Advancing Cardiac Diagnostics: Deep Learning Approaches for ECG-Based Heart Condition Analysis and Reconstruction

THE ERDŐS INSTITUTE:
Deep Learning Boot Camp (May-Summer 2024)

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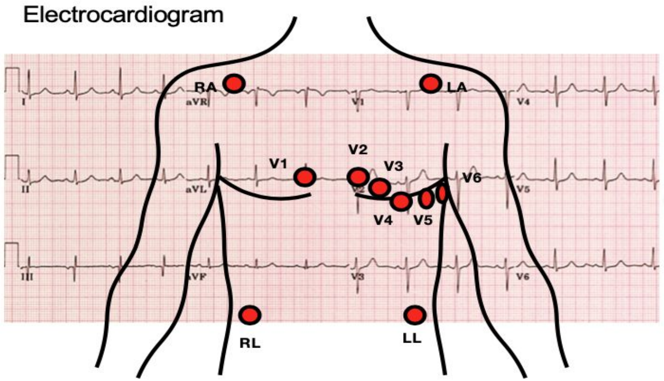
Introduction

The Importance of Cardiac Diagnostics

- **Cardiovascular diseases** are a major factor in worldwide fatalities.
- The World Health Organization states that these diseases are the primary cause of global mortality, leading to approximately **17.6 million deaths each year.**
- Abnormal electrical rhythms or arrhythmia are responsible for most instances of sudden death.
- Detecting these conditions early and providing prompt treatment are crucial for lowering mortality rates.

Importance of the Electrocardiogram (ECG)

- **Echocardiography** plays a crucial role in the diagnosis of ventricular arrhythmias.
- It is a **non-invasive** and **cost-effective** method capable of distinguishing a wide variety of diseases, including ventricular myocardial infarction and bundle branch blocks.



Introduction

Goal for this project:

- Developing deep learning models to enhance heart condition diagnosis.

Classification Tasks:

- Utilized ECG Heartbeat Categorization Dataset from Kaggle.

Reconstruction Tasks:

- Used simulated intracardiac voltage recordings from the 2023 Data Science Challenge (DSC) at Lawrence Livermore National Laboratory (LLNL).

Impact of the Project

- Simplifies complex ECG interpretation and map translation.
- Reduces reliance on cardiologist expertise, speeding up patient assessment.
- Makes advanced diagnostics more accessible to frontline healthcare providers.

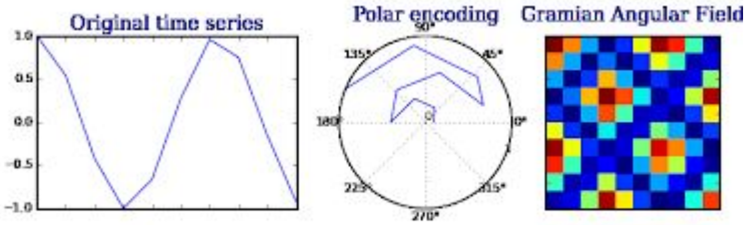
Data Processing: ECG vs. GAF

Raw ECG Signals:

- Preserved signal integrity.
- Critical for detecting subtle anomalies.
- Maintained clinical interpretability.

Gramian Angular Fields (GAF):

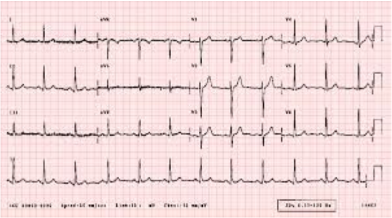
- Transformed ECG data into images.
- Enabled use of CNN architectures (VGG, ResNet, DenseNet).
- Facilitated effective transfer learning.

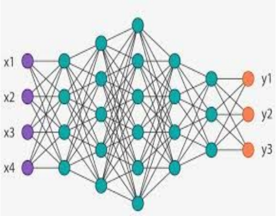


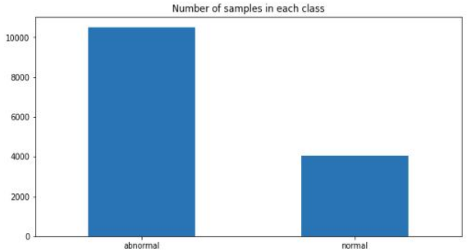
Objective 1: Heartbeat Binary Classification

Problem Description:

Classify heartbeats as either normal or irregular using ECG data.

