Multivariate Symbolic Aggregate Approximation for ECG Analysis

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Outline

1. Introduction and Background
2. Methods
3. Results
4. Conclusions

Motivation and Relevance

- heart diseases kill more people a year than any other disease
- ischemic heart disease (IHD) makes up 16% of global deaths
- IHD can be diagnosed using a stress test and electrocardiogram (ECG or EKG)
- manual ECG analysis is slow and error-prone

→ computerized ECG analysis can help

What is an ECG?

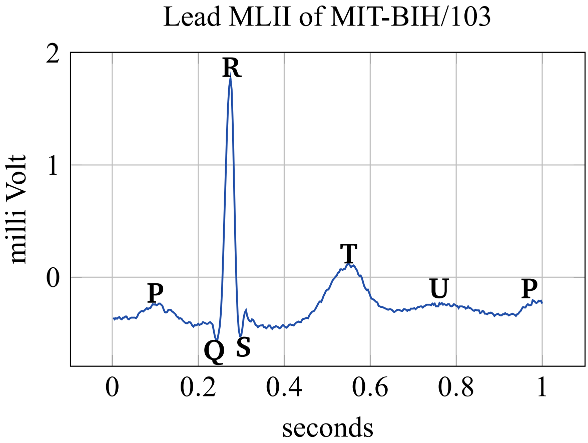


Figure 1: Annotated ECG of one heartbeat

- records the heart’s electrical activity
- contains up to 12 leads (simultaneous measurements)

Steps of ECG Analysis I

General steps:

(1) signal acquisition and filtering

(2) data transformation or preparation for processing

(3) waveform recognition

(4) feature extraction

(5) classification or diagnosis

Steps of ECG Analysis II

This work's focus:

(1) signal acquisition and filtering

→ **data transformation** or preparation for processing

(3) waveform recognition

(4) feature extraction

→ **classification** or diagnosis

Research Questions & Hypothesis

- using the MIT-BIH ECG database, determine the parameters maximizing HOT SAX and HOT MSAX recall
- compare recall value for best parameters

→ HOT MSAX should have higher recall than HOT SAX if both use their best parameters

Previous Research

- Lin *et al.* (2003):
  Symbolic Aggregate Approximation (SAX)—simplified, symbolic representation

- Keogh *et al.* (2005):
  Heuristically Ordered Time series using SAX (HOT SAX)—discord discovery algorithm using SAX

- Anacleto *et al.* (2020):
  Multivariate SAX (MSAX)—expands SAX to multivariate time series

This Work’s Novel Contributions

- application of MSAX to ECG discord discovery
- the HOT MSAX algorithm
- the expansion of HOT SAX to multivariate time series through HOT MSAX

SAX and MSAX – Overview

SAX	MSAX
Application	
univariate time series e.g. a single ECG lead	multivariate time series e.g. multiple ECG leads
Steps	
(1) univariate z-normalization (2) PAA dimension reduction (3) SAX discretization	(1) multivariate z-normalization (2) PAA dimension reduction (3) SAX discretization

SAX and MSAX – Step (2)

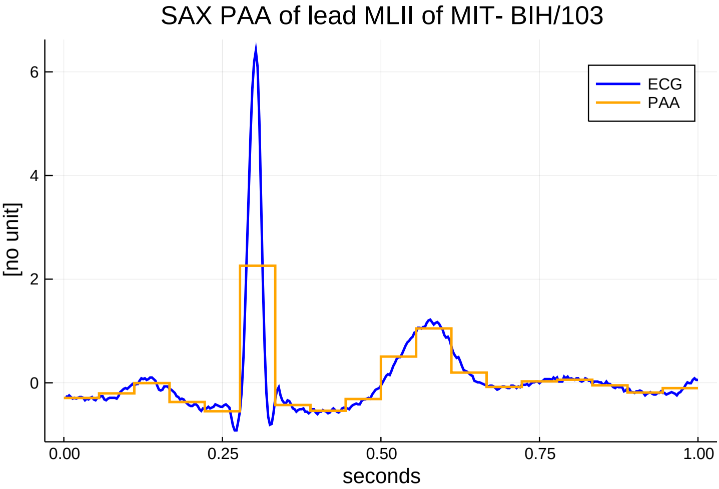


Figure 2: ECG with PAA (MIT-BIH/103, $w = 18$, $T = 360$)

SAX and MSAX – Step (3)

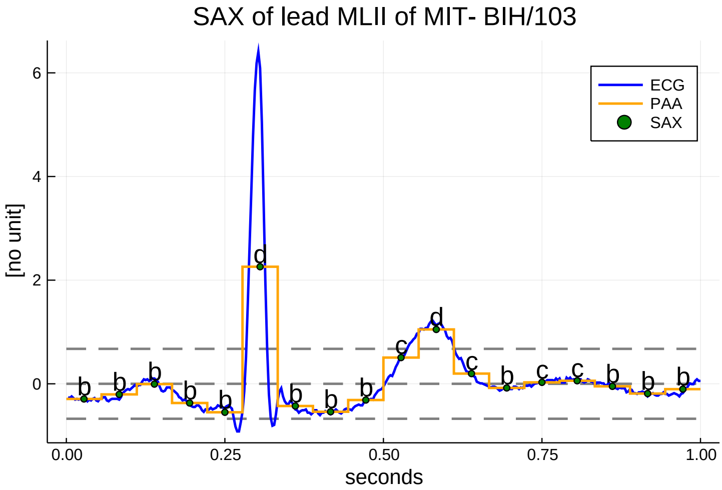


Figure 3: ECG with SAX (MIT-BIH/103, $w = 18$, $T = 360$)

SAX and MSAX – Distance Measure

- basically the sum of distances between symbols
- symbol distance is based on difference of breakpoints
- lower-bounds Euclidean Distance, corresponds to “real” distance

