

FpA-Musicologie

Présentation des recherches doctorales

Paul Lascabettes & Gonzalo Romero García



ircam
Centre
Pompidou



 **SORBONNE**
UNIVERSITÉ



Un doctorat ?

- C'est quoi ?

Un doctorat ?

- C'est quoi ?
- Pourquoi faire un doctorat ?

Un doctorat ?

- C'est quoi ?
- Pourquoi faire un doctorat ?
- Comment faire un doctorat ?

Un doctorat ?



en mathématiques
appliquées à la musique

Un doctorat ?

Domaines :

Géométrie, algèbre,
topologie... et d'autres !

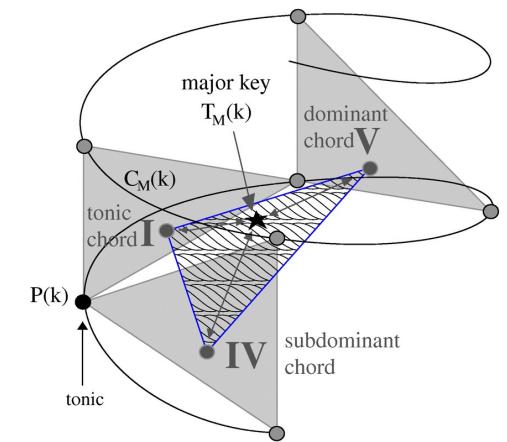
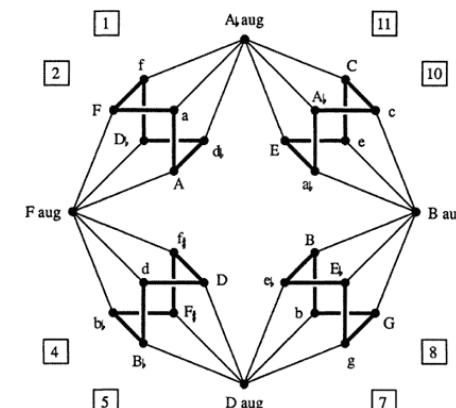
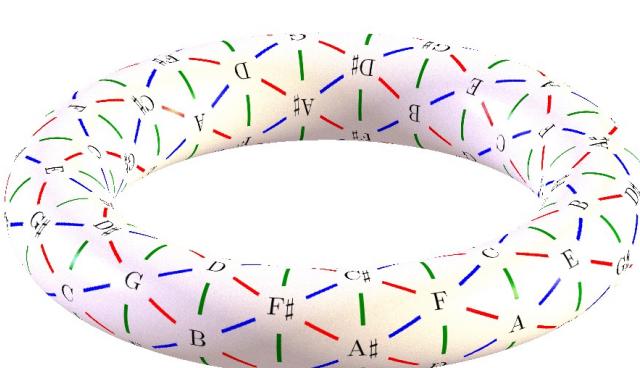
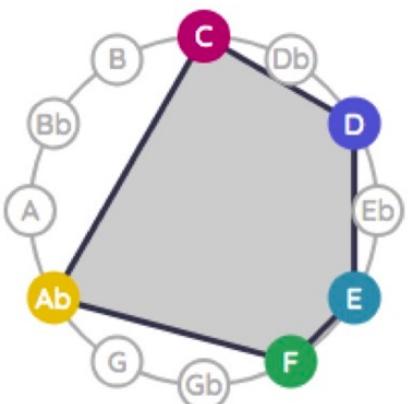
en mathématiques
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appliquées à la musique



Mon doctorat ☺

Mon doctorat ☺



Elaine Chew



Corentin Guichaoua
→ informatique



Daniel Bedoya
→ perception

Mon doctorat ☺



Elaine Chew



Carlos Agon



Corentin Guichaoua
→ informatique



Daniel Bedoya
→ perception



Moreno Andreatta



Isabelle Bloch
→ mathématiques

Chapitre 1 : Étudier la performance (avec du transport optimal)

"Lettre à Elise"

Bagatelle No. 25 en La mineur (WoO 59)

Ludwig van Beethoven

"Lettre à Elise"

Bagatelle No. 25 en La mineur (WoO 59)

Ludwig van Beethoven

The musical score consists of three staves of music for two voices. The top staff is in treble clef, the middle staff is in bass clef, and the bottom staff is also in bass clef. The key signature is one sharp (F#). The time signature changes between common time (indicated by '8') and 3/8.

Annotations:

- Poco moto**: Dynamic marking at the beginning of the piece.
- pp**: Dynamics indicating piano dynamic.
- Color-coded ovals**: Various notes are highlighted with colored ovals (blue, red, green, yellow, and light blue) to draw attention to specific melodic or harmonic features.
- Measure numbers**: Measure 1, Measure 8 (with first and second endings), and Measure 15 are explicitly numbered.

"Lettre à Elise"

Bagatelle No. 25 en La mineur (WoO 59)

Ludwig van Beethoven

The musical score consists of three staves of music for two voices. The top staff is in treble clef and common time (indicated by a '3'). The bottom staff is in bass clef and common time. The first measure starts with a dynamic of *poco moto* and *pp*. The music features eighth-note patterns and sixteenth-note figures. Various notes are highlighted with colored ovals: red ovals are placed over notes in measures 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15; yellow ovals are placed over notes in measures 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15; green ovals are placed over notes in measures 8, 9, 10, 11, 12, 13, and 14; and blue ovals are placed over notes in measures 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15. Measure numbers 8, 15, and 16 are indicated above the staves.

"Lettre à Elise"

Bagatelle No. 25 en La mineur (WoO 59)

Ludwig van Beethoven

The musical score consists of three staves of music for two voices. The top staff is in treble clef, the middle staff is in bass clef, and the bottom staff is also in bass clef. The key signature is one sharp (F#), and the time signature is common time (indicated by '8'). The tempo is marked 'Poco moto' and dynamics include 'pp' (pianissimo) and various slurs.

Annotations:

- Poco moto**: Above the first measure.
- pp**: Dynamics at the beginning of the first measure.
- Color-coded ovals**: Various notes are highlighted with colored ovals:
 - Purple oval**: Circles a group of eighth-note pairs in the first measure.
 - Blue oval**: Circles a group of eighth-note pairs in the first measure.
 - Red ovals**: Circles groups of eighth-note pairs in measures 1, 2, and 3.
 - Yellow ovals**: Circles groups of eighth-note pairs in measures 1, 2, and 3.
 - Green oval**: Circles a group of eighth-note pairs in measure 8, 2nd ending.
 - Blue oval**: Circles a group of eighth-note pairs in measure 8, 2nd ending.
 - Blue ovals**: Circles groups of eighth-note pairs in measures 15 and 16.
 - Yellow ovals**: Circles groups of eighth-note pairs in measures 15 and 16.
- Measure numbers**: '1.', '2.', '8.', and '15.' are placed above the staves to indicate specific measures.

"Lettre à Elise"

Bagatelle No. 25 en La mineur (WoO 59)

Ludwig van Beethoven

The musical score consists of three staves of music for two voices. The top staff is in treble clef, the middle staff is in bass clef, and the bottom staff is also in bass clef. The key signature is one sharp (F#). The time signature changes between common time (indicated by '8') and 3/8 time.

Annotations:

- Poco moto**: Dynamic marking at the beginning of the piece.
- pp**: Dynamics indicating piano dynamic.
- Color-coded ovals**: Various notes are circled with colored ovals (purple, blue, red, green, yellow, light blue) to highlight specific melodic or harmonic features.
- Measure numbers**: Measure 1, Measure 8 (with first and second endings), and Measure 15 are explicitly numbered.

"Lettre à Elise"

Bagatelle No. 25 en La mineur (WoO 59)

Ludwig van Beethoven

The musical score consists of three staves of music for two voices. The top staff is in treble clef, G major (three sharps), and common time. The bottom staff is in bass clef, C major (no sharps or flats), and common time. Measure 1 starts with a dynamic *pp* and a tempo marking *Poco moto*. The music features various note patterns, some of which are highlighted with colored ovals: purple, blue, red, yellow, green, and light blue. Measure 8 begins with a repeat sign and two endings (1 and 2). Measure 15 starts with a dynamic *p*. The score includes several rests and changes in key signature.



Comment faire
comprendre
le découpage ?

Comment faire comprendre le découpage ?

Faire varier le tempo et le volume.

Comment faire comprendre le découpage ?

Faire varier le tempo et le volume.

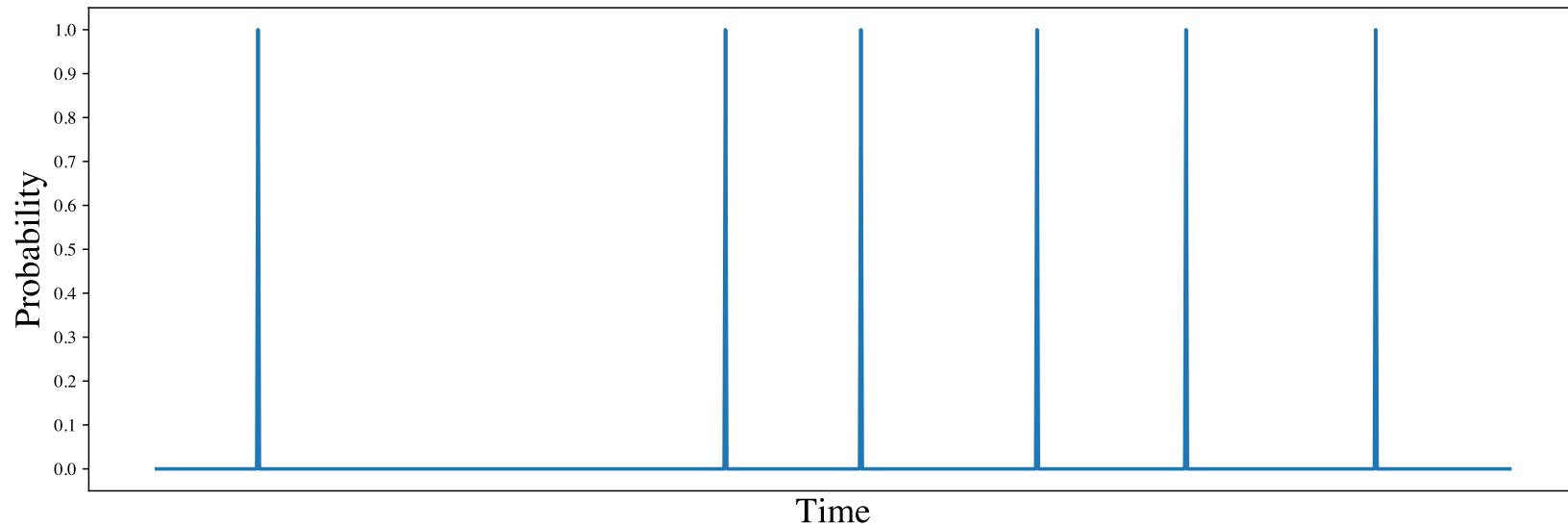
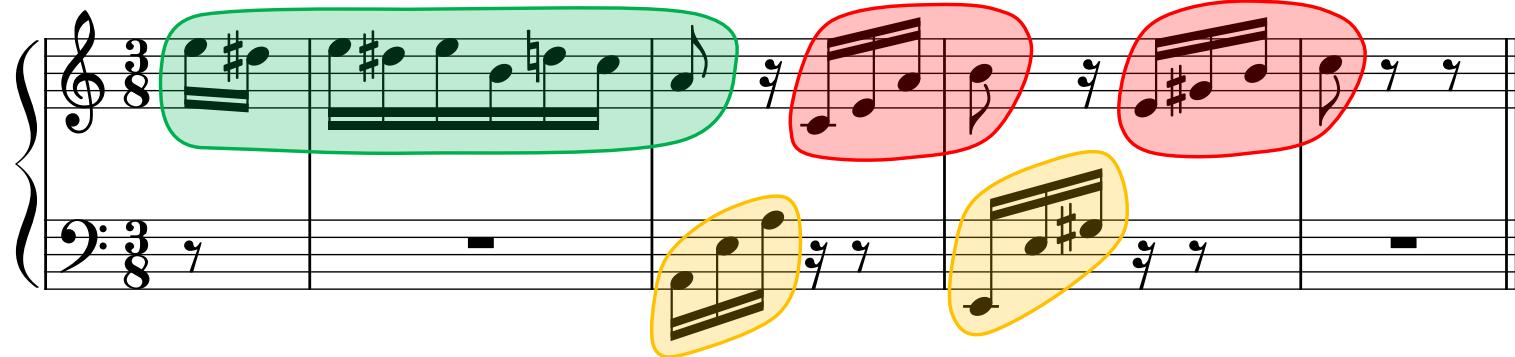
Mais comment les faire varier ?

Comment faire comprendre le découpage ?

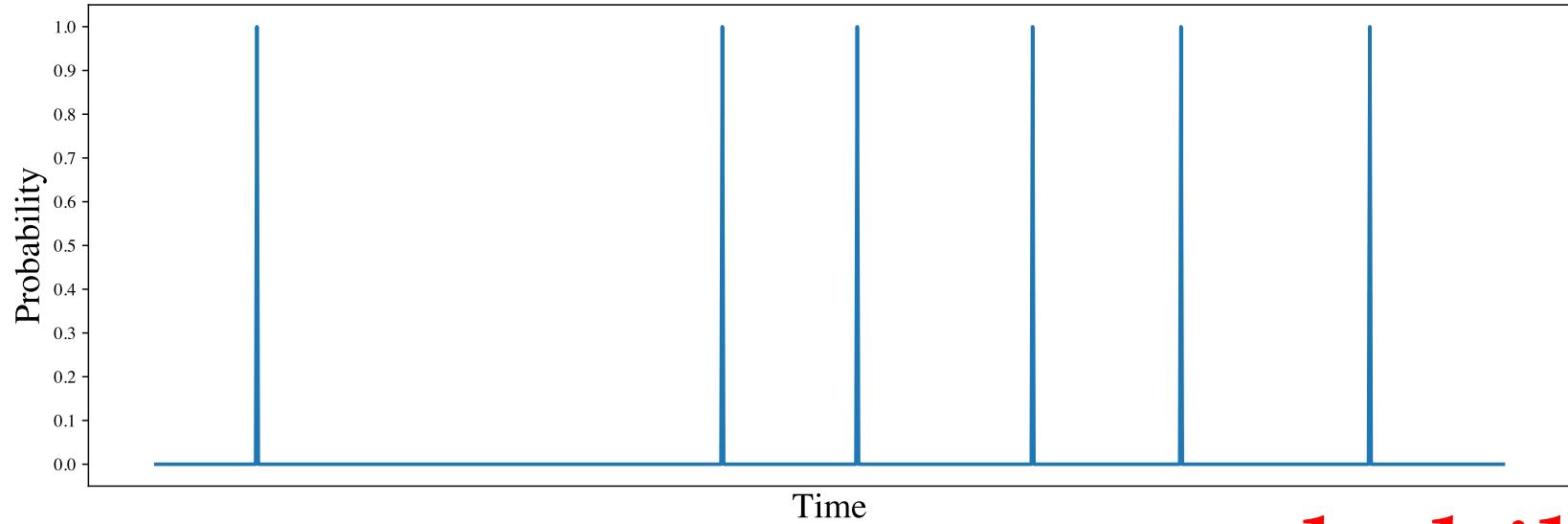
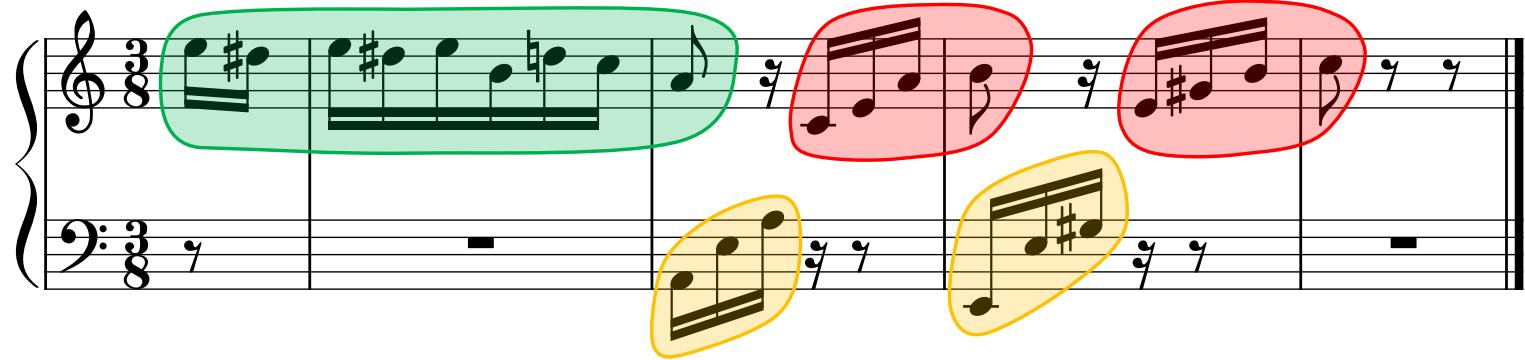
Faire varier le tempo et le volume.

Mais comment les faire varier ?

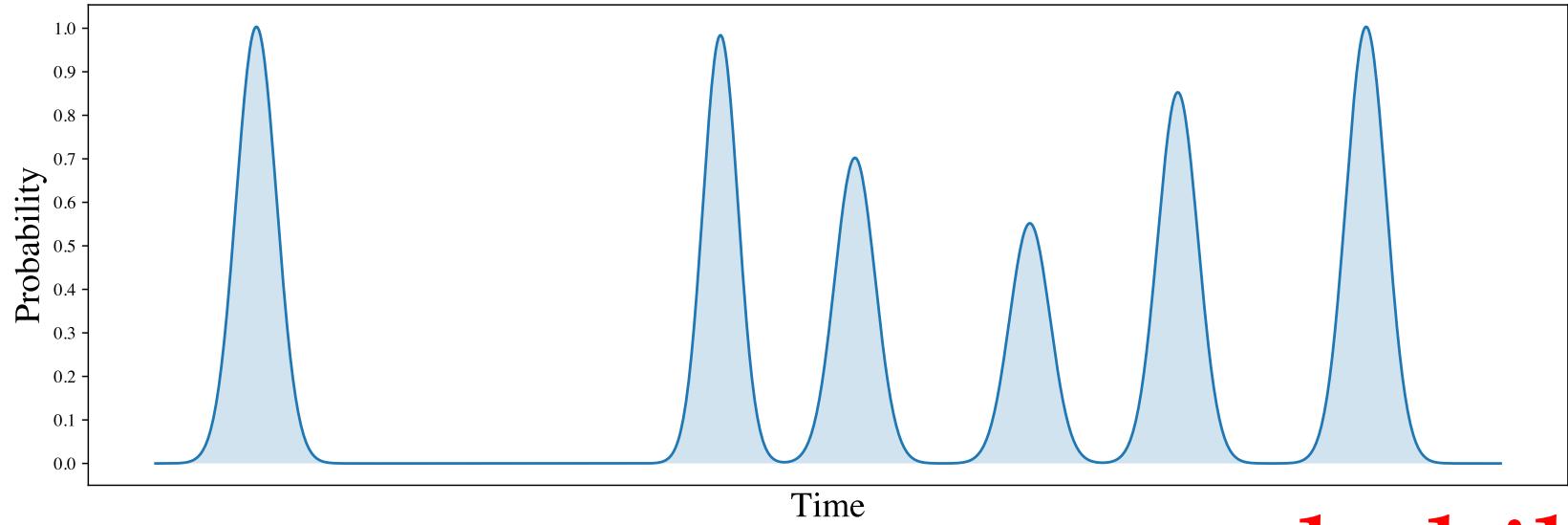
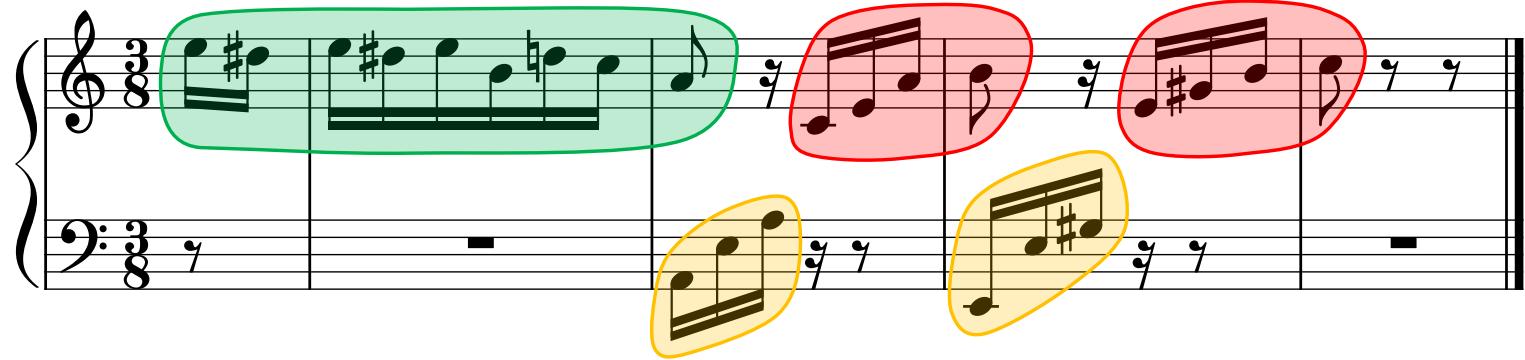
Avec des arcs !



Frontières verticales



Frontières ~~verticales~~ probabilistes



Frontières ~~verticales~~ probabilistes



Étudier quelles performances ?

Étudier quelles performances ?

Il faut que ça soit du piano [1].

[1] Carlos E Cancino-Chacón, Maarten Grachten, Werner Goebel, and Gerhard Widmer. Computational models of expressive music performance: A comprehensive and critical review. *Frontiers in Digital Humanities*, 5:25, 2018.



Étudier quelles performances ?

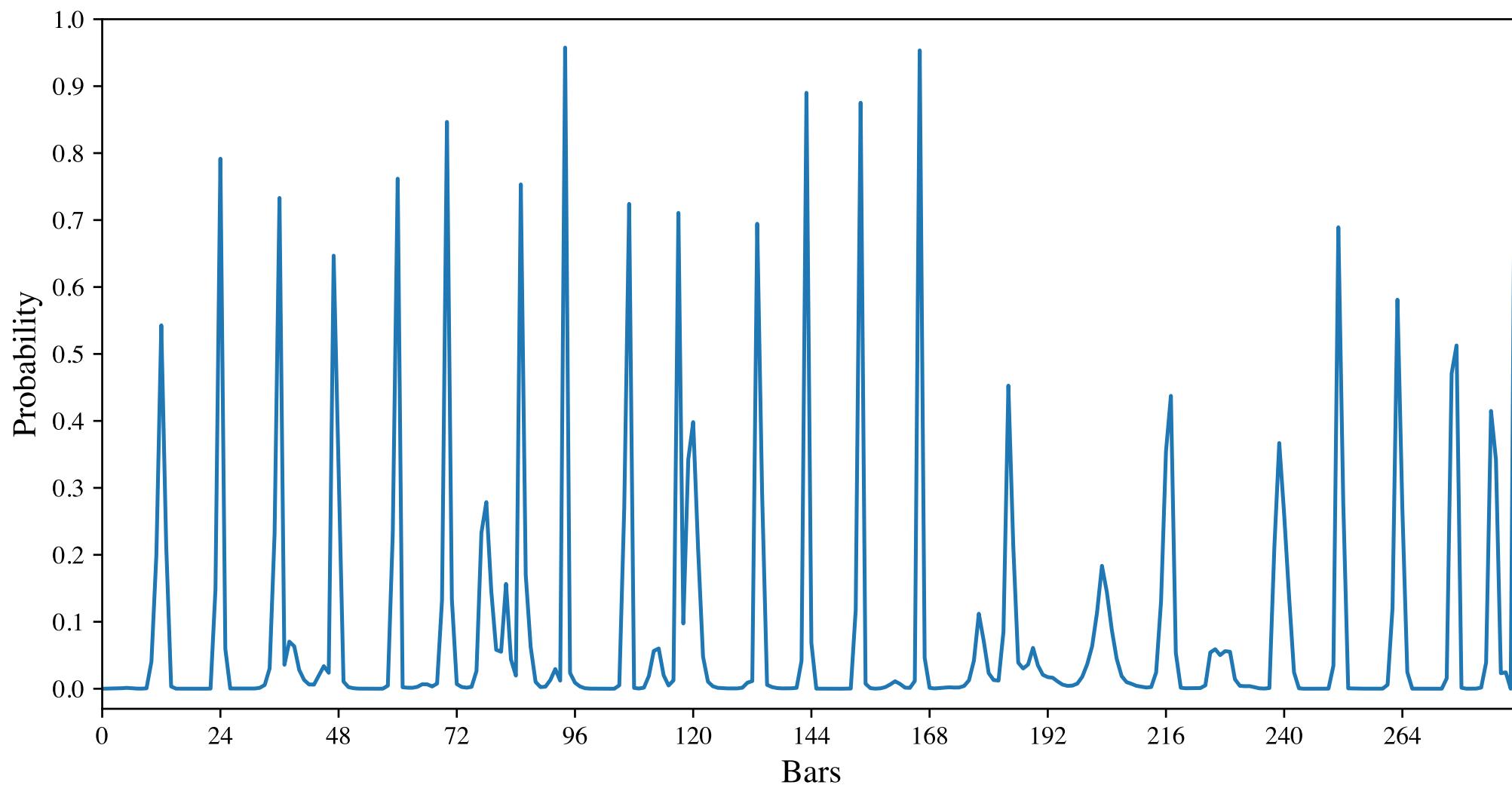
Il faut que ça soit du piano [1].

Dataset : Mazurkas de Chopin [2]

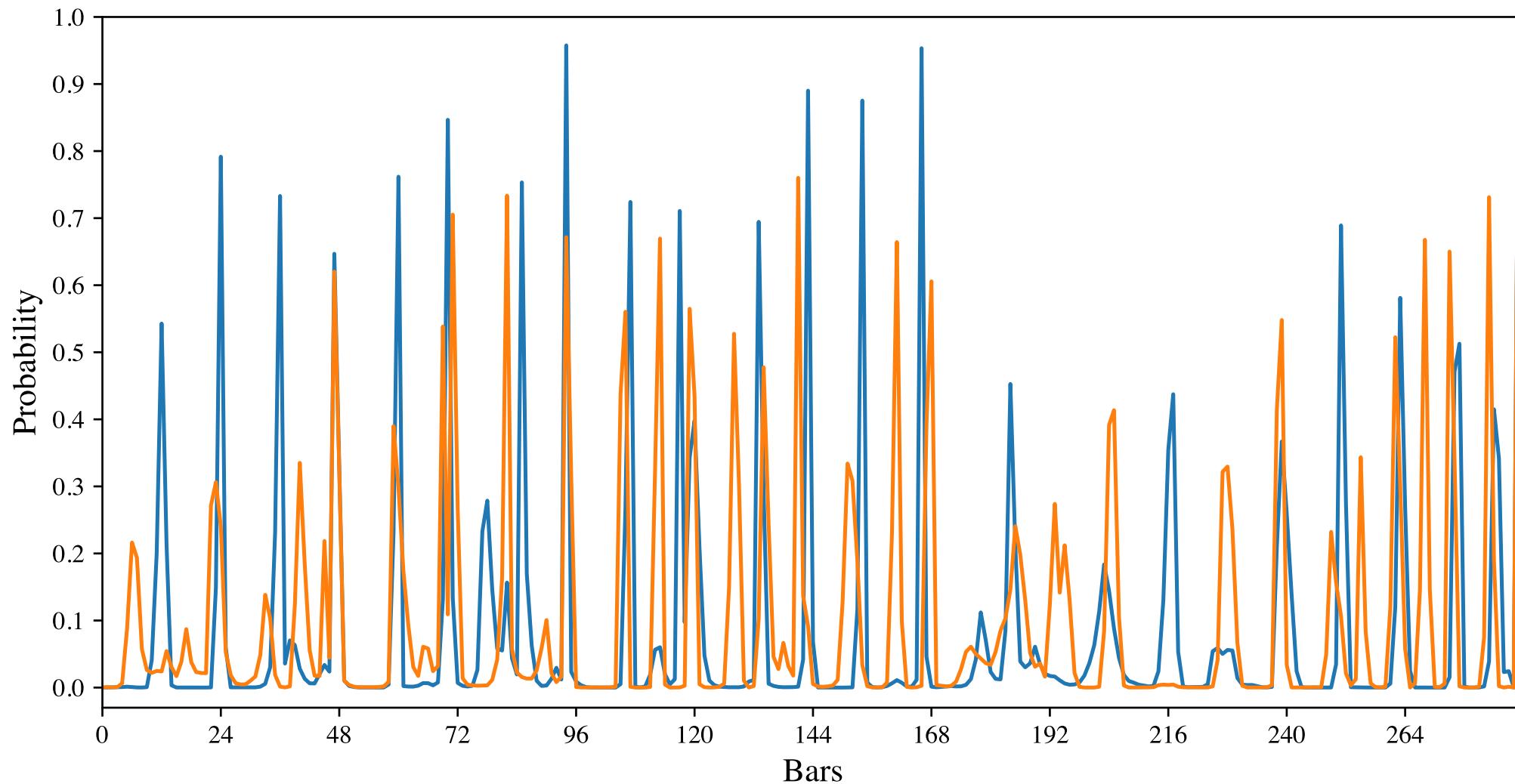
2000 performances de 50 Mazurkas

[1] Carlos E Cancino-Chacón, Maarten Grachten, Werner Goebel, and Gerhard Widmer. Computational models of expressive music performance: A comprehensive and critical review. *Frontiers in Digital Humanities*, 5:25, 2018.

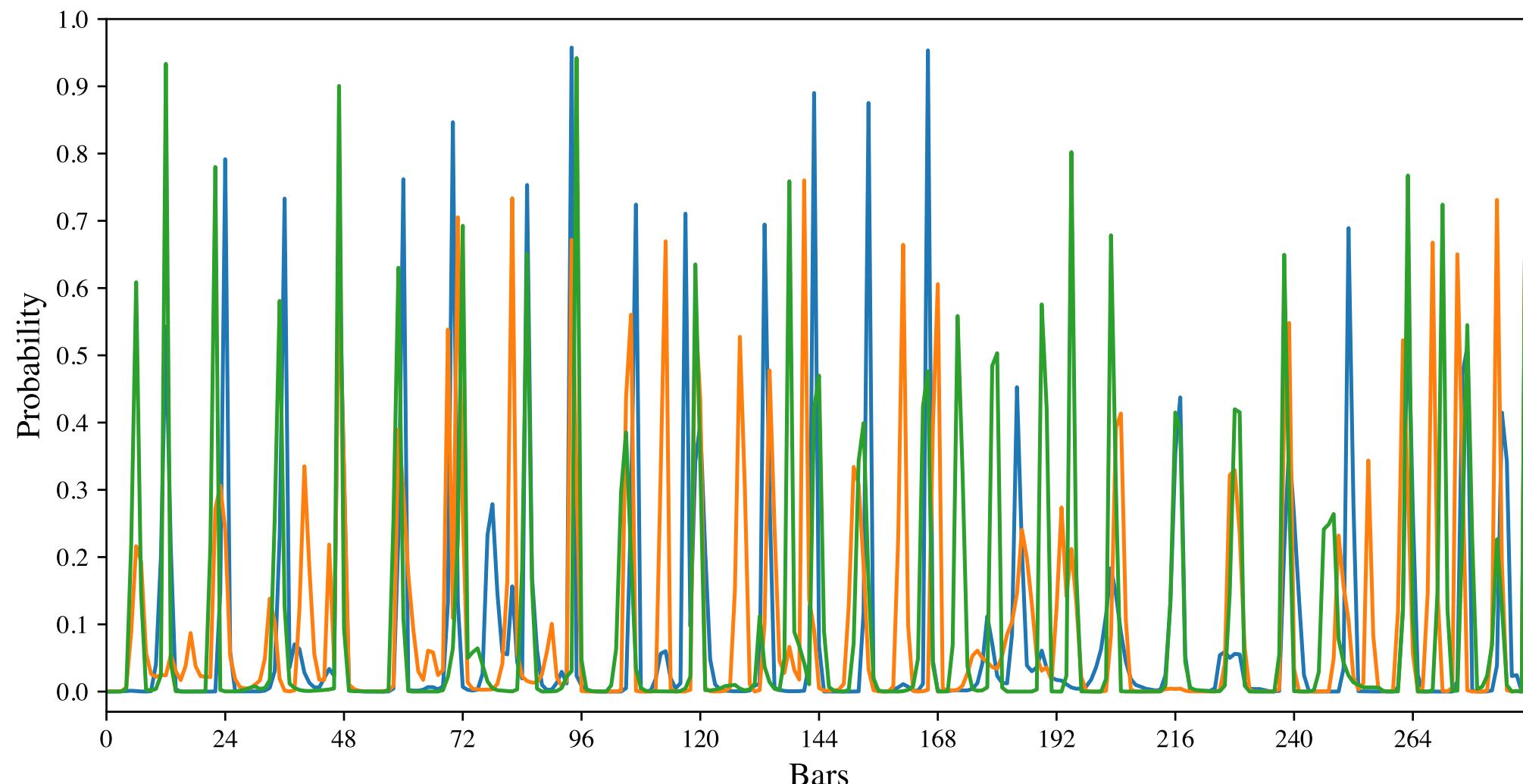
[2] Katerina Kosta, Oscar F. Bandtlow, and Elaine Chew. MazurkaBL: Score-aligned loudness, beat, expressive markings data for 2000 Chopin Mazurka recordings. In *Proceedings of the International Conference on Technologies for Music Notation and Representation (TENOR)*, number 4, 2018.



