



# Fundamentals of Music Processing

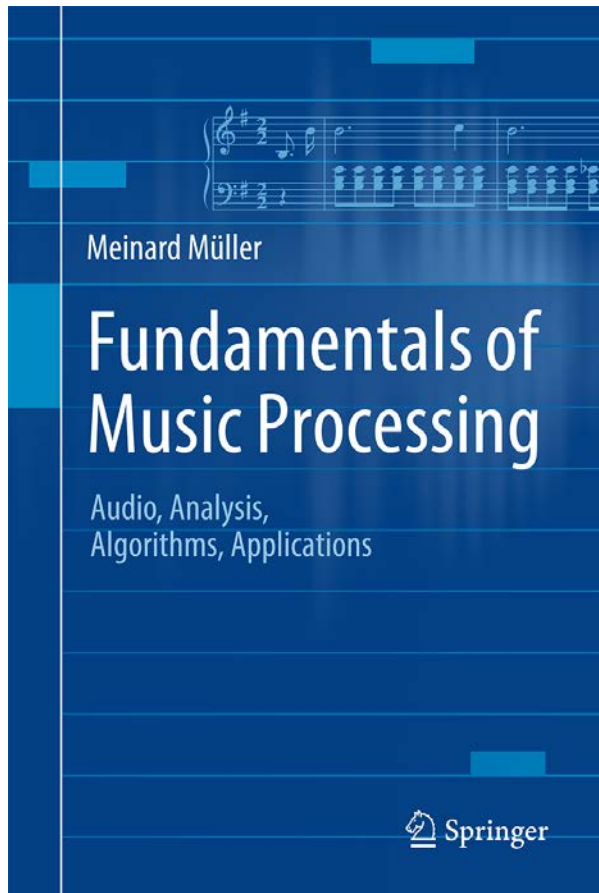
## Chapter 4: Music Structure Analysis

Meinard Müller

International Audio Laboratories Erlangen

[www.music-processing.de](http://www.music-processing.de)

# Book: Fundamentals of Music Processing

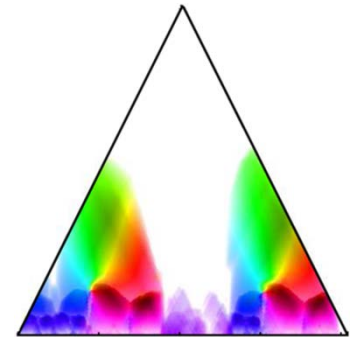


Meinard Müller  
Fundamentals of Music Processing  
Audio, Analysis, Algorithms, Applications  
483 p., 249 illus., 30 illus. in color, hardcover  
ISBN: 978-3-319-21944-8  
Springer, 2015

Accompanying website:  
[www.music-processing.de](http://www.music-processing.de)

# Chapter 4: Music Structure Analysis

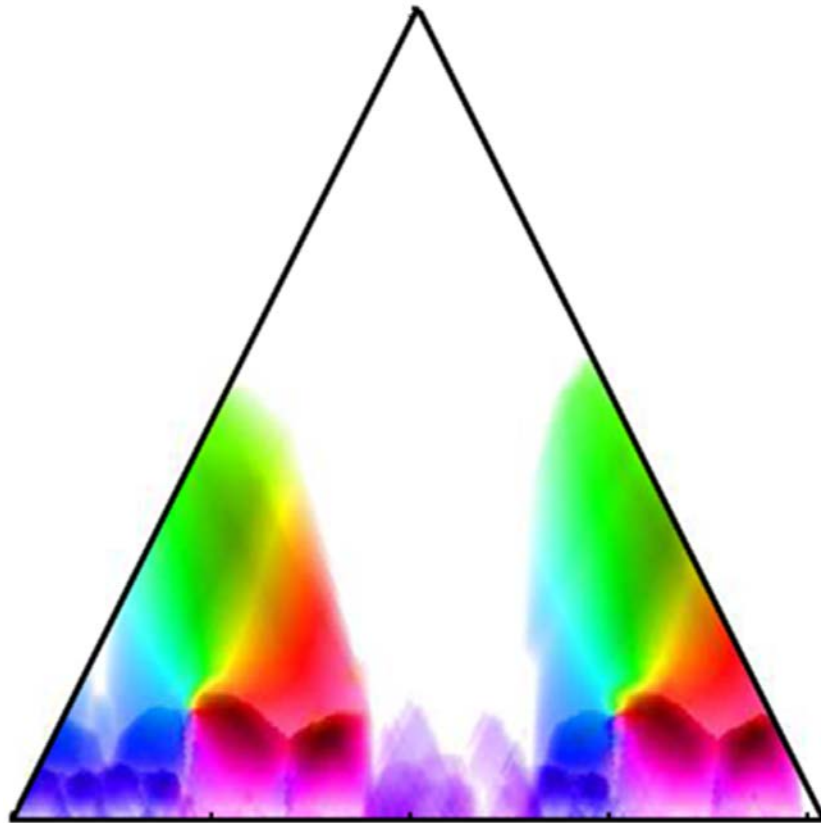
- 4.1 General Principles
- 4.2 Self-Similarity Matrices
- 4.3 Audio Thumbnailing
- 4.4 Novelty-Based Segmentation
- 4.5 Evaluation
- 4.6 Further Notes



In Chapter 4, we address a central and well-researched area within MIR known as music structure analysis. Given a music recording, the objective is to identify important structural elements and to temporally segment the recording according to these elements. Within this scenario, we discuss fundamental segmentation principles based on repetitions, homogeneity, and novelty—principles that also apply to other types of multimedia beyond music. As an important technical tool, we study in detail the concept of self-similarity matrices and discuss their structural properties. Finally, we briefly touch the topic of evaluation, introducing the notions of precision, recall, and F-measure.

# 4 Music Structure Analysis

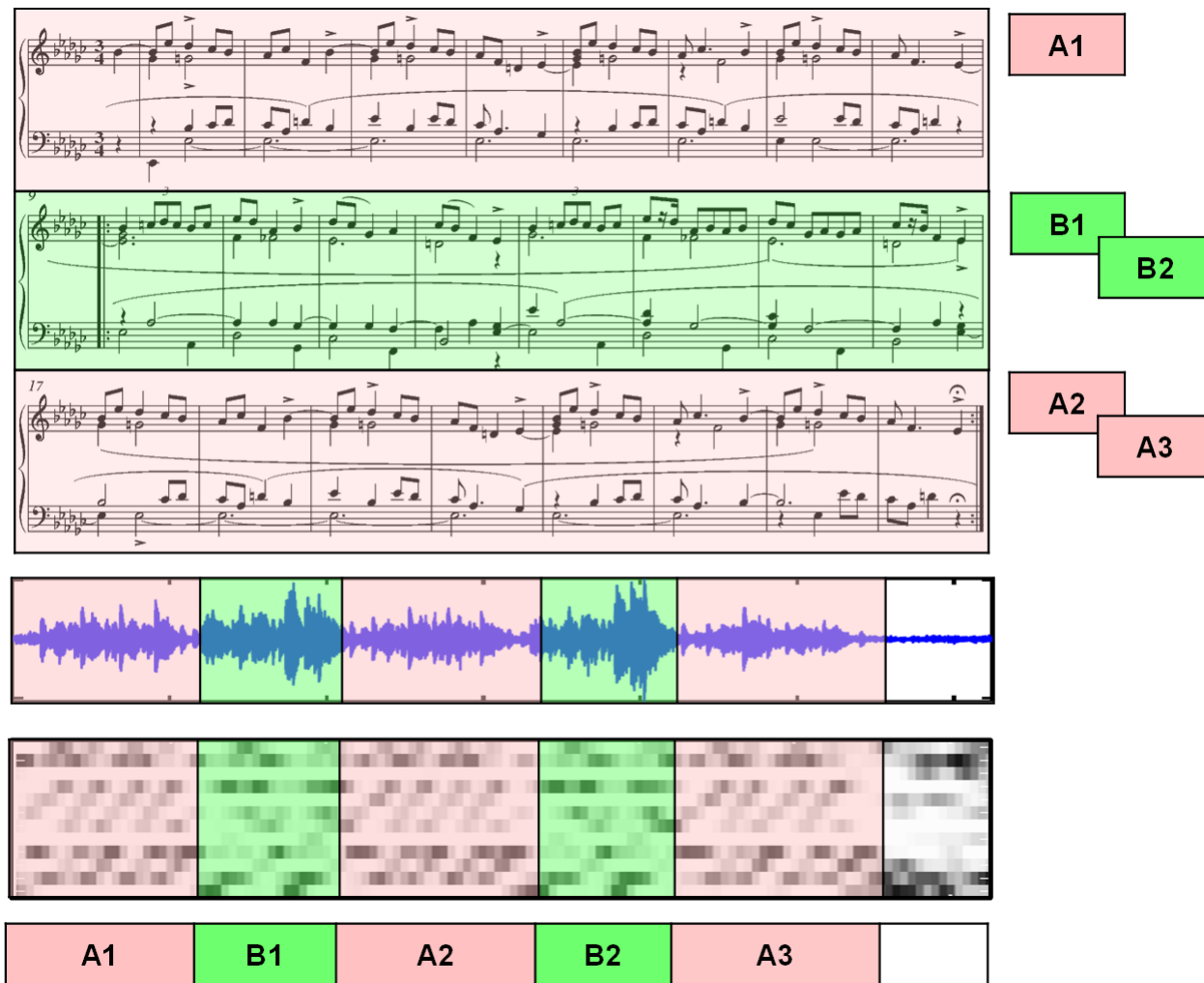
Teaser





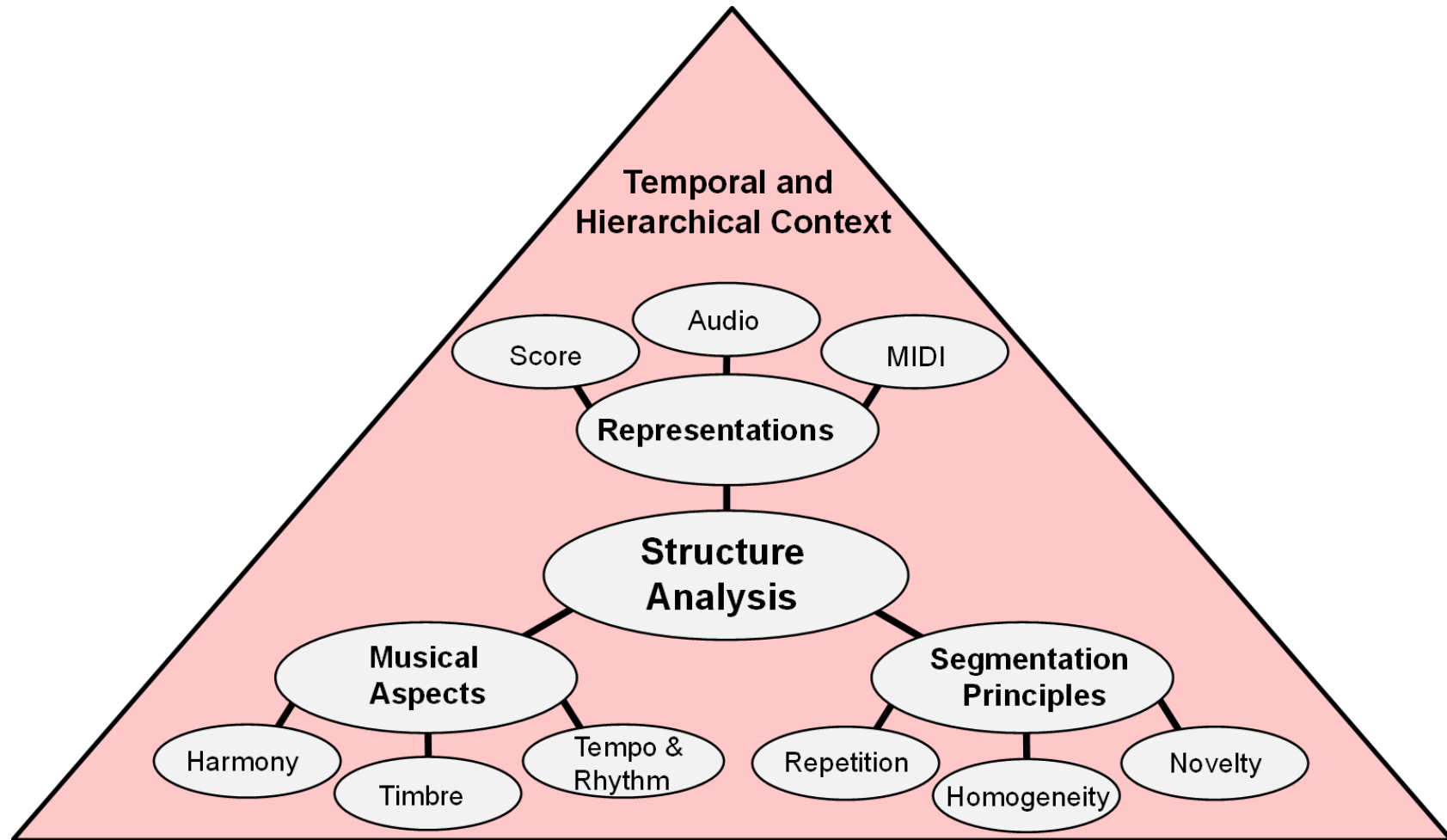
# 4 Music Structure Analysis

Fig. 4.1



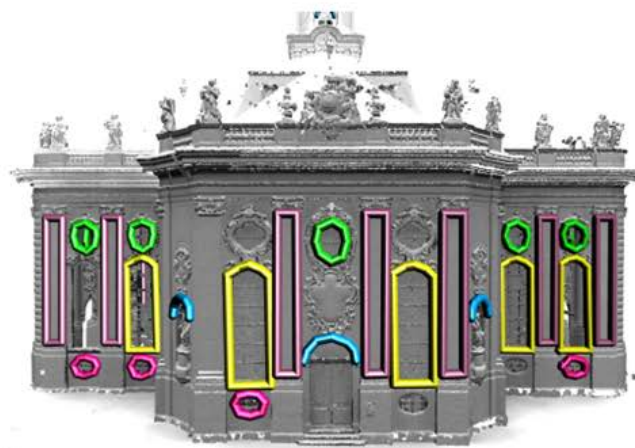
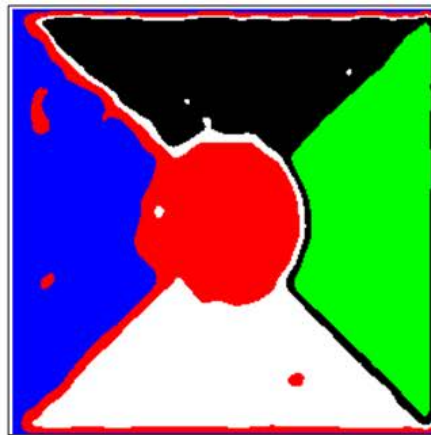
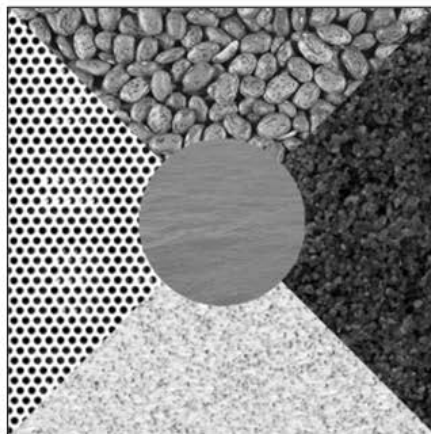
# 4.1 General Principles

Fig. 4.2



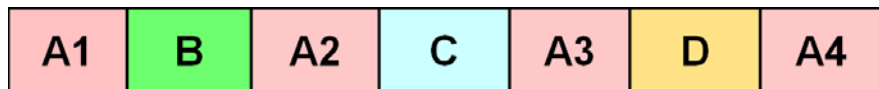
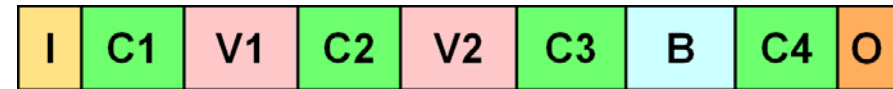
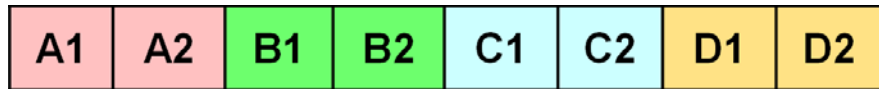
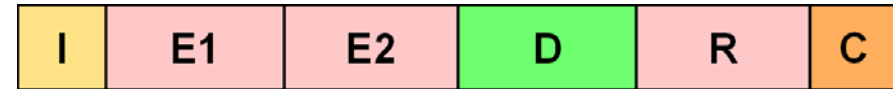
# 4.1 General Principles

Fig. 4.3



# 4.1 General Principles

Fig. 4.4



# 4.1 General Principles

Fig. 4.5

The musical score is divided into two main sections: **A** and **B**.

**Section A: Allegro.** This section begins in 2/4 time with a key signature of one flat. It features a melody in the upper voice and a rhythmic accompaniment in the lower voice. Dynamics include *f* (forte), *ff* (fortissimo), and *mf* (mezzo-forte). Tempo markings include *Allegro.*, *poco rit.*, and *in tempo*. The section concludes with a double bar line and a repeat sign.

**Section B: Vivace.** This section begins in 2/4 time with a key signature of one sharp. It features a melody in the upper voice and a rhythmic accompaniment in the lower voice. Dynamics include *f*, *ff*, *p* (piano), and *legg.* (leggiero). Tempo markings include *Vivace.*, *poco ritard.*, *in tempo*, and *rit.*. The section is divided into sub-sections **C**, **D**, and **E**. It concludes with a double bar line and a repeat sign.



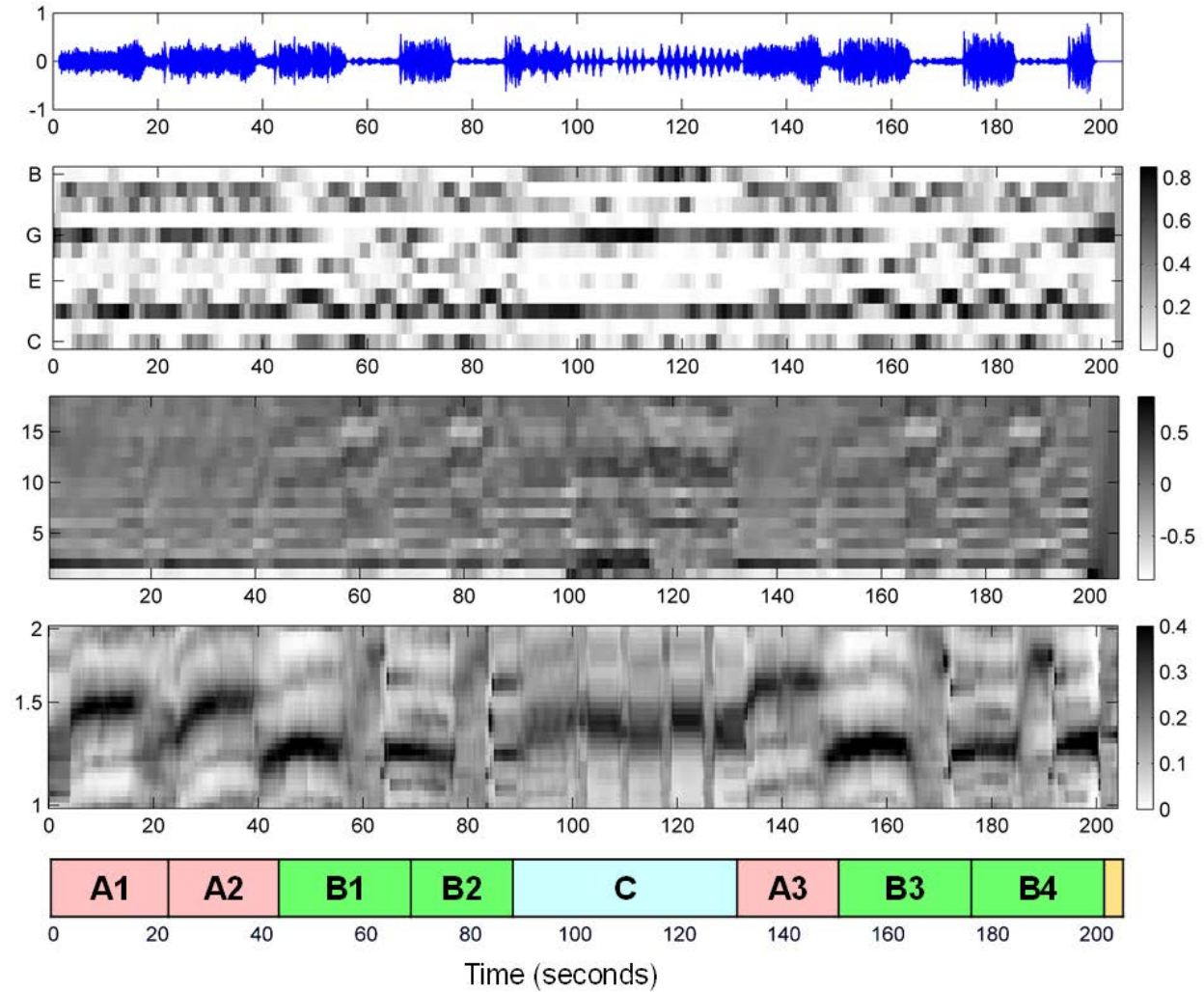
# 4.1 General Principles

Fig. 4.5

The image displays a musical score with several staves. The score is divided into sections labeled A1, A2, B1, B2, C, A3, B3, B4, and D. The sections are highlighted with colored boxes: A1 and A2 are pink, B1 and B2 are green, C is light blue, A3 is pink, B3 and B4 are green, and D is yellow. The score includes various musical notations such as notes, rests, and dynamic markings like *f*, *ff*, *p*, *marc.*, *poco rit.*, *in tempo*, *poco ritard.*, *legg.*, and *ff marcato*. The tempo markings include *Allegro.* and *Vivace.*. The score is written in 2/4 time and features a variety of rhythmic patterns and articulations.

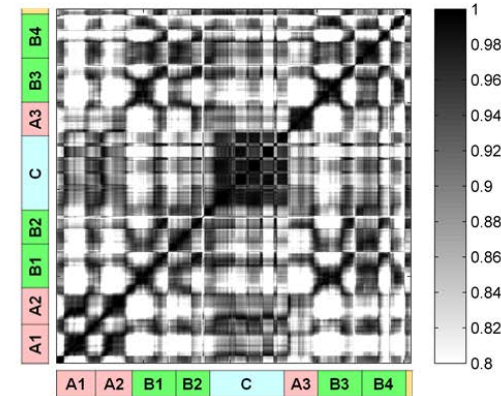
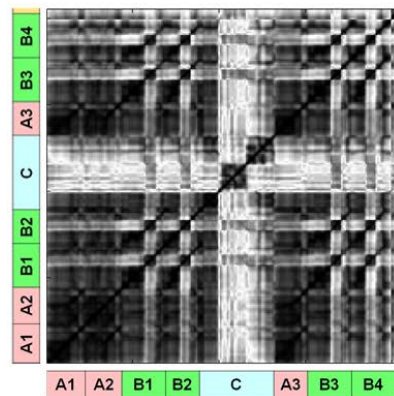
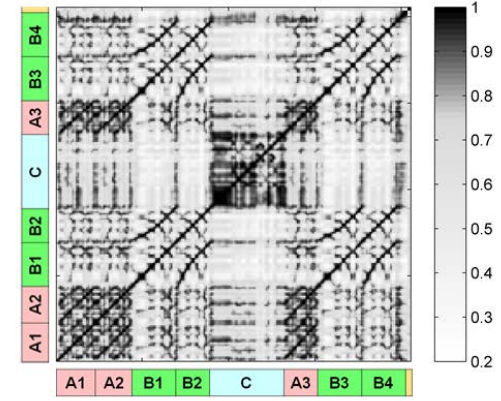
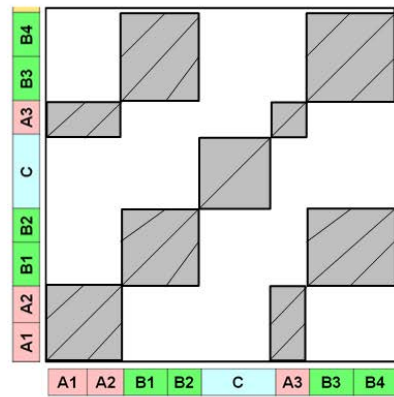
# 4.1 General Principles