Table 1: Distance matrix for 5 symbols.

	a	b	c	d	e
a	0	0	0.59	1.09	1.68
b	0	0	0	0.51	1.09
c	0.59	0	0	0	0.59
d	1.09	0.51	0	0	0
e	1.68	1.09	0.59	0	0

HOT SAX and HOT MSAX – Overview

- HOT SAX: find discords in SAX-represented time series
- speeds up the “brute force” approach
- classifies time series segments into “discord” and “non-discord”
- HOT MSAX: uses MSAX instead of SAX
- HOT MSAX can work with multivariate time series

HOT SAX and HOT MSAX – Heuristic

- two assumptions:
  - time series discords are rare
  - similar segments are similarly rare
- speed up discord discovery:
  - consider rarest segments first
  - consider segments similar to the rarest first

Parameter Optimization

- perform HOT SAX and HOT MSAX for many parameter combinations
- find recall for each combination
- recall threshold of 95%, then sort by precision
- choose top 10 of those parameters for each method
- choose best parameters using box plot, interquartile range, outliers

Overview of Results

Table 2: Coarse Overview of Results. Shown are sets of parameters for each method that satisfy the recall threshold of 95%.

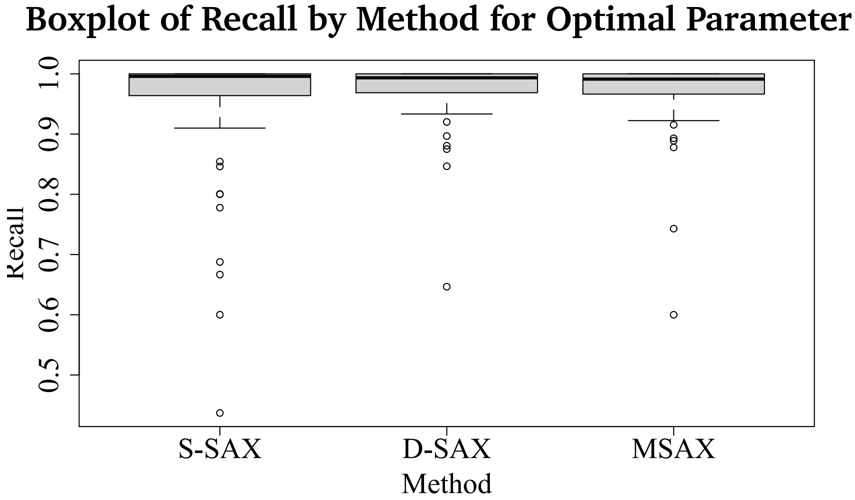
Method	Total Sets	Sets Satisfying recall $\geq$95%
S-SAX	4,968	99 (1.2%)
D-SAX		192 (3.9%)
MSAX		255 (5.1%)

Best Parameter Sets by Method

Table 3: Best Parameter sets for each of the methods. Best overall parameters highlighted in bold.

Parameter / Method	k	w, m	a
S-SAX	-1	36	21
D-SAX	-1	**12**	24
MSAX	-1	**12**	**17**

Comparing Best Parameter Sets – Recall



Comparing Best Parameter Sets – Recall

Table 4: Statistical measures for recall of optimal parameter sets. Best overall values highlighted in bold.

Method \ Measure	IQR	Median	Outliers
S-SAX	0.035	**99.60%**	11
D-SAX	**0.030**	99.35%	**6**
MSAX	0.033	99.13%	**6**

Discussion

- no statistically significant difference in recall for the methods

→ hypothesis cannot be supported

- MSAX has both the smallest alphabet size and highest dimension reduction

→ this points to MSAX being more efficient in achieving the same results

- Anacleto, Vinga, and Carvalho [5] showed similar performance for ECG classification, supports this work's conclusion

Conclusion

- could not demonstrate superiority of HOT MSAX for best parameters
- contributed the HOT MSAX method to literature
- HOT MSAX was found to be more efficient than HOT SAX
- showed viability of a discord classifier for ECG analysis

References I

[1] G. B. Moody and R. G. Mark, *MIT-BIH Arrhythmia Database*, physionet.org, 1992. DOI: 10.13026/C2F305.

[2] J. Lin, E. Keogh, S. Lonardi, and B. Chiu, "A symbolic representation of time series, with implications for streaming algorithms," in *Proceedings of the 8th ACM SIGMOD Workshop on Research Issues in Data Mining and Knowledge Discovery - DMKD '03*, San Diego, California: ACM Press, 2003, pp. 2–11. DOI: 10.1145/882082.882086.

[3] C. Zhang *et al.*, "Anomaly detection in ECG based on trend symbolic aggregate approximation," *Mathematical Biosciences and Engineering*, vol. 16, no. 4, pp. 2154–2167, 2019, ISSN: 1547-1063. DOI: 10.3934/mbe.2019105.

[4] E. Keogh, J. Lin, and A. Fu, "HOT SAX: Efficiently Finding the Most Unusual Time Series Subsequence," in *Fifth IEEE International Conference on Data Mining (ICDM'05)*, Houston, TX, USA: IEEE, 2005, pp. 226–233. DOI: 10.1109/ICDM.2005.79.

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[5] M. Anacleto, S. Vinga, and A. M. Carvalho, “MSAX: Multivariate Symbolic Aggregate Approximation for Time Series Classification,” in *Computational Intelligence Methods for Bioinformatics and Biostatistics*, P. Cazzaniga, D. Besozzi, I. Merelli, and L. Manzoni, Eds., ser. Lecture Notes in Computer Science, Cham: Springer International Publishing, 2020, pp. 90–97. DOI: 10.1007/978-3-030-63061-4_9.

Thank You!