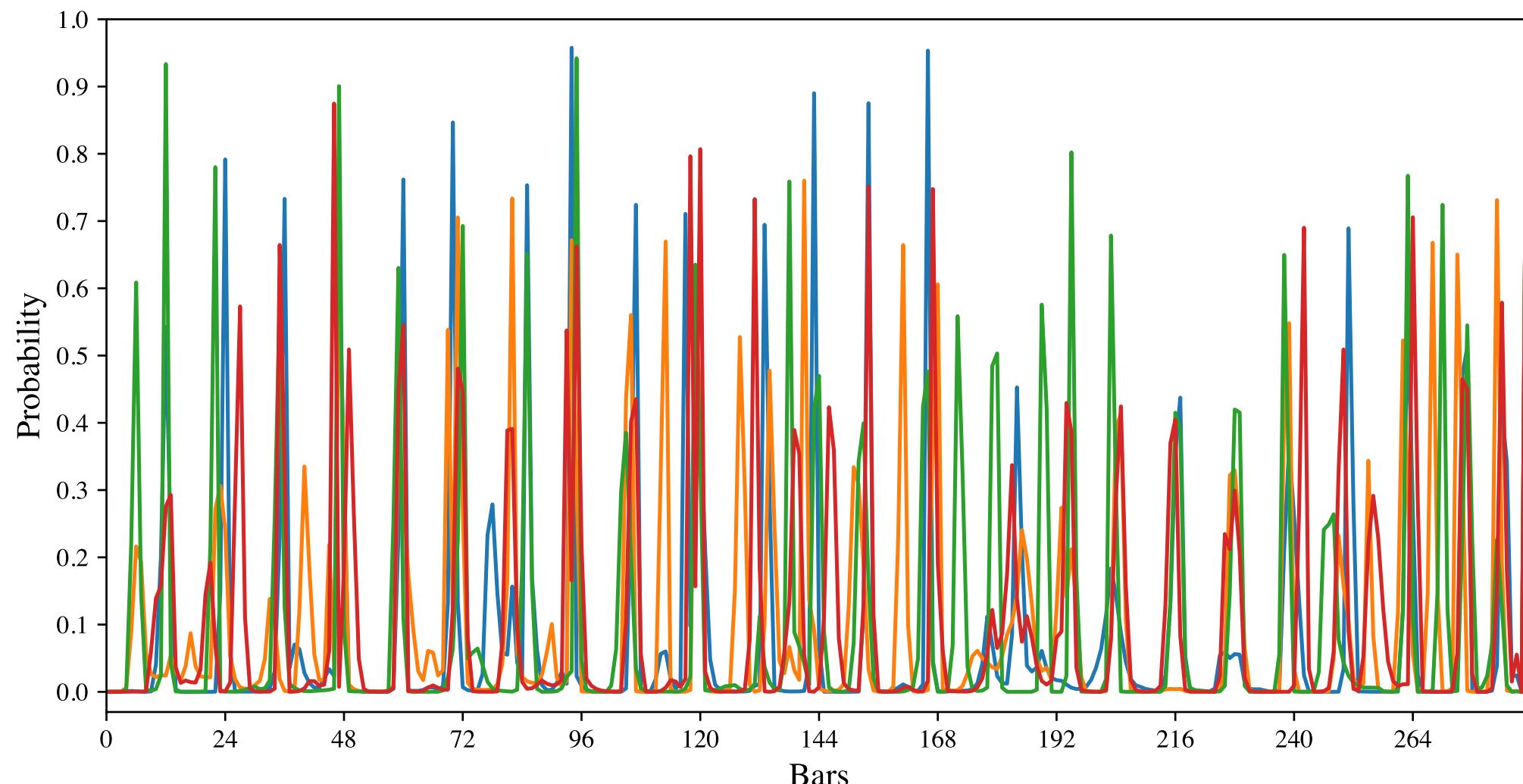
Mazurka Op.06 No.2



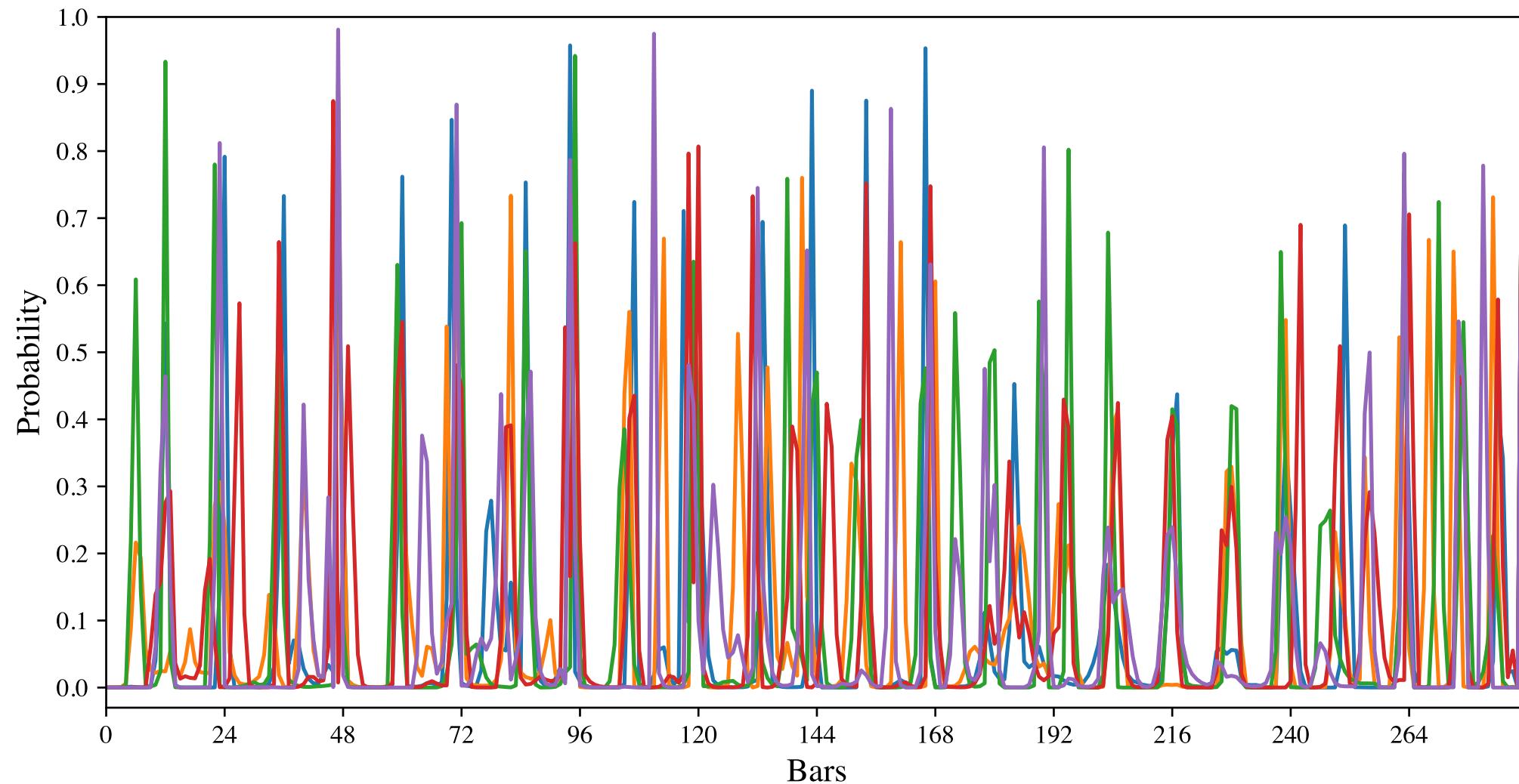
Mazurka Op.06 No.2



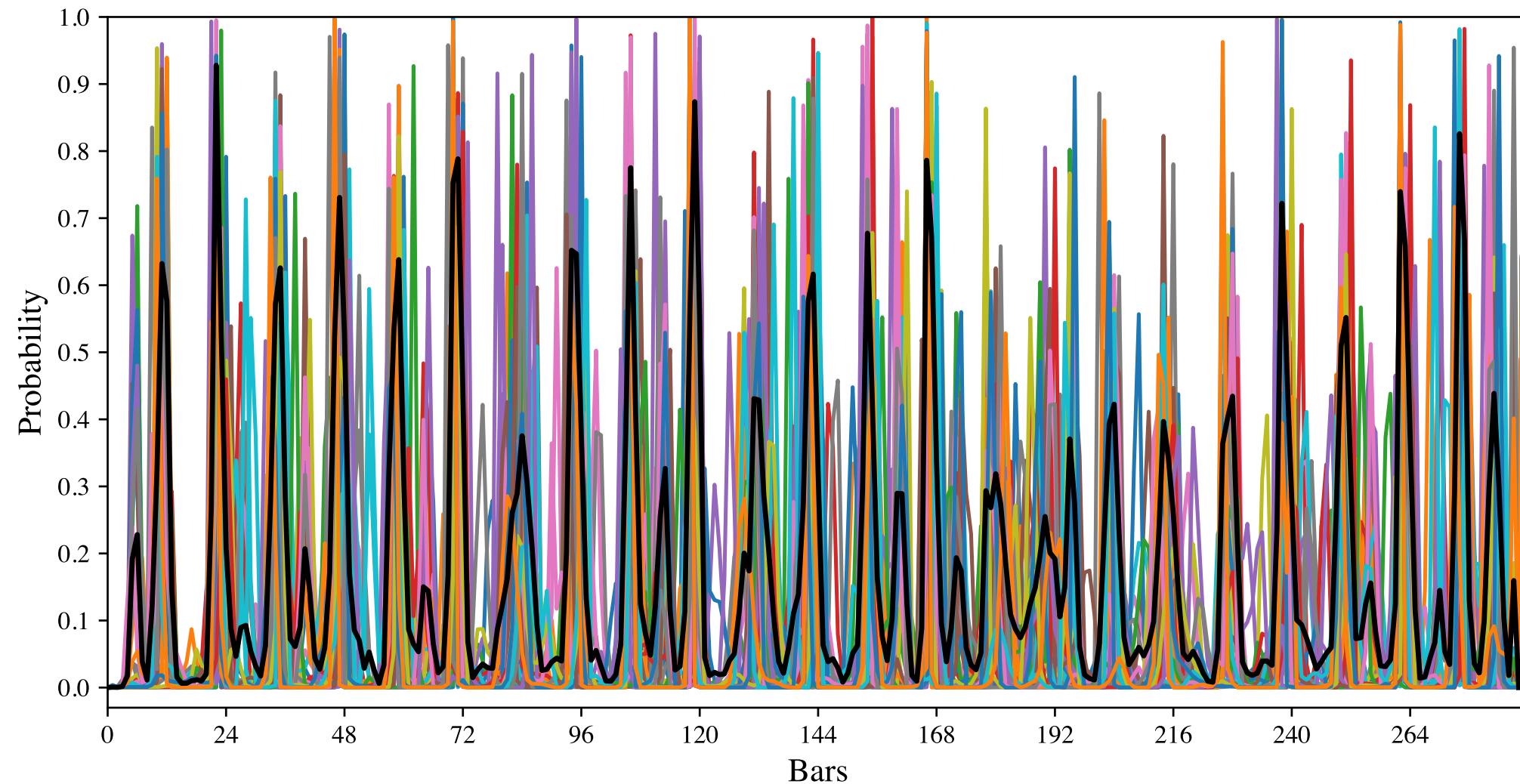
Mazurka Op.06 No.2



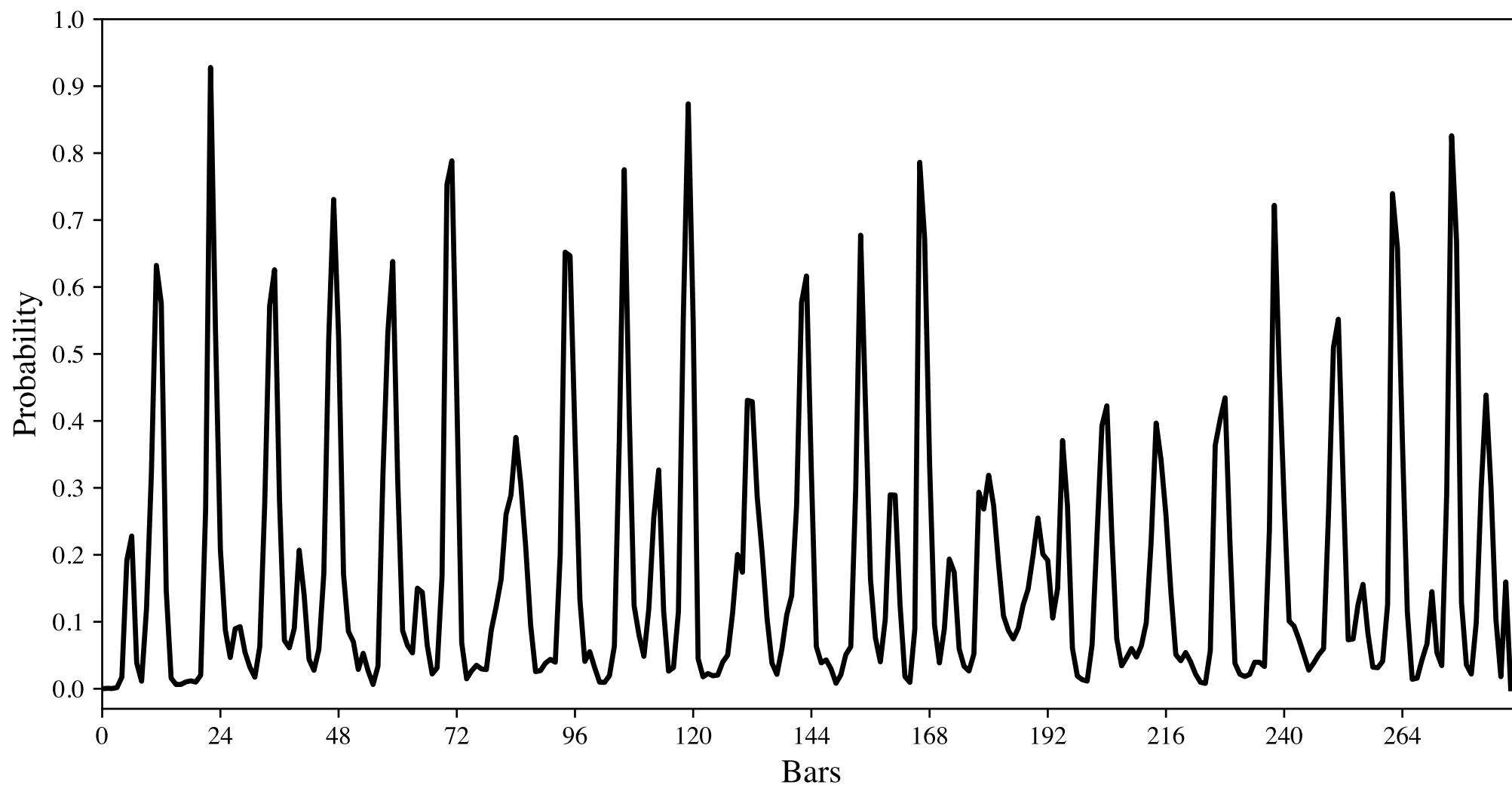
Mazurka Op.06 No.2



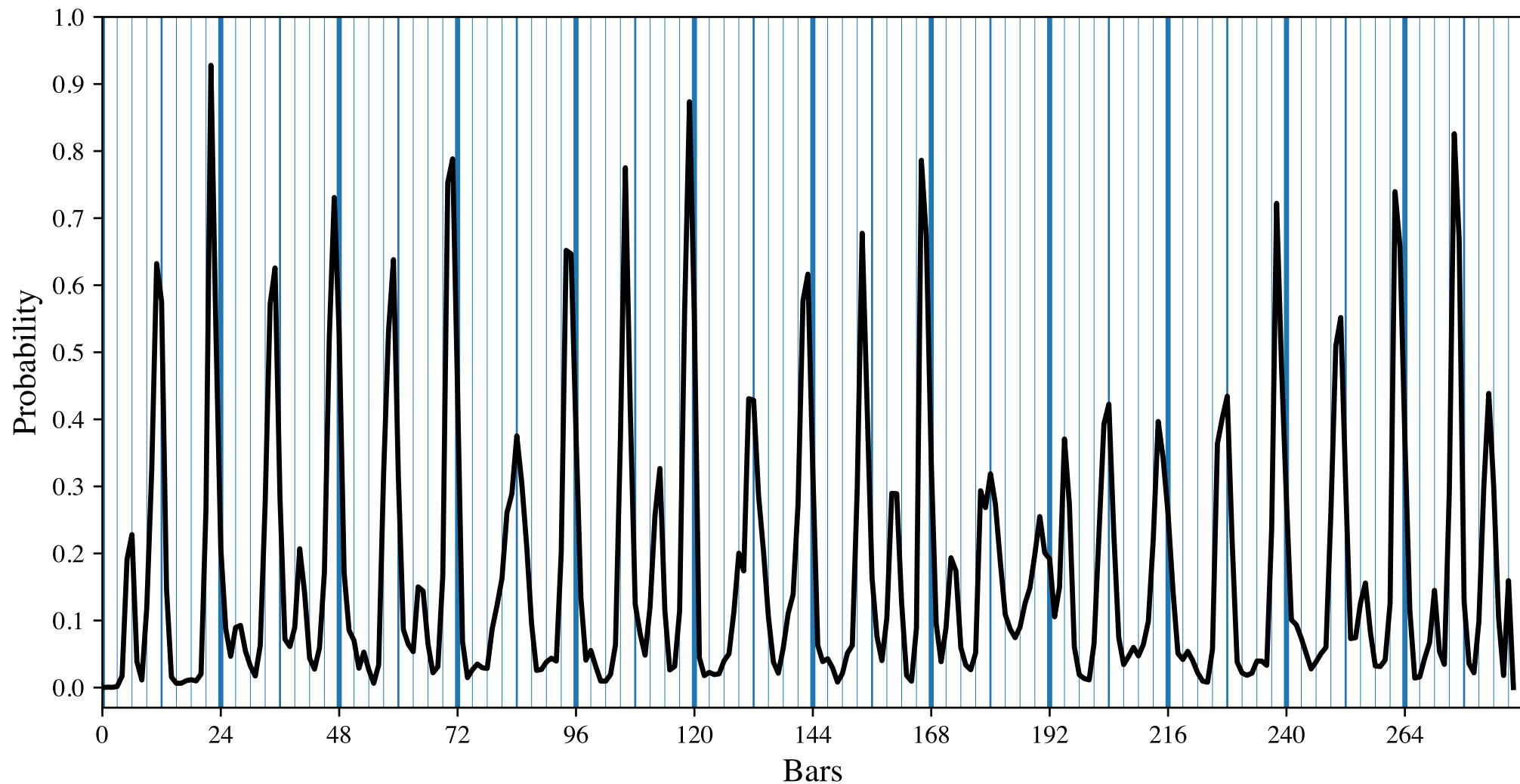
Mazurka Op.06 No.2



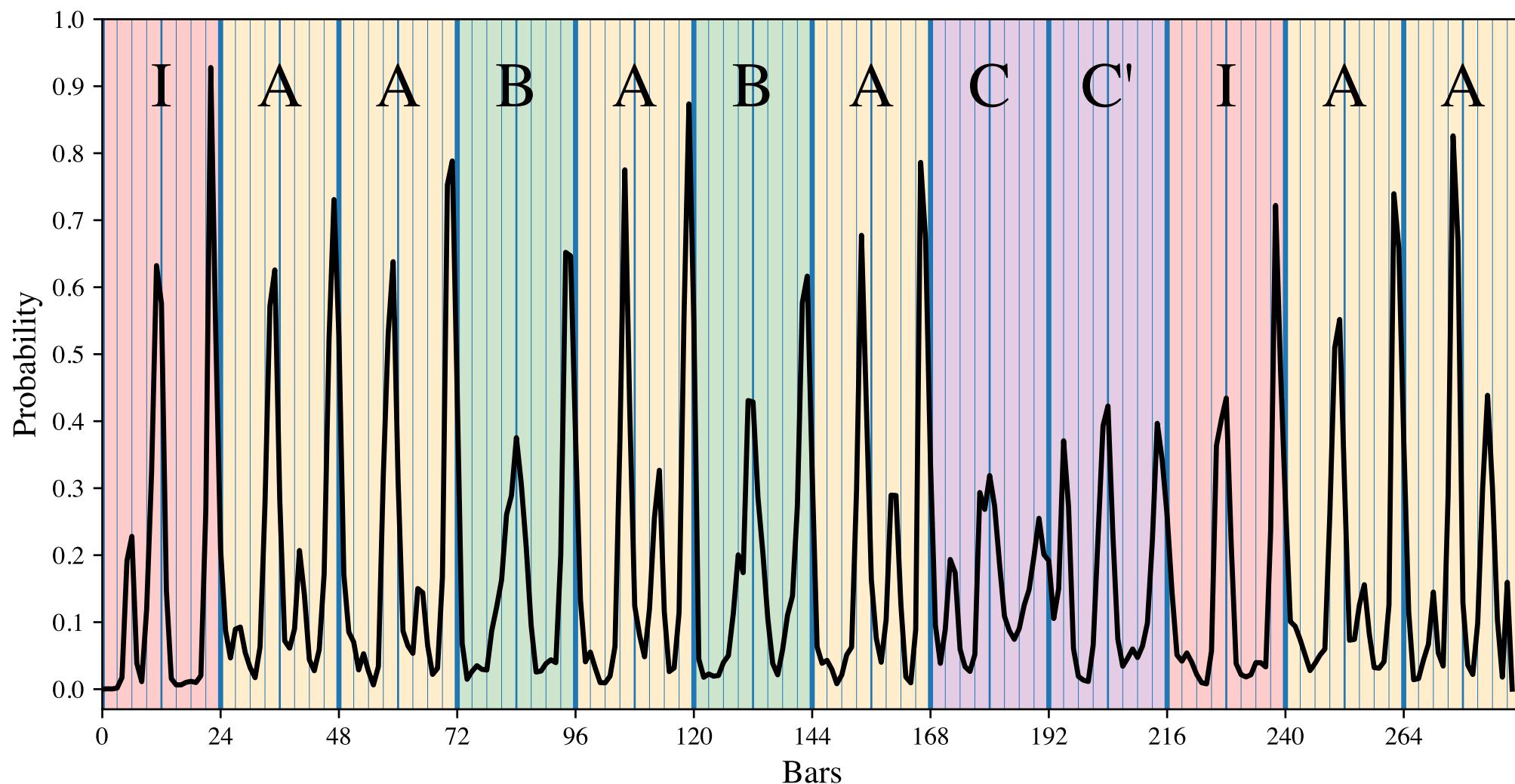
Mazurka Op.06 No.2



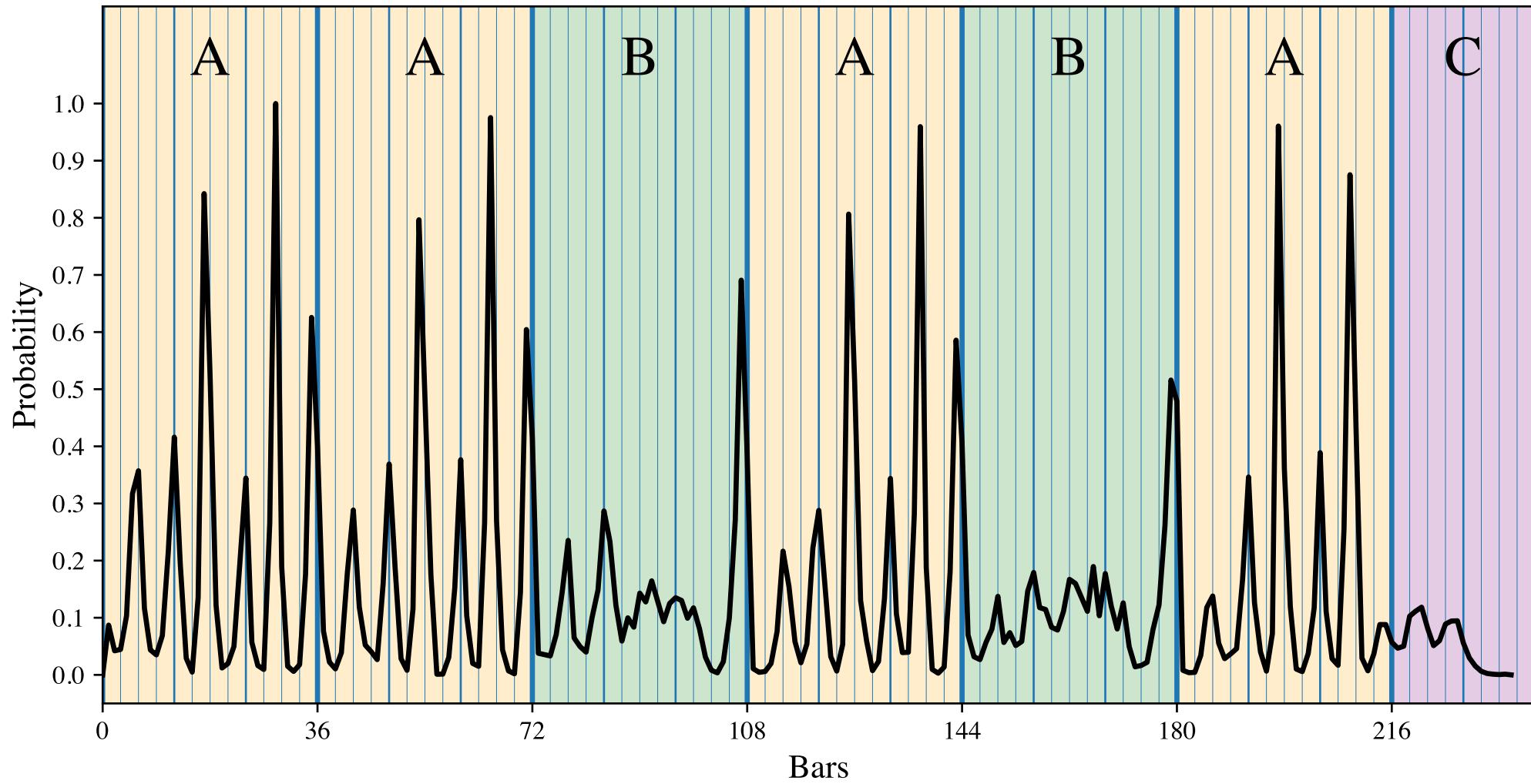
Mazurka Op.06 No.2



Mazurka Op.06 No.2



Mazurka Op.06 No.2

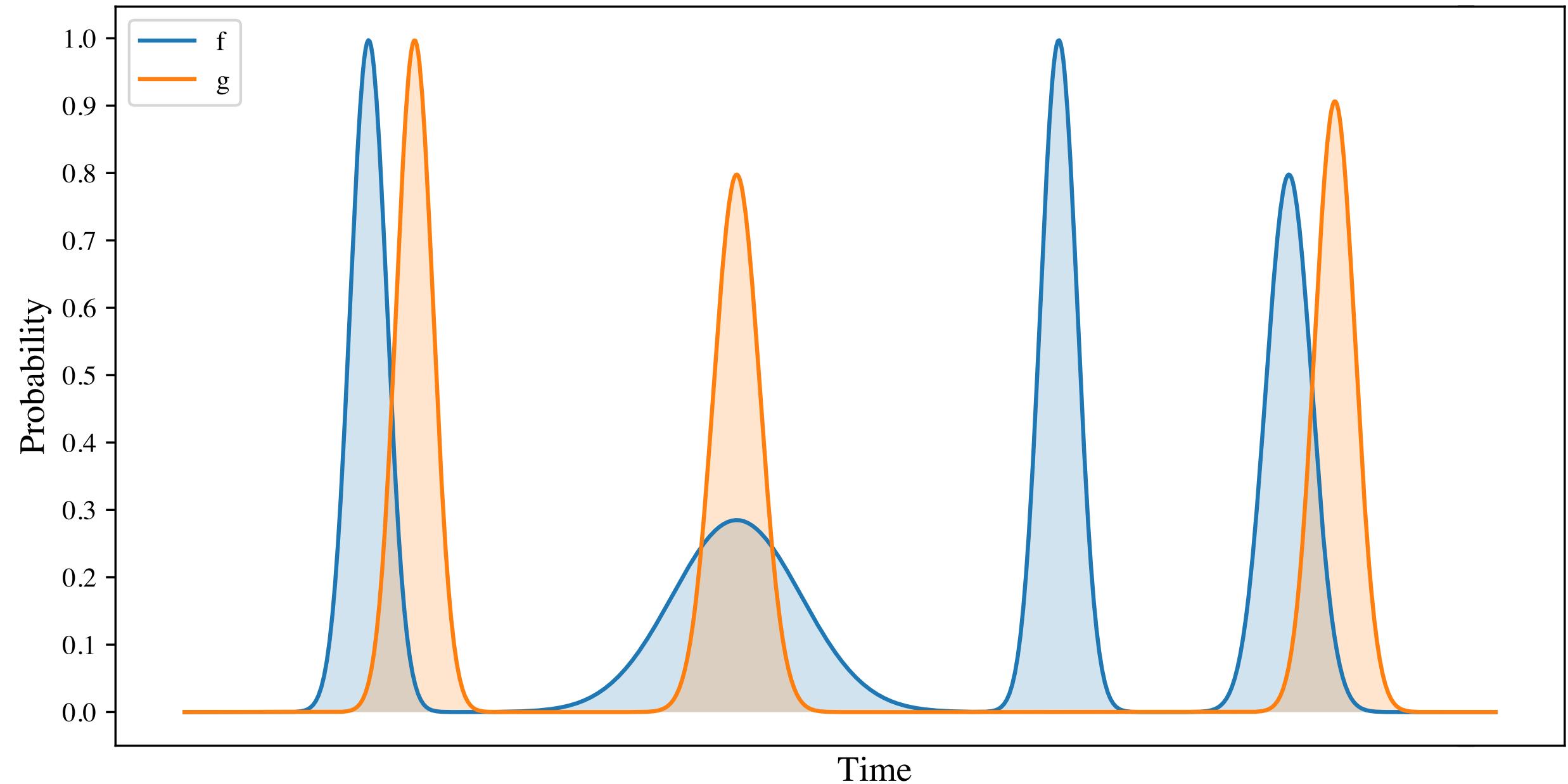


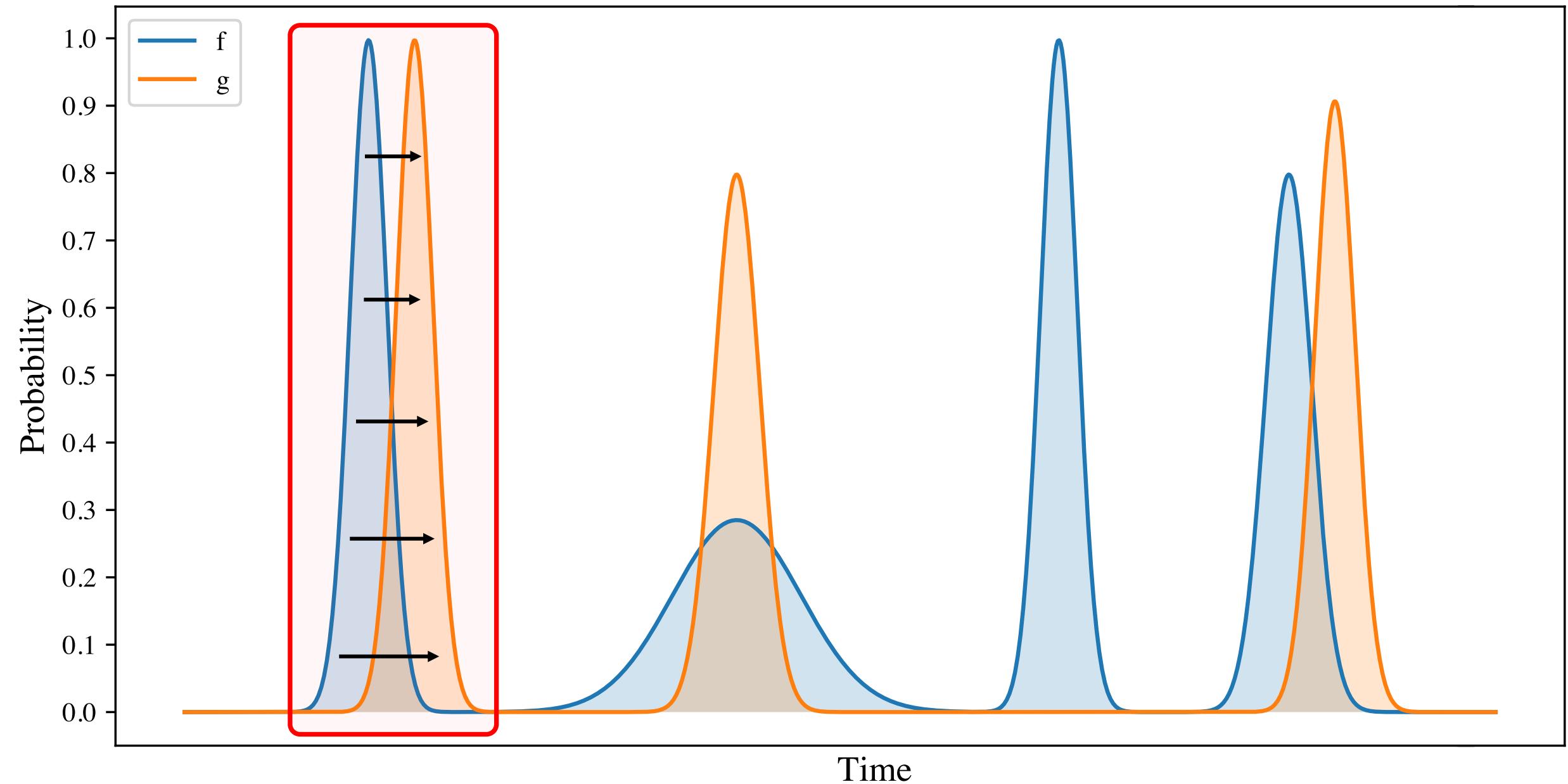
Mazurka Op.24 No.3

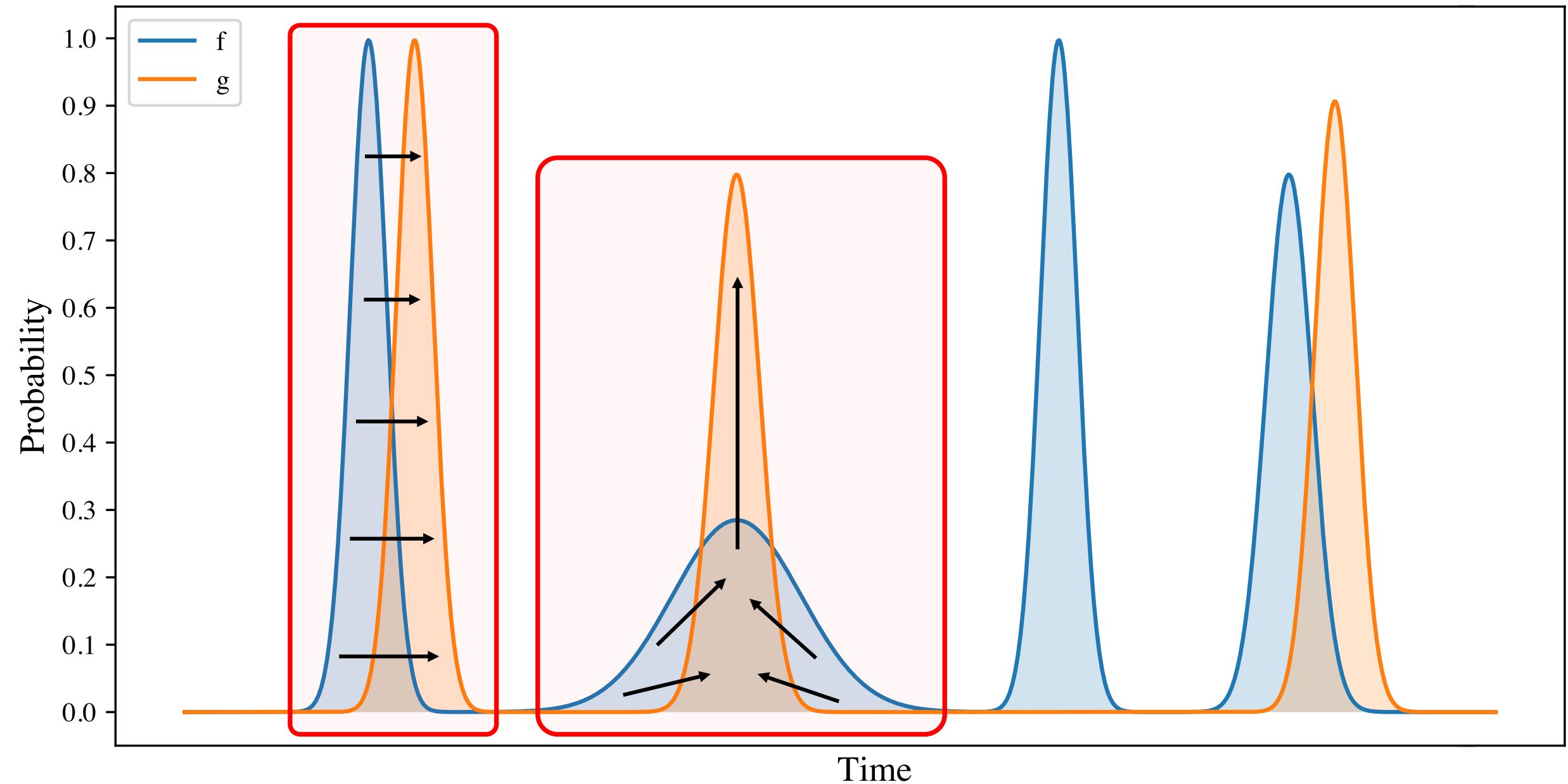
Moyenne des performances est liée à la structure de la partition.

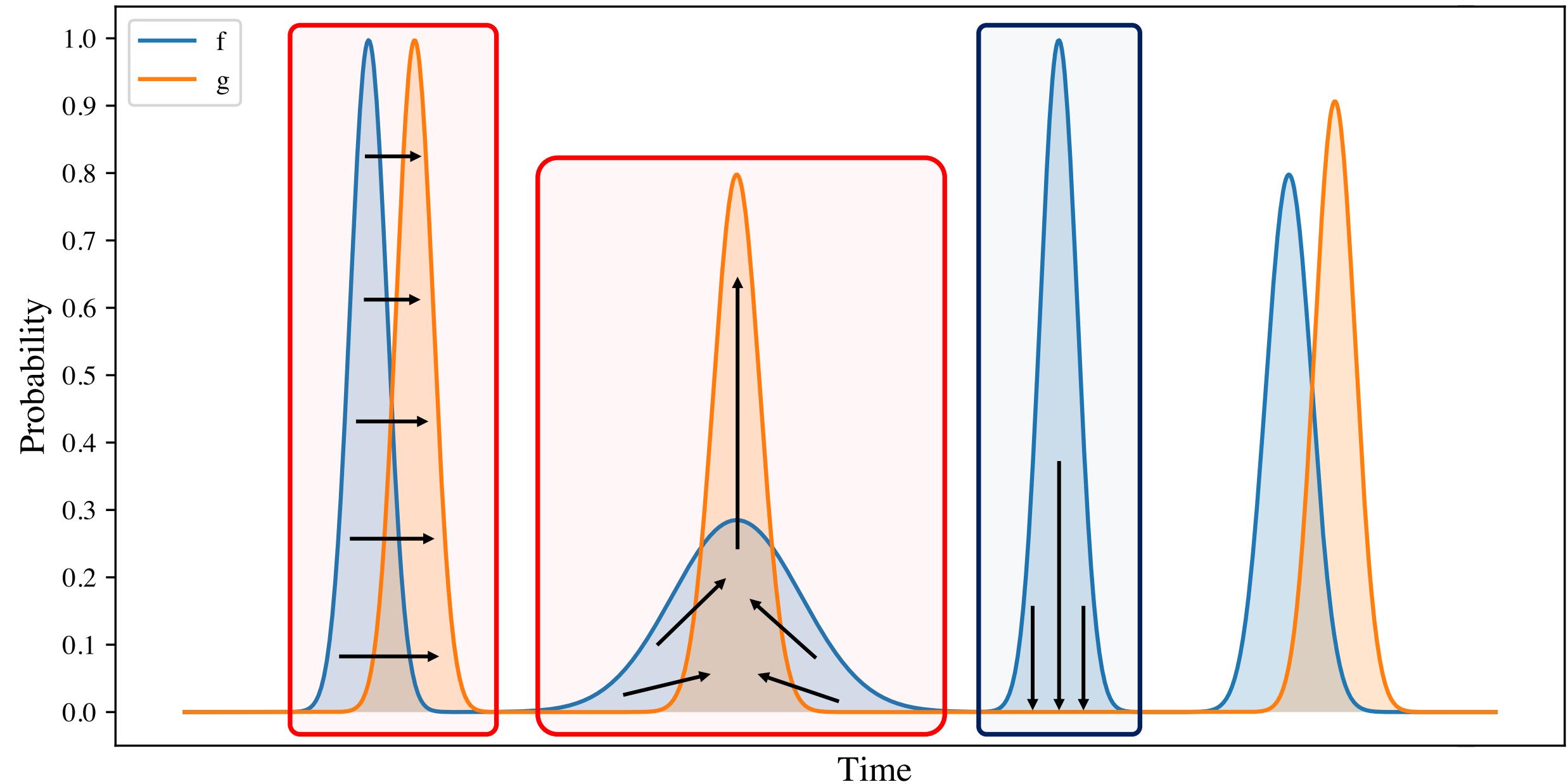
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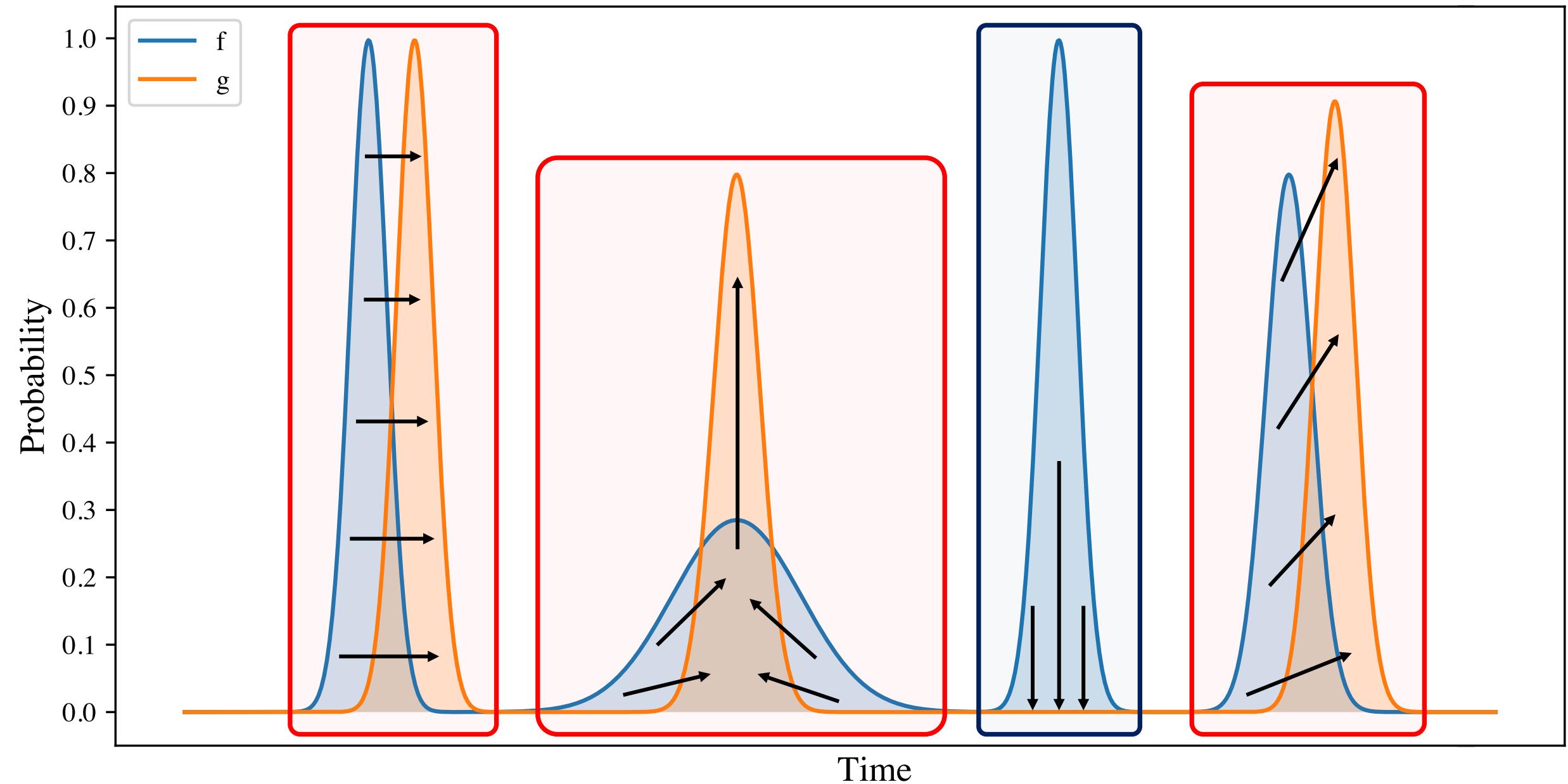
→ Sens musical !



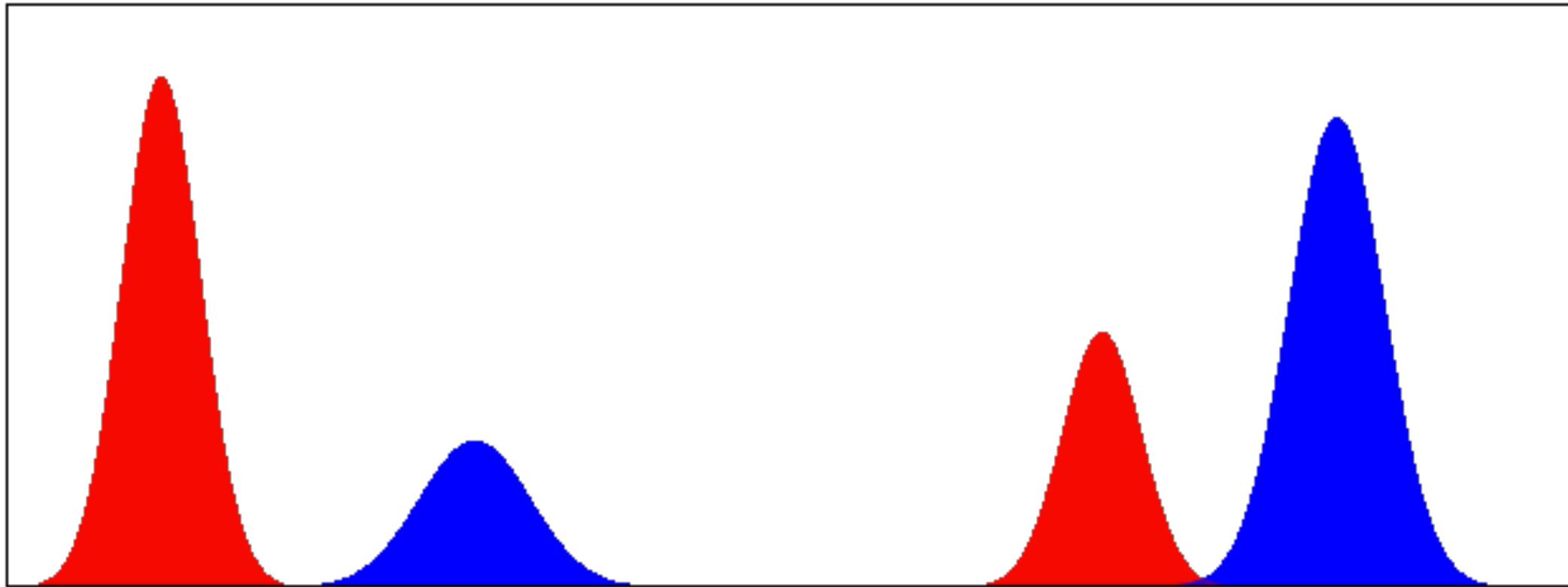








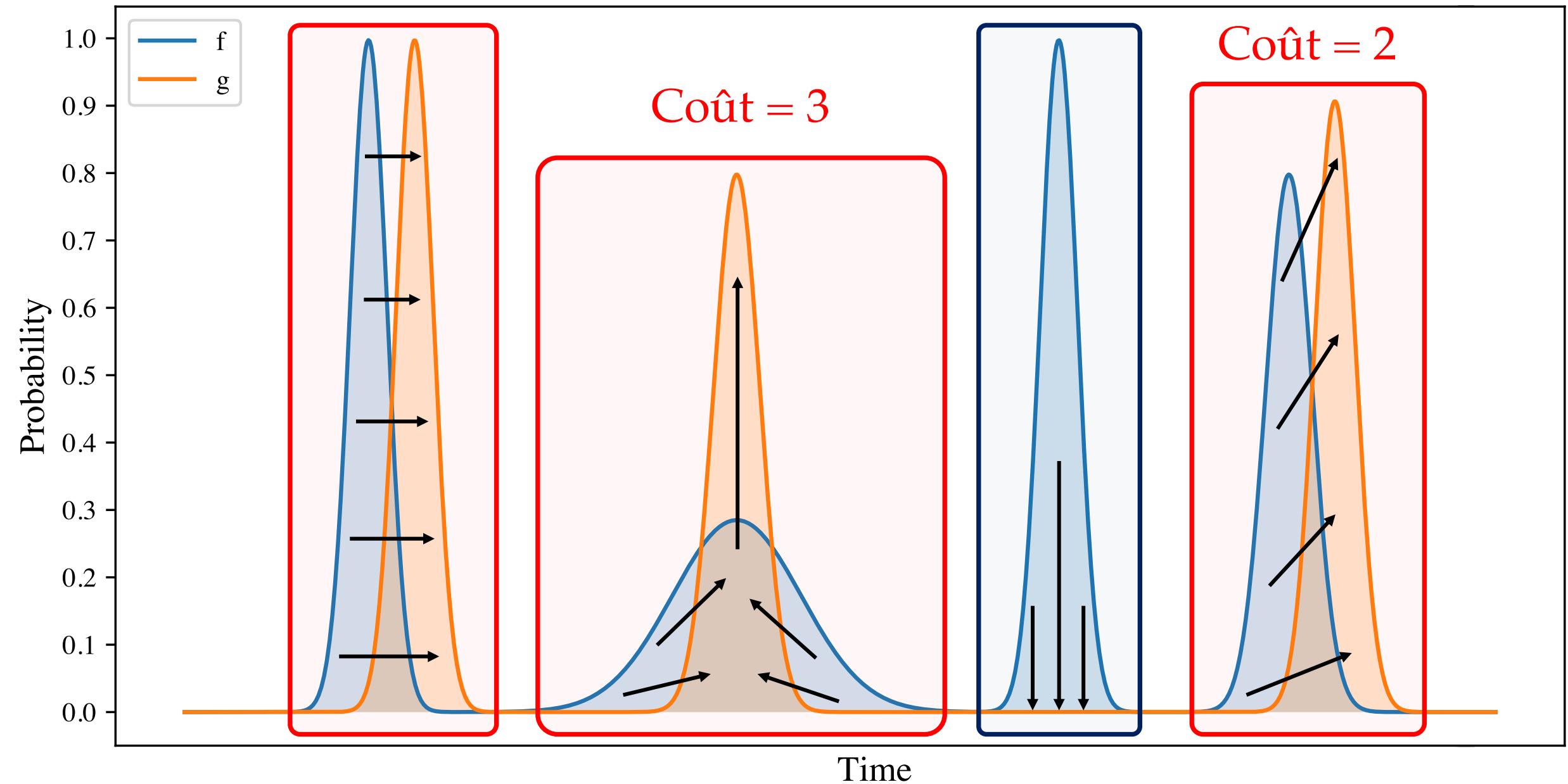
Transport Optimal

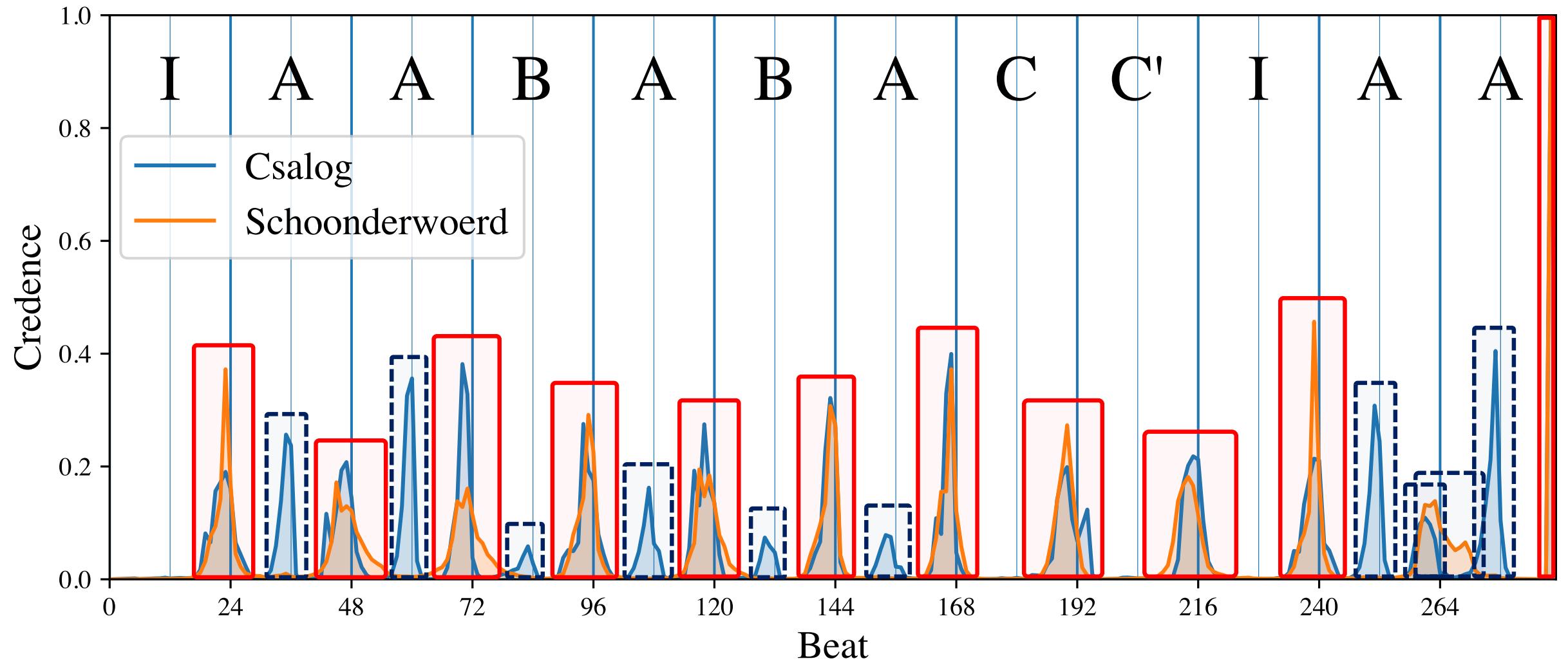


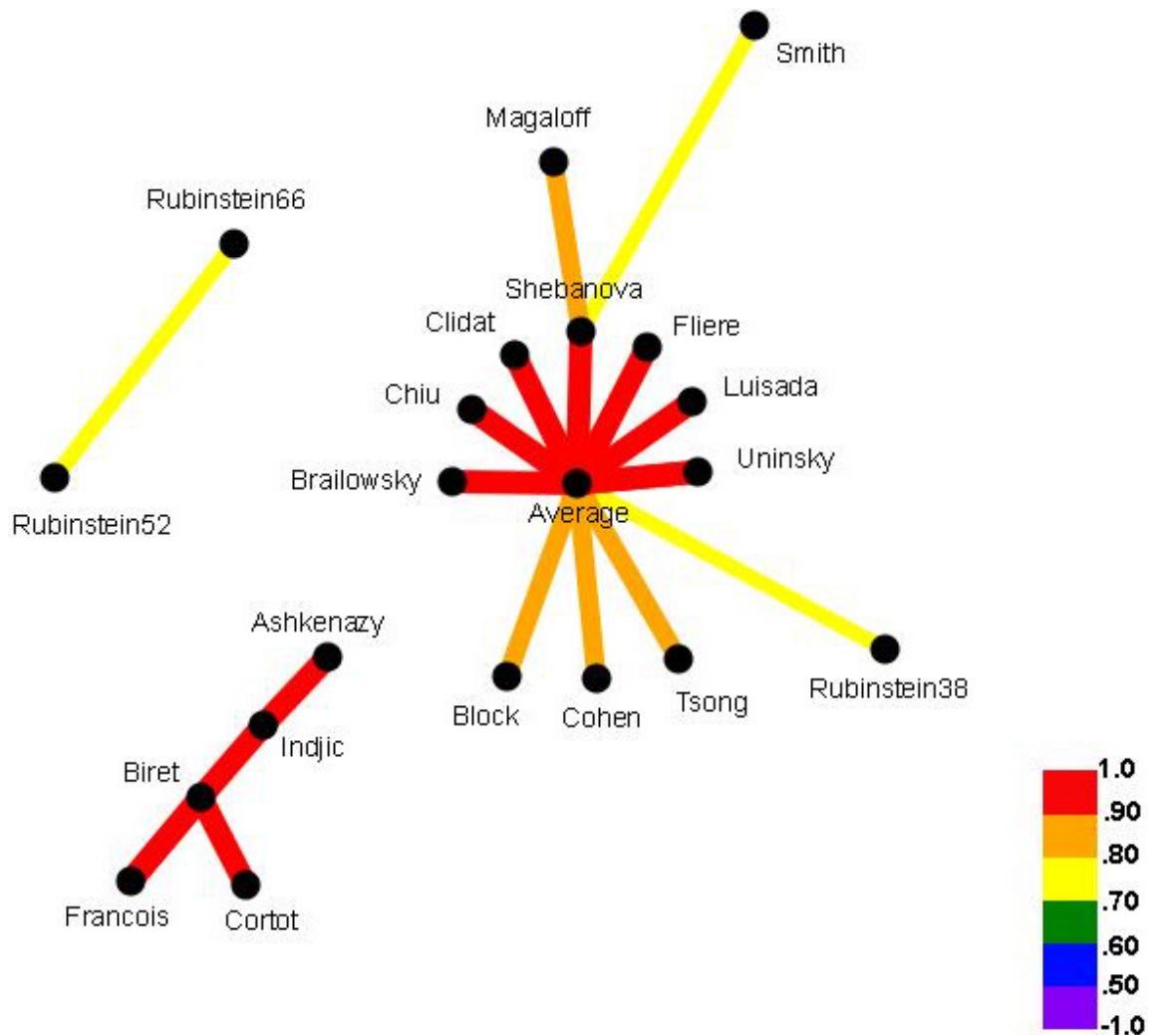
Coût = 2

Coût = 5

Coût = 2



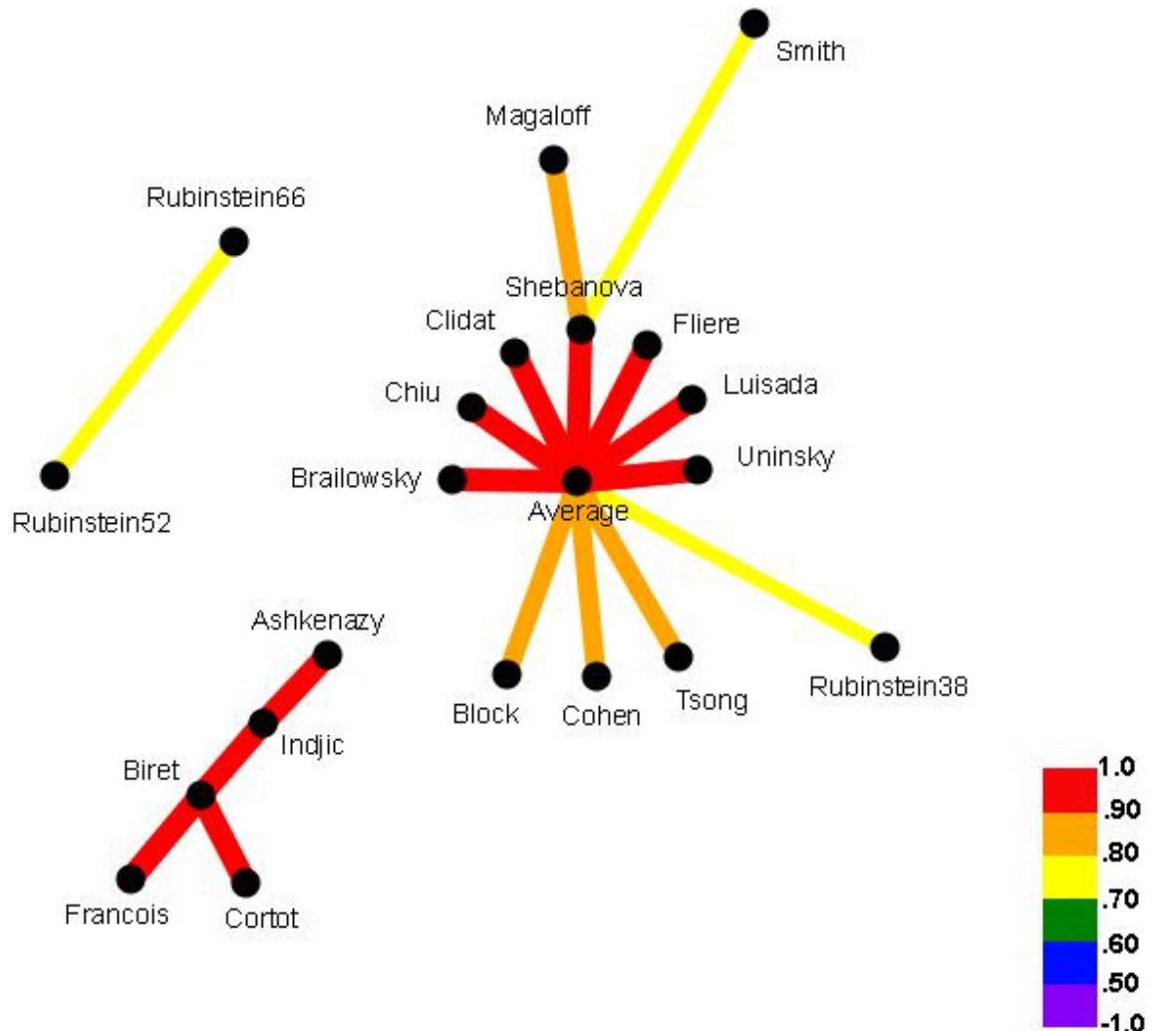




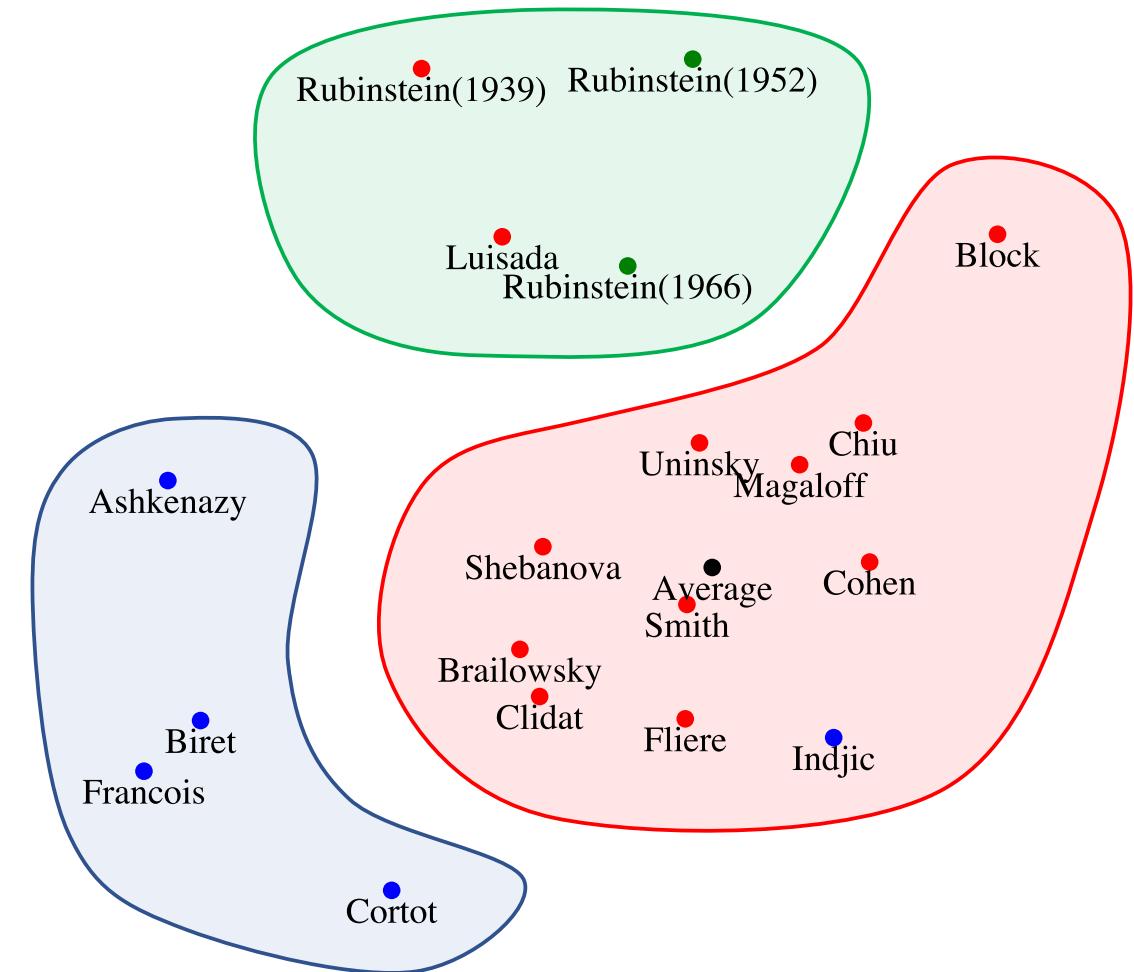
Correlation Network

fait à la main par Nicholas Cook [3]

Mazurka Op.68 No.3



Correlation Network par Nicholas Cook.



Similarity Map avec les frontières probabilistes et le transport optimal.

Chapitre 2 :

Étudier la performance

(avec le simplex du rythme)

The rhythm simplex

.The rhythm simplex

Idée: Un rythme à 3 intervalles peut être représenté en 2 dimensions.

.The rhythm simplex

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Pourquoi pas en 3D ?

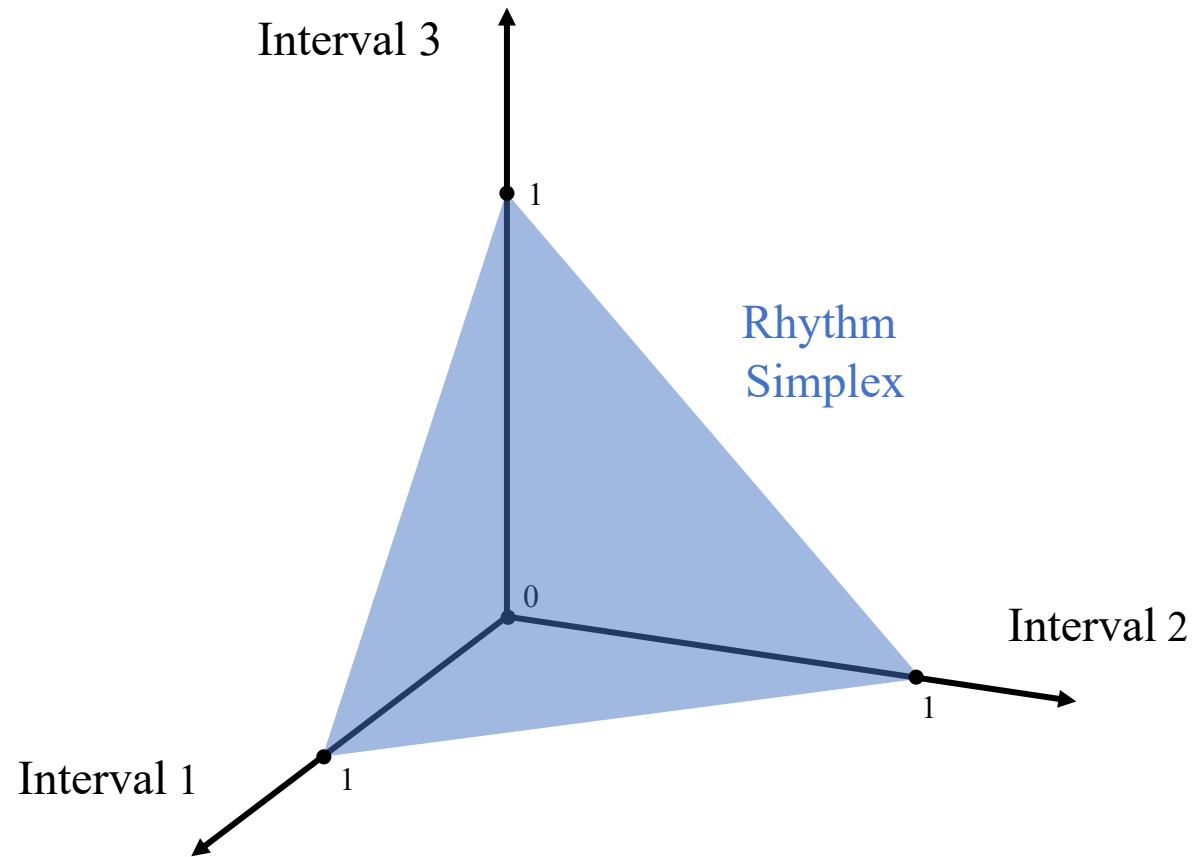
.The rhythm simplex

Idée: Un rythme à 3 intervalles peut être représenté en 2 dimensions.

Pourquoi pas en 3D ?

Parce que on fixe la durée totale à 1.

The rhythm simplex



The rhythm simplex

(0.25, 0.50, 0.25)

(0.25, 0.25, 0.50)

The rhythm simplex

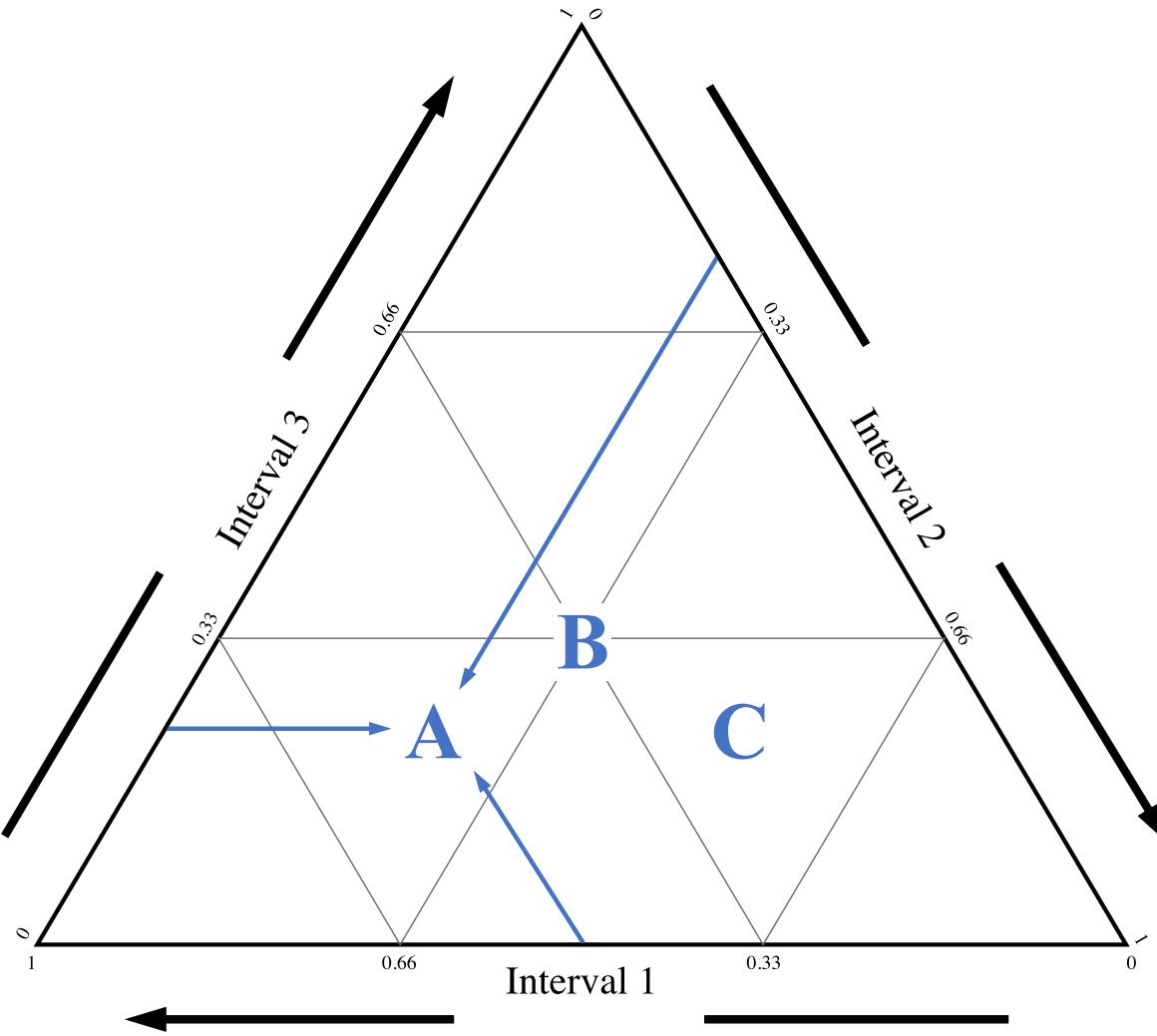
(0.25, 0.50, 0.25)



(0.25, 0.25, 0.50)



The rhythm simplex



A : [0.50, 0.25, 0.25]



B : [0.33, 0.33, 0.33]

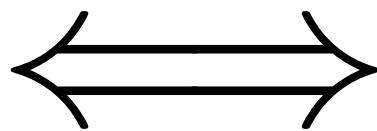


C : [0.25, 0.50, 0.25]



The rhythm simplex

Un rythme à
3 intervalles



Un point dans le
rhythm simplex

.Liens avec COSMOS

.Liens avec COSMOS

Ici on aime bien les rythmes à 3 intervalles...

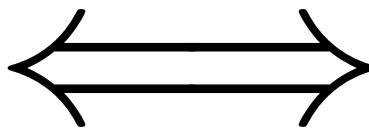
.Liens avec COSMOS

Ici on aime bien les rythmes à 3 intervalles...

... à cause du MazurkaBL dataset.

.Liens avec COSMOS

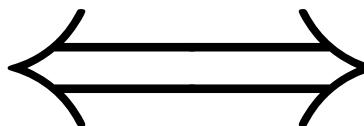
Un rythme à
3 intervalles



Un point dans le
rhythm simplex

.Liens avec COSMOS

~~Un rythme à
3 intervalles~~

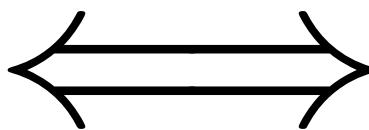


Un point dans le
rhythm simplex

Une mesure d'une
performance de Mazurka

.Liens avec COSMOS

Une performance
d'une mazurka



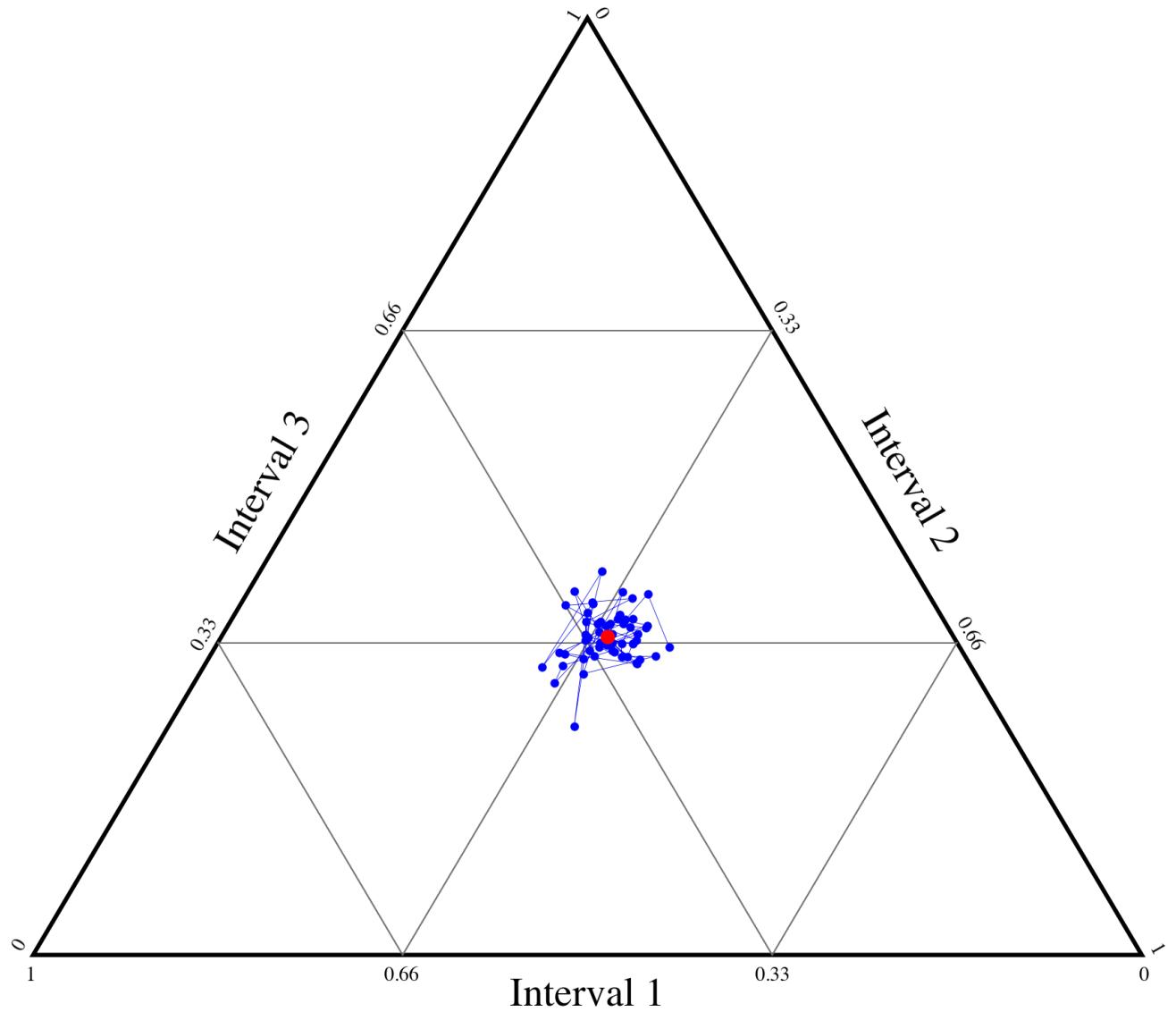
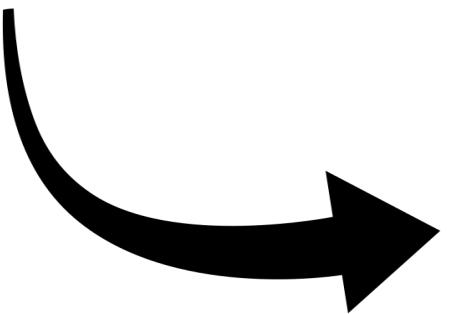
Pleins de points dans
le rhythm simplex

.Rhythm simplex and Mazurkas

Performance de Ashkenazy
Mazurka 68-3

Rhythm simplex and Mazurkas

Performance de Ashkenazy
Mazurka 68-3

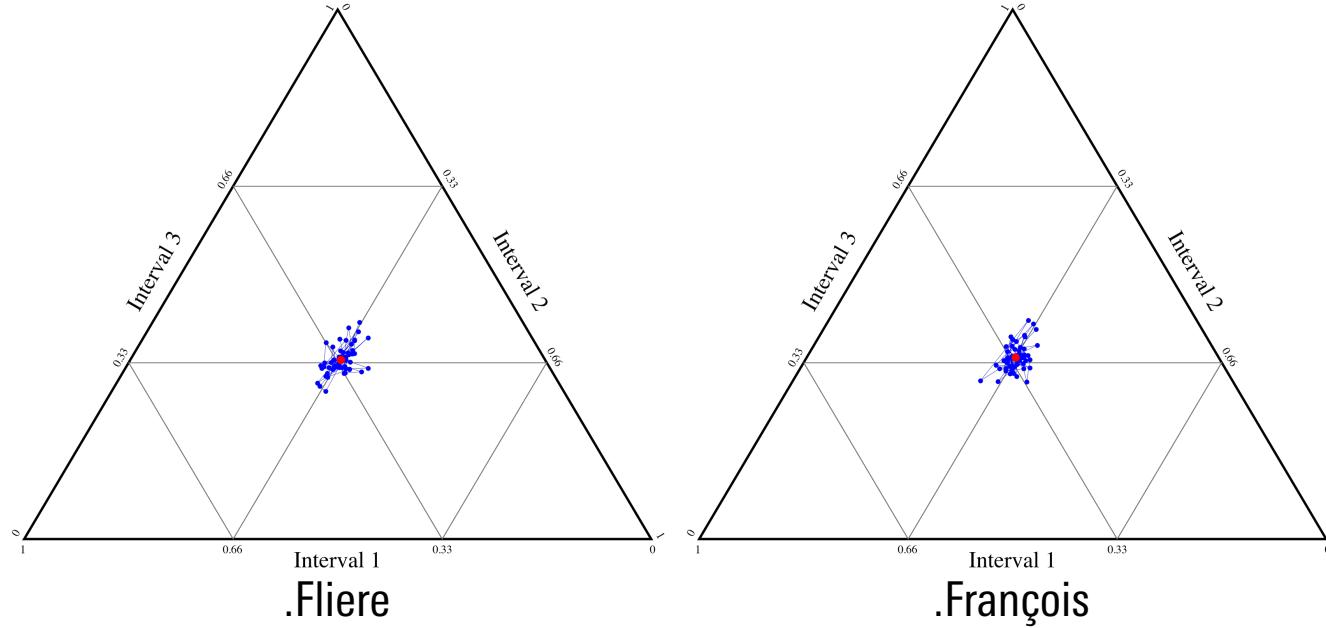


.Rhythm simplex and Mazurkas

Dès fois c'est
très compacte...

