Real-Time Wide-Area Dynamic Monitoring Using Characteristic Ellipsoid Method

Funded by DOE through CERTS

Presented by Dr. Yuri V. Makarov on behalf of the project team

NASPI Meeting
Orlando, FL
February 29 – March 1, 2012

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Project Team

(in alphabetic order)

- Mr. Jeff Dagle (P.E., Program Manager, Chief Engineer)
- Dr. Ruisheng Diao (Research Engineer, decision trees)
- Dr. Pavel V. Etingov (Senior Research Engineer)
- Dr. Spenser Hays (Scientist, statistics and forecasting)
- Dr. Jian Ma, (P.E., Project Lead, Research Engineer)
- Dr. Yuri V. Makarov (Principal Investigator, Chief Scientist)
- Mr. Carl H. Miller (Research Engineer)
- Mr. Mark Morgan (Manager, also has a nice voice).
- Dr. Tony B. Nguyen (Senior Research Engineer)
- Dr. Enrico De Tuglie (Assoc. Prof., Politecnico di Bari, Italy)
- Dr. Ning Zhou (Senior Research Engineer)

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Acknowledgements

- DOE, EE Office
- Philip N. Overholt, DOE
- Jeffery E. Dagle, PNNL, CERTS PM
- Dr. Joseph H. Eto, LBNL, CERTS PM
- Matthew Gardner, Dominion Power, NASPI RITT Chair
- Alison Silverstein, NASPI Manager
- Carl H. Imhoff, Manager, Electric Infrastructure Market Sector, PNNL
- Dale King, Product Line Manager, PNNL

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Project Overview

- The objective is to develop a more informative, actionable and predictive phasor-based application.
- Support: PNNL-LDRD in 2007; and U.S. DOE's Office of Electricity Delivery and Energy Reliability through the Consortium for Electric Reliability Technology Solutions (CERTS)
- Developed *a new CELL methodology* and *a demonstration tool capable of*:
  - Monitoring dynamic behaviors of power systems
  - Identifying system disturbances
  - Providing wide-area situation awareness far beyond a single control area
  - *Supplying predictive and actionable information* (in progress) – DOE Peer Review recommendation
- *Field demonstration* (in progress).

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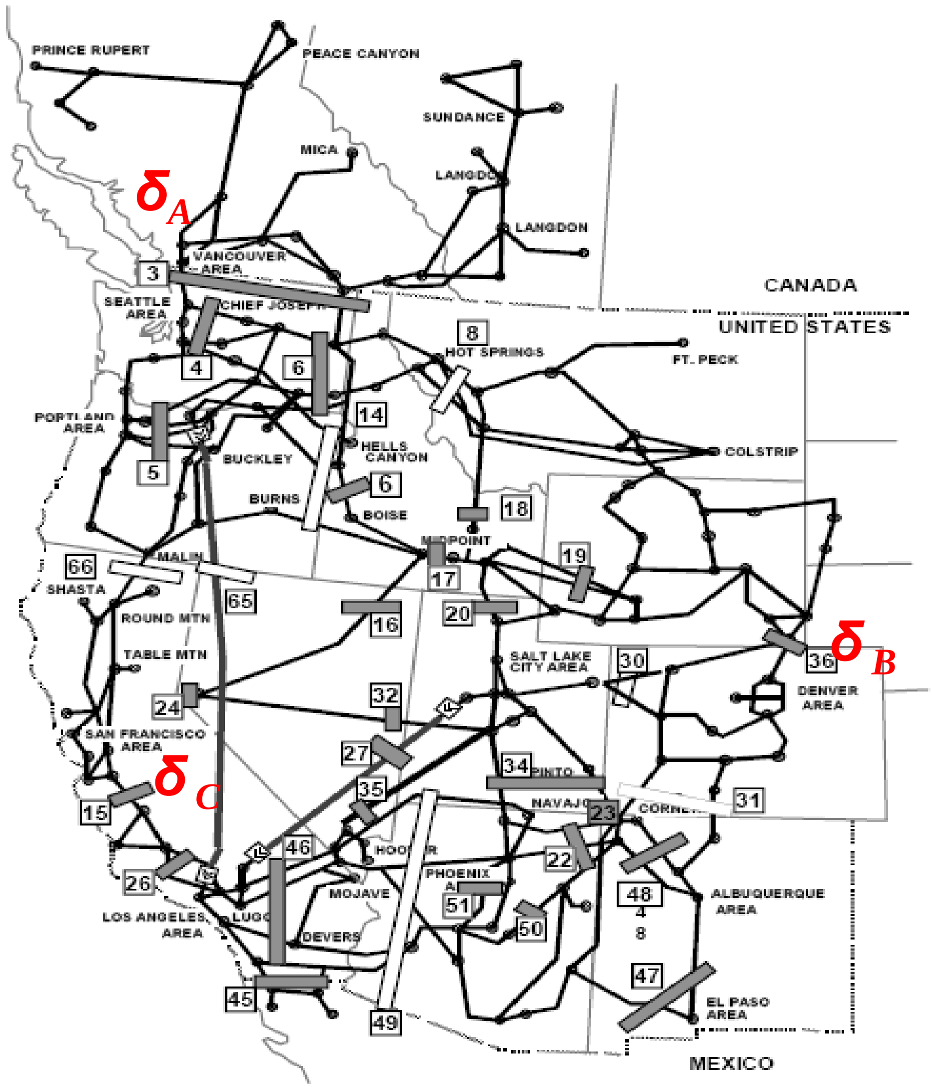
The Idea of CELL (1)