Fig. 4.6



# 4.2 Self-Similarity Matrices

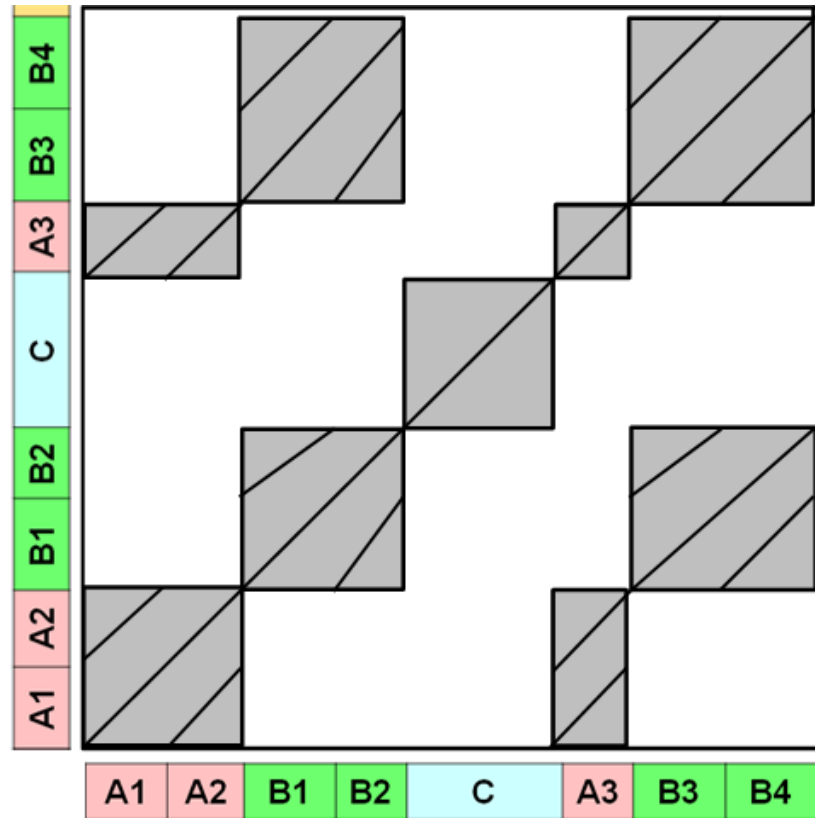
Fig. 4.7





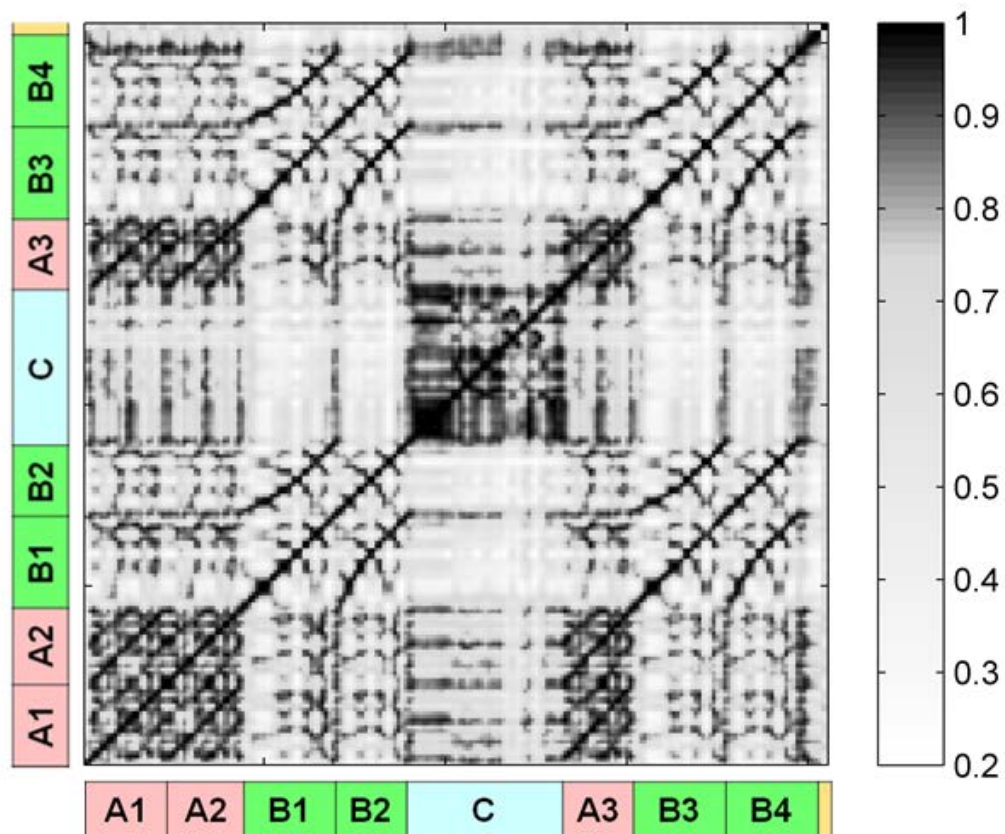
# 4.2 Self-Similarity Matrices

Fig. 4.7



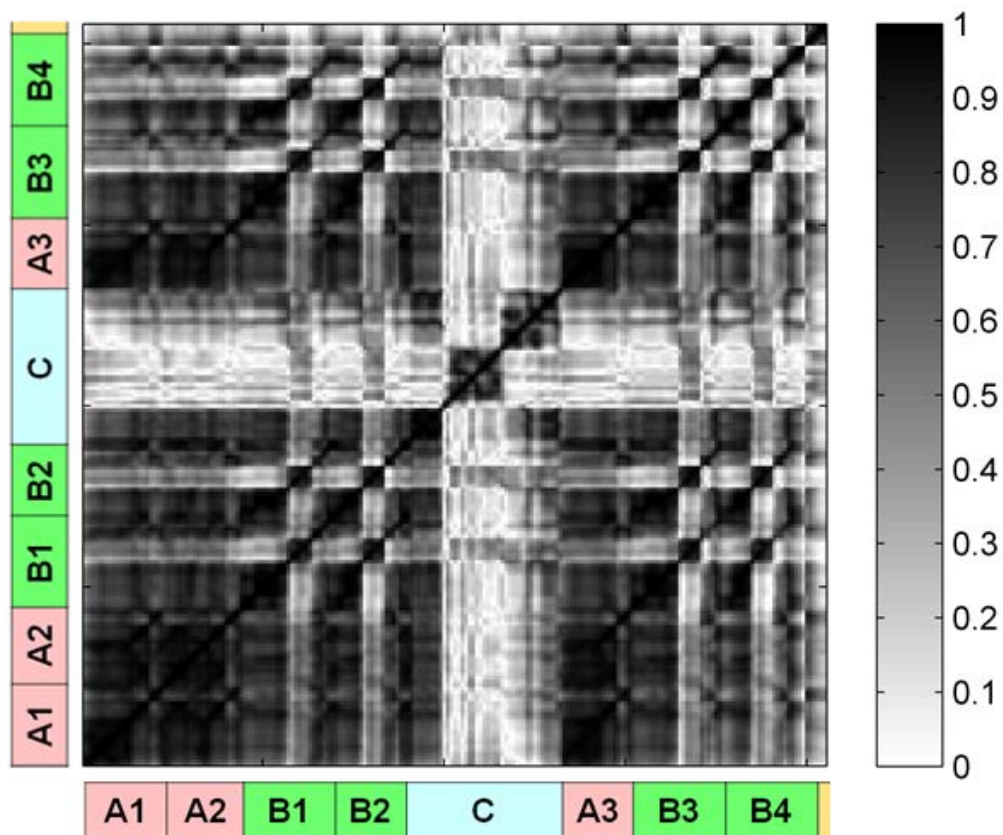
## 4.2 Self-Similarity Matrices

Fig. 4.7



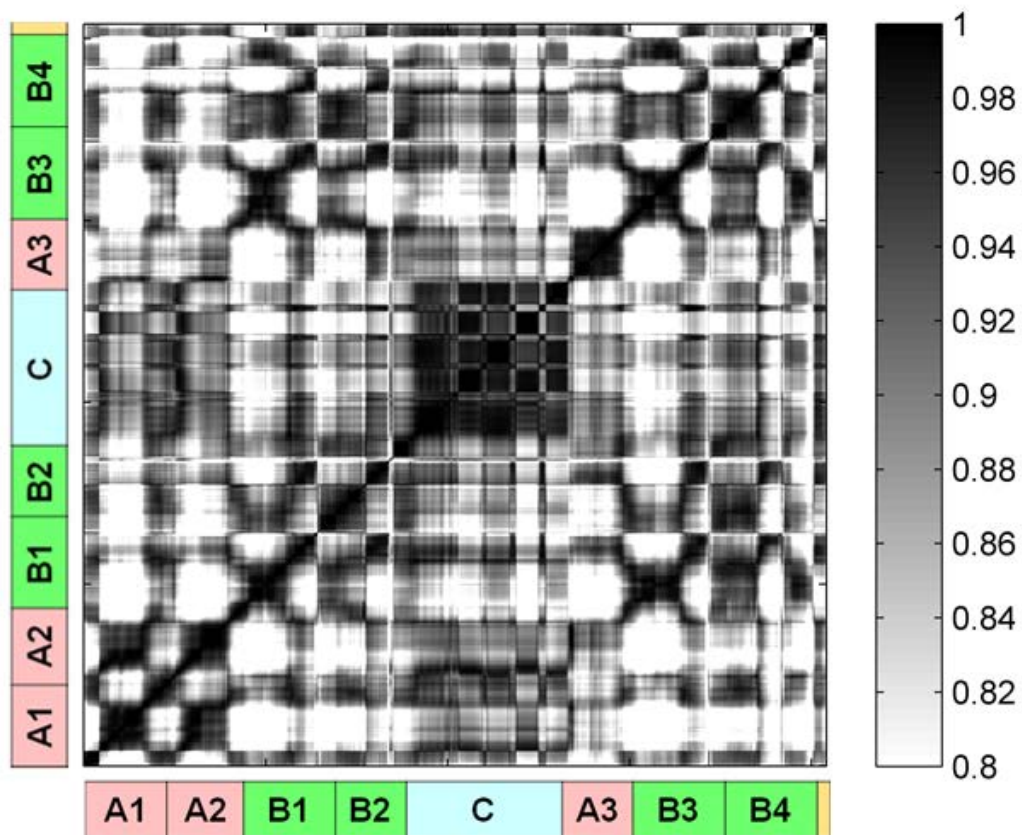
## 4.2 Self-Similarity Matrices

Fig. 4.7



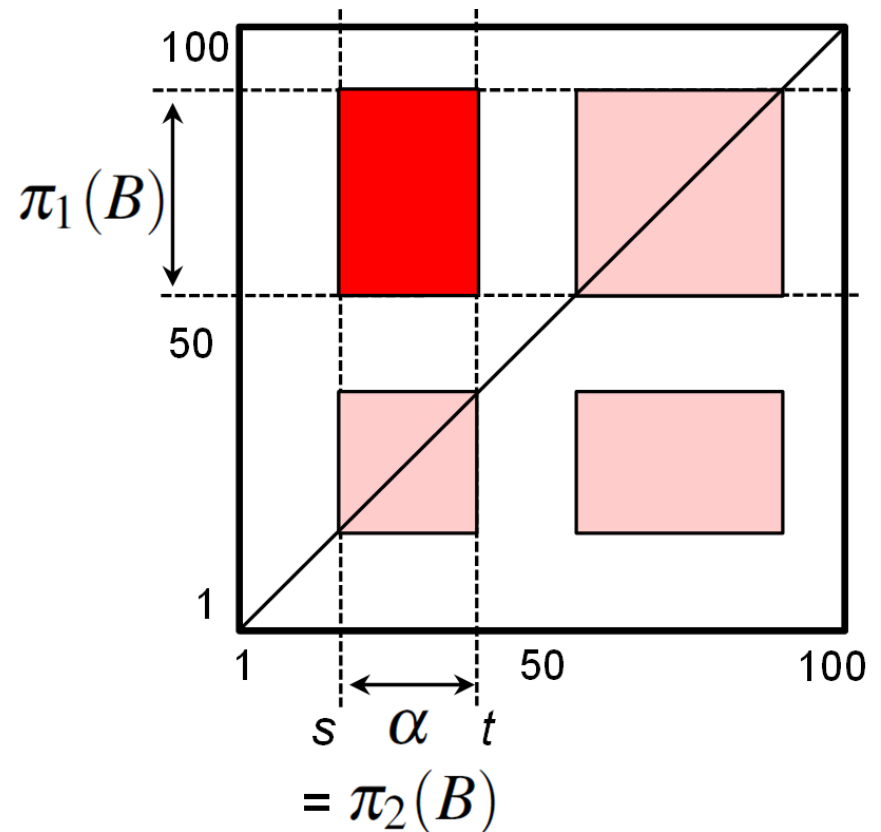
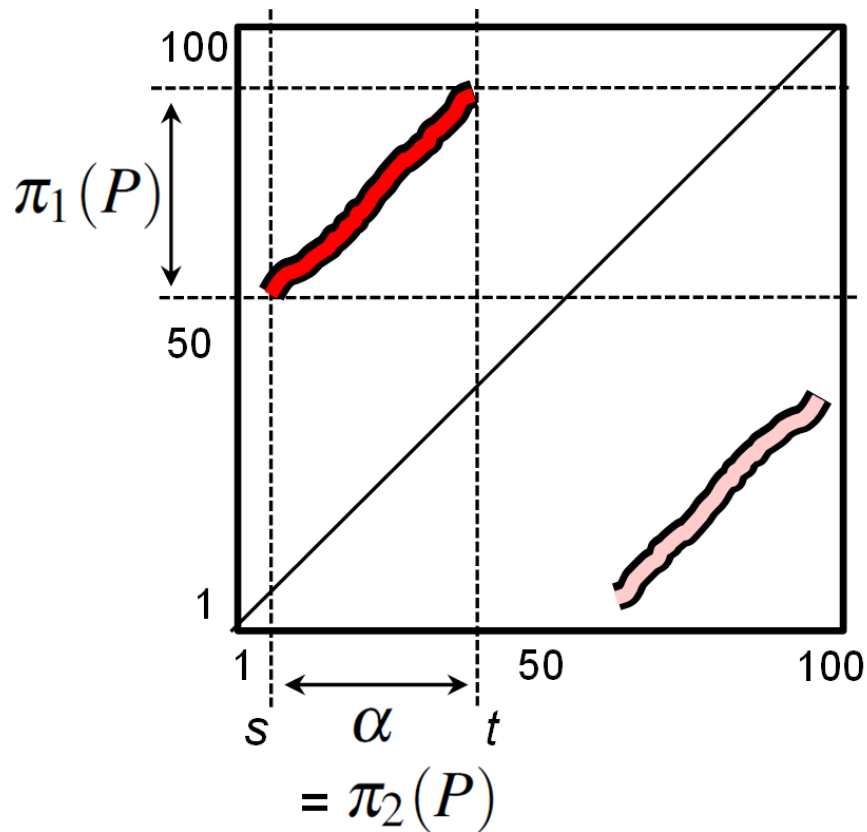
## 4.2 Self-Similarity Matrices

