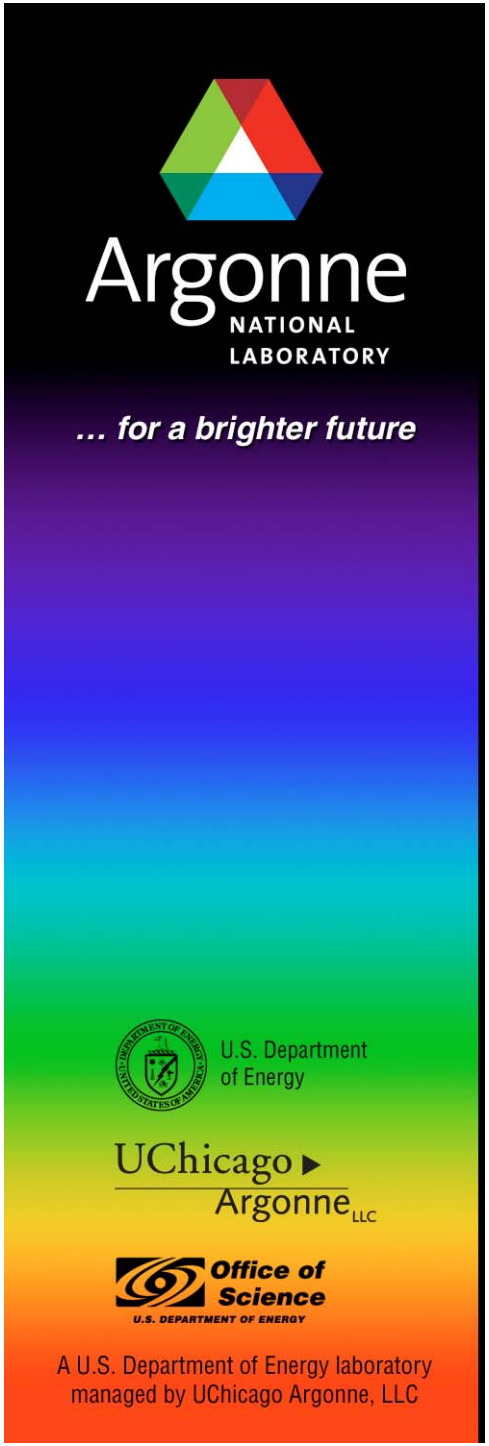

PHEV Control Strategy Optimization Using MATLAB Distributed Computing: From Pattern to Tuning

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Argonne National Laboratory
Sponsored by Lee Slezak, U.S. DOE

G. Sharma
The MathWorks

Outline

- Introduction
- Setup
- Global Optimization for Patterns
- Real Time Controller
- DIRECT Optimization for Tuning
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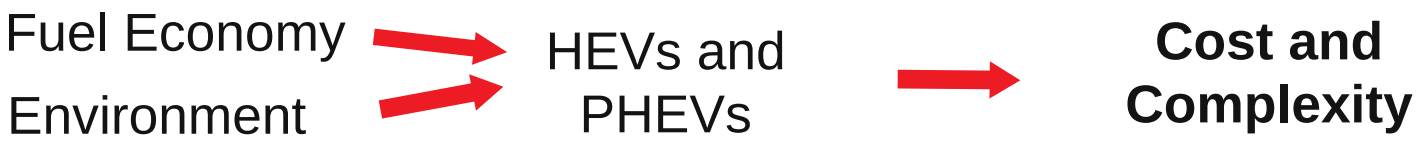
New Constraints = More Complex Vehicle



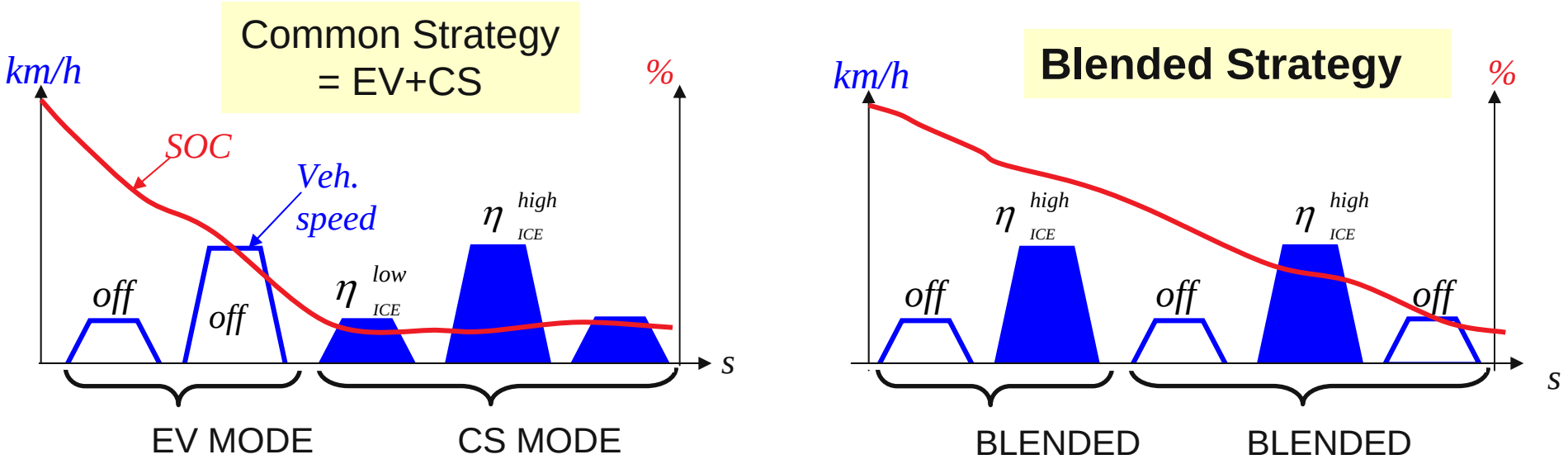
- Higher use of math-based tools before and during design:
  - Model-Based design
  - Physical modeling
  - Monte Carlo analysis
  - …
- Caveat:
  - Increased detail of modeling, complexity
  - Increased number of simulations

