Detection of Cardiovascular Conditions on ECG Signals via Deep Learning Methods

Shahane Tigranyan [1,*], Aram Avetisyan[2],
Sergey Skorik[2], Karen Avetisyan[1], Sevak Sargsyan[1]

[1]Center of Advanced Software Technologies, Russian - Armenian University
[2]Institute for System Programming of the Russian Academy of Sciences

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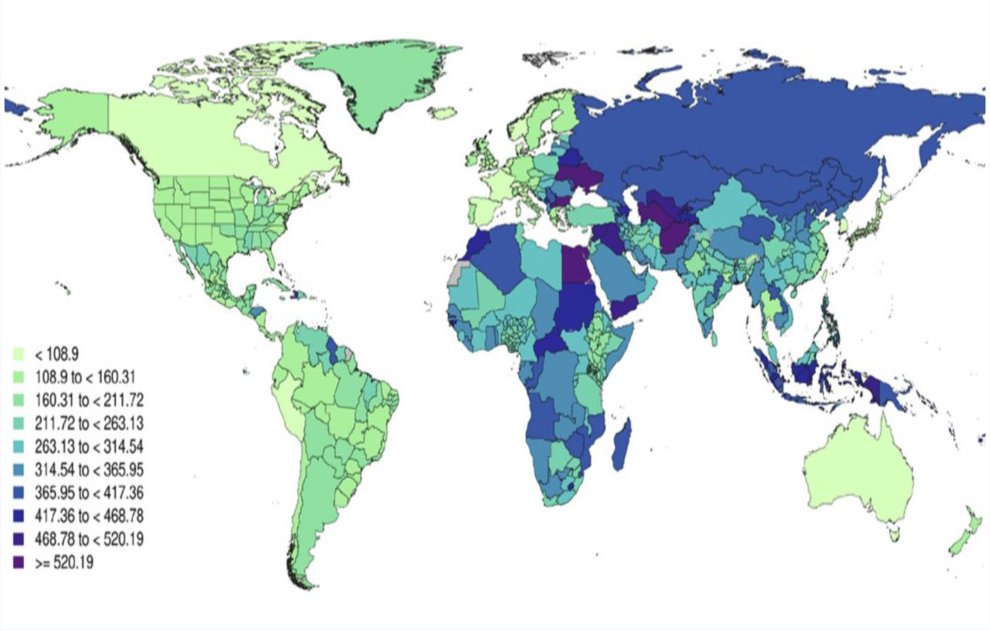
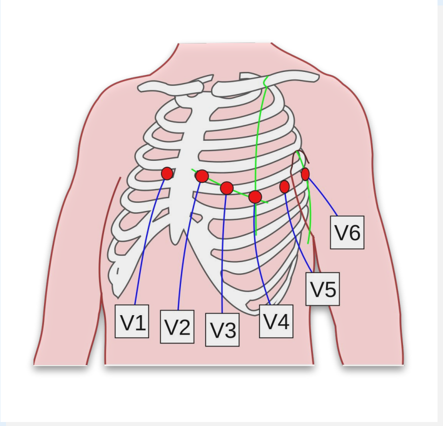
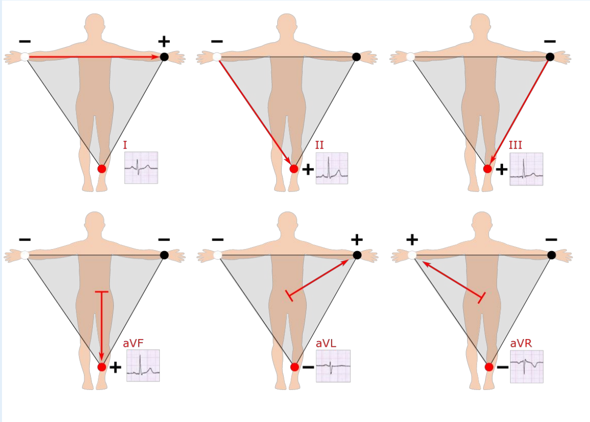
Cardiovascular diseases (CVDs) are **the leading cause of death** globally. (dark blue and purple regions – with the highest number of deaths)

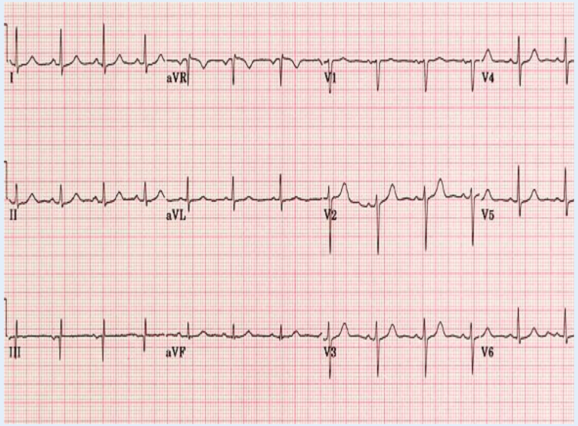


[1] https://www.who.int/ru/news/item/09-12-2020-who-reveals-leading-causes-of-death-and-disability-worldwide-2000-2019

ECG (Electrocardiogram) is a fast and cheap medical test measuring heart electrical activity. It is used to detect heart problems and monitor the heart's status.





