# Incipient Failure Identification for Common Grid Asset Classes

## Advanced Sensing and Data Analytics

Electric Advisory Committee Meeting
February 26 + 27, 2020

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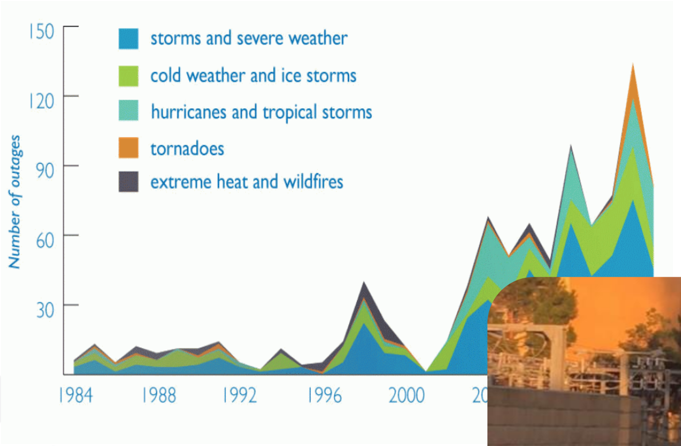
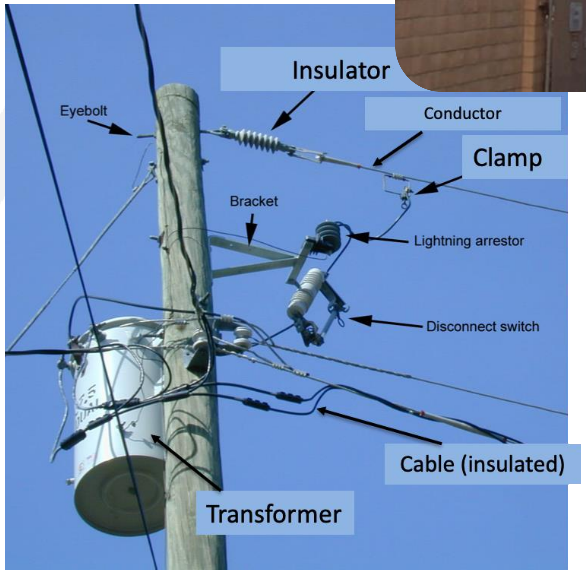
Oak Ridge National Laboratory
National Energy Technology Laboratory
Sandia National Laboratories

# Overview and Problem Statement

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

- ✓ Individual sensing of all components on the grid is a challenge, the grid is aging, and the approaches to identifying critical failures on so many components are limited by data silos and specific analytics for each component
- ✓ Incipient Failure of devices can impact resiliency, reliability and safety - in particular in regions with high fire and weather issues
- ✓ **Project will, in 3 years, operationalize a multi variate, multi modal approach to diagnose and prescribe remediation pathways for both short term but critical failures locally and incipient growing problems centrally in commonly utilized equipment throughout the country**



