EPRI | ELECTRIC POWER RESEARCH INSTITUTE

In Search of the Holy Grail of PMU Applications for Visualization and Prediction of Cascading Outages

Stephen Lee

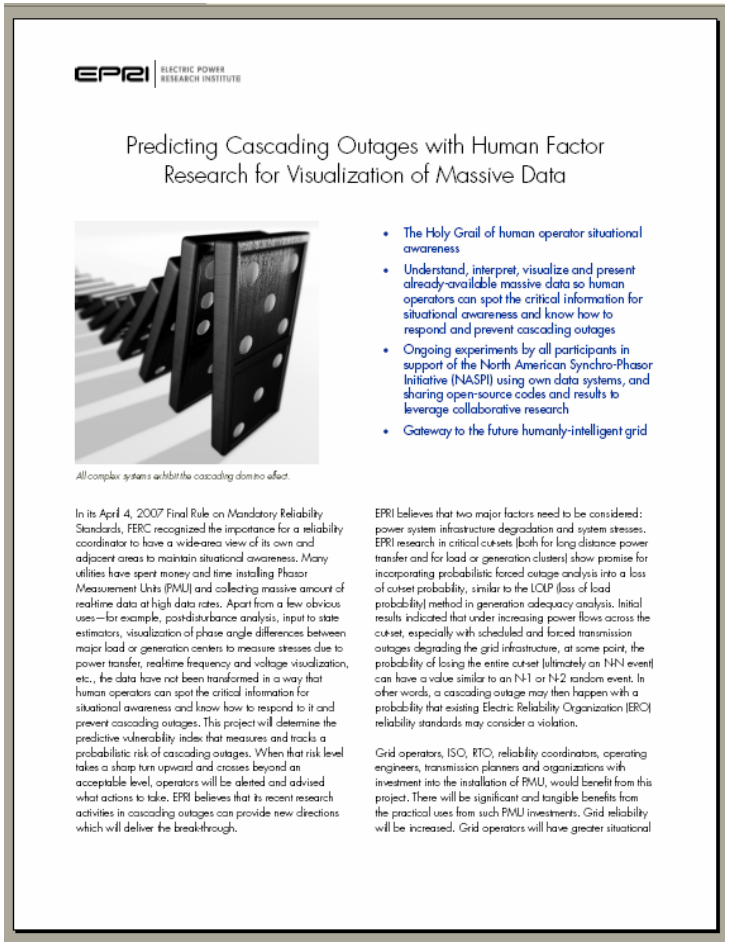
Sept 6, 2007

NASPI, Montreal

The Search is Getting Somewhere!

Research project on predicting cascading outages with human factor research

- Collaborative Research Opportunity with EPRI
  - In coordination with NASPI
  - Task force meetings and webcasts
  - Pooling of resources
    - Funding to support research in methodologies and human factors
    - Inhouse resources to support coding of computation and visualization modules
    - Sharing of results and algorithms
  - Enable experiments for each participant, using own EMS or PI servers
  - HTM pilot software available to funders
  - Vendors welcome to join



EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Predicting Cascading Outages with Human Factor Research for Visualization of Massive Data

All complex systems exhibit the cascading domino effect.

- The Holy Grail of human operator situational awareness
- Understand, interpret, visualize and present already-available massive data so human operators can spot the critical information for situational awareness and know how to respond and prevent cascading outages
- Ongoing experiments by all participants in support of the North American Synchro-Phasor Initiative (NASPI) using own data systems, and sharing open-source codes and results to leverage collaborative research
- Gateway to the future humanly-intelligent grid

In its April 4, 2007 Final Rule on Mandatory Reliability Standards, FERC recognized the importance for a reliability coordinator to have a wide-area view of its own and adjacent areas to maintain situational awareness. Many utilities have spent money and time installing Phasor Measurement Units (PMU) and collecting massive amount of real-time data at high data rates. Apart from a few obvious uses—for example, post-disturbance analysis, input to state estimators, visualization of phase angle differences between major load or generation centers to measure stresses due to power transfer, real-time frequency and voltage visualization, etc., the data have not been transformed in a way that human operators can spot the critical information for situational awareness and know how to respond to it and prevent cascading outages. This project will determine the predictive vulnerability index that measures and tracks a probabilistic risk of cascading outages. When that risk level takes a sharp turn upward and crosses beyond an acceptable level, operators will be alerted and advised what actions to take. EPRI believes that its recent research activities in cascading outages can provide new directions which will deliver the break-through.