Fig. 4.7



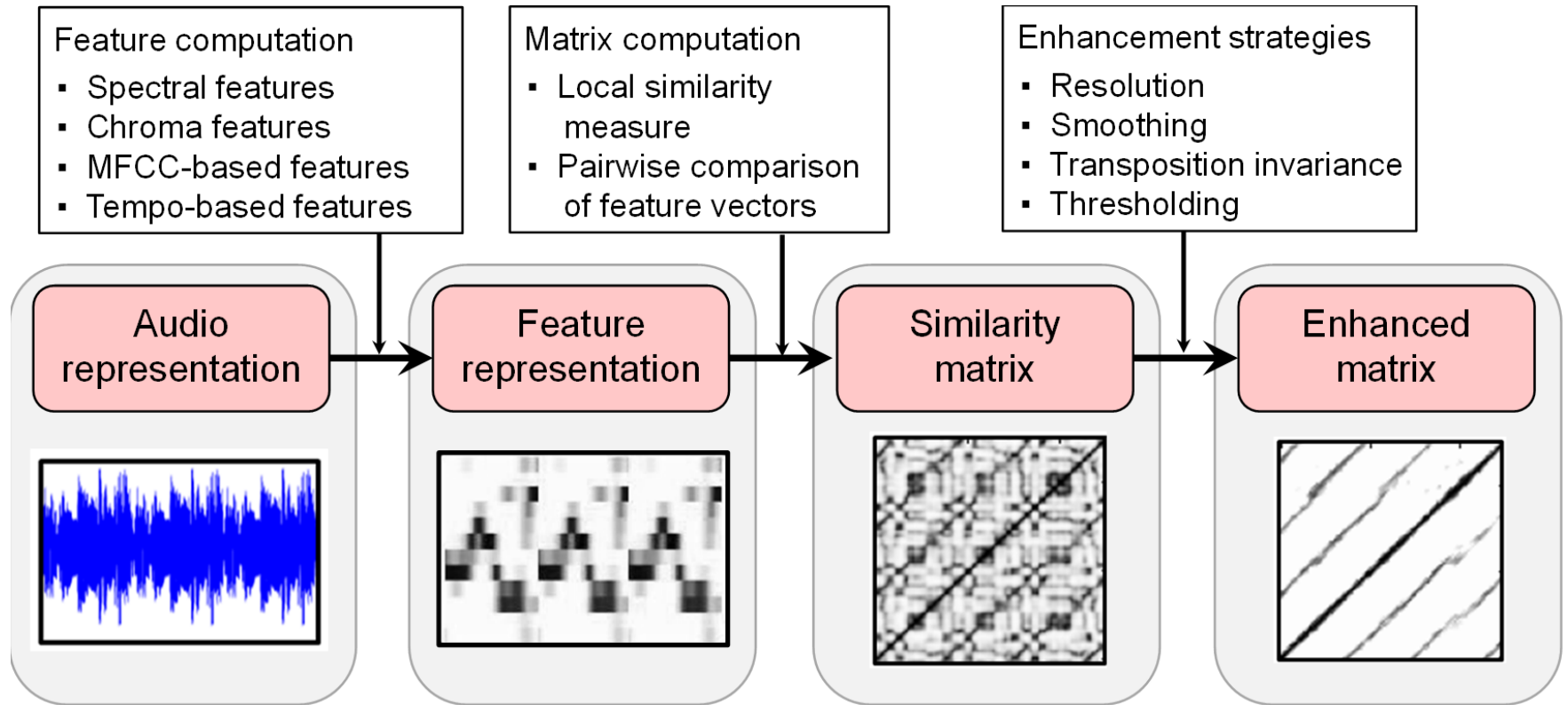
# 4.2 Self-Similarity Matrices

Fig. 4.8



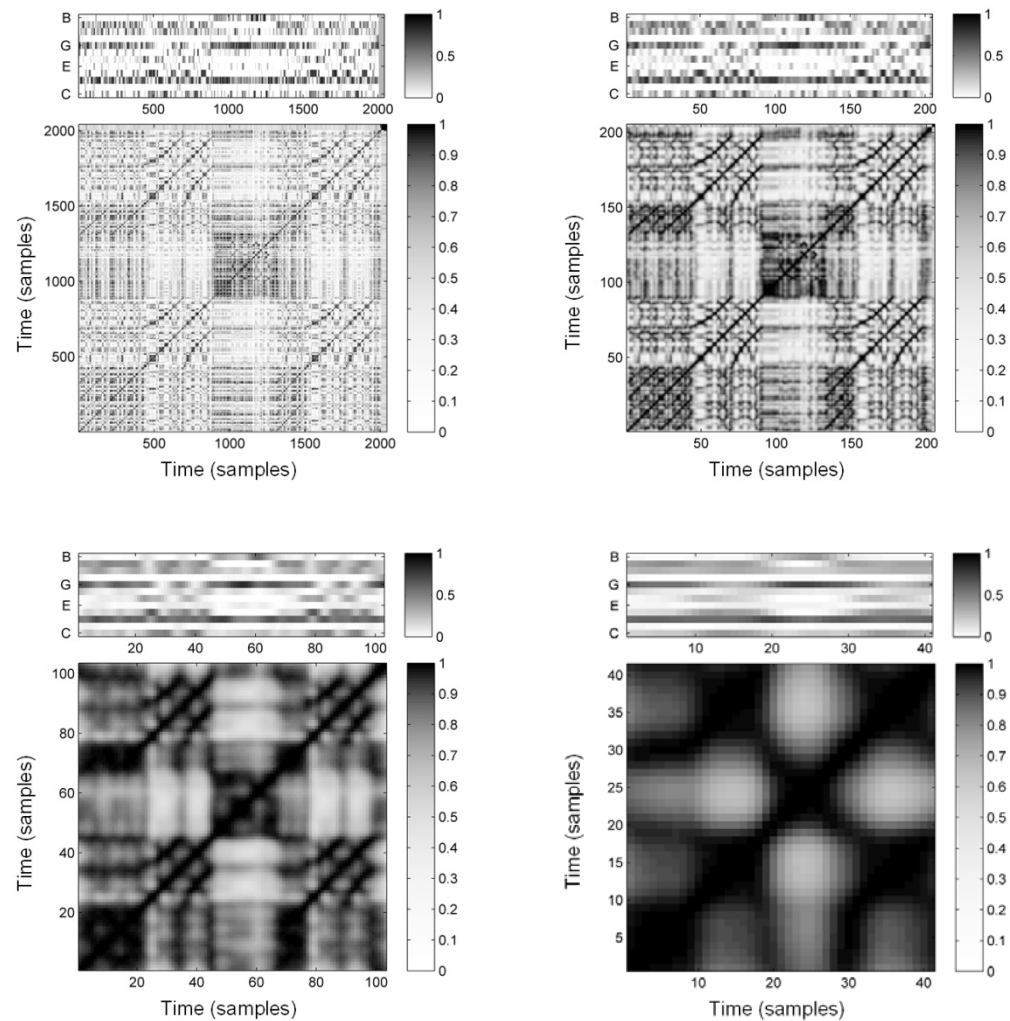
# 4.2 Self-Similarity Matrices

Fig. 4.9



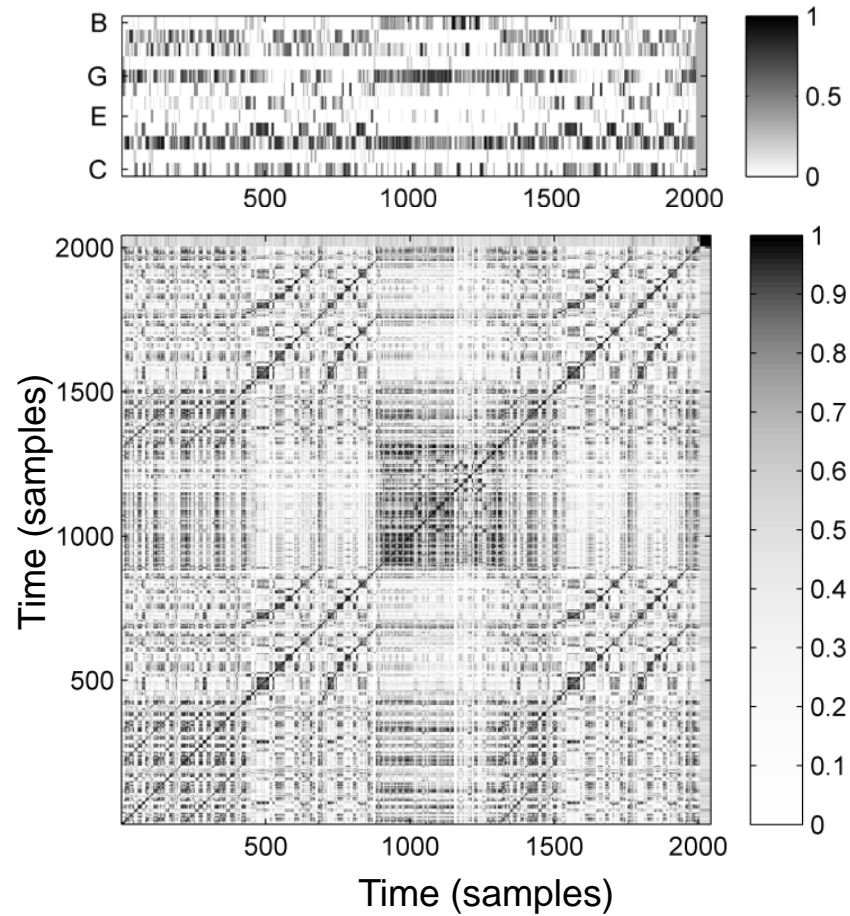
# 4.2 Self-Similarity Matrices

Fig. 4.10



# 4.2 Self-Similarity Matrices

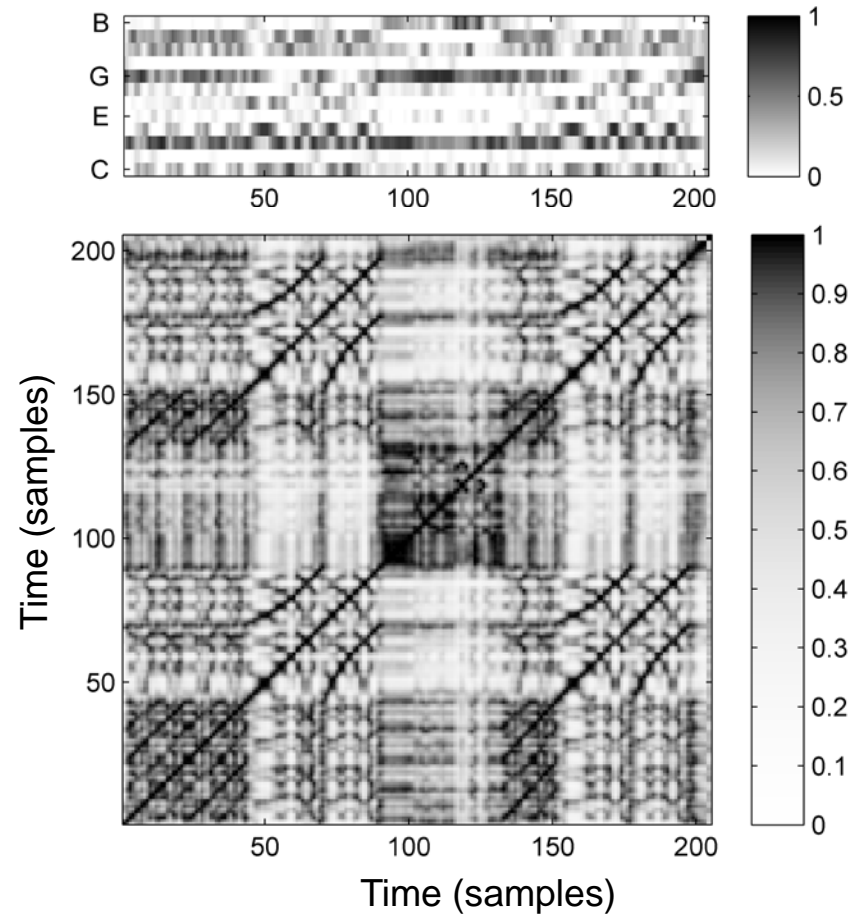
Fig. 4.10





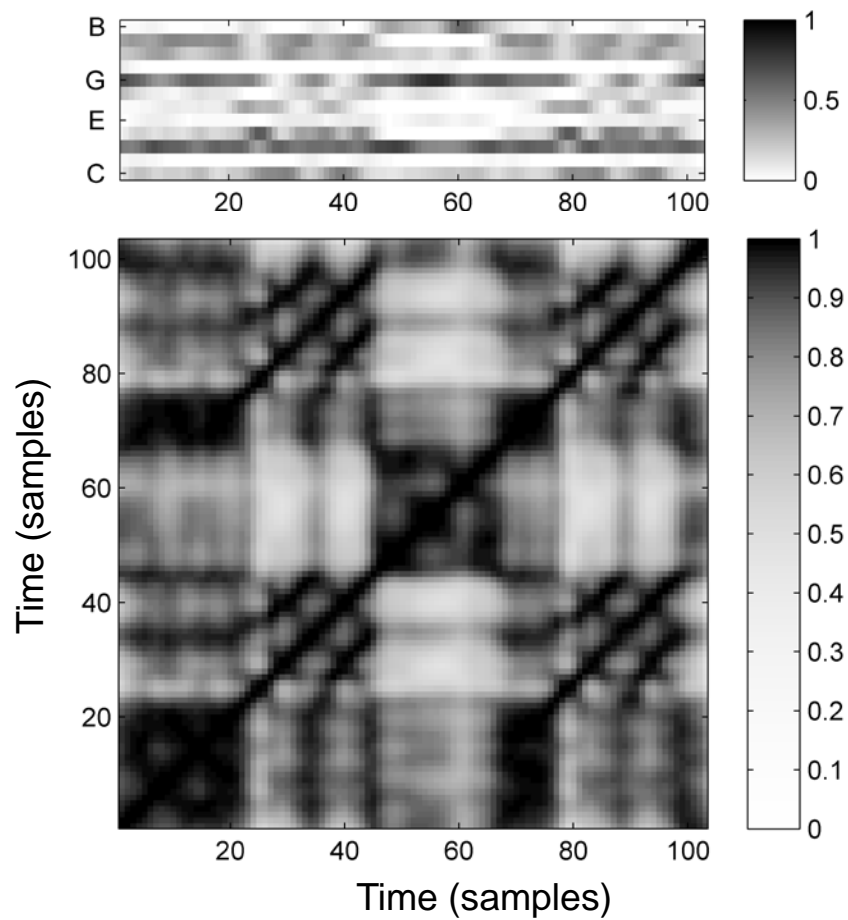
## 4.2 Self-Similarity Matrices

Fig. 4.10



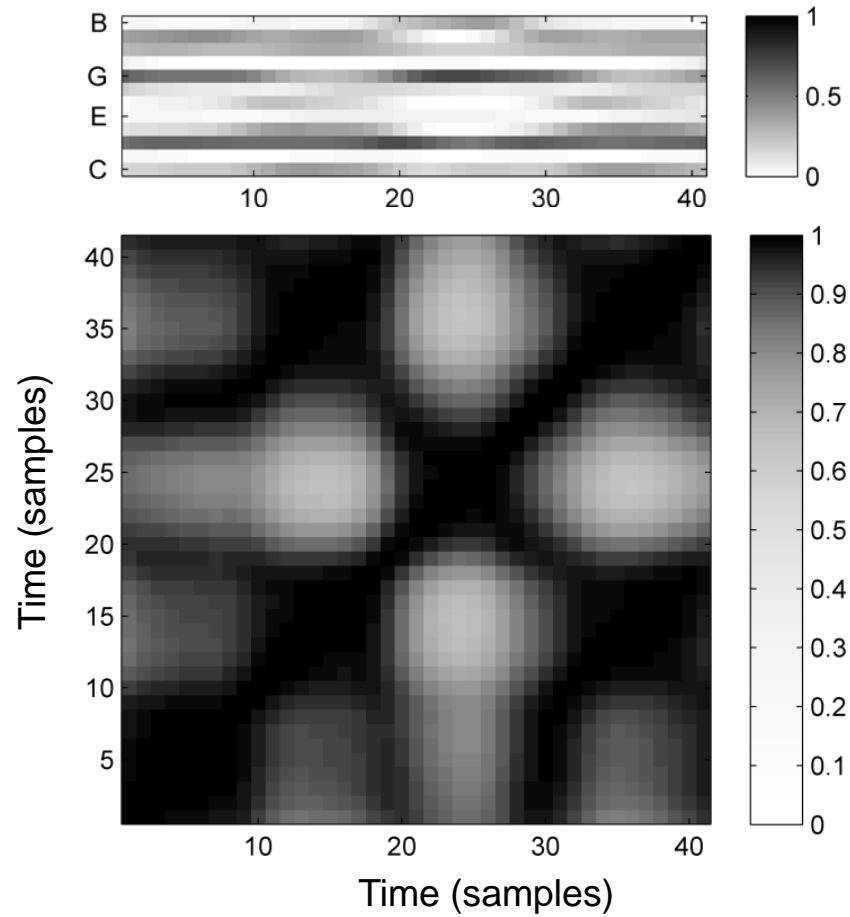
## 4.2 Self-Similarity Matrices

Fig. 4.10



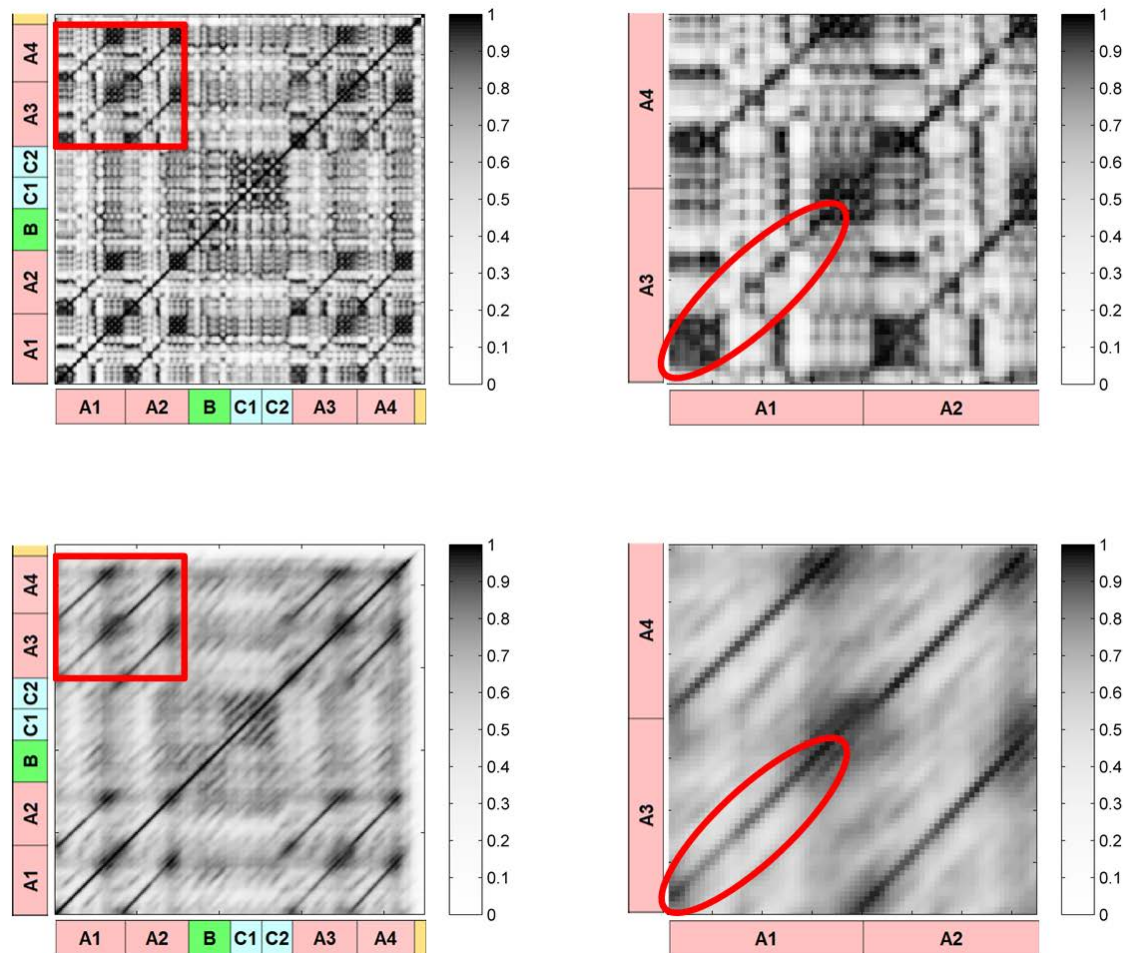
## 4.2 Self-Similarity Matrices

Fig. 4.10



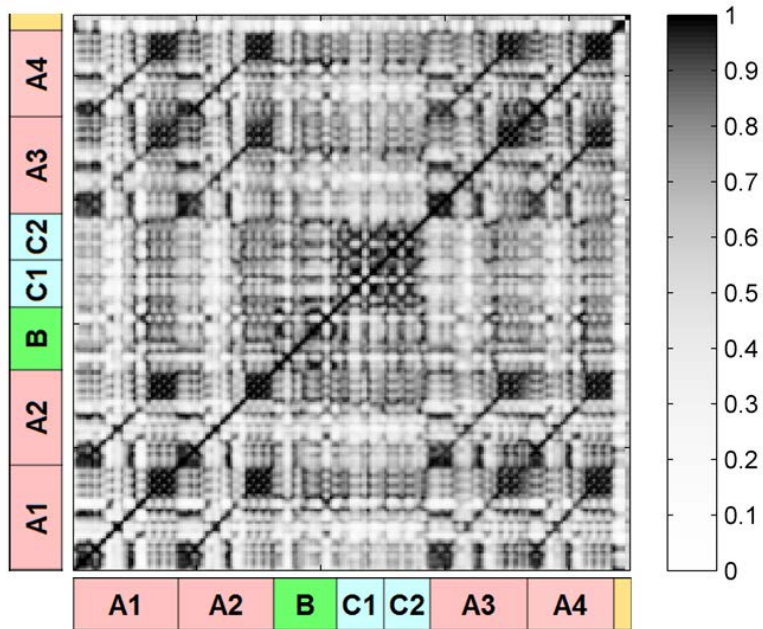
# 4.2 Self-Similarity Matrices

Fig. 4.11



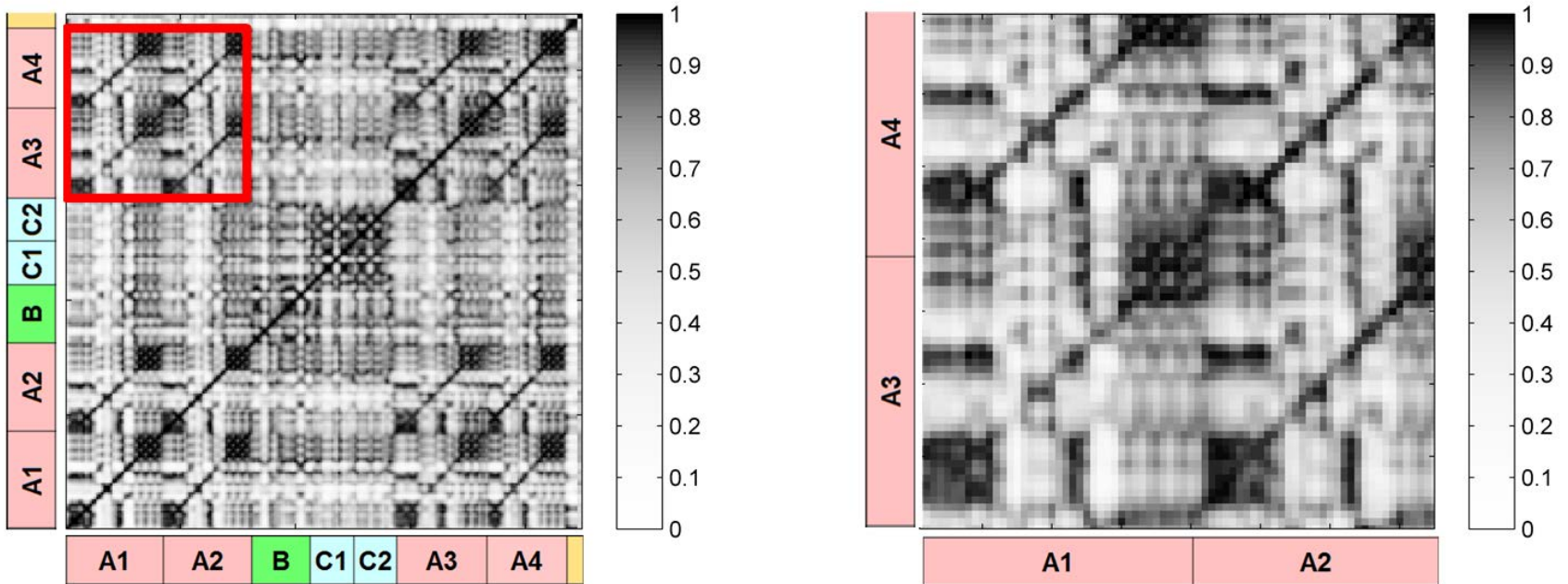
# 4.2 Self-Similarity Matrices

Fig. 4.11



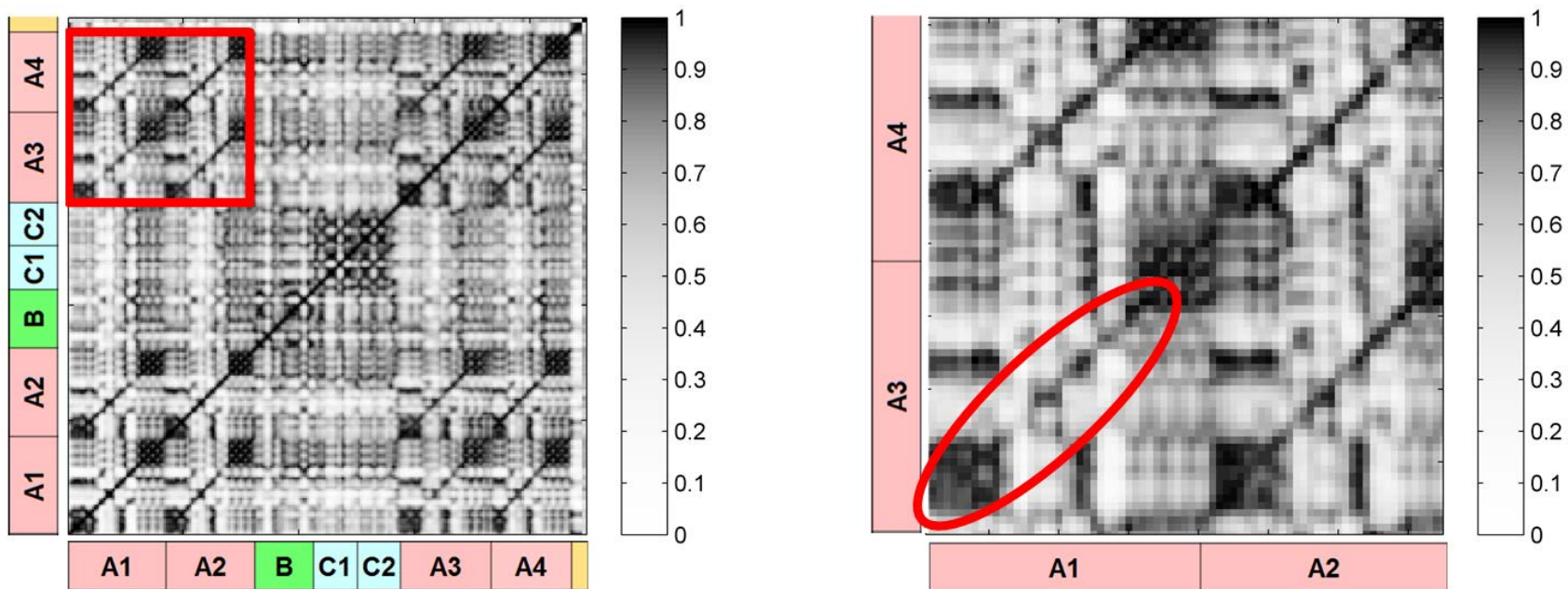
# 4.2 Self-Similarity Matrices

Fig. 4.11



## 4.2 Self-Similarity Matrices

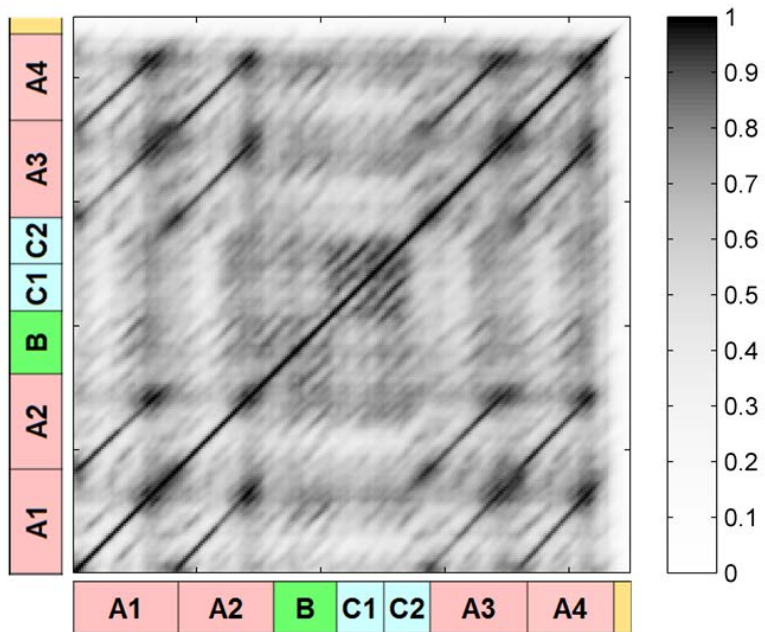
Fig. 4.11





## 4.2 Self-Similarity Matrices

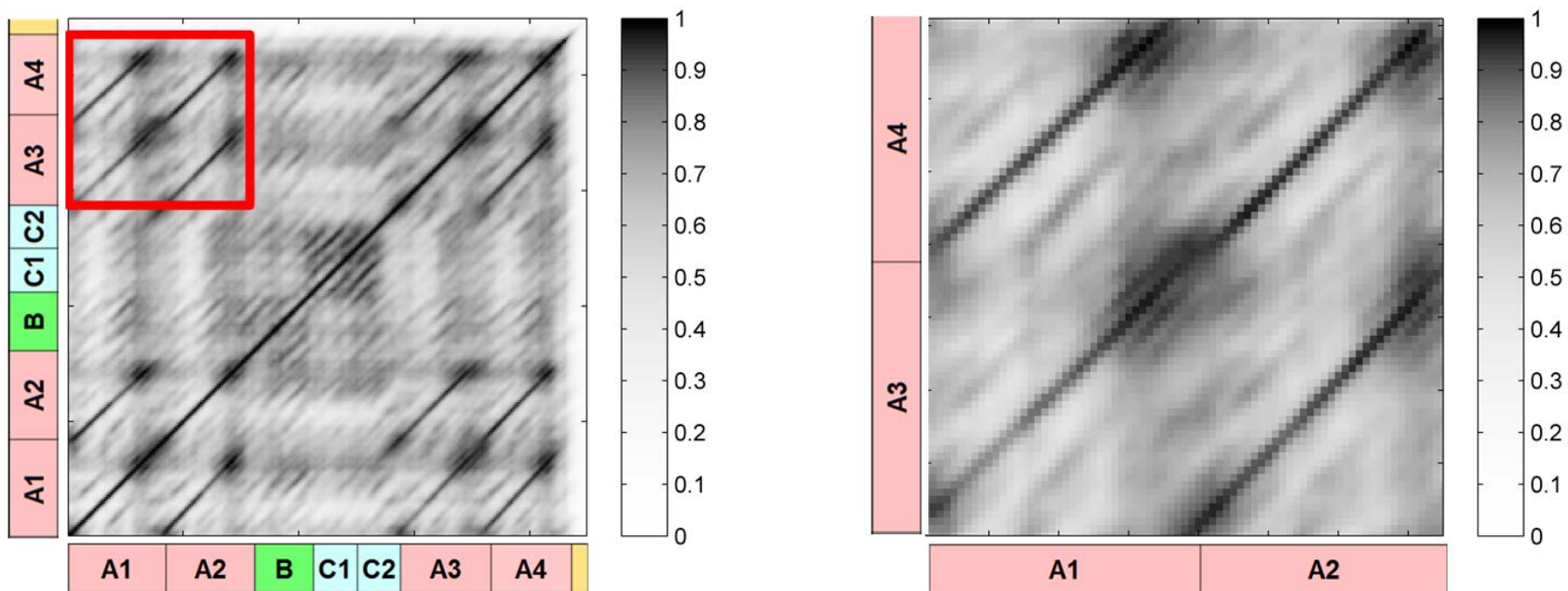
Fig. 4.11





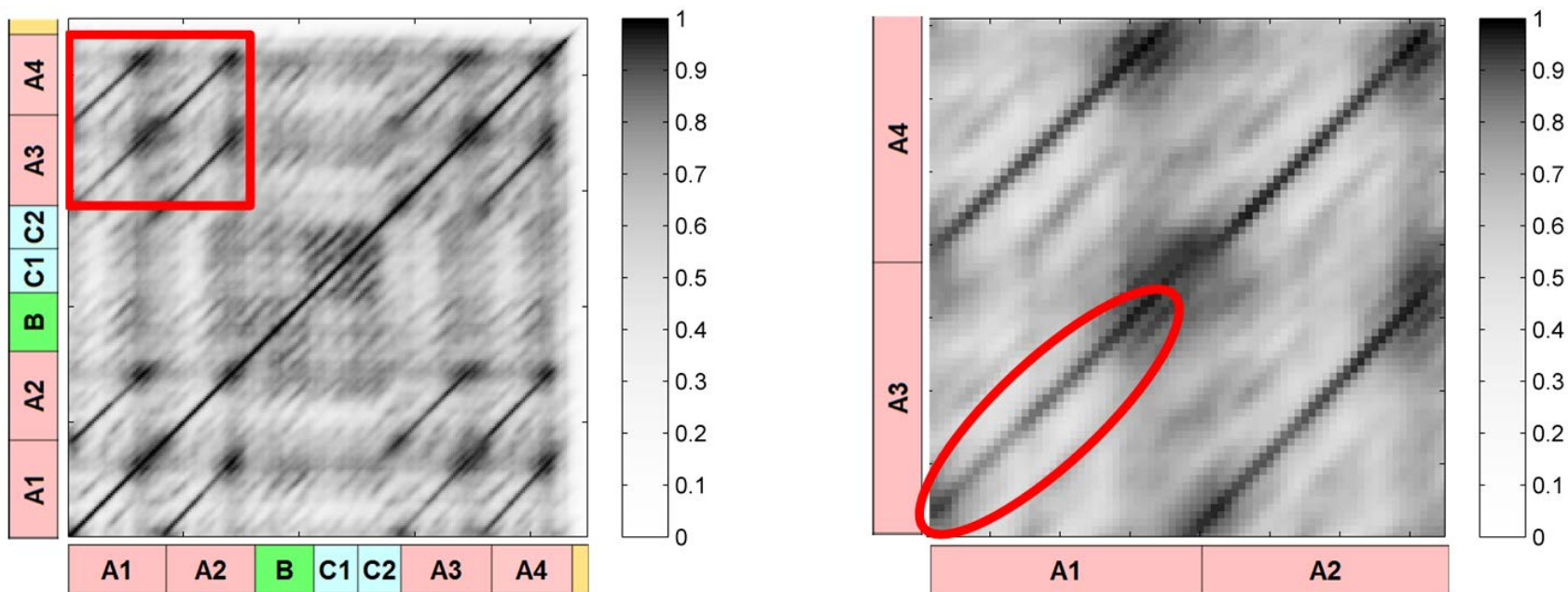
## 4.2 Self-Similarity Matrices

Fig. 4.11



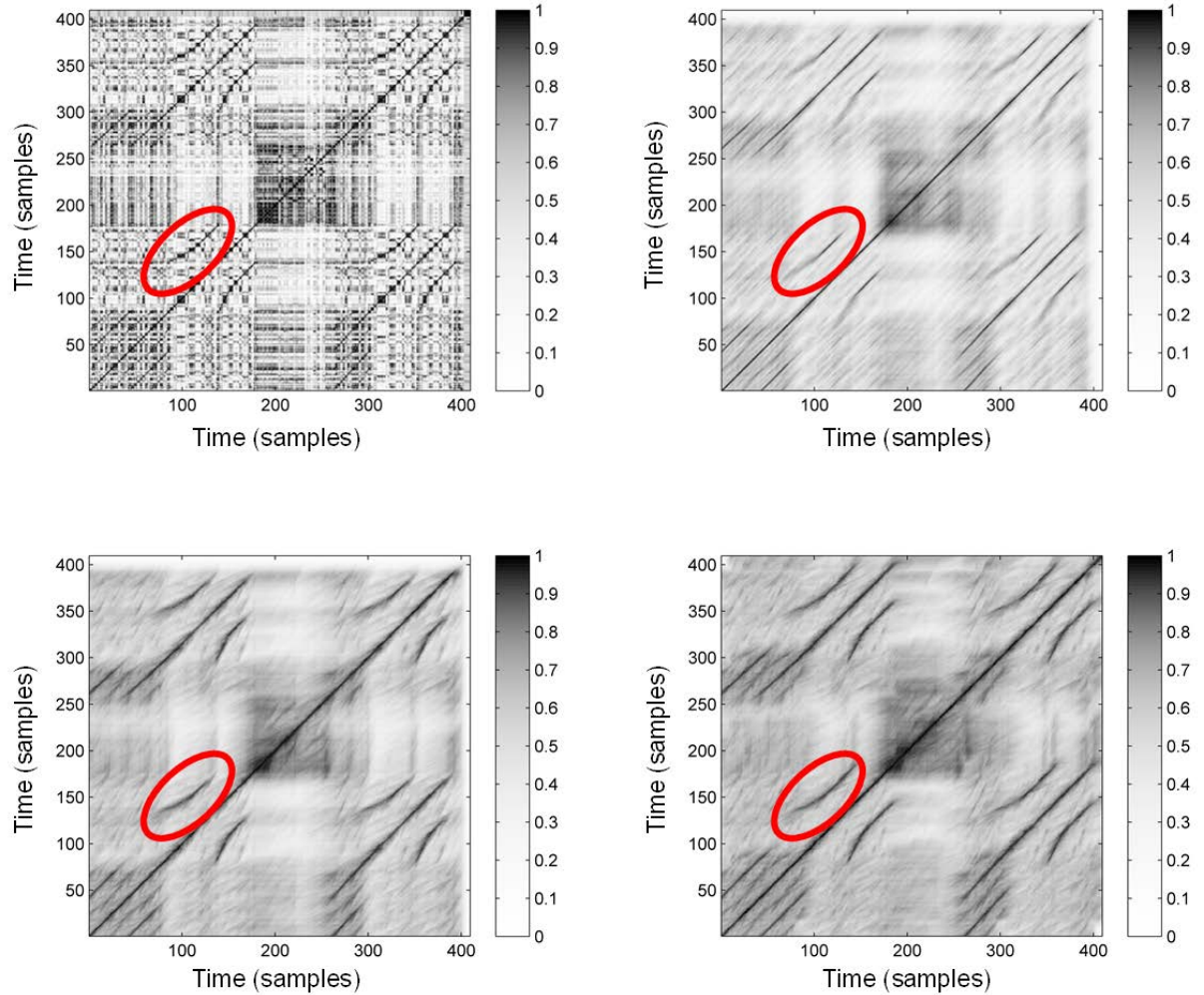
