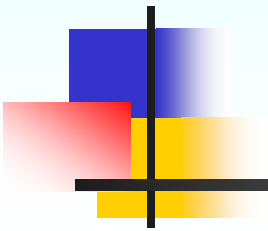

Abnormal Events Management in Complex Process Plants: Challenges and Opportunities in Intelligent Supervisory Control

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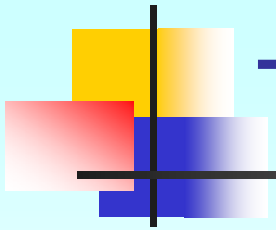
Outline

- Introduction
  - What is AEM and why is it important?
  - Intelligent Supervisory Control
  - Challenges and Issues
- Various approaches
  - Model based and Process History based methods
  - Relative Merits and Demerits
- Process Hazards Analysis (PHA)
- Emerging Trends
- Future Directions



Talk Philosophy

- Broad overview
  - Not a detailed, in-depth review
  - Identify key concepts, issues, challenges
  - Compare and contrast different approaches

Introduction

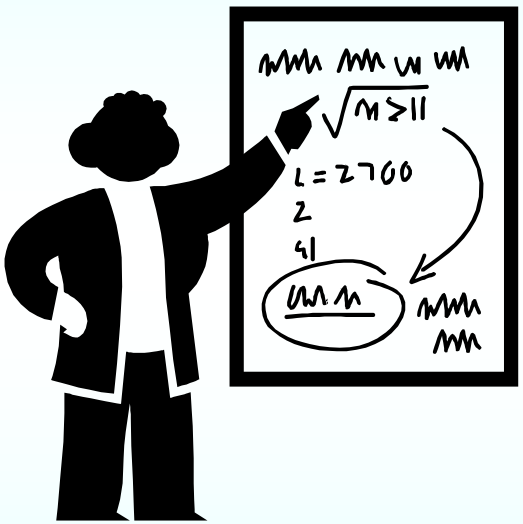
- Abnormal events are deviations in process behavior from normal operating regime
  - Safety problems
  - Environmental concerns
  - Quality problems and Economic losses
- Why do abnormal situations occur?
  - Human errors
  - Equipment degradation and failures
- **This is really a Process Control Problem**

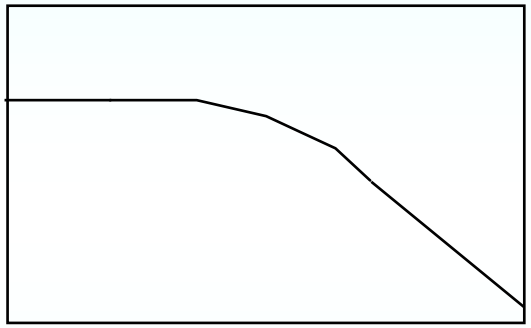


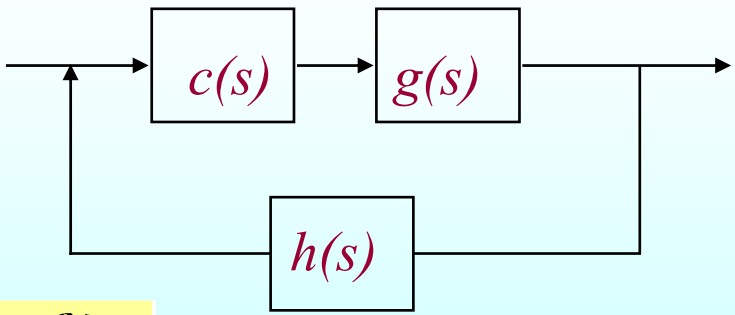
Academic View of Process Control

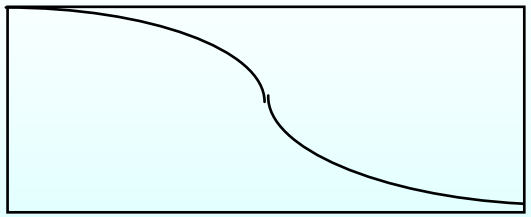
$$L[f(t)] \equiv \bar{f}(s) = \int_0^\infty f(t) e^{-st} dt$$