=> Longer calculation, analysis and development time

More Complex Vehicle = More Sensitive Control

Higher Electric Energy
Higher Electric Power
→ Higher Control Freedom → **Fuel Savings Potential**

- Depending on various driven distance, several modes are possible during charge depleting: Electric-only (EV) and Blended



Optimization Evaluates Control Strategy's Potential

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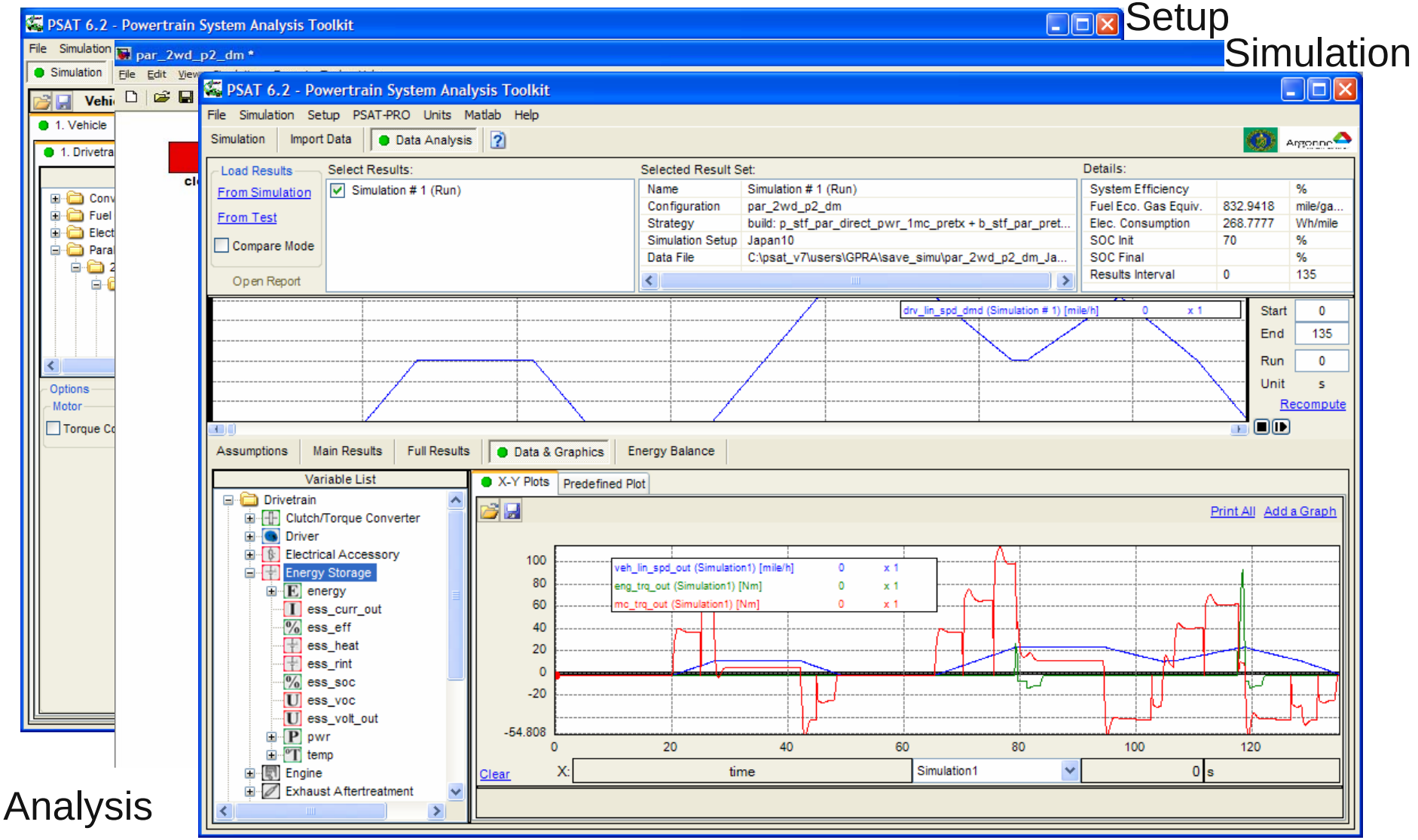
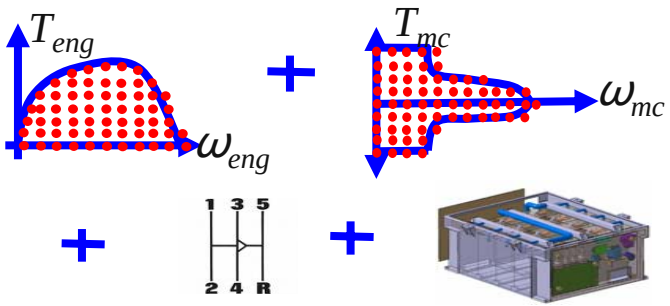
Tool: PSAT – Powertrain Systems Analysis Toolkit

