ECG Heartbeat Classification through Machine Learning

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Contents

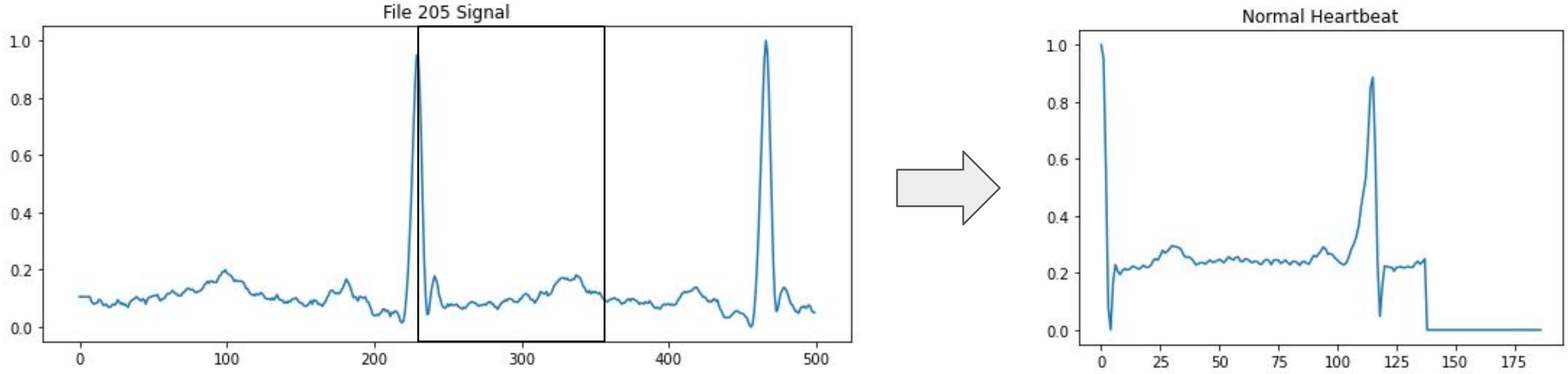
Introduction

- Work Background: Applying Deep Learning to Radar System Architecture
    - Python, Tensorflow/Keras, MATLAB

- Goal: Show my approach and thought process in applying Machine Learning given a set of data

Problem Background

- Using a Kaggle ECG Heartbeat Categorization Dataset
  - https://www.kaggle.com/datasets/shayanfazeli/heartbeat
  - 1-dimensional signal data
  - Contains Training/Testing Datasets from MIT-BIH and PTB ECG Databases
  - Signals correspond to either normal heartbeats or heartbeats affected by different arrhythmias and infarctions
    - Each signal contains one beat
- Explore performance when applying Machine Learning to this data

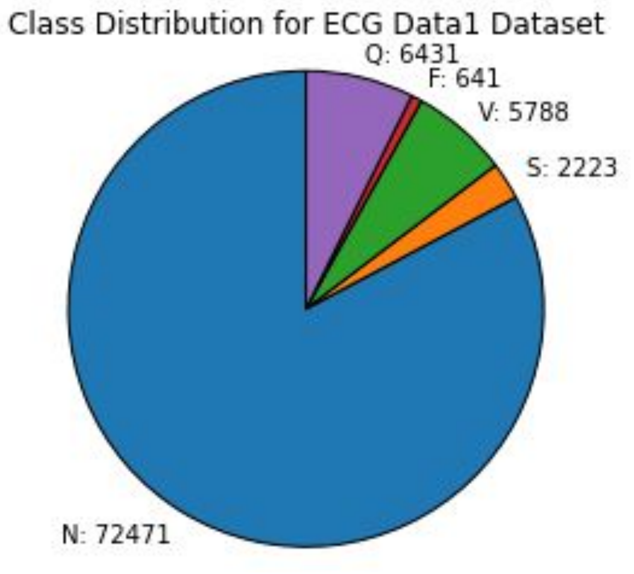


Problem Background - Approach

- Exploratory Data Analysis
  - Understand data trends
  - Look for possible biases/balance of object classes
- Machine Learning Application
  - Build and train machine learning model through a supervised approach
- Model Analysis
  - Utilize explainability tools to better understand model performance

Dataset Analysis

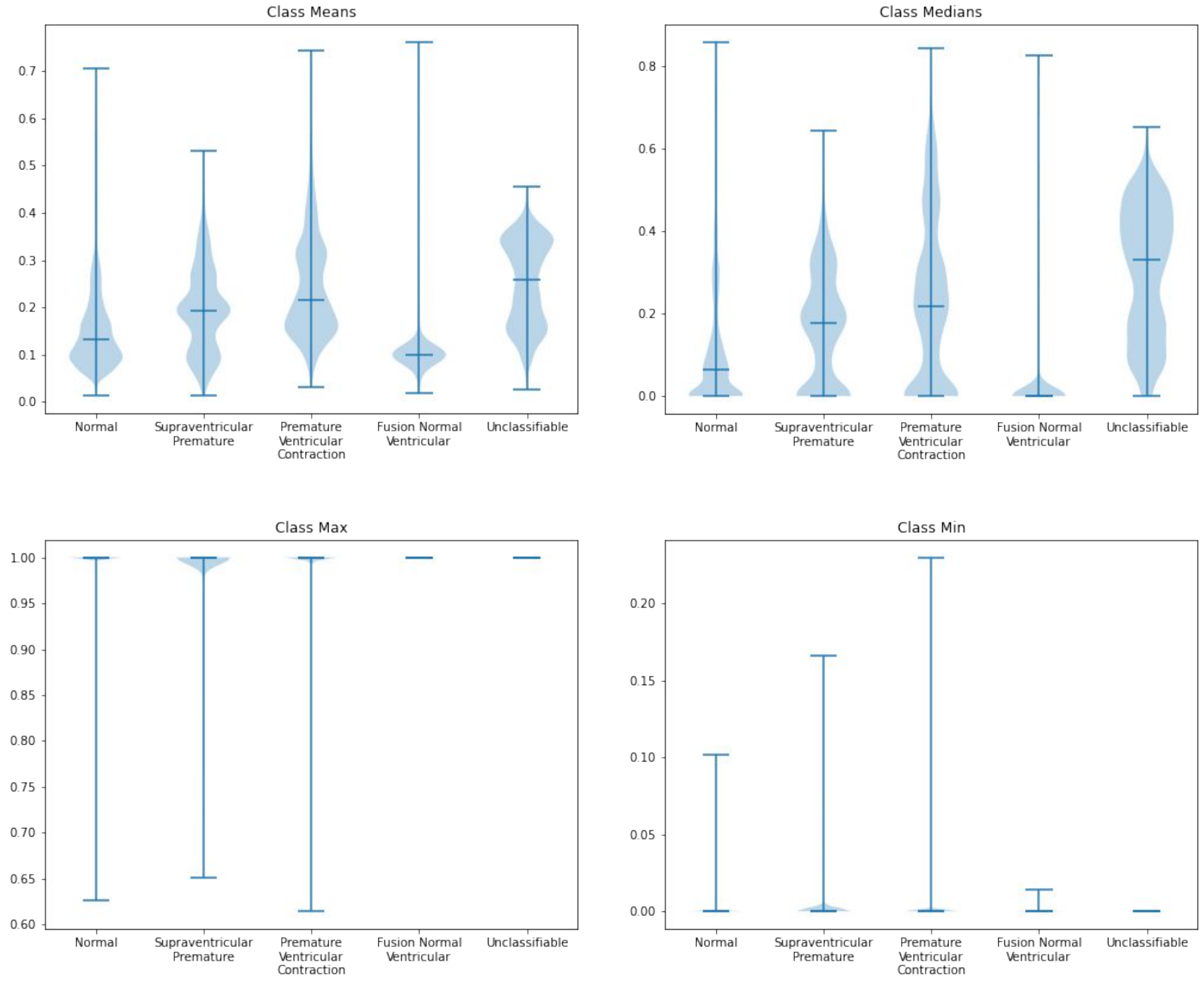
- Checking the class distribution within the MIT-BIH training dataset shows that normal heartbeats are the highest represented class
- The fusion of ventricular and normal beats are underrepresented in comparison
  - Imbalance of the data may influence the performance of the machine learning model