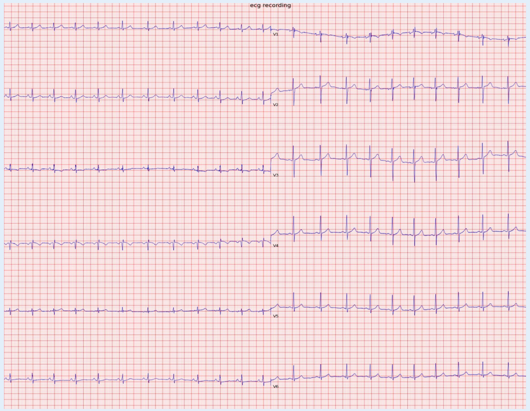


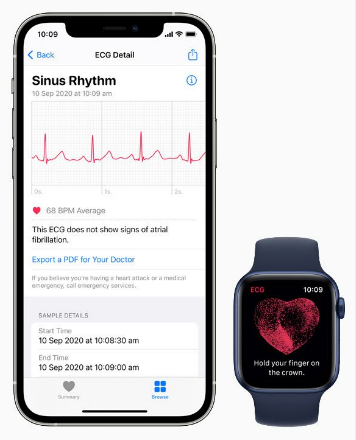
ECG

12-lead signals

Single-lead signals

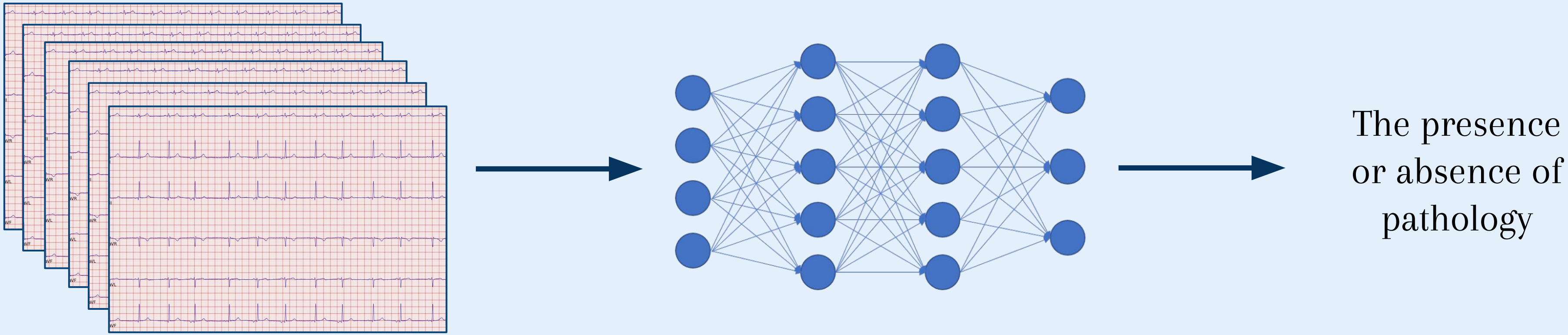
24 hour holters





ECG analysis

Deep learning is used to automate ECG analysis to detect pathologies of the cardiovascular system.



- 12-lead ECG Analysis
- Single-lead ECG Analysis
- ECG Delineation
- ECG Service

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Why does current solution not work?

Datasets:

- Small in size
- Not diverse in pathologies
- Annotated by small groups of cardiologists
- Hospitals use different cardiographs

Models:

- Not stable to data source changes

Objectives

Proposed methodology:

- resilient to changes in datasets
- improves classification quality of more diseases
- demonstrates applicability in the clinical setting

Data

- **PTB-XL** - publicly available
- **TIS** - closed

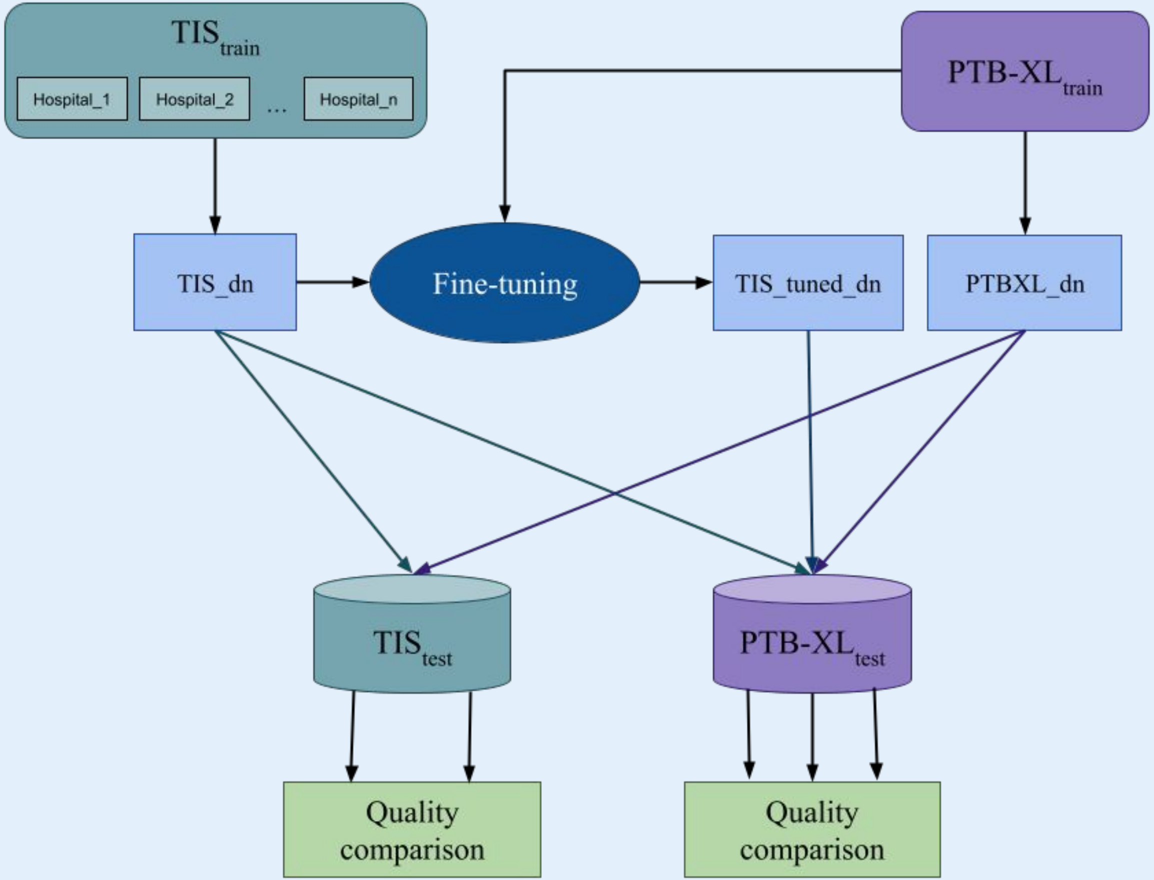
	TIS	**PTB-XL**
Total	581.151	21.799
Age		
18 - 29	55.459	1.246
30 - 49	141.629	3.930
50 - 69	275.941	9.689
>= 70	108.122	6.801
Sex		
male	211.347	11.354
female	369.804	10.445
Frequency		
500 Hz	464.797	21.799
1000Hz	116.354	0
Number of doctors	129	2

