

# *In Situ* Adaptive Tabulation for Non-linear MPC

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# Model vs. Computational Reduction

- Model Reduction
  - Objective: Reduce the number of states while preserving the most important system dynamics
- Computational Reduction
  - Objective: Reduce the computational time to integrate a model while preserving all of the system dynamics

# Current Industrial Implementation of NMPC

- Linear model MPC with non-linear bias modeled with an artificial neural network

$$\dot{x} = Ax + Bu$$

$$y = Cx + \text{NeuralNet}$$

# Proposed Implementation of NMPC

- Non-linear model (ODE or DAE) MPC

$$\dot{x} = f_1(x, u)$$

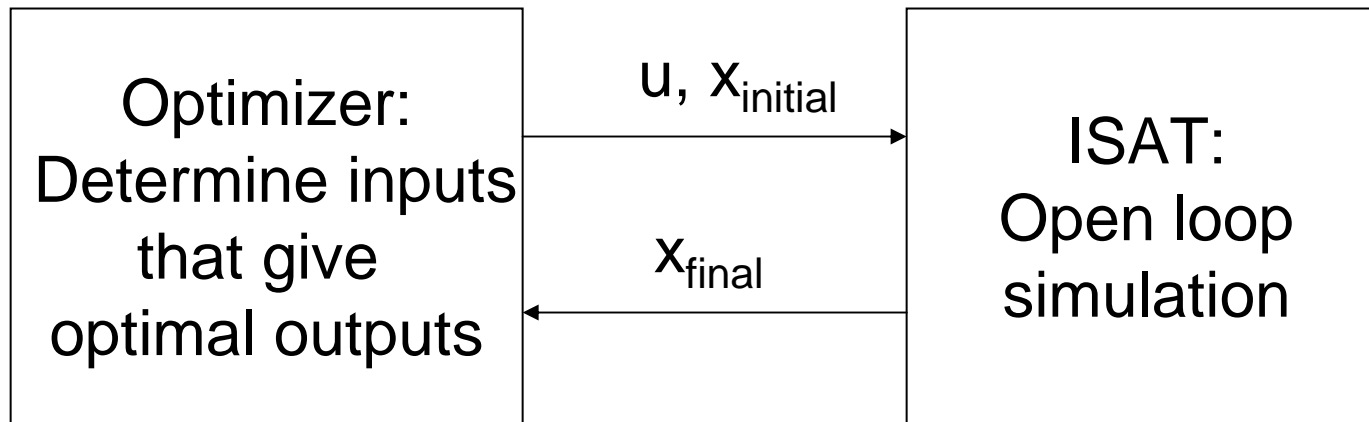
$$0 = f_2(x, u)$$

$$y = h(x, u)$$

- *In Situ* Adaptive Tabulation (ISAT)
  - Adaptable to process shifts / grade changes
  - Reliable error control
  - *In situ* training – It learns as it goes
  - No restrictions on the model

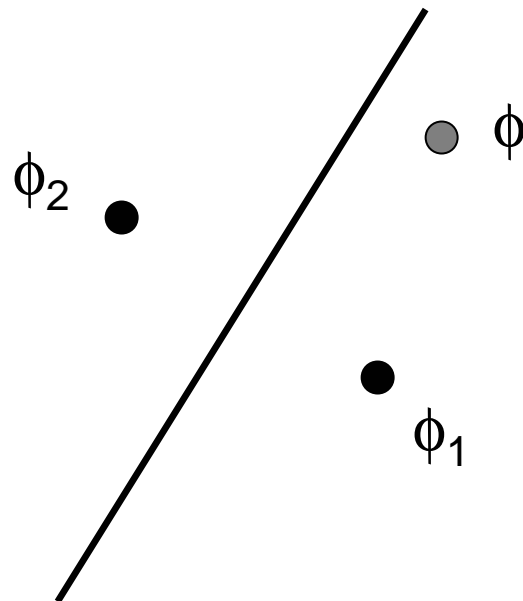
# ISAT with NMPC

- ISAT replaces the open loop integrator



# ISAT Search

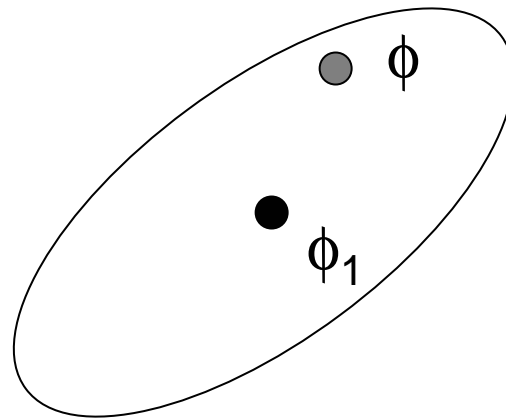
- Binary Tree Architecture
  - Search times are  $O(\log_2(N))$  compared with  $O(N)$  for a sequential search