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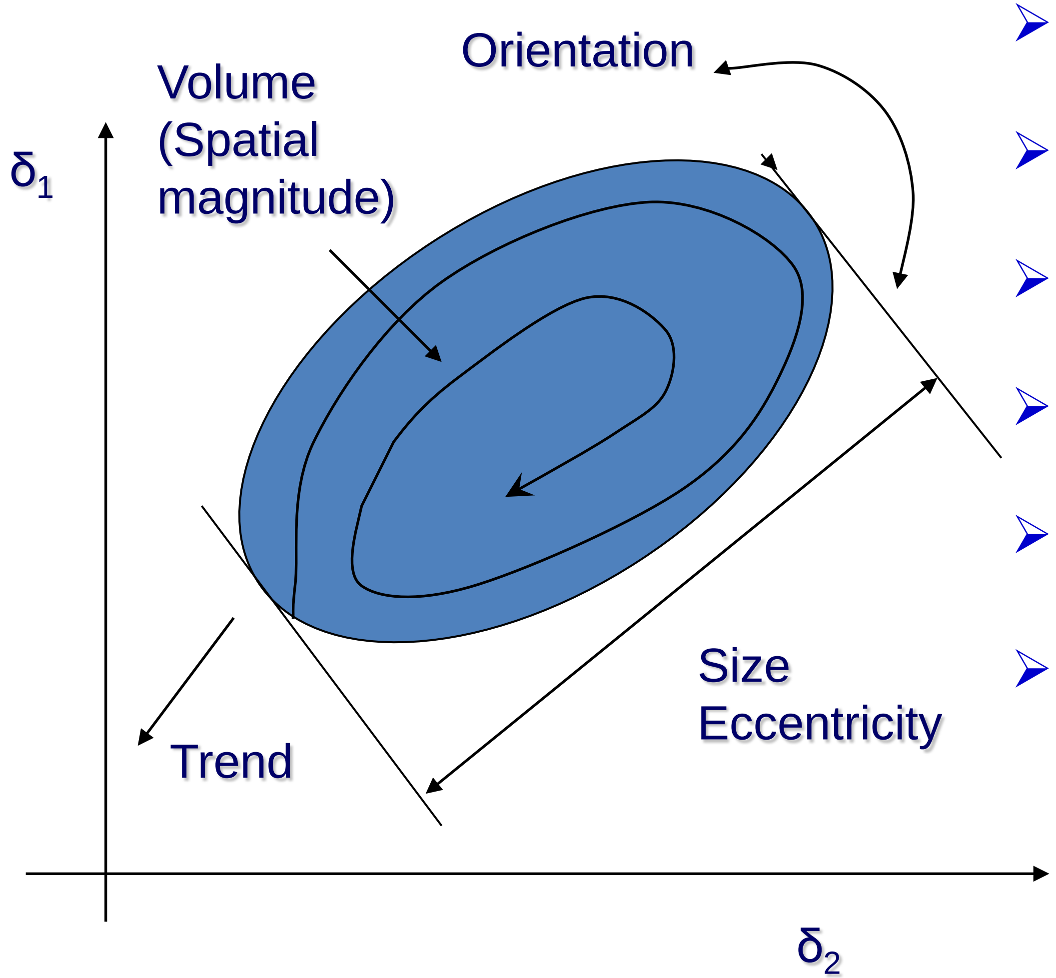
The Idea of CELL (2)



- Sudden volume change
  System disturbance
- Volume and shape
  Spread of disturbance
- Orientation
  Disturbance location
- Shape and orientation
  System's prevailing motions
- Speed of volume change
  Generalized damping
- Use *decision trees* to recognize disturbances and their attributes

