Deep Learning Application for Power Grid Event Detection and Classification

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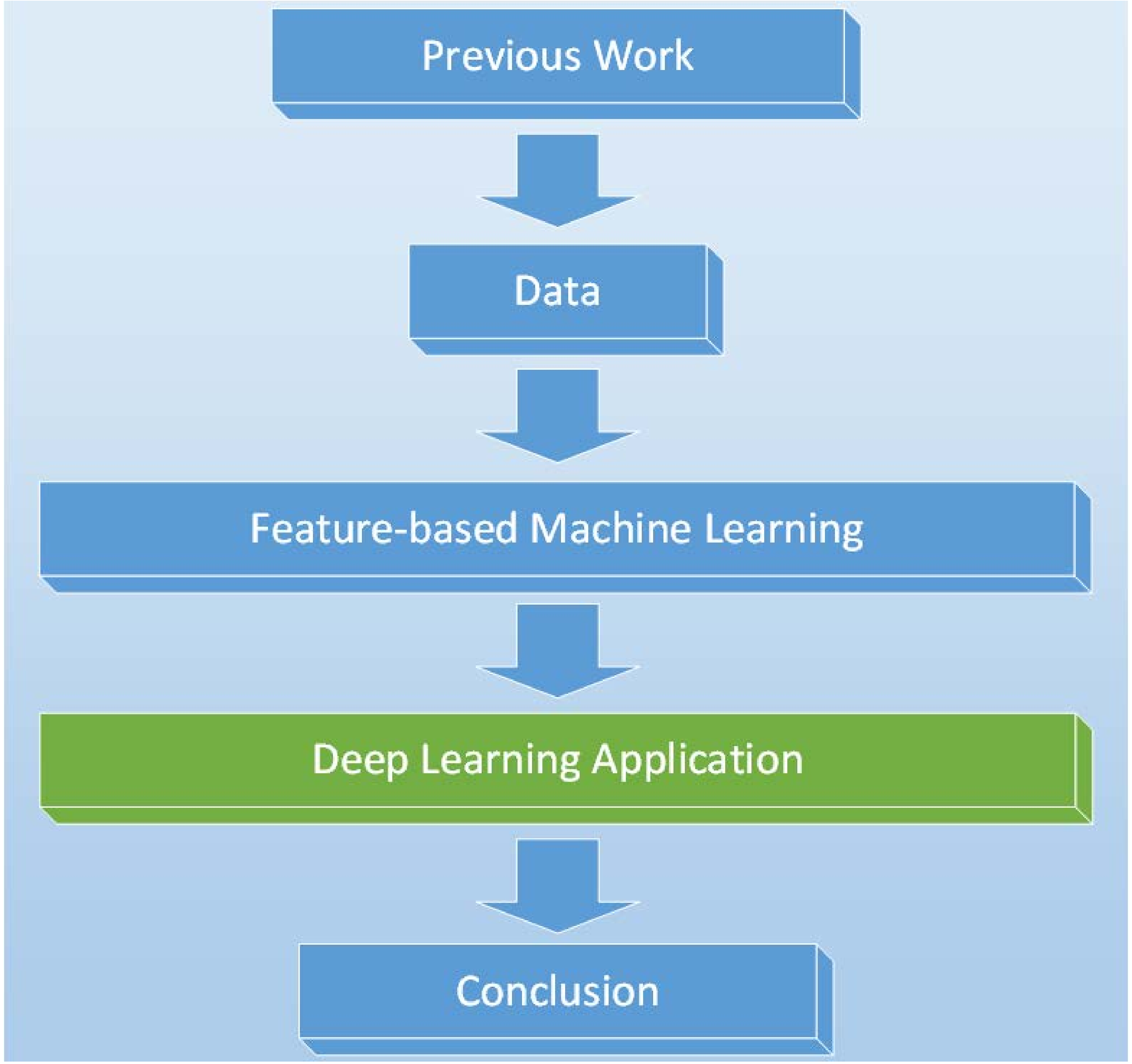
Outline


Previous Work
Data
Feature-based Machine Learning
Deep Learning Application
Conclusion

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PNNL Big Data Pathway

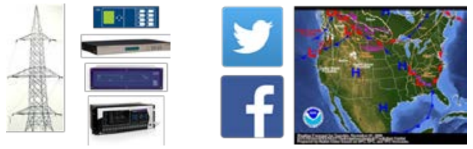
Aircraft safety
Morning Report
w/ NASA

Analytics Using
State Estimator
Data
w/ EI

Data
Investigations
Using PMU Data
(uncovering data
quality issues,
etc.)