$$\phi = \begin{bmatrix} u \\ x_0 \end{bmatrix}$$

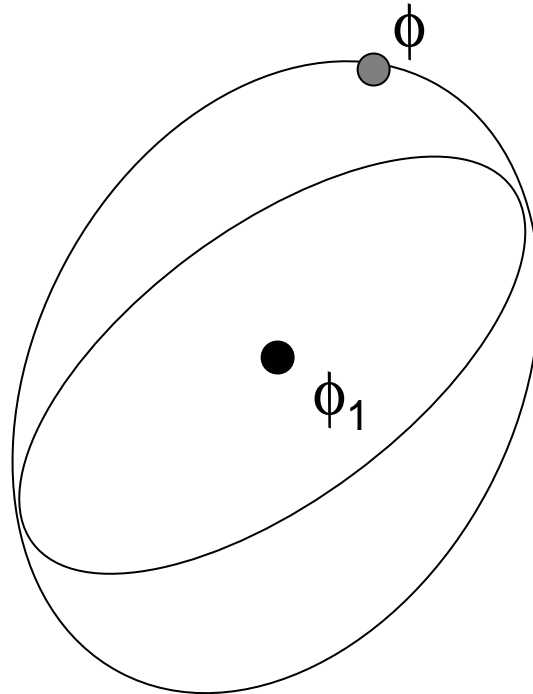
# ISAT Integration

- Scenario #1: Inside the region of accuracy



# ISAT Integration

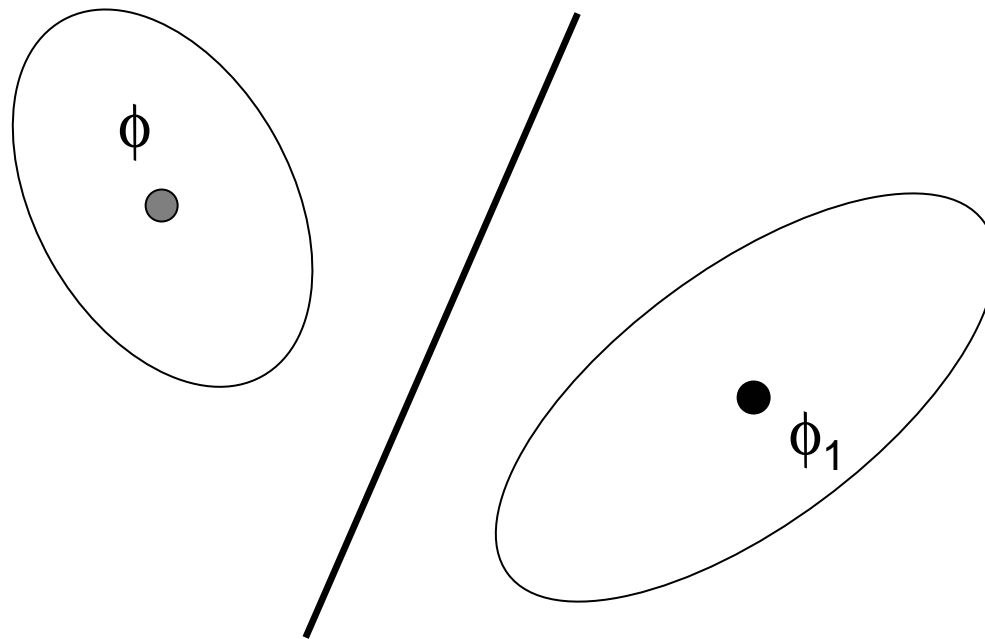
- Scenario #2: Outside the region of accuracy but within the error tolerance





# ISAT Integration

- Scenario #3: Outside the region of accuracy and outside the error tolerance



# ISAT Performance

- Successfully implemented with ODE and DAE models
- Computational speedup generally in the range of 20 – 500 times
- Storage <100MB for 96 state DAE model with a  $10^{-3}$  tolerance on all states
- Constraints

# Future Directions

- Fault detection
- Bottleneck: Reliable non-linear models
  - Model database
    - Chemical Systems
      - Distillation Columns
      - Reactors
    - Mechanical Systems
  - Contribute your non-linear models
    - Contact: [john\\_hedengren@hotmail.com](mailto:john_hedengren@hotmail.com)
    - Web-site: <http://www.che.utexas.edu/~john/research/>