

# A Real-Time Knowledge-Based System for Automated Monitoring and Fault Diagnosis of Batch Processes

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# Presentation Outline

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- Motivation and Objectives
- Multivariate Statistical Process Monitoring
- Integration of Software
- Rule Base
- Batch Expert
- Conclusions

# Motivation and Objectives

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- Fundamental model development is **Costly and Time - consuming**
- Time-variant, non-linear process dynamics, highly correlated variables
- Batch-to-batch variation
- Multivariate Statistical Process Monitoring (MSPM) scheme for effective on-line monitoring
- KBS integration provides real-time supervision

# Characteristics of Batch Processes

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- Time-variant behavior
- Nonlinear, slow and irreversible process dynamics
- Infrequent on-line measurements
- Constrained operation
- Presence of disturbance effects
- Reproducibility

# Statistical Process Monitoring

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- Assess process for productivity and product quality
- Use process variables and implement quality control strategies
- SPM of Batch Processing Issues
  - End-of-batch quality characterization
  - Within-batch assessment at end-of-batch
  - Within-batch prognosis in real-time

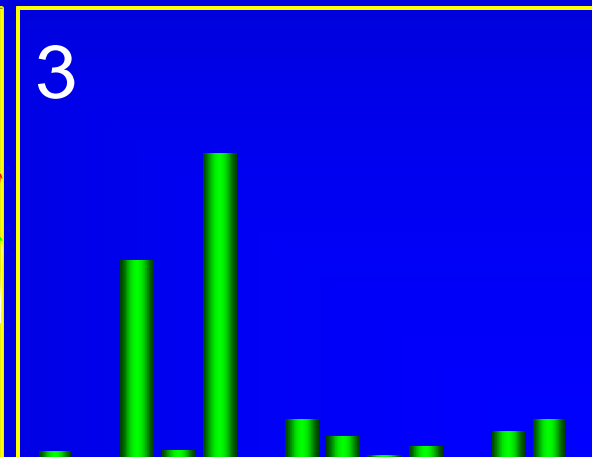
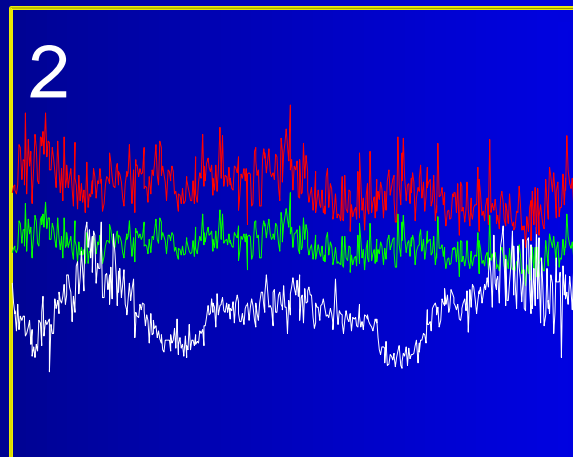
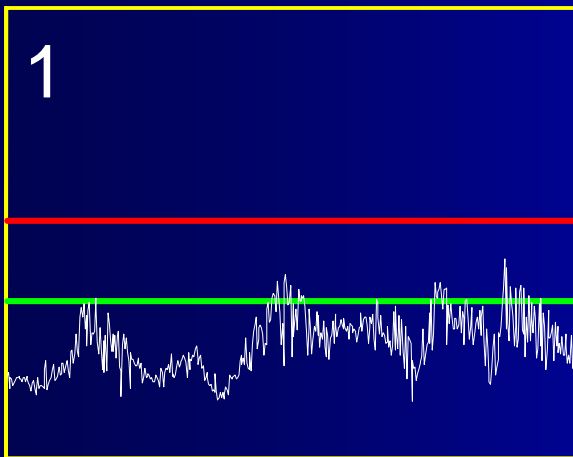
# Multivariate Statistical Process Monitoring

- Use of *in-control* runs in the *historical* database
- Development of the statistical model that characterizes normal operation (NOC)
- Computation of control chart limits for use in monitoring future batches

Simulations with and without disturbances were conducted to test the capabilities of MSPM Techniques

