MATLAB EXPO

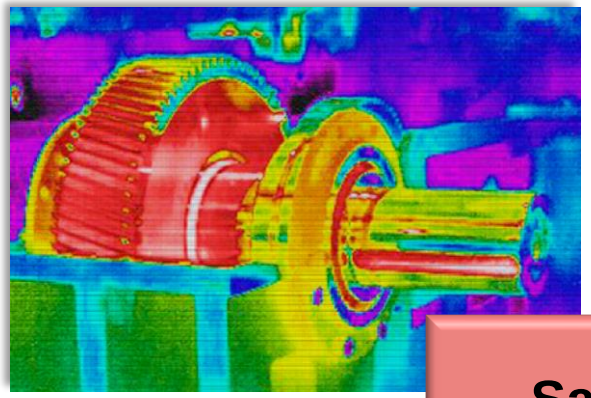
November 13–14, 2024 | Online

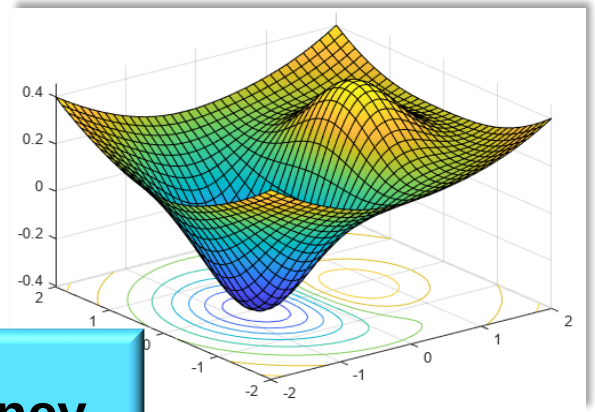
Two Paths Towards Real-Time HIL Simulation of EV Thermal Management Systems

Dr. Yifeng Tang, MathWorks

MathWorks

Thermal management systems in electric vehicles ensures safety, efficiency, comfort, and cost reduction





Safety

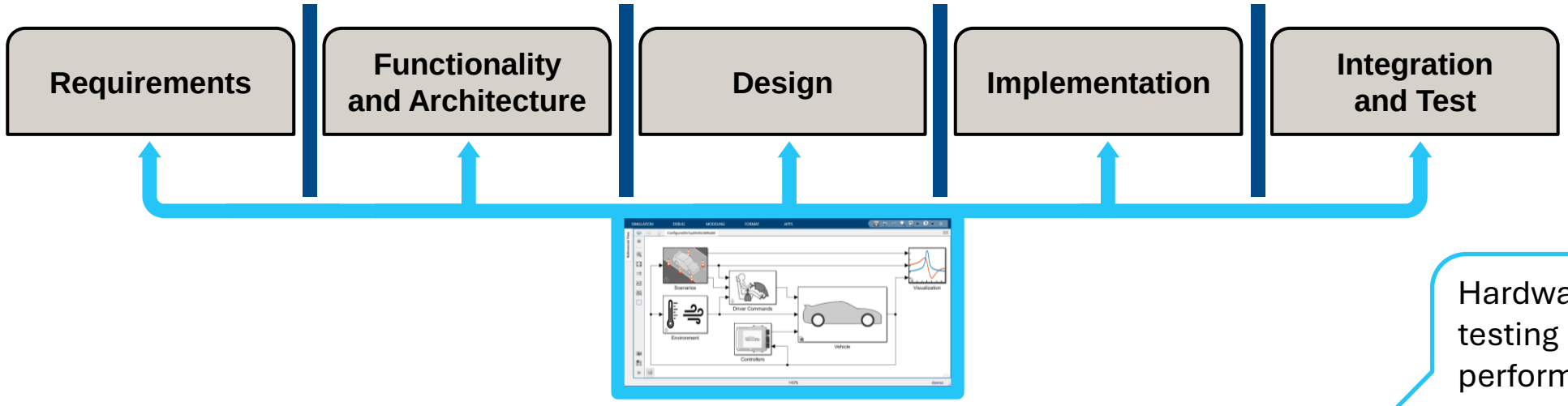
Efficiency

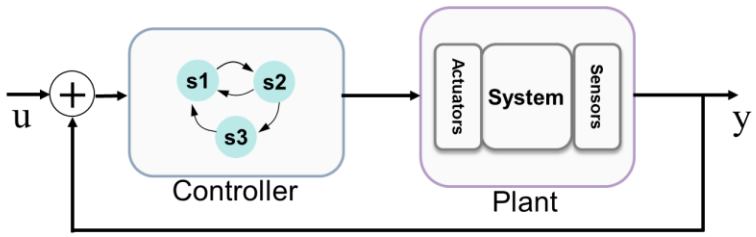
Comfort

Cost

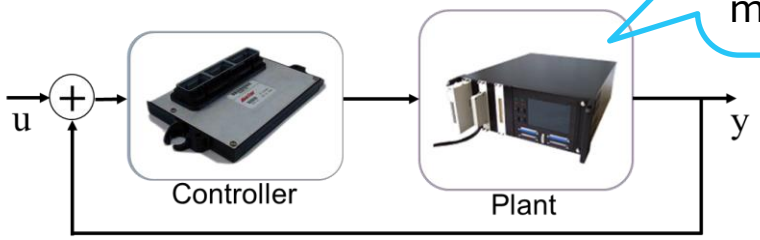
Model-Based Design improves how you design and deliver complex engineered systems

Systematic use of models as a digital thread





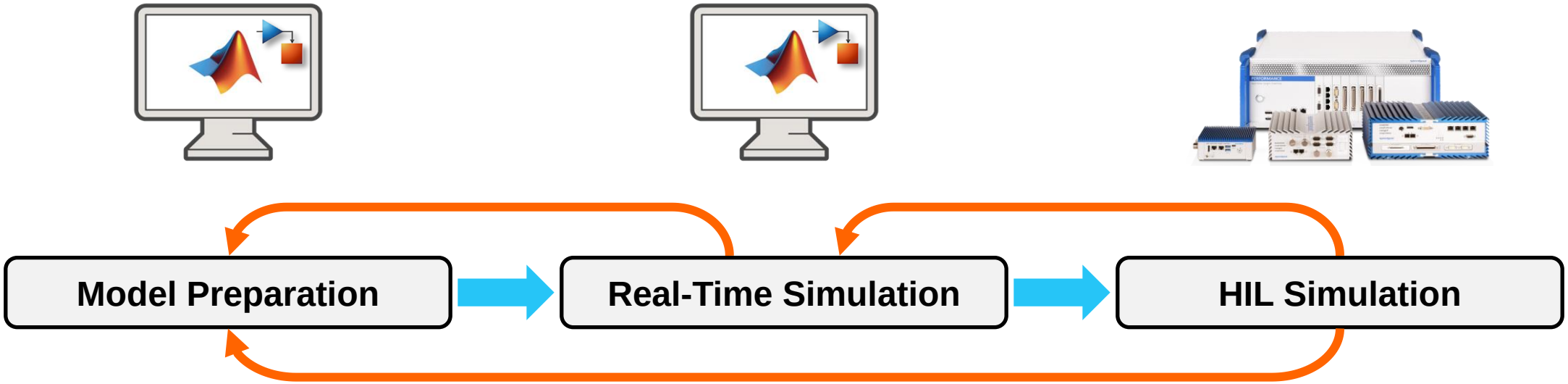
Optimize system design in **one simulation environment**



Automate with **code generation** and **model-based verification**

Hardware-in-the-loop (HIL) testing requires real-time performance of the simulation model of the physical system

Configuring models for real-time simulation and HIL testing can be an iterative process



