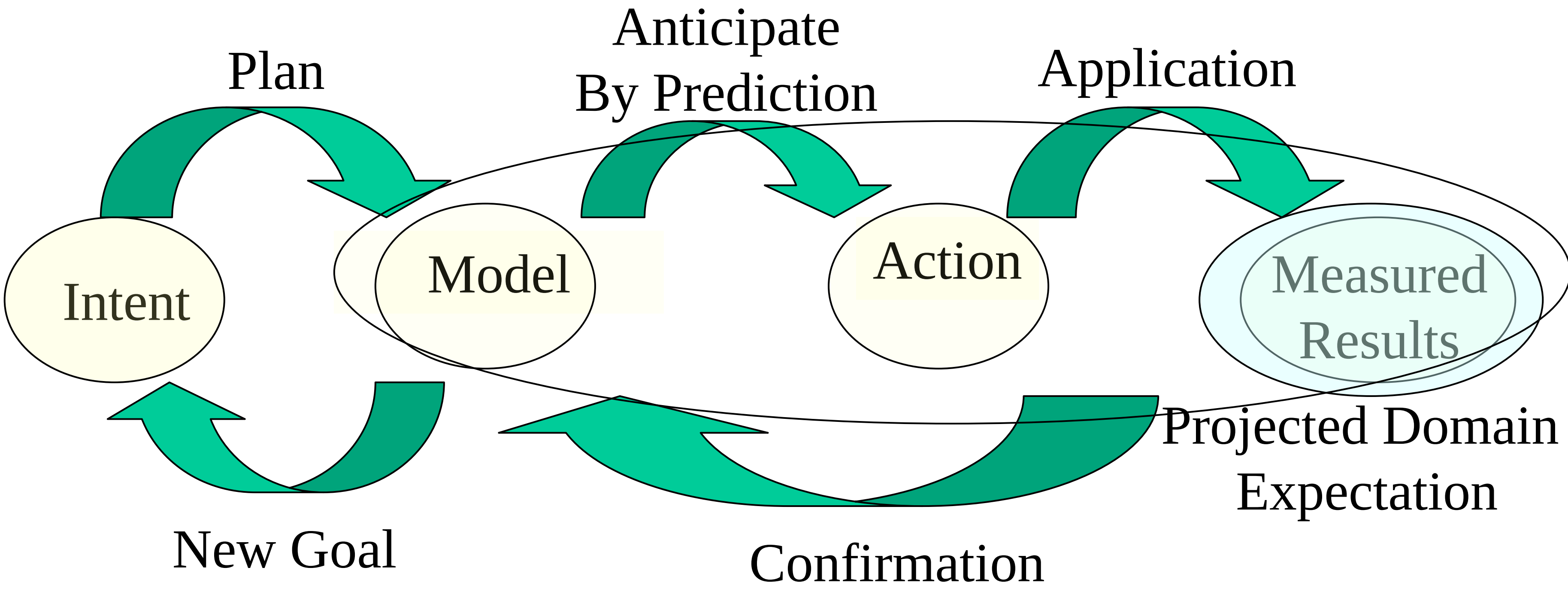
The Variable Structure Systems and Cognition

S. Habibi, J. Tjong, & M. Al-Shabi
Department of Mechanical Engineering
McMaster University

Overview

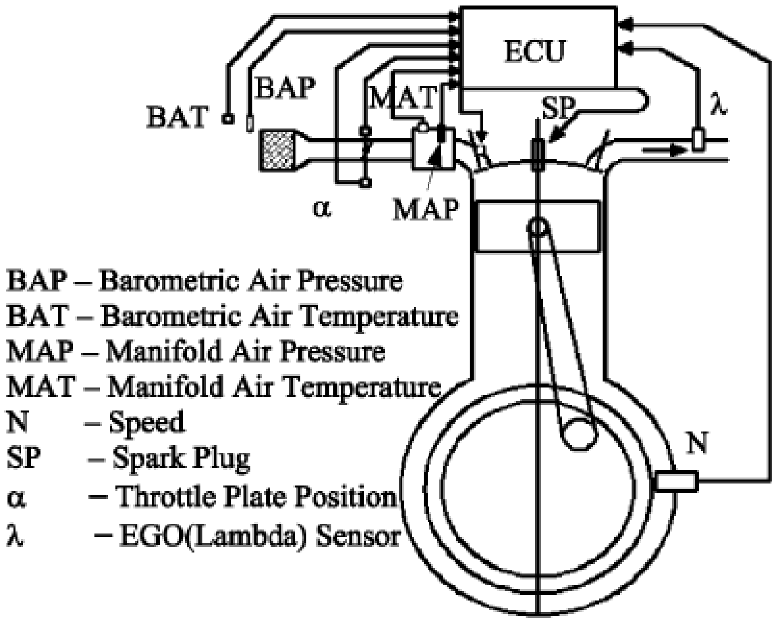
- Hypothesis
- Feedfoward Control and Wear in Automotive Systems
- Overview of the Variable Structure Systems and Sliding Mode Control
- Variable Structure Filter
- Examples
- Questions