# Approach

Detect and Classify the Problem Locally

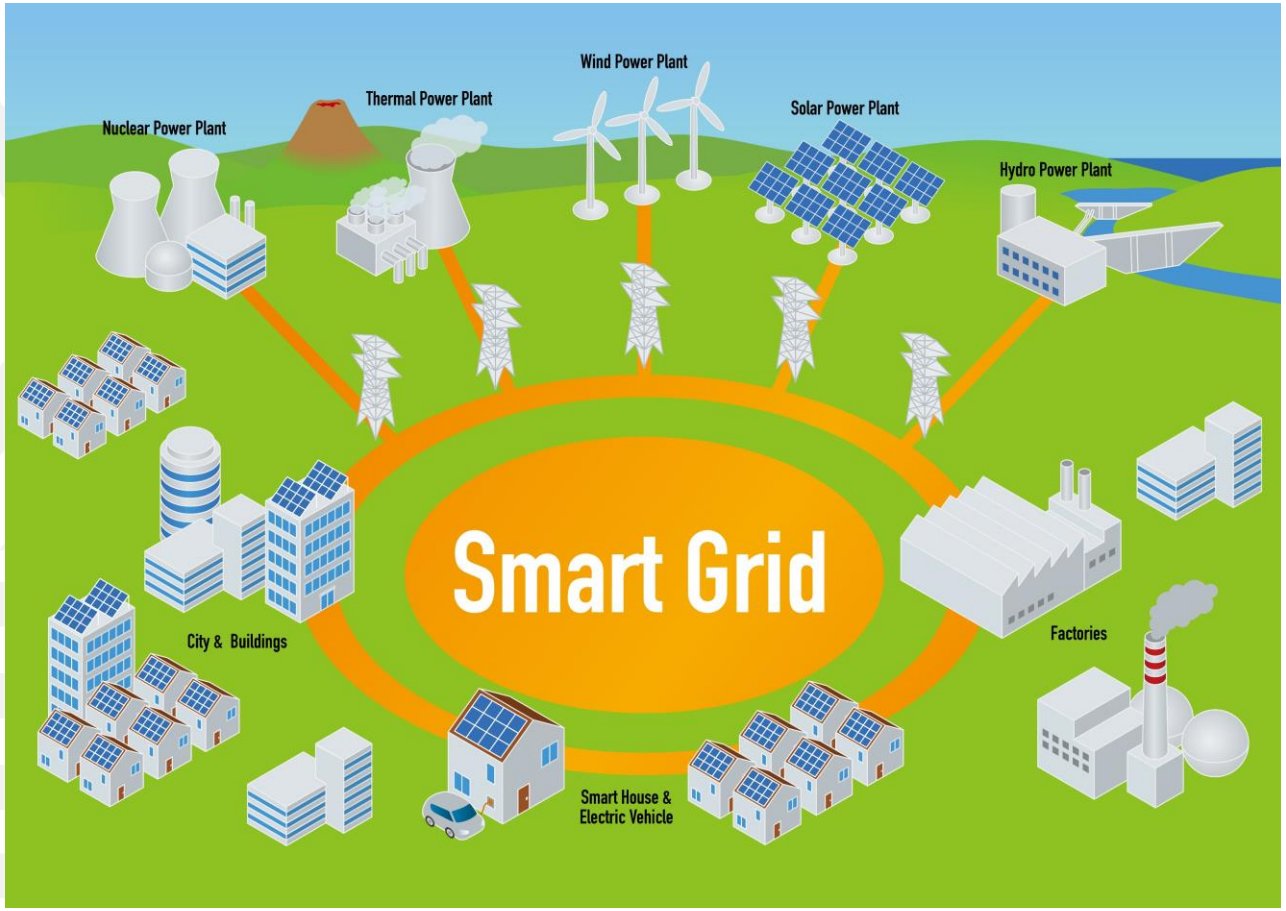
→

Predict, Diagnose and Prescribe Centrally

→

Determine Location & Remediate

# Data fusion across time is paramount to situation awareness



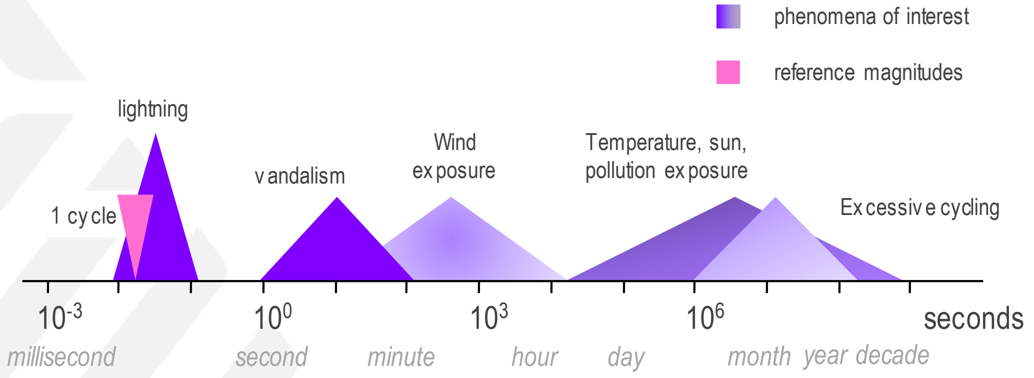

**A single entity is described by a diverse collection of sensors that measure different information over time.**

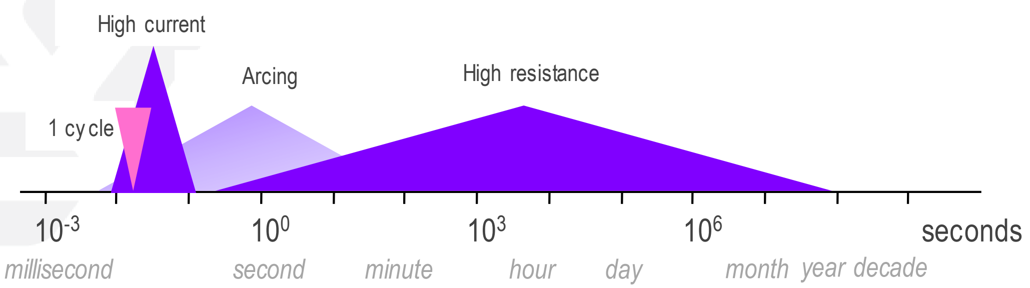
# Common fault types and causes of failure: Initial Setup of Features

Fault type describes the electrical effect, cause