Optimize simulation speed and ensure accurate results

Choose solver settings and verify real-time viability

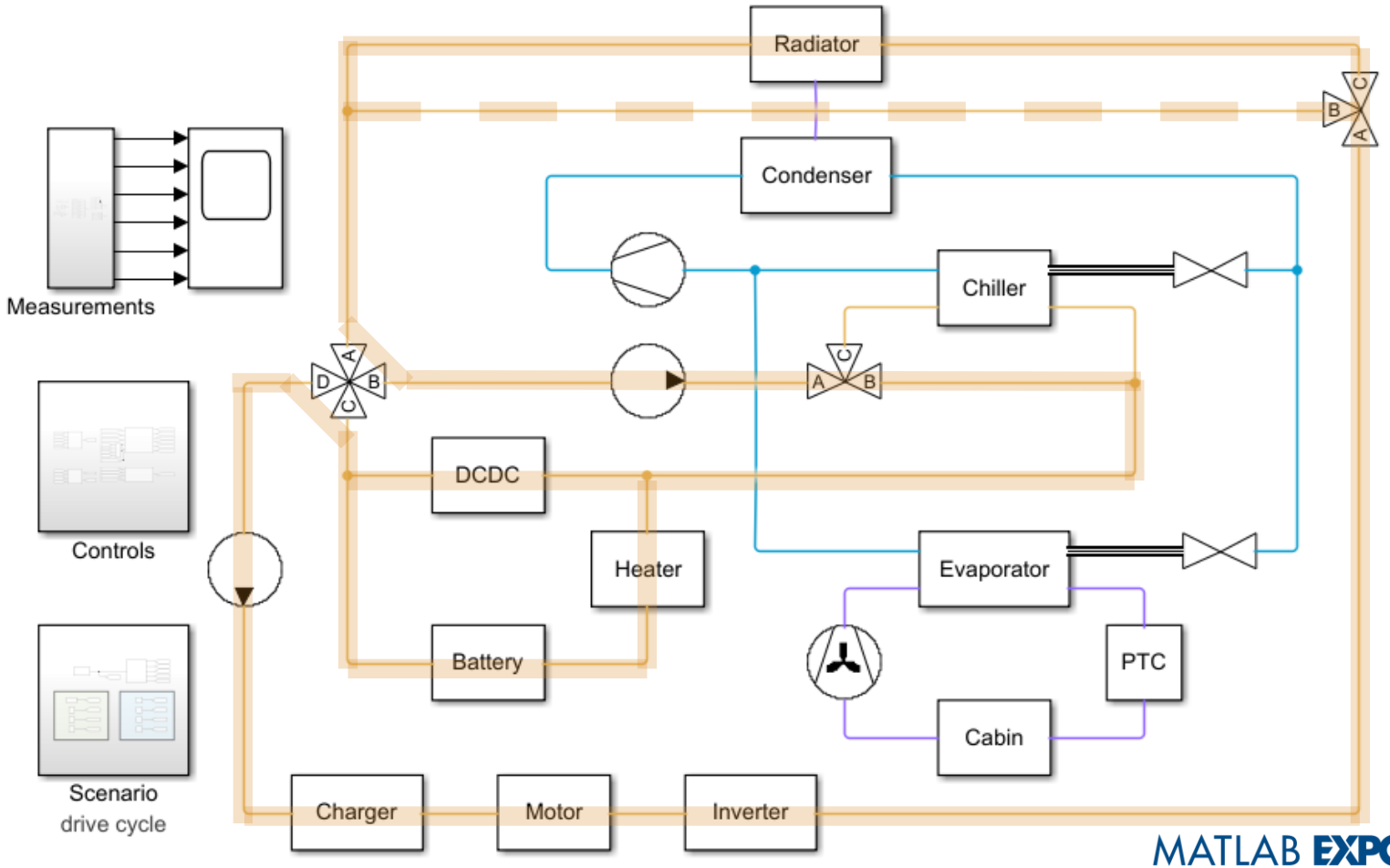
Verify HIL capability and test controller design

Documentation (link)

Simscape Fluids offers realistic EV thermal management system example model with closed-loop control

System architecture, components, and controls are modeled based on real vehicle information

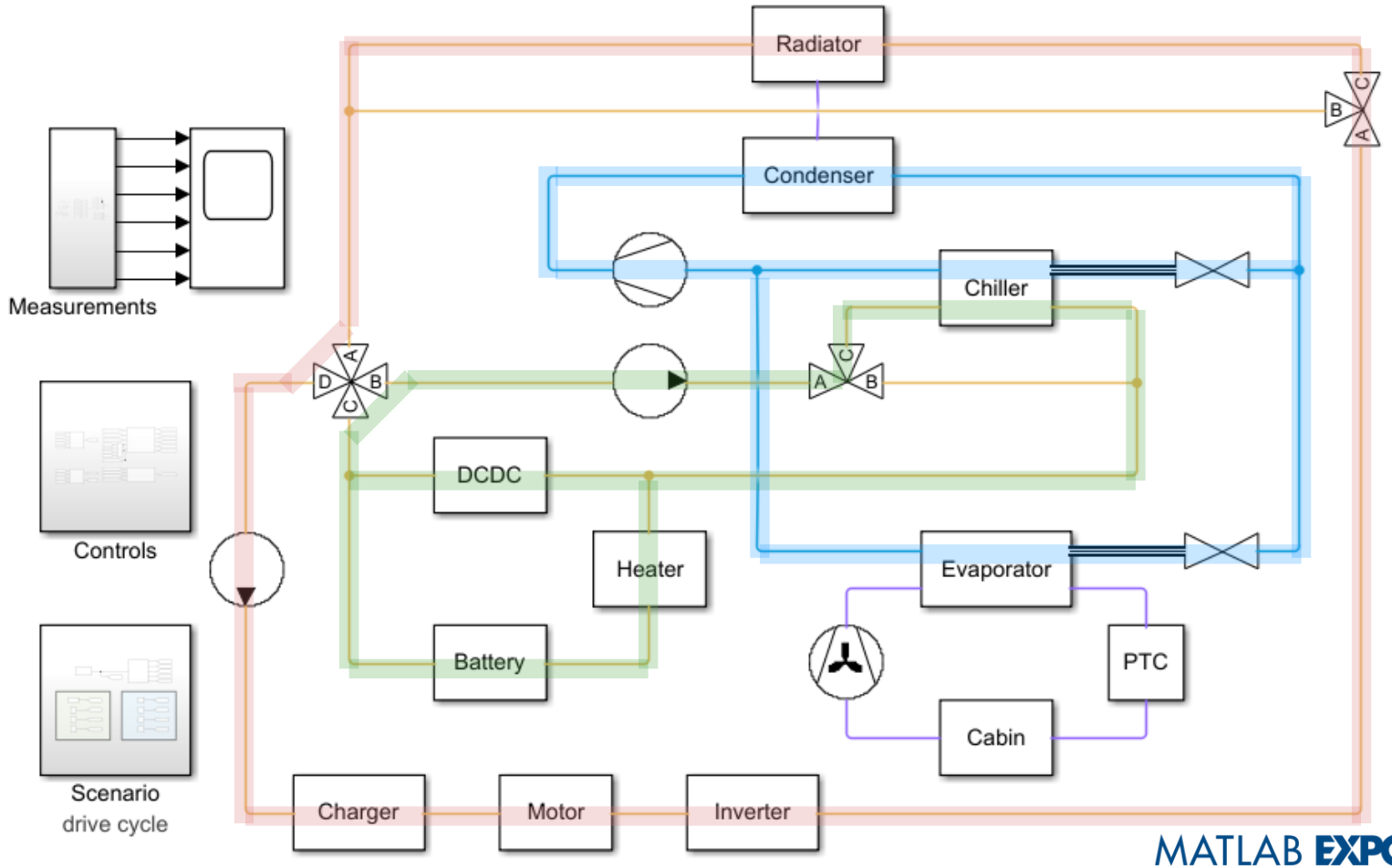
Coolant loop in cool weather



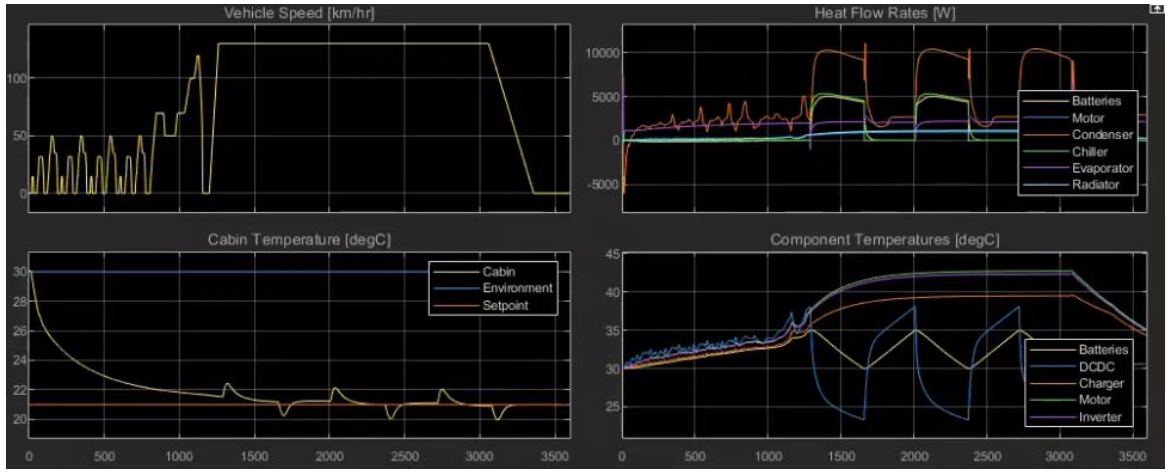
Simscape Fluids offers realistic EV thermal management system example model with closed-loop control

