Biomedical Signal Processing

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An Analysis of the Organization of Atrial Fibrillation

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Paper Overview

A Method for Quantifying Atrial Fibrillation Organization Based on Wave-Morphology Similarity

Faes et al., IEEE Transactions on Biomedical Engineering, 2002

Presenting an innovative method for quantifying the degree of organization of atrial fibrillation (*AF*) by analyzing the morphological similarity between atrial activation waves.

Key Goals

- To classify AF based on its level of organization (from flutter to disorganized Type III).
- To provide a numerical index (*SI - Similarity Index*) that measures how similar atrial waves are to each other.
- To support the diagnosis and treatment of atrial fibrillation.

A Method for Quantifying Atrial Fibrillation Organization Based on Wave-Morphology Similarity

Luca Faes*, Giandomenico Nollo, Renzo Antolini, Fiorenzo Gaita, and Flavia Ravelli

***Abstract*—A new method for quantifying the organization of single bipolar electrograms recorded in the human atria during atrial fibrillation (AF) is presented. The algorithm relies on the comparison between pairs of local activation waves (LAWs) to estimate their morphological similarity, and returns a regularity index (ρ) which measures the extent of repetitiveness over time of the detected activations. The database consisted of endocardial data from a multipolar basket catheter during AF and intraatrial recordings during atrial flutter. The index showed maximum regularity ($\rho = 1$) for all atrial flutter episodes and decreased significantly when increasing AF complexity as defined by Wells (type I: $\rho = 0.75\pm0.23$; type II: $\rho = 0.35\pm0.11$; type III: $\rho = 0.15\pm0.08$; $P < 0.01$). The ability to distinguish different AF episodes was assessed by designing a classification scheme based on a minimum distance analysis, obtaining an accuracy of 85.5%. The algorithm was able to discriminate among AF types even in presence of few depolarizations as no significant ρ changes were observed by reducing the signal length down to include five LAWs. Finally, the capability to detect transient instances of AF complexity and to map the local regularity over the atrial surface was addressed by the dynamic and multisite evaluation of ρ, suggesting that our algorithm could improve the understanding of AF mechanisms and become useful for its clinical treatment.**

***Index Terms*—Atrial fibrillation (AF), endocardial signals, rhythm classification, signal processing, tachyarrhythmia organization, waveform morphology.**

I. INTRODUCTION

ATRIAL fibrillation (AF) is a commonly encountered cardiac disorder, which occurs in up to 10% of individuals older than 70 years of age [1], and is associated with increased risk for stroke and/or embolic events [2], [3]. Although it is not yet clear how AF occurs, human studies and animal models have demonstrated that it is associated with the propagation throughout the atrial tissue of multiple activation wavelets, resulting in complex ever-changing patterns of electrical activity [4], [5]. As a consequence, during AF, the electrogram morphology changes constantly both in time and space showing different levels of spatiotemporal organization, according to a definition of organization as repetitive wave morphologies in the AF signals. Since the various morphologies reflect different spatial activation patterns such as slow conduction, wave collision, and conduction blocks [6], the analysis of the waveform changes of the endocardial signals acquired during AF plays an important role in the understanding of the mechanisms responsible for its induction and maintenance. Furthermore, the analysis of the degree of complexity characterizing the shape of the activation waves provides an electrophysiologic, instead of anatomic, help for guiding the catheter ablative therapy of AF [7], [8]. Up to now, the evaluation of the morphological features of the atrial activations is performed by a subjective qualification of the extracellular recordings following predefined rules [9].

Several algorithms for the quantitative analysis of AF organization have been reported in the literature. Since a rigorous definition of organization does not exist, various approaches have been adopted including monovariate [10] and bivariate [11] frequency analysis, cross-correlation techniques [12], linear prediction [13], and nonlinear analysis [14], [15]. All these techniques proposed for evaluating the regularity of AF electrical pattern require a significant manipulation of the atrial waveforms and the lack of a direct evaluation of the characteristics of the activation waves limits their potentiality in distinguishing among different degrees of AF complexity. Moreover, these methods work on the complete atrial recording, including also part of the signal during which the analyzed atrial site is not activated by the depolarizing wave fronts. On the other hand, the signal morphology is often overlooked by analyzes that characterize AF by means of the occurrence time of the atrial activations [16] or the atrial interval [17], [18].