EPRI believes that two major factors need to be considered: power system infrastructure degradation and system stresses. EPRI research in critical cut-sets (both for long distance power transfer and for load or generation clusters) show promise for incorporating probabilistic forced outage analysis into a loss of cut-set probability, similar to the LOLP (loss of load probability) method in generation adequacy analysis. Initial results indicated that under increasing power flows across the cut-set, especially with scheduled and forced transmission outages degrading the grid infrastructure, at some point, the probability of losing the entire cut-set (ultimately an N-N event) can have a value similar to an N-1 or N-2 random event. In other words, a cascading outage may then happen with a probability that existing Electric Reliability Organization (ERO) reliability standards may consider a violation.

Grid operators, ISO, RTO, reliability coordinators, operating engineers, transmission planners and organizations with investment into the installation of PMU, would benefit from this project. There will be significant and tangible benefits from the practical uses from such PMU investments. Grid reliability will be increased. Grid operators will have greater situational

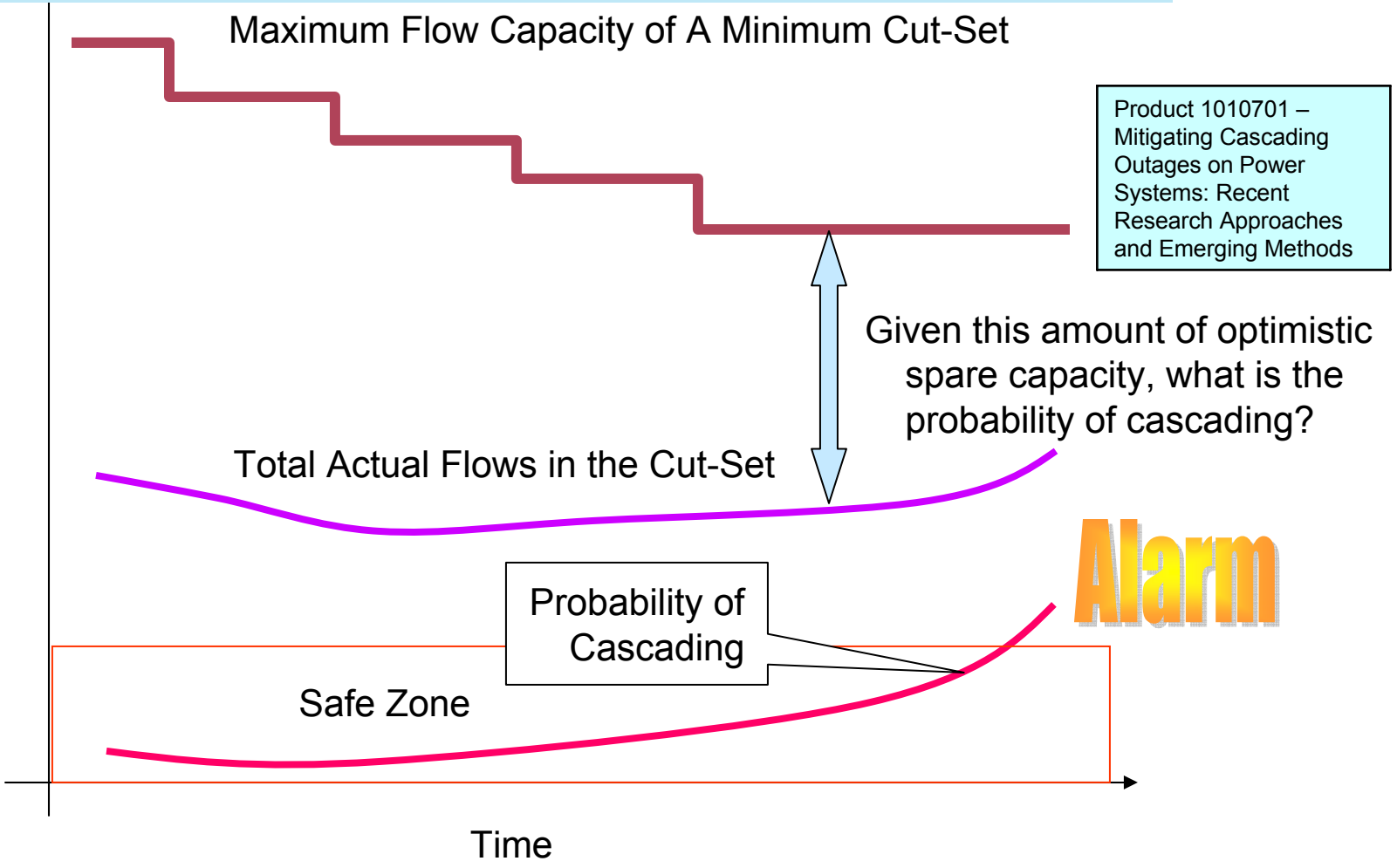
EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Prior EPRI research results on structural degradation, deterministic and probabilistic system stress indices