DISAT

Data **I**ntegrity
Situational
Awareness **T**ool
(PMU Data
Analytics w/ BPA)



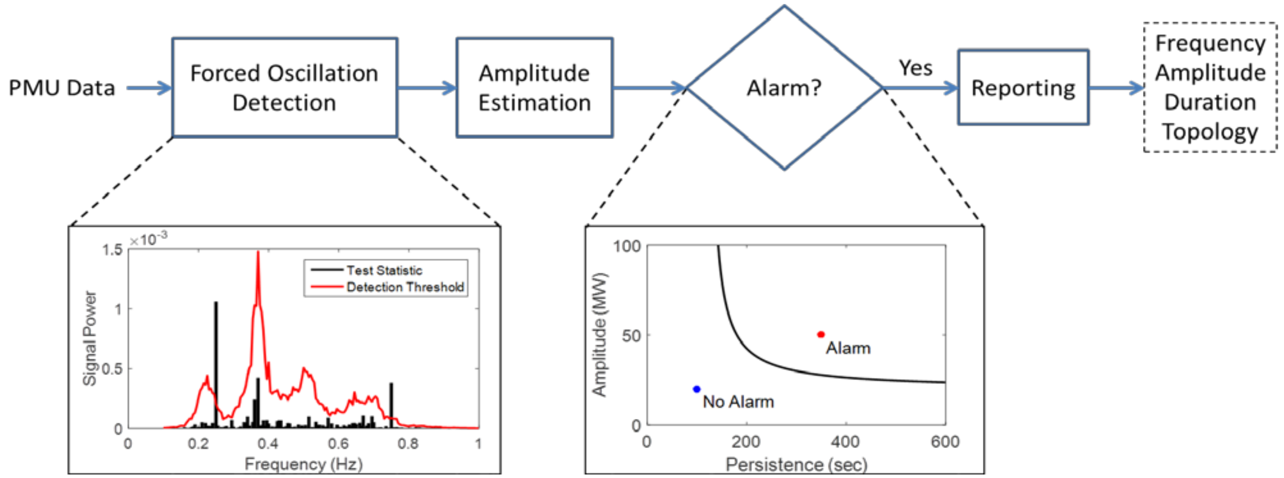
GMLC, ESAMS, and Beyond
Machine learning basis
Many additional data streams
Predictive analytics

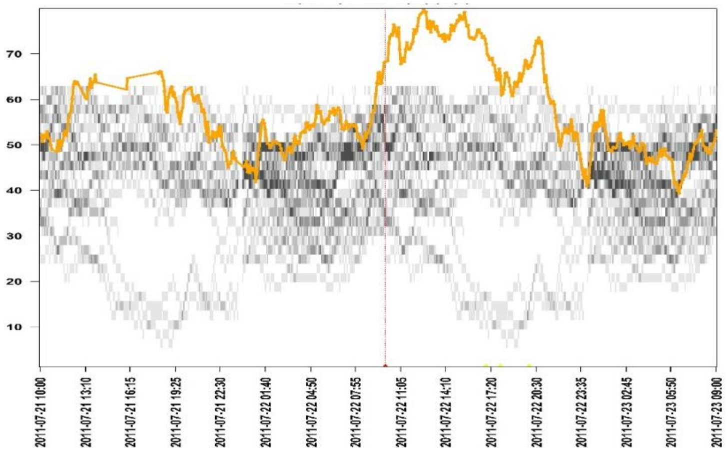
ESAMS – Eastern Interconnect Situational Awareness Monitoring System