- N: Normal Beat
- S: Supraventricular premature beat
- V: Premature ventricular contraction
- F: Fusion of ventricular and normal beat
- Q: Unclassifiable beat

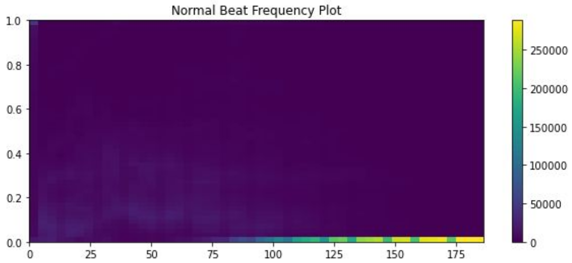
Dataset Analysis

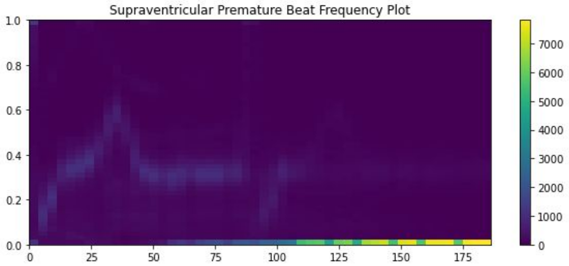
- Check the data distribution for each class in the dataset
    - Looking at Mean, Median, Max, and Min values for each class sample
- Means and medians plots show some statistical differences between classes
- This view of the data does not give a good idea of how the data actually looks

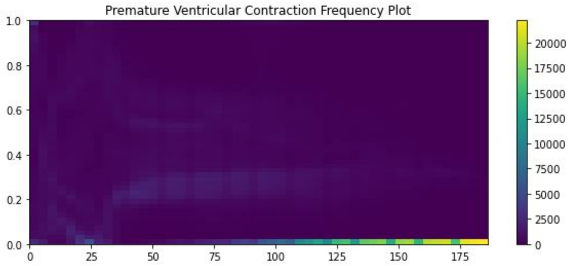


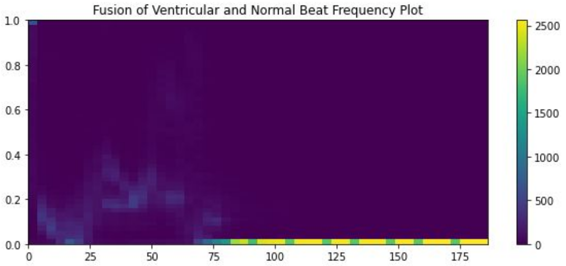
Dataset Analysis

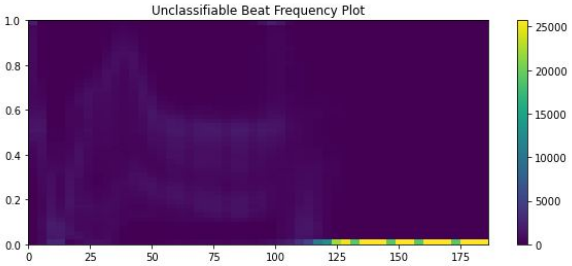
- Visualizing the frequency of values for each class shows that the trailing zeros in the samples are overwhelming the plot values
  - Given that the trailing zeros are artifacts of the dataset preparation, these data points may influence machine learning model predictions in a negative way





