

# Advanced Machine Learning for Event Classification on PMU Data

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# Advanced Machine Learning for Event Classification on PMU Data

**Objective:** A pro-active approach to improving the *reliability* and *situational awareness* of power systems based on **detection** and **classification of local and global events**

**Data:** Sparsely located PMU devices deployed across **three US interconnections:**

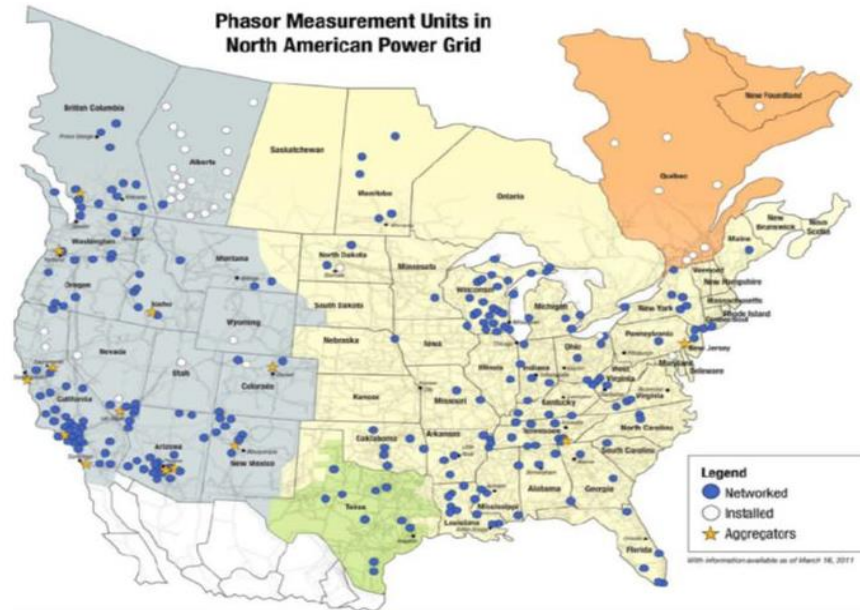
- *Eastern* Interconnection
- *Western* Interconnection
- *Texas (ERCOT)* Interconnection

**Existing solutions:** Traditional ML models

- challenges: *high dimensionality, autocorrelation, etc.*
- require adaptations in model design and evaluation
- rely on *missing, unreliable, or imprecise* labels
- do not characterize *local vs global* events
- typically utilize only a single PMU variable

**Our approach:**

- Utilize *all available channels*, as well as each channel separately
- Consider representationally more *advanced* methods (capable of modeling signal data)
- Employ *automated* feature learning
- Analyze the effect of different labelling mechanisms on *local/global* event characterization





# Prediction Methods

## Model Variants

### *Traditional*

- Decision Tree (**DT**)
- Logistic Regression (**LR**)
- Multilayer Perceptron (**MLP**)
- Support vector machine (**SVM**)

### **Single-channel CNN**

- Single-channel Convolutional Neural Network (**SC-CNN**)

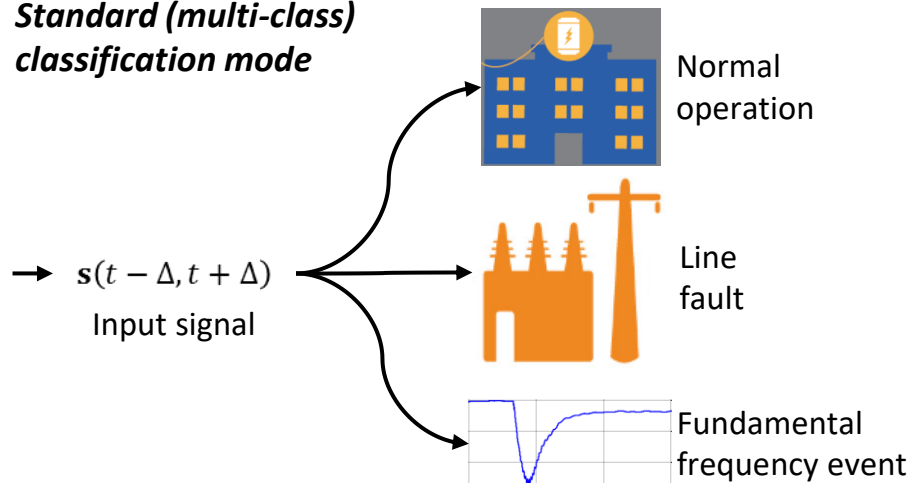
### **Multi-channel CNN**

- Parallel Channel Filtering CNN (**PCF-CNN**)
- Simultaneous Channel Filtering CNN (**SCF-CNN**)

