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Building Confidence through Design in AI-driven Engineered Systems

Avinash Nehemiah, MathWorks

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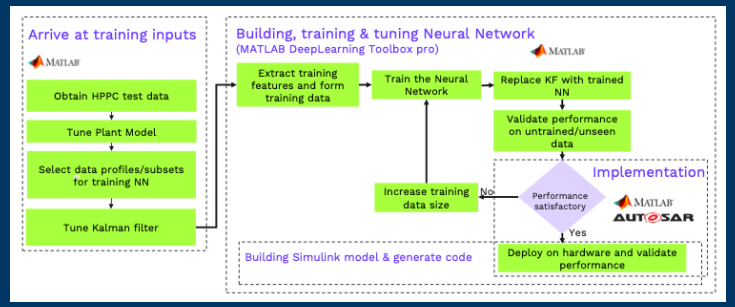
Applications of **AI in automotive** industry

Top **questions and concerns**

5 techniques to **build confidence** through design

The use of AI for engineered systems in Automotive continues to grow



(KPIT) Virtual Sensor

Battery SOC and SOH Estimation using a Hybrid Machine Learning Approach

(Subaru) ROM

AI ROM to decrease time for Transmission Control system analysis

(APTIV) Data Generation

Converting test data to simulation using AI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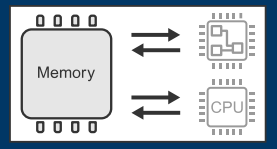
Questions and concerns we need to answer to build confidence

1. Are we using the best available **AI model** ?
2. How can we test impact of adding AI-based component to my **system design** ?
3. Do I have enough **compute and memory** to use an accurate AI model ?
4. Is it possible to **verify and validate** the AI model ?
5. Can I use my **target hardware** during development?

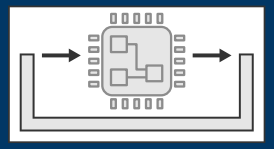
AI Modeling

System-level Simulation



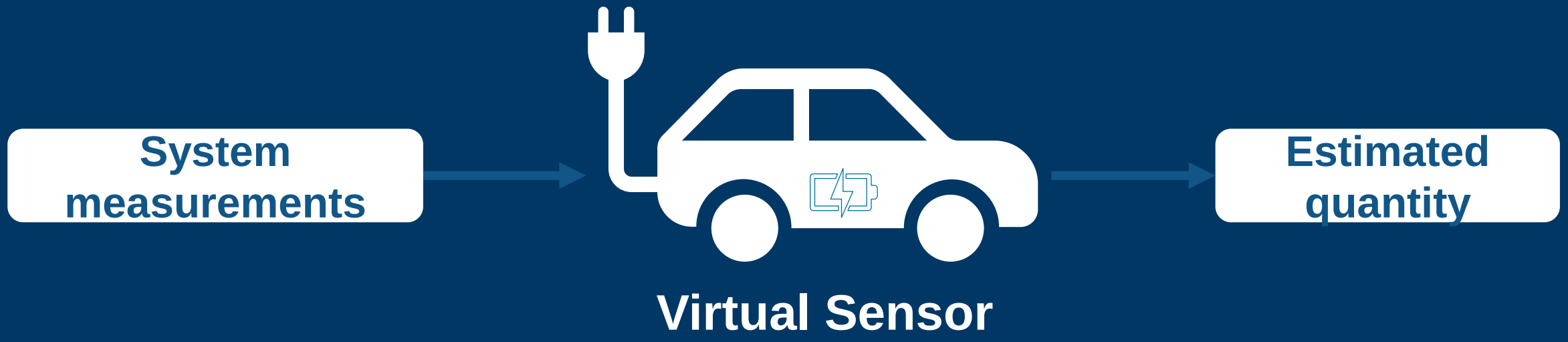
Memory and Execution Time

Verification and Validation



Testing on Hardware

Today we'll focus on Virtual Sensor modeling use case



A Virtual Sensor mimics a physical sensor using data from other measurements to estimate the quantity of interest

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Why are virtual sensors relevant ?

A **physical sensor** may be:

- Expensive
- Slow
- Noisy
- Unreliable
- Not feasible
- Unmanufacturable
- Degrading over time
- Requiring redundancy
- etc.

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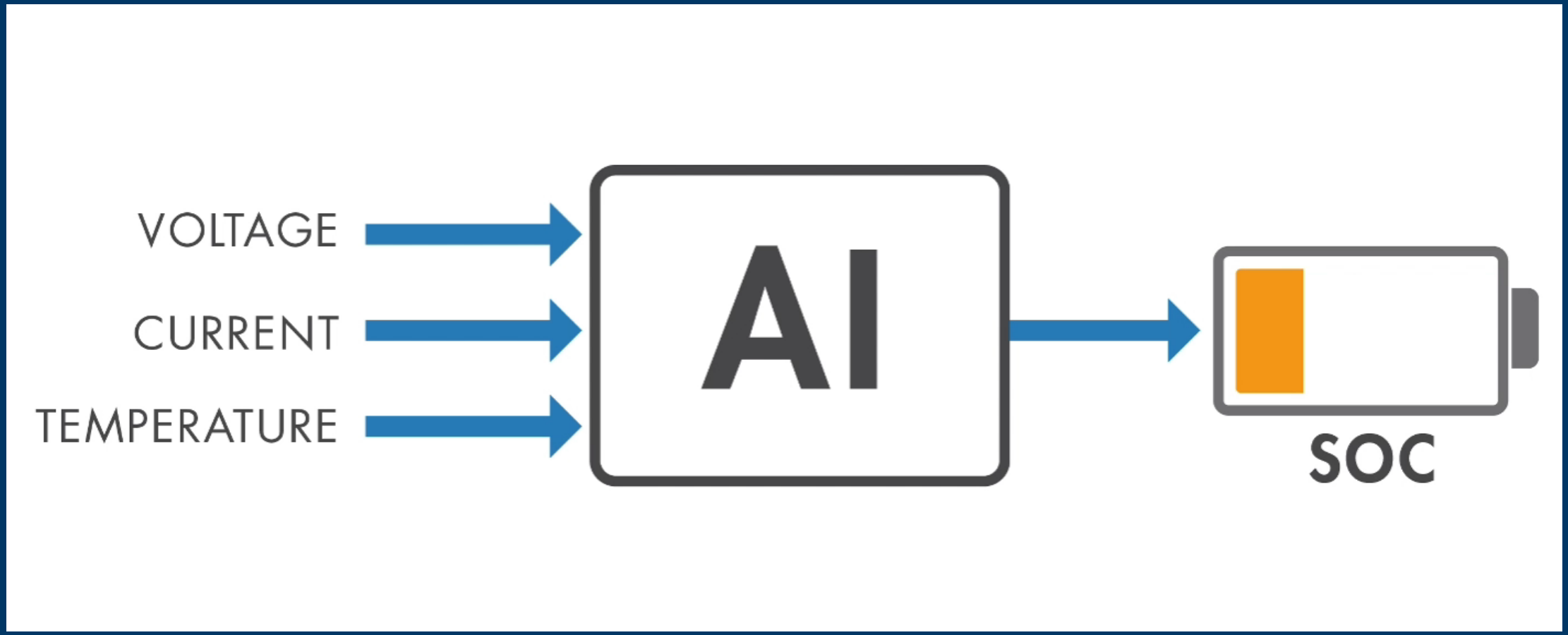
AI Virtual Sensor for Battery State-of-Charge Estimation



