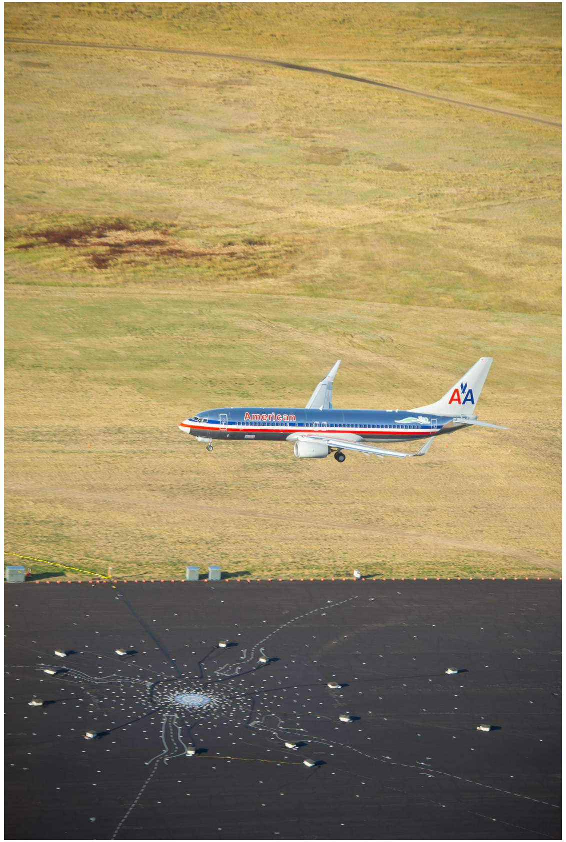
Environmental Noise Contamination Detection

Todd Schultz, Rahul Birmiwal, Sean Miller

20 Feb 2019

Project Motivation

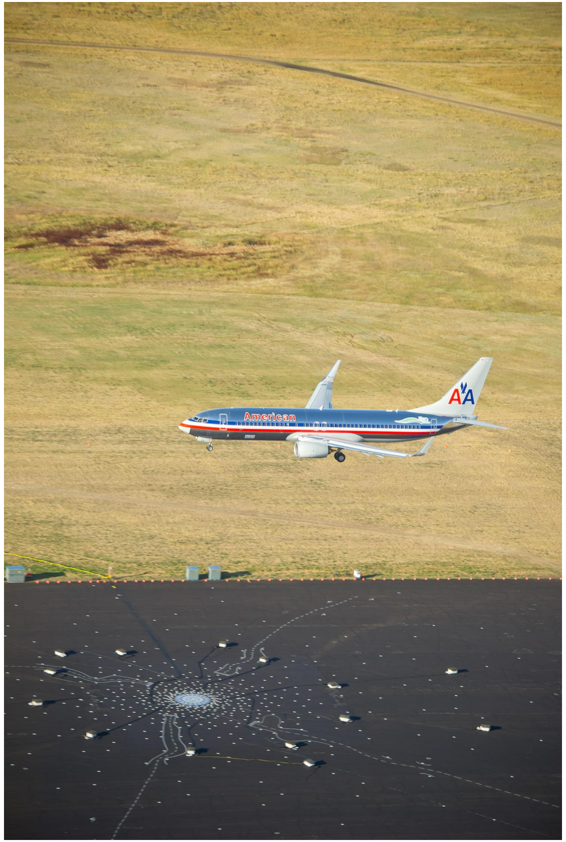
- Noise reduction is being targeted by regulatory agencies around the world
- Community noise testing is expensive
- Noise certification testing done at remote locations
- Noise contamination still possible from birds, insects, livestock, wildlife, and road traffic
- Noise contamination can increase recorded noise levels
- Personnel used to monitor recordings for contamination