Data

For experiments we chose 7 pathologies:

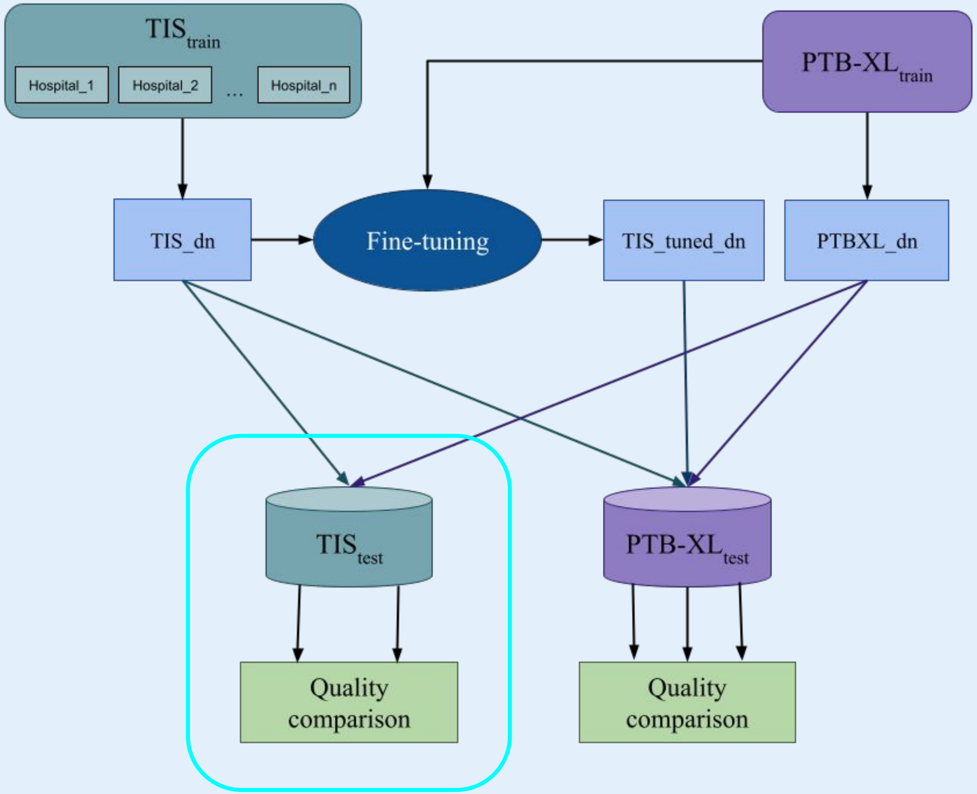
- Atrial Fibrillation - AFIB
- Sinus Tachycardia - STACH
- Sinus Bradycardia - SBRAD
- Premature Ventricular Complexes - PVC
- Left Bundle Branch Block - LBBB
- Right Bundle Branch Block - RBBB
- First-degree AV Block - 1AVB

Experiments



Experiments

1. In the first experiment, models are trained on PTB-XL and TIS. After that, the models are evaluated on the TIS test set.

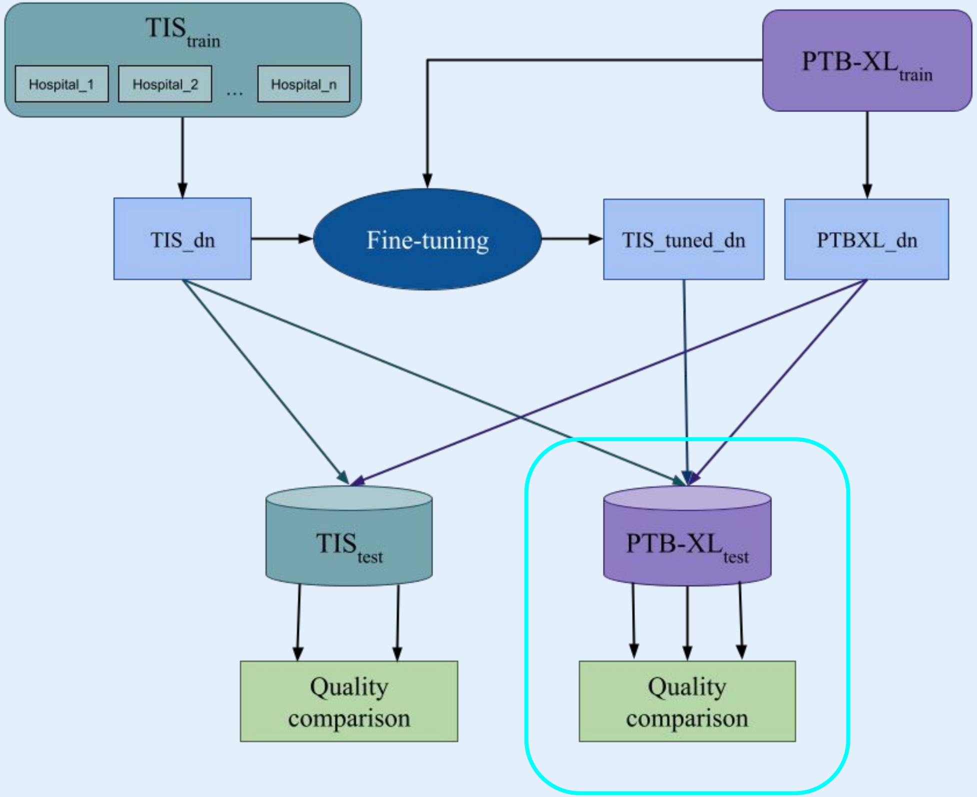


Train	Pathology															
	AFIB				1AVB				RBBB				LBBB			
	Sens.	Spec.	G-mean	F2	Sens.	Spec.	G-mea n	F2	Sens.	Spec.	G-mea n	F2	Sens.	Spec.	G-mean	F2
PTB-XL _dn	0.956	0.980	0.968	0.832	0.750	**0.940**	0.840	0.435	0.913	0.907	0.910	0.702	0.732	**0.985**	0.849	0.546
TIS_dn	**0.982**	**0.991**	**0.986**	**0.917**	**0.963**	0.933	**0.948**	**0.52**	**0.950**	**0.917**	**0.933**	**0.74**	**0.911**	0.977	**0.942**	**0.582**

Train	Pathology											
	STACH				SBRAD				PVC			
	Sens.	Spec.	G-mea n	F2	Sens.	Spec.	G-mean	F2	Sens.	Spec.	G-mean	F2
PTB-XL_dn	0.504	**0.980**	0.703	0.530	0.538	**0.954**	0.716	0.487	0.931	0.931	0.931	0.551
TIS_dn	**0.977**	0.937	**0.957**	**0.847**	**0.987**	0.945	**0.966**	**0.801**	**0.987**	**0.984**	**0.986**	**0.852**

Experiments

1. In the first experiment, models are trained on PTB-XL and TIS. After that, the models are evaluated on the TIS test set.
2. In the second experiment, a third model is added: trained on TIS and fine-tuned on PTB-XL. After that, the models are evaluated on the PTB-XL test set.