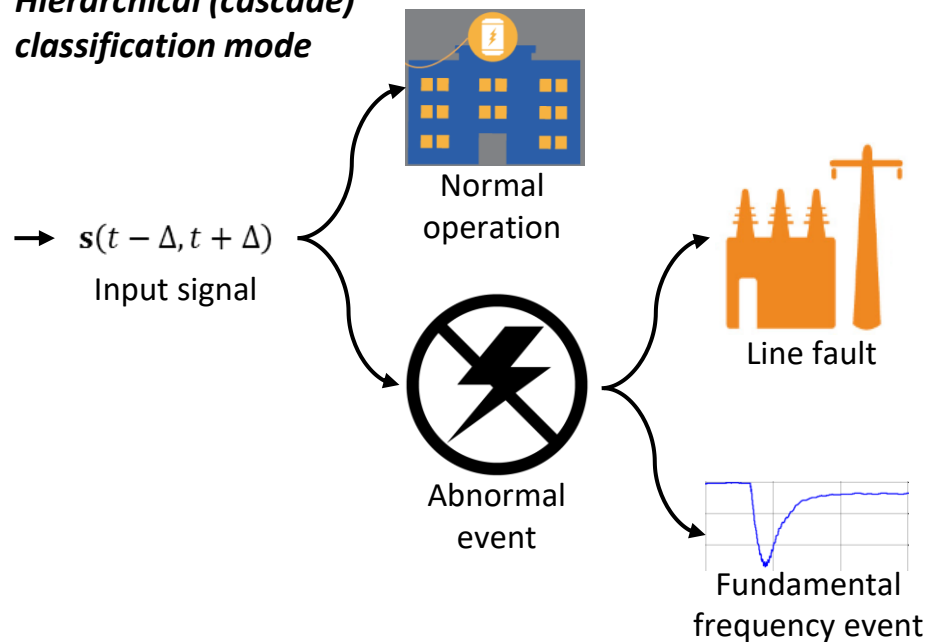
## Classification modes

- *Standard* (multi-class)
- *Hierarchical* (cascade)
  - Detected events are classified into line or freq. events

### *Standard (multi-class) classification mode*



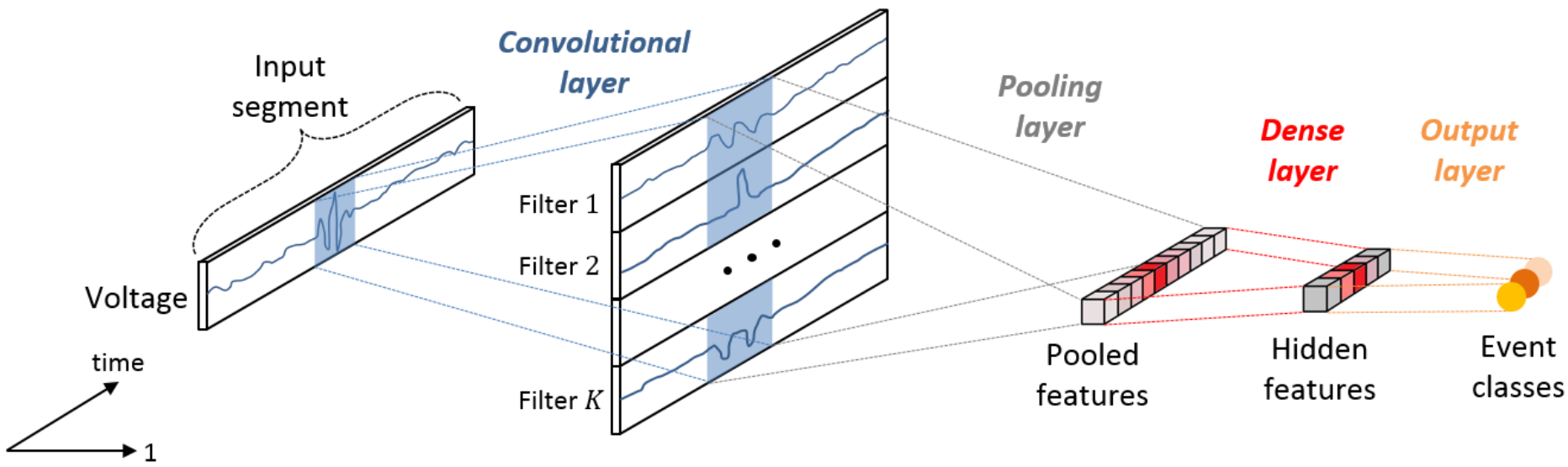
### *Hierarchical (cascade) classification mode*