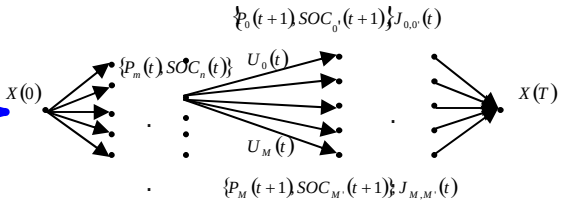


Process: 3-Way Approach to Control Optimization

Global Optimization



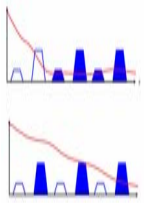
Backward model



Bellman Principle

⇨ Optimal Control Pattern, Minimal Fuel Cons.

Control Design



Various Control Principles

+

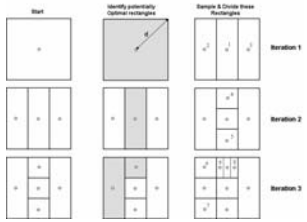
Rule-Based Control Design

⇨ Various PSAT Control Strategies

Derivative Free Optimization

+

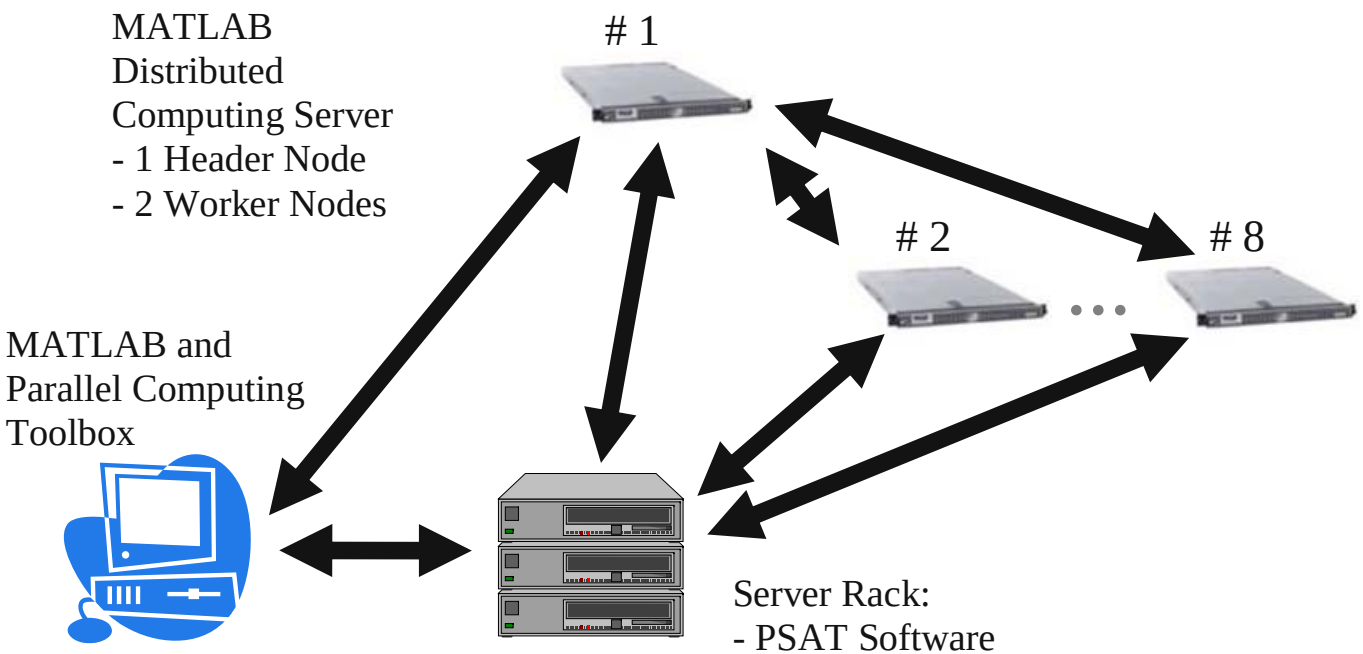
Control Logic



DIRECT Algorithm

⇨ Optimally tuned Parameters

Hardware: Computation Time Requires Distributed Computing



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Finding Control Patterns Fast(er)