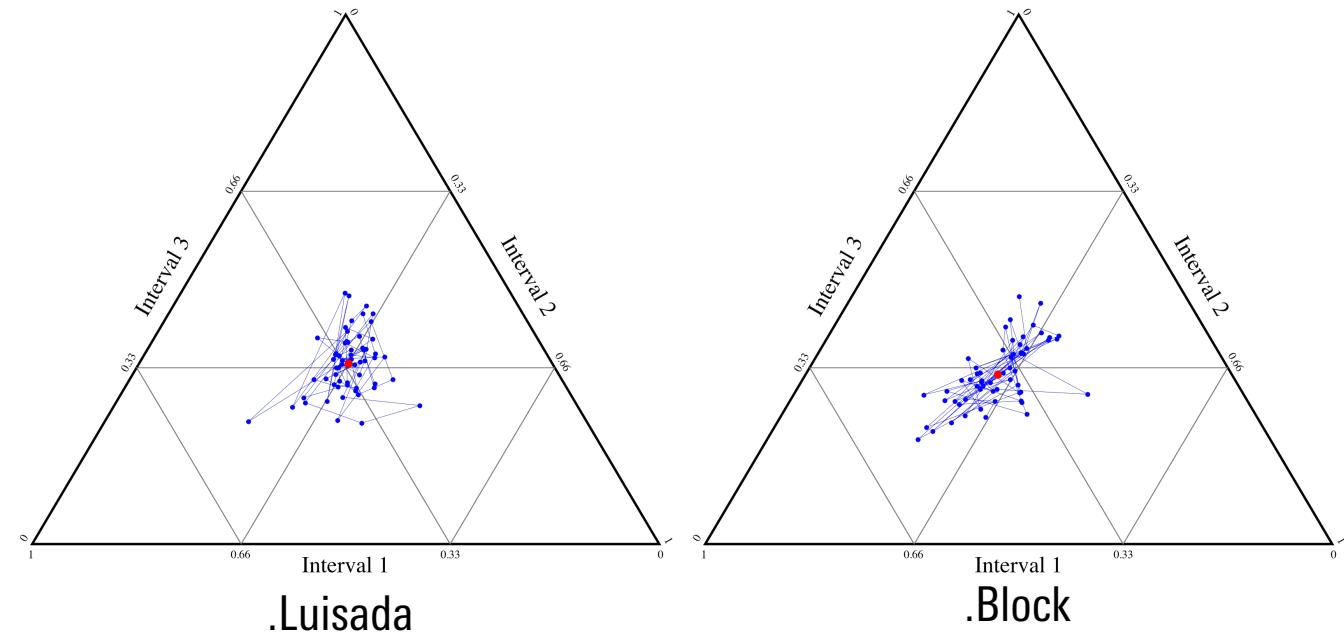
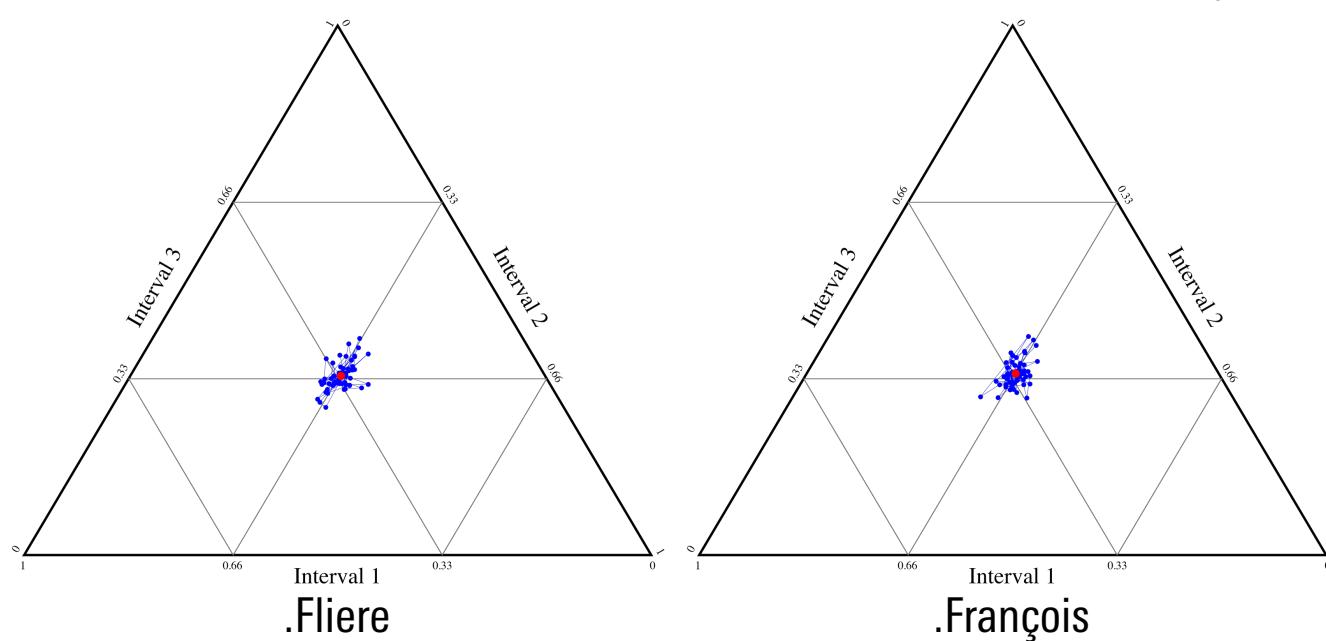
.Rhythm simplex and Mazurkas

Dès fois c'est
très compacte...



.Rhythm simplex and Mazurkas

Dès fois c'est
très compacte....



...et dès fois non.

.Rhythm simplex and Mazurkas

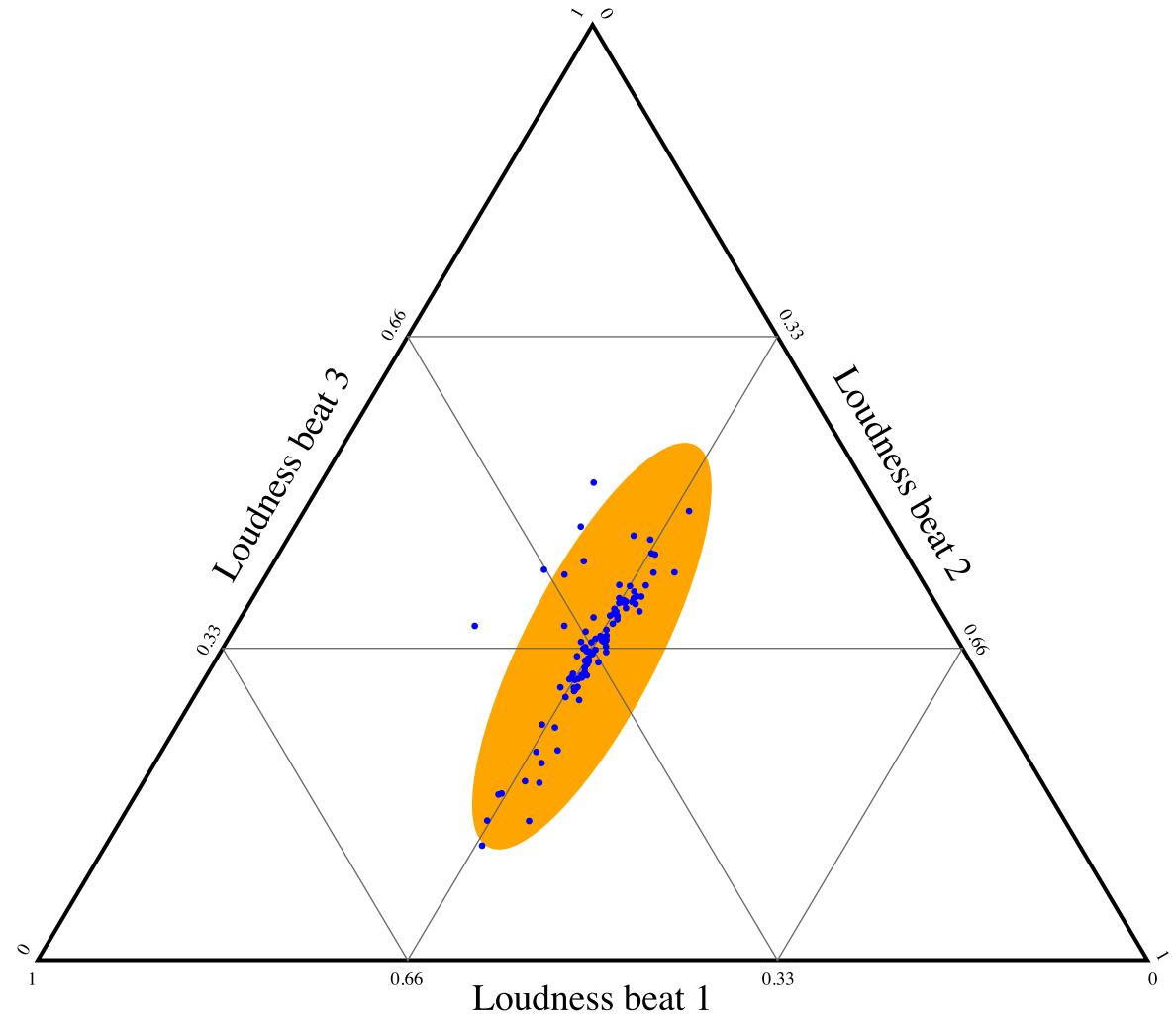
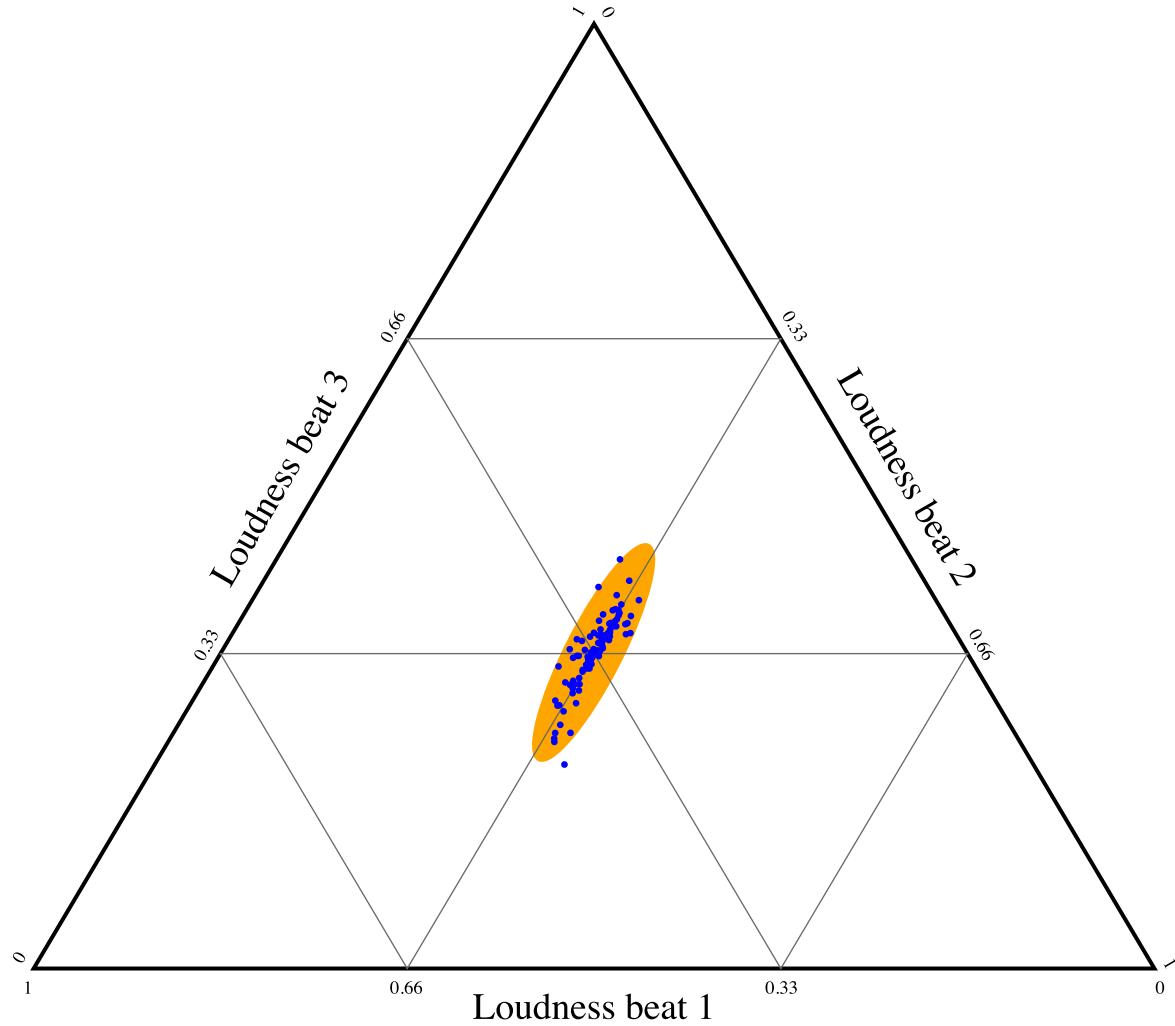
Comment mesurer la compacité ???

.Rhythm simplex and Mazurkas

Comment mesurer la compacité ???

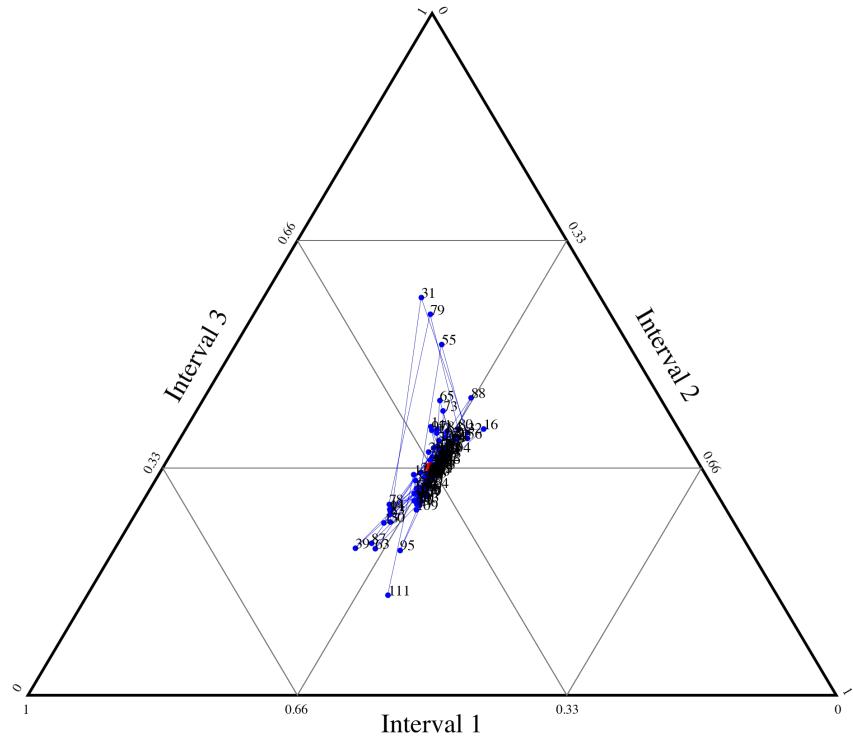
Avec la **matrice de covariance**,
on peut tracer une ellipse et mesurer son aire !

.Rhythm simplex and Mazurkas

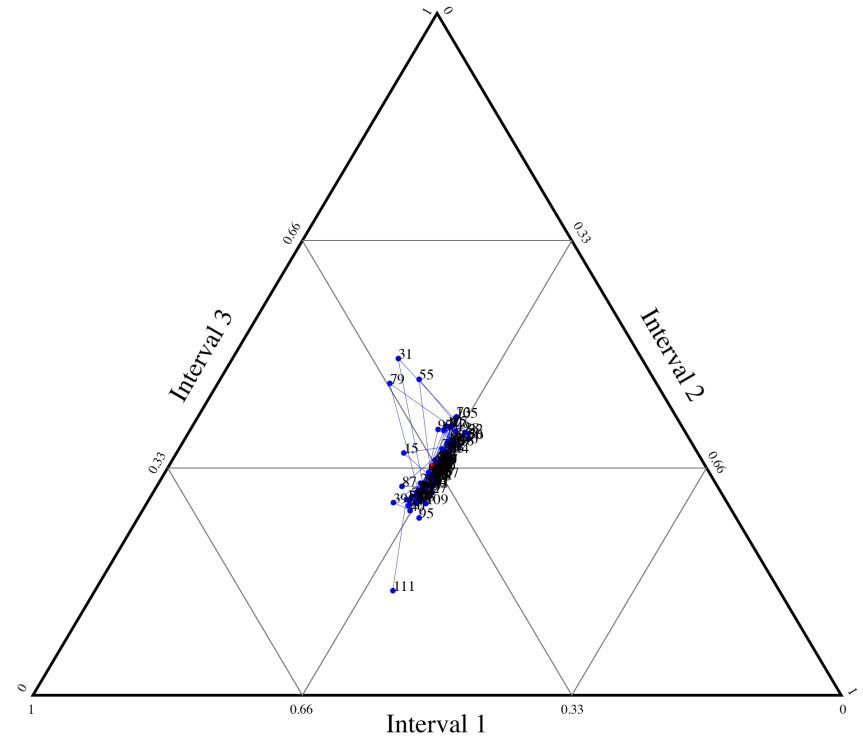


.Rhythm simplex and Mazurkas

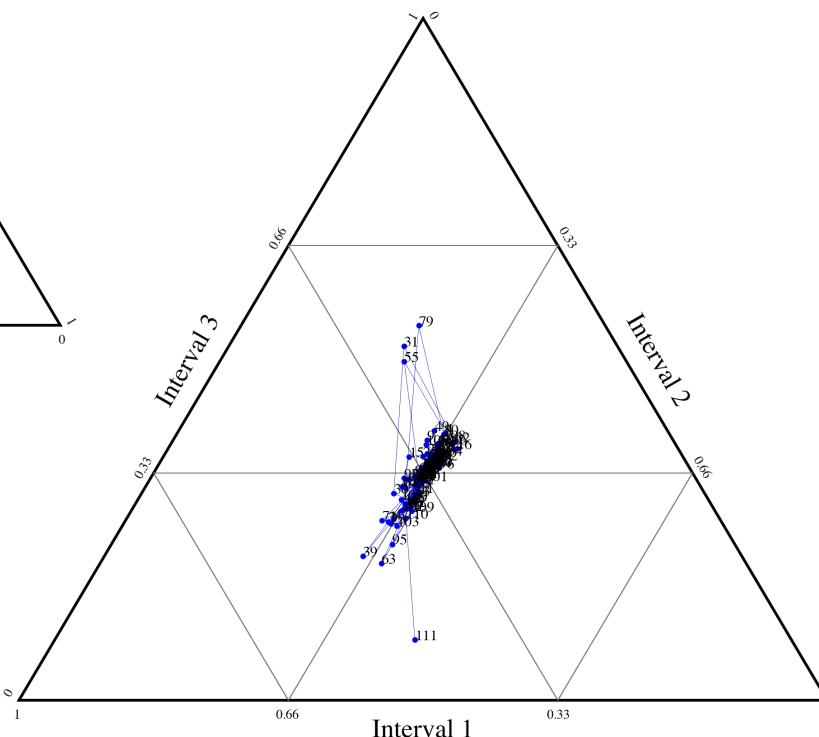
Mazurka06-1_Ashkenazy(1981)



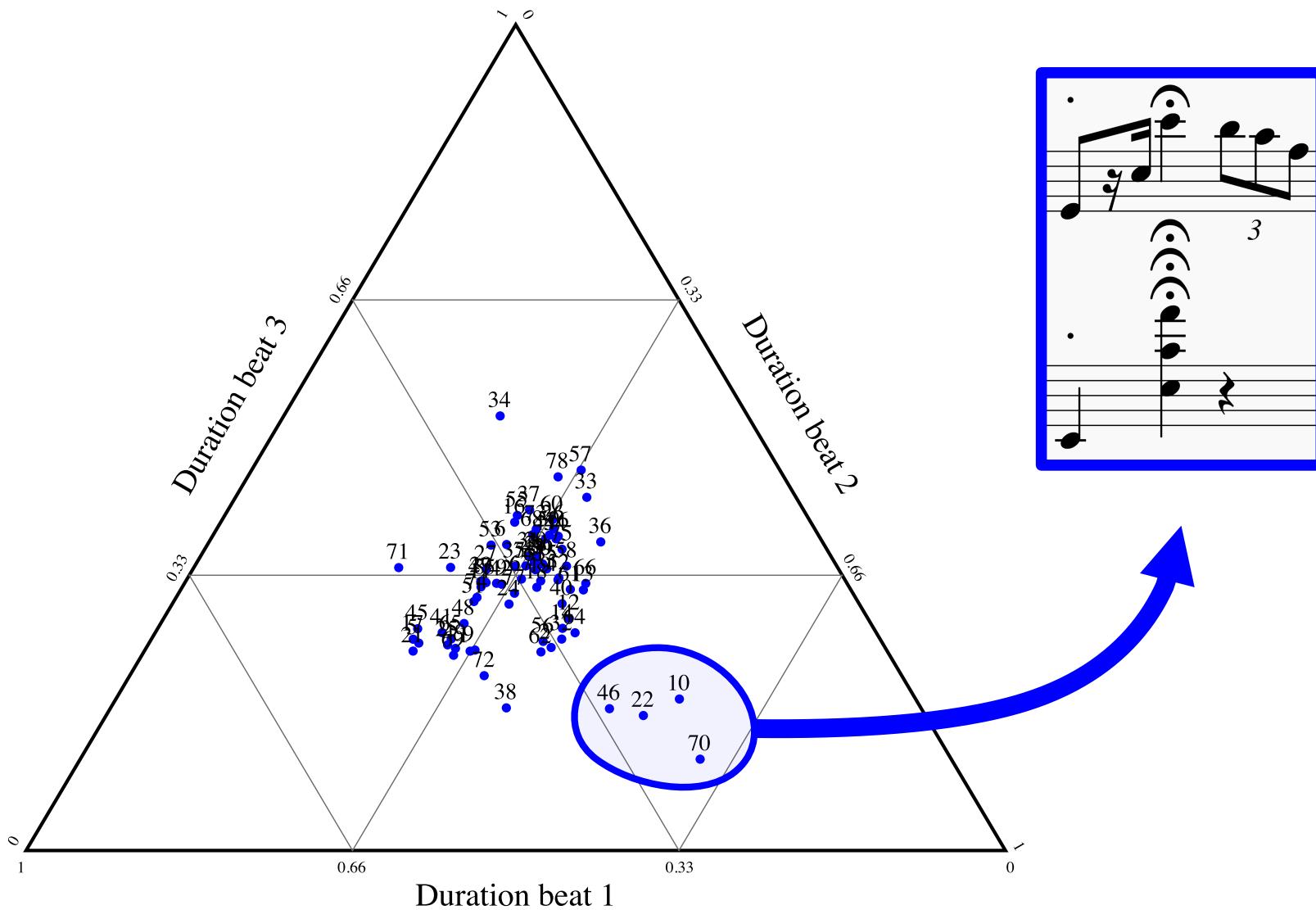
Mazurka06-1_Barbosa(1983)



Mazurka06-1_Biret(1990)



Rhythm simplex and Mazurkas

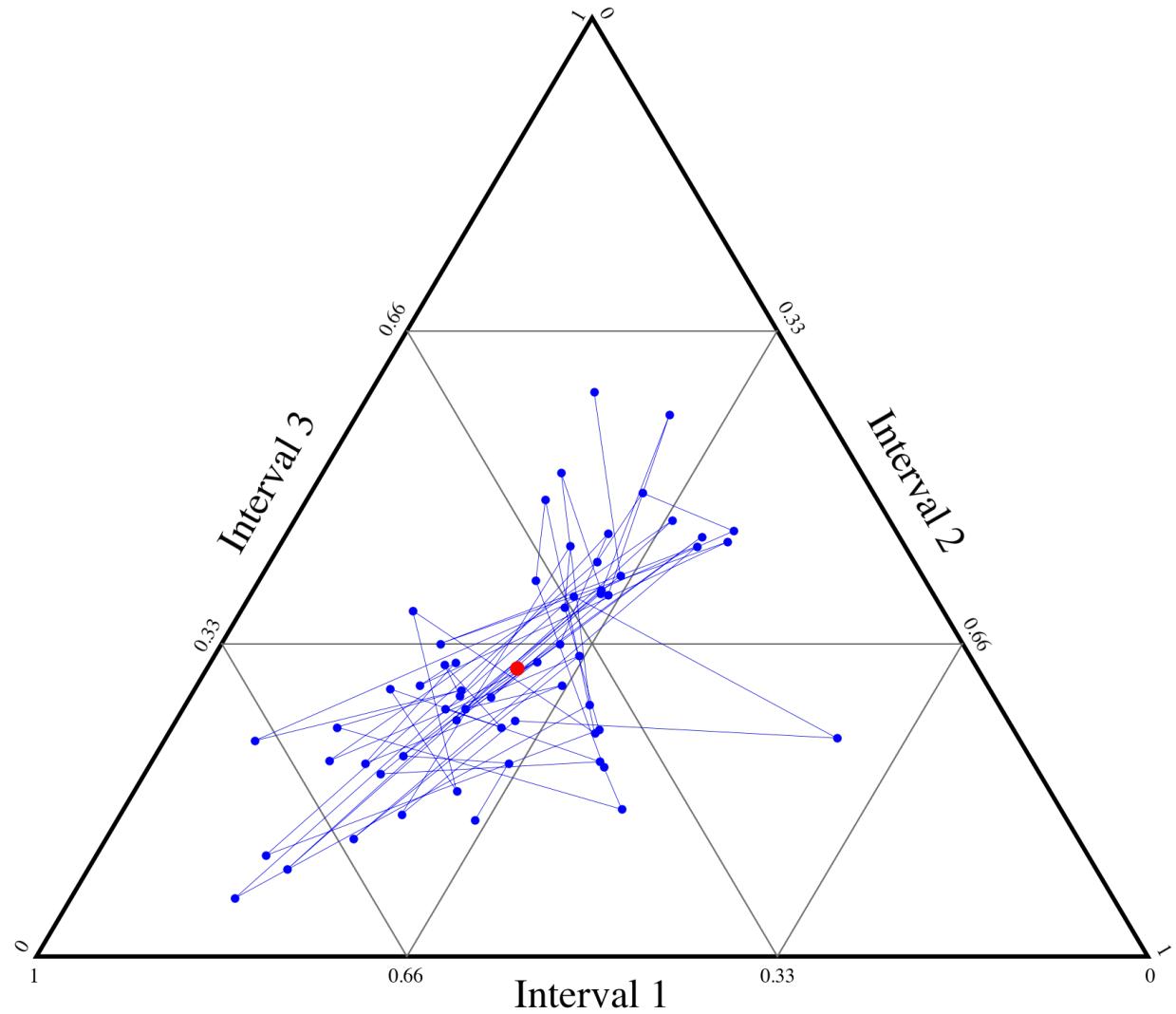


.Rhythm simplex and Mazurkas

Comment la position évolue ?

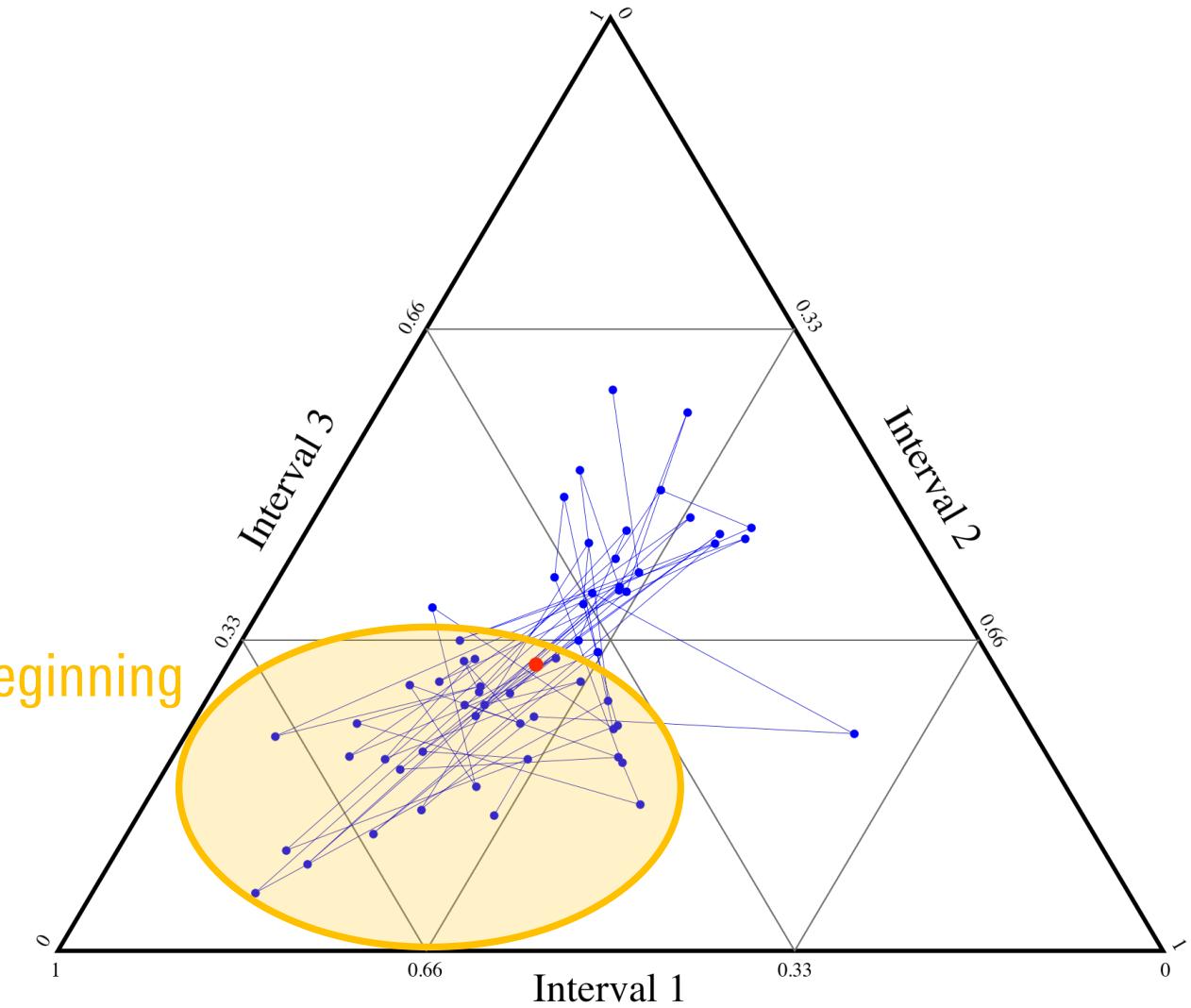
.Rhythm simplex and Mazurkas

Comment la position évolue ?



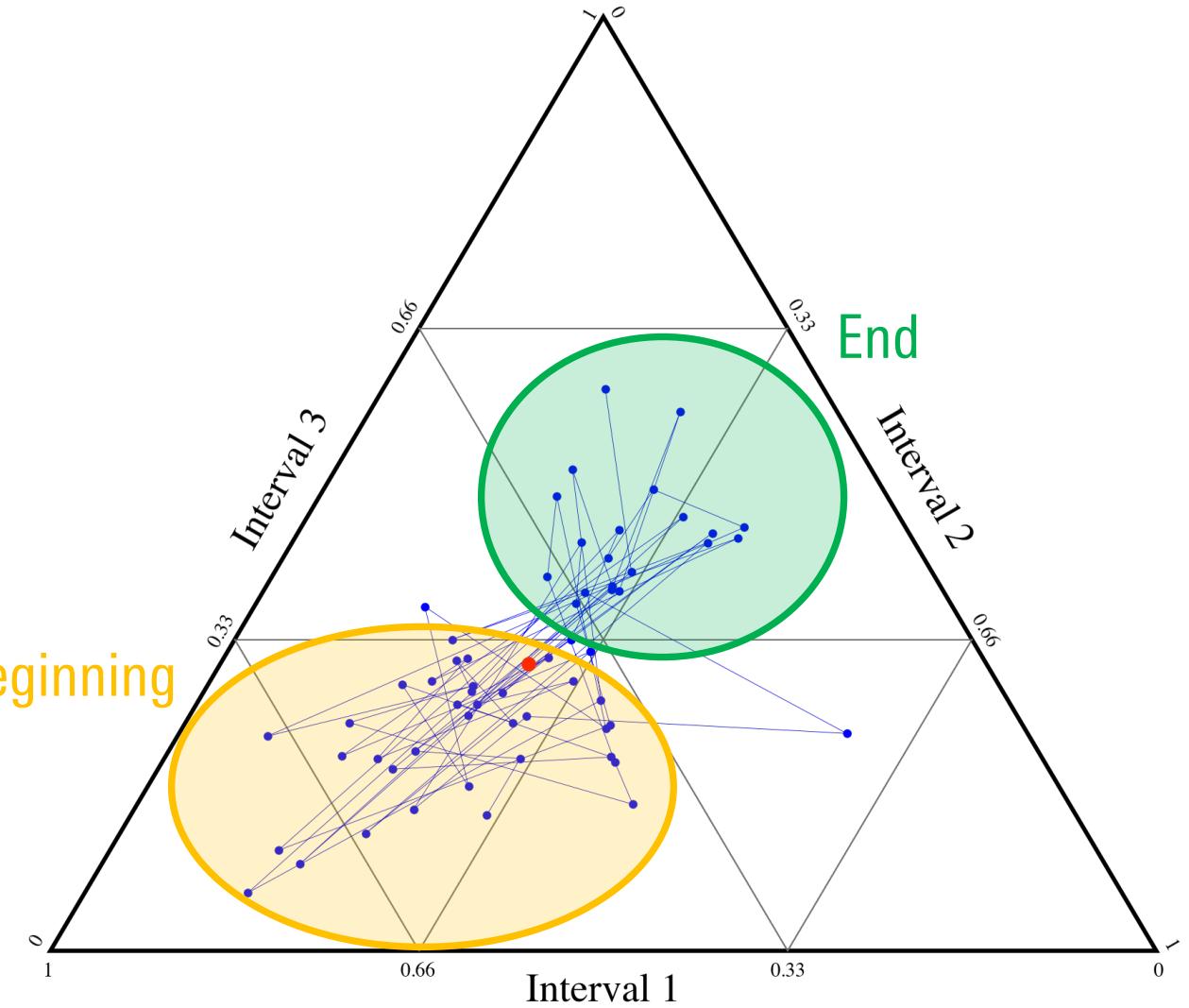
.Rhythm simplex and Mazurkas

Comment la position évolue ?



.Rhythm simplex and Mazurkas

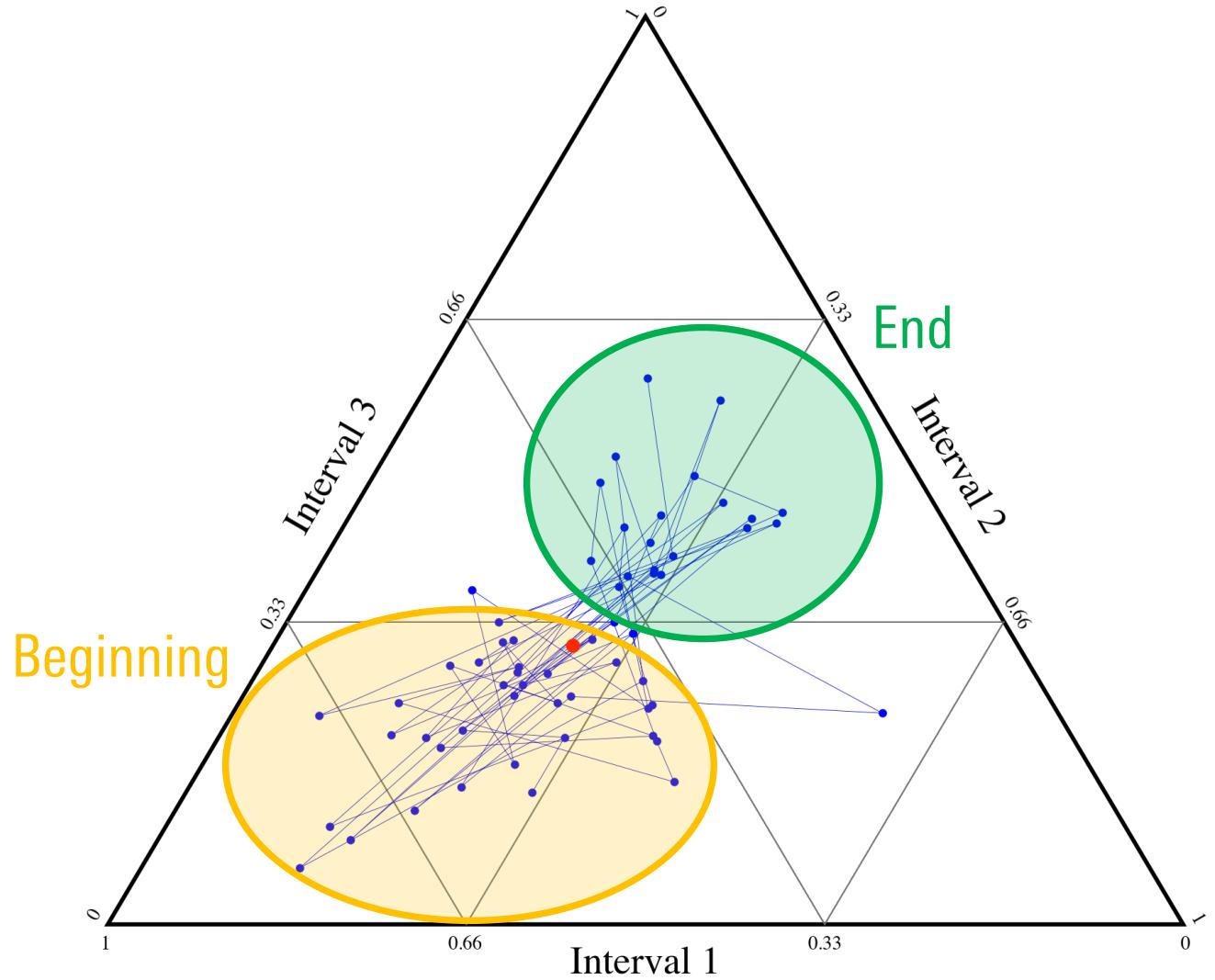
Comment la position évolue ?



.Rhythm simplex and Mazurkas

Comment la position évolue ?

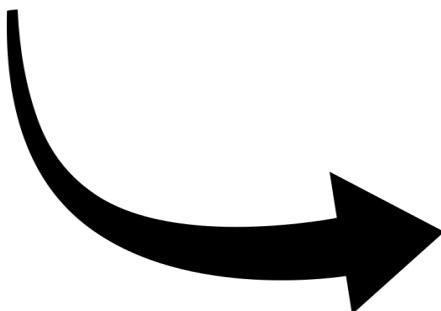
Mettre les points sur
une échelle de temps



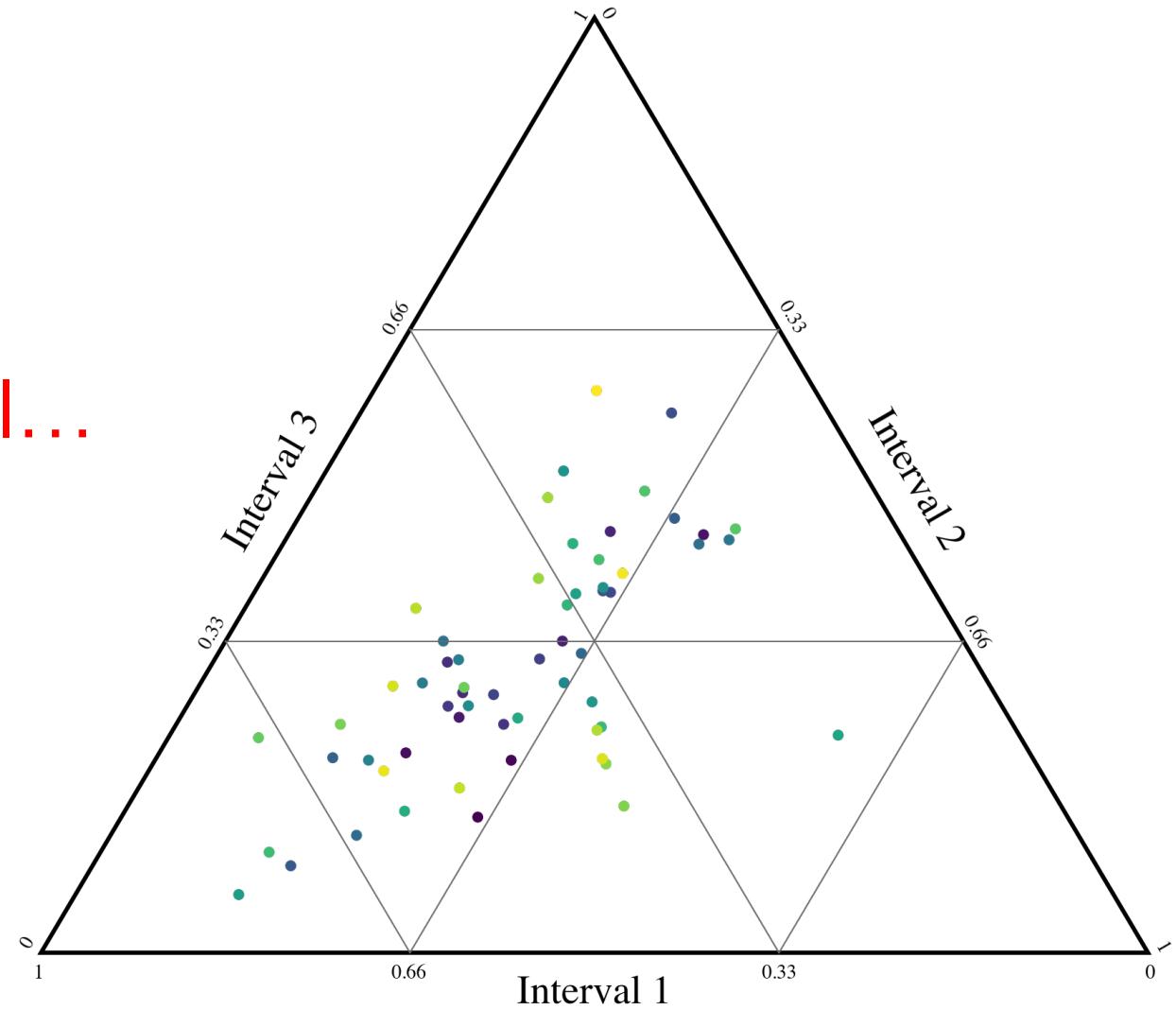
.Rhythm simplex and Mazurkas

Comment la position évolue ?

Mettre les points sur
une échelle de temps



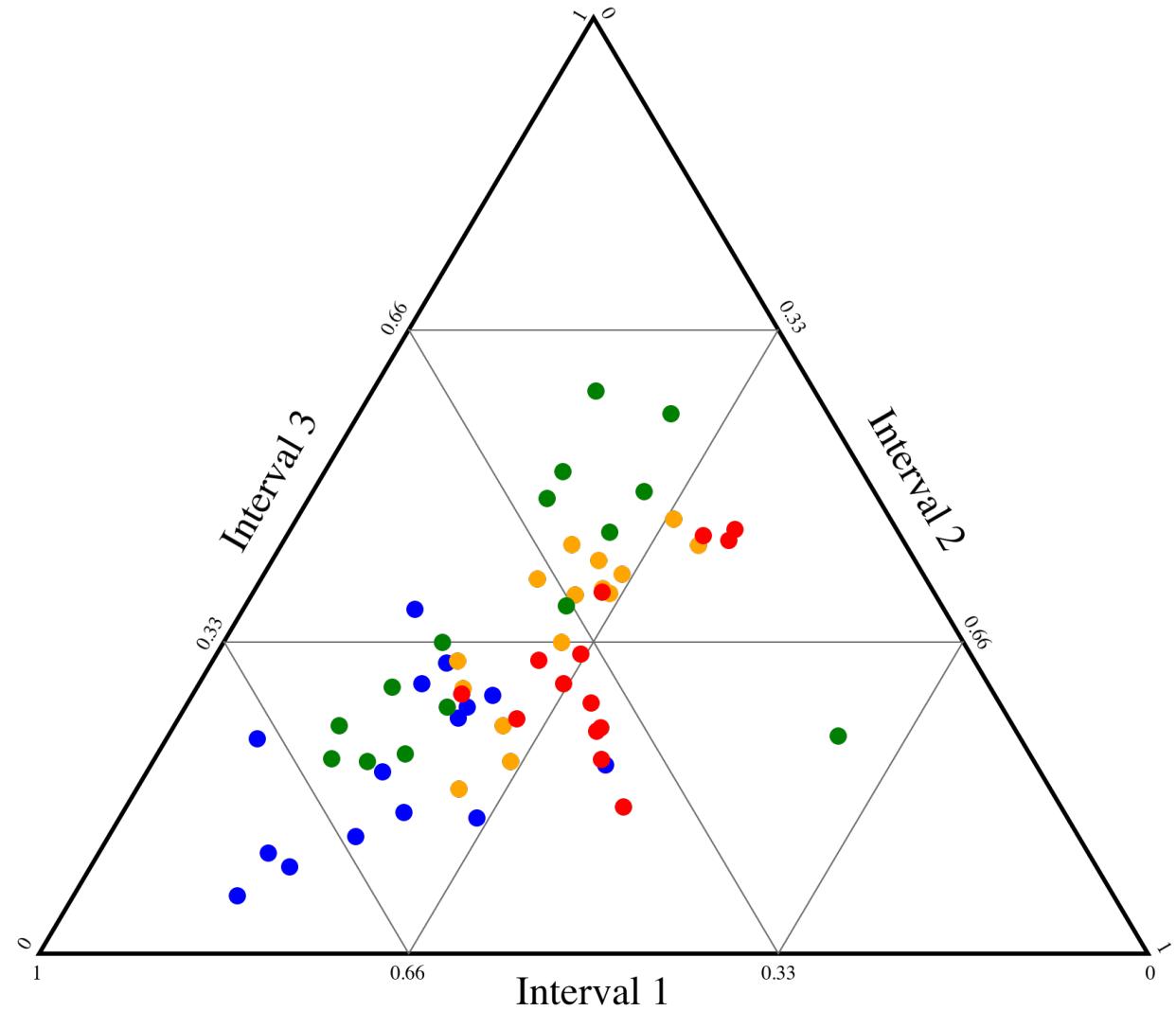
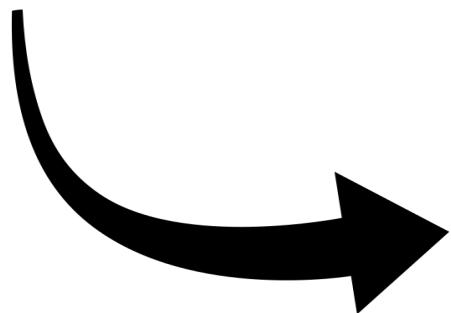
Rien de spécial...



.Rhythm simplex and Mazurkas

Comment la position évolue ?

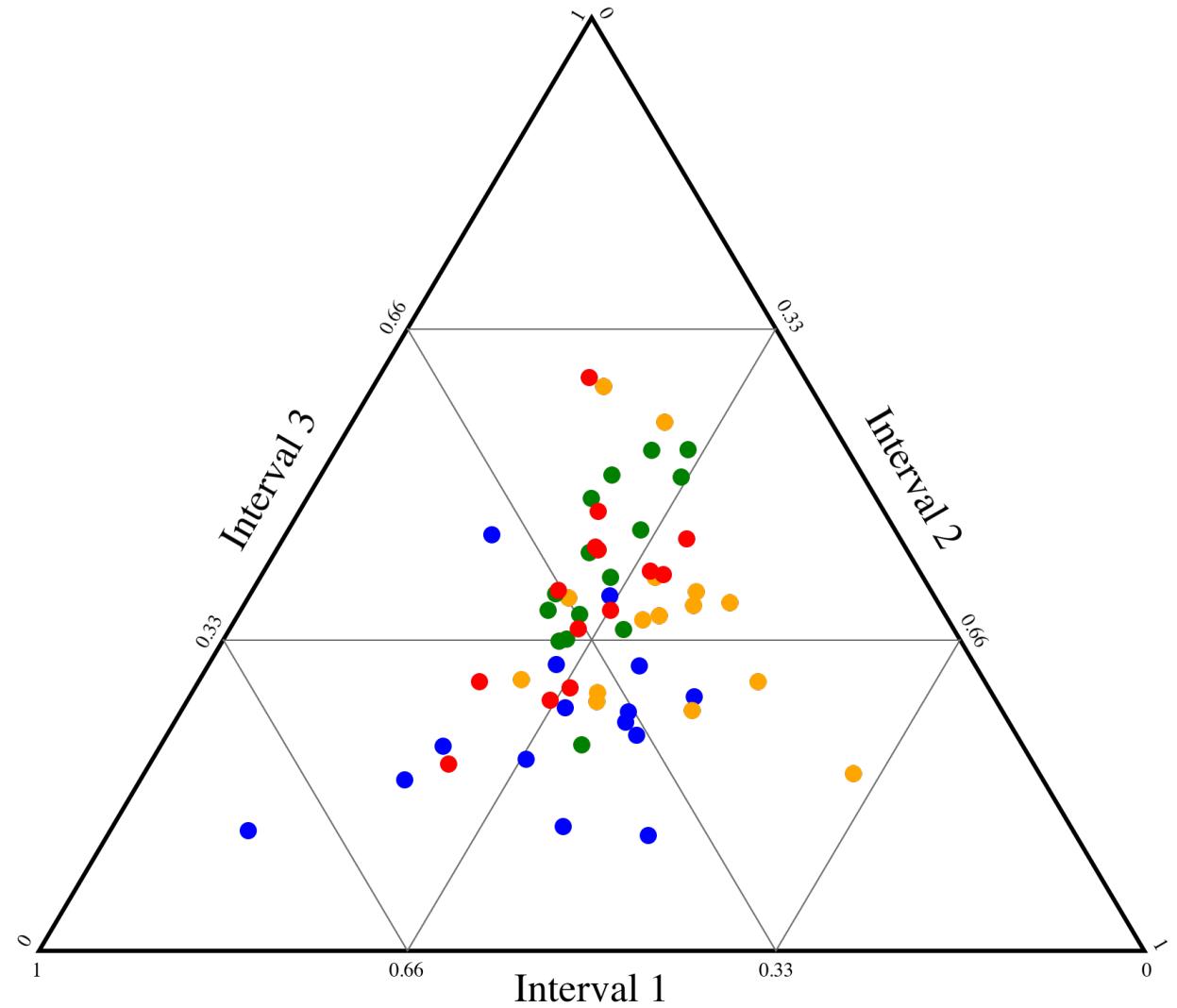
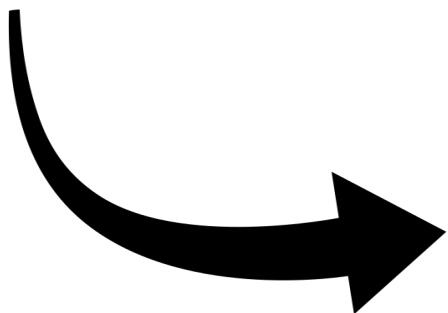
Représente chaque mesure
par une couleur modulo 4
(blue, orange, green, red)



Rhythm simplex and Mazurkas

Comment la position évolue ?

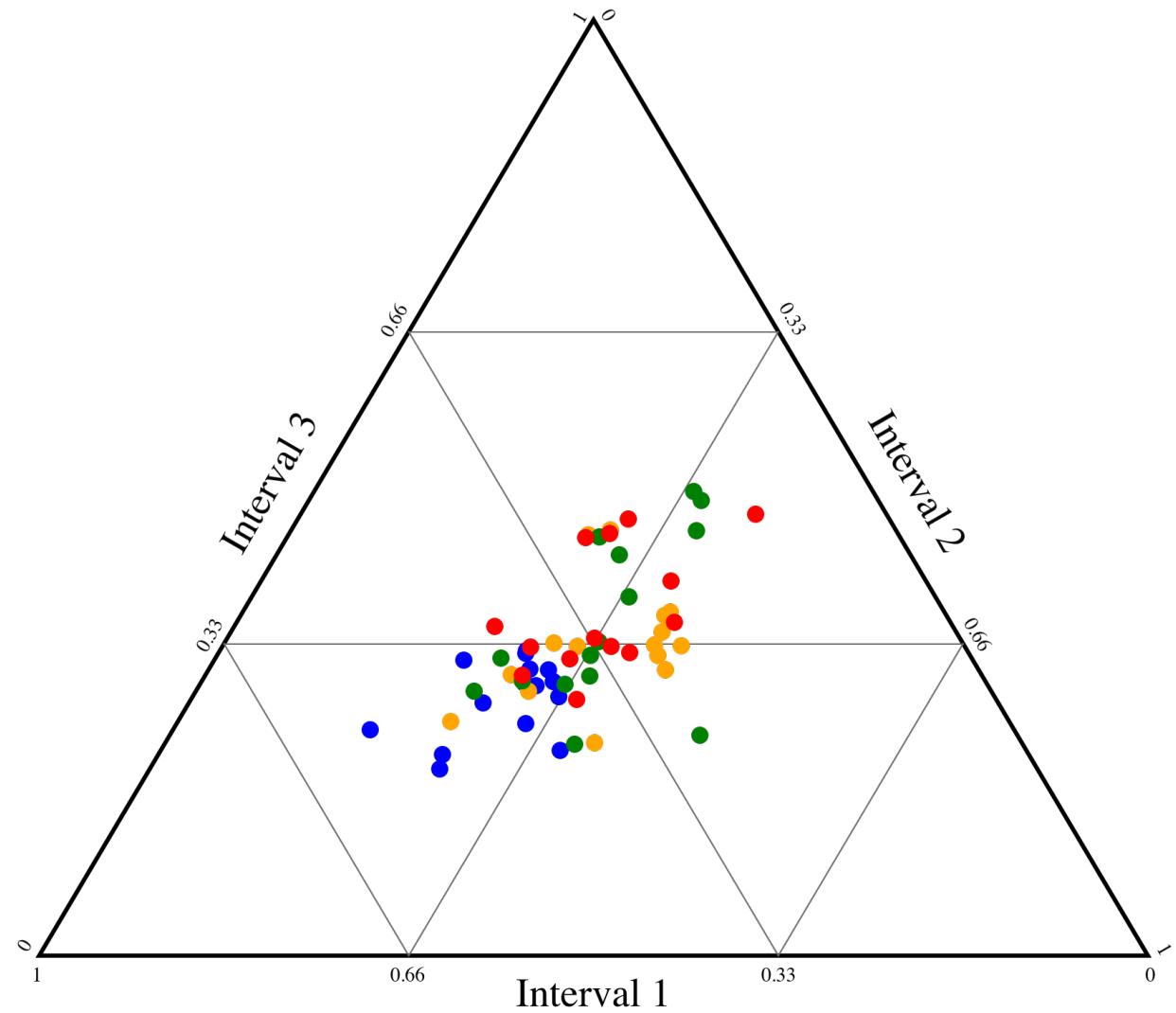
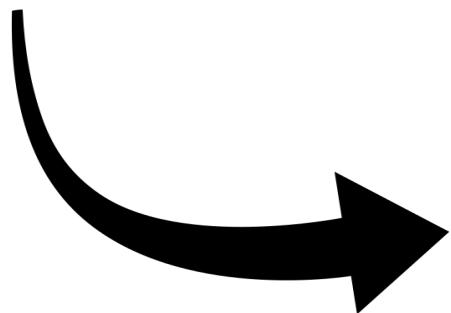
Représente chaque mesure
par une couleur modulo 4
(blue, orange, green, red)



Rhythm simplex and Mazurkas

Comment la position évolue ?