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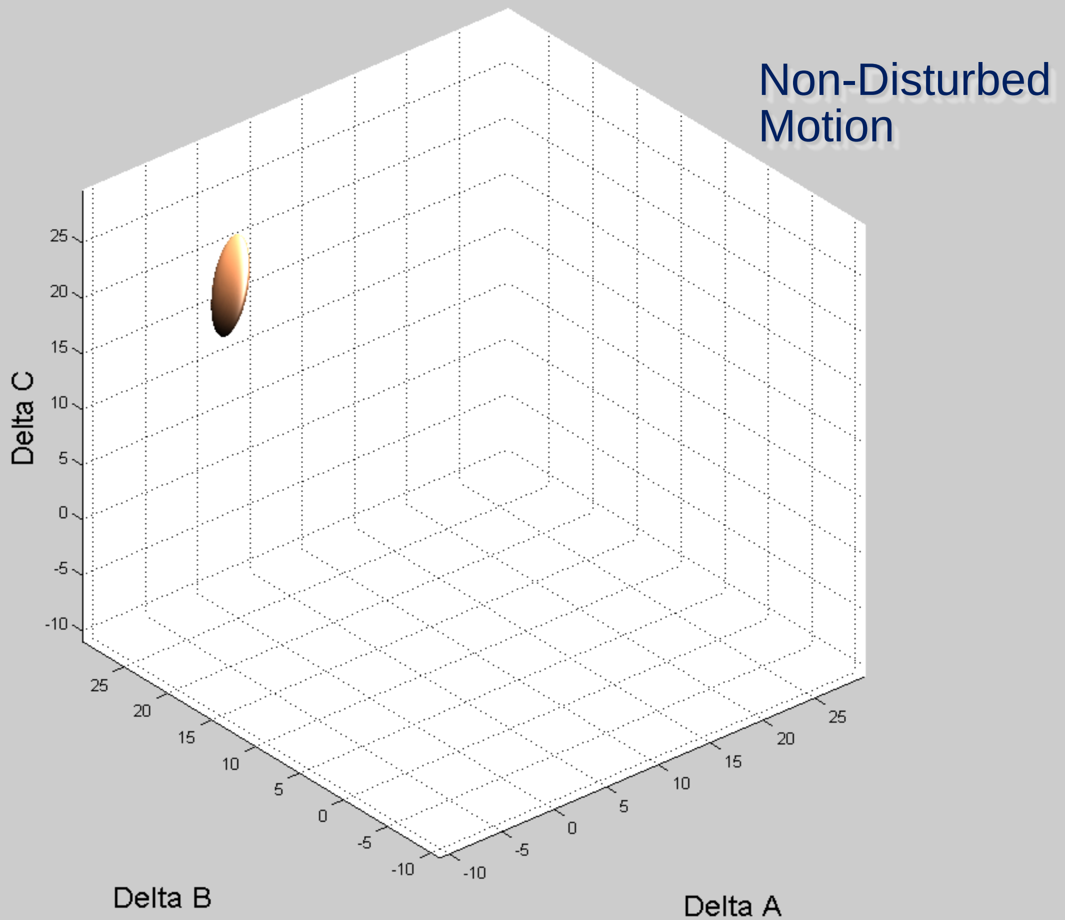
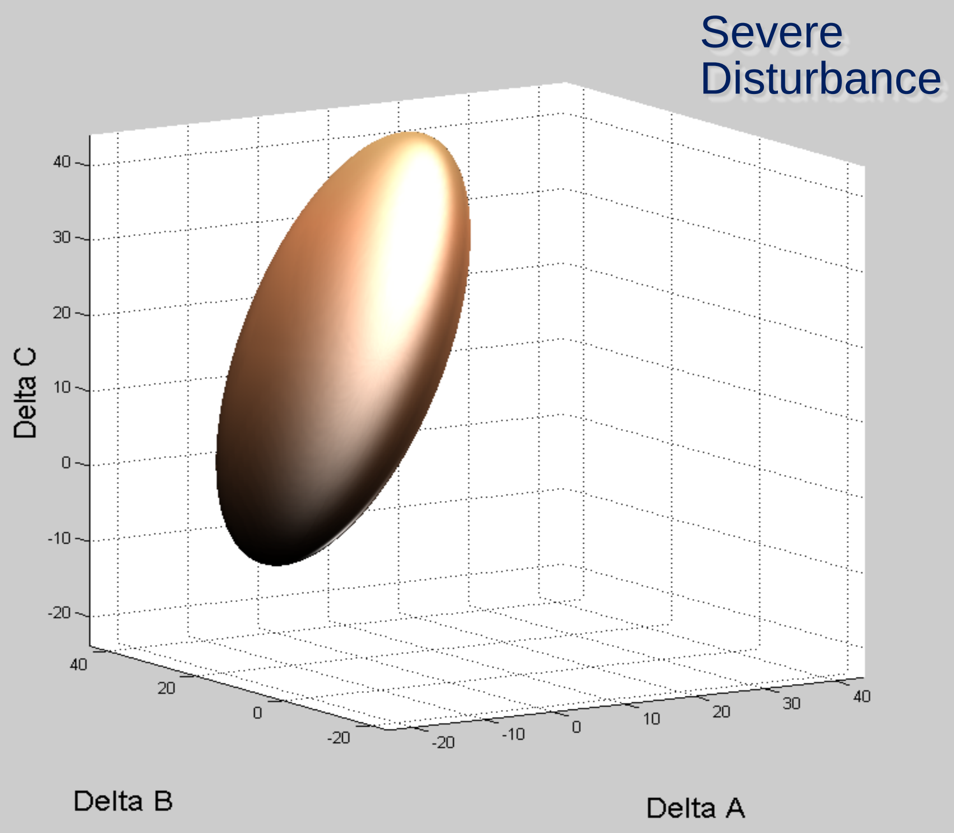
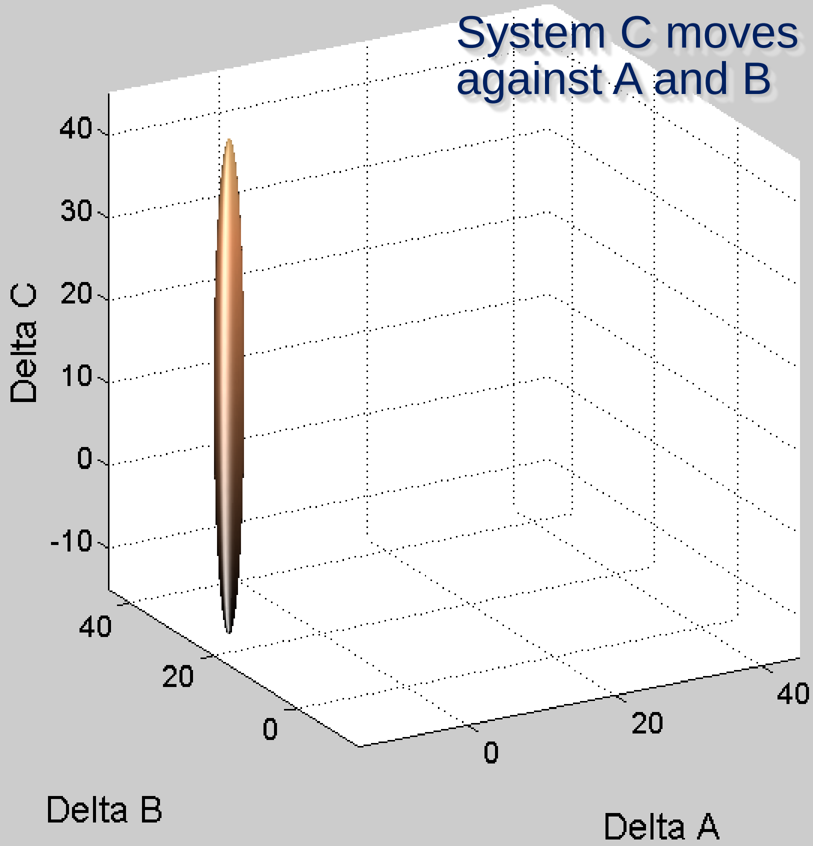
The Idea of CELL (3)