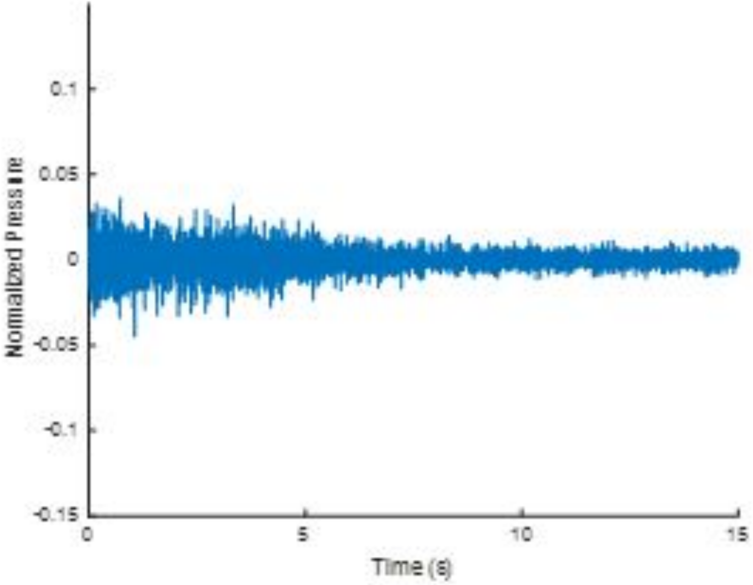
Project Goal

- Research the feasibility of automating the detection of environmental noise contamination contained in acoustic measurements for aircraft community noise testing
    - Investigate wide range of feature and model types
    - Document performance and recommendations to proceed

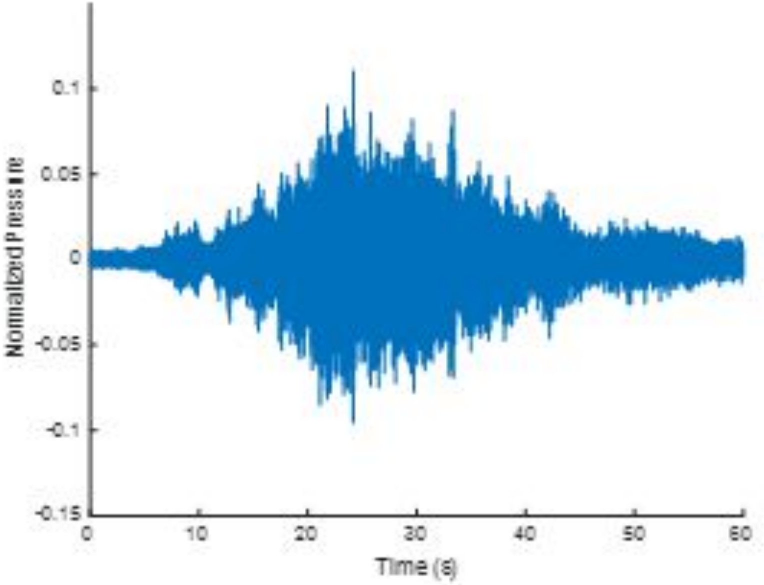
[Bird 01] [Plane 08]



