모델 기반 설계를 활용한 인공지능 시스템 개발

YouTube Live Webinar
2021-10-27

송완빈 과장
Application Engineer @ MathWorks
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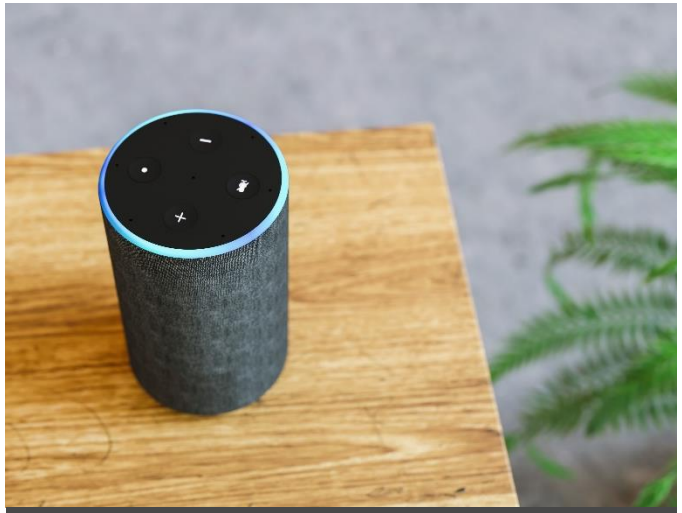
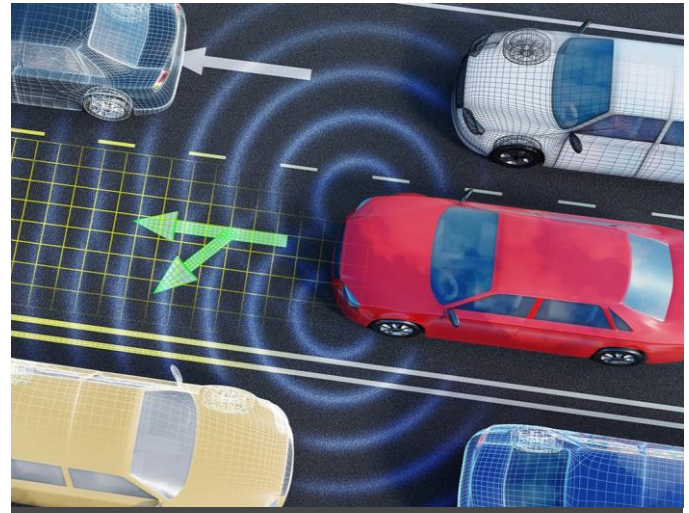
Deep learning is part of our everyday lives



Speech Recognition

Face Detection



Automated Driving

Deep Learning in MATLAB used in Industry

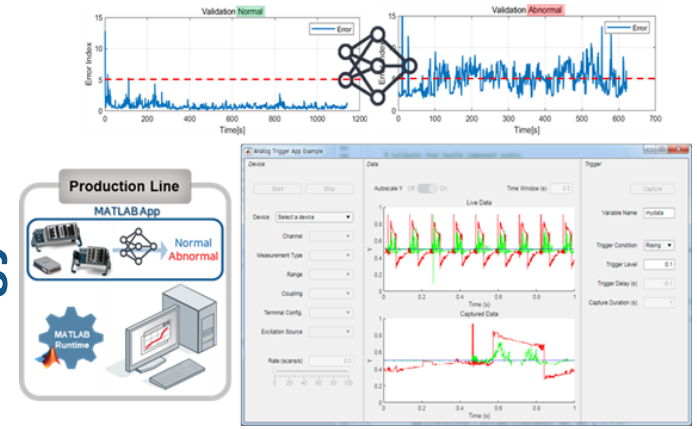
BMW

Oversteering Detection

Atlas Copco

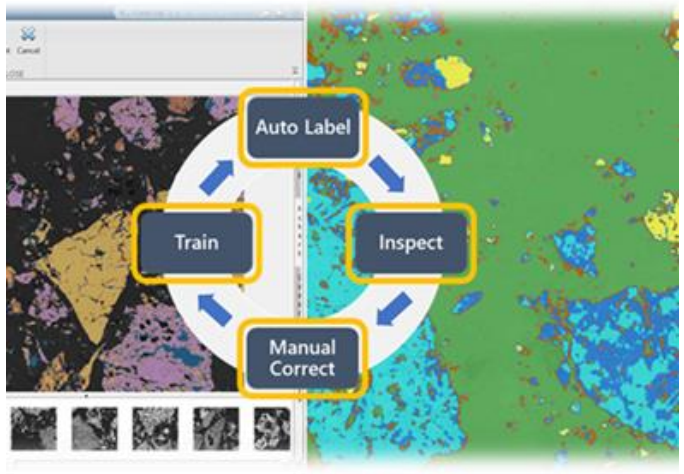
Digital Twins of Compressors

LG Energy Solution



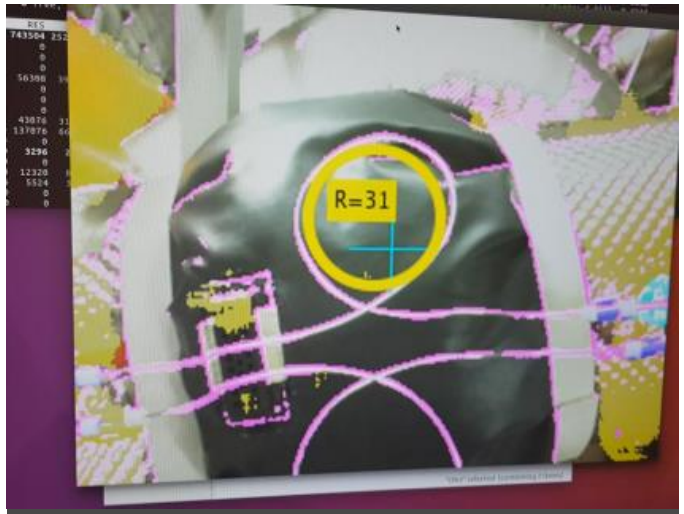
Condition monitoring system

Hyundai Steel



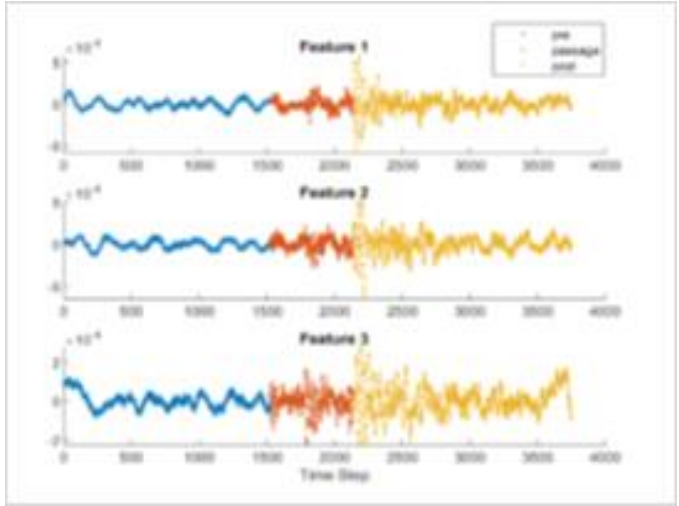
Steel Image Analysis

AirBus



Defect Detection

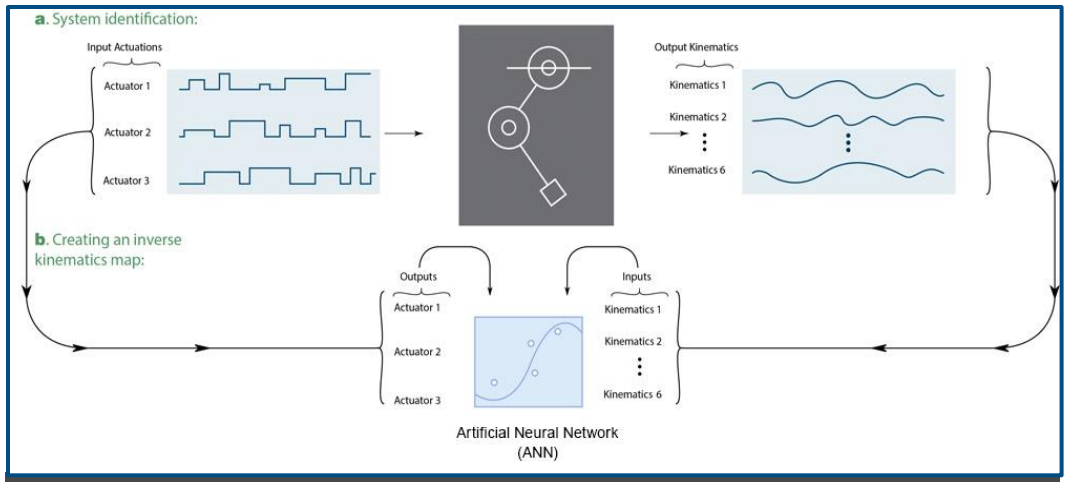
Shell



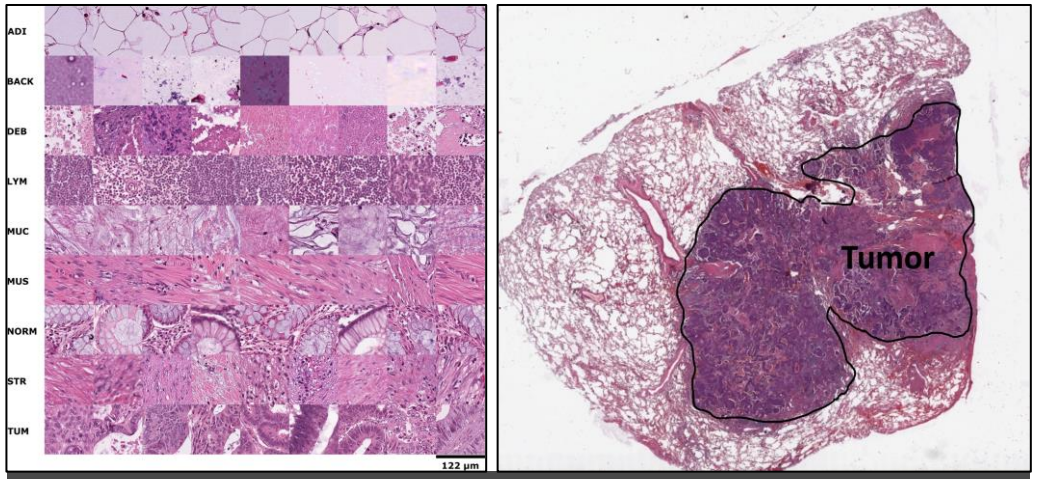
Seismic Event Detection

Deep Learning and AI in Research

University of Southern California



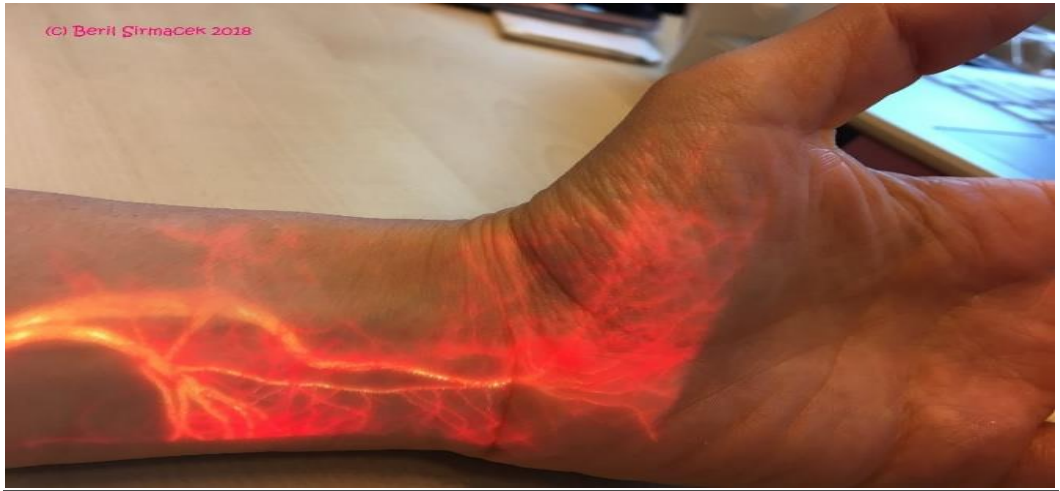
Reinforcement Learning for Robotic Arm



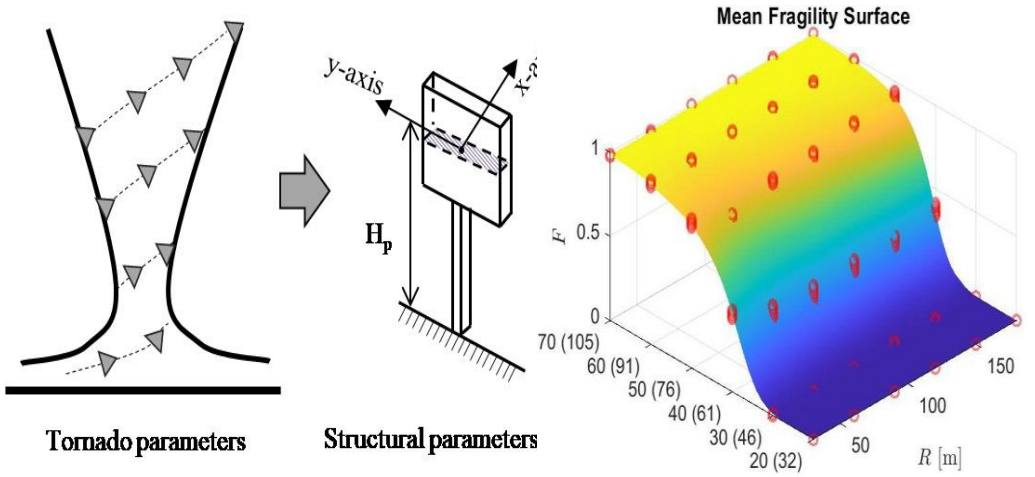
Deep Learning for Tumor Detection

DKFZ Heidelberg

University of Twente



Augmented Reality of blood flow



Neural Networks simulate tornadic wind load

Northeaster University

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AI-driven system design

Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability

Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation

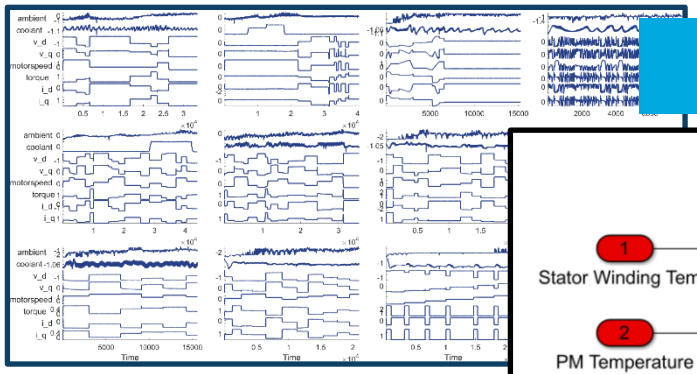
Deployment

- Embedded devices
- Enterprise systems
- Edge, cloud, desktop

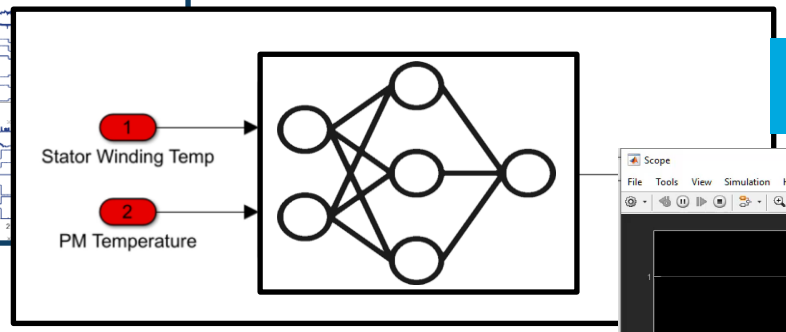
Deep learning for signals

Deep learning for motor temperature estimation

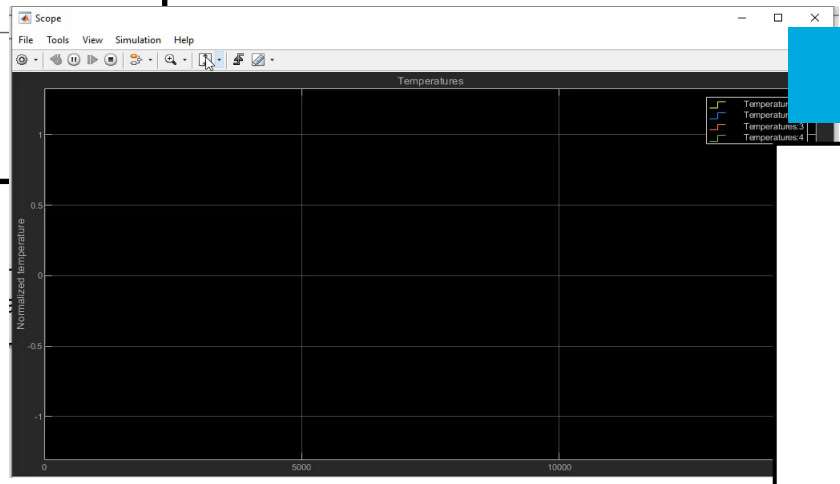
Data Preparation



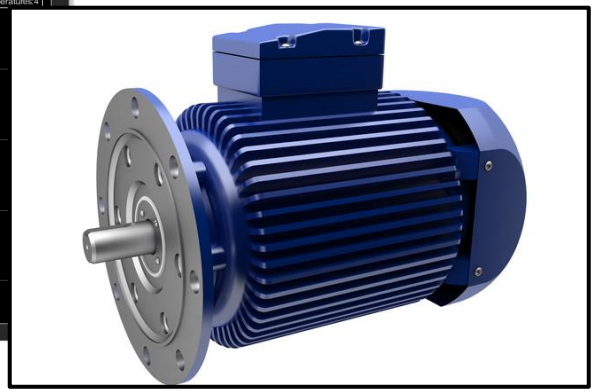
AI Modeling



Simulation & Test



Deployment



Continental uses data-driven engine temperature models for ECU development

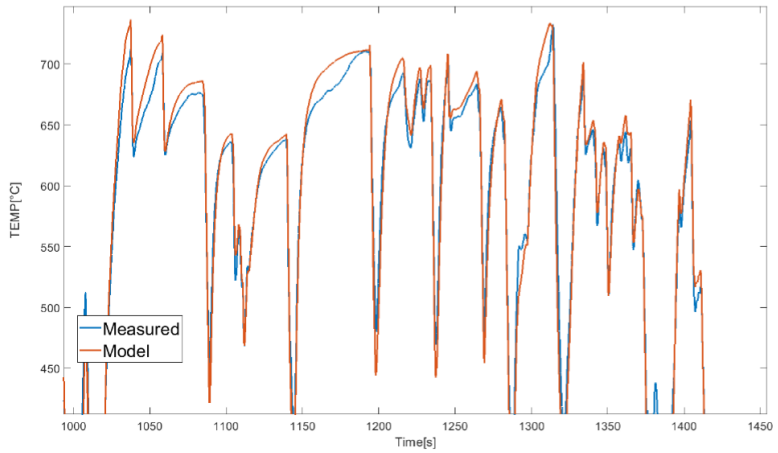
Classical ECU Functions
Advantages/Disadvantes