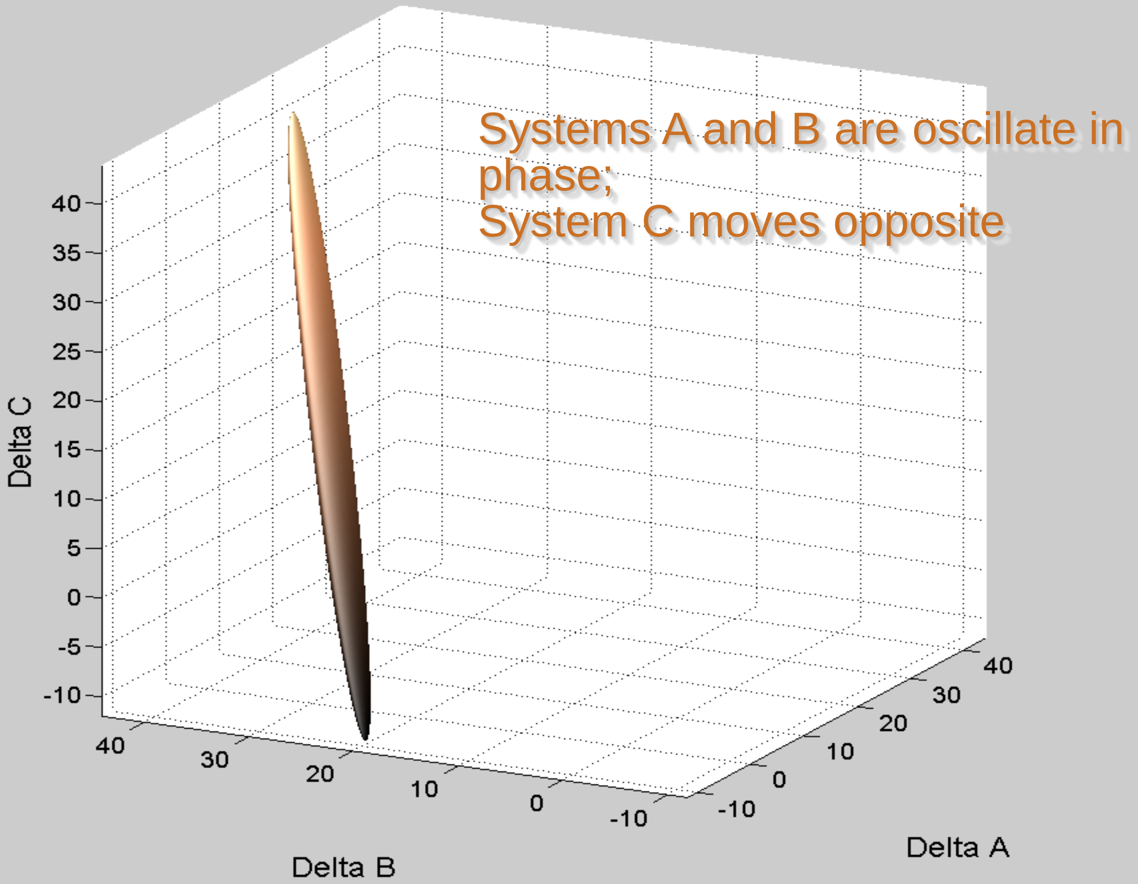
The Idea of CELL (4)



The Idea of CELL (5)



The Idea of CELL (6)



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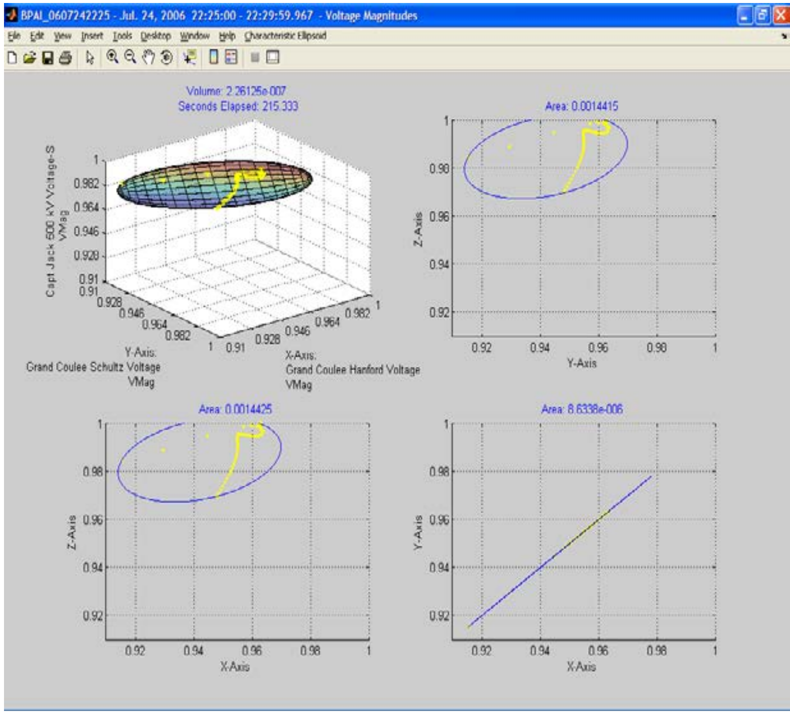
Methodology of CELL

- System behavior ➡ trajectory in phasor measurements space ➡ the most recent part of the trajectory ➡ CELL
- Trajectory ➡ differential and algebraic equations (DAE)
- DAE ➡ single quadratic algebraic equation:

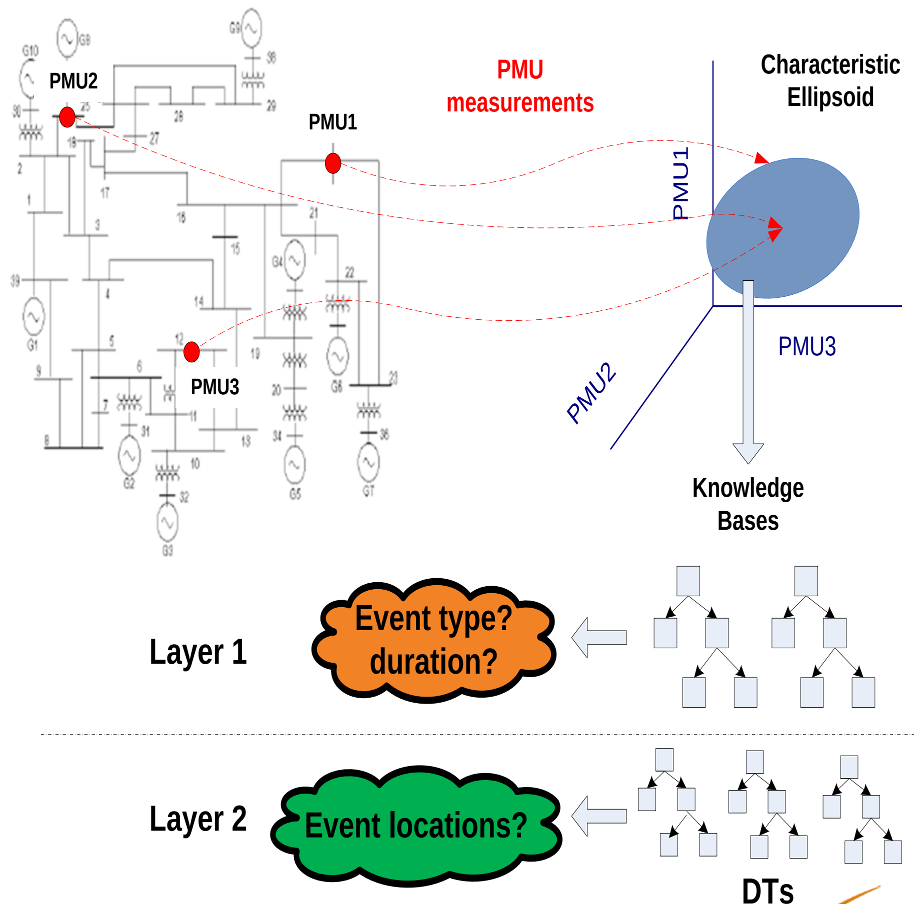
$$\begin{cases} \dfrac{dx_1}{dt} = F_1(x_1, x_2, \dots, x_n) \\ \dfrac{dx_2}{dt} = F_2(x_1, x_2, \dots, x_n) \\ \dots \\ \dfrac{dx_n}{dt} = F_n(x_1, x_2, \dots, x_n) \end{cases} \Rightarrow a_1 y_1^2 + a_2 y_2^2 + \dots + a_n y_n^2 = c$$