Data Example-Time Series

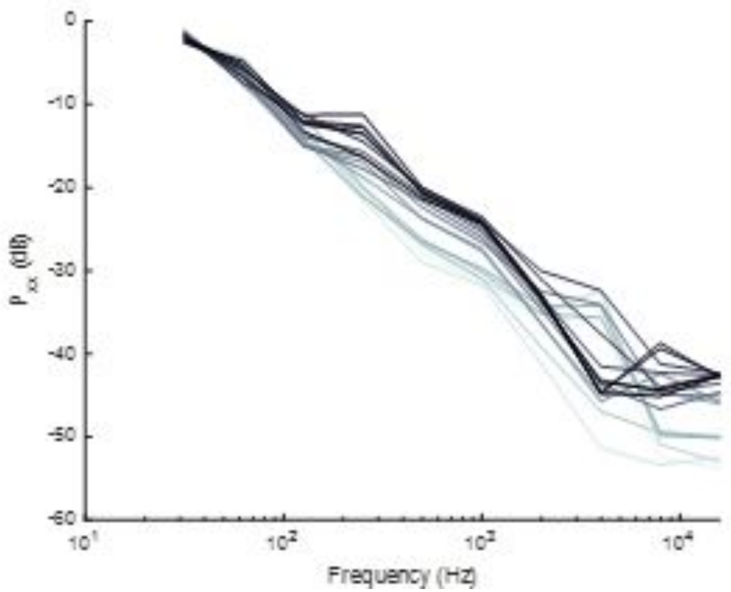


Bird 01

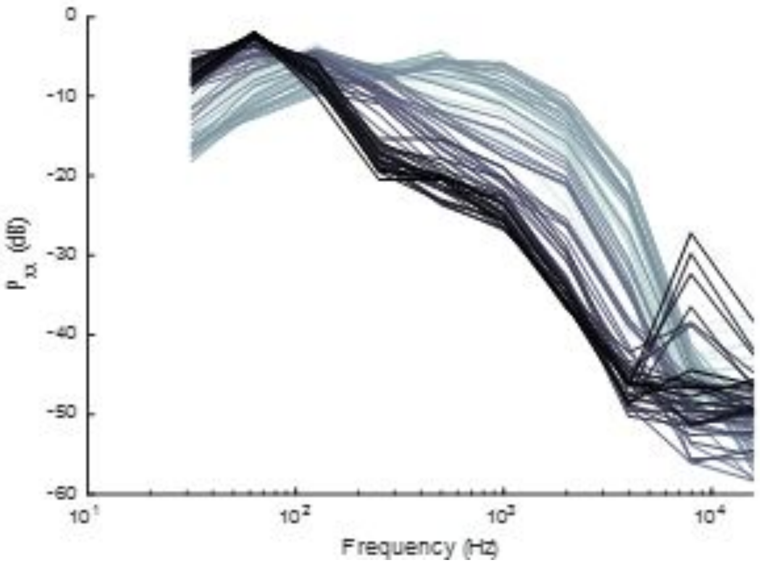


Plane 08

Data Example-Octave Spectrum



Bird 01

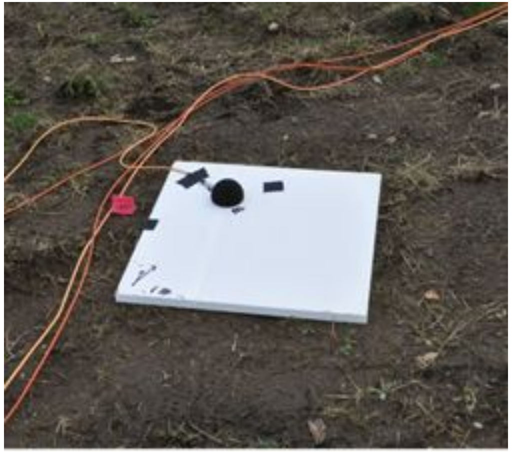


Plane 08

Data

Data

- 66 audio files from Boeing Test & Evaluation
  - Wave file recordings
  - Anonymized by an unknown normalization factor
  - 49 aircraft (737, A350, Q400 turboprop, etc)
  - 10 ambient
  - 7 contamination
- 6 audio file from US National Parks Service
  - Public domain data
  - Non-consistent sampling rate and uncalibrated levels
  - Crickets, bison, common raven, sparrow, Steller’s jay, and yellow-rumped warbler
- Total of 233 MB of audio



Project Challenges

- How to turn audio recordings into features?
  - Separate into blocks
  - Process each block for features
  - Accumulate feature sets as function of time
  - Does this make streaming processing difficult later?
- How to quantify contamination levels?
  - Only use audio recordings that are of only a single noise source
  - Combine aircraft or ambient with contamination examples to create contaminated audio
  - Allows for control of signal-to-noise ratio