Advantages	Disadvantage
Physically motivated	Require development (modelling + coding)
High understanding of whats going on (intermediate signals have typically physical units)	Require methodology development for calibration = training
Enabling “transfer learning” for single HW change	Require tooling for the tra (backpropagation)
	Require very special mea engine test bench


Continental Electrification & Data Analytics Internal 11.04.19 Michael Wutz, © C

Continental Electrification & Data Analytics Internal 11.04.19 Michael Wutz, © Continental AG

Deep Dynamical Systems
Temperature example 40min of driving (validation)



Continental Electrification & Data Analytics Internal 11.04.19 Michael Wutz, © Continental AG

[Link to presentation]

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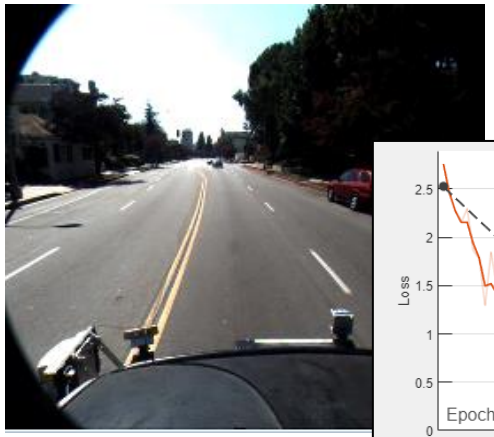
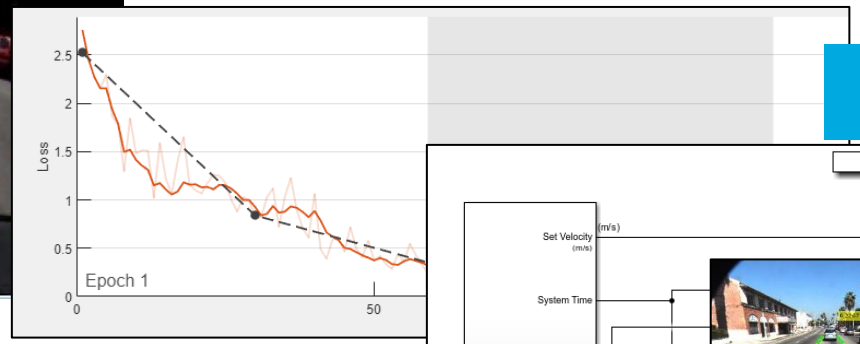
Deep learning for images and video

Deep learning for vehicle detection

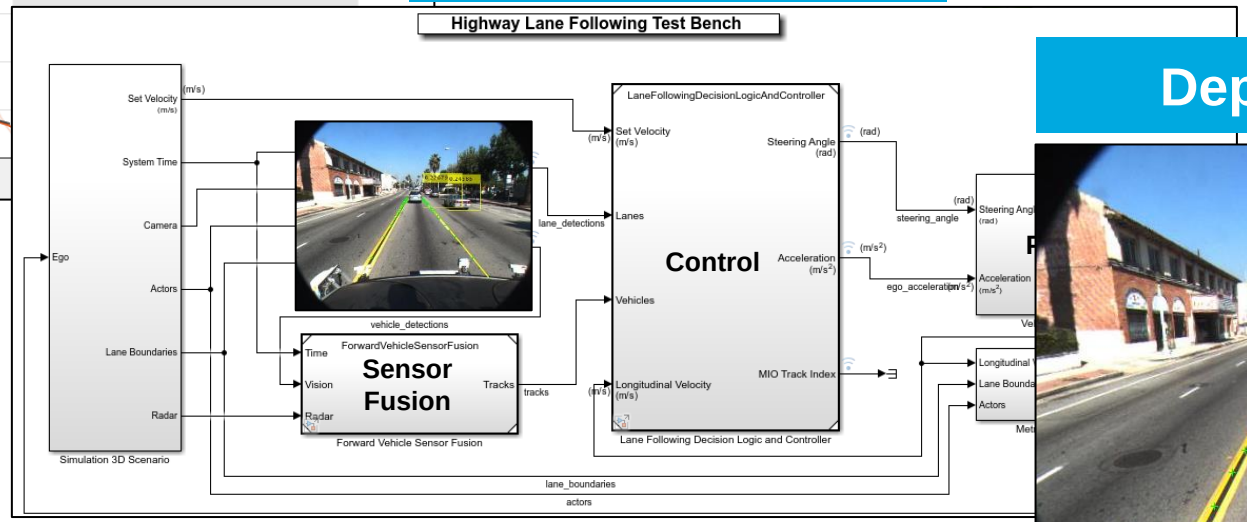
Data Preparation



AI Modeling



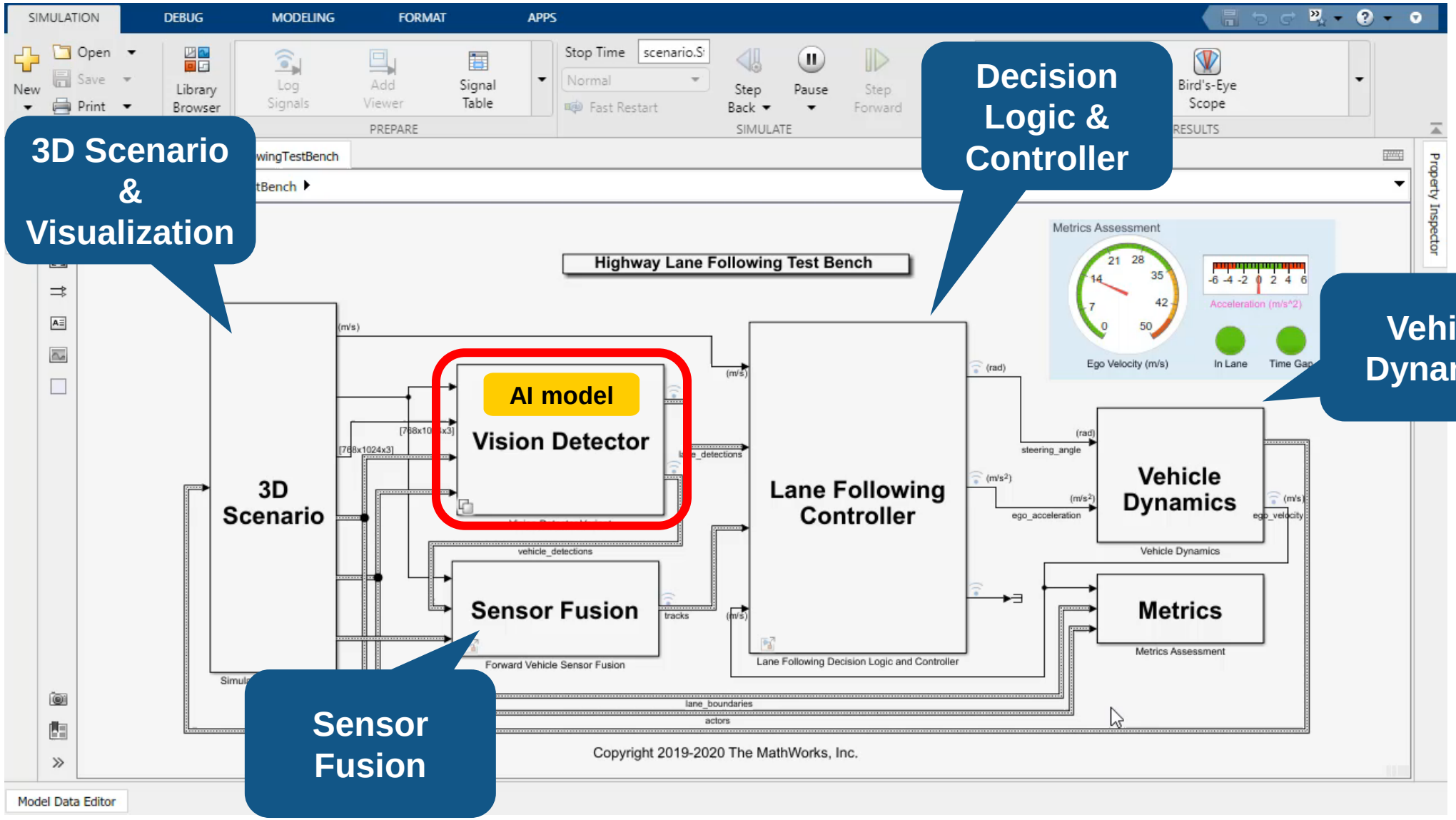
Simulation & Test



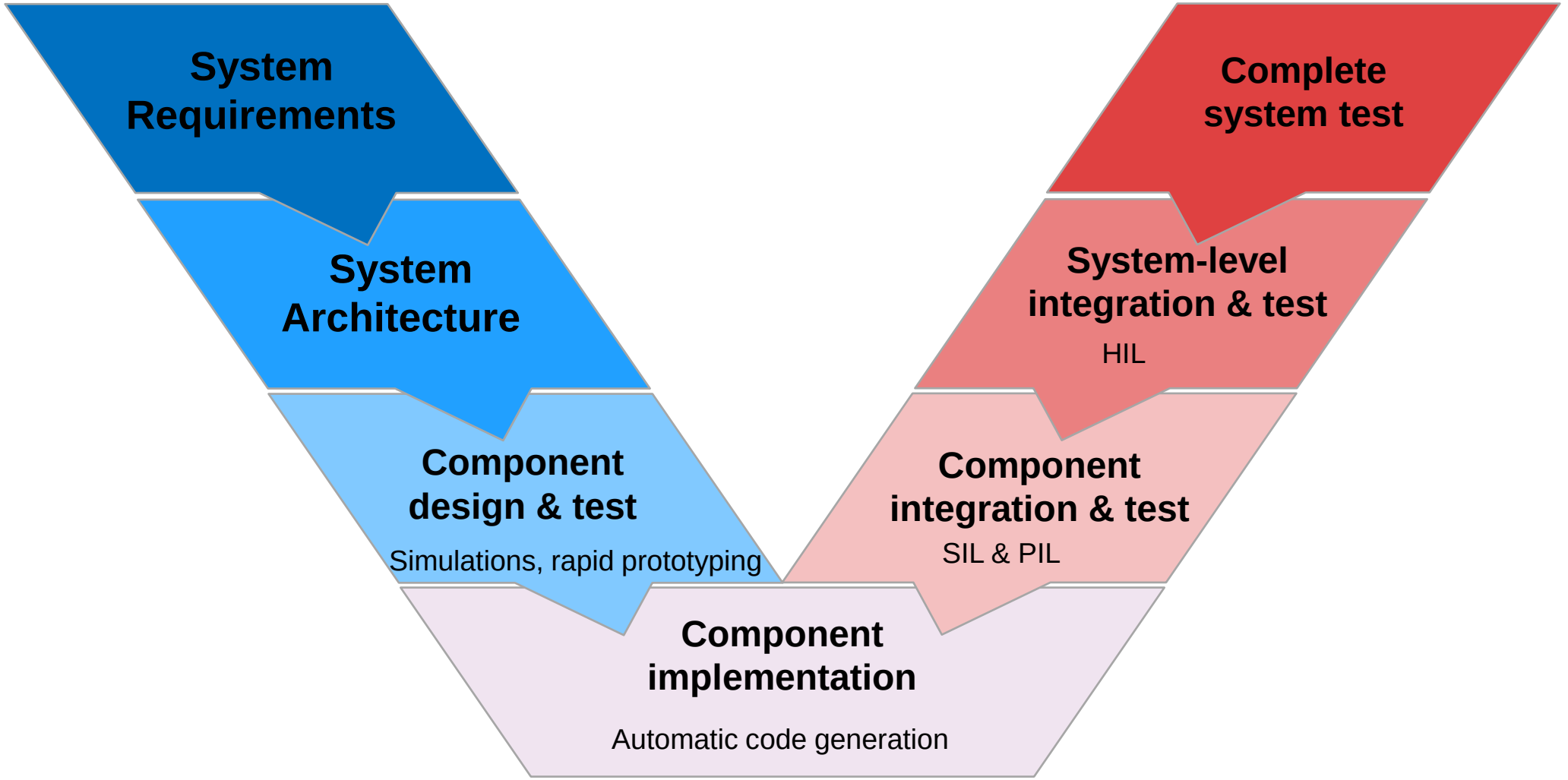
Deployment

Deep learning is often part of a larger system

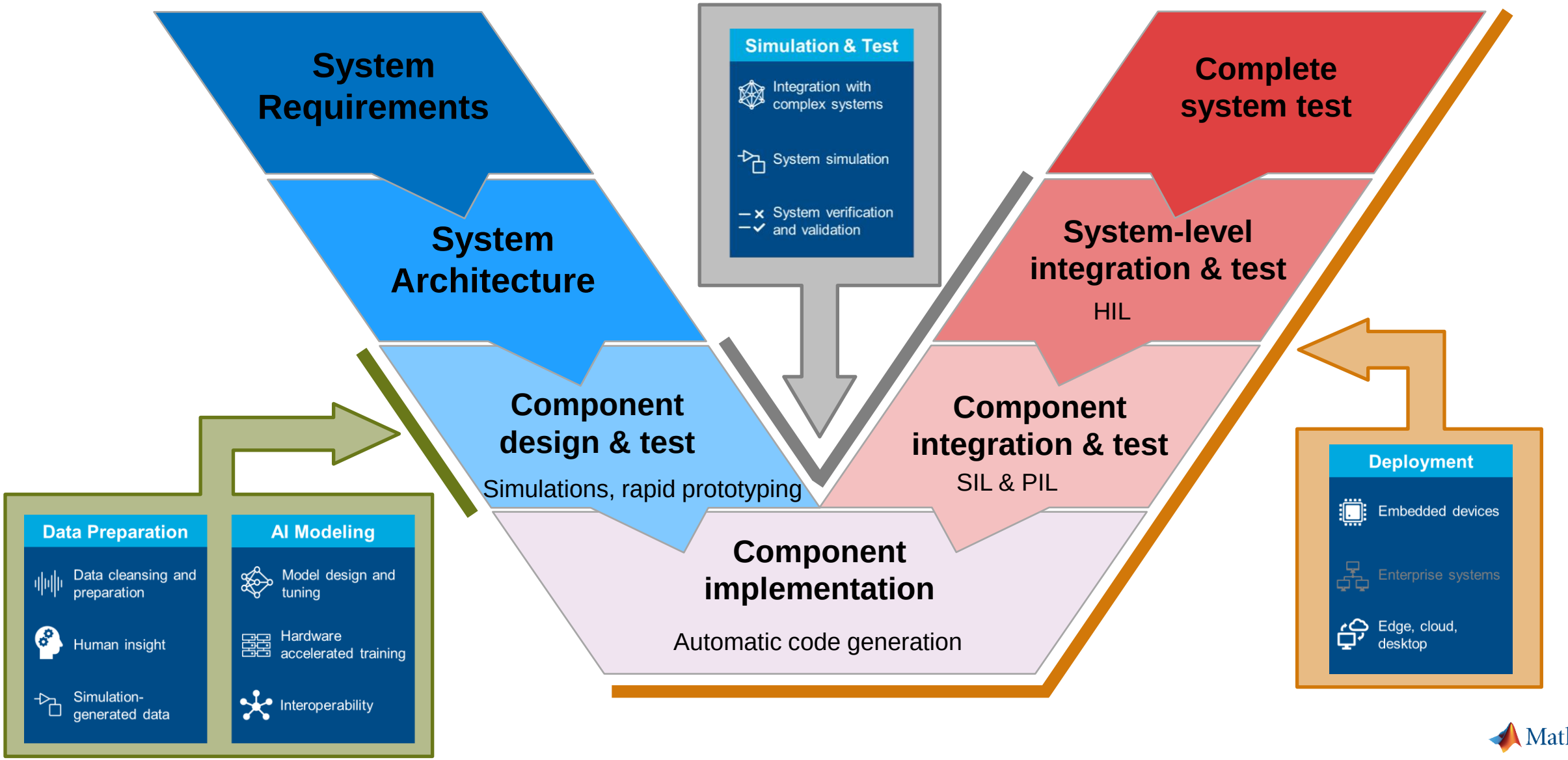
Simulate and test all your components together in Simulink



Development workflow with Model-Based Design



AI system development with Model-Based Design



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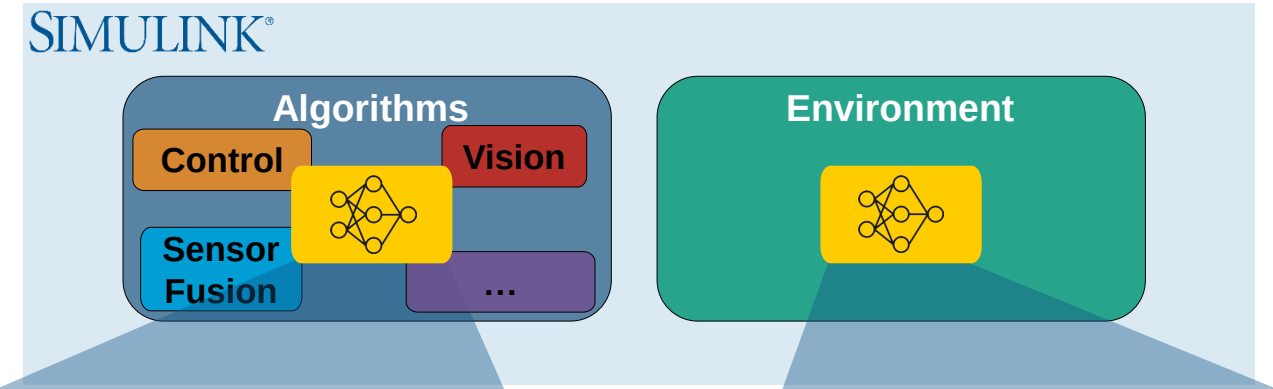
What can you do with AI?

