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Translational Knowledge: From Collecting Data to Making Decisions in a Smart Grid

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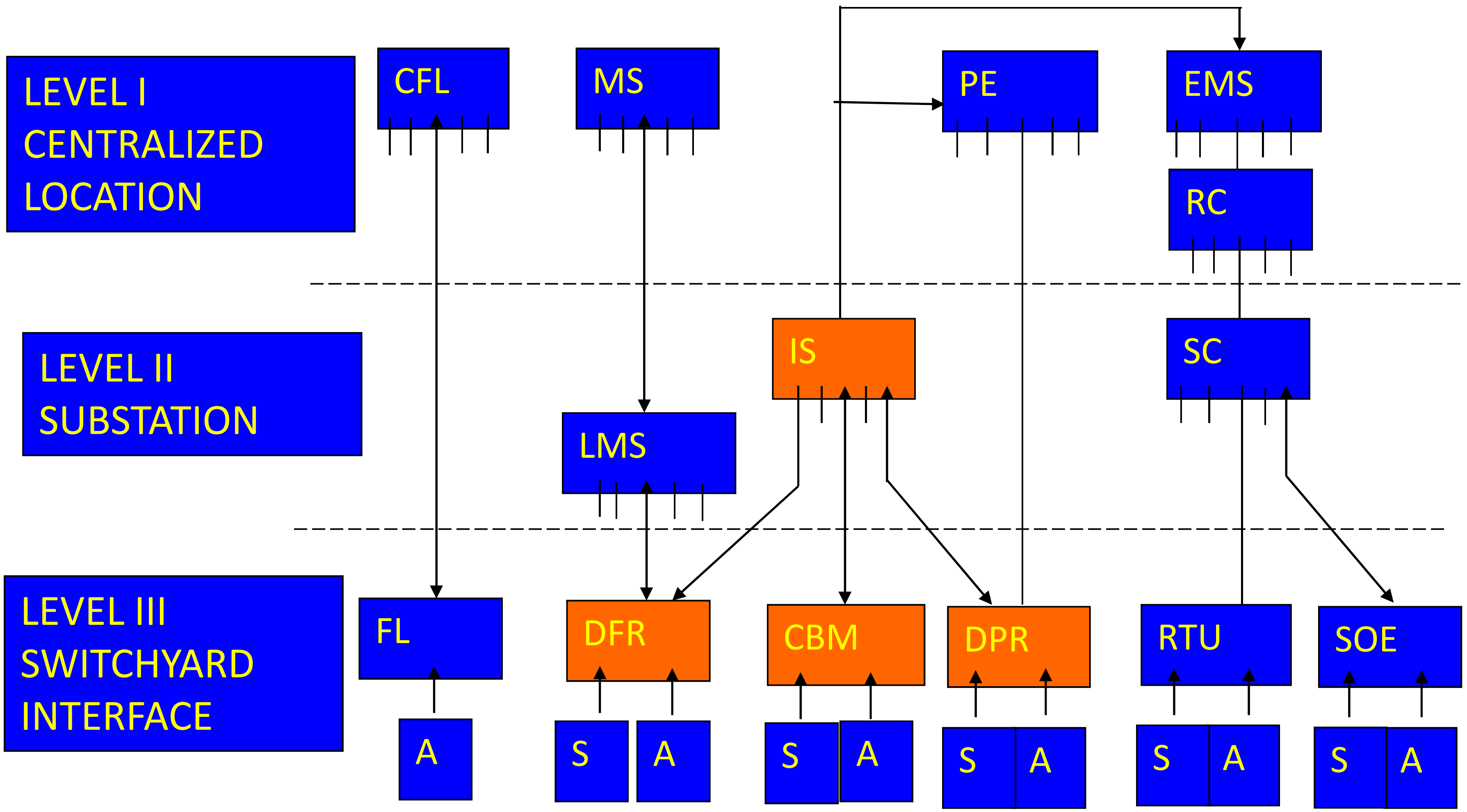
Outline

- Background
- Optimal Fault Location
- Intelligent Alarm Processing
- Inherently Adaptive Fault Detection and Classification
- Conclusions

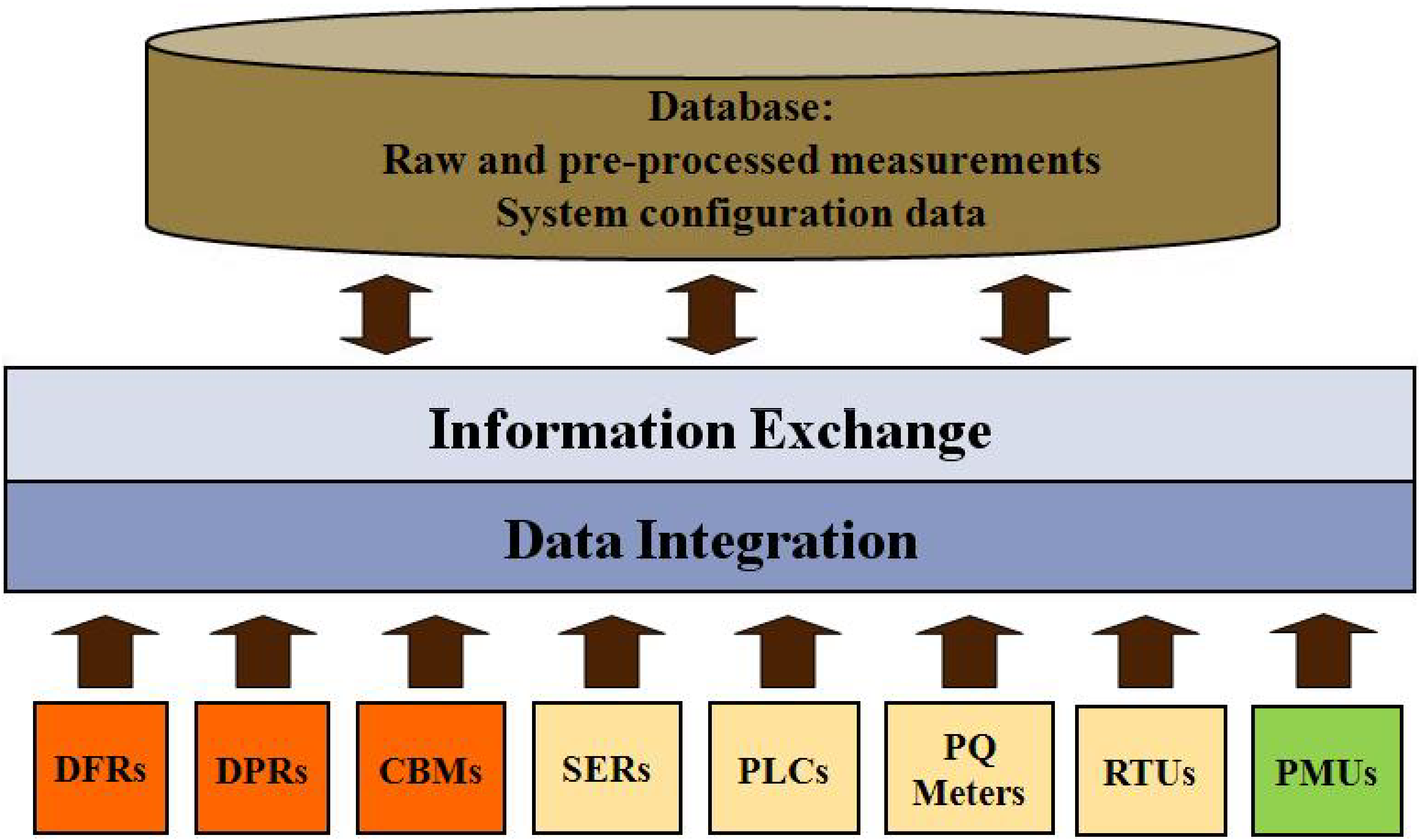
- Data Integration
- Information Exchange
- Temporal Considerations
- Spatial Considerations