In this paper, a new algorithm for the evaluation of the organization of the atrial electrograms during AF based on wave-morphology similarity is presented. The algorithm quantifies the regularity of an atrial electrogram by measuring the extent of repetitiveness over time of its consecutive activation waves. Since the analysis is focused on the shape of the waveforms occurring in correspondence of the local activations of the atrial tissue, the morphology of the atrial activations is the element by which the algorithm differentiates among various degrees of AF organization. Thus, unlike other published algorithms the proposed method analyzes the signal only in correspondence of the depolarizing wave fronts, excluding parts with low informative content and poor signal-to-noise ratio (SNR). Furthermore, it provides a local measure of AF organization since the analysis is performed on single atrial signals. The performance of the

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Methods & Data

Two complementary datasets to validate the algorithm on different recording modalities:

IAFDB (*Intracardiac Atrial Fibrillation Database*)

- 32 recordings (from 8 patients)
- Sampling frequency: 1000 Hz (1 kHz)
- Signal type: Bipolar endocardial recordings from the right atrium
- Positions: SVC, IVC, TVA, AFW (*superior vena cava*, *inferior vena cava*, *tricuspid valve*, *free wall*)

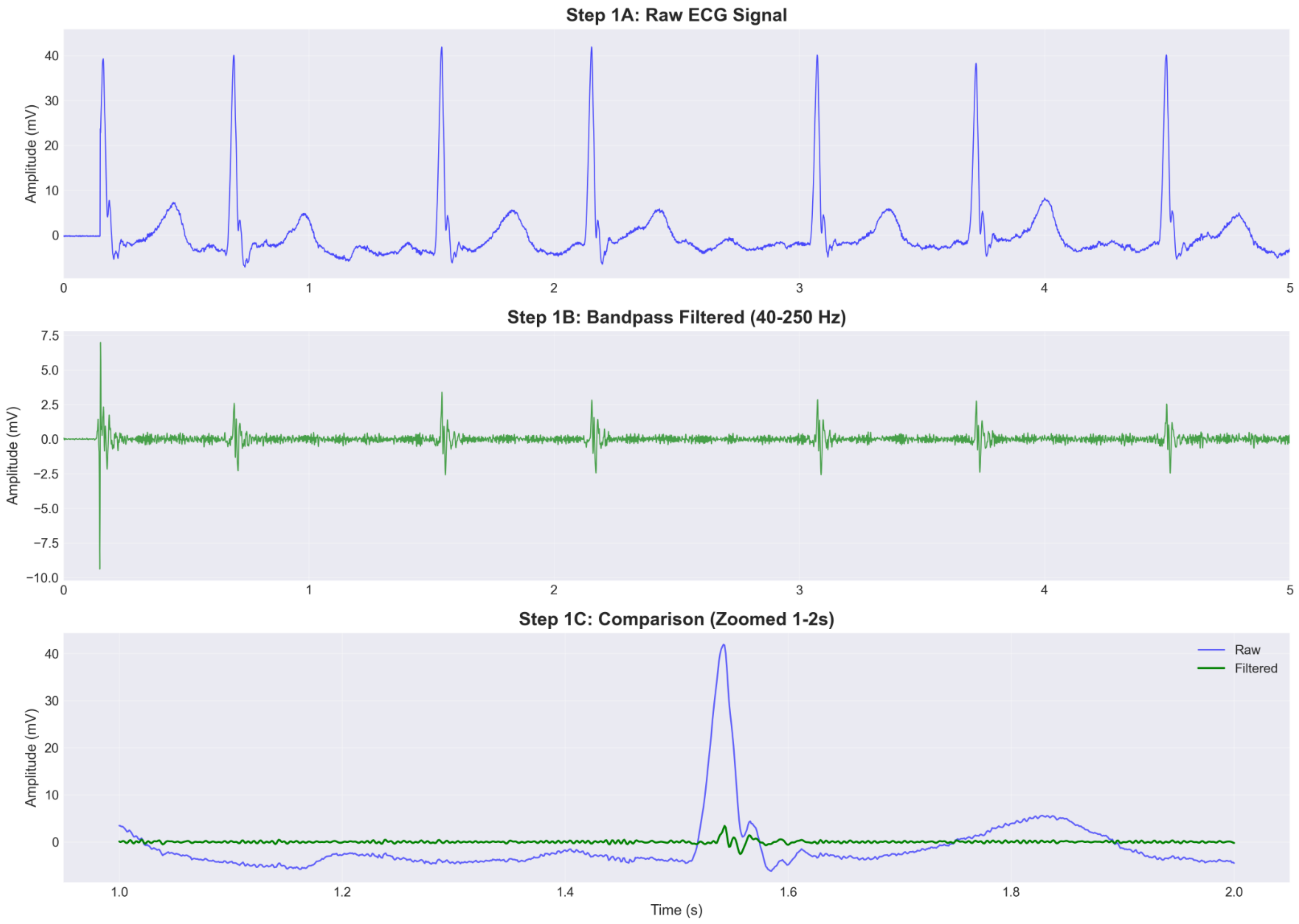
AFTDB (*AF Termination Challenge Database*)