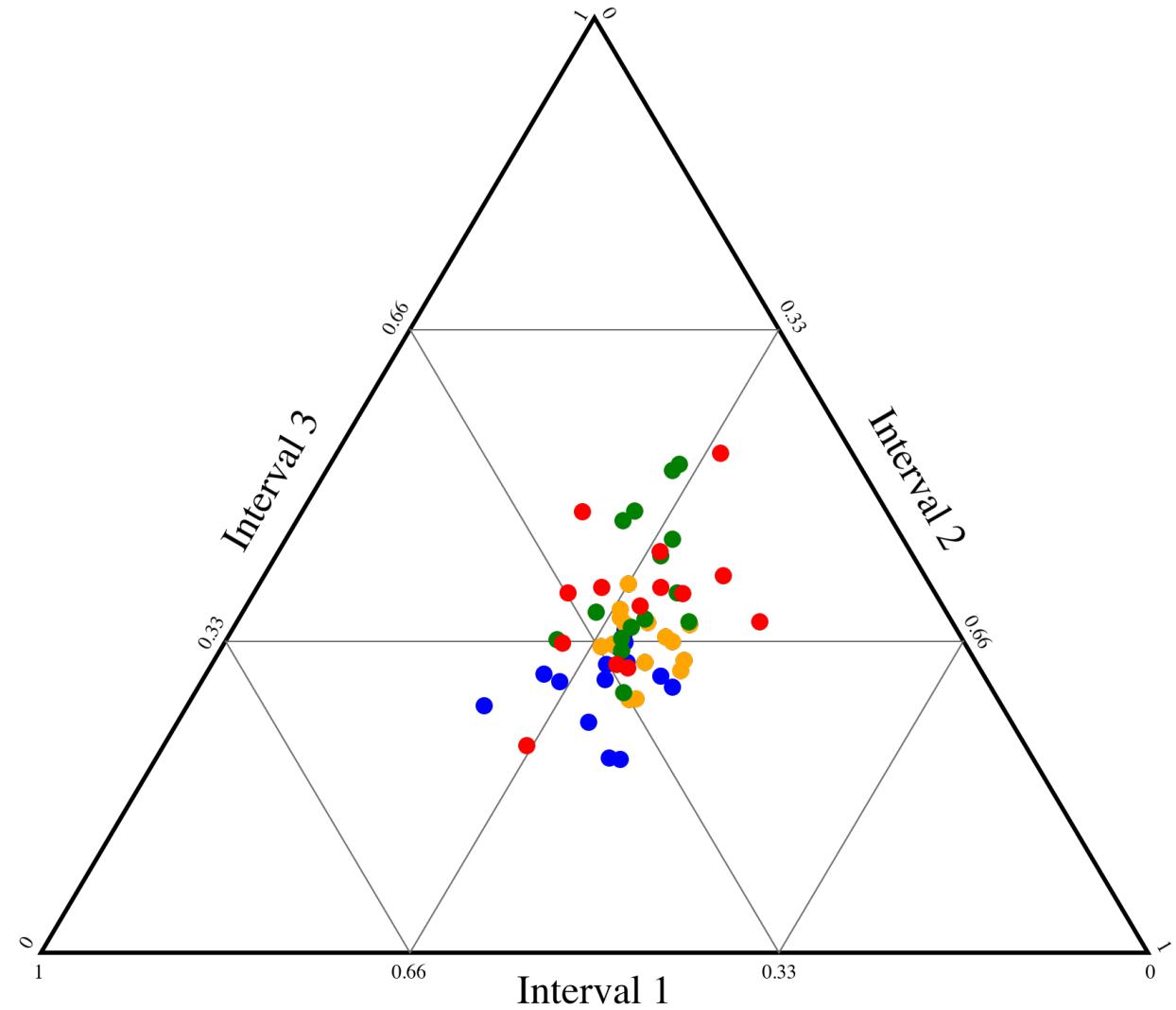
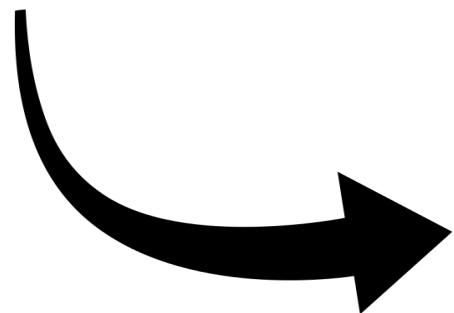
Représente chaque mesure
par une couleur modulo 4
(blue, orange, green, red)



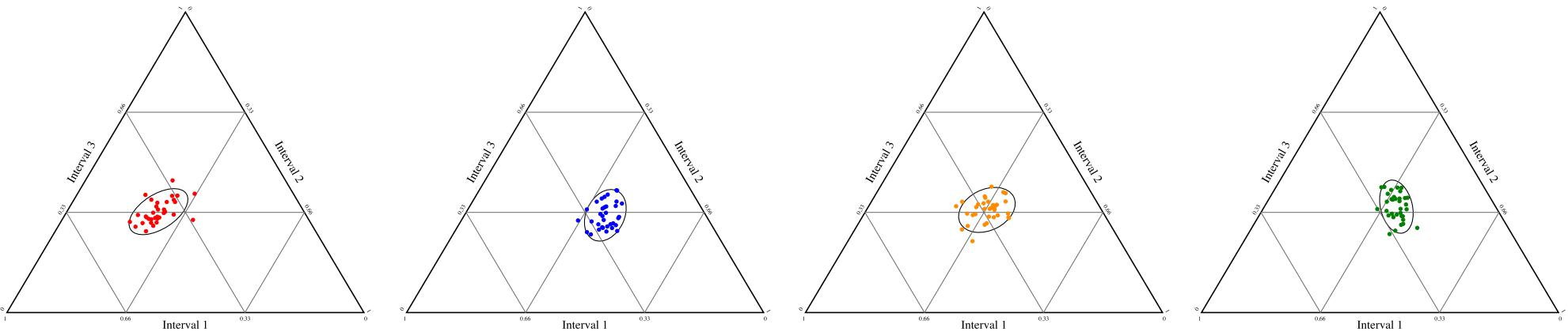
Rhythm simplex and Mazurkas

Comment la position évolue ?

Représente chaque mesure
par une couleur modulo 4
(blue, orange, green, red)



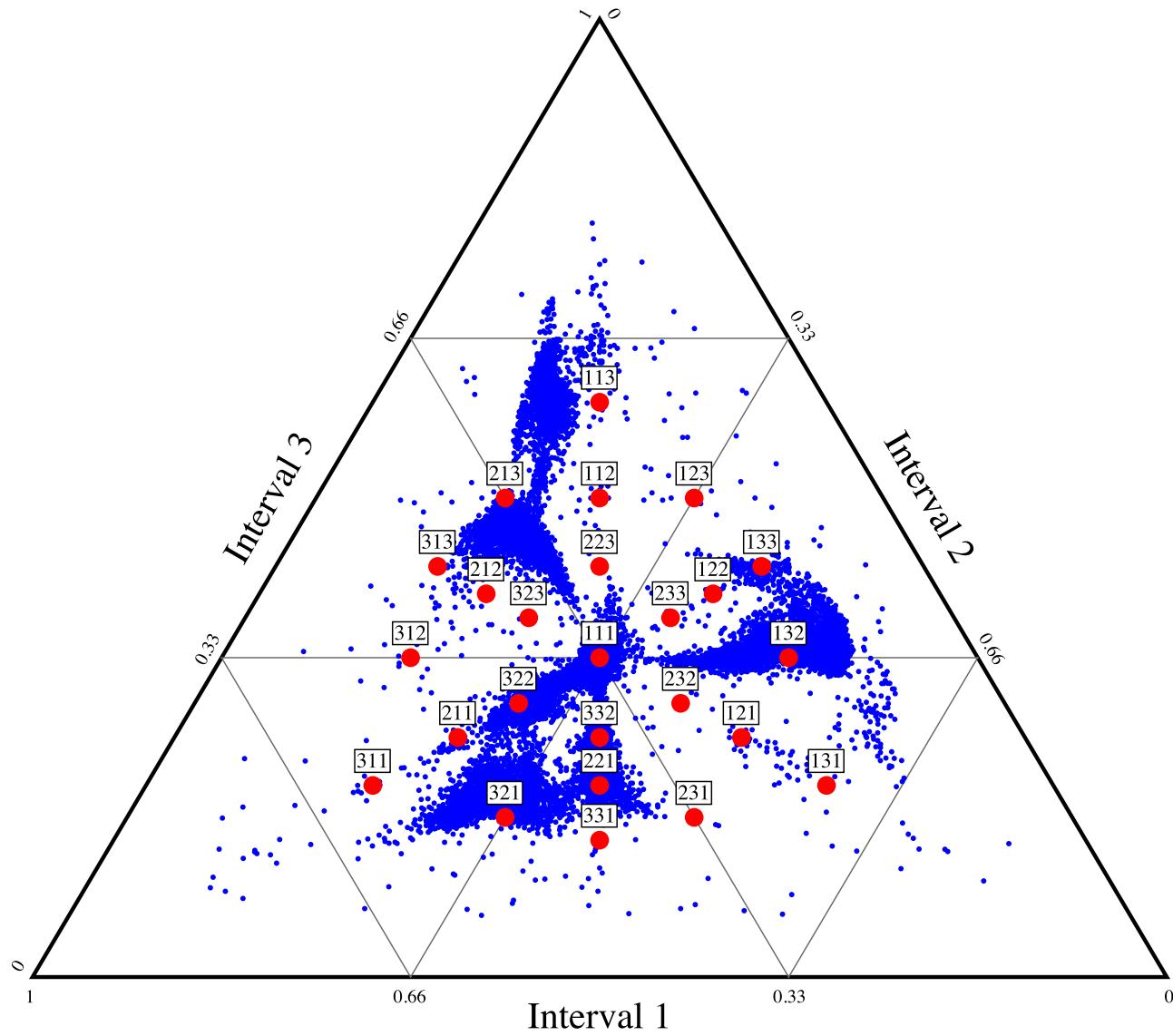
Rhythm simplex and Mazurkas



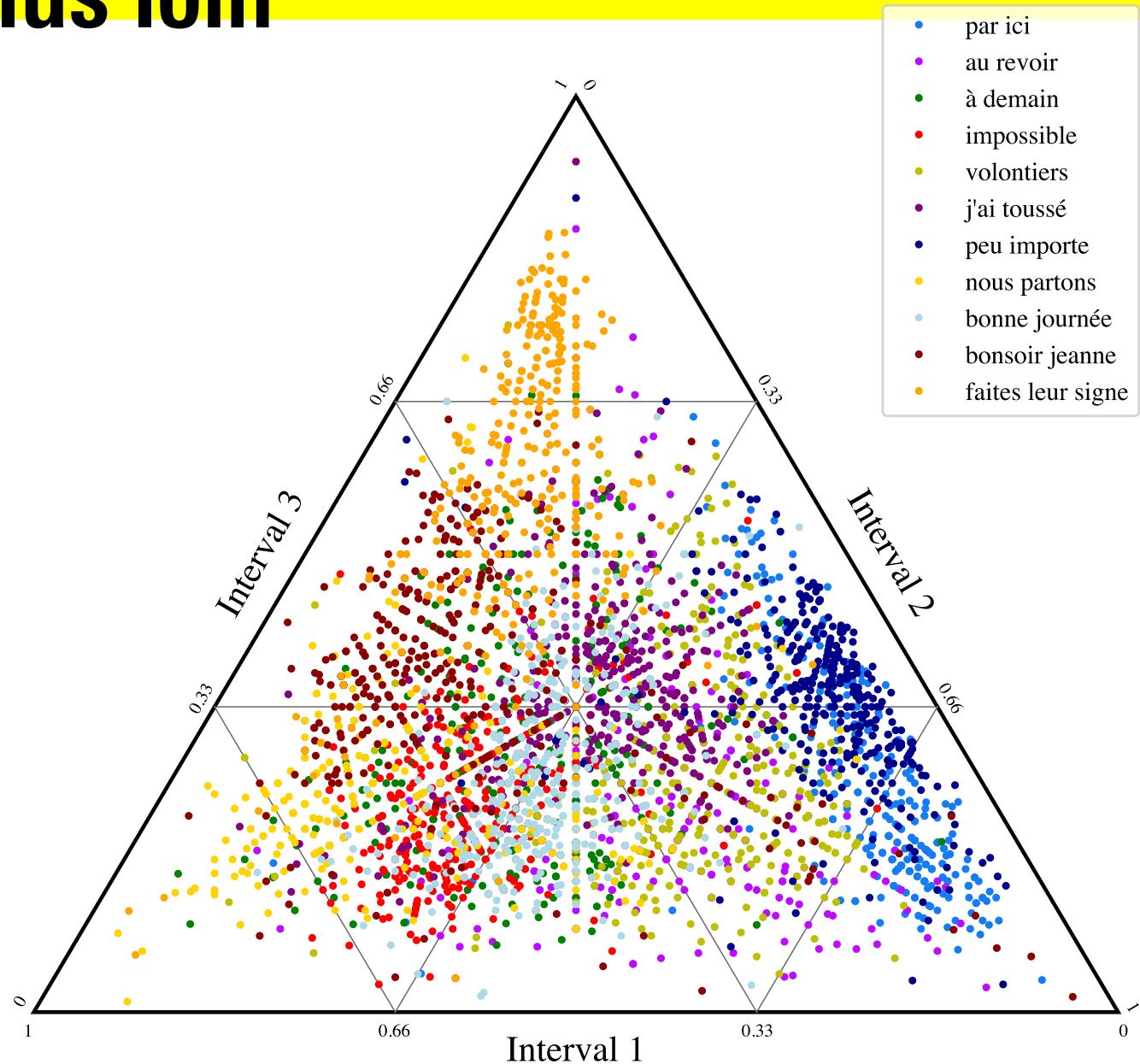
A musical score for a piano in 3/4 time. The key signature has two sharps. The score consists of four measures. The first measure is a rest. The second measure is highlighted with a red box and contains a triplet of eighth notes. The third measure is highlighted with a blue box and contains a triplet of eighth notes. The fourth measure is highlighted with an orange box and contains a triplet of eighth notes. The fifth measure is highlighted with a green box and contains eighth notes and sixteenth notes.

Mazurka 06-1

Pour aller plus loin



.Pour aller plus loin



.Rhythm simplex and Mazurkas

Pour résumer :

.Rhythm simplex and Mazurkas

Pour résumer :

- Représenter une performance dans le simplex

.Rhythm simplex and Mazurkas

Pour résumer :

- Représenter une performance dans le simplex
 - Calcul de la compacité

.Rhythm simplex and Mazurkas

Pour résumer :

- Représenter une performance dans le simplex
 - Calcul de la compacité
- Nouvelle distance pour les points extrêmes

.Rhythm simplex and Mazurkas

Pour résumer :

- Représenter une performance dans le simplex
 - Calcul de la compacité
- Nouvelle distance pour les points extrêmes
 - Trajectoires communes des performers

.Rhythm simplex and Mazurkas

Pour résumer :

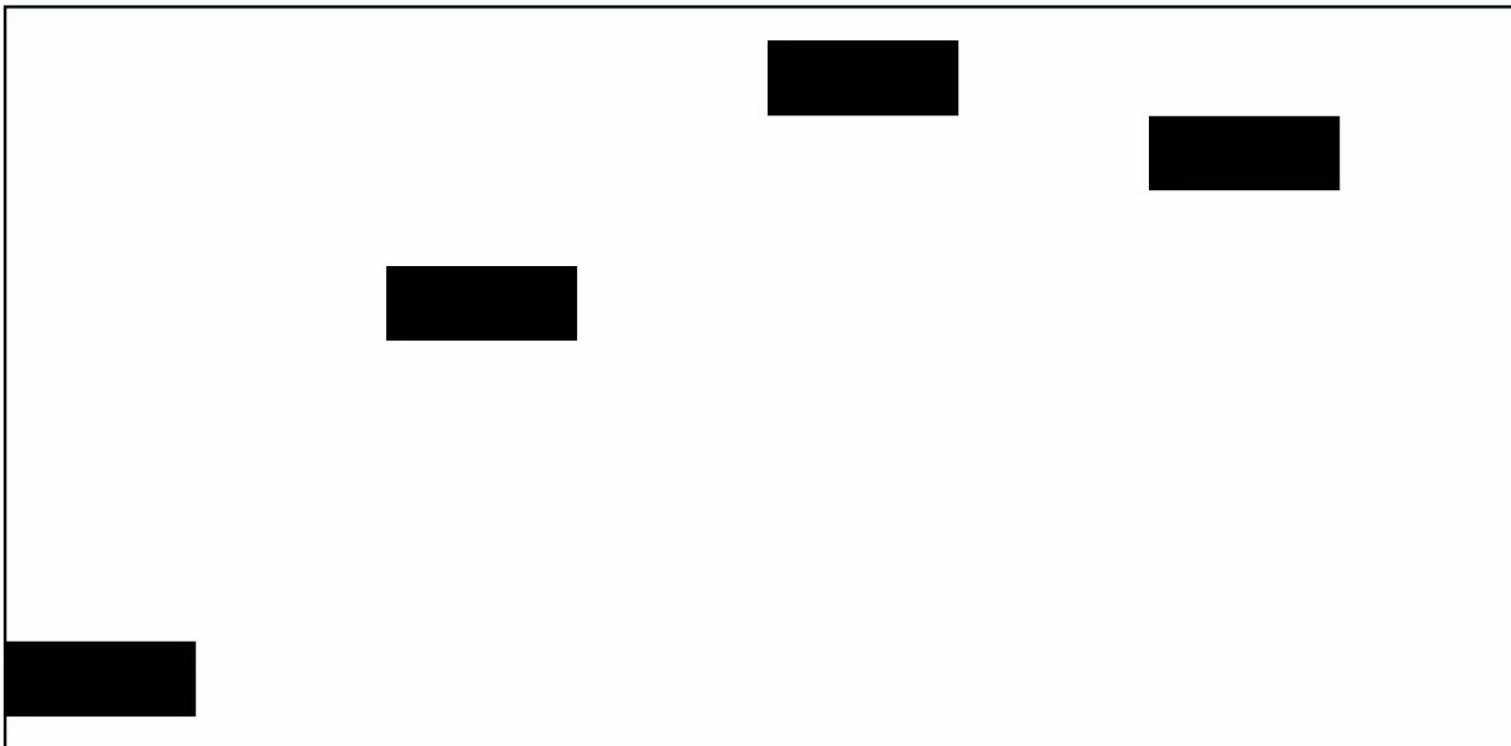
- Représenter une performance dans le simplex
 - Calcul de la compacité
- Nouvelle distance pour les points extrêmes
 - Trajectoires communes des performers
 - Trajectoires en fonction de la partition

Chapitre 3 :

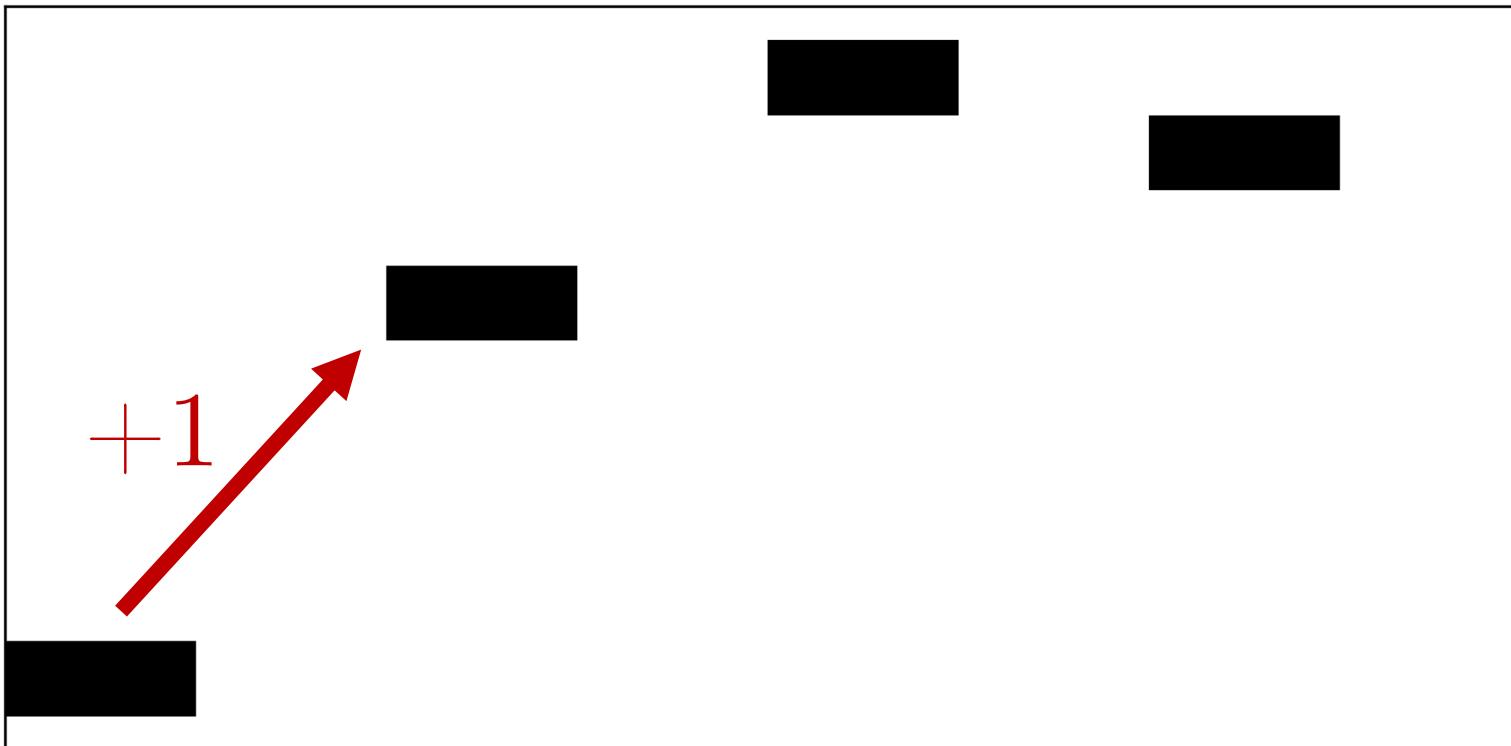
Étudier la partition

(motifs et structures musicales)

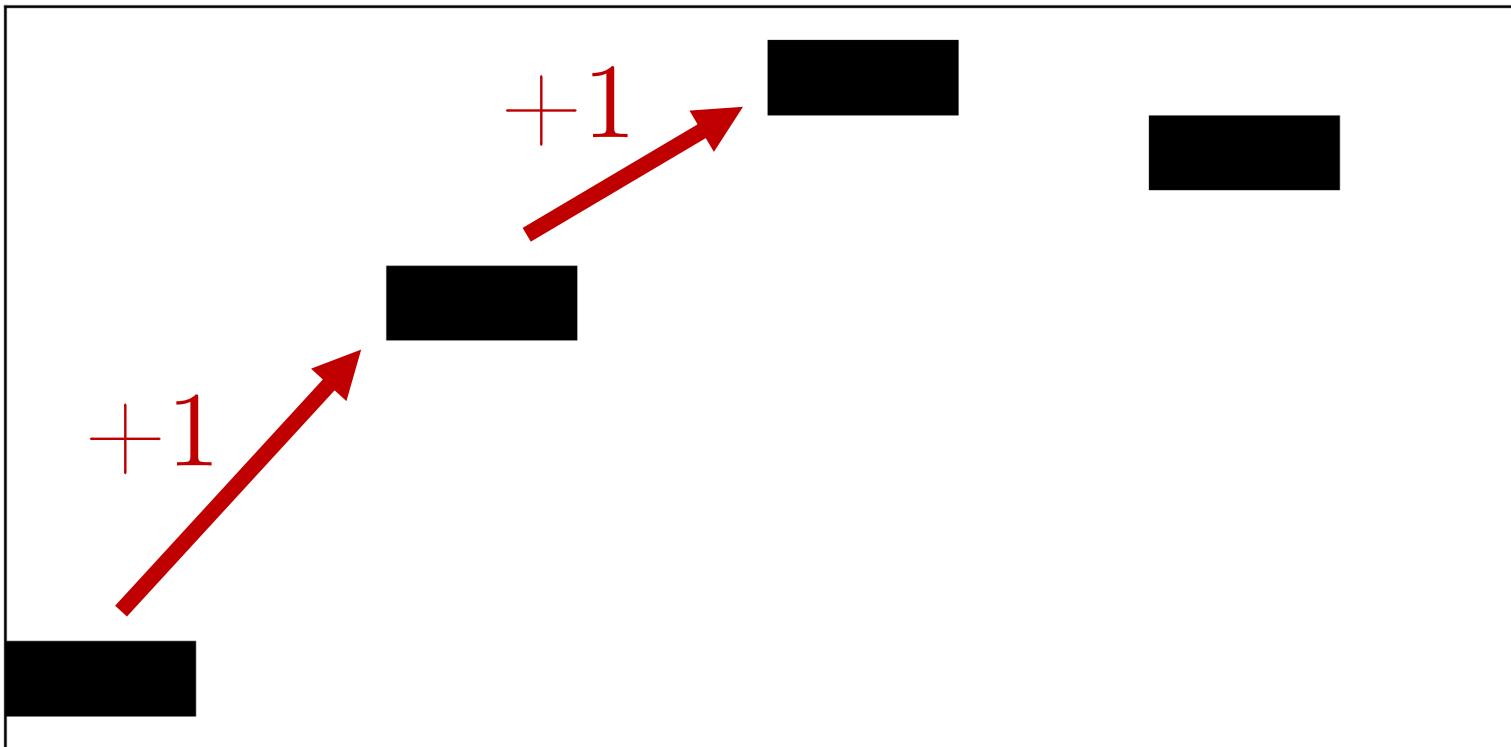
The Melodic Contour



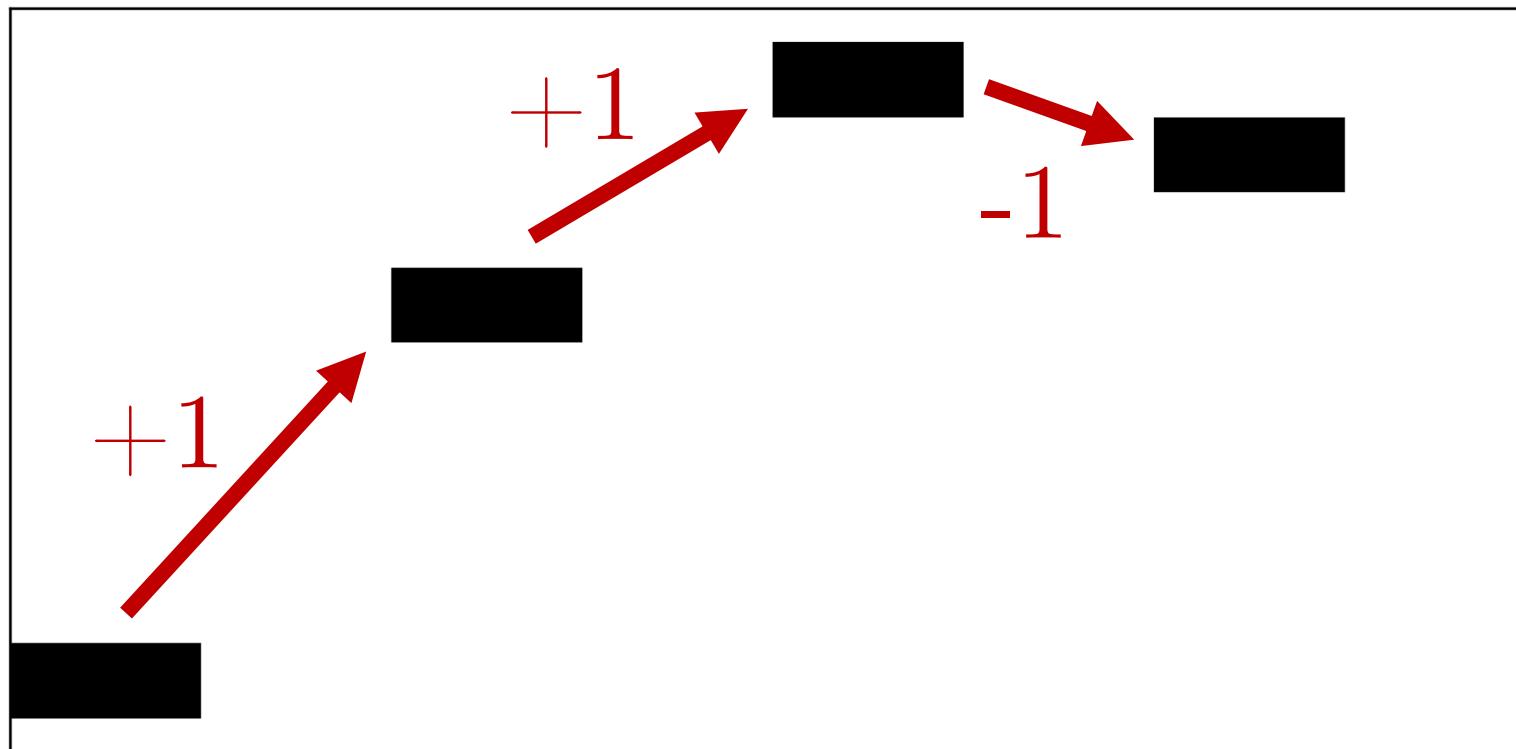
The Melodic Contour



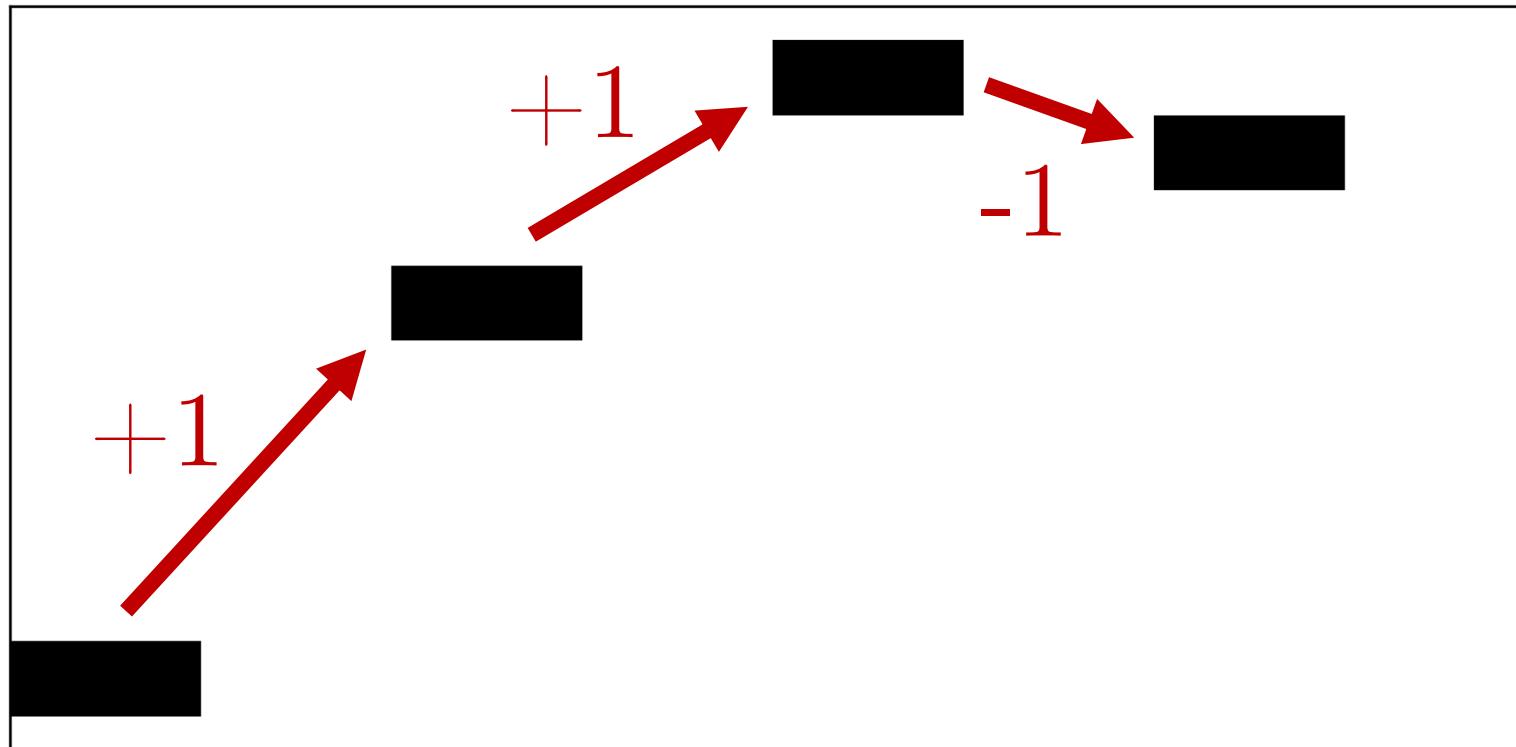
The Melodic Contour



The Melodic Contour

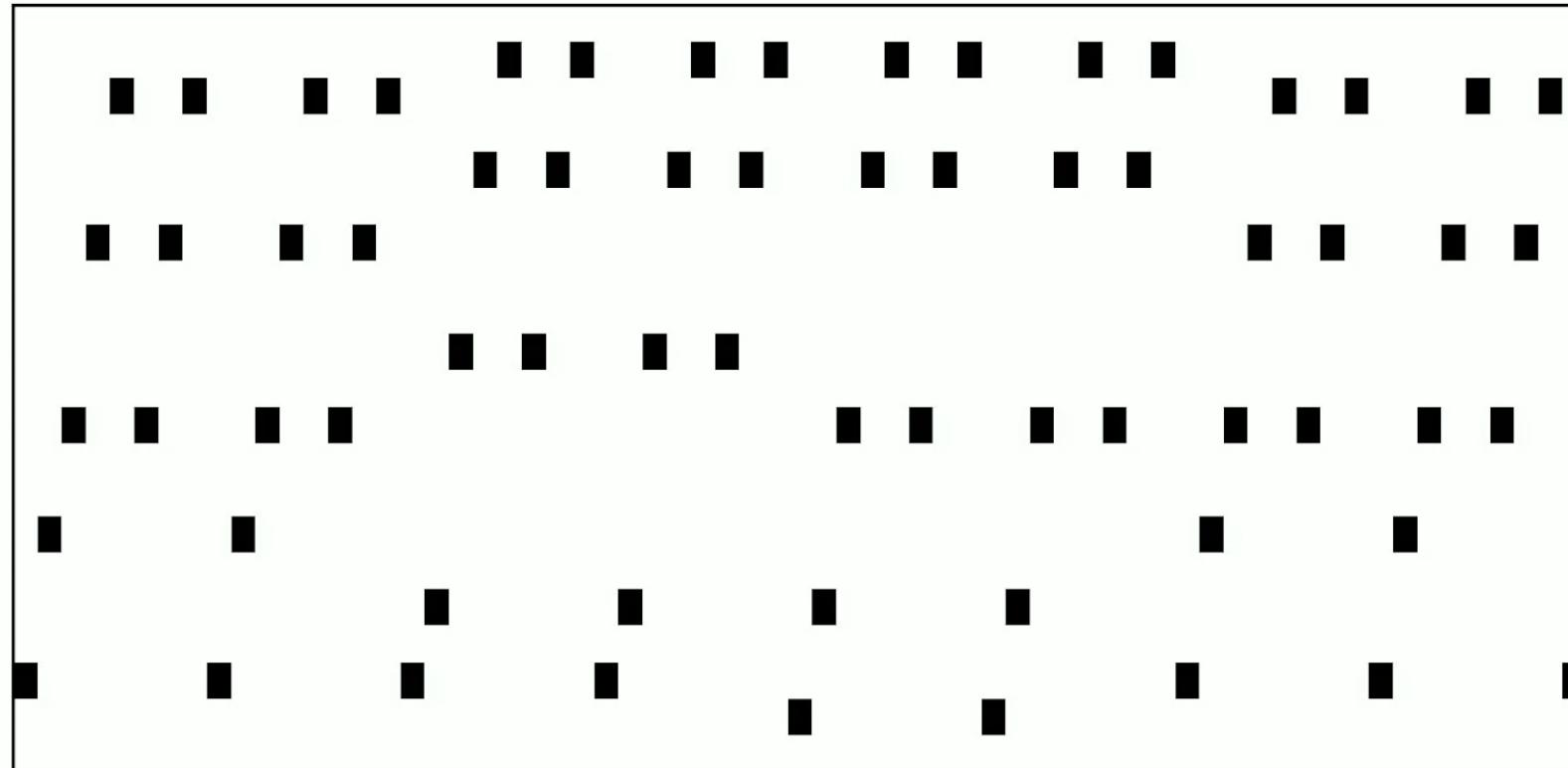


The Melodic Contour



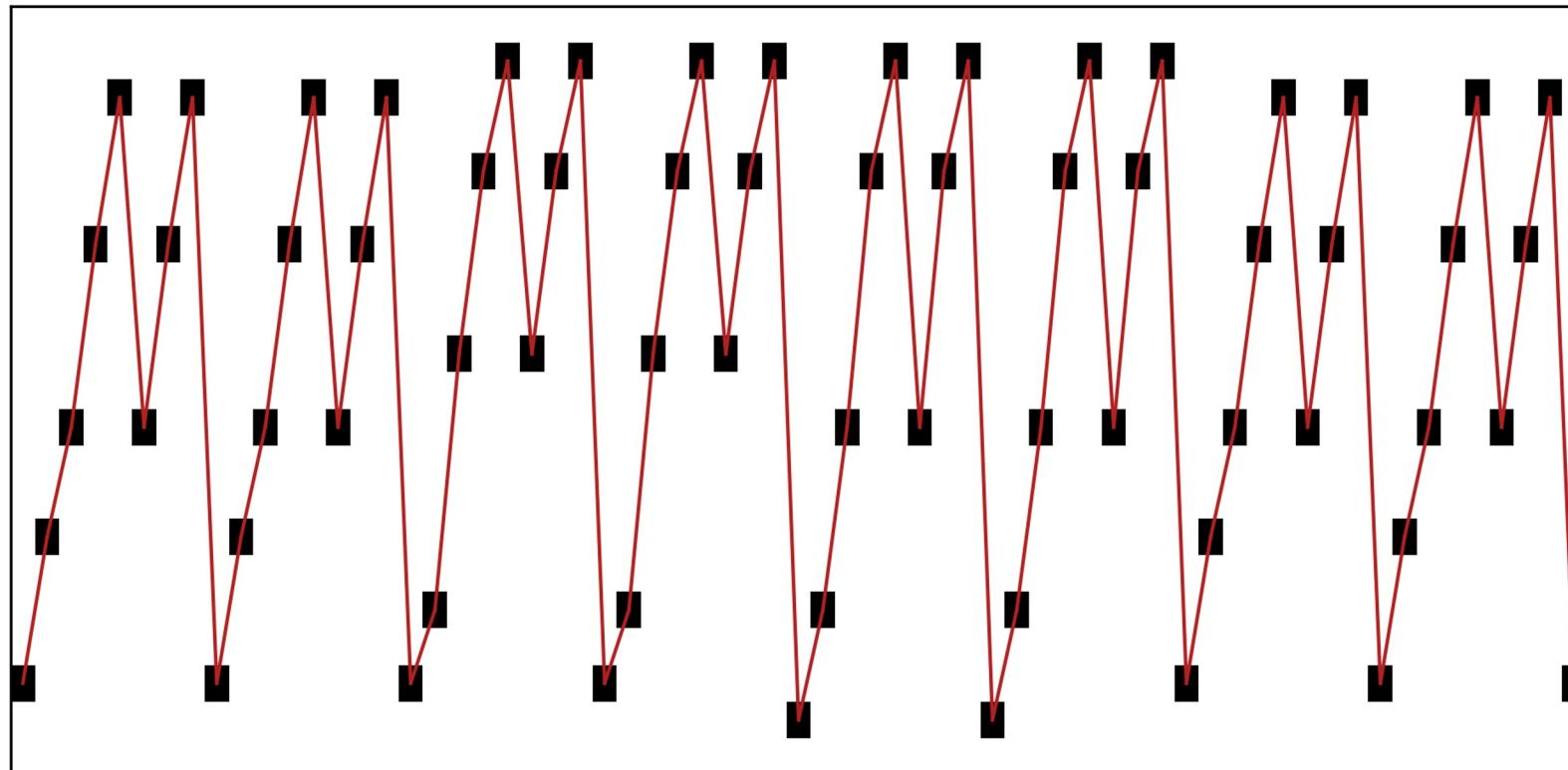
Melodic Contour = {+1,+1,-1}

The Melodic Contour

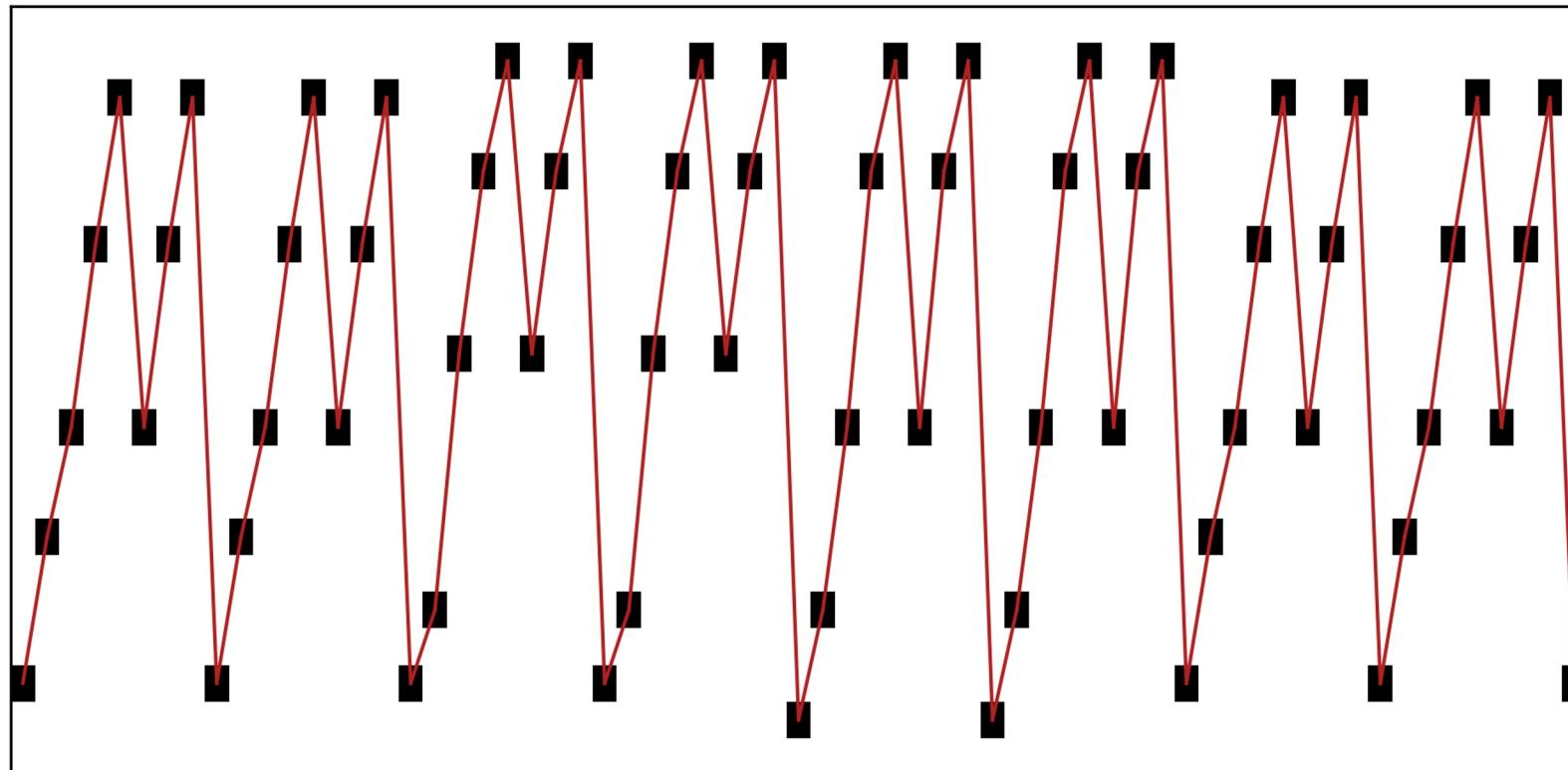


Bach's Prelude in C Major, BWV 846

The Melodic Contour

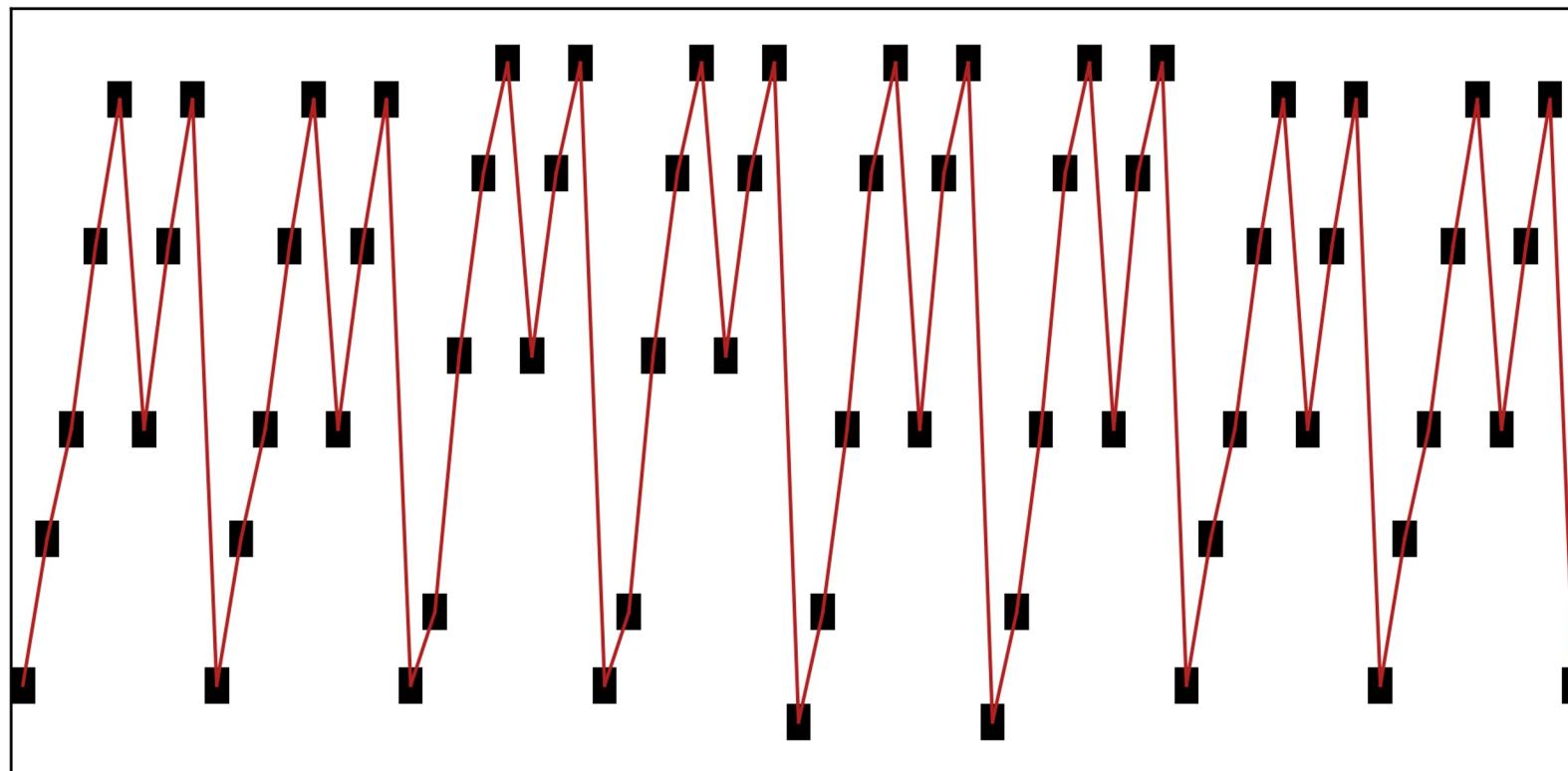


The Melodic Contour



Melodic Contour = $\{+1,+1,+1,+1,-1,+1,+1,-1,+1,+1,+1,-1,+1,+1,-1,+1,+1,\dots\}$

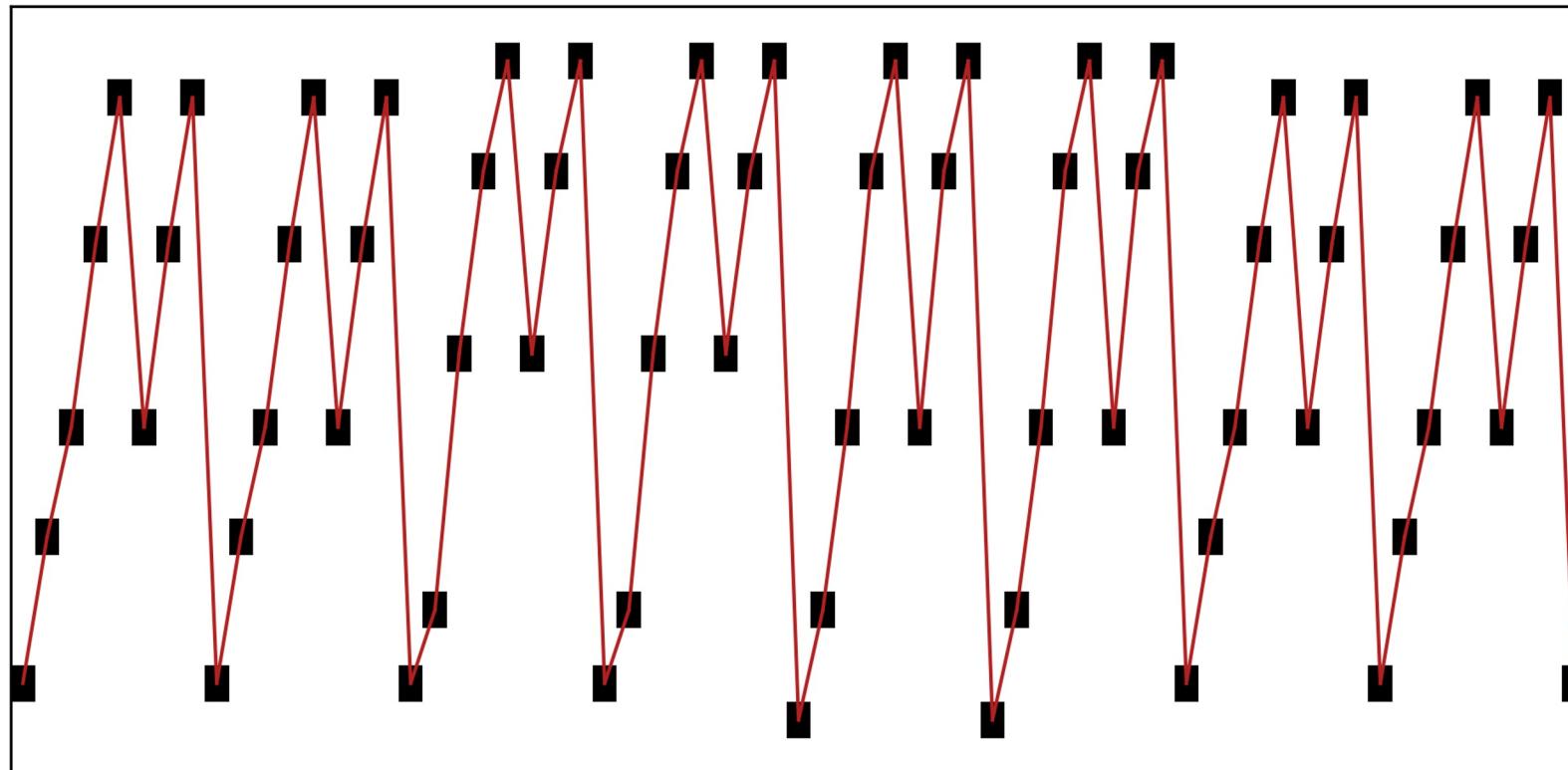
The Melodic Contour



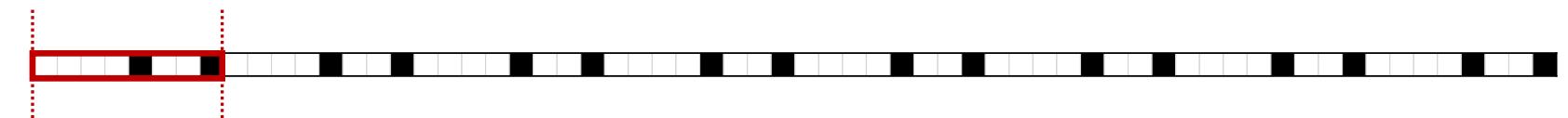
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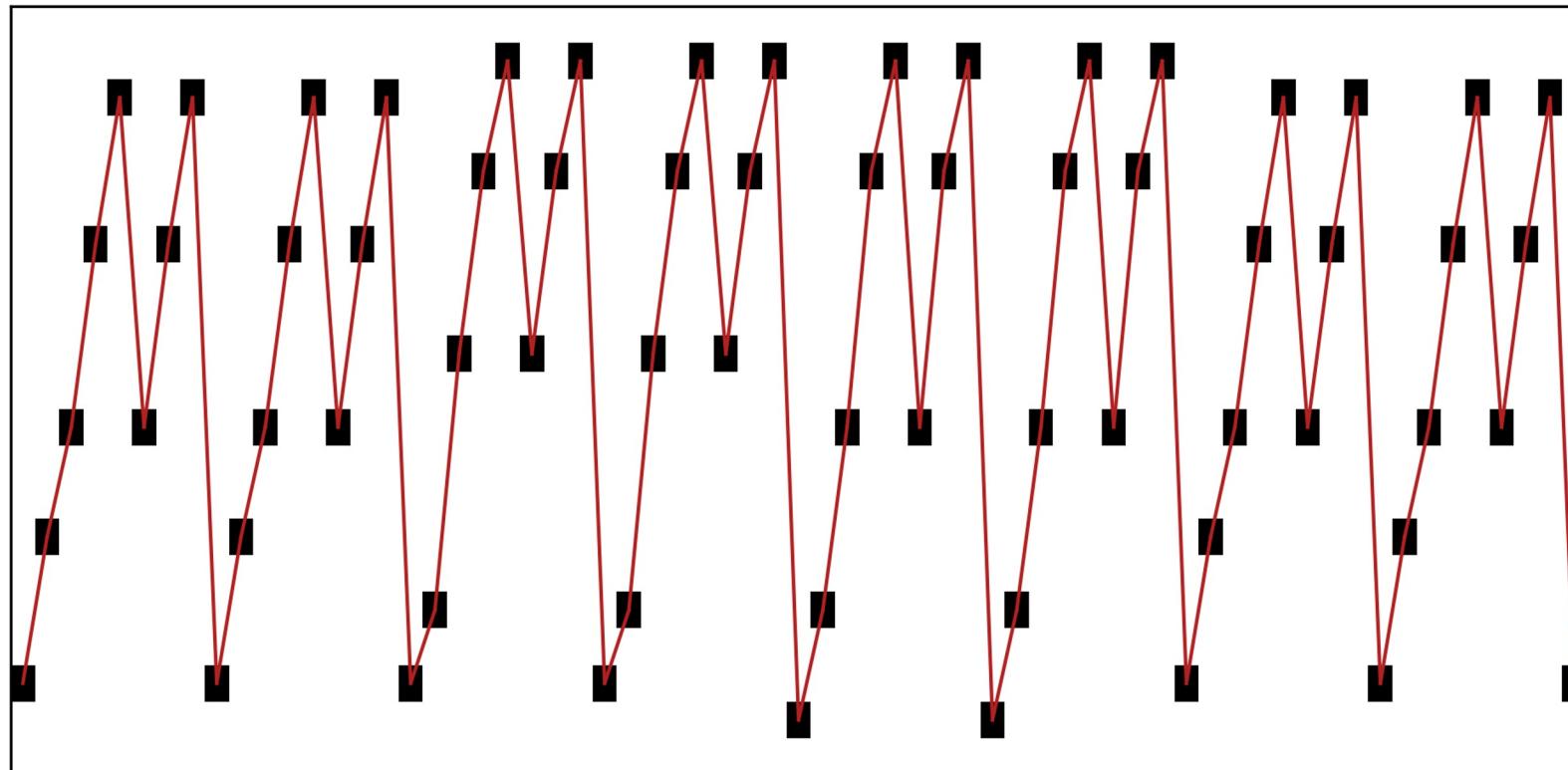
The Melodic Contour