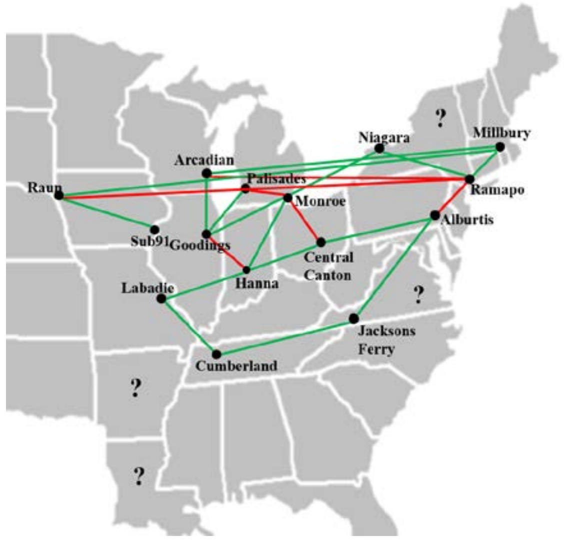
Project Objective:

To introduce a common, high-level interconnection-wide view based on synchrophasor information

- Detect and identify forced and natural oscillations
- Monitor wide area phase angle pairs and identify when values are outside of normal ranges
- Detect current atypical behavior based upon baselining previous behavior
- Recently installed at PJM







Research Questions

- Will deep learning be useful for PMU data analytics?
  - Since it has been successful in so many areas…
- Which deep learning technique and how to implement?
  - Convolutional neural network (CNN) vs. Recurrent neural network (RNN) (Long short-term memory (LSTM))
  - What kind of data preprocessing do we need for PMU data to be used by deep learning?
- What are the advantages and disadvantages of deep learning compared to traditional feature-based time series machine learning for PMU data?

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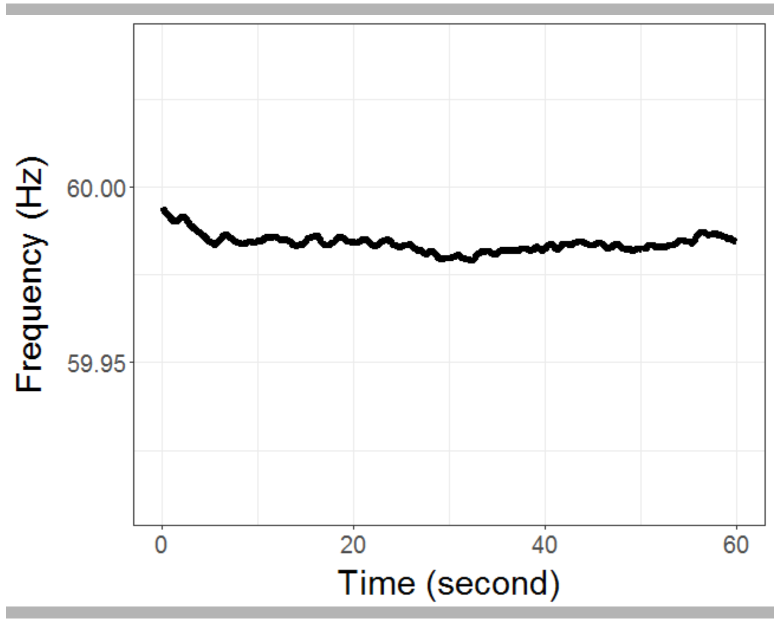
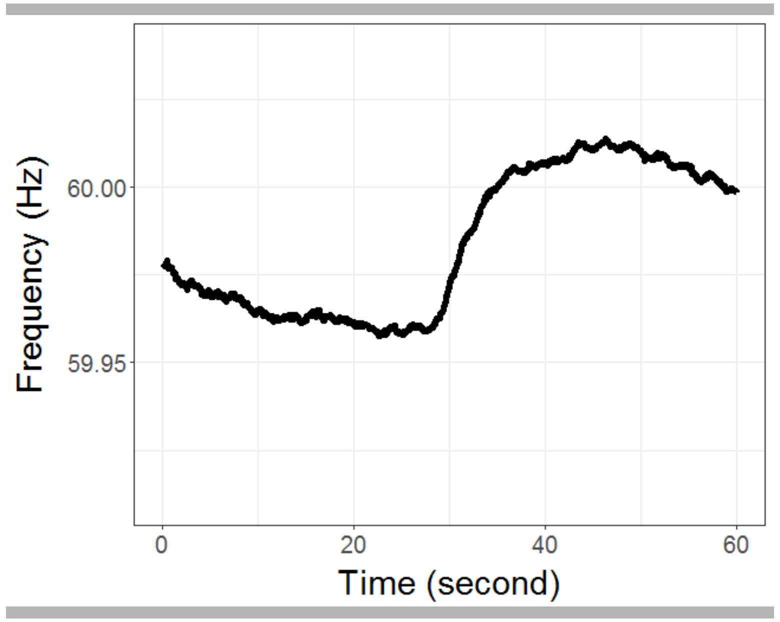
PMU Data