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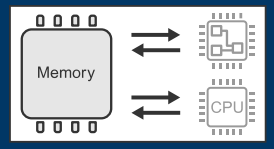
Questions and concerns we need to answer to build confidence

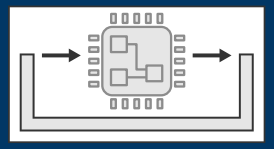
AI Modeling

System-level Simulation



Memory and Execution Time

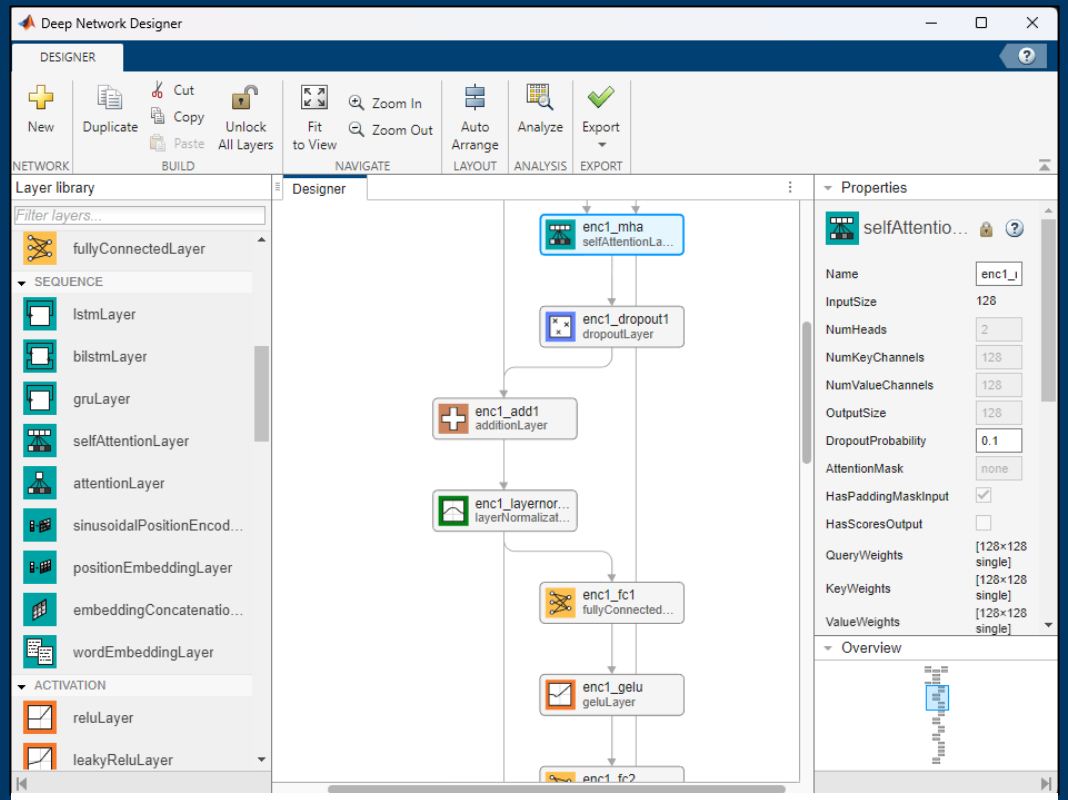
Verification and Validation



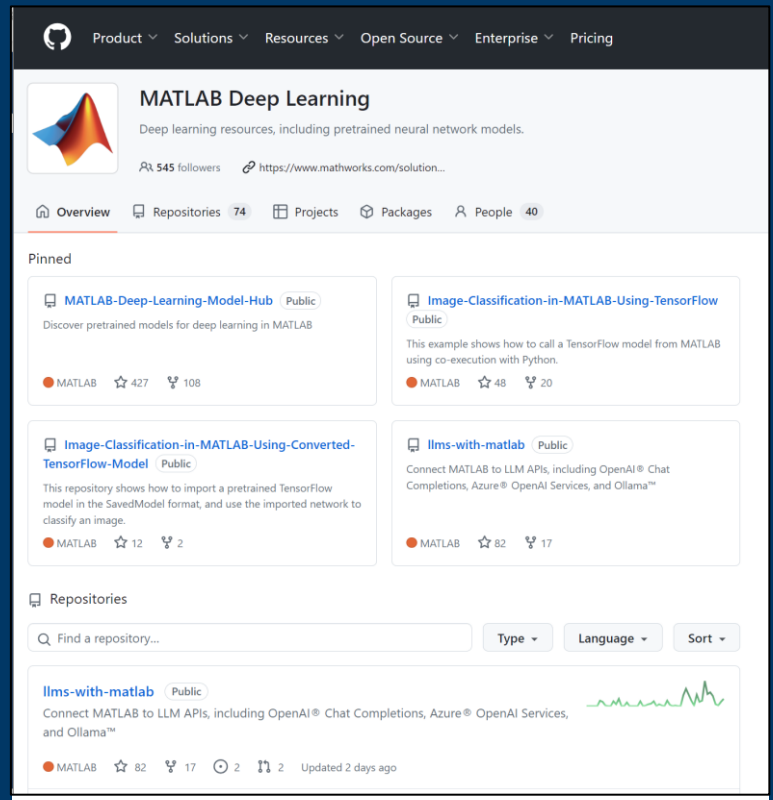
Testing on Hardware

5 keys to building confidence