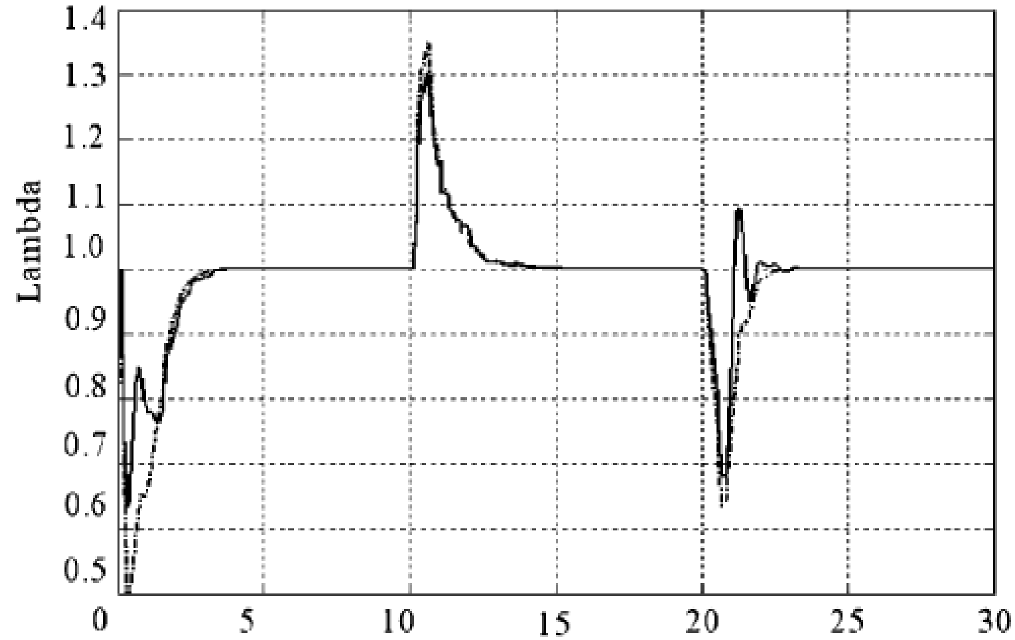
Behavioral Model

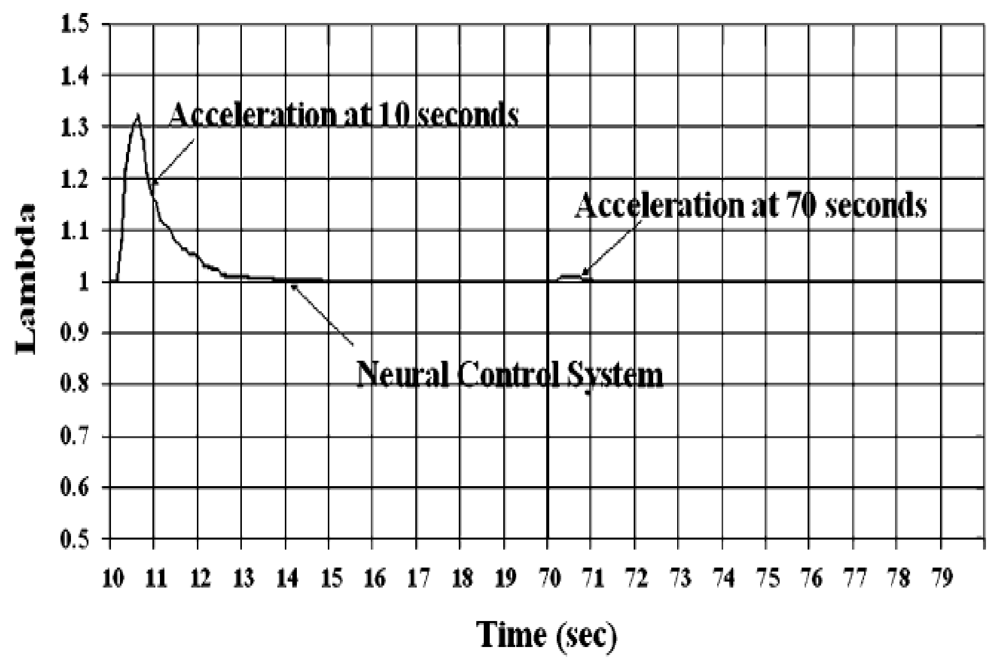


Model-based Feedforward Control

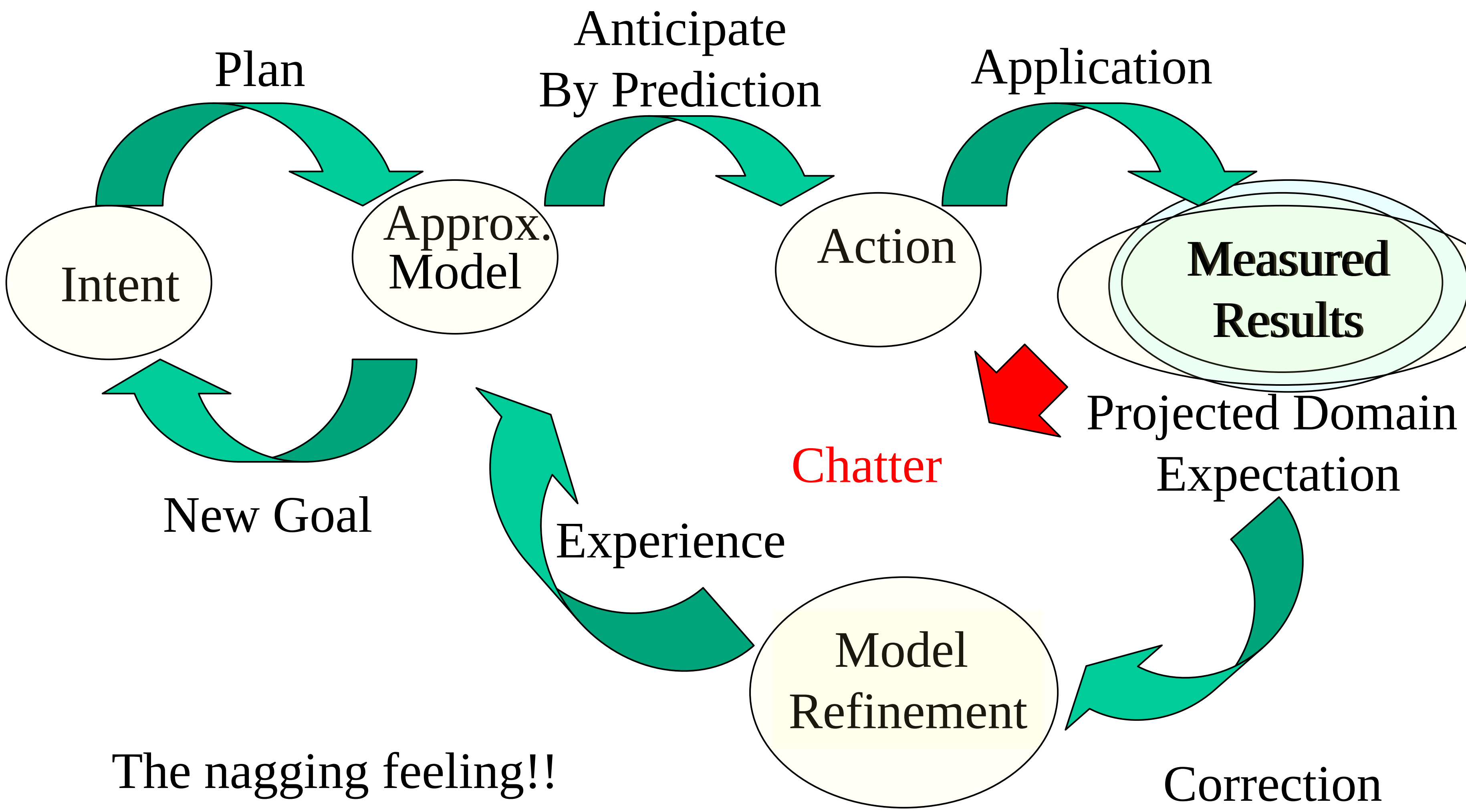
Automotive Control Context







Hypothesis



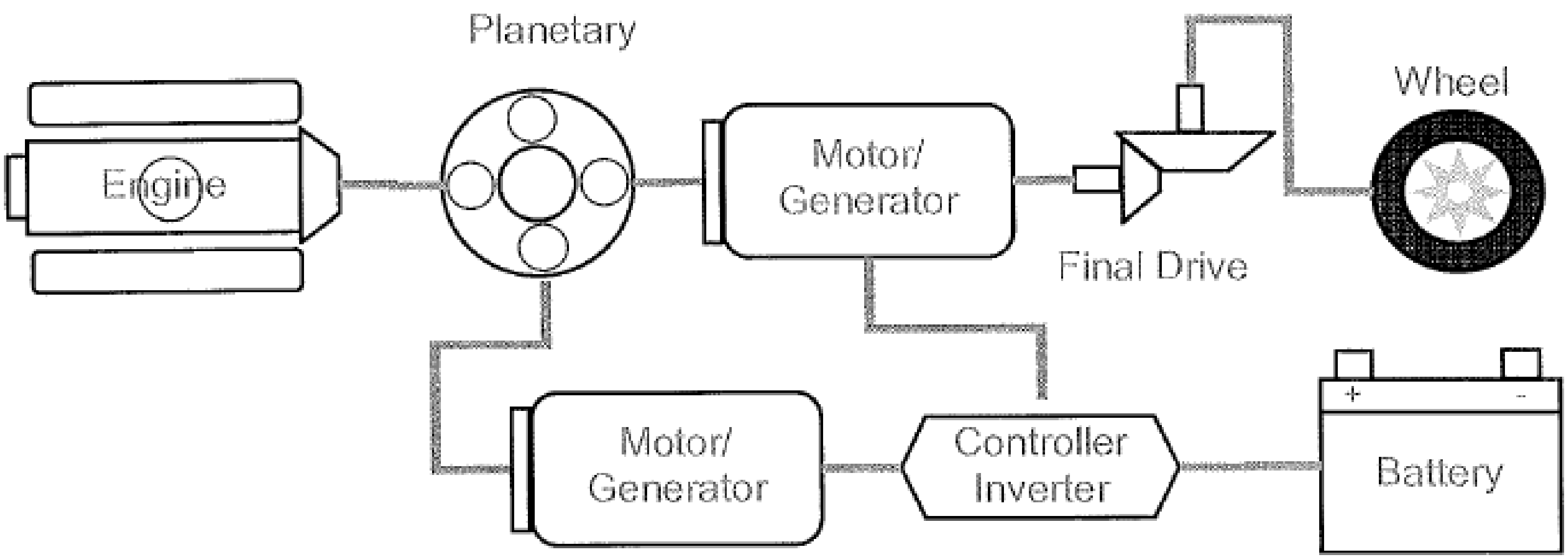
The nagging feeling!!

Hybrid Vehicles

Ford Escape Hybrid

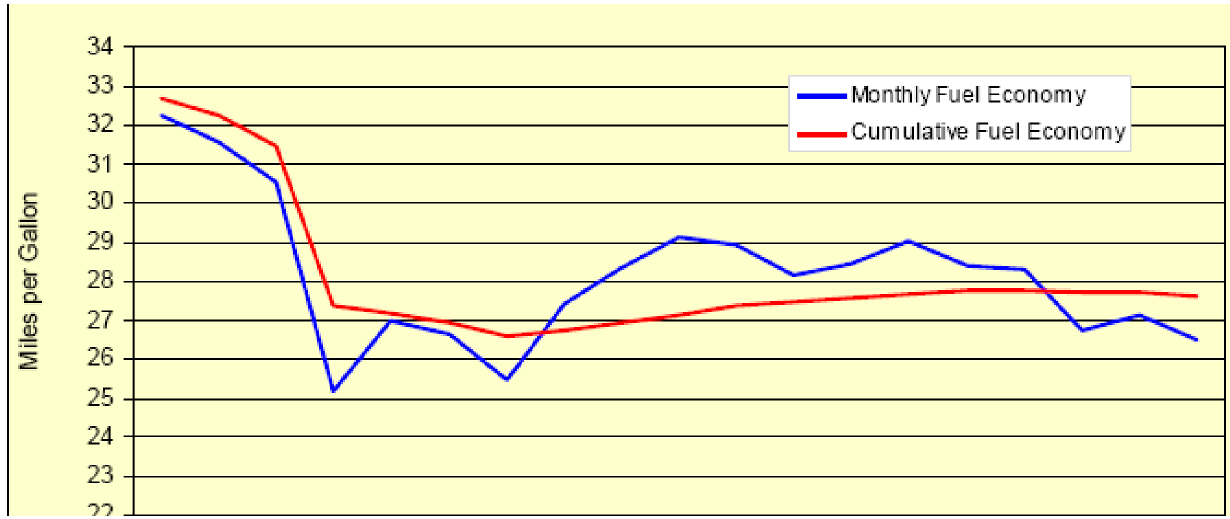
Regeneration

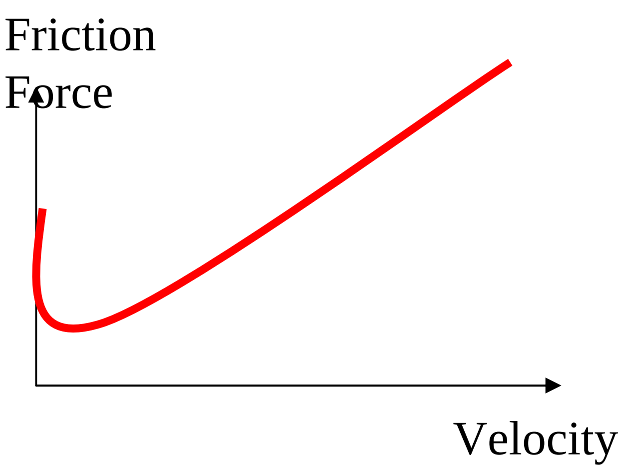
Steady-State
Engine Operation



Fuel Economy Hybrid

Monthly Fuel Economy





Friction characteristic is accurately described by a quadratic function of velocity

Can be tracked in real-time by parameter estimation using minimal sets of sensor but multiple banks of filters

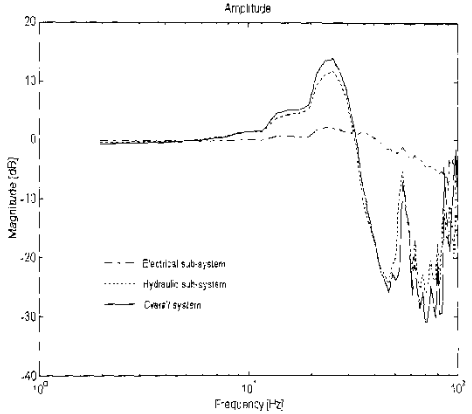
Modeling & Model Identification

Black Box Model by System Identification

Experiments

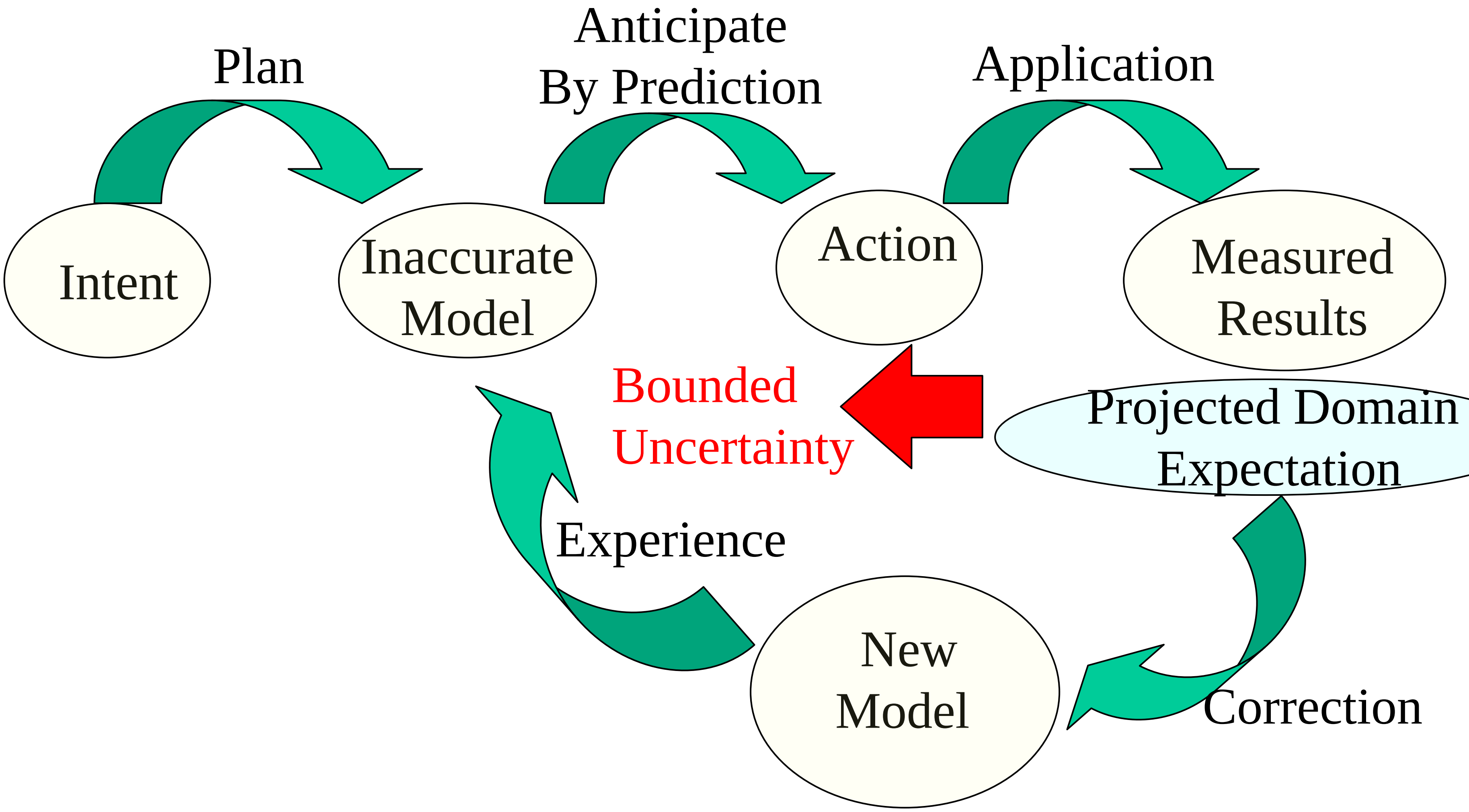
Validated Model

Physical Model



Sensitivity Analysis

Hypothesis



Plan
Anticipate
By Prediction
Application
Intent
Inaccurate
Model
Action
Measured
Results
Bounded
Uncertainty
Projected Domain
Expectation
Experience
New
Model
Correction

Research Thrust - White Box PHMS

- Model & Fault Characterization
  - Physical Modeling
  - System Identification & Dynamic Significance
  - Analysis & Model Structure Simplification
  - Experimentation for Model Parameter Quantification
  - Sensitivity Analysis
  - Mapping to Fault Conditions
- Robust Parameter Tracking Theory
  - State and P

  overc

Variable Structure Filter

- Prognosis by Association
  - Expert knowledge
  - Experimentation
  - In-vehicle data collection and monitoring

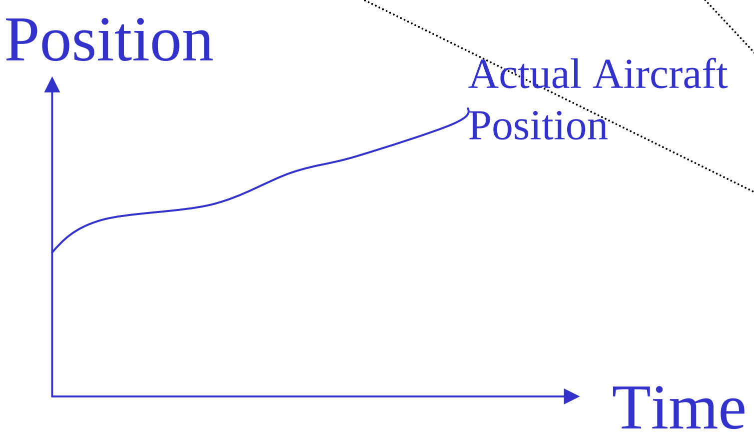
“Achilles Heel” of White Box Condition Monitoring