- Optimization procedure ➡ minimize the volume of CELL
- CELL *encloses* all recent points of system trajectory
- Key characteristics of CELL:
  - *volume*
  - *eccentricity*
  - *orientation of axes*
  - *derivative of the volume*
  - *characteristic sizes*
  - *projection of axes*



CELL + DT Methodology

- Moving from CELL's characteristic to physically meaningful information
- Decision trees are employed
- Physically meaningful system events and behaviors:
  - ♦ *disturbances*
    (type, location, size, etc)
  - ♦ *generalized damping*
  - ♦ *coherency of motions*



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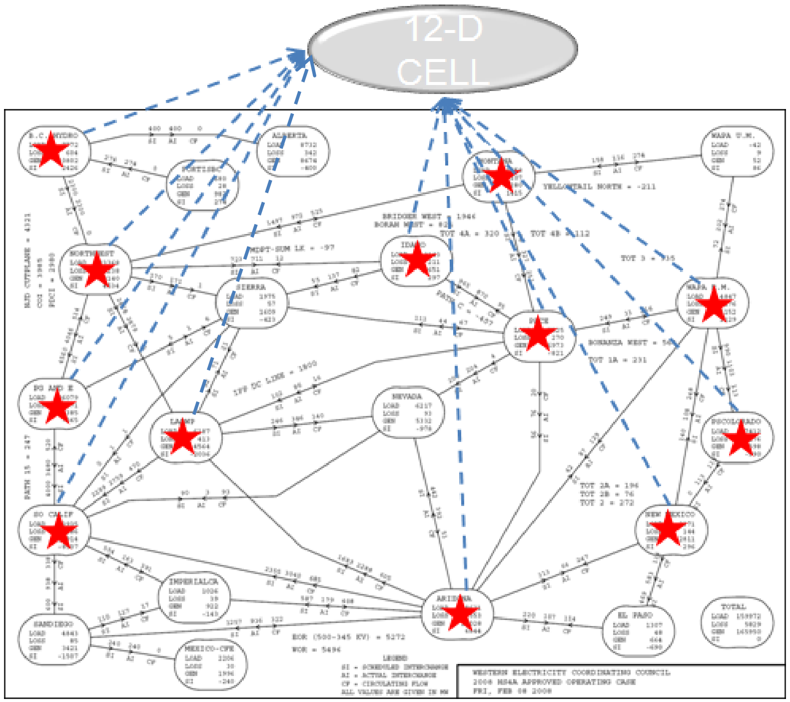
CELL+DT Results

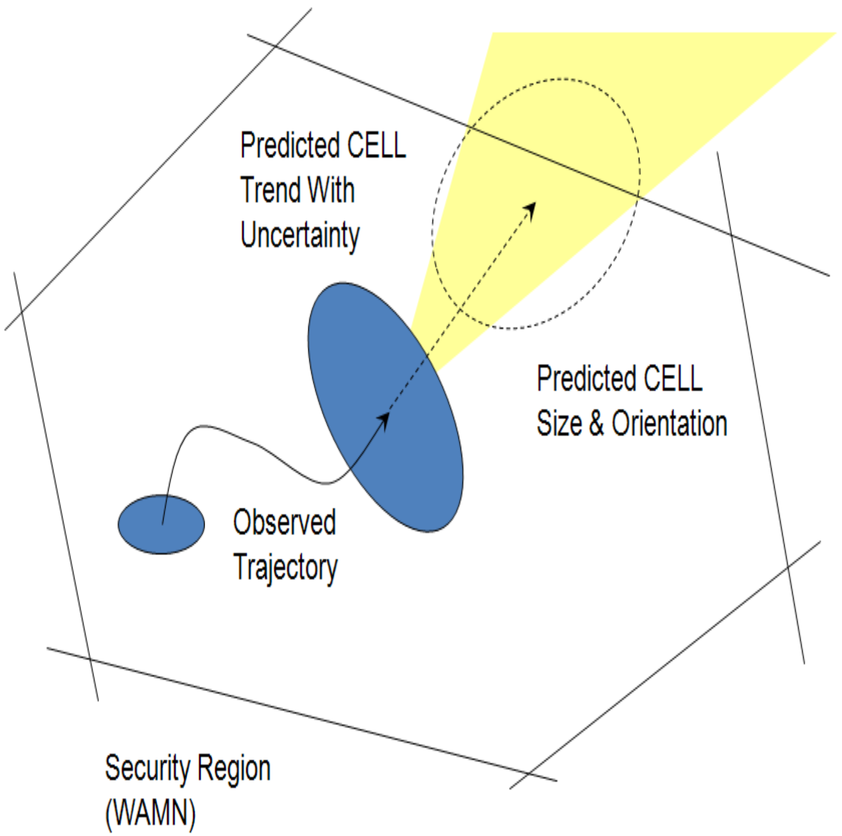
- Tested on the full WECC operational model:
  - 16,031 buses
  - 3,993 transmission lines
  - 3,216 generators
  - 6,330 transformers
- Operating conditions
  - 2009 heavy summer base case
  - 25 operating conditions
- Simulated five type of events at various locations
  - Generator trips: 112 machines
  - Line trips: 117 transmission lines
  - Three-phase faults: 111 bus locations
  - Load loss: 34 loads
  - Shunt switching: 23 locations
  - Over 19K simulations
- Select only 12 PMUs across WECC to identify types and locations of various events

