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

\[
\begin{align*}
\dot{x} &= f_1(x, u) \\
0 &= f_2(x, u) \\
y &= h(x, u)
\end{align*}
\]

• *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

Optimizer: Determine inputs that give optimal outputs

\[ u, x_{\text{initial}} \]

ISAT: Open loop simulation

\[ x_{\text{final}} \]
ISAT Search

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