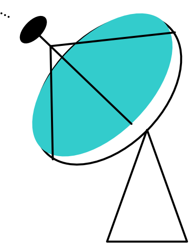
Continuous Monitoring
Data Analysis
Labor intensive

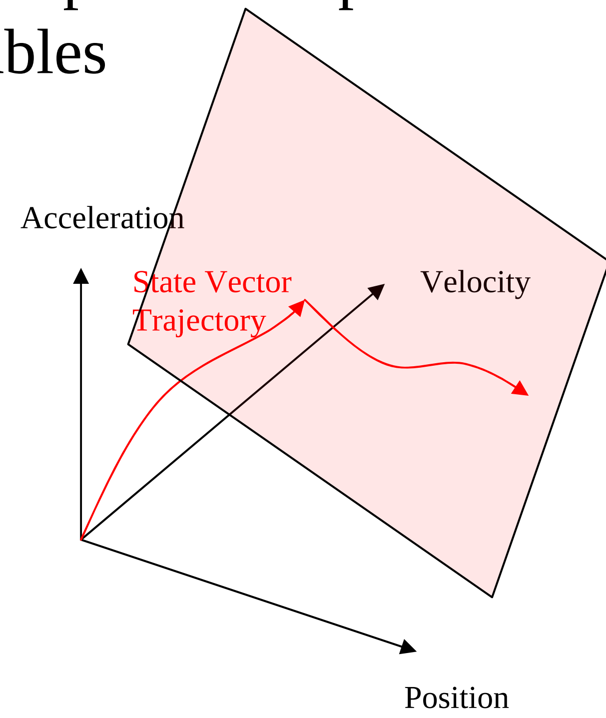
Variable Structure Systems

States:
- Position
- Velocity
- Acceleration

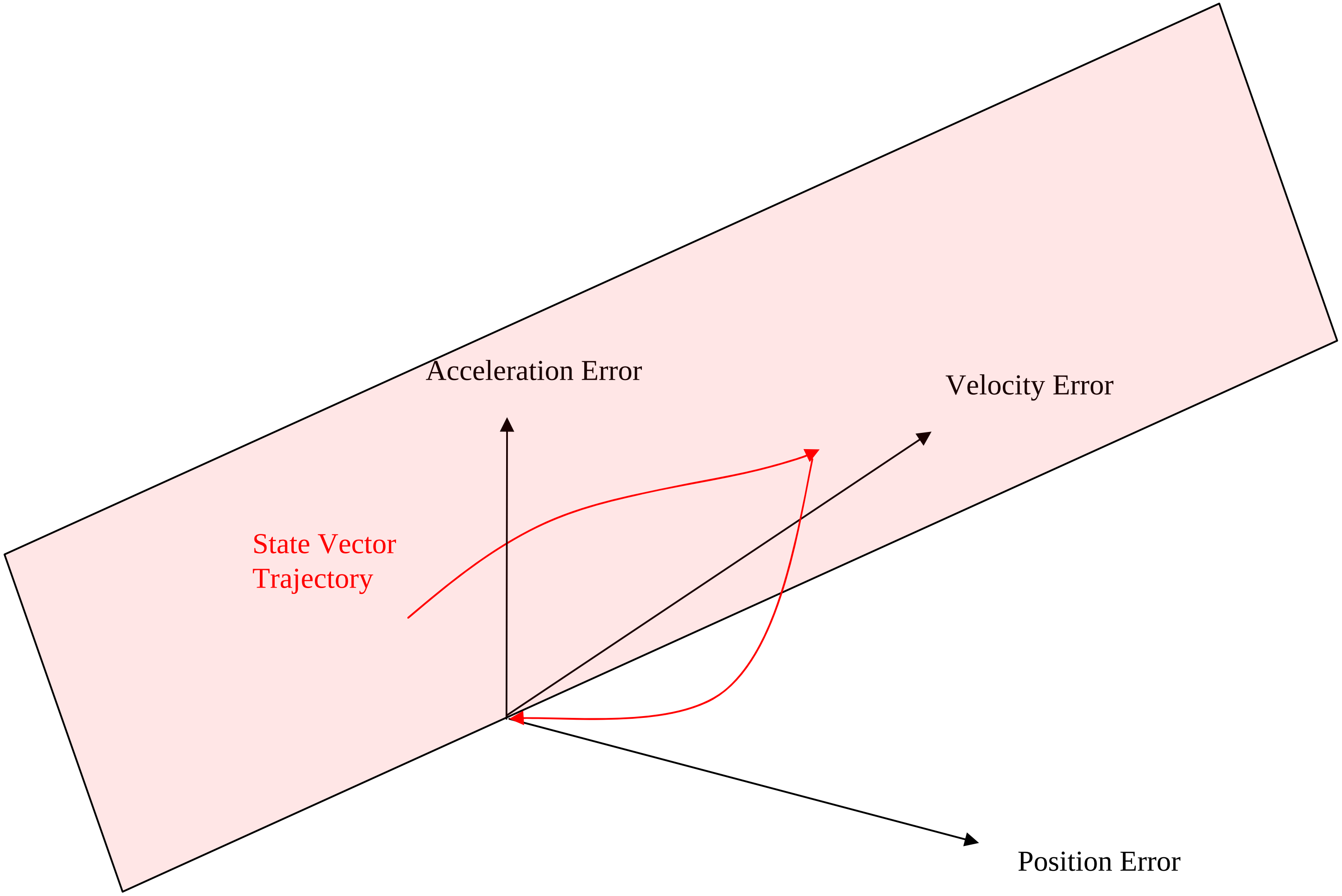
State space = n-dimensional space made up of state space variables