Train	Pathology															
	AFIB				1AVB				RBBB				LBBB			
	Sens.	Spec.	G-mean	F2	Sens.	Spec.	G-mean	F2	Sens.	Spec.	G-mean	F2	Sens.	Spec.	G-mean	F2
PTB-XL_dn	0.929	0.969	0.949	0.868	0.905	0.884	0.894	0.566	0.972	0.942	0.957	0.855	0.842	0.980	0.908	0.762
TIS_dn	**0.952**	0.953	0.953	0.850	**0.918**	0.859	0.888	0.531	**0.985**	0.938	0.961	0.856	**0.992**	0.907	0.948	0.599
TIS_tuned_dn	0.942	**0.972**	**0.957**	**0.884**	0.892	**0.923**	**0.908**	**0.644**	**0.985**	**0.947**	**0.966**	**0.873**	0.917	**0.982**	**0.949**	**0.827**

Train	Pathology											
	STACH				SBRAD				PVC			
	Sens.	Spec.	G-mean	F2	Sens.	Spec.	G-mean	F2	Sens.	Spec.	G-mean	F2
PTB-XL_dn	0.951	0.962	0.957	0.804	0.789	**0.928**	0.856	0.551	0.956	0.953	0.954	0.821
TIS_dn	0.982	0.906	0.943	0.665	0.961	0.848	0.902	0.481	0.991	0.970	0.981	0.895
TIS_tuned_dn	**0.963**	**0.979**	**0.971**	**0.876**	**0.891**	0.913	**0.902**	**0.575**	**0.987**	**0.980**	**0.983**	**0.921**

Additional experiments

To estimate the quality of DNNs in clinical practice, we compared their prediction with the independent evaluation of 500 ECG from PTB-XL by three doctors from different hospitals.

Train	**Pathology**											
	AFIB				**1AVB**				**RBBB**			
	Sens.	**Spec.**	**G-mean**	**F2**	**Sens.**	**Spec.**	**G-mean**	**F2**	**Sens.**	**Spec.**	**G-mean**	**F2**
TIS_tuned_dn	0.942	0.972	0.957	0.884	0.892	0.923	**0.908**	0.644	0.985	0.947	**0.966**	0.873
Doctor1	0.941	0.985	0.963	0.914	0.882	0.913	0.897	0.600	0.946	0.896	0.921	0.758
Doctor2	0.941	0.978	0.960	0.899	0.529	0.959	0.712	0.464	0.649	0.987	0.800	0.674
Doctor3	0.941	0.987	**0.964**	0.920	0.765	0.963	0.858	0.657	0.676	0.900	0.780	0.571

Additional experiments

Pathology	Sensitivity	Specificity	G-mean
Atrial Fibrillation	0.981	0.975	0.978
Ventricular Premature Complexes	0.958	0.890	0.923
Sinus Tachycardia	0.912	0.939	0.926
Sinus Bradycardia	0.918	0.977	0.947
First Degree AV Block	0.921	0.923	0.922
Incomplete Right Bundle-Branch Block	0.825	0.936	0.878
Complete Right Bundle-Branch Block	0.963	0.980	0.972
Complete Left Bundle-Branch Block	0.965	0.970	0.967
Supraventricular Premature Complexes	0.930	0.861	0.894
Left-axis Deviation	0.877	0.952	0.914
Right-axis deviation	0.939	0.960	0.949

- 12-lead ECG Analysis
- Single-lead ECG Analysis
- ECG Delineation
- ECG Service