# MSPM Tools

1. Hotelling  $T^2$  Charts
2. Squared Prediction Error (SPE) Charts
3. Contribution Plots (to SPE and  $T^2$ )



# Multivariate Statistical Modeling for On-line Process Monitoring

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Multiway Principal Components Analysis (MPCA)

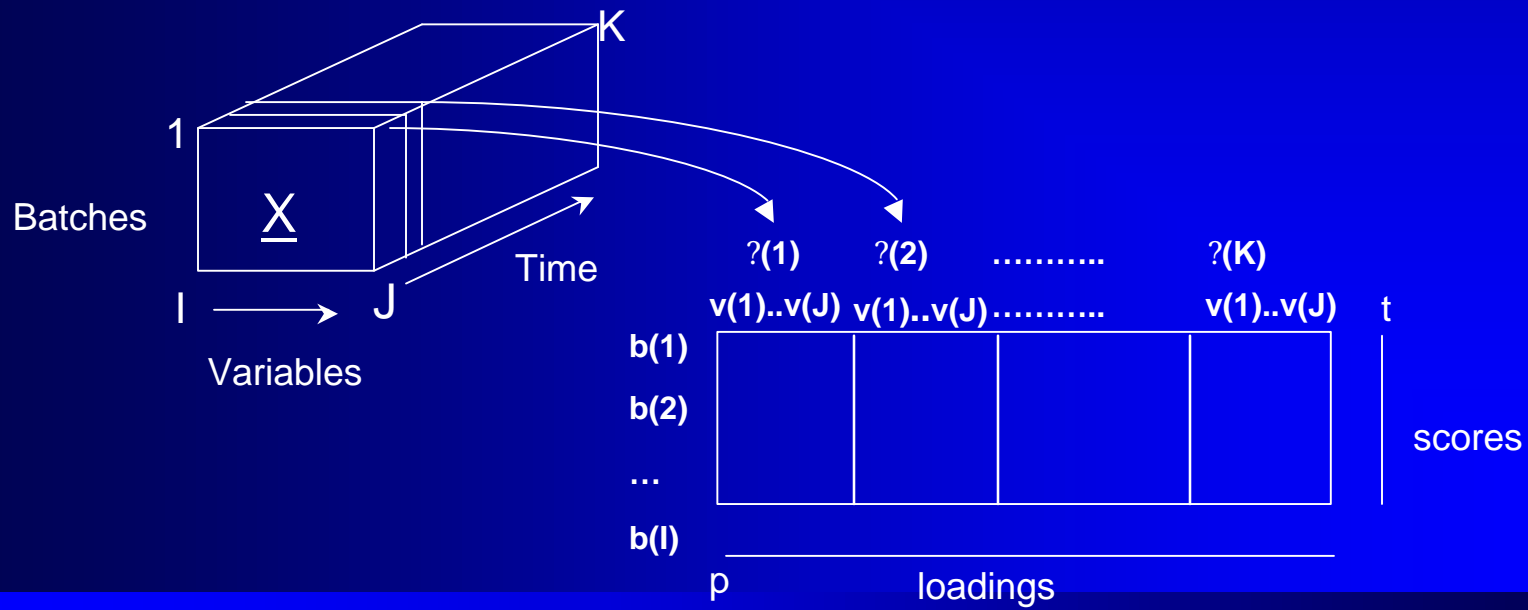
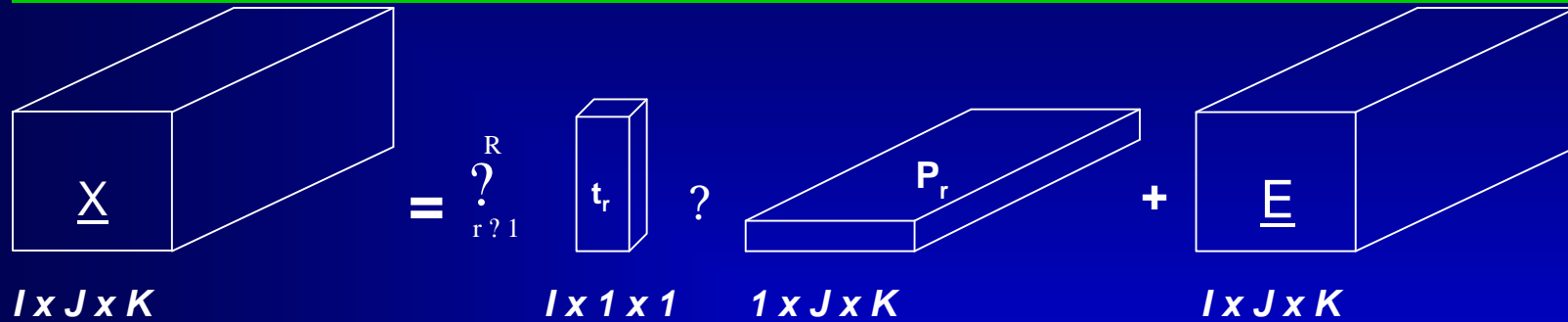