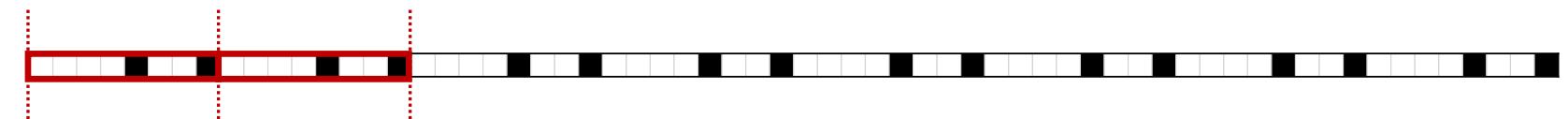
Melodic Contour =



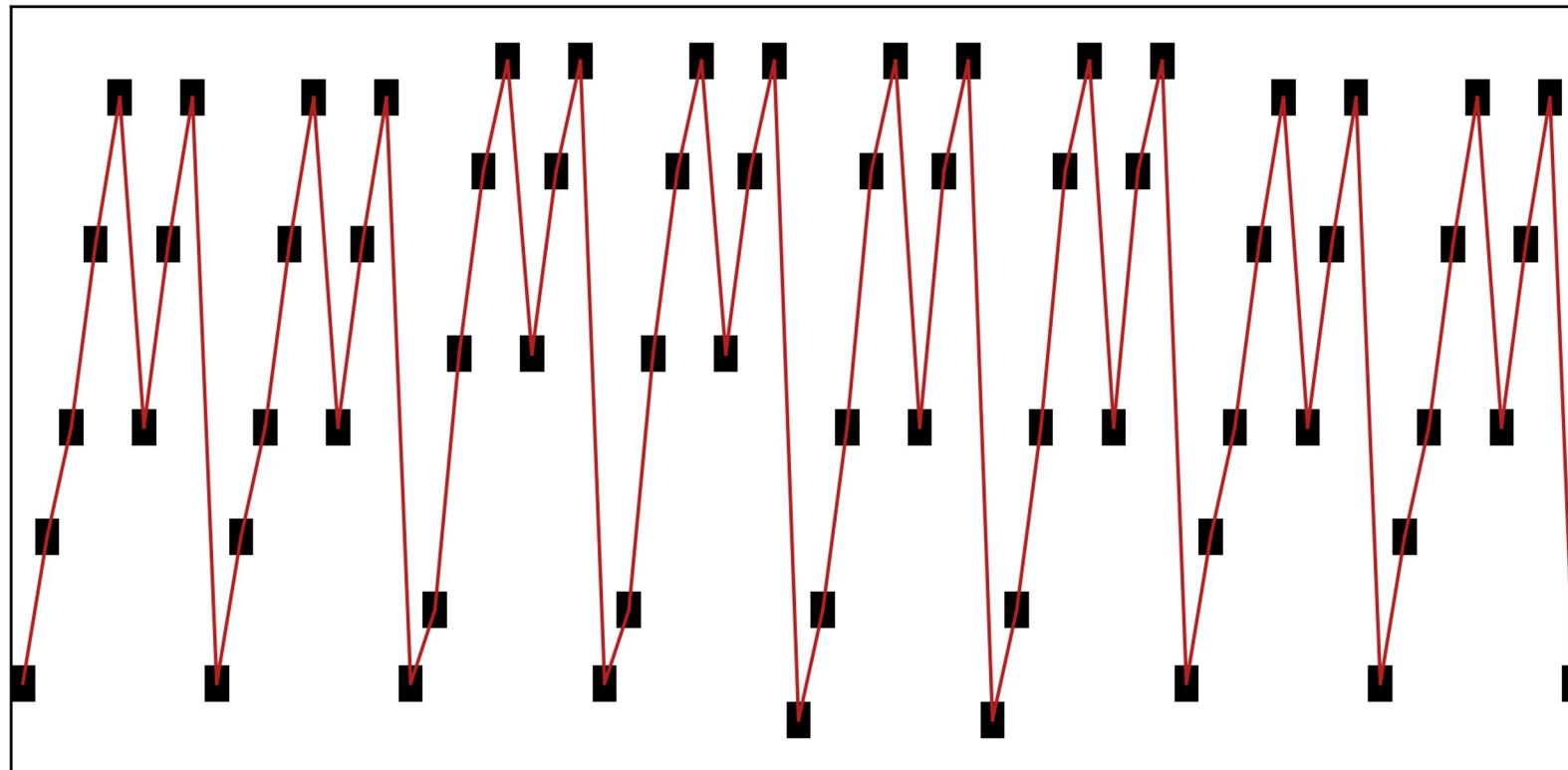
The Melodic Contour



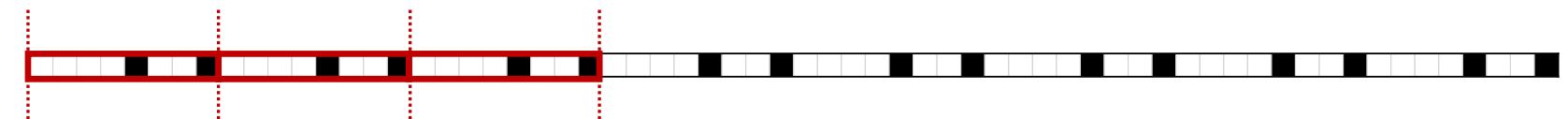
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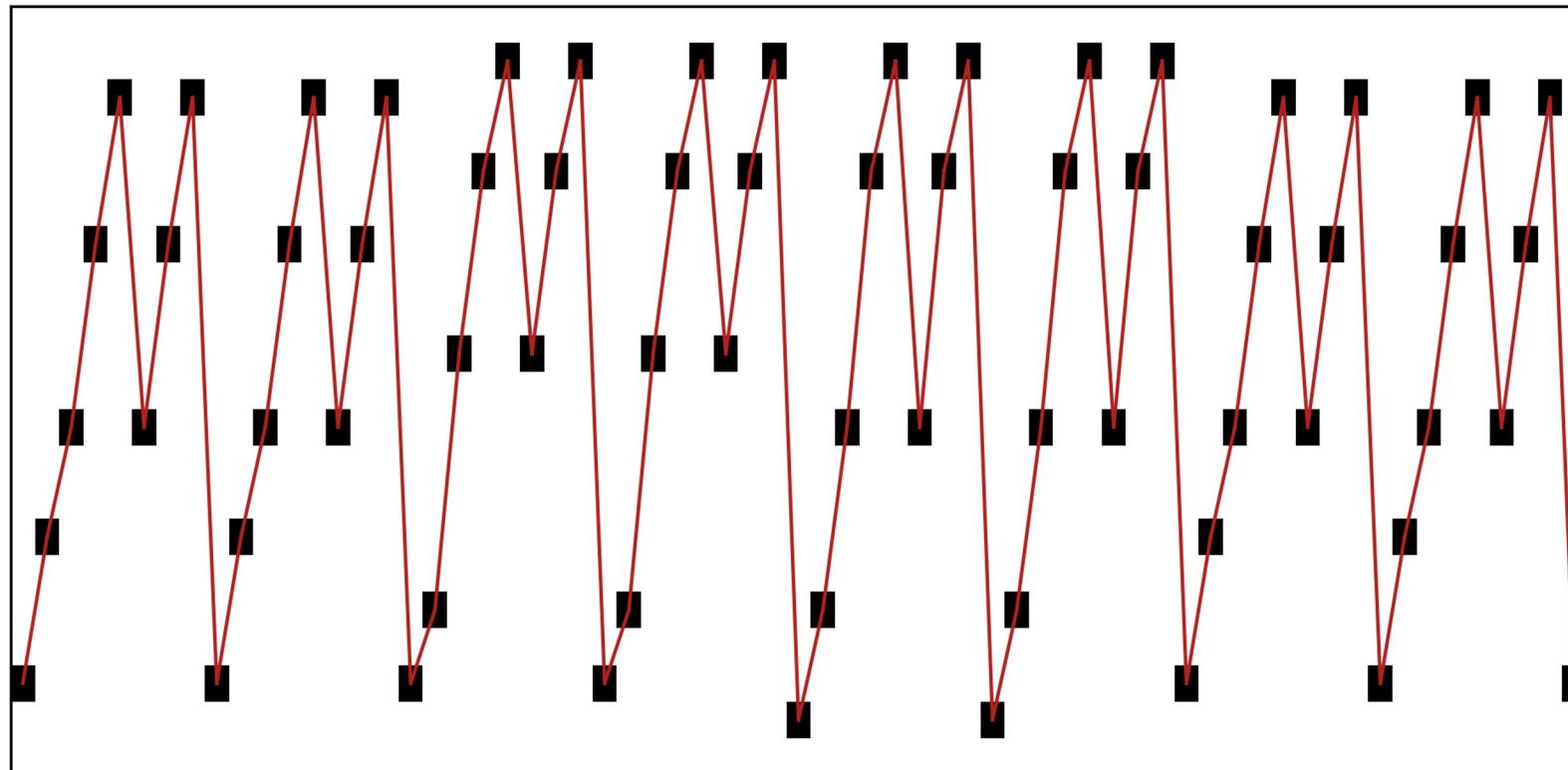
The Melodic Contour



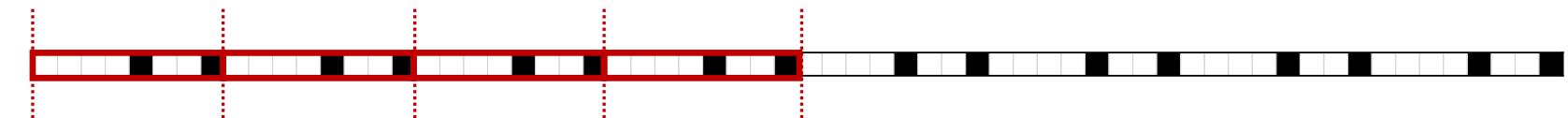
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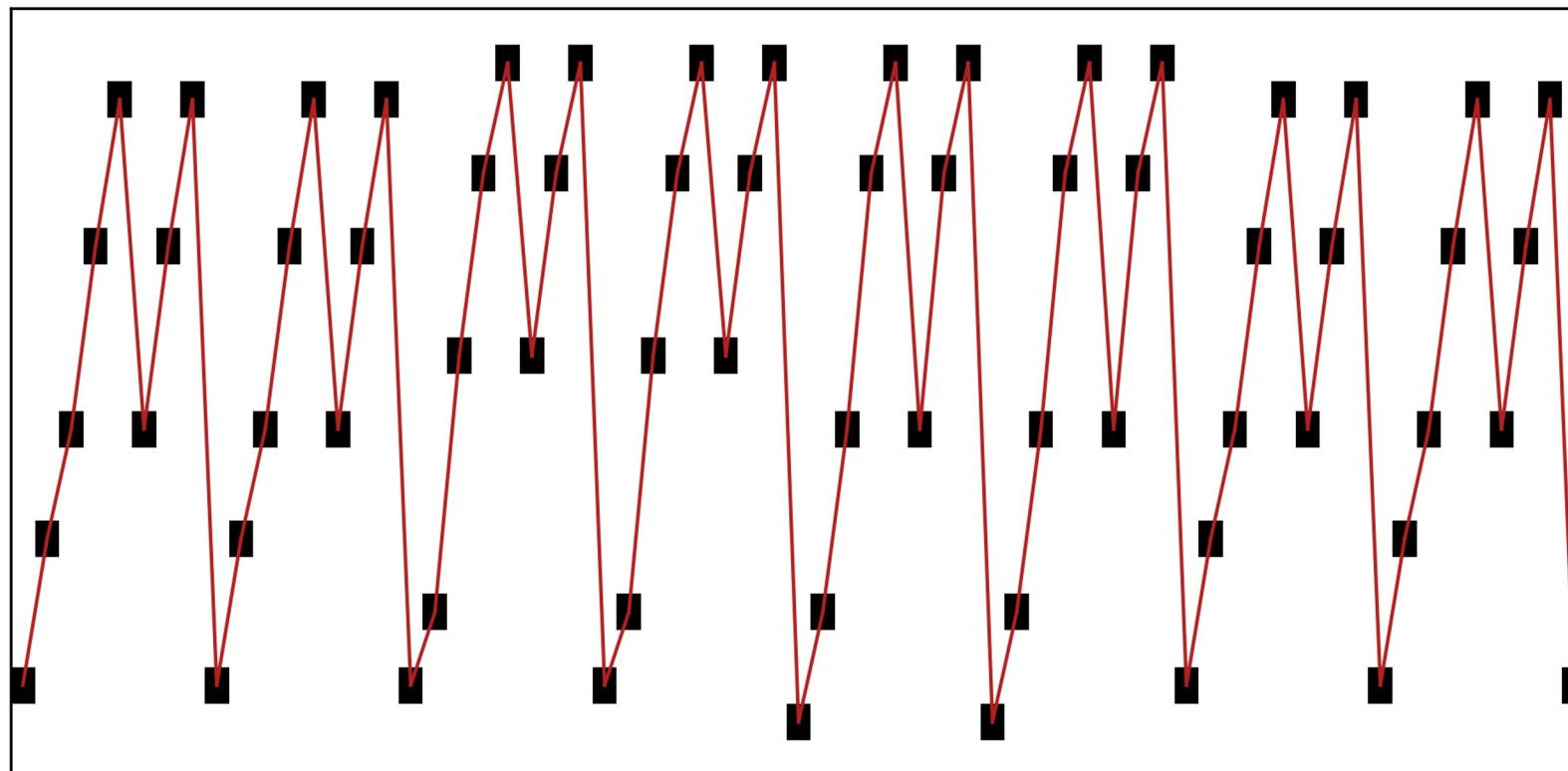
The Melodic Contour



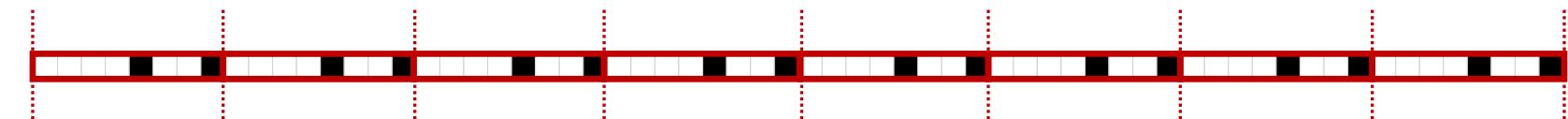
Melodic Contour =



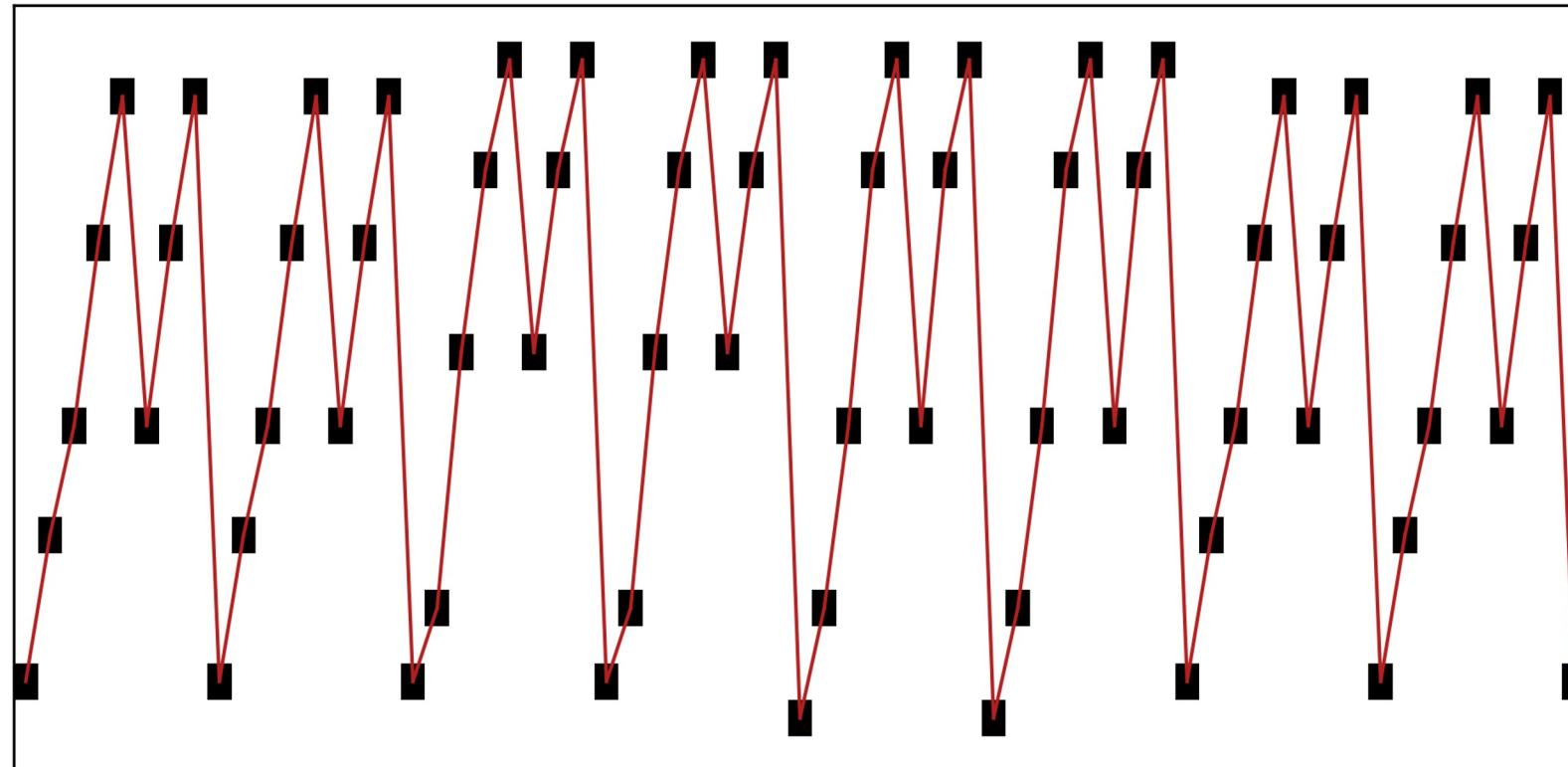
The Melodic Contour



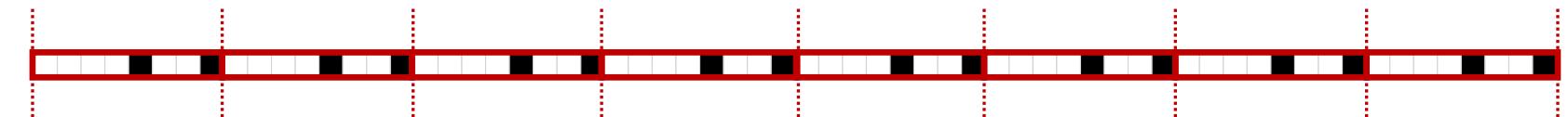
Melodic Contour =



The Melodic Contour



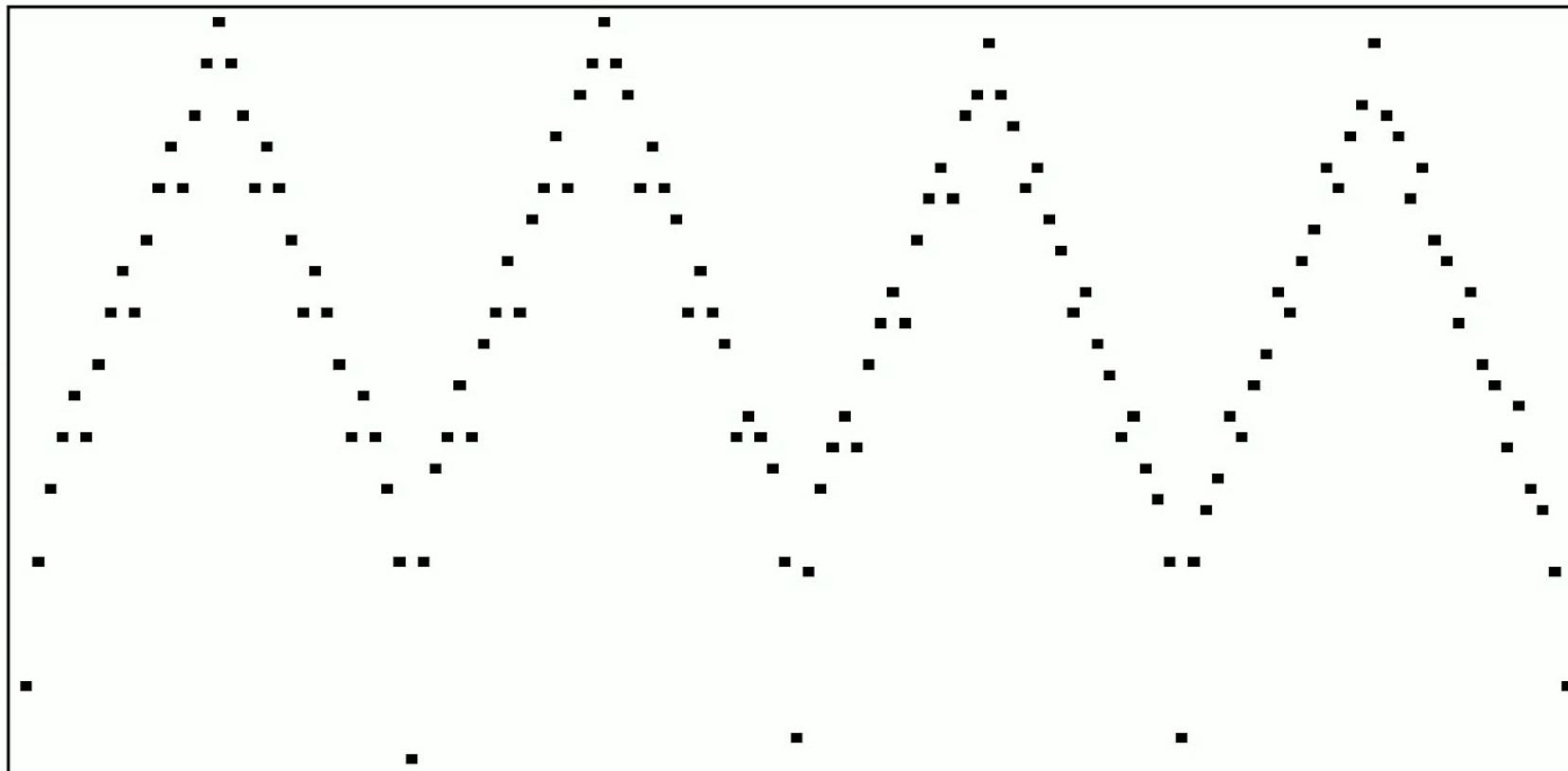
Melodic Contour =



Pattern =

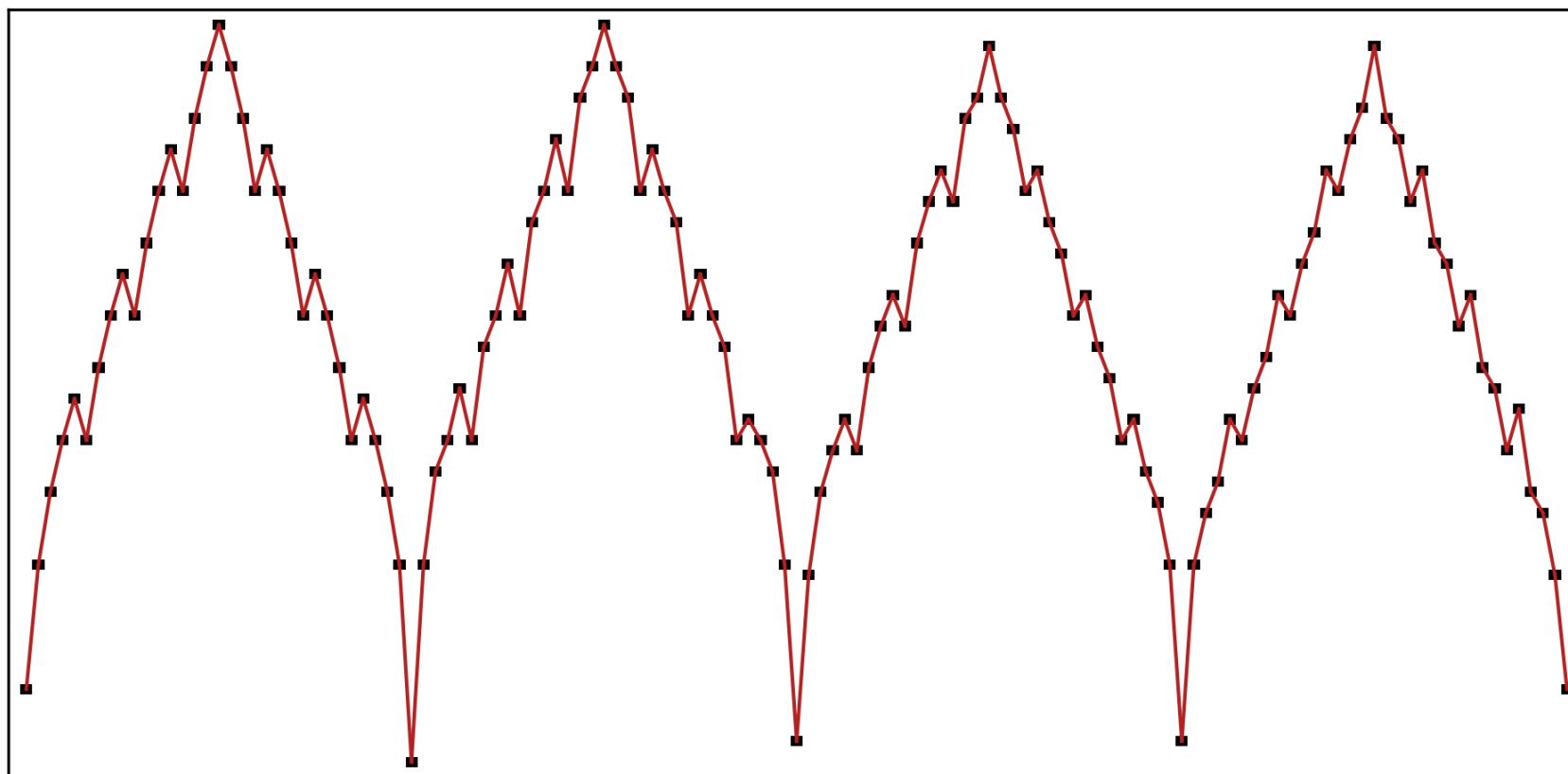


The Melodic Contour

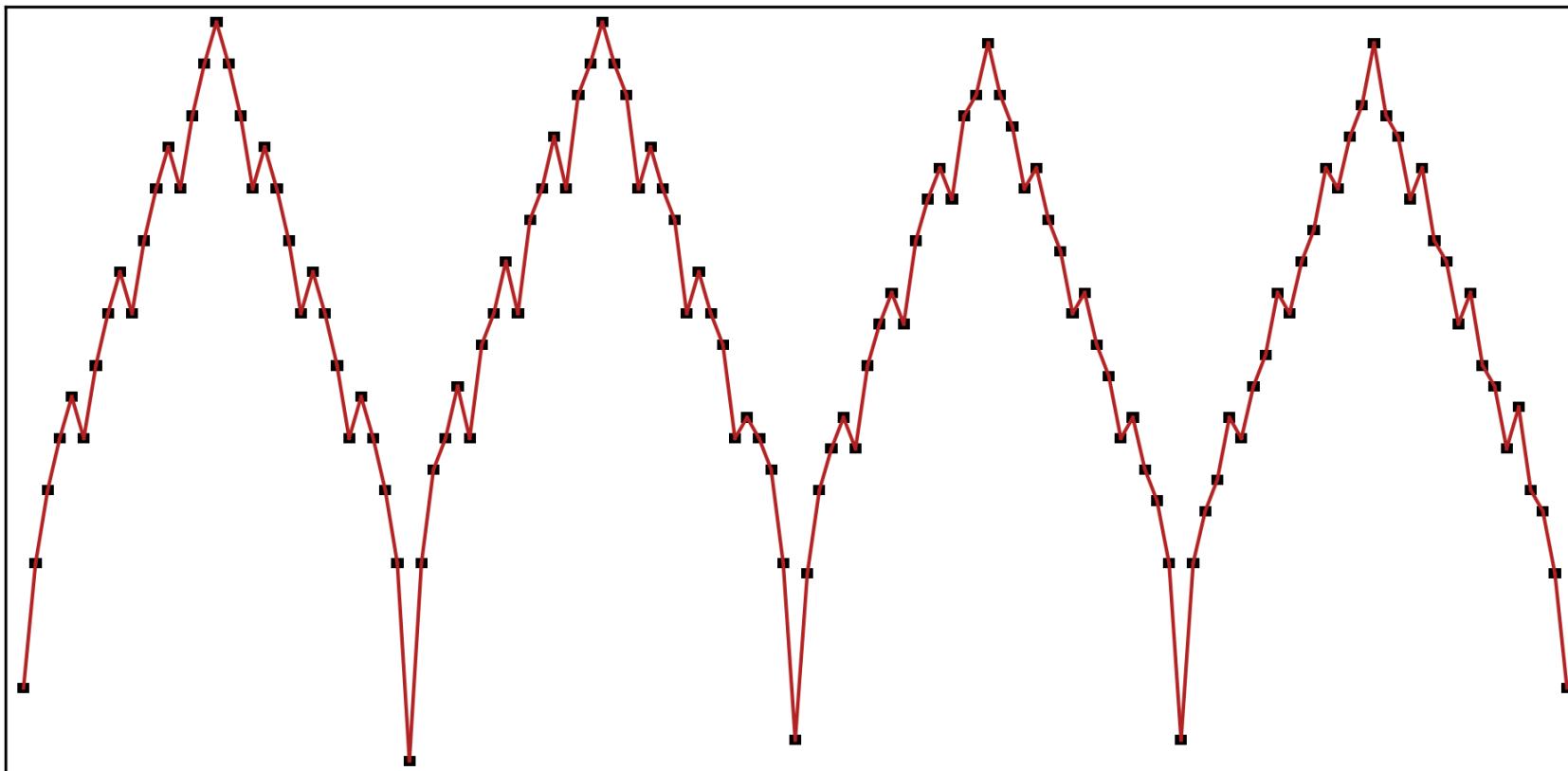


Chopin's Étude Op. 10, No. 1

The Melodic Contour

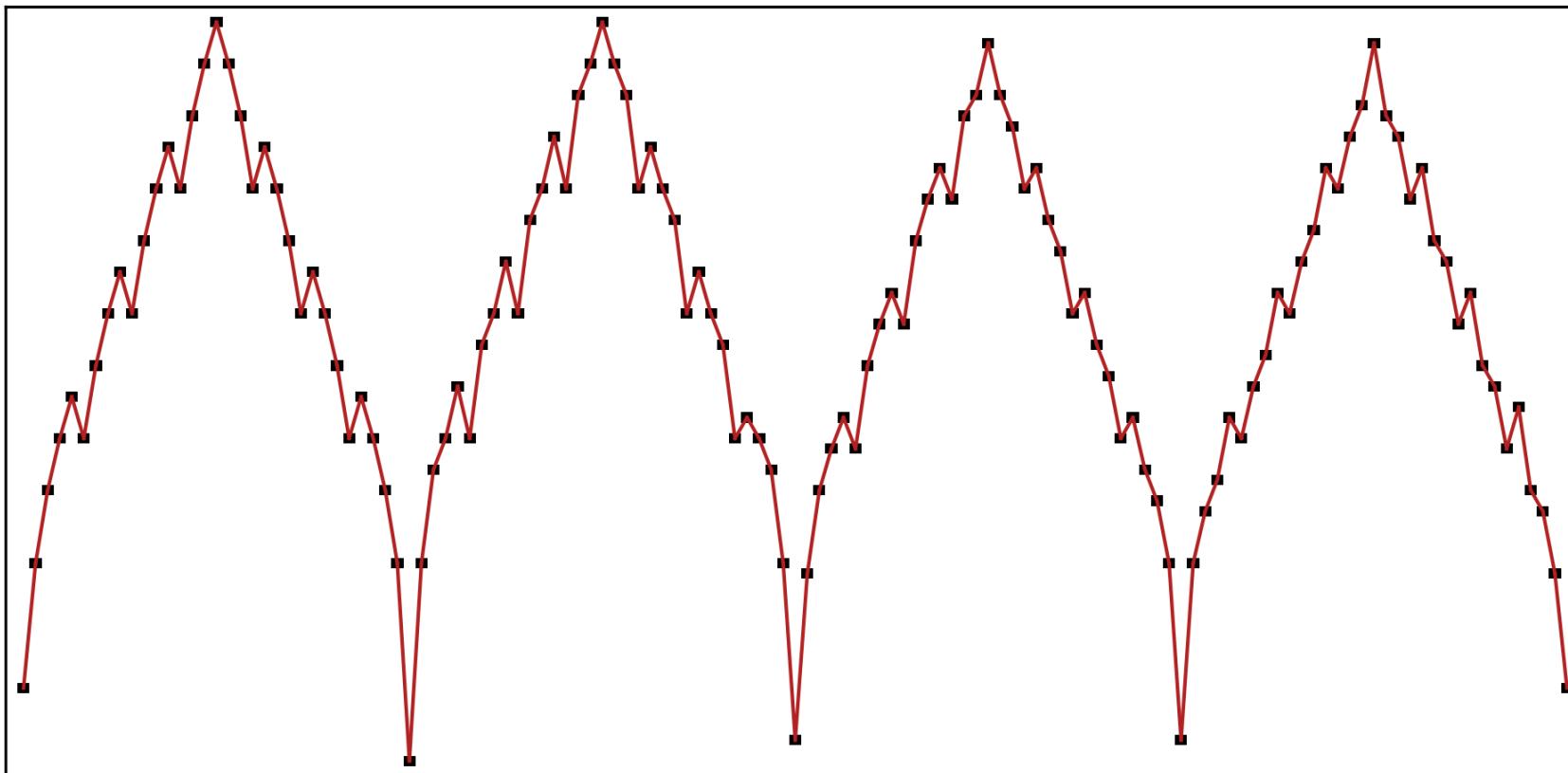


The Melodic Contour

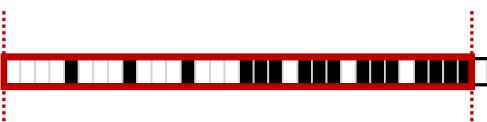


Melodic Contour =

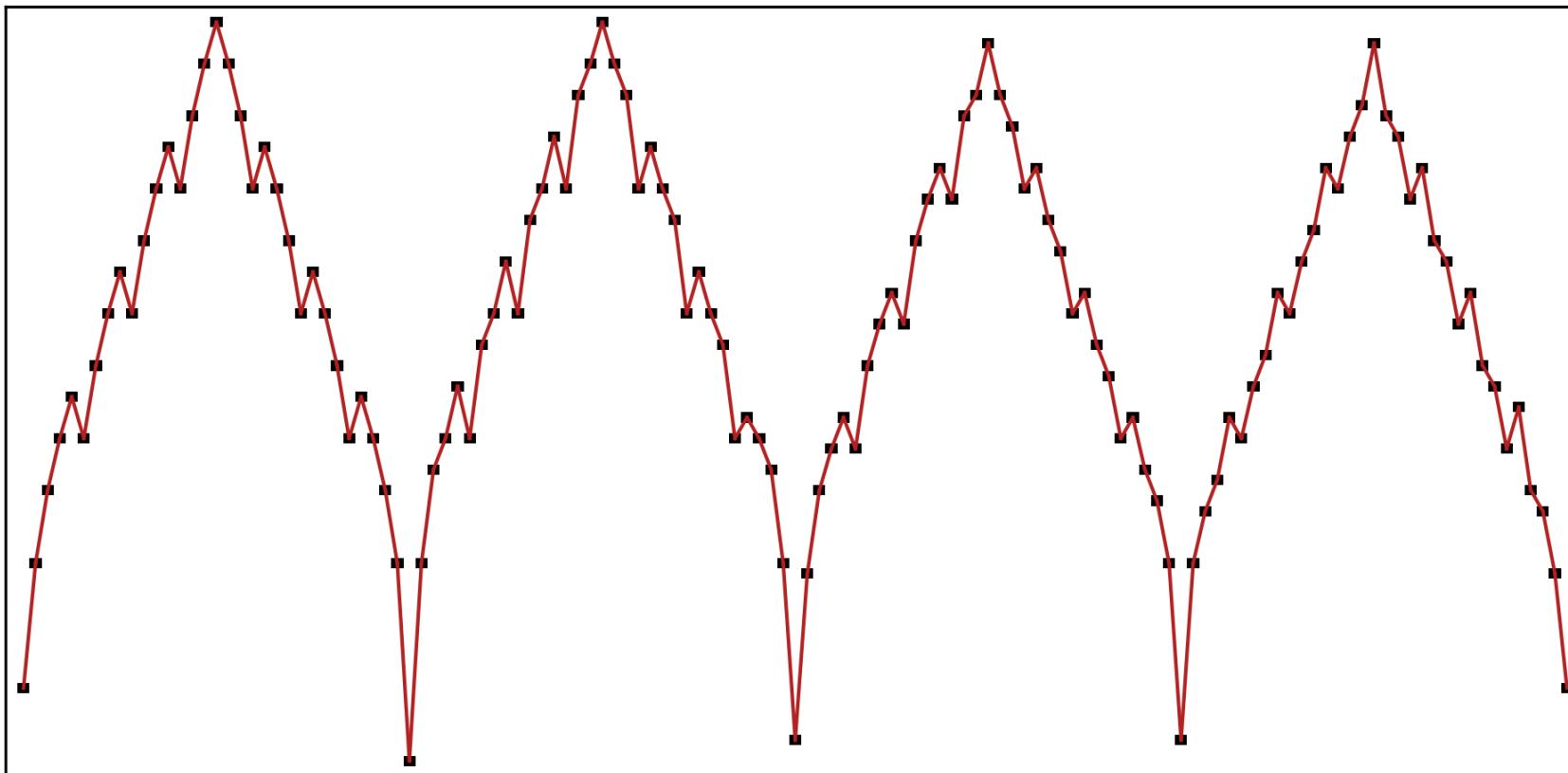
The Melodic Contour



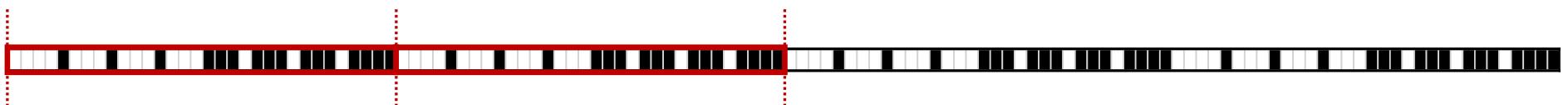
Melodic Contour =



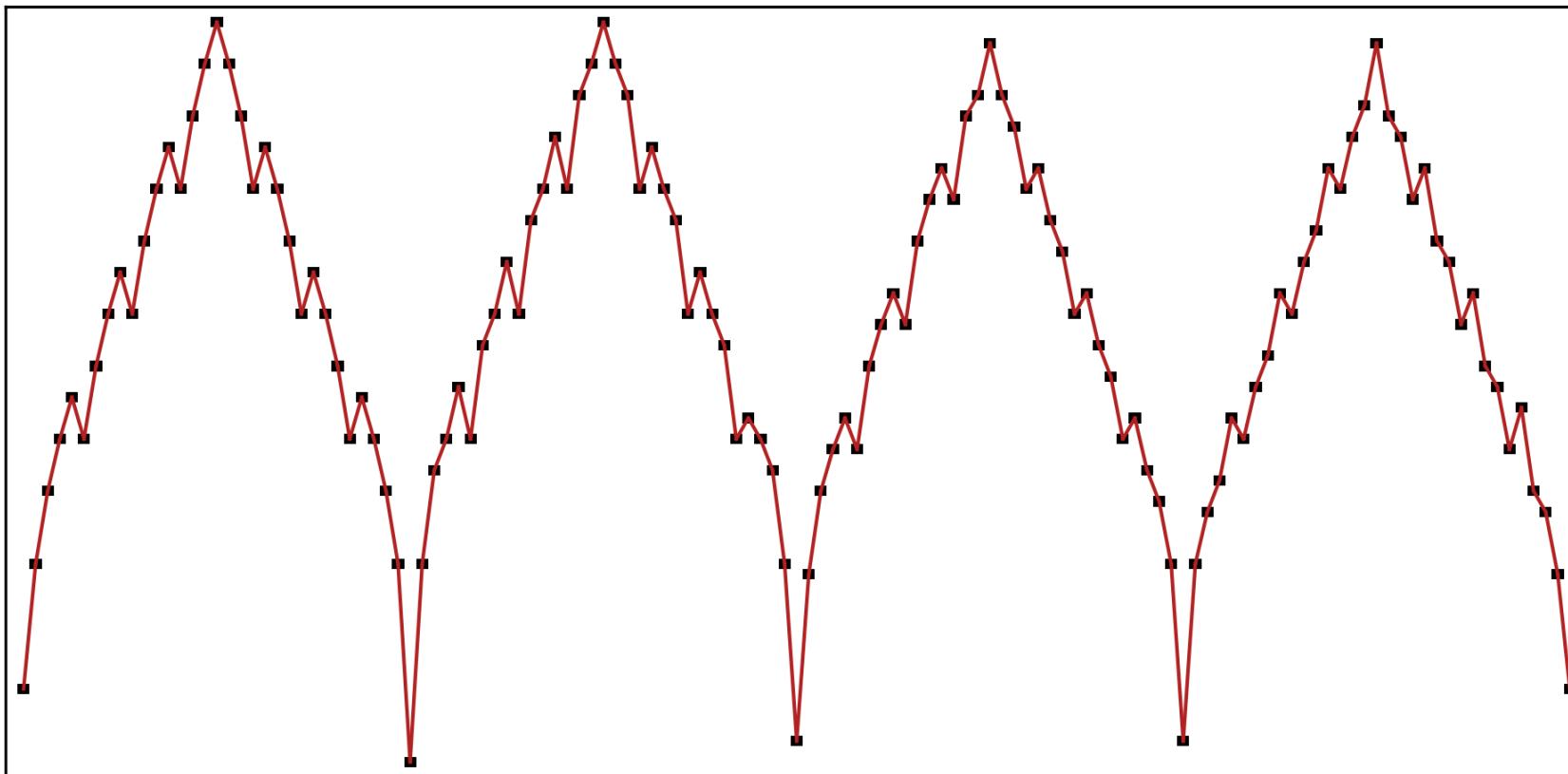
The Melodic Contour



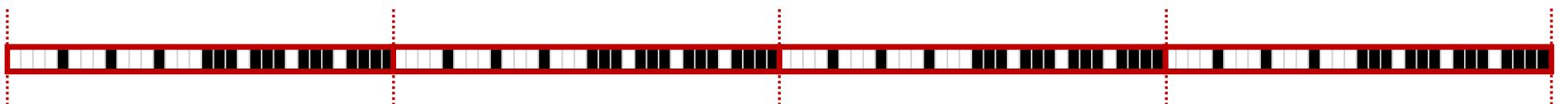
Melodic Contour =



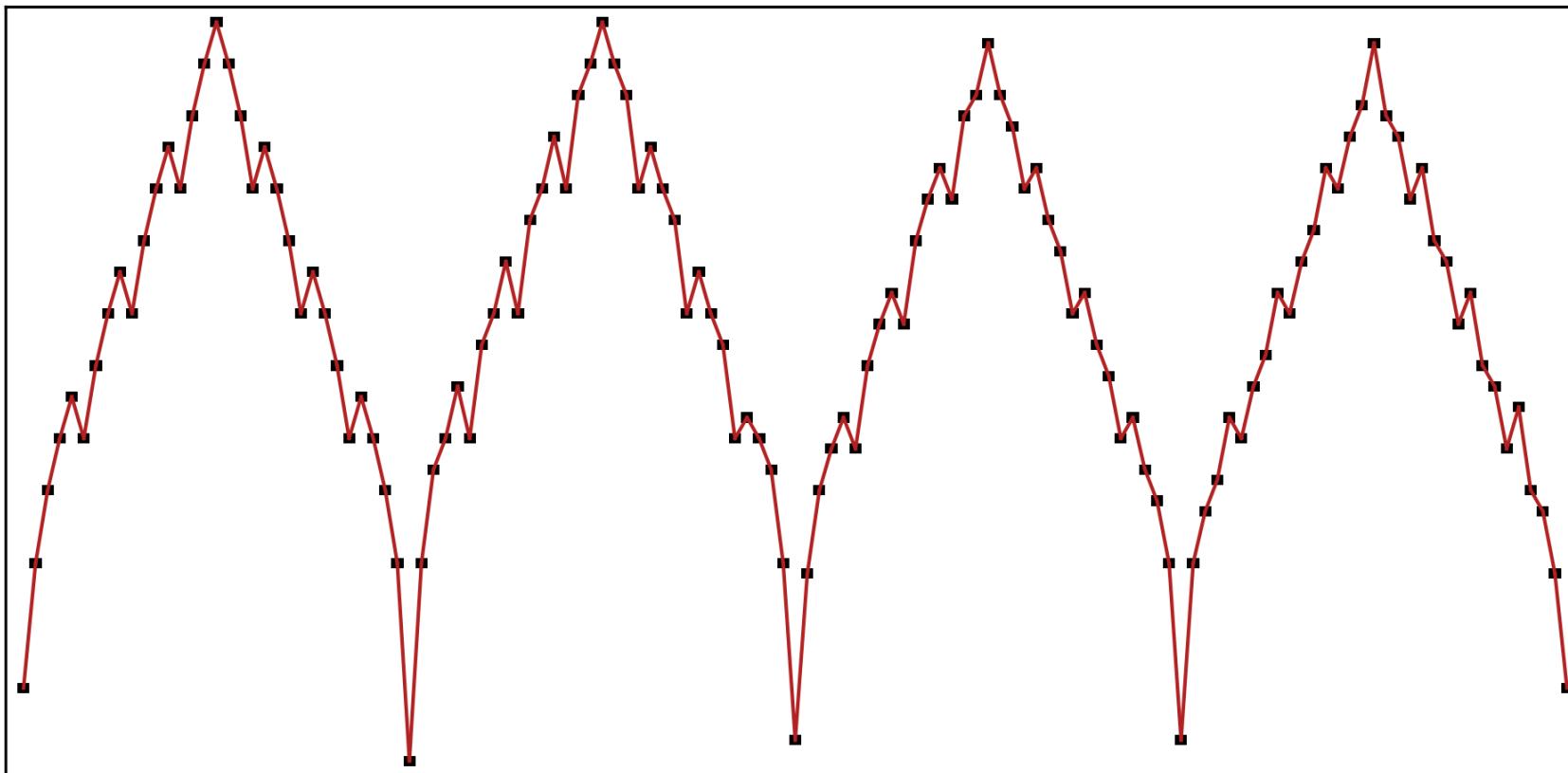
The Melodic Contour



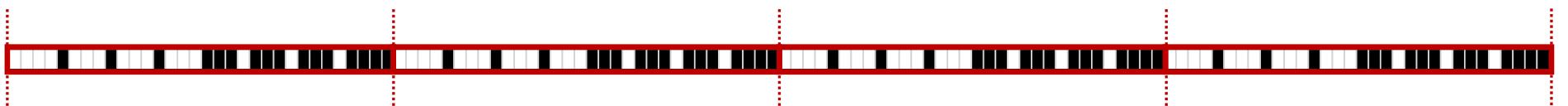
Melodic Contour =



The Melodic Contour



Melodic Contour =



Pattern =



.Question

.Question

Can we do the same with more
than just monophonic voice ?

The Chord Contour

Melodic Contour: direction of the pitch variation between two **notes**.

The Chord Contour

Melodic Contour: direction of the pitch variation between two **notes**.



A NUMBER!

The Chord Contour

Melodic Contour: direction of the pitch variation between two **notes**.

Chord Contour: direction of the pitch variations between two **chords**.



A **NUMBER!**

The Chord Contour

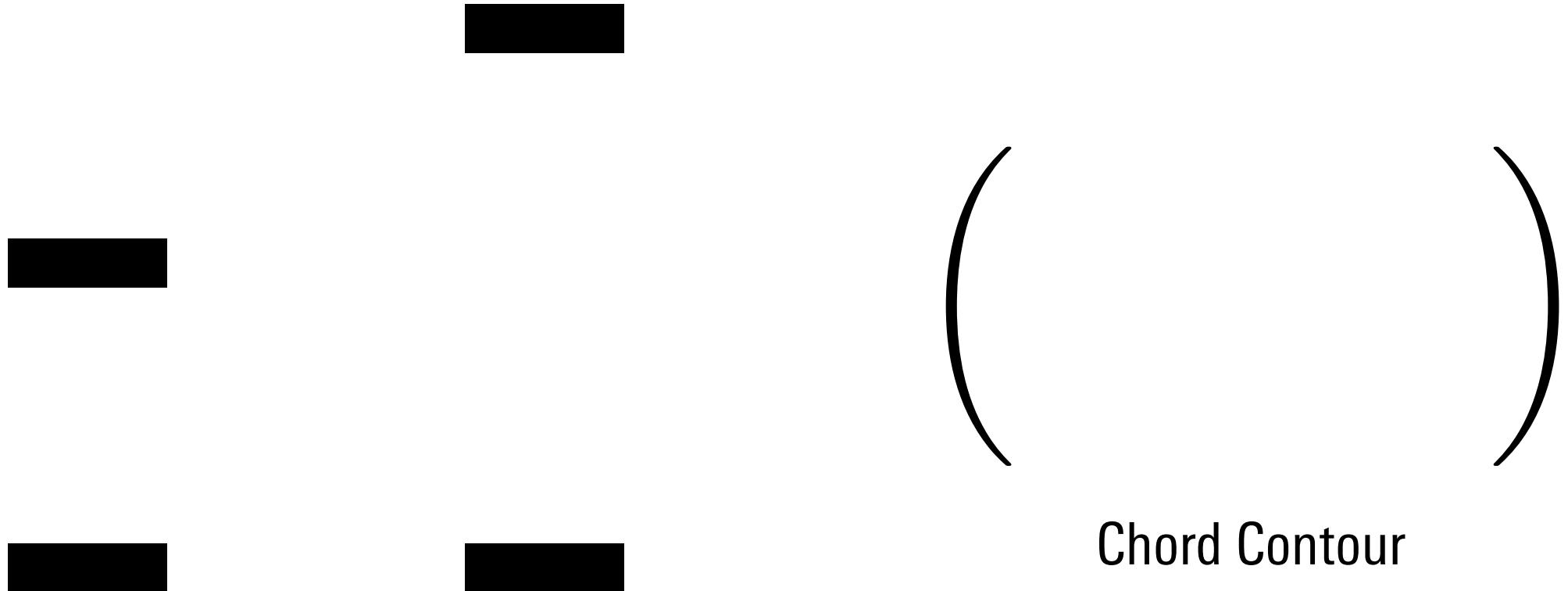
Melodic Contour: direction of the pitch variation between two **notes**.

Chord Contour: direction of the pitch variations between two **chords**.