of failure describes the exposure or abuse that lead to the fault. There can be multiple causes and multiple effects, on differing time-scales including constant or intermittent failures.

e.g: **Cause:** High wind causes tree to falls into conductor. **Effect**: arcing and high current (e.g. line to ground short)

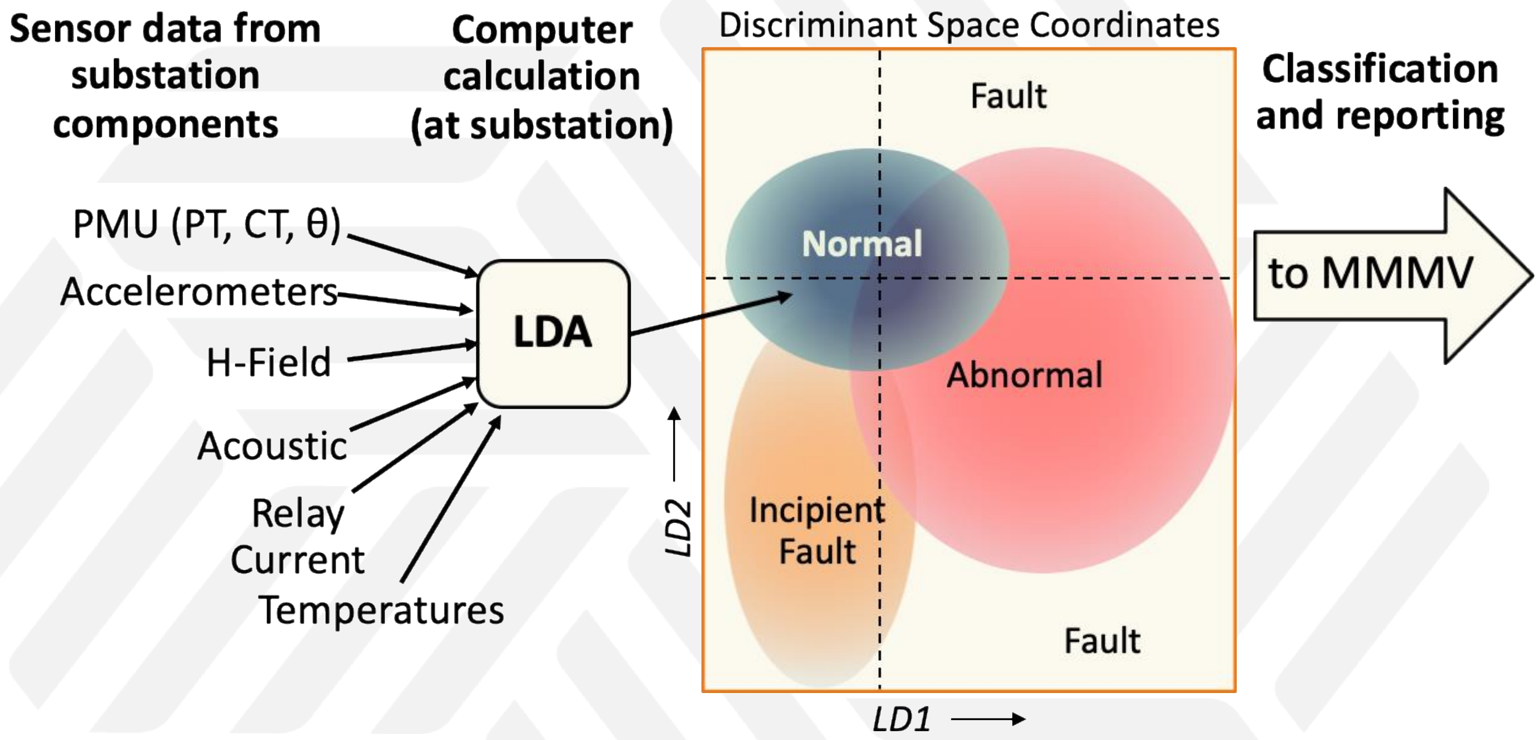
- Causes: Factors that lead to equipment degradation
  - Environmental: moisture, sun, airborne pollutants, animals, wind, lightning, temperature, vibration, earthquake, wildfire, animals
  - Electrical: exceeding electrical ratings of components either voltage or current, or excessive cycling (e.g. contactor actuation cycles)
  - Quality: leaking, poor maintenance, incorrect installation
  - Human interactions: vandalism, digging/construction
- Effects: Common electrical fault types
  - High current (e.g. line to line, or line to ground short)
  - High resistance (e.g. degrading connection which leads to localized heating)
  - Open circuit
  - Arcing (often co-incident, or immediately preceding, or following other fault types)