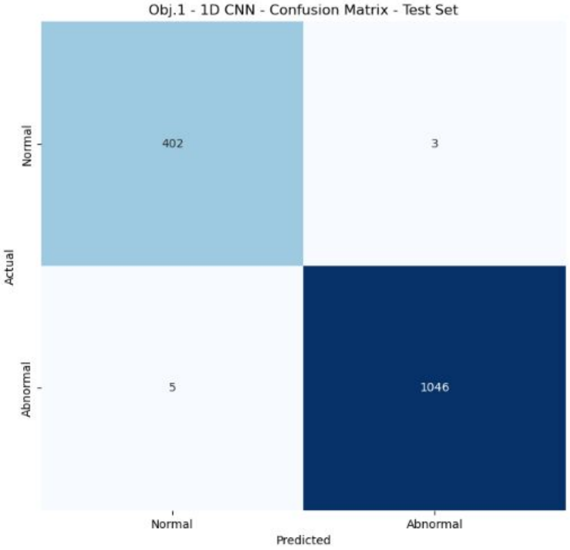






Model Selection & Results :

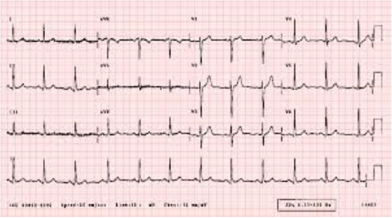
	Model	Accuracy	FNR
0	XGBoost (ECG)	97.53%	2.85%
1	XGBoost (GAF)	96.57%	4.29%
2	CNN1D (ECG)	99.45%	0.5%
3	CNN2D (GAF)	98.01%	2.5%

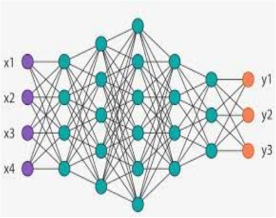


Objective 2: Heartbeat Multi-Classification

Problem Description:

Extend the classification to multiple types of irregular heartbeats.



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0: "Normal",
1: "Artial Premature",
2: "Premature ventricular contraction",
3: "Fusion of ventricular & normal",
4: "Fusion of paced & normal"
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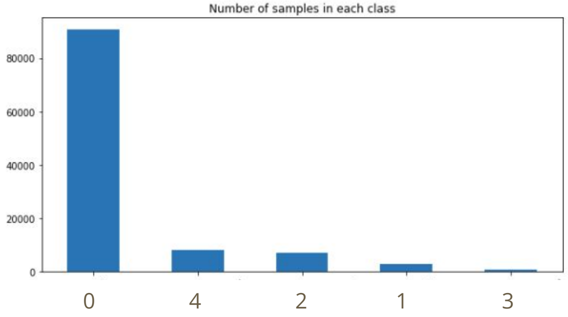
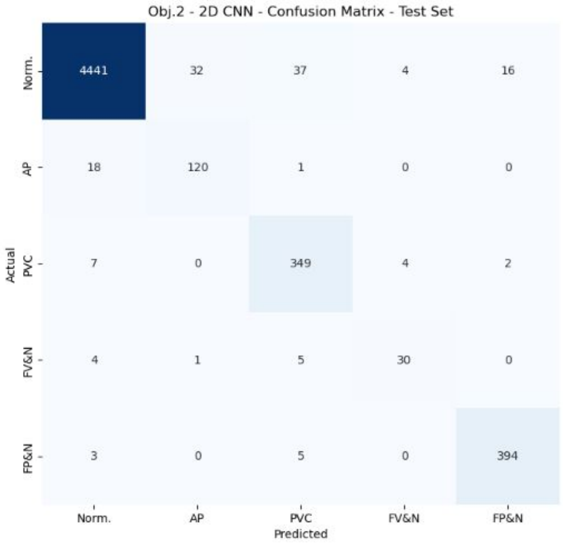


Model Selection & Results:

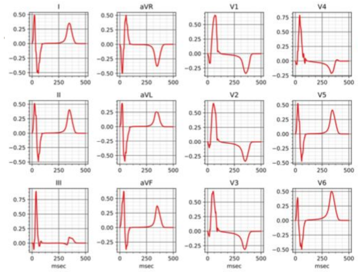
	Model	Accuracy	FNR
0	XGBoost (ECG)	96.49%	4.85%
1	XGBoost (GAF)	96.71%	5.39%
2	CNN1D (ECG)	97.77%	5.79%
3	CNN2D (GAF)	97.46%	4.99%

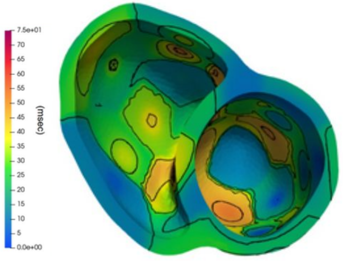


Objective 3: Activation Map Reconstruction

Problem Description:

Reconstruct heart activation maps from ECG signals. These maps visually represent the electrical activity across the heart's surface over time.





