# FOA 1861 FINAL PROJECT BRIEFING
# BIG DATA ANALYSIS OF SYNCHROPHASOR DATA

## Machine Learning Guided Operational Intelligence From Synchrophasors

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# Project Overview/Background

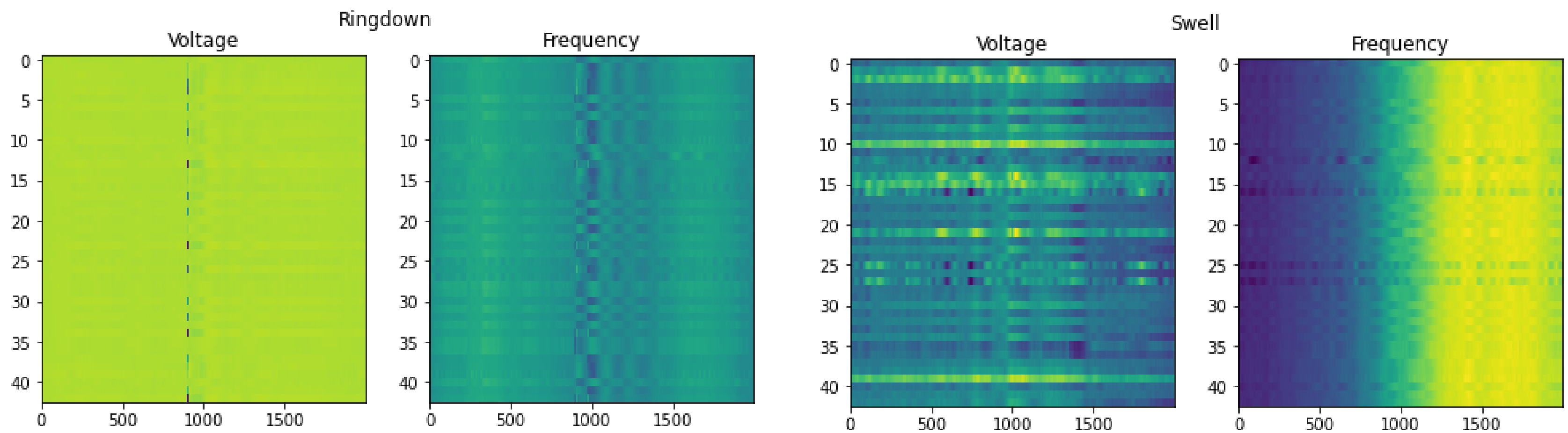
- Research Objectives
  - Pre-process PMU data and mitigate data anomalies
  - Identify explainable power system event features
  - Identify precursor conditions
  - Develop resilient machine learning tools and event detection methods
- Use power engineering tools such as SynchroWave Event Detector to aid in analysis and characterization
- Contrast deep learning with feature engineering

# Experimental Results

- Data handling formed a large portion of our efforts
- Interconnect B had the highest quality data, followed by Interconnect C, then Interconnect A
- Our PCA-based anomaly mitigation technique was successful in correcting GPS-spoofed PMU data
- We developed multiple approaches for event detection using techniques such as Critical Slowing Down (CSD), spectral signatures and many others
- The adaptation and application of a causal inference algorithm is effective for event time localization

# Experimental Results

- Simple imputation methods (linear regression) can be effective
- Deep-learning and feature-engineering based detectors performed similarly, however:
  - Feature-engineering based detectors performed more predictably
  - Deep-learning based detectors were more flexible