Two ways of leveraging AI in MATLAB and Simulink

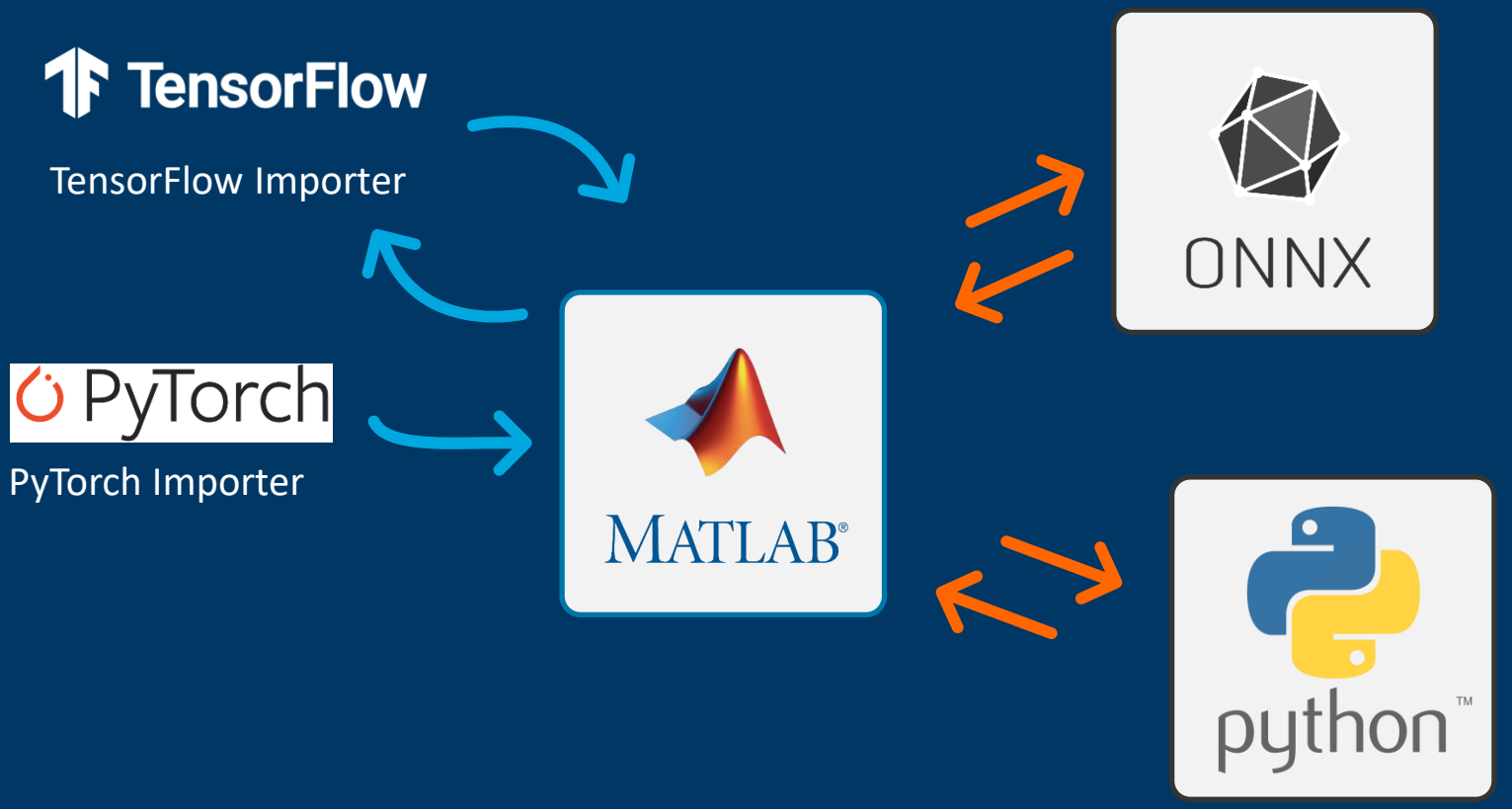


Build your own models

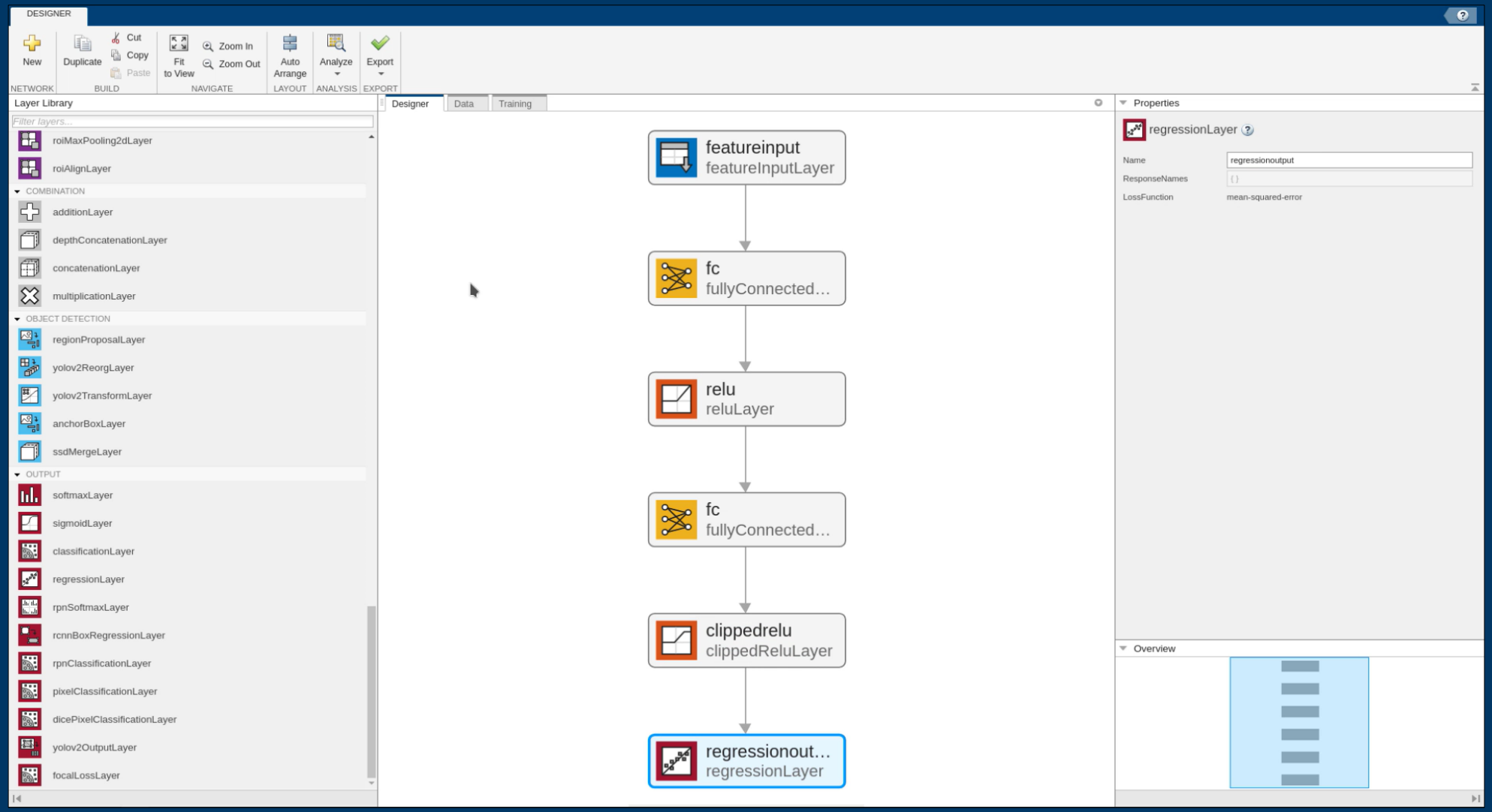


Leverage models from research

Build, run, or fine-tune models locally



Create a white-box model from scratch in MATLAB



Low Code AI Model Development

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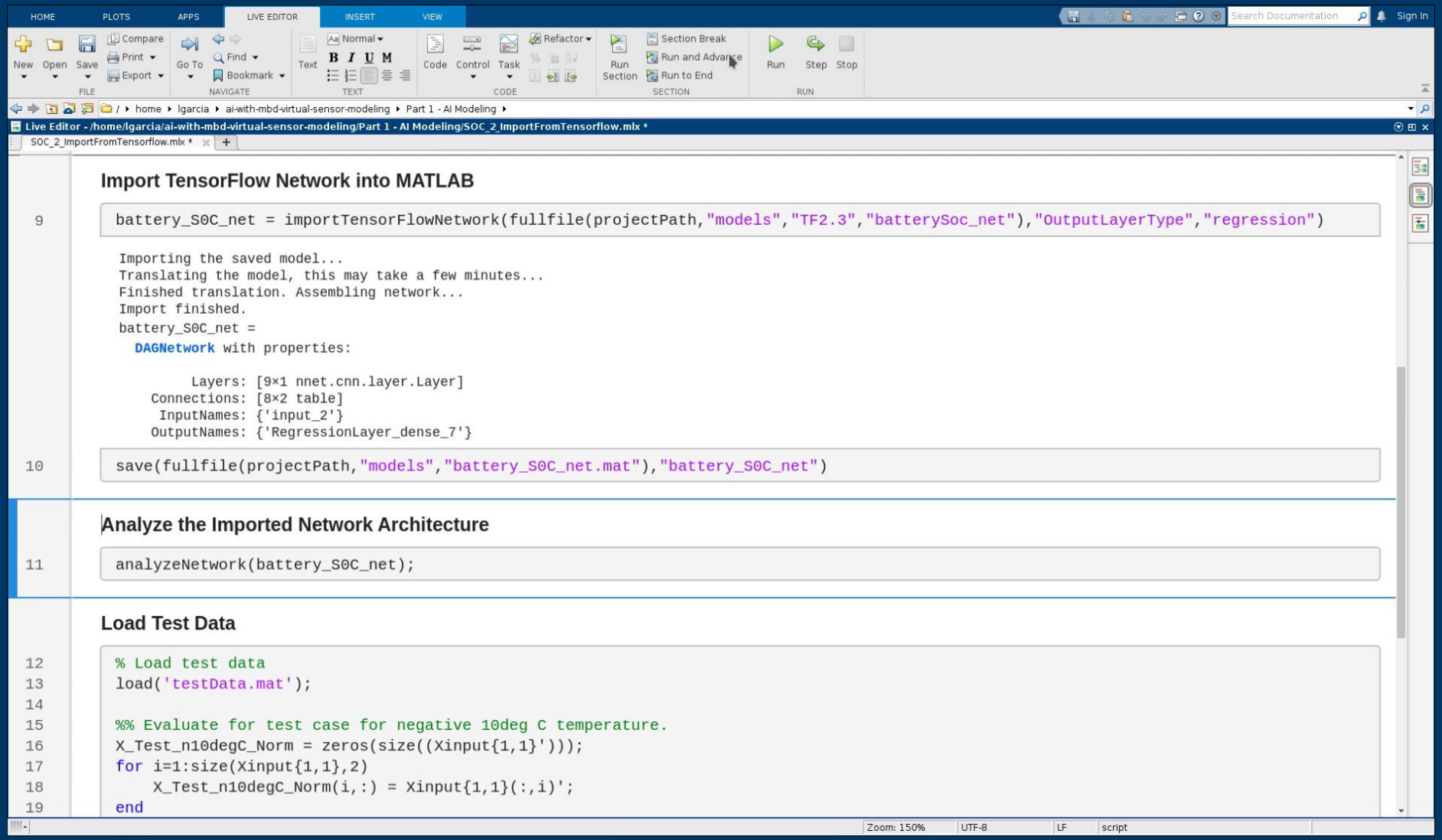
Programmatically create model in MATLAB



