

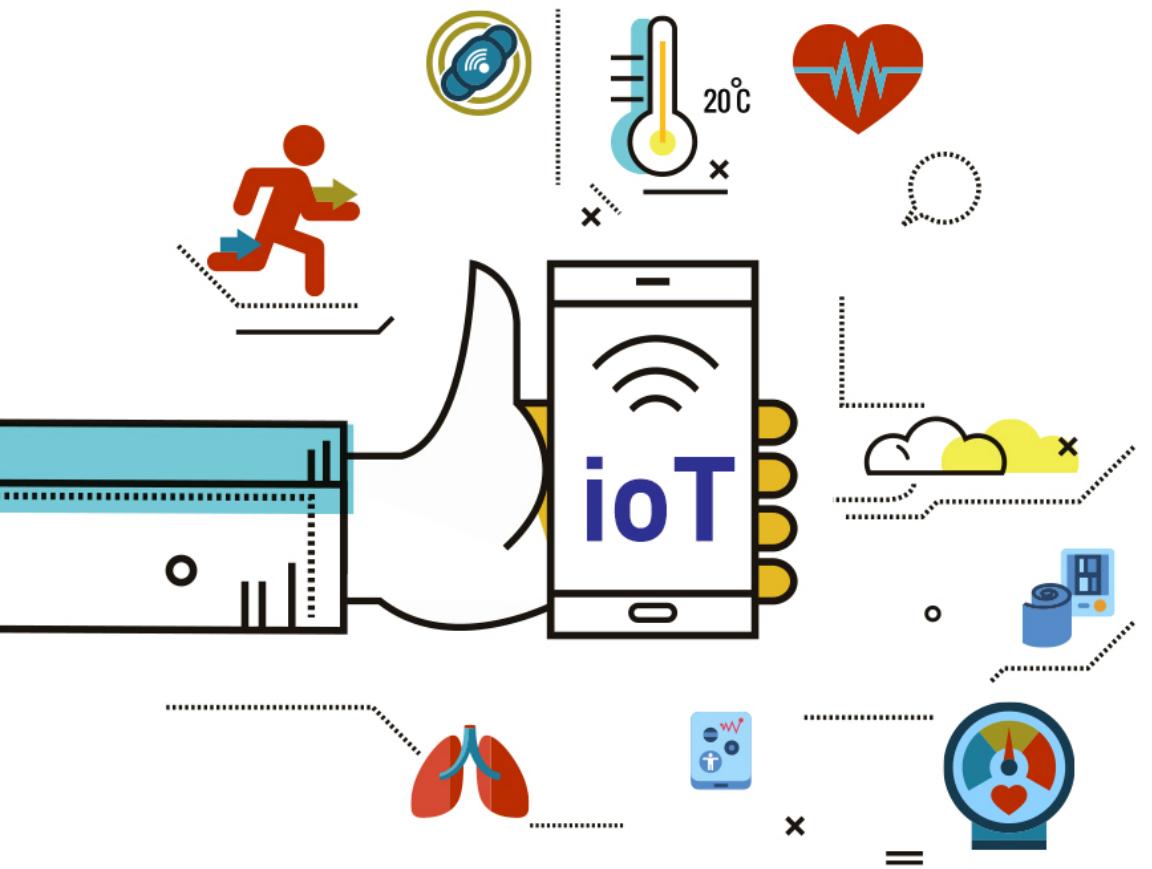
# Automatic Real-time Beat-to-beat Detection of Arrhythmia Conditions

**Giovanni Rosa**, Gennaro Laudato, Angela Rita Colavita, Simone Scalabrino, and Rocco Oliveto



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# IoT for Healthcare

# Internet of Medical Things

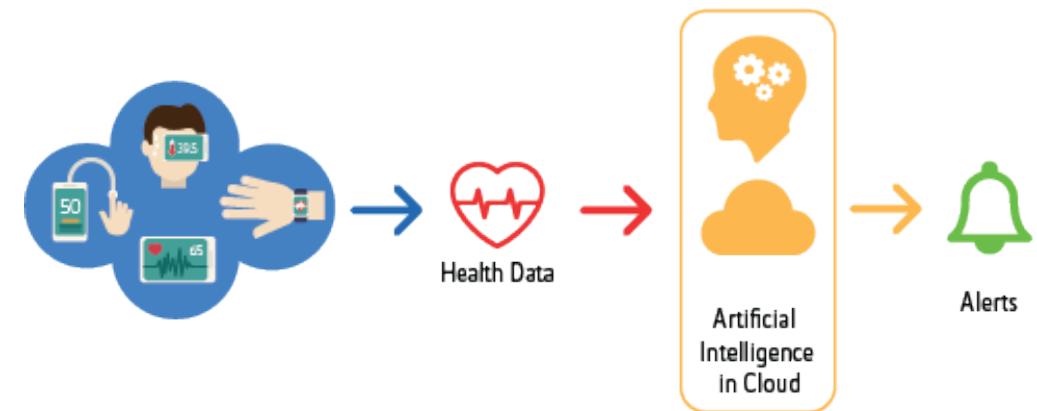


Preventive care

Long-term care and  
chronic diseases

# Internet of Medical Things

AI and Smart Wearables  
for  
early anomaly detection



# Internet of Medical Things

Preventive medical support  
thanks to  
early notified anomalies



## ECG Feature Extraction and Classification Using Wavelet Transform and Support Vector Machines

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**Abstract**—This paper presents a new approach to the feature extraction for reliable heart rhythm recognition. This system of classification is comprised of three components including data preprocessing, feature extraction and classification of ECG signals. Two different feature extraction methods are applied together to extract features from ECG signals. The wavelet transform is used to extract the coefficients of the waveforms as the features of each ECG segment. Simultaneously, autoregressive model is used to extract the features of the waveform of ECG waveform. Then the support vector machine(SVM) with Gaussian kernel is used to classify different ECG heart rhythm. Comparative experiments are conducted to evaluate the performance of the proposed method. From computer simulations, the overall accuracy for recognition of 6 heart rhythm types reaches 99.69%.

### I. INTRODUCTION

The electrocardiogram (ECG) is routinely used in clinical practice, which describes the electrical activity of the heart. In physical checkups at hospitals, physicians usually record ECGs for the patient has complained to work harder cardiac diseases. The Holter ECG device is used most frequently for recording the ECG. Physicians apply the device to a patient when they need to monitor his/her ECG to find a few abnormal cycles in the ECG throughout a day. Physicians can also measure the shapes of these waves and complexes. They calculate parameters to determine whether the ECG shows signs of cardiac disease or not. The parameters are the height and the intervals of these waves, such as RR interval, PP interval, QT interval, and ST segments. Recording of the ECG points and calculations of the parameters is a tedious routine for the physician. Therefore, there is an urgent need for an automatic ECG recognition system to reduce the burdens of interpreting the ECG.

Various studies have been done for classification of various cardiac arrhythmias [1][2][3][4]. In this paper, we propose the combination of wavelet transform and AR model as the feature extraction method, then use the SVM to classify the ECG heartbeats. The proposed approach is validated in the MIT-BIH Arrhythmia Database[5] and get high accuracy of classification.

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### II. ECG DATA AND PREPROCESS

All ECG data were obtained from MIT-BIH arrhythmia database that contains records of many patients with different arrhythmias abnormalities. The frequency of the ECG data was 360Hz. Each record has its respective annotation file that indicate the class of the heartbeat. A single channel ECG is collected and used to algorithm evaluation. Since there are categories of abnormal heartbeats in one record, we select different abnormal QRS complexes from several records. Six types of QRS complexes appeared frequently in the database. These are: normal(NORMAL), left bundle branch block(LBBB), right bundle branch block(RBBB), paced beat(PACE), premature ventricular contraction(PVC) and atrial premature contraction(APC).

In the data preprocessing process, continuous ECG signals are divided into many segments which represent one heartbeat. The extracted data of ECG complexes is centered around R peak. Considered that some PVC duration is great and sometimes R peak detection may not be the center of the complex, we set the center of the complex to be the fiducial point and 400ms after with the R peak point is the 908 point. The R peak is detected using the Pan and Tompkins algorithm[6]. Thus, each segment must contain one ECG heartbeat. Fig.1 shows typical waveforms of six types of ECG segments.

### III. FEATURE EXTRACTION

The recognition of heart rhythms requires generation of the feature vector which represents the original ECG segment. A feature vector is a collection of numbers which represents representing the ECG signals in such a way, that the differences among the ECG waveforms are suppressed for the waveforms of the same type but are emphasized for the waveforms belonging to different types of heartbeats. We perform the feature processing of heartbeats on the single heartbeat of the ECG, proposing the description or representation by wavelet transform and AR model.

Zhao et al. (2005)

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**Abstract**—This paper presents a new approach to the feature extraction for reliable heart rhythm recognition. This system of classification is comprised of three components including data preparation, feature extraction and support vector machines (SVM) for classification of ECG signals. Two different feature extraction methods are applied together to extract features of ECG signals. The wavelet transform is used to extract the coefficients of the waveforms as the features of each ECG segment. Simultaneously, autoregressive model (AR) is used to extract the features of the waveform of ECG waveform. Then the support vector machine(SVM) with Gaussian kernel is used to classify different ECG heart rhythm. Comparative experiments are conducted to evaluate the performance of the proposed method. From computer simulations, the overall accuracy of classification for recognition of 6 heart rhythm types reaches 99.49%.

### I. INTRODUCTION

The electrocardiogram (ECG) is routinely used in clinical practice, which describes the electrical activity of the heart. In physical checkups or because of physicians' suspicion, ECG often has to be recorded to track further cardiac conditions. The Holter ECG device is used most frequently for recording the ECG. Physicians apply the device to a patient when they need to monitor his/her ECG to find a few abnormal cycles in the ECG throughout a day. Physicians can analyze the shapes of those waves and interpret them. They calculate parameters to determine whether the ECG shows signs of cardiac disease or not. The parameters are the height and the interval of some waves, such as RR interval, PP interval, QT interval, and ST segments. Recognition of the various波形 and calculations of the parameters is a tedious routine for the physician. Therefore, there is an urgent need for an automatic ECG recognition system to reduce the burdens of interpreting the ECG.

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## DETECTION OF SMALL VARIATIONS OF ECG FEATURES USING WAVELET

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**ABSTRACT**—ECG contains very important clinical information about the cardiac activities of heart. The feature of small variations in ECG signal with time-varying morphological characteristics needs to be extracted by signal processing method because there are not visible of graphical ECG signal. Small variations of simulated normal and noise corrupted ECG signals have been extracted using FFT and wavelet. The waves found to be more precise over conventional FFT in finding the small abnormalities in ECG signals.