# (1) Detect and Classify the Problem Locally

Local Severity of Fault – Initial Response - LDA Illustration

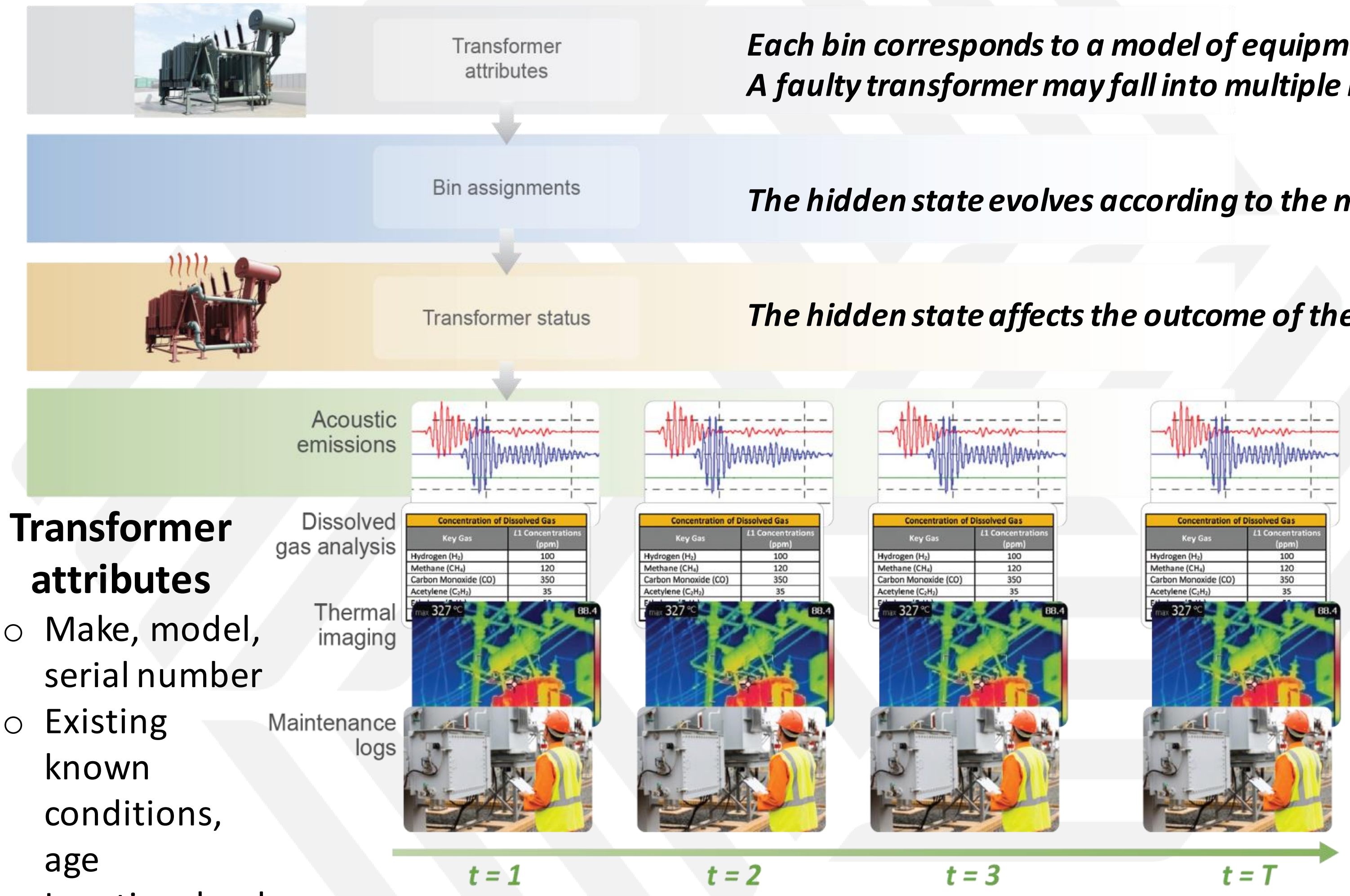



Discriminant analysis is supervised pattern recognition and can be used for optimal classification of conditions based upon any number of sensor channels.
Set of discrimination rules are constructed from training data and then they are used to classify new observations into predefined groups.

Using previously recorded sensor data with known classification, LDA coefficients are statistically determined for optimum classification with various classes located in linear discriminant (LD) space. The diagram above shows real-time transformation of new sensor data into LD coordinates, from which the class is determined and reported.

# (2) Predict, Diagnose and Prescribe Centrally for Failure Detection

MMMV approach: Mixture model for state estimation, Deep neural networks for feature learning