Conventional Techniques

Adaptive Hierarchical PCA



# 3-way Array Unfolding and Decomposition

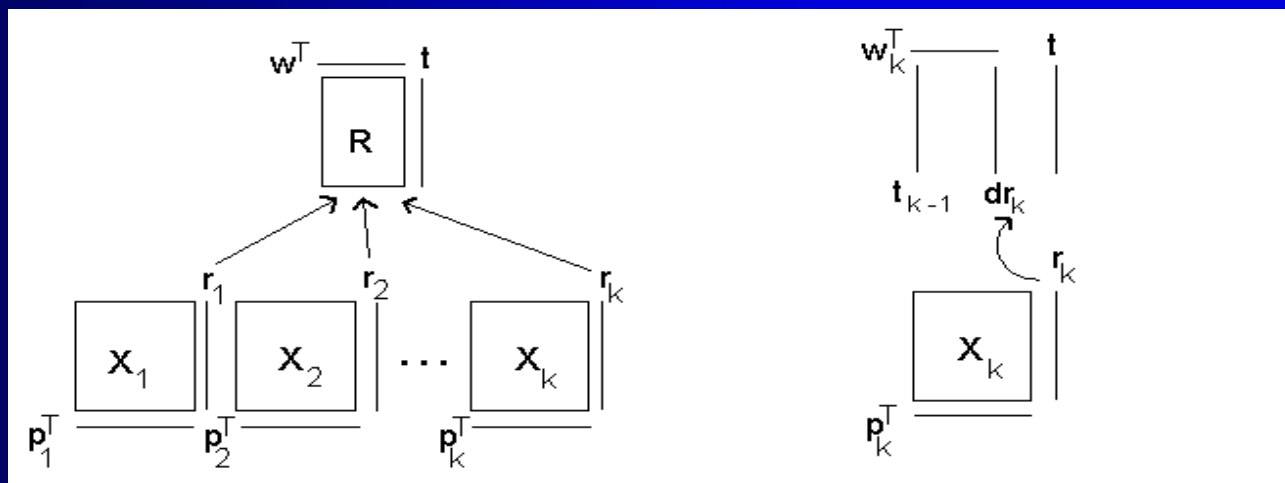


# On-line Process Monitoring

- Use loadings to predict scores and calculate residuals as the batch progresses
- $X_{\text{new}}(K? J)$  incomplete until the end of the operation
- Conventional solutions
  - Fill the unknown observations with zeros
  - Assume the future deviations will remain at their current values
  - Use principal components of the reference set to predict missing values

# On-line Process Monitoring

- Adaptive hierarchical MPCA
  - Divide the data block  $\underline{X}$  into  $K$  block of two-dimensional ( $I \times J$ ) arrays
  - Develop MPCA model iteratively based on each time slice