**Keywords**: ECG, wavelet, FFT, Holter, cardiac, arrhythmia, feature extraction, statistical parameters.

### I. INTRODUCTION

Electrocardiogram (ECG) is a graphical record of the electrical activity that is generated by depolarization and repolarization of the atria and ventricles. It is well suited for analysis by joint time-frequency and time-scale distributed ECG signal processing [1]. The ECG signal morphology characteristic, identified as the P-QRS-T complex, has signal frequencies are distributed (1 low frequency, 7-9 P waves, 10 Q waves, 1 R waves, 1 S waves, 1 T waves, 1 U waves, 1000ms duration) [2]. The heart muscle becomes ischemic or infarcted, characteristic changes are seen in the ECG. The heart muscle becomes ischemic or infarcted, characteristic changes are seen in the ECG. Ischemia also causes changes in conduction velocity and action potential duration, which results in fragmentation in the depolarization front and appearance of low-amplitude notch-like structures in the ECG signal [3]. The statistical properties of ECG wave are generally changed over time tending to be quasi-stationary. A Holter monitor is an electronic device that records the ECG signal for 24 hours. An automatic algorithm and software is needed to analyze this huge amount of 24 hours Holter ECG signals. A major challenge in this field is how to extract the ECG signal and extraction important features of it.

Recently wavelets have been used in a large number of signal processing applications. Wavelet packet method is a generalization of wavelet decomposition that offers a rich range of possibilities for signal analysis. The multi-resolution framework makes wavelets a very powerful tool for signal processing [4]. The time [5] and the frequency location of wavelets makes it a powerful tool for feature extraction [6]. There is some work for feature extraction of ECG signal [7-16]. Karel *et al.* proposed the performance criteria to measure the quality of a wavelet, based on the principle of maximum entropy [7]. In this paper, we have developed and evaluated an electrocardiogram (ECG) feature extraction system based on the multi-resolution wavelet transform [8]. David *et al.* presented a method to reduce the baseline wander in the ECG signal by wavelet decomposition [9]. Shantha *et al.* discussed the design of good wavelet for cardiac signal from perspective of

$$\text{Cscaleposition} := \int f(t) \cdot \text{Cscaleposition}(t) dt$$

The results of the CWT are many wavelet coefficients  $C_{\psi}$ , where  $\psi$  are a function of scale and position. Multi-scale representation by the appropriate scaled and shifted wavelet yields the constituent wavelets of the original signal.

For many signals, the low-frequency content is the most important part. It is what gives the signal its identity.

The high-frequency content, on the other hand,

impairs flavor or nuance. To gain a better appreciation of the process, consider the inverse of the Fourier transform of a signal. The decomposition process can be iterated, with successive approximations being decomposed into smaller and smaller signals until the signal is broken down into many lower resolution components. This is called the wavelet decomposition.

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**Abstract**—This paper presents a new approach to the feature extraction for reliable heart rhythm recognition. This system of classification is comprised of three components including data pre-processing, feature extraction and support vector machines. Two different feature extraction methods are applied together to extract features from ECG signals. The wavelet transform is used to extract the coefficients of the waveform as the features of each ECG segment. Simultaneously, autoregressive model (AR) is used to extract the features of the waveform of ECG waveform. Then the support vector machine(SVM) with Gaussian kernel is used to classify different ECG heart rhythm. Comparative experiments show that the performance of the proposed method is from computer simulations, the overall accuracy of classification for recognition of 6 heart rhythm types reaches 99.69%.

### I. INTRODUCTION

The electrocardiogram (ECG) is routinely used in clinical practice, which describes the electrical activity of the heart. In physical checkups or because of physical exercise, the ECG signal is often used to monitor the health condition of the heart. The Holter ECG device is used most frequently for recording the ECG. Physicians apply the device to a patient when they need to monitor his/her ECG to find any new abnormal cycles in the ECG throughout a day. Physicians can also monitor the shape of these waves and their amplitudes. They calculate parameters to determine whether the ECG shows signs of cardiac disease or not. The parameters are the height and the interval of some waves, such as RR interval, PP interval, QT interval, and ST segments. Recording of the ECG points and calculations of the parameters is a tedious routine for the physician. Therefore, there is an urgent need for an automatic ECG recognition system to reduce the burden of interpreting the ECG.

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### ABSTRACT

ECG contains very important clinical information about the cardiac activities of heart. The feature of small variations in ECG signal with time-varying morphological characteristics needs to be extracted by signal processing method because there are not visible of graphical ECG signal. Small variations of simulated normal and noise corrupted ECG signals have been extracted using FFT and wavelet. The waves found to be more precise over conventional FFT in finding the small abnormalities in ECG signals.

### II. ECG DATA AND PREPROCESS

All ECG data were obtained from MIT-BIH arrhythmia database that contains records of many patients with different types of abnormalities. The sampling frequency of the ECG data was 360Hz. Each record has its respective annotation file that indicate the class of the heartbeat. A single channel ECG is collected and used to algorithm evaluation. Since there are many categories of abnormalities in one record, we select different abnormal QRS complexes from several records. Six types of QRS complexes appeared frequently in the database. Therefore, we mainly deal with six types of QRS complexes which include sinus (SINUS), left bundle branch block (LBBB), right bundle branch block (RBBB), paced beat(PACE), premature ventricular contraction(PVC) and atrial premature contraction(APC).

In the data preprocessing process, continuous ECG signals are converted into discrete form which is called one heartbeat. The extracted data of ECG complexes is centered around R peak. Considered that some PVC duration is great and sometimes R peak detection may not be the center of QRS complex. Therefore, the R peak is detected using Pan and Tompkins algorithm[6]. The R peak is detected using the Pan and Tompkins algorithm[6]. Thus, each segment must contain one ECG heartbeat. Fig.1 shows typical waveforms of six types of ECG segments.

### III. FEATURE EXTRACTION

The recognition of heart rhythms requires generation of the feature vector which represents the original ECG segment. A multi-resolution feature extraction method is proposed. They represent the ECG signals in such a way, that the differences among the ECG waveforms are suppressed for the waveforms of the same type but are emphasized for the waveforms belonging to different types of heartbeat. We perform the feature extraction process of our system on the single heartbeat of the ECG, proposing the description or representation of wavelet for cardiac signal from the perspective of good

Recently wavelets have been used in a large number of applications. The wavelet packet method is a generalization of wavelet decomposition that offers a rich range of possibilities for signal analysis. The multi-resolution framework made wavelets a very powerful tool for feature extraction [6]. There is some work for feature extraction of ECG signals [7-16]. Karel et al. proposed the performance criteria to measure the quality of a wavelet, based on the principle of maximum entropy. They proposed a multi-resolution developed and evaluated an electrocardiogram (ECG) feature extraction system based on the multi-resolution wavelet transform [8]. David et al. presented a method to reduce the baseline wander in the ECG signal by decomposing the ECG signal into one signal in broken down into many lower resolution components. This is called the wavelet decomposition.

$$\text{Cscaleposition} := \int f(t) \text{Cscaleposition}(dt)$$

The results of CWT are many wavelet coefficients  $C_{\omega, k}$  which are a function of frequency and position. Multi-resolution analysis by the appropriate scaled and shifted wavelet yields the constituent wavelets of the original signal.

For many signals, the low-frequency content is the most important part, it is what gives the signal its identity.

The high-frequency content, on the other hand, imparts flavor or nuance. To gain a better appreciation of the process, consider the multi-resolution wavelet transform of a signal. The decomposition process can be iterated, with successive approximations being decomposed into smaller and smaller elements of the signal [9]. Shantha et al. discussed the design of good wavelet for cardiac signal from the perspective of good

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32nd Annual International Conference of the IEEE EMBS  
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## Wavelet Leader Based Multifractal Analysis of Heart Rate Variability during Myocardial Ischaemia

Roberto Fabio Leonardiuzzi, Gastón Schlotthauer and María Eugenia Torres

**Abstract**— Heart rate variability is a non invasive and indirect measure of the autonomic control of the heart. Therefore, alterations to this control system caused by myocardial ischaemia are reflected in changes in the complex and irregular fluctuations of this variable. In this paper we propose a new approach of analysis of this kind of fluctuations, since it gives a description of the singular behavior of a signal. Recently, a new approach based on wavelet leaders has been proposed for the analysis of multifractal formalism, which shows remarkable improvements over previous methods. In this work we propose to perform a short-time windowed wavelet leader based multifractal analysis. The main advantage of this new method provides appropriate indexes that could be used for the detection of myocardial ischaemia.

### I. INTRODUCTION

MYOCARDIAL ischaemia (MI) is understood to be the temporary lack of a blood supply to the myocardial tissue. In extreme cases this situation results in an myocardial necrosis. Therefore, the early detection of ischaemia is of great clinical interest. Traditionally, the assessment of this condition has been approached by means of the analysis of parameters derived from the electrocardiogram (ECG), such as the deviation of the ST segment [1]. However, this method suffers from a low specificity, given that other phenomena, such as posture changes, cause similar modifications in the ST segment [1].

It is known that the nervous system (ANS) regulates the heart rate via the stimulation of the sympathetic node. At any time, the heart rate represents the net effect of the parasympathetic and sympathetic stimulation that slows it down or speeds it up, respectively. Both the ANS and the sympathetic nervous system are involved in resting fluctuations. The ANS is tonically active in resting fluctuations. These phenomena result in the complex and irregular fluctuations shown by the heart rate, known as heart rate variability (HRV) [2].

Reverses of electrocardiographic alterations, ischaemia causes early metabolic and hemodynamic changes. These changes are detected by chemoreceptors and baroreceptors which are involved in cardiac reflexes mediated by the ANS [3]. These receptors can respond to metabolic and non-invasive ways to the alterations of the ANS caused by ischaemia. This was the hypothesis assumed in [1], [3], where MI was assessed by time-frequency and

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Leonarduzzi et al. (2010)

## ECG Feature Extraction and Classification Using Wavelet Transform and Support Vector Machines

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### I. INTRODUCTION

The electrocardiogram (ECG) is routinely used in clinical practice, which describes the electrical activity of the heart. In physical checkups at hospitals, physicians use ECGs to detect heart disease and have been used to track further cardiac complications. The Holter ECG device is used most frequently for recording the ECG. Physicians apply the device to a patient when they need to monitor his/her ECG to find few abnormal cycles in the ECG throughout a day. Physicians can also examine the shape of these waves and amplitudes. They calculate parameters to determine whether the ECG shows signs of cardiac disease or not. The parameters are the height and the interval of some waves, such as RR interval, PP interval, QT interval, ST segments. Recovery time of the heart, peak points and calculations of the parameters is a tedious routine for the physician. Therefore, there is an urgent need for an automatic ECG recognition system to reduce the burdens of interpreting the ECG.