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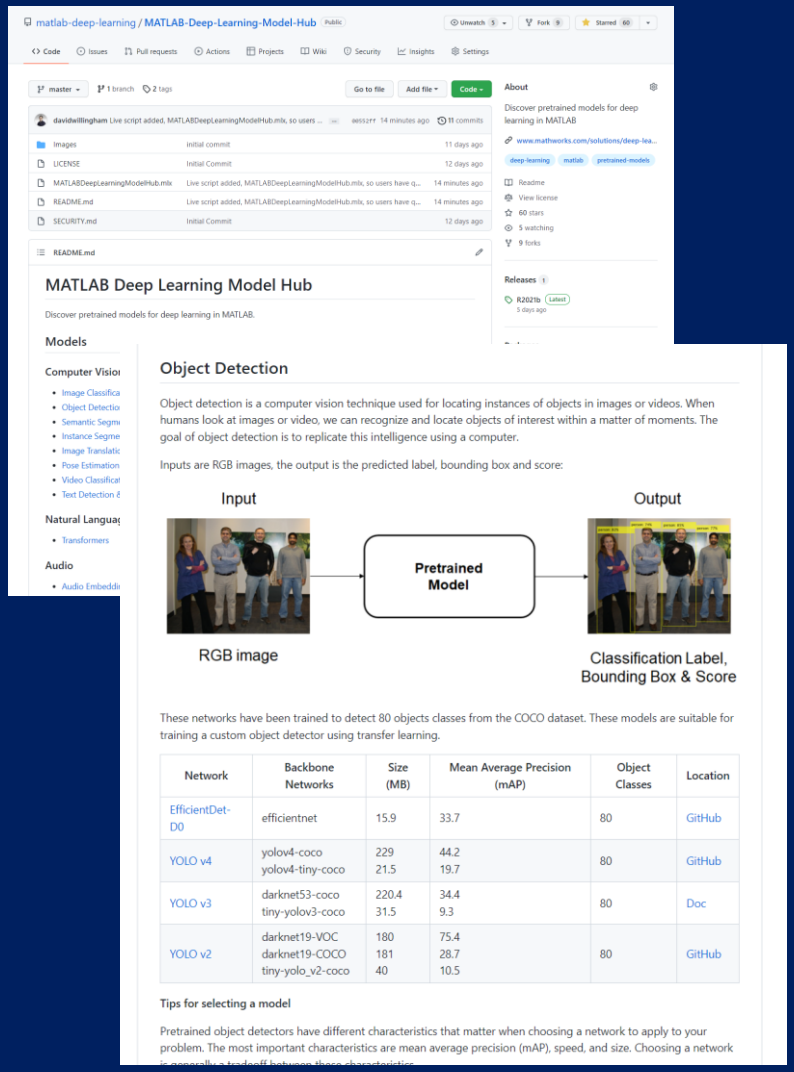
Discover the latest pretrained models – on GitHub

MATLAB Deep Learning Model Hub

- Quick reference to over 60* pretrained models in:
  - Computer Vision
  - Natural Language Processing
  - Audio
  - Lidar
  - * New models added every month



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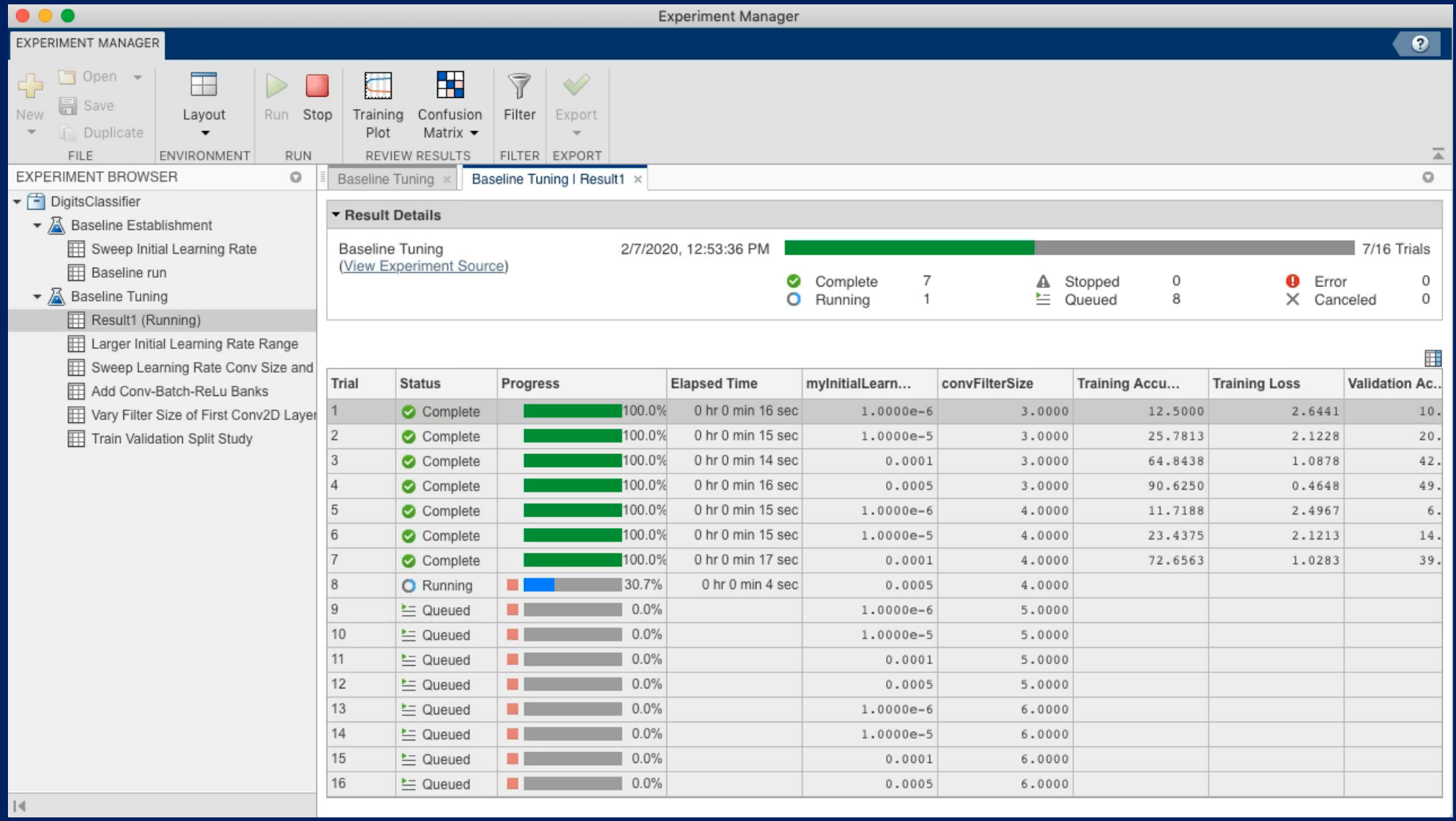
Run experiments to find the best AI model