# Single-Channel CNN Architecture

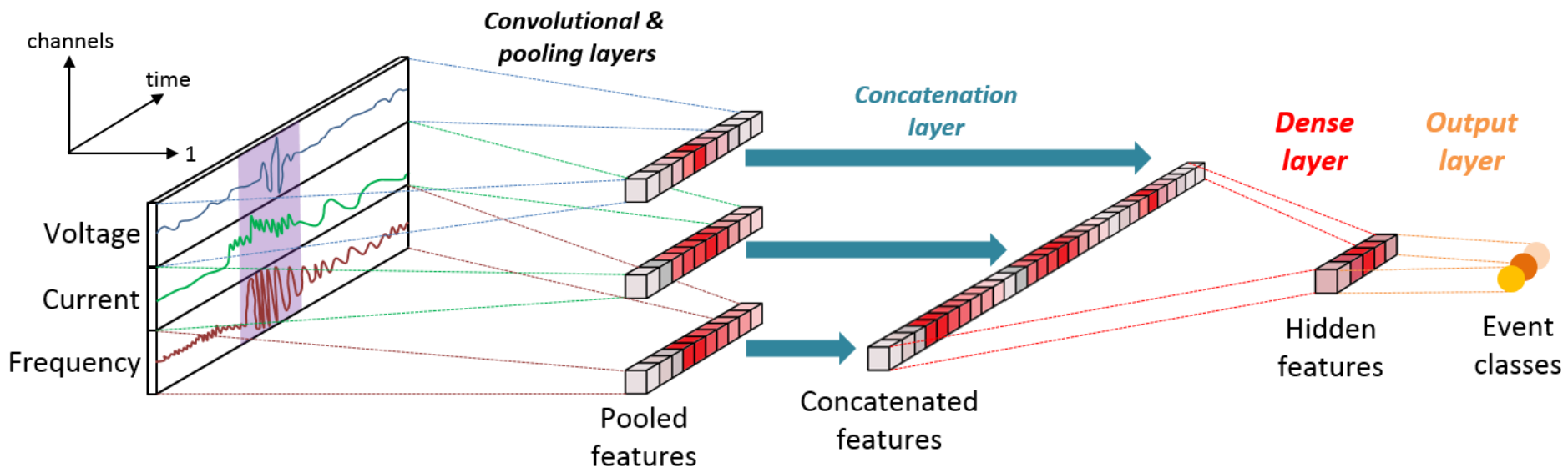
Single-Channel (SC) CNN utilizing voltage signal segments