System architecture, components, and controls are modeled based on real vehicle information

Coolant loop in hot weather

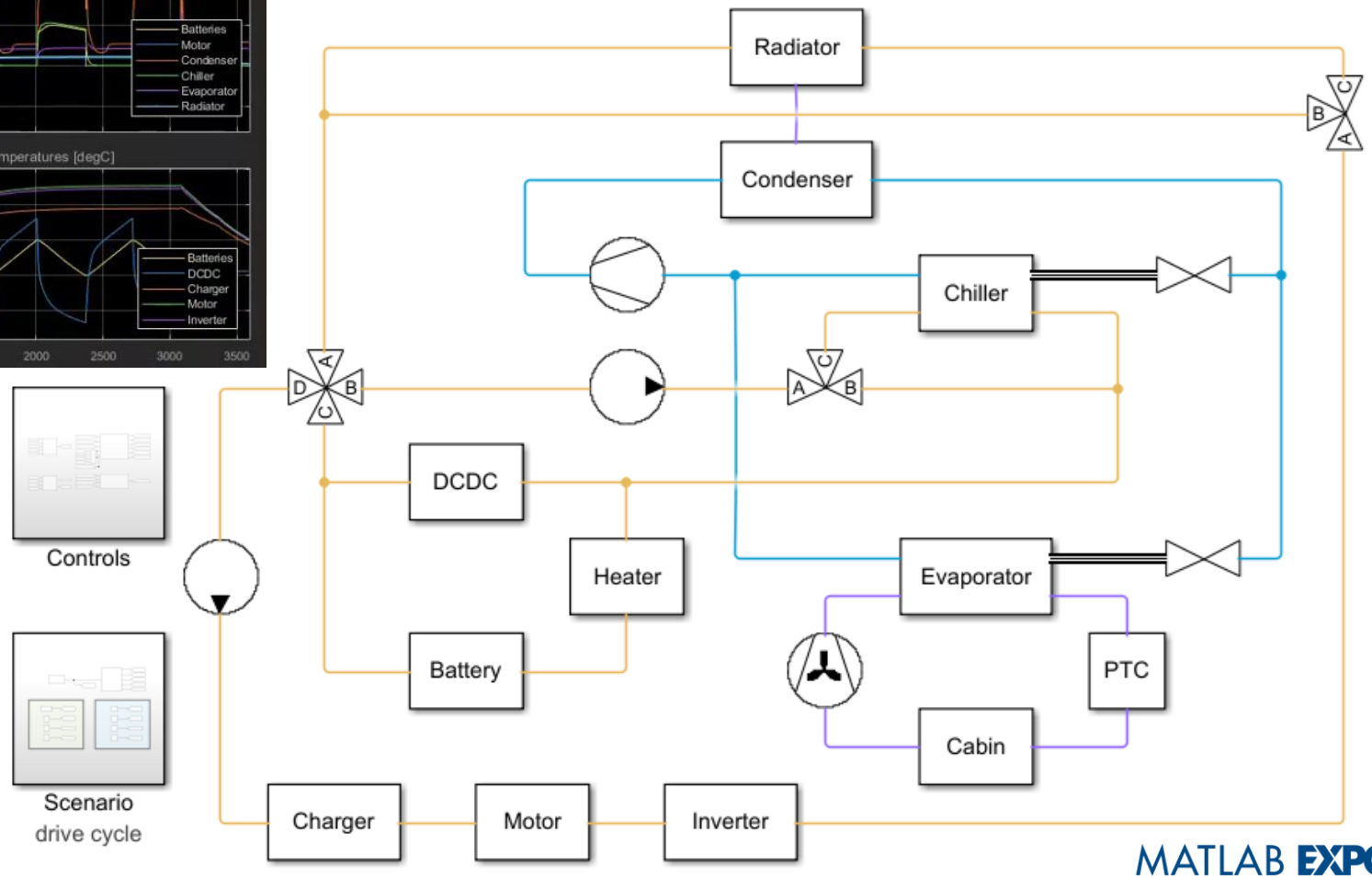


Simscape Fluids offers realistic EV thermal management system example model with closed-loop control



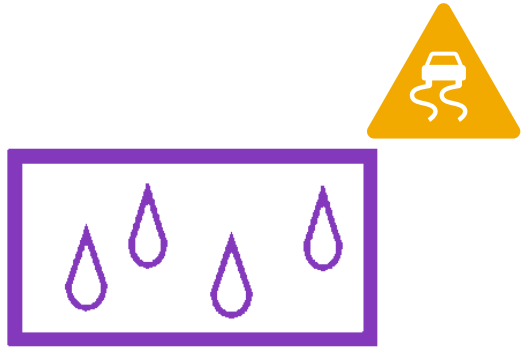
System architecture, components, and controls are modeled based on real vehicle information

Simulation runs efficiently with variable step solver but is not real-time ready with fixed-step solver

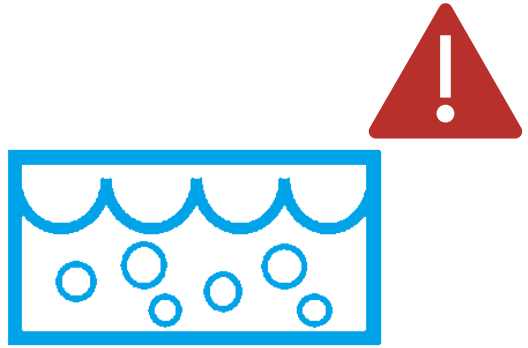


Real-time simulation can be challenging for complex thermo-fluids systems that includes refrigeration

Thermal Liquid models are straightforward to configure for real-time simulation



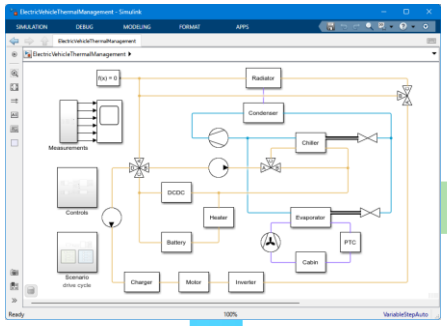
Moist Air models may require more analysis and adjustments for real-time simulation

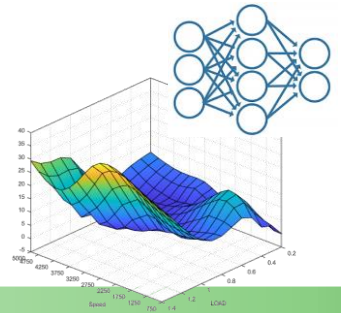


Two-Phase Fluid models contain more complicated physics and can be difficult to configure for real-time simulations

Two Paths towards Real-Time Simulation of Complex Thermofluids Systems

Simulation Models





- Data-driven, reduced-order model (ROM) for complex subsystems (e.g., refrigeration)
- Leverage AI, machine learning, and statistical regression capabilities from MathWorks tools

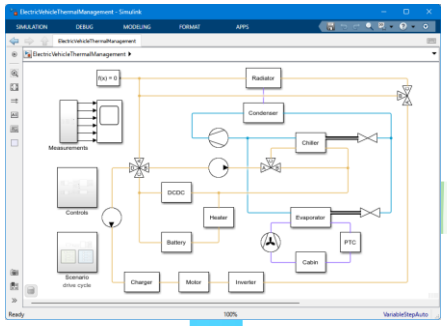
Solver profiler

Real-Time Target Machines

- Optimize numerical efficiency using diagnostic tools
- Apply domain expertise; adjust model fidelity & parameters

Two Paths towards Real-Time Simulation of Complex Thermofluids Systems

Simulation Models



- Data-driven, reduced-order model (ROM) for complex subsystems (e.g., refrigeration)
- Leverage AI, machine learning, and statistical regression capabilities from MathWorks tools