$$\dot{x} = f(x,u)$$
$$y = h(x,u)$$





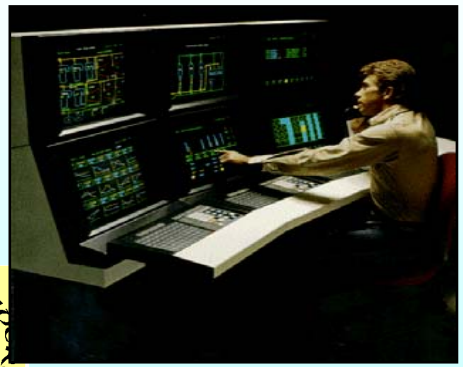




A → B

Operator's View of Process Control

- Pump A pumping oil has tripped - **Cause Unknown**
- You switch to Pump B. That also trips - **Cause Unknown**
- Soon hundreds of alarms are going off – **Cause(s) Unknown**
- With in minutes you have an explosion and a fire. Two people are killed and a few hurt at this point.
- It is 10:00 in the night
- The plant manager is in Aberdeen, Scotland, and not available
- You are on top of an off-shore oil platform in the middle of the North Sea



You are the Shift Supervisor: What do you do?

Process Safety is a Major Concern: The BIG Ones

- Piper Alpha Disaster, Occidental Petroleum Scotland, 1988
  - Off-shore oil platform explosion
  - 164 people killed
  - $2 Billion in losses

- Union Carbide, Bhopal, India, 1984
  - MIC release into atmosphere
  - 3000-10,000 people killed
  - 100,000 injured
  - $0.5-1.0 Billion in losses

The BIG Ones: More recently….

- Mina Al-Ahmedhi Refinery,KPCL,Kuwait, June 2000
  - Leak led to flammable vapor release and explosion
  - 7 people killed, 50 injured
  - $400 Million in losses

- Petrobras, Brazil, March 2001
  - Off-shore oil platform explosion
  - 10 people killed, $5 Billion in losses
  - Platform sank into the Atlantic Ocean

AEM Lessons Learned

- Need intelligent real-time operator support
- Need more thorough PHA and integration with AEM
  - New OSHA/EPA regulations
- Importance of Operator Training
- Management/Organization commitment to AEM and PHA