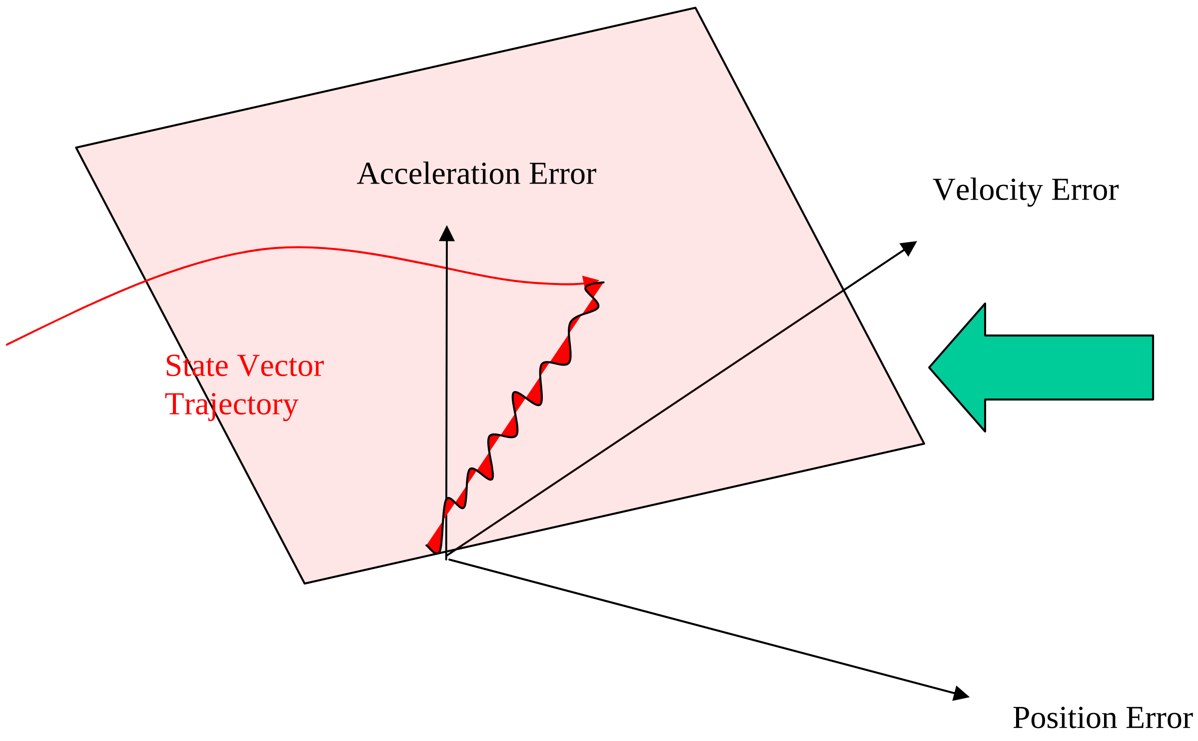




Variable Structure Control

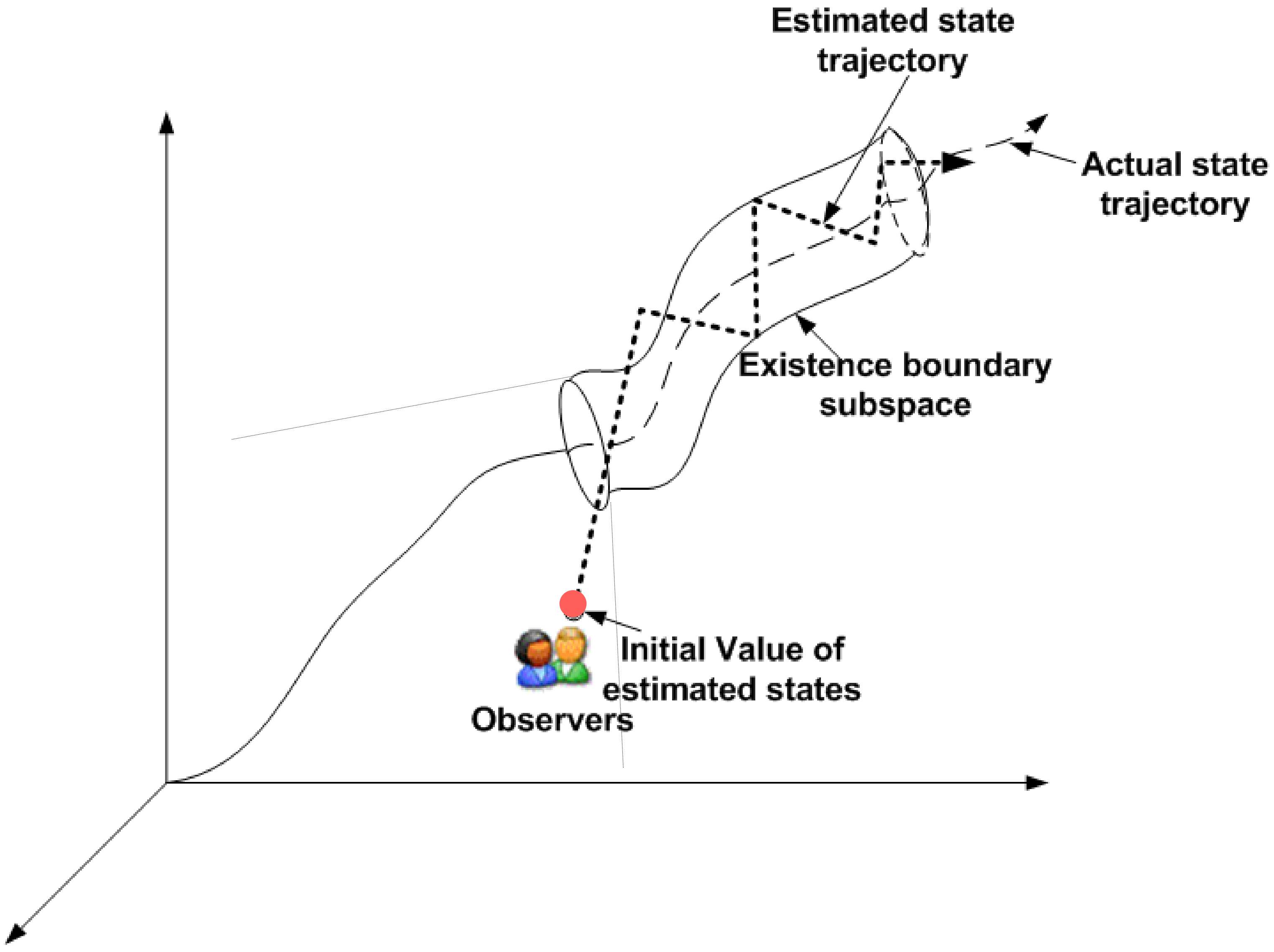


Sliding Mode Control

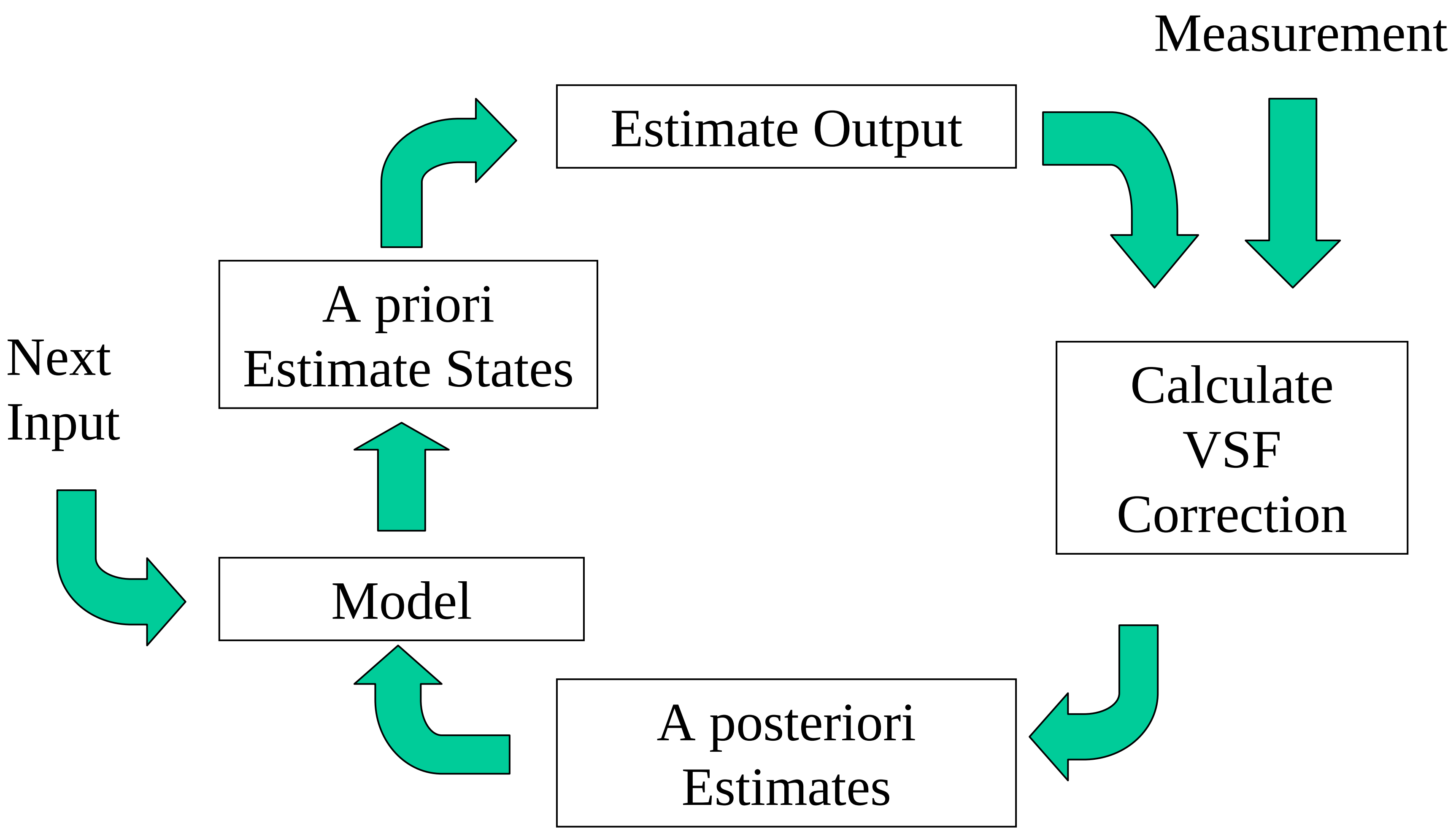


While on the switching Surface, robust to perturbations

Variable Structure Filter
For Robust Parameter Tracking



Variable Structure Filter Predictor-Corrector Method



Theorem

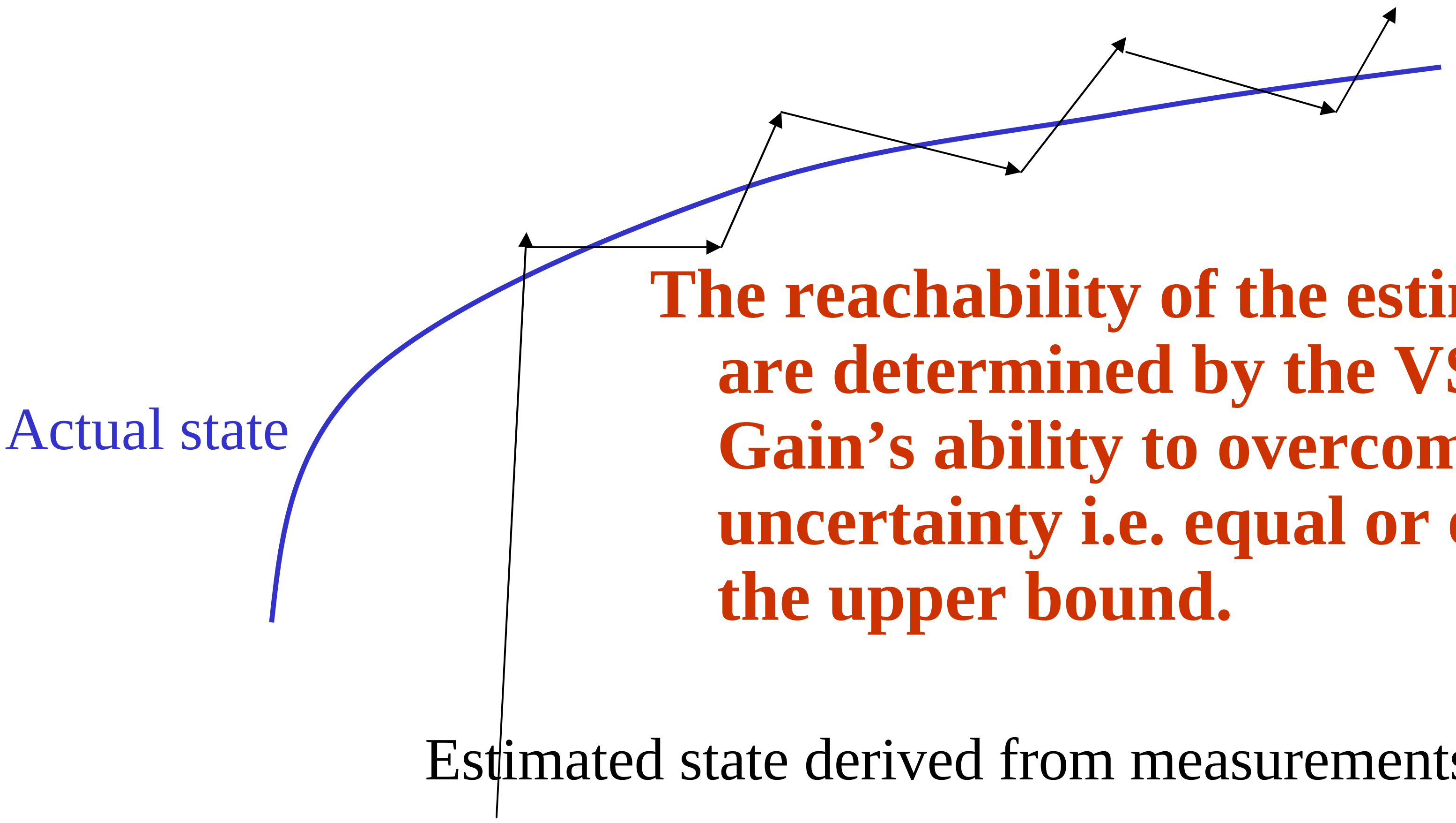
- The following gain structure results in convergence to a boundary layer:

$$\mathbf{K}_k = \left|\hat{\mathbf{H}}^{+}\left(\left|\mathbf{e}_{z_{k|k-1}}\right|_{\mathbf{ABS}} + \mathbf{Y}\left|\mathbf{e}_{z_{k-1|k-1}}\right|_{\mathbf{ABS}}\right)\right|_{\mathbf{ABS}} \circ \mathbf{s}_{\mathbf{gn}}(\mathbf{e}_{z_{k|k-1}})$$

- Boundary layer width can be explicitly linked to uncertainties

VSF Action

The VSF gain retain the estimated output to within a neighborhood of the measured output.

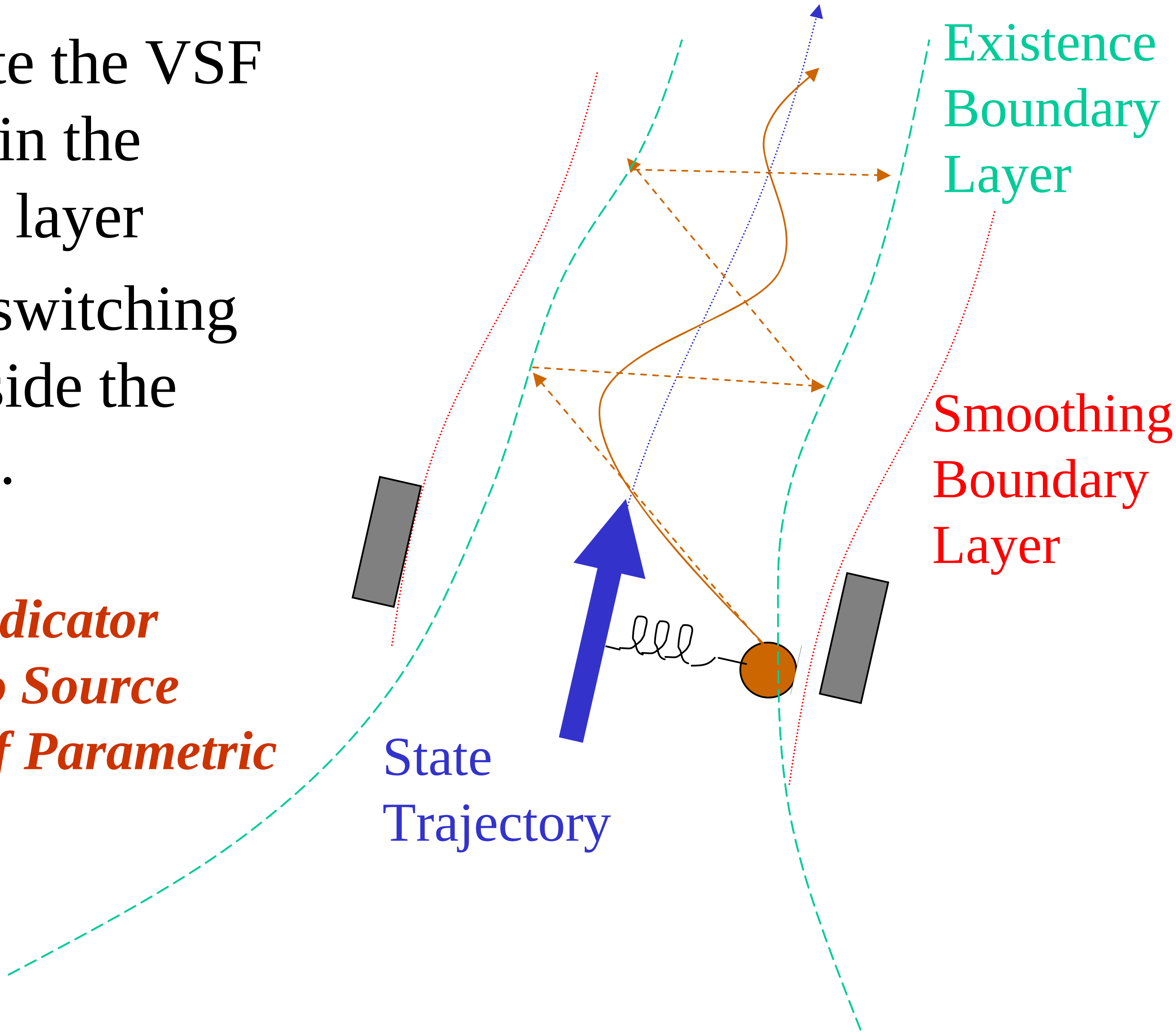


The reachability of the estimates are determined by the VSF Gain's ability to overcome uncertainty i.e. equal or exceed the upper bound.