Data Preprocessing

Working With Audio Files

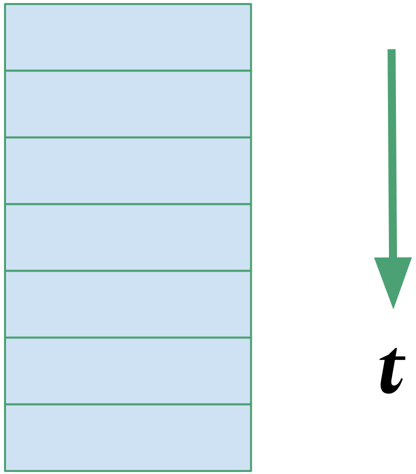
For each audio signal

Working With Audio Files

Separate into (overlapping) blocks

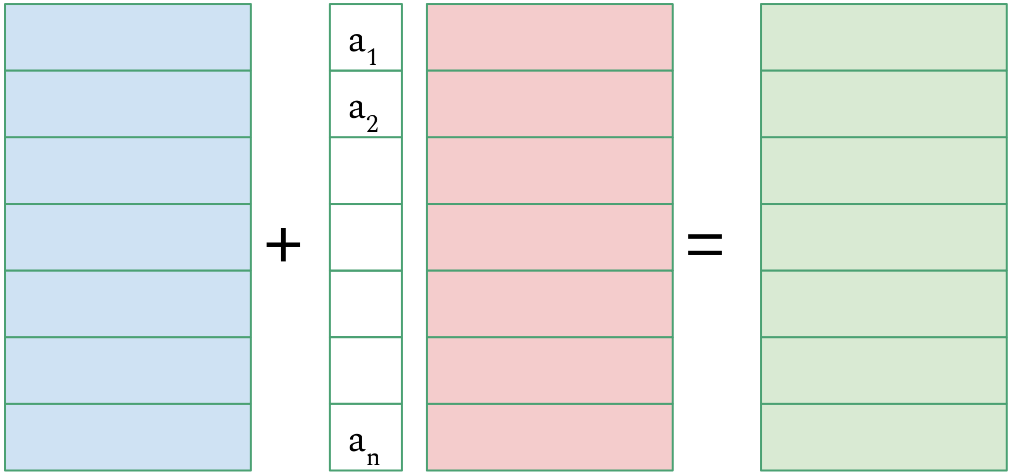
Working With Audio Files

Stack the blocks



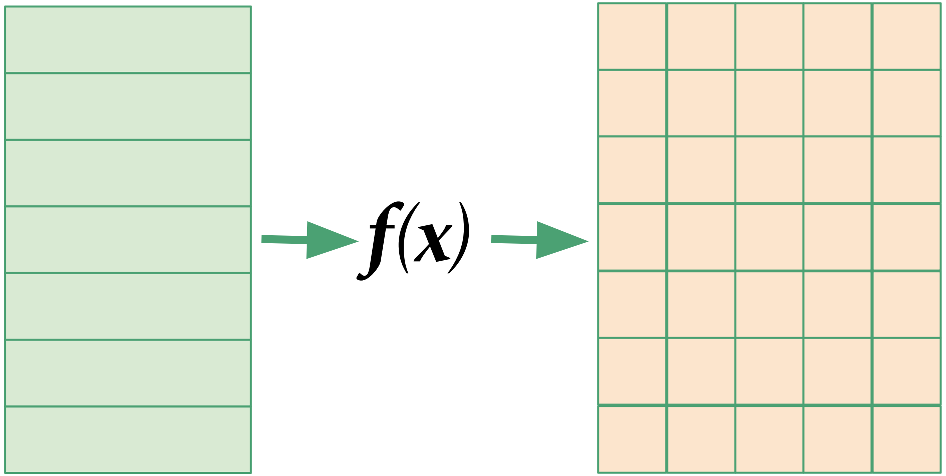
Working With Audio Files

Add contamination (adjust levels of each block to achieve SNR)