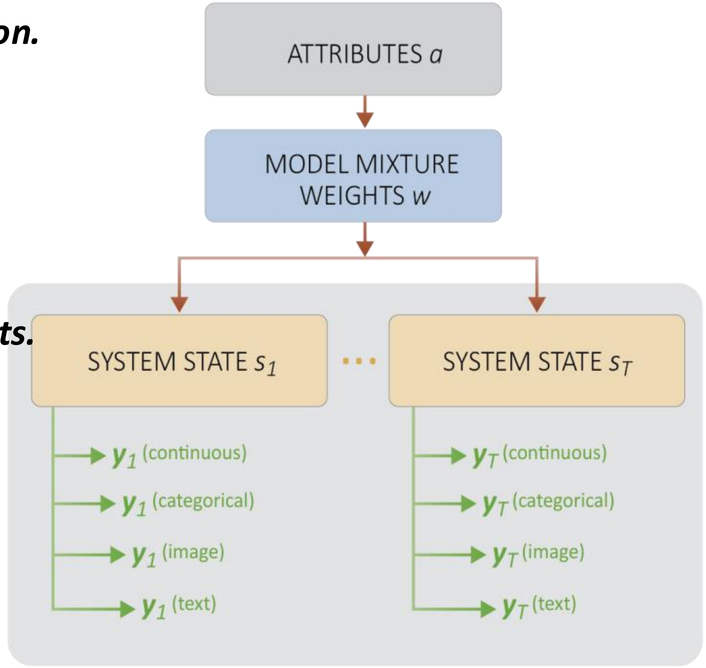

***Each bin corresponds to a model of equipment degradation.***
***A faulty transformer may fall into multiple bins.***

***The hidden state evolves according to the mixture model.***

***The hidden state affects the outcome of the measurements.***

**Transformer attributes**

- Make, model, serial number
- Existing known conditions, age
- Location, load

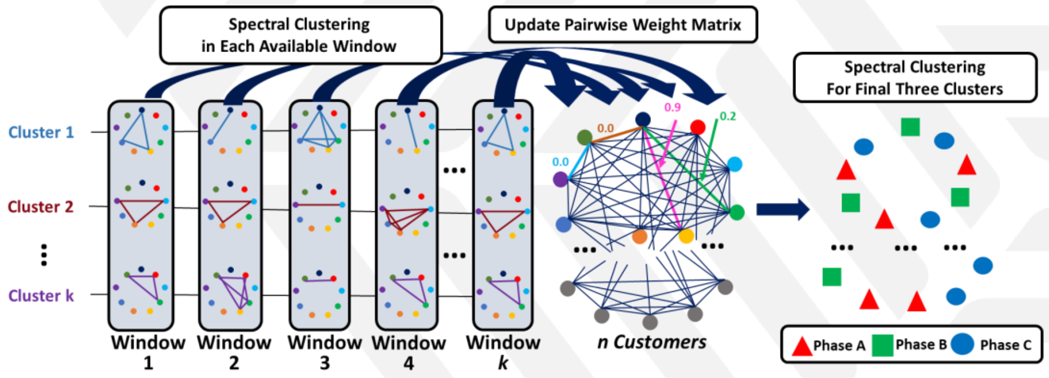


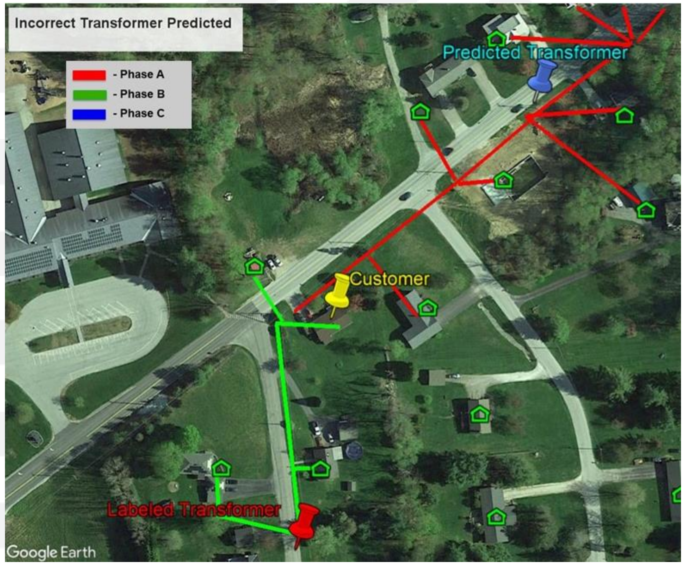

**Simultaneously:**

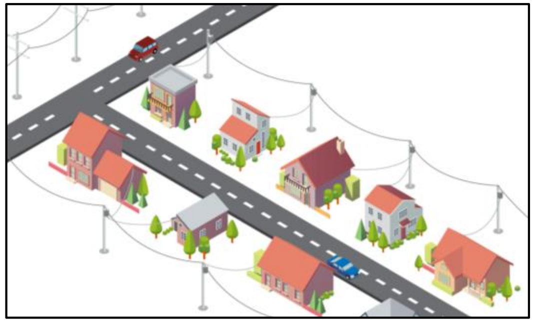
- Fuse information from disparate sources
- Learn the underlying temporal structure of the data

# (3) Determine Location & Remediate Topology and Locational Estimation

- “Once we know its there, how do we find it”
- Develop machine learning algorithms combined with advanced protection techniques to determine the location after LDA classifies the fault category and severity
- Identify what phase and location of fault from fused data set
- Bring grid models into data fusion to understand the impacts of failures, using locational information from measurements and the connected network in between
- Apply dynamically adapting grid models to modify states based on incoming data