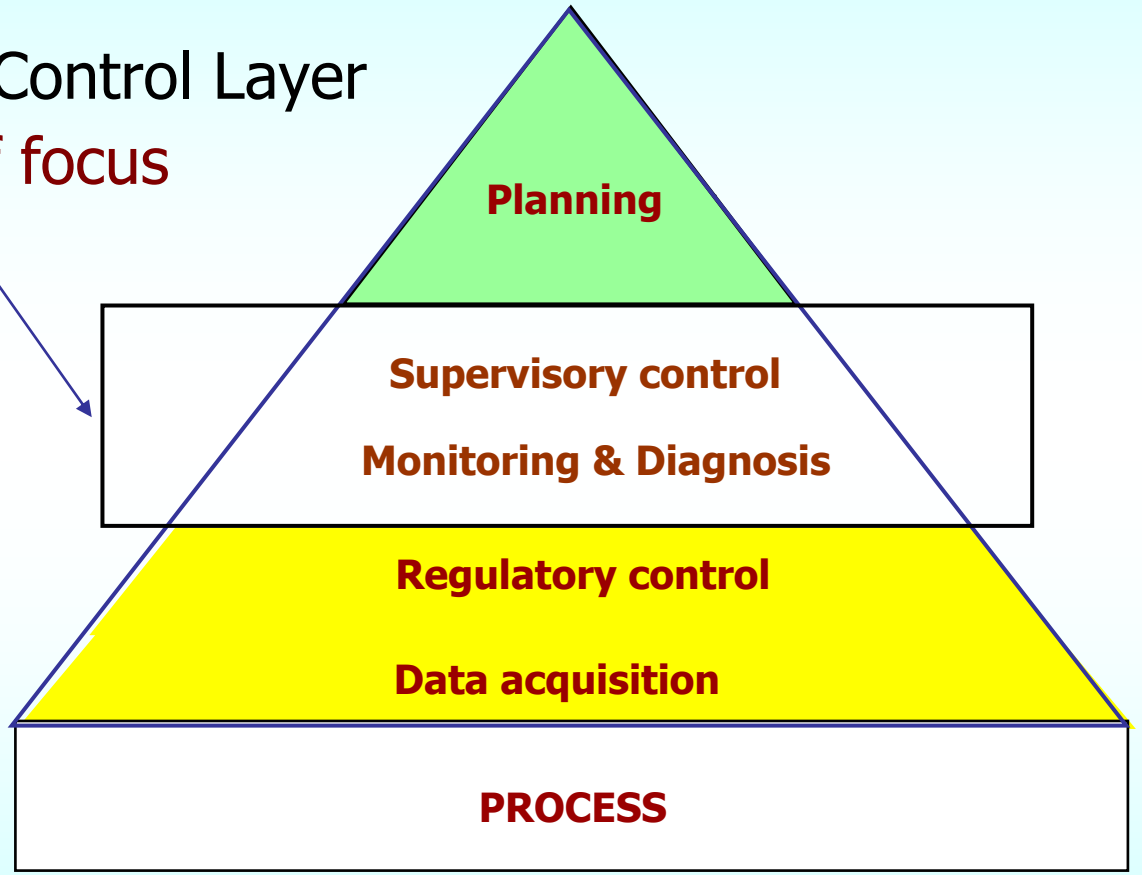
AEM Problem: Important and Challenging

- $20B+ impact on U.S. economy; $10B impact on petrochemical companies
- Petrochemical companies have rated AEM their #1 problem
- Modern plants are more difficult to control, diagnose and manage

Process Operations Pyramid

Intelligent Control Layer

Area of focus



Increasing Timeframe

Next Control Frontier:Intelligent Control

- **What are Intelligent Control Systems?**
  - Computer-based systems that can assist human operators with **higher-level** decision making to manage a complex process plant safely and optimally
  - **Beyond** Regulatory Control
- **Real-time Supervisory Control Decisions**
  - Process Fault Diagnosis and Control: Abnormal Events Management (AEM)
  - Alarm analysis and interpretation
  - Optimal control
  - Start-up and shut down
- **Next Frontier in Control Systems Design and Analysis**

AEM Challenges

- Intelligent Control System
  - Fundamental Issues: Knowledge Representation and Search
  - Implementation Issues
- Integration with other systems
  - Regulatory Control, Real-Time Optimizers, Scheduling, Databases etc.
- People/Organization Issues
  - Operator Acceptance, Training
  - Liability

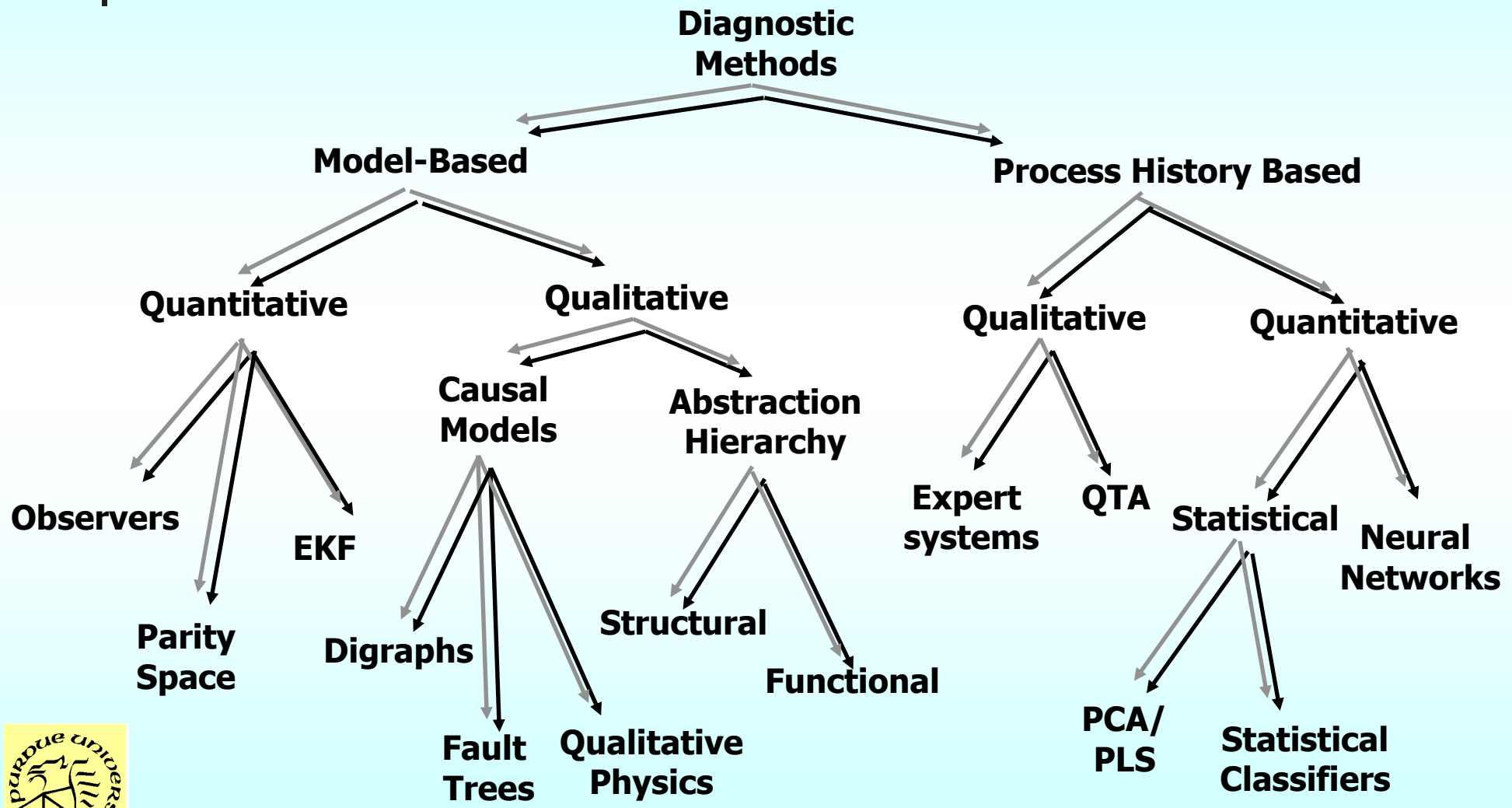
Desirable Features of an Intelligent Control System