Single-lead ECG

- **Problems:**

  Limited number of single-channel ECGs

- **Proposal:**

  Pre-train models on 12-lead ECGs and then retrain on 1-lead ECGs

  ➢ 1-lead ECGs are similar to lead I of a 12-lead ECG

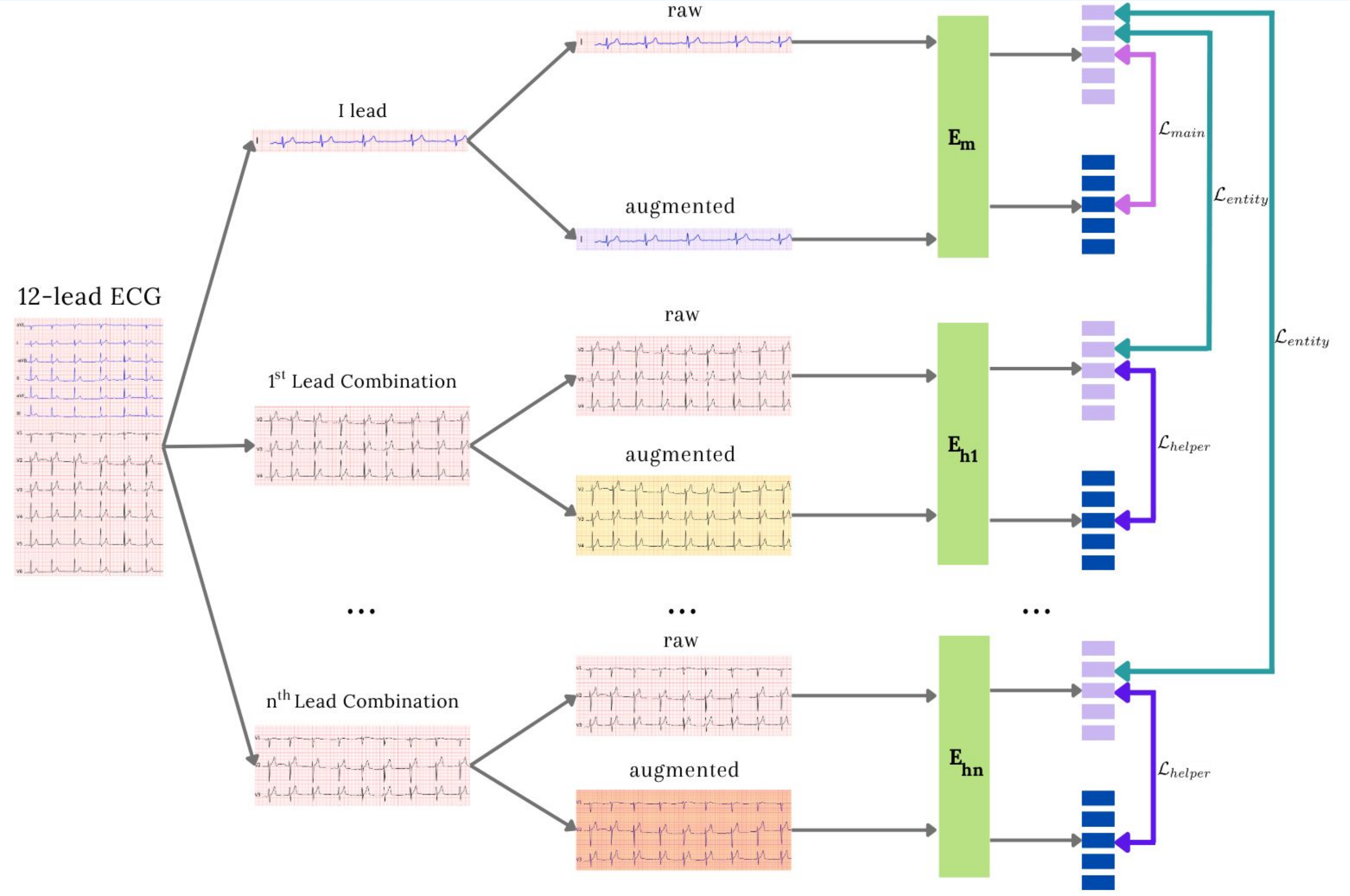
  ➢ 12-lead ECGs contain more information than a single-lead ECG

- **Training:**

  ➢ Using lead I of a 12-lead ECG for training

  ➢ Using the 12-lead ECG labeling

Lead Combinations with Contrastive Learning (LC-CL)



LC-CL: Experiments

- We conduct 2 experiments to determine the effectiveness of our approach.
- We use ResNet1d50 as an encoder for all experiments.
- G-mean and F1-score metrics are used to evaluate the quality.

Settings:

- Different combinations of leads for the LC-CL method to determine the optimal combination.
- Comparison of the proposed method with existing contrast methods.

LC-CL: Experiments

We compare lead combinations for the LC-CL method and the supervised approach.

We consider 3 lead combinations:

- 1vs11 - one helper encoder (11 leads except I)
- 1vs1vs6 - two helper encoders (lead II + 6 chest leads)
- 1vs7 - one helper encoder (lead II and 6 chest leads)

Train	**AFIB**		**1AVB**		**PVC**		**CLBBB**	
	G-mean	F1-score	G-mean	F1-score	G-mean	F1-score	G-mean	F1-score
Supervised	0.849	0.377	0.804	0.192	0.878	0.383	0.939	0.353
LC-CL (1vs11)	0.933	**0.601**	0.868	0.270	**0.935**	0.504	**0.973**	**0.462**
LC-CL (1vs1vs6)	0.925	0.577	0.867	0.249	0.901	0.618	0.944	0.453
LC-CL (1vs7)	**0.934**	0.591	**0.887**	**0.280**	0.920	**0.634**	0.962	0.430

LC-CL: Experiments

- We compare our LC-CL method with Supervised and two contrast methods: SimCLR and TS-TCC.
- We choose the 1vs7 LC-CL model configuration in this comparison.

Train	AFIB		1AVB		PVC		CLBBB	
	G-mean	F1-score	G-mean	F1-score	G-mean	F1-score	G-mean	F1-score
Supervised	0.849	0.377	0.804	0.192	0.878	0.383	0.939	0.353
SimCLR	0.927	0.620	0.863	0.267	0.943	0.620	0.966	0.492
TS-TCC	0.947	**0.738**	0.874	0.262	**0.962**	0.677	**0.969**	0.525
LC-CL	**0.950**	0.694	**0.884**	**0.282**	0.941	**0.759**	**0.969**	0.671

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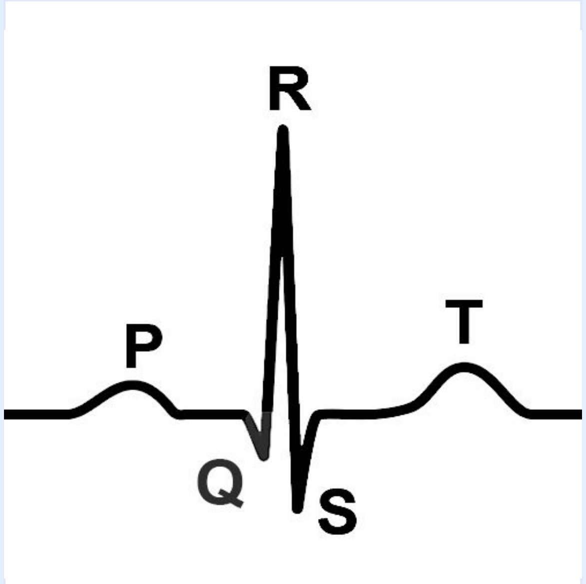
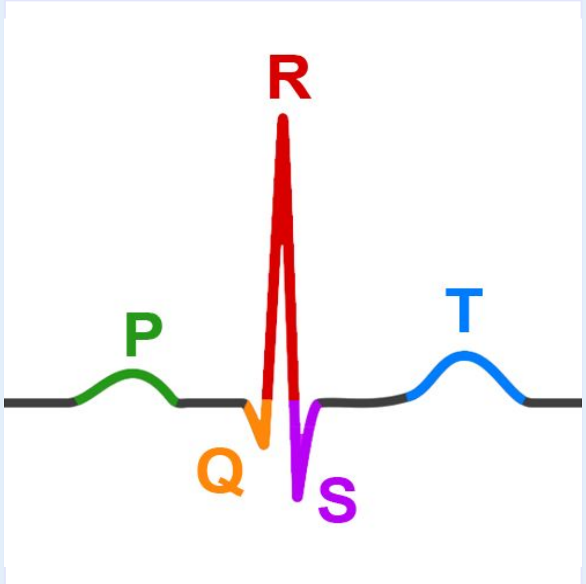
ECG Delineation