## 4.2 Self-Similarity Matrices

Fig. 4.11



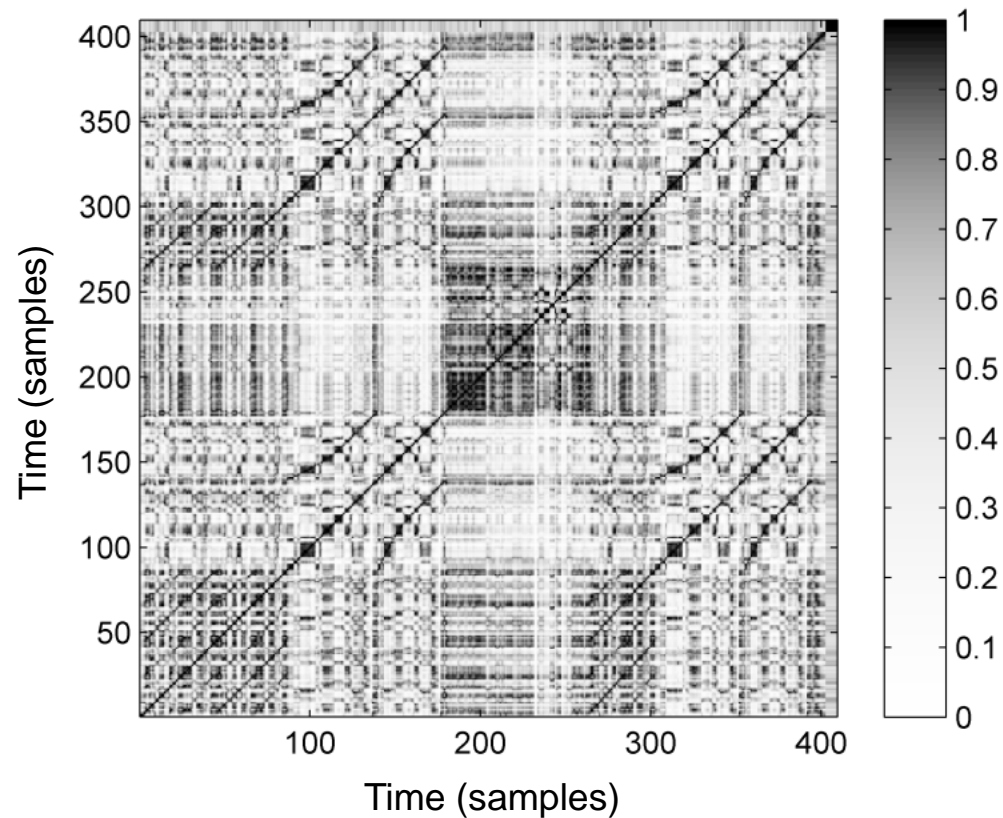
# 4.2 Self-Similarity Matrices

Fig. 4.12



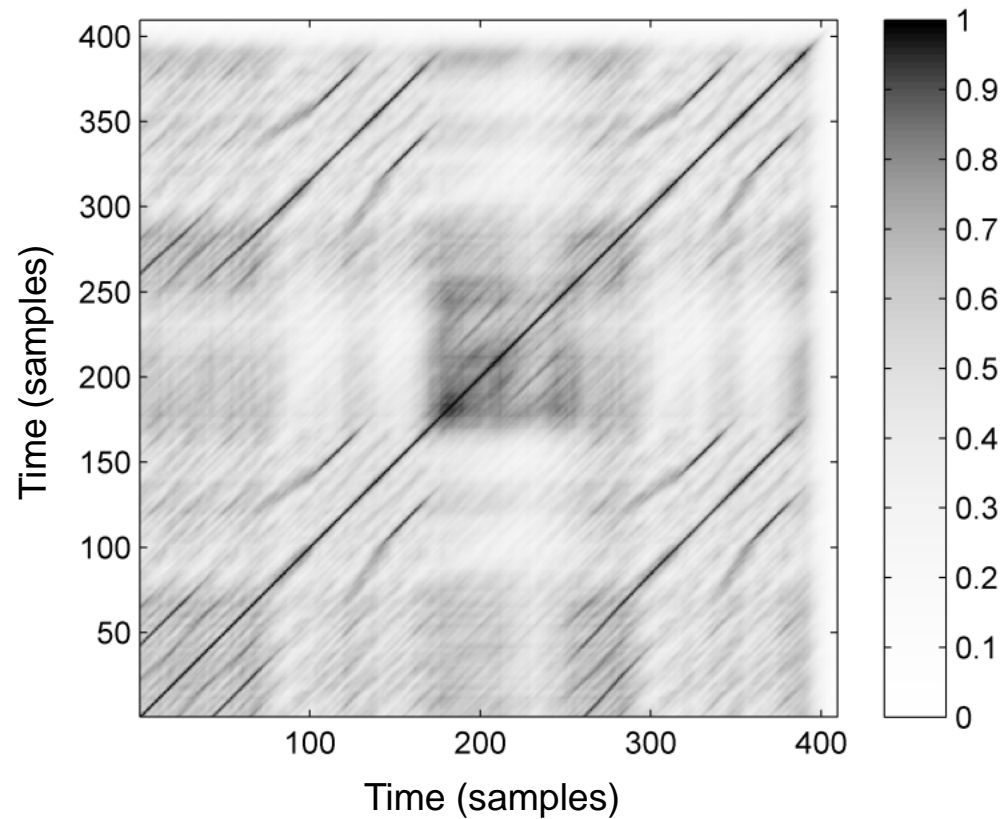
## 4.2 Self-Similarity Matrices

Fig. 4.12



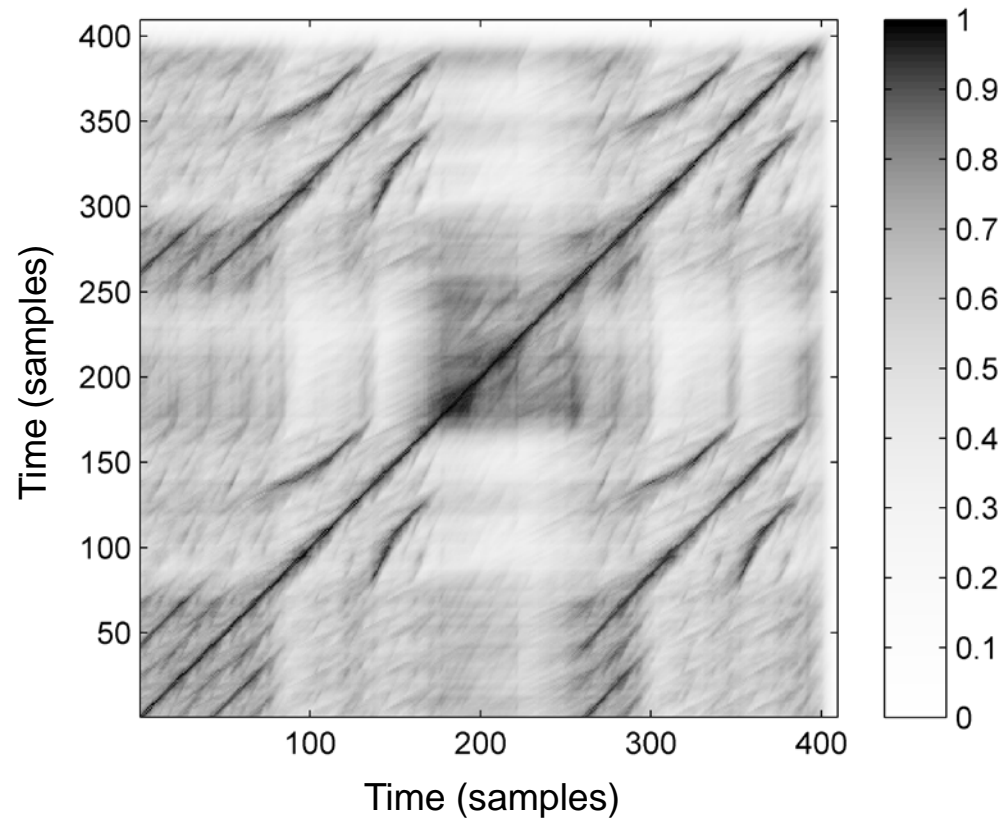
## 4.2 Self-Similarity Matrices

Fig. 4.12



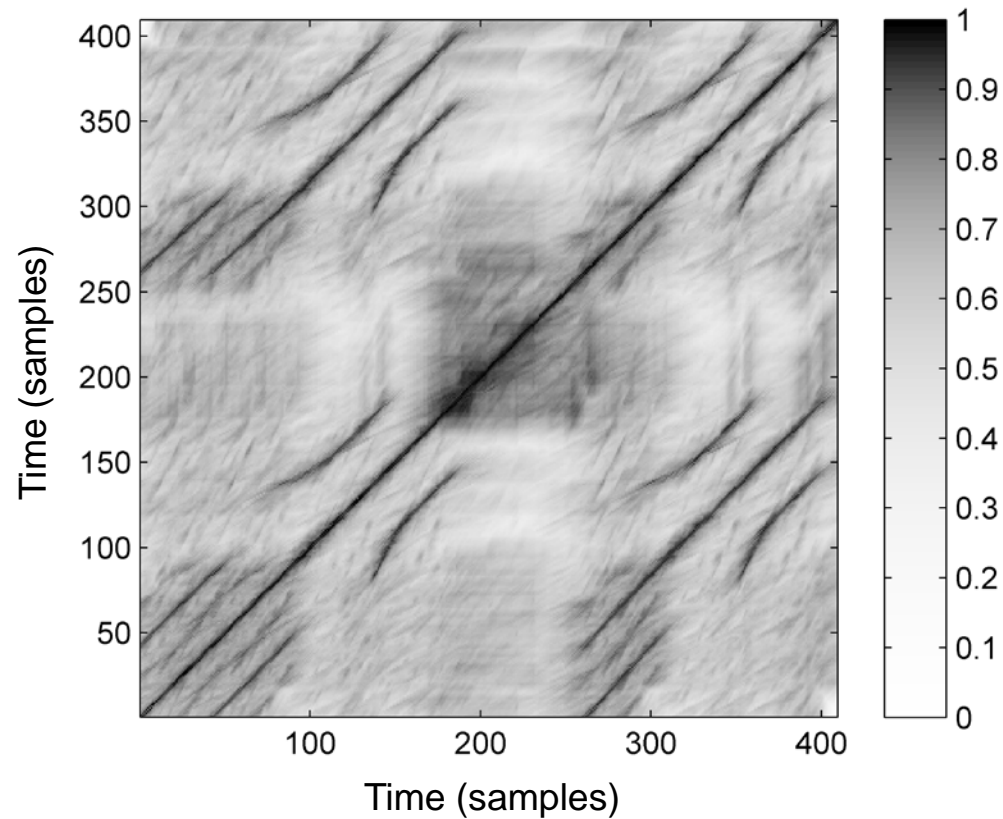
## 4.2 Self-Similarity Matrices

Fig. 4.12



## 4.2 Self-Similarity Matrices

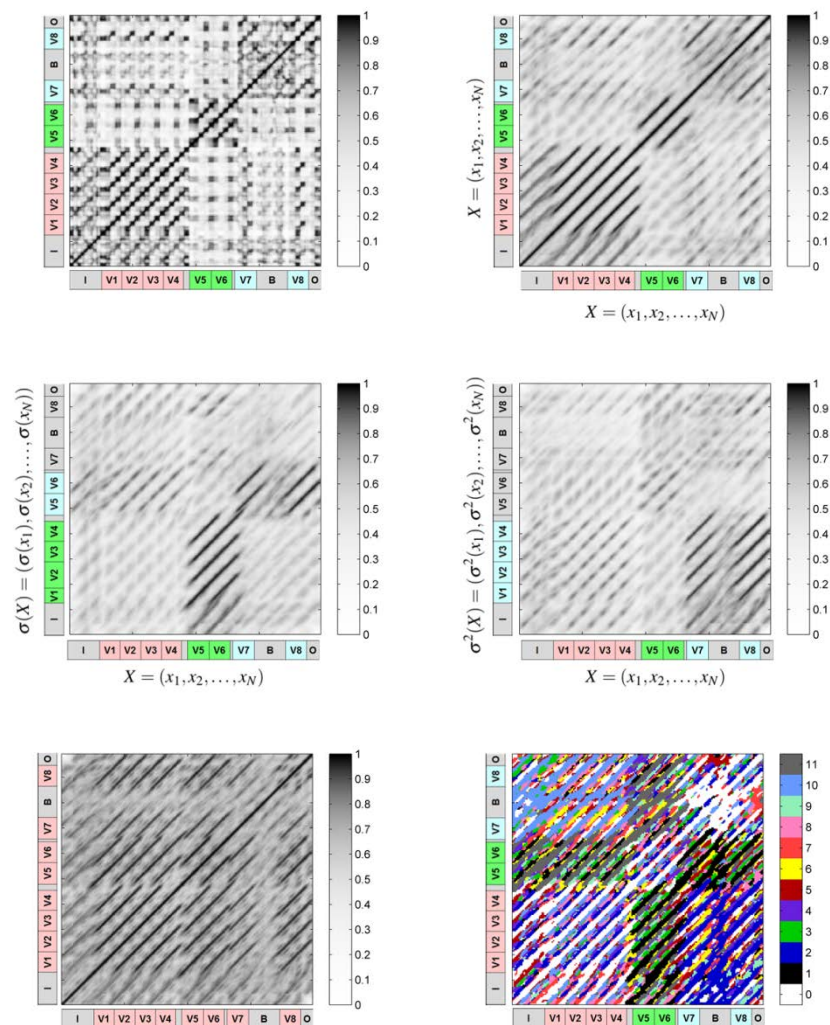
Fig. 4.12





# 4.2 Self-Similarity Matrices

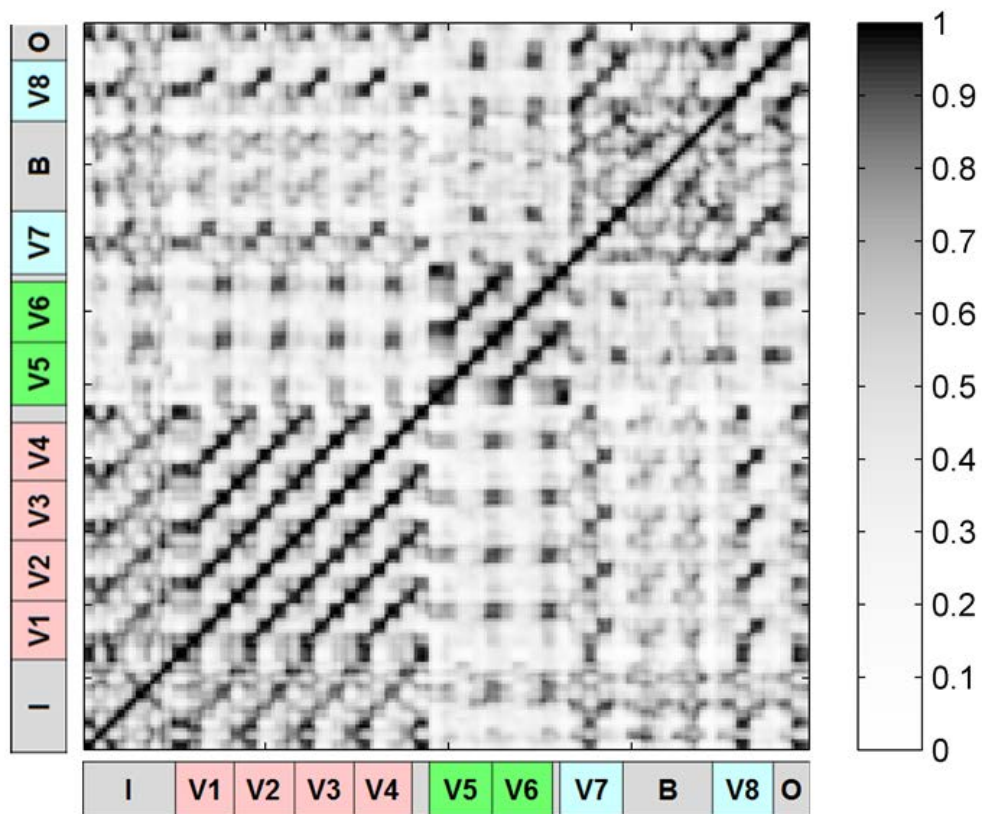
Fig. 4.13





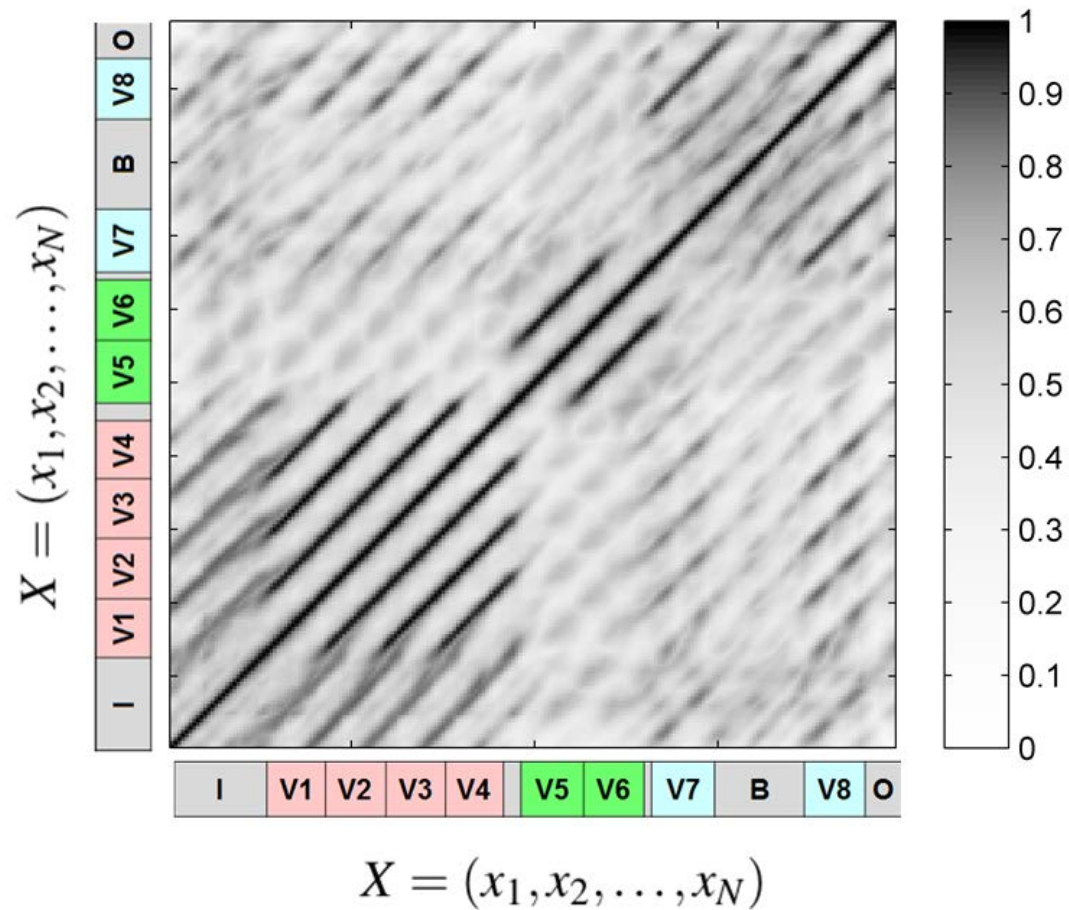
## 4.2 Self-Similarity Matrices

Fig. 4.13



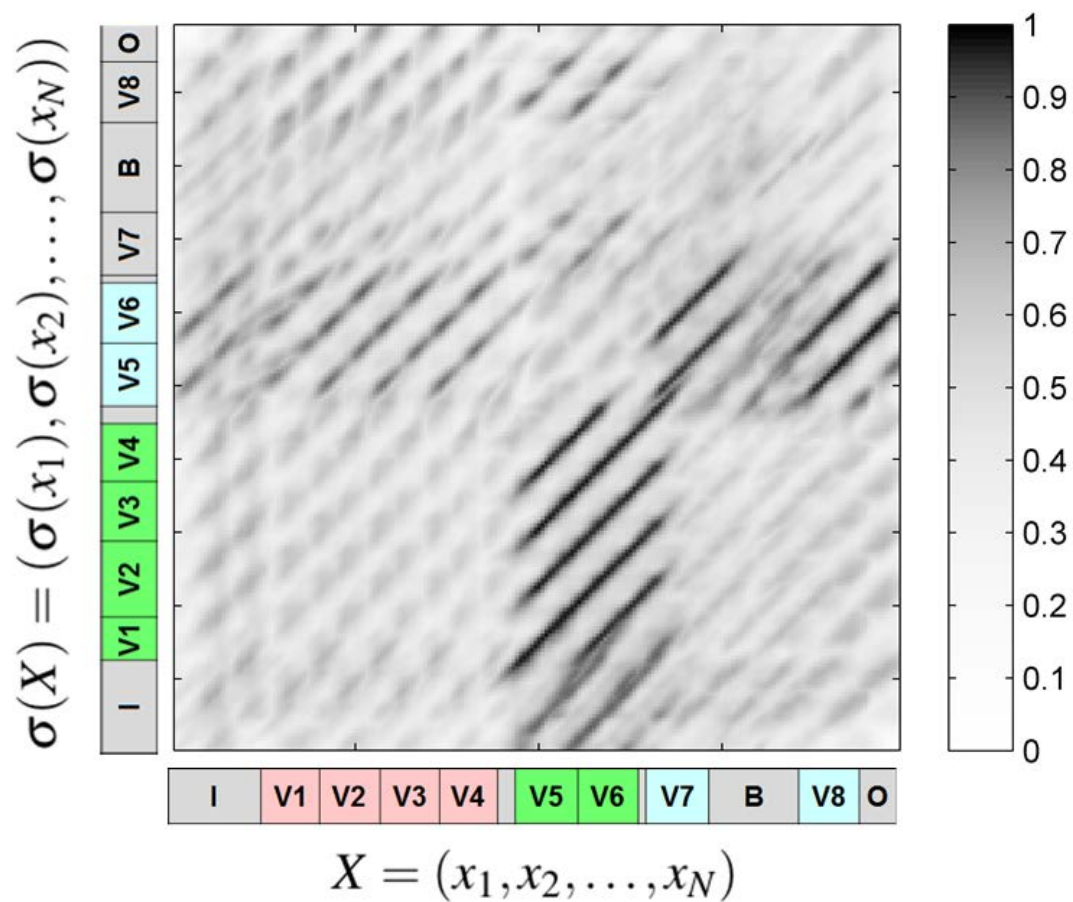
# 4.2 Self-Similarity Matrices

Fig. 4.13



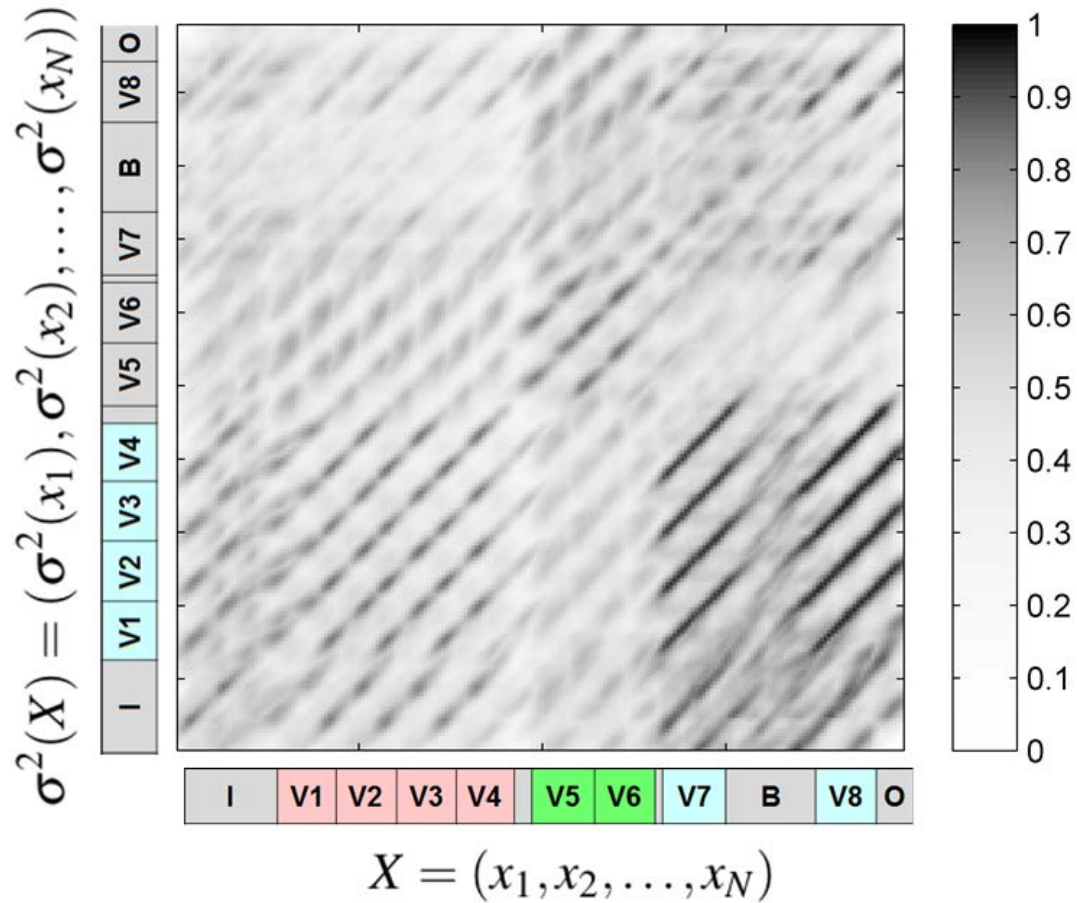
## 4.2 Self-Similarity Matrices

Fig. 4.13



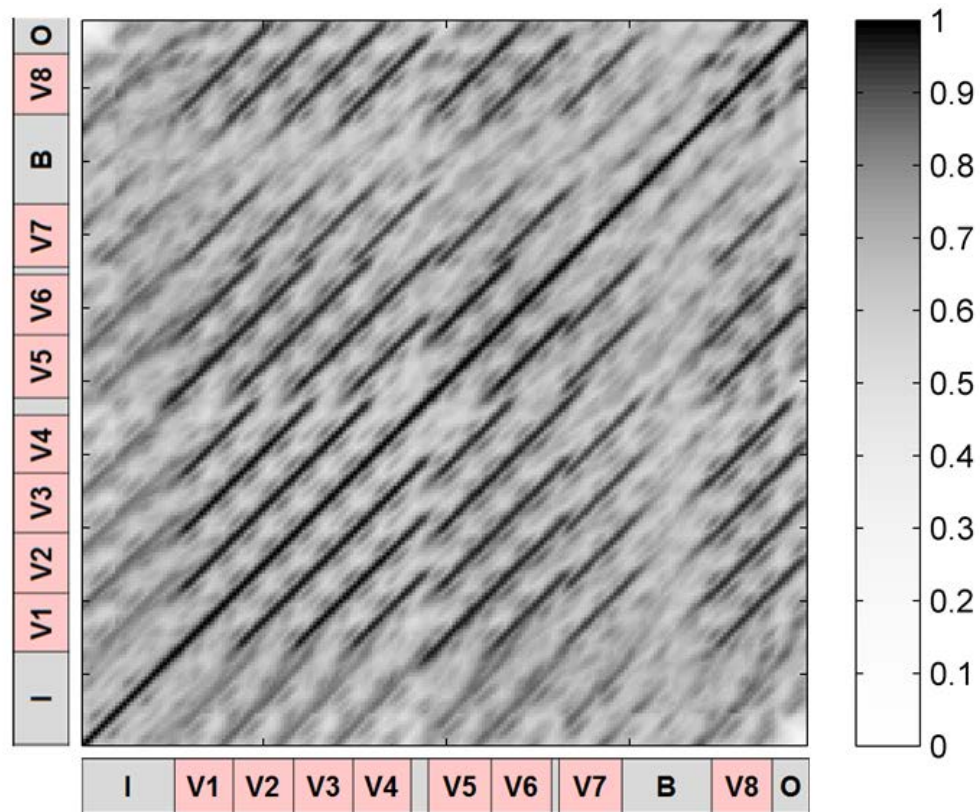
# 4.2 Self-Similarity Matrices

Fig. 4.13



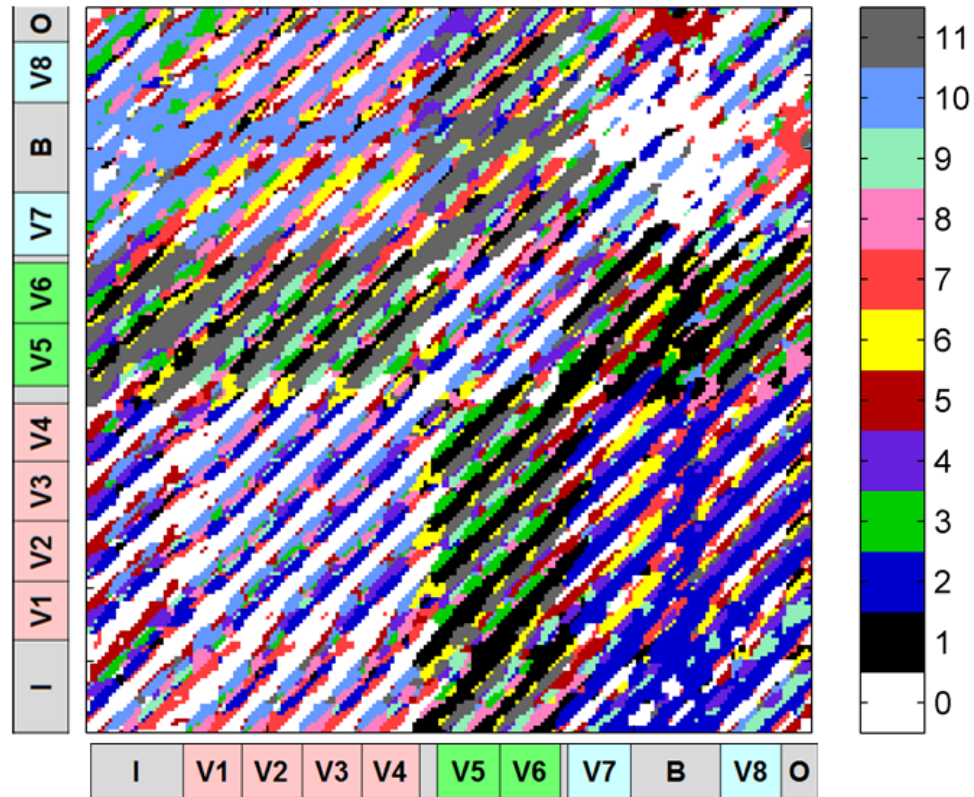
# 4.2 Self-Similarity Matrices

Fig. 4.13



# 4.2 Self-Similarity Matrices

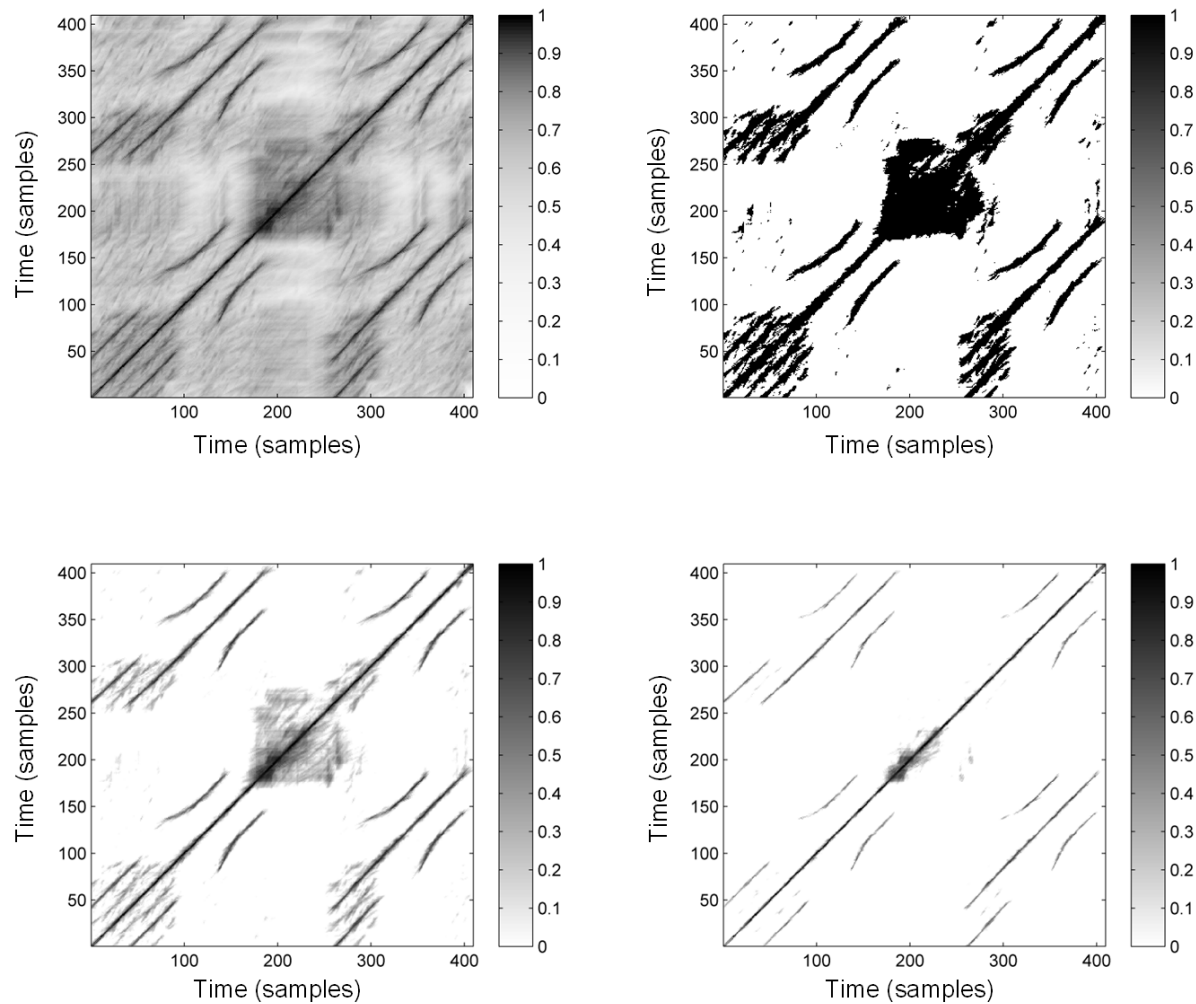
Fig. 4.13





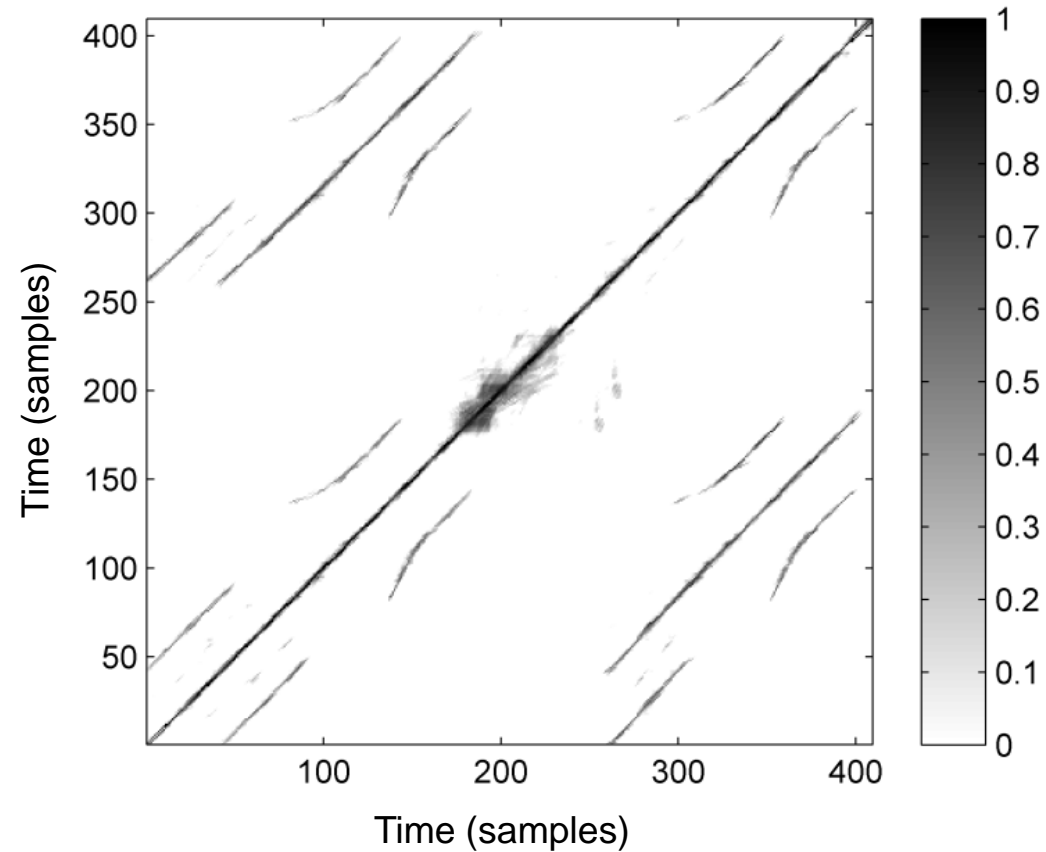
# 4.2 Self-Similarity Matrices

Fig. 4.14