- **Is the model slow**? Not possible to get real time for HIL?
  - Speed up high fidelity models by creating AI based surrogate models
- **Is the model inaccurate** for certain outputs compared to lab data?
  - Increase accuracy of complex processes, like emission calculations, by using data driven models trained on measured lab data
- Is there **a sensor value you would like to have** but that you can only afford to get in labs?
  - Create virtual sensors using AI
- Many more…

Integrating deep learning models into Simulink



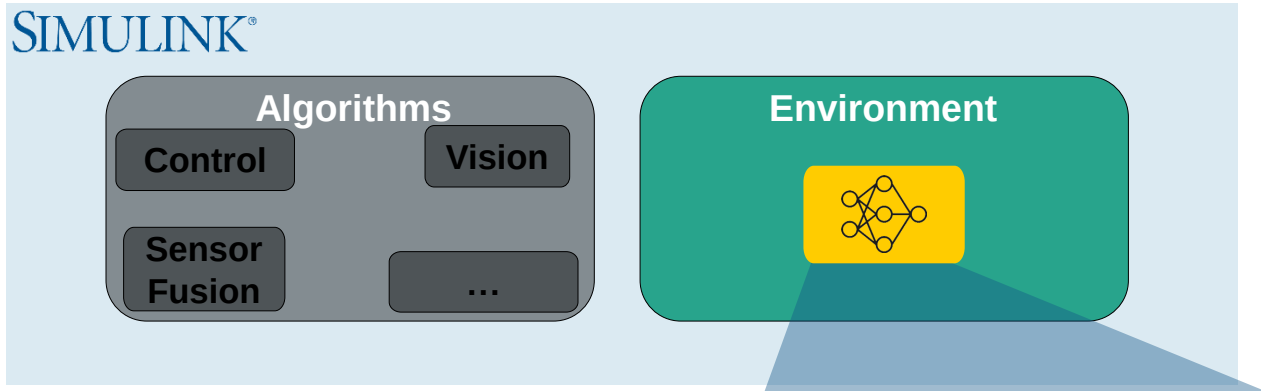
AI for algorithm development

- Simulate for system-level testing
- Verify system requirements
- Deploy to CPU/GPU/ECU

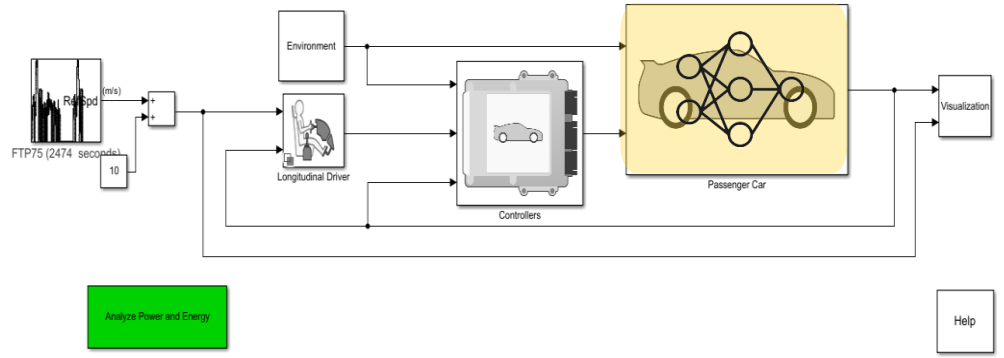
AI for environment modeling

- Speed up high-fidelity Simulink model
- Reduce Simulink model complexity
- Enable HIL tests if first-principles model cannot be obtained

Deep learning for environment modeling



AI for environment modeling



Deep Learning for engine surrogate model

Physics-based vs data-driven modeling

First principles models and data-driven models can co-exist

First-principles models
Physics, math, domain knowledge

Data-driven models
Statistics, optimization, AI

Advantages

- May capture (global) parameterizable behaviors with low/high fidelity
- Have clear (explainable) physical meaning
- Do not require data engineering

Challenges

- Can be challenging/impossible to derive
- Require significant time for derivation
- Require expertise in the respective domain

Advantages

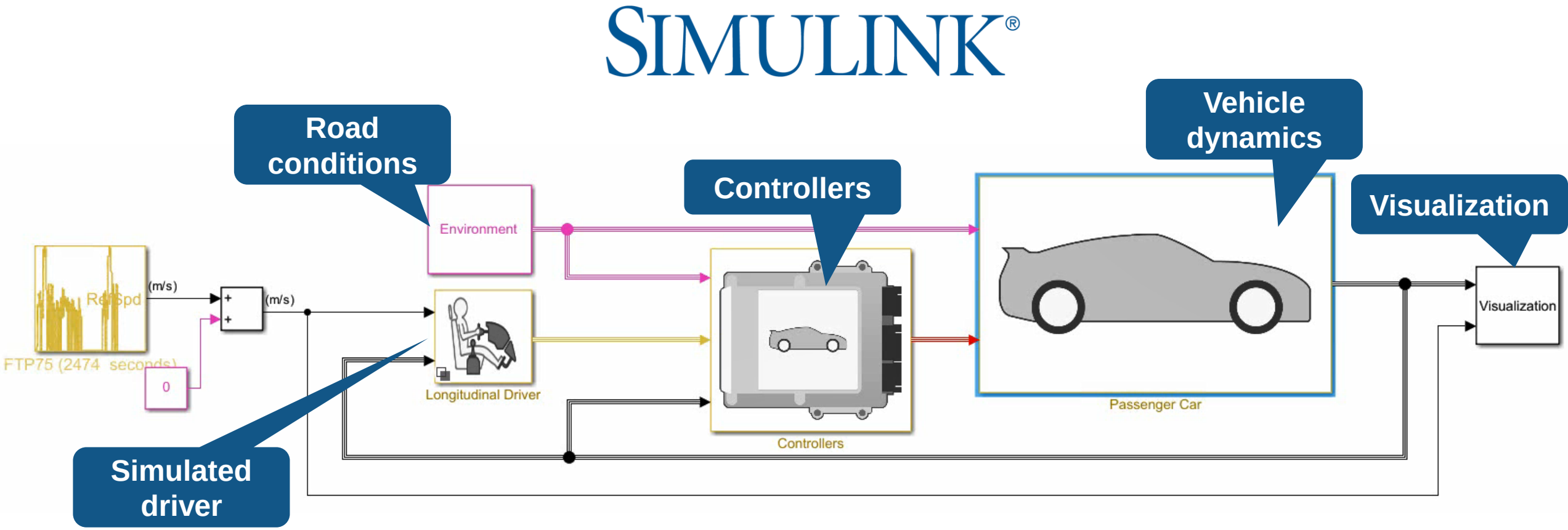
- May succeed when first-principles models are unavailable or challenging/impossible to find
- May reduce complexity, simulate faster
- Can leverage existing, measured data
- Do not require domain knowledge

Challenges

- Require a lot of data
- Are often not
  - interpretable, explainable
  - easily parameterizable in a physically meaningful way
- Cannot extrapolate well beyond training data

Example overview

Replacing a first-principles engine model with an AI-based surrogate

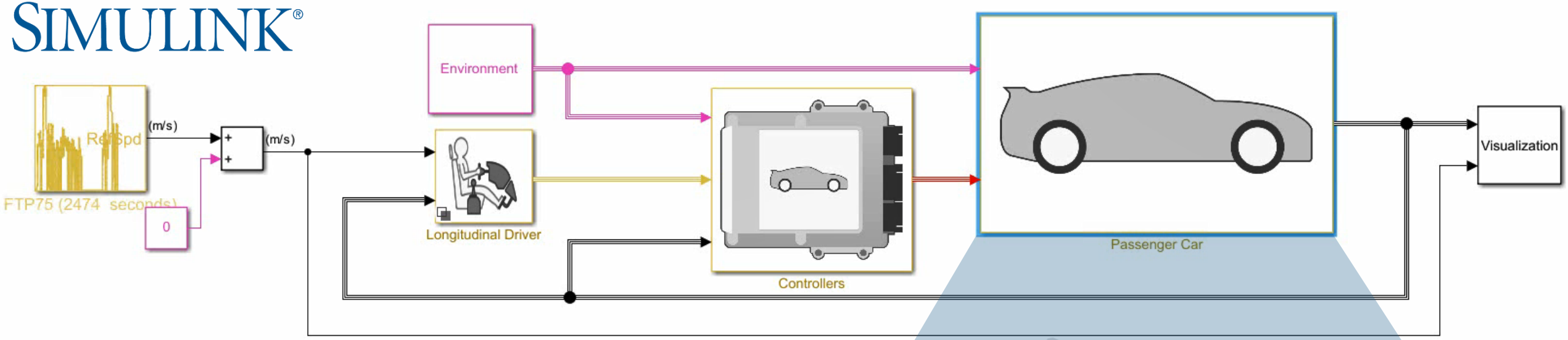


Closed-loop control of vehicle speed

Example overview

Replacing a first-principles engine model with an AI-based surrogate

SIMULINK®



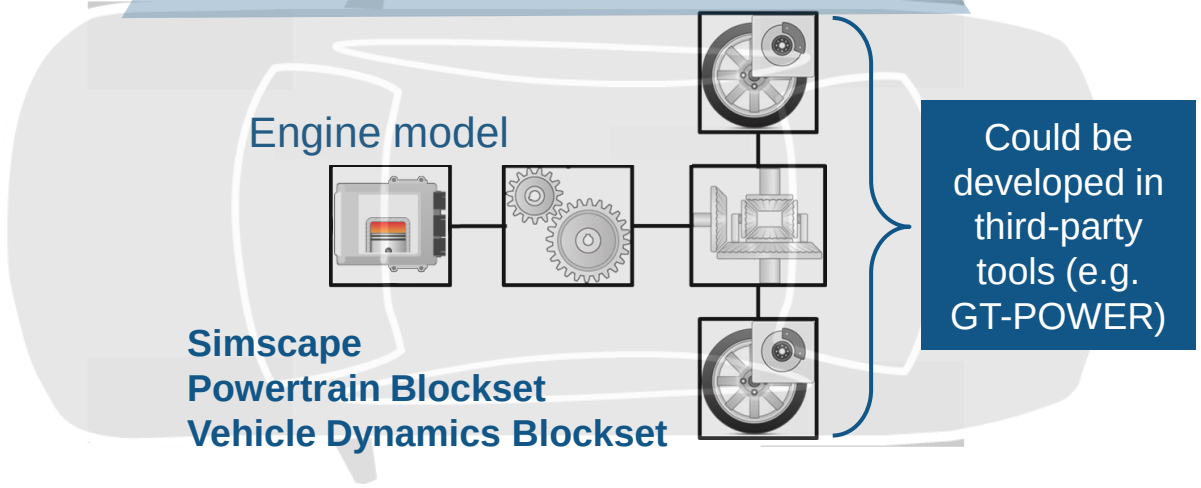
High fidelity

↓

Complex model

↓

Slow simulation

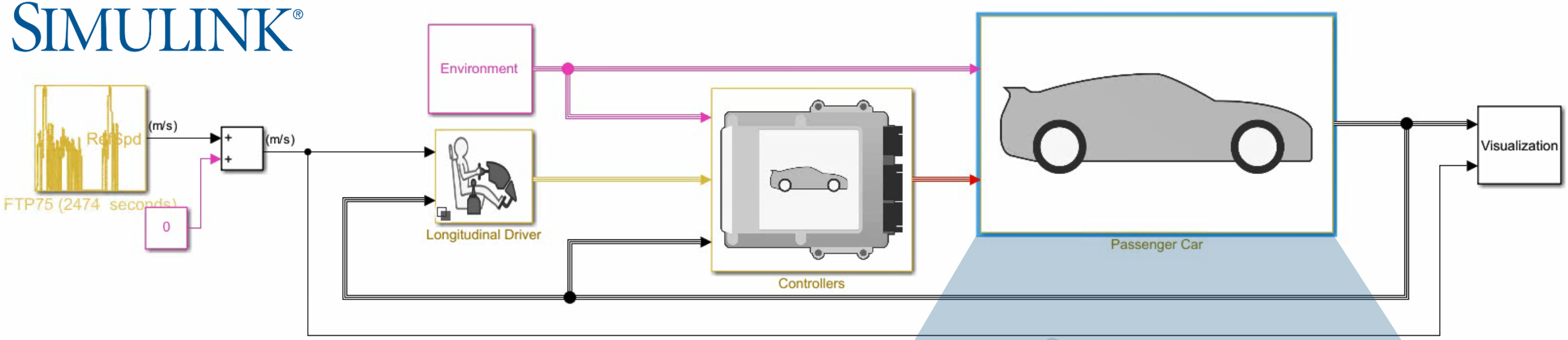


Could be developed in third-party tools (e.g. GT-POWER)

Example overview

Replacing a first-principles engine model with an AI-based surrogate

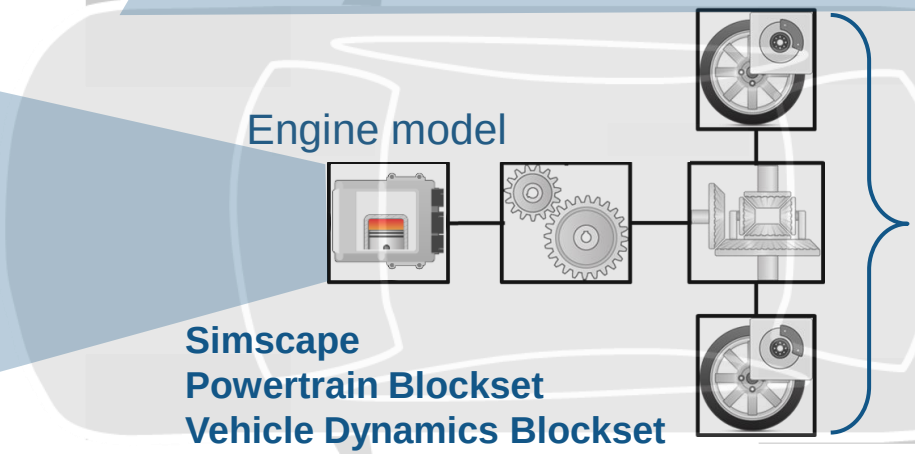
SIMULINK®



Inputs
Engine speed (RPM)
Ignition timing
Throttle position
Wastegate valve

Outputs
Engine Torque

Deep Learning Toolbox



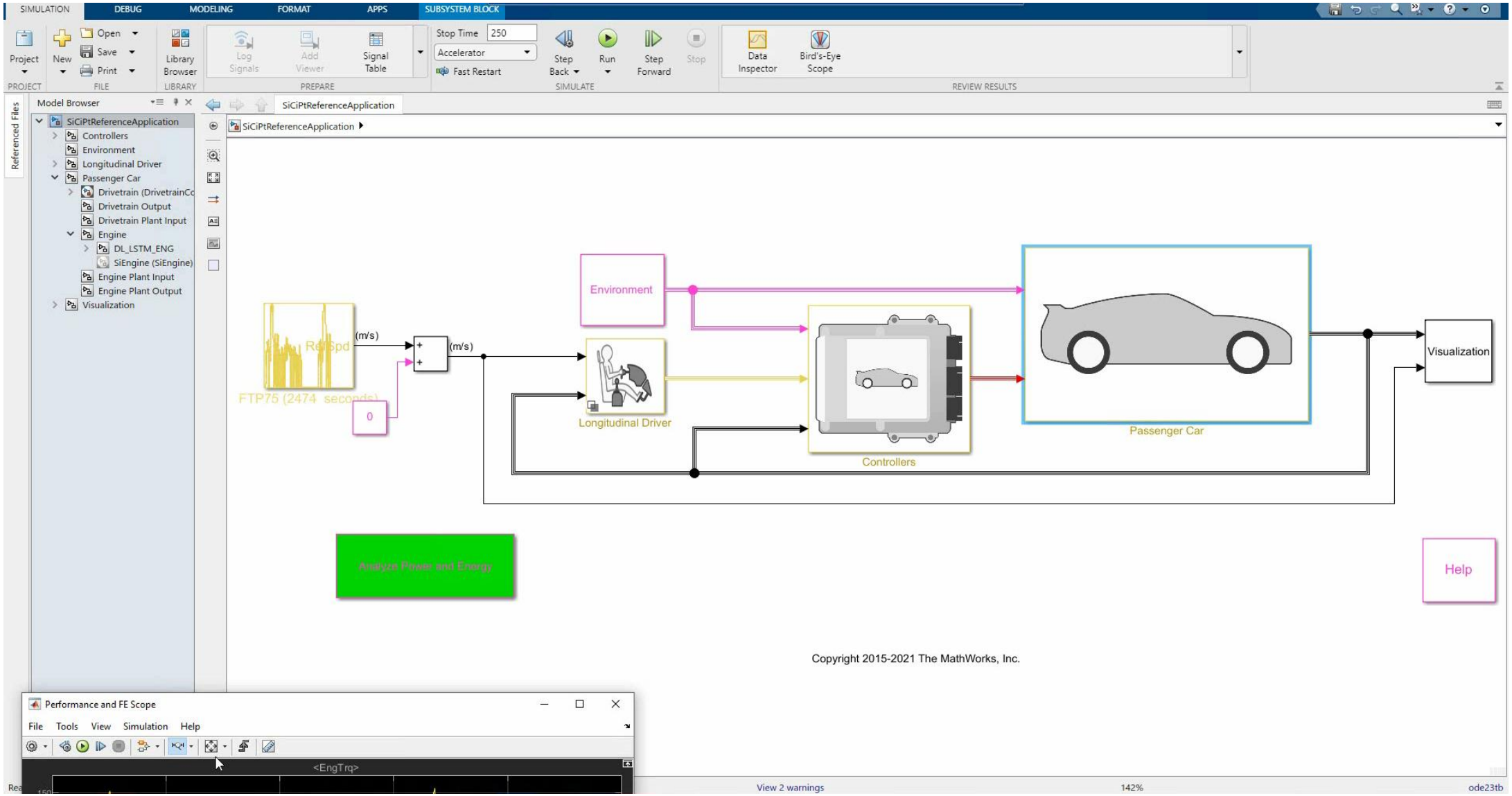
Simscape
Powertrain Blockset
Vehicle Dynamics Blockset

Could be developed in third-party tools (e.g. GT-POWER)