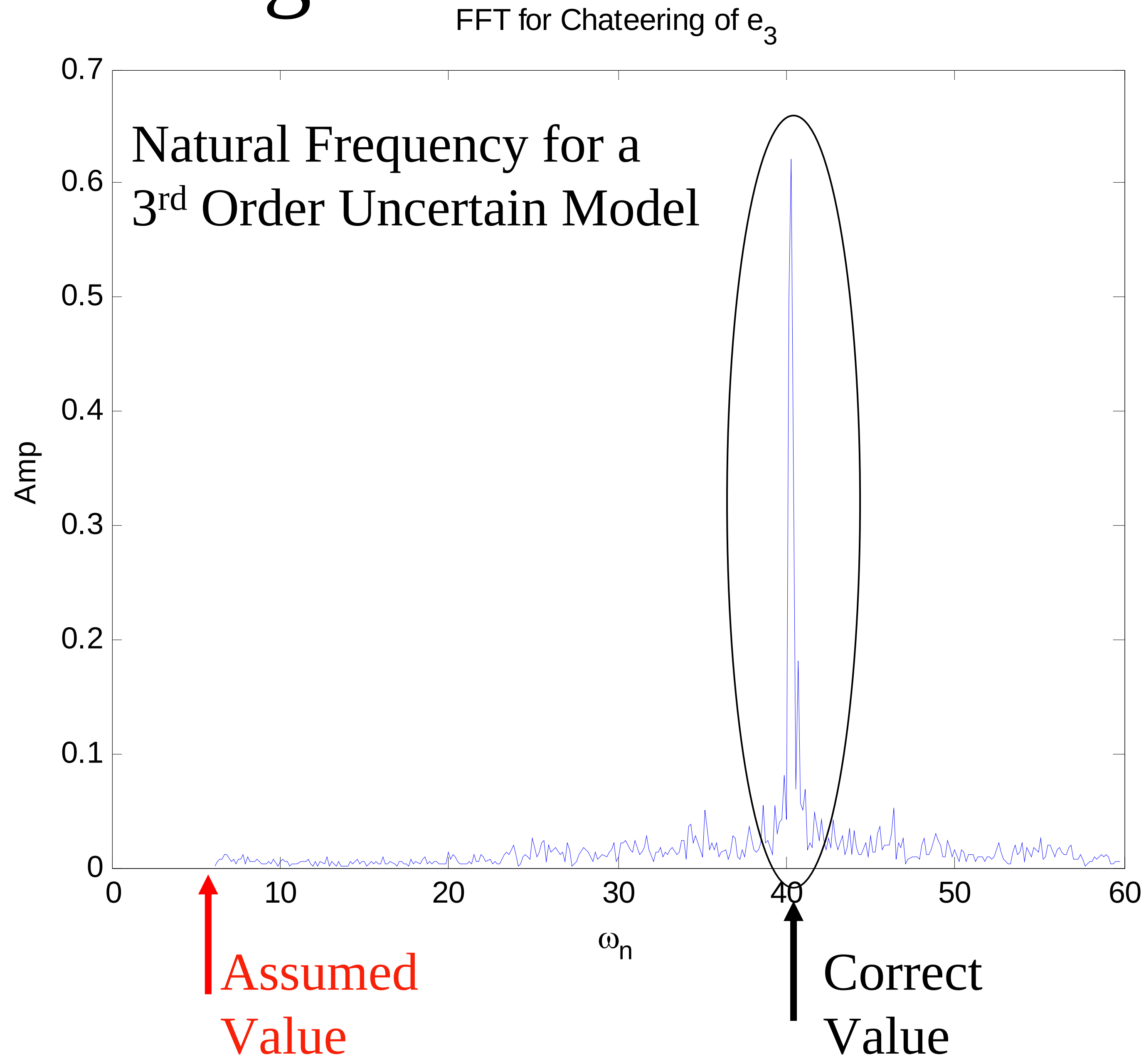
Smoothing Boundary Layer

- Interpolate the VSF gain within the boundary layer
- revert to switching form outside the boundary.

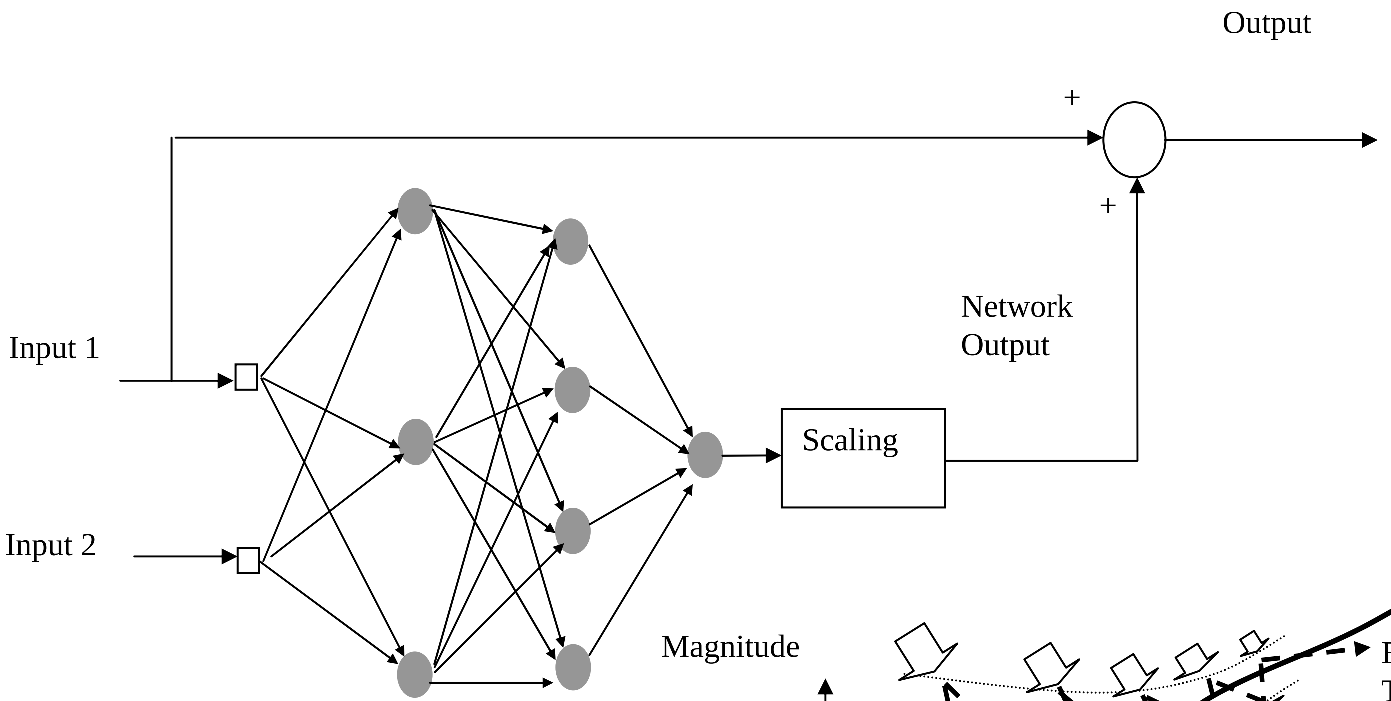
Secondary Indicator Pertaining to Source And Range of Parametric Uncertainty