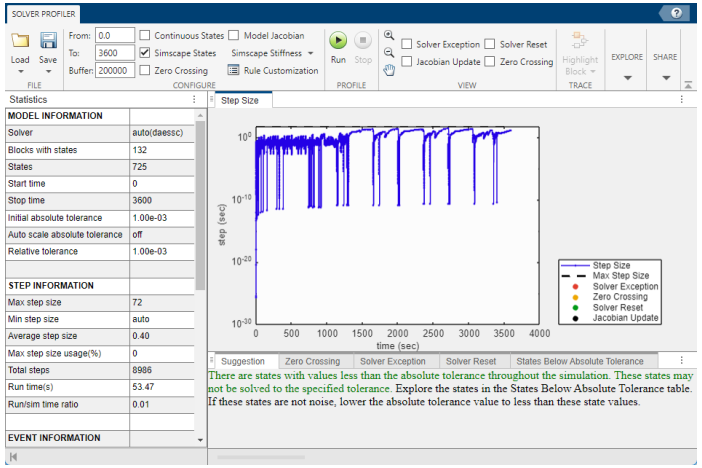
Simscape

Solver profiler

Real-Time Target Machines

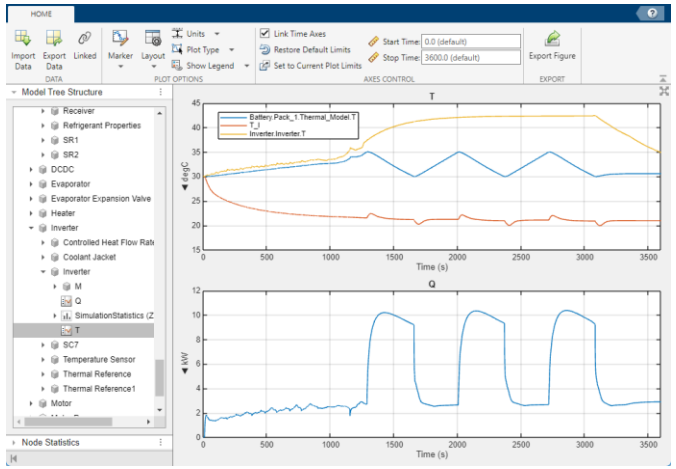
- Optimize numerical efficiency using diagnostic tools
- Apply domain expertise; adjust model fidelity & parameters

Simulink & Simscape provides diagnostic tools to analyze and improve numerical performance



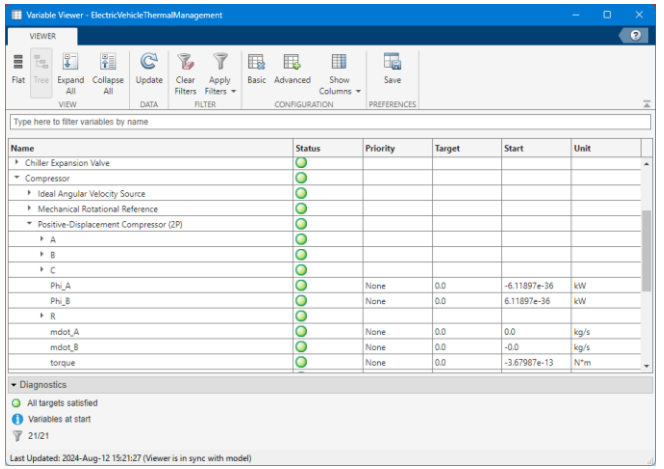
Solver Profiler

Identify solver performance bottlenecks



Simscape Result Explorer

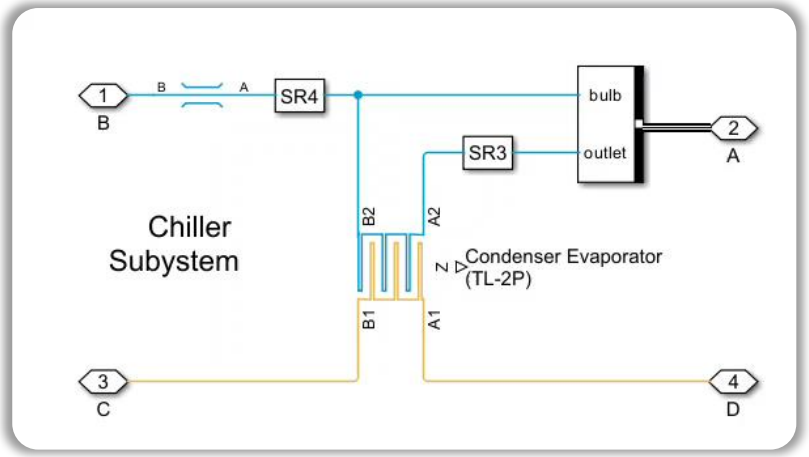
Navigate and plot simulation data



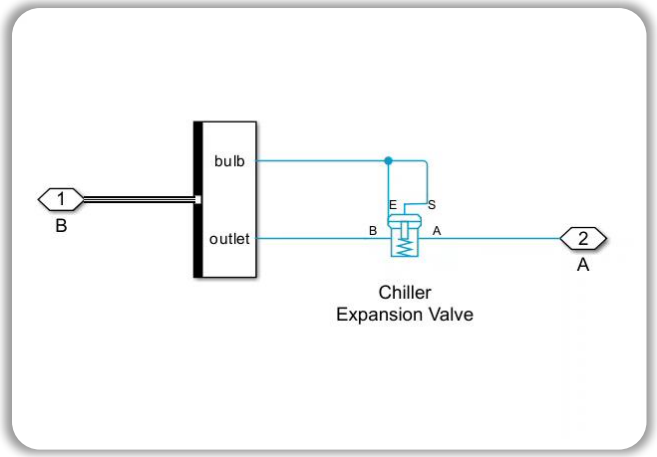
Simscape Variable Viewer

Check variable initialization results

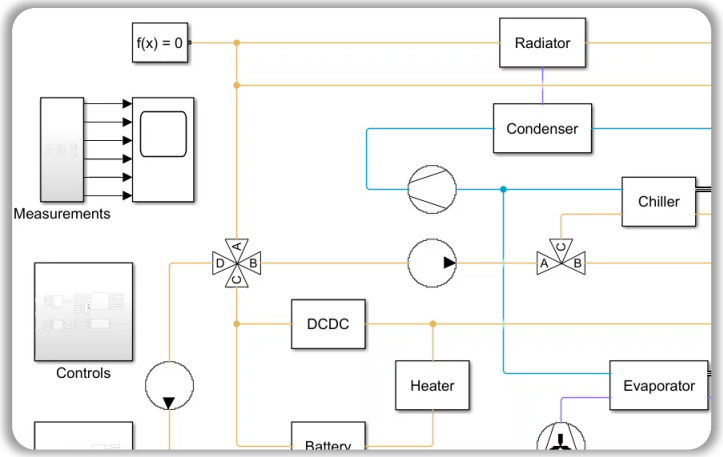
Adjust component fidelity and solver settings to prepare models for real-time simulations