- 80 recordings in total (30 learning sets + 50 test sets)
- Sampling frequency: 128 Hz
- Duration: 60 seconds per record
- Signal type: 2-channel surface ECG groups:
  - Group N: Non-terminating AF (>1 hour)
  - Group S: AF terminates after 1 minute
  - Group T: AF terminates immediately (<1 sec)

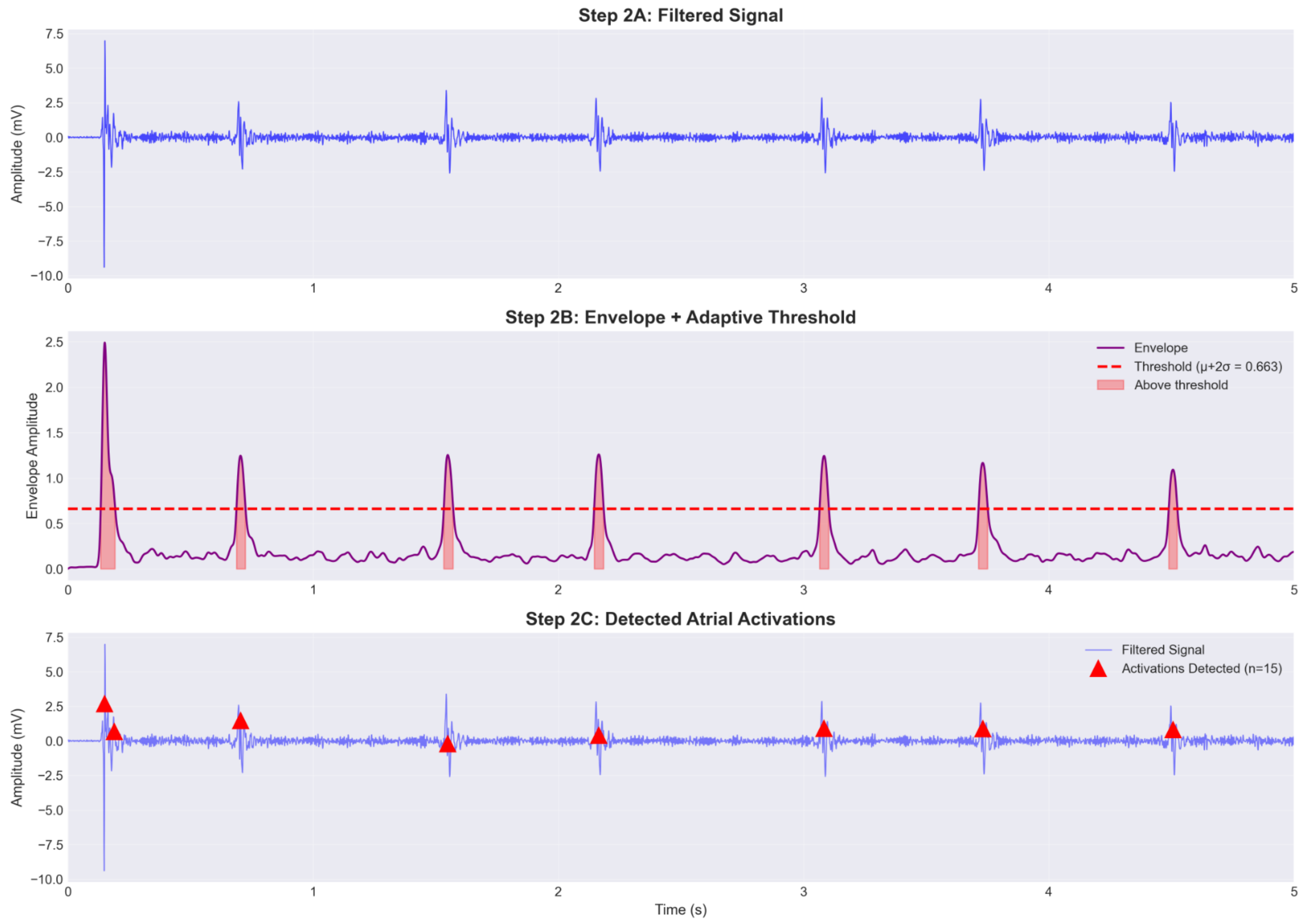
Why two datasets? In order to demonstrate that the algorithm works on different acquisition modes

Algorithm - Part 1 (Preprocessing and Detection)

Step 1: Bandpass Filtering (40-250 Hz)