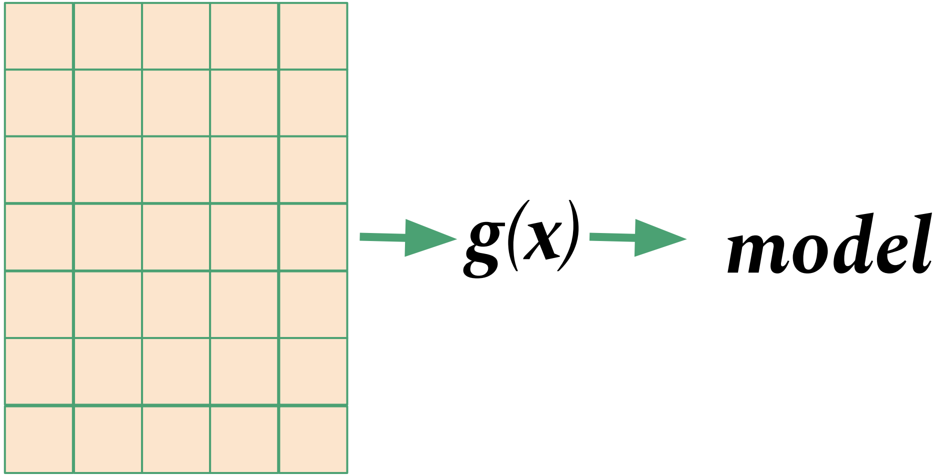
Working With Audio Files

Generate features



Working With Audio Files

Train the model



Feature Set and Model Exploration

Initial Broad Investigation-Features

- Octave Spectrum
  - Full octave with 10 features
  - ⅓ octave with 29 features
- Mel-frequency Cepstral Coefficients
  - 13 features
- Modified Mel-frequency Cepstral Coefficients
  - Extended frequency range up to 20 kHz
  - 13 features
  - 26 features
- FFT
  - Δf = 25 Hz with 799 features
  - Δf = 100 Hz with 200 features
- Continuous Wavelet Transform
  - Scalograms
  - Scalograms bag-of-features with 500 features
- Discrete Wavelet Transform
  - Wavelet Variance (Percival UW)
  - Shannon entropy
  - Mean/SD of subband coefficients
  - Coiflet, Haar, Daubechies
  - 2-5 levels of transform
  - 7, 13, 17, 49 features

Initial Broad Investigation-Models

- Logistic Regression
- Trees
  - Fine
  - Medium
  - Coarse
- SVM
  - Linear
  - Quadratic
  - Cubic
  - Gaussian (Fine, Medium, Coarse)
- Ensembles / Forests
  - Boosted
  - Bagged
- Subspace KNN
- Neural Nets
  - Shallow
  - Convolutional
  - Long Short Term Memory