Use system-level component model



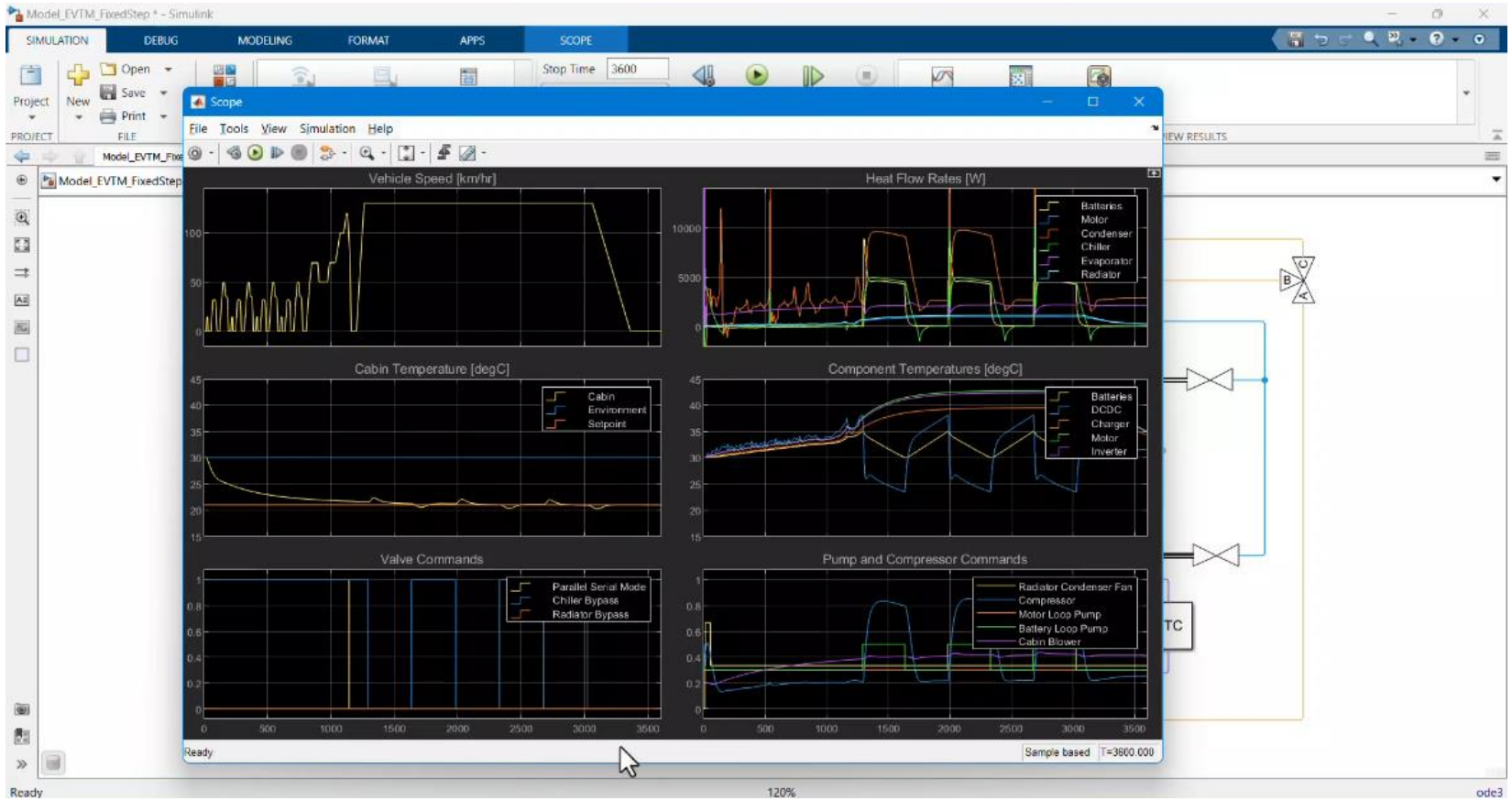
Slow down actuator & sensor dynamics



Adjust fixed-step, fixed-cost solver settings

Iteratively identify simulation bottlenecks and improve numerical performance and robustness

Real-time simulation can be achieved for EV thermal management models by optimizing numerical performance

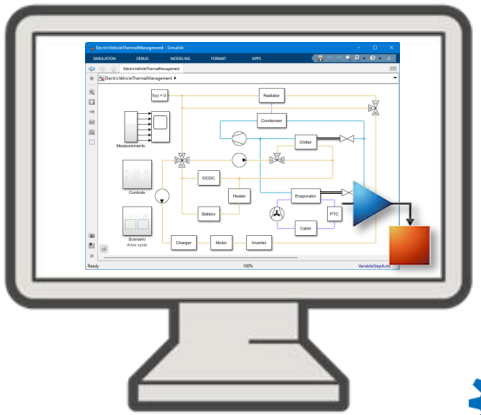


Simulates at 4x real-time speed on desktop computer

Identify and make more adjustment to the model as needed

Test with more scenarios before proceeding to HIL testing

Simulink Real-Time™ and Speedgoat® hardware offer native integration with MATLAB and Simulink for HIL



Connect hardware to verify and validate embedded software using Simulink Real-Time and Speedgoat systems

Simulink Real-Time

Real-Time Target Machine

MATLAB

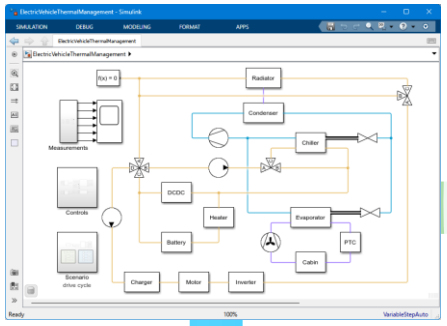
Simulink

Simulink Real-Time and Speedgoat hardware are designed for MATLAB and Simulink

Speedgoat Performance Real-Time Target Machine

Two Paths towards Real-Time Simulation of Complex Thermofluids Systems

Simulation Models



- Data-driven, reduced-order model (ROM) for complex subsystems (e.g., refrigeration)
- Leverage AI, machine learning, and statistical regression capabilities from MathWorks tools

Simscape

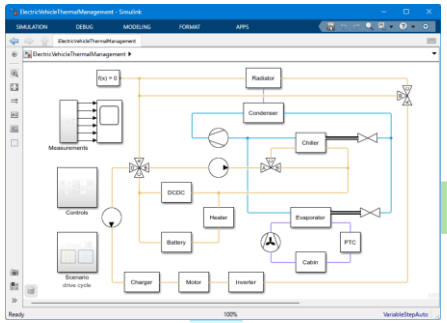
Solver profiler

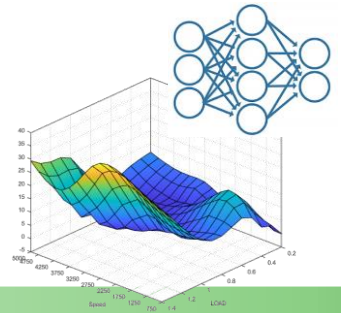
Real-Time Target Machines

- Optimize numerical efficiency using diagnostic tools
- Apply domain expertise; adjust model fidelity & parameters

Two Paths towards Real-Time Simulation of Complex Thermofluids Systems

Simulation Models





- Data-driven, reduced-order model (ROM) for complex subsystems (e.g., refrigeration)
- Leverage AI, machine learning, and statistical regression capabilities from MathWorks tools

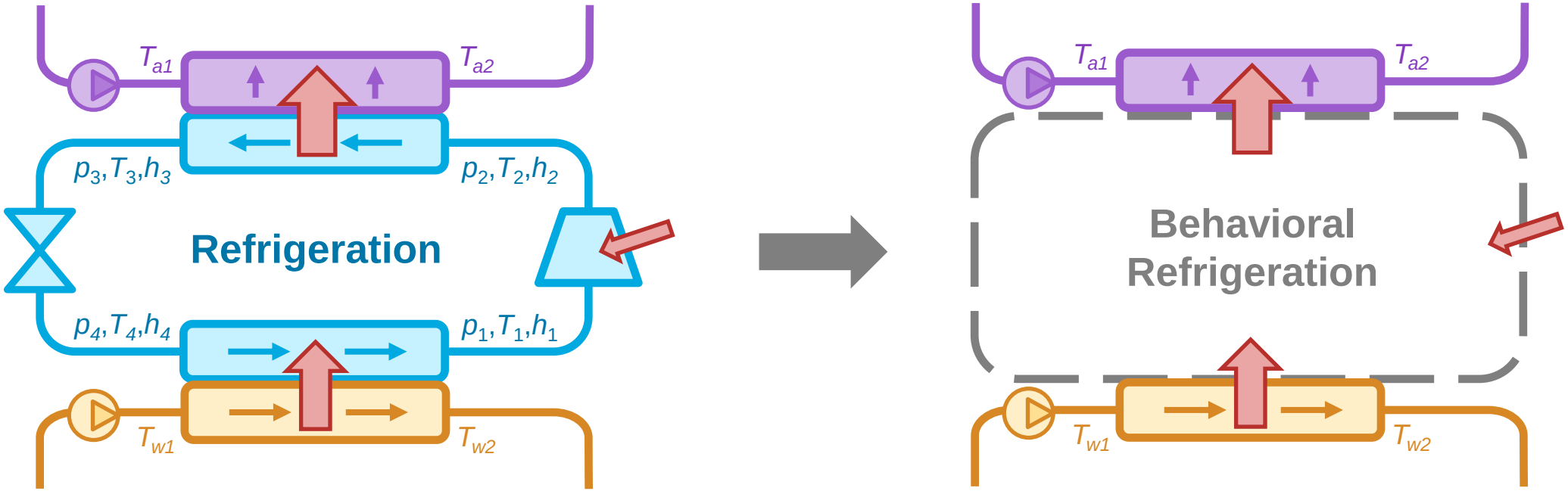
Simscape

Solver profiler

- Optimize numerical efficiency using diagnostic tools
- Apply domain expertise; adjust model fidelity & parameters