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wavelet filter banks [12]. Nikolayev and Gusev proposed a two-stage algorithm for electrocardiographic (ECG) signal denoising with Wiener filtering in the translation-invariant wavelet domain [13]. Most of the work focused on the large size abnormalities with respect to the extraction of small variations of the ECG signal using FFT and wavelet method. Most of the clinically useful information about the heart is found in the intervals and amplitudes defined by the duration (duration of peaks, peaks, frequency components, and time duration). In this paper, FFT and wavelet methods are developed for the extraction of small variations of the ECG signal. The results of signal processing is found to be superior to the conventional FFT method in finding the small abnormalities in ECG signals.

### 2. MATERIALS AND METHODS

ECG signals both normal and noise corrupted have been used for this study. Matlab. These signals are analyzed by the wavelet method (Matlab wavtool). Continuous wavelet transform (CWT) is defined as the convolution of the signal multiplied by scaled, shifted versions of the window function  $\psi$

$$\text{CWT}[\text{position}] = \int f(t)\psi^*(\text{position})dt$$

The results of the CWT are many wavelet coefficients  $C_{\psi}(t)$ , which are a function of time and position. Multi-resolution framework make wavelet a very powerful tool for feature extraction [6]. The time and frequency locality of wavelets makes it into a powerful tool for feature extraction [6]. There is some work for feature extraction of ECG signals [7-16]. Karel et al. proposed the performance criteria to measure the quality of a wavelet, based on the principle of maximum entropy [7]. We have proposed a feature developed and evaluated an electrocardiogram (ECG) feature extraction system based on the multi-resolution wavelet decomposition [8]. David et al. presented a method to reduce the baseline wander in the ECG signal by wavelet [9]. Shantha et al. discussed the design of good wavelet for cardiac signal from the perspective of good

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This new method provides appropriate indexes that could be used for the detection of myocardial ischaemia.

### I. INTRODUCTION

MYOCARDIAL ischaemia (MI) is understood to be the temporary lack of a blood supply to the myocardial tissue. In extreme cases this situation results in an myocardial necrosis. Therefore, the early detection of ischaemia is of great clinical interest. Traditionally, the assessment of this condition has been approached by means of the analysis of parameters derived from the time variability of the heart rate, such as the standard deviation of the ST segment (SDST).

However, this method suffers from a low specificity, given that other phenomena, such as posture changes, cause similar modifications in the ECG [1].

It is known that the sinus nodal system (ANS) regulates the heart rate via the stimulation of the sinoatrial node. At any time, the heart rate represents the net effect of the parasympathetic and sympathetic stimulation that slows it down or speeds it up, respectively. Both the ANS and the sympathetic nervous system (SNS) are tonically active in resting conditions. The SNS phenomena result in the complex and irregular fluctuations that are known as heart rate variability (HRV) [2].

Reverses of electrocardiographic alterations, ischaemia causes early metabolic and hemodynamic changes. These changes are detected by chemoreceptors and baroreceptors which are involved in cardiac reflexes mediated by the ANS [3]. These changes can lead to an increase in the heart rate and non-invasive tests like the alterations of the ANS caused by ischaemia. This was the hypothesis assumed in [1], where MI was assessed by time-frequency and

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entropy

## ECC Classification Using Wavelet Packet Entropy and Random Forests

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**Abstract**—The electrocardiogram (ECG) is one of the most important techniques for heart disease diagnosis. Many traditional methodologies of feature extraction and classification have been widely applied to ECG analysis. However, the effectiveness and efficiency of such methodologies remain to be improved, and much existing research did not consider the separation of training and testing samples from the same set of patients (so called inter-patient scheme). To cope with these issues, in this paper, we propose a method to classify ECG signals using wavelet packet entropy (WPE) and random forests (RF). The proposed method follows the American Heart Association (AHA) and Medical Research Institute (AMI) recommendations and the inter-patient scheme. Specifically, we firstly decompose the ECG signals by wavelet packet decomposition (WPD), and then calculate entropy from the decomposed coefficients as representative features, and finally use RF to build an ECG classification model. To the best of our knowledge, it is the first time that WPE and RF are used to classify ECG following the inter-patient scheme. The experimental results show that the proposed method outperforms the state-of-the-art methods. The experimental results are superior to those by several state-of-the-art competing methods, showing that WPE and RF is promising for ECG classification.

**Keywords:** ECG classification; wavelet packet entropy; feature extraction; random forests; AAMI and MI features

### I. Introduction

The electrocardiogram (ECG) records the tiny electrical activity produced by the heart over a period of time by placing electrodes on a patient's body, which has become the most widely used non-invasive technique for heart disease diagnosis in the clinics. Due to the high mortality rate of heart diseases, since the last decades, ECG classification has drawn lots of researchers' attention.

Typically, the classification of ECG signals has four phases: preprocessing, segmentation, feature extraction and classification. The preprocessing phase is mainly aimed at detecting and attenuating frequencies of the ECG signal related to artifacts, which also usually perform signal normalization and entropy calculation. After the segmentation, the signal is divided into smaller segments, which can better express the electrical activity of the heart [1]. Nowadays, most researchers can get good results from preprocessing and segmentation by some popular techniques or tools [2]. Therefore, most of the literature focuses upon the last two phases.

Feature extraction plays an important role in pattern classification, especially in signal or image classification. Features can be extracted from the raw data or the transformed domain of segmented

Entropy 2016, 18, 285; doi:10.3390/e18020285

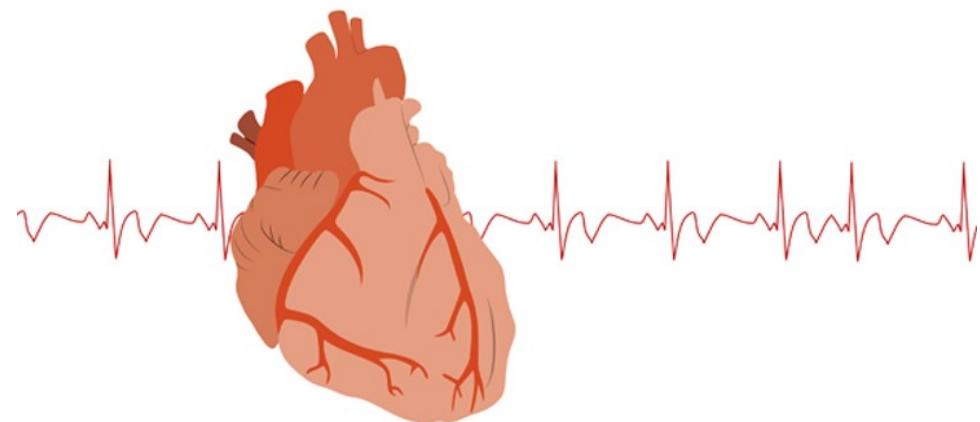
www.mdpi.com/journal/entropy

Li et al. (2016)

A need for automatic systems having **real-time** anomaly detection with **high accuracy**



# **NovEl APproach for the autOmatic reaL-time beat-to-beat detection of arrhythmia conditions (NEAPOLIS)**

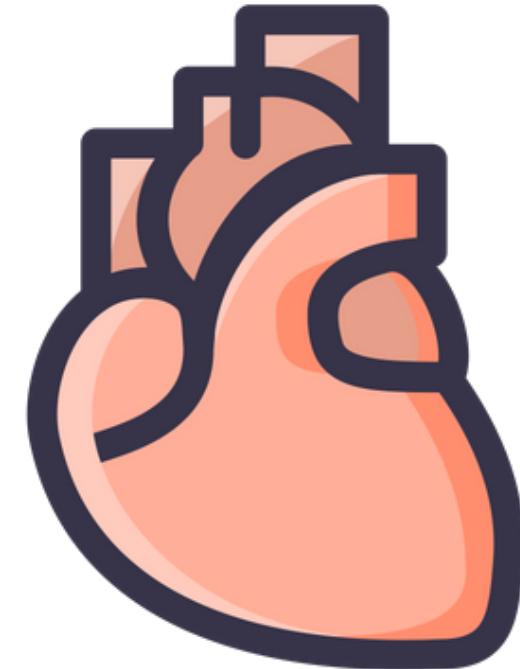


# Arrhythmia conditions

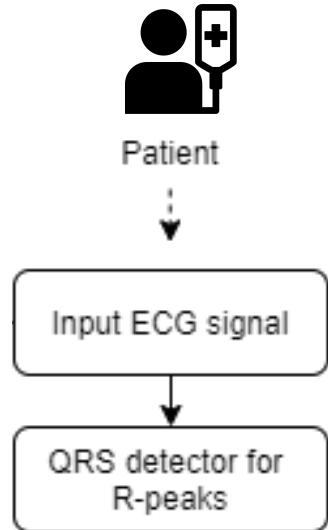
**Left and Right Bundle Branch Block (LBBB and RBBB)**