Background

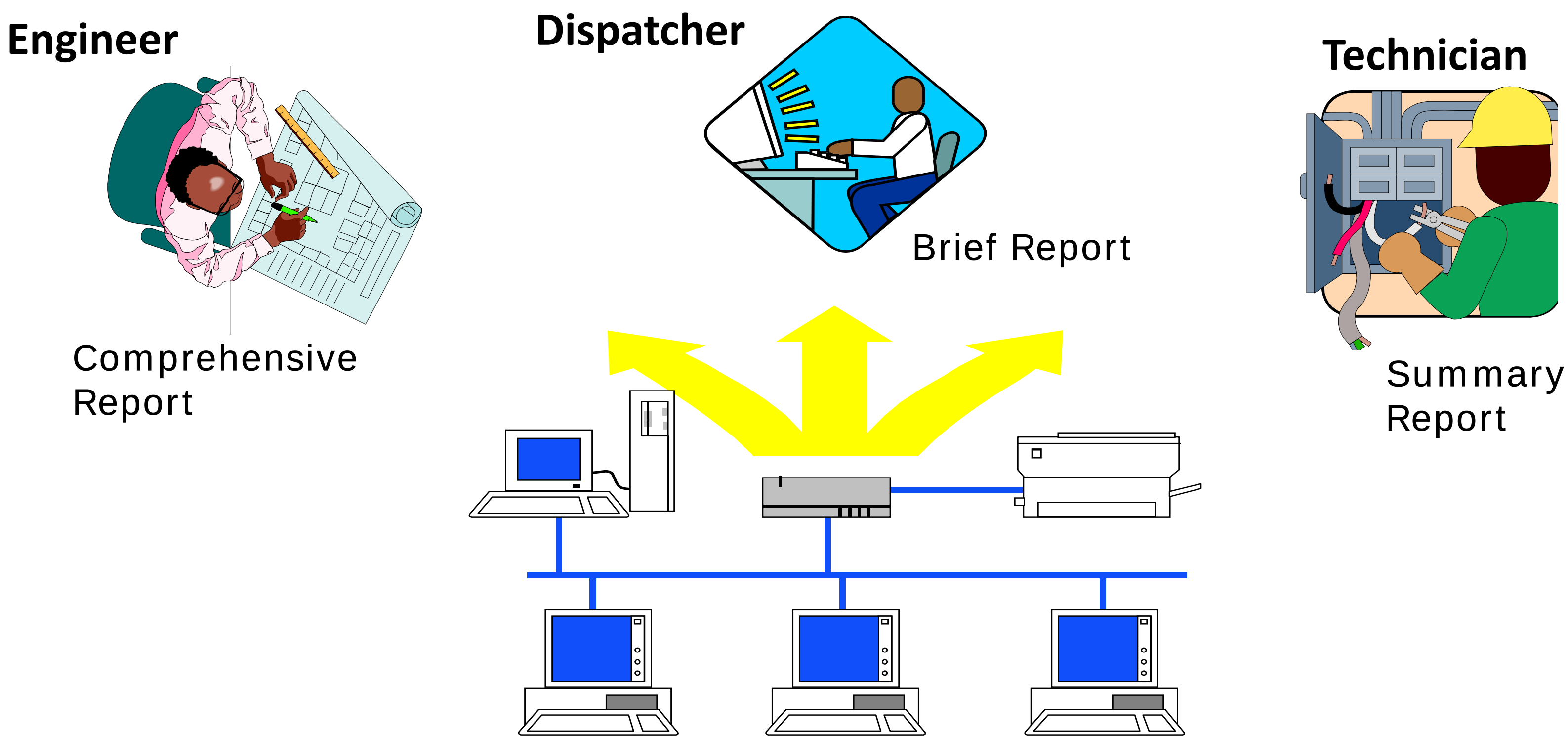
Data Integration



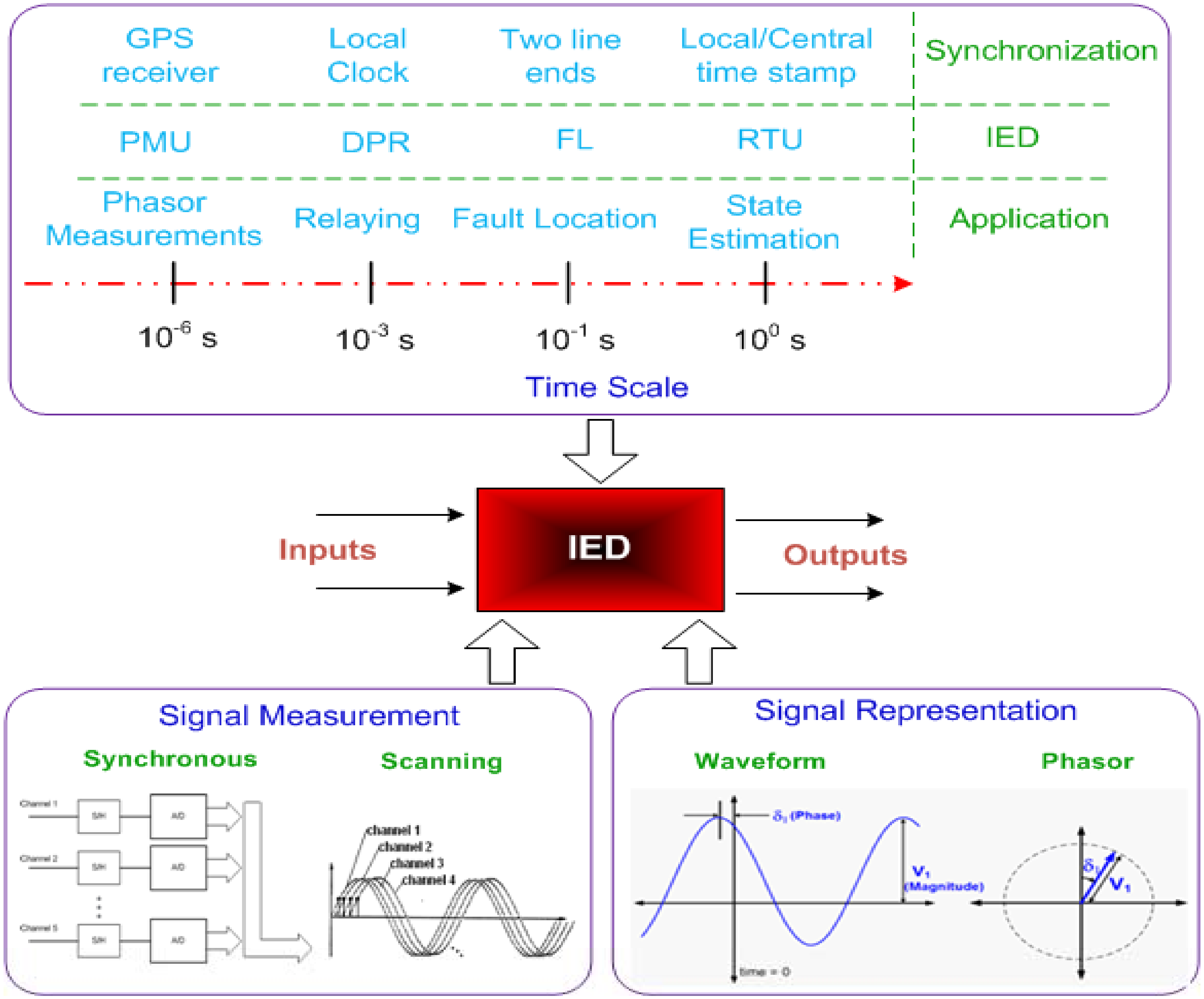
Information Exchange



Information Exchange



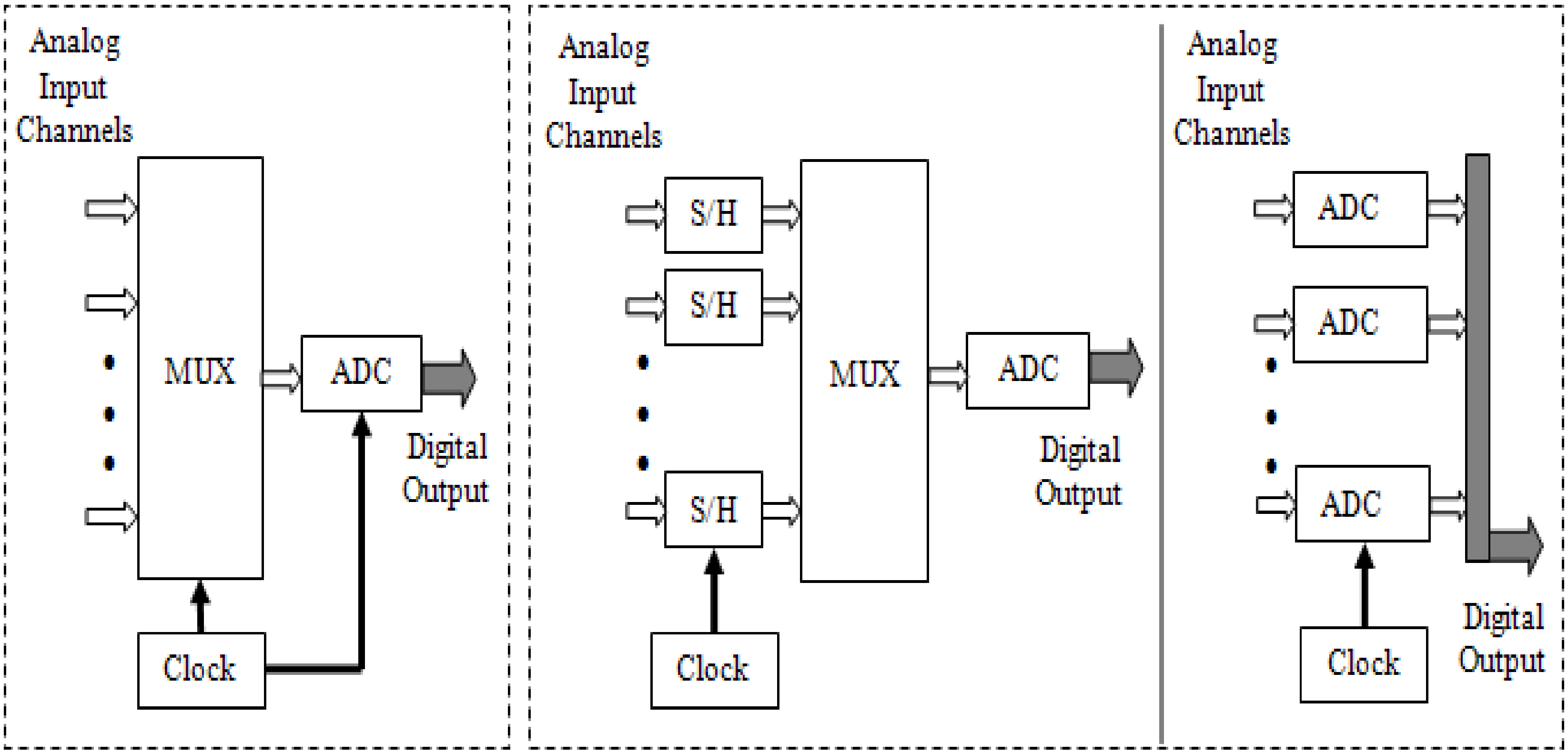
Temporal Considerations



Temporal Considerations

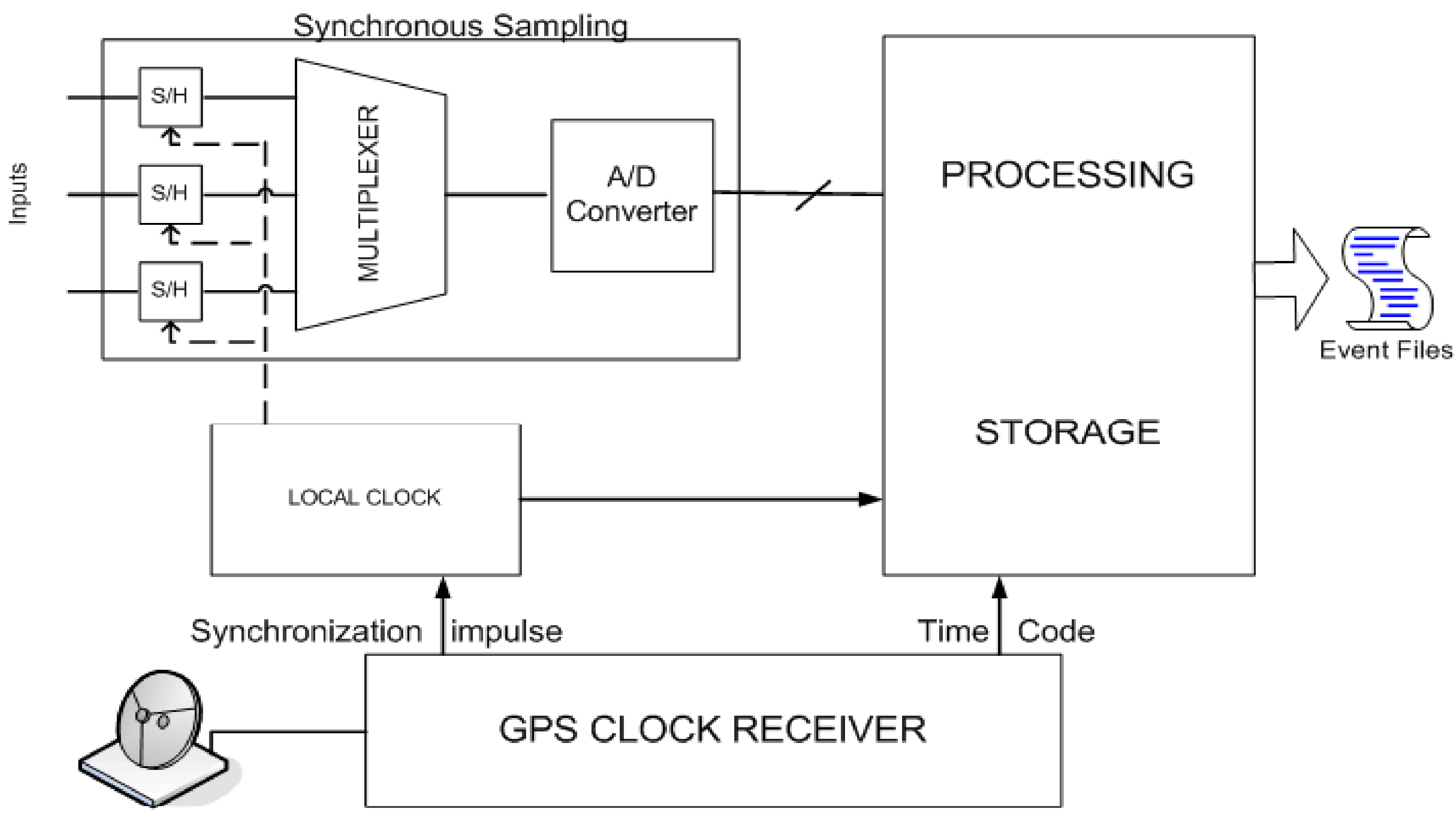
- Relative and absolute time as a reference for correlating power system events
- Sampling clock time as a reference for synchronous signal sampling vs. scanning
- Time window as a reference for waveform representation in time and frequency domain
- Implementation of the time reference