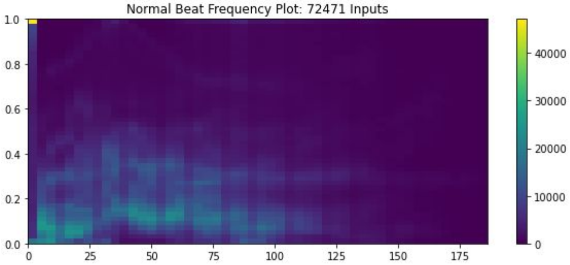


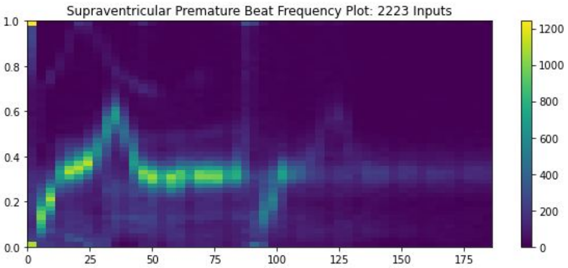


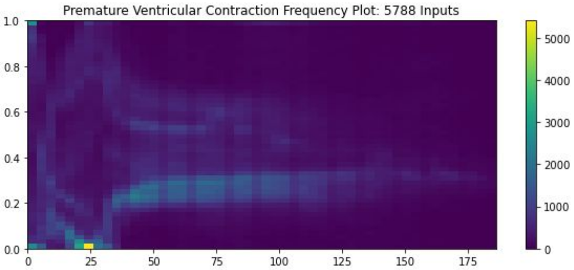


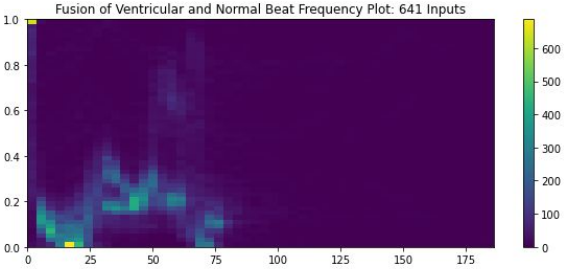
Dataset Analysis

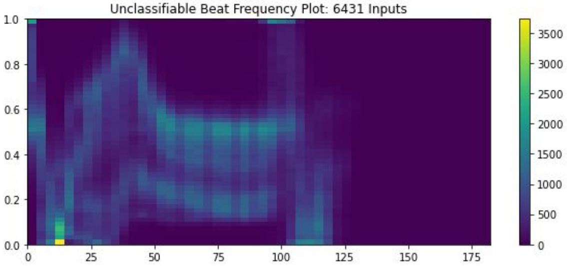
- Removing trailing zeros shows the true sample frequencies for each class





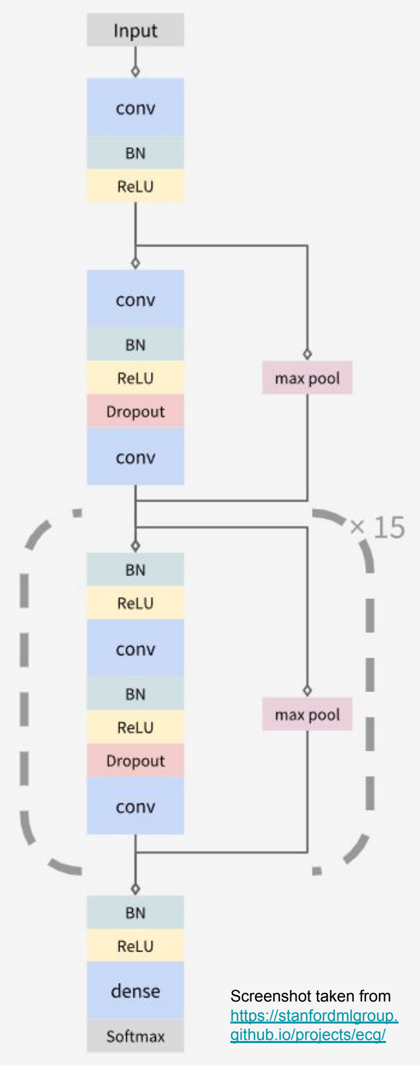






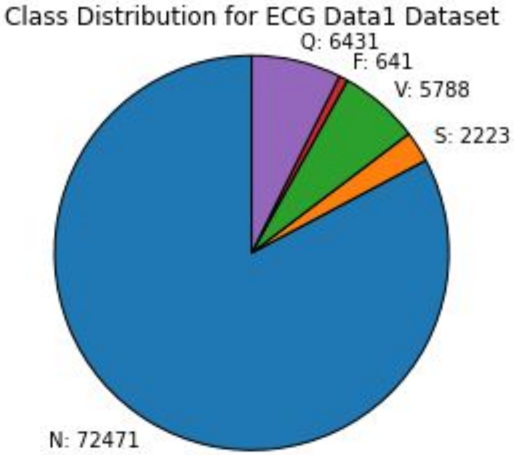
Applying Machine Learning

- Initial classifier tested will be a variation of the ResNet Deep Learning architecture
  - Other classifiers such as Random Forests, Bayesian Networks, Gradient Boosting Models, etc. could also be applied, but for the purposes of this analysis only this Deep Learning model will be utilized
  - Implementing model architecture outlined in this paper: https://stanfordmlgroup.github.io/projects/ecg/

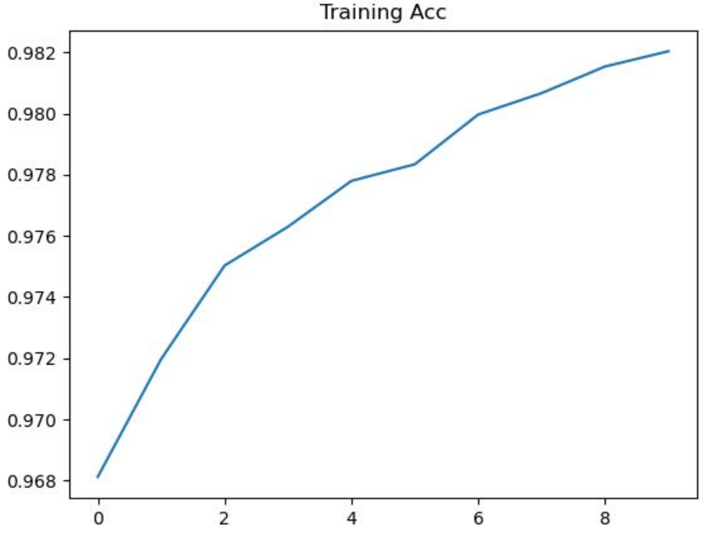


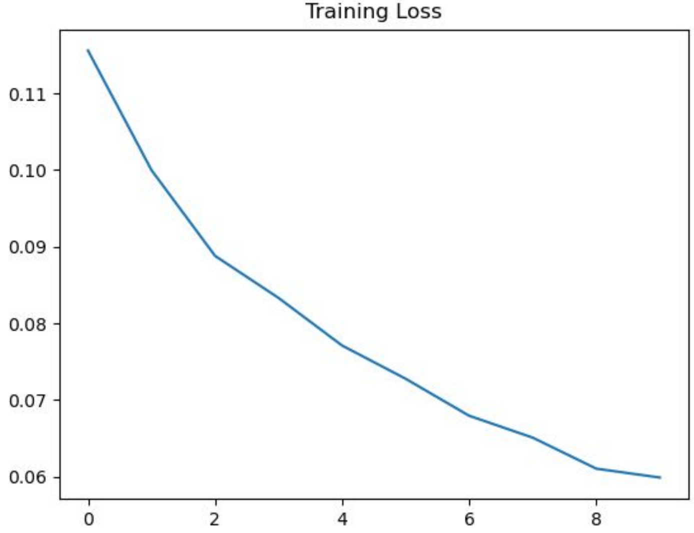
Screenshot taken from https://stanfordmlgroup.github.io/projects/ecg/