**Premature Ventricular Contraction (PVC)**

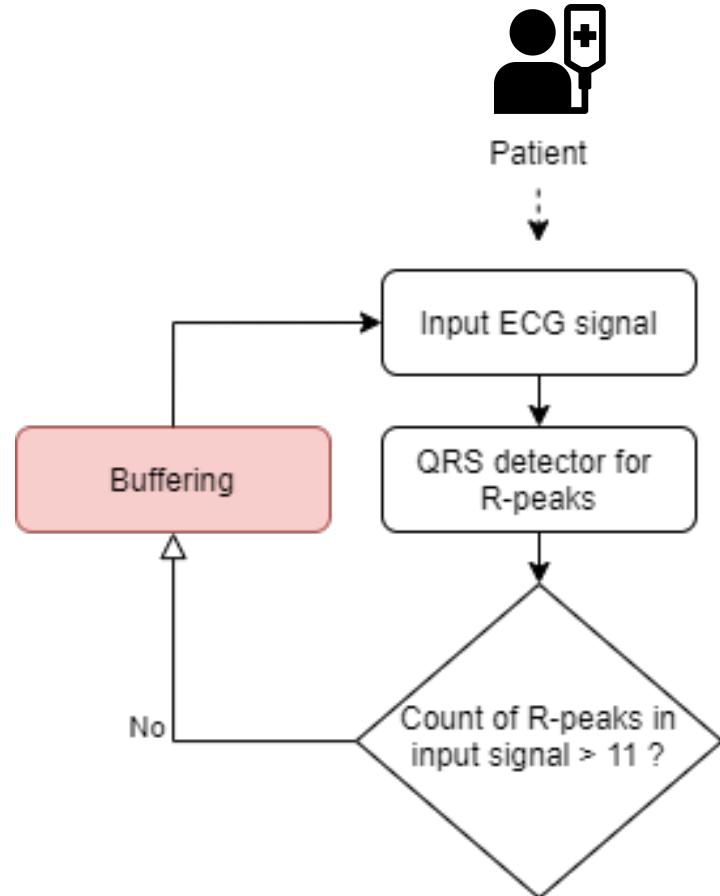
**Atrial Premature Beats (APB)**



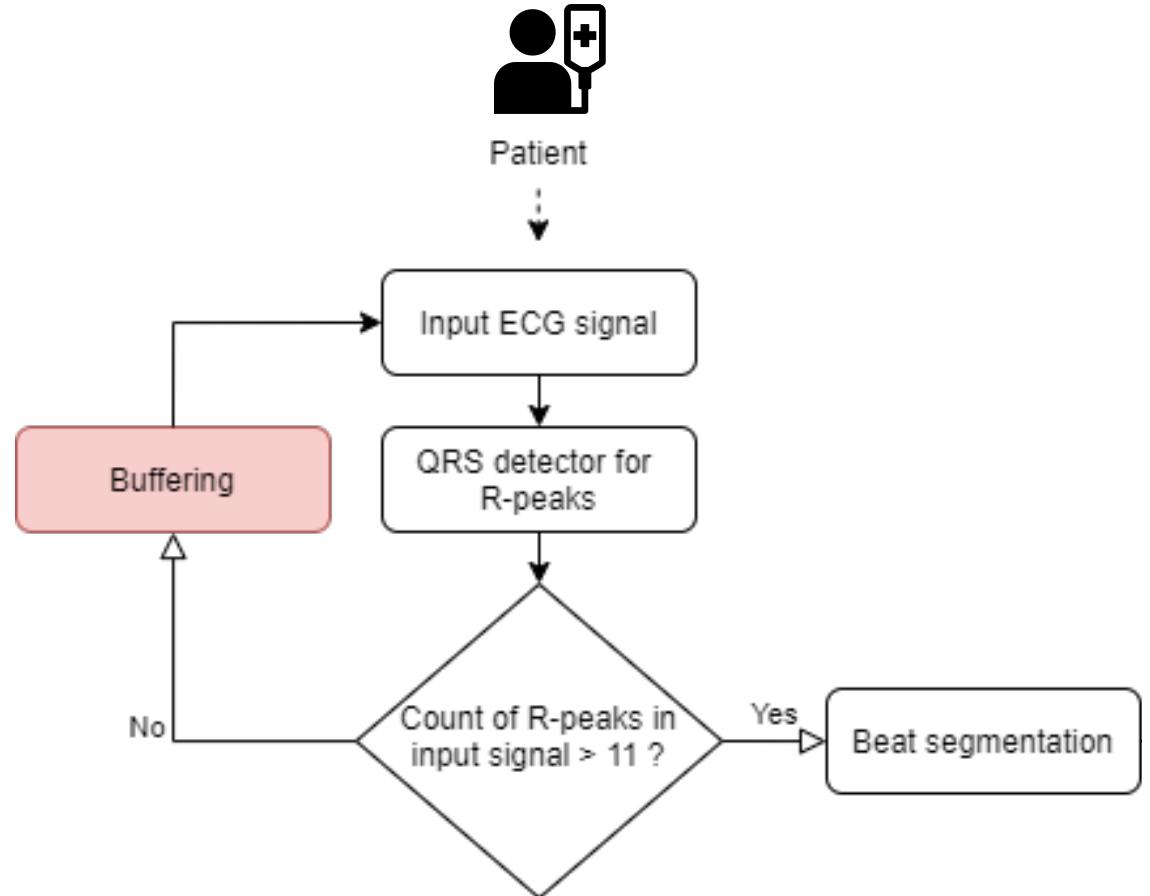
# NEAPOLIS in a nutshell



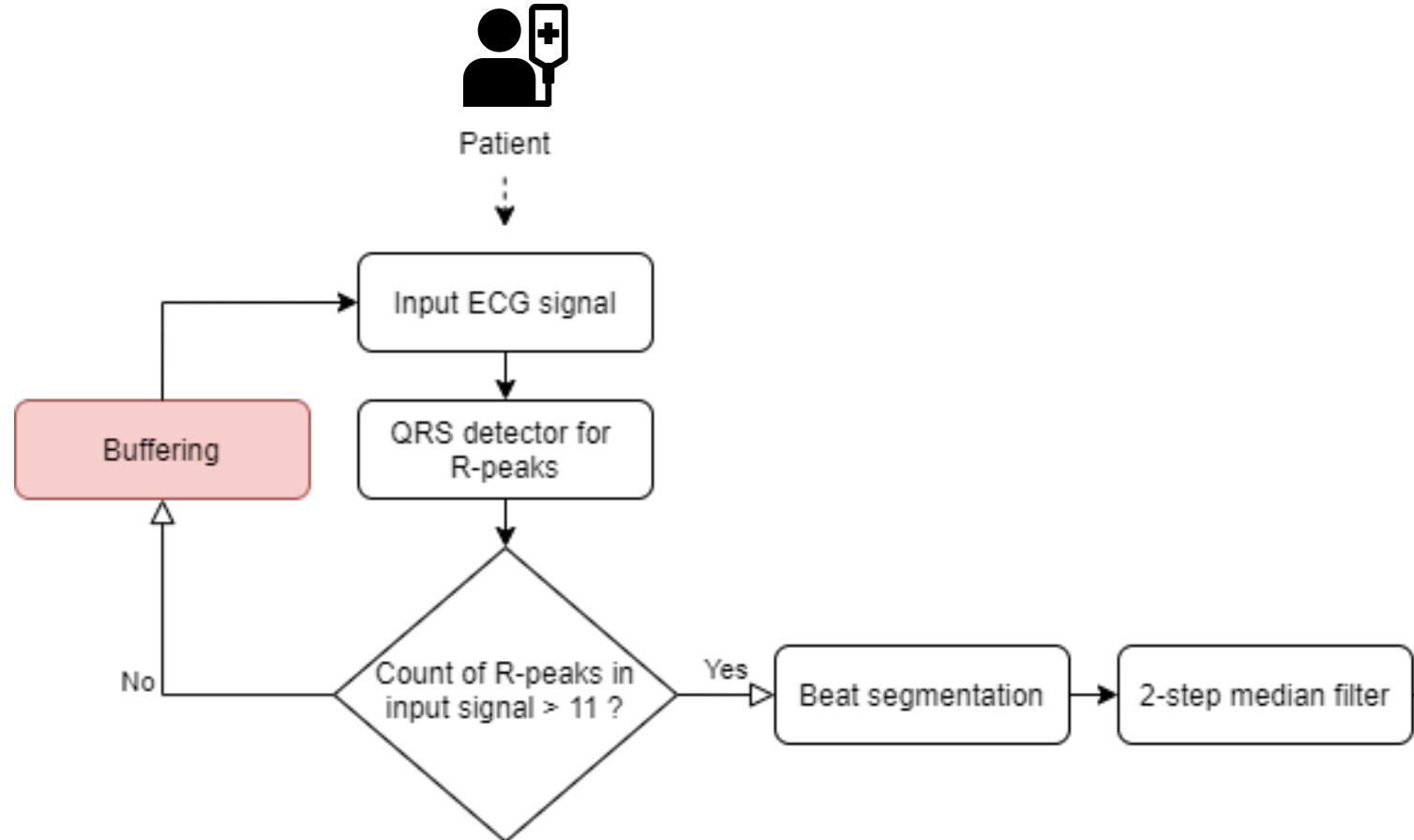
# NEAPOLIS in a nutshell



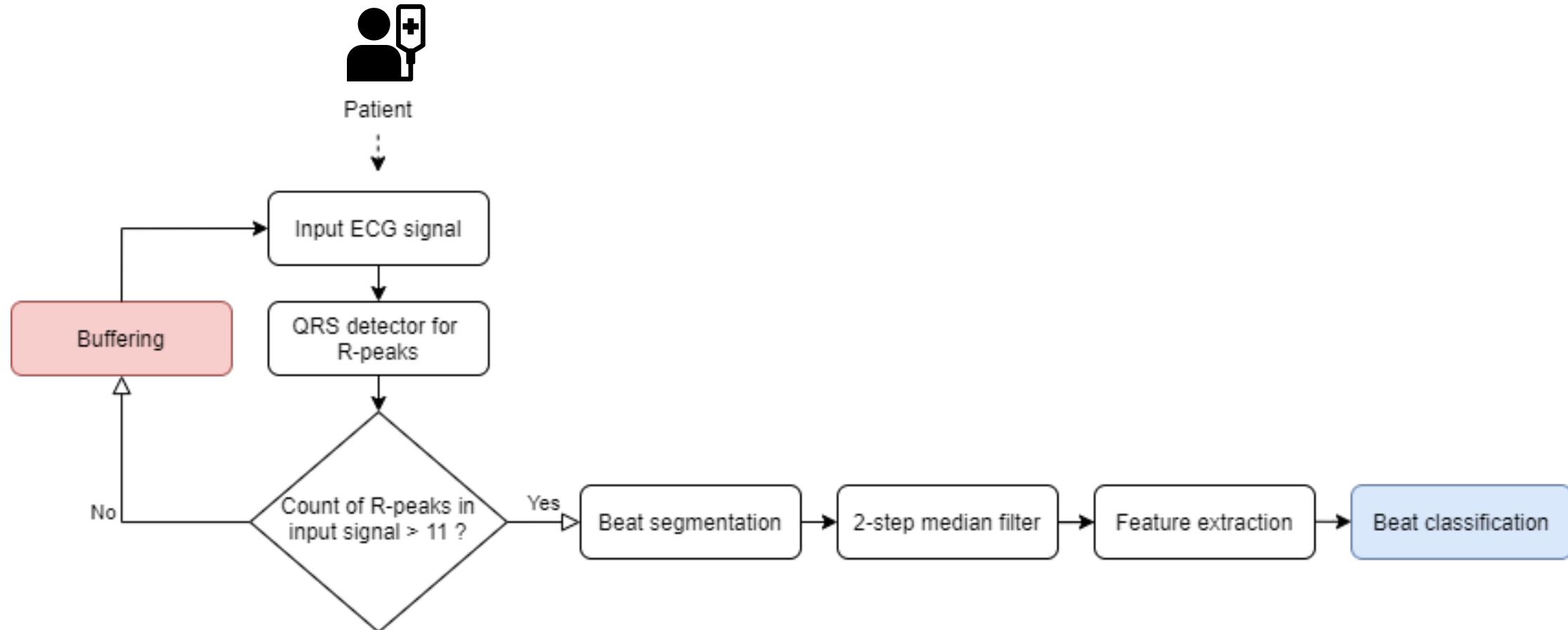
# NEAPOLIS in a nutshell



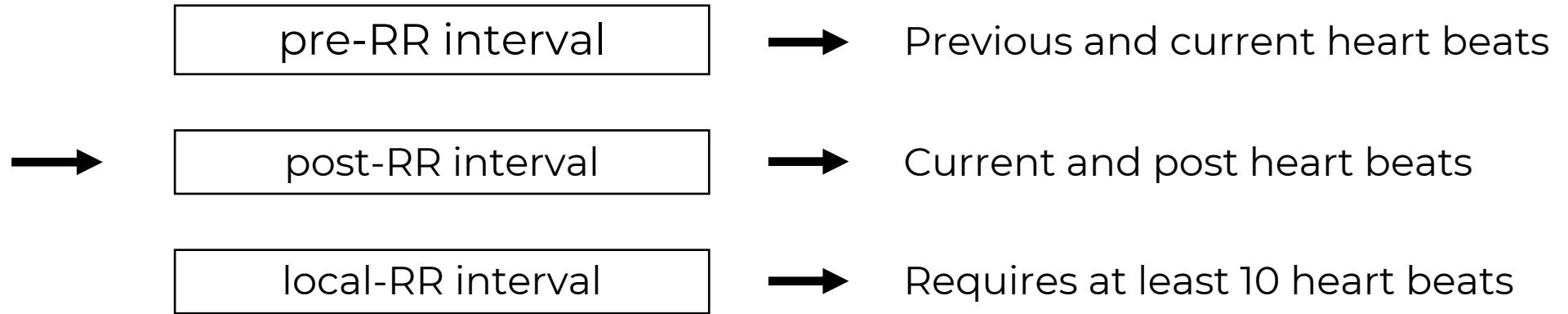
# NEAPOLIS in a nutshell



# NEAPOLIS in a nutshell

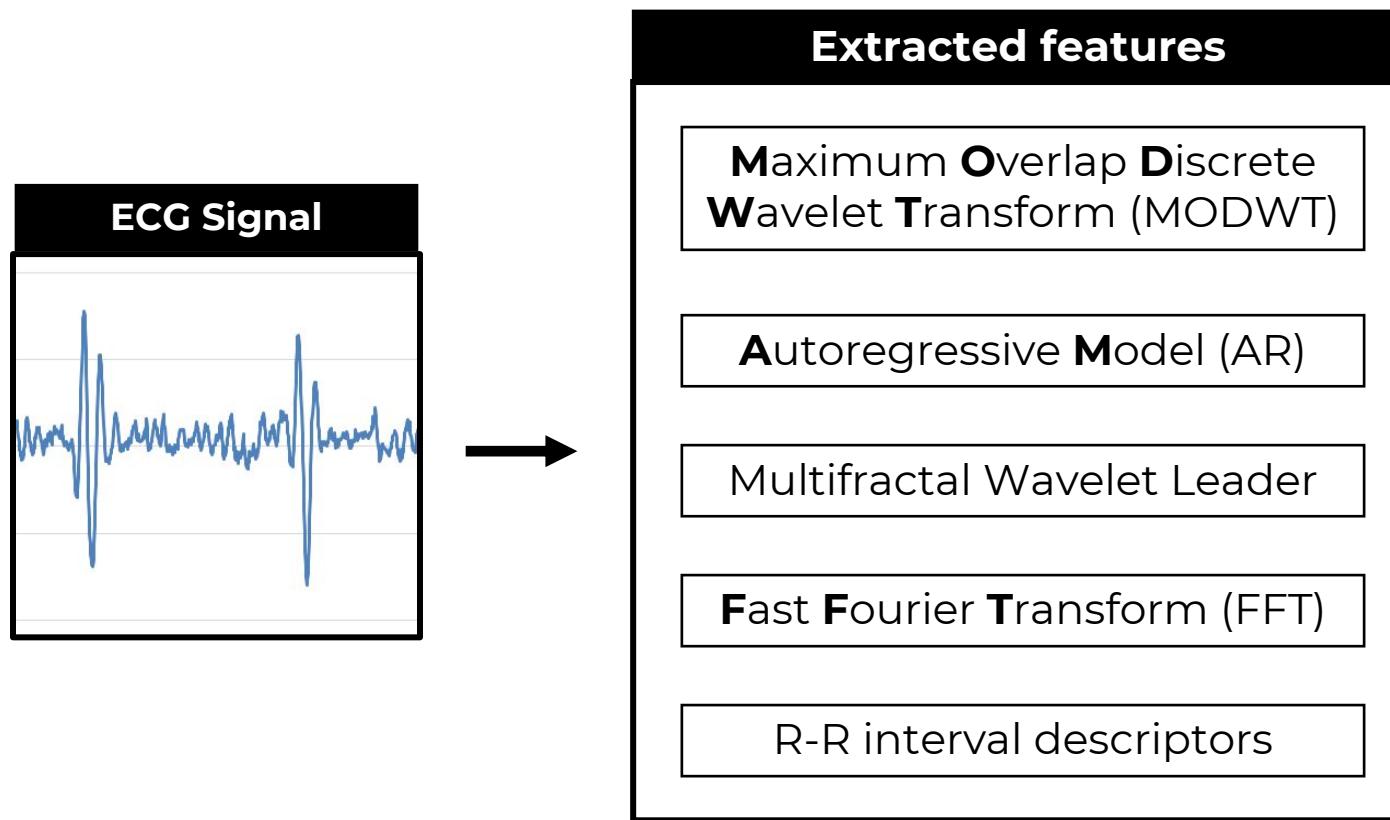