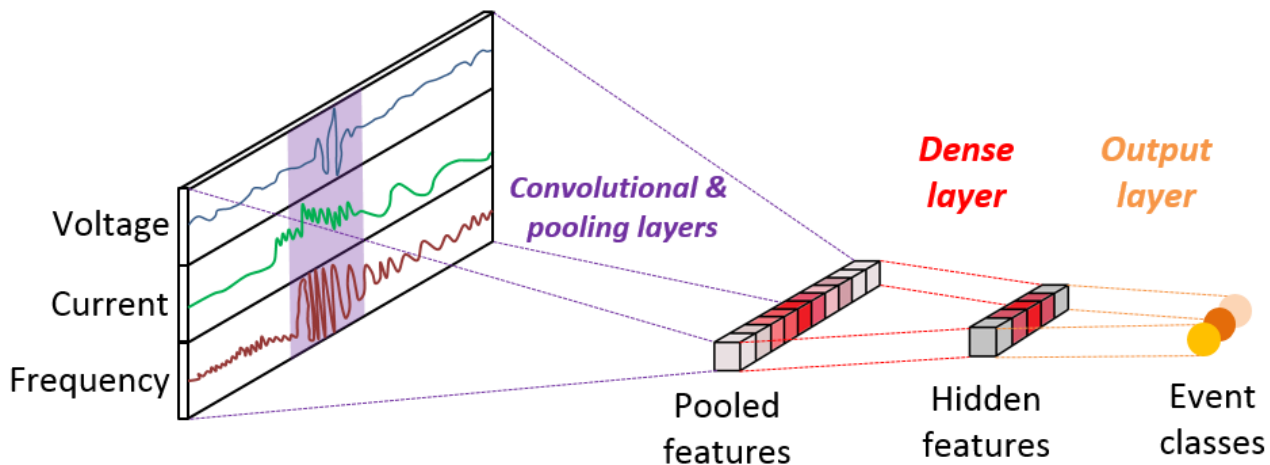


# Multi-Channel CNN Variants

## Parallel Channel Filtering (PCF) CNN



## Simultaneous Channel Filtering (SCF) CNN

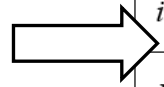




# Overall Effect of Event Labeling on Event Classification

## Event Logs: Rapidly refined vs partially inspected vs fully inspected 2 years at 38 PMU from Western U.S.

Event Log Advantages	Rapidly refined	Partially inspected	Fully inspected
Handpicked normal operation segments	✓	✗	✓
Narrower time intervals	✓	✓	✓
Single event per interval	✗	✓	✓
Precise intervals (centered events)	✗	✓	✓
Visually & inspected events	✗	✓	✓ <sup>+</sup>
Labeling time *	38 hrs.	~2 months (120 hrs.)	2.5 months (150 hrs.)



Event Log	Number of labeled segments		
	Total	Grouped by type	
<i>Rapidly refined</i> ('16)	1170	Normal	467
		Line	454
		Frequency	249
<i>Partially inspected</i> ('16)	1748	Normal	1311
		Line	227
		Frequency	210
<i>Fully inspected</i> ('16)	921	Normal	481
		Line	229
		Frequency	211
Holdout ('17)	879	Normal	426
		Line	273
		Frequency	180

## Results

- **CNNs** outperformed traditional models in most cases
- **Hierarchical models** consistently outperformed the standard multiclass variants
- **Multi-channel CNNs** outperformed all alternatives
  - Hierarchical single channel filtering architecture was sufficient for fully refined event log
  - Hierarchical parallel channel filtering architecture was the most appropriate in the other cases
- **Voltage** was more relevant than current/frequency
- **Increased** accuracy was achieved as more curated event logs were used



# Gradual Effect of Event Labeling on Event Classification

## *Four distinctive performance regions:*

- (1) Sudden improvement obtained by fully inspecting only 2 months of rapidly refined segments
- (2) Performance stabilizes up until 5 months of fully inspected data are replaced
  - requires 16 to 28 days of inspection time
- (2) Lift in performance once 6 months of segments are fully inspected
  - translates into 12% more inspection time
  - no significant change for 7 months
- (3) Inspecting  $\geq 8$  months: performance is similar to the most accurate CNN (hierarchical parallel channel filtering based)
  - requires the expert to devote 2 to 2.5 months
  - ~20% to 60% more inspection time

## Observations:

- When domain expert's time is **extremely limited**  $\Rightarrow$  label **at least 2 months** of data is suggested
- **Otherwise**  $\Rightarrow$  inspect  $\geq 8$  months to achieve significantly improved accuracy