## 4.2 Self-Similarity Matrices

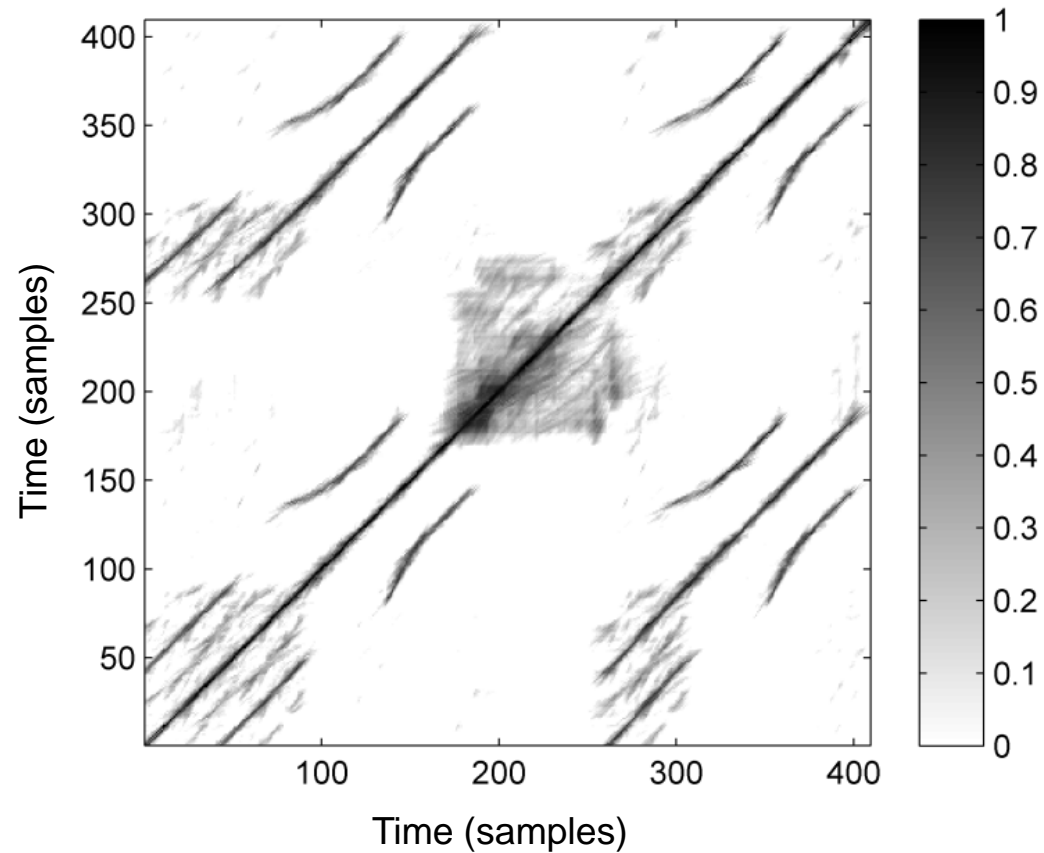
Fig. 4.14





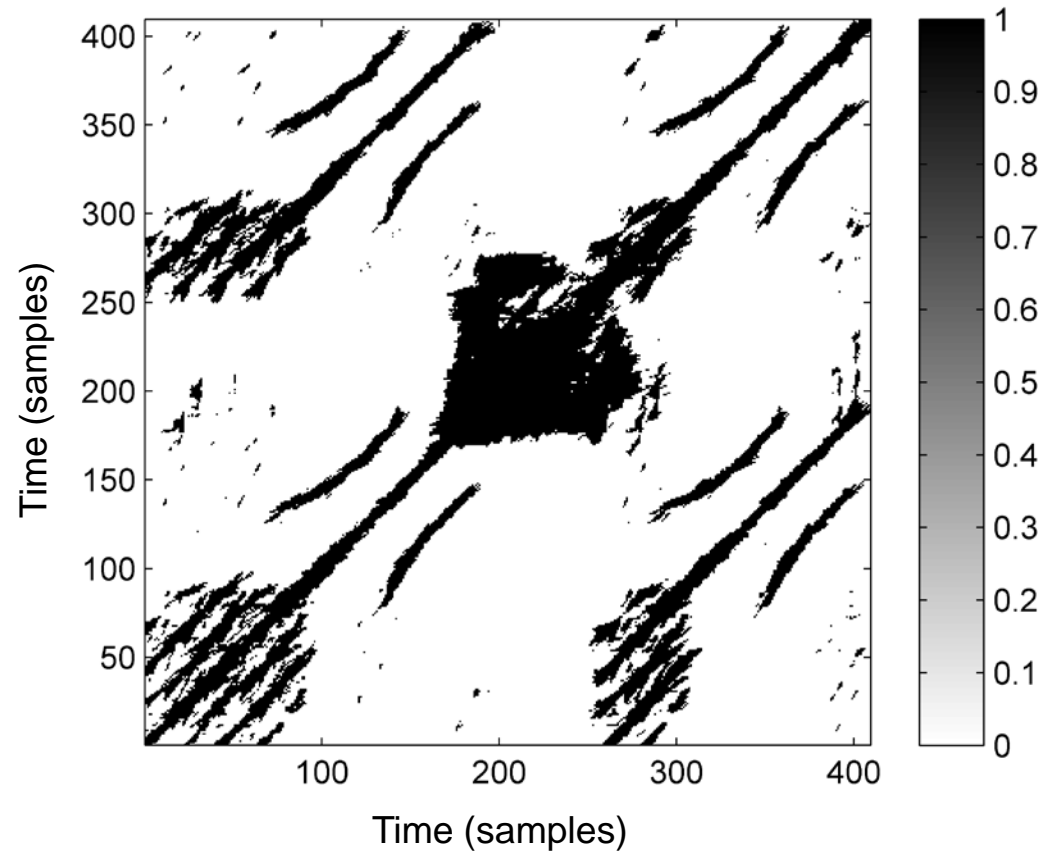
## 4.2 Self-Similarity Matrices

Fig. 4.14



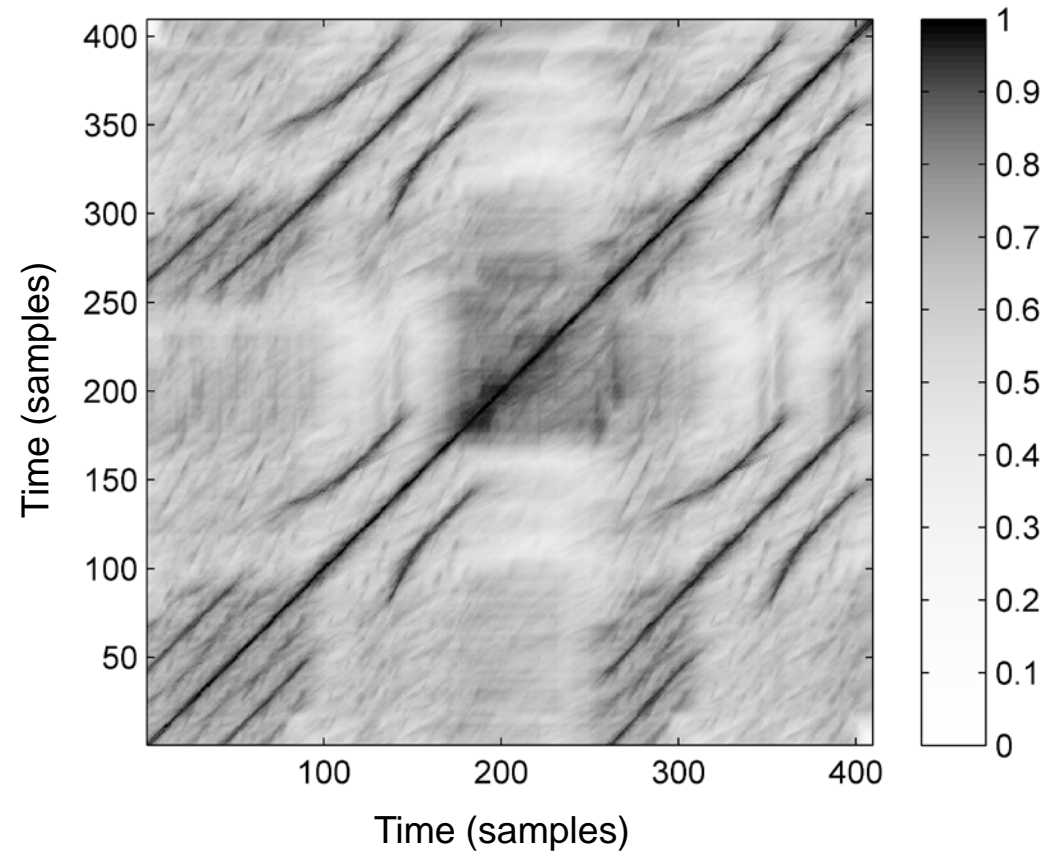
## 4.2 Self-Similarity Matrices

Fig. 4.14



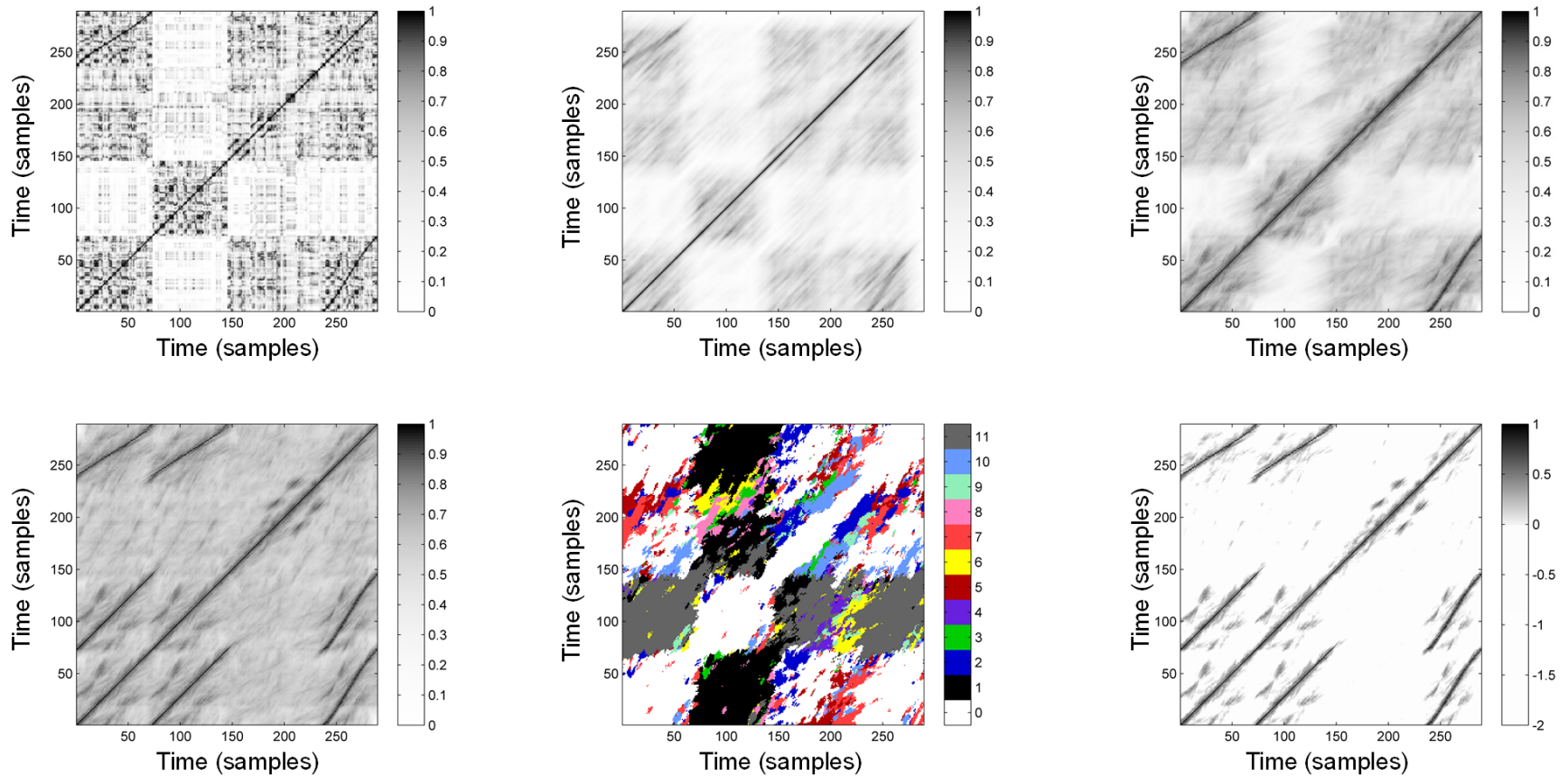
## 4.2 Self-Similarity Matrices

Fig. 4.14



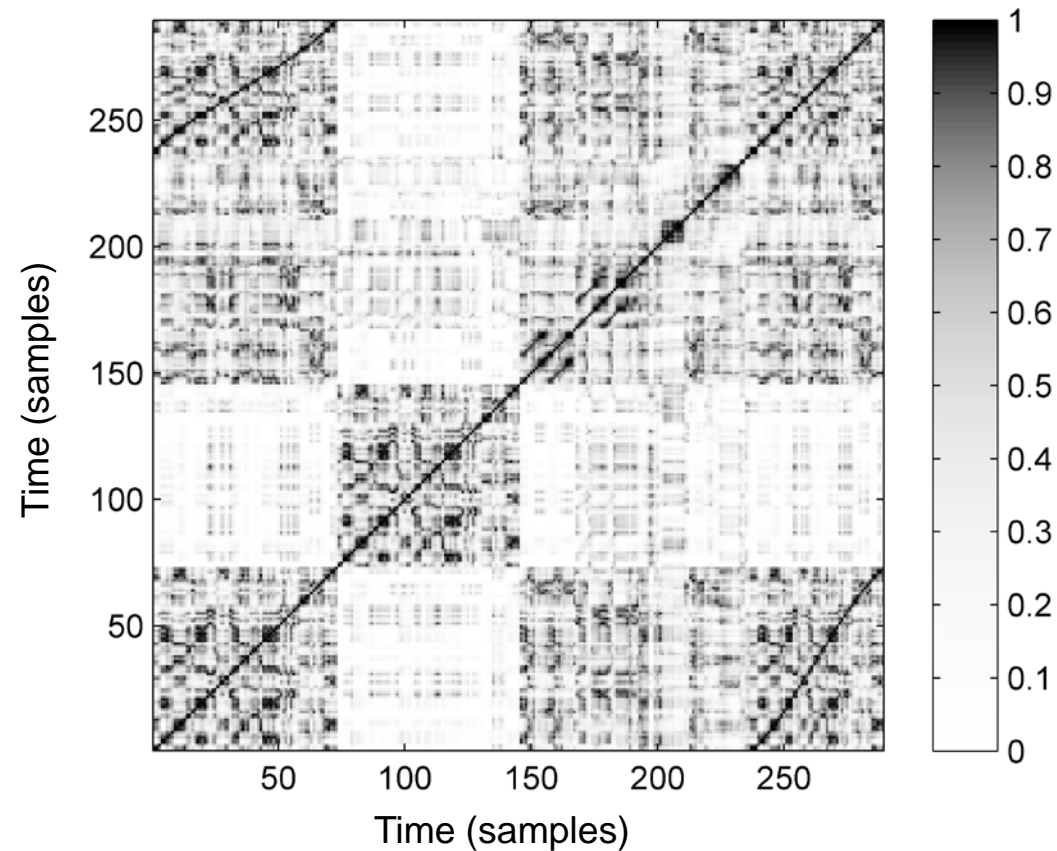
# 4.2 Self-Similarity Matrices

Fig. 4.15



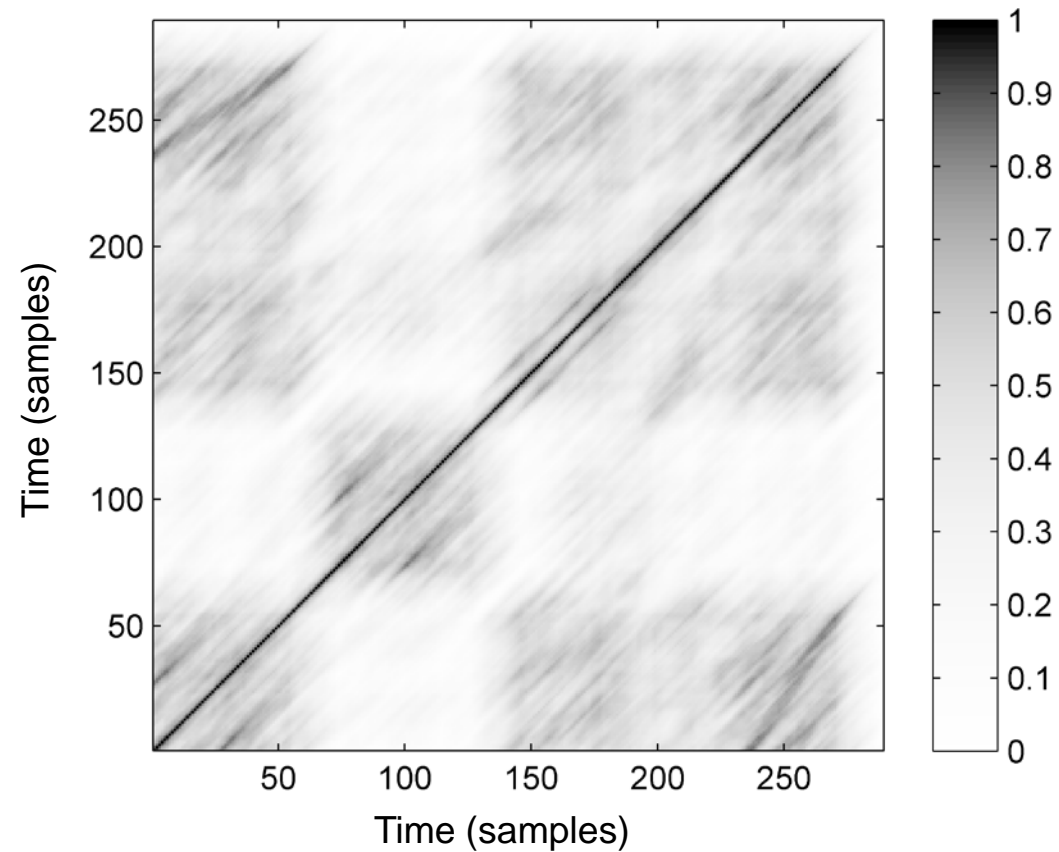
## 4.2 Self-Similarity Matrices

Fig. 4.15



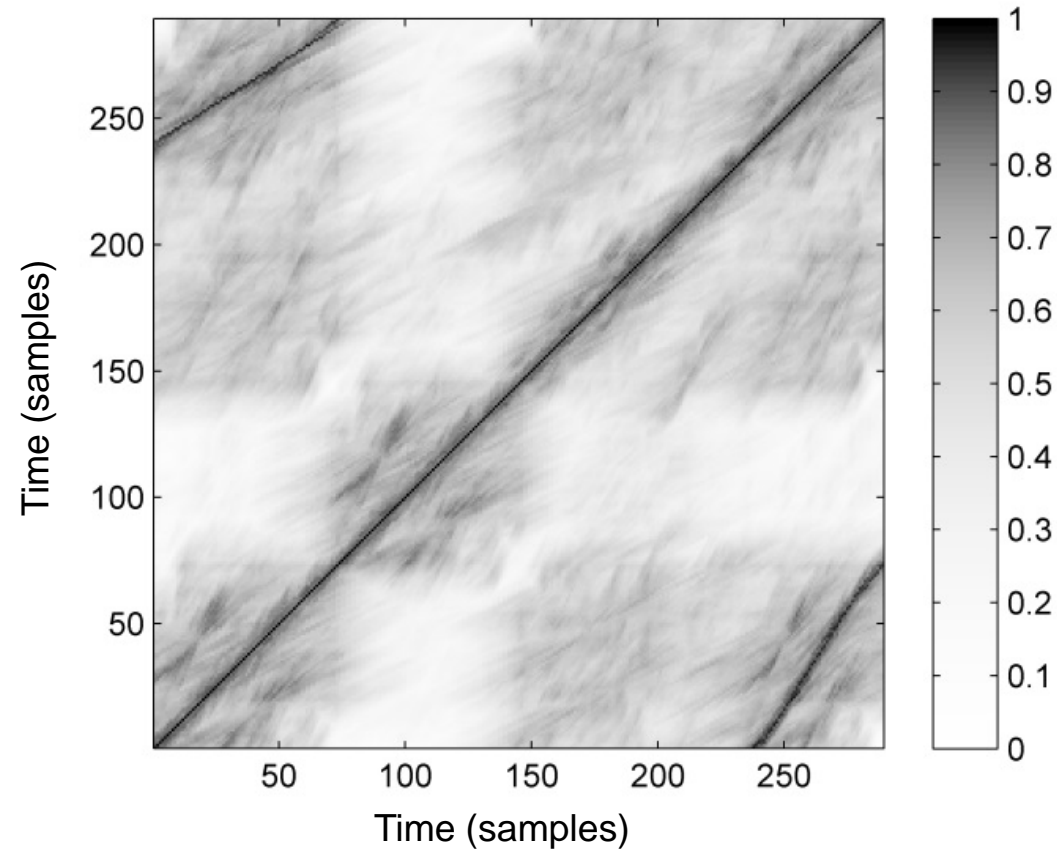
## 4.2 Self-Similarity Matrices

Fig. 4.15



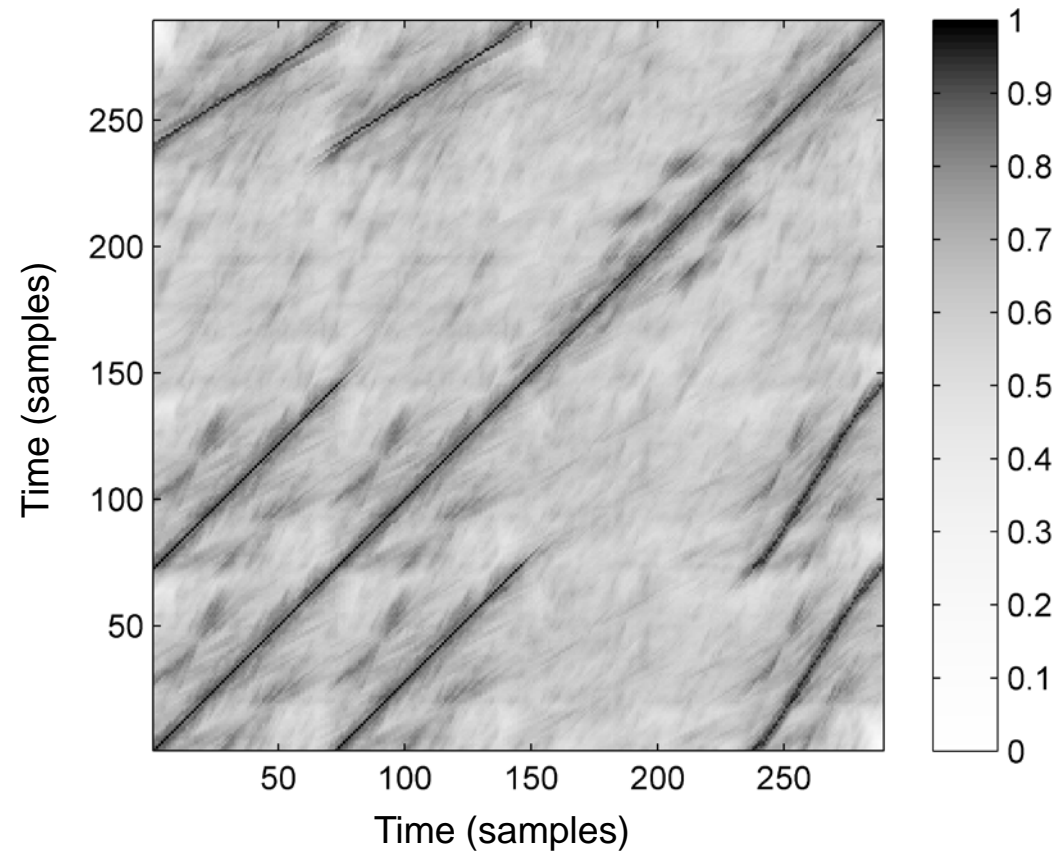
## 4.2 Self-Similarity Matrices

Fig. 4.15



## 4.2 Self-Similarity Matrices

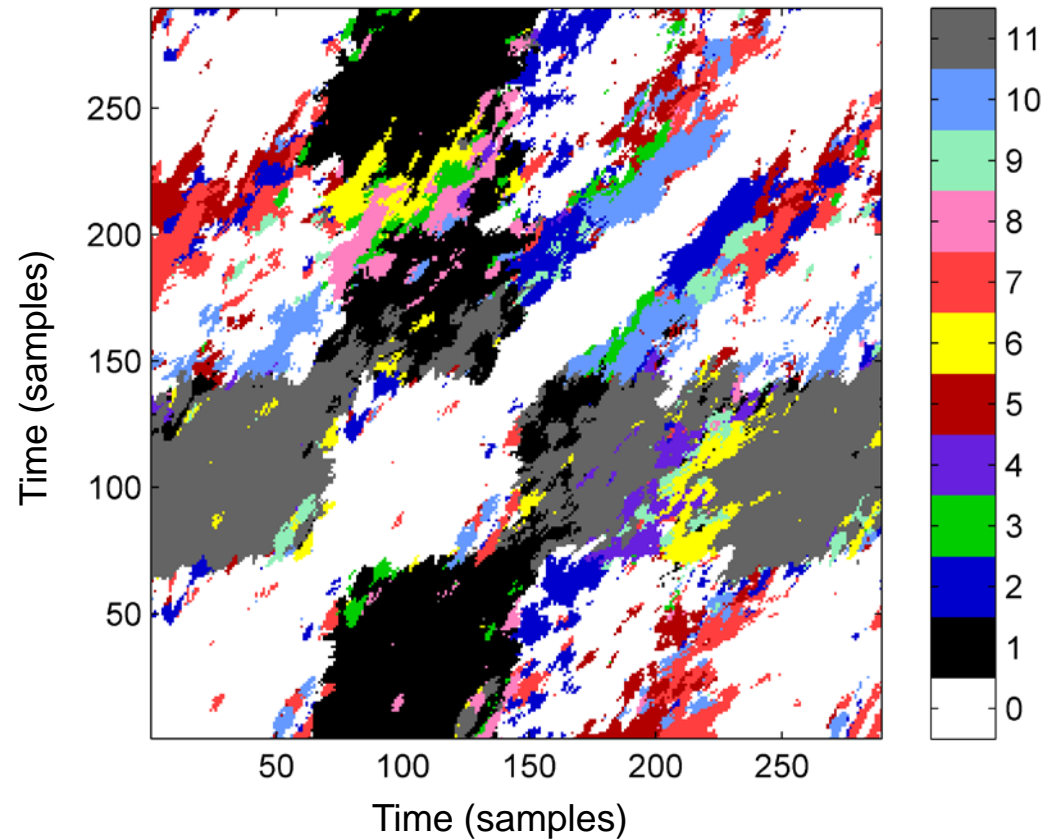
Fig. 4.15





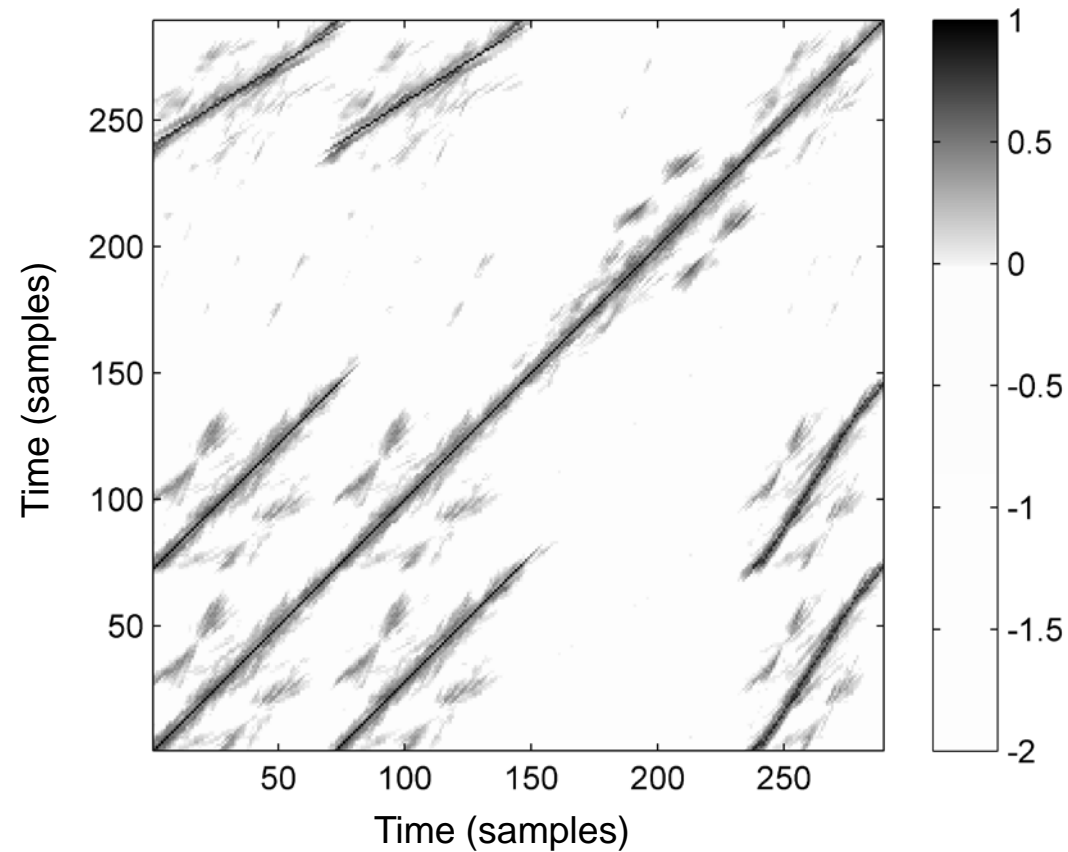
## 4.2 Self-Similarity Matrices

Fig. 4.15



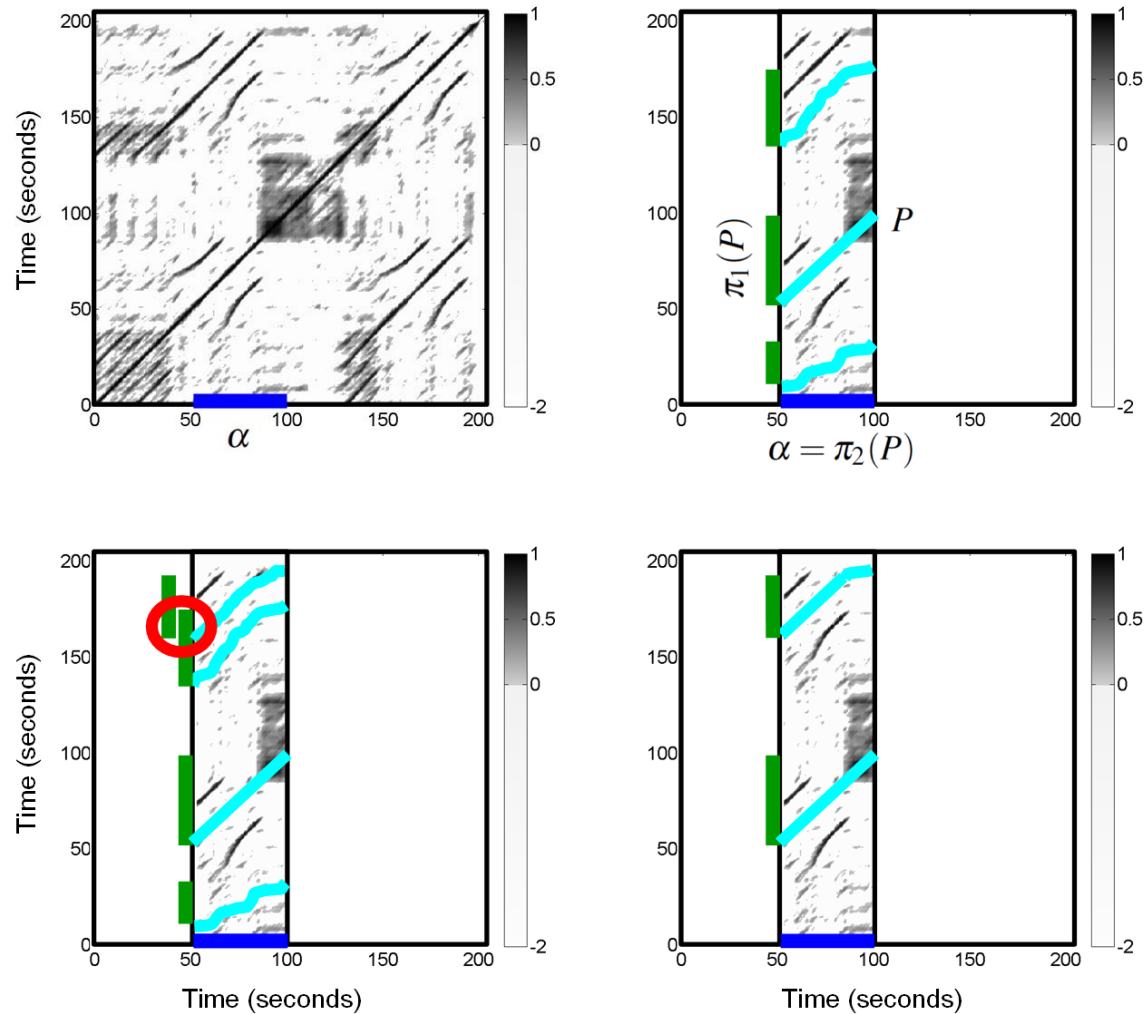
## 4.2 Self-Similarity Matrices

Fig. 4.15



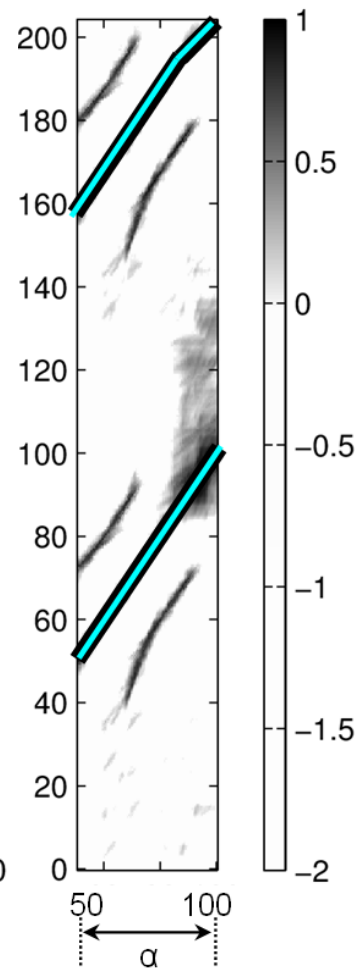
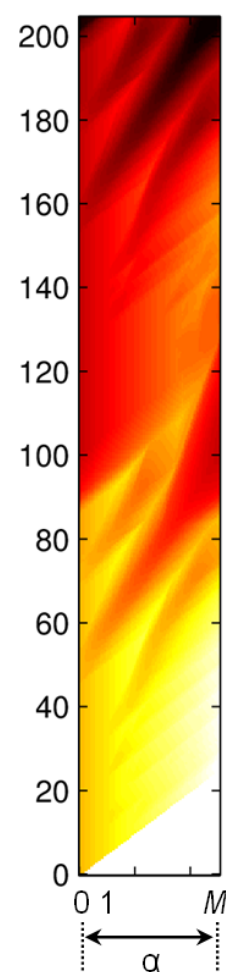
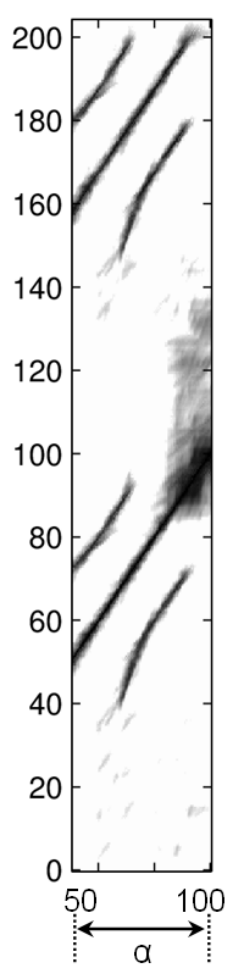
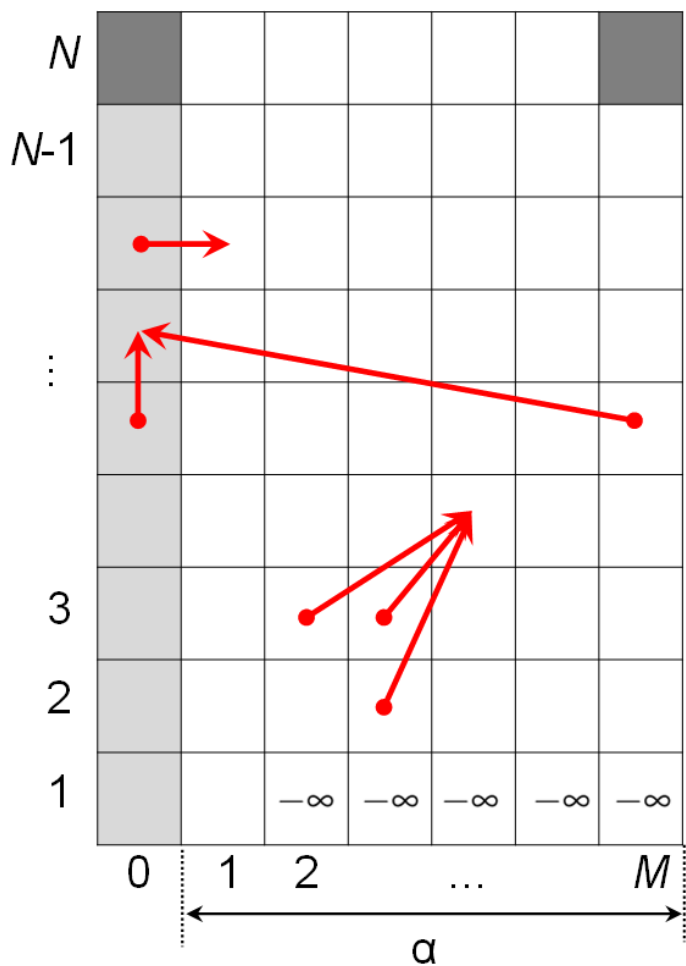
# 4.3 Audio Thumbnailing