Trial	Status	Progress	Elapsed Time	myInitialLearn...	convFilterSize	Training Accu...	Training Loss	Validation Ac..
1	Complete	100.0%	0 hr 0 min 16 sec	1.0000e-6	3.0000	12.5000	2.6441	10.
2	Complete	100.0%	0 hr 0 min 15 sec	1.0000e-5	3.0000	25.7813	2.1228	20.
3	Complete	100.0%	0 hr 0 min 14 sec	0.0001	3.0000	64.8438	1.0878	42.
4	Complete	100.0%	0 hr 0 min 16 sec	0.0005	3.0000	90.6250	0.4648	49.
5	Complete	100.0%	0 hr 0 min 15 sec	1.0000e-6	4.0000	11.7188	2.4967	6.
6	Complete	100.0%	0 hr 0 min 15 sec	1.0000e-5	4.0000	23.4375	2.1213	14.
7	Complete	100.0%	0 hr 0 min 17 sec	0.0001	4.0000	72.6563	1.0283	39.
8	Running	30.7%	0 hr 0 min 4 sec	0.0005	4.0000			
9	Queued	0.0%		1.0000e-6	5.0000			
10	Queued	0.0%		1.0000e-5	5.0000			
11	Queued	0.0%		0.0001	5.0000			
12	Queued	0.0%		0.0005	5.0000			
13	Queued	0.0%		1.0000e-6	6.0000			
14	Queued	0.0%		1.0000e-5	6.0000			
15	Queued	0.0%		0.0001	6.0000			
16	Queued	0.0%		0.0005	6.0000			

Spectrum of ways to leverage AI models

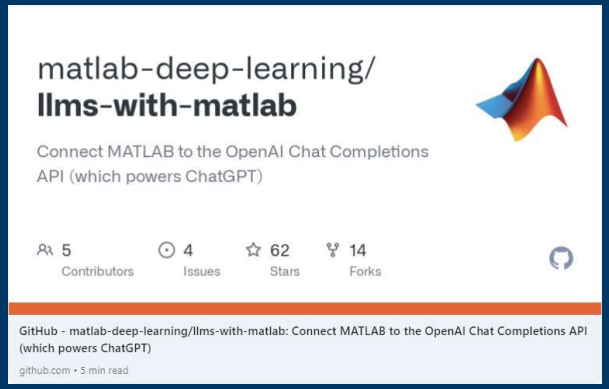
Build, run, or fine-tune models locally

Connect to top performing models in the cloud

Connect to top performing models in the cloud

Rank* (UB)	Model	Arena Score	95% CI	Votes	Organization
1	Gemini-1.5-Pro-Exp-0801	1300	+6/-5	12672	Google
2	GPT-4o-2024-05-13	1286	+3/-2	69832	OpenAI
2	GPT-4o-mini-2024-07-18	1280	+6/-4	12047	OpenAI
4	Claude 3.5 Sonnet	1271	+3/-4	40174	Anthropic
4	Gemini-Advanced-0514	1266	+3/-4	50686	Google
4	Meta-Llama-3.1-405b-Instruct	1262	+6/-7	8454	Meta