Synchronous Sampling vs. Scanning

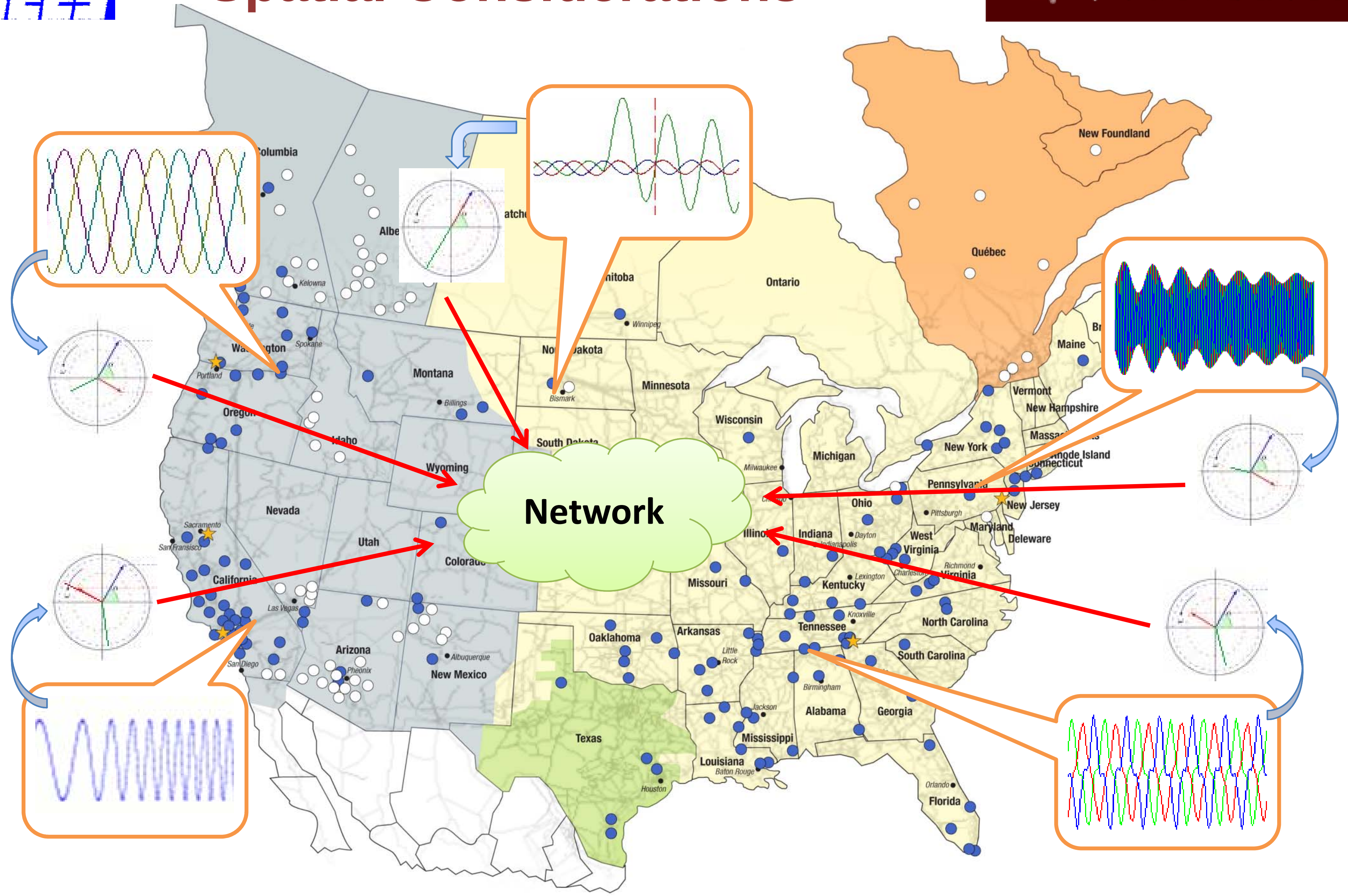


Scanning **Synchronous Sampling**

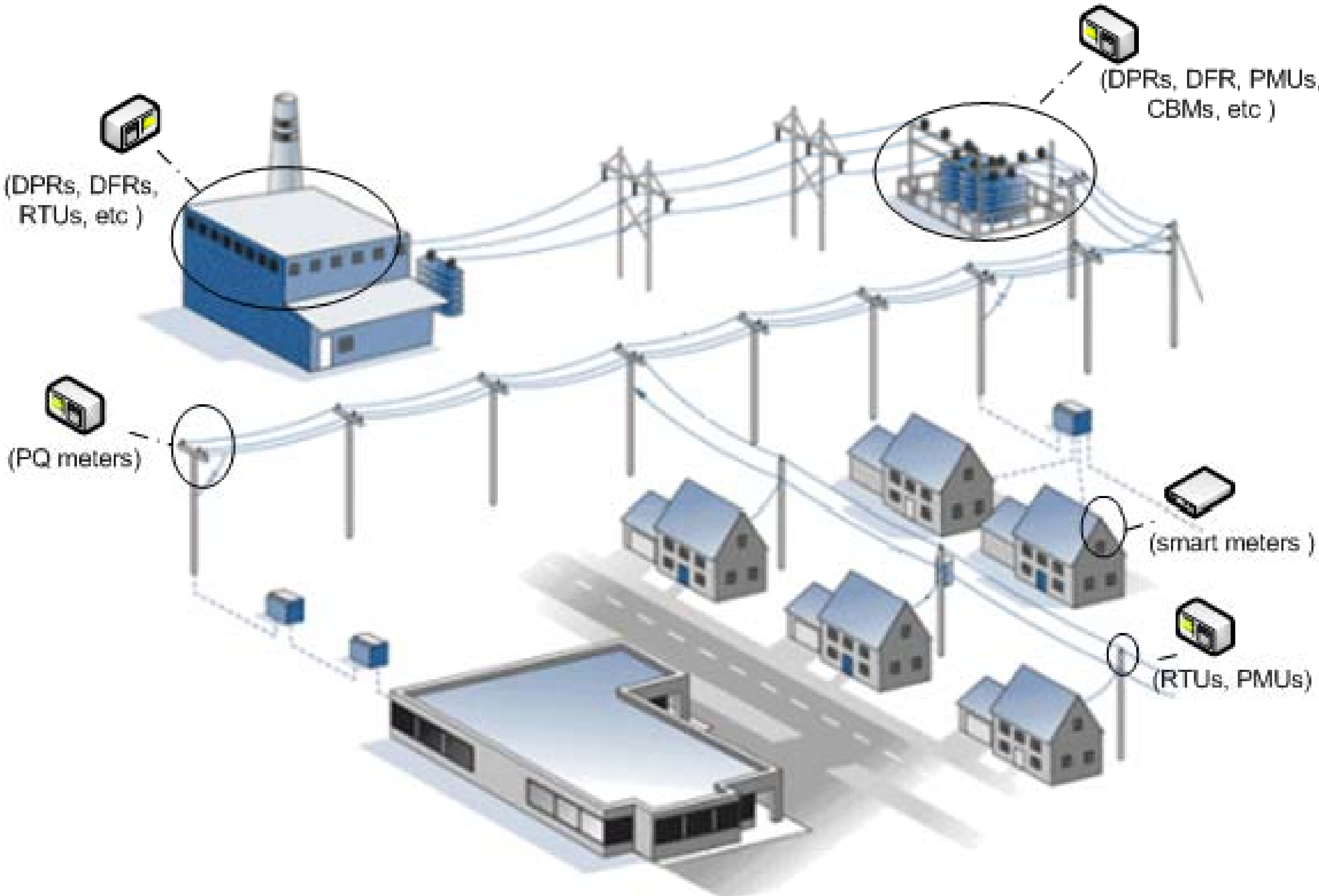
GPS Synchronization



Spatial Considerations



Spatial Considerations



Spatial Considerations

- Location as a reference for data processing and information extraction
- Location as a reference for model representation

Application	Temporal	Spatial	Model
Optimal Fault Location	Synchronized or unsynchronized phasor or sample vector	Local and system-wide	Power System Network for short circuit study
Intelligent Alarm Processing	Synchronized or unsynchronized phasors	Substation and system-wide	Petri-Net Logic for cause-effect representation
Inherently Adaptive Fault Detection and Classification	Synchronized sample vector	Local	Power system model for training pattern clustering

- Overview
- Translational knowledge
  - Data Processing
  - Information Extraction
  - Implementation
- Case Study

Optimal Fault Location

Overview of Fault Location Algorithms

- Phasor based Methods

  Use fundamental frequency component of the signal and lumped parameter model
- Time-domain based Methods

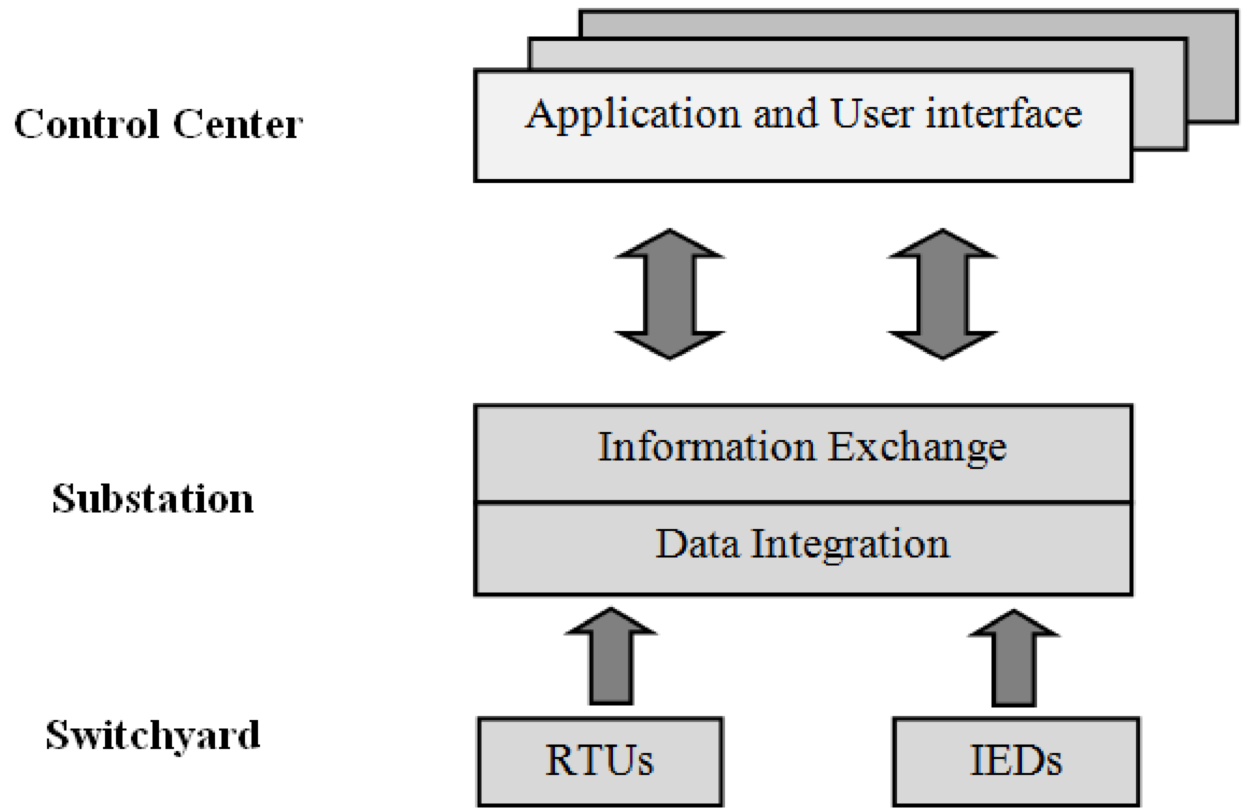
  Use transient components of the signal and lumped or distributed parameter model
- Traveling wave based Methods

  Use correlation between the forward and backward travelling waves along a line or direct detection of the arrival time

- o Single end
- o Double end
- o Synchronized
- o Unsynchronized
- o Phasors
- o Samples

An Optimal Solution

- Substation Data Flow



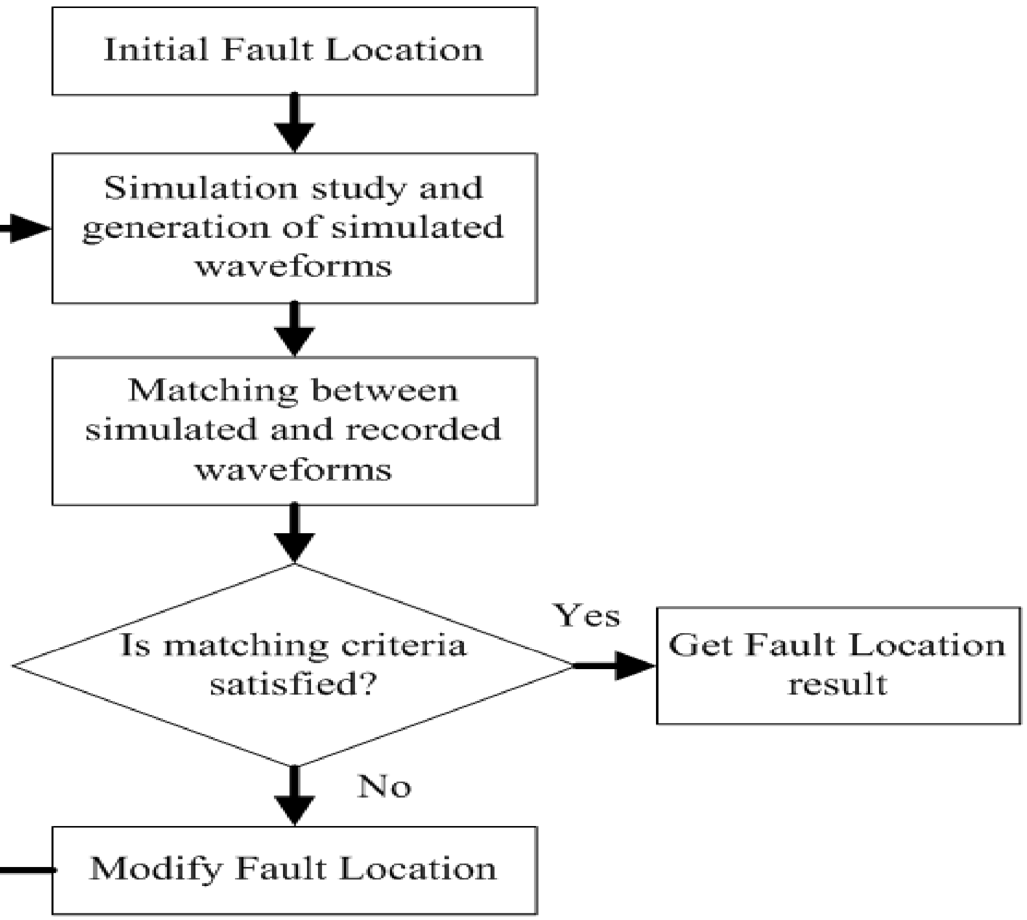
Data Processing

- System level data
  - Power system model data
  - PI Historian data
  - Sequence data
- Field data (recorded by IEDs)
  - Event data
  - Waveform data
- Substation interpretation data