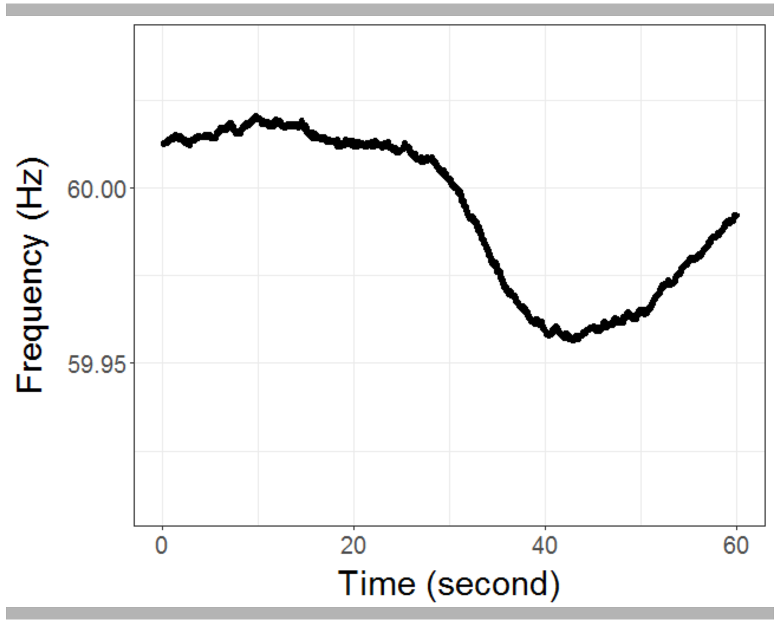
- Obtained from Western Interconnect;
- 2016 to present;
- 12 PMUs;
- Hundreds of events.