- Early detection & diagnosis
- Isolability : discriminate between failures
- Robustness : to noise & uncertainities
- Novelty Identifiability : novel malfunction
- Explanation facility : Fault propagation
- Adaptability : Processes change & evolve
- Reasonable storage & computational requirement
- Multiple Fault Identifiability : Difficult requirement

Diagnostic Approaches – Brief Review

- Process Fault Diagnosis: First Step in Intelligent Control
- Diagnostic Philosophies
  - Source of Process knowledge
    - Process Model
    - Process History
  - Form of Process knowledge
    - Qualitative
    - Quantitative
- Process Model : *Deep, Causal or Model-Based knowledge*
- Process History : *Shallow, Compiled, Evidential knowledge*

Classification of Diagnostic Methods



Comparison of Different Diagnostic Methods

	Observer	Digraphs	Abstraction Hierarchy	Expert Systems	QTA	PCA	Neural Networks
Quick Detection and Diagnosis	✓	?	?	✓	✓	✓	✓
Isolability	✓	×	×	✓	✓	×	✓
Robustness	✓	✓	✓	✓	✓	✓	✓
Novelty Identifiability	?	✓	✓	×	?	✓	✓
Classification Error	×	×	×	×	×	×	×
Adaptability	×	✓	✓	×	?	×	×
Explanation Facility	×	✓	✓	✓	✓	×	×
Modelling Requirement	?	✓	✓	✓	✓	✓	✓
Storage & Computation	✓	?	?	✓	✓	✓	✓
Multiple Fault Identifiability	✓	✓	✓	×	×	×	×