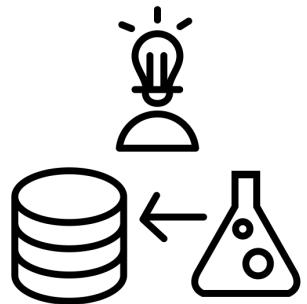
# Selected features



Single beat

# Selected features





# Experiment

# MIT-BIH Database

**48**  
ECG Recordings

**30**  
Minutes of recording

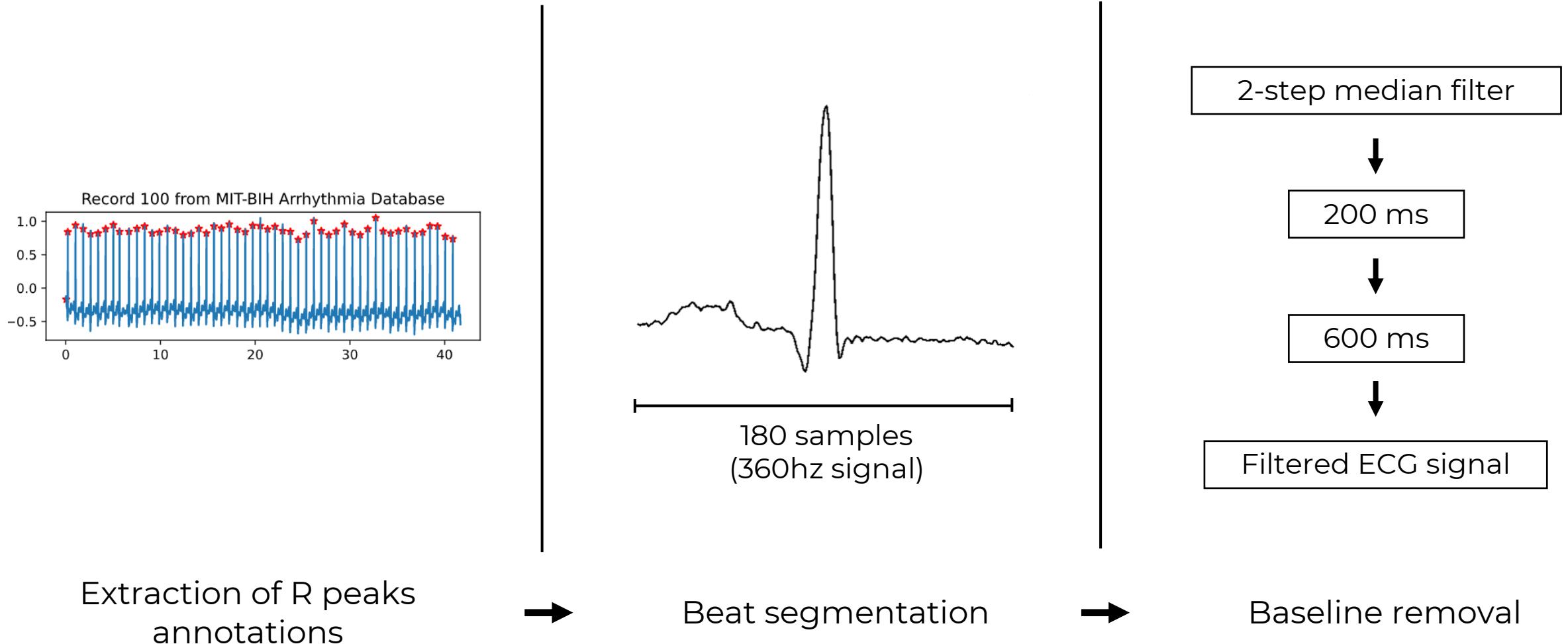
**PhysioNet**

The Research Resource for Complex Physiologic Signals

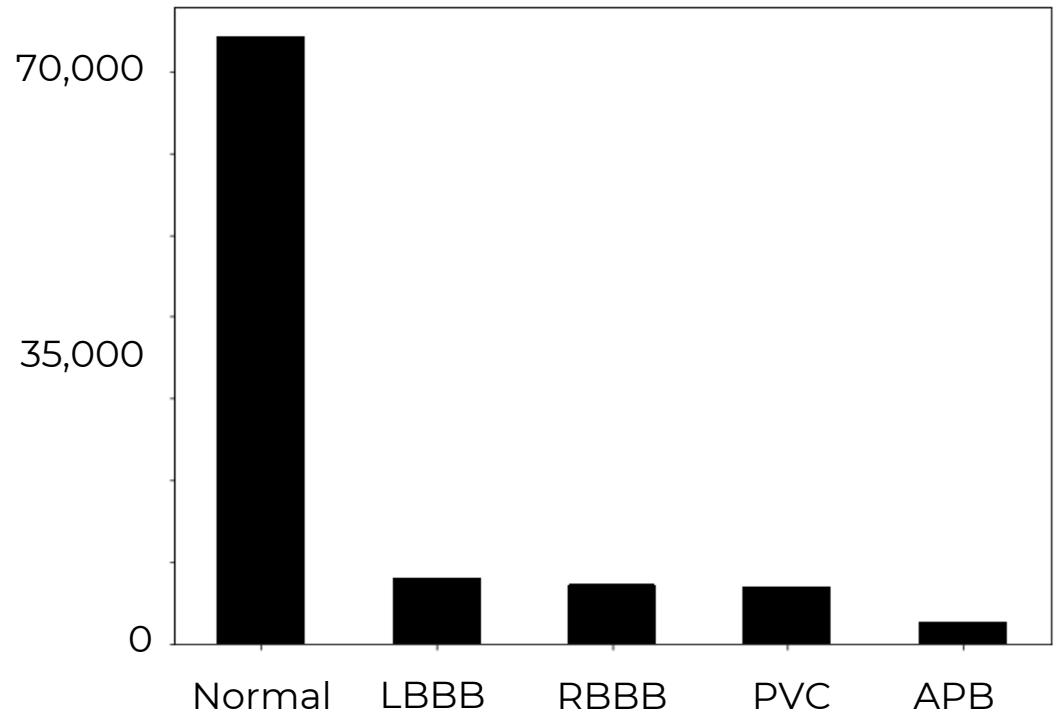
**~110,000**  
Labelled heart beats

Goldberger et al. (2000); Moody and Mark (2001)

# Data extraction



# Data extraction



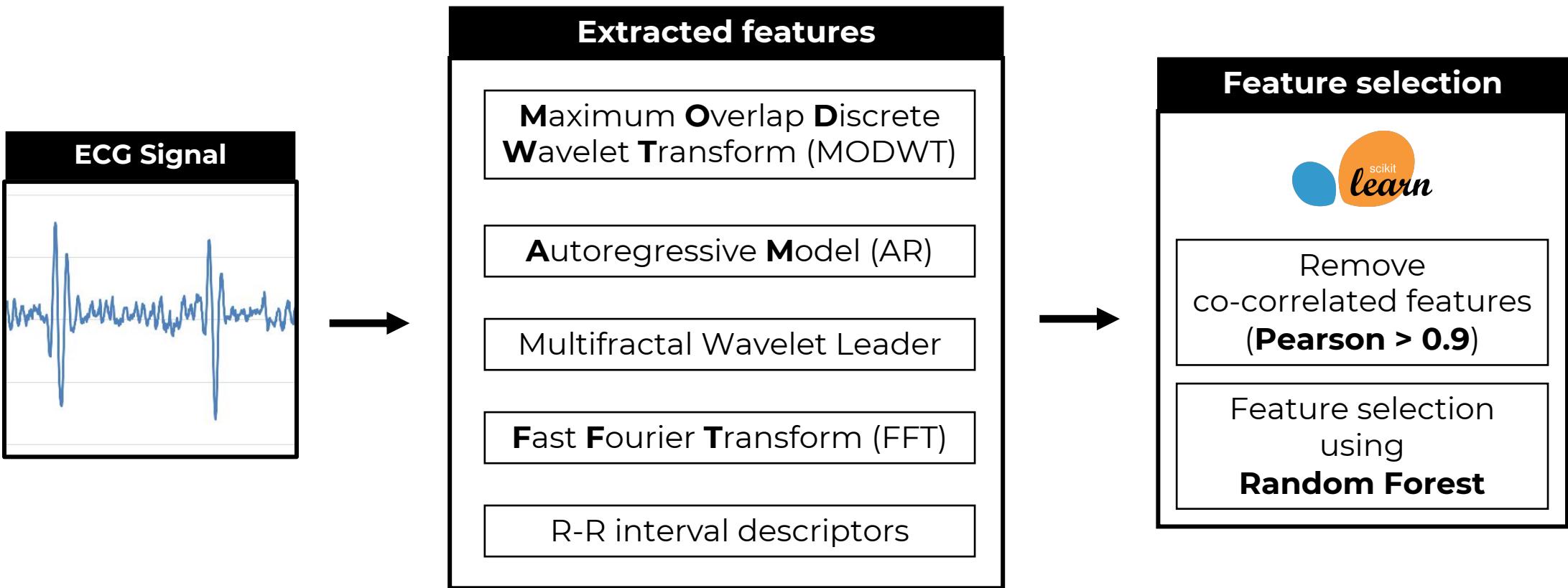