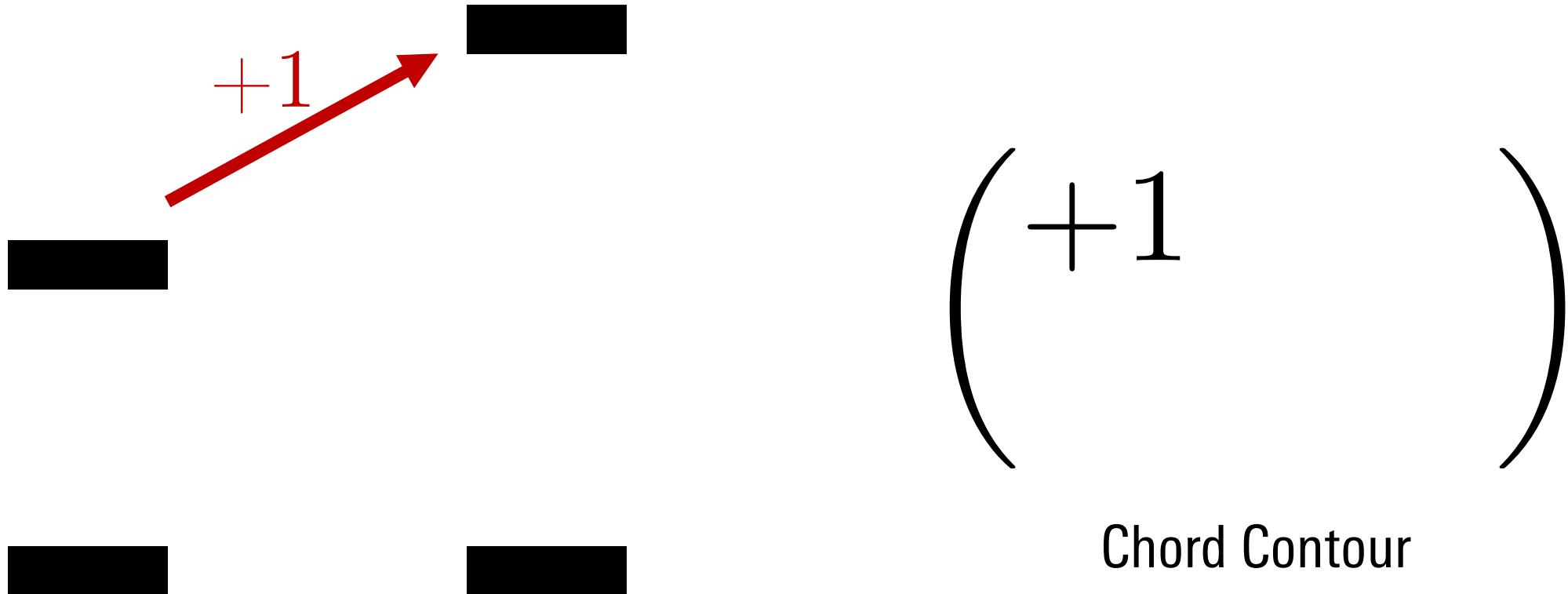
A **NUMBER!**

A **MATRIX!**

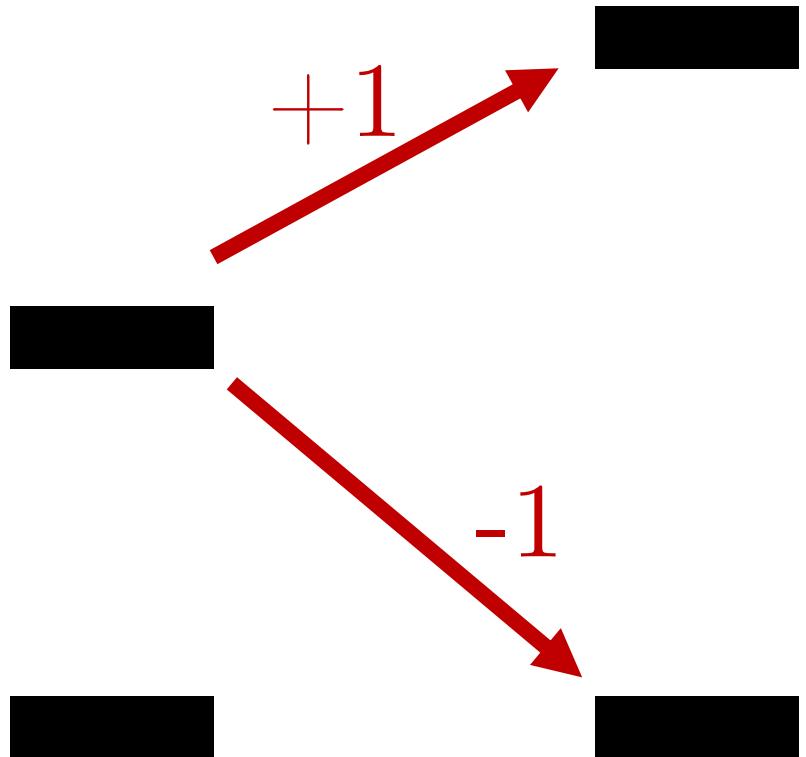
The Chord Contour



The Chord Contour



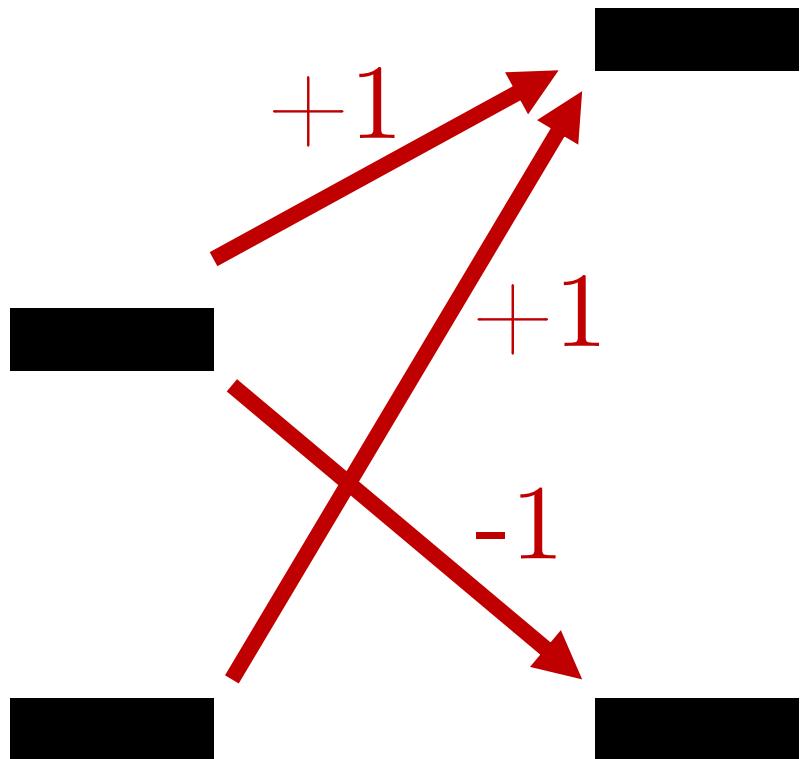
The Chord Contour



$$\begin{pmatrix} +1 & -1 \end{pmatrix}$$

Chord Contour

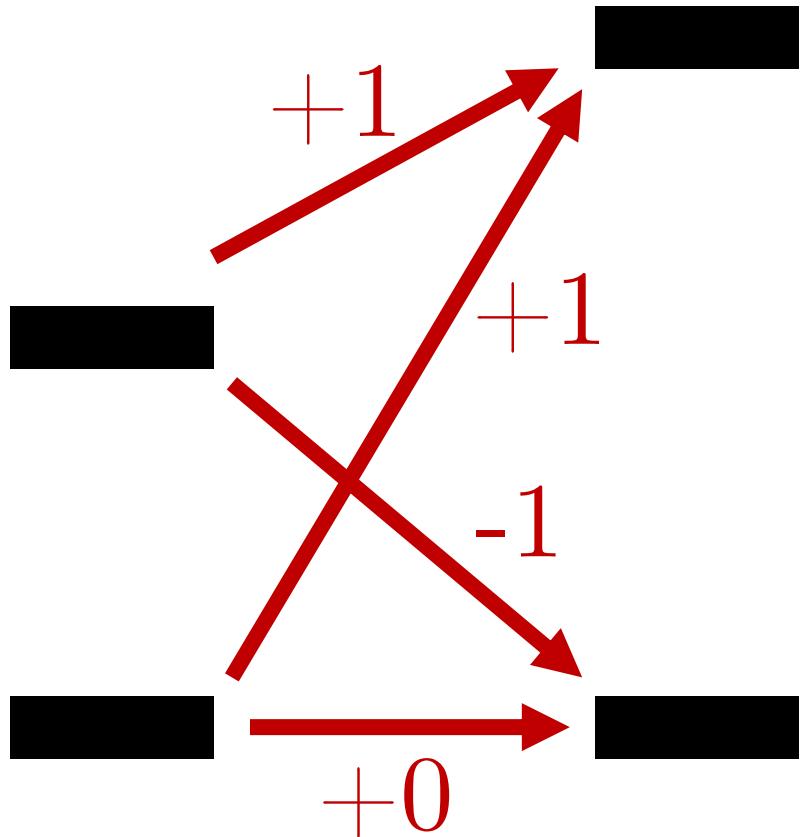
The Chord Contour



$$\begin{pmatrix} +1 & -1 \\ +1 & \end{pmatrix}$$

Chord Contour

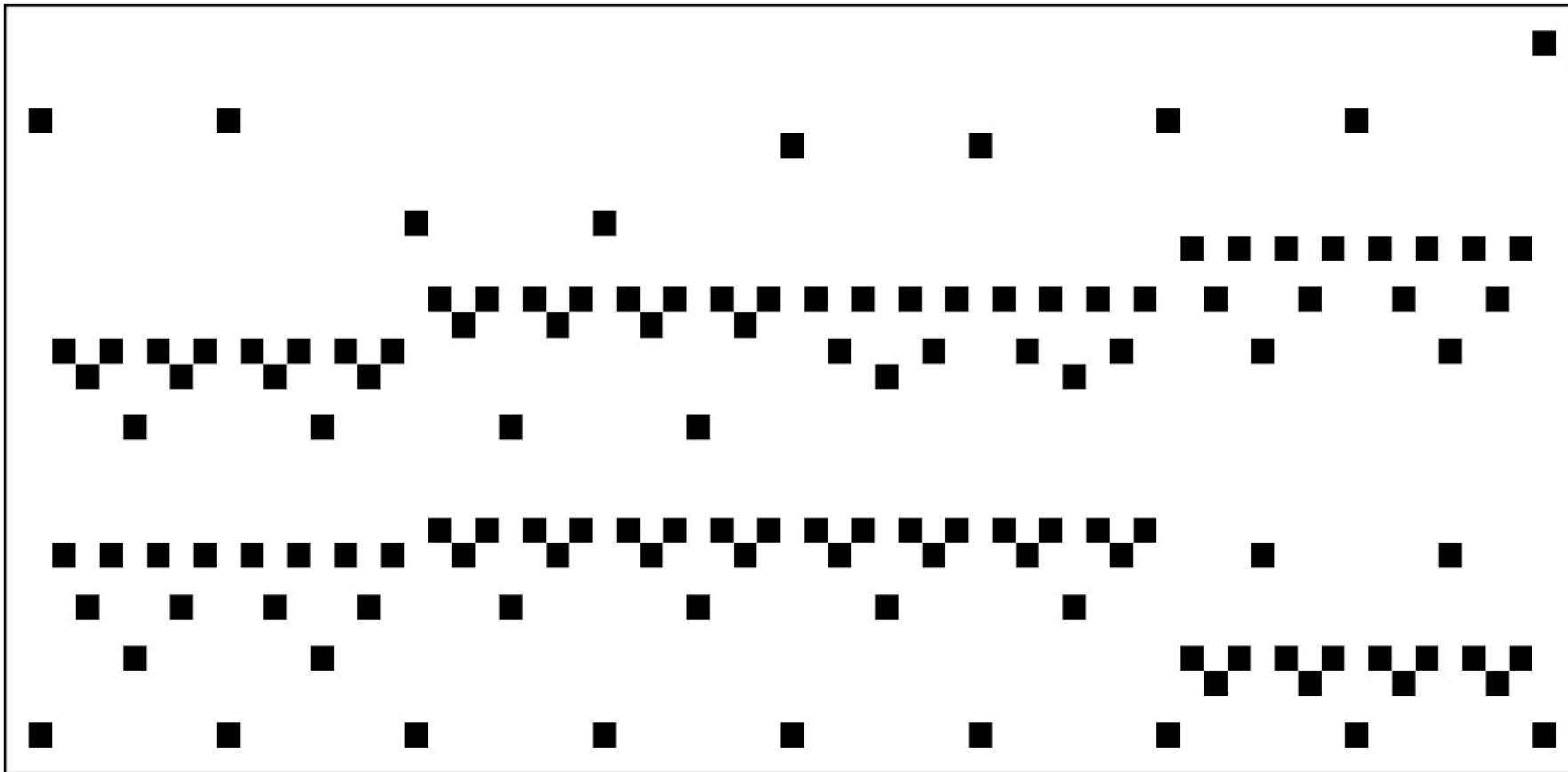
The Chord Contour



$$\begin{pmatrix} +1 & -1 \\ +1 & +0 \end{pmatrix}$$

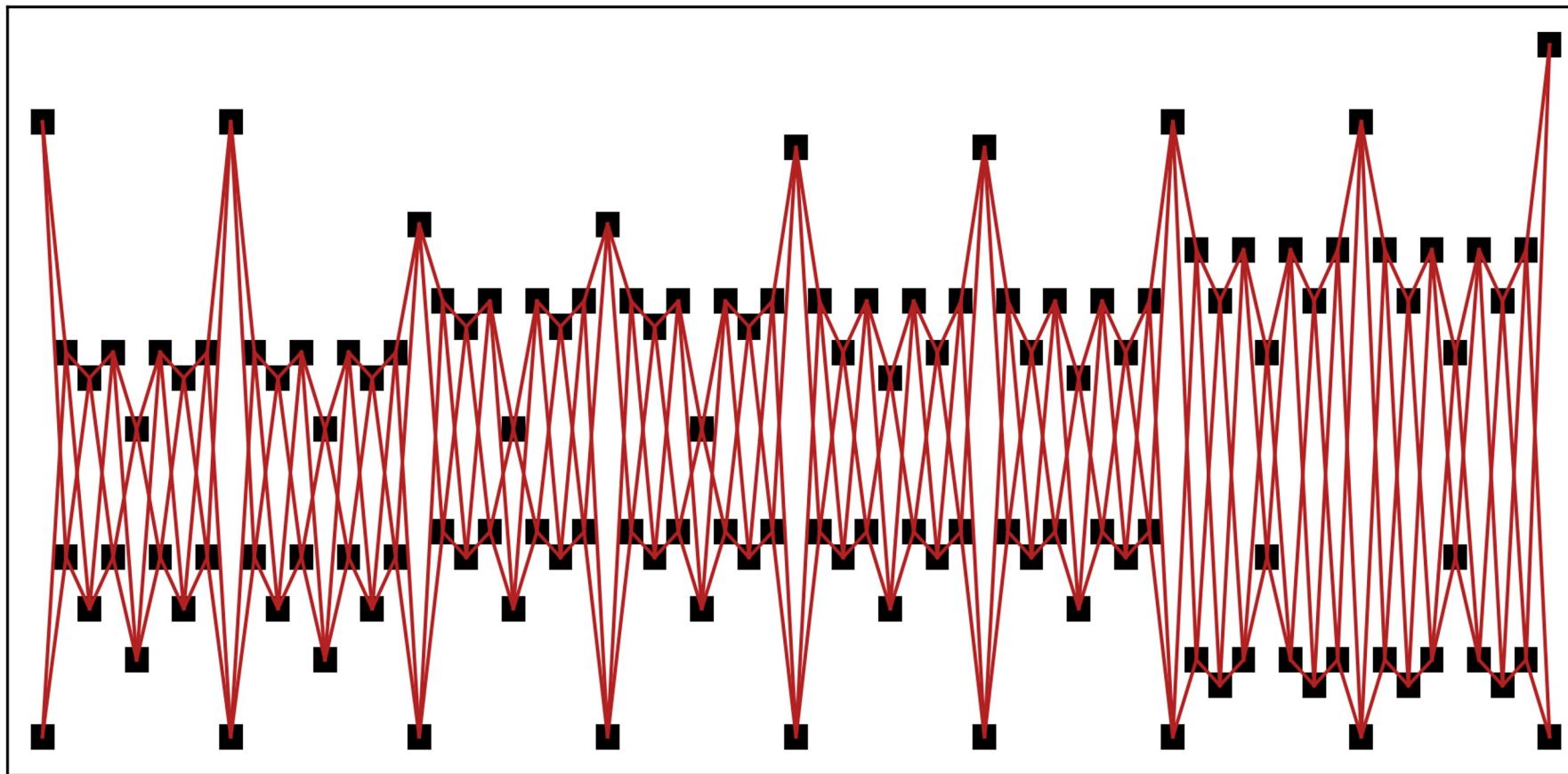
Chord Contour

The Chord Contour

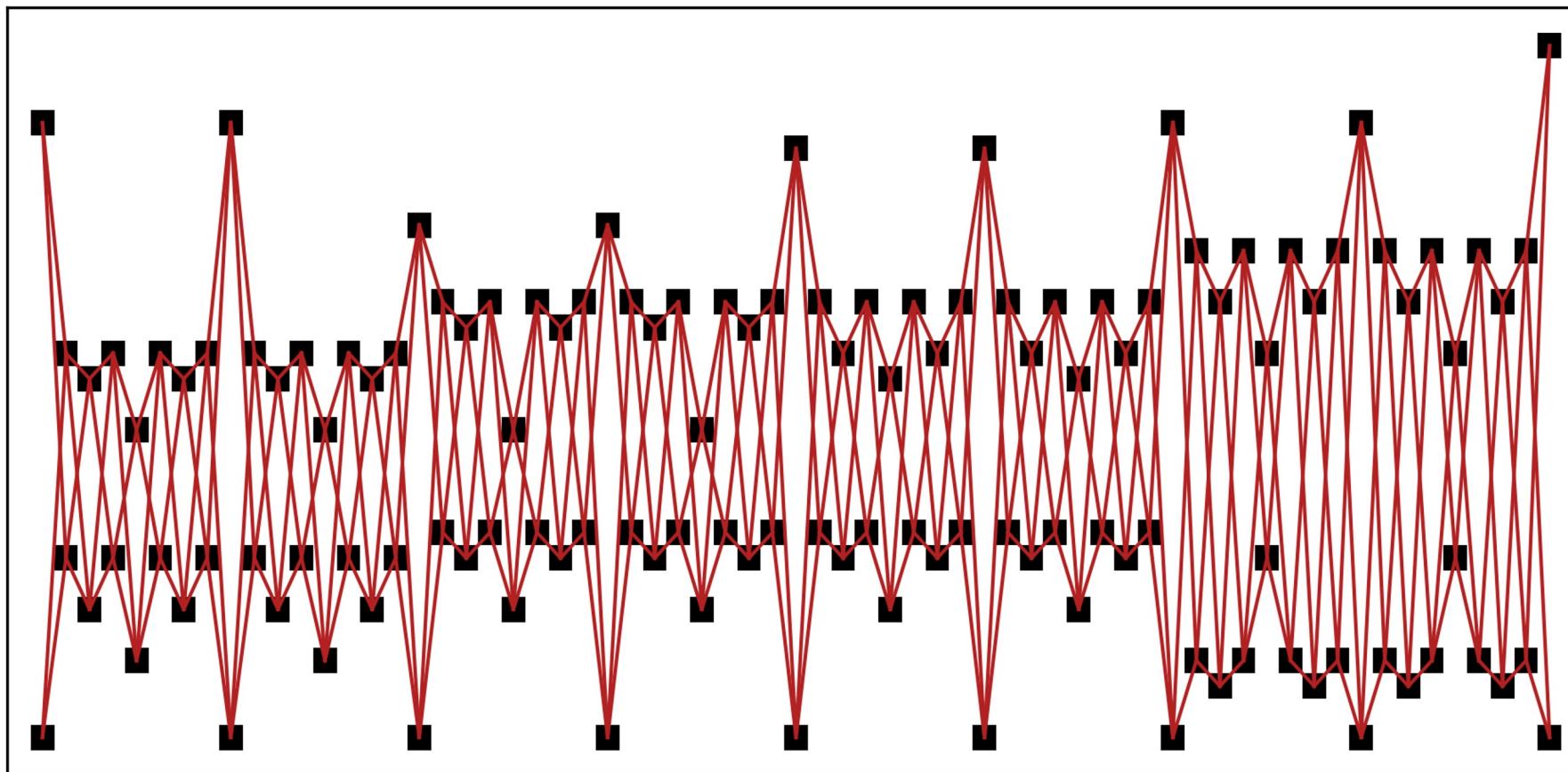


Bach's Prelude in C Minor, BWV 847

The Chord Contour

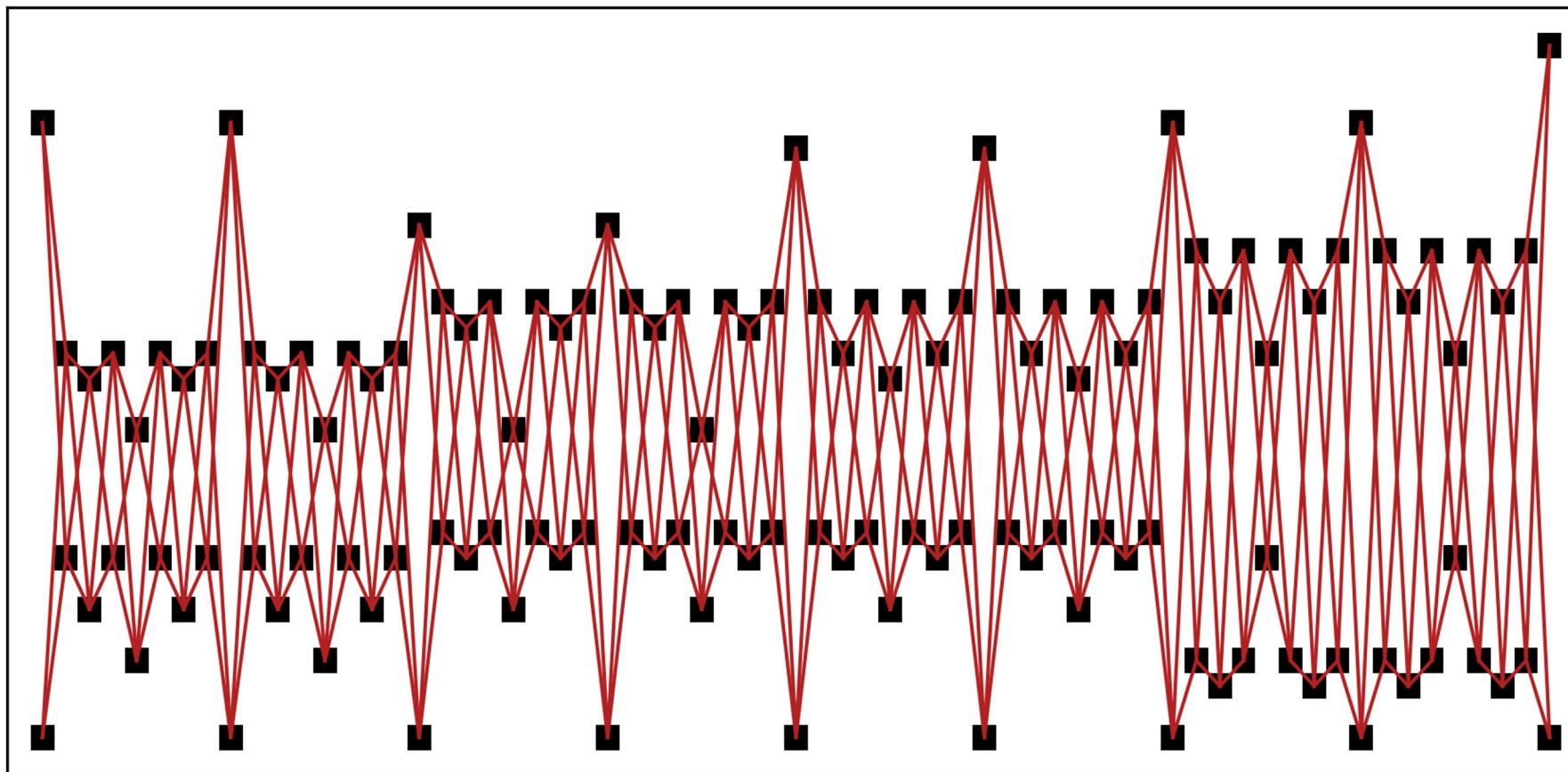


The Chord Contour



Chord Contour = 

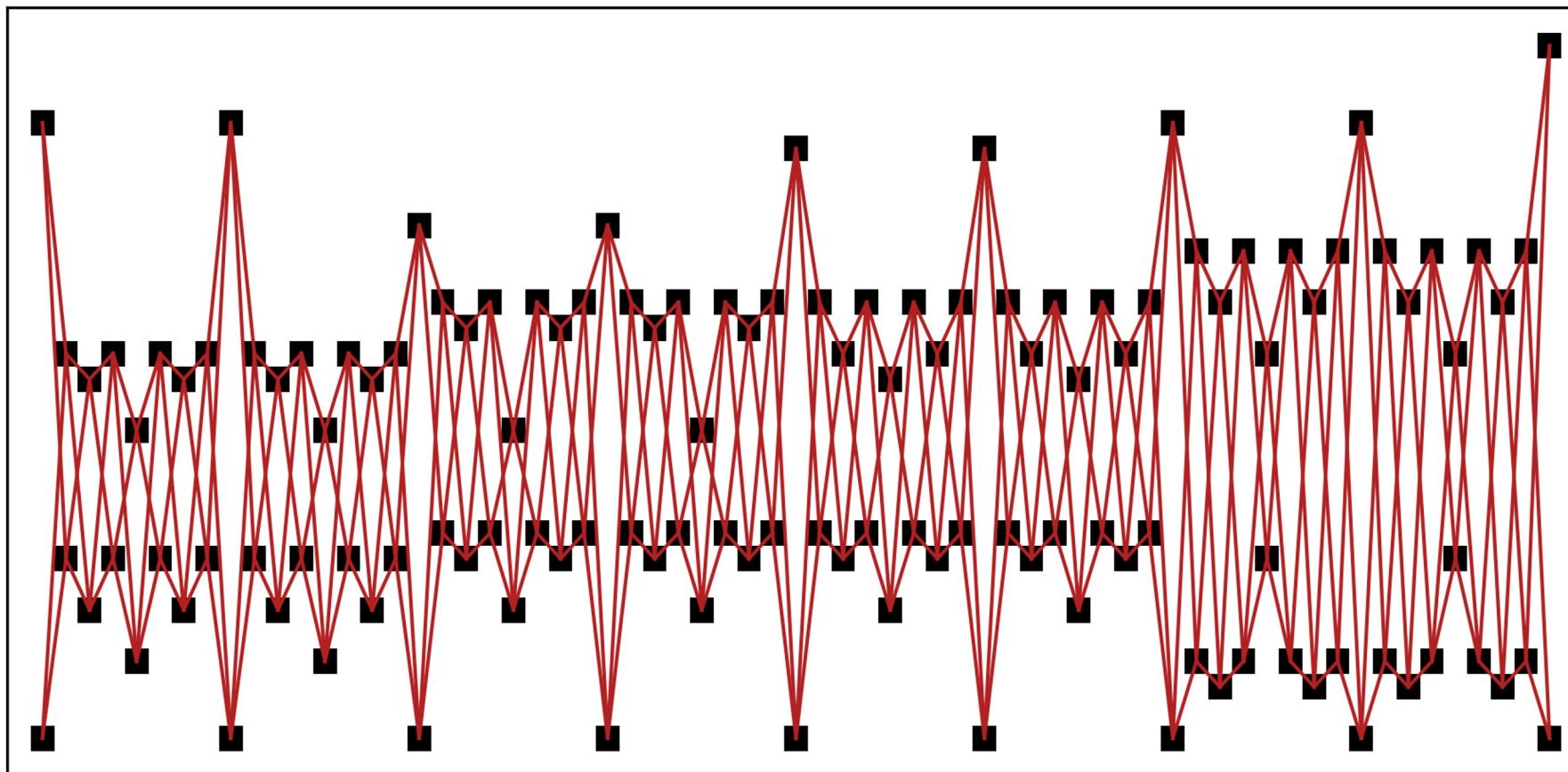
The Chord Contour



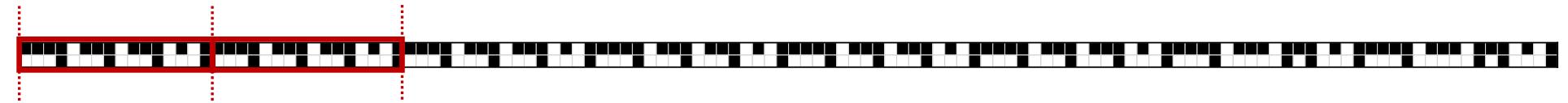
Chord Contour =



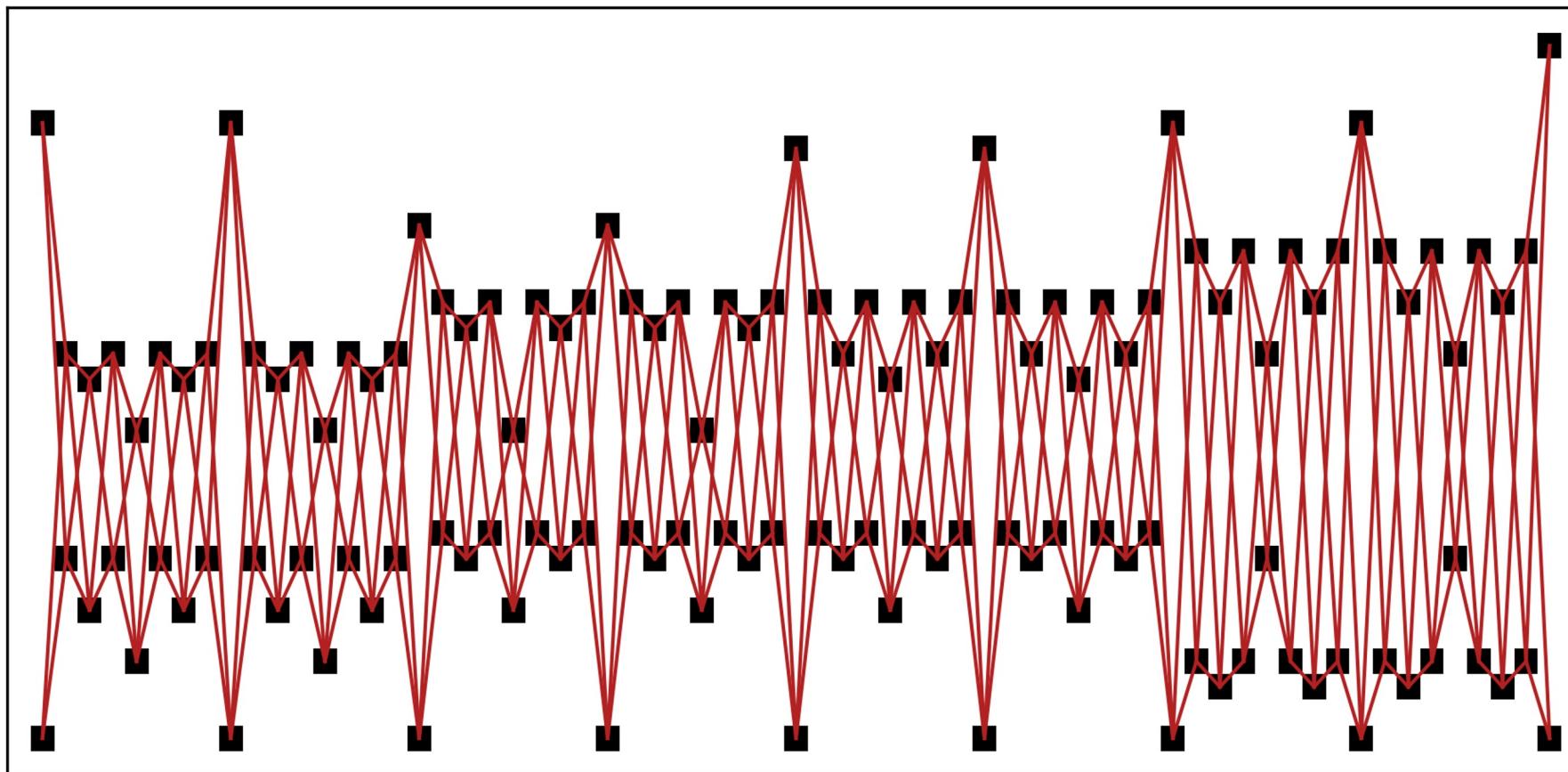
The Chord Contour



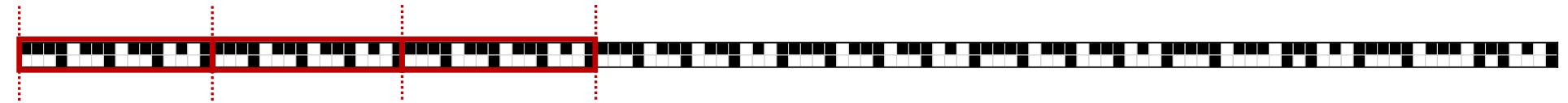
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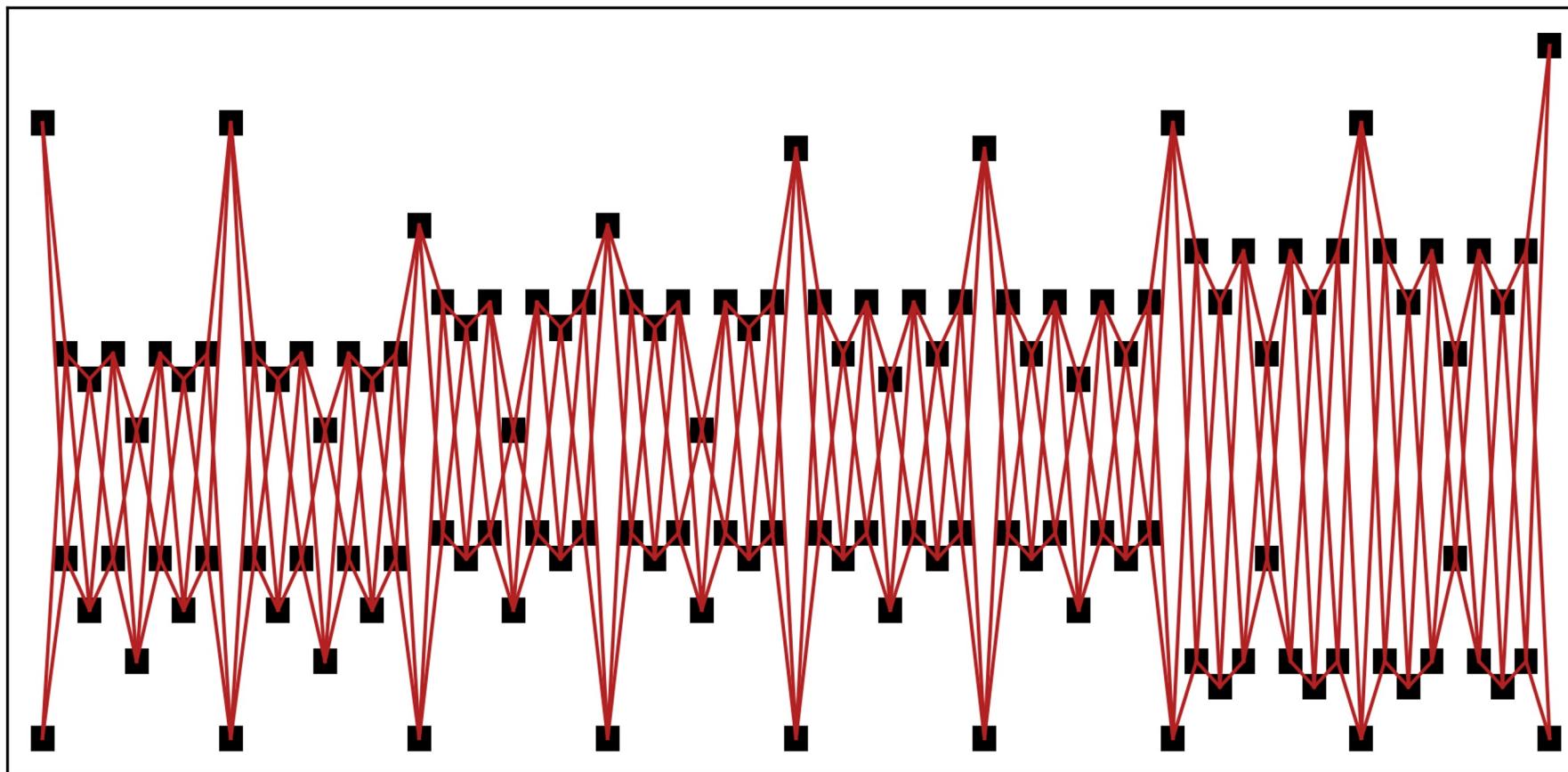
The Chord Contour



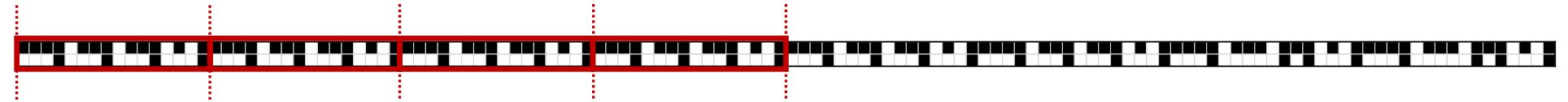
Chord Contour =



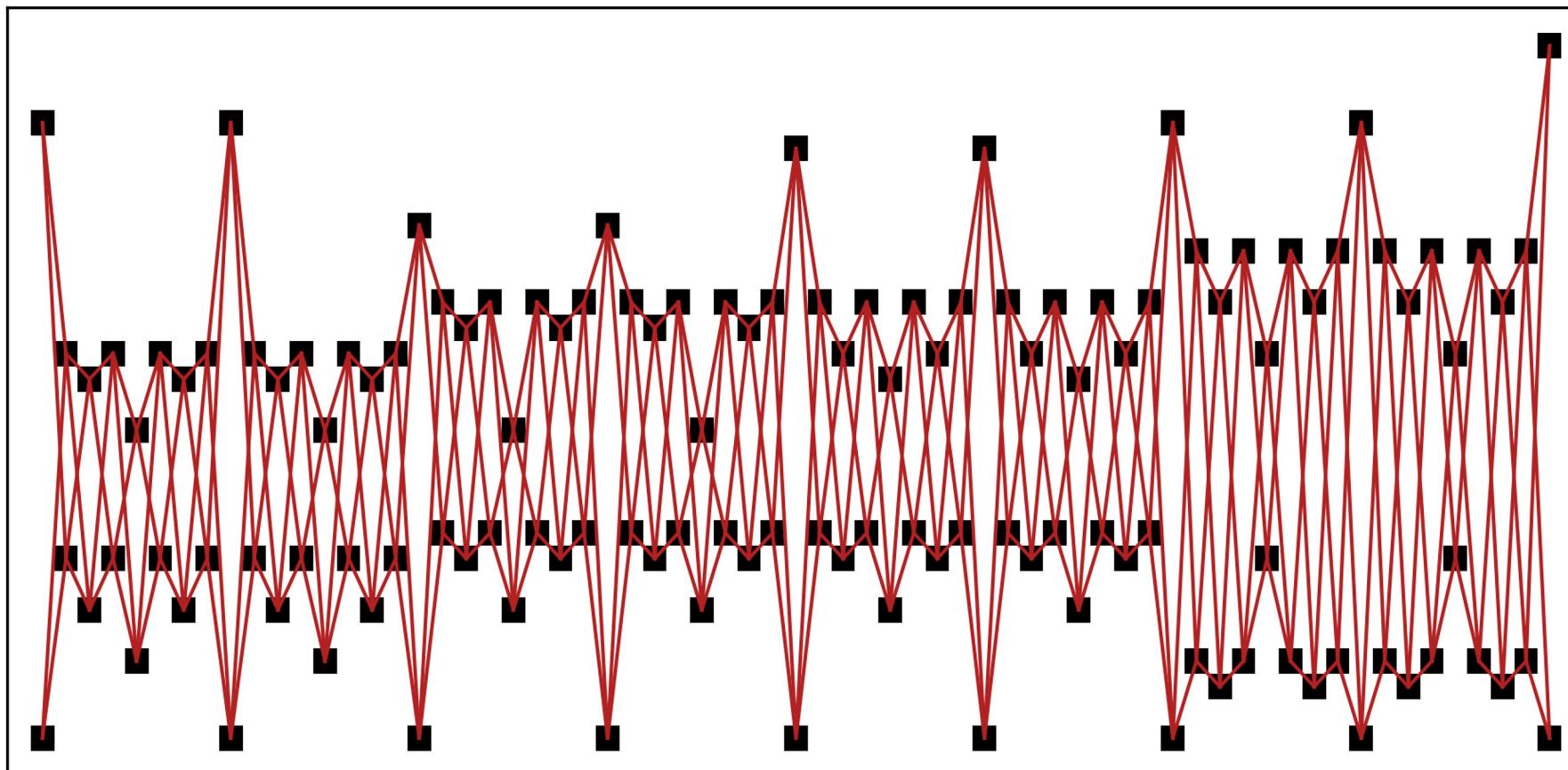
The Chord Contour



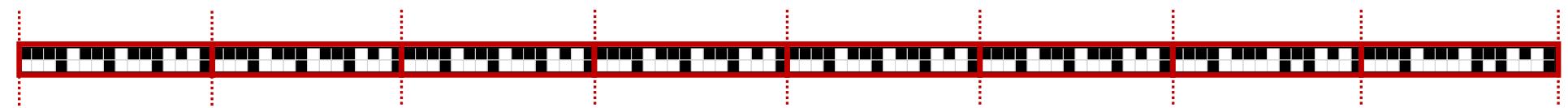
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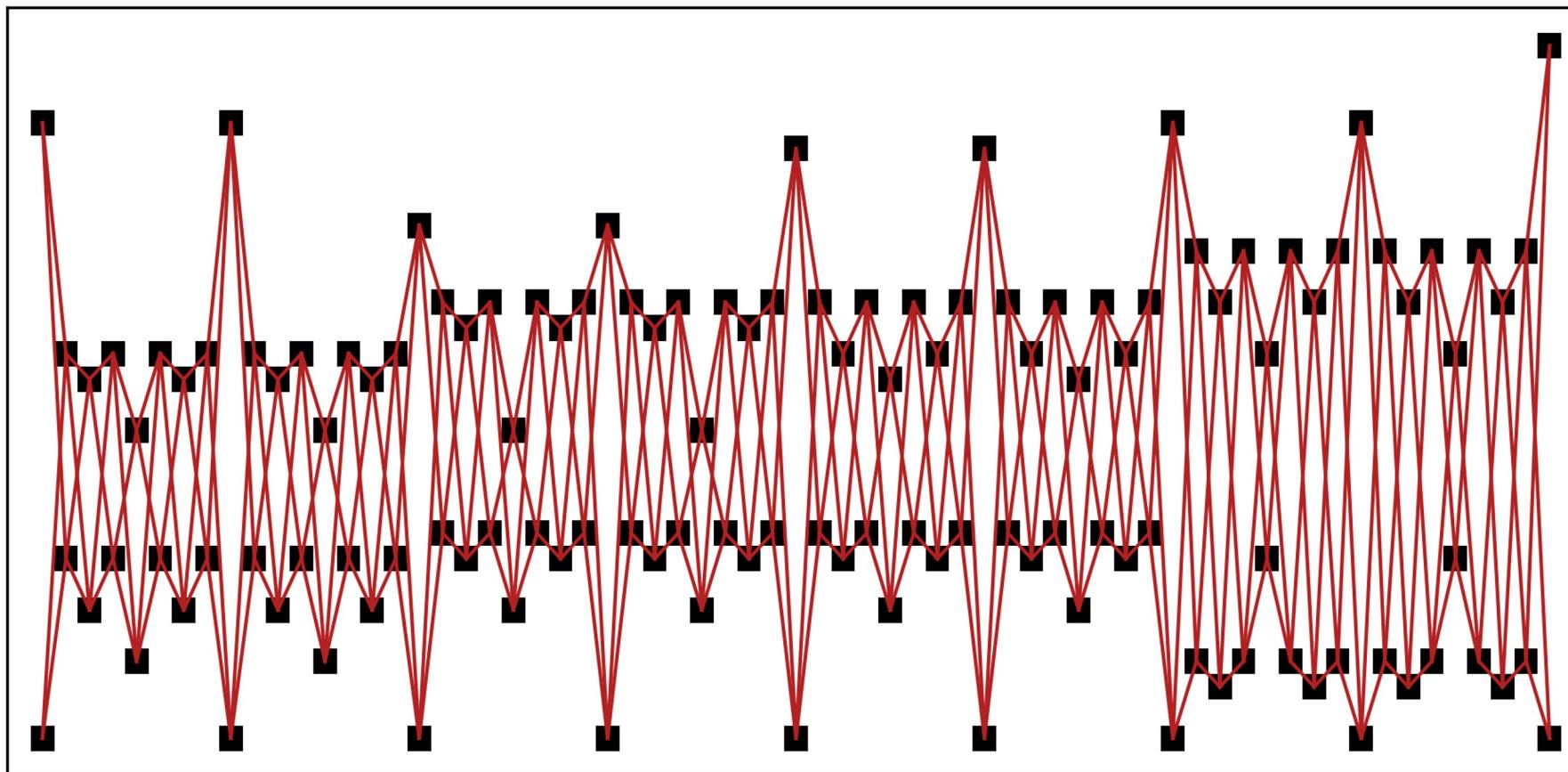
The Chord Contour



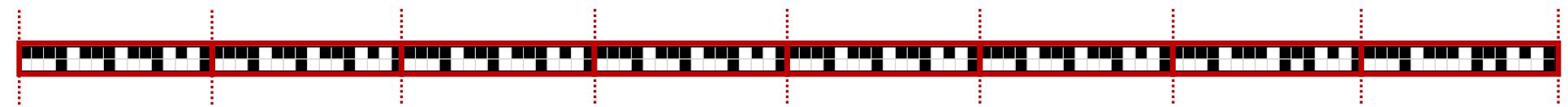
Chord Contour =



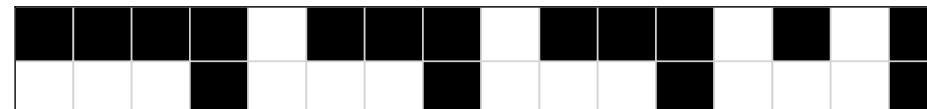
The Chord Contour



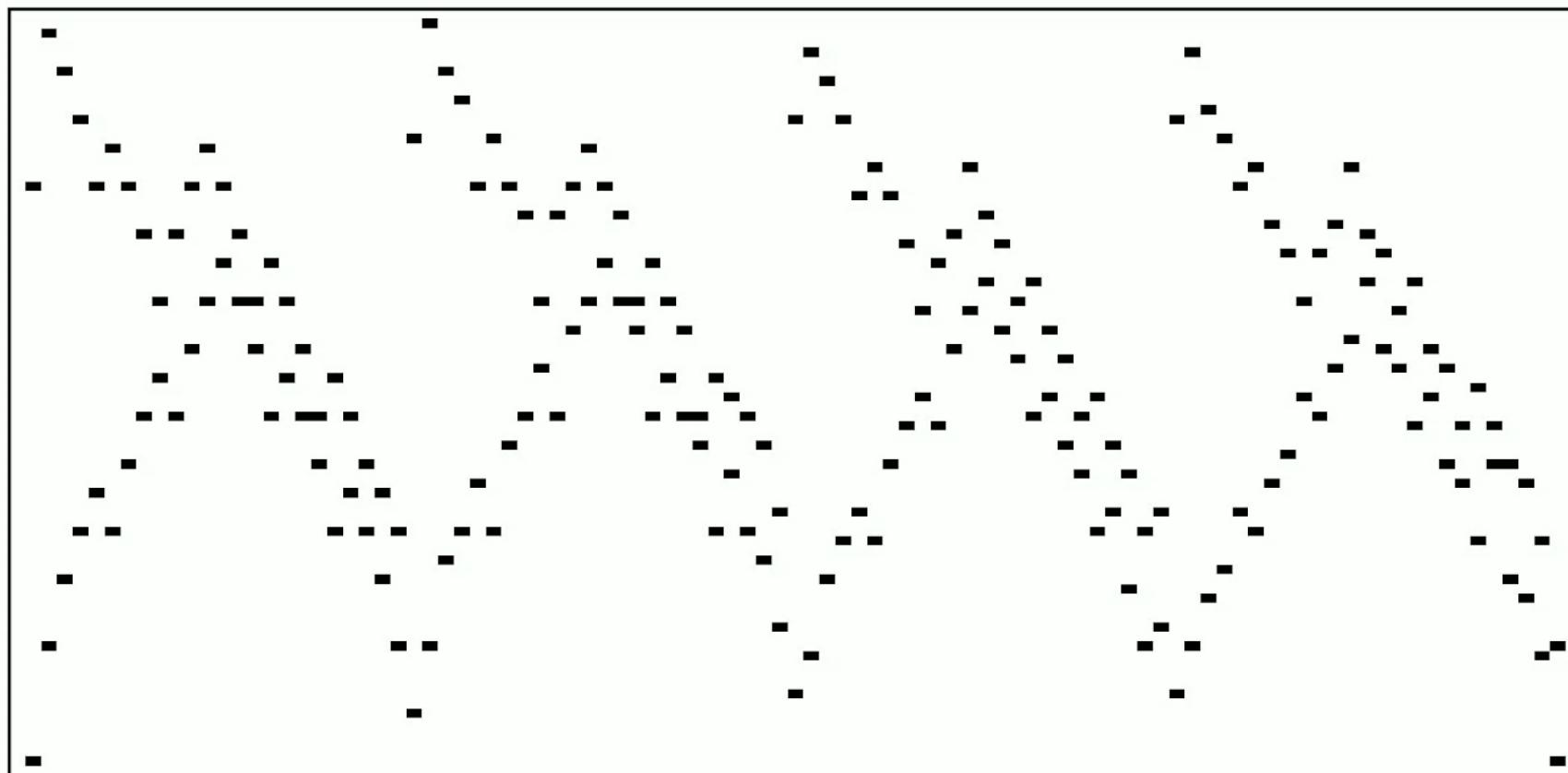
Chord Contour =



Pattern =

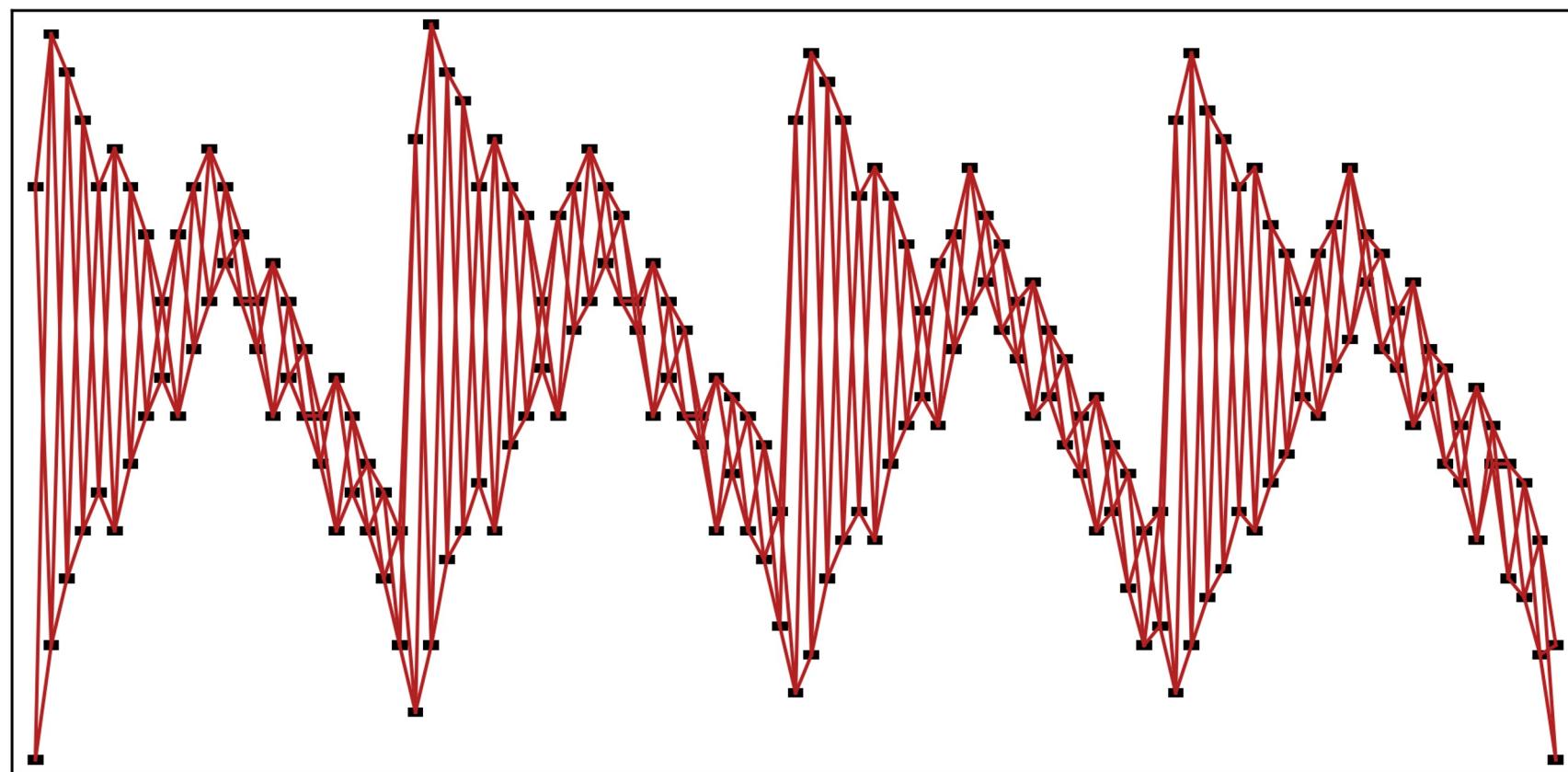


The Chord Contour

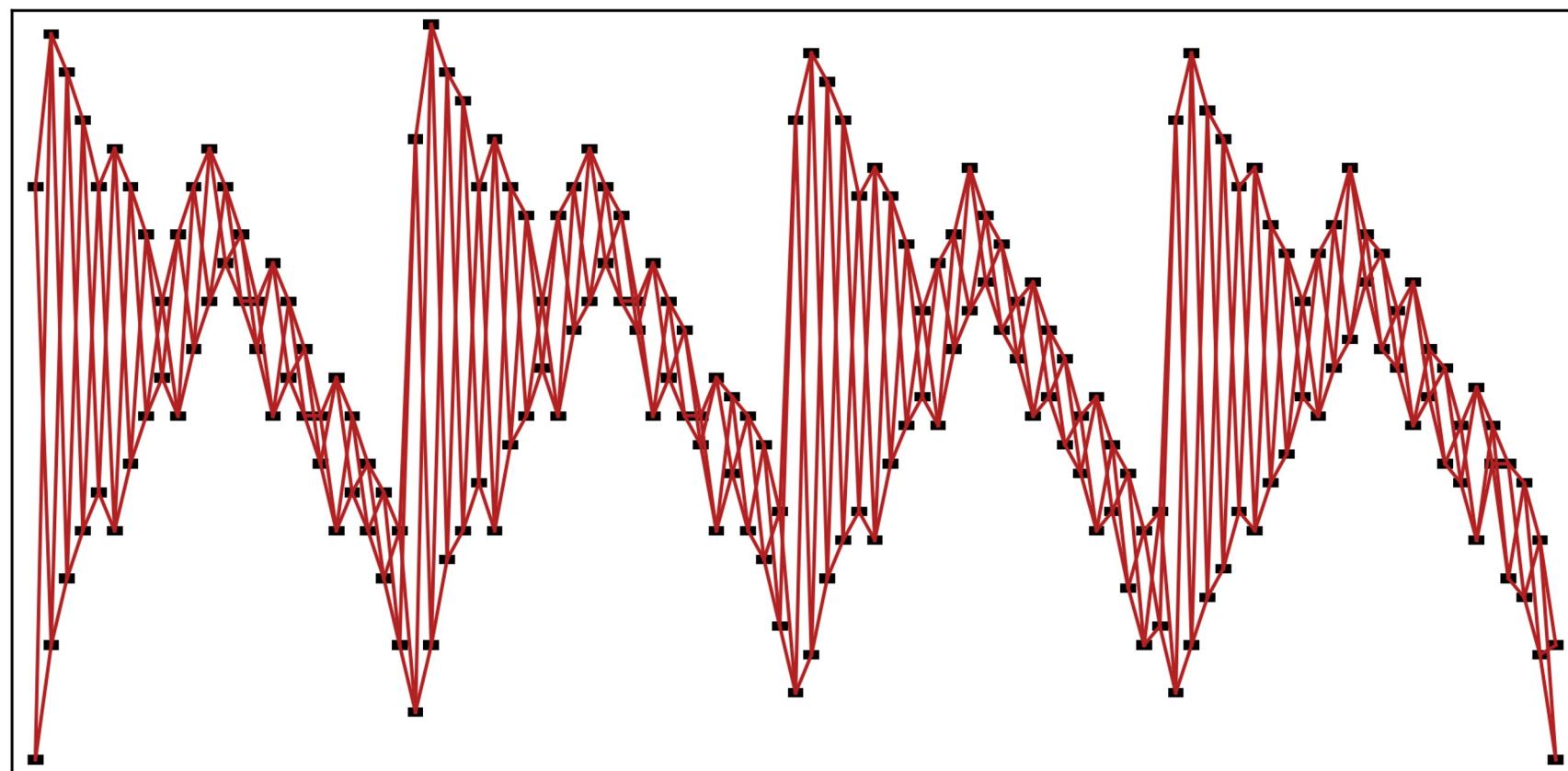


Godowsky's arrangement Op. 10 No. 1.