# Incipient Failure Detection – Impact Score (Task 1)

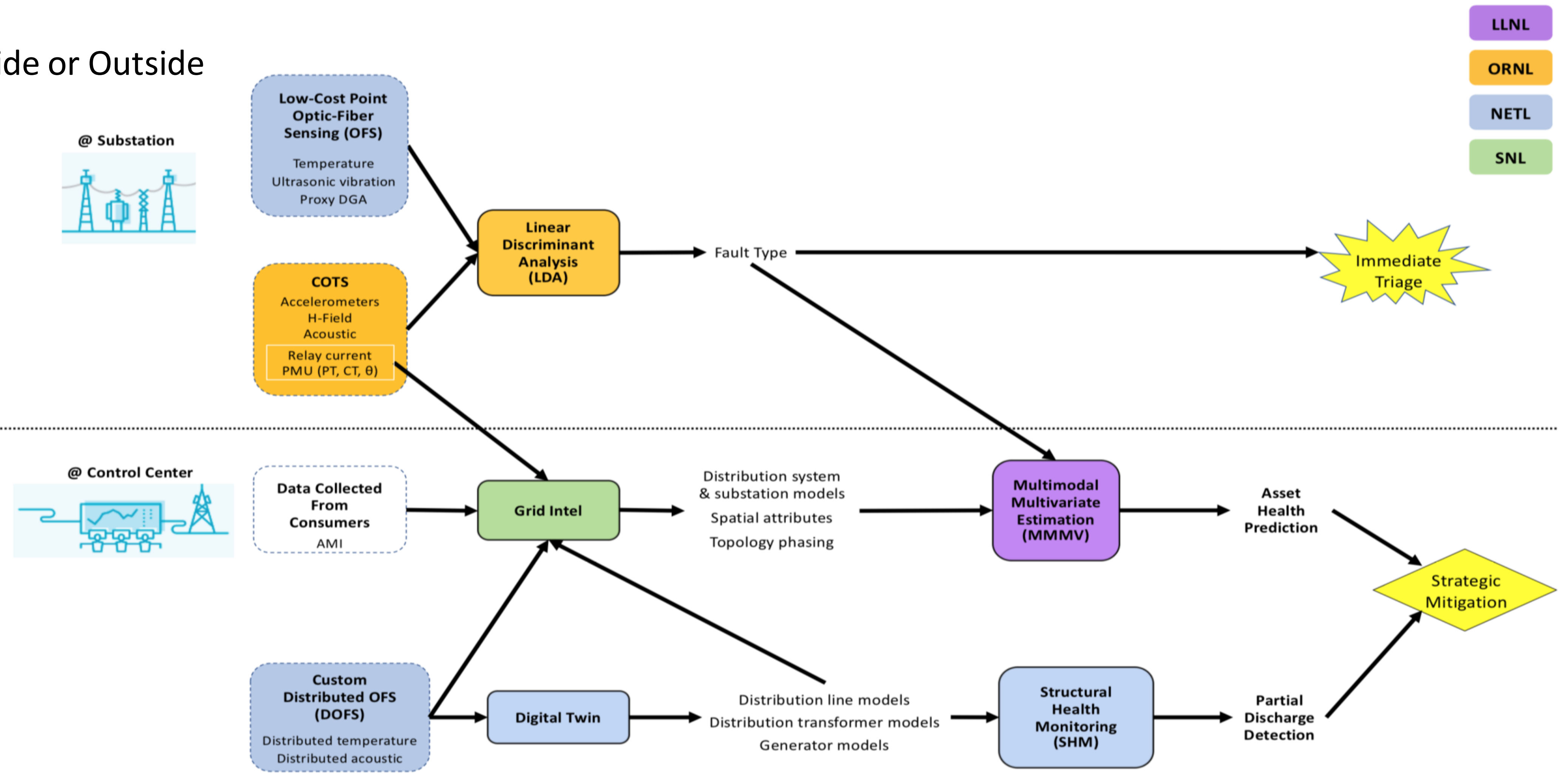
- To make efforts most impactful, need to focus on fault cases where degradation can be detected and acted on prior to hazard being present and on fault cases that have the highest potential harm.
- Propose an FMEA-like ranking scheme to guide focus-areas.
  - 1) Identify cause & effect, 2) rank by severity, likelihood of detection and duration of symptoms, 3) Multiply rankings together for each cause & effect. Highest scored cause/effect combos are most impactful to pursue.
  - Draft ranking scale:
    - **Severity:** High (3) – immediate human safety hazard, Medium (2) – possible to develop into safety hazard, Low (1) – loss of service, equipment degradation
    - **Likelihood of detection** (is there an electrical quantity that we can measure to "see" this failure?): High (3) – proven sensors already detecting in field, Medium (2) – lab-scale demo working, or sensor deployment cost high, Low (1) – conceptual
    - **Duration of symptoms**: Long (3) – minute to days, Medium (2) – 1 s to 1 minute, Short (1) 100ms – 1s, too fast to take protective action (0) <100ms (specific timing that is too short for action will depend on speed of action of possible protection mechanisms)

## Ranking examples

| Cause | Effect | Severity | Detection Likelihood | Duration of Symptom | Overall Score |
|---|---|---|---|---|---|
| Clamp corrosion | High resistance joint -> localized heating | 1 | 2 (temperature, high impedance, power loss) | 3 | 6 |
| Clamp corrosion | Localized heating -> arcing | 2 | 2 (high frequency signal in current and/or voltage, power loss/voltage drop) | 2 | 8 |
| Tree hitting conductor | High current ground fault | 3 | 3 | 0 *assume over current protection works | 0 |
| Tree hitting conductor | Arcing | 3 | 2 | 0-1 (depending on local protection and intermittency of fault) | 0 or 6 |