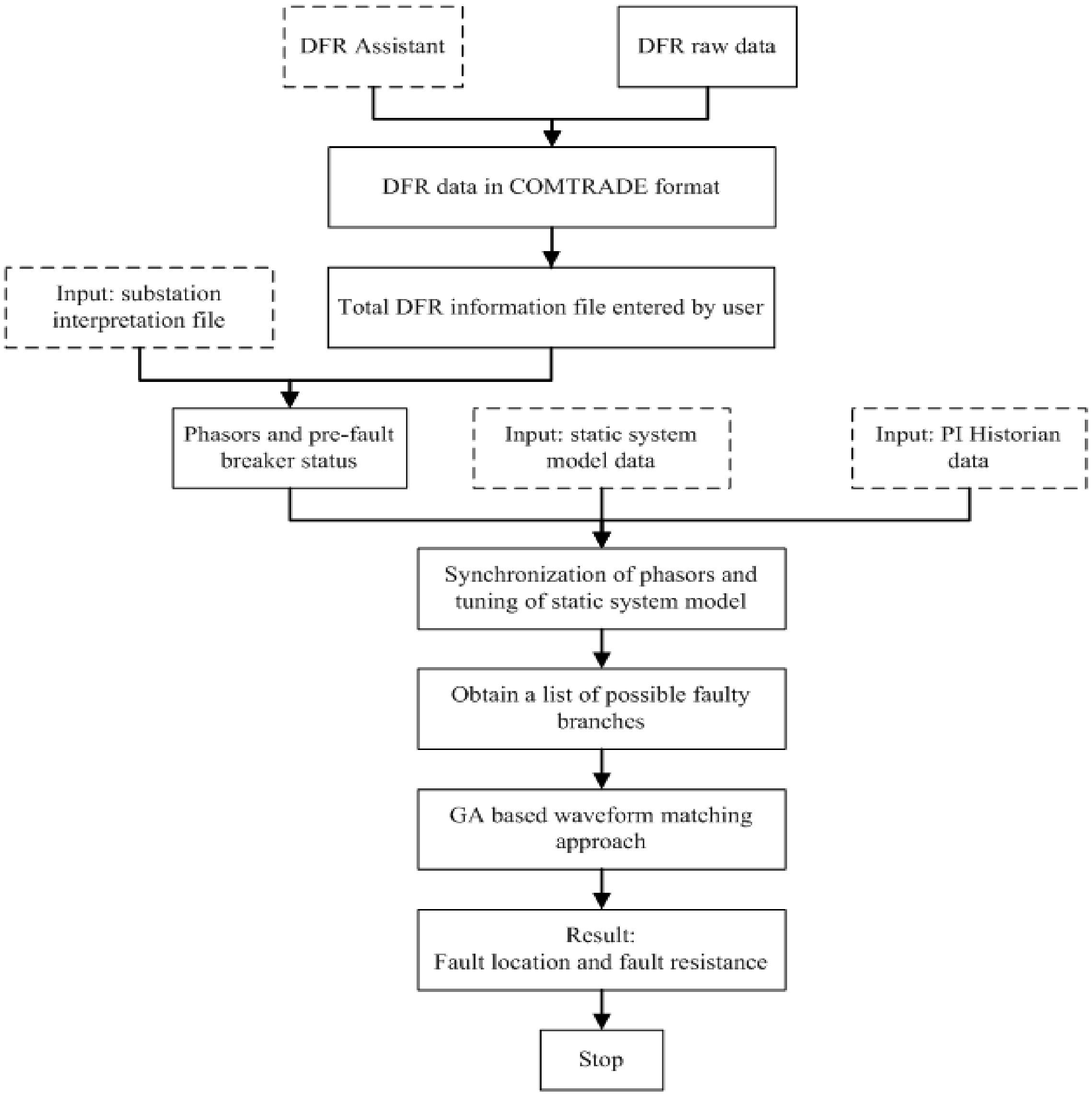
Information Extraction

- Extraction of phasors
  - Remove high-frequency noise
  - Remove decaying dc-offset
- Synchronization of phasors
- Tuning the power system model with real-time power system conditions
  - Updating power grid topology
  - Updating generation and load data

Translational Knowledge through matching system wide sparse measurement with power system model



Implementation



Case Study

Evaluate the following issues:

- Various number of files
- Specifying the search region
- Using preprocessed fault location estimation
- Using different quantities for the match
- Evaluating differences in the accuracy

One test case provided by the utility:

- Two subsequent (in 5 ms gap) phase to ground faults
- PI Historian data provided for two substations
- DFR triggered for only one substation

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Intelligent Alarm Processing

Overview of Alarm Processing

Issues that operators face:

- Alarms which are not descriptive enough
- Alarms which are too detailed
- Too many alarms during a system disturbance
- False alarms
- Multiplicity of alarms for the same event
- Alarms changing too fast to be read on the display
- Alarms not in priority order

Alarm processing algorithms:

- Expert System (ES) technique
- Fuzzy Logic (FL) technique
- Petri-Nets (PN) technique
- Fuzzy Reasoning Petri-Nets (FRPN) technique

Solution by Matching Data with Models

This approach assumes that filed data and model of the relay actions are matched leading to a cause-effect analysis.

- Suppress multiple alarms from one event;
- Generate a single conclusion through logical cause-effect relationship;
- Automate the process to get answers quickly;
- Make graphical and numerical information concise and easy to follow.

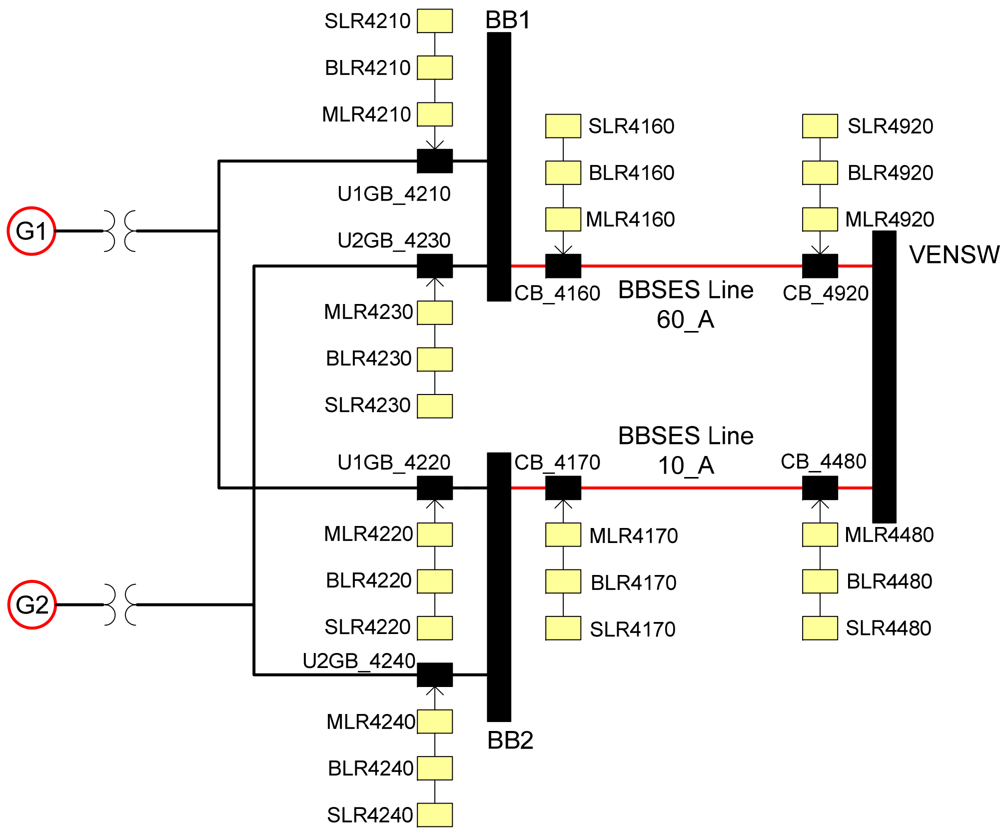
Data Processing

- Input data list:

Data from RTU of SCADA (Main data)
1 CB status change alarms (Opening and Closing)
2 Trip signal of main transmission line relays
3 Trip signal of primary backup transmission line relays
4 Trip signal of secondary backup transmission line relays
5 Trip signal of bus relays

Data from Digital Protective Relays (Additional data)
1 Pickup & Operation signals of main transmission line relays
2 Pickup & Operation signals of primary backup transmission line relays
3 Pickup & Operation signals of secondary backup transmission line relays
4 Pickup & Operation signals of bus relays