- Holy Grail – Extract succinct information - Diagnose and Advise
- The goal is a “Predictive” Vulnerability Index that measures the risk of cascading outages
- Factors leading to cascading outages:
  - Structural Degradation
    - Scheduled and unscheduled outages
  - System Stresses
    - Load level
    - MVA flows, MW losses, MVAR losses
  - Sudden disturbances

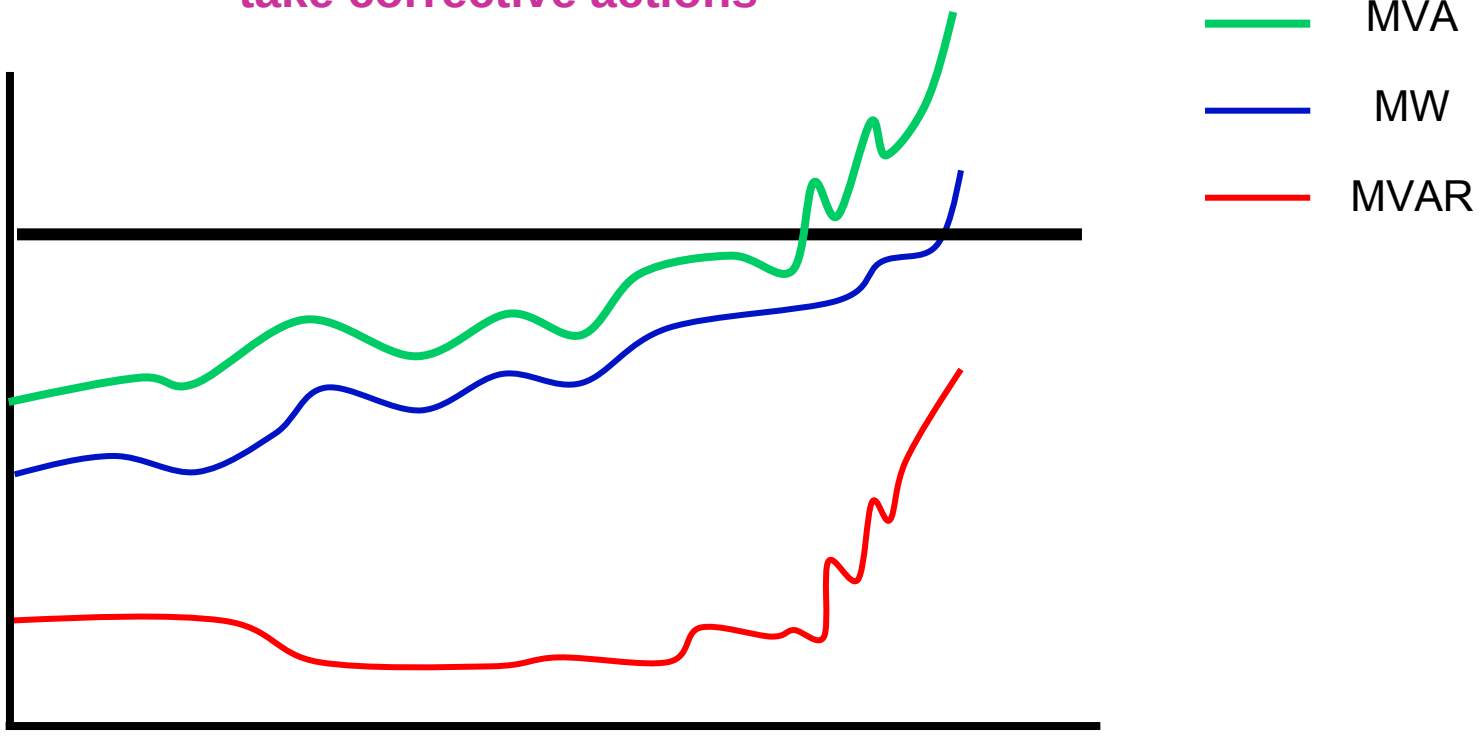
Stress Indicator

EPRI's research in Cut-Sets is a key to know the structural integrity or degradation of the power grid



Reactive Power Flow is a Precursor

Precursors are valuable for warning operators with enough time to take corrective actions