- Robustness:
  - Different Cycles (e.g.: Urban, Highway,…)
  - Different Distances
  - Different Initial SOC

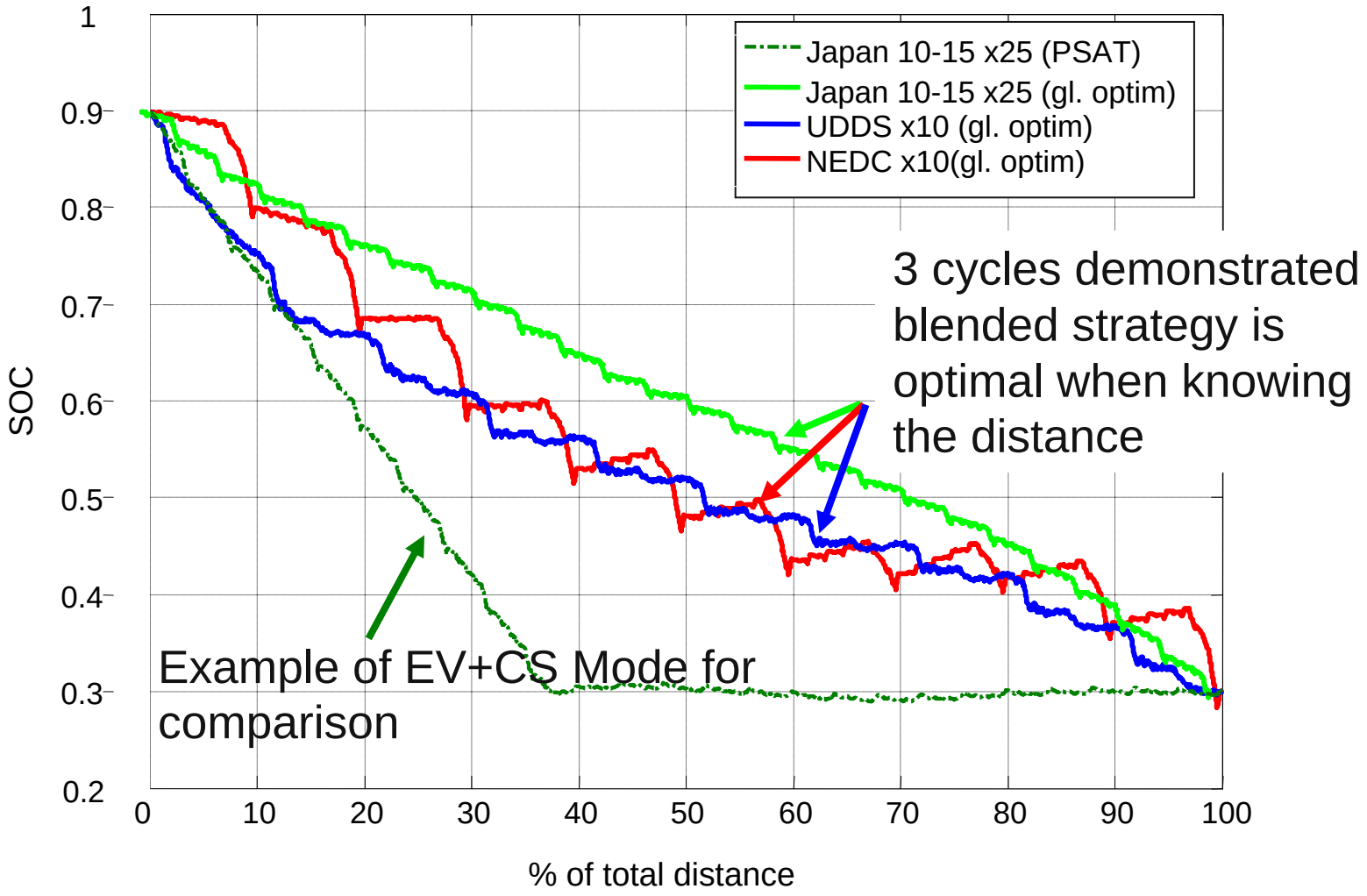
    => Set of 45 simulations

    => Sequential computation time ~ 2 weeks

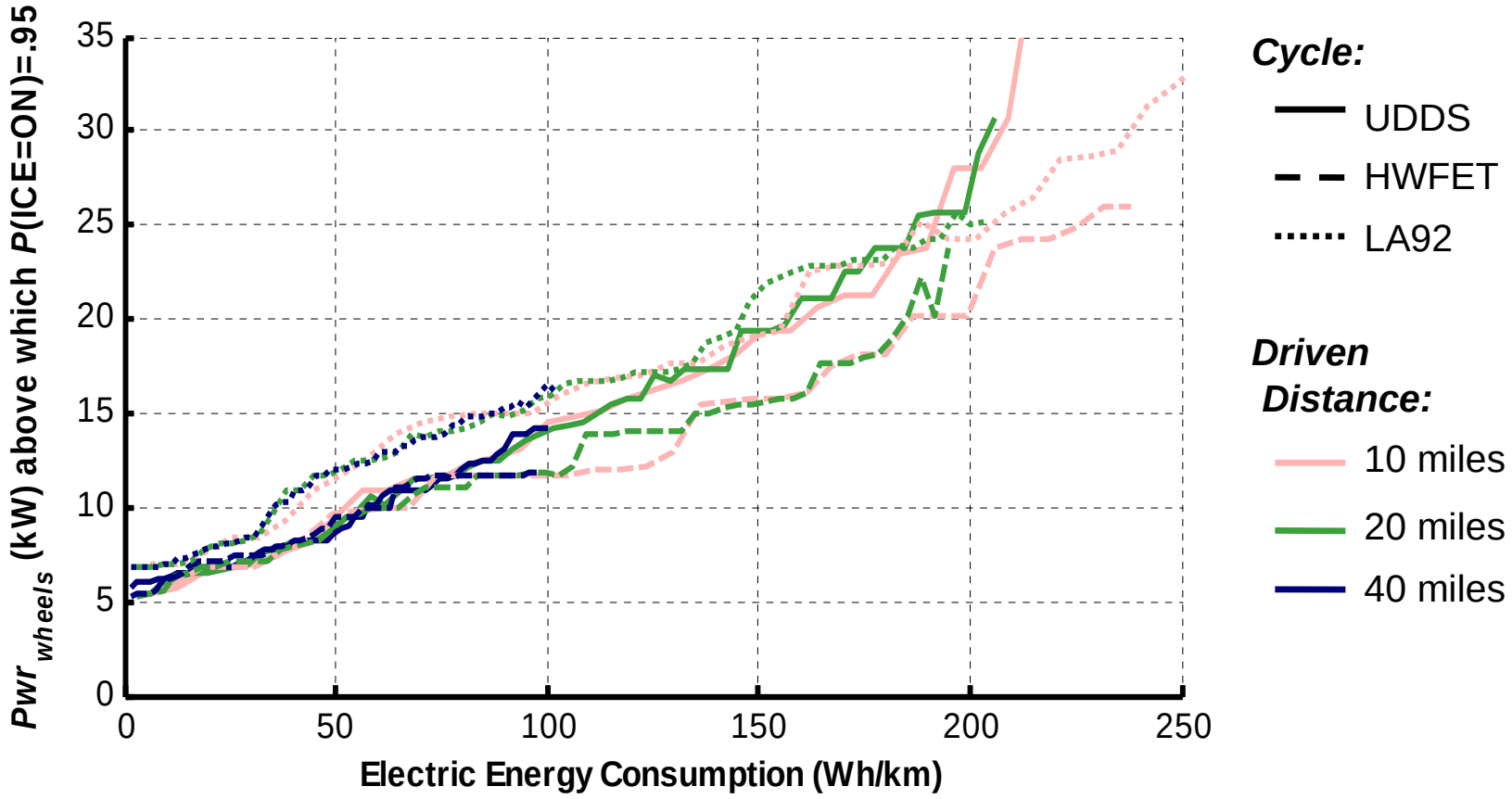
- Using Distributed Computing:
  - Simulations run in parallel

    => Running time ~ 12 hours

Global Optimization Showed Minimal Fuel Consumption Achieved in Blended Mode



Global Optimization Showed Engine Starting Condition Almost Proportional to Electrical Consumption