Applying Machine Learning

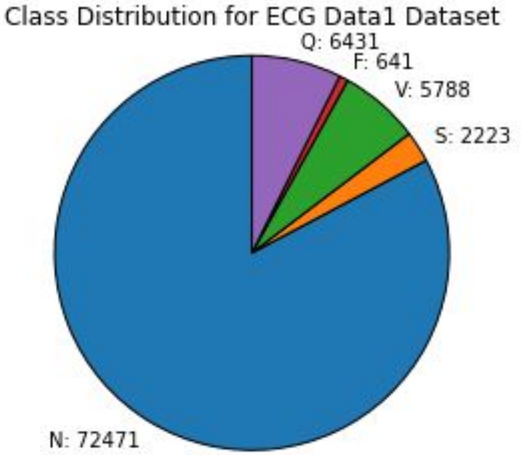


- First ResNet Model trained on MIT-BIH data with no class balancing
- Dataset split into Training/Validation/Test sets at 80/10/10
- Training accuracy makes it appear that model is performing very well against this dataset, with a test accuracy of 97.76%

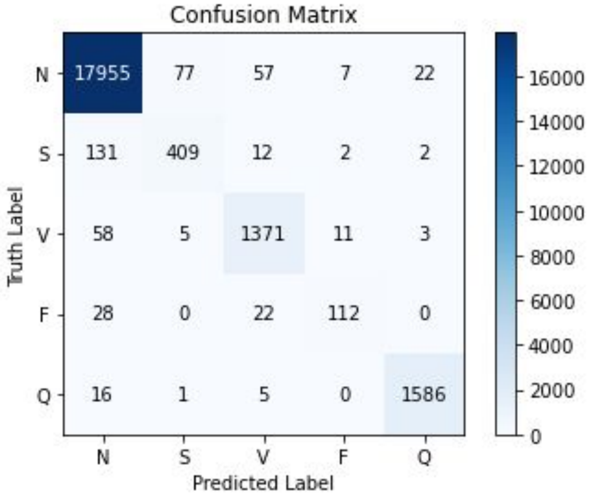


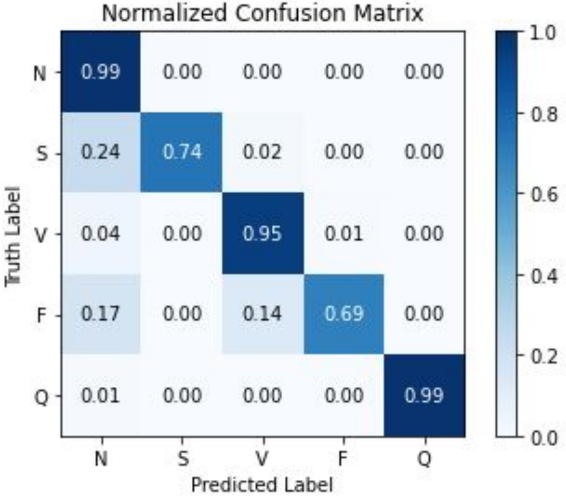


Applying Machine Learning

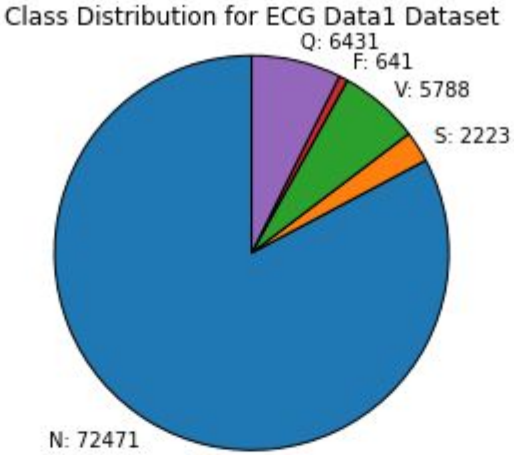


- Running the model on the MIT-BIH Test dataset shows that the model does have a very high accuracy, but also has a tendency to classify anomalous heartbeats as normal heartbeats
  - While the magnitude of the errors are relatively small, this could be concerning since missing a potential sign of a health defect is a much larger issue than misclassifying a normal beat as an anomalous one

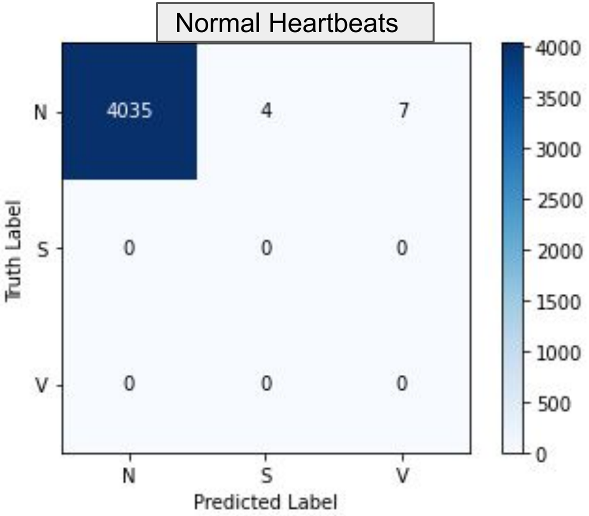


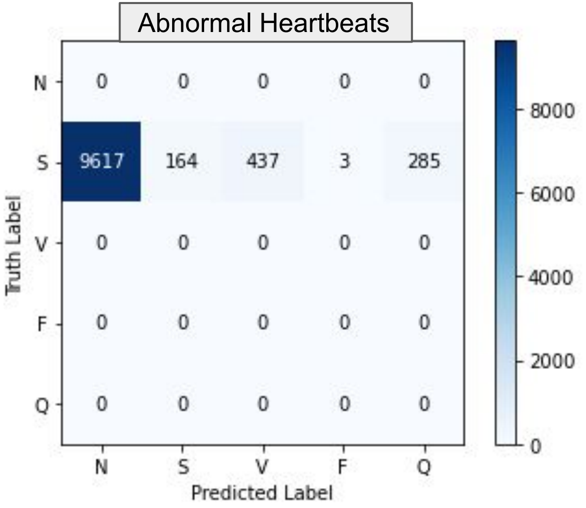


Applying Machine Learning



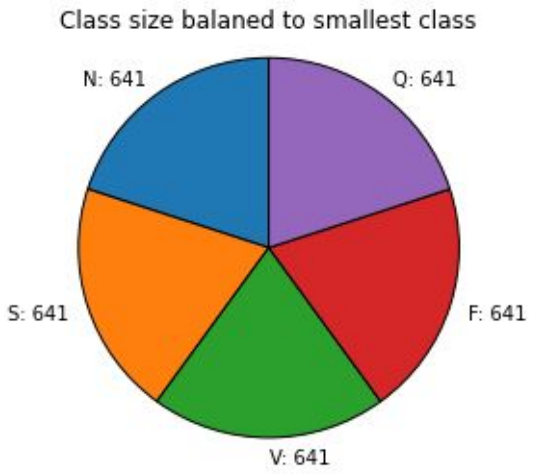
- The PTB dataset contains only two classes, for normal and anomalous heartbeats
    - Testing this model against this data shown a concerning pattern, and it appears this model is overfit towards the Normal Heartbeat class