The Chord Contour

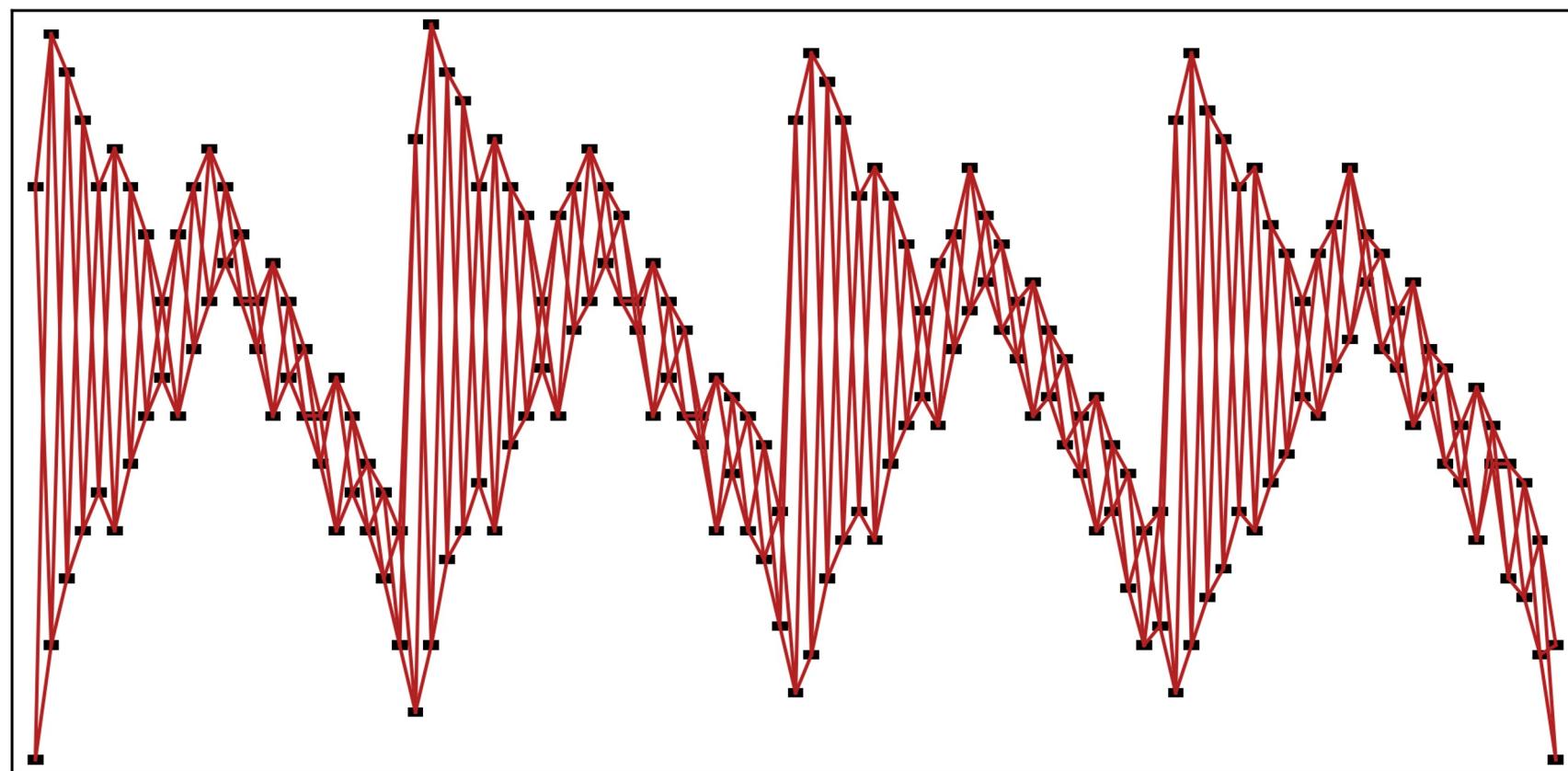


The Chord Contour

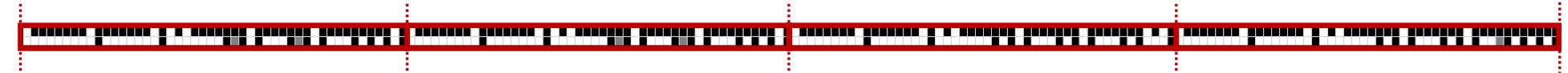


Chord Contour = 

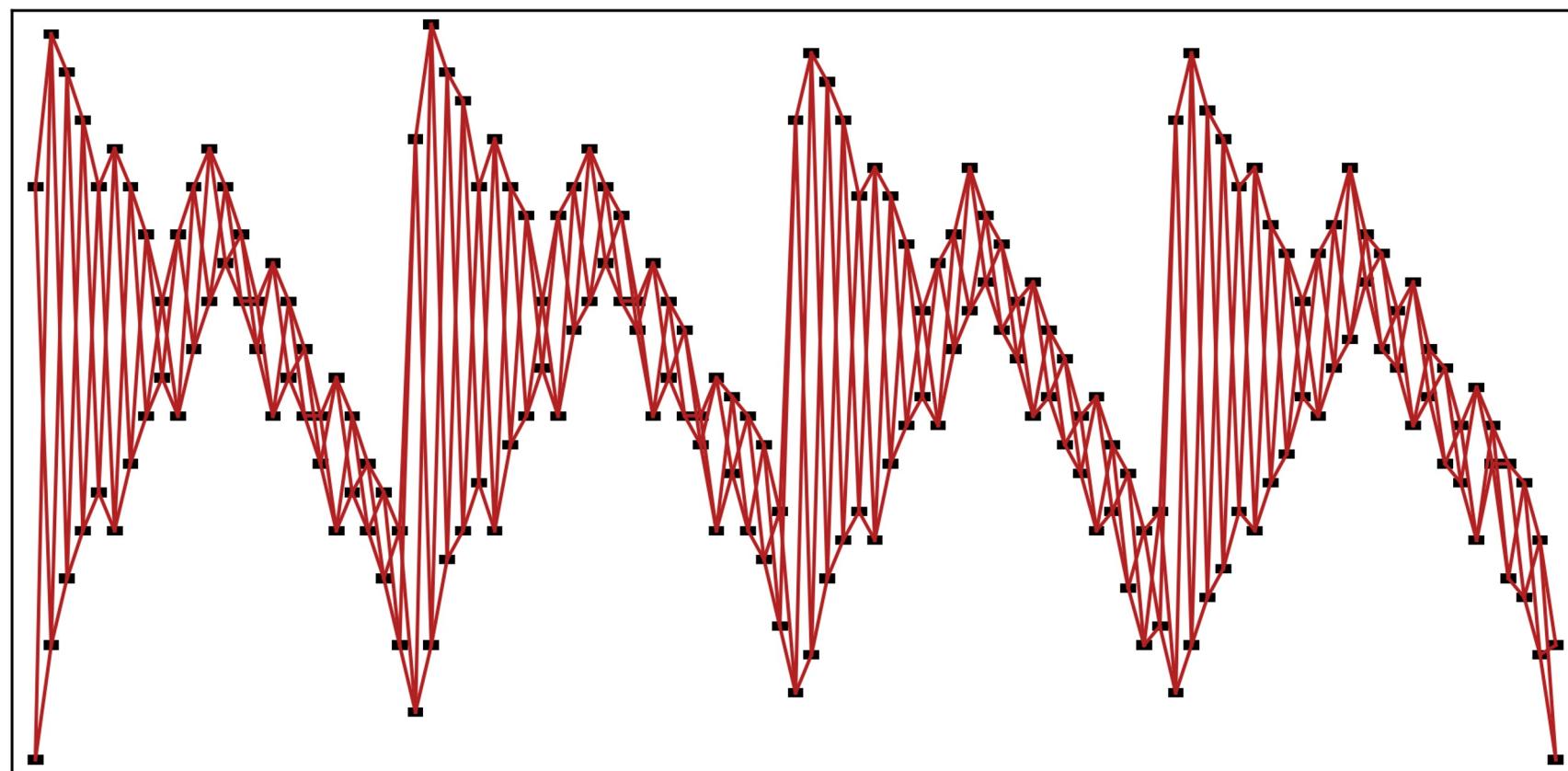
The Chord Contour



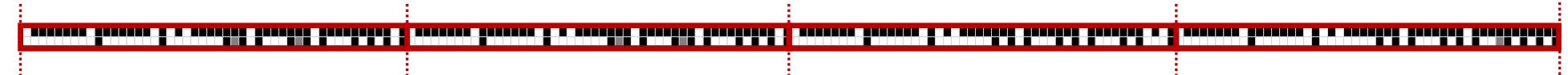
Chord Contour =



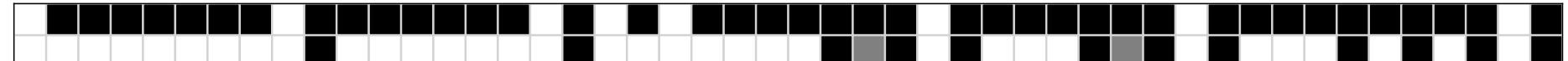
The Chord Contour



Chord Contour =



Pattern =



The Chord Contour

- Generalization of the melodic contour

The Chord Contour

- Generalization of the melodic contour
- Representation of musical patterns

The Chord Contour

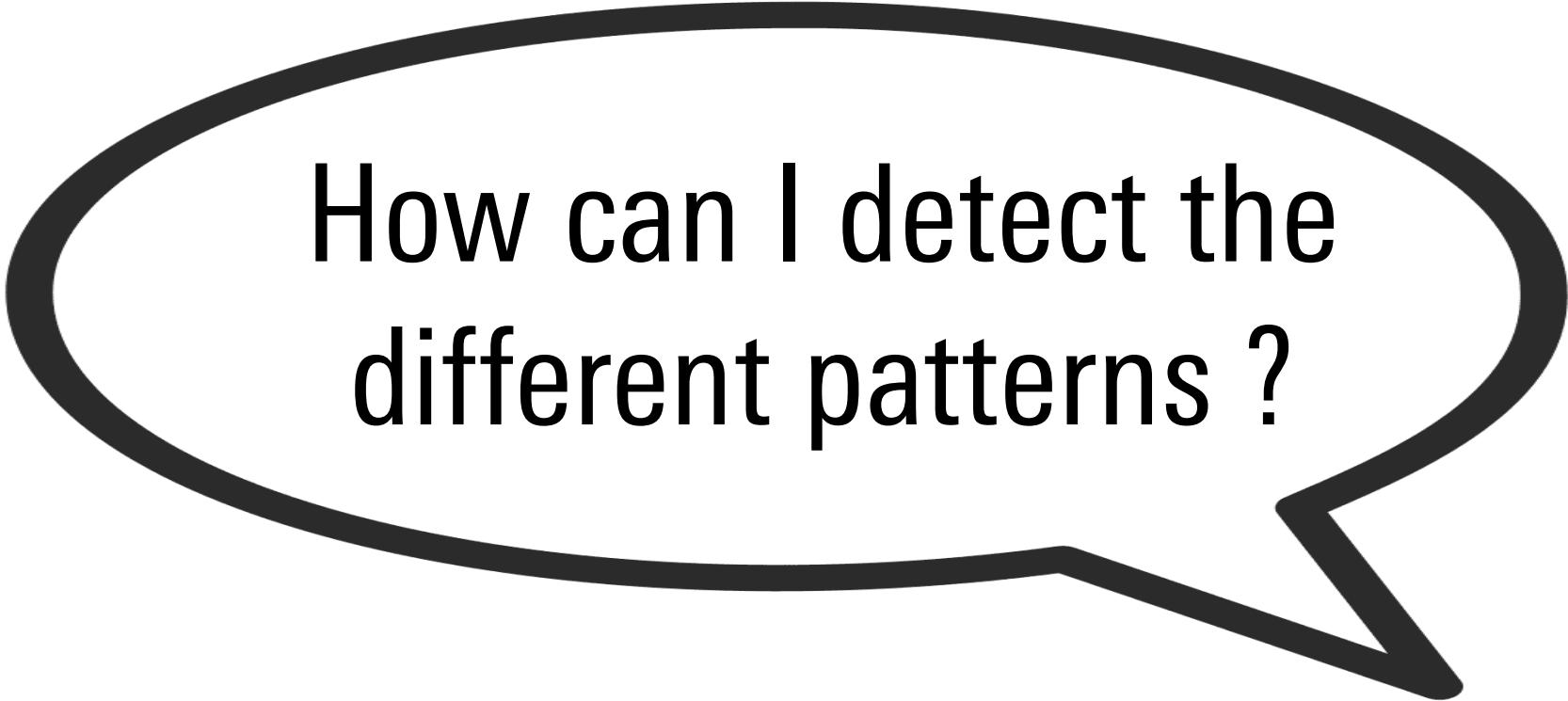
- Generalization of the melodic contour
- Representation of musical patterns
- Summarize the information

The Chord Contour



March of the Dwarfs – Edvard Grieg

The Chord Contour



How can I detect the
different patterns ?

The Self-Distance Matrix

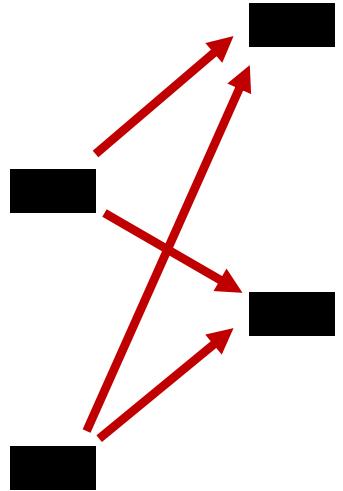
Detect musical structure: **Self-Distance Matrix**

The Self-Distance Matrix

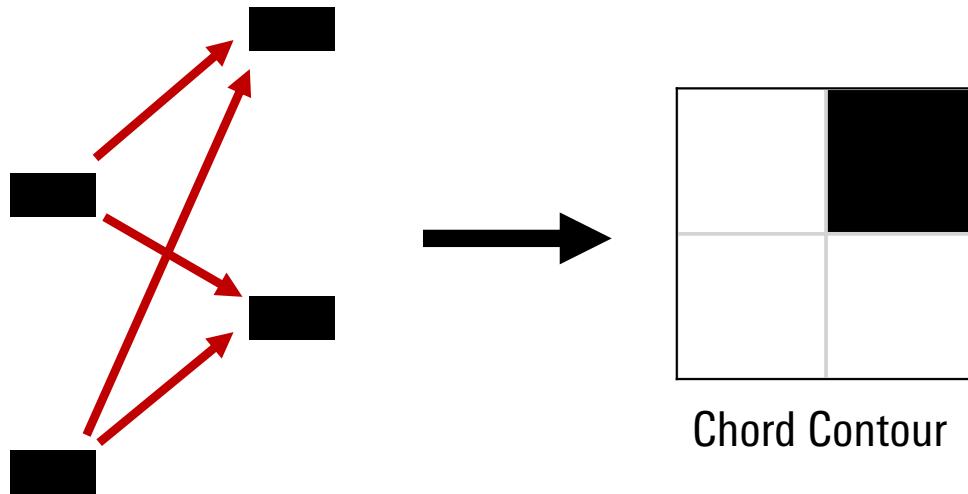
Detect musical structure: **Self-Distance Matrix**

Distance between two chord contours:
Number of notes that we have to change

The Self-Distance Matrix

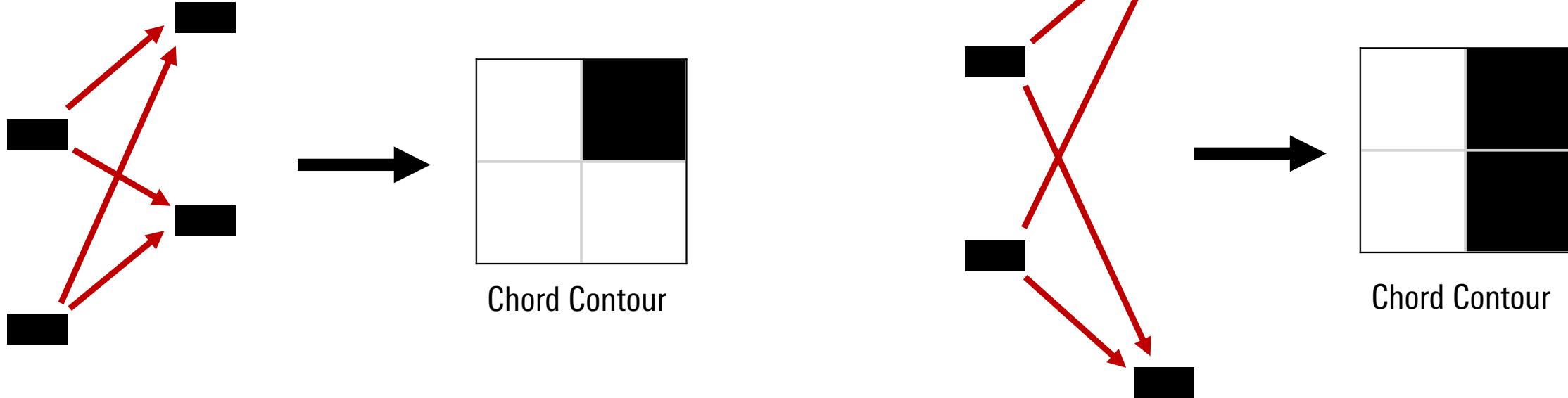


The Self-Distance Matrix

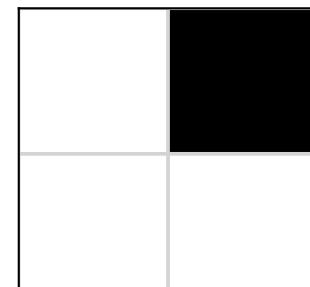
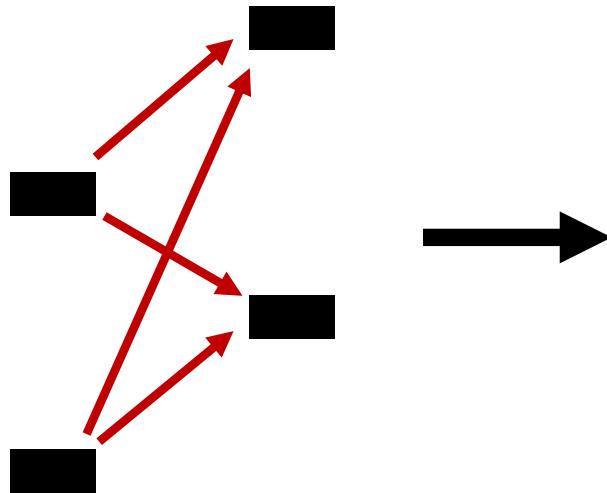


Chord Contour

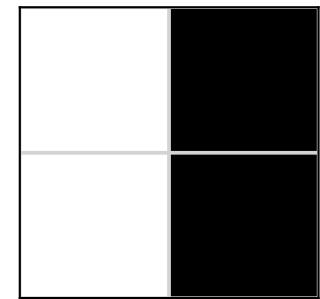
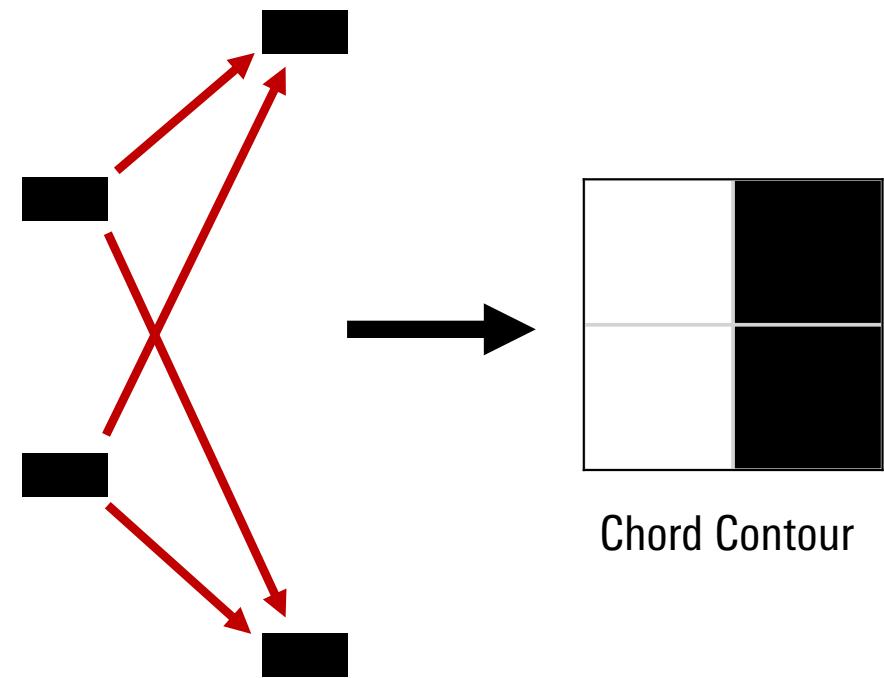
The Self-Distance Matrix



The Self-Distance Matrix



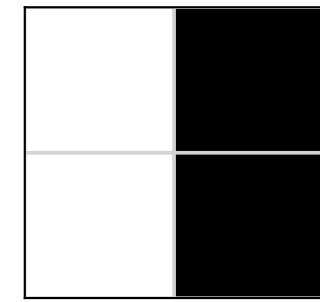
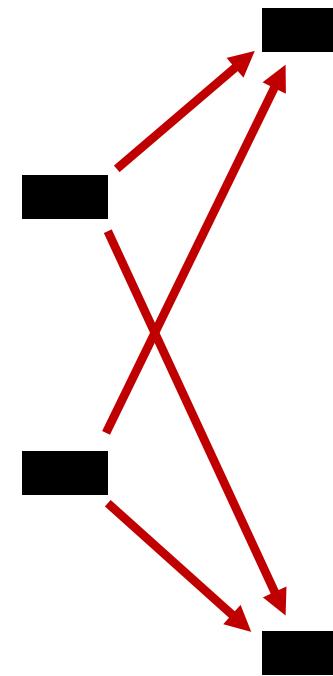
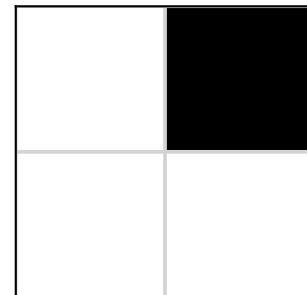
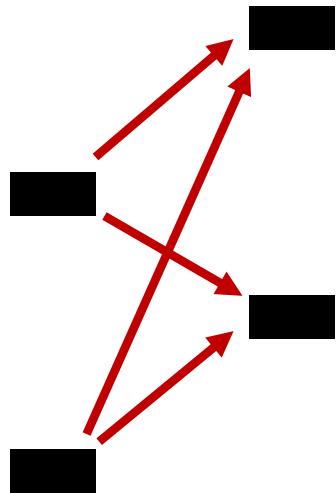
Chord Contour



Chord Contour

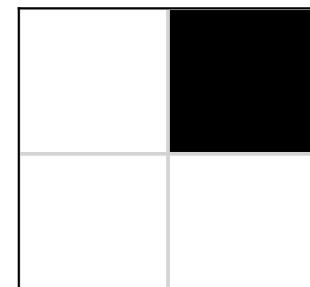
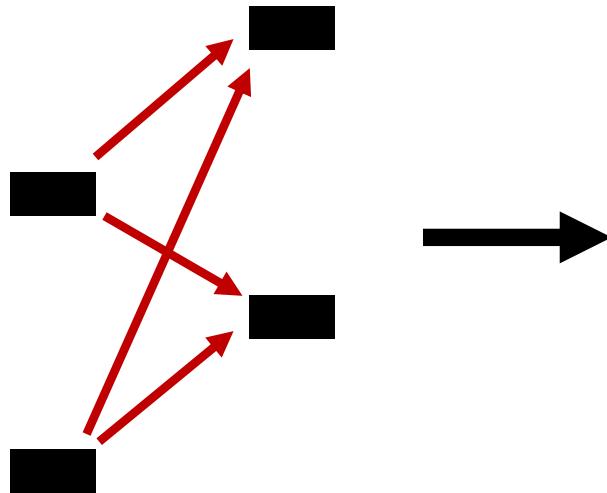
$$d\left(\begin{array}{|c|c|} \hline & \text{black} \\ \hline \text{white} & \text{white} \\ \hline \end{array}, \begin{array}{|c|c|} \hline & \text{black} \\ \hline \text{white} & \text{black} \\ \hline \end{array} \right) = ?$$

The Self-Distance Matrix

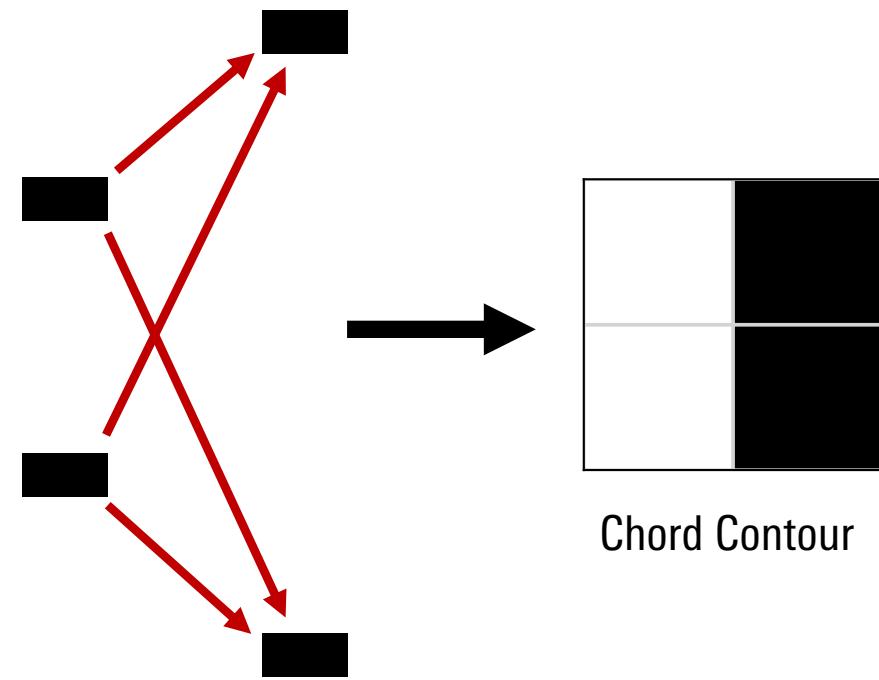


$$d\left(\begin{array}{|c|c|} \hline & \text{black} \\ \hline \text{white} & \text{black} \\ \hline \end{array} , \begin{array}{|c|c|} \hline & \text{black} \\ \hline \text{white} & \text{black} \\ \hline \end{array} \right) = ?$$

The Self-Distance Matrix



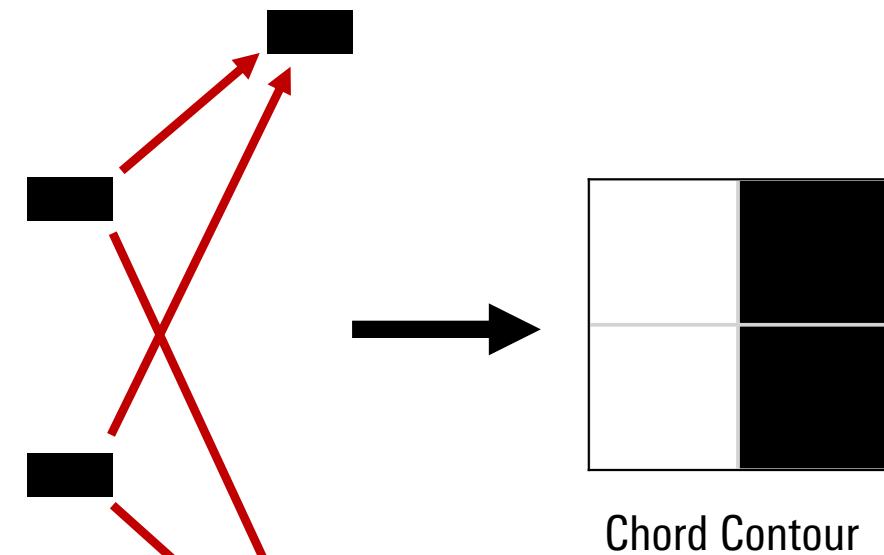
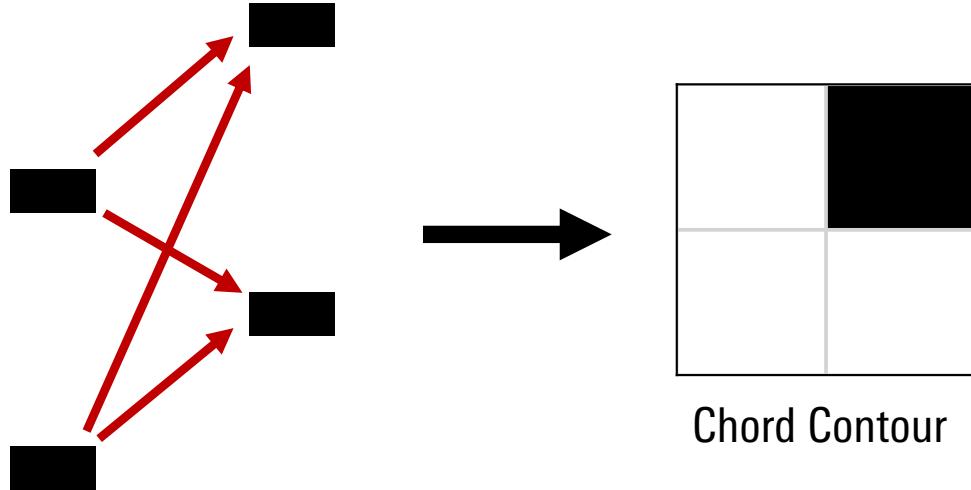
Chord Contour



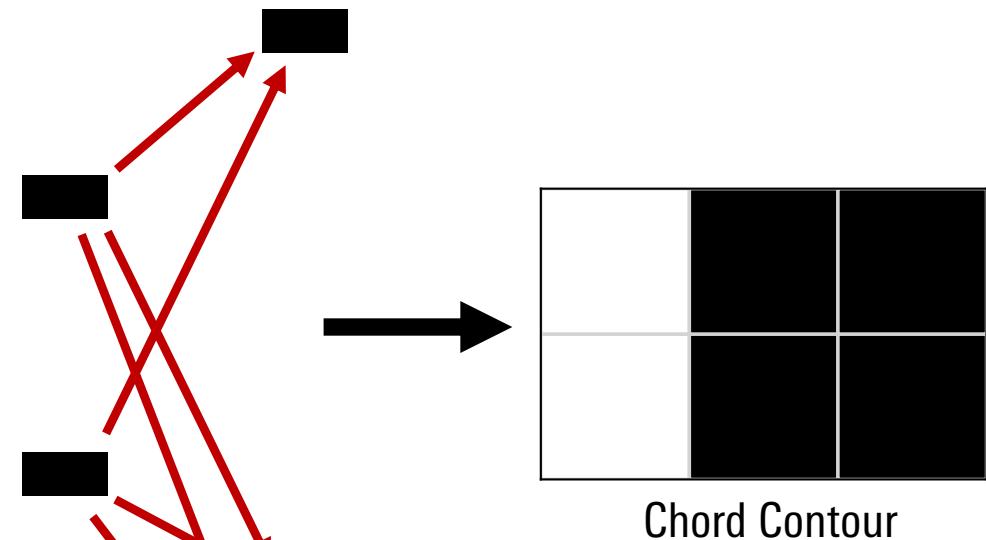
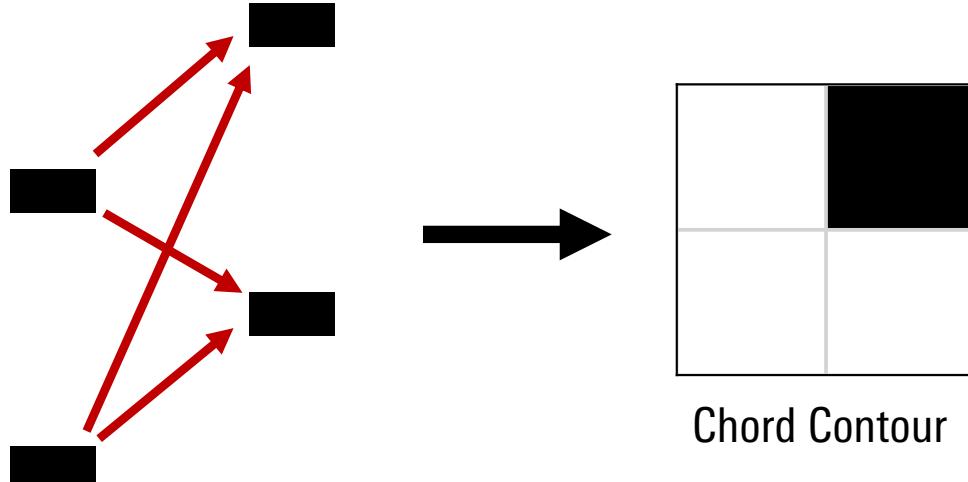
Chord Contour

$$d\left(\begin{array}{|c|c|} \hline & \text{black} \\ \hline \text{white} & \text{black} \\ \hline \end{array} , \begin{array}{|c|c|} \hline & \text{black} \\ \hline \text{white} & \text{black} \\ \hline \end{array} \right) = 1$$

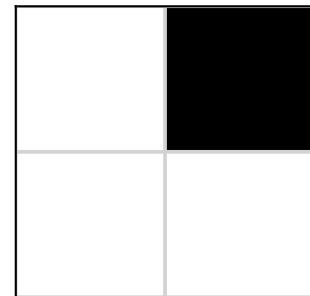
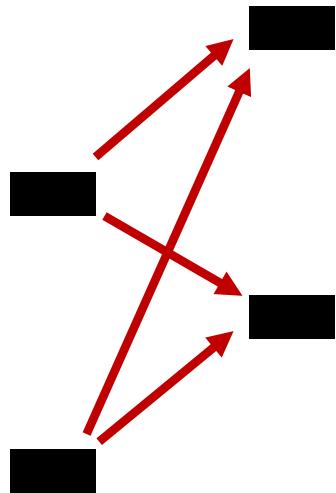
The Self-Distance Matrix



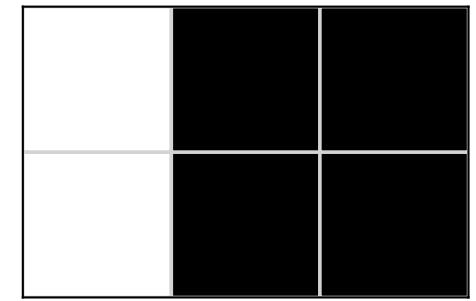
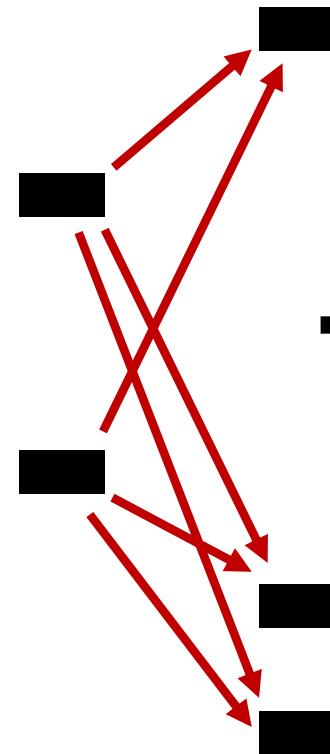
The Self-Distance Matrix



The Self-Distance Matrix



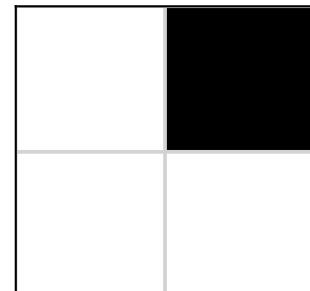
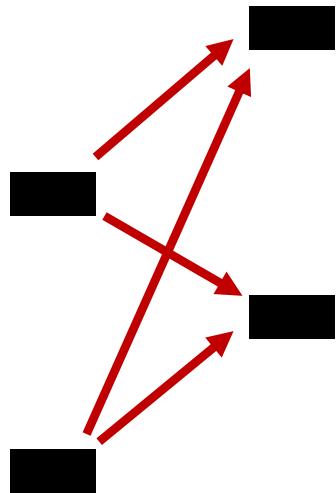
Chord Contour



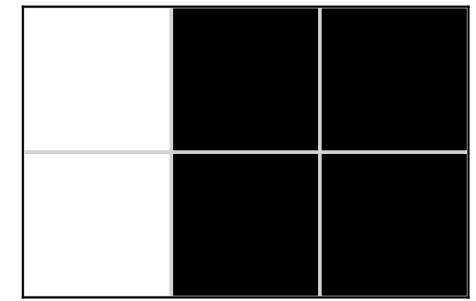
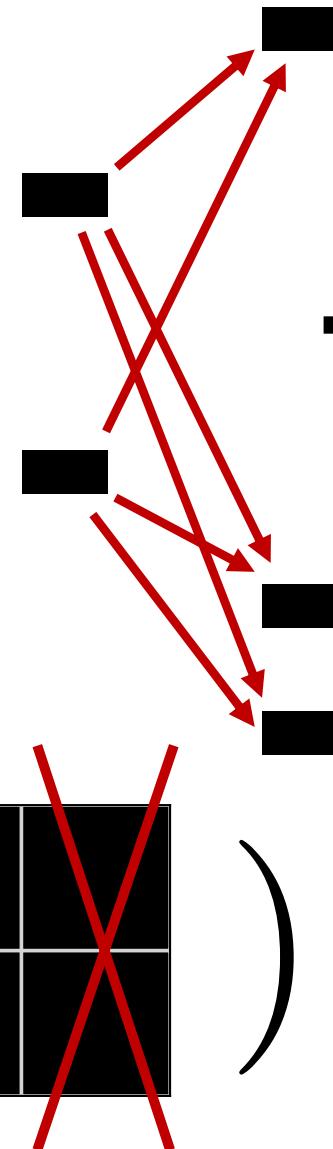
Chord Contour

$$d(\begin{array}{|c|c|} \hline & \text{Black} \\ \hline \text{White} & \\ \hline \end{array}, \begin{array}{|c|c|c|} \hline & \text{Black} & \\ \hline \text{White} & \text{Black} & \\ \hline \end{array}) = ?$$

The Self-Distance Matrix



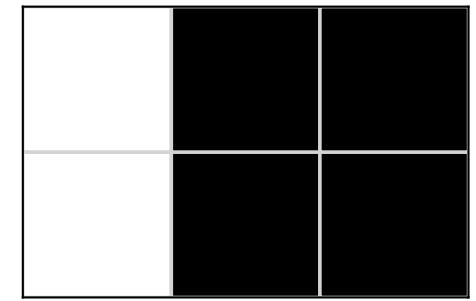
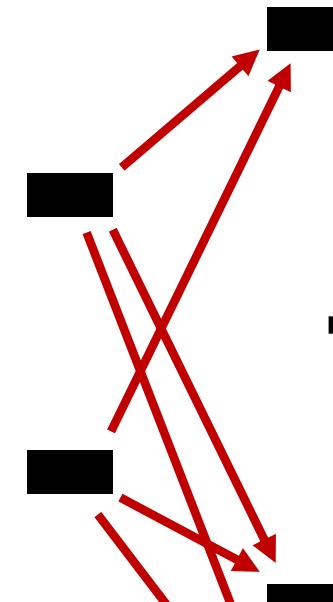
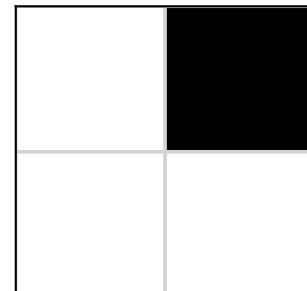
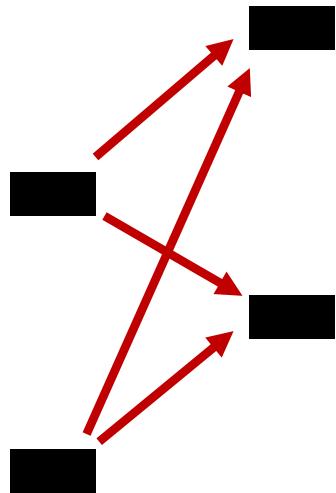
Chord Contour



Chord Contour

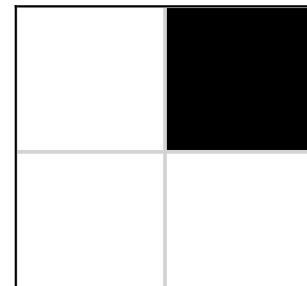
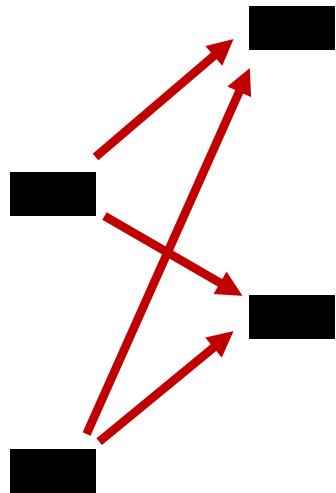
$$d(\begin{array}{|c|c|} \hline & \text{Black} \\ \hline \text{White} & \\ \hline \end{array}, \begin{array}{|c|c|c|} \hline & \text{Black} & \\ \hline \text{White} & \text{Black} & \\ \hline \text{White} & & \text{Black} \\ \hline \end{array}) = ?$$

The Self-Distance Matrix

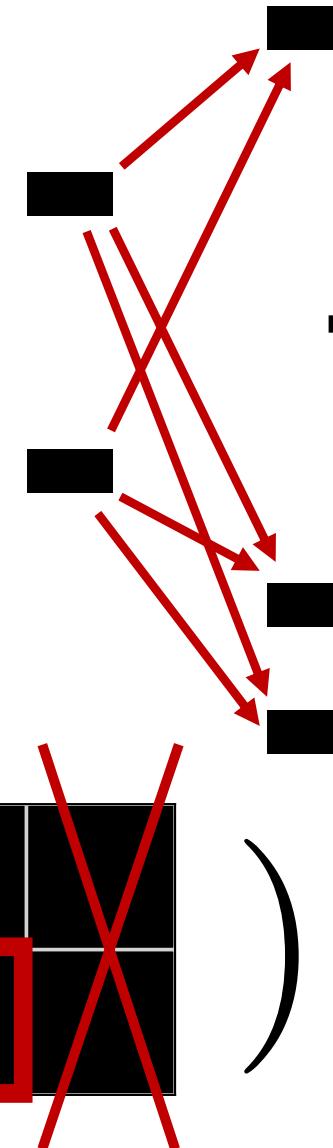


$$d(\begin{array}{|c|c|} \hline & \text{black} \\ \hline \text{white} & \text{black} \\ \hline \end{array}, \begin{array}{|c|c|c|} \hline & \text{black} & \text{black} \\ \hline \text{white} & \text{black} & \text{black} \\ \hline \end{array}) = ?$$

The Self-Distance Matrix



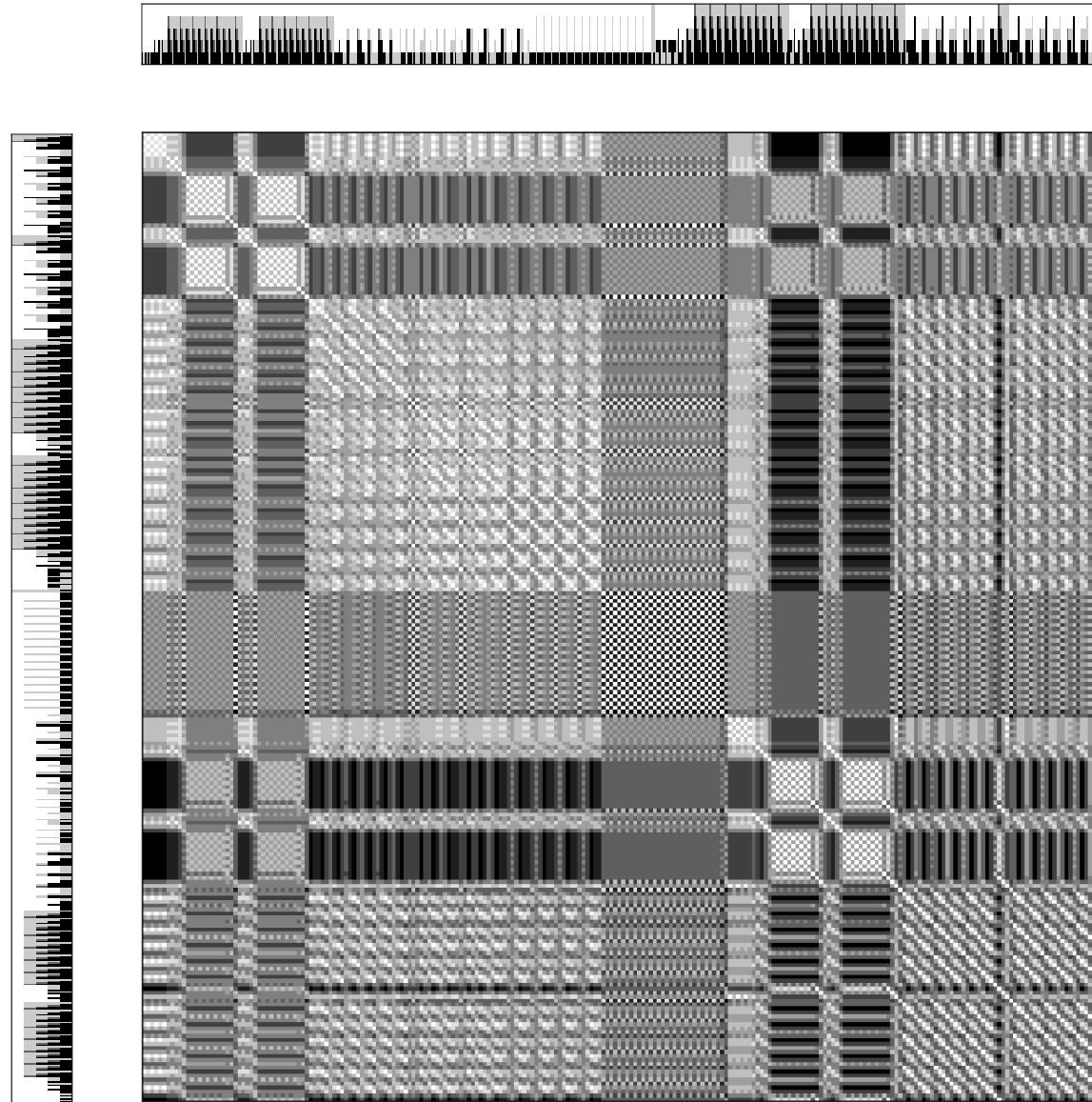
Chord Contour



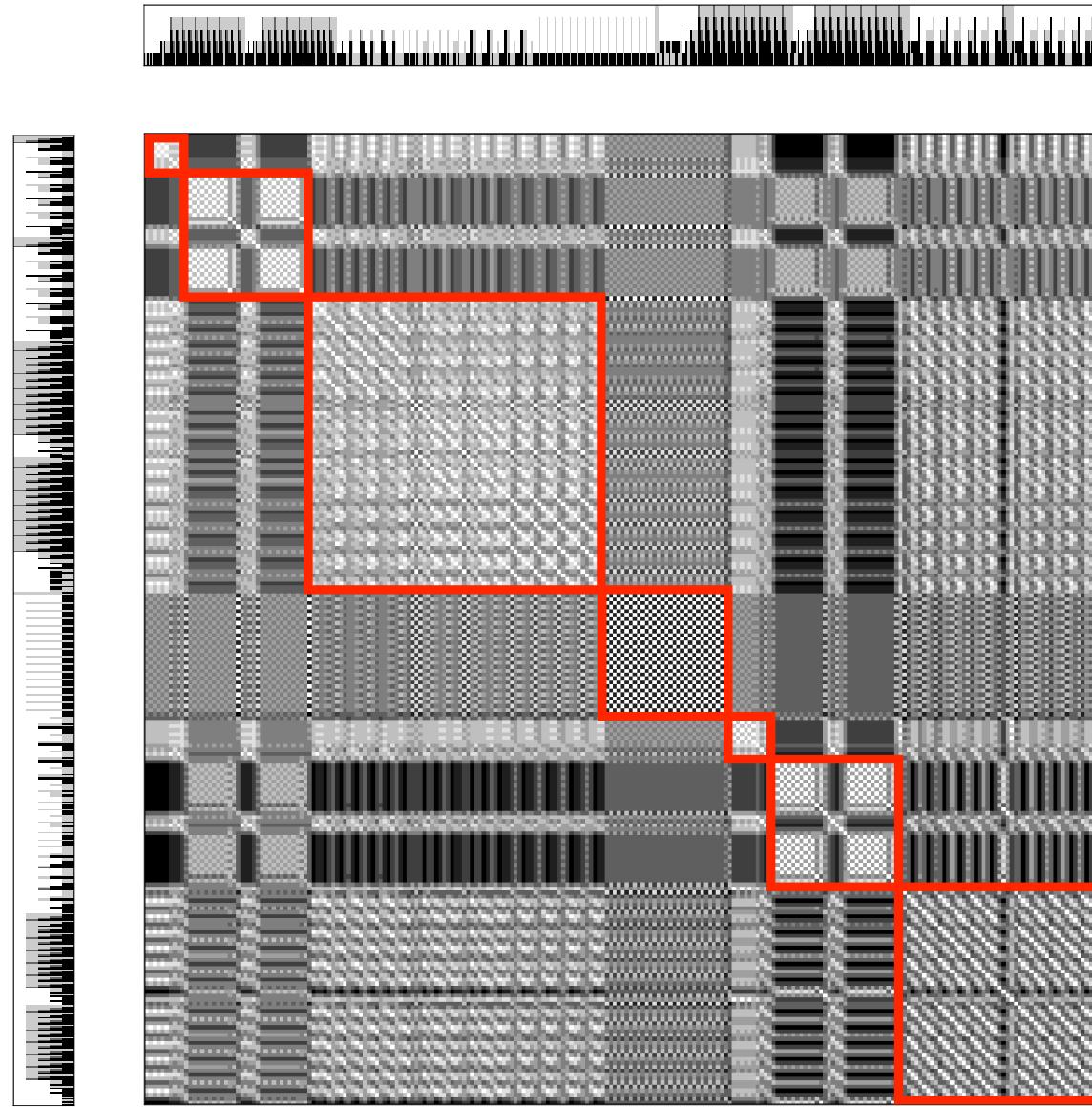
Chord Contour

$$d\left(\begin{array}{|c|c|} \hline & \text{black} \\ \hline \text{white} & \text{black} \\ \hline \end{array} , \begin{array}{|c|c|c|} \hline & \text{black} & \text{black} \\ \hline \text{white} & \text{black} & \text{black} \\ \hline \end{array} \right) = 2$$

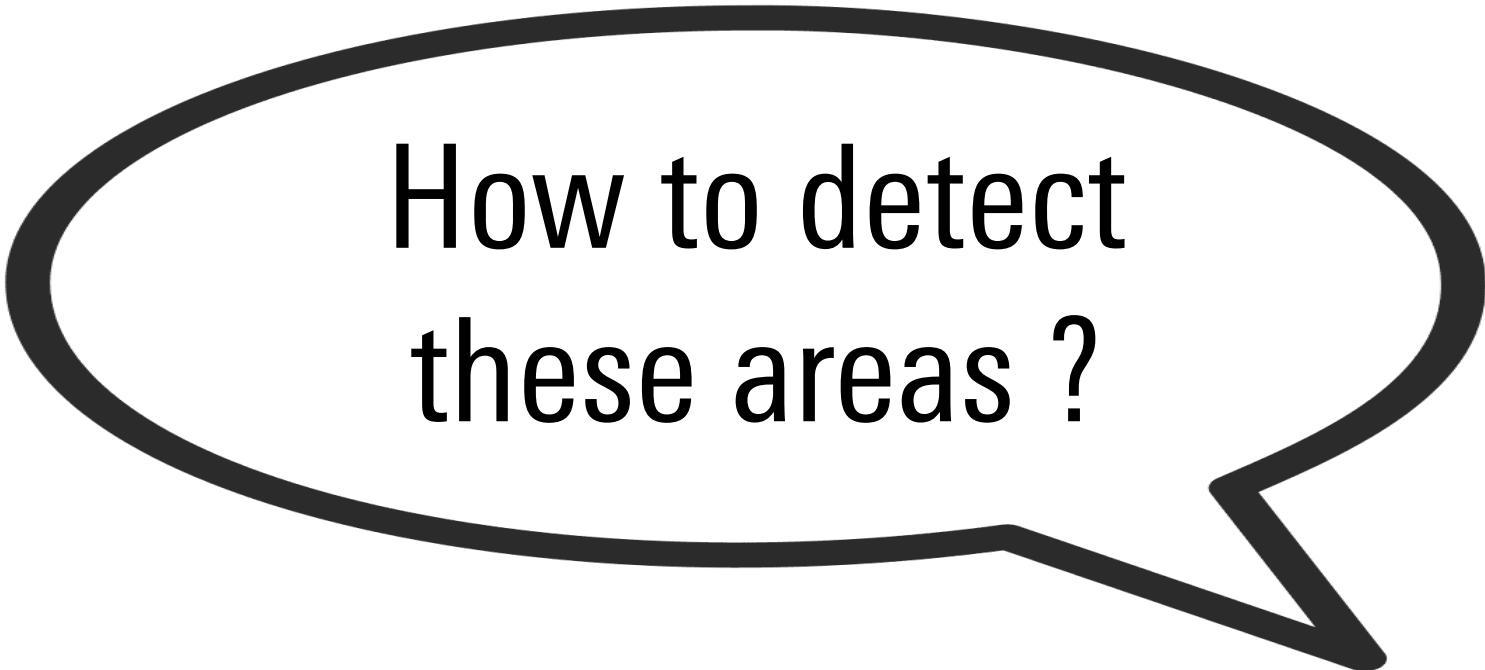
The Self-Distance Matrix



The Self-Distance Matrix



The Self-Distance Matrix



How to detect
these areas ?