Fig. 4.16



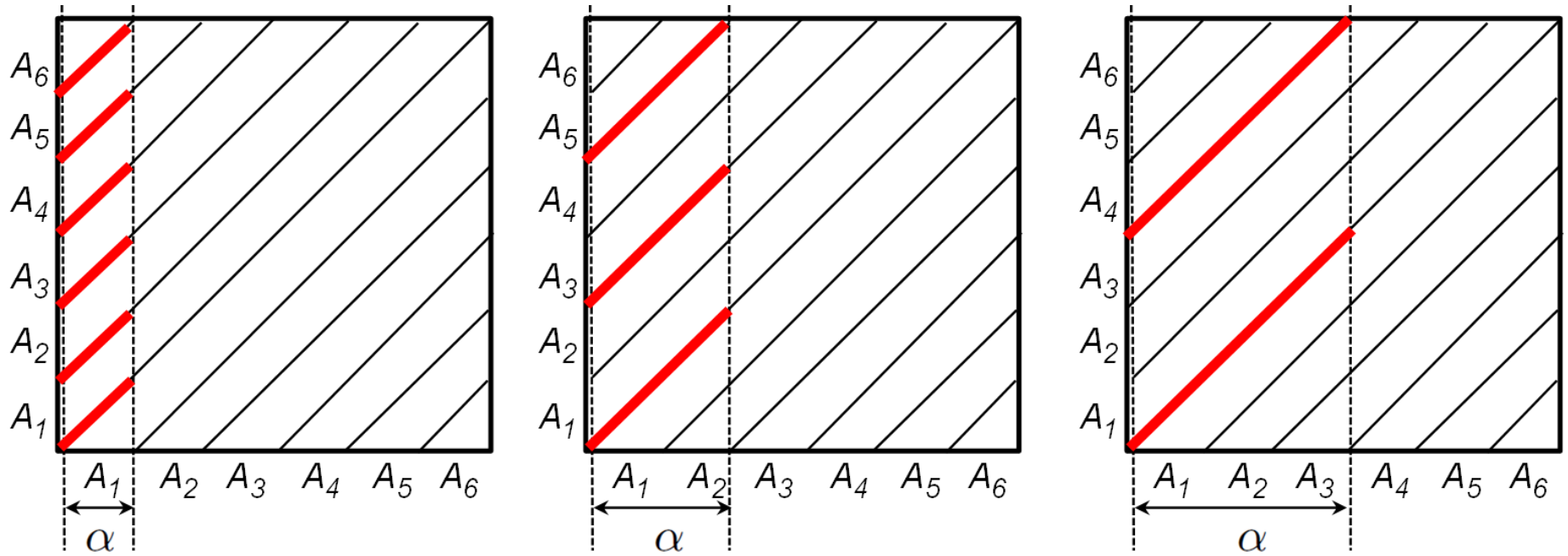
# 4.3 Audio Thumbnailing

Fig. 4.17



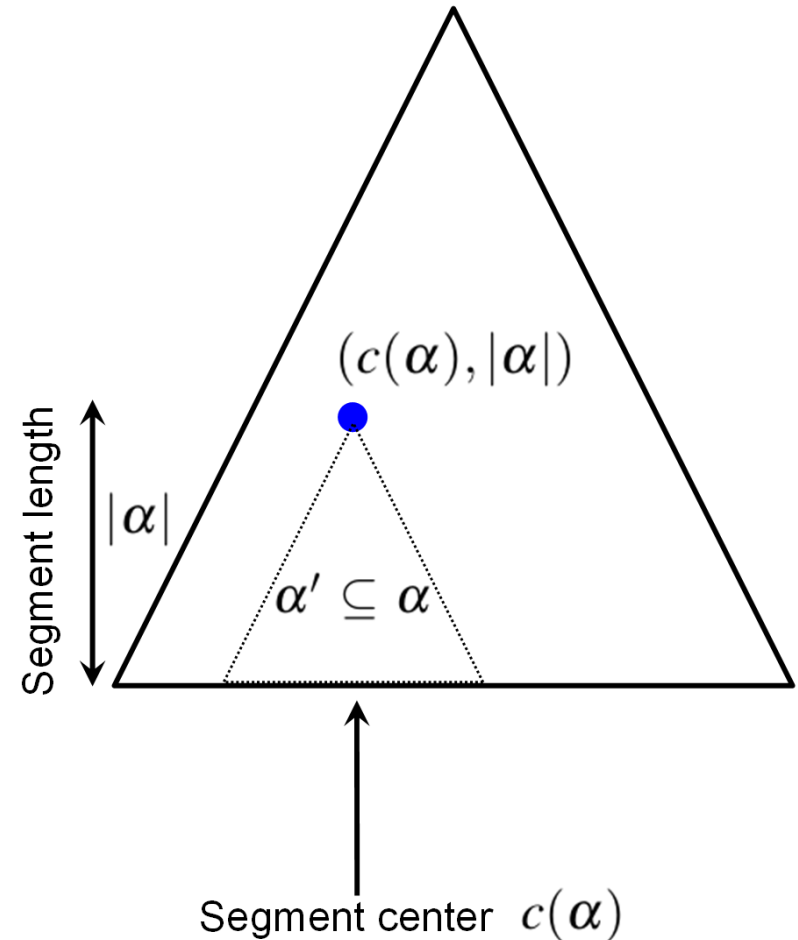
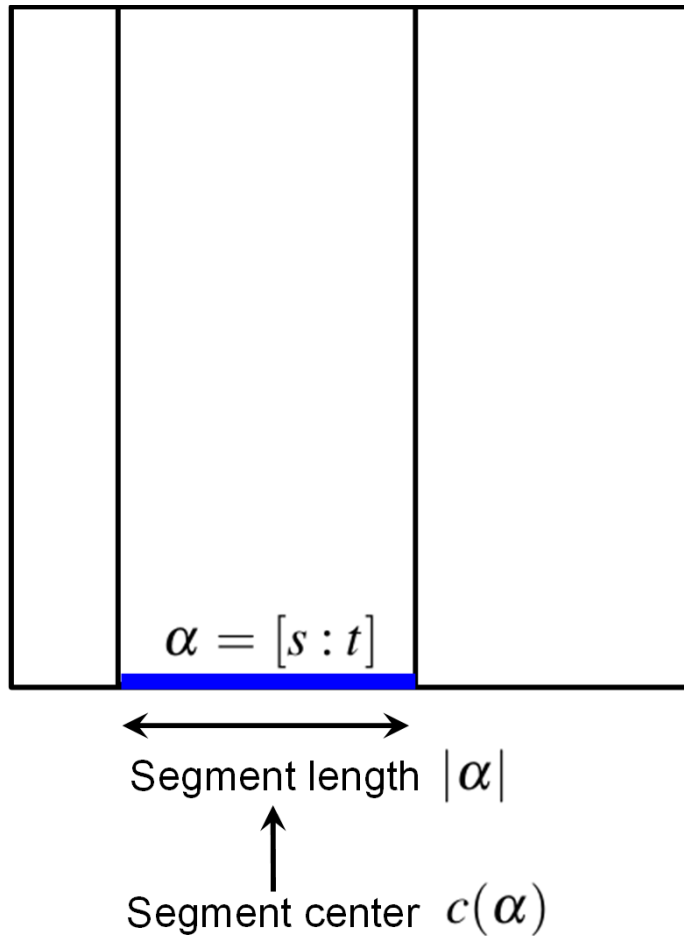
# 4.3 Audio Thumbnailing

Fig. 4.18



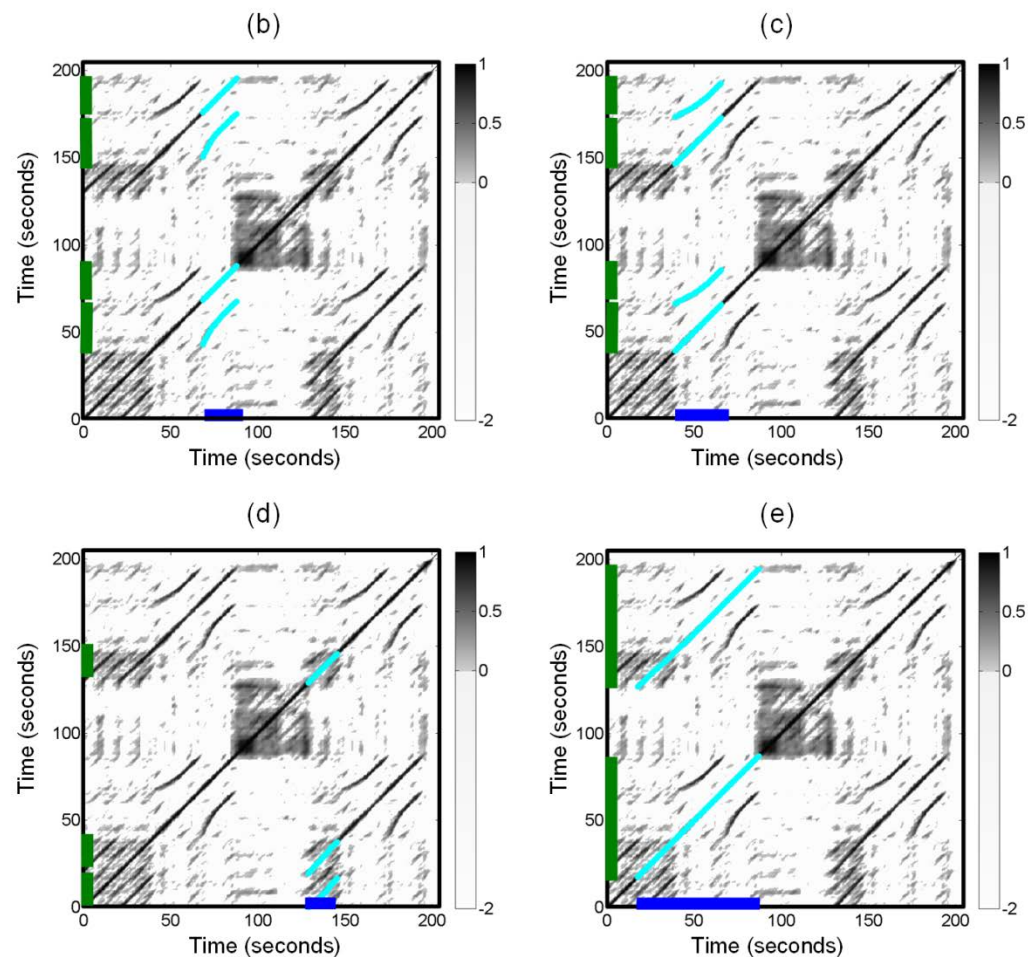
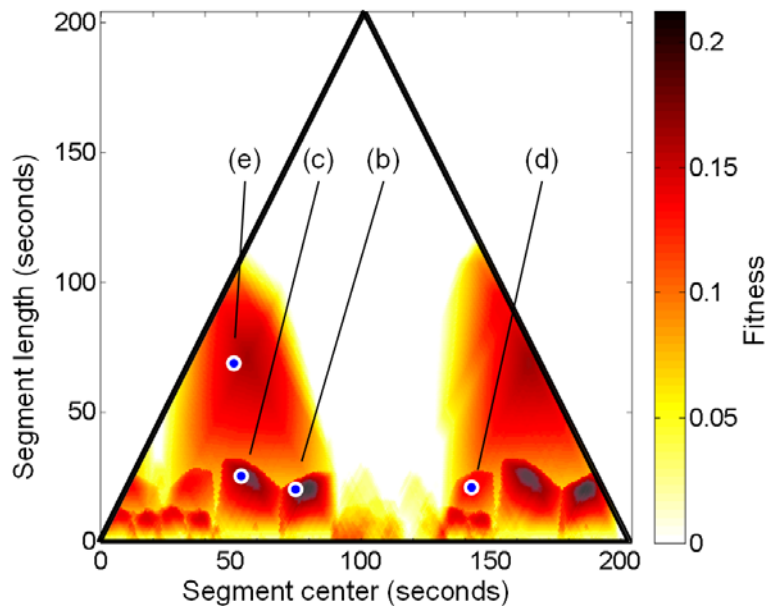
# 4.3 Audio Thumbnailing

Fig. 4.19



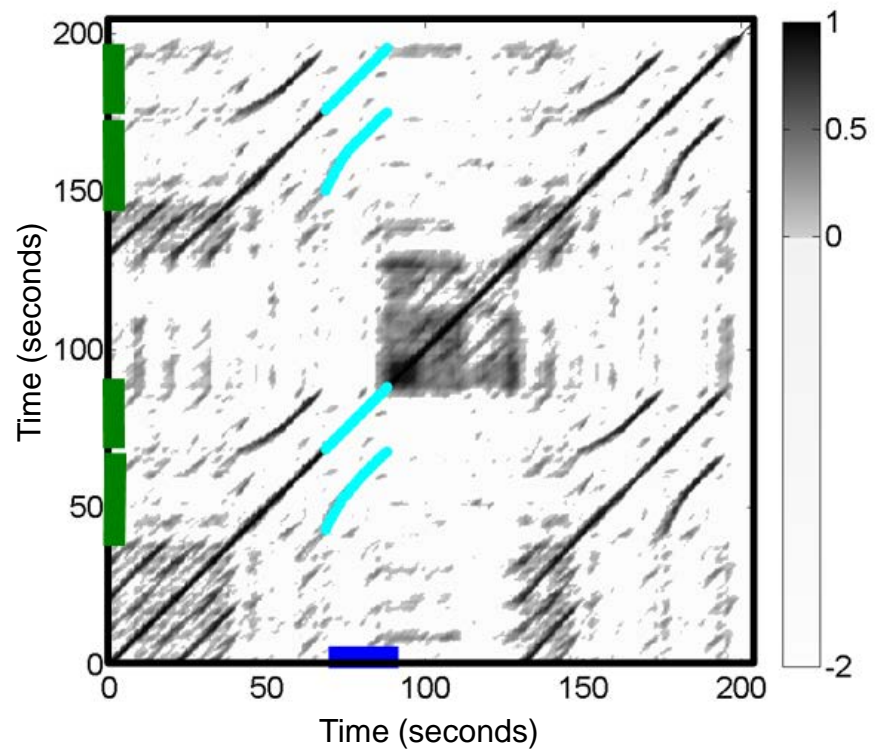
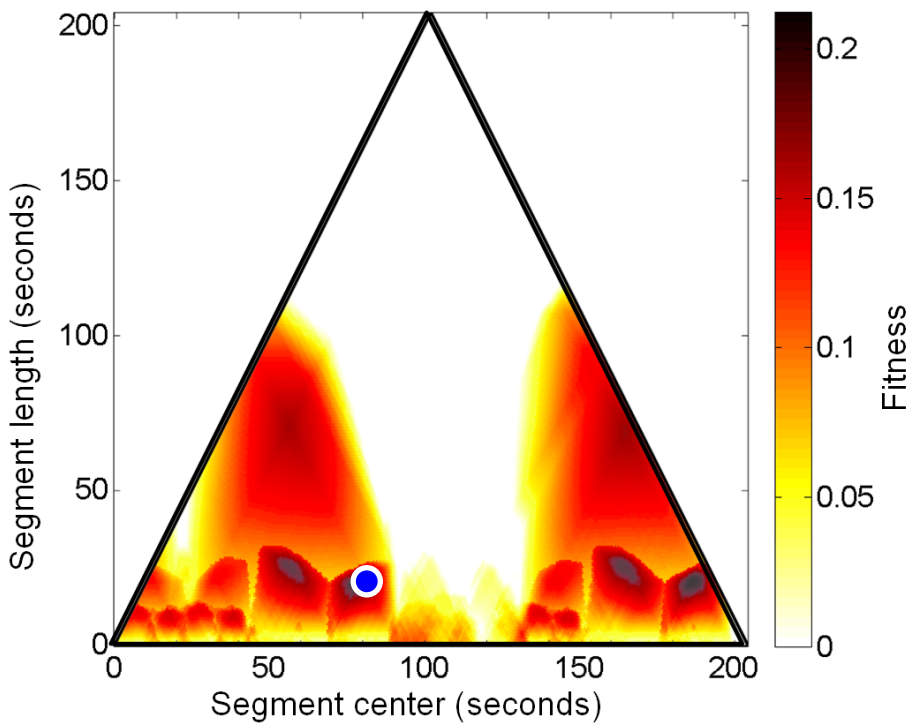
# 4.3 Audio Thumbnailing

Fig. 4.20



# 4.3 Audio Thumbnailing

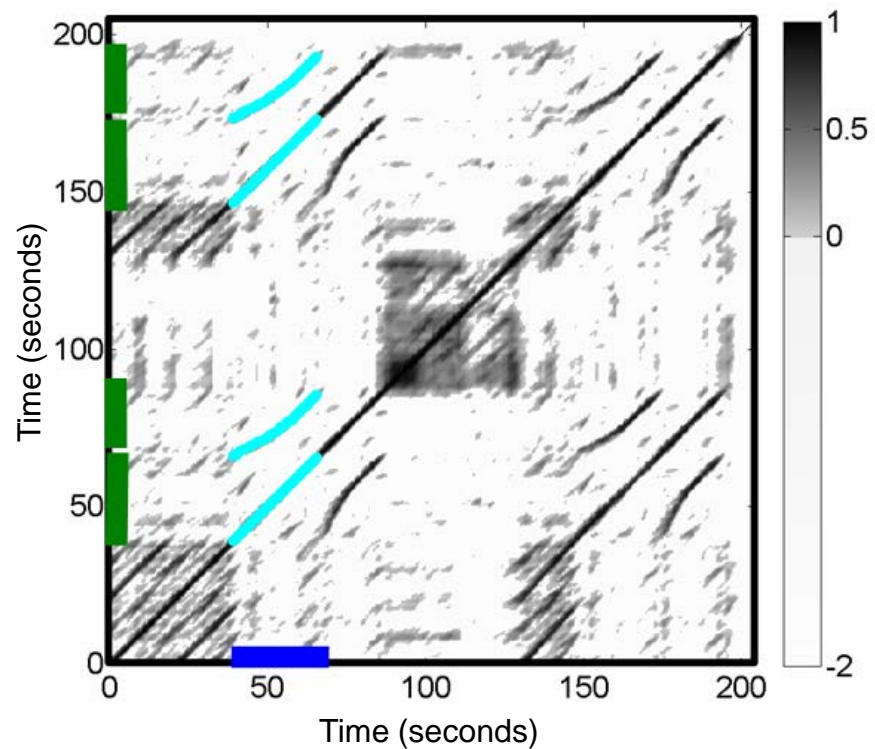
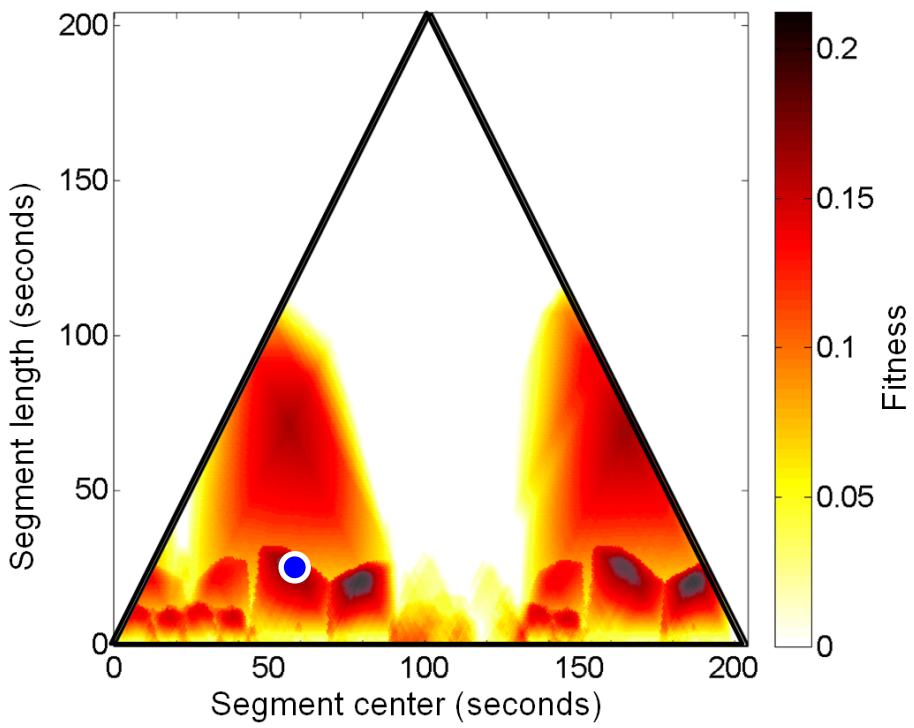
Fig. 4.20





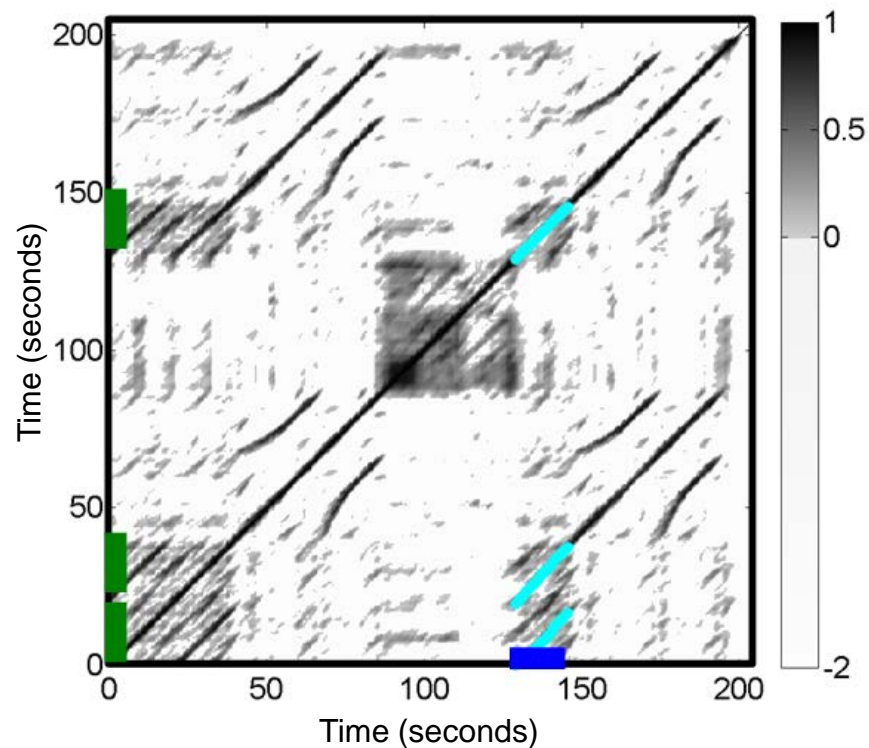
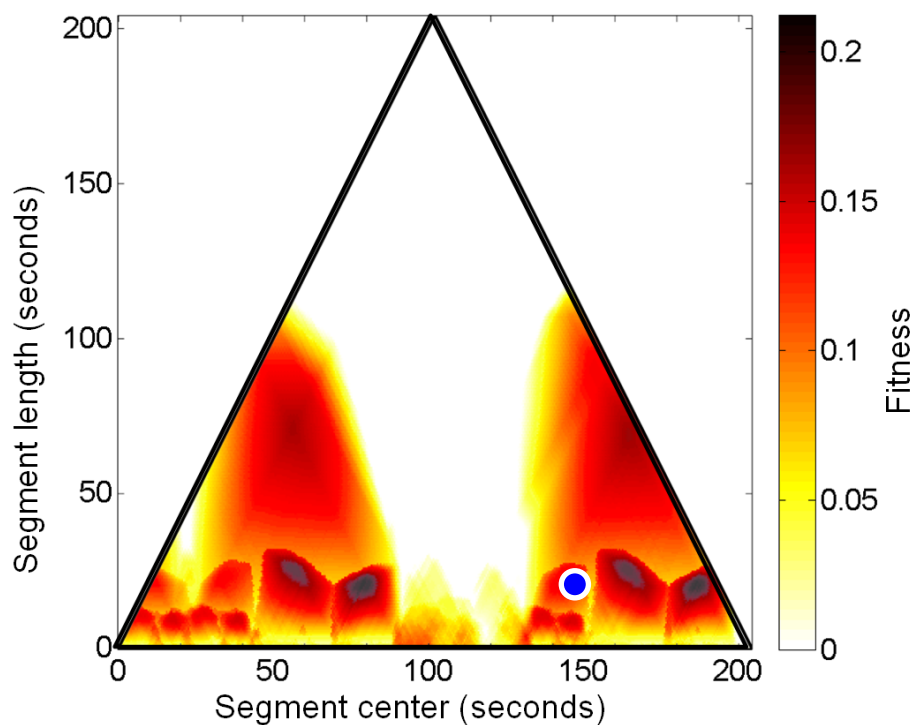
# 4.3 Audio Thumbnailing

Fig. 4.20



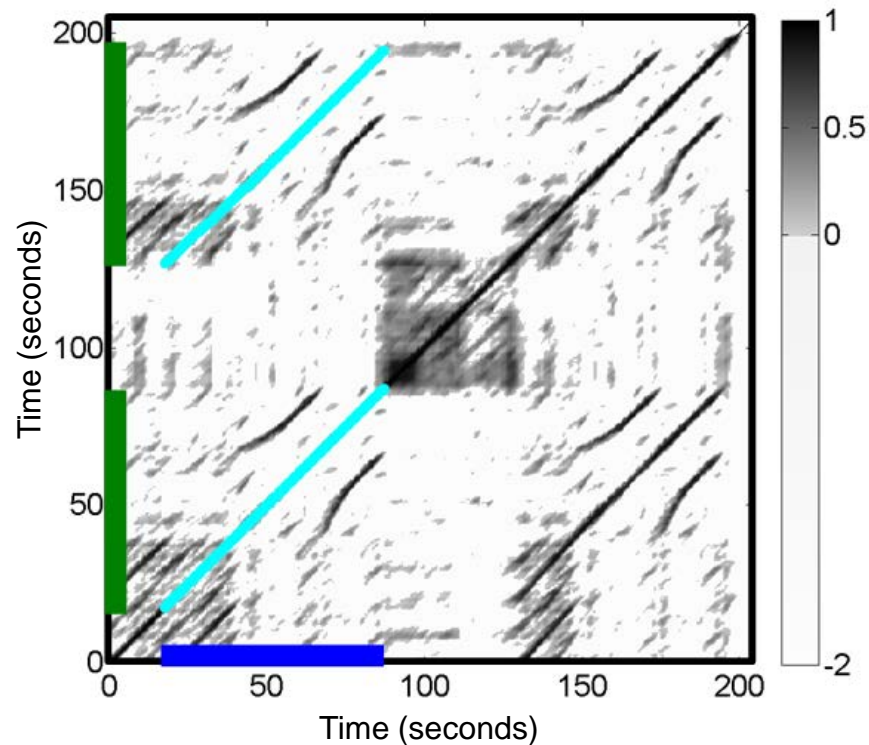
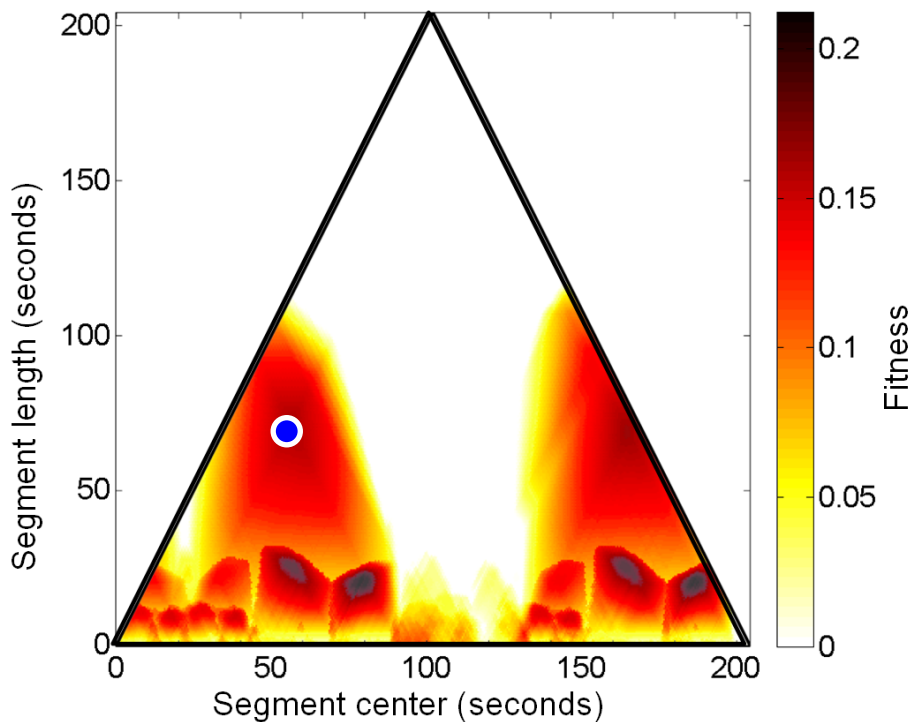
# 4.3 Audio Thumbnailing