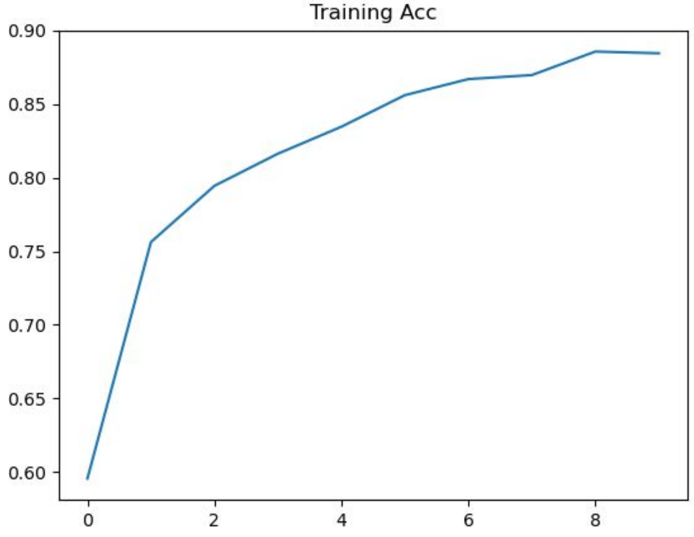


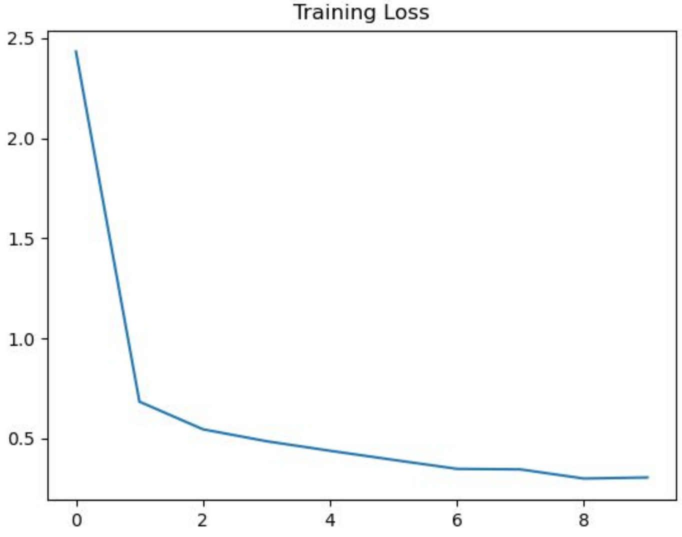


Applying Machine Learning

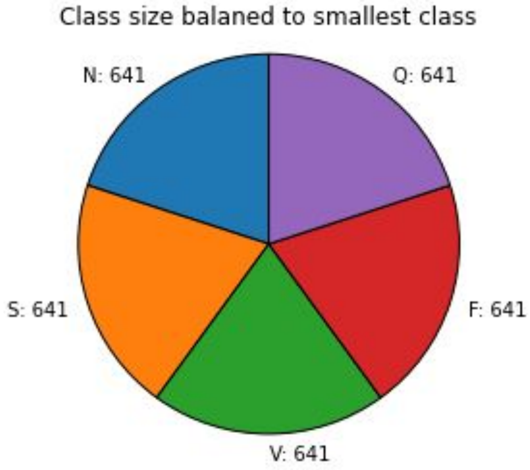
- Training the ResNet model against a smaller but balanced dataset shows that model performs slightly worse in comparison
- The test accuracy also dropped rather significantly at 61.96%



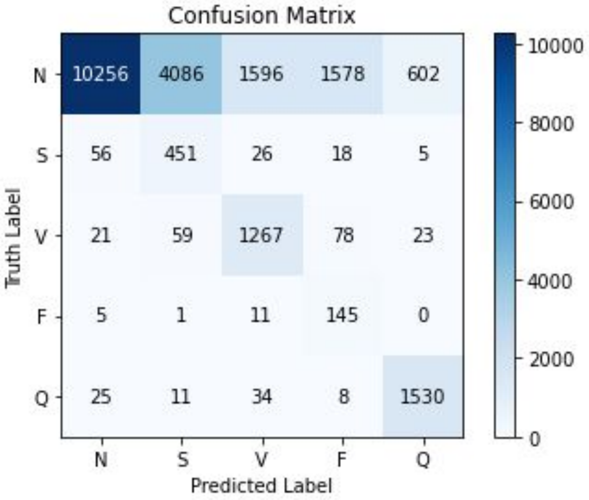


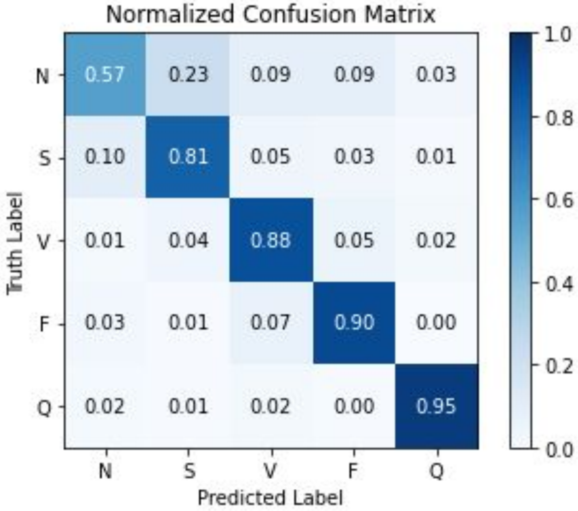


Applying Machine Learning



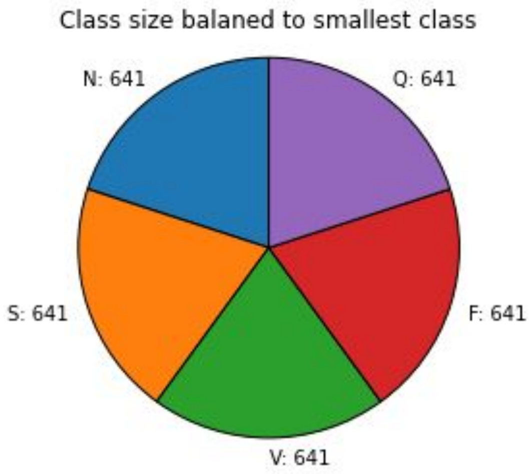
- However, looking at the confusion matrix plots, the model performance shows a better balance in performance across all classes
- There are fewer false negatives when using this model, though this is offset with a larger amount of anomalous false positives