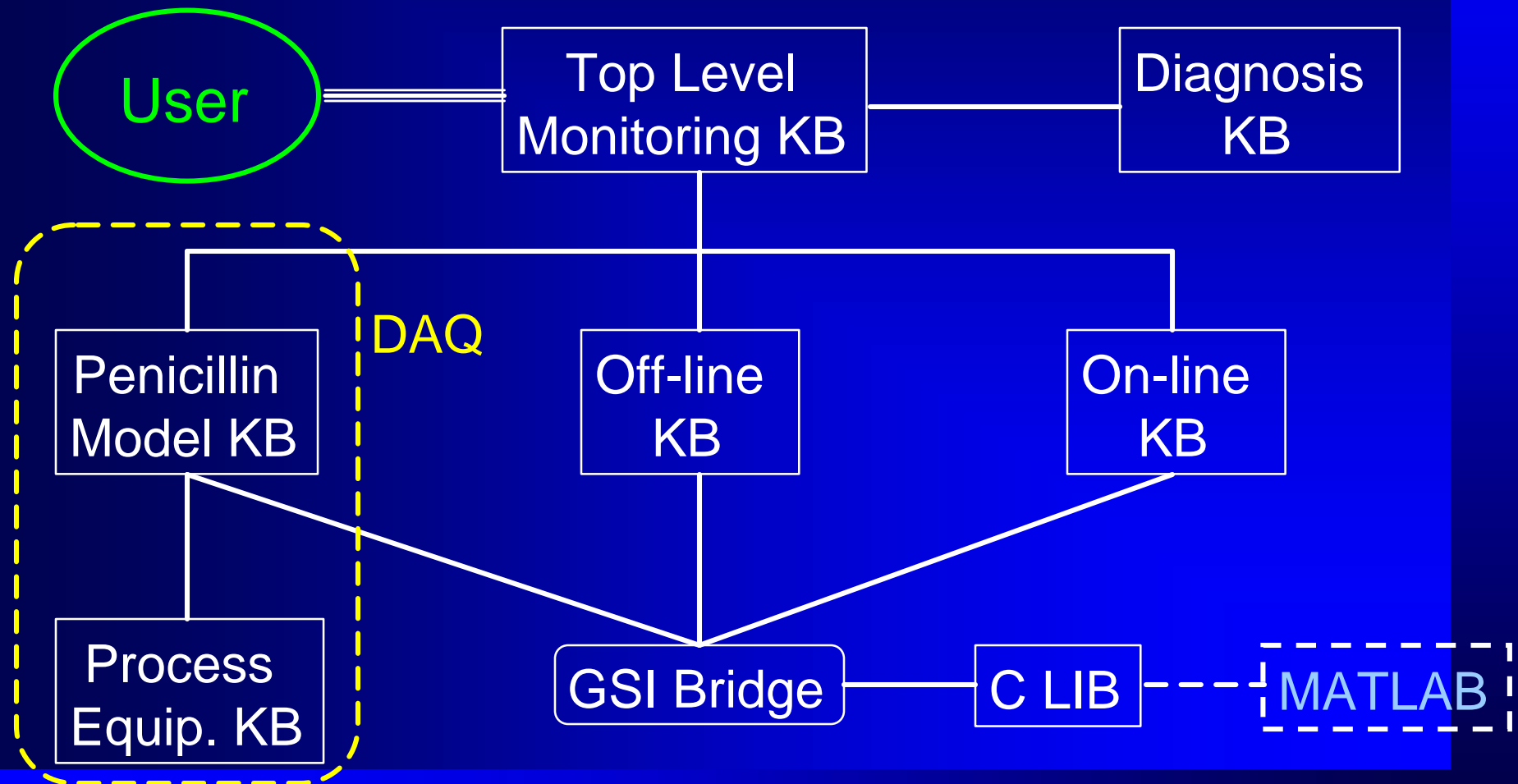


# Integration of Methods

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- G2 KBS Development Software
  - Create real-time intelligent applications
  - Graphical programming / user interface
  - Object oriented paradigm (OOP)
  - Modularization of software
  - Natural language programming
  - May be edited and recompiled without downtime

# Integration of Software



# Rule Base – General

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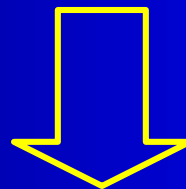
IF ( $T^2$  OR SPE > 99% UCL)

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IF (Contribution [  $i$  ] > Threshold [  $i$  ])