Each ECG record consists of PQRST segments

Task: To identify segments and intervals of PQRST complexes



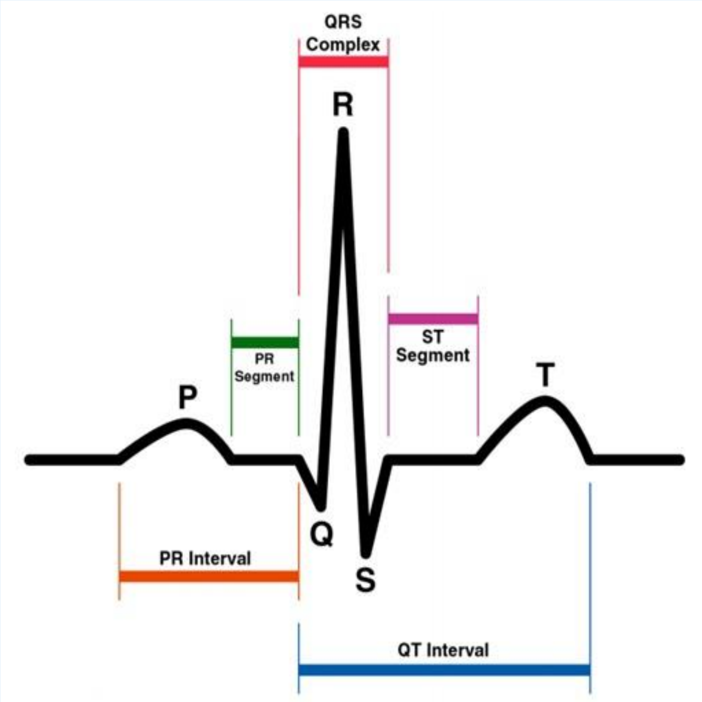


ECG Delineation

Task: Find the positions of peaks, beginnings and ends of intervals on the ECG recording – QRS complex, P wave, T wave.

Existing segmentation methods:

- ➢ **“mathematical”:** filtering and searching for locally largest/smallest values. They start to make big mistakes for segmenting some of the complexes (P wave, T wave).
- ➢ **Neural networks (Unet):** there are few open datasets on segmentation (LUDB, QTDB).



ECG Delineation

Metrics:

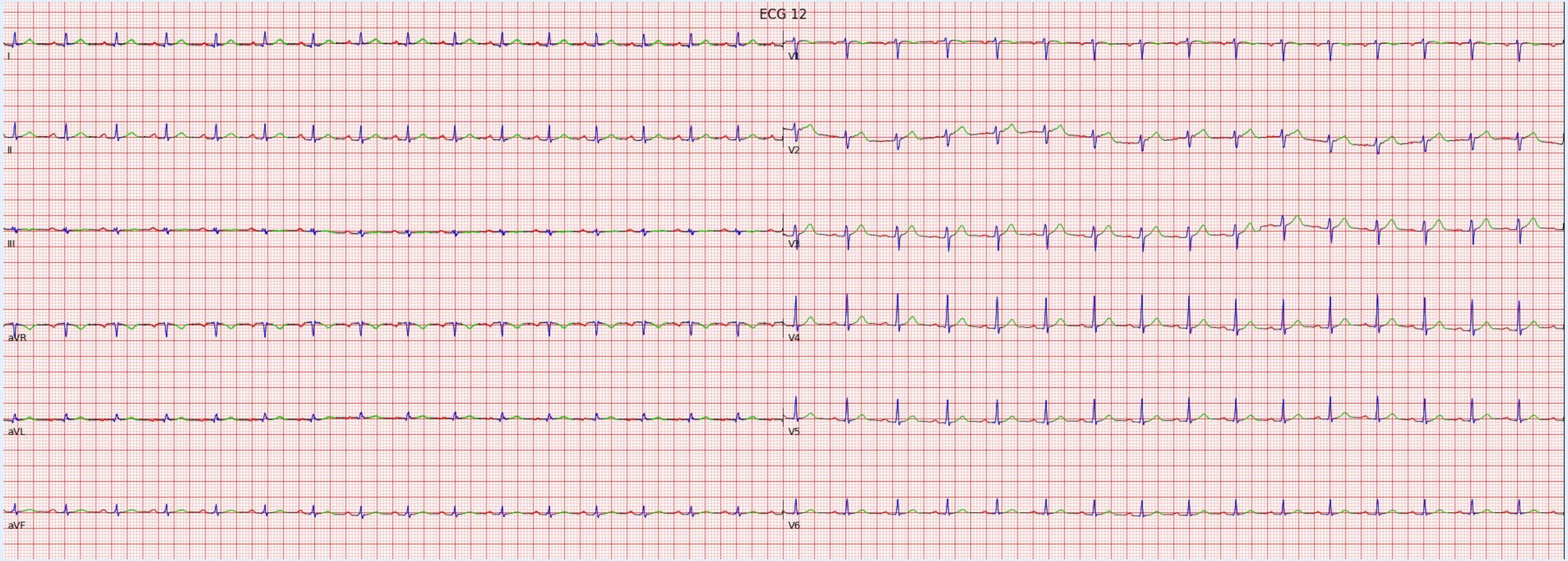
- **True Positives** – The predicted point fell into the neighborhood (window tolerance) of the corresponding ground truth point with the same class.
- **False Positives** – The predicted point did not fall into any neighborhood of the corresponding ground truth point.
- **False Negatives** – Ground truth points for which there were no predicted points in the neighborhood.