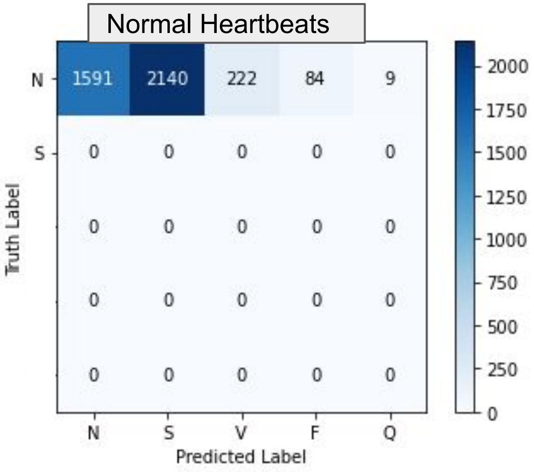


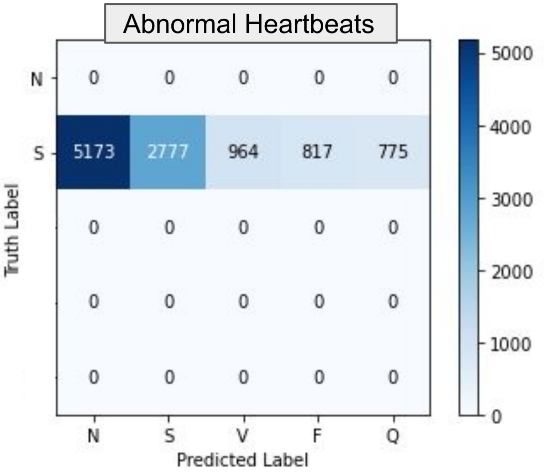


Applying Machine Learning

- Testing against the PTB Datasets, classification for normal heartbeats is worse compared to the first model
- Performance against the abnormal heartbeats shows that this model has not overfit as poorly as the first model, does not classify everything in this dataset as a normal heartbeat







Applied Machine Learning - Summary

- A lot of working with machine learning applications requires an in-depth look at the data that is being applied to the model itself
- Higher accuracy does not mean a better model, performance is always context dependent
    - For health applications, it would be critical to ensure that any model does not classify potential health risks as normal
- Directions for improving the current data and model architecture include:
    - Changing weights for different object classes
    - Augmenting data for classes with fewer samples

Model Analysis

- Explainable AI (XAI) is a rapidly growing field and is critical for measuring trustworthiness, confidence, and fairness of a given AI model
- Research in exaplainability in computer vision and natural language processing is much more prevalent than for time-series data
- Use SHAP library to calculate Shapely values for ML inputs
  - Helps explain prediction of an instance by computing the contribution of each feature to the prediction
  - The “features” for this analysis would be the individual points within a heartbeat sample
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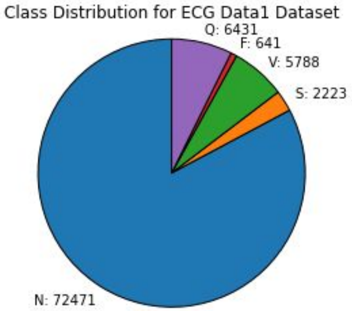
Model Analysis - Normal Heartbeat



- Plots generated by overlaying the SHAP values for each class on top of the original input
  - This information shows what patterns in the input sample contribute to each prediction
  - Certain signal features show a positive correlation for one classification and a negative one for another, which can help identify what local characteristics the model is using for classifications
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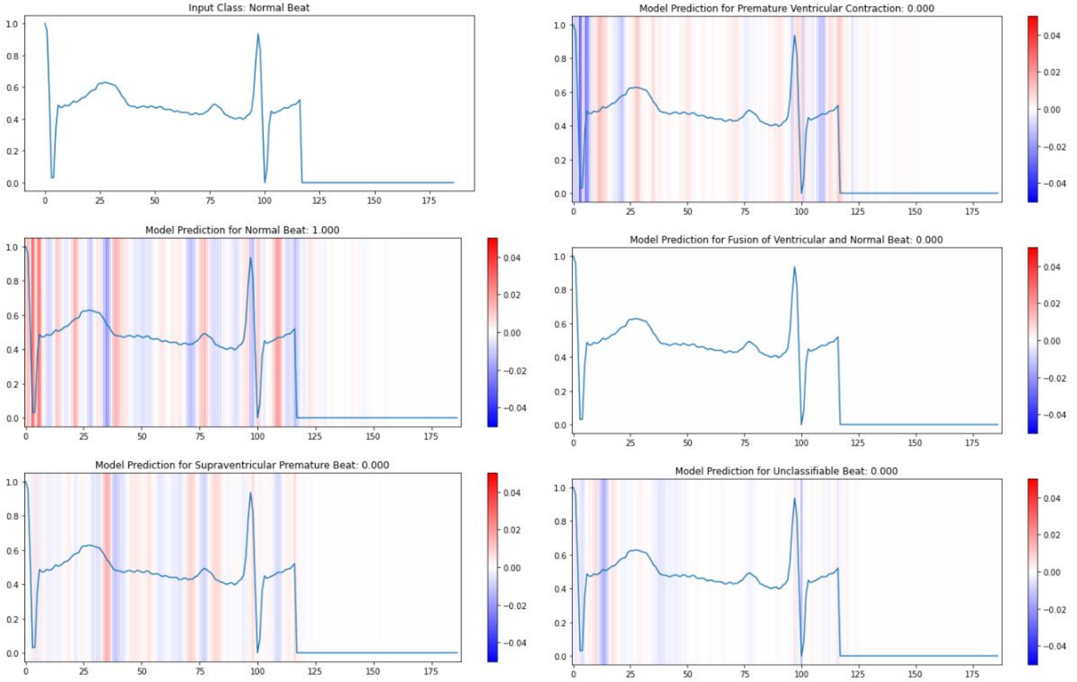
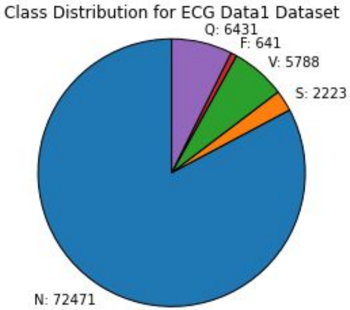
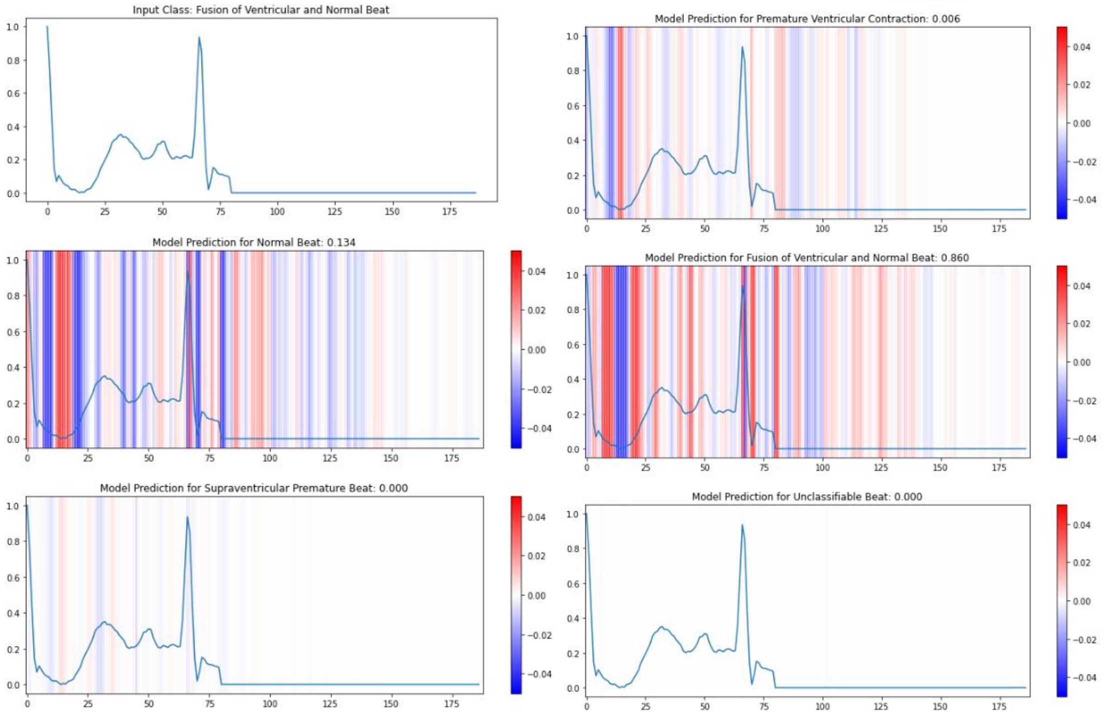