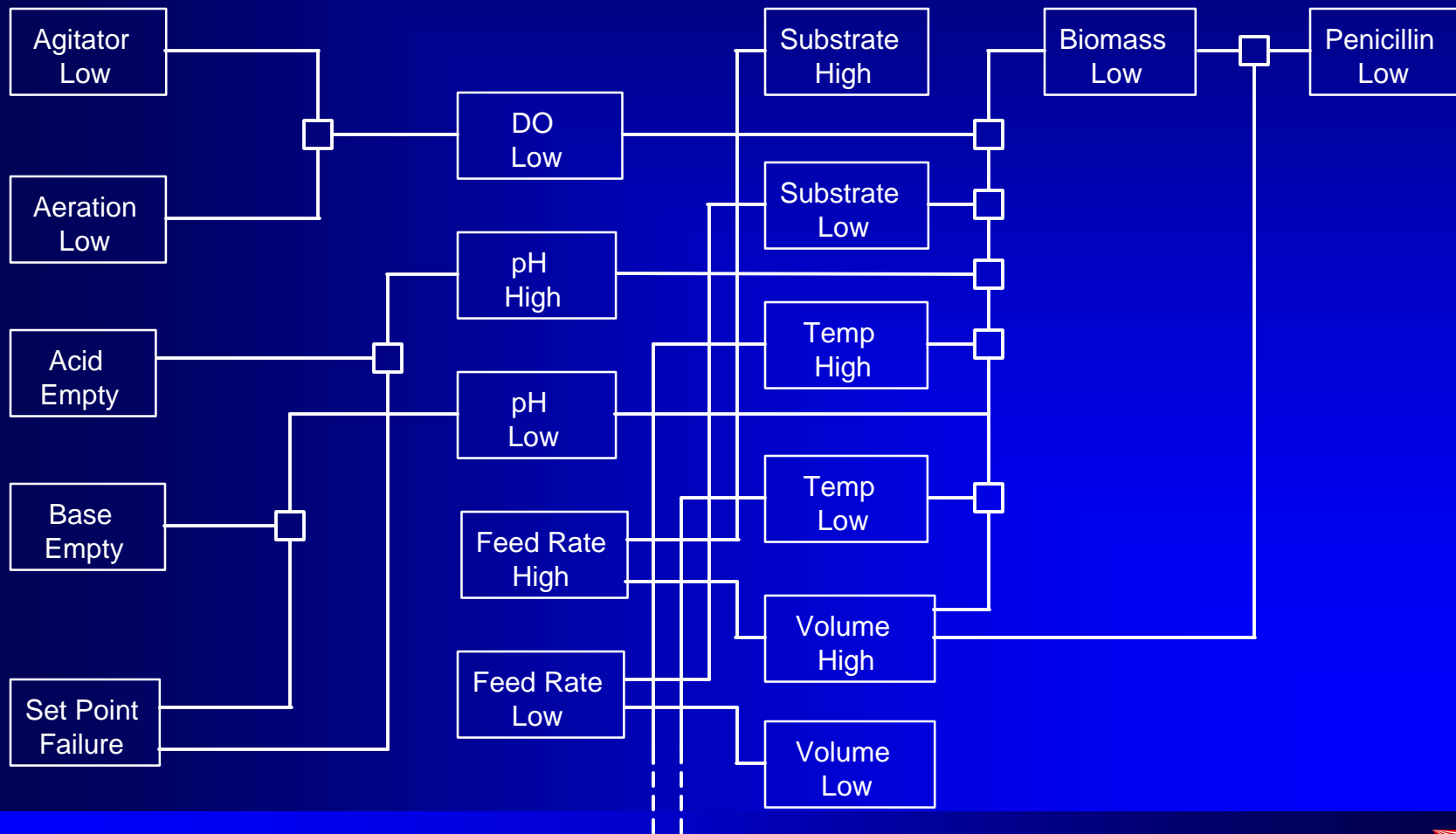
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Activate diagnosis workspace of variable  $i$