Black-box ← → **White-box**

Example overview

System-level simulation



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AI-driven system design

Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability

Simulation & Test

- Integration with complex systems
- System simulation
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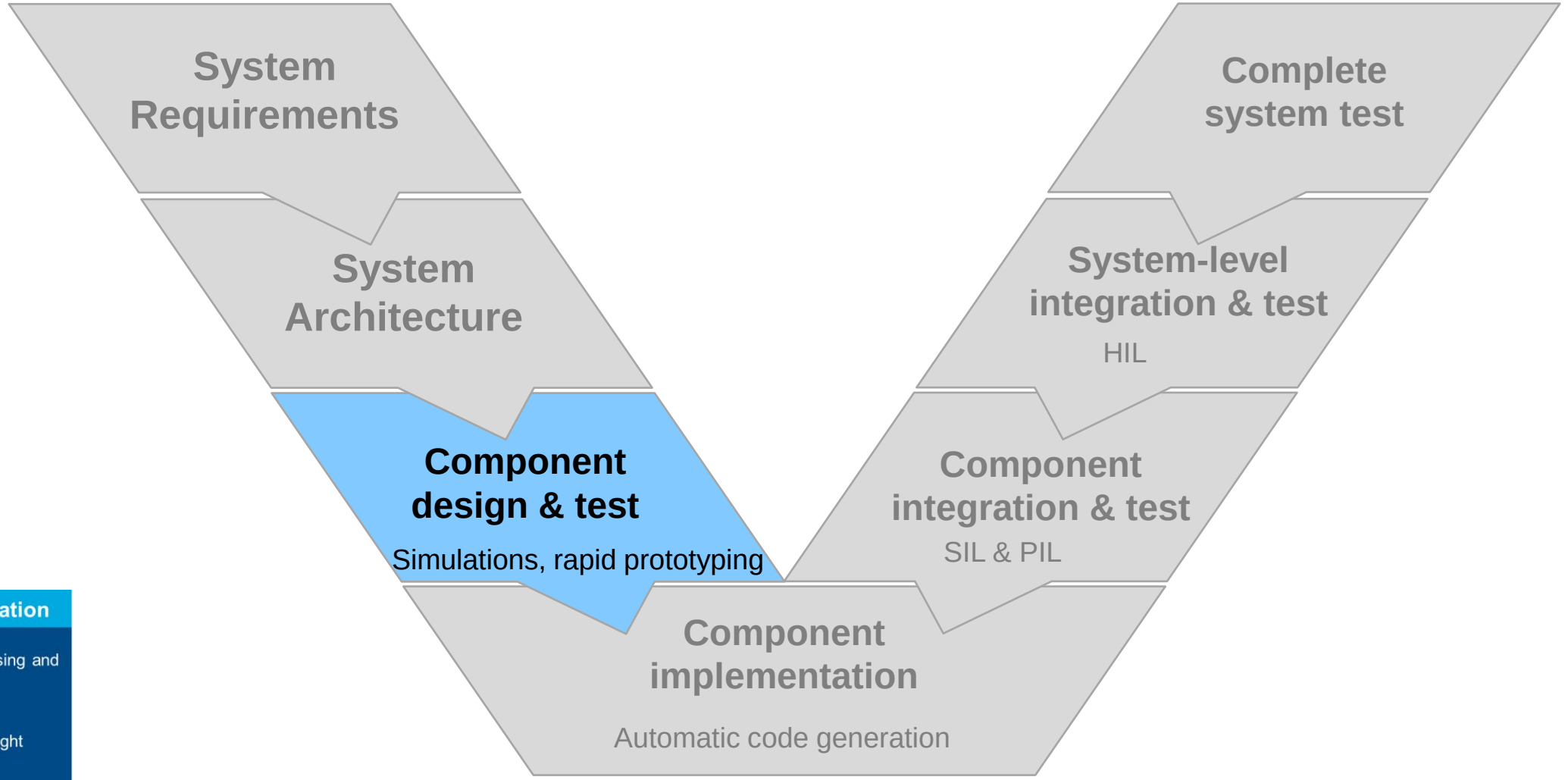
Deployment

- Embedded devices
- Enterprise systems
- Edge, cloud, desktop

AI system development with Model-Based Design



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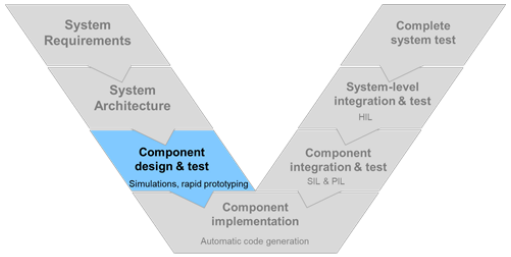
Data preparation represents most of your AI effort



Data Preparation

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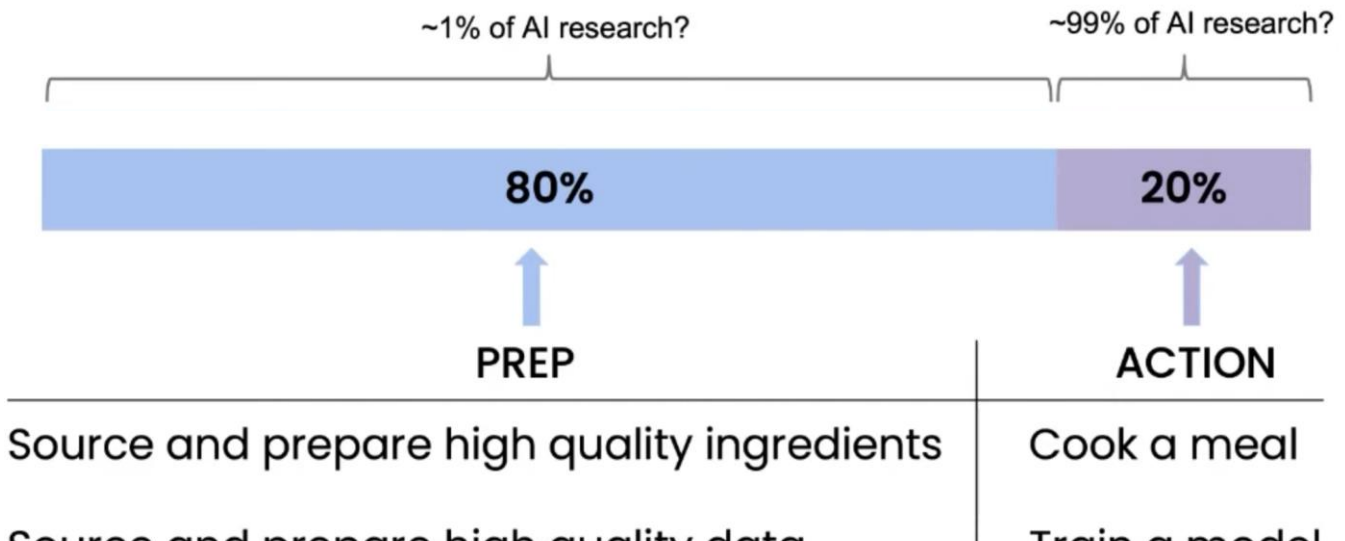
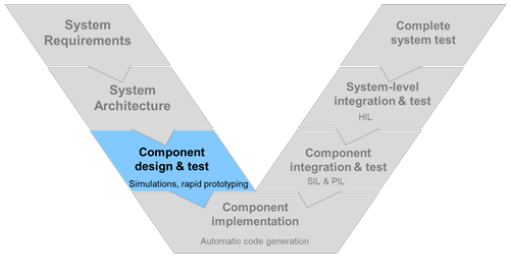
Data is Food for AI



Source: Andrew NG slide from MLOps 2021

Generate synthetic data for training



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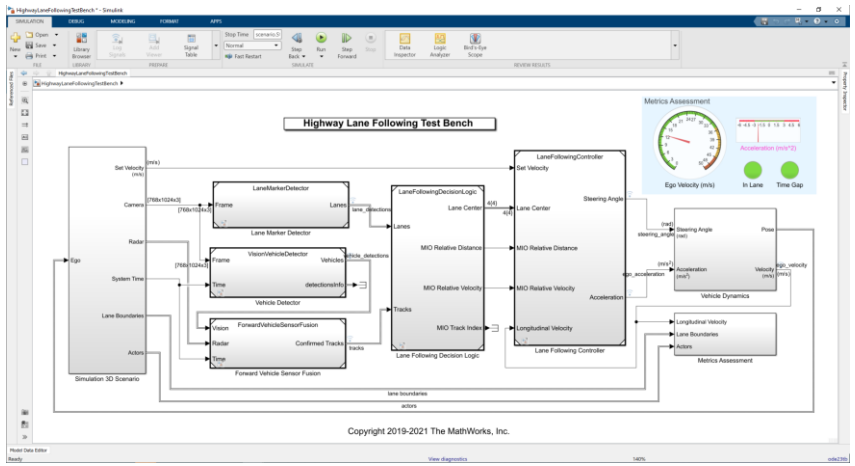
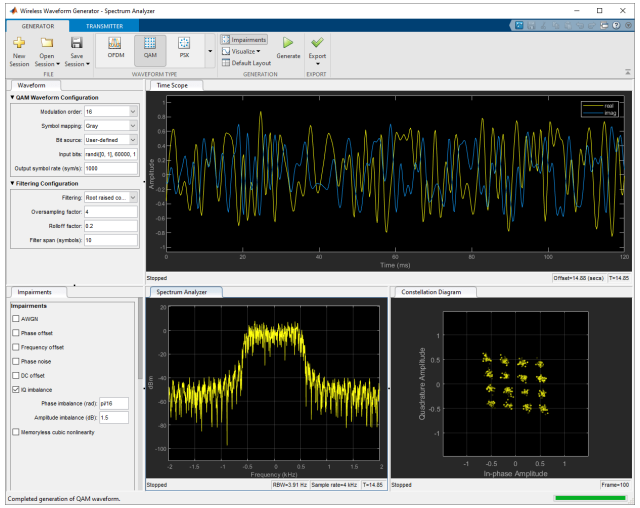


Simulink/Simscape

GANs

Unreal Engine®



Wireless Waveform Generator

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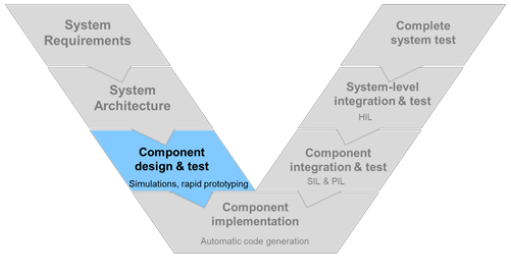
Data preparation demo



Data Preparation

- Data cleansing and preparation
- Human insight
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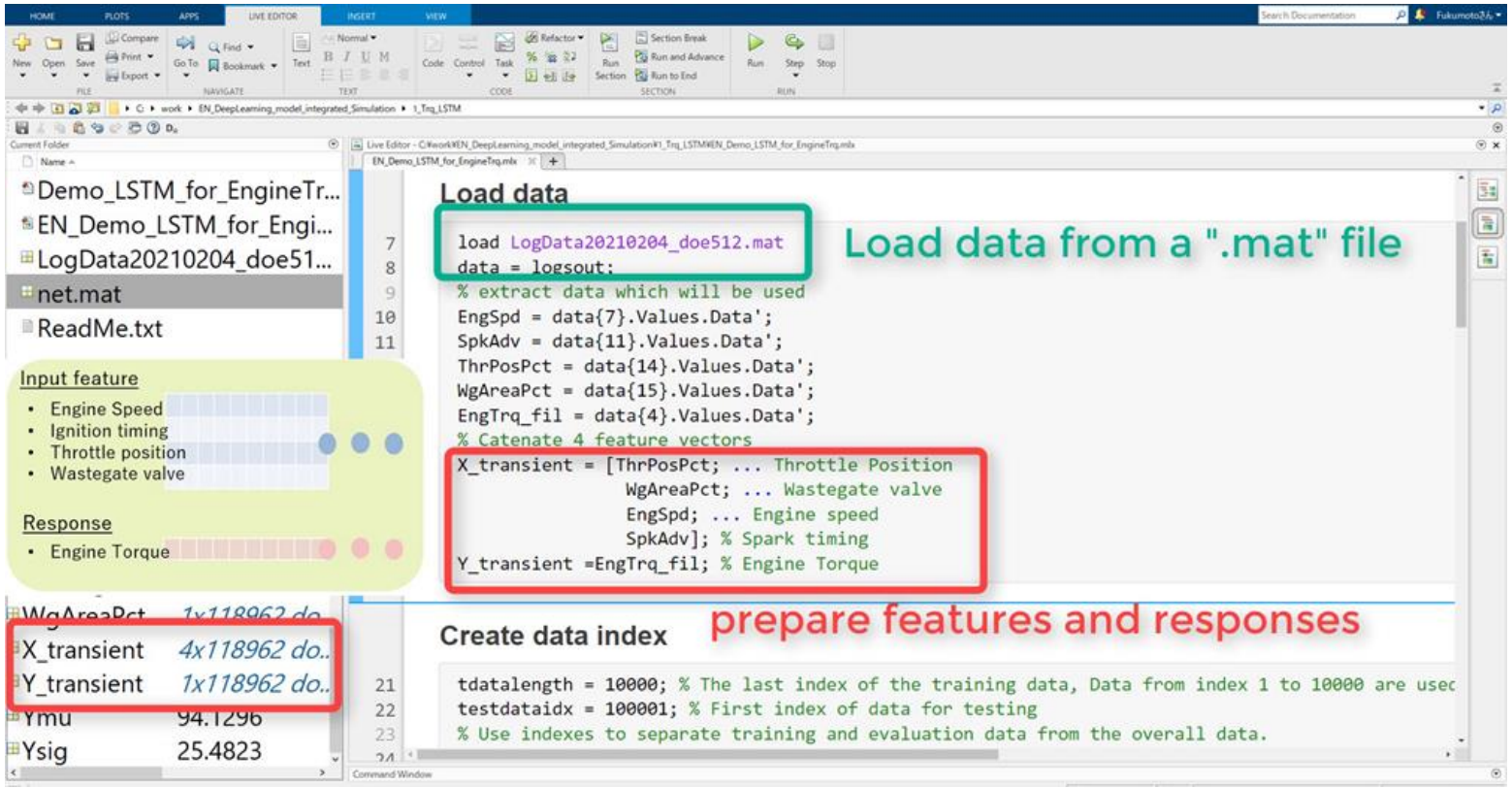
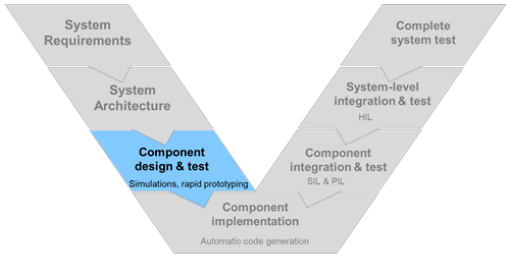
Open Part 1



Data preparation demo



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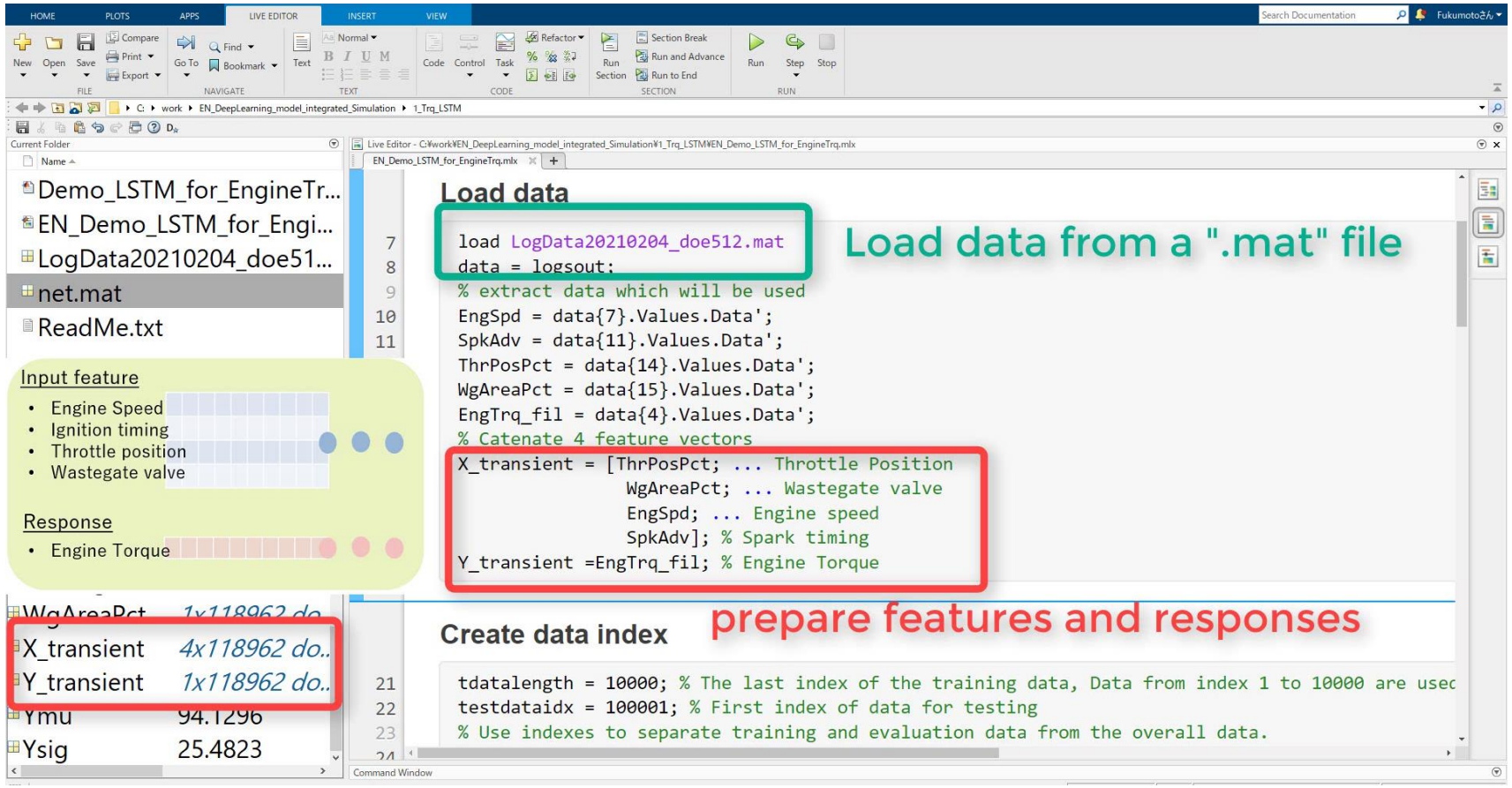