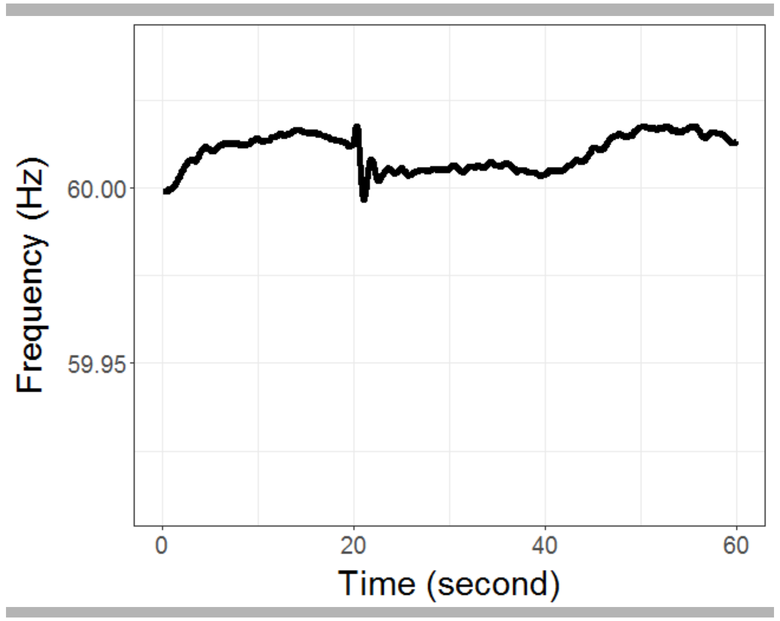
Normal Minute



Event Type A

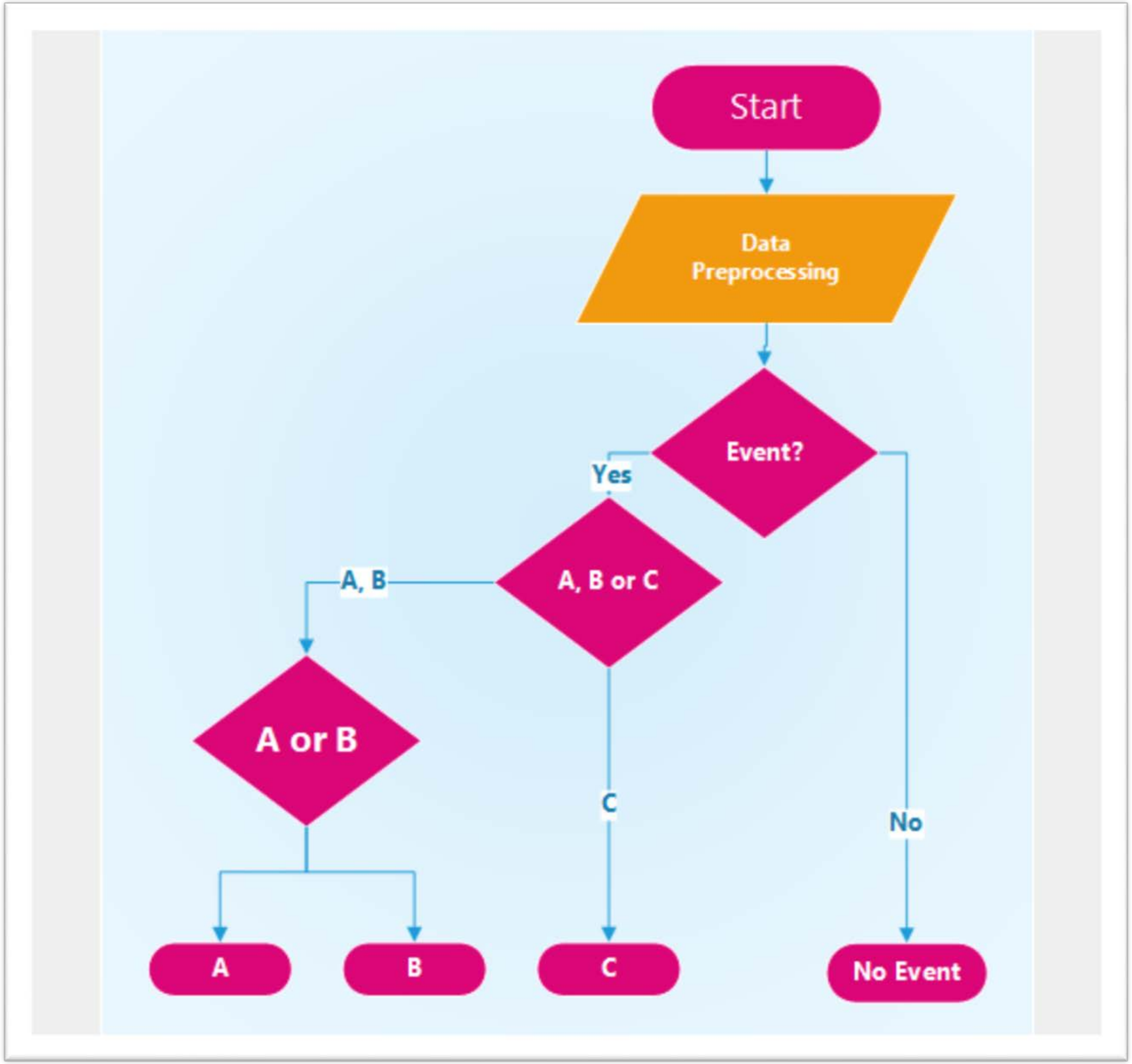


Event Type B



Event Type C

Event Detection and Classification Steps



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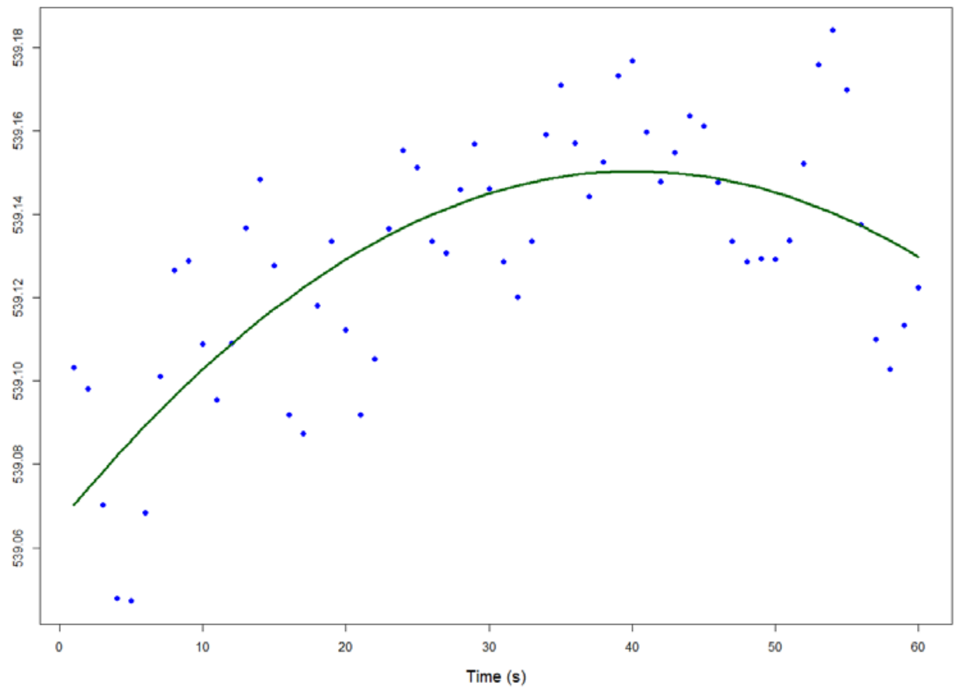
Feature-based Machine Learning

- Feature extraction: “16 signature elements” (Amidan and Ferryman 2005).
- The goal is to capture the essential information of a time series while reducing dimensionality.
- Quadratic Regression: $y = a + b\,x + c\,x^2 + \varepsilon$
  - Maximum,
  - mean,
  - minimum,
  - and standard deviation of a, b, c, ε.



Feature-based Machine Learning

- Gradient boosting machine (GBM).
- Relies on the extracted features as inputs.
- An ensemble of weak learners to form a stronger learner.
- Weak learners are typically decision trees.
- Fitting on residuals of previous learners.