Broad Investigation Results

Model Performance for SNR 6 dB	# Features	Block length (s)	Logistic regression	Fine tree	Medium tree	Coarse tree	Boosted trees ensemble	Bagged trees ensemble	Linear SVM	Quadratic SVM	Cubic SVM	Fine Gaussian SVM	Medium Gaussian SVM	Coarse Gaussian SVM	Subspace KNN	Neural Net	CNN	LSTM NN
Cepstral	13	1	75.8%	83.1%	81.1%	75.6%	85.0%	86.8%	77.2%	87.3%	89.1%	85.7%	88.0%	80.4%				
Cepstral	13	2	78.3%	85.2%	82.5%	76.3%	86.3%	88.2%	79.0%	89.5%	***91.9%***	88.6%	89.3%	80.5%		86.7%		
Cepstral	26	1	78.0%	81.8%	78.9%	75.6%	85.0%	85.5%	79.0%	88.8%	89.7%	76.3%	88.1%	79.7%				
Cepstral	26	2	80.2%	85.2%	81.4%	74.3%	85.9%	88.3%	80.4%	***90.7%***	***92.8%***	80.9%	90.3%	79.7%		***92.5%***		61.8%
1/3 Octaves	29	1	70.7%	83.7%	80.2%	75.3%	85.1%	89.0%	70.3%	77.5%	81.2%	71.9%	75.4%	70.1%				
1/3 Octaves	29	2	72.8%	87.5%	82.8%	77.3%	87.5%	***91.9%***	71.7%	79.7%	83.8%	76.6%	76.5%	71.5%		71.5%		
Octaves	10	1	67.3%	82.0%	79.4%	72.7%	82.2%	86.3%	66.6%	76.4%	80.0%	78.0%	75.6%	66.8%				
Octaves	10	2	67.8%	84.7%	80.6%	73.7%	84.2%	89.0%	66.5%	77.0%	81.2%	81.1%	76.8%	66.9%		77.4%		
MFCC	13	2	76.3%	82.0%	78.2%	72.1%	83.5%	85.3%	76.8%	85.2%	87.4%	83.8%	87.0%	77.0%				
MFCC	13	1	74.1%	80.4%	78.9%	68.8%	81.6%	82.9%	75.3%	83.0%	84.6%	80.5%	84.8%	76.4%		77.5%		
FFT (25 Hz resolution)	799	0.041	61.3%	78.4%	75.8%	70.0%												
FFT (100 Hz resolution)	200	0.01	68.3%	76.8%	74.0%	69.6%												
CWT Scalogram	150528	1															***92.9%***	
CWT Scalogram	150528	3															85.1%	
CWT Scalogram	150528	5															83.3%	
CWT Scalogram Bag of Features	500	1	81.0%	75.5%	74.2%	73.3%	82.1%	82.0%	83.1%	86.4%	87.1%	60.5%	86.1%	79.9%				
CWT Scalogram Bag of Features	500	3	80.7%	73.2%	73.7%	75.3%	84.8%	82.7%	86.7%	87.7%	88.6%	59.1%	87.9%	81.6%				
CWT Scalogram Bag of Features	500	5	55.0%	73.0%	74.1%	70.6%	82.3%	81.7%	88.0%	89.4%	***90.9%***	60.2%	87.7%	81.6%				
DWT (Coiflet2, 4 levels)	29	1	70.0%	90.4%	88.3%	78.1%	***91.2%***	***93.1%***	80.1%	86.2%	88.6%	84.8%	82.3%	76.0%		81.5%		76.4%
DWT (Coiflet2, 4 levels)	29	2	75.4%	***91.6%***	88.1%	80.1%	***91.0%***	***93.3%***	80.5%	87.3%	***90.5%***	85.8%	82.4%	77.6%		81.5%		78.2%
DWT (Coiflet2, 5 levels)	49	2	81.5%	***91.7%***	89.1%	79.3%	***92.3%***	***94.2%***	82.1%	88.0%	***90.6%***	87.2%	83.5%	78.8%		82.3%		
DWT (Coiflet2, 5 levels, Hampel Filter)	49	2	81.0%	***91.7%***	88.7%	79.3%	***92.1%***	***94.0%***	82.0%	88.9%	***91.5%***	87.6%	83.8%	76.8%	76.5%	84.9%		
DWT (Coiflet2, 4 levels, Hampel Filter)	29	2	70.1%	***92.1%***	88.6%	80.0%	***91.1%***	***93.5%***	80.7%	87.9%	***90.8%***	86.3%	82.7%	77.8%		83.1%		
DWT (Coiflet2, 3 levels, Hampel Filter)	17	2	67.1%	89.7%	87.5%	78.1%	89.6%	***92.9%***	79.0%	84.4%	52.0%	85.9%	81.1%	76.5%	81.3%	81.4%		
DWT (Debauchies4, 4 levels)	29	1	64.4%	90.1%	86.0%	81.1%	88.9%	***91.6%***	77.2%	80.6%	51.4%	81.5%	77.6%	66.1%	71.1%			
DWT (Haar, 4 levels)	29	1	53.8%	77.0%	73.1%	68.7%	76.4%	80.5%	71.5%	76.4%	58.7%	76.1%	73.9%	70.4%	67.1%			
DWT (Coiflet2, 4 levels, no entropy)	25	2	71.6%	***90.6%***	85.7%	81.6%	88.3%	***92.1%***	79.2%	57.1%	49.9%	76.3%	67.9%	61.0%	54.1%			
DWT (Coiflet2, 2 levels)	7	2	70.1%	89.0%	84.6%	78.9%	88.2%	***92.3%***	68.8%	71.8%	53.9%	77.7%	74.0%	61.5%	73.7%			