Detection	Sensitivity	PPV
P-wave onset detection	0.967	0.956
P-wave offset detection	0.967	0.956
QRS onset detection	0.987	0.998
QRS offset detection	0.987	0.998
Q-wave onset detection	0.951	0.955
Q-wave offset detection	0.938	0.942

$$Sensitivity = \frac{TP}{TP + FN}$$

$$PPV = \frac{TP}{TP + FP}$$

ECG Delineation



P-wave

QRS

T-wave

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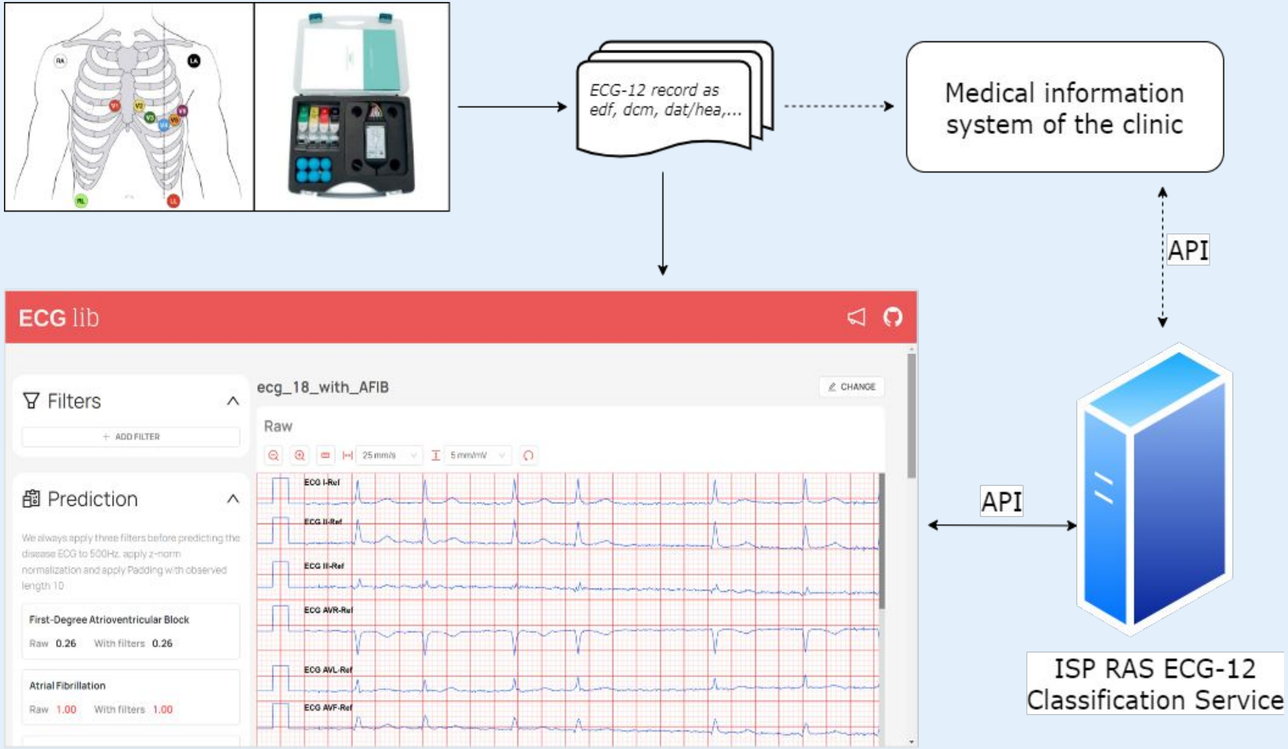
ECG Service

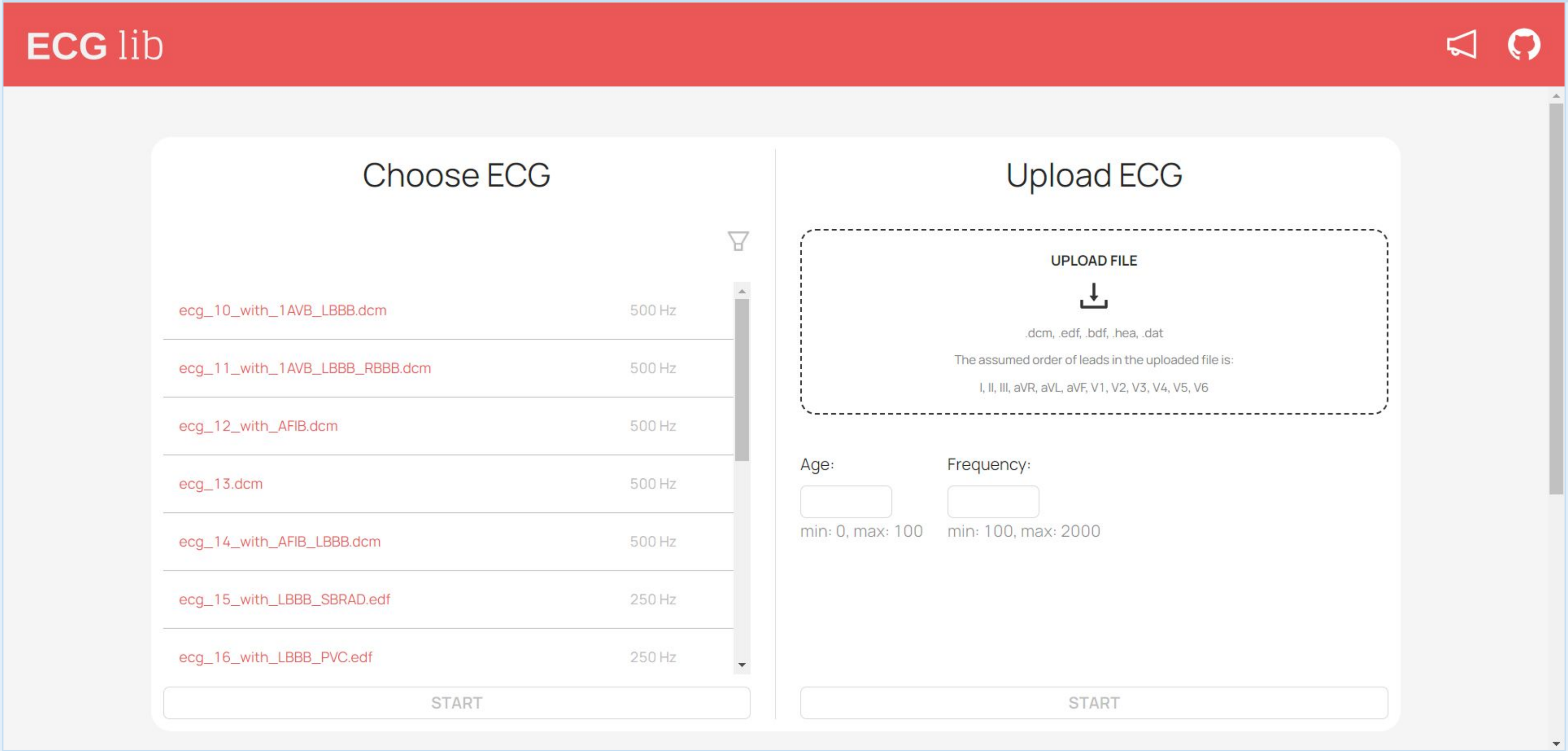
ECG signal is uploaded manually or automatically transferred from cardiograph.