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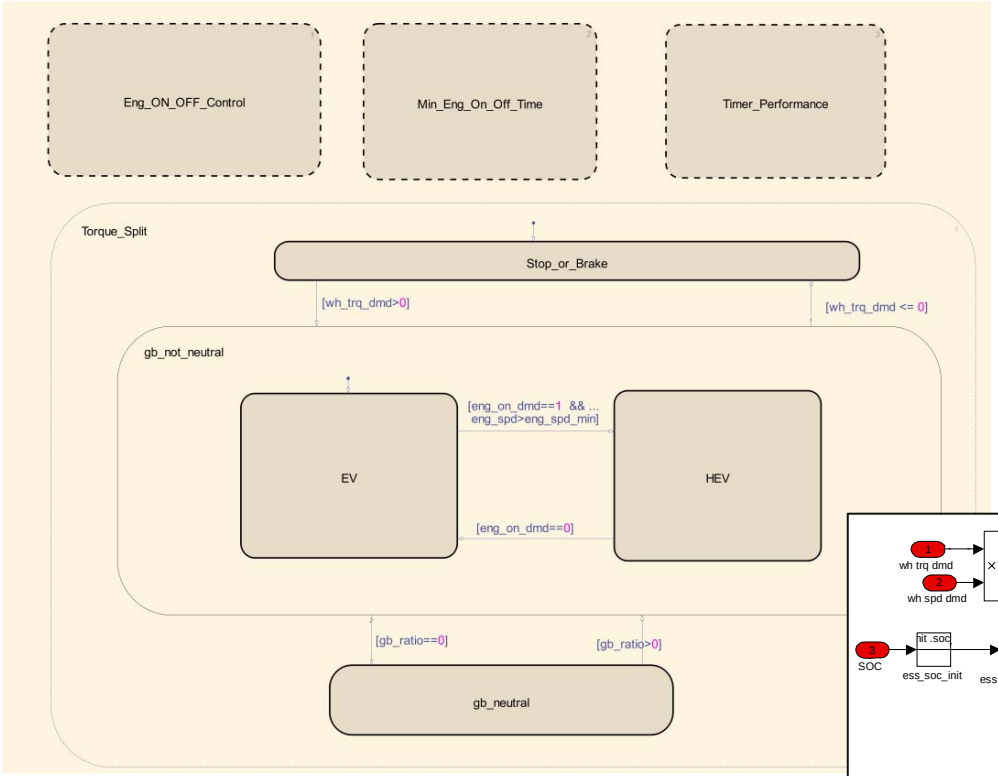
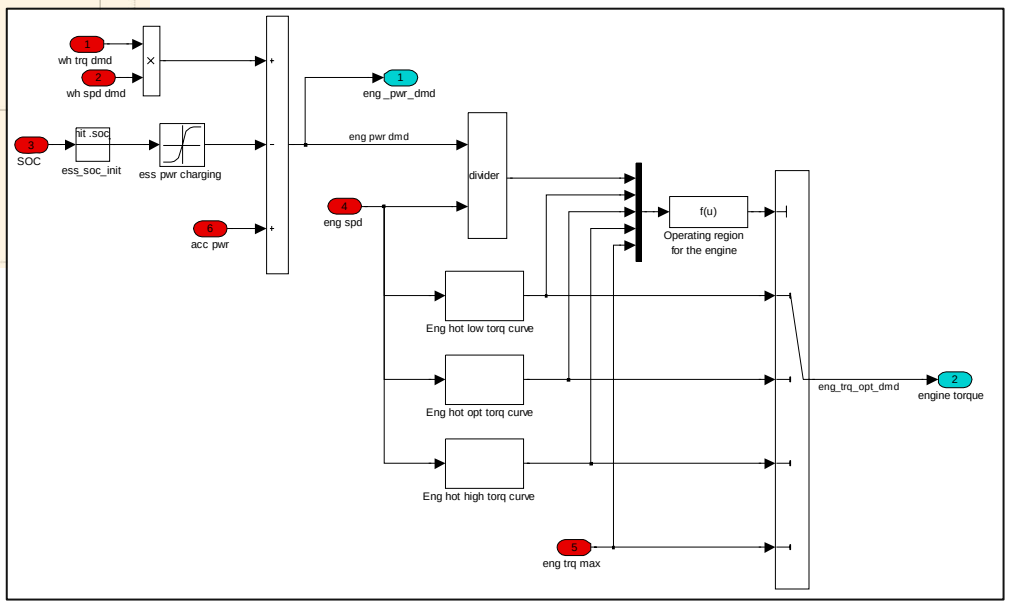
Engine ON/OFF Logic & Engine Torque Request