.Mathematical Morphology

Morphological filters used in image processing

.Mathematical Morphology

Morphological filters used in image processing

For us: Homogenize areas in the Self-Distance Matrix

.Mathematical Morphology



Image

.Mathematical Morphology



Image

1	1	1
1	1	1
1	1	1

Filter

.Mathematical Morphology



Image

1	1	1
1	1	1
1	1	1

Filter



Opening

.Mathematical Morphology



Image

1	1	1
1	1	1
1	1	1

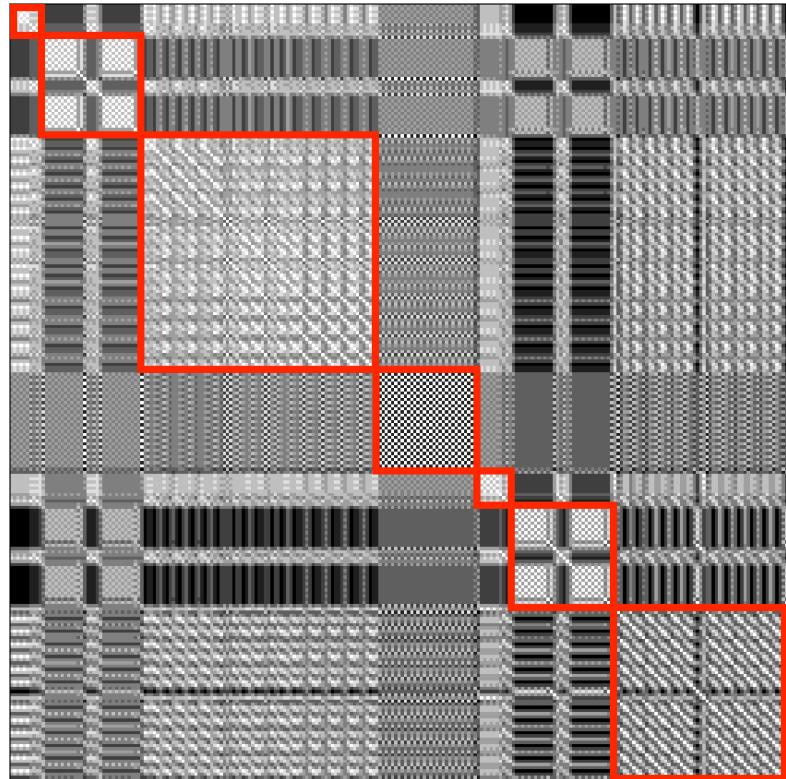
Filter



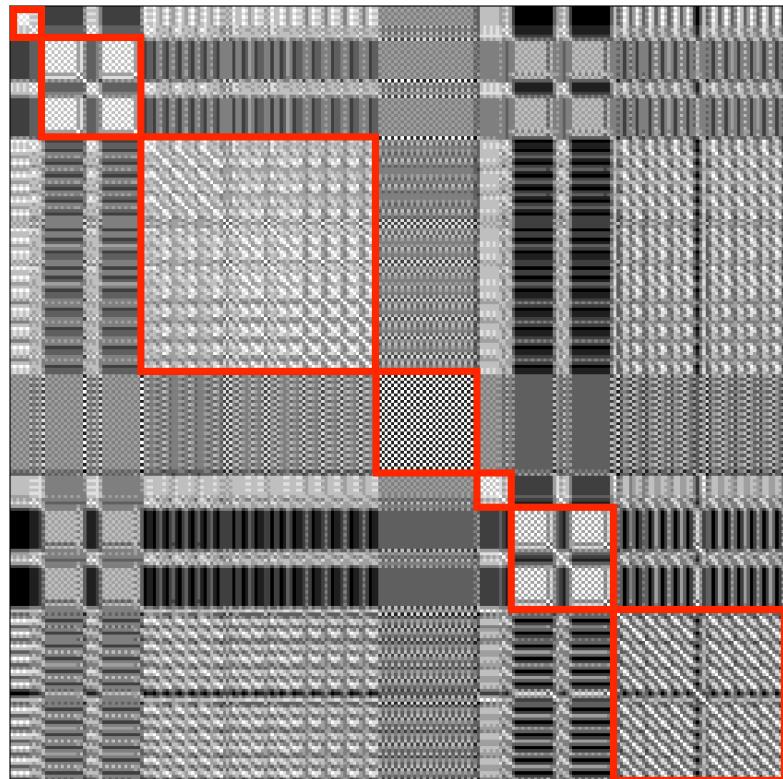
Opening

Remove small details (high local values)

.Mathematical Morphology

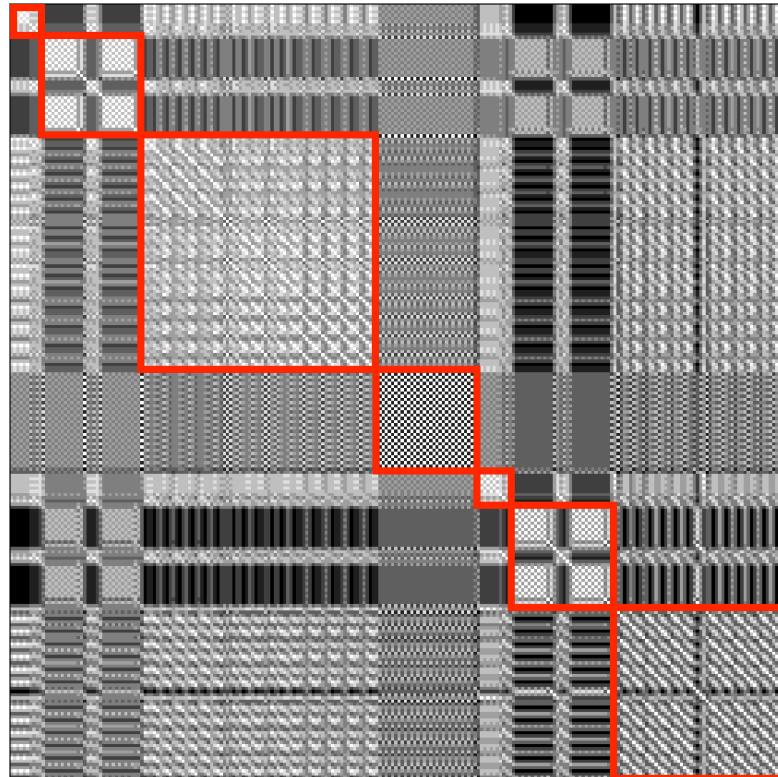


.Mathematical Morphology



We want to detect **blocks**,

.Mathematical Morphology



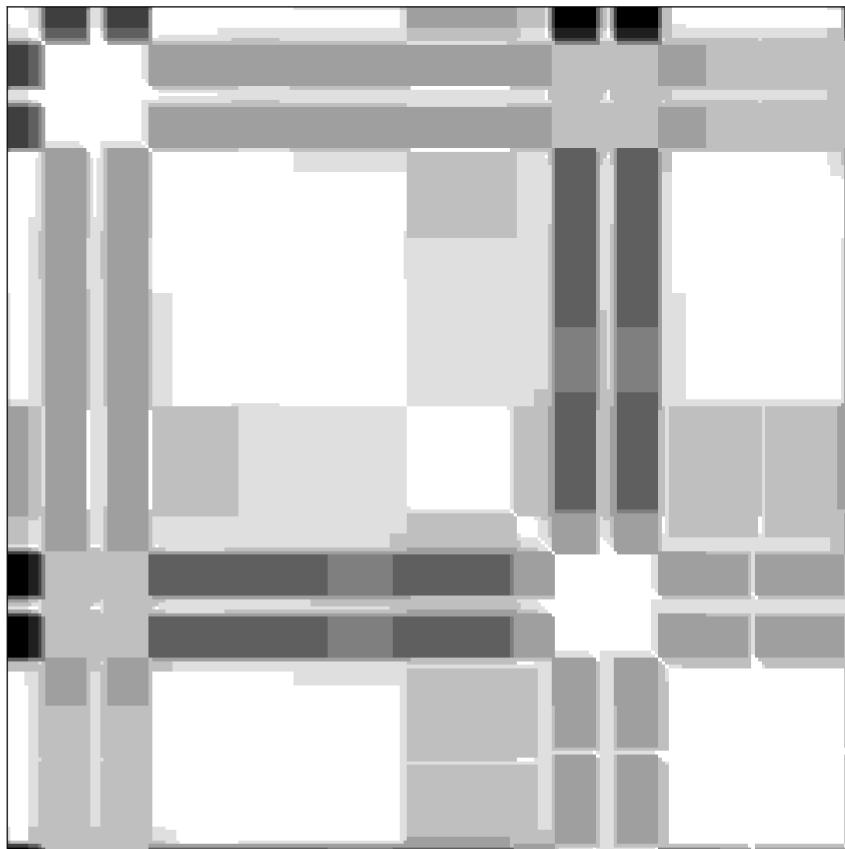
We want to detect **blocks**,
the filter has to be:

Constant & Square Shaped

1	1	1
1	1	1
1	1	1

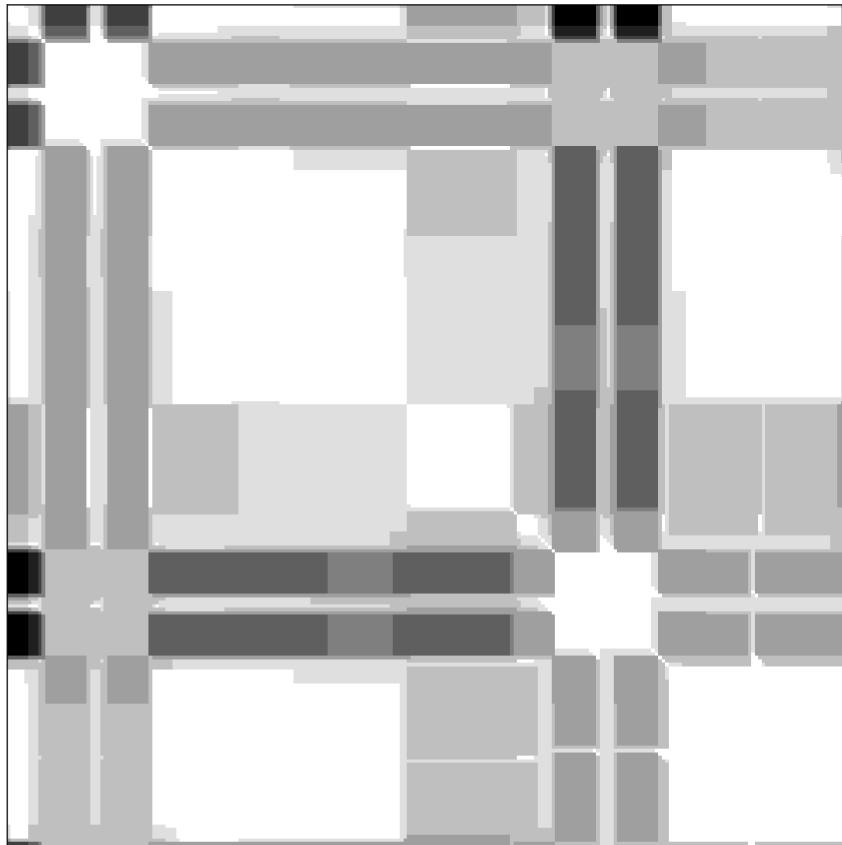
Filter

.Mathematical Morphology

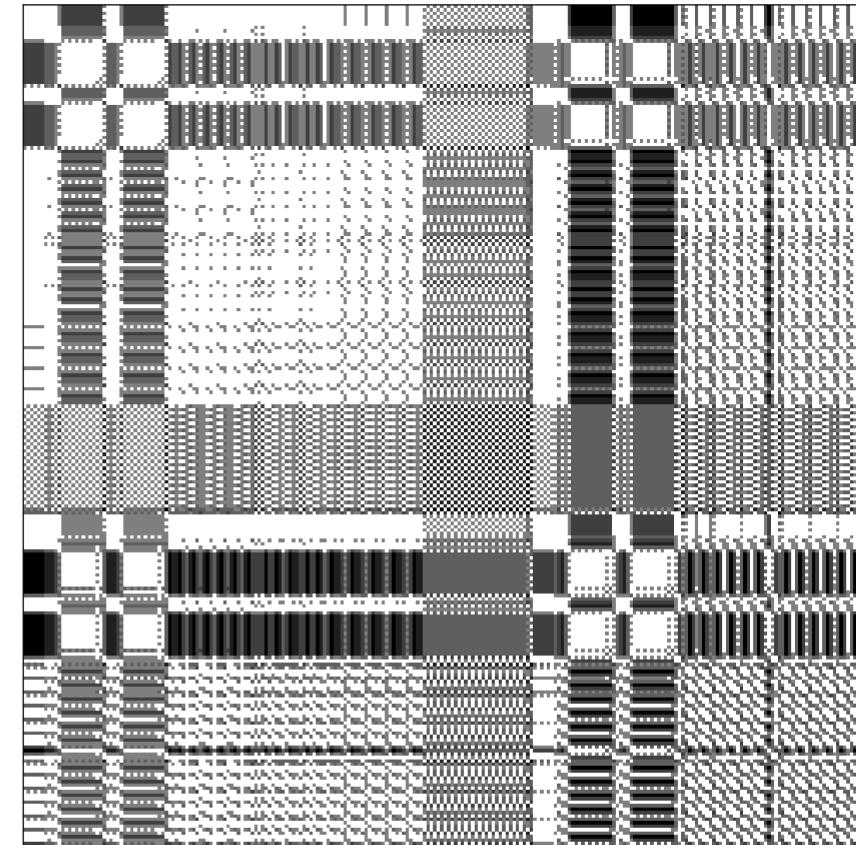


Morphological filter

.Mathematical Morphology



Morphological filter



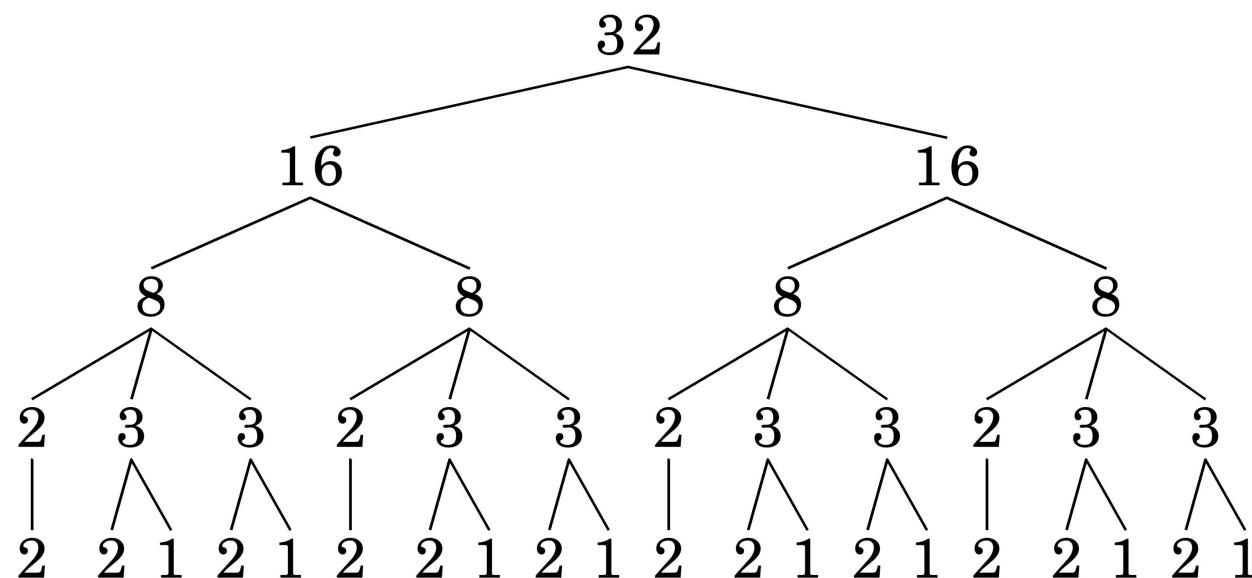
Threshold

.Mathematical Morphology

You can change the
size of the filter !!

.Mathematical Morphology

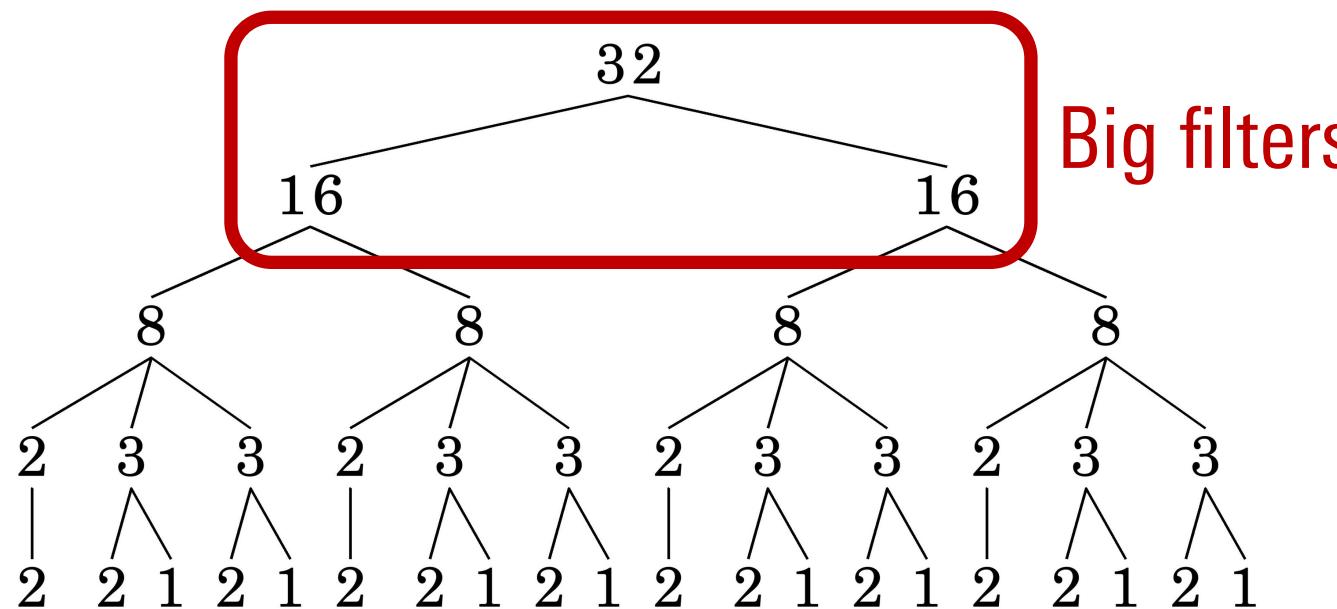
You can change the size of the filter !!



Hierarchical structures

.Mathematical Morphology

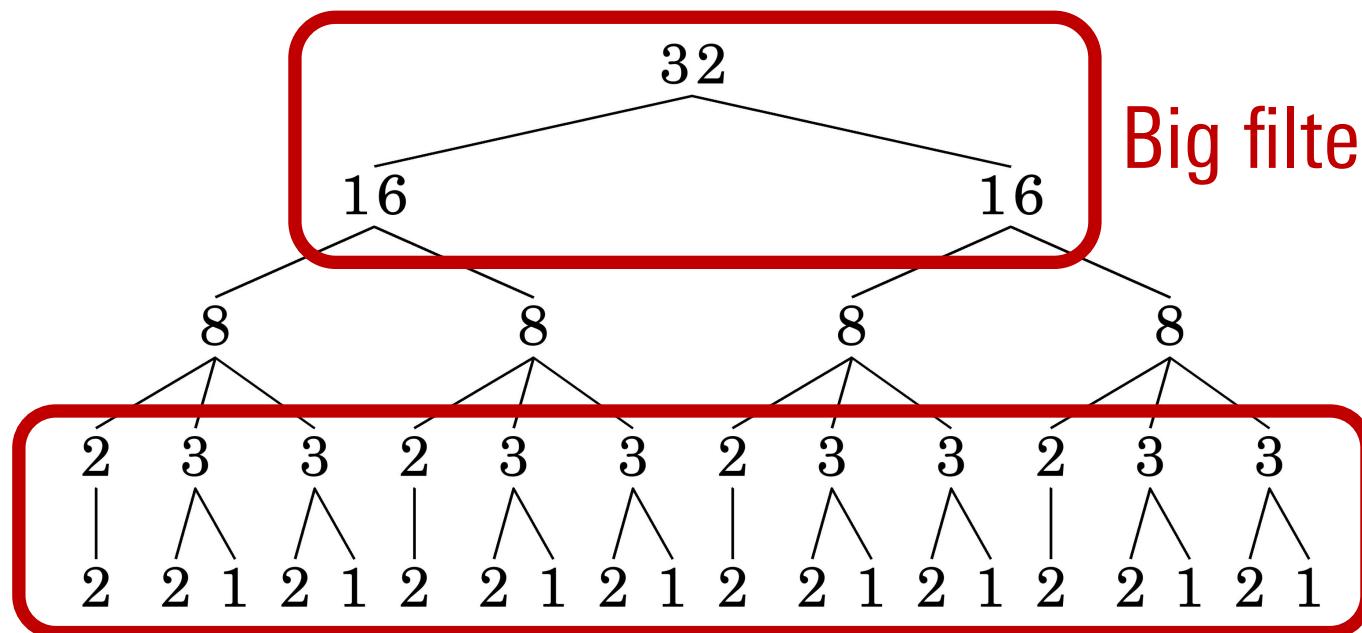
You can change the size of the filter !!



Hierarchical structures

.Mathematical Morphology

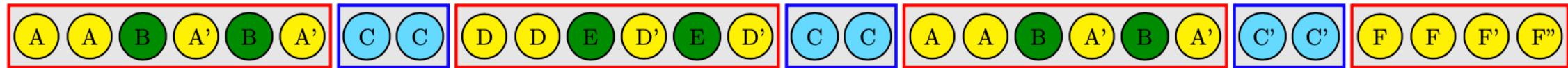
You can change the size of the filter !!



Hierarchical structures

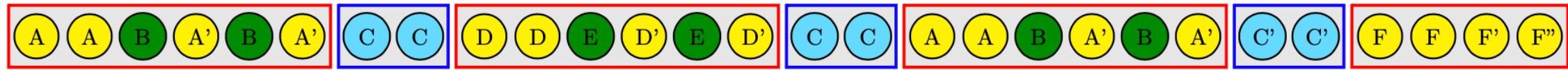
Small filters

.Mathematical Morphology

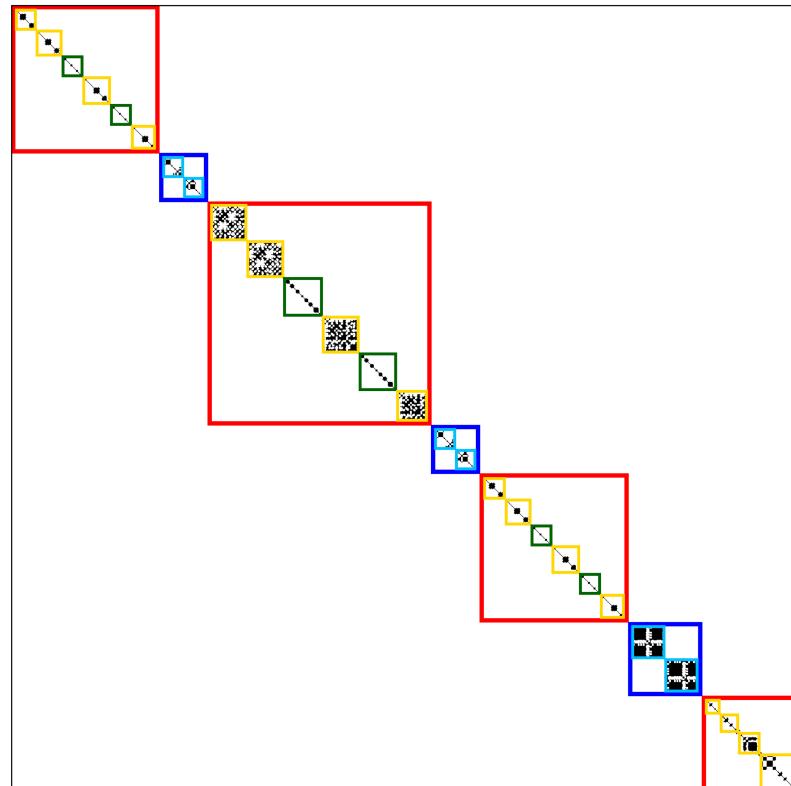


Hierarchical structures of Alla Turca (W.A. Mozart)

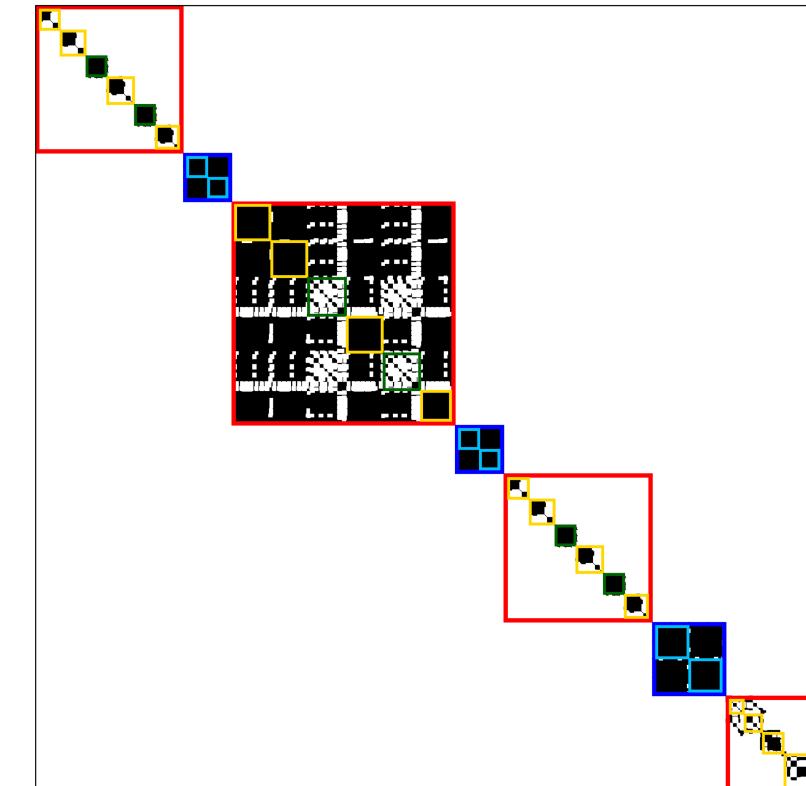
.Mathematical Morphology



Hierarchical structures of Alla Turca (W.A. Mozart)



3x3 morphological filter



6x6 morphological filter

.Mathematical Morphology

- Zero values around the diagonal

.Mathematical Morphology

- Zero values around the diagonal
- Self-distance matrix or self-similarity matrix

.Mathematical Morphology

- Zero values around the diagonal
- Self-distance matrix or self-similarity matrix
- It's fast to compute it

.Mathematical Morphology

Music structure analysis:
homogeneity and repetition

.Mathematical Morphology

with
mathematical
morphology

Music structure analysis:

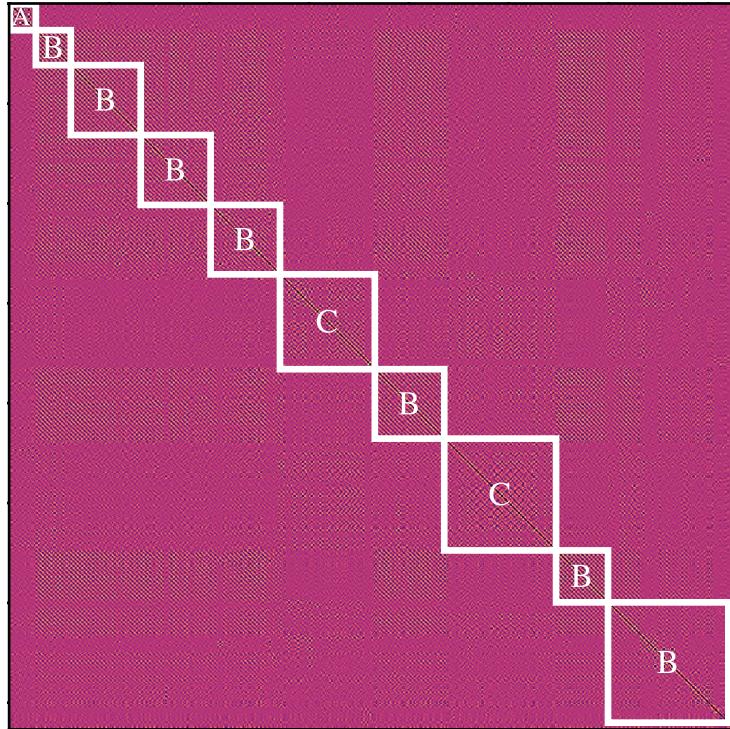
homogeneity and repetition

.Mathematical Morphology



Yann Teytaut
PhD student at Ircam

.Mathematical Morphology



Self-distance matrix (audio signal)...

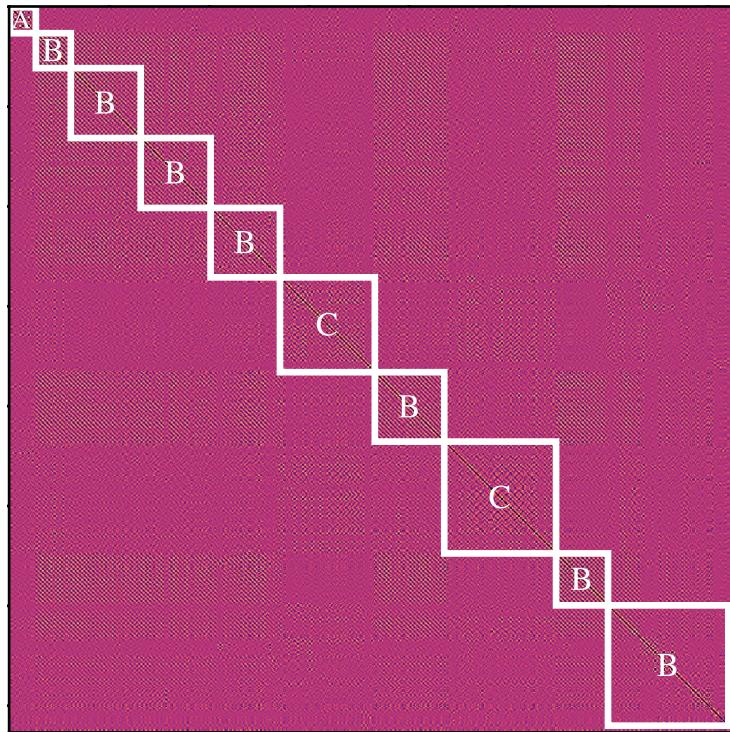


Yann Teytaut
PhD student at Ircam

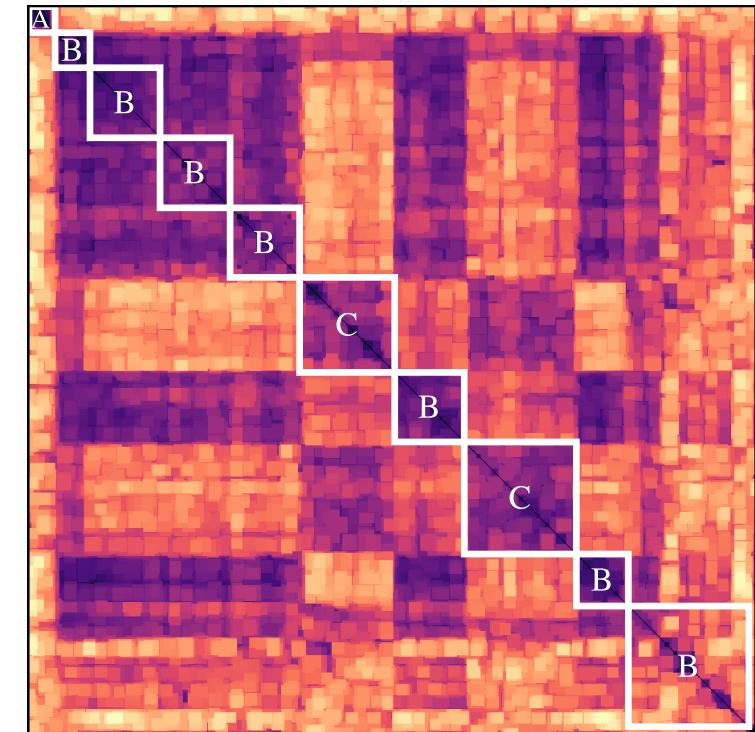
.Mathematical Morphology



Yann Teytaut
PhD student at Ircam

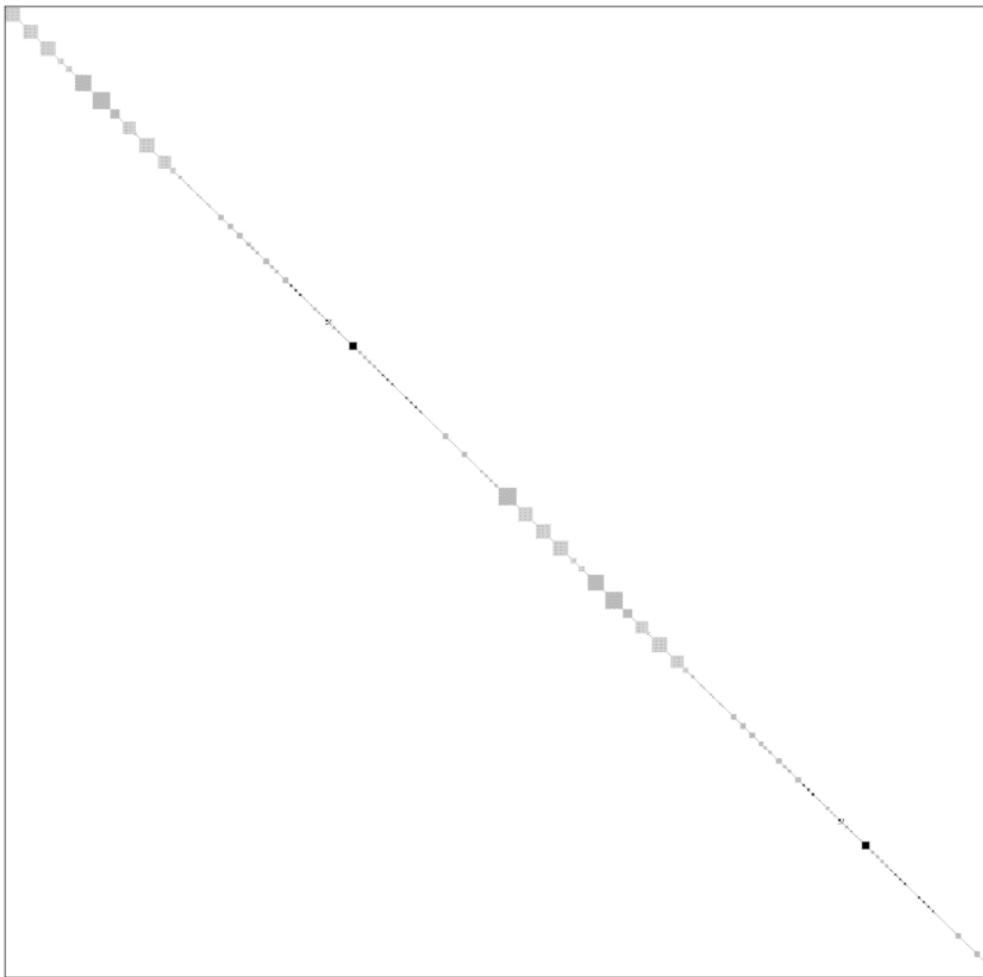


Self-distance matrix (audio signal)...



...with morphological filter !

.Bonus



Chapitre 4 : Étudier la partition (avec la morphologie mathématique)

.Idées pour appliquer la MM



Image

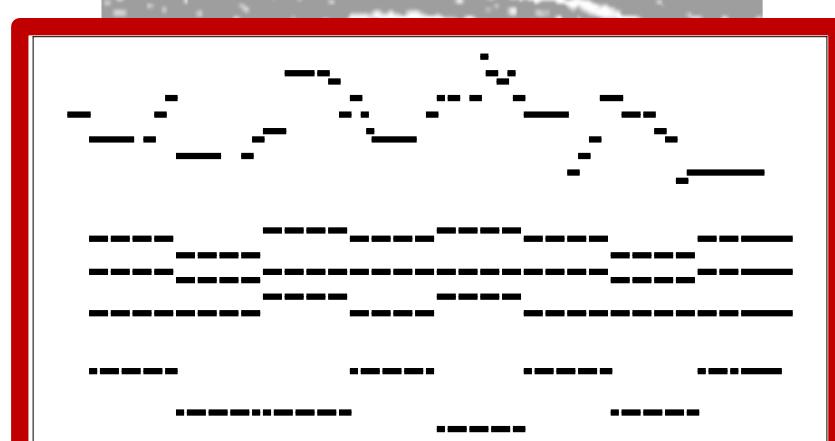
1	1	1
1	1	1
1	1	1

Filter



Opening

.Idées pour appliquer la MM



Image



Filter



Opening

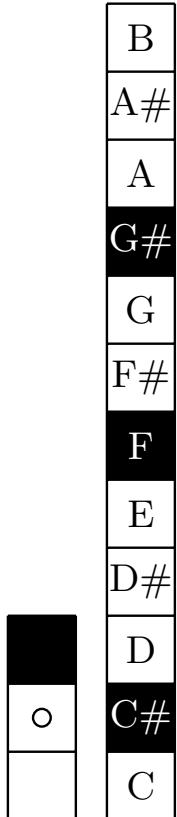
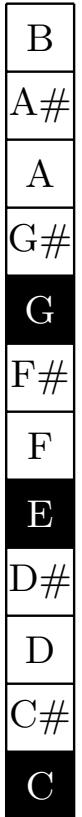
Morphologie binaire => Piano roll

.Opérations de base de la MM

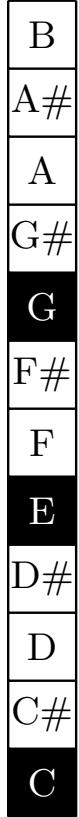
B
A#
A
G#
G
F#
F
E
D#
D
C#
C

(a) X

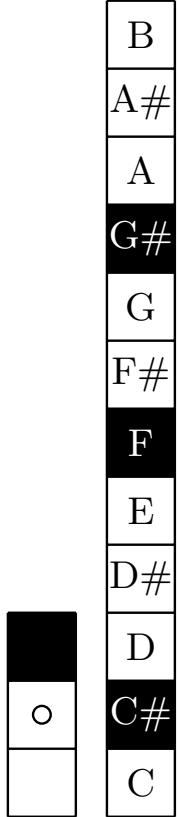
.Opérations de base de la MM



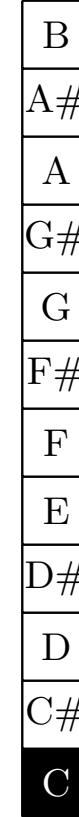
.Opérations de base de la MM



(a) X

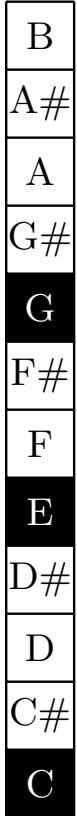


(b) $X \oplus B$

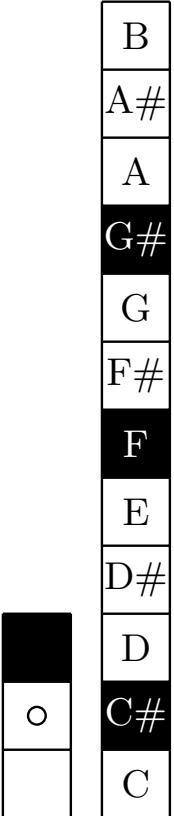


(c) $X \ominus B$

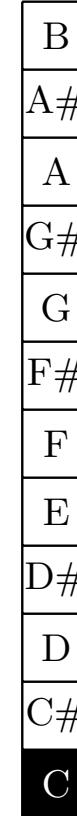
.Opérations de base de la MM



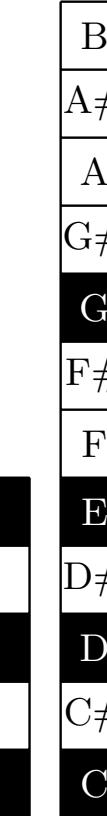
(a) X



(b) $X \oplus B$

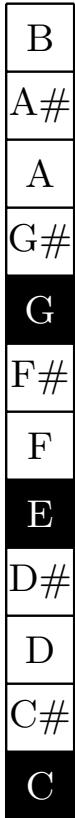


(c) $X \ominus B$

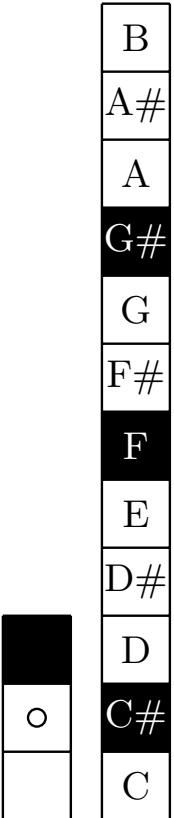


(d) $X \bullet B$

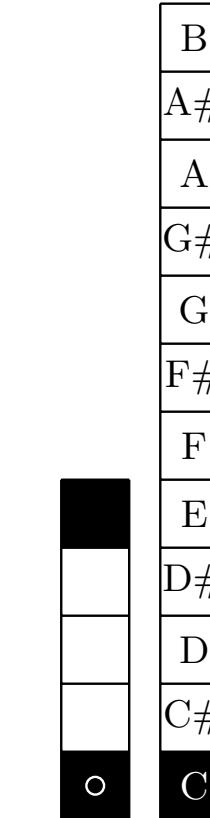
.Opérations de base de la MM



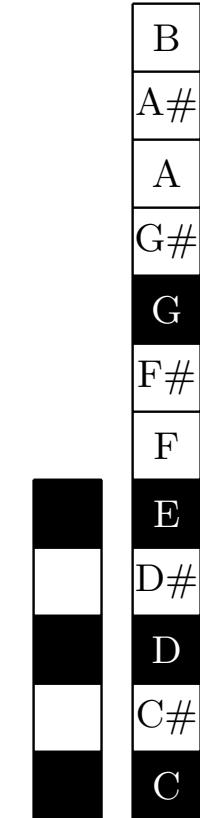
(a) X



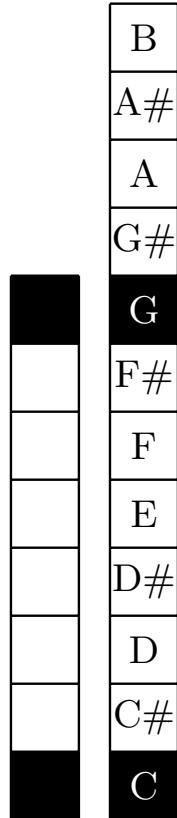
(b) $X \oplus B$



(c) $X \ominus B$

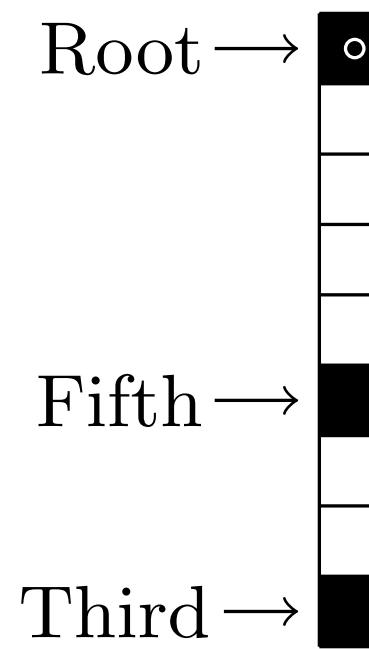
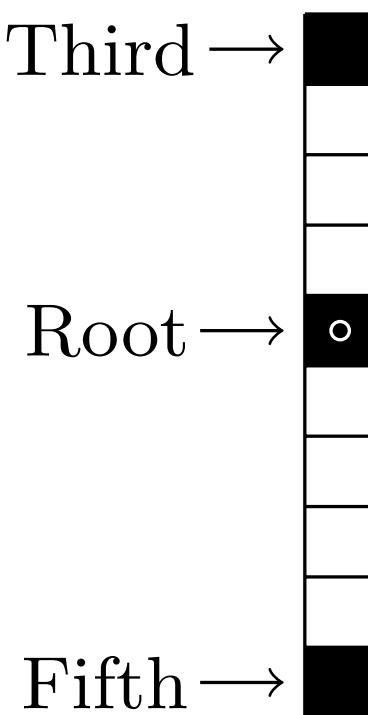
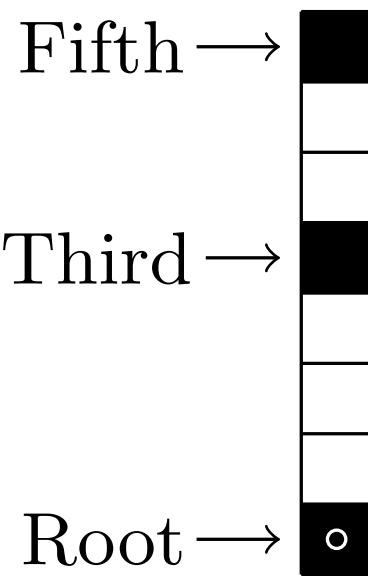


(d) $X \bullet B$

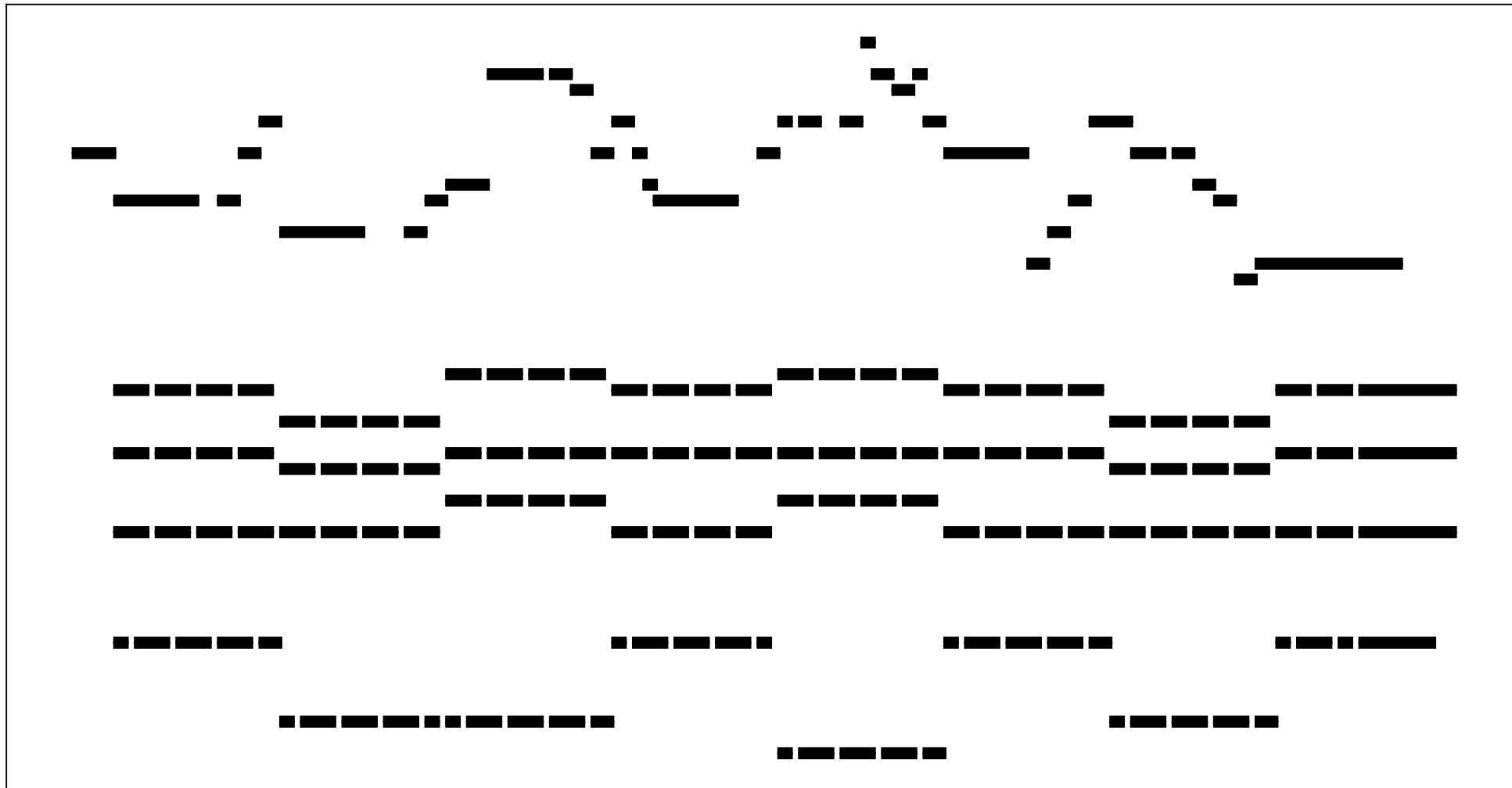


(e) $X \circ B$

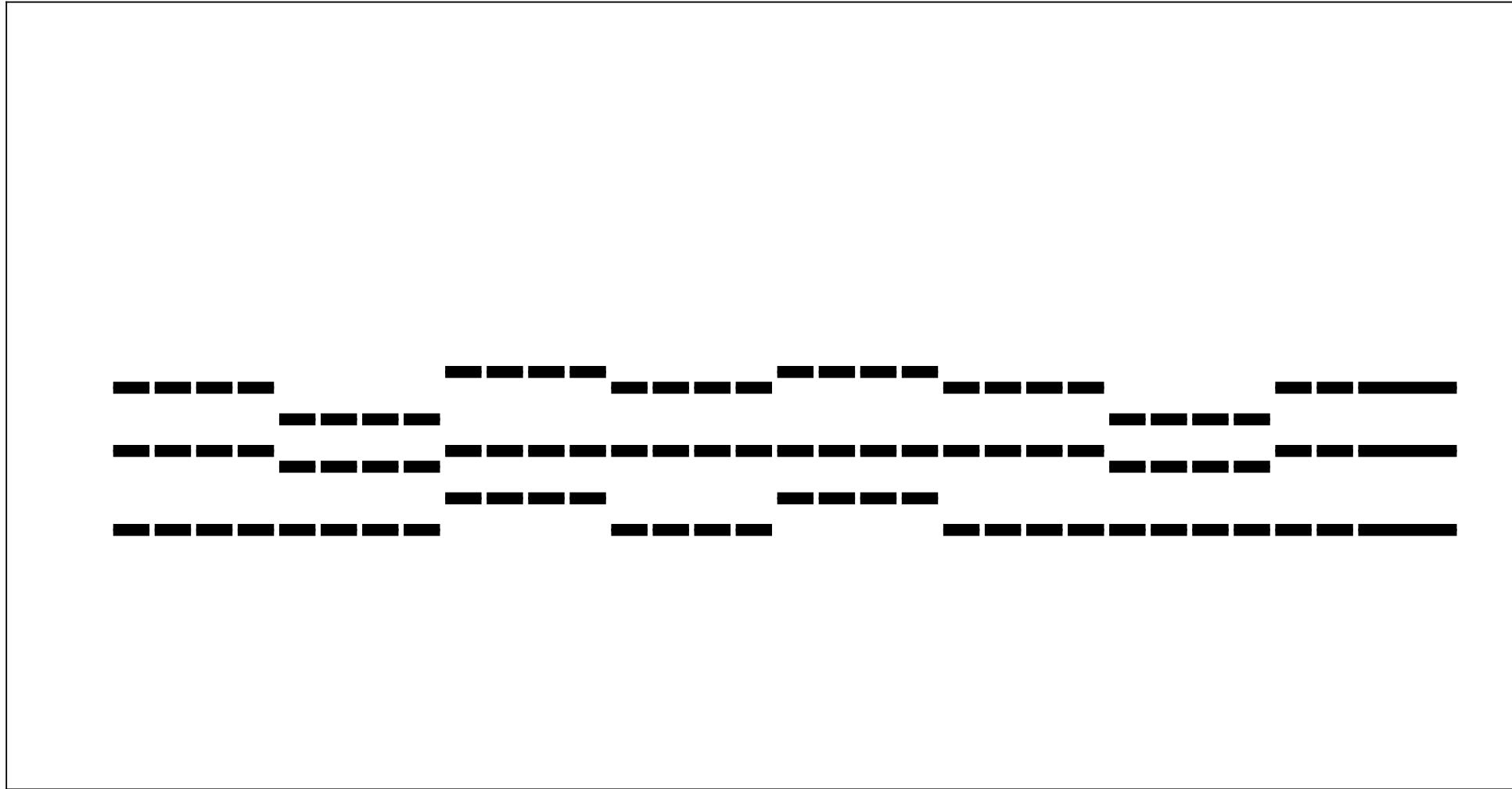
.Adapter le filtre



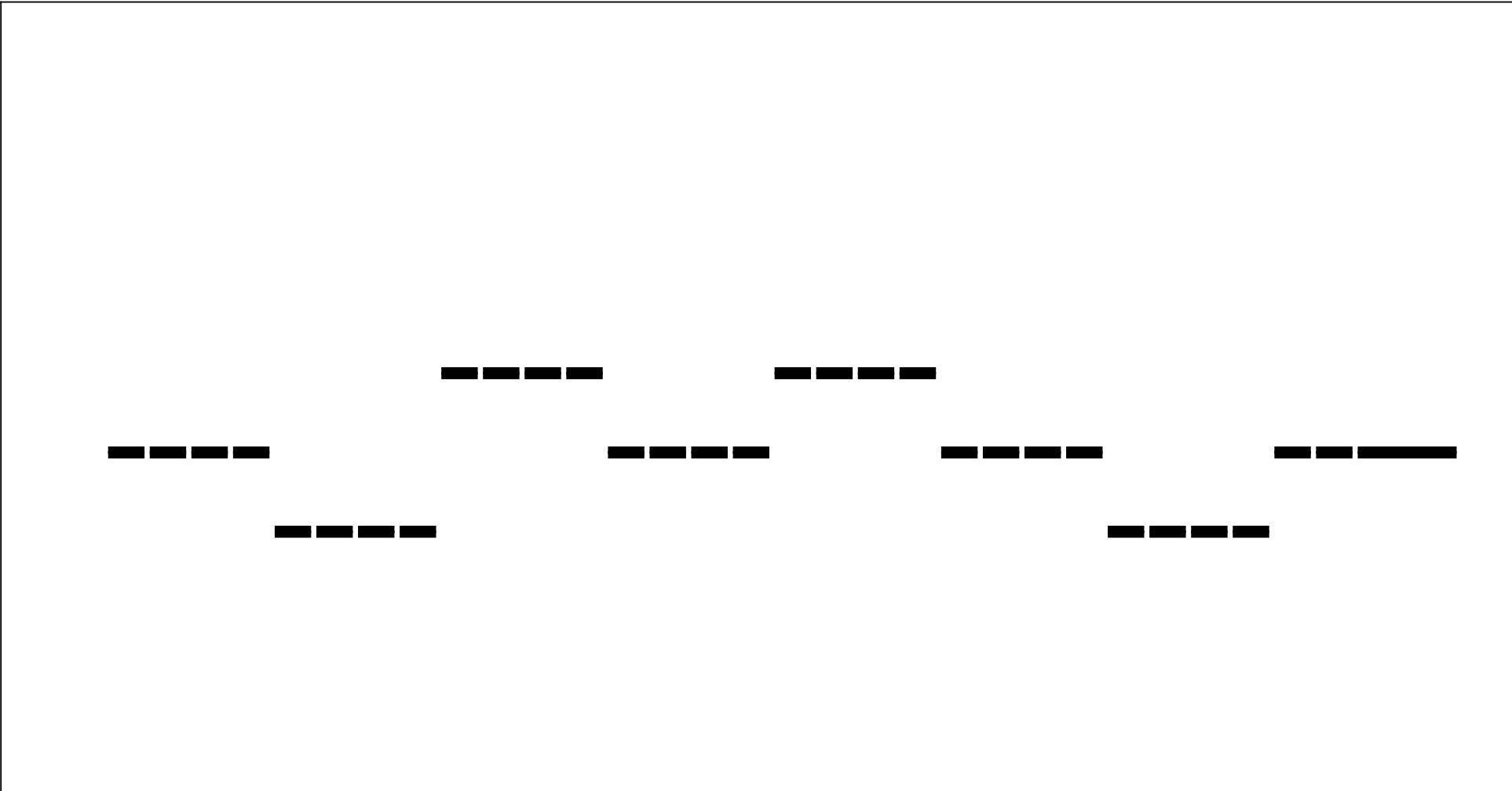
.Adapter le filtre



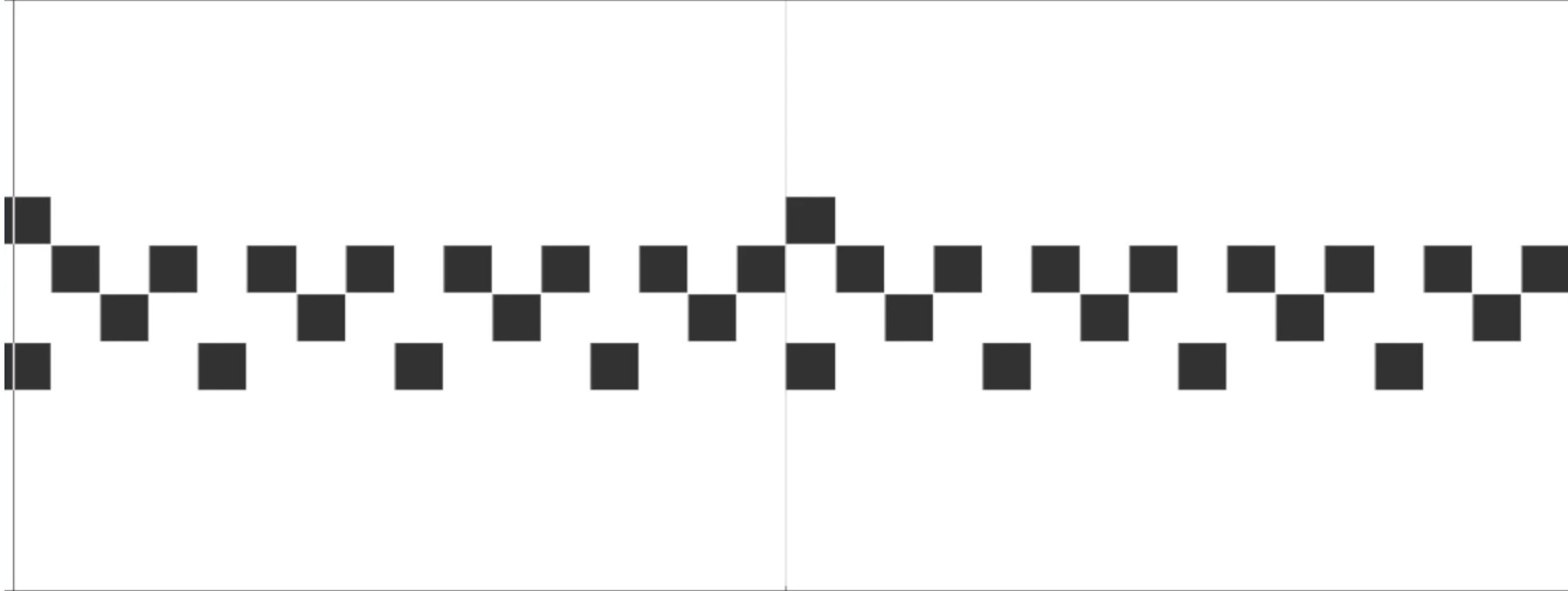
.Adapter le filtre



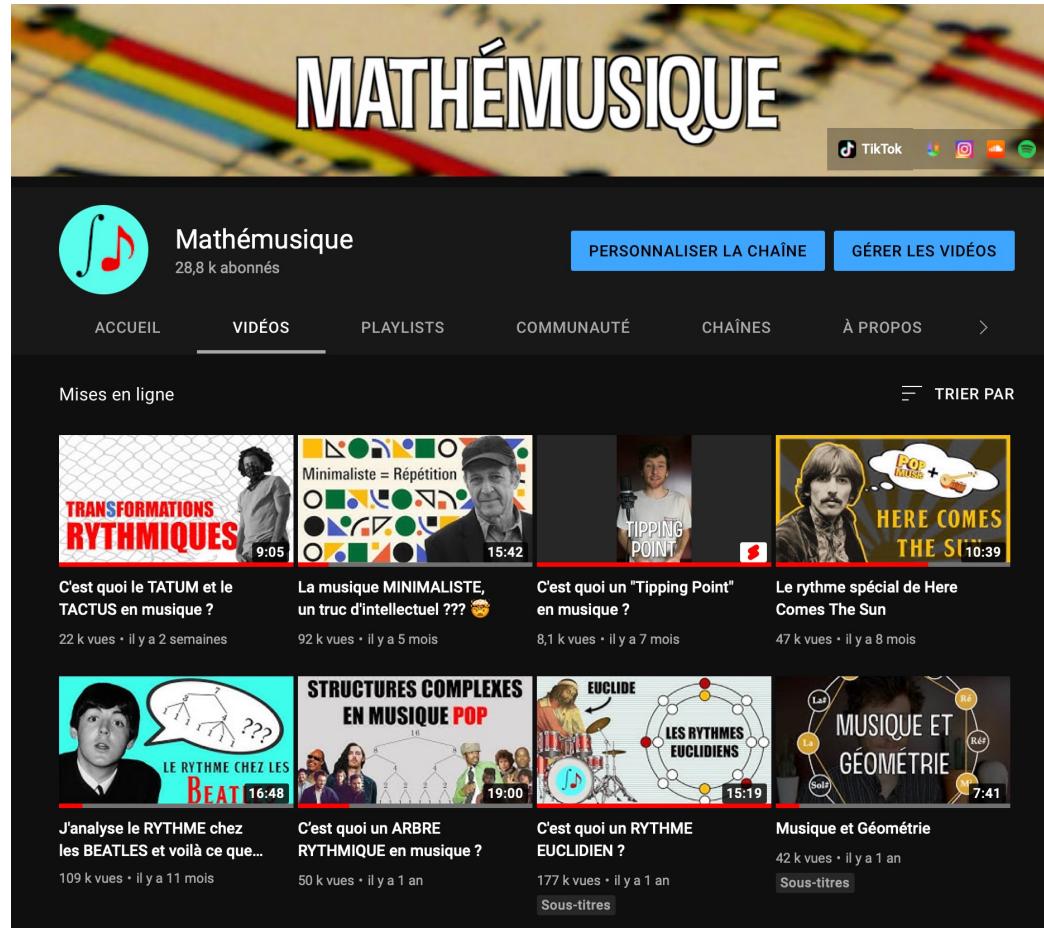
.Adapter le filtre



.Adapter le filtre



Fin !



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Bureau : A112 (1er étage)