- Performance (overall average accuracy)
  - Event types (5 types): *97.48%*;
  - Fault locations (9 zones): *99.01%*
  - Line trip locations (9 zones): *95.21%*
  - Load loss locations (3 zones): *98.24%*
  - Generator trip locations (13 zones): *97.86%*

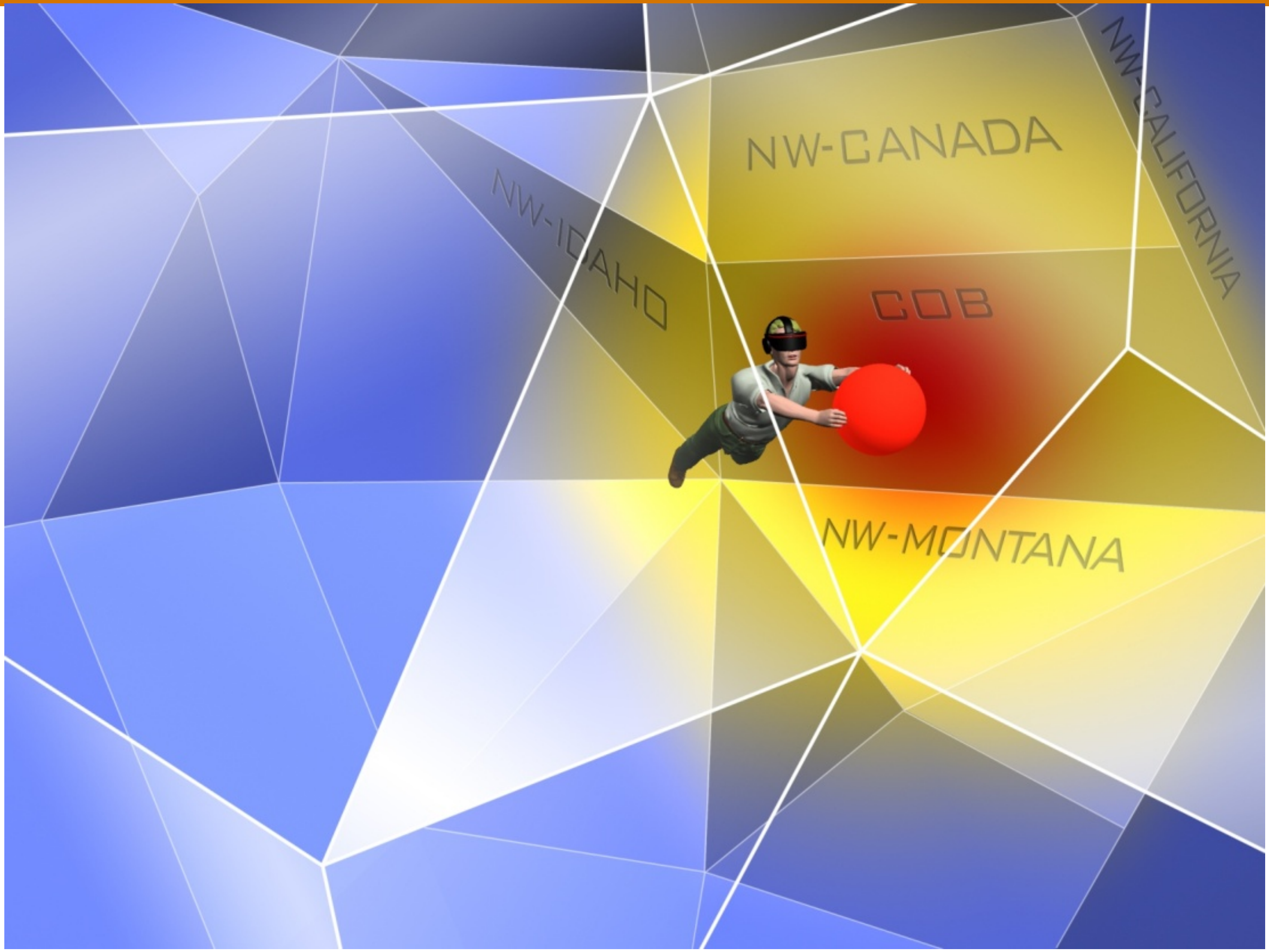


Predictive CELL (1)

- Evaluate available security margin
  - Build security region represented as wide area nomograms
  - Calculate the shortest distance to security boundary
- Build probabilistic CELL
  - Statistical analysis with different confidence levels
  - Calculate CELL's probabilistic characteristic indices
- Predict future CELL trace (center, shape and orientation)
  - Violation type and probability
  - Places where possible violation may occur
  - Time remaining to violation
- Propose preventive corrective actions when needed