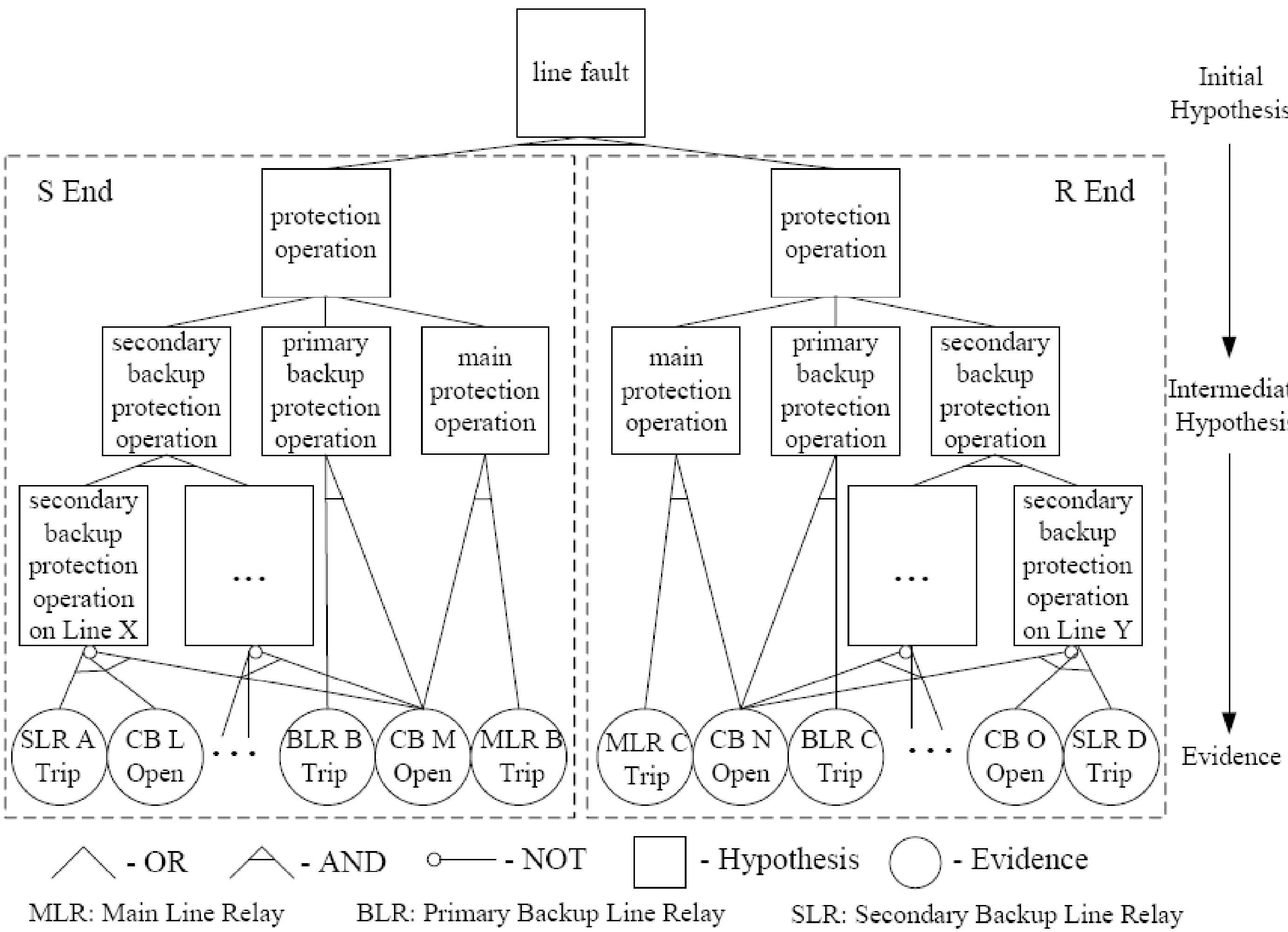
Information Extraction



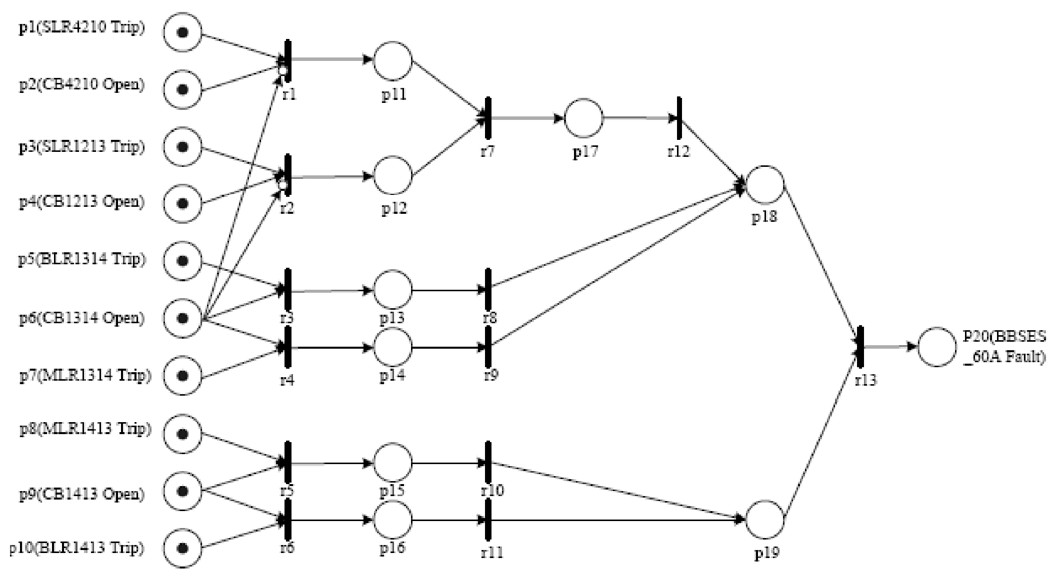
- Stage I: System topology is analyzed based on CBs status data;
- Stage II: FRPN diagnosis and operation.

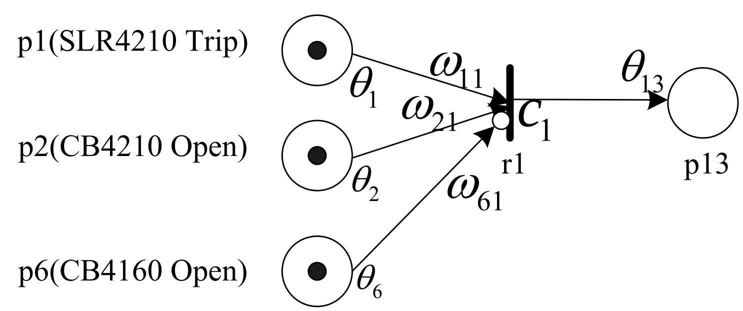
Implementation

Translational Knowledge through matching SCADA and relay data with the reasoning diagnosis model



Implementation





$$\theta_{13} = [\theta_1\omega_{11} + \theta_2\omega_{21} + (1-\theta_6)\omega_{61}]c_1$$

- A FRPN model for BBSES_60A fault
- An Example of "Weighted Average" Operation

Case Study

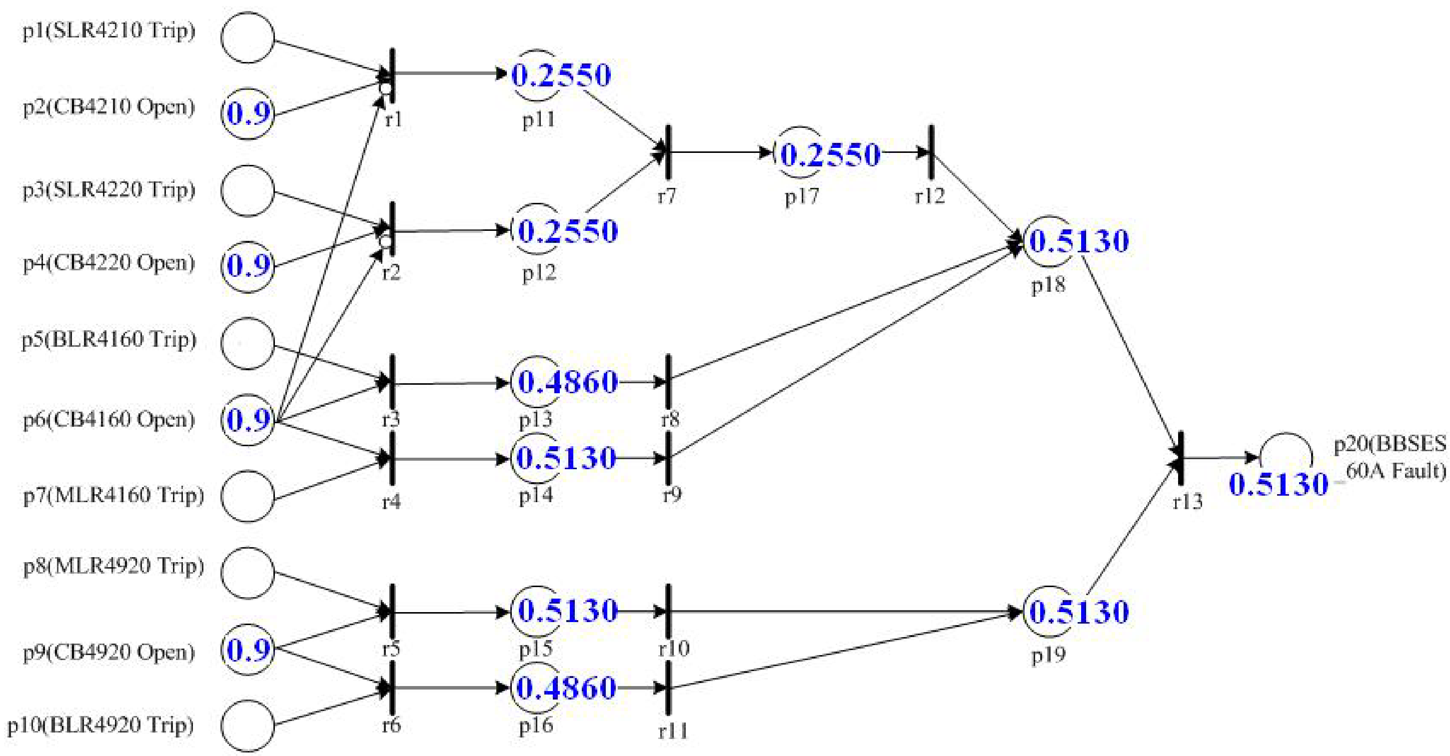
- Alarm Screen Shot

1	AREA	CATEGORY	EVENT	EXECDEF	LOCATION	TEXT	TIME
1084	GENERATN	AGC-MAJOR	0	RGMW	LOCAL	ERCOT -NEWMAN NEWMA_5 UNIT MW GEN TELEMETRY UNAVAILABLE	9-5-2007 7:52:56 AM
1085	GENERATN	AGC-MINOR	0	RGHZL	LOCAL	ERCOT FREQUENCY ALARM LIMIT EXCEEDED	9-5-2007 7:53:00 AM
1086	GENERATN	AGC-MINOR	0	RGACE	LOCAL	ERCOT ACE EMERGENCY LIMIT EXCEEDED	9-5-2007 7:53:00 AM
1087	GENERATN	AGC-MAJOR	0	RGLMW	LOCAL	STA_LD2 LAAR MW TLM AVAILABLE	9-5-2007 7:53:00 AM
1088	ERCOT	LOG2	1	ACKLOG	LOCAL	(05 / 07:52:56 ERCOT -NEWMAN NEWMA_5 UNIT MW) acked by: OverlayDel on A For Area(s): GENERATN -Alarm A022C1F	9-5-2007 7:53:04 AM
1089	ERCOT	LOG2	1	DELLOG	LOCAL	(05 / 07:52:56 ERCOT -NEWMAN NEWMA_5 UNIT MW) deleted by: OverlayDel on For Area(s): GENERATN -Alarm A022C1F	9-5-2007 7:53:04 AM
1090	GENERATN	AGC-MAJOR	0	RGMW	LOCAL	ERCOT -NEWMAN NEWMA_5 UNIT MW GEN TELEMETRY AVAILABLE	9-5-2007 7:53:00 AM
1091	GENERATN	AGC-MINOR	0	JAGCND	LOCAL	ERCOT JAGC REQ MW NOT FULLY DISTRIBUTED	9-5-2007 7:53:04 AM
1092	ERCOT	TBD	0	S002	INKSDA	INKS DAM UN INKS_G1 SCM OFF	9-5-2007 7:53:03 AM
1093	ERCOT	TBD	0	S002	WIRTZ	WIRTZ UN WIRTZ_G2 SCM OFF	9-5-2007 7:53:03 AM
1094	ERCOT	345KV_BRKR	0	S002	VENSW	VENSW CB CB_4480 ST OPEN	9-5-2007 7:53:05 AM
1095	ERCOT	345KV_BRKR	0	S002	VENSW	VENSW CB CB_4920 ST OPEN	9-5-2007 7:53:05 AM
1096	ERCOT	TBD	0	S002	BUCHAN	BUCHAN UN BUCHANG1 SCM OFF	9-5-2007 7:53:05 AM
1097	ERCOT	TBD	0	S002	BUCHAN	BUCHAN UN BUCHANG2 SCM OFF	9-5-2007 7:53:05 AM
1098	ERCOT	TBD	0	S002	BUCHAN	BUCHAN UN BUCHANG3 SCM OFF	9-5-2007 7:53:05 AM
1099	ERCOT	345KV_BRKR	0	S002	BBSES	BIG BROWN SES CB CB_4160 ST OPEN	9-5-2007 7:53:05 AM
1100	ERCOT	345KV_BRKR	0	S002	BBSES	BIG BROWN SES CB CB_4170 ST OPEN	9-5-2007 7:53:05 AM
1101	GENERATN	AGC-MAJOR	0	RGLMW	LOCAL	_KT_LD2 LAAR MW TLM AVAILABLE	9-5-2007 7:53:04 AM
1102	GENERATN	AGC-MAJOR	0	RGUOFF	LOCAL	ERCOT -BBSES UNIT1 UNIT OFFLINE	9-5-2007 7:53:08 AM
1103	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG10 UNIT ONLINE	9-5-2007 7:53:08 AM
1104	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG2 UNIT ONLINE	9-5-2007 7:53:08 AM
1105	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG3 UNIT ONLINE	9-5-2007 7:53:08 AM
1106	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG4 UNIT ONLINE	9-5-2007 7:53:08 AM
1107	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG5 UNIT ONLINE	9-5-2007 7:53:08 AM
1108	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG6 UNIT ONLINE	9-5-2007 7:53:08 AM
1109	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG7 UNIT ONLINE	9-5-2007 7:53:08 AM
1110	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG8 UNIT ONLINE	9-5-2007 7:53:08 AM
1111	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -FORMOSA FORMOSG9 UNIT ONLINE	9-5-2007 7:53:08 AM
1112	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -SRB SRB_G4 UNIT ONLINE	9-5-2007 7:53:12 AM
1113	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -WIRTZ WIRTZ_G2 UNIT ONLINE	9-5-2007 7:53:12 AM
1114	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -BUCHAN BUCHANG1 UNIT ONLINE	9-5-2007 7:53:12 AM
1115	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -BUCHAN BUCHANG2 UNIT ONLINE	9-5-2007 7:53:12 AM
1116	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -BUCHAN BUCHANG3 UNIT ONLINE	9-5-2007 7:53:12 AM
1117	GENERATN	AGC-MAJOR	0	RGUON	LOCAL	ERCOT -INKSDA INKS_G1 UNIT ONLINE	9-5-2007 7:53:12 AM
1118	GENERATN	AGC-MAJOR	0	RGQDYN	LOCAL	DYNEGY QSE FBIAS TELEM UNAVAIL	9-5-2007 7:53:12 AM
1119	GENERATN	AGC-MAJOR	0	RGUOFF	LOCAL	ERCOT -SRB SRB_G4 UNIT OFFLINE	9-5-2007 7:53:16 AM
1120	ERCOT	GEN_BRKR	0	S002	BBSES	BIG BROWN SES CB U1GB_4220 ST OPEN	9-5-2007 7:53:15 AM
1121	ERCOT	GEN_BRKR	0	S002	BBSES	BIG BROWN SES CB U2GB_4240 ST OPEN	9-5-2007 7:53:15 AM
1122	ERCOT	GEN_BRKR	0	S002	BBSES	BIG BROWN SES CB U1GB_4210 ST OPEN	9-5-2007 7:53:15 AM
1123	ERCOT	GEN_BRKR	0	S002	BBSES	BIG BROWN SES CB U2GB_4230 ST OPEN	9-5-2007 7:53:15 AM
1124	GENERATN	AGC-MAJOR	0	RGQDYN	LOCAL	AEPC QSE FBIAS TELEM UNAVAIL	9-5-2007 7:53:16 AM
1125	GENERATN	AGC-MAJOR	0	RGQDYN	LOCAL	AEPSQ3 QSE FBIAS TELEM UNAVAIL	9-5-2007 7:53:16 AM
1126	GENERATN	AGC-MAJOR	0	RGQDYN	LOCAL	DYNEGY QSE FBIAS TELEM AVAILABLE	9-5-2007 7:53:16 AM
1127	GENERATN	AGC-MAJOR	0	RGUOFF	LOCAL	ERCOT -BBSES UNIT2 UNIT OFFLINE	9-5-2007 7:53:20 AM
1128	ERCOT	TBD	0	S002	SDSES	SANDOW SES LAAR LD1_1430 ST OPEN	9-5-2007 7:53:25 AM
1129	ERCOT	138KV_BRKR	0	S002	UVALDE	UVALDE CB 8800_CB ST OPEN	9-5-2007 7:53:25 AM
1130	ERCOT	TBD	0	S002	SDSES	SANDOW SES LAAR LD1_1430 LSTS DISABLED	9-5-2007 7:53:25 AM