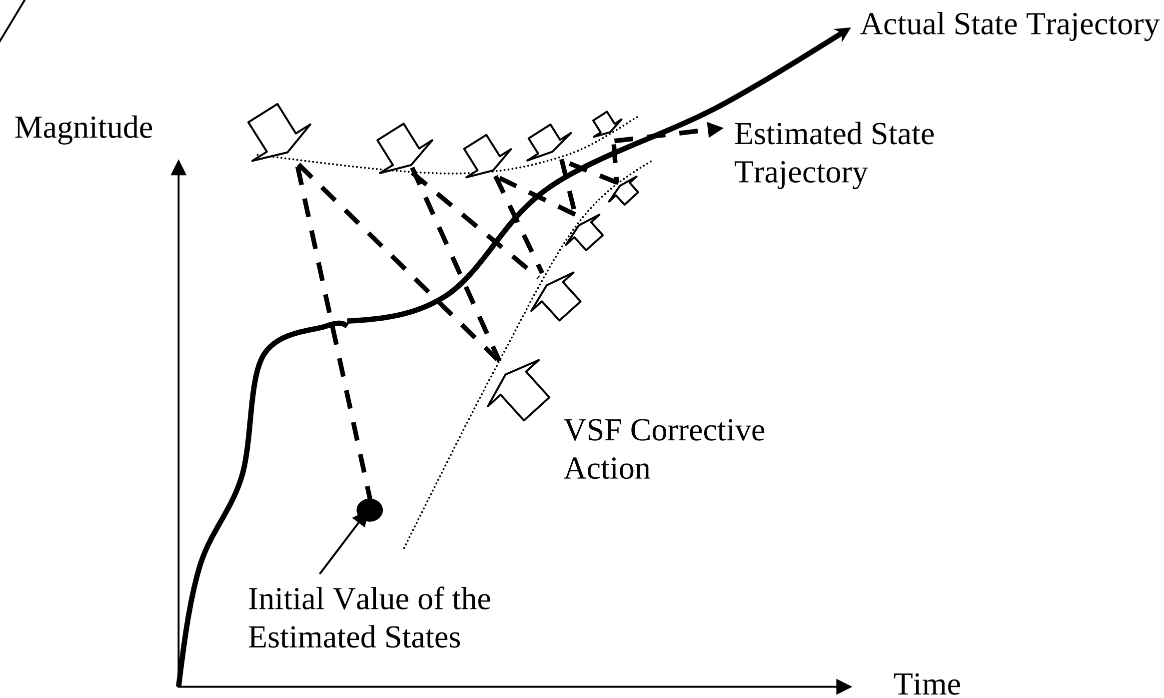


Chattering – Information Content



Network Elements or Neurons



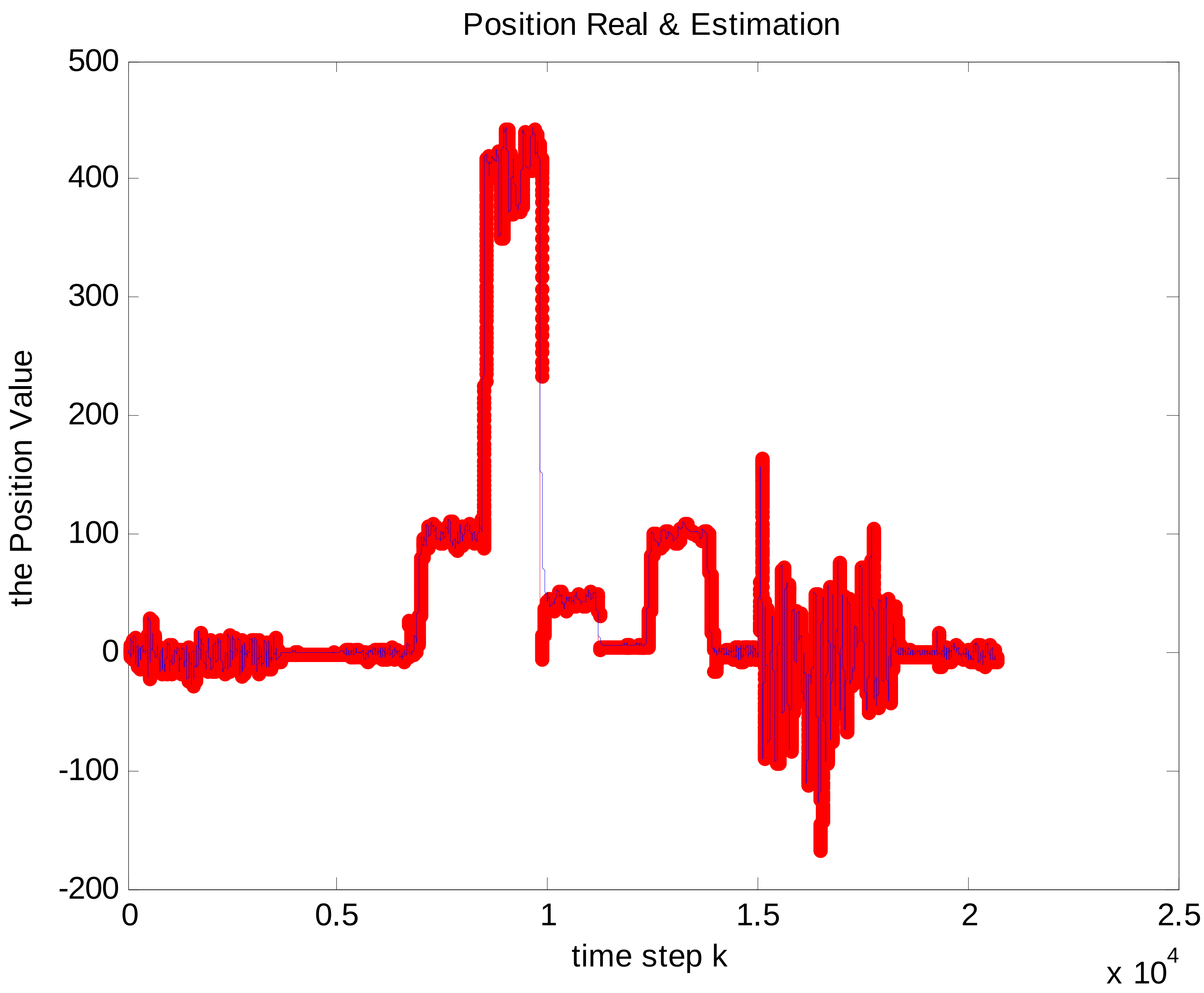


Example
State and Parameter Tracking

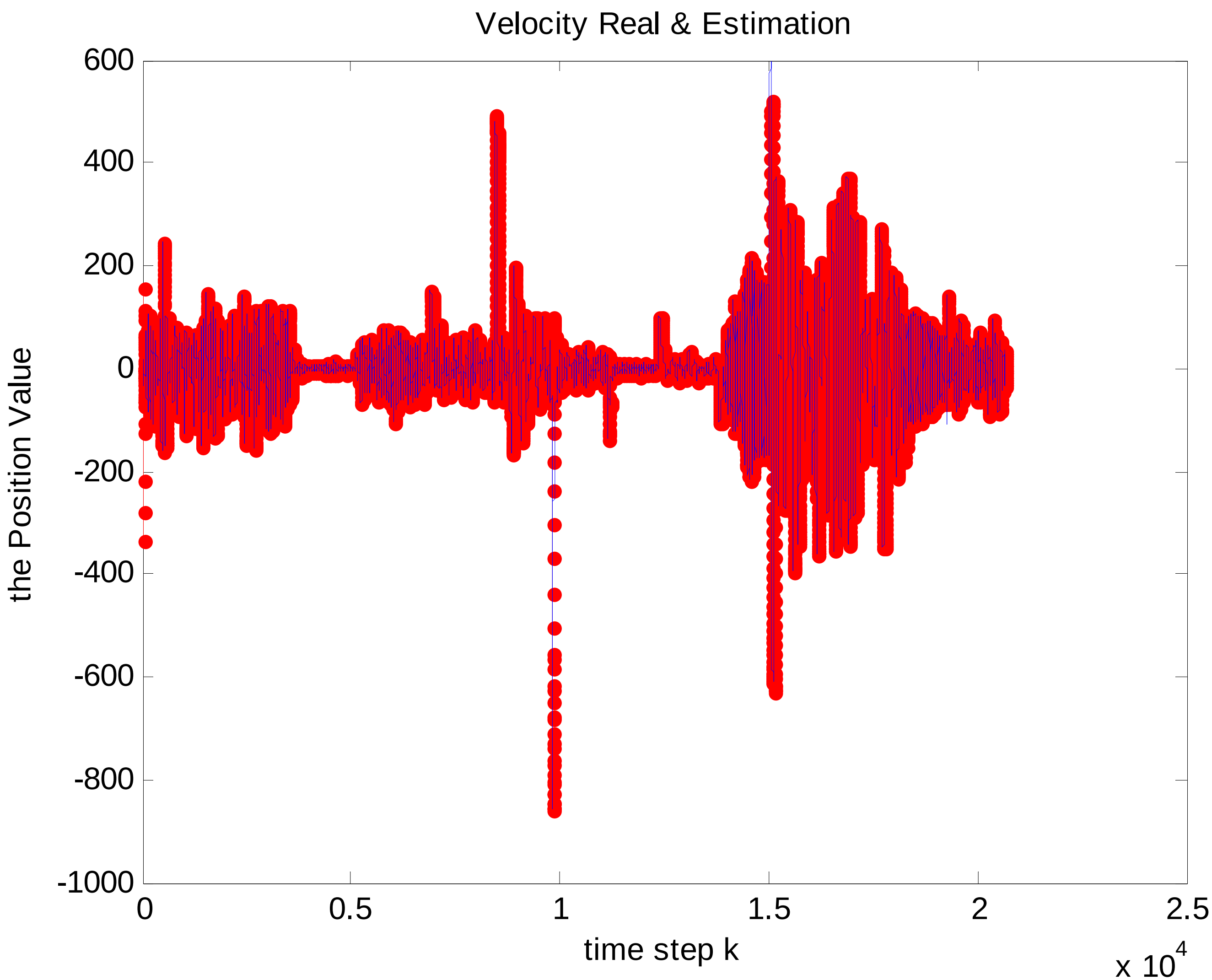
Uncertain 2nd order system

$$\frac{P\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

States - 1


Position Real & Estimation
500
400
300
200
100
0
-100
-200
the Position Value
0
0.5
1
1.5
2
2.5
time step k
x 10^4

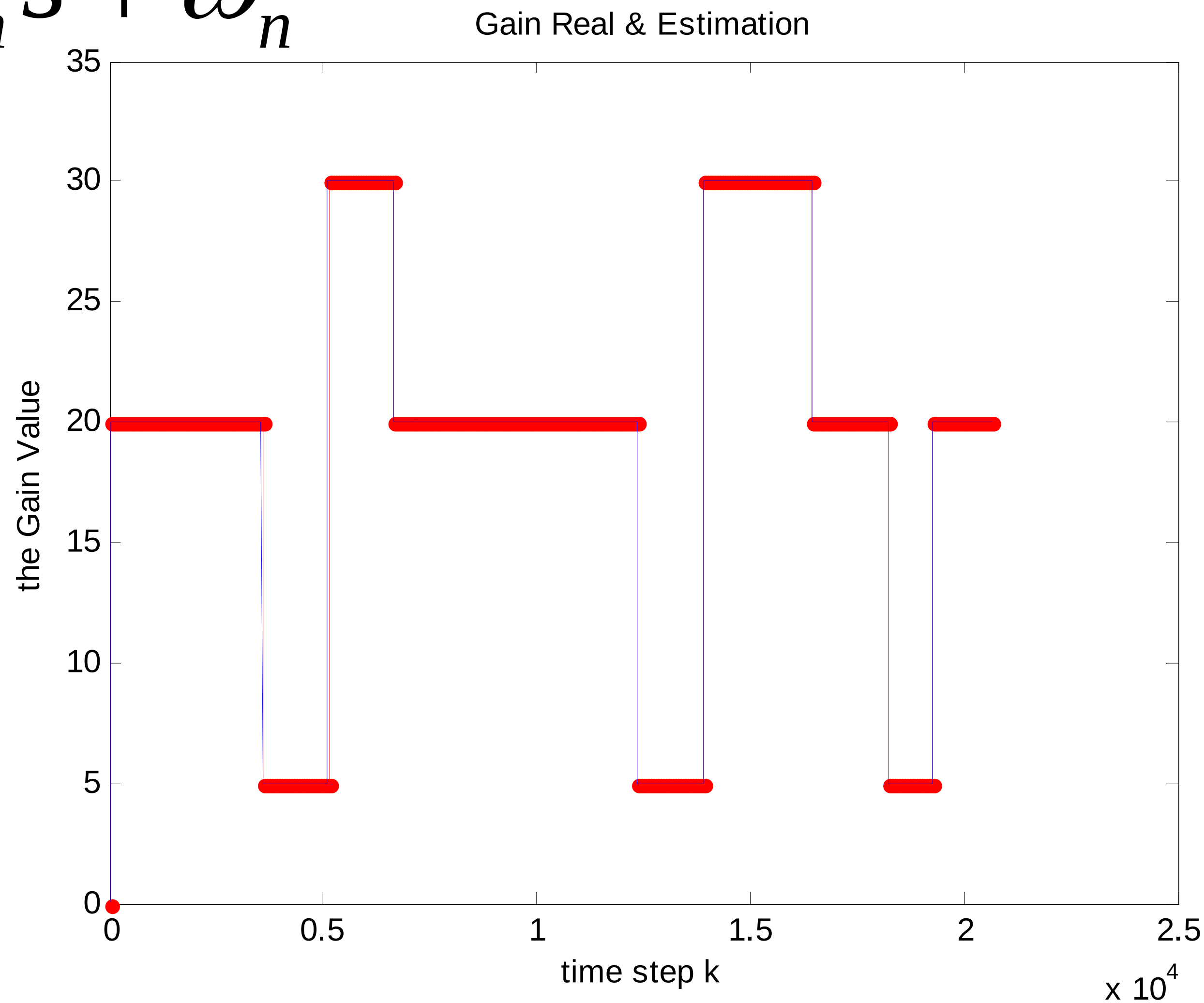
State 2



Velocity Real & Estimation
600
400
200
0
-200
-400
-600
-800
-1000
the Position Value
0
0.5
1
1.5
2
2.5
time step k
x 10^4