**~99,000**  
heart beats

What are the most important features for  
the beat-to-beat classification of  
arrhythmia conditions?

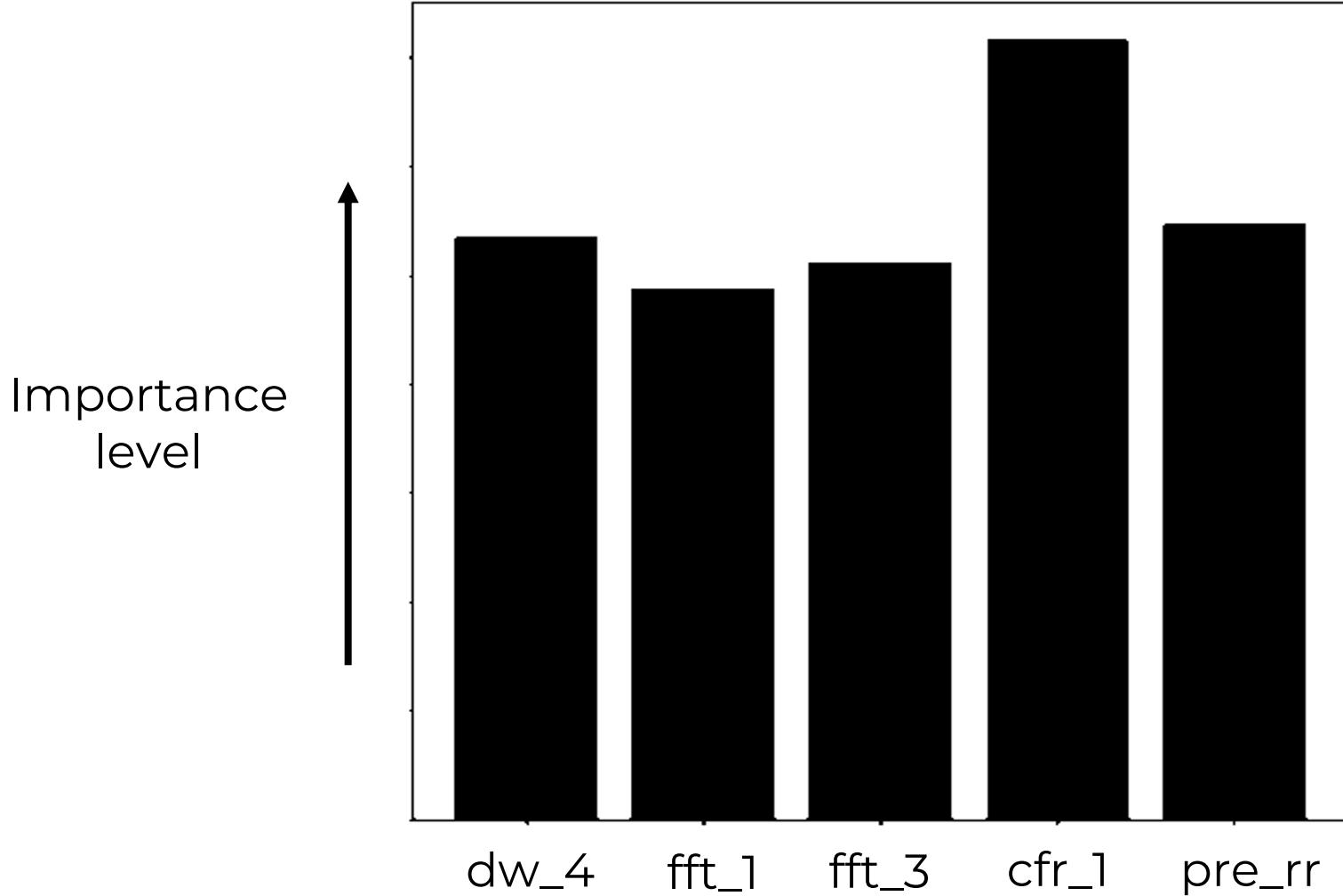
RQ1



# Selected features



# Selected features - Top 5



**dw** = Discrete Wavelet

**fft** = Fast Fourier Transform

**cfr** = AR model reflection coefficient

**pre\_rr** = pre-RR interval

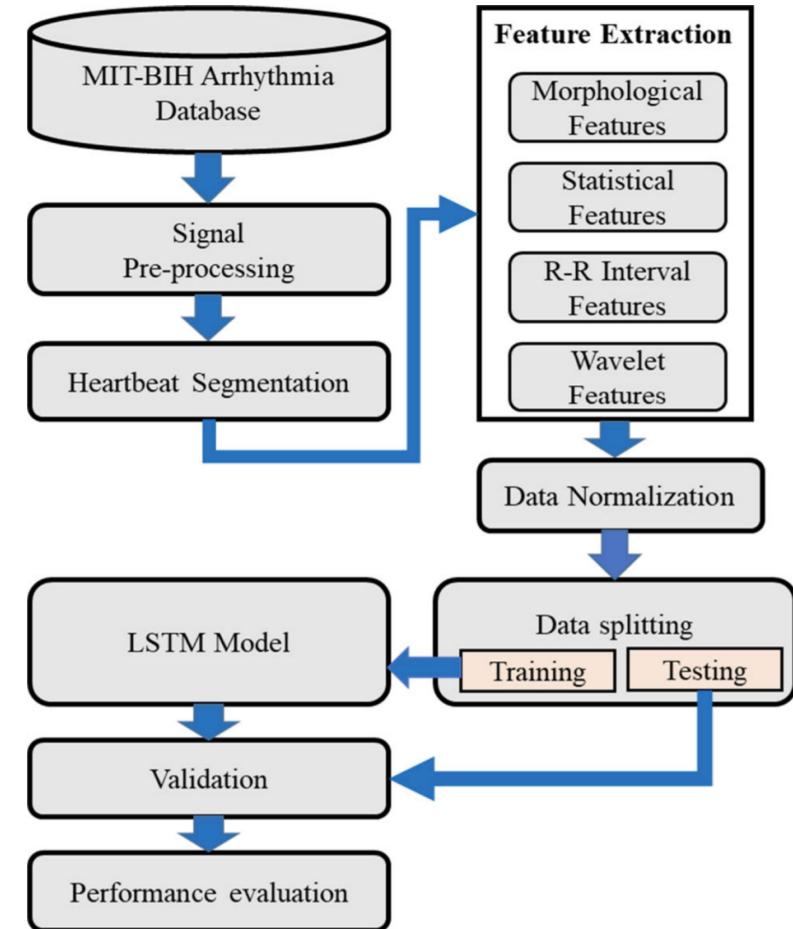
What is the accuracy of NEAPOLIS?