Leaderboard: https://huggingface.co/spaces/lmsys/chatbot-arena-leaderboard



Text Generation Models

Create internal assistants that have knowledge about internal documentation

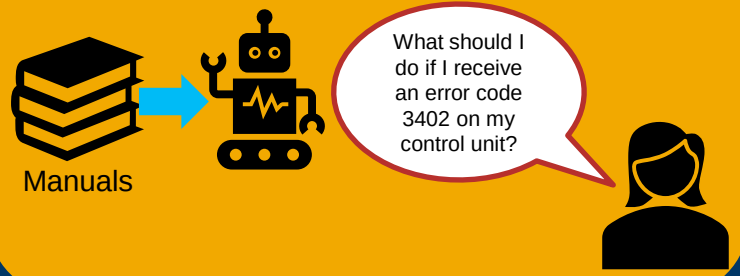


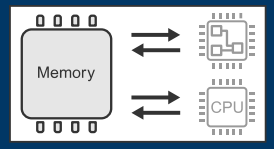
Image Generation Models

Generate images to test robustness of systems

Questions and concerns we need to answer to build confidence

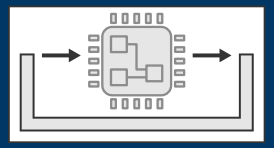
AI Modeling

System-level Simulation



Memory and Execution Time

Verification and Validation



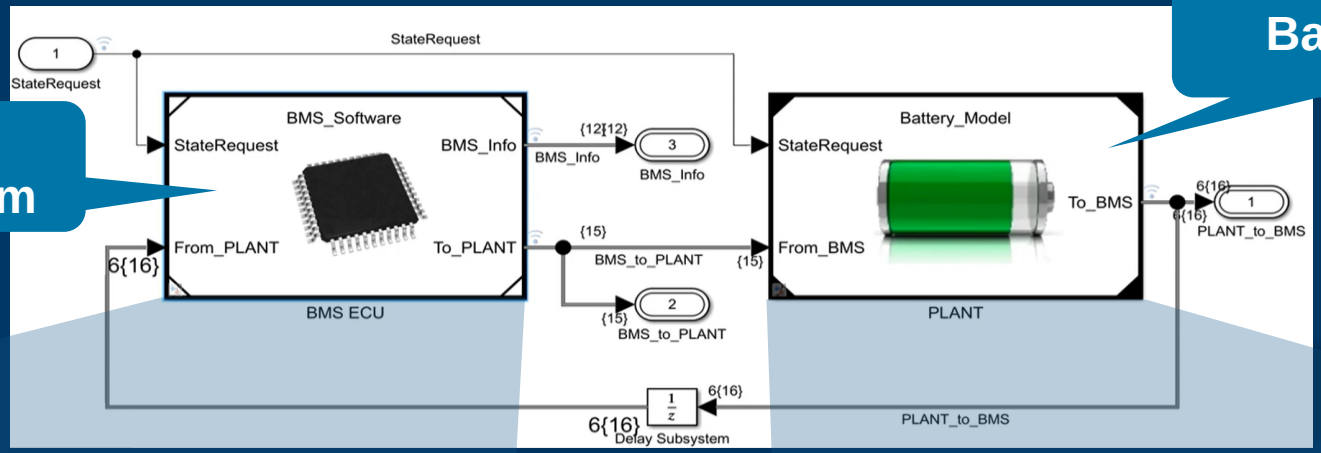
Testing on Hardware

5 keys to building confidence

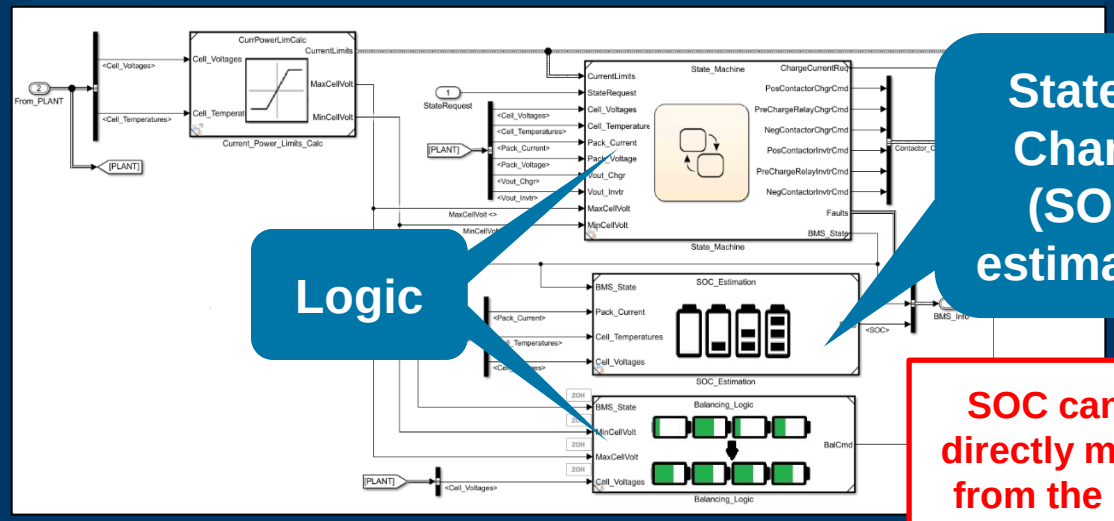
1. Access and explore state of art AI models

Use Simulink to create a system-level model that incorporates the AI virtual sensor

ECU Battery Management System



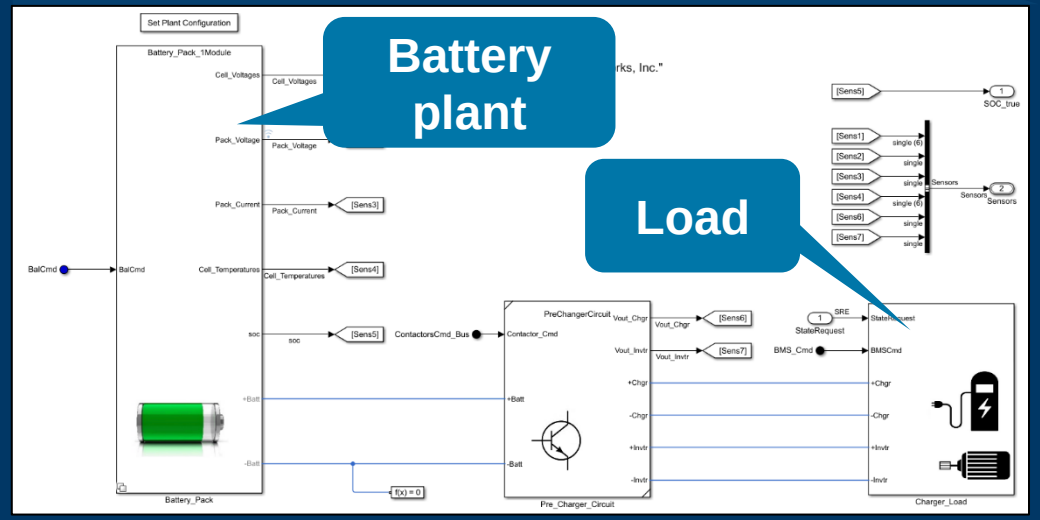
Battery



Logic

State of Charge (SOC) estimation

SOC cannot be directly measured from the battery!



Battery plant

Load

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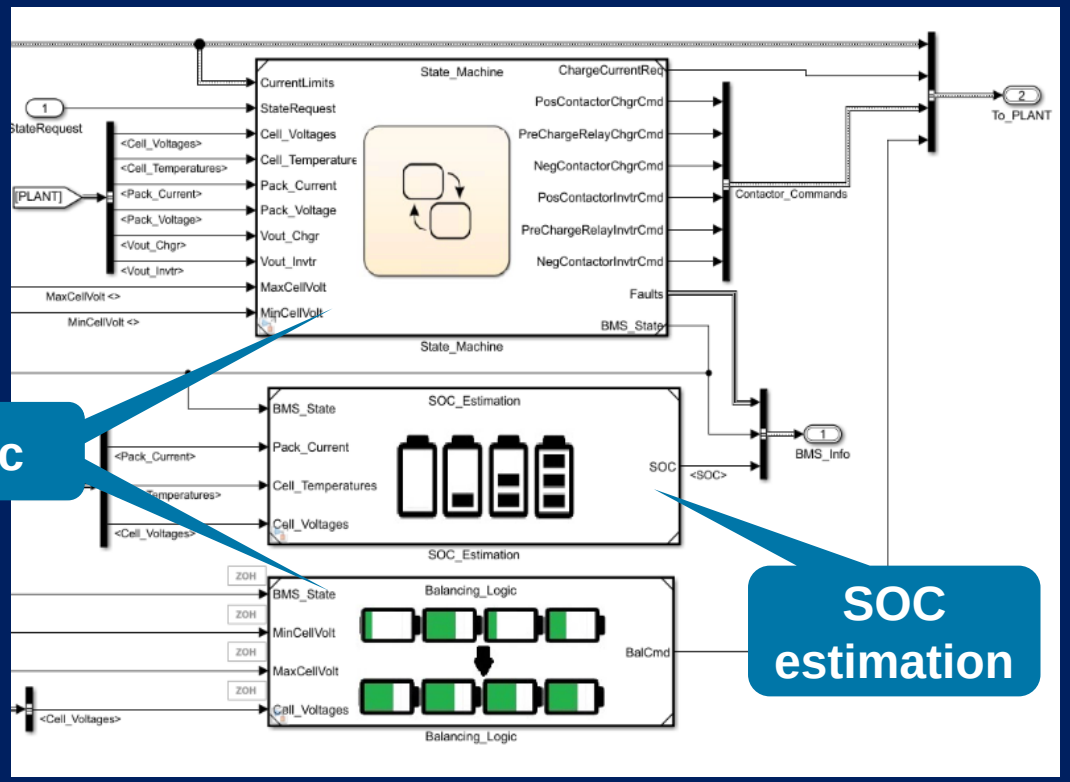
Virtual sensor for Battery State of Charge (SOC) estimation