Parameter/State Estimation Error

$$\frac{P\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$



Parameter/State Estimation Error

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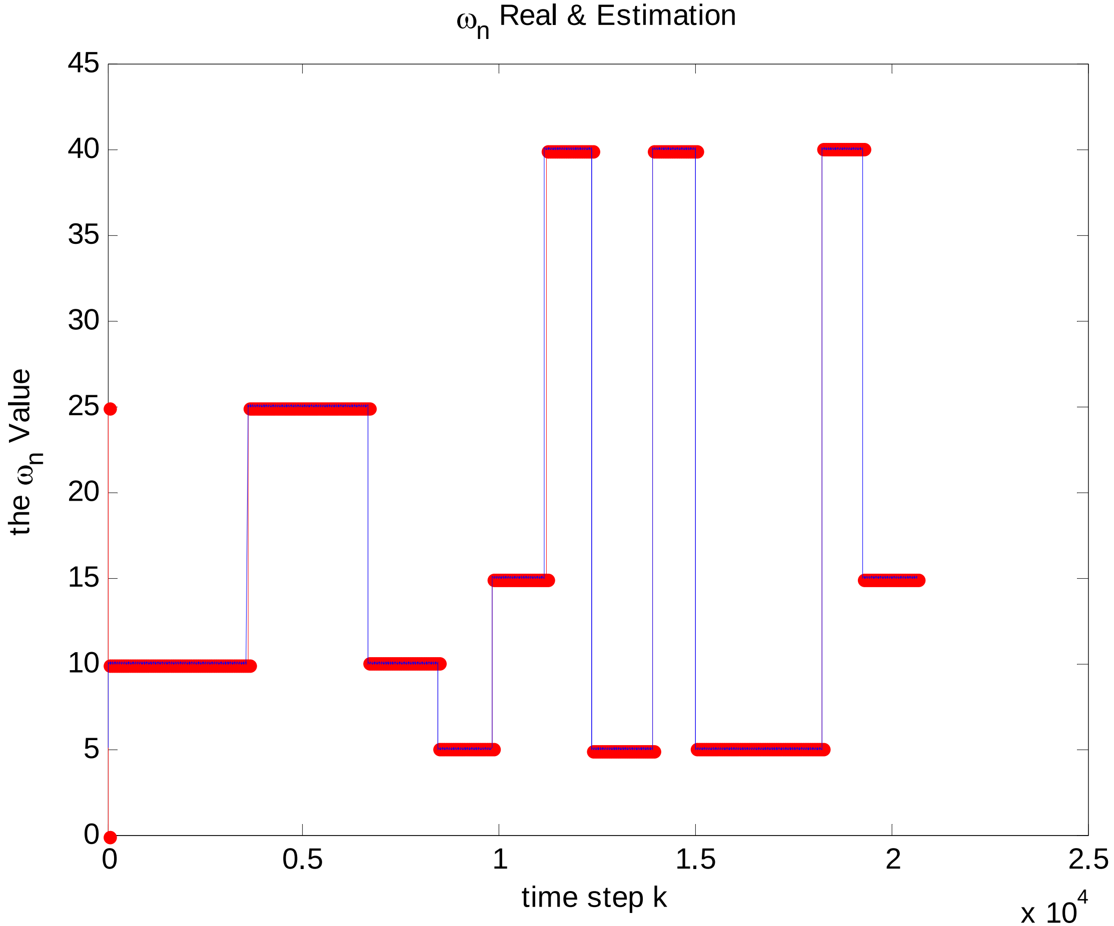
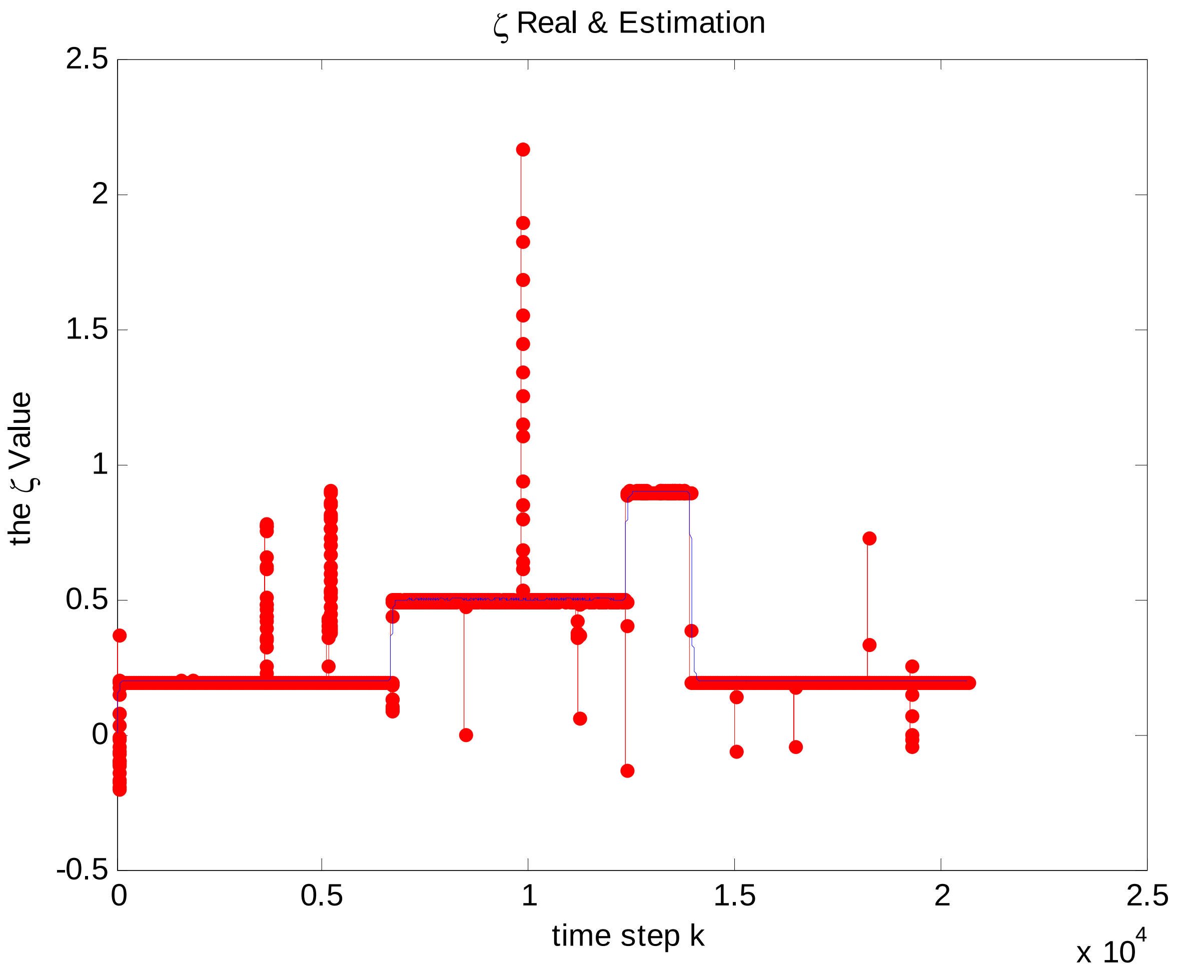


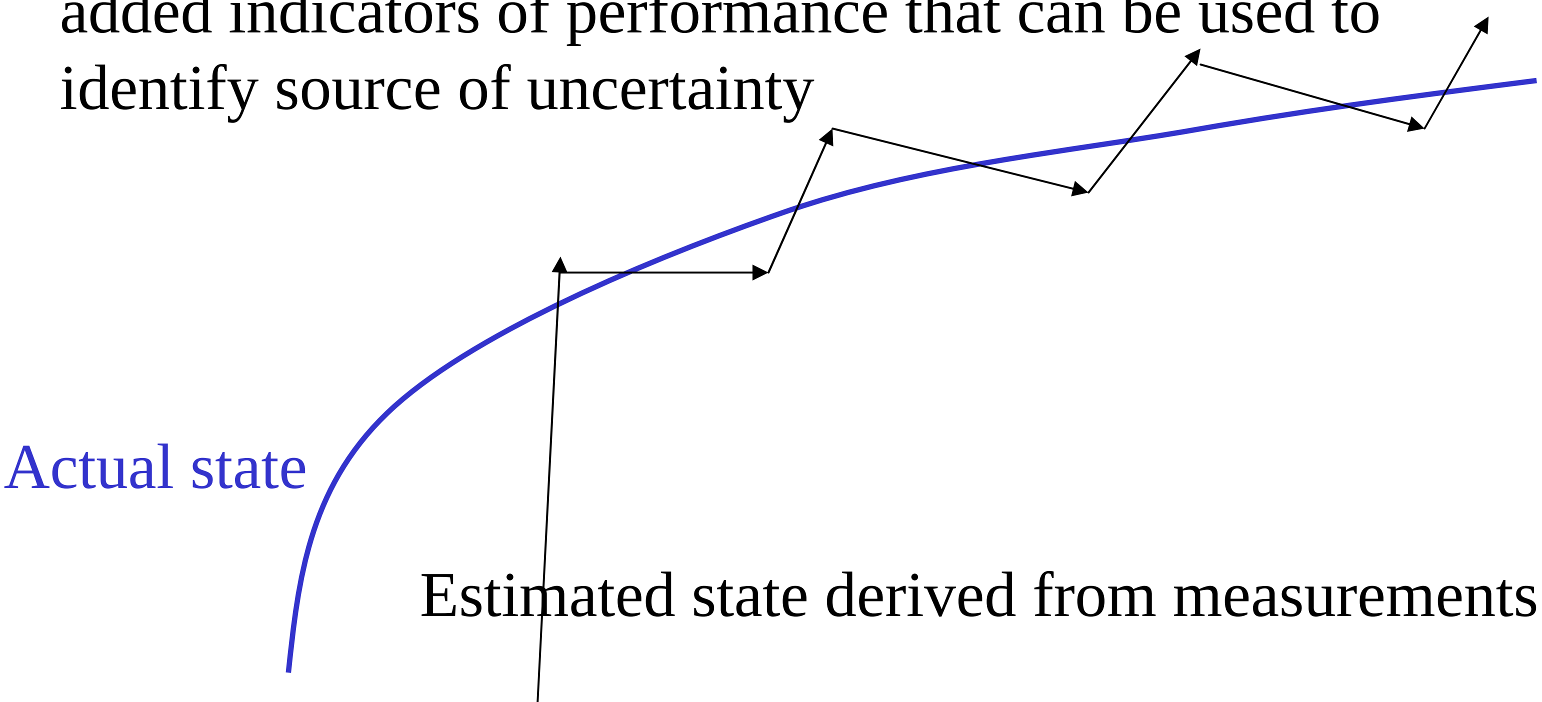
Parameter/State Estimation Error

$$\frac{P\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

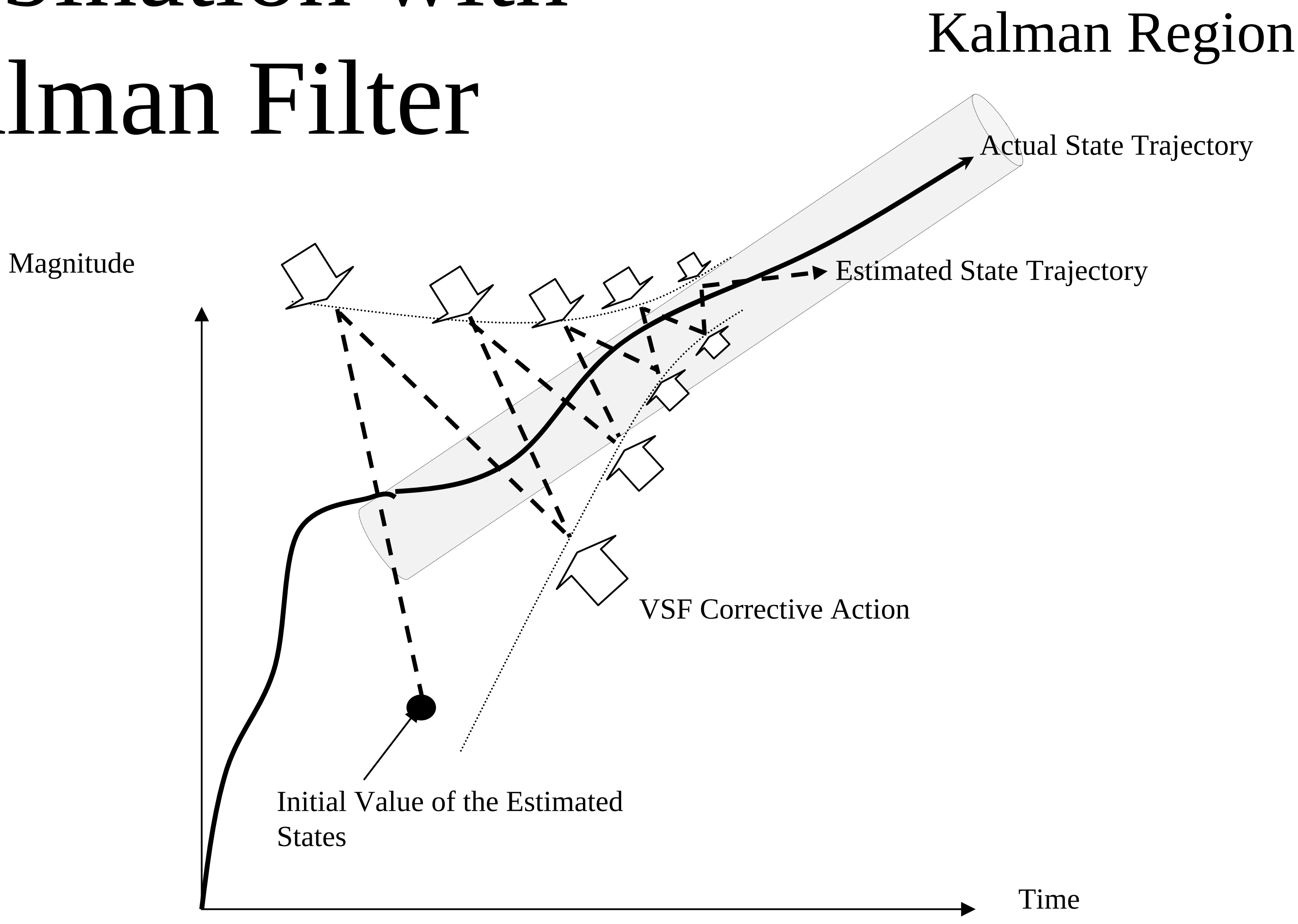


Parameter Estimation Using Variable Structure Filter

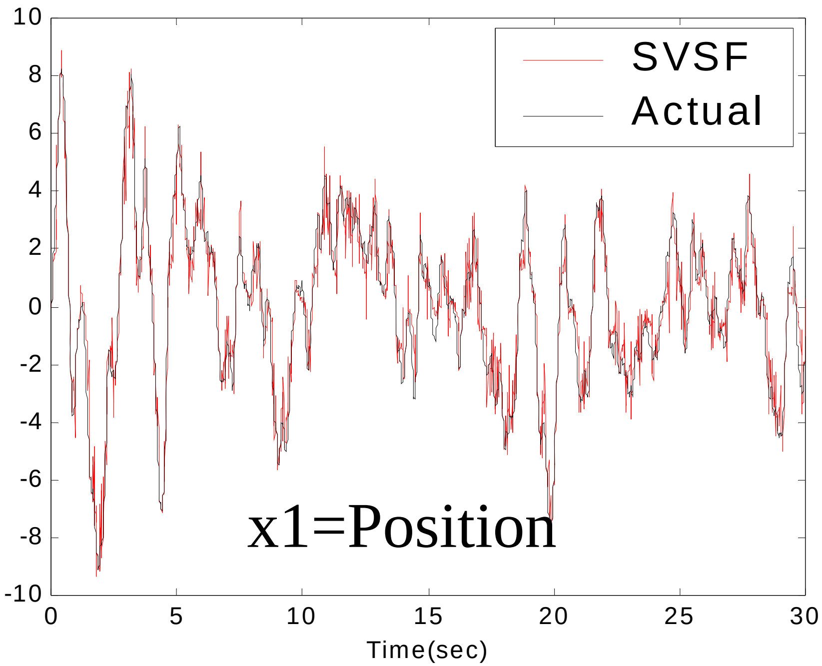
- Accommodates multiple parameter changes in the model and guarantees numerical stability of the estimation process given bounded uncertainties
- Allows performance recovery against uncertainty by adaptation and self tuning
- Minimizes the requirement for additional sensors due to its added indicators of performance that can be used to identify source of uncertainty