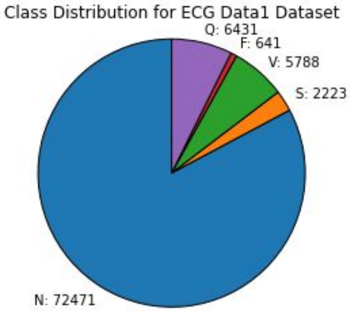
Model Analysis - Fusion Heartbeat



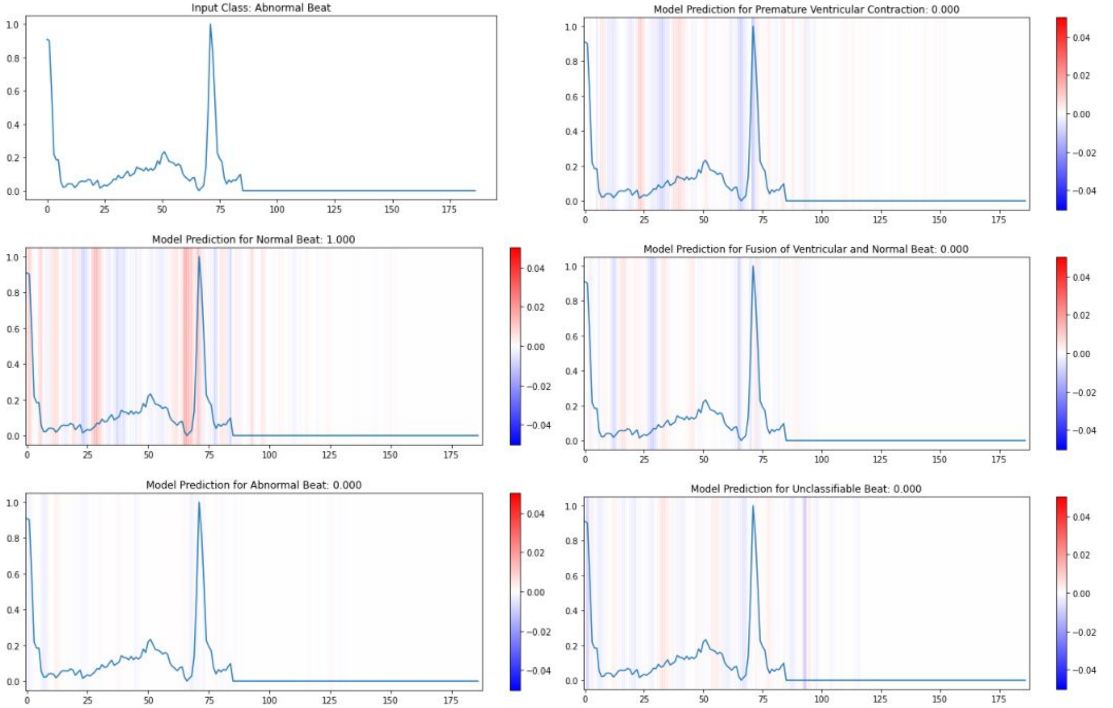
- Previously, it was noted that the trailing zeros may affect the model performance
  - When classifying against a sample from the Fusion heartbeat class, it can be seen that the trailing zeros are contributing a non-negligible amount to the model prediction
  - This is concerning, since this implies the machine learning model is making classifications based on decisions made when creating the dataset, and not purely due to the features of the sample itself