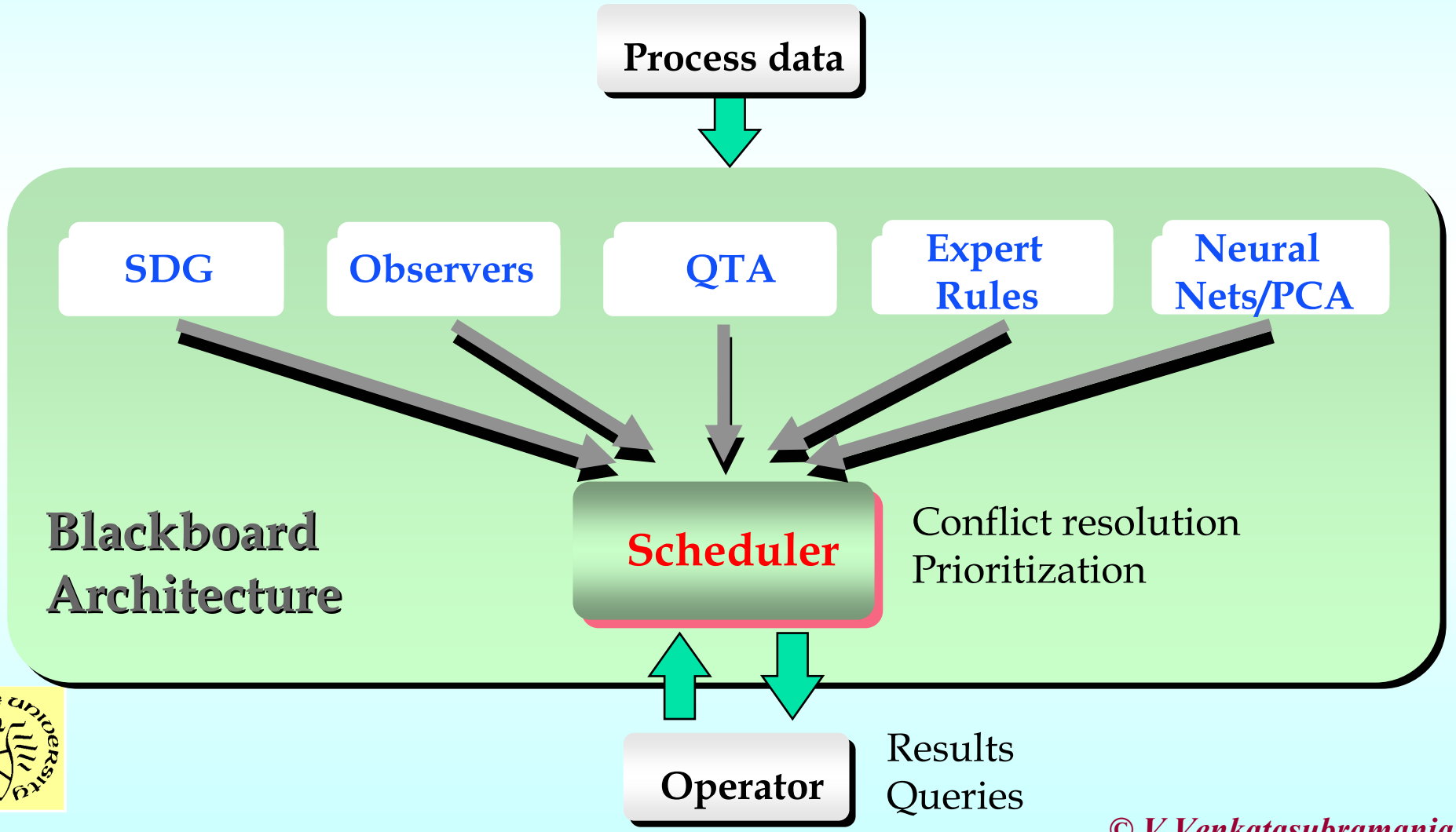
No single method achieves all

Emerging Trends Towards AEM

Hybrid Framework

- **No single** method meets all the criteria of a 'good' diagnostic method
- **A Hybrid** Framework
  - Involving different methodologies
  - Based on a collective and synergistic approach to problem solving seems most promising (Mylaraswamy & Venkatasubramanian, 1997)
  - Compensate one method's weakness with the strengths of another's
- **Dkit** implemented in G2
  - Effectiveness demonstrated on Model IV FCCU by successfully diagnosing wide varieties of faults
  - Combined causal model-based diagnosis with statistical classifiers
  - Basis for the prototype of the Honeywell ASM Consortium
  - Licensed to Honeywell by Purdue University

Diagnostic ToolKit (Dkit)



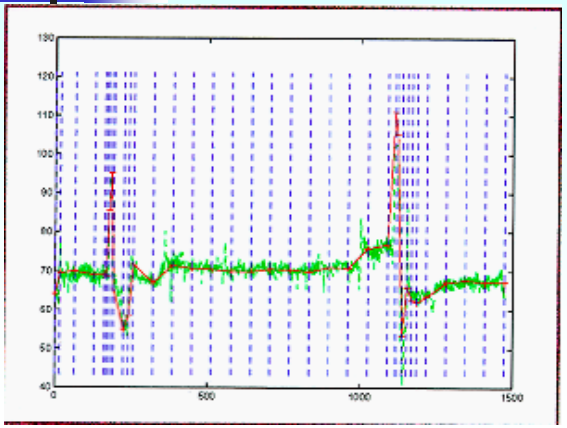
ASM Consortium: Pilot Study at ExxonMobil