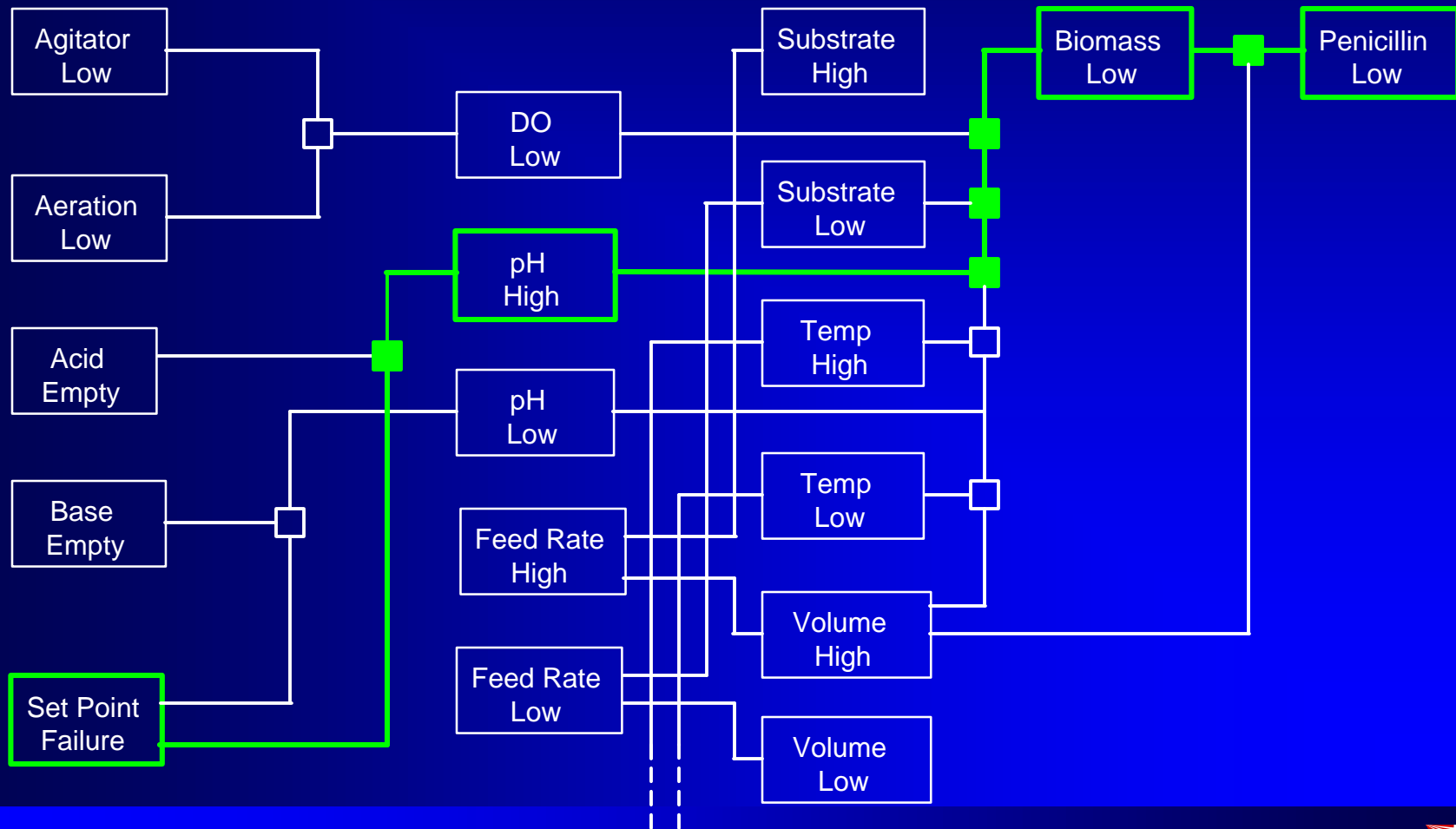


Process Specific Rules

# Rule Base – Process Specific

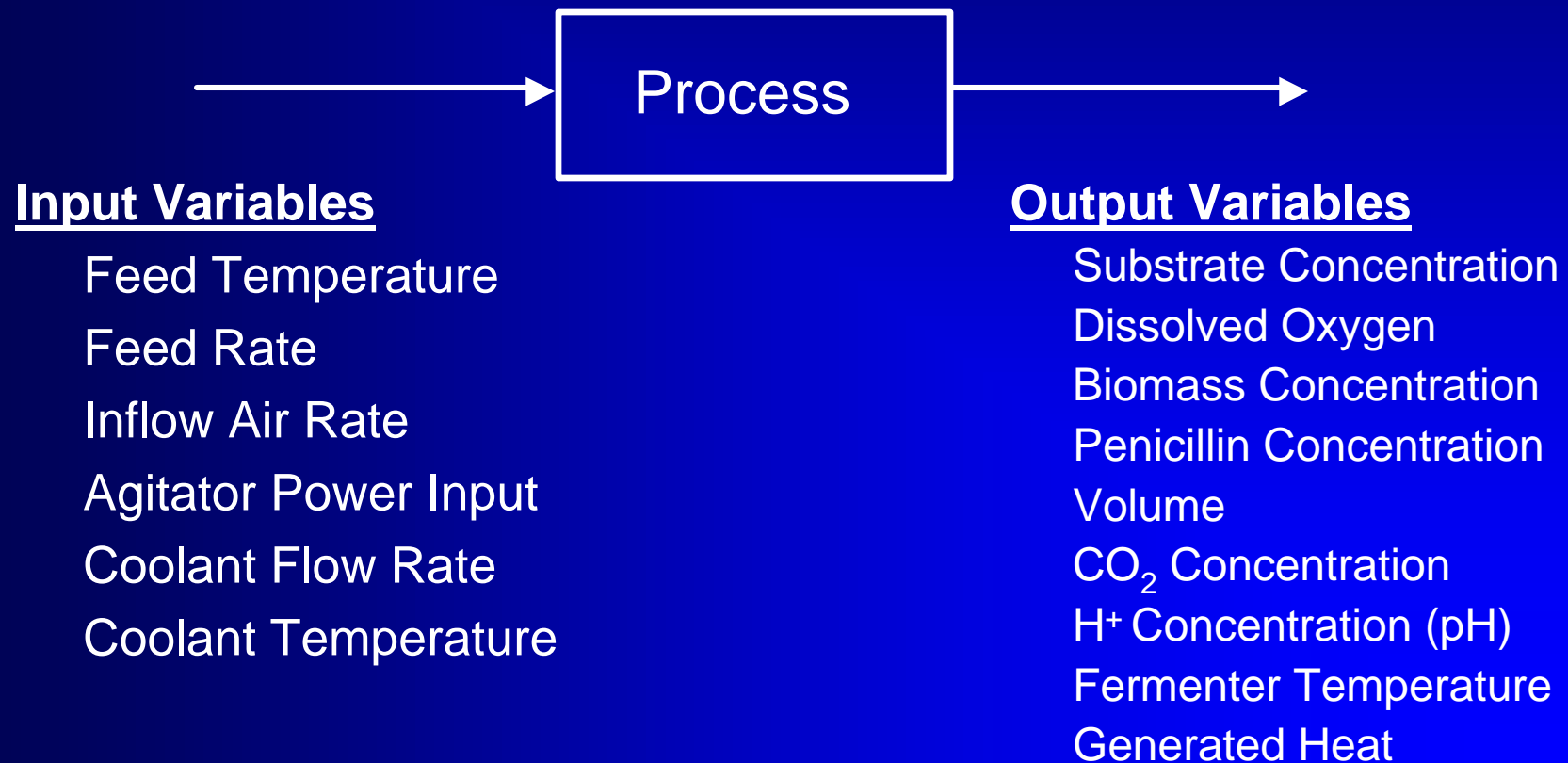


# Rule Base – Process Specific

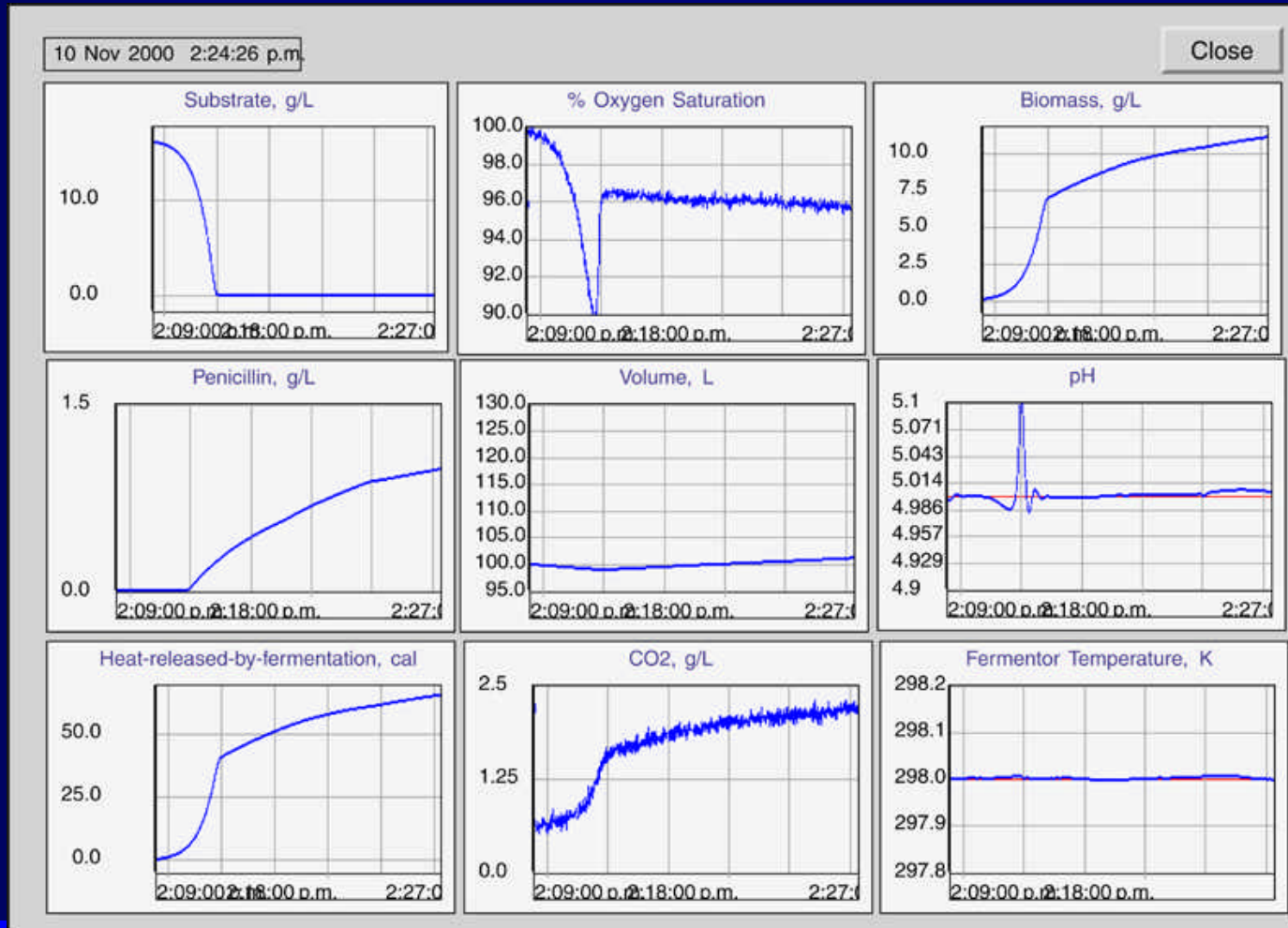




# Process I/O Structure



# Process Variables Normal Operation



# Matlab Modules

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- Simulation and monitoring code prototyped in Matlab
- Matlab files converted to C with Matlab C Compiler
- G2 Standard Interface (GSI) bridge:
  - Bridge between G2 and external C functions
  - Provides network communications
  - Portable code

# BatchExpert™ Software

- On-line process monitoring in real-time
- End-of-batch process monitoring
- Fault detection and diagnosis
- Phase detection
- MSPM and physiological-based alarming
- Advising on the corrective actions
- Flexible, modularized structure allowing the addition of new modules

# Conclusions

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- An effective integrated on-line monitoring system developed
- Combined implementation of heuristics and statistical inference
- Flexible modular software structure for further extensions

# Contact

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