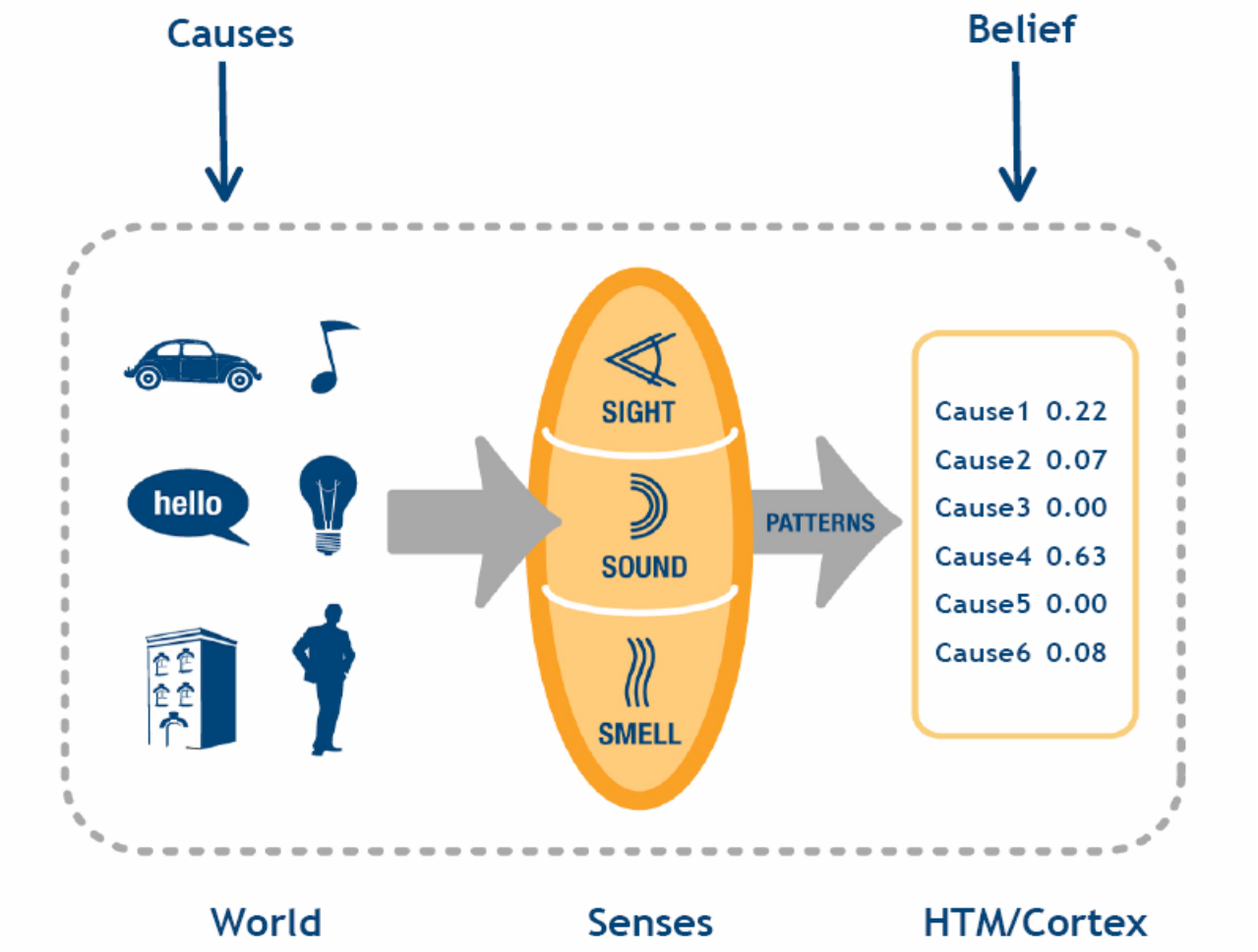


Time Period = 15 minutes

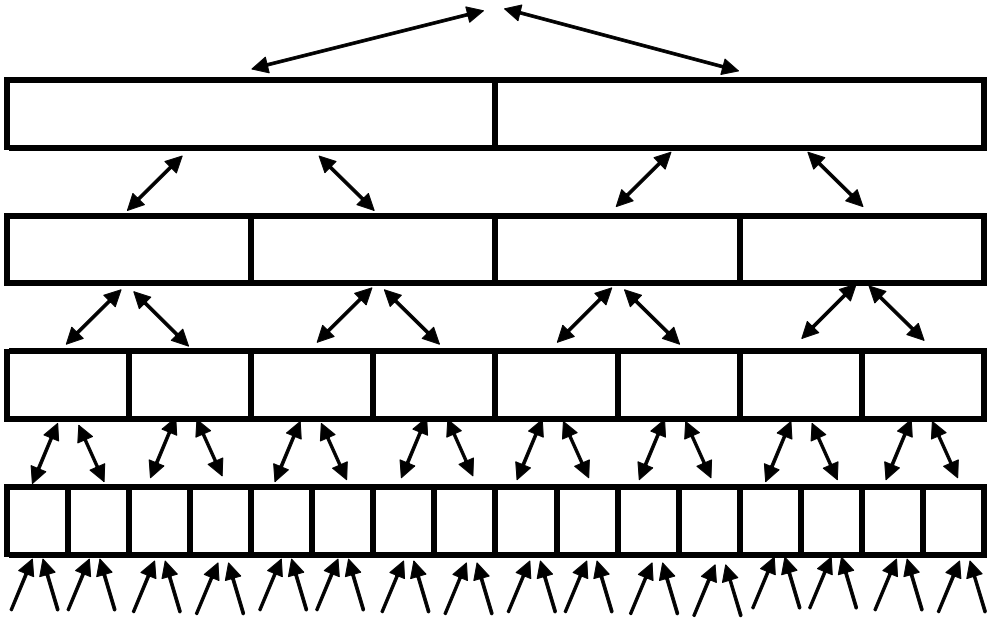
What is New?