- BRCP Cold Ends; 500+ sensors, sampled every minute
- Started Feb. 1998. Historical data consists of annotated data for ~2months

CHALLENGES

- Problem size
  - # of sensors
  - Noisy Data : Robustness
  - Unreliable/Missing Data
- Incomplete annotations and operator logs
  - Not every event is captured
- Distinguish operational events from abnormalities
  - Routine Controller actions
  - Shutdown of a unit
- Definition of normal operation
  - Normal Region keeps shifting: Changes in Feed Quality, Market demands etc.

QTA at BRCP for Process Monitoring & Diagnosis



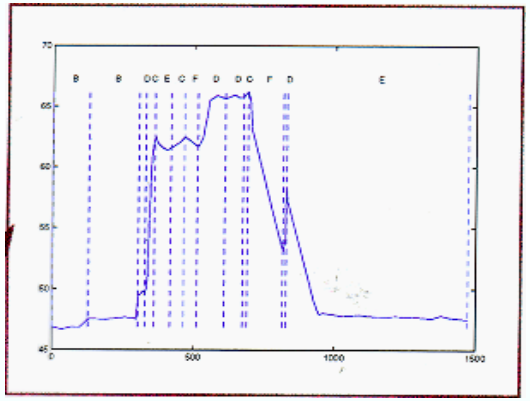
Data

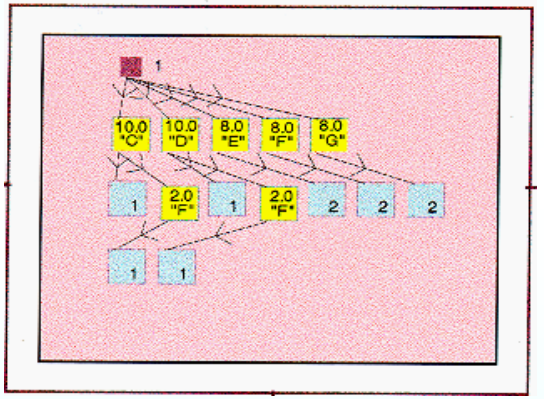
BSplines Data Compression

Time-Window Analysis (Frequency Check)