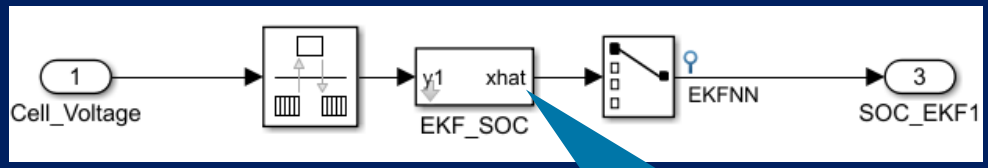


Logic

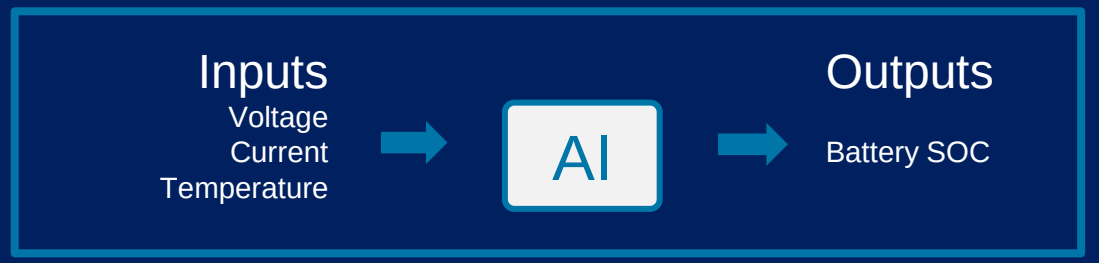
SOC estimation

Why AI over Kalman filtering?

- No need of an internal battery model
- Training directly on measured data
- Capture very complex data relationships



Extended Kalman filter



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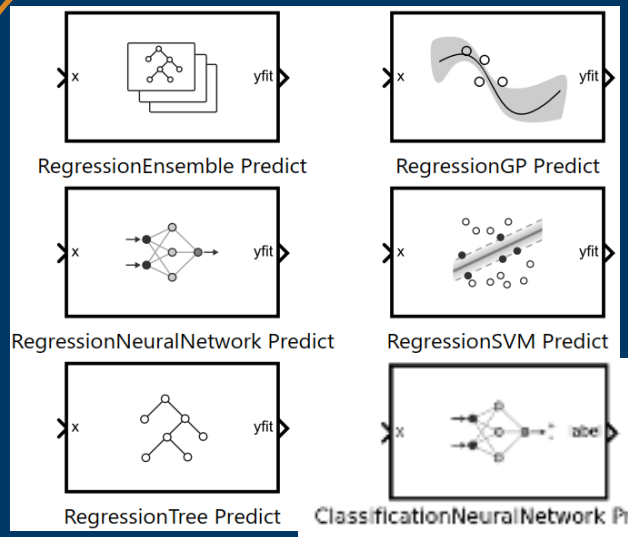
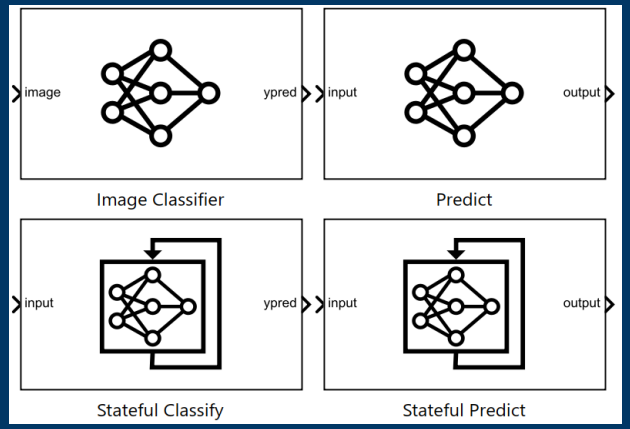
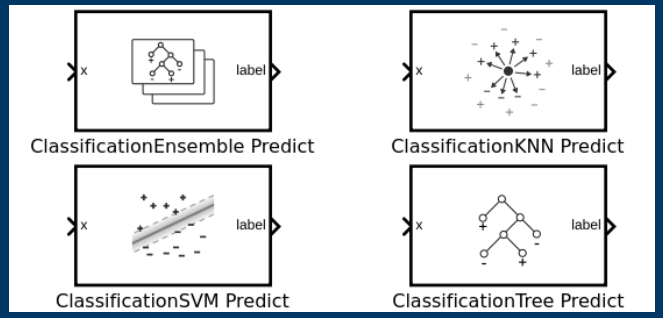
Simulink now includes more AI blocks for more applications

AI core

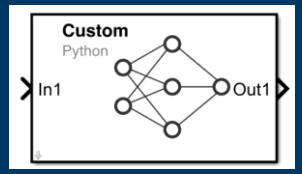


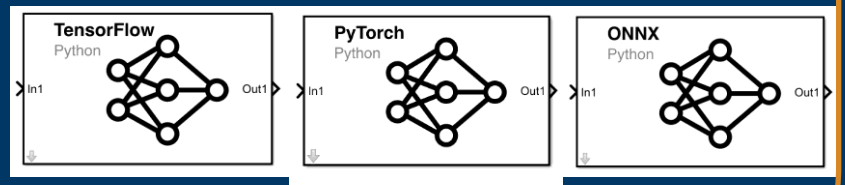


Neural network classify and predict blocks
And the list of layer blocks
(Deep Learning Toolbox)



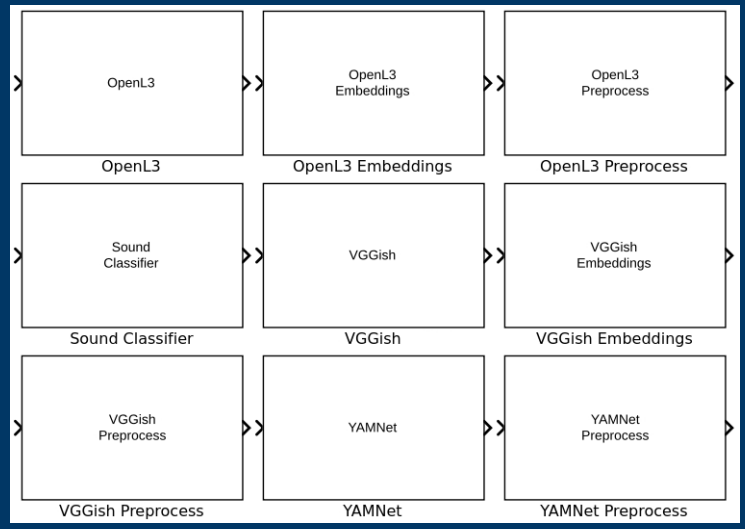
Regression and classification blocks
And more (incremental and cluster analysis blocks)
(Statistics and Machine Learning Toolbox)