- Research in Human Cognition
- Human brain is much faster and more correct than supercomputers in:
  - Learning from massive data to discover causes in the world
  - Given new input data, infer causes from past knowledge
  - Make short term prediction unconsciously
  - Use observed deviations from prediction to detect anomalies
  - React to anomalies with reflex action
  - Capable of thinking and apply lessons from more distant past
- Human cortex works in layers / hierarchies
  - Successive layers apply filters and association to form higher abstraction (beliefs) from sensory data

How Human Brain Works



Human Brain



Beliefs

- Line X-Y tripped
- P MW of generation in CAj tripped
- CAk in risk of voltage collapse

Anomalies in adjacent brain cells infer causes -> beliefs

- Geographical location
- Association across data types

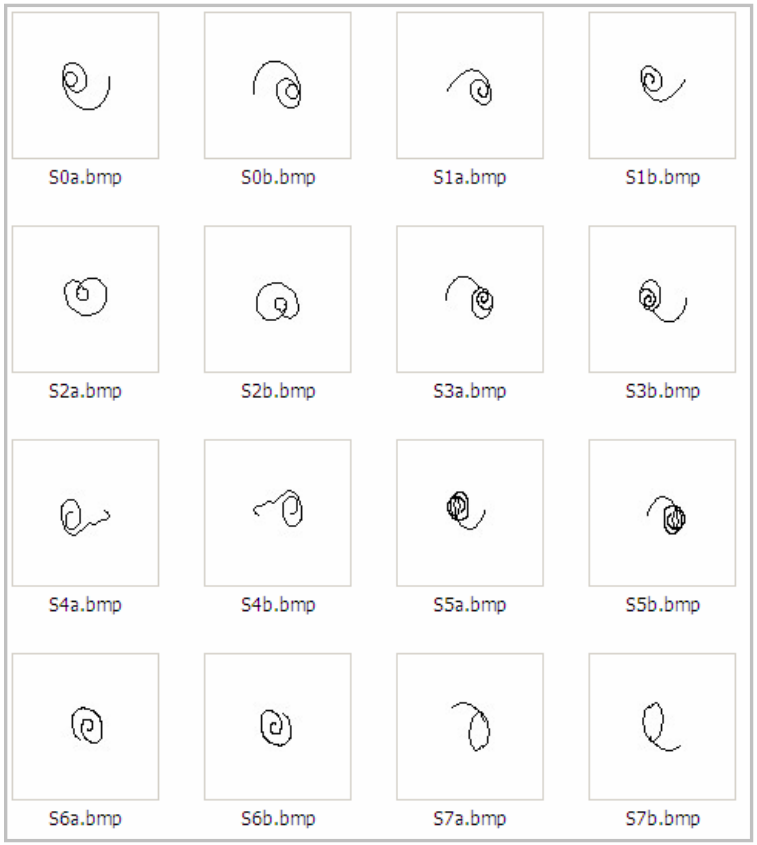
Sensory Data

Distributed according to electrical neighborhoods

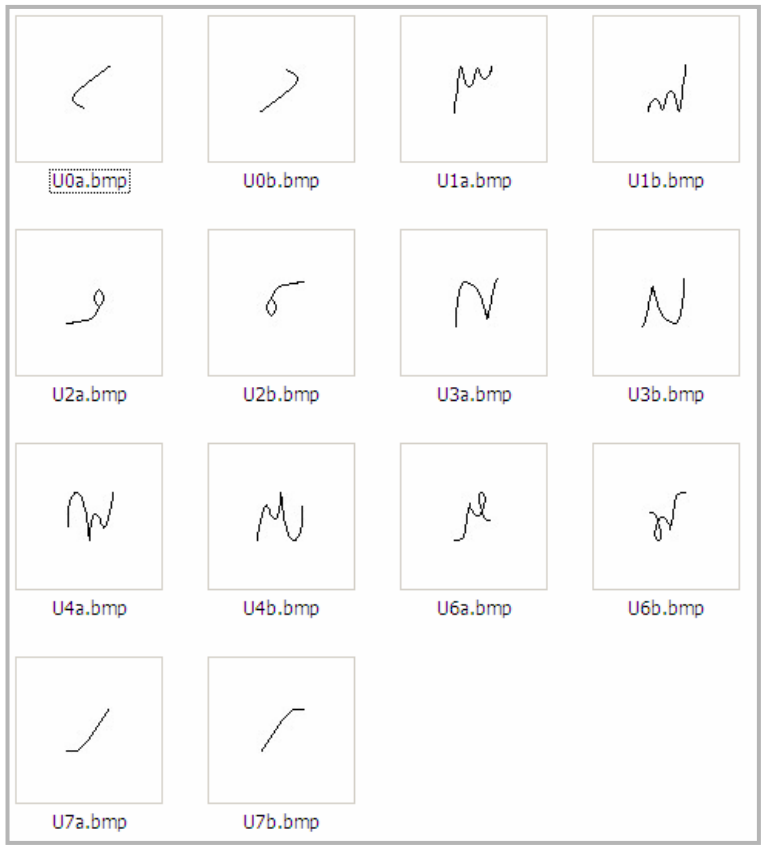
V, I, f, δ, MW, MVAR, MVA, P & QLosses, Energy Functions, Z_{app}

Two-dimensional patterns, phase space or combination of two variables, e.g., P-f, Q-V