Observations/Comments

- If accuracy is low, confusion matrix tends to be skewed with high false negative rate
- Conventional models and shallow neural networks achieve >90% accuracy
- Long short term memory network not performing as expected
  - Likely requires creating unique, varying input sequences for training
- GPUs only necessary for training convolutional neural network

Remaining Project Work

Remaining Work

- Down select to only 3 feature/model combinations
- Optimization of model hyperparameters
- Increase performance metric to include
  - Accuracy
  - F1 score
  - False positive rate
  - False negative rate
- Detailed study of performance for:
  - Varying SNR
  - Percent of signal block contaminated
  - Randomization of blocks contaminated
- Monte Carlo simulation of randomized parameters
  - To simulate real-world scenario

Select Feature/Models

- Wavelets (Coiflet2, 5 level, T=2s)/bagged trees
    - Best overall with accuracy of 94.2% (best overall)
- Wavelets (Coiflet2, 4 level, T=2s)/bagged trees
    - Accuracy of 93.3% (4rd best overall)
- Cepstral (26 feature T=2 s)/cubic SVM
    - Best non-NN, non-wavelet performer with accuracy of 92.8% (7th best overall)

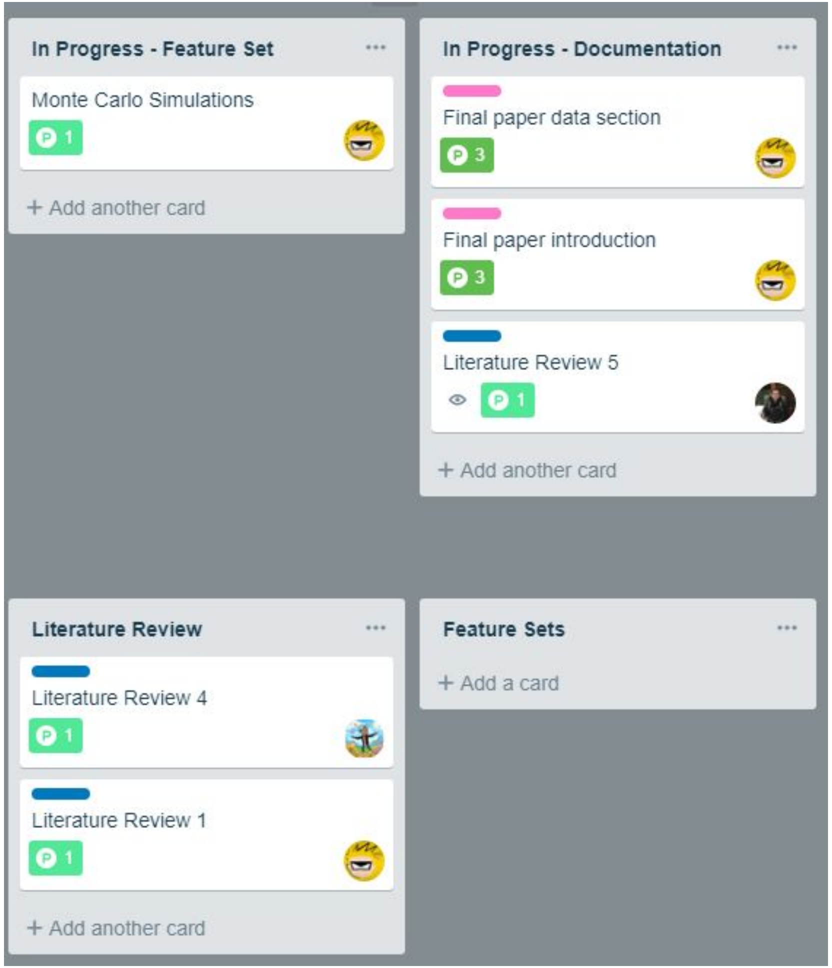
- *Coiflet2*: Coiflet wavelet with 2 vanishing moments
- *T = 2s*: block length