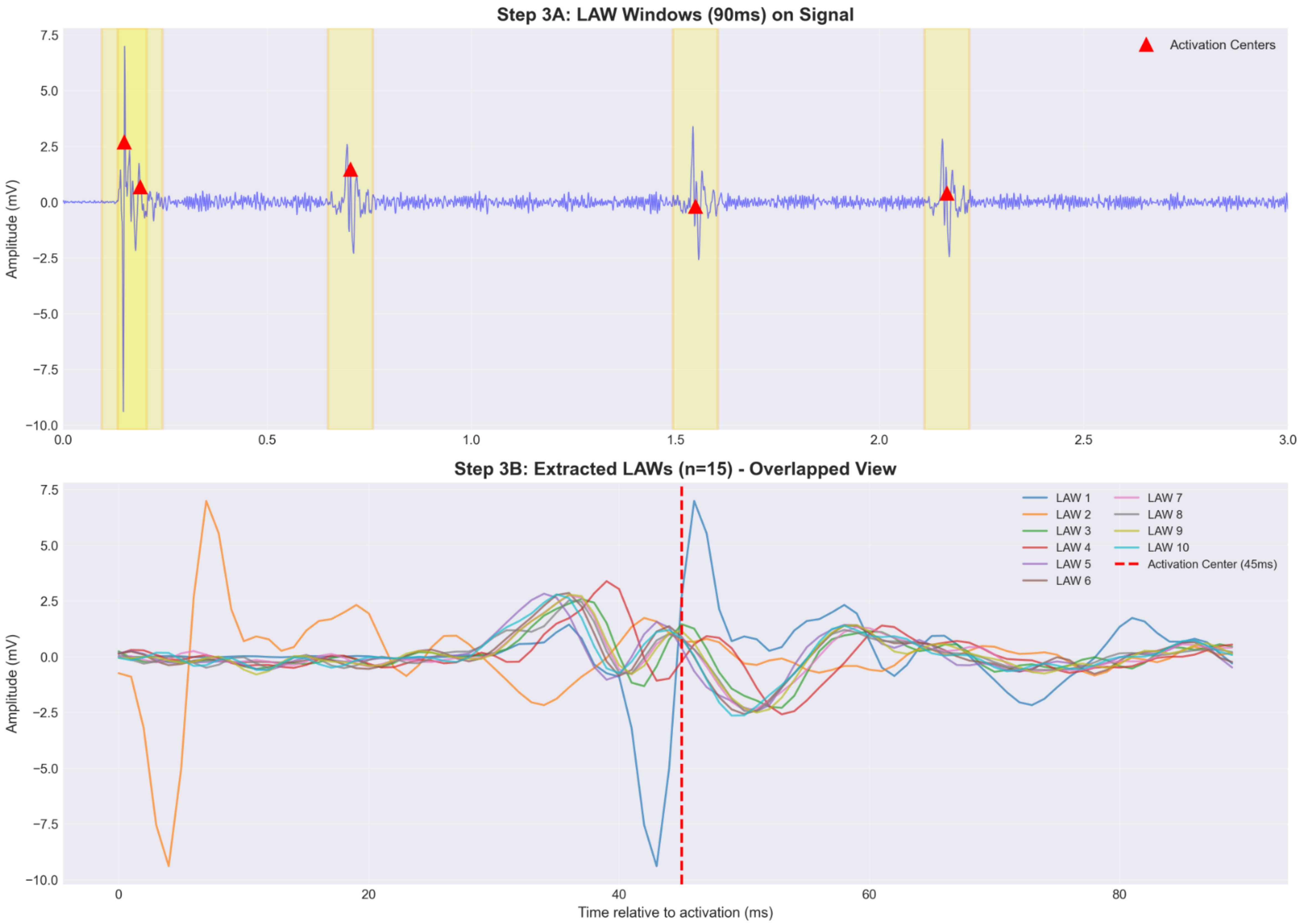


Step 2: Detection of Atrial Activations

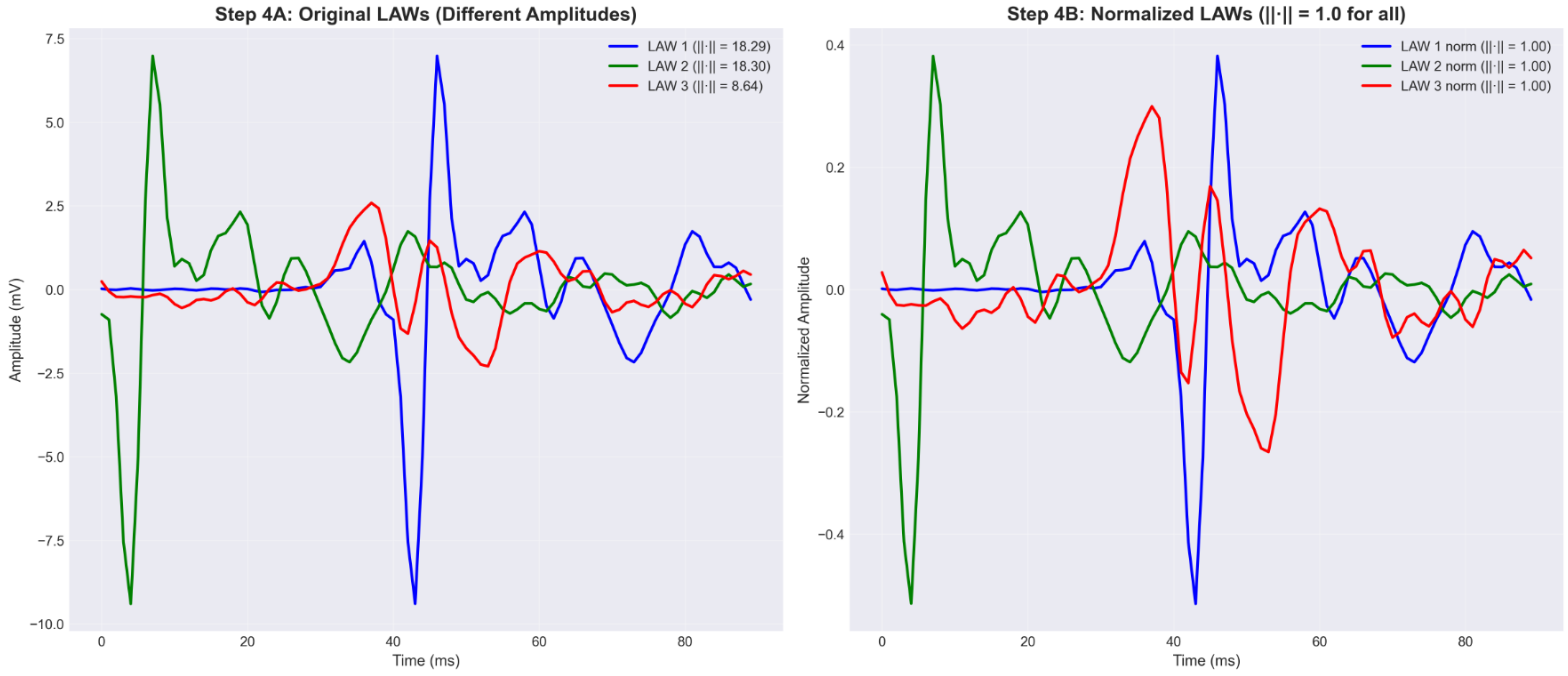


Algorithm - Part 2 (LAWs Extraction and Normalization)

Step 3: Extraction of LAWs (Local Activation Waves)