# Technical Approach – Combined Solution – Bringing it together, integration to platform

Inside or Outside



# Industry Participation

## Industry Role, Coordination

- Provide Data to the project (EPRI, SCE, PG&E, EPB)
- Commercial integration of algorithms to applications for asset management (OSISoft), sensor deployment (utility Partners)
- Guidance on Project through IAB meetings
- Transition of Algorithms to practice, operationalize lab level

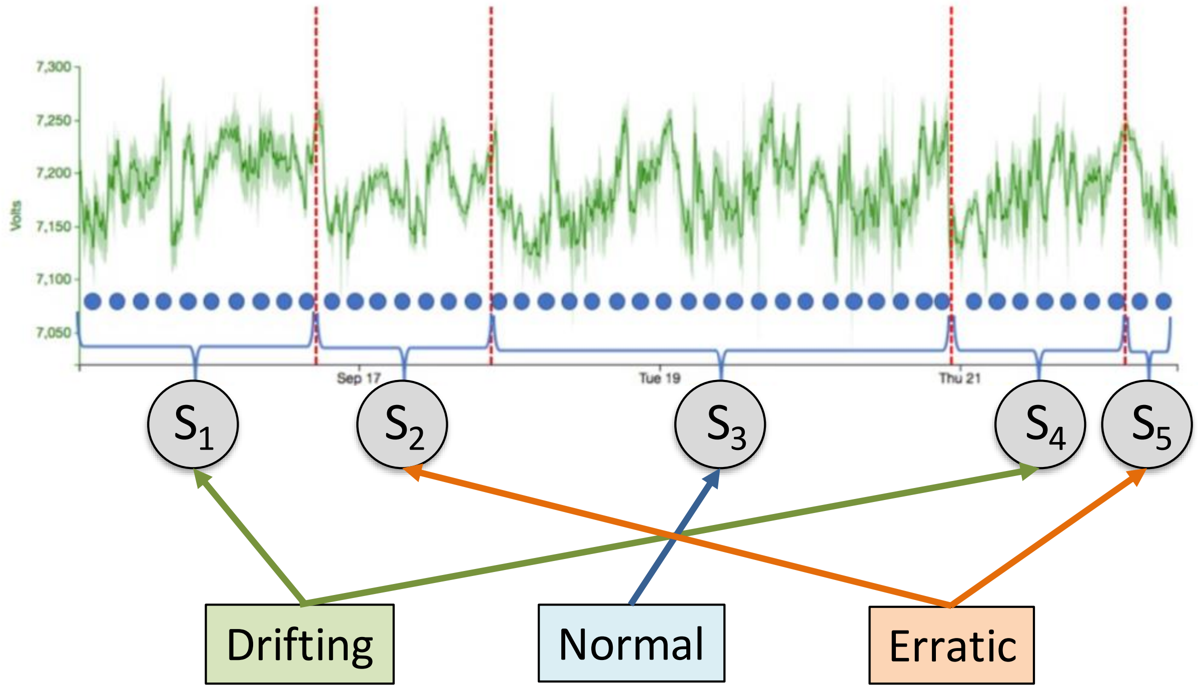
## Scalability and Feasibility

- Data is available to the project immediately, from multi-modal sources, application is inherently scalable as it addresses a need for massive analytics of failure modes
- Leveraging another industries progress and investment, and prior project use cases
- Define requirements for computing and architecture integration with utility and commercial partners

# Summary

- ► Project Kicking Off (3 years, 2 demonstration)
- ► Industrial Advisory Board No 1. @ LLNL March 19
- ► Contact:
  - ■ Emma Stewart stewart78@llnl.gov
  - ■ Brenda Ng ng1@llnl.gov
  - ■ Yarom Polsky (Co-PI) polskyy@ornl.gov

# Clustering of highly sampled micro PMU data




**Using Hierarchical Dirichlet Process**

The first layer partitions the time series into segments exhibiting similar behavior.

The second layer clusters the segments that are likely generated from the same statistical process.