Training Cases with Phase-Space Patterns

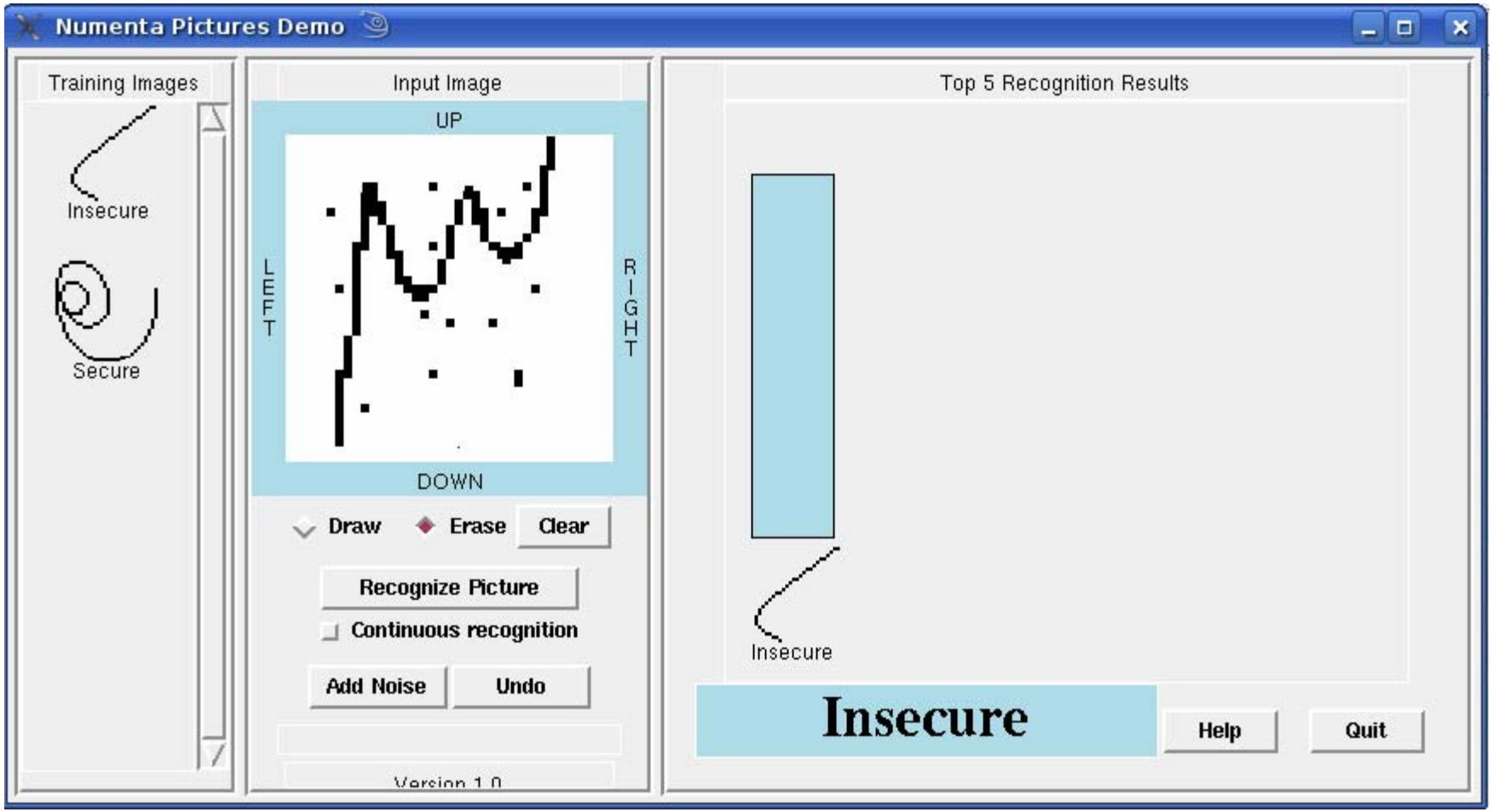


Stable

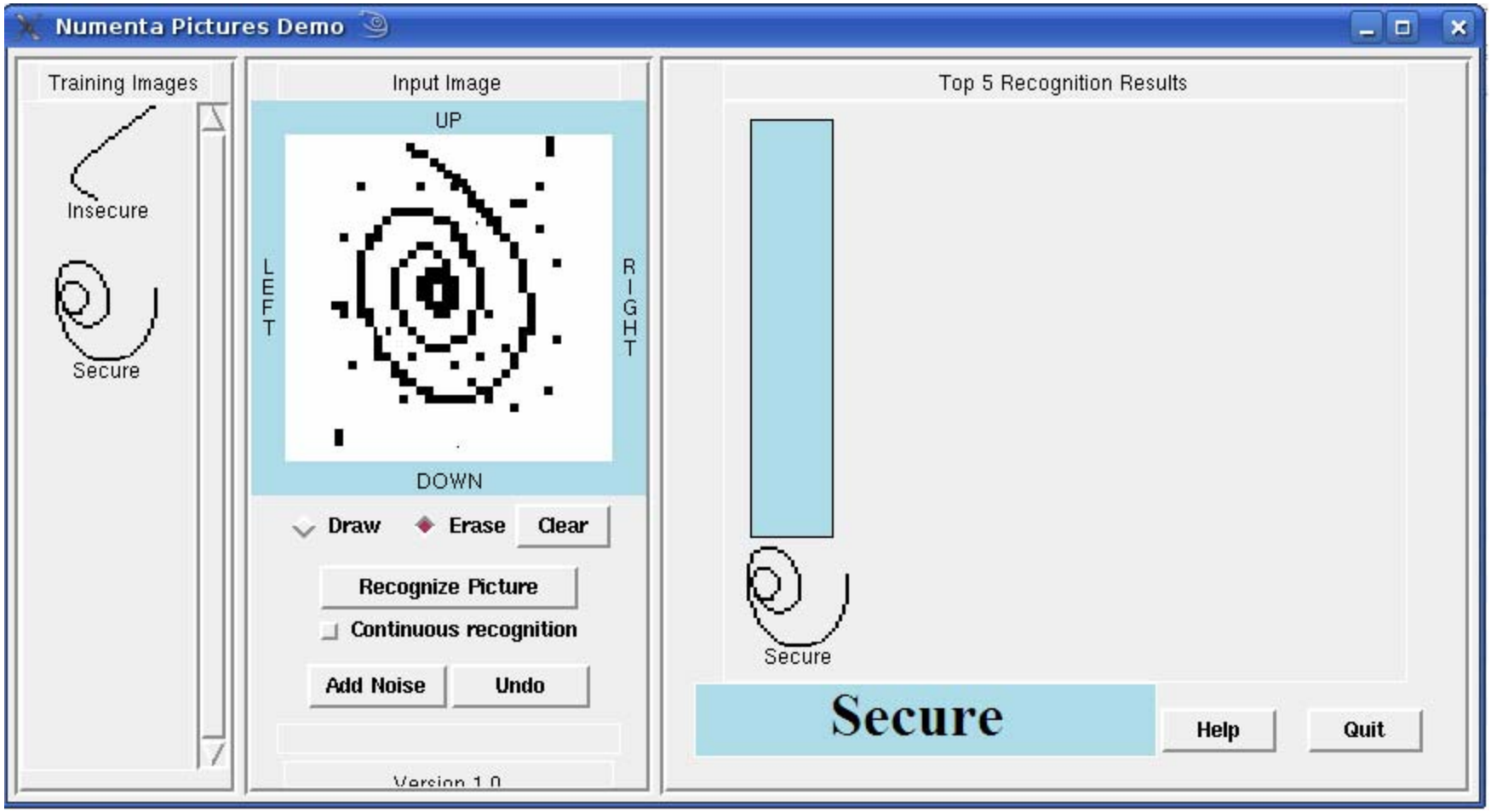


Unstable