Work Tracking

- Using Trello to track our work
  - Agile Tools
- 5 Story Points = ~ 1 Week of Work
- ~60 points of work remaining after 2/6

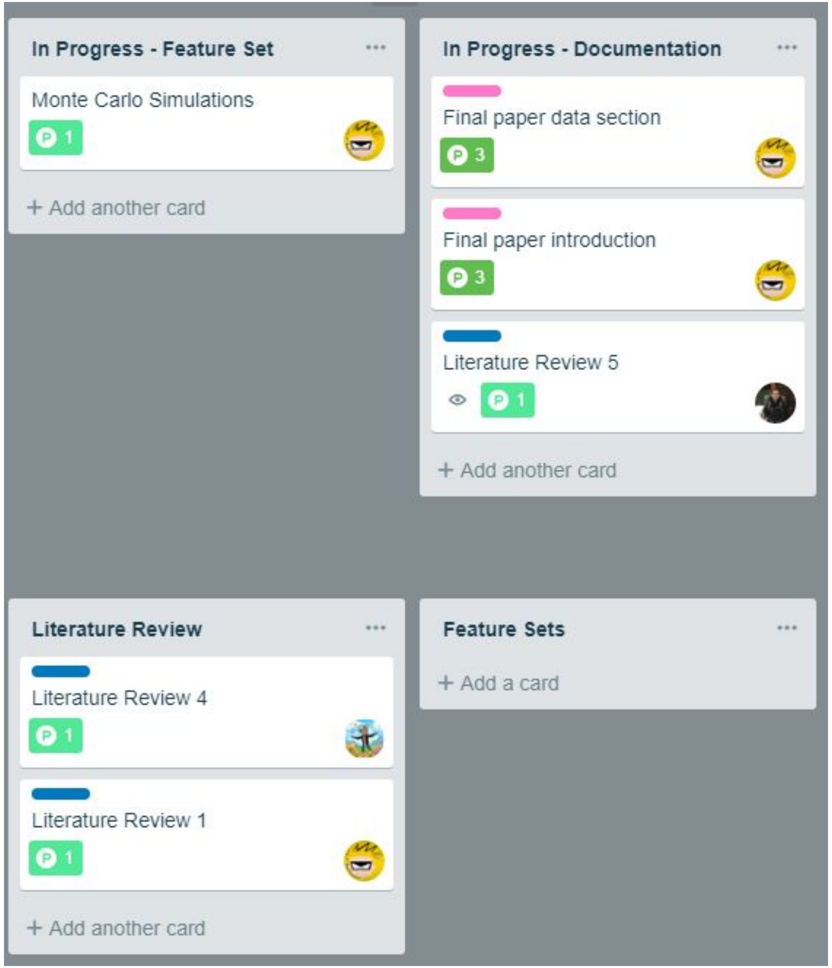
Workflow

1. Stories are added to separate backlog lists
2. Stories are moved to In Progress
3. Stories are closed or removed



Remaining Work

Epic	Story Points
In Progress - Feature Set	1 points
In Progress - Documentation	7 points
In Progress - Course Assignments	3 points
In Progress - Machine Learning	5 points
Poster Session	6 points
Machine Learning	25 points
Literature Review	2 points
Documentation	6 points
Course Assignments	3 points



Q&A