RQ2



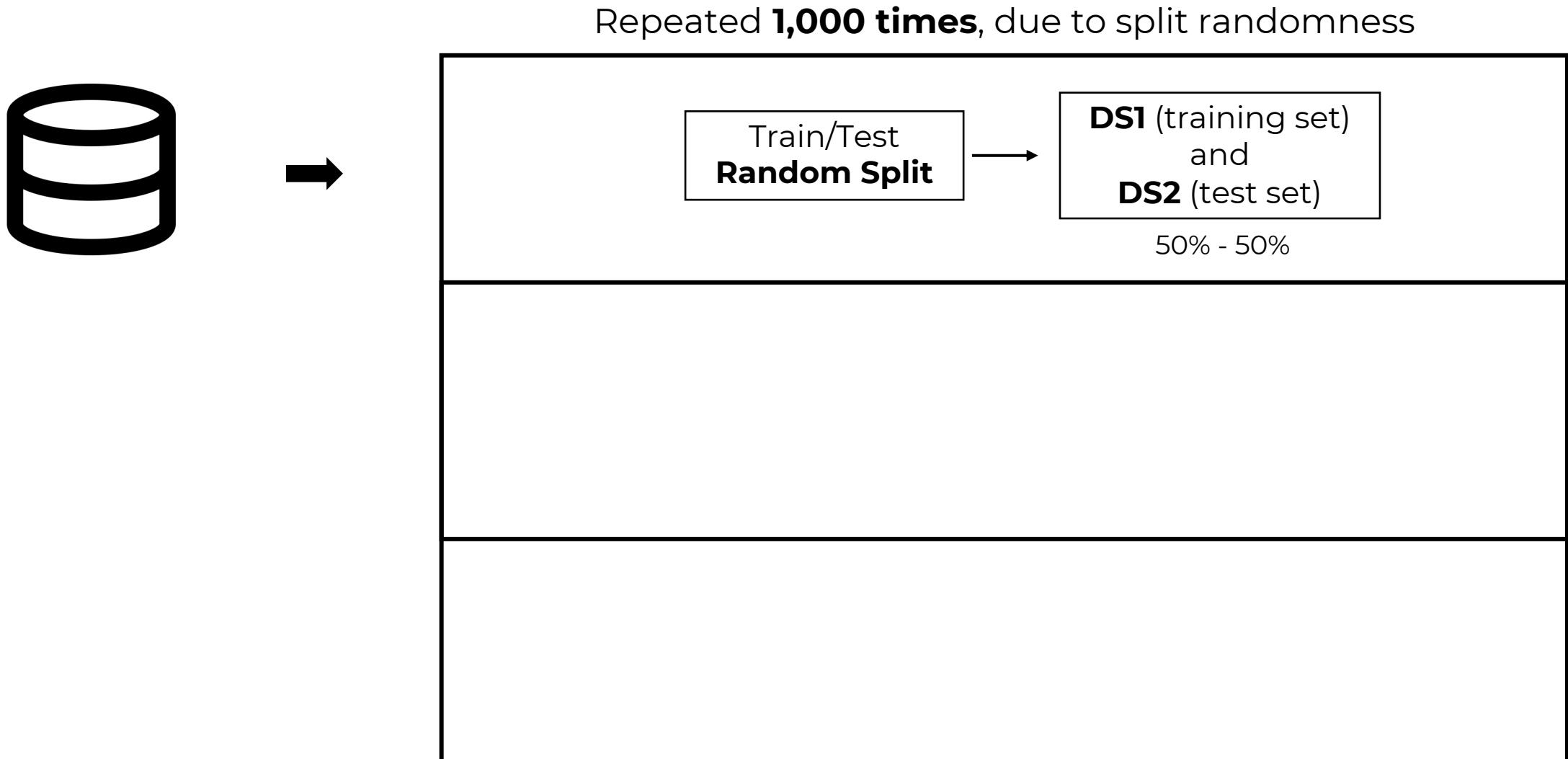
# Selected baseline

Heart Beats classification  
via LSTM Model

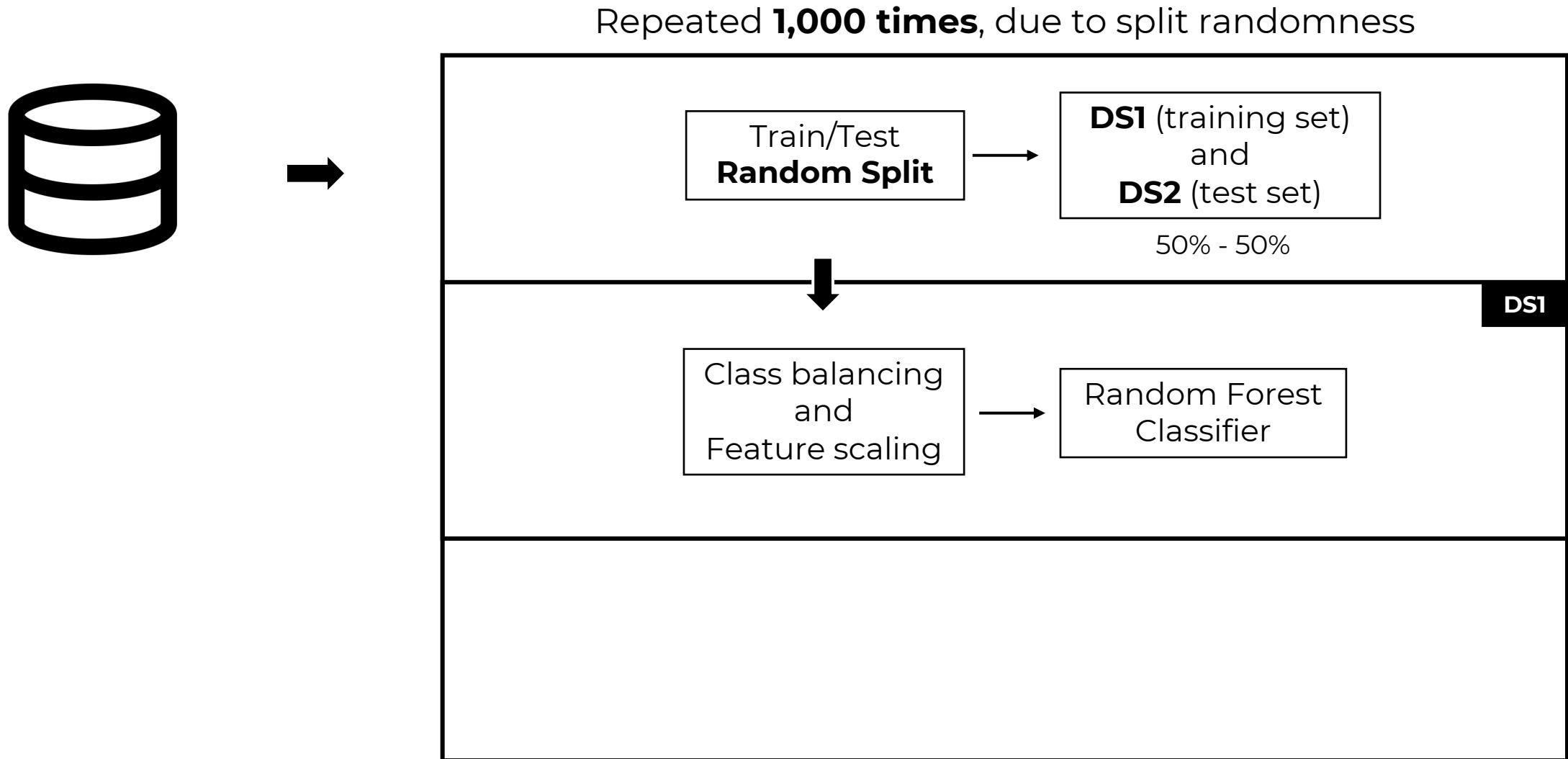


Pandey and Janghel (2020)