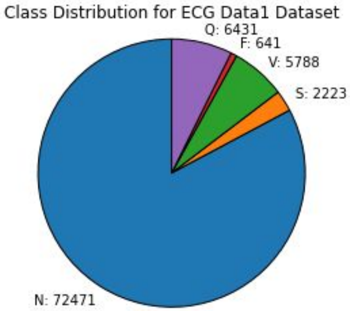


Model Analysis - PTB Abnormal



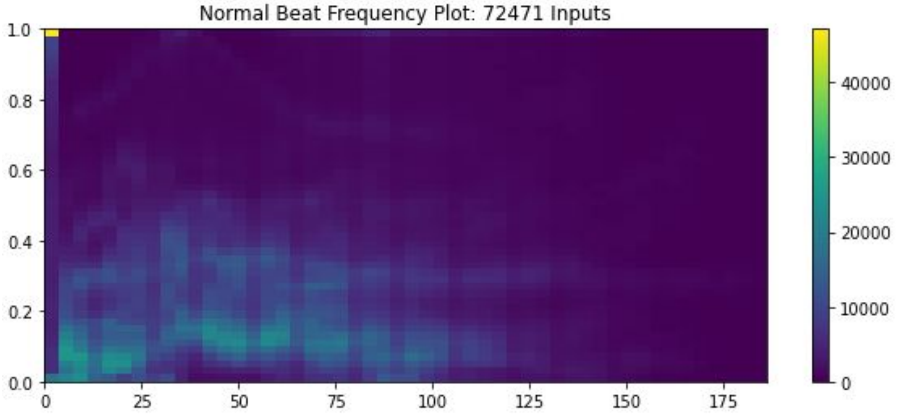
- For the PTG heartbeat data, the model overfit to classifying every sample as a normal beat
  - Only looking at the SHAP values for the abnormal inputs does not give a clear picture of the misclassifications

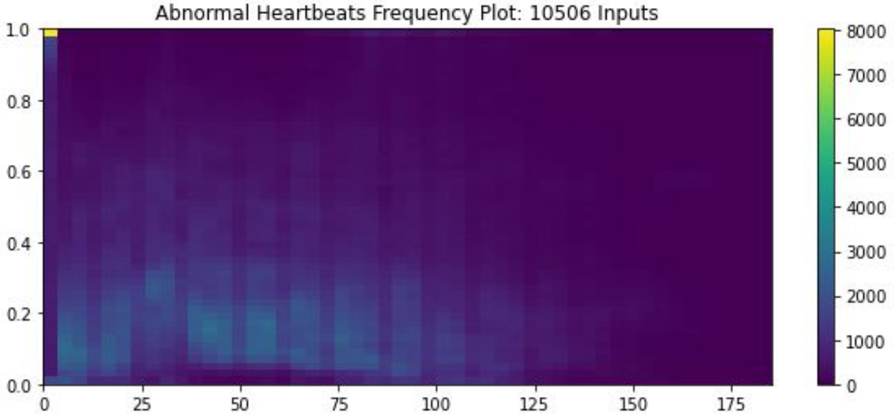




Model Analysis - PTB Abnormal

- Going back to the overall signal frequency plots, the misclassifications look a little more reasonable
    - Data trends for the abnormal heartbeats in the PTB Abnormal dataset occupy a similar range of values to the normal heartbeats in the MIT-BIH dataset





Model Analysis

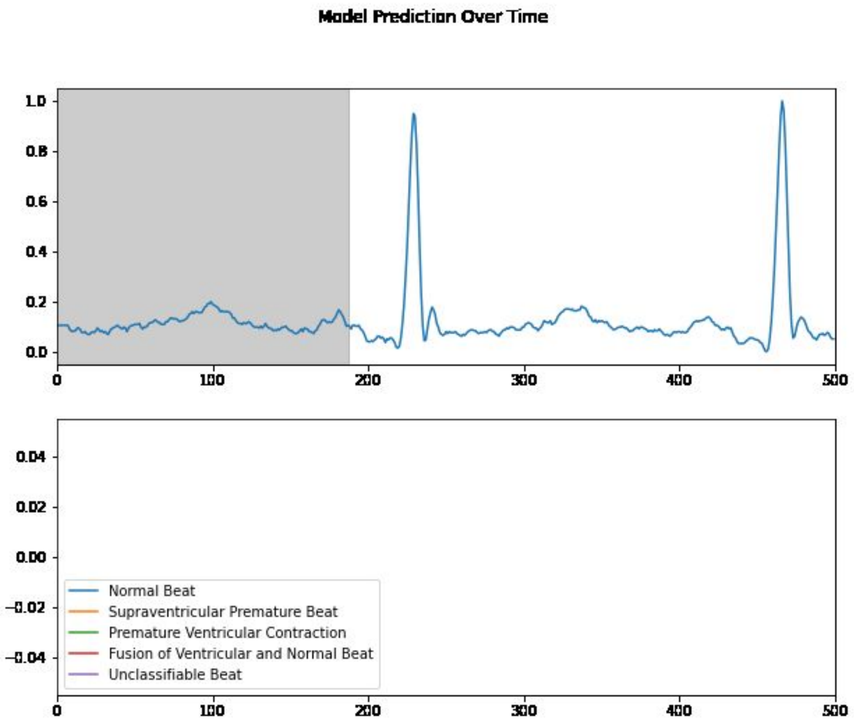
- The tools available to analyze 1D data isn’t as robust or as easy to understand as the tools available for other domains, such as image classification
  - Some of these tools can be adapted to try to get better insight into the performance of a machine learning model trained on time-series data

Further Work

- There are still several areas that can be further explored just within this constrained problem in classifying heartbeats
  - Better model training to have the ability to classify against multiple datasets
  - Further analysis on model performance to identify patterns that match to specific heartbeat classifications
- Even outside of looking at the machine learning model, there is also the question of how this solution could be implemented in a real medical application
  - Currently, the model is only trained on individual heartbeats
    - Leave model inputs as is and have a separate processing step after collecting ECG data?
    - Reformat data/model implementation to handle real-time classifications of heartbeats when getting the ECG readings?

Further Work

- If the model were to be used for real time classification, more significant changes would be necessary, as can be seen in this example
  - Model is not prepared to hand this input stream
- How ML model is being applied is another consideration to keep in mind



Summary

- Overall, this presentation was made with the goal to show my approach to handling a generic problem by utilizing deep learning models

- Questions?

Libraries Used

SHAP

matplotlib

TensorFlow

NumPy

jupyter

scikit learn

pandas

Sources

- https://www.kaggle.com/datasets/shayanfazeli/heartbeat
- Moody GB, Mark RG. The impact of the MIT-BIH Arrhythmia Database. IEEE Eng in Med and Biol 20(3):45-50 (May-June 2001). (PMID: 11446209)
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Extra Information

- Supraventricular Premature Beat
  - Present within subjects with and without heart disease
  - Particularly present in patients with mitral valve disease and those with left ventricular dysfunction
- Premature Ventricular Contraction
  - Extra heartbeats beginning in hearts two lower pumping chambers (sensation of skipping a beat)
- Fusion of Ventricular and Normal Beat
  - Occurs when electrical impulses from different sources act upon the heart at the same time
- Unclassifiable Beat
  - Heartbeats that do not fall under other categorizations

Extra Information

- Precision - Proportion of positive identifications that are correct
- Recall - Proportion of actual positives that were identified correctly
- Fscore - Harmonic Mean of Precision and Recall