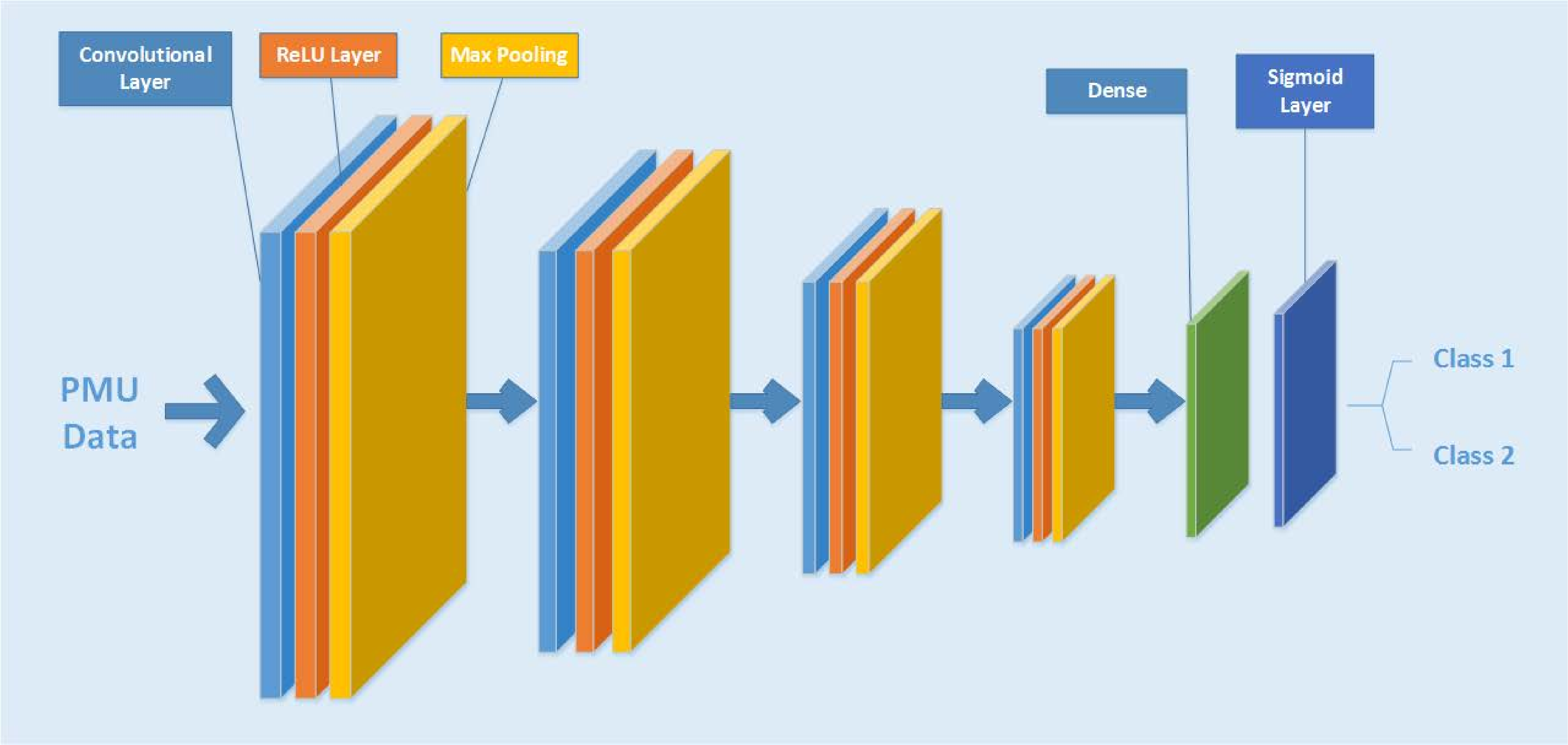
Deep Learning: CNN vs LSTM

- Convolutional neural network (CNN) vs. Long short-term memory (LSTM)

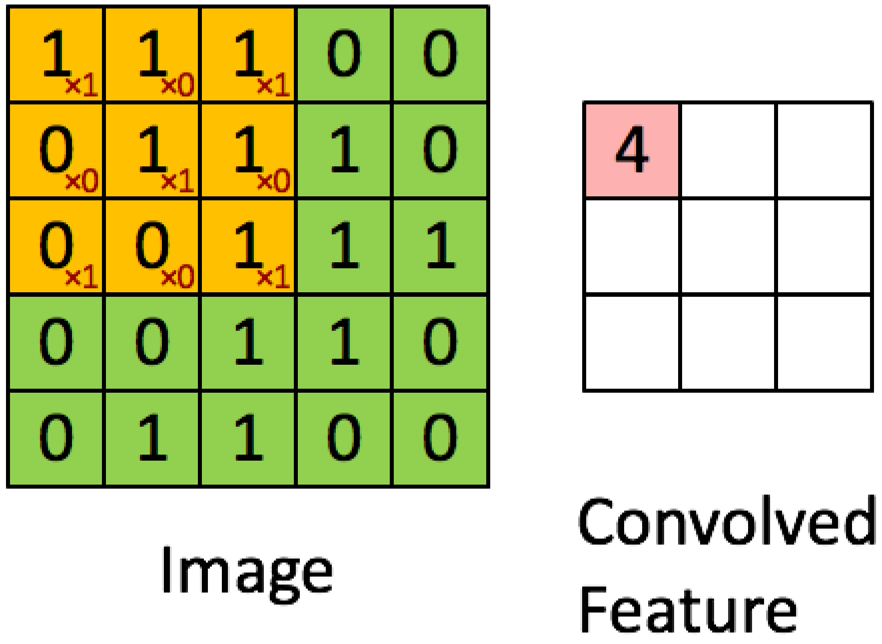
- Theoretically, LSTM fits time series data better since it focuses on temporal correlation;
- However, practically, CNN works better for PMU data!

- PMU data has high sampling rate;
- 1-dimensional CNN is very good at capturing patterns (shapes) of PMU data.