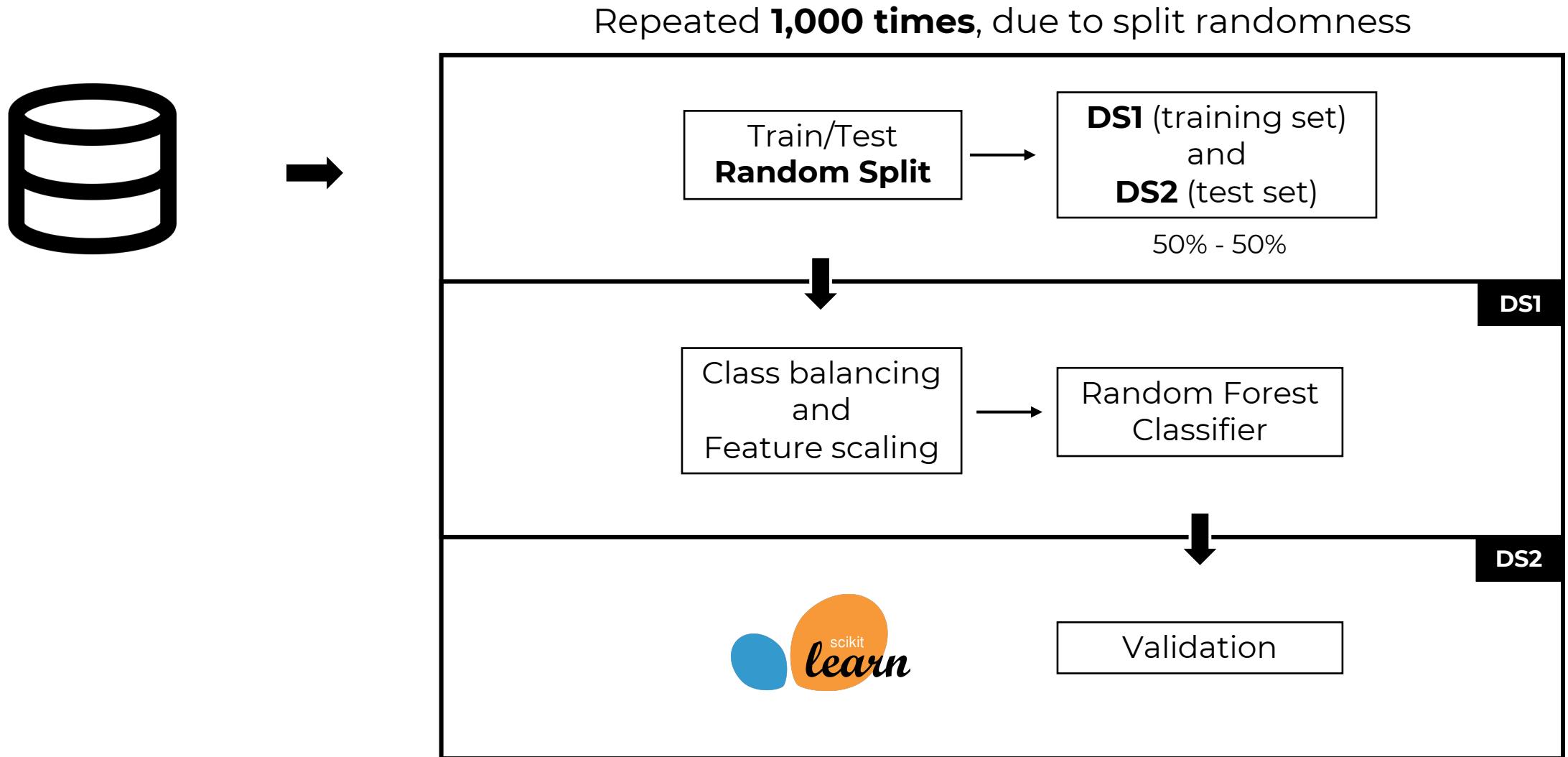
# Classification



# Classification



# Classification



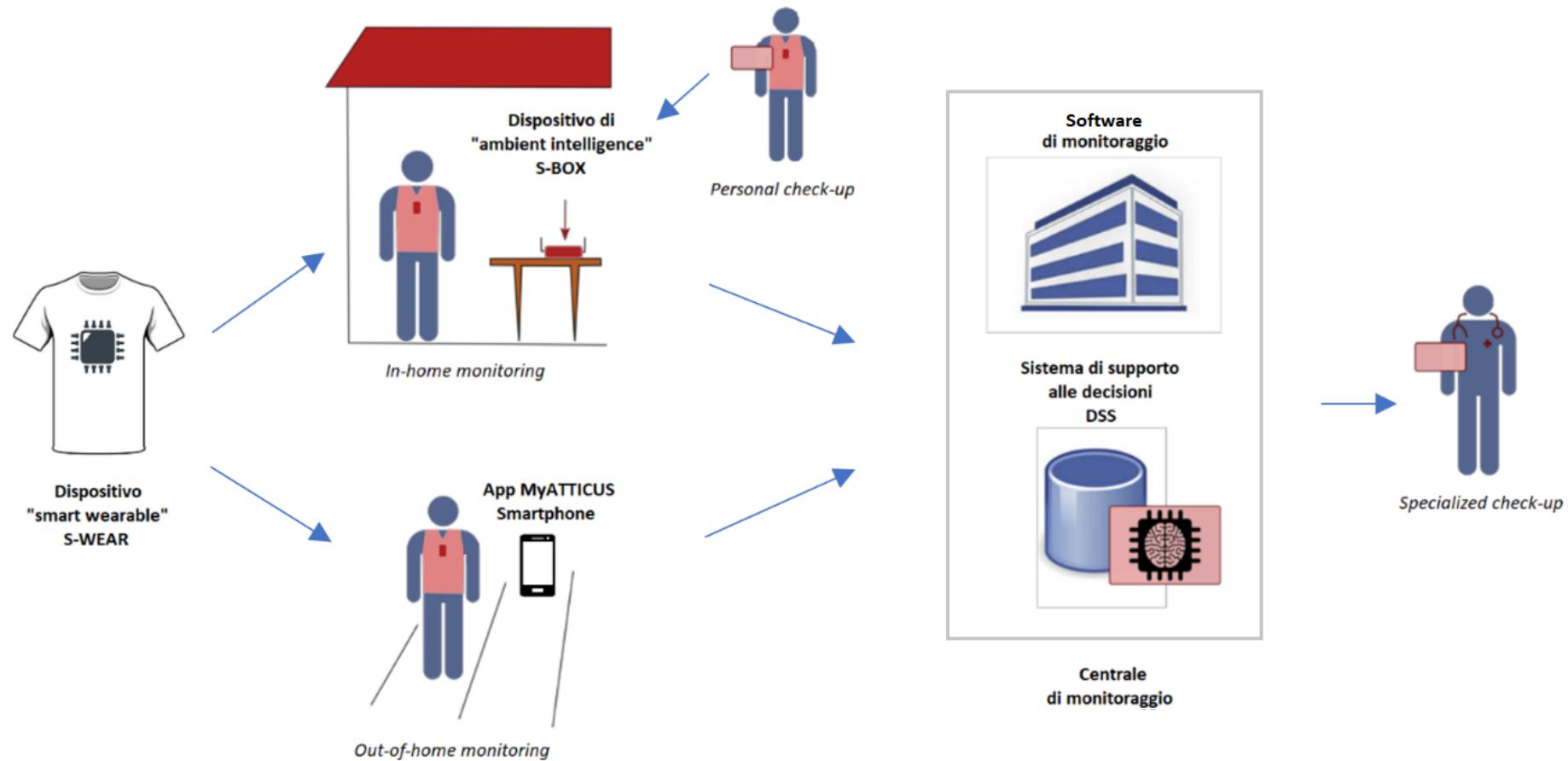
# Overall Results

Average metrics	NEAPOLIS	(Pandey et al., 2020)
Sensitivity	97.16 ( <b>+ 2.27</b> )	94.89
Specificity	99.53 ( <b>+ 0.39</b> )	99.14
Precision	97.22 ( <b>+ 0.49</b> )	96.73
F1 score	97.18 ( <b>+ 1.41</b> )	95.77

# Results (for each class)

Metric	Normal	LBBB	RBBB	PVC	APB
Sensitivity	99.34 <b>(+ 0.03)</b>	98.53 <b>(+ 1.01)</b>	99.18 <b>(+ 0.21)</b>	98.28 <b>(+ 3.10)</b>	90.48 <b>(+ 7.00)</b>
Specificity	98.29 <b>(+ 1.84)</b>	99.96 <b>(+ 0.04)</b>	99.97 <b>(+ 0.04)</b>	99.61 <b>(- 0.02)</b>	99.81 <b>(+ 0.02)</b>
Precision	99.43 <b>(+ 0.59)</b>	99.50 <b>(+ 0.45)</b>	99.68 <b>(+ 0.63)</b>	95.02 <b>(- 0.05)</b>	92.49 <b>(+ 0.85)</b>
F1 score	99.39 <b>(+ 0.32)</b>	99.01 <b>(+ 0.73)</b>	99.43 <b>(+ 0.42)</b>	96.62 <b>(+ 1.49)</b>	91.47 <b>(+ 4.10)</b>

# NEAPOLIS is part of a real IoMT system



**ATTICUS**  
Ambient-intelligent Tele-monitoring System



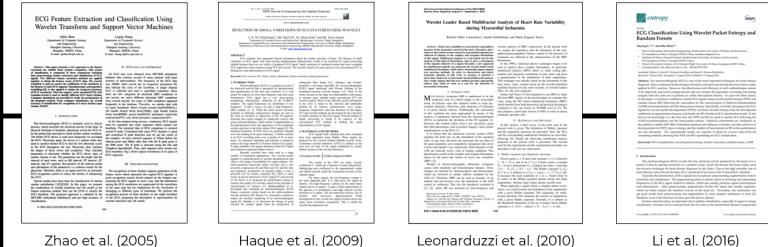
# Summary

## Internet of Medical Things

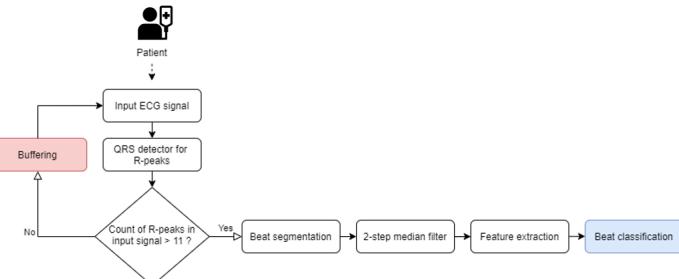


Preventive care

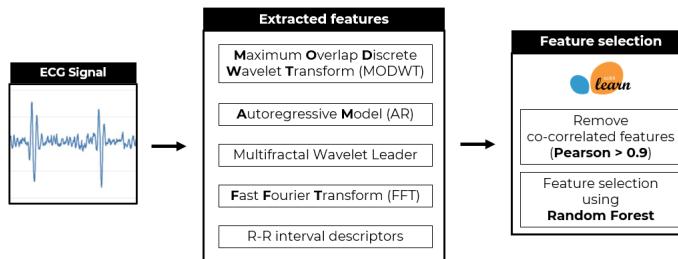
Long-term care and chronic diseases



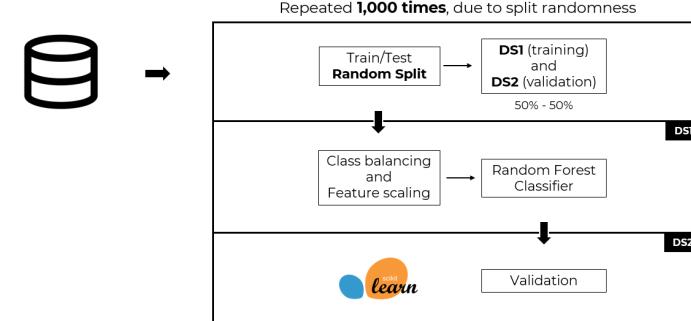
## NEAPOLIS in a nutshell



## Selected features



## Classification



## Results - for each class

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