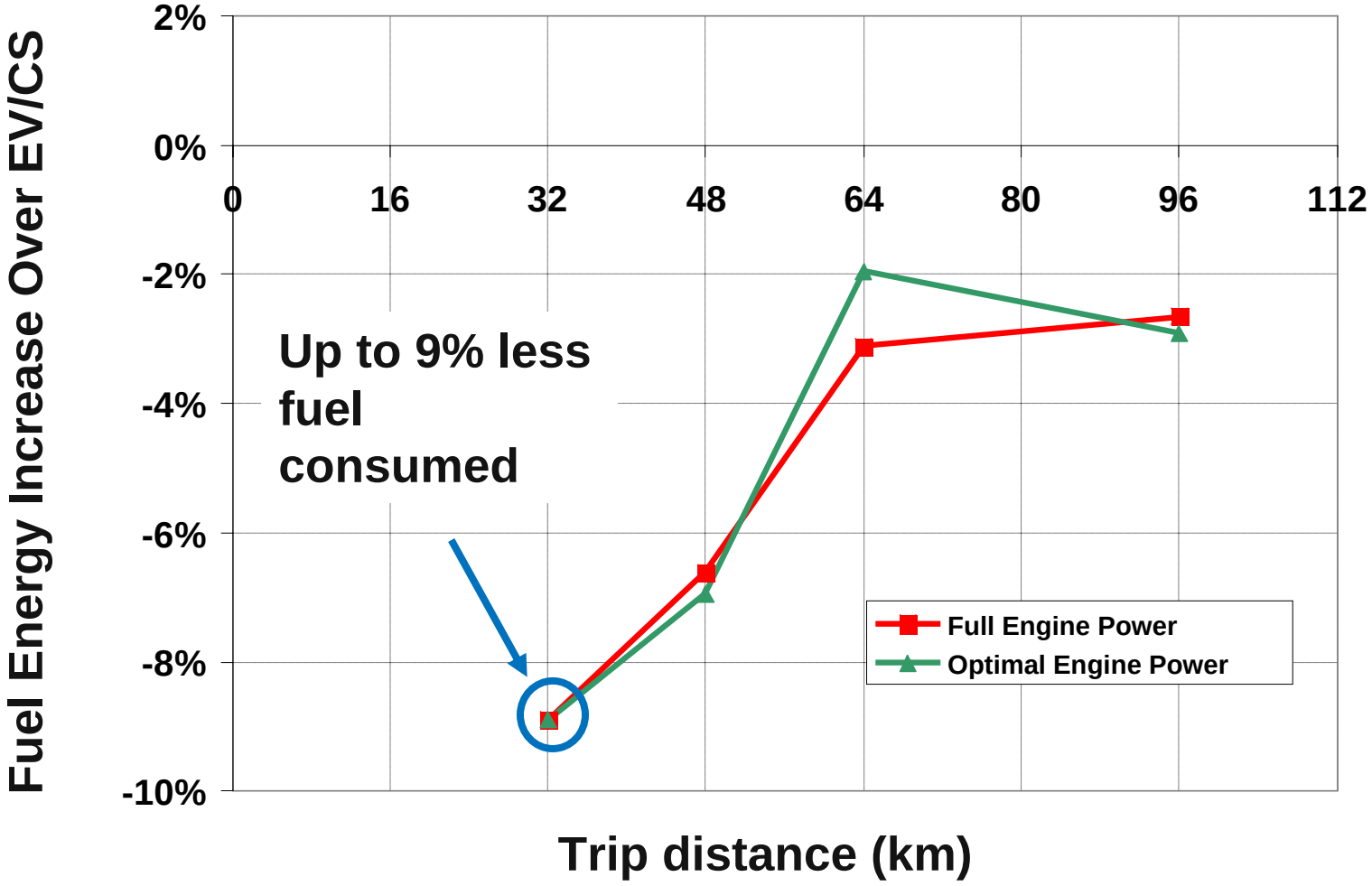


Engine ON / OFF Logic in Stateflow



Engine Torque Demand in Simulink

Blended Control Strategy Design Showed Significant Improvements Over EV Mode



10 miles AER vehicle run on several UDDS cycles

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Control Parameter Tuning with DIRECT

- Robustness:
  - Different Cycles
  - Different Distances
- Iterative Process:
  - Control space is sampled at each iteration
  - One simulation is run for each sample
  - Control space is re-sampled around the ‘best’ Simulation

    => Convergence after 30 iterations ~ 400 simulations

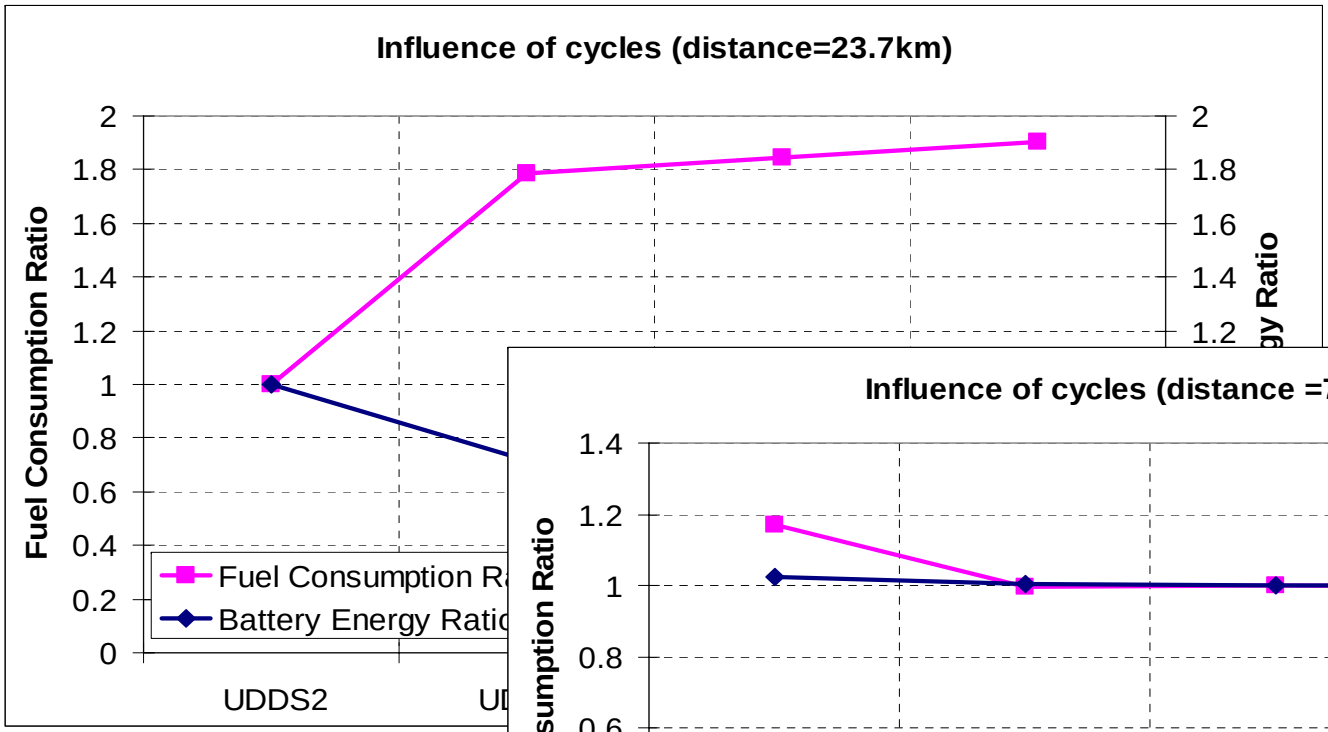
    => Sequential computation time ~ 2 days