Virtual Reality Representation of the CELL Within the Security Region



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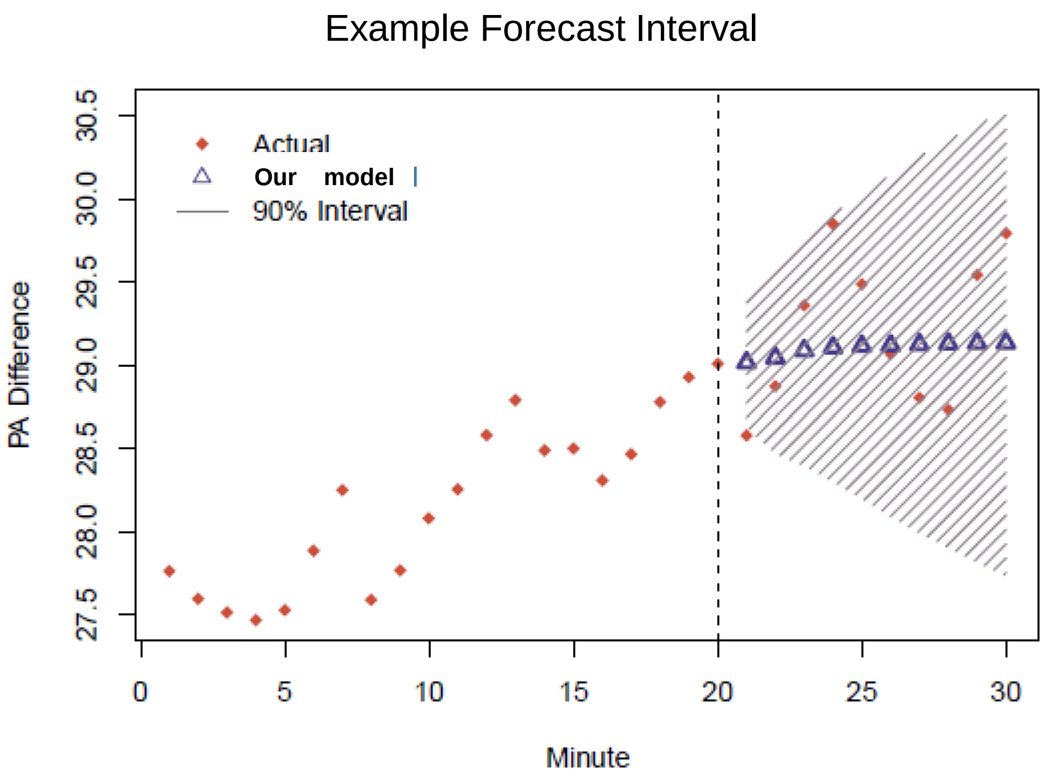
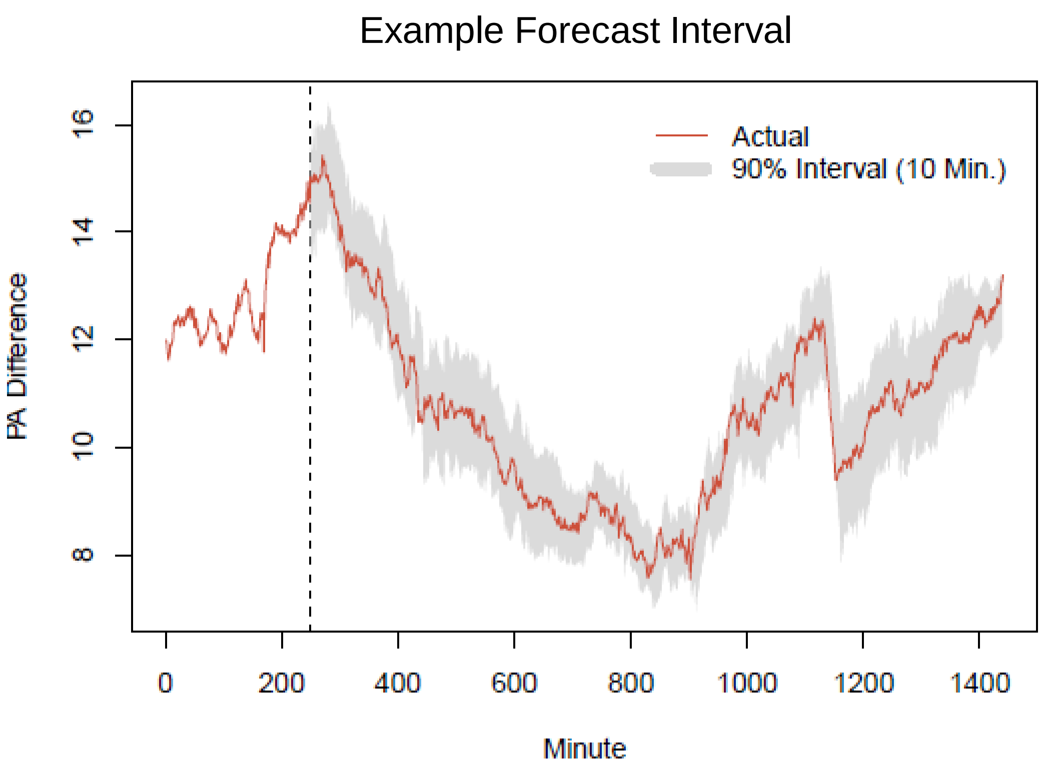
Predictive CELL (2)

- Example:
  - 90% probability forecast interval.
  - 1 to 10 minutes ahead.
  - 9/10 actual values are found within forecast region.
  - 7/10 predicted values within ±0.5 electrical degree of the actual.



Predictive CELL (3)



- Example (cont.):
  - Forecasts updated by minute (after initial 2 hrs).
  - 90% confidence.
  - 10-minute ahead forecasts.

- Other than one large drop, series within bounds.
- *Detected large deviations – this is a signal that the system starts to move strangely or faster*.