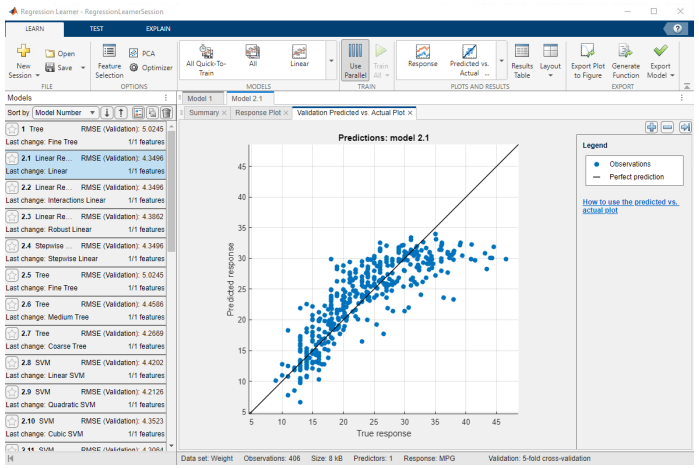
Real-Time Target Machines

Data-driven models focus on the effect of complex subsystems as functions of the input conditions



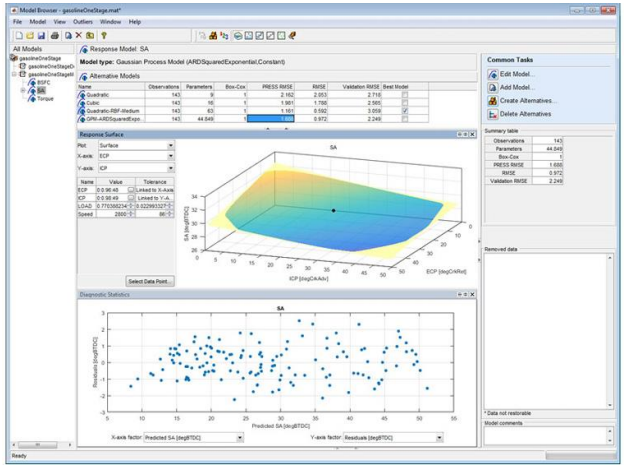
Use empirical or simulation data to model the heat flow and sensor feedback signals

Multiple MathWorks tools can be used to build data-driven models to be integrated in Simulink and Simscape



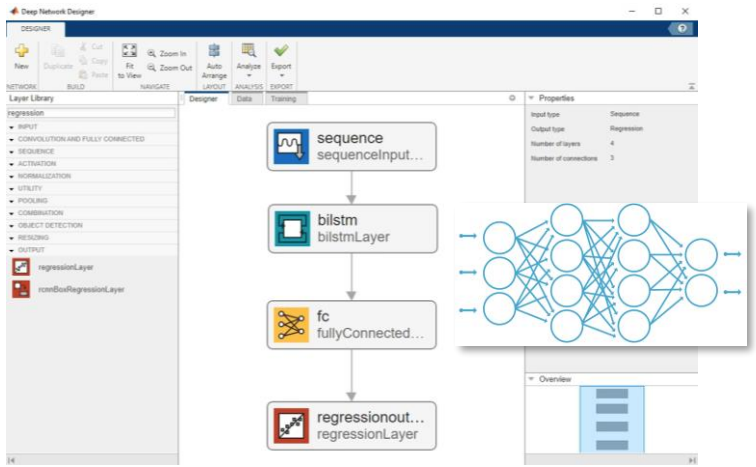
Regression

Interactively train, validate, and tune regression models; generate MATLAB code for programmatic regression.



Model-Based Calibration

Apps and design tools for modeling complex nonlinear systems



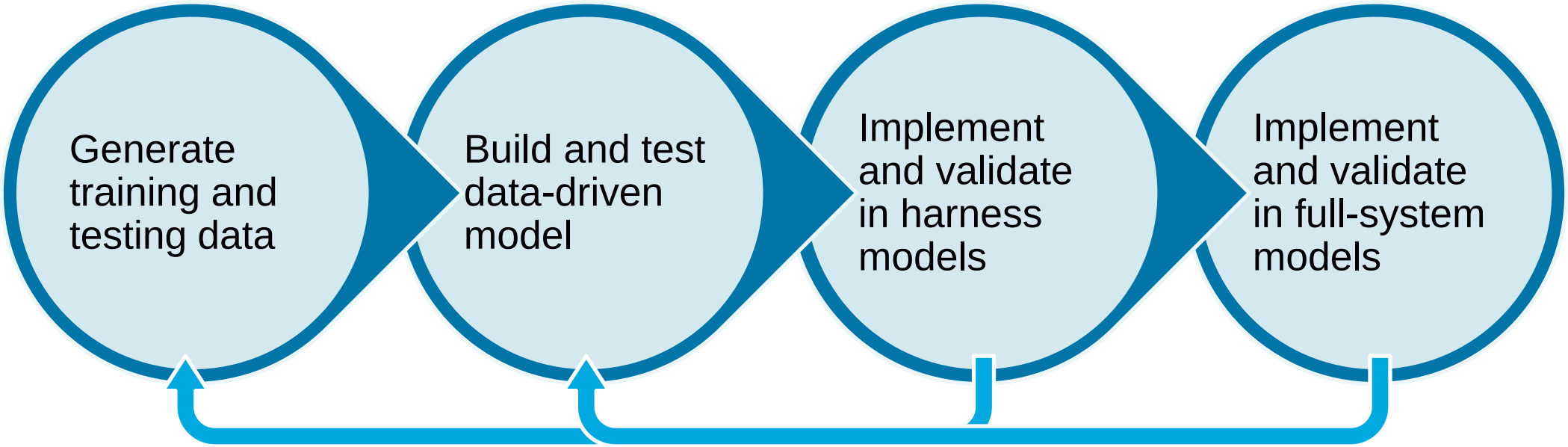
Neural Network / Neural State-Space

Design and train neural networks for static and dynamic models

Also see: Reduced Order Modeler App

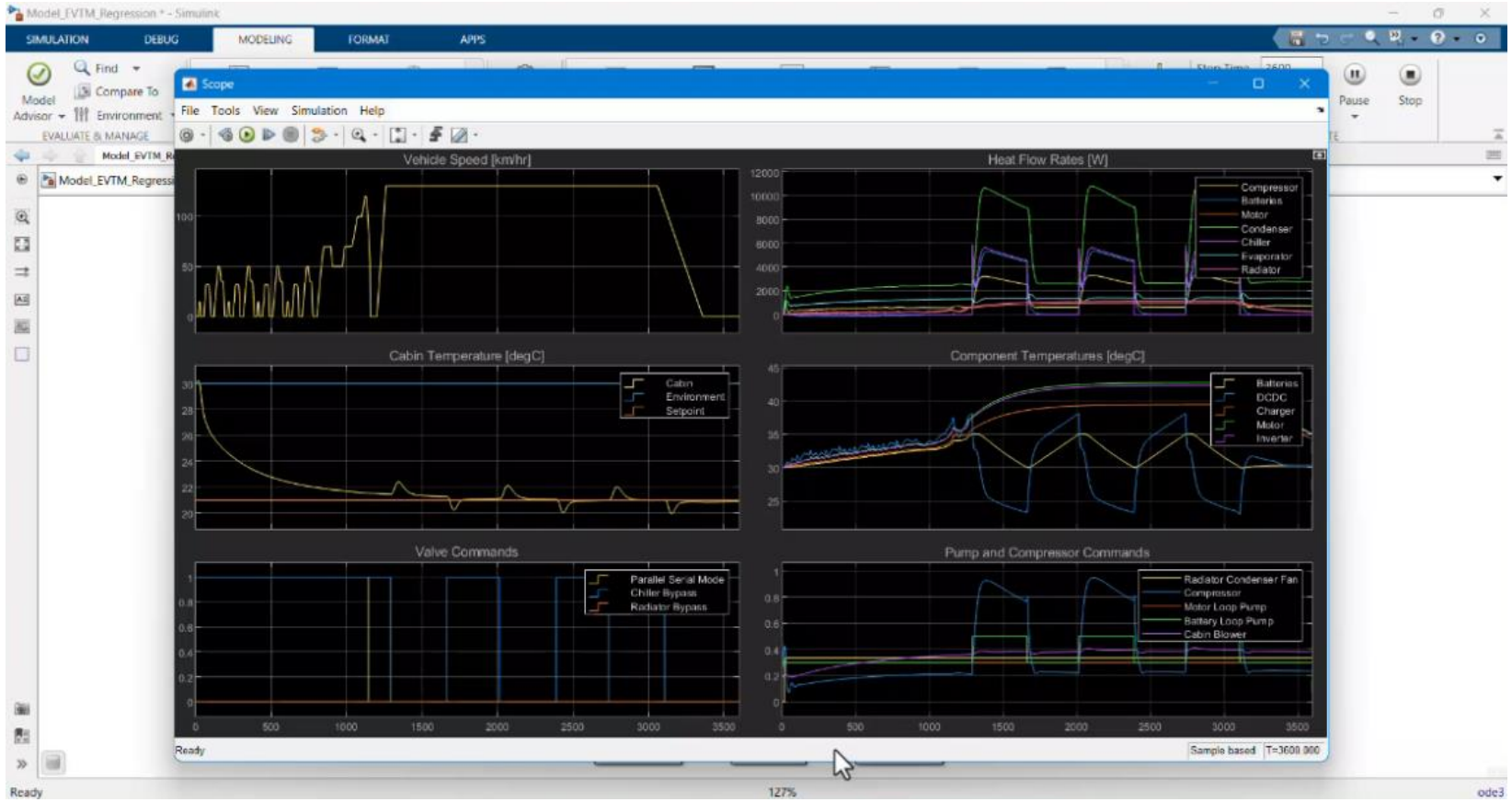
Find more information on Reduced Order Modeling

The workflow for building a data-driven refrigeration system model is established



Findings from the verification and implementation stages may require iterations of earlier steps

Speed up simulation by using a reduced-order model to capture the effects of the refrigeration system



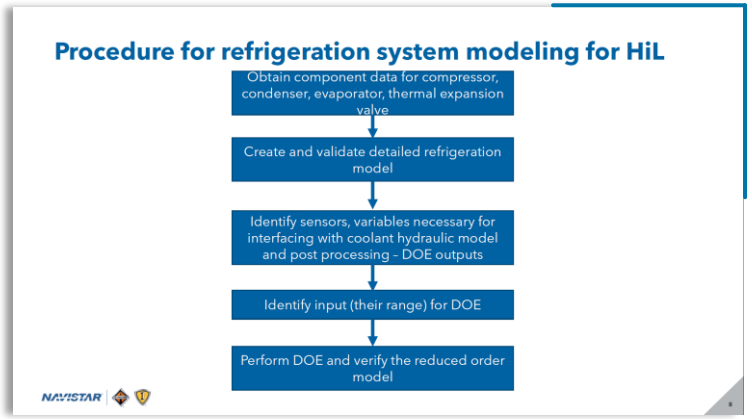
Simulates at 10x real-time speed on desktop computer

Data-driven ROM predicts correct heat flow and sensor feedback signals

Test with more scenarios before proceeding to HIL testing

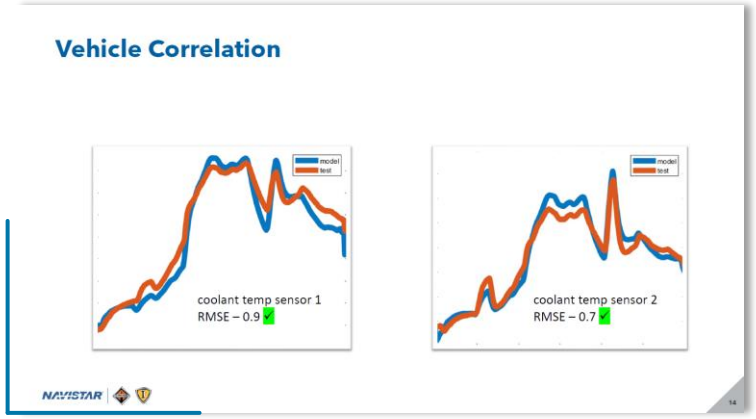
Navistar uses a data-driven approach to perform HIL simulations of the thermal management system for electric trucks

Presentation at MathWorks Automotive Conference 2024 (link)

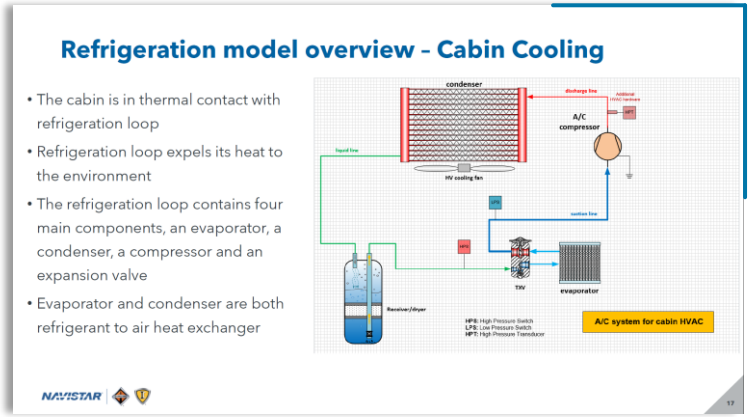


Generated data-driven model of the battery chiller system

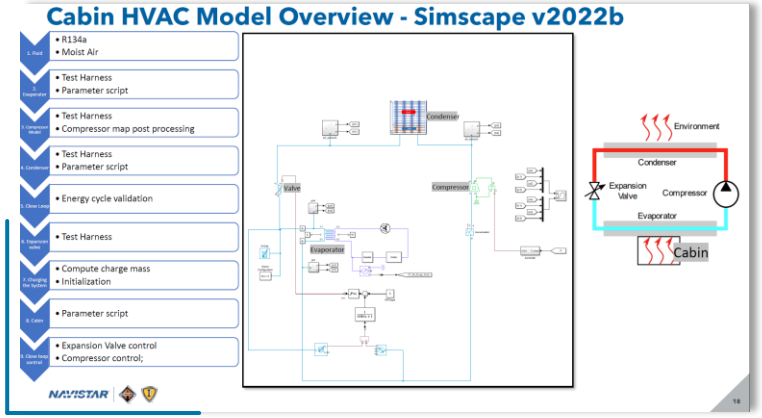
Simscape based thermal system model correlated well with the vehicle



Workflow extended to the refrigeration system in cabin cooling

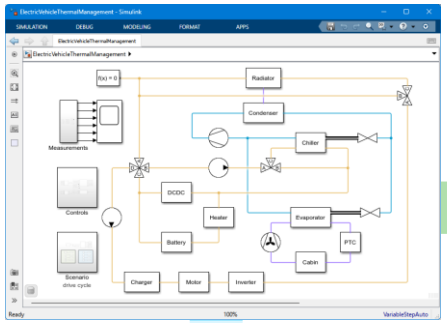


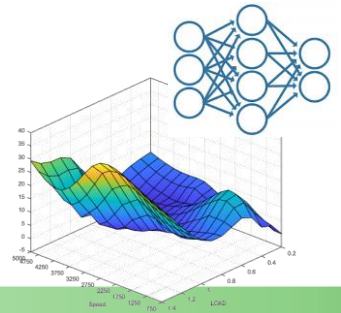
Building real-time model of cabin cooling system in Simscape Fluids



Two Paths towards Real-Time Simulation of Complex Thermofluids Systems

Simulation Models





- Data-driven, reduced-order model (ROM) for complex subsystems (e.g., refrigeration)
- Leverage AI, machine learning, and statistical regression capabilities from MathWorks tools

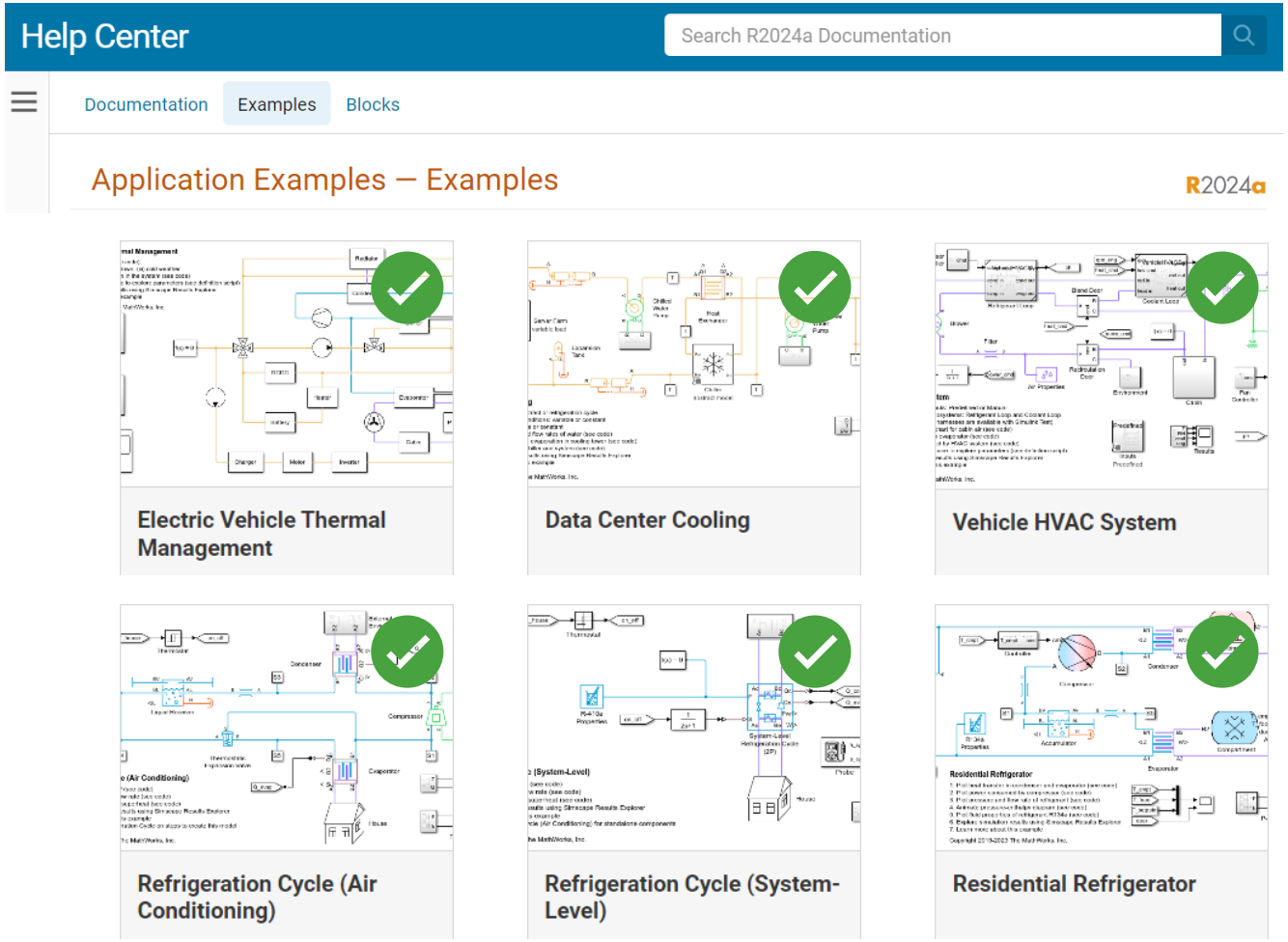
Simscape

Solver profiler

- Optimize numerical efficiency using diagnostic tools
- Apply domain expertise; adjust model fidelity & parameters

Real-Time Target Machines

Your opportunity to explore these reliable and consistent real-time simulation approaches



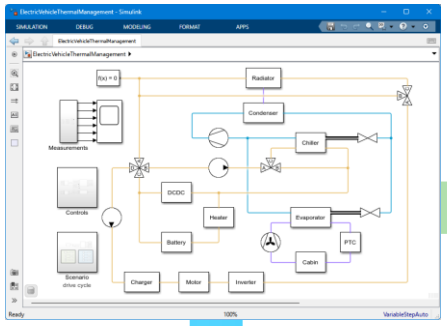
Can be configured to perform real-time simulations

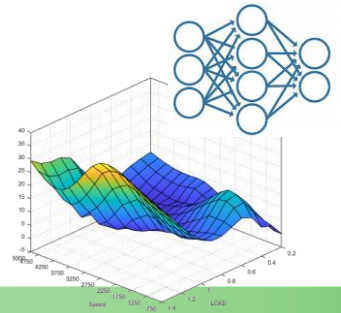
MathWorks Resources:

- Technical engagement project
- Hands-on workshop
- Customized training
- Consulting service

Two Paths towards Real-Time Simulation of Complex Thermofluids Systems

Simulation Models





- Data-driven, reduced-order model (ROM) for complex subsystems (e.g., refrigeration)
- Leverage AI, machine learning, and statistical regression capabilities from MathWorks tools

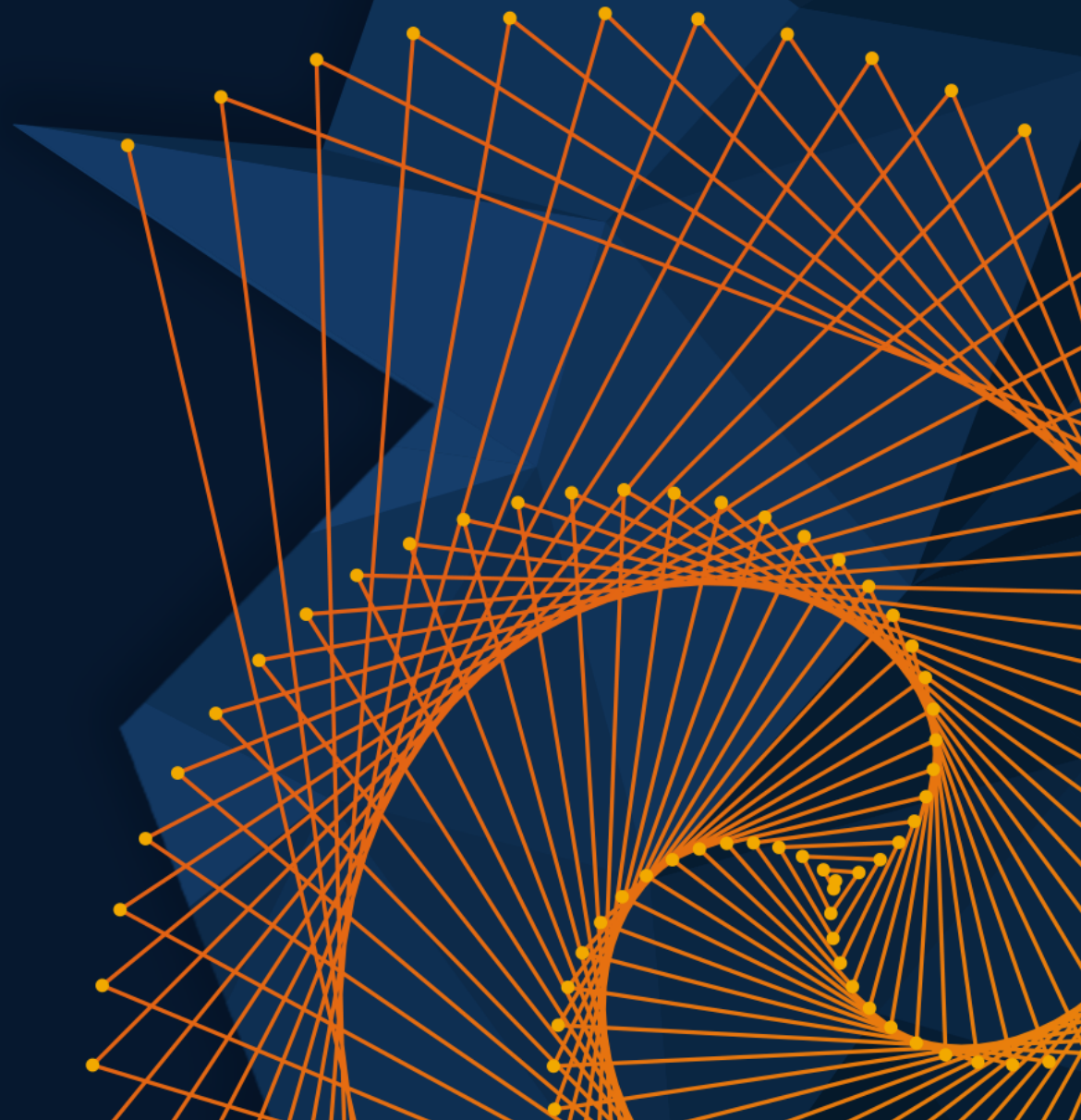
Solver profiler

Real-Time Target Machines

- Optimize numerical efficiency using diagnostic tools
- Apply domain expertise; adjust model fidelity & parameters

MATLAB EXPO

Thank you



MathWorks®