Convolutional Neural Network Model in this Study



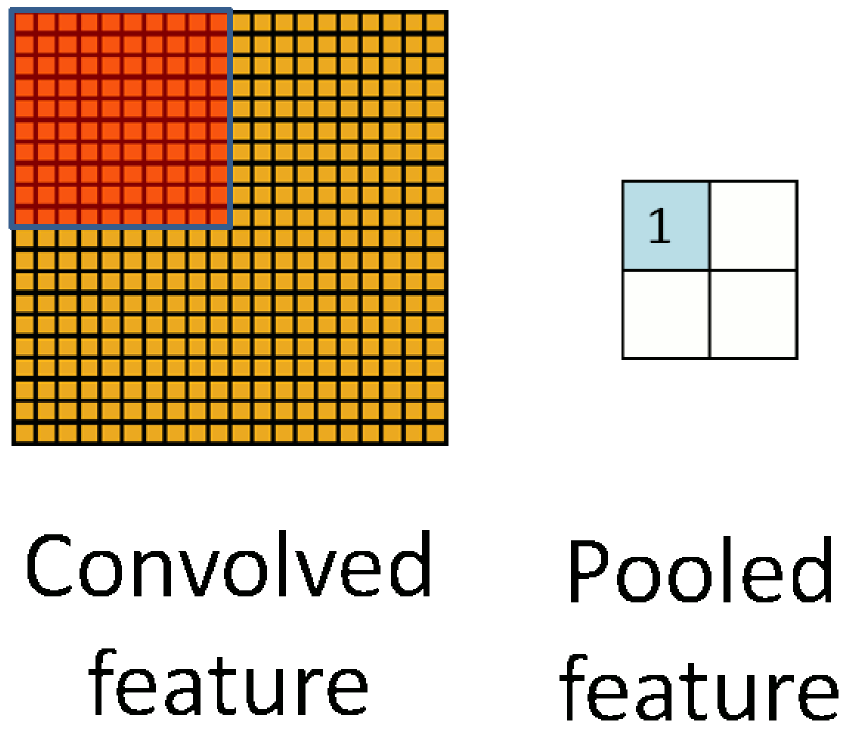
Convolutional Layer



- Filters (or kernels) stride through the data to create feature mapping;
- Detects specific features at some spatial (or temporal) position in the data;
- Automatic feature generation.

Source: hackernoon.com

Max Pooling



- A form of down-sampling;
- The exact location of a feature is not very important;
- Reduce overfitting;
- Deeper layers learn bigger picture.

Source: hackernoon.com

Results (10-fold cross validation)

	CNN (Deep Learning)	GBM (Machine Learning)
Step 1 (Normal vs. Events)	95.5% ± 2.8%	95.0% ± 2.5%
Step 2 (A, B vs. C)	96.2% ± 2.0%	96.5% ± 2.0%
Step 3 (A vs. B)	97.4% ± 2.3%	96.6% ± 1.7%

1. Results are overall accuracy. Sensitivity and specificity are quite similar.
2. Results are based on 487 events from over 1 year of PMU data.

Deep Learning Conclusions

- **Deep learning provides automatic feature extraction, while machine learning needs features to be already engineered and extracted;**
- Deep learning is more complicated to implement with various structure options and more hyper-parameter tuning;
- Deep learning is more difficult to converge, have to try different optimizers and learning rates;
- However, deep learning has a greater potential to fit more power grid applications because of its ability to adapt to unseen problems;

- Future work: focus on applying DL for multiple-channel PMU data.

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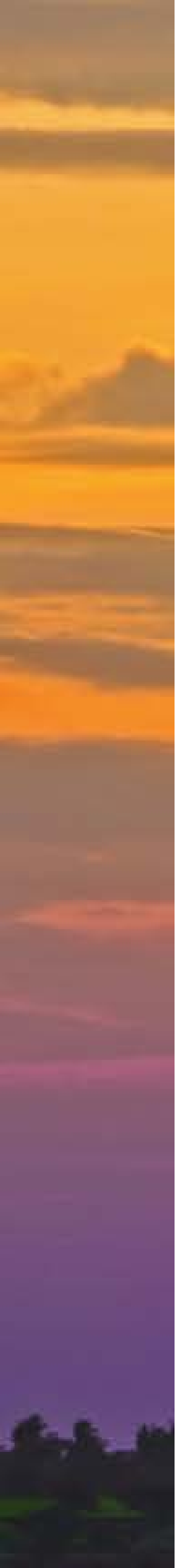

Thank you

Questions?