The response is sent back to the user interface.

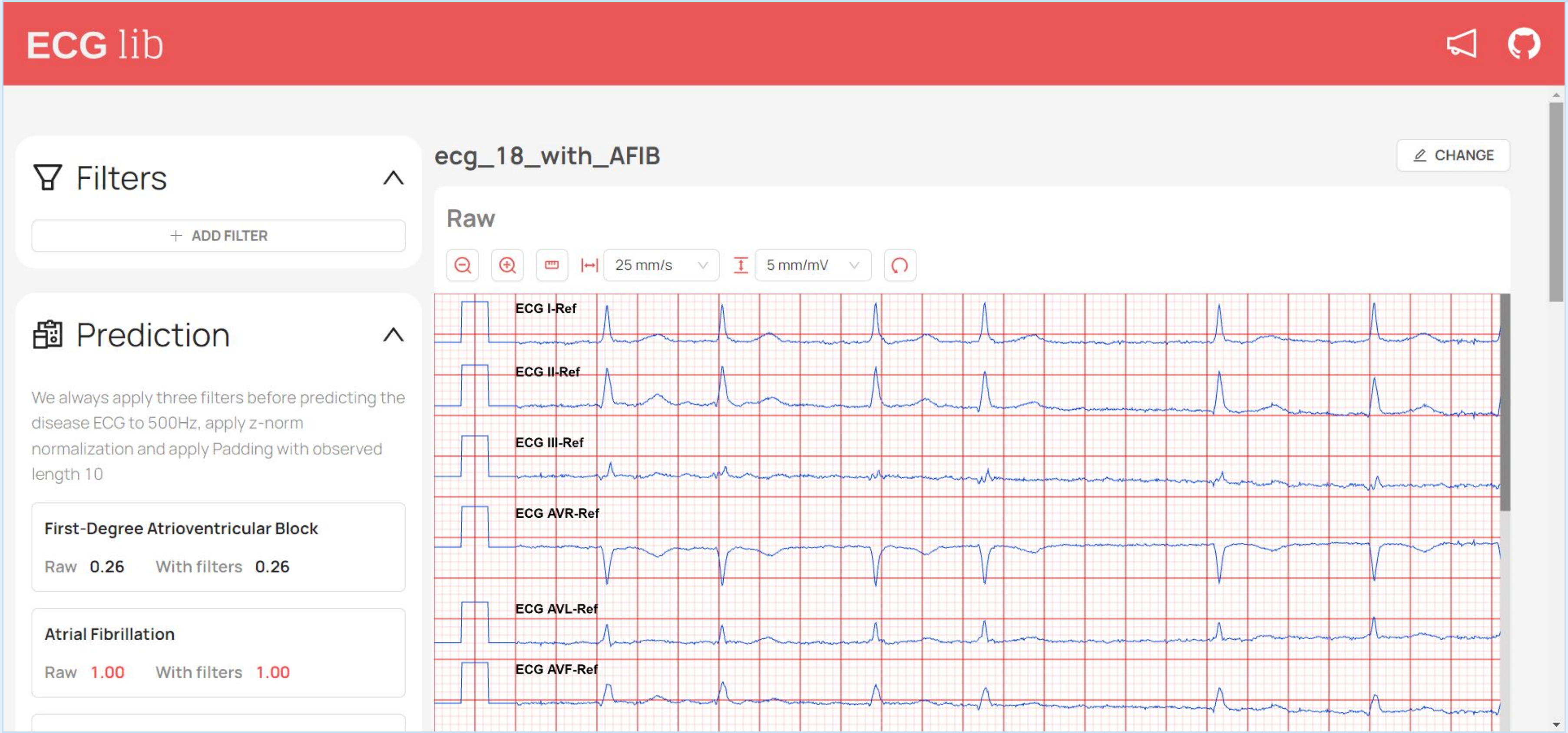
The classification service can be integrated with the medical system via API.



ECG Service


ECG lib
Choose ECG
ecg_10_with_1AVB_LBBB.dcm
500 Hz
ecg_11_with_1AVB_LBBB_RBBB.dcm
500 Hz
ecg_12_with_AFIB.dcm
500 Hz
ecg_13.dcm
500 Hz
ecg_14_with_AFIB_LBBB.dcm
500 Hz
ecg_15_with_LBBB_SBRAD.edf
250 Hz
ecg_16_with_LBBB_PVC.edf
250 Hz
START
Upload ECG
UPLOAD FILE
.dcm, .edf, .bdf, .hea, .dat
The assumed order of leads in the uploaded file is:
I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5, V6
Age:
min: 0, max: 100
Frequency:
min: 100, max: 2000
START

ECG Service


ECG lib
Filters
ADD FILTER
Prediction
We always apply three filters before predicting the disease ECG to 500Hz, apply z-norm normalization and apply Padding with observed length 10
First-Degree Atrioventricular Block
Raw 0.26 With filters 0.26
Atrial Fibrillation
Raw 1.00 With filters 1.00
ecg_18_with_AFIB
CHANGE
Raw
25 mm/s
5 mm/mV
ECG I-Ref
ECG II-Ref
ECG III-Ref
ECG AVR-Ref
ECG AVL-Ref
ECG AVF-Ref

Other Research Directions

- Federated Learning
- Affective Computing (Emotion Recognition)
- Speech Technologies

ECGlib

CardioLab

Thank you!!!

shahane.tigranyan99@gmail.com