Case 1:

Condition: No protective relay signals. CB4210, 4220, 4160 4920 status changes are detected.

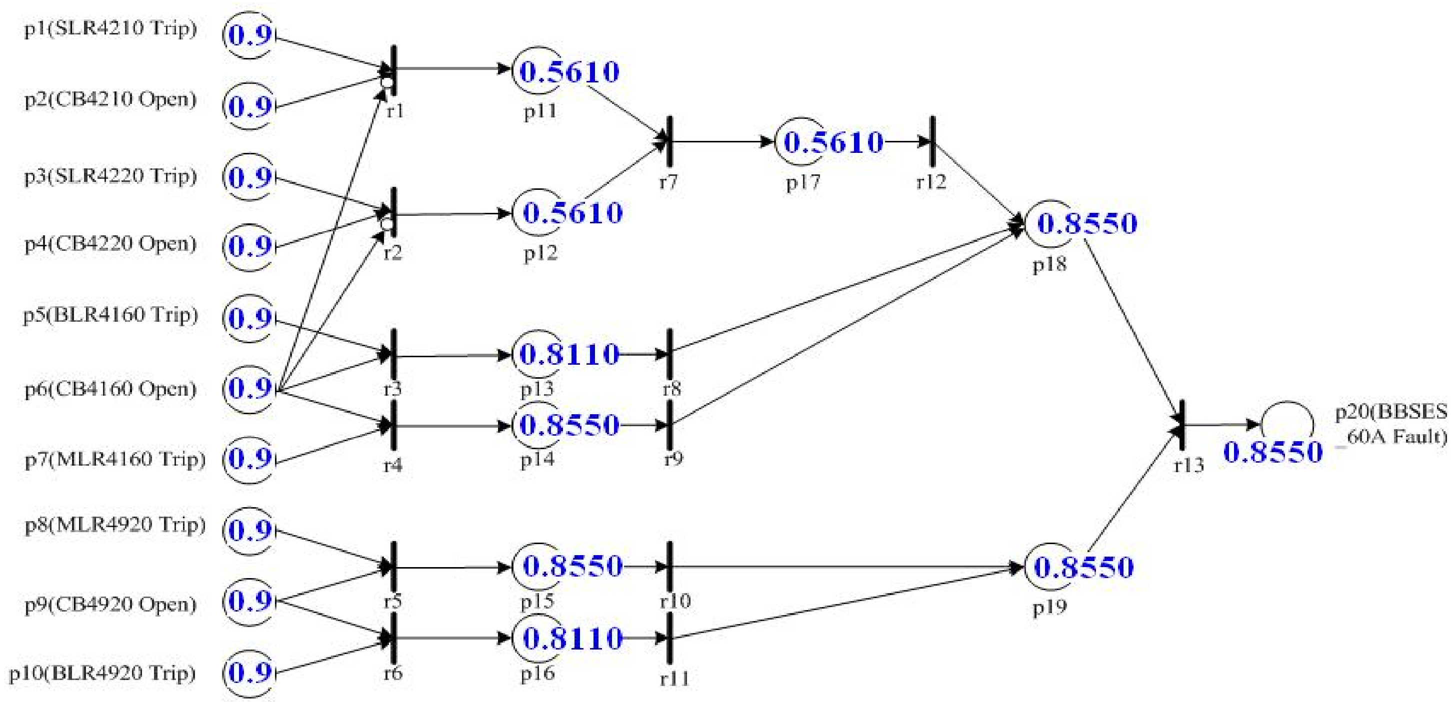
Diagnosis result: Line BBSES_60A is faulted, and its truth value is 0.5130.



Case 2:

Condition: Operation of CB is tripped by associated relays. Received relays signals. CB4210, 4220, 4160 4920 status changes are detected.

Diagnosis result: Line BBSES_60A is faulted, and its truth value is 0.8550. with the input of related relay signals, the fault certainness has been increased dramatically.



Advantages

- The fault alarm analysis report can be generated automatically and immediately after the fault occurs.
- The FRPN models can be built in advance based on power system and protection system configurations and stored in files.
- The FRPN models can be easily modified according to the changes of input data as well as power system and protection system configuration.
- This solution can use only SCADA data and does not need detailed data from IEDs or other measurement devices.

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  - Data Processing
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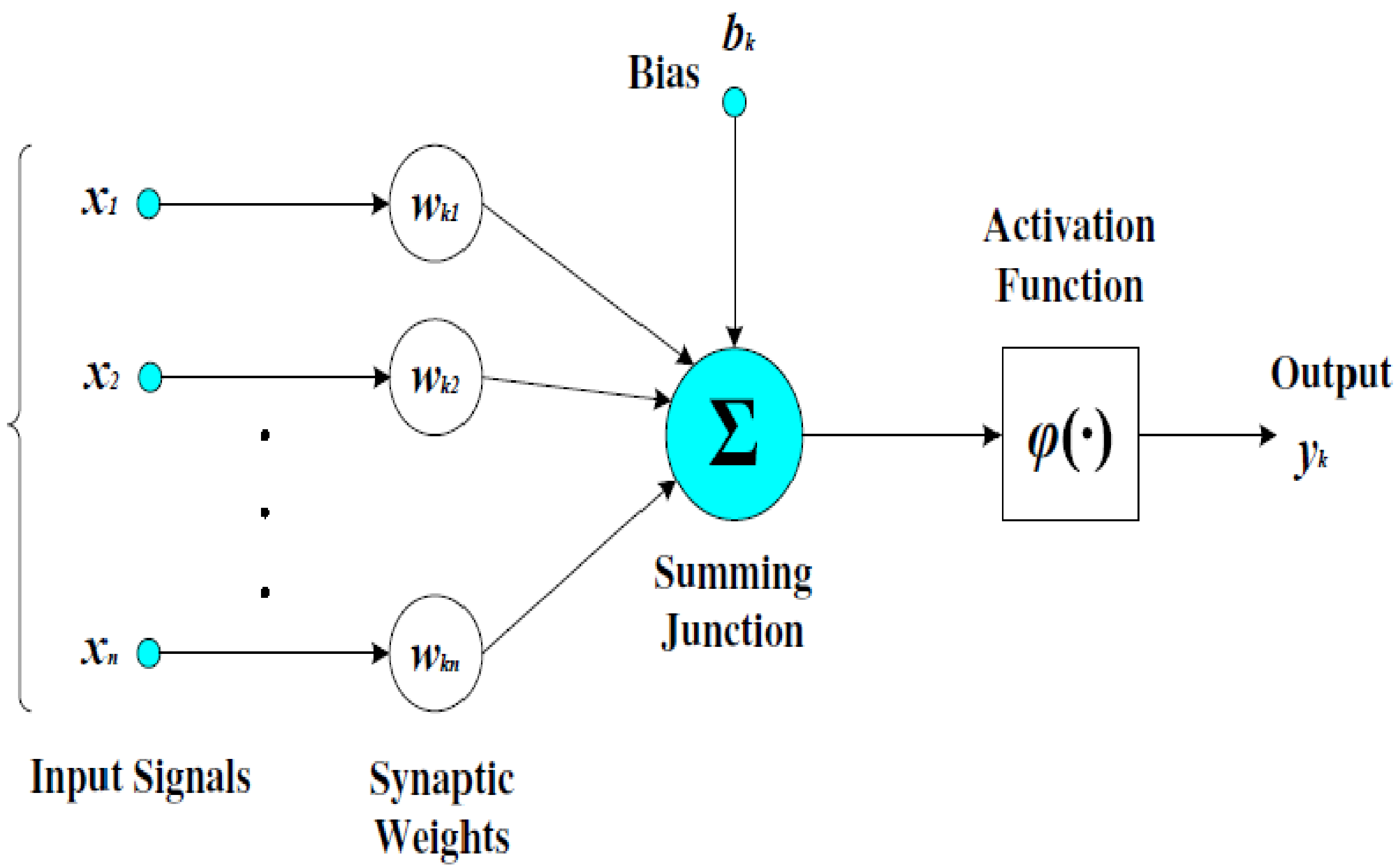
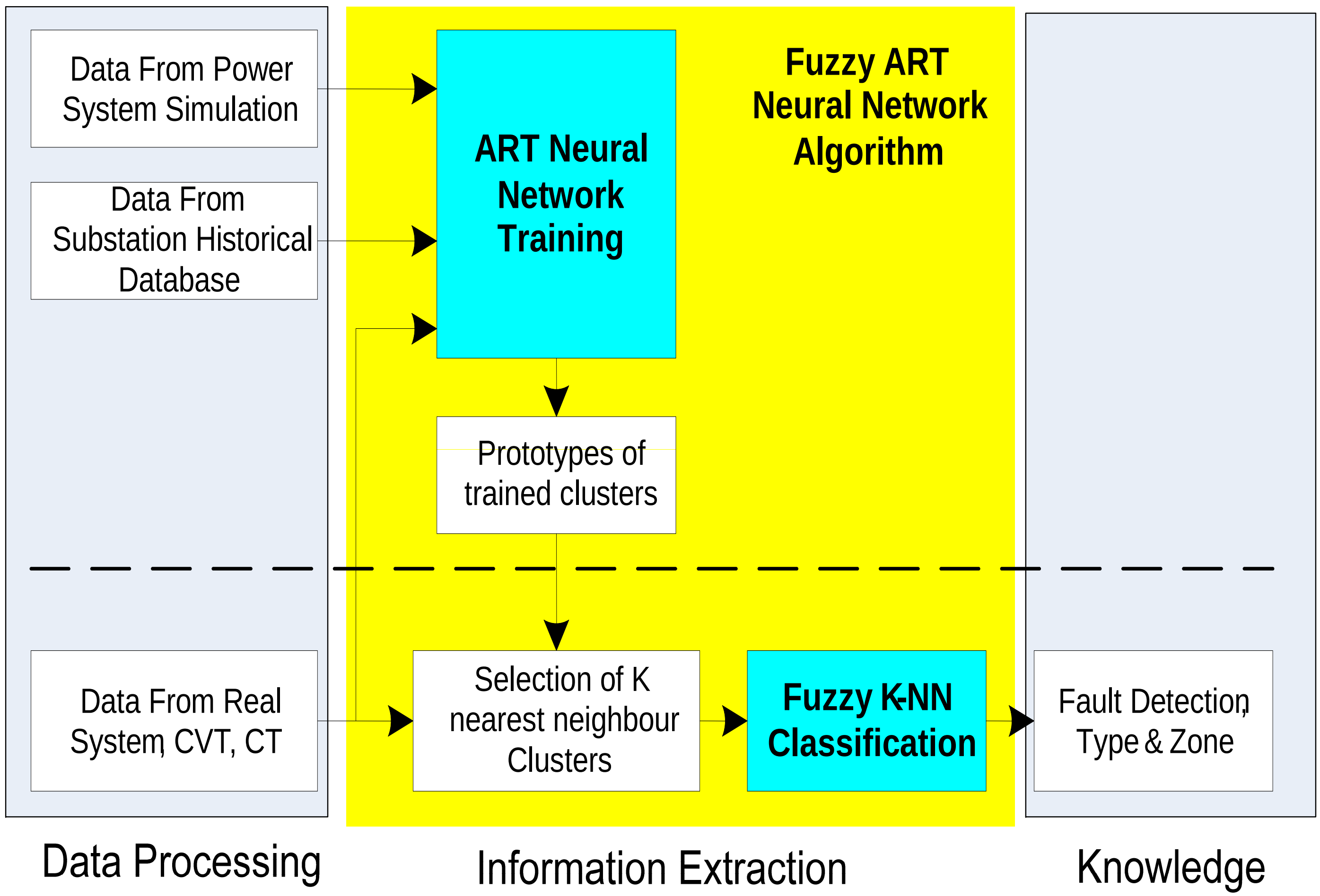
Inherently Adaptive Fault Detection and Classification