2-dimensional visualizations of event tensors

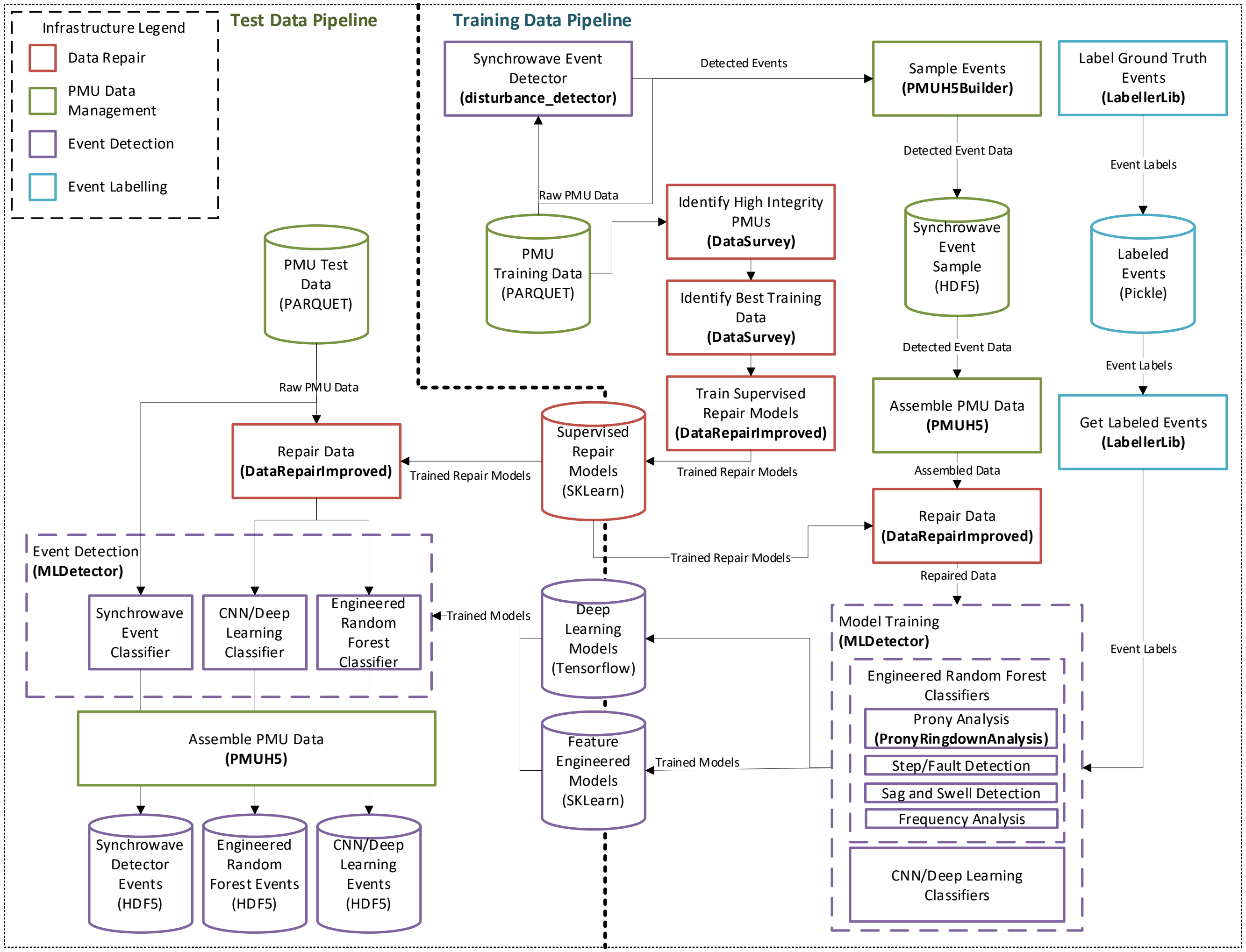
# Technical Accomplishments

- Developed and validated an effective data anomaly mitigation technique that can be used for real-time data correction of spoofed data streams
- Unsupervised event detector based on extraction of spectral signatures from the PMU data
- Feature extraction methods that can be used to improve the performance of various neural network classifier architectures

# Technical Accomplishments

- **Modular software pipeline for analyzing and performing event detection on any PMU dataset**
- High performance storage and retrieval system for PMU data
- System for detecting and removing bad data
- System for statistically analyzing an interconnect and flagging problematic PMUs
- System for repairing bad PMU data
- System for calculating informed event features
- Labeling system
- Event detector implementing three classifier systems side-by-side
  - SynchroWave Event Detector
  - Feature Engineered Random Forests
  - Convolutional Neural Networks

# Event Detector Pipeline



# Value of Work

- A software platform to accelerate future research
  - Working with large datasets
  - Identify, filter, and repair bad data
  - Generalizable event detection algorithms
  - Rapid research iterations and improvements to modules
- Tools to protect against spoofed measurements
- An analytics platform to help operators identify anomalies
- Though anonymized data can be limiting when applying power engineering techniques, there is still plenty of research opportunity with the datasets we have

# Readiness for Commercialization

- Our research was performed with SEL SynchroWave Operations in mind—modular software
- Our current pipeline is at an 8/10 readiness level to be implemented as an operational system for event detection
  - Detect anomalies
  - Suggest the type of event
- SynchroWave Operations is a perfect channel to transition this research to the field, even on a beta-test basis

SEL-5702 Synchrowave Operations

# Being Ready for ML & BD Analytics

- Feature engineered techniques were more reliable, but deep learning techniques were more flexible
- Power engineering knowledge helped make up for lack of good quality labeled data
- Key challenges
  - Handling of bad data was the biggest stumbling block when applying ML methods to PMU data
  - Lack of topological data prevented use of classical techniques to flag bad data and repair it
- Key improvements to data
  - Utilities should be proactive about identifying and remedying PMU data issues
  - We recommend attempting to improve the accuracy of event log timestamps and physical location information

# Lessons Learned

- A substantial amount of time was needed to manage data.
- While initially time consuming, approaching data science from a software engineering perspective can accelerate later research.
- The FOA 1861 dataset is still a useful research tool as is.
- Differentiating between statistically anomalous events, bad data, and physically meaningful events can be challenging

# Next Steps

- A wealth of research is needed to still address:
  - Event localization
  - Improved classification methods and imputation models
- Our efforts focused on physics-*informed* modeling. Future efforts could focus on physics-*enabled* modeling.
  - Challenging to contrast machine learning methods against power engineering without a physical model
- Combining modeling and/or topological details would help us interpret ML/AI results better
- Our toolchain could be used as an online or offline analytics tool for operators, and there is still plenty of opportunity to implement additional functionality

# Publications

- A. Lassetter, E. Cotilla-Sanchez, and J. Kim, “Using Critical Slowing Down Features to Enhance Performance of Artificial Neural Networks for Time-Domain Power System Data”, accepted for presentation at *International Conference on Smart Energy Grid Engineering, 2021.*

- S. De Silva, J. Kim, and E. Cotilla-Sanchez, “Data Driven Sparse Error Correction for PMU Measurements under GPS Spoofing Attacks”, *IEEE PES Conference on Innovative Smart Grid Technologies (ISGT)*, pp. 1–5, February 2021.

- D. Senaratne, J. Kim, and E. Cotilla-Sanchez, “Spatio-Temporal Frequency Domain Analysis of PMU Data for Unsupervised Event Detection”, *IEEE PES Conference on Innovative Smart Grid Technologies (ISGT)*, pp. 1–5, February 2021.

# Thank You!