Novel Faults

Update KB





Linear Trend Extraction Using Derivatives

Knowledge Base Patterns -> Faults

Known Faults

PREPROCESSING

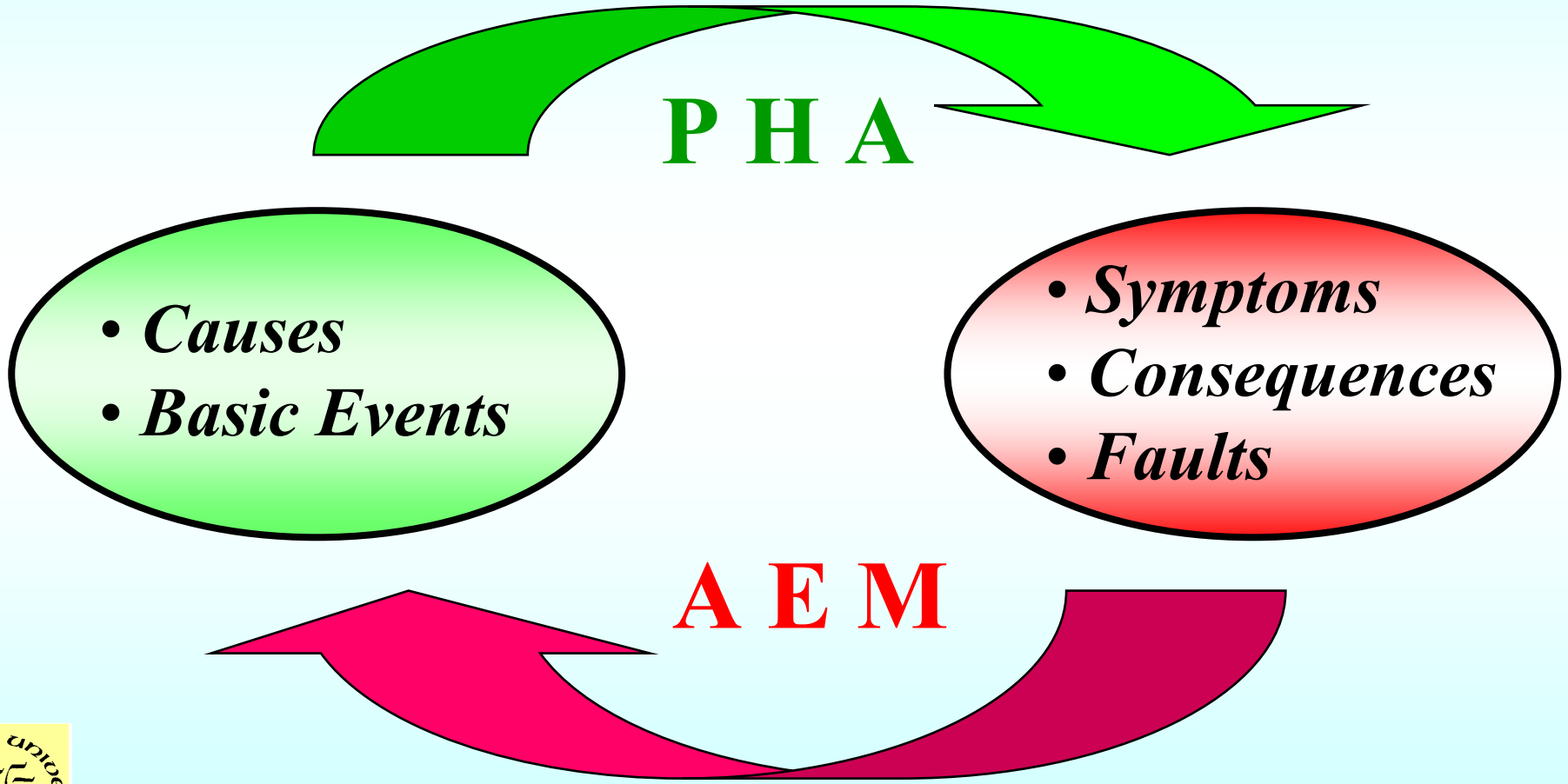
FEATURE EXTRACTION

FEATURE CLASSIFICATION

Training & Testing of QTA on Real-Time Process

- Training of QTA done using data over the initial 3 weeks
- Identified all significant events with a few false alarms
- Earlier than process alarms by about 30 mins
  - Oil accumulation in ND-02
  - Leaky valve affecting downstream temperature
- Robust to process noise/shifts in the normal regime of the process
- Adaptive: Incrementally add new event classes to the knowledge base
- Honeywell licensed the technology from Purdue in June 1999
  - In the process of being commercialized by Honeywell Hi-Spec

AEM & PHA



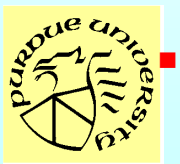
Process Hazards Analysis (PHA)

- PHA is the proactive identification, evaluation and mitigation of process hazards

- HAZOP analysis is the most widely used PHA approach

Motivation for Automation

- PHA requires significant amount of time, effort and specialized expertise
  - 1~8 weeks to complete a typical PHA study
  - $4-5 billion/year expenses for CPI, 1% of sales, 10% of profits
  - About 25,000 plant sites are covered by PSM 1910
- An automated PHA system can:
  - Make the PHA more thorough and consistent
  - Reduce the time and effort of the team
  - Handle information overload and complexity
  - Document results for regulatory compliance
  - Handle management of change with ease
  - Train new operators
  - Online abnormal situation management applications