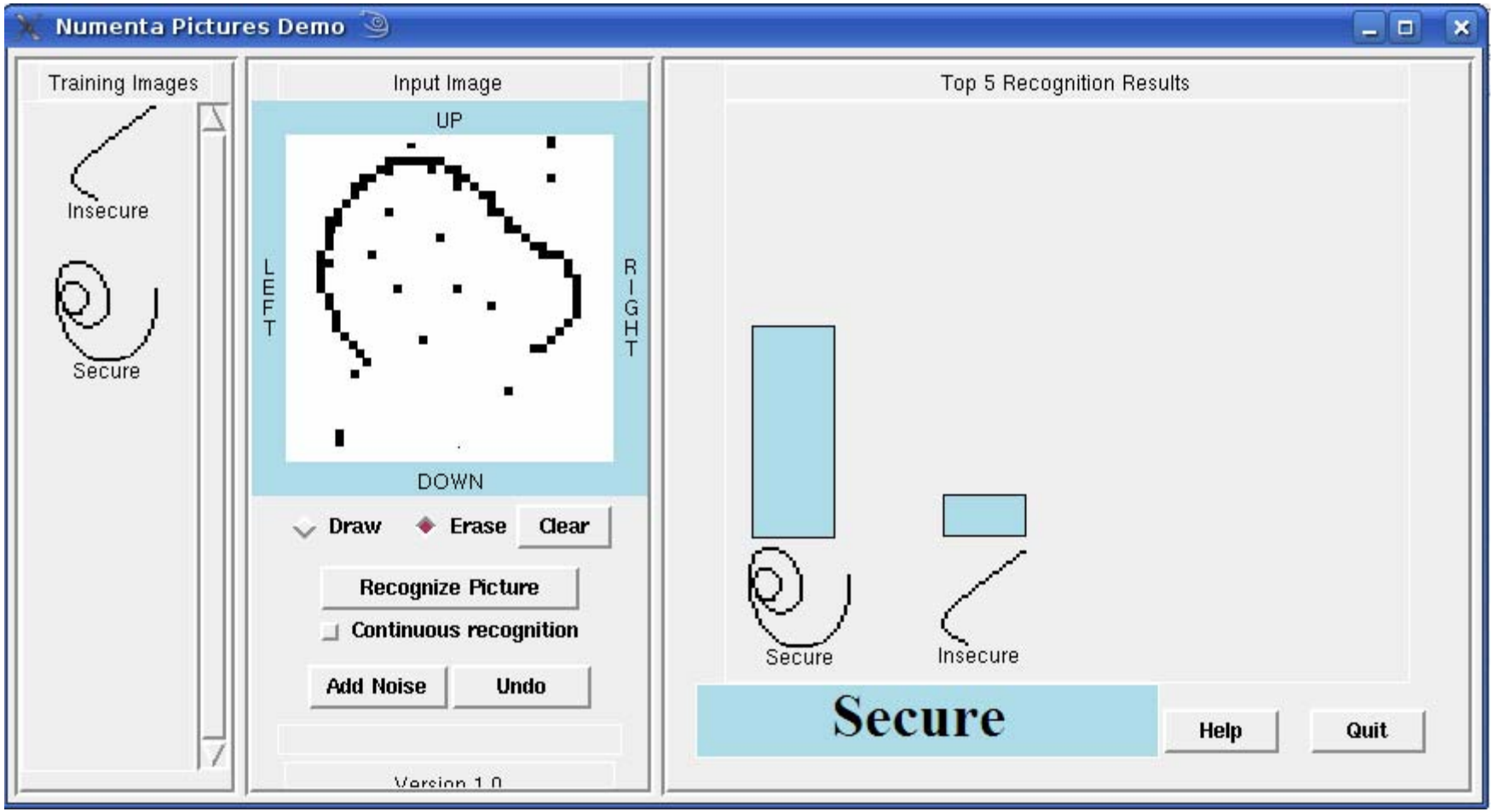
Stability Pattern Recognition Program – Insecure



Stability Pattern Recognition Program - Secure



Stability Pattern Recognition Program – More Likely Secure Than Insecure



Special Presentation Friday

- Please join us at 12:00 noon in Riopell for one hour