Fig. 4.20



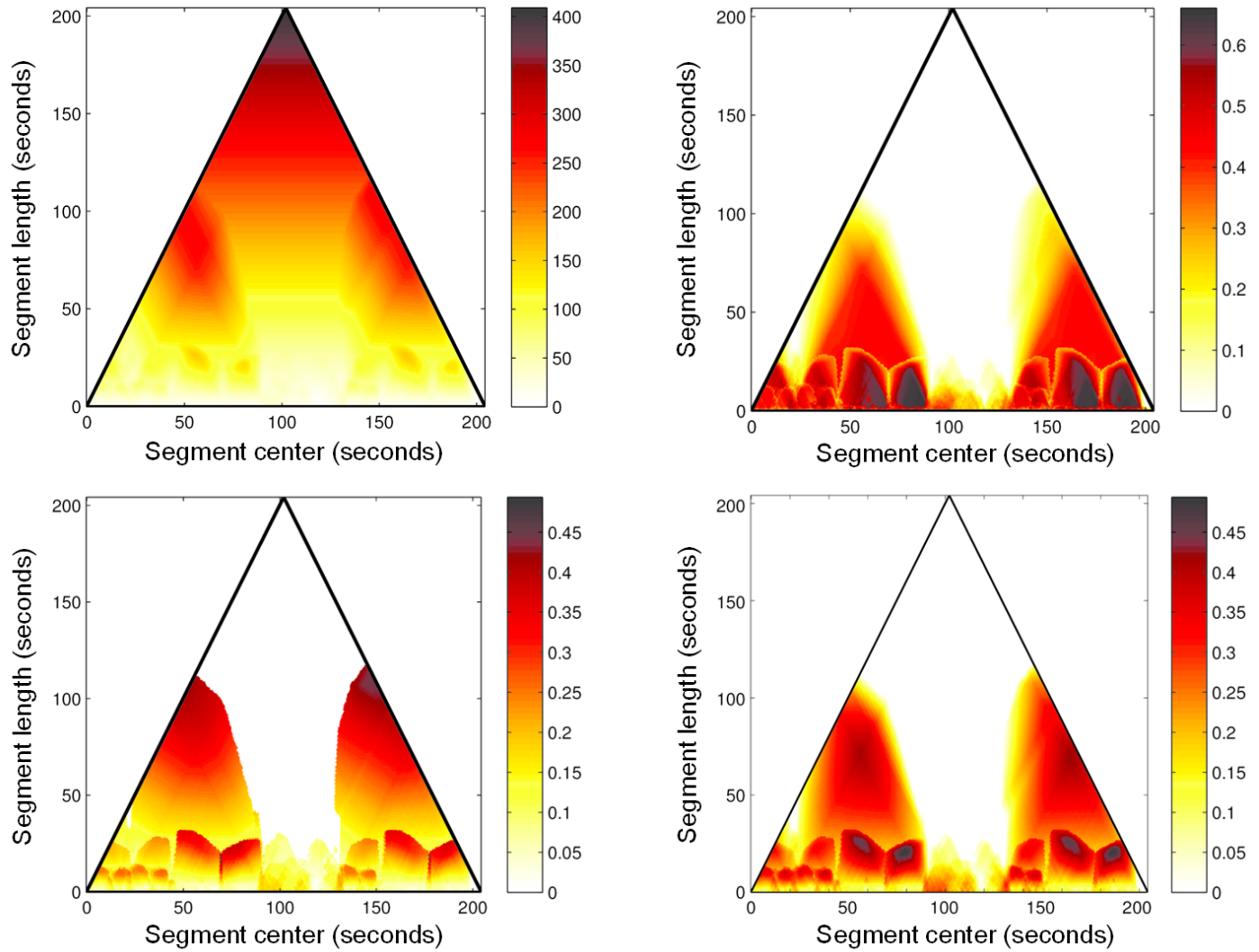
# 4.3 Audio Thumbnailing

Fig. 4.20



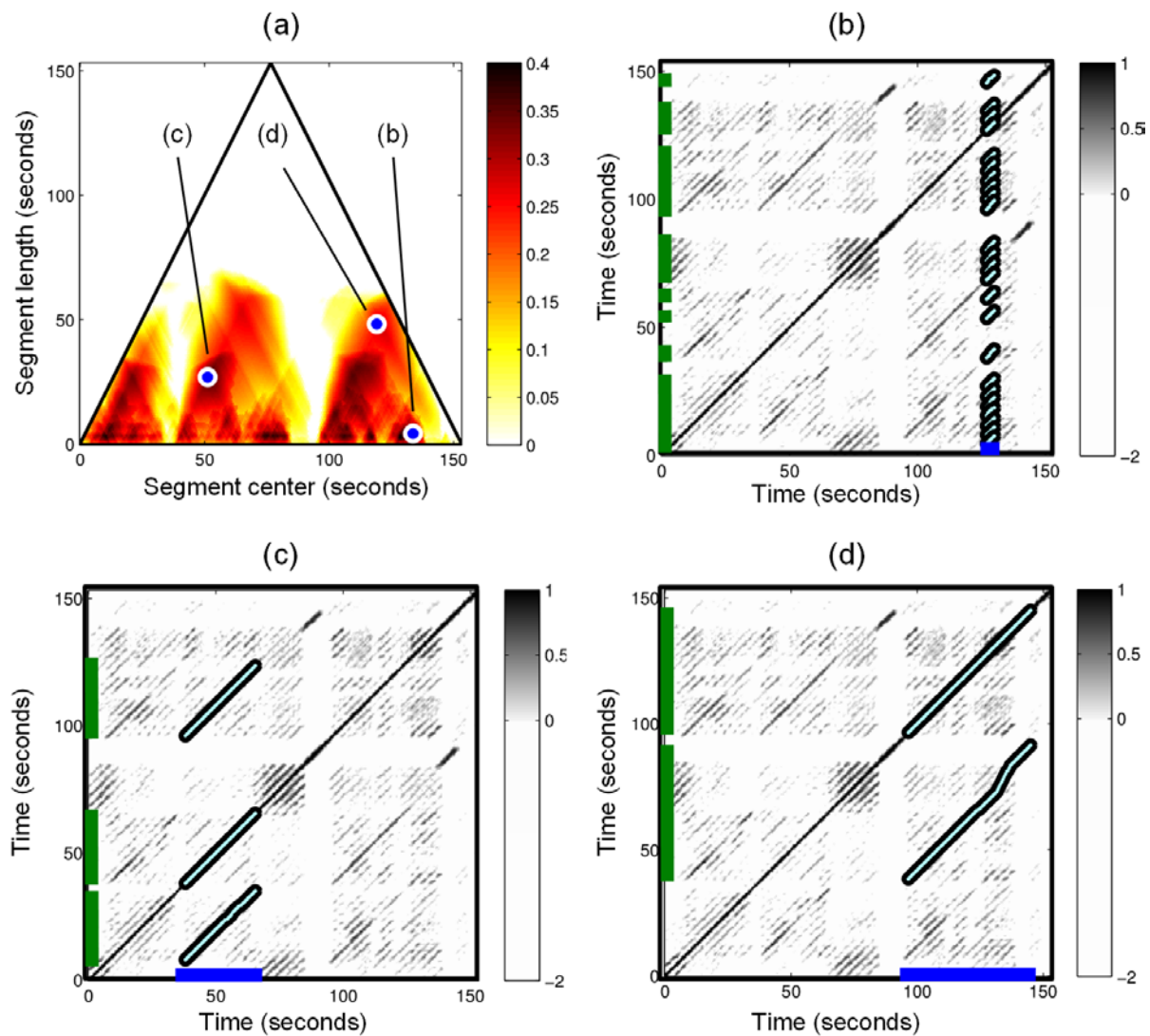
# 4.3 Audio Thumbnailing

Fig. 4.21



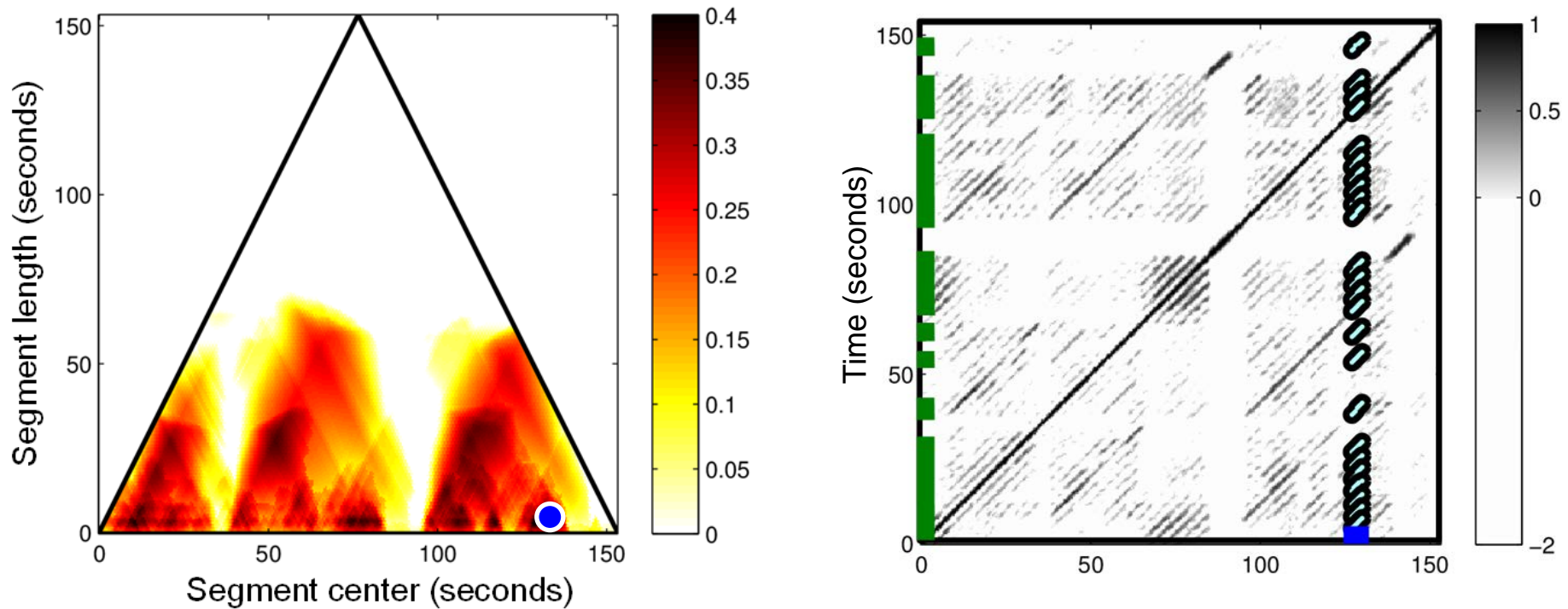
# 4.3 Audio Thumbnailing

Fig. 4.22



# 4.3 Audio Thumbnailing

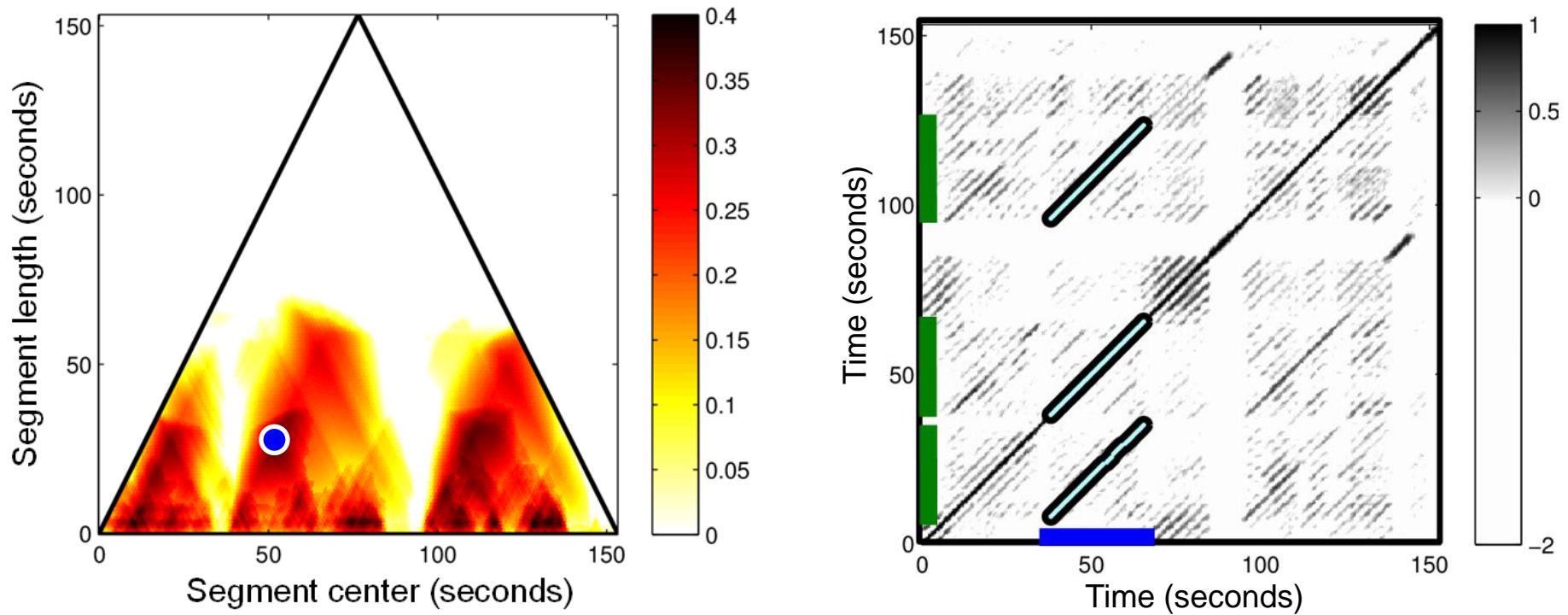
Fig. 4.22





# 4.3 Audio Thumbnailing

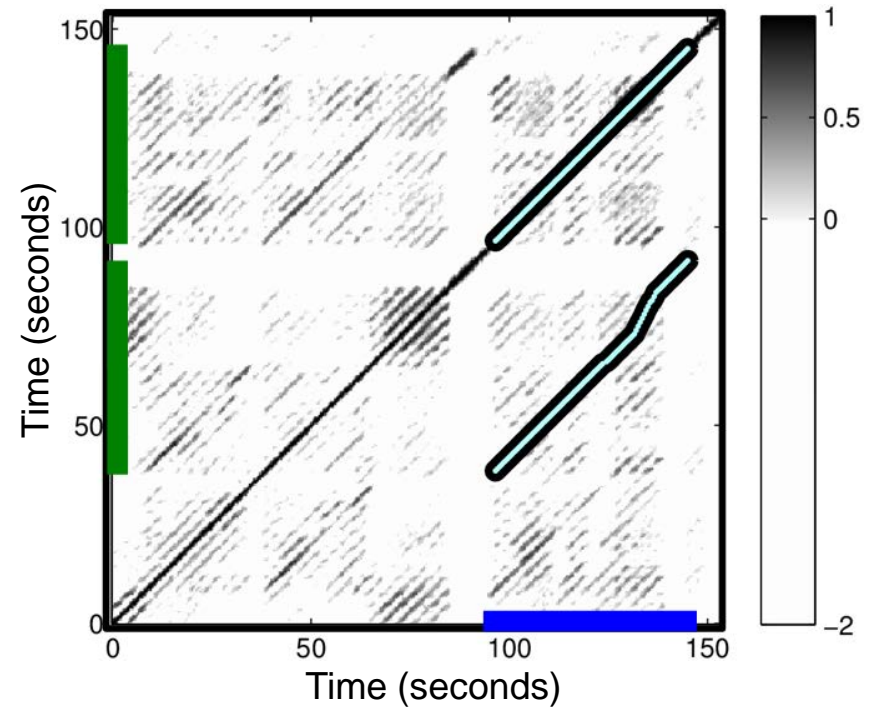
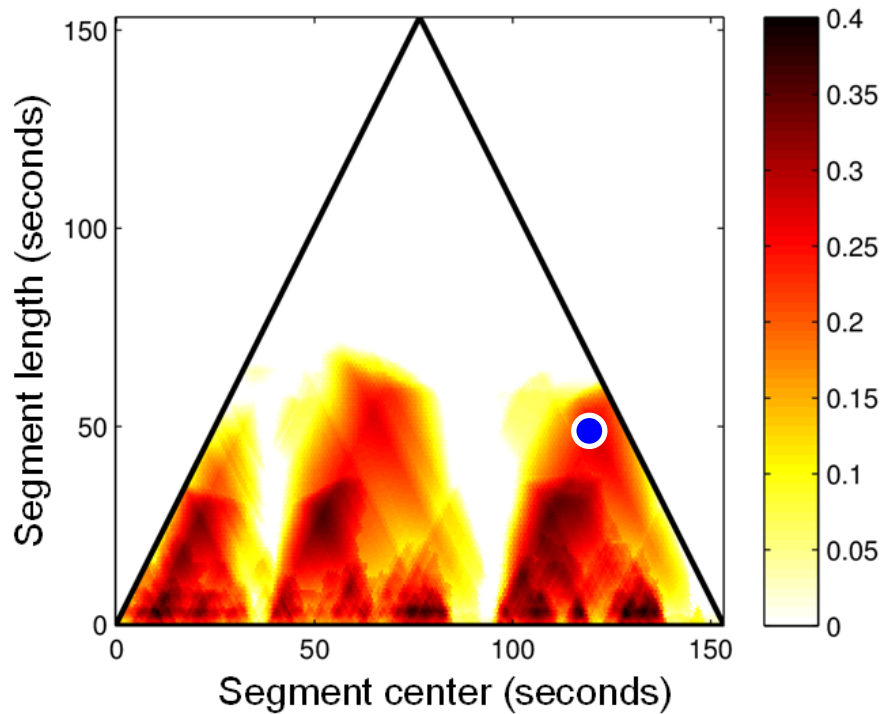
Fig. 4.22





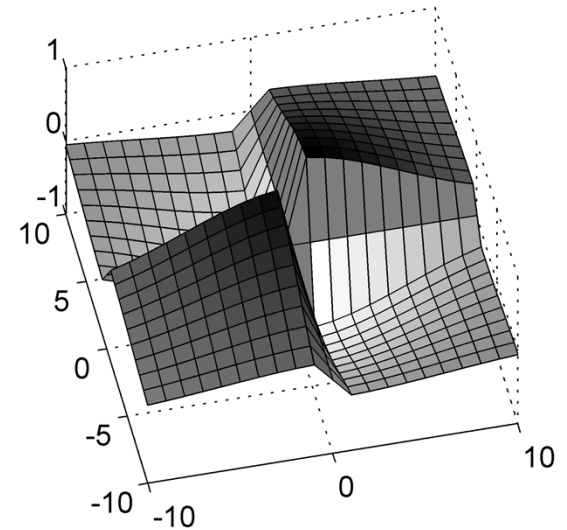
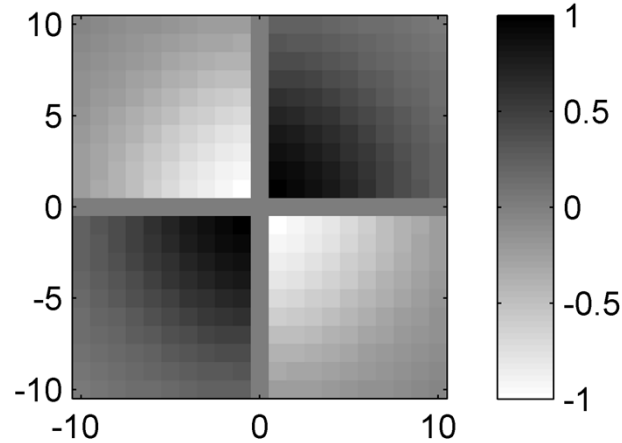
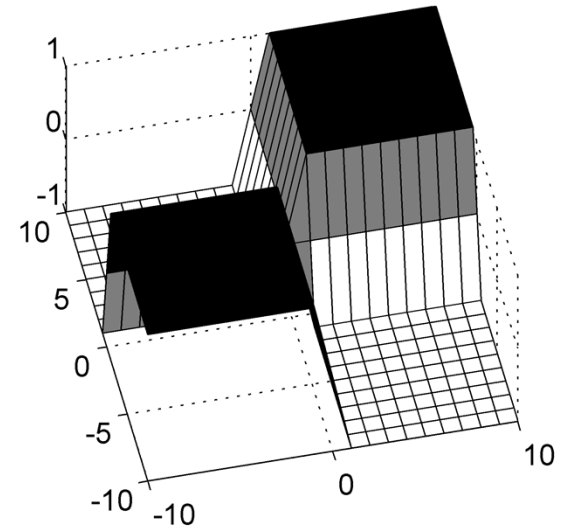
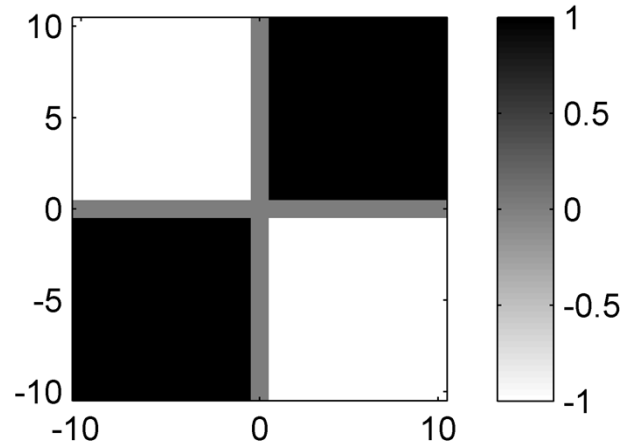
# 4.3 Audio Thumbnailing

Fig. 4.22



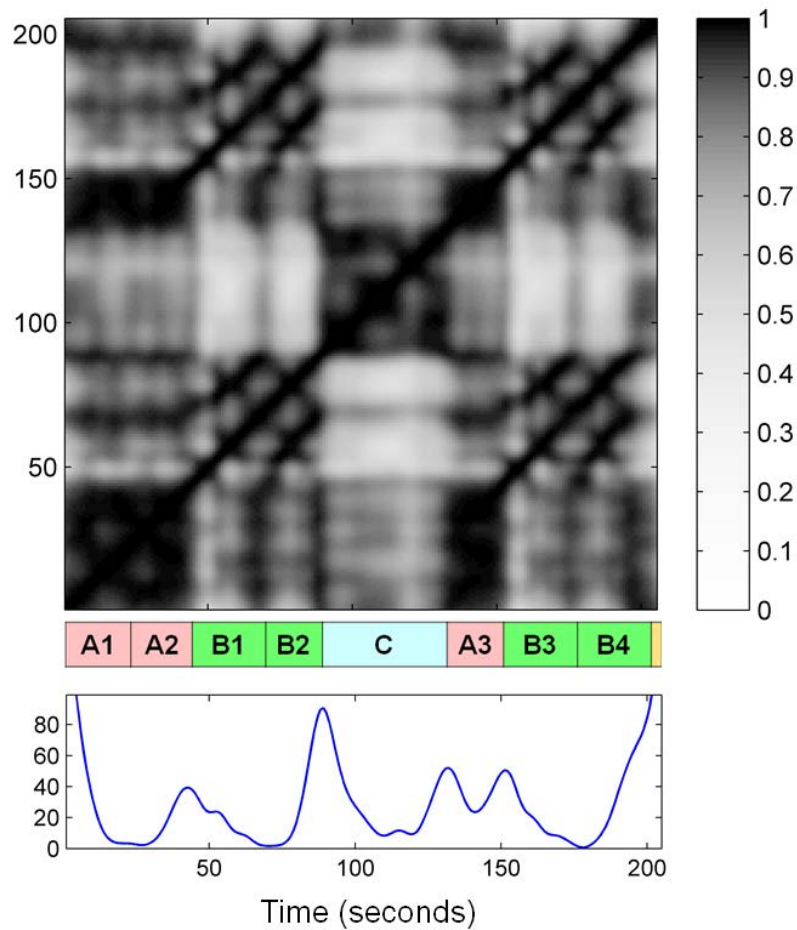
# 4.4 Novelty-Based Segmentation

Fig. 4.23



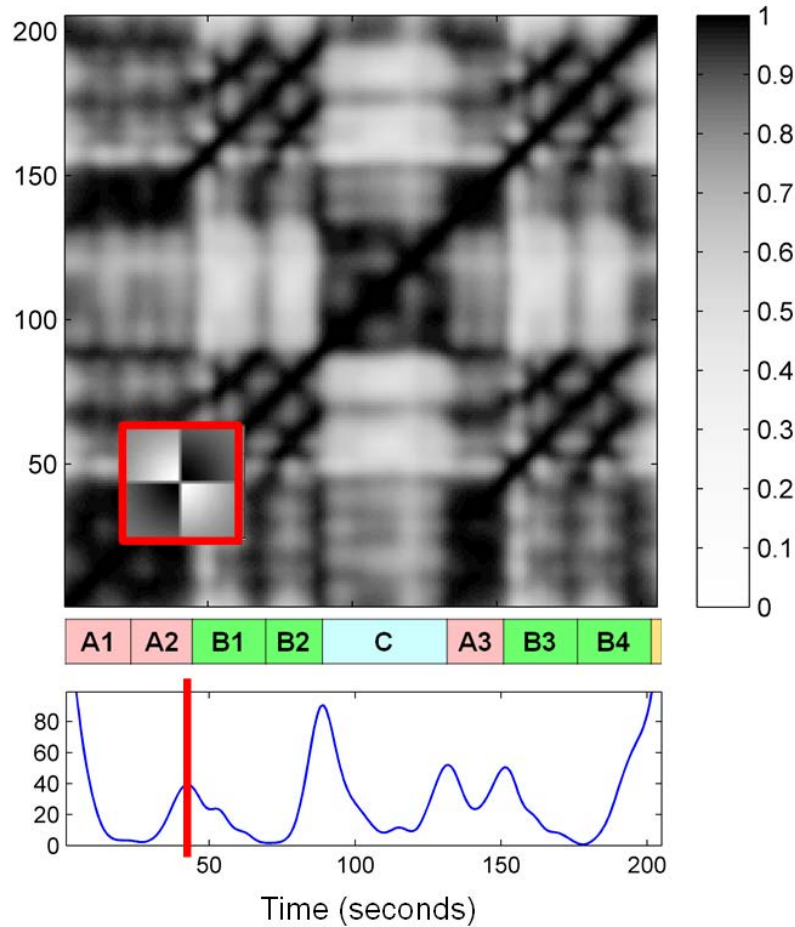
# 4.4 Novelty-Based Segmentation

Fig. 4.24



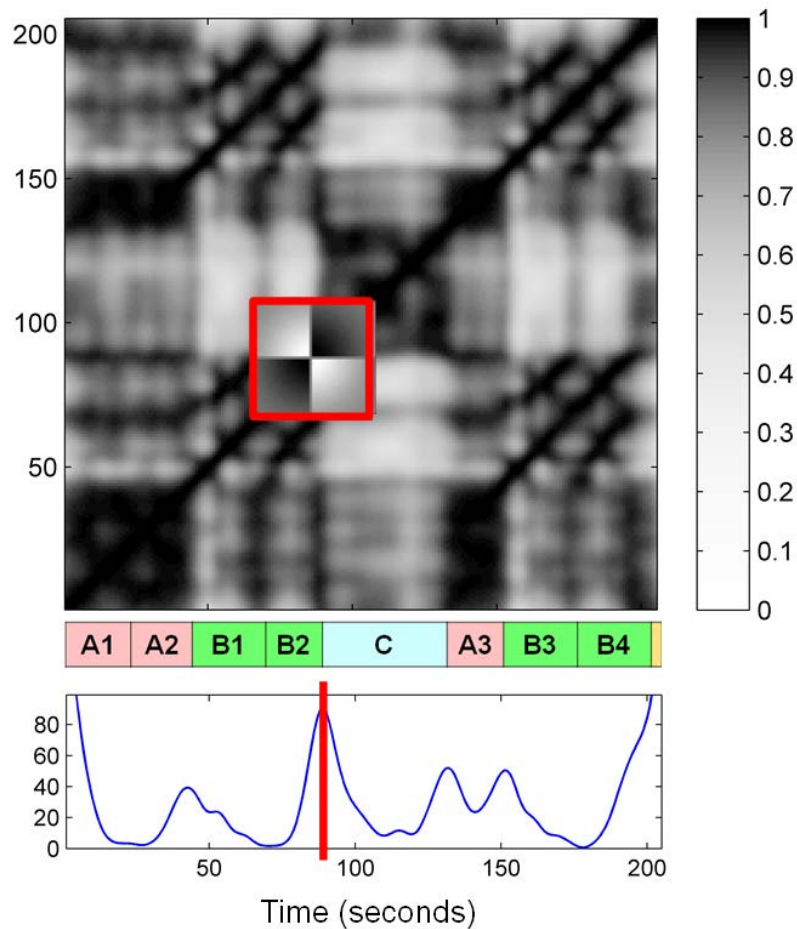
# 4.4 Novelty-Based Segmentation

Fig. 4.24



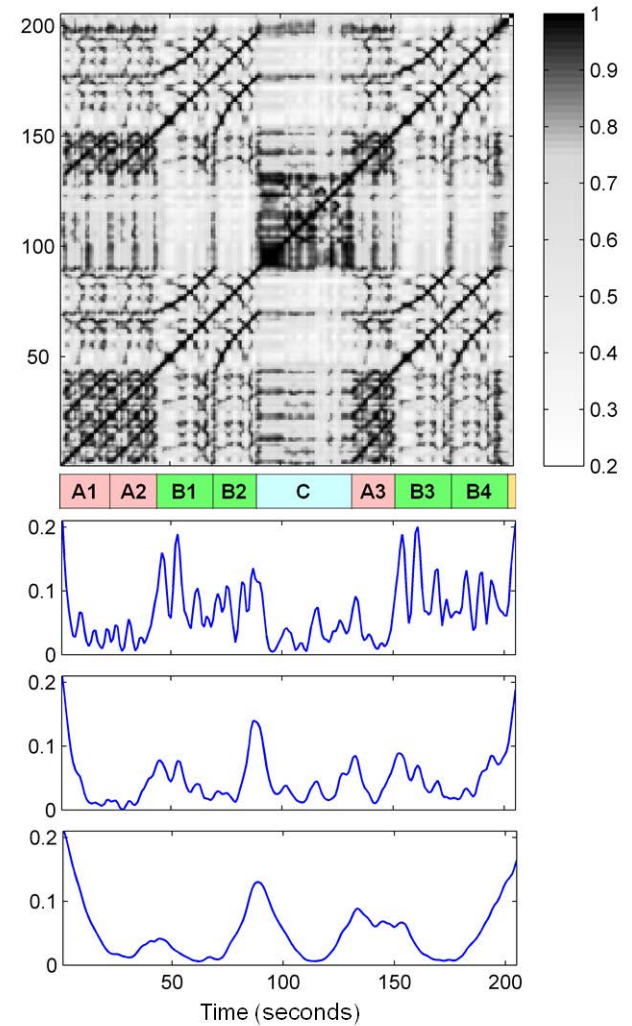
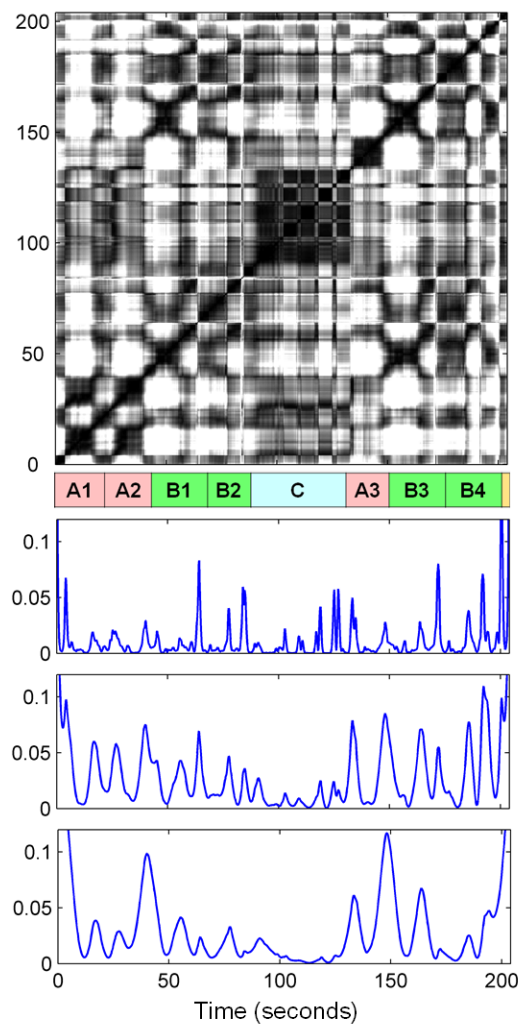
# 4.4 Novelty-Based Segmentation