Future Directions

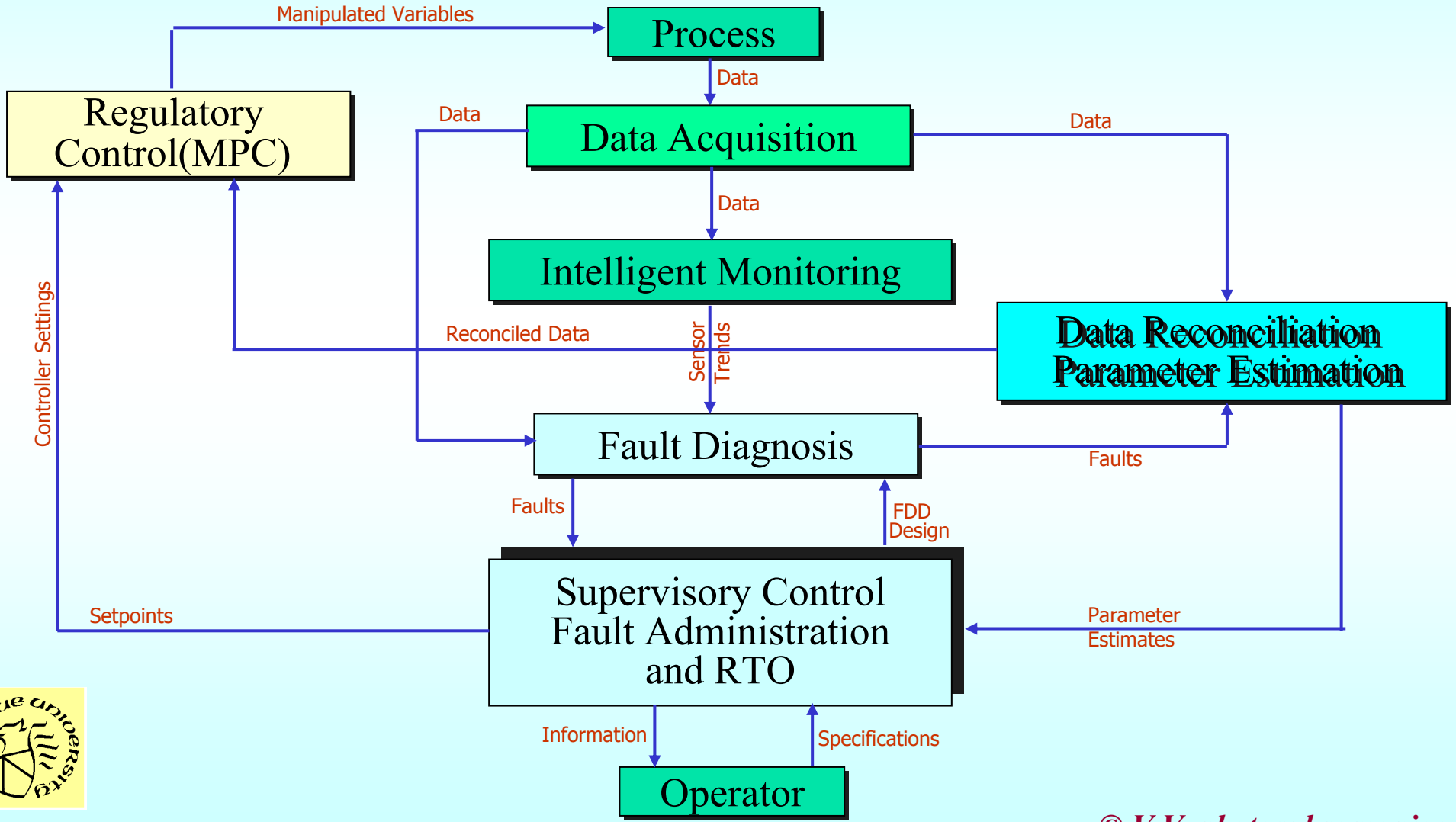
Prediction is Difficult, particularly about the Future…..

Niels Bohr

Future Directions in AEM

- Hybrid Intelligent Control Systems
  - System development/implementation, knowledge maintenance/management
- AEM-PHA Integration
- Integration with other systems
- People/Organization Issues
  - Operator Acceptance, Training
  - Commitment, Liability

Computer Integrated Process Operations



Future Directions

Operator Training for Safe Operations

Training: Developing Countries

When they don't value safety
in their personal lives....

Courtesy: The Hindu, Jan 2001

What are the chances that they will take it seriously in your process plants?

Summary

- Complexity and size of modern chemical plants make it difficult to manage abnormal events (AEM) and analyze process hazards (PHA) effectively

- AEM has been identified as a very important problem by the process industries
  - Next Control Frontier: Intelligent Supervisory Control (ISC) Systems

- ISC systems can make a substantial improvement to current AEM practices in a variety of process industries

- We reviewed the approaches, challenges, emerging trends and future directions
  - **Model based and Process history based approaches**
  - **Hybrid Systems**
  - **AEM/PHA integration, Integrated operations, Training**

- Considerable challenges remain but we have made great progress in the last decade and the future potential is enormous and exciting

Acknowledgements

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