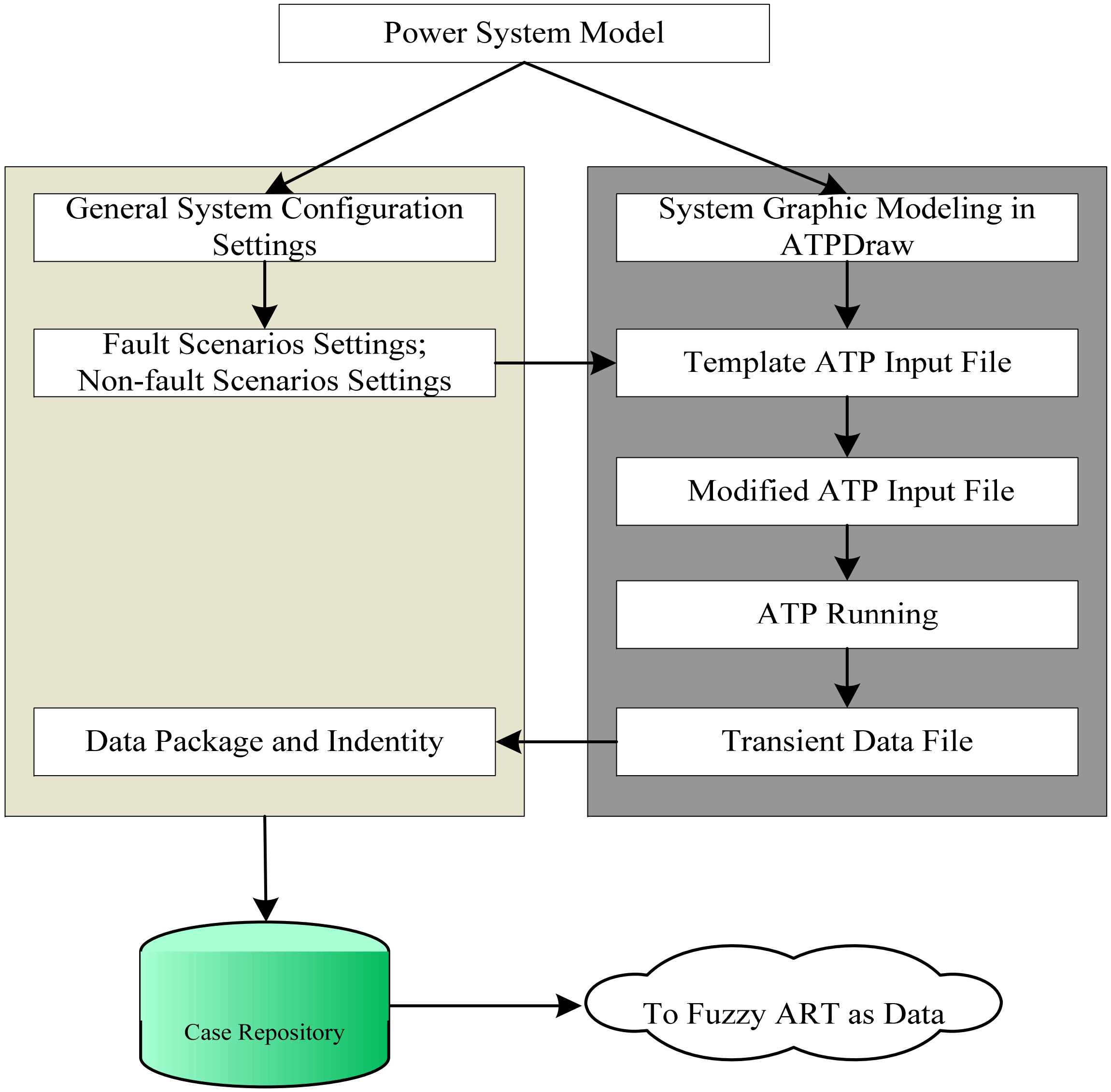
Overview of Neural Network Algorithms



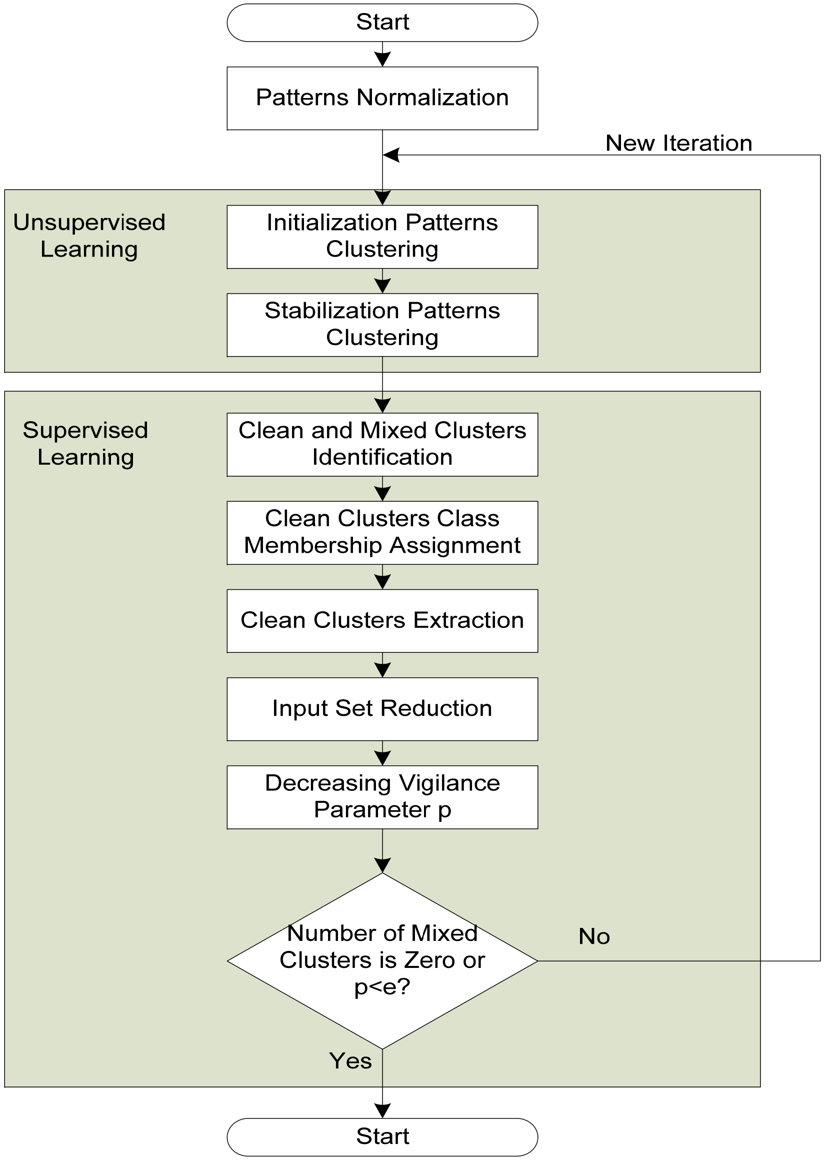
Fuzzy ART Neural Network Algorithm

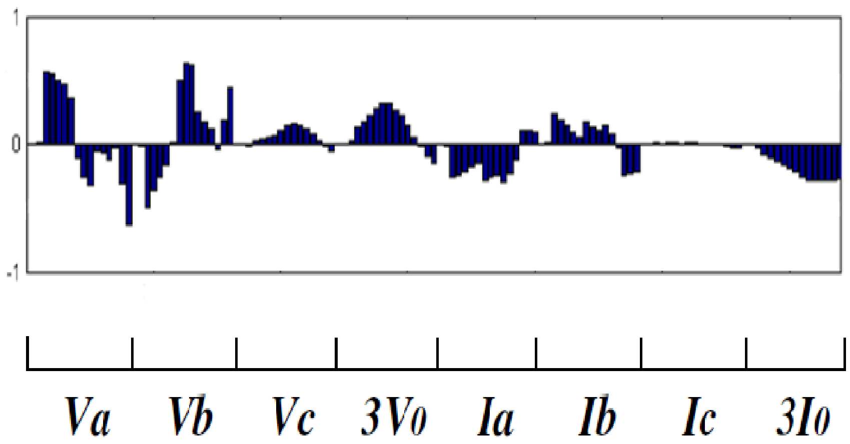


Data Processing



Information Extraction

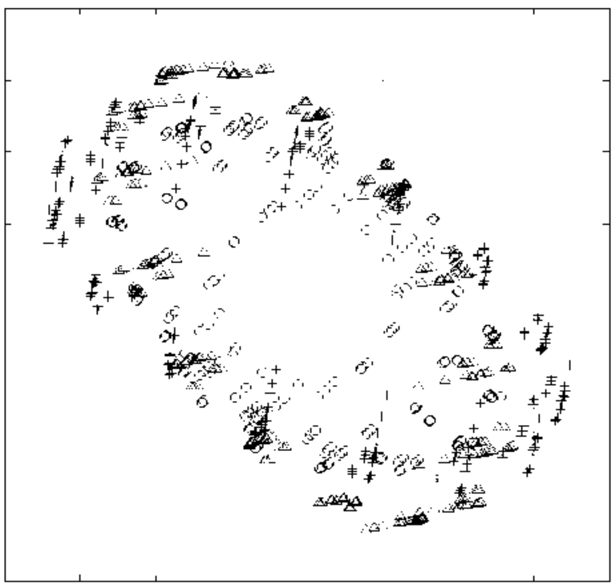


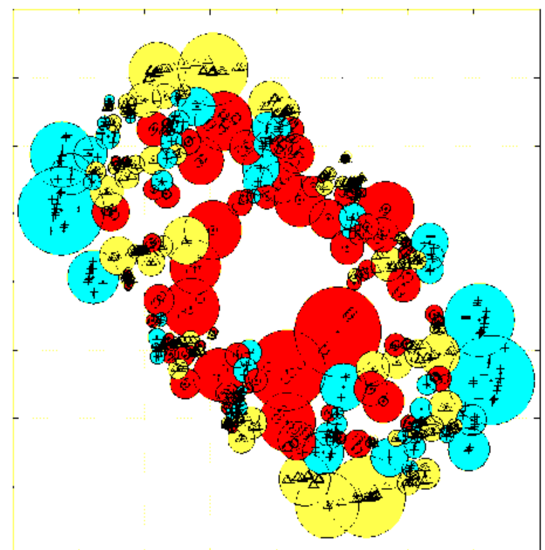


Implementation

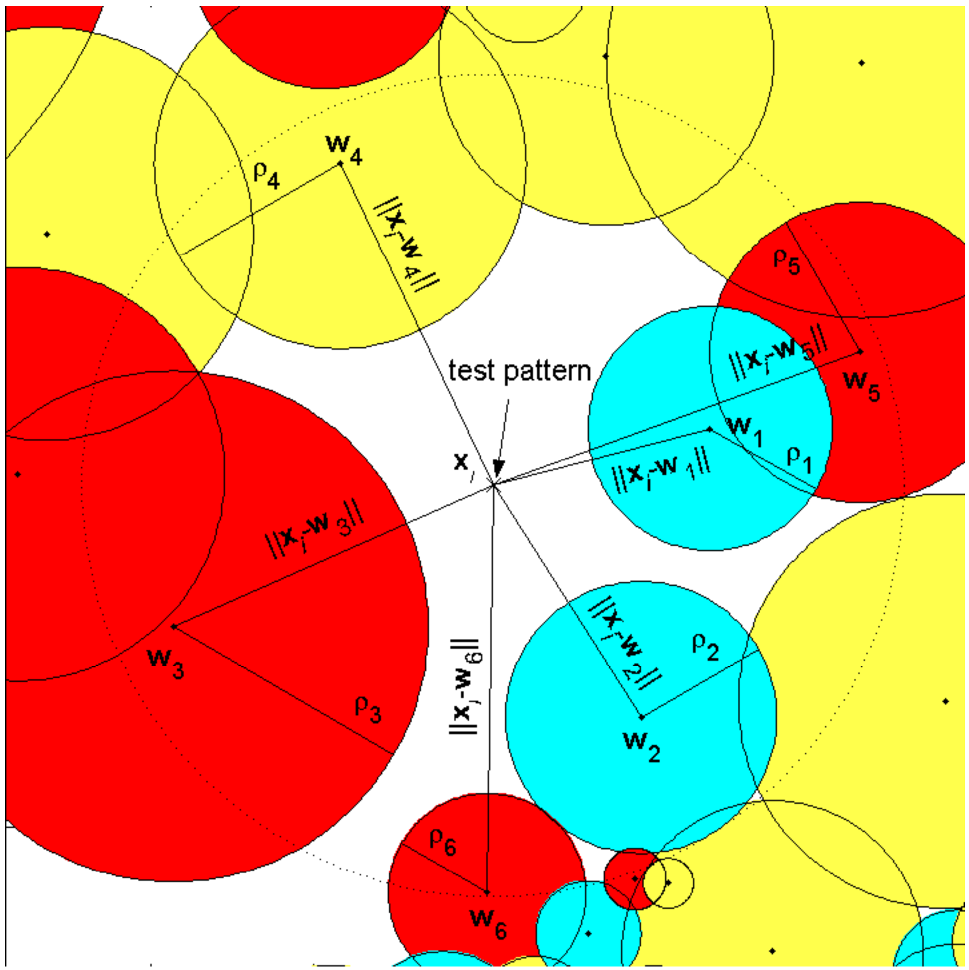
Detecting and Classifying Faults by Mapping Data to Labeled Clusters

- The raw training patterns - information
- The patterns are allocated to the clusters after a training processing - knowledge

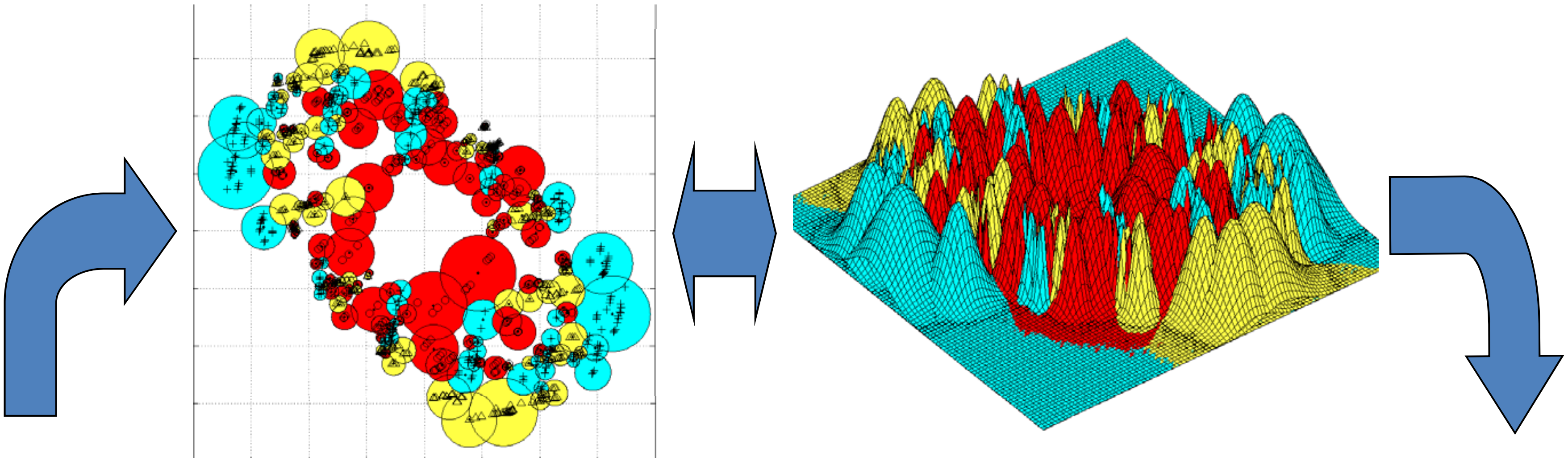


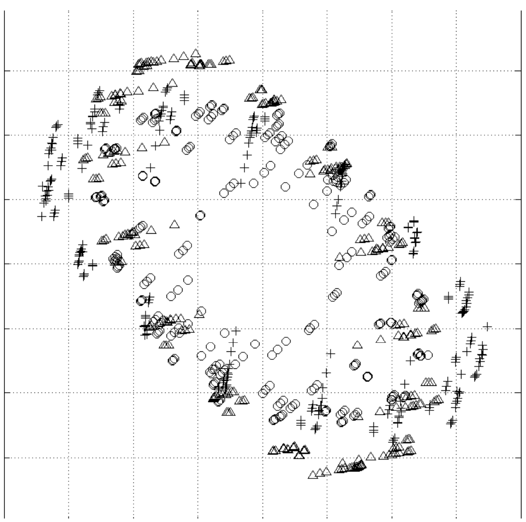


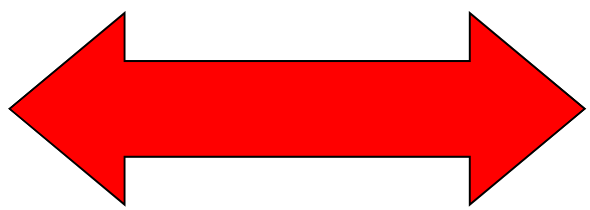
Fuzzification of NN outputs