Fig. 4.24



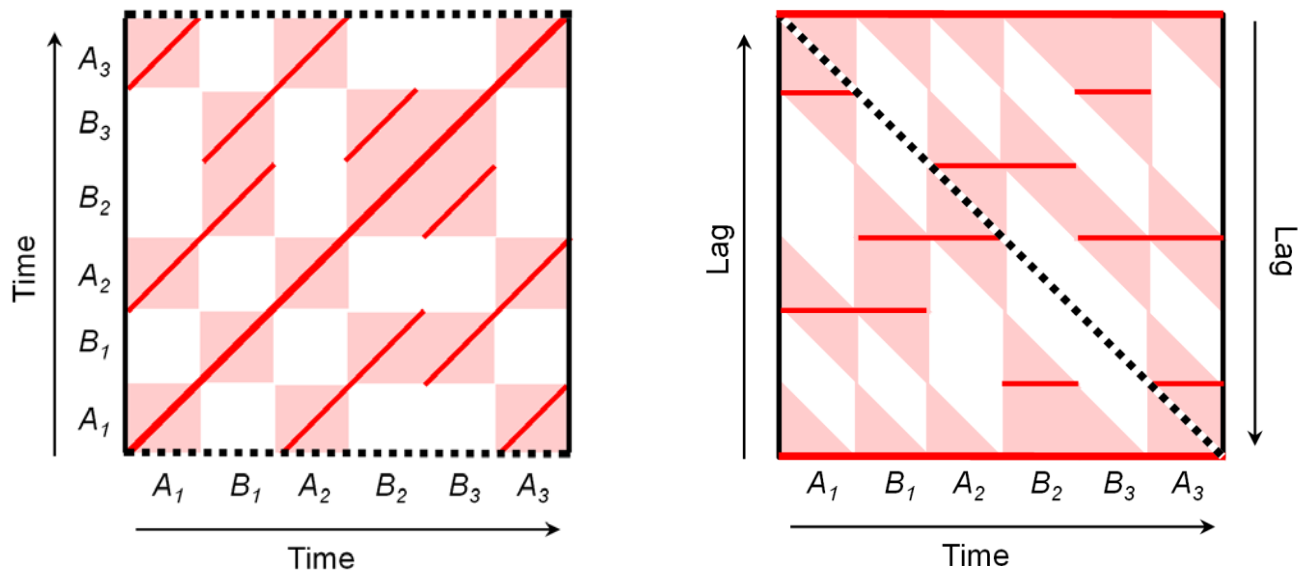
# 4.4 Novelty-Based Segmentation

Fig. 4.25



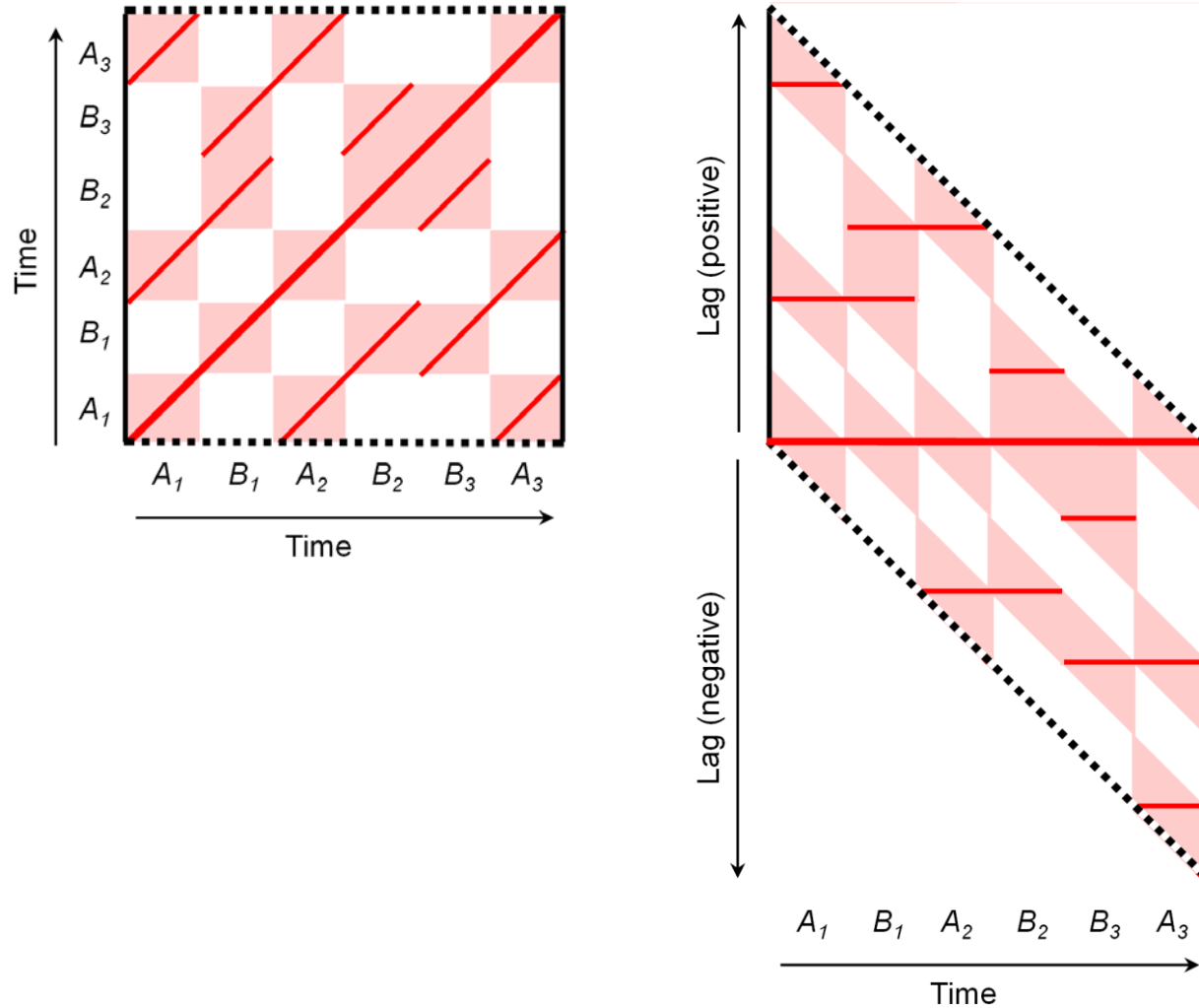
# 4.4 Novelty-Based Segmentation

Fig. 4.26



# 4.4 Novelty-Based Segmentation

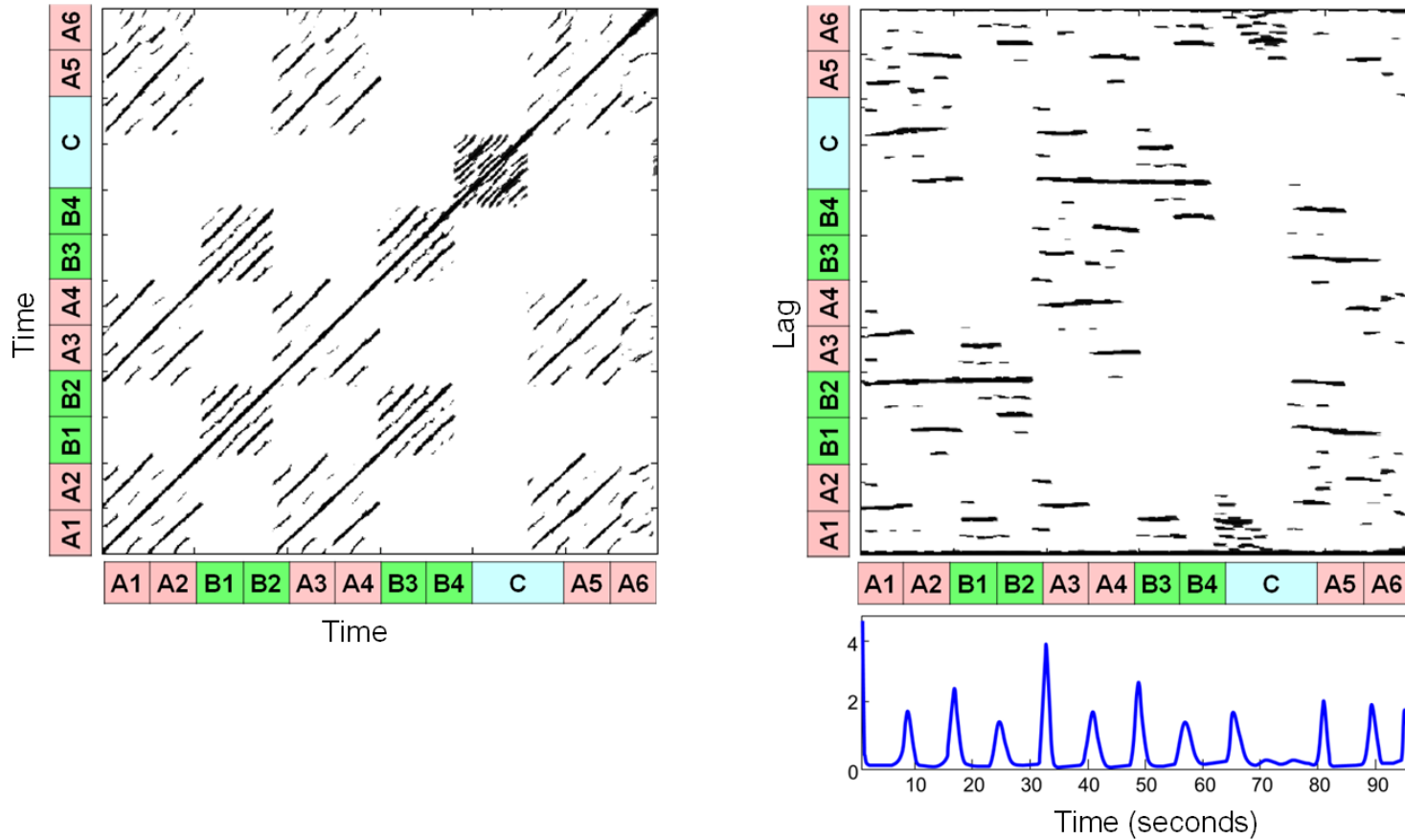
Fig. 4.26





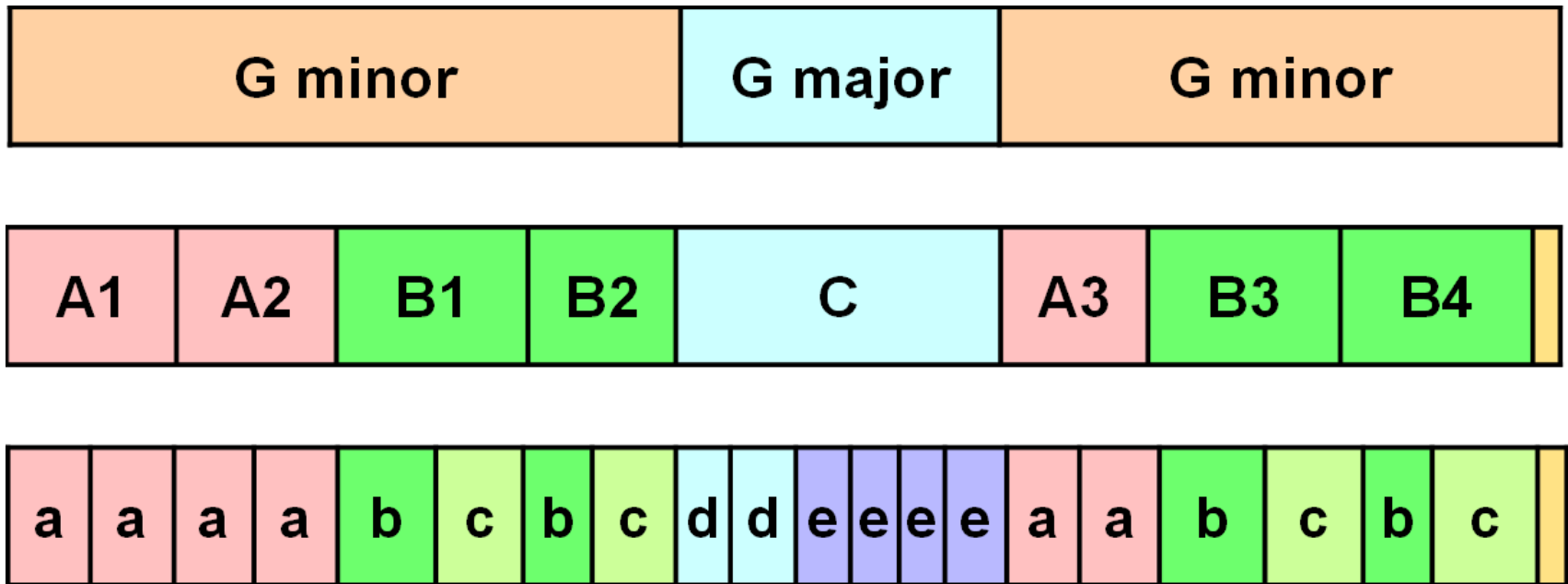
# 4.4 Novelty-Based Segmentation

Fig. 4.27



# 4.5 Evaluation

Fig. 4.28



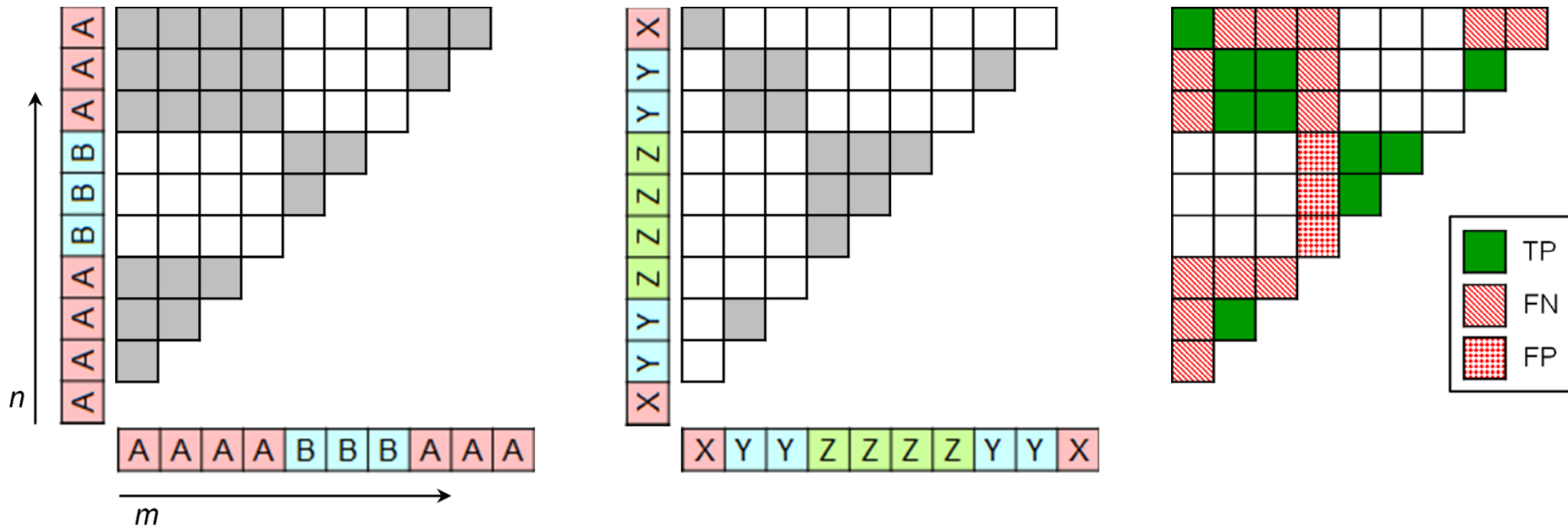
# 4.5 Evaluation

Fig. 4.29

		Reference annotation ("Ground truth")		
		Positive	Negative	
Estimated annotation ("Algorithm")	Positive	True positive (TP)	False positive (FP)	$P = \frac{\#TP}{\#TP + \#FP}$
	Negative	False negative (FN)	True negative (TN)	
		$R = \frac{\#TP}{\#TP + \#FN}$		$F = \frac{2PR}{P + R}$

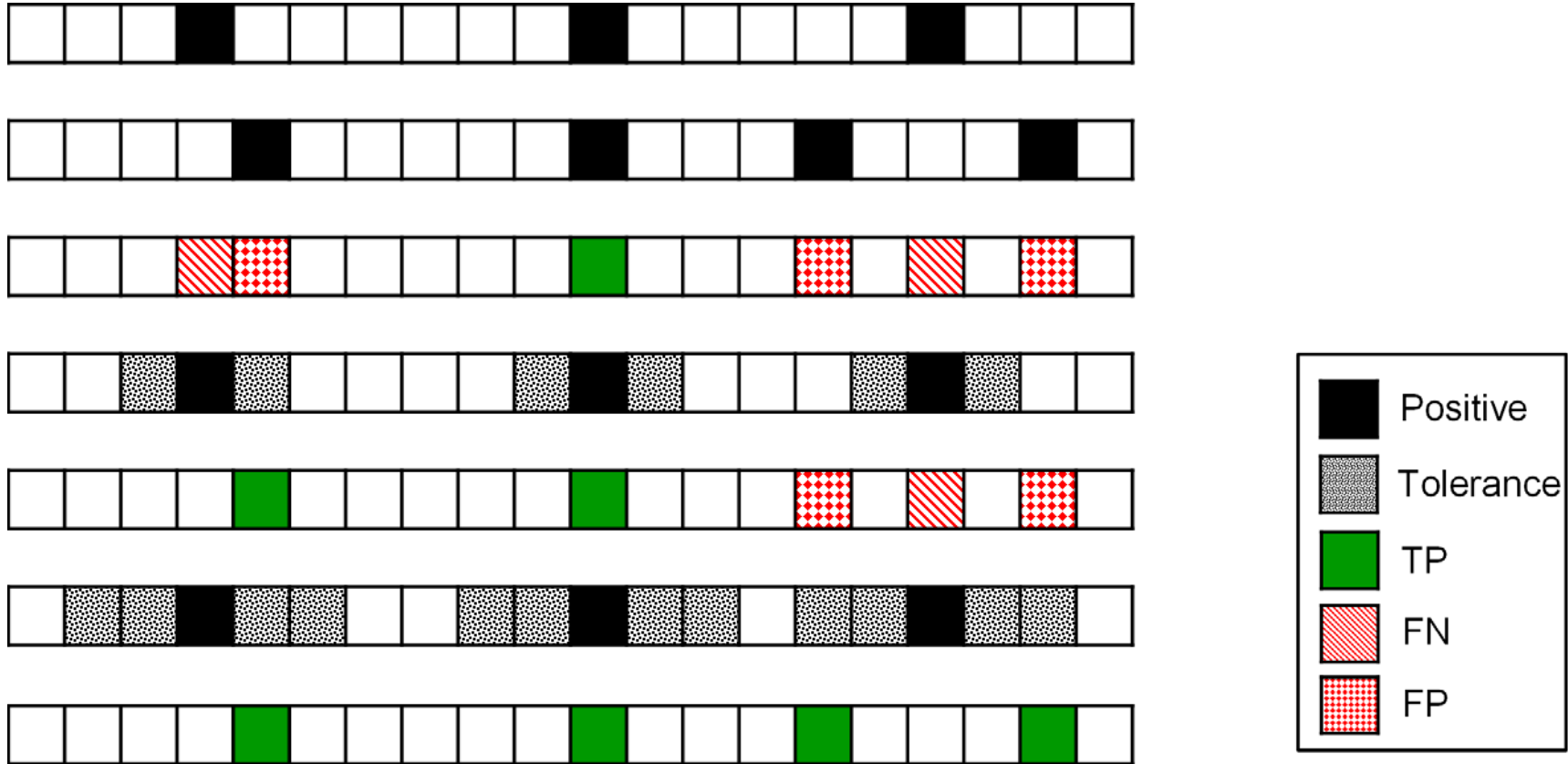
# 4.5 Evaluation

Fig. 4.30



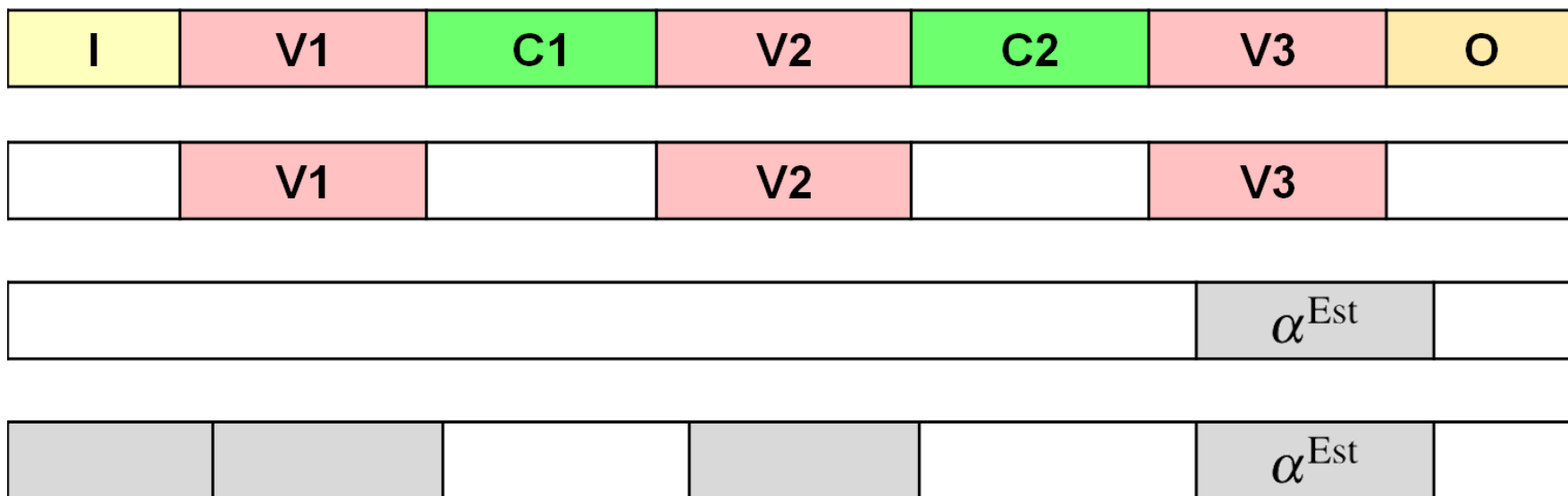
# 4.5 Evaluation

Fig. 4.31



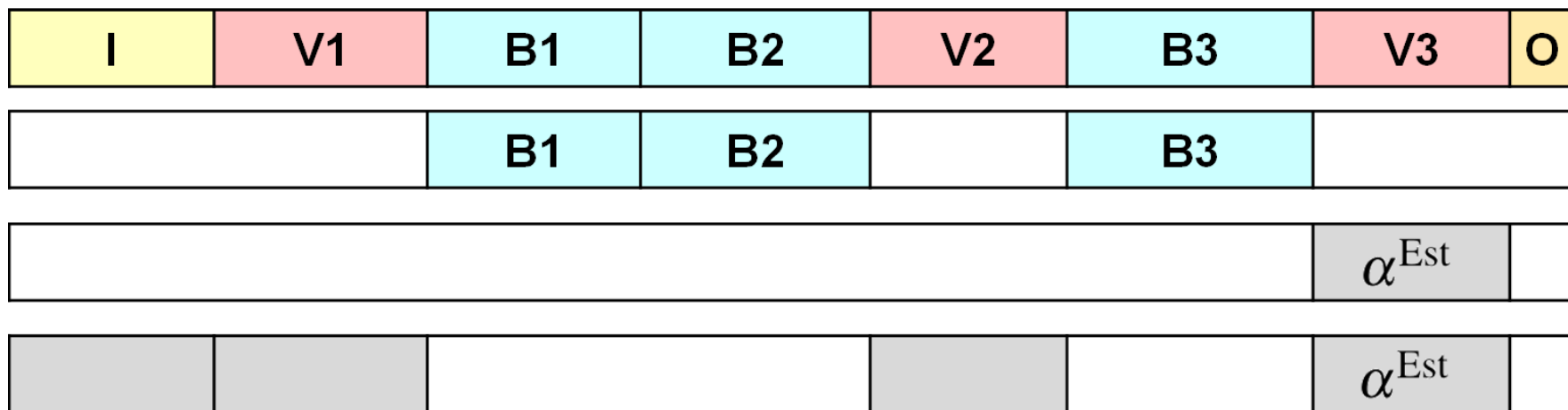
# 4.5 Evaluation

Fig. 4.32



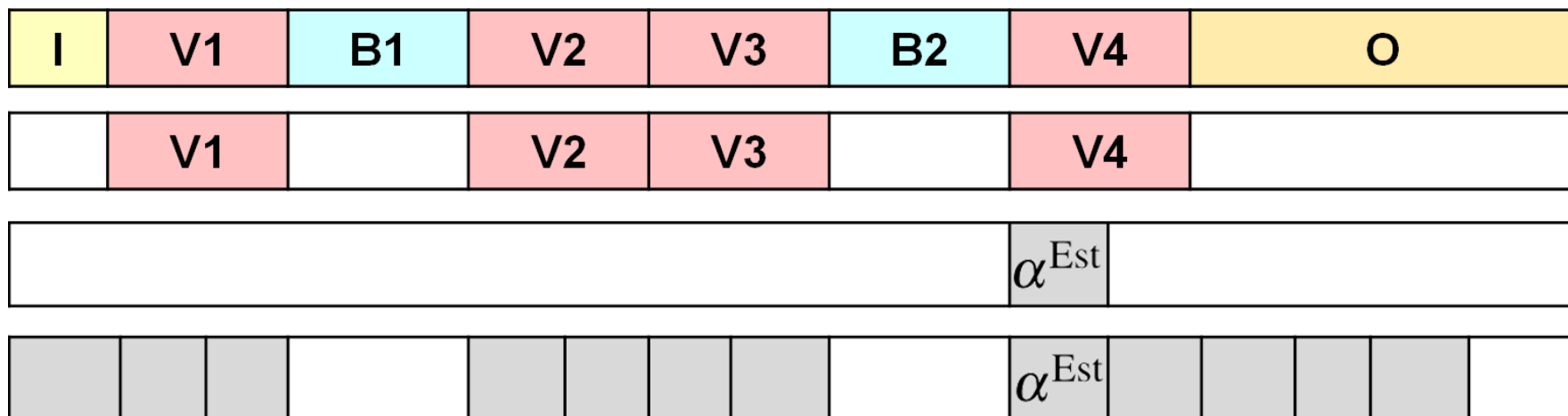
# 4.5 Evaluation

Fig. 4.33



# 4.5 Evaluation

Fig. 4.33





# 4.5 Evaluation

Fig. 4.33