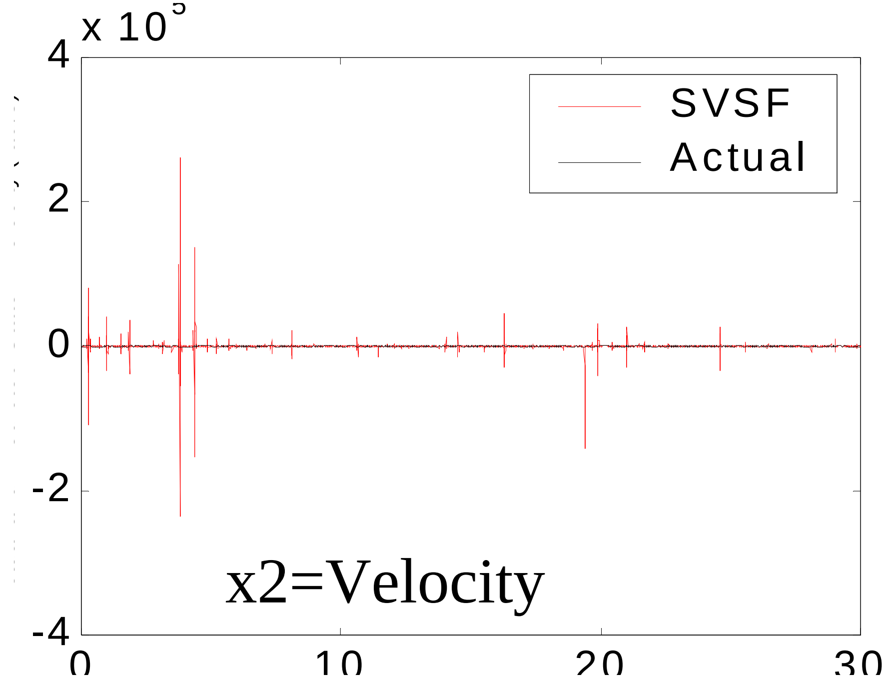


Combination with Kalman Filter



Parameter/State Estimation Error

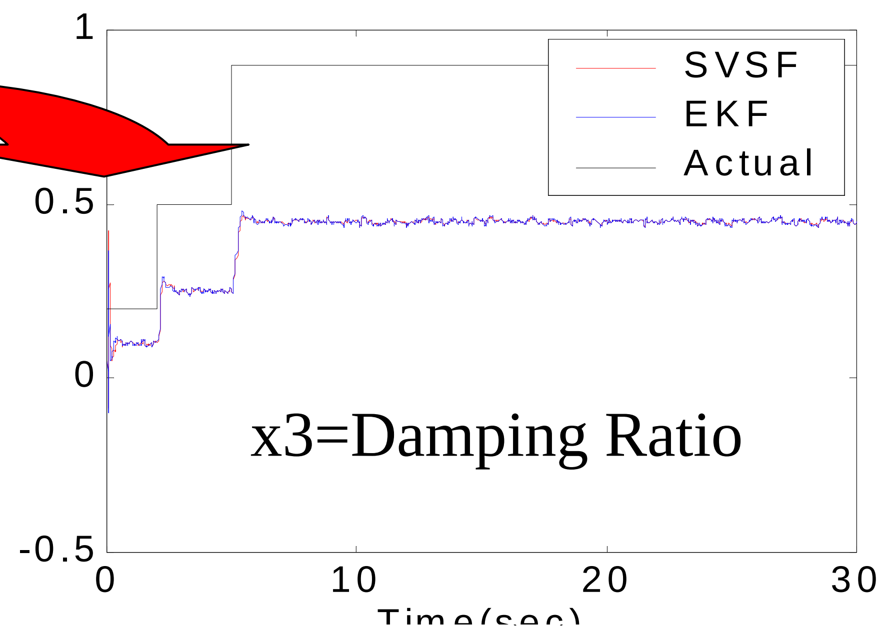




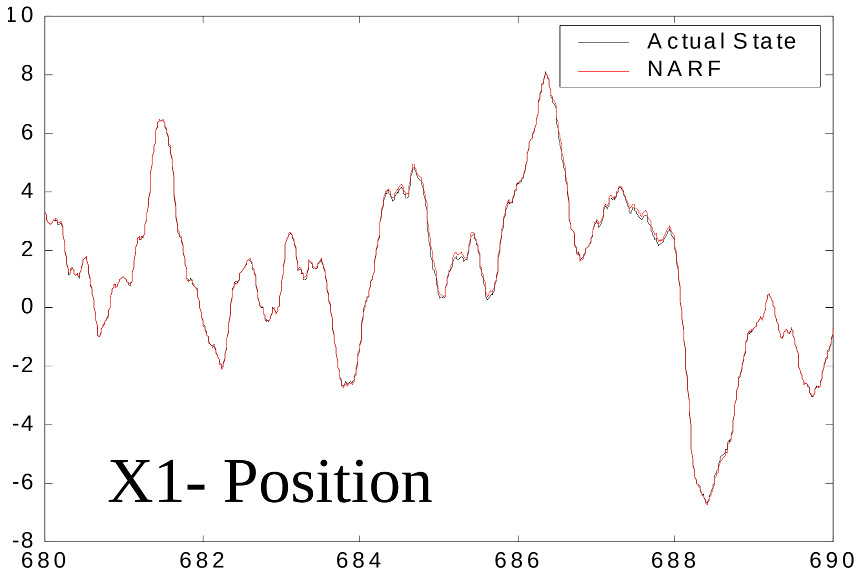
$$\frac{12\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$$

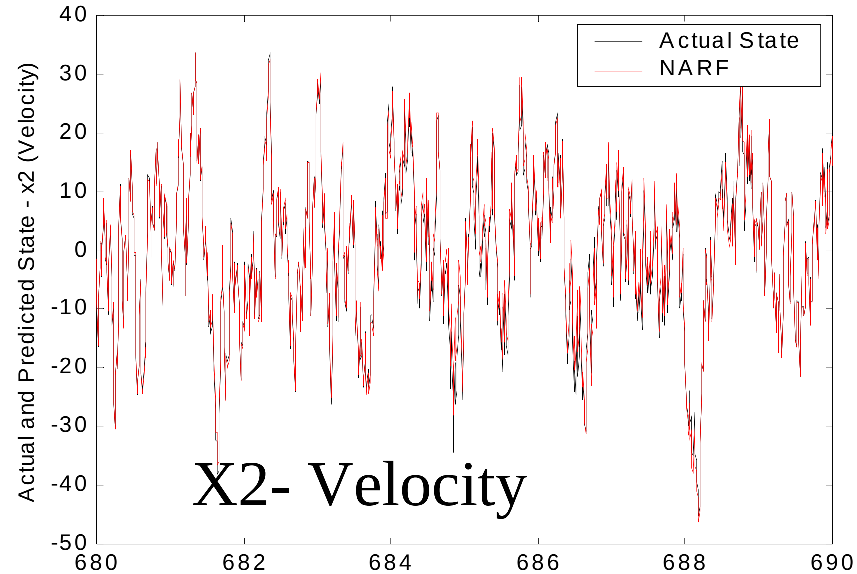
$$\omega_n = 5$$

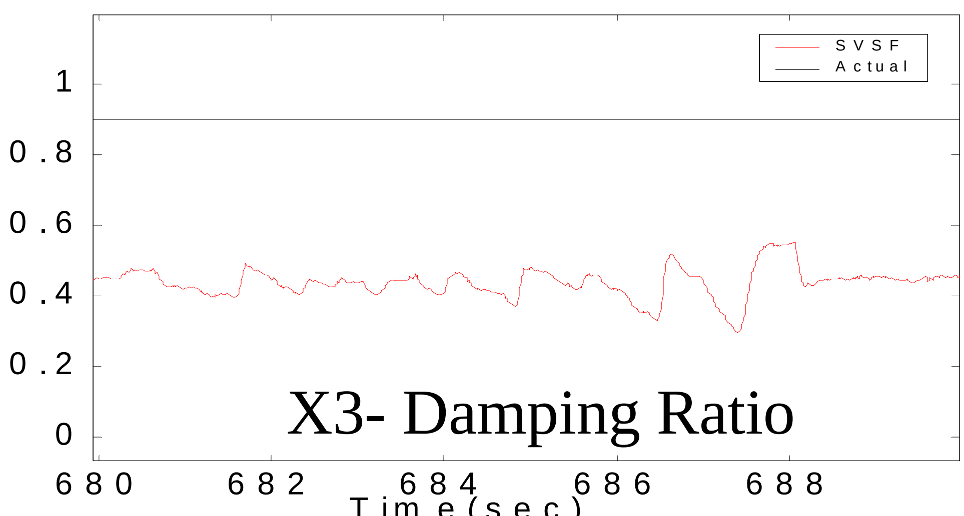
$$\hat{\omega}_n = 30$$



Parameter/State Estimation Uncertain Model







Advanced Technology Vehicles

Performance
Reliability

Maintaining
Fuel Efficiency

Driver Profile

Wear

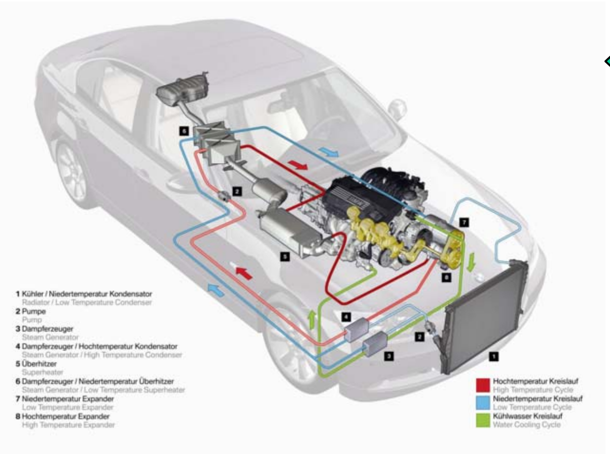
Energy Recovery

Energy Storage

Power Management

Architecture

Component Specs

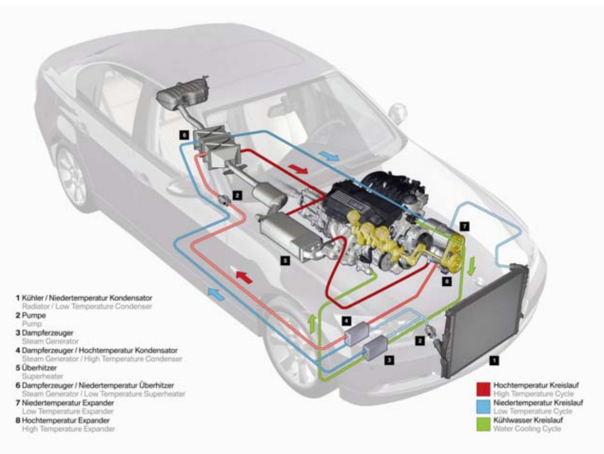


Thermal Management

Regeneration

Steady-State
Engine Operation

Advanced Technology Vehicles



Thermal Management

Regeneration

Steady-State
Engine Operation

Performance
Reliability

Cognitive Car

Regulate

Predict

Adapt

Learn

Sensing

Model

Architecture

Component Specs

Evolution of Intelligent Systems

Cognitive Car

Cognitive dynamic systems build up rules of behavior over time through learning from continuous experiential interactions with the environment, and thereby deal with environmental uncertainties.

Intelligence &
Cognitive Dynamics
In Group/Parallel Systems

Power train
Control
Applications

Diagnostics

Safety

Energy Recovery

Hybrid Architecture

Questions