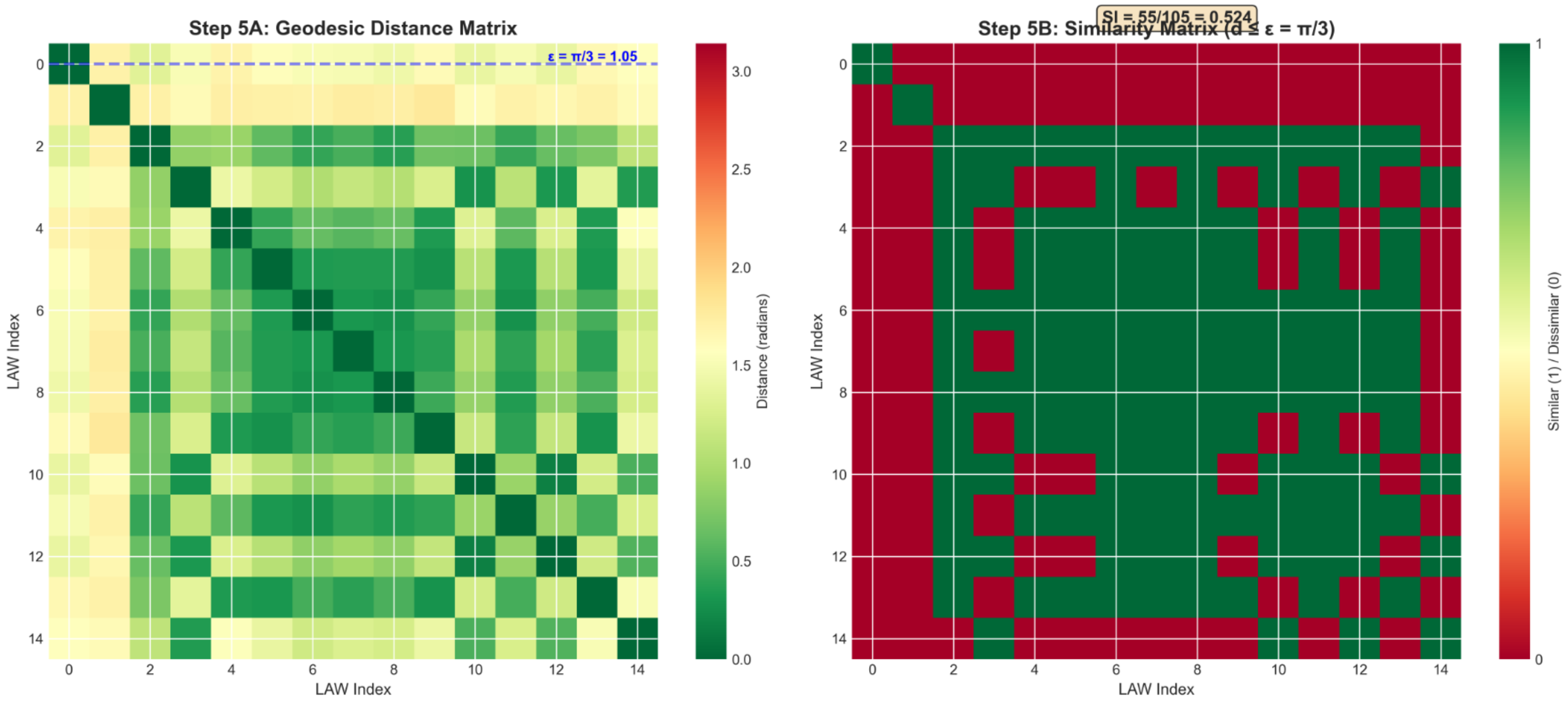


Step 4: L2 normalization