True Activation Time

<u>Focus on Raw ECG Data:</u>

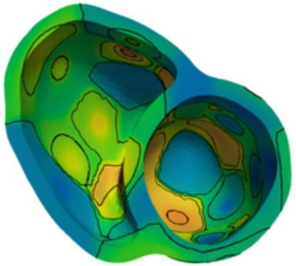
- Chose to use raw ECG data due to large GAF image sizes.

Model Development:

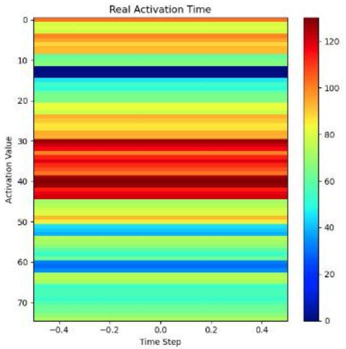
- Built a 1D CNN tailored for sequential ECG data.

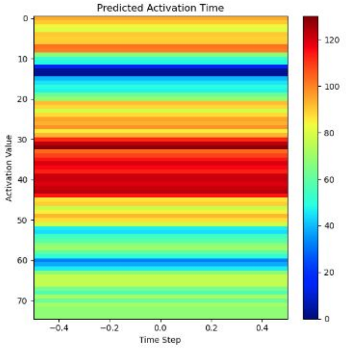
Results:

Visualization demonstrated successful spatial-temporal pattern reconstruction.



Predicted Activation Time



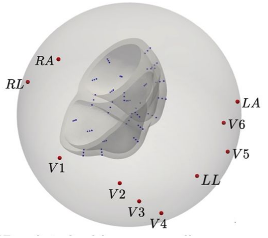


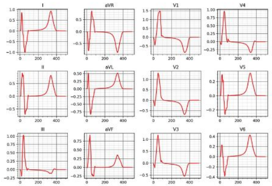
Generated activation maps that aligned closely with actual heart activity.

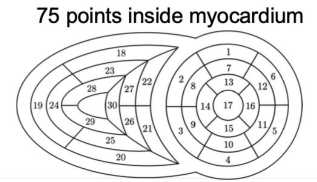
Objective 4: Transmembrane Potential Reconstruction

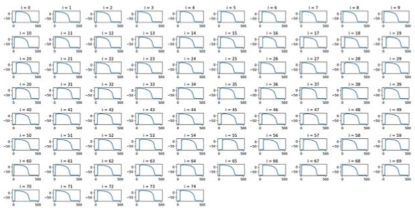
Problem Description:

Reconstruct transmembrane potential maps from ECG signals. These maps depict the voltage differences across the heart cells' membranes, offering a detailed view of the heart's electrical state at the cellular level.





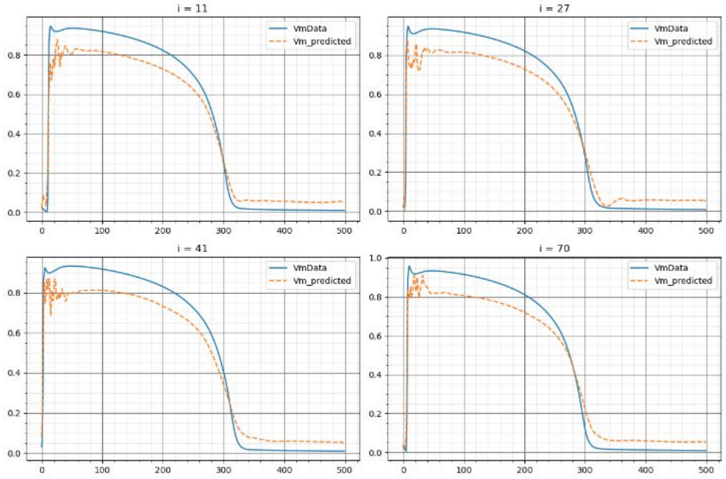




Model Enhancement:

- Extended the 1D CNN from Obj. 3 by incorporating LSTM layers.
- Aimed to better capture temporal information in ECG signals.

Results



Future Work

Leveraging HPC:

Significant computational resources required for current exploration.

Access to High-Performance Computing (HPC) is critical for optimizing and scaling the models.

Plan to refine and expand the work using HPC to meet increased computational demands and achieve more comprehensive results.

Exploring GAF and established computer vision architecture

- Apply Vision Transformers (ViTs) to 2D GAF images.
- ViTs process images as sequences of patches, similar to NLP.
- Advantages:
  - Self-attention may enhance understanding of spatial hierarchies.
  - Possibility to add temporal encoding or temporal attention to better capture temporal information

Acknowledgement

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