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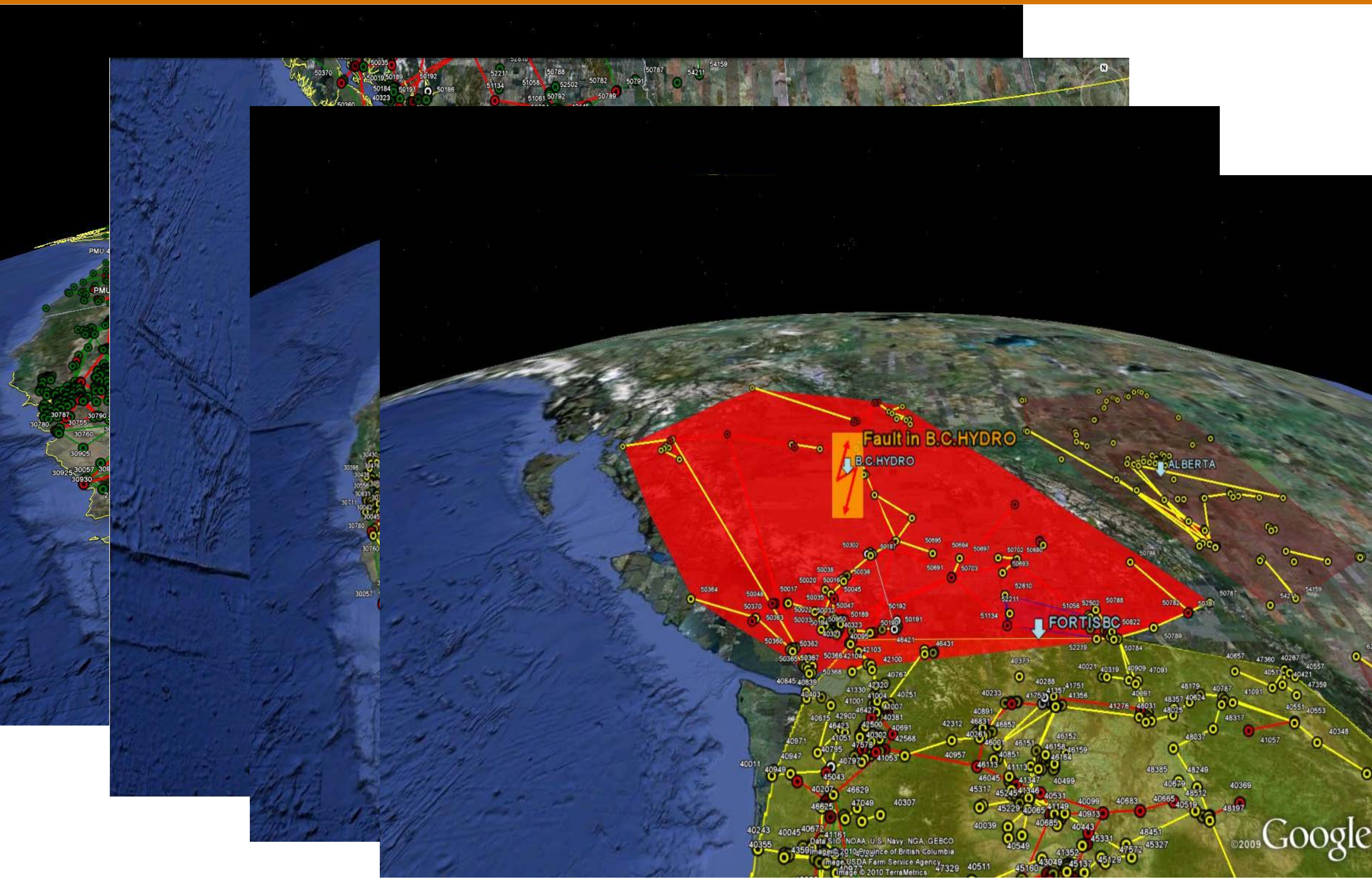
GUI Voice + Graphics (in progress)



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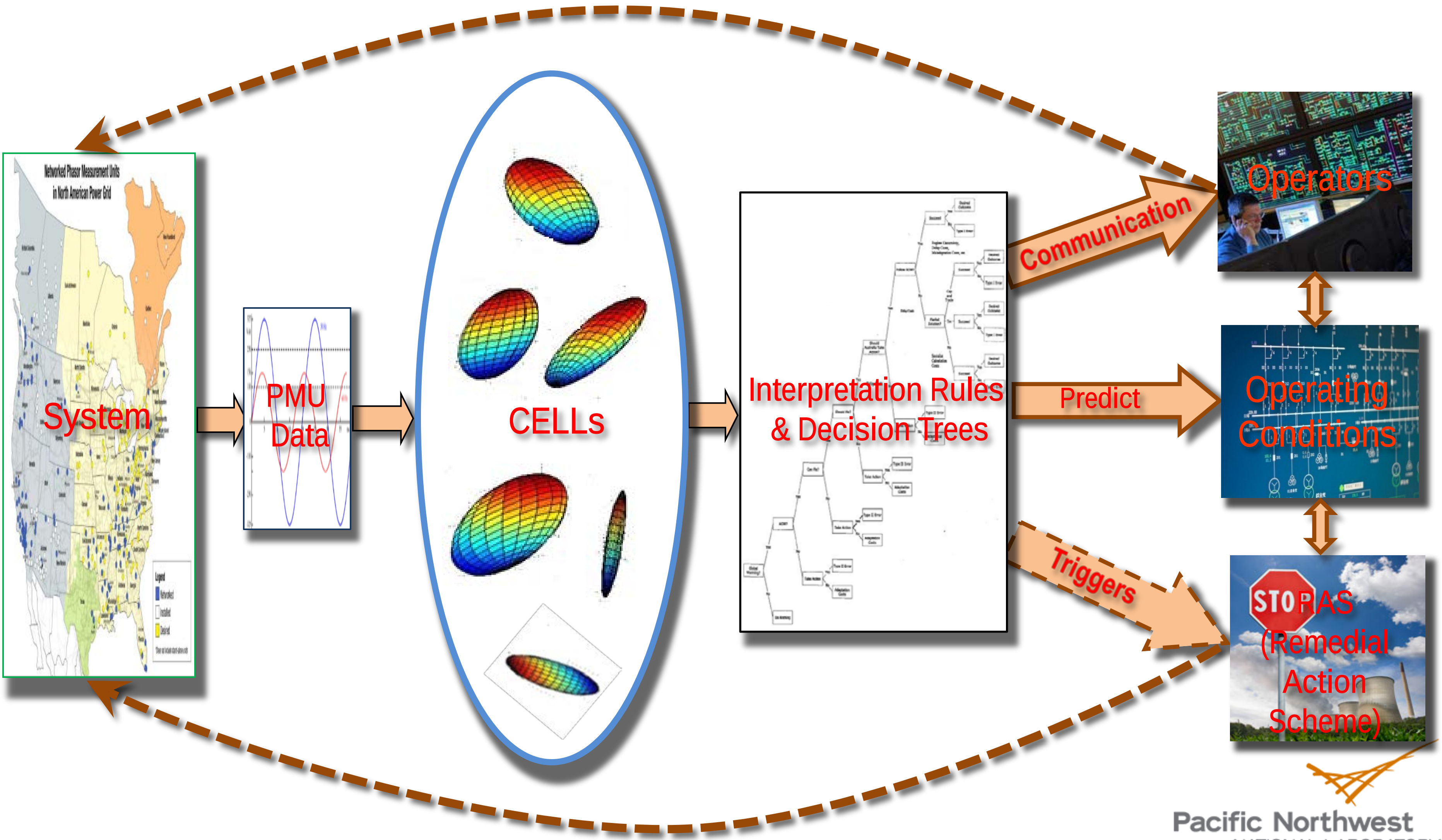
Future Work



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