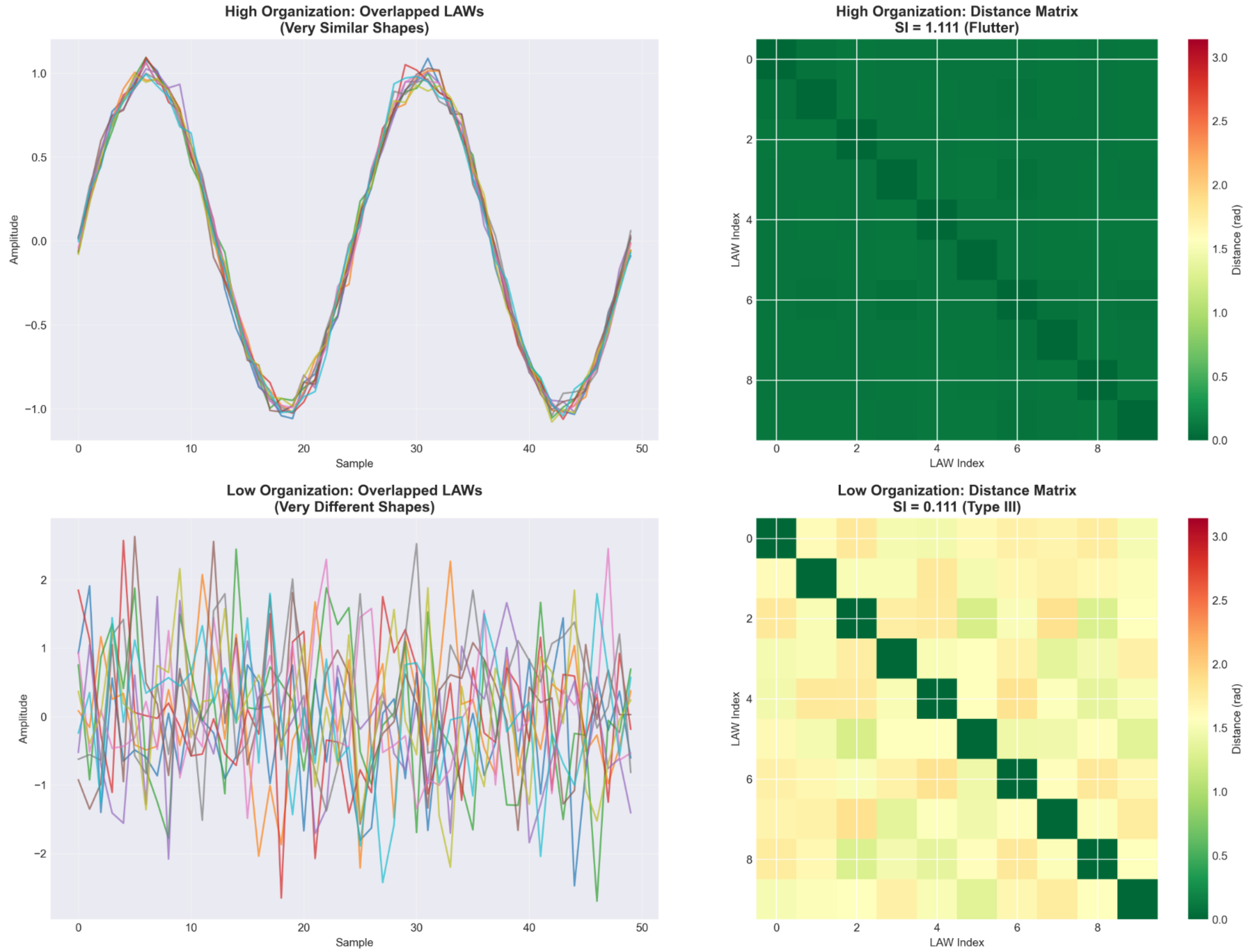


Algorithm - Part 3 (Similarity Index Calculation)