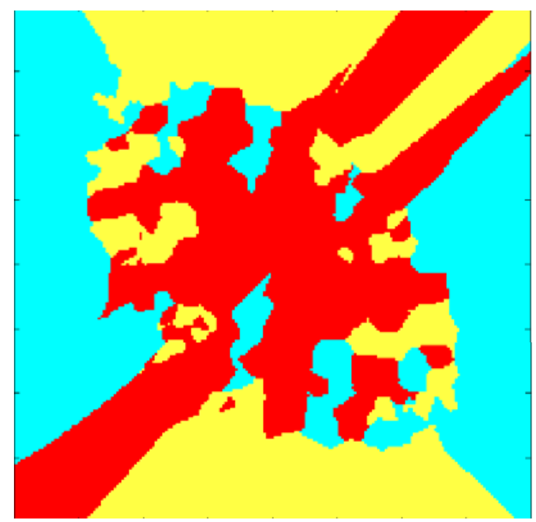


Final Implementation



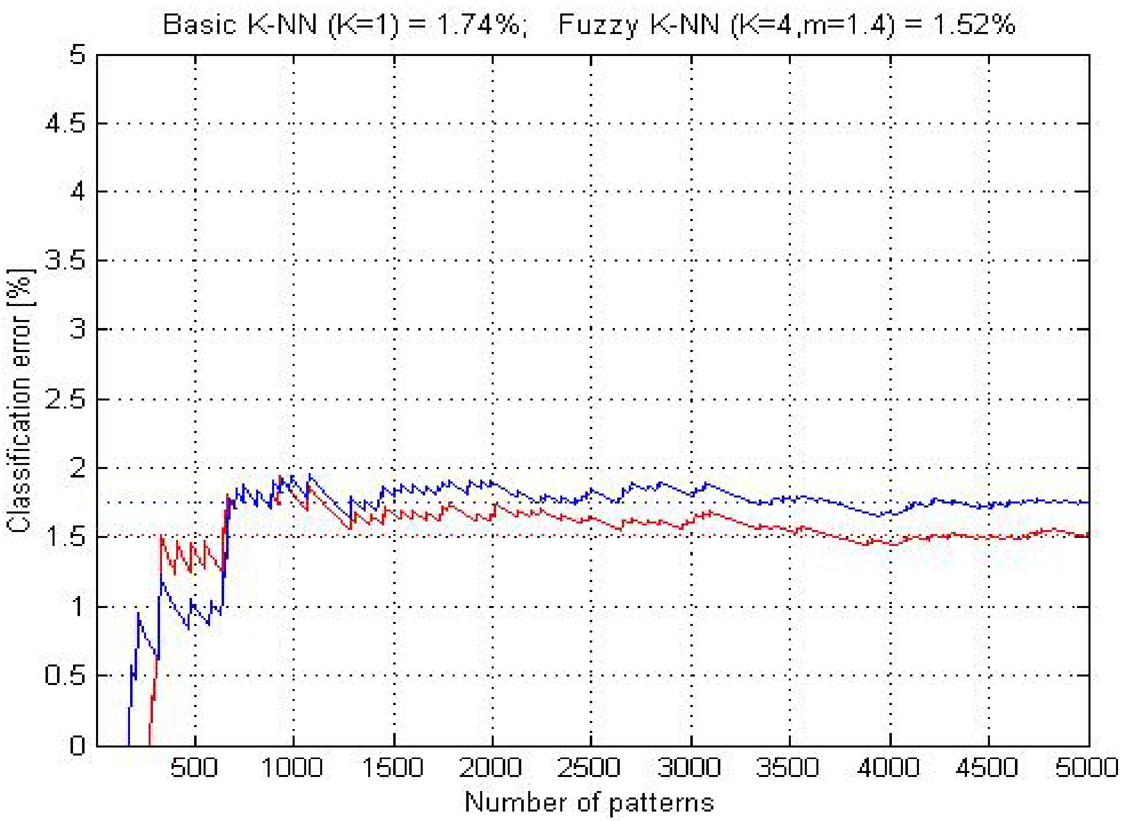






Case Study

Error results of neural network fault classification tools



"You are completely free to carry out whatever research you want, so long as you come to these conclusions."

Conclusions

- **Fault location**: matching field data with model data creates an optimal solution ;
- **Alarm processing**: matching data to the model of relaying logic creates an intelligent cause-effect analysis;
- **Protective relaying**: matching data vectors from the field signals with cluster of patterns designating fault types created an inherently adaptive protection.

Thank you!

Questions?

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