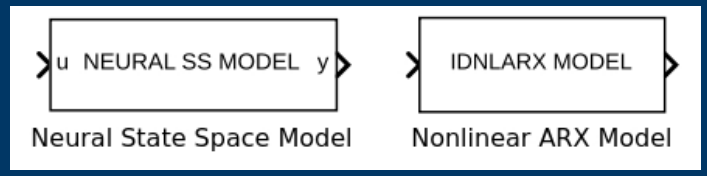


Co-execution blocks

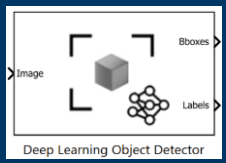
Specialized



Audio Toolbox



System Identification Toolbox



Computer Vision Toolbox

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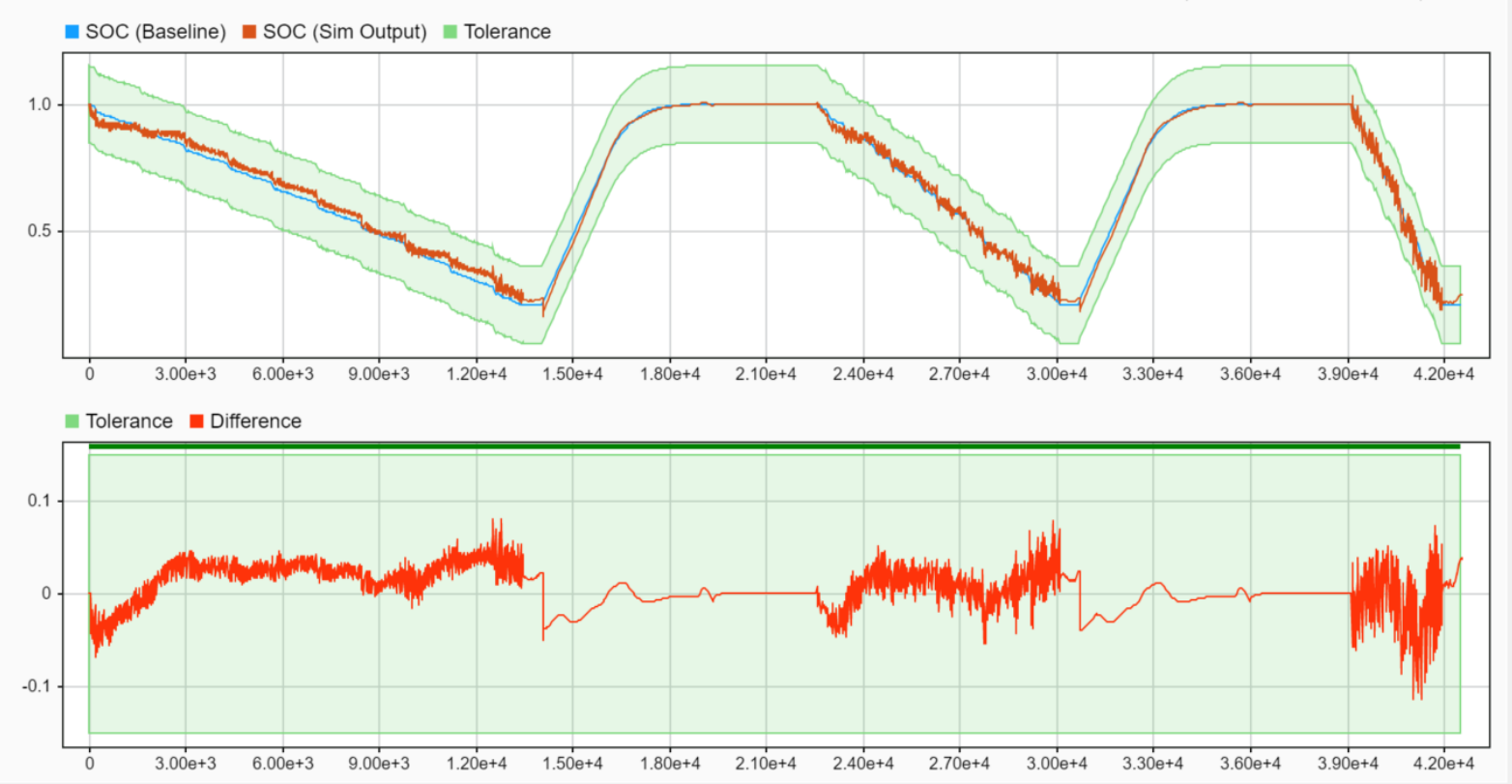
Perform baseline testing in simulation

Use Data-Driven Tests in Simulation to Assert **Accuracy**



Baseline Data

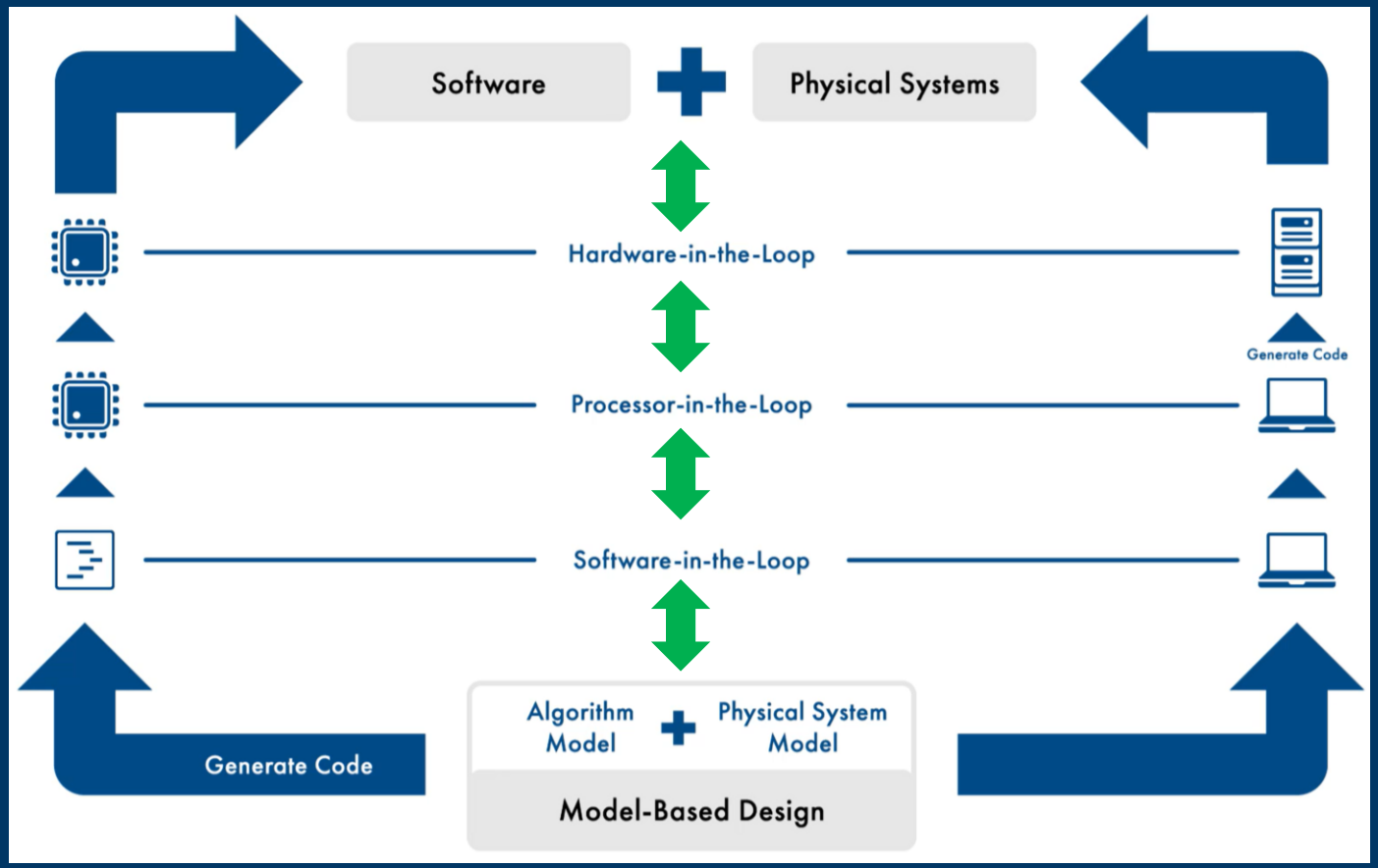
Ground truth
e.g., lab measurements