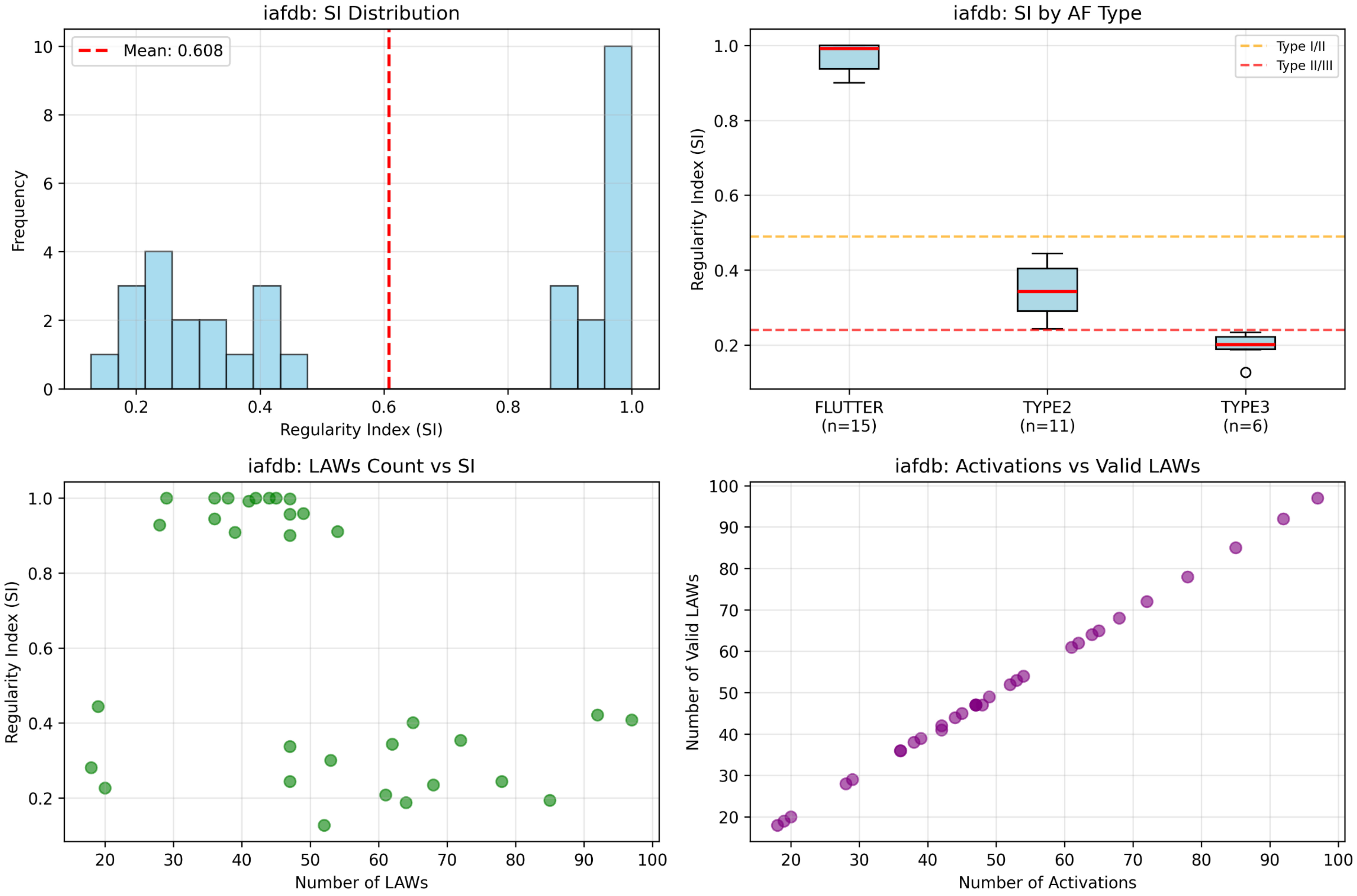
Step 5: Geodetic Distances



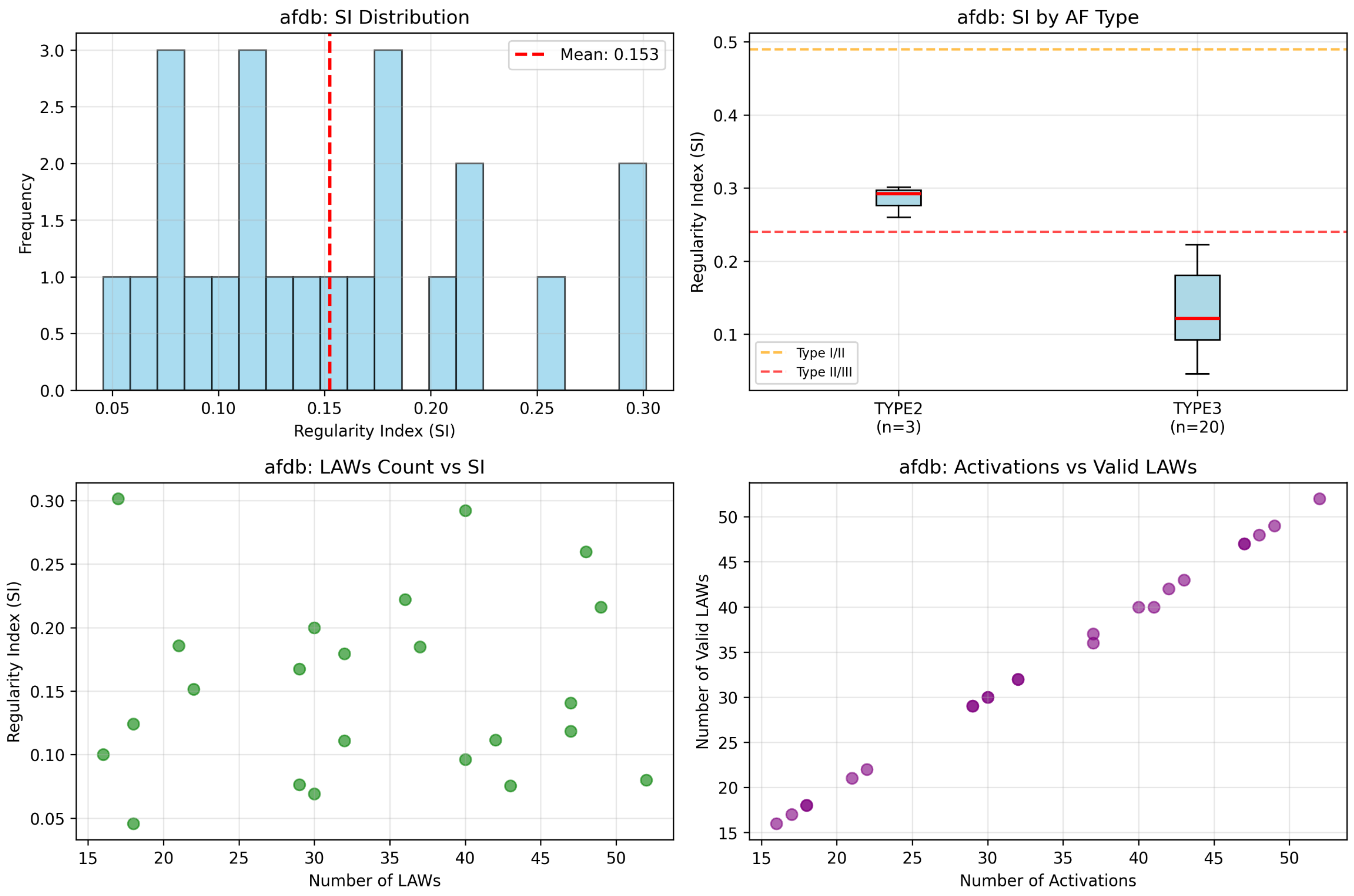
Step 6: Similarity Index



Results - IAFDB (Intracardiac) Dataset



Results - AFTDB Dataset (Superficial ECG)



Conclusions

Metric	IAFDB	AFDB
Average SI	0.608 ± 0.350	0.153 ± 0.072
Sampling frequency	977 Hz	250 Hz
LAW samples	~88	~23
Signal type	Intracardiac	Surface ECG
Range SI	[0.127, 1.000]	[0.046, 0.301]
Classification	47% Flutter, 34% Type II, 19% Type III	0% Flutter, 13% Type II, 87% Type III
Total records	32	23

Thank You