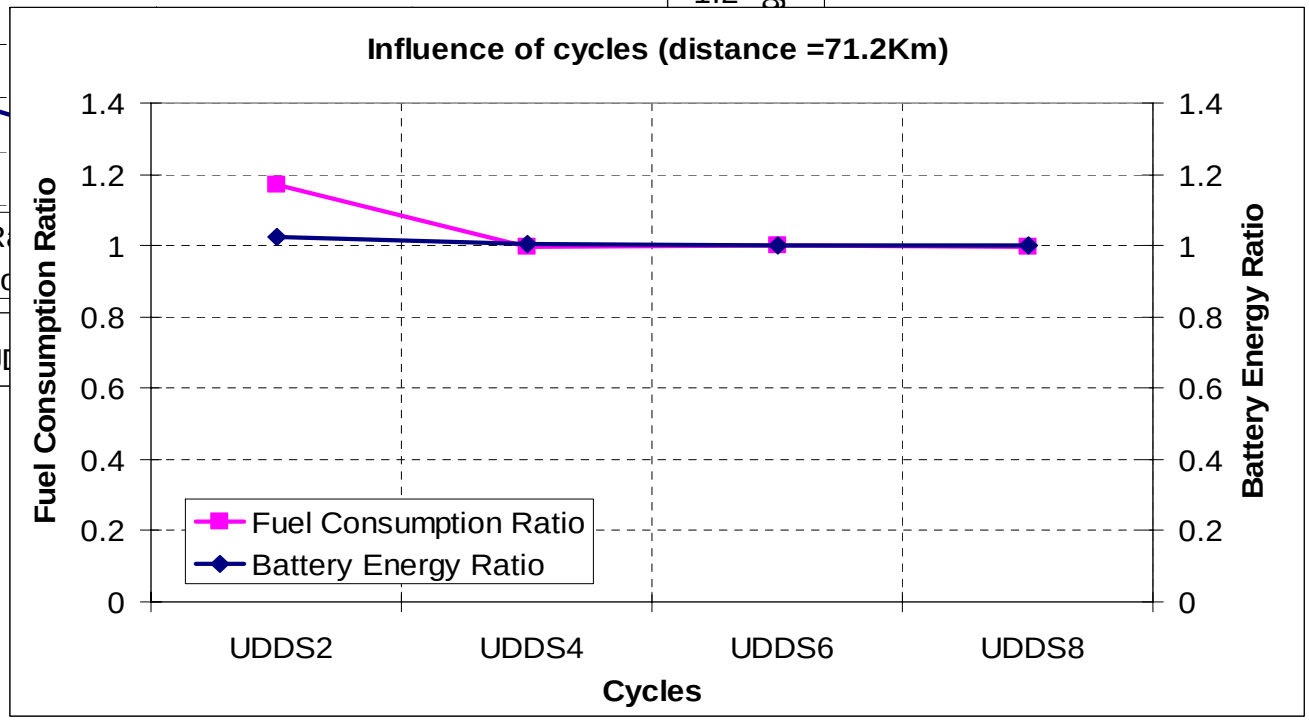
- Using Distributed Computing:
  - Simulations run in parallel

    => Running time ~ 5 hours

The Longer the Electrical Distance, the More Robust

Tuned for a short distance (2xUDDS)





Tuned for a longer distance (6xUDDS)

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Conclusion

- Using a combination of optimization techniques and modeling based on PSAT and MATLAB, we were able to:
  - single out control patterns,
  - implement them in Simulink and Stateflow,
  - tune their parameters.
- Only the use of distributed computing allows this process to be performed in a timely manner:
  - After setting up the MATLAB Parallel Computing Toolbox, and Distributed Computing Servers, it took only 1 hour of development to get the first simulations running.
  - The optimization times were reduced from more than 2 weeks to less than a day.

References

- ***Plug-in Hybrid Electric Vehicle Control Strategy: Comparison between EV and Charge-Depleting Options***
  Sharer, P. / Rousseau, A. / Karbowski, D. / Pagerit, S.
  SAE World Congress 2008, April 2008
- ***Impact of Component Size on Plug-In Hybrid Vehicle Energy Consumption Using Global Optimization***
  Karbowski, D. / Haliburton, C. / Rousseau, A.
  EVS 23, December 2007
- ***Plug-in Hybrid Electric Vehicle Control Strategy Parameter Optimization***
  Rousseau, A. / Pagerit, S. / Gao, D.
  EVS 23, December 2007
- ***Plug-in Vehicle Control Strategy: From Global Optimization to Real Time Application***
  Karbowski, D. / Rousseau, A. / Pagerit, S. / Sharer, P.
  EVS22, October 2006.
- ***Global Optimization to Real Time Control of HEV Power Flow: Example of a Fuel Cell Hybrid Vehicle***
  Pagerit, S. / Rousseau, A. / Sharer, P.
  EVS 21, April 2005.