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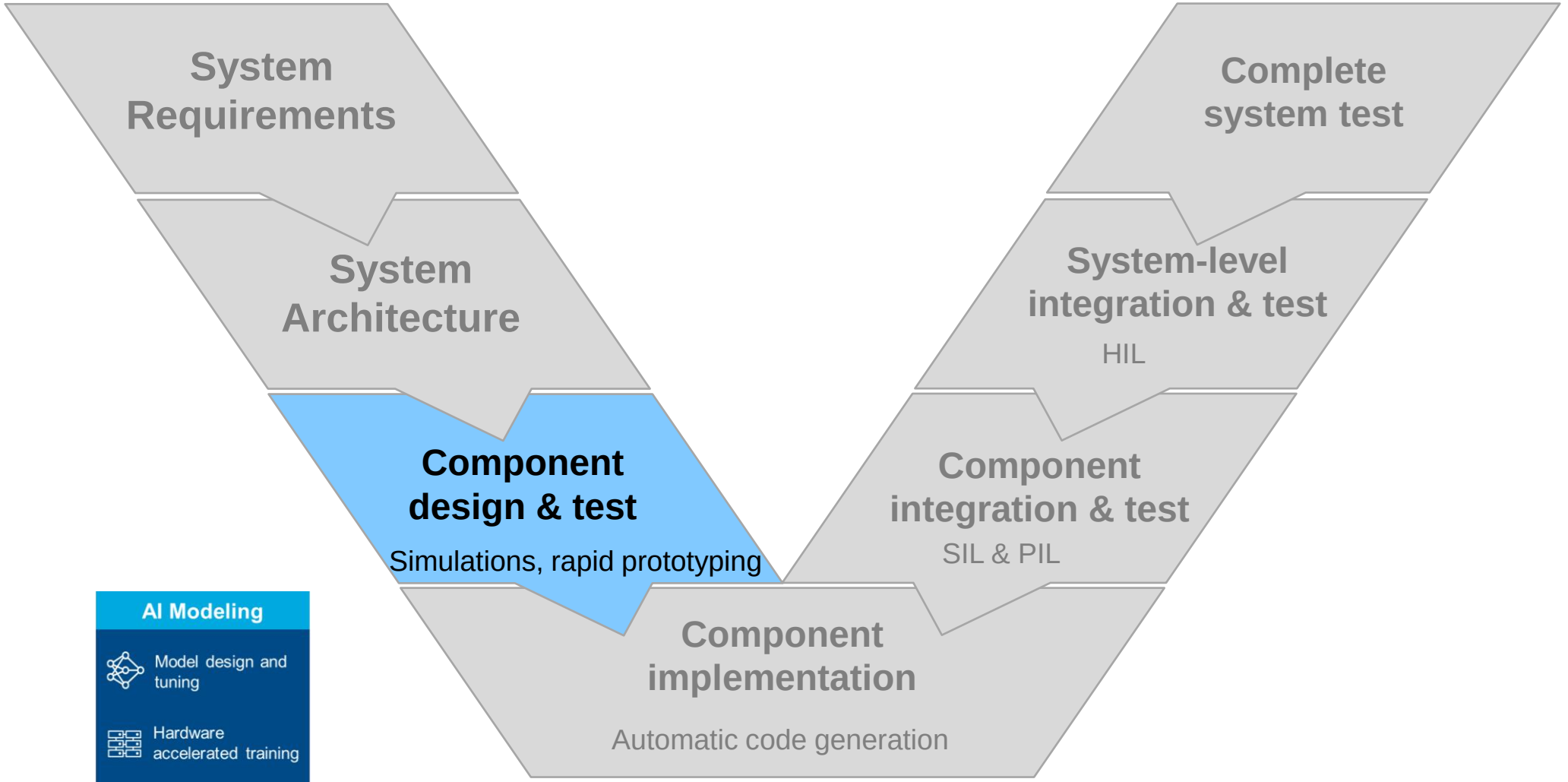
AI system development with Model-Based Design



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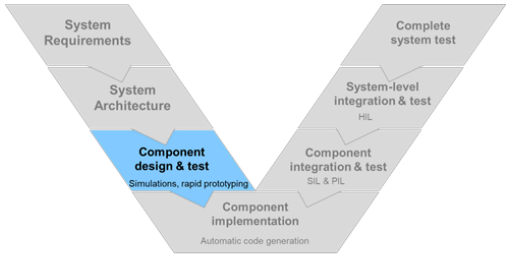
Start with a complete set of algorithms and pre-built models



AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability

Algorithms

Machine learning
Trees, Naïve Bayes, SVM…

Deep learning
CNNs, GANs, LSTM, MIMO…

Reinforcement learning
DQN, A2C, DDPG…

Regression
Linear, nonlinear, trees…

Unsupervised learning
K-means, PCA, GMM…

Predictive maintenance
RUL models, condition indicators…

Bayesian optimization

Pre-built models

Image classification models
AlexNet, GoogLeNet, VGG, SqueezeNet, ShuffleNet, ResNet, DenseNet, Inception…

Reference examples

Object detection
Vehicles, pedestrians, faces…

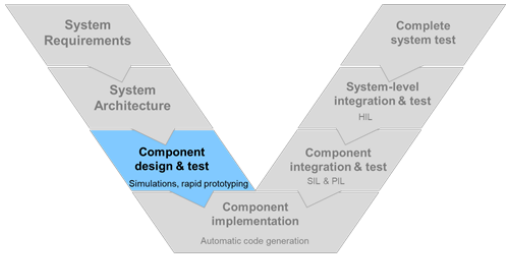
Semantic segmentation
Roadway detection, land cover classification, tumor detection…

Signal and speech processing
Denoising, music genre recognition, keyword spotting, radar waveform classification…

…and more…

AI modeling demo: Creating and training the LSTM model

Use LSTM networks to capture time dependencies in time-series data



AI Modeling

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Inputs

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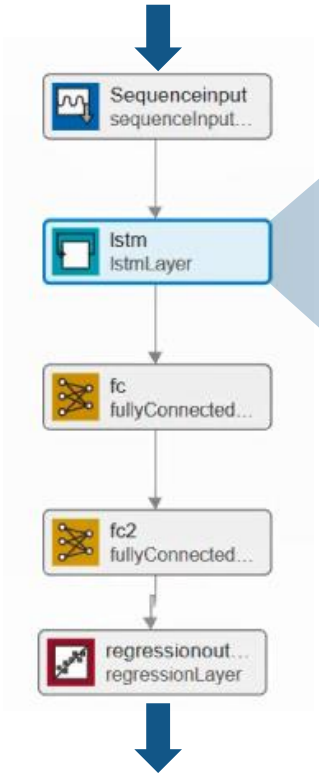
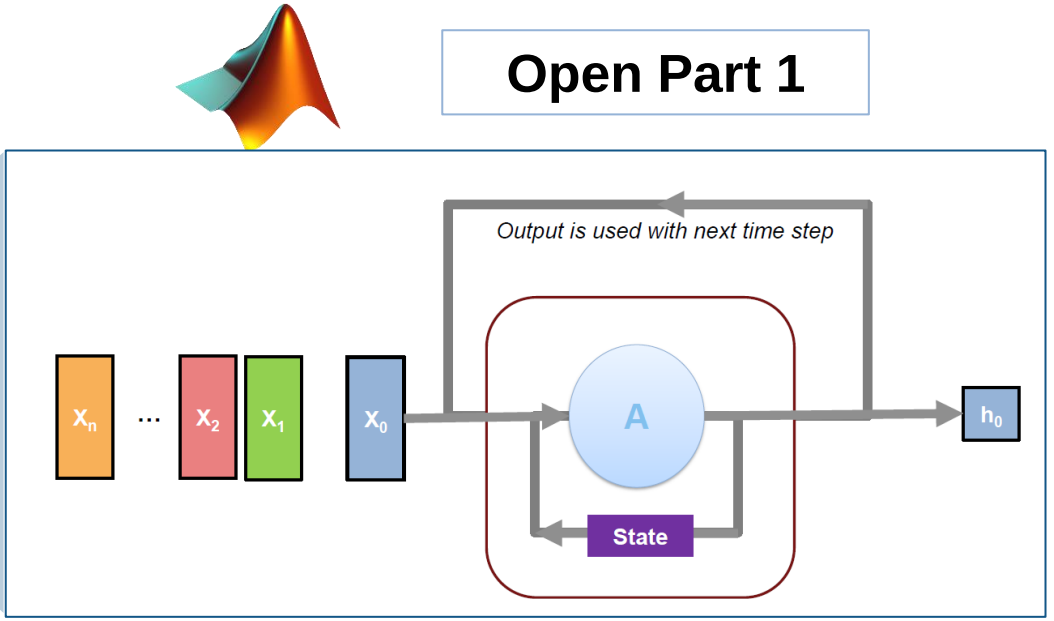


Outputs

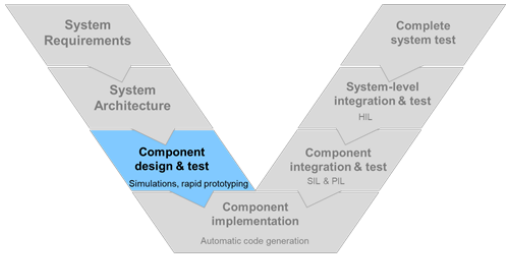
Engine Torque



LSTMs carry a memory cell (state) throughout

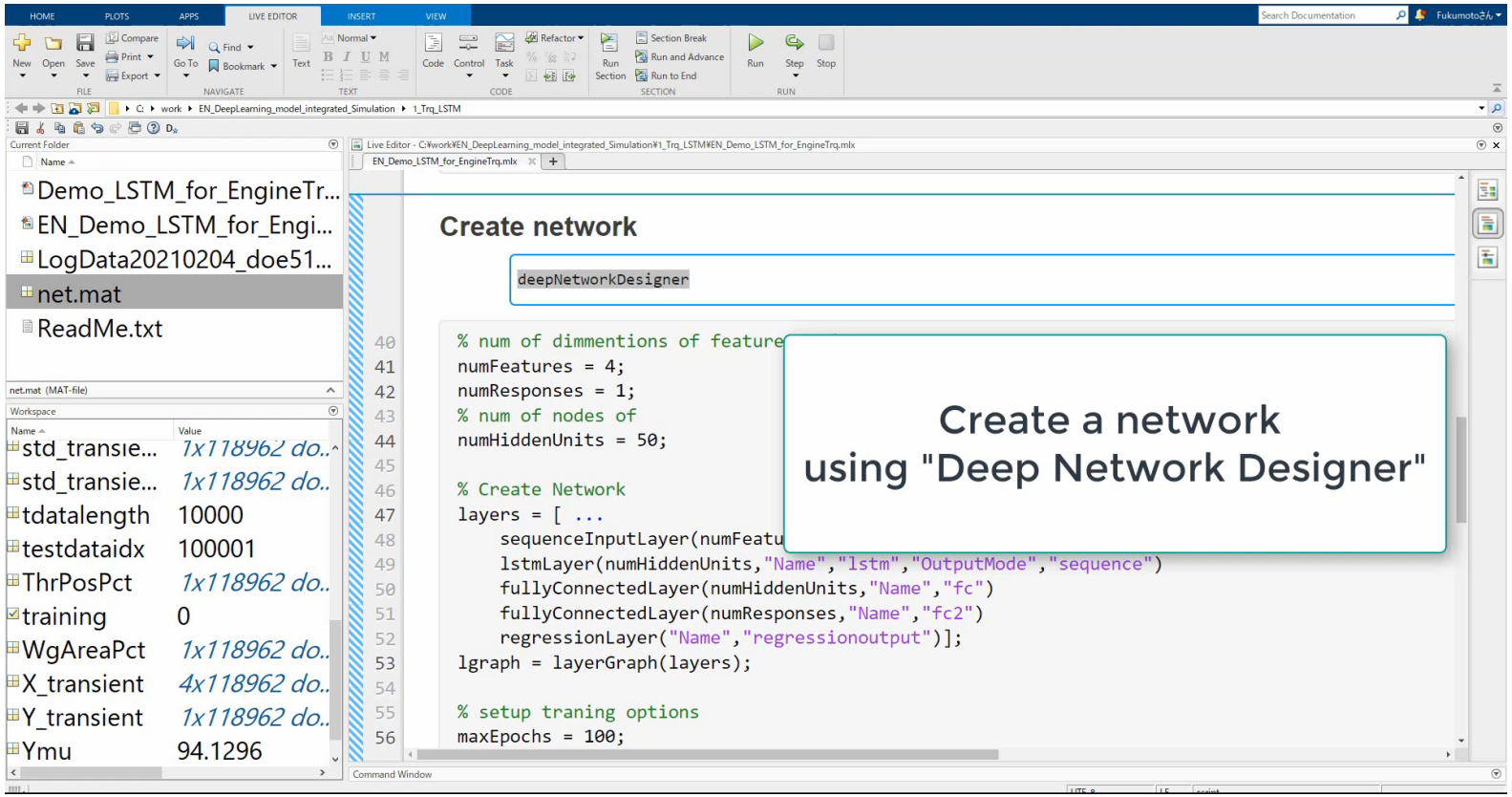
AI modeling demo: Creating and training the LSTM model

Use LSTM networks to capture time dependencies in time-series data



AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability



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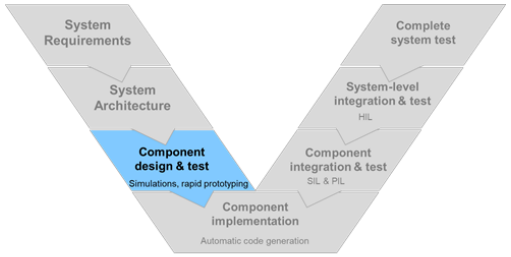
AI modeling demo: Creating and training the LSTM model

Training results



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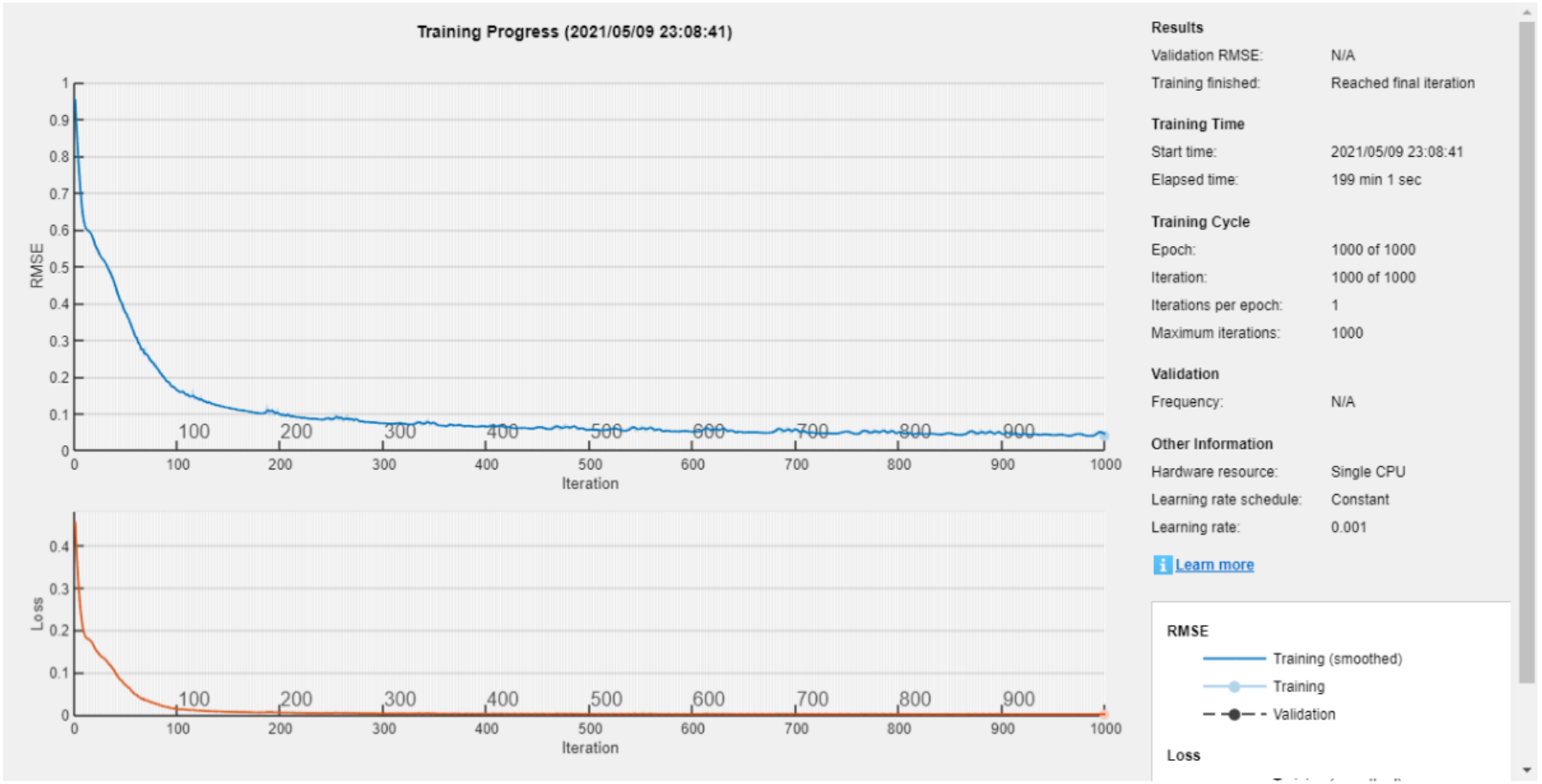

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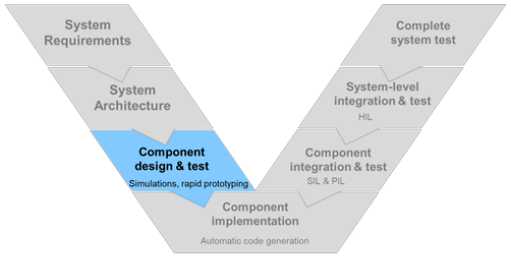
MATLAB interoperates with other frameworks

Framework Interoperability bridges the gap between data science, engineering and production



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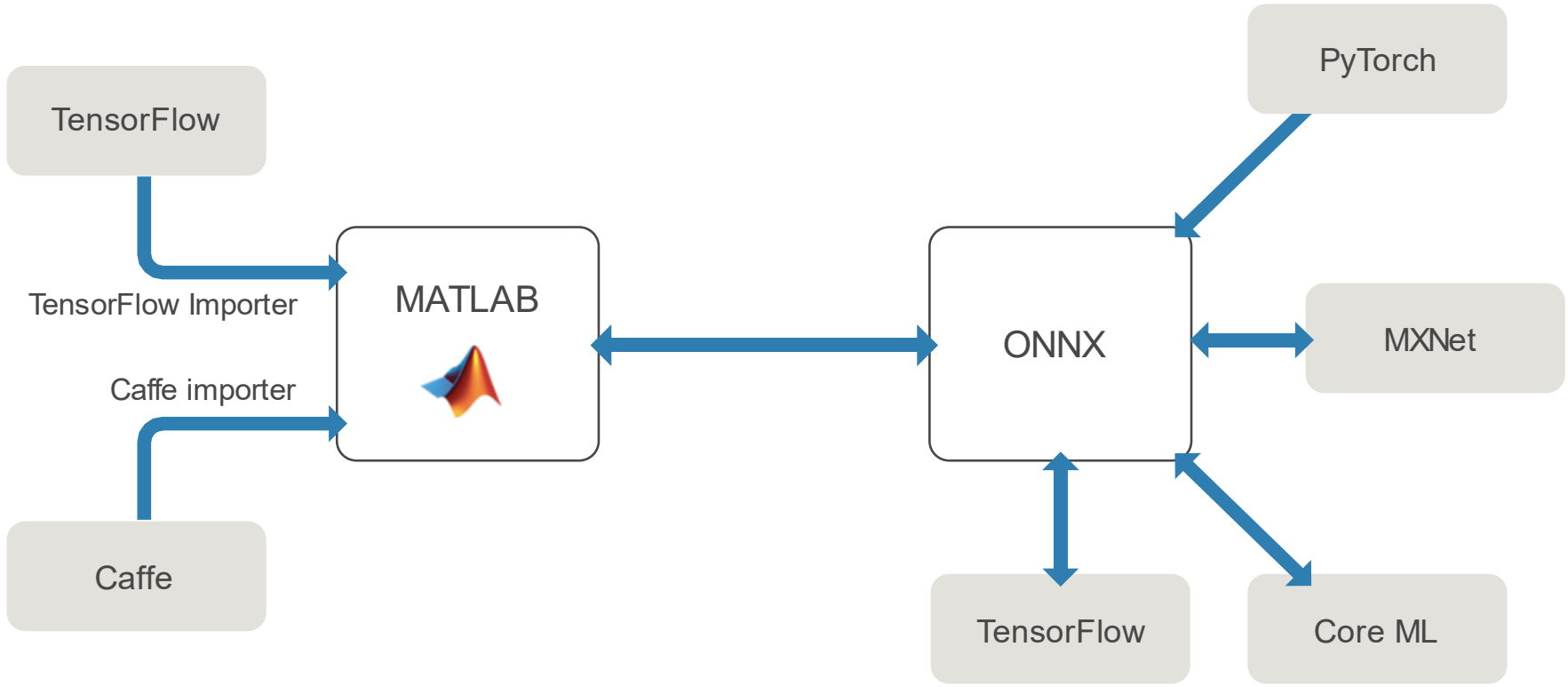

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AI-driven system design

Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability

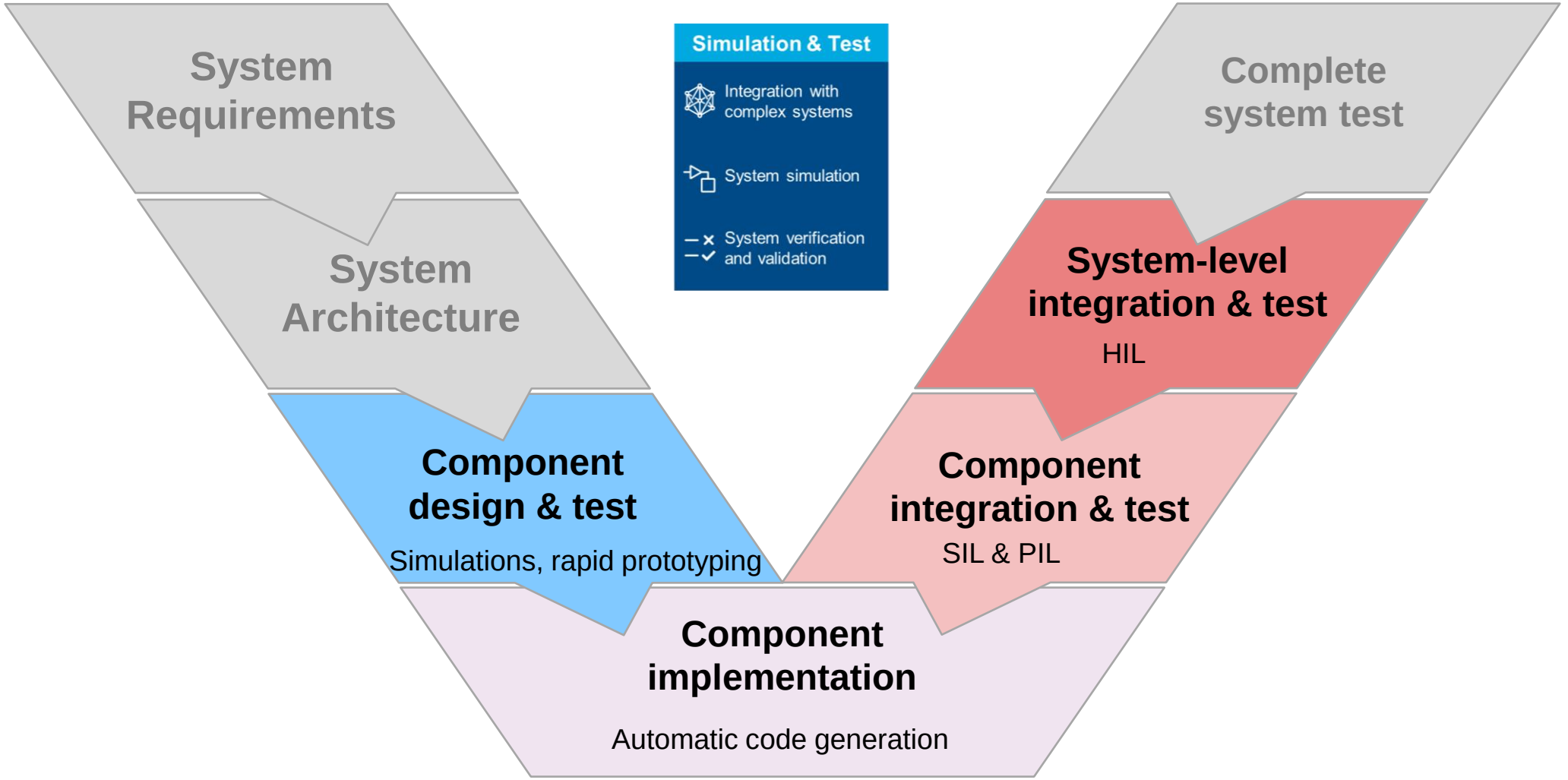
Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation

Deployment

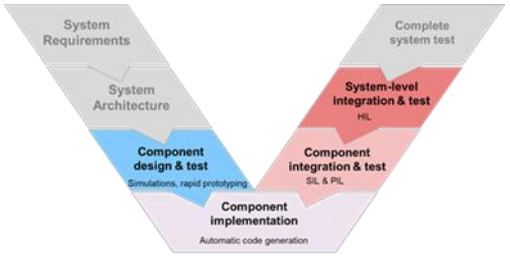
- Embedded devices
- Enterprise systems
- Edge, cloud, desktop

AI system development with Model-Based Design



Use deep learning within *entire system models* in Simulink

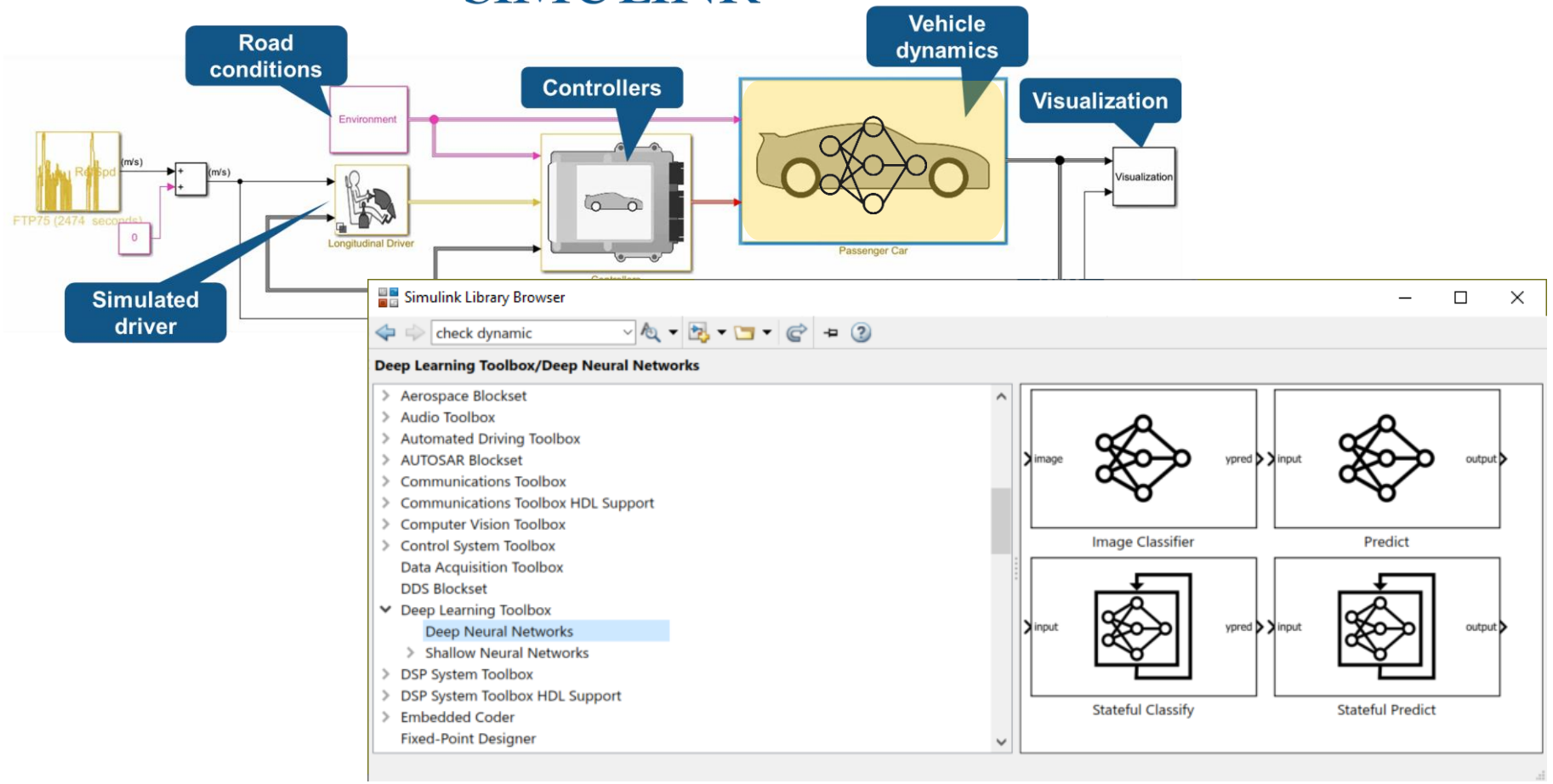
Integrate your deep learning model with your other algorithms for system-level simulation and test



Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation

SIMULINK®



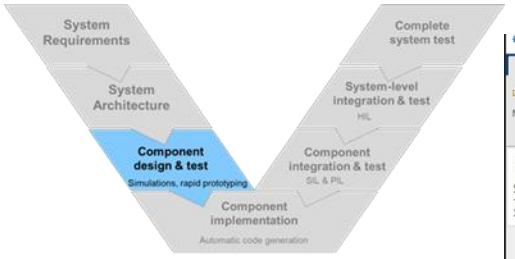
Use Deep Learning Toolbox block library to bring trained deep learning models into Simulink

MathWorks®

Simulation demo

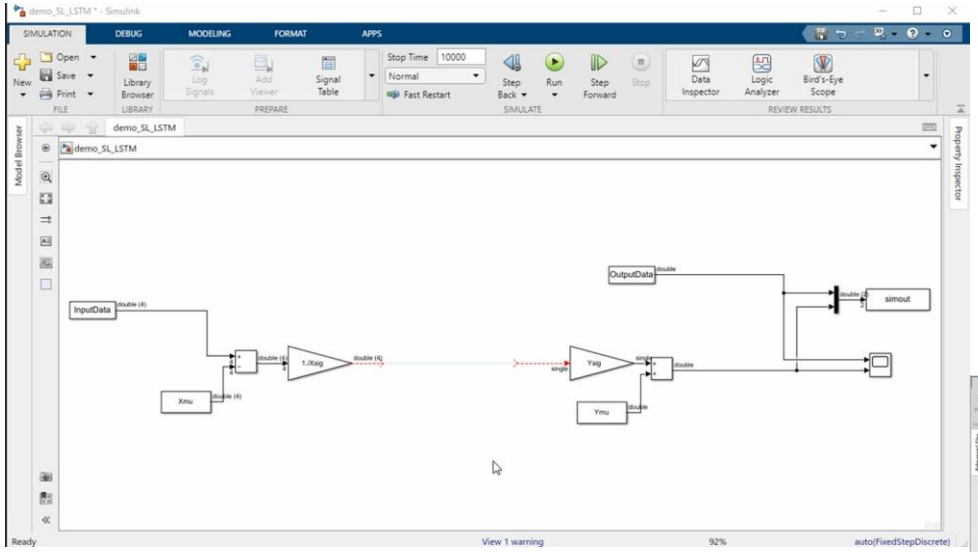
Open Part 2

Integration of trained
AI model into Simulink



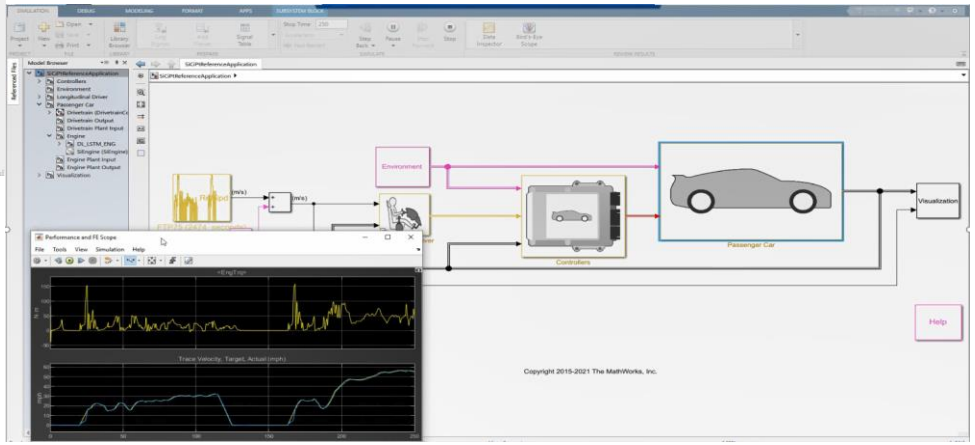
Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation



Open Part 3

System-level simulation



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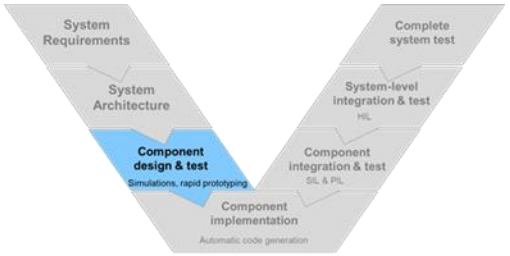
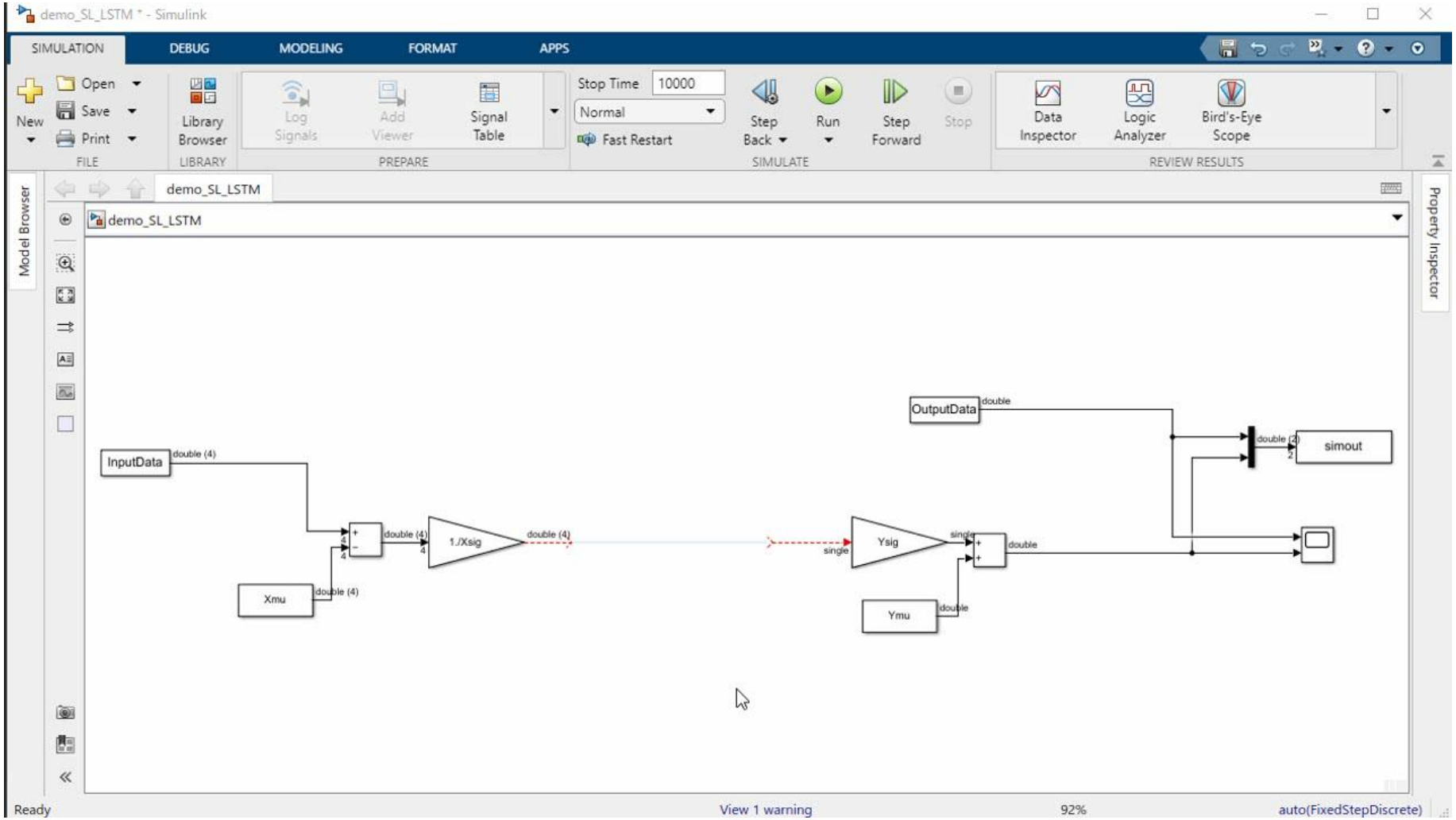
Simulation demo: Integration of trained AI model into Simulink



Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation



A GPU is not required here because the neural network is not very deep

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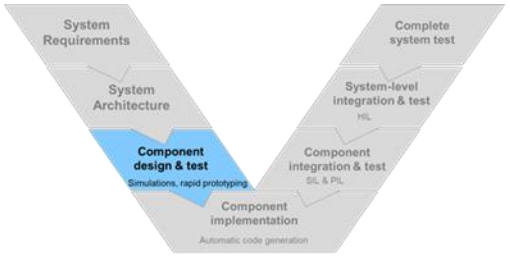
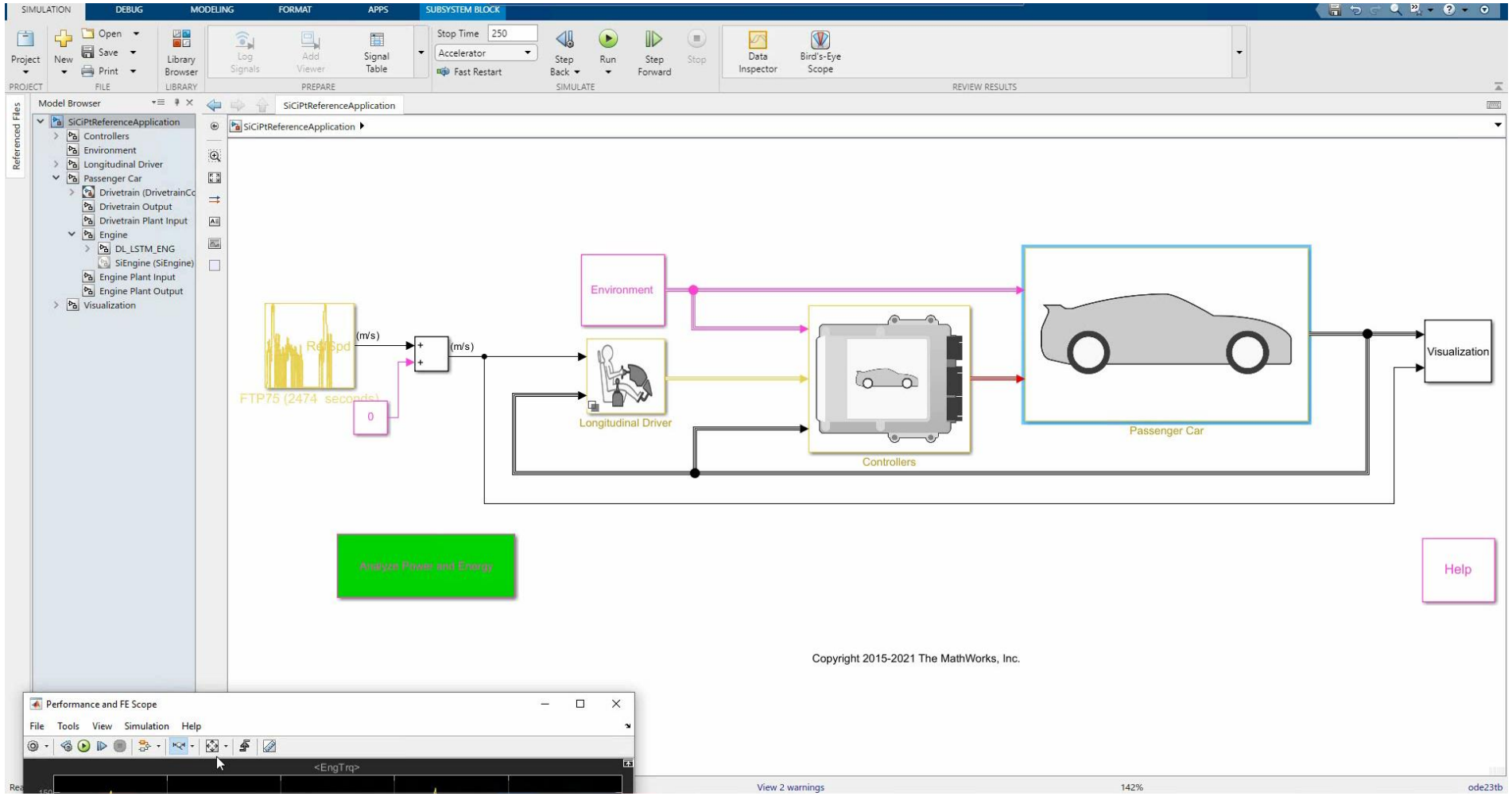
Simulation demo: System-level simulation



Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation



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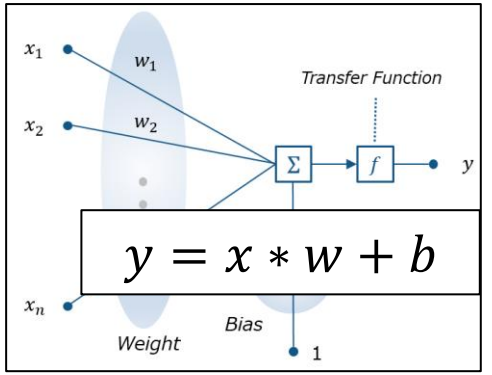
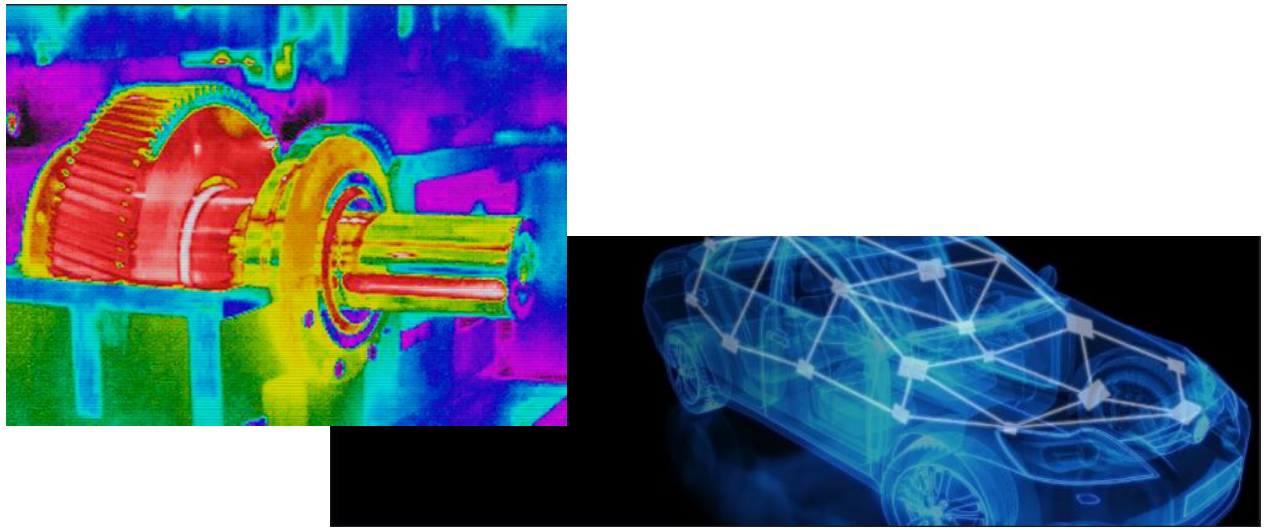
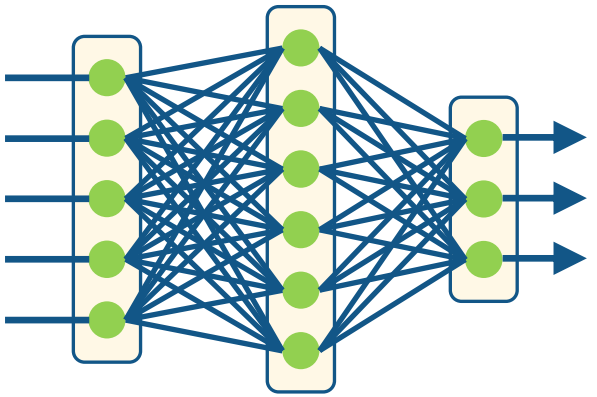
Speeding up with ROM (Reduced Order Model)



- Detailed simulation with 3D-CAE tool

(Large calculation load per step)





- Deep Learning model
  - ✓ Reduced order
  - ✓ Libraries for inference
  - ✓ Parallelization on GPU

Dimension compression and simulation speed-up
using deep learning models

AI-driven system design

Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability

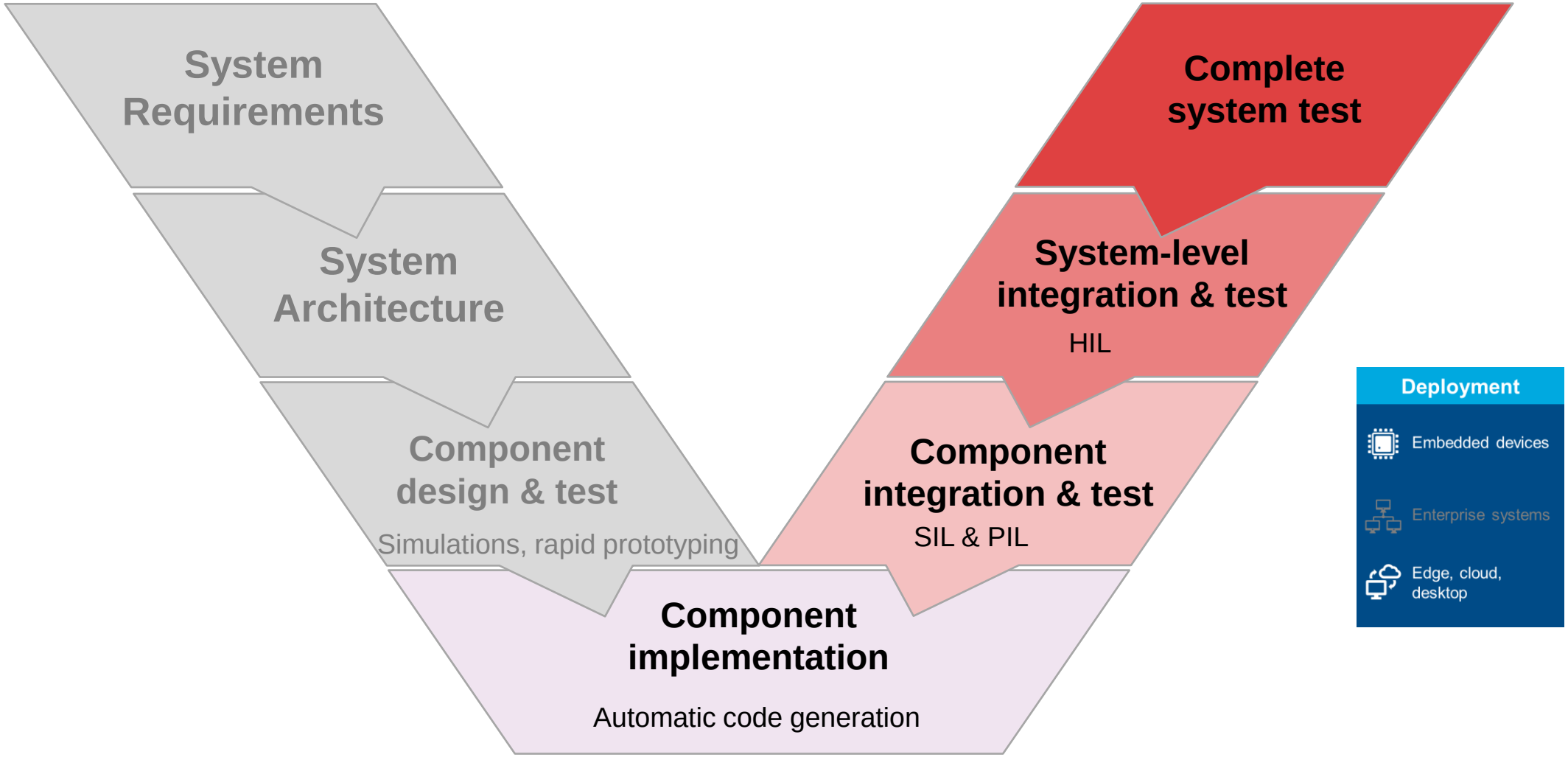
Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation

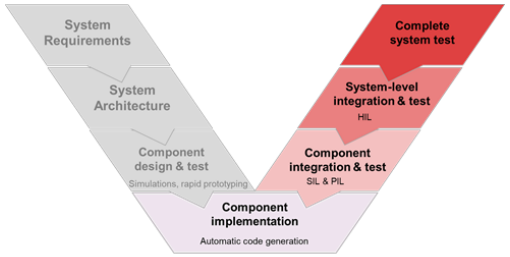
Deployment

- Embedded devices
- Enterprise systems
- Edge, cloud, desktop

AI system development with Model-Based Design

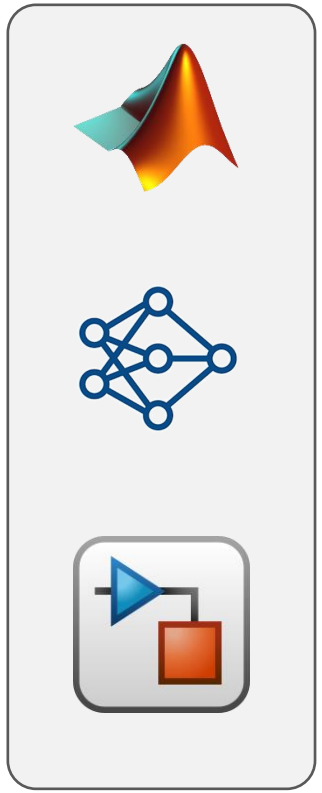


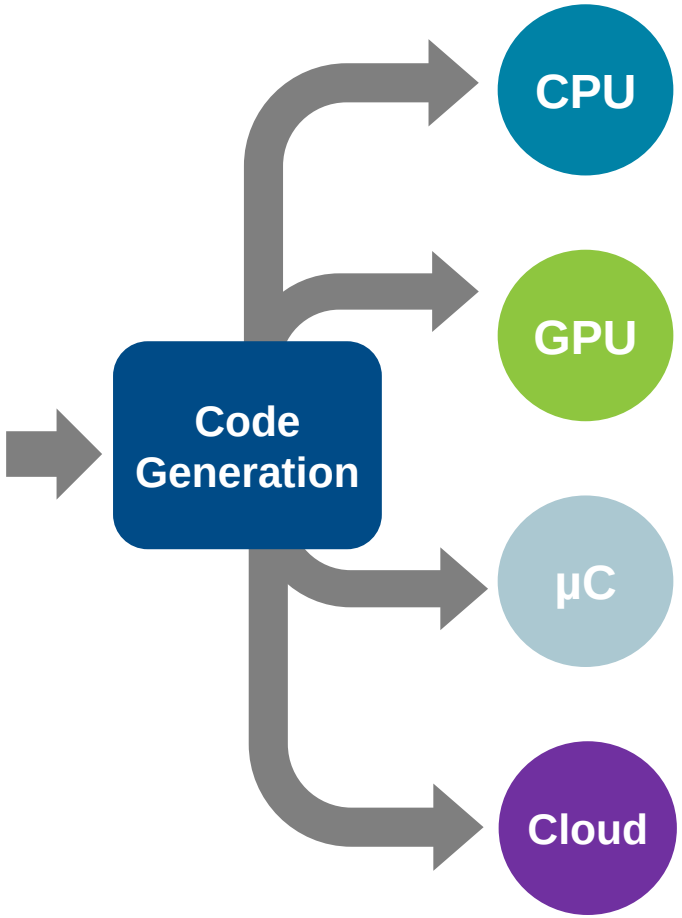
Deploy to target with zero coding errors



Deployment

- Embedded devices
- Enterprise systems
- Edge, cloud, desktop





Any CPU
No Library needed

oneDNN
Library

ARM Compute
Library

NVIDIA

NXP
STMicroelectronics
Texas Instruments

amazon web services
kafka
hadoop
Azure
CLOUDERA
DOMINO
docker
databricks

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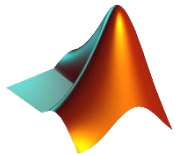
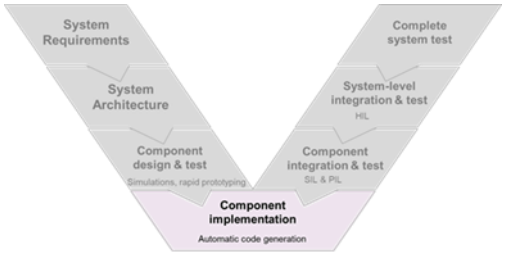
Deployment demo: Automatic C code generation

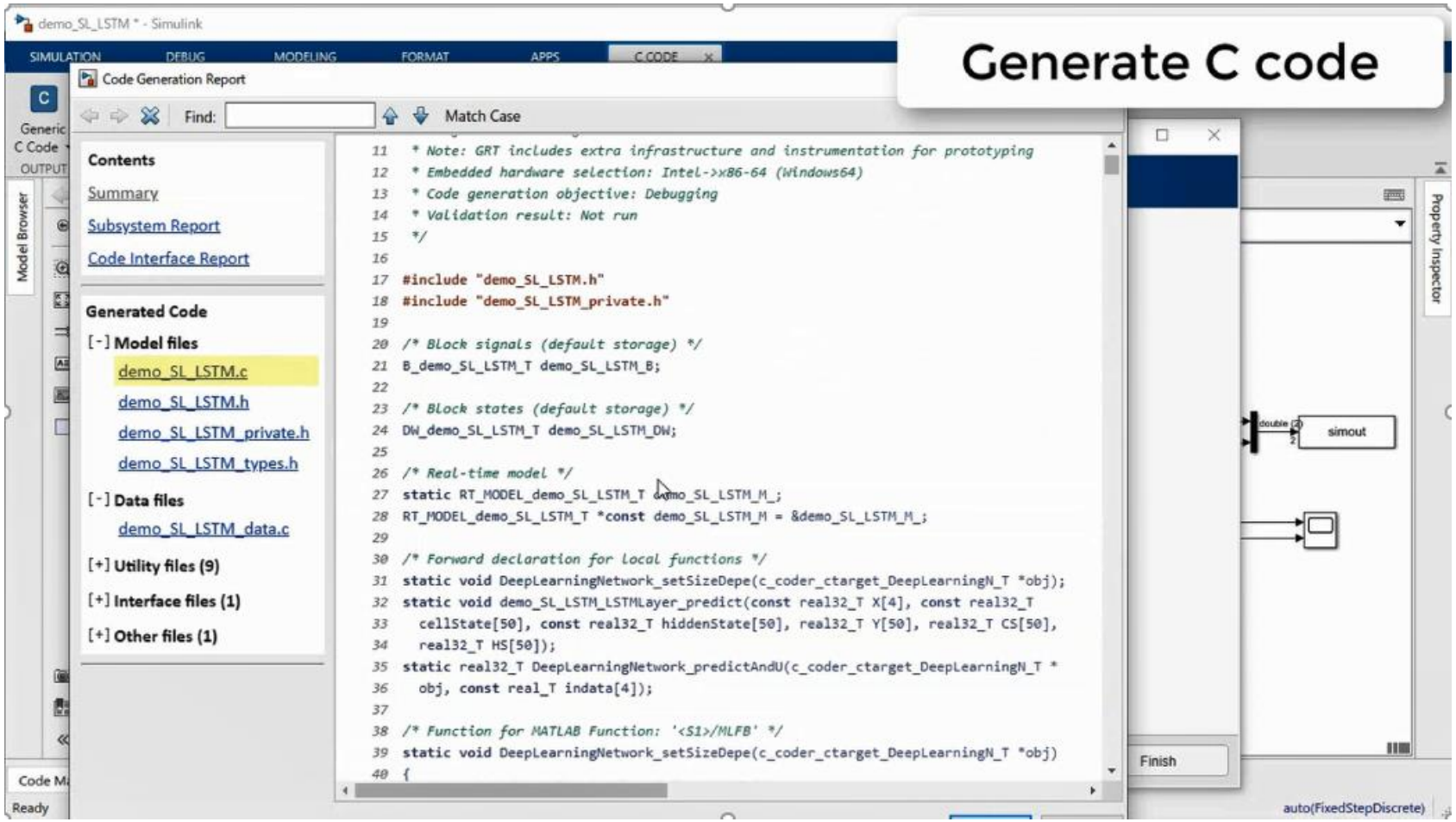


Open Part 4



Deployment

- Embedded devices
- Enterprise systems
- Edge, cloud, desktop




```
11  * Note: GRT includes extra infrastructure and instrumentation for prototyping
12  * Embedded hardware selection: Intel->x86-64 (Windows64)
13  * Code generation objective: Debugging
14  * Validation result: Not run
15  */
16
17 #include "demo_SL_LSTM.h"
18 #include "demo_SL_LSTM_private.h"
19
20 /* Block signals (default storage) */
21 B_demo_SL_LSTM_T demo_SL_LSTM_B;
22
23 /* Block states (default storage) */
24 DW_demo_SL_LSTM_T demo_SL_LSTM_DW;
25
26 /* Real-time model */
27 static RT_MODEL_demo_SL_LSTM_T demo_SL_LSTM_M_;
28 RT_MODEL_demo_SL_LSTM_T *const demo_SL_LSTM_M = &demo_SL_LSTM_M_;
29
30 /* Forward declaration for local functions */
31 static void DeepLearningNetwork_setSizeDepe(c_coder_ctarget_DeepLearningN_T *obj);
32 static void demo_SL_LSTM_LSTMLayer_predict(const real32_T X[4], const real32_T
33   cellState[50], const real32_T hiddenState[50], real32_T Y[50], real32_T CS[50],
34   real32_T HS[50]);
35 static real32_T DeepLearningNetwork_predictAndU(c_coder_ctarget_DeepLearningN_T *
36   obj, const real_T indata[4]);
37
38 /* Function for MATLAB Function: '<S1>/MLFB' */
39 static void DeepLearningNetwork_setSizeDepe(c_coder_ctarget_DeepLearningN_T *obj)
40 {
```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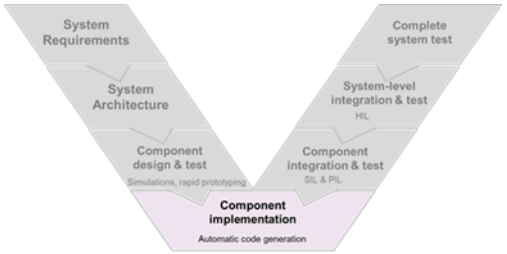
Deployment demo: Automatic C code generation



Deployment

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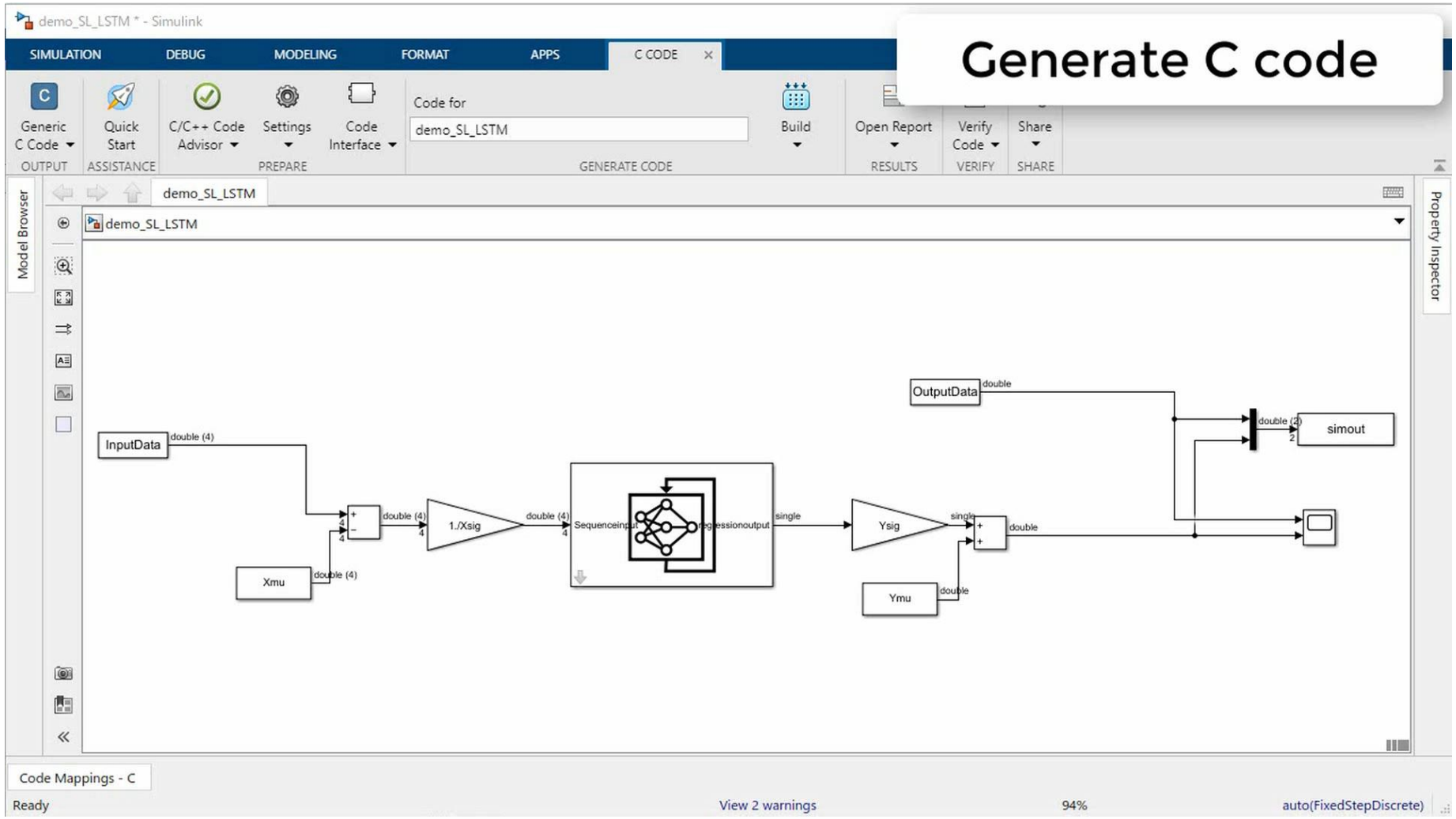

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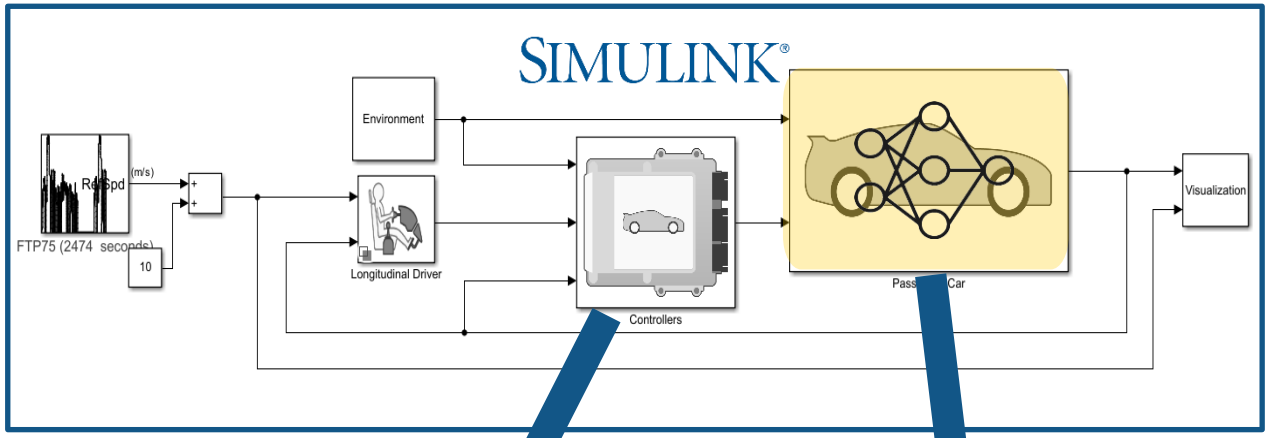
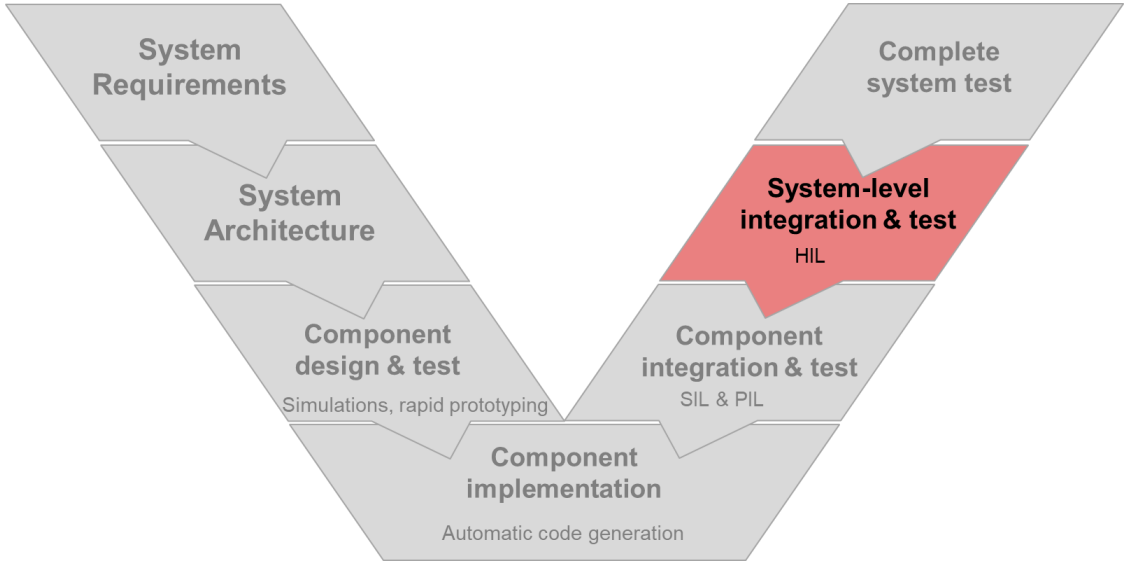
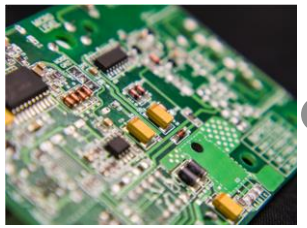
Deployment demo: Hardware-in-the-loop simulation





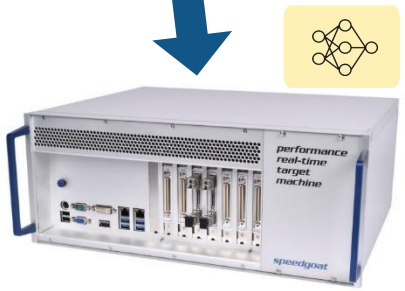
Code generation from algorithm

Code generation from plant model



Target platform

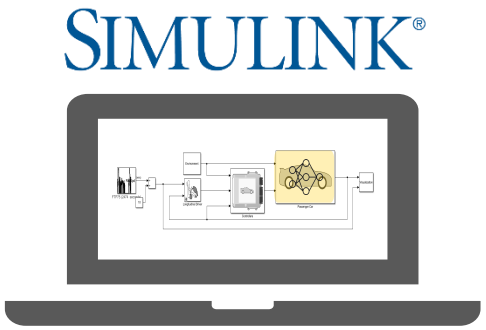
I/O



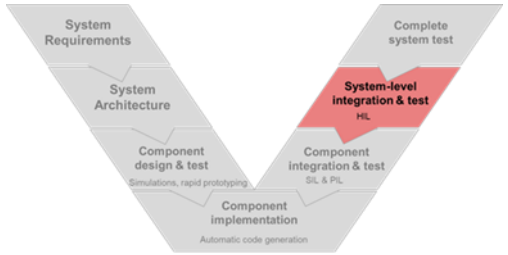
Real-time computer

Build & download models
Adjust parameters

Monitor signals



Deployment demo: Hardware-in-the-loop simulation



Deployment

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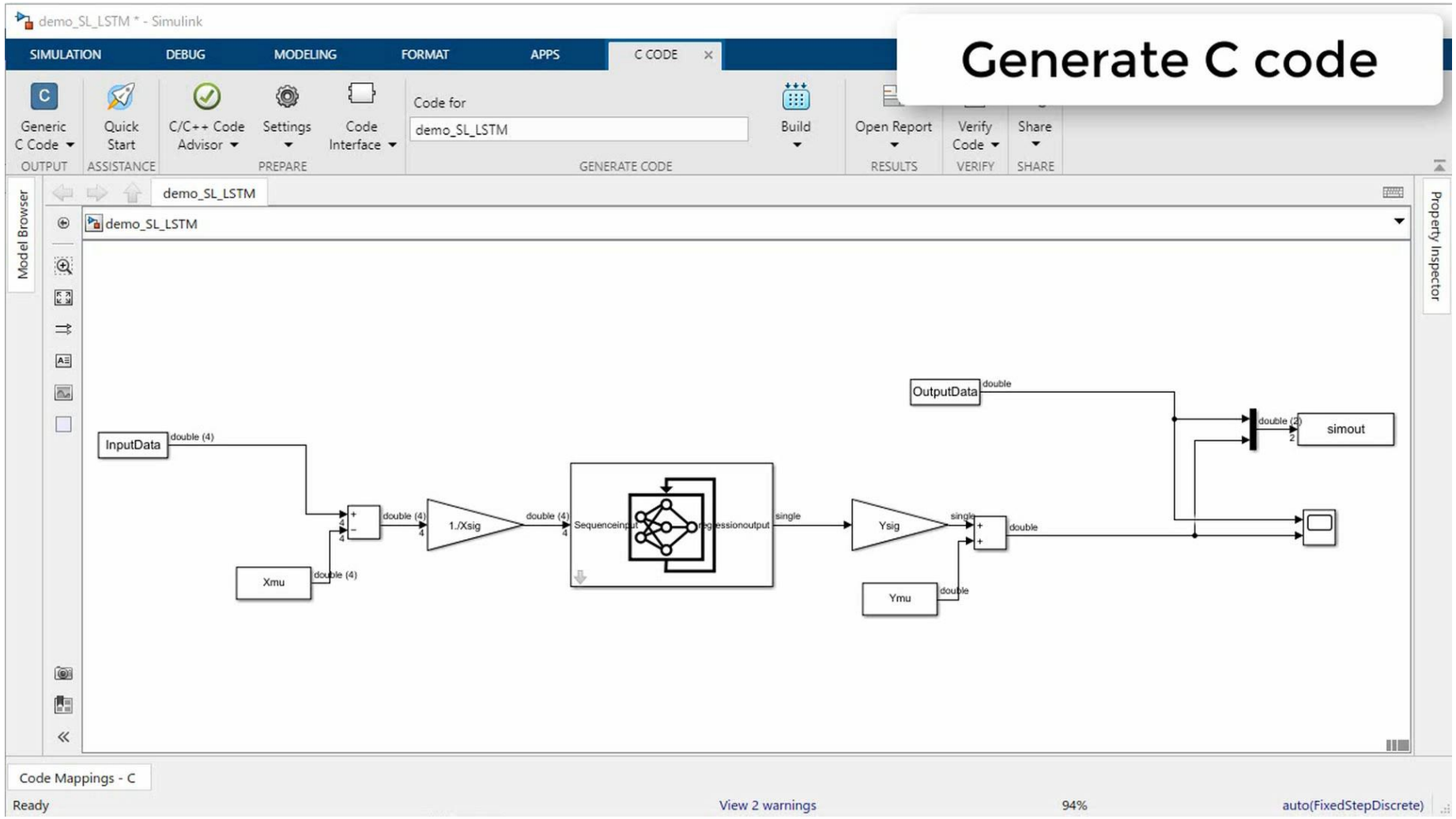

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Conclusion

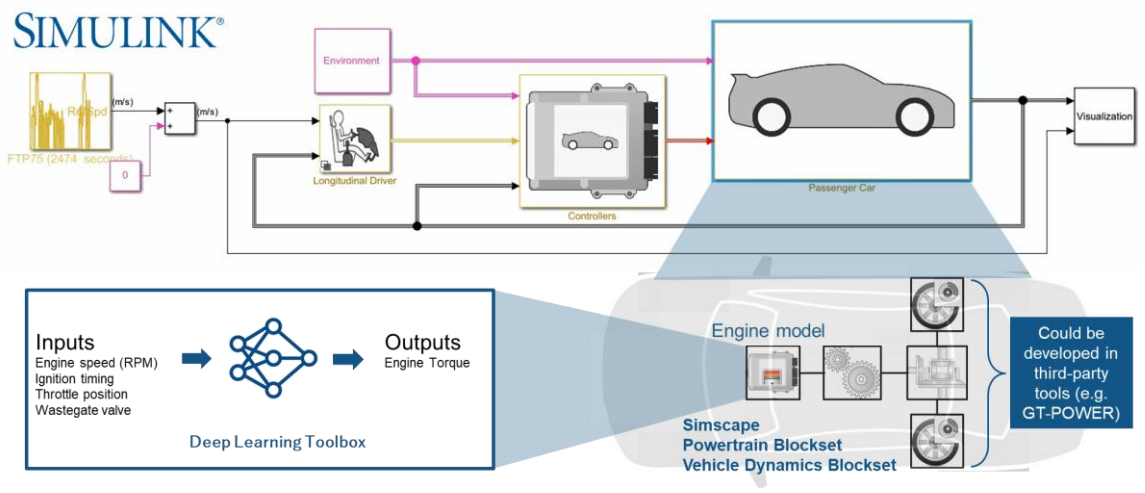
Replacing a first-principles engine model with an AI-based surrogate

First principles models and data-driven models can co-exist

First-principles models — **Data-driven models**

White-box — **Gray-box** — **Black-box**

- Preprocessed synthetic data generated from Simulink
- Trained a deep learning-based LSTM model to replace part of the complex dynamics of a vehicle engine
- Integrated trained network into Simulink for system-level simulation together with first-principles components
- Generated C code and performed HIL tests



MathWorks: helping engineers & scientists build Deep Learning solutions

The Platform

MATLAB, Simulink, and over 100 add-on products for specialized applications

Your People

Helping you build an agile workforce today and preparing tomorrow's engineers

Our Expertise

From onboarding and implementation to solving advanced engineering challenges

감사합니다

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Application Engineer @ MathWorks
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