of music.
- Repetition can be exact or inexact.
- Discovery of patterns is subjective!



Human vs. automatic pattern discovery:

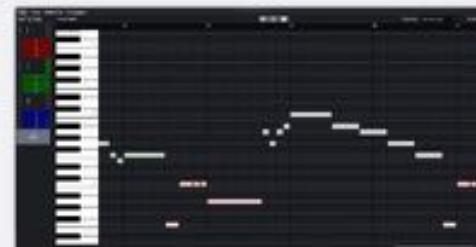
- Humans have been shown to be much better at finding **salient** patterns.
- We need more data to train and design algorithms for pattern discovery.
- Methods to manufacture such data are outdated.

Challenges in pattern discovery:

There are no clear rules on how long a pattern should be. It should not consist of "several" patterns & an infeasible task to decide the corner of a song that is difficult to decide in the course of music patterns.

Most methods of extracting music are done using short, most, and bottlenecked approaches. We focus on long, explicit, fine and intermediate.

## 2) ANOMIC



**ANOMIC** is a novel software tool designed for musical pattern annotation. Features:

- Written in C++ and XAML using Visual Studio. Open-source!
- Compatible with Windows.
- User-friendly and customisable piano-roll interface.
- Support for the widespread MIDI music format (including MIDI channel separation) and JAMS annotation files.
- Audio playback.
- Transposition-invariant, polyphony-robust automatic exact pattern occurrence matching.

Repository: <https://github.com/StephanWells/ANOMIC>  
Instruction video: <https://hanjui1.com/annotationtoolvideo>

## 3) Evaluation

ANOMIC was evaluated by means of a **user study**, where participants were tasked to annotate repeated patterns in six MIDI files of excerpts of classical music and then take a survey querying them on their experience.

26

participants

6

MIDI files to annotate

# Master Student Project Last Year:

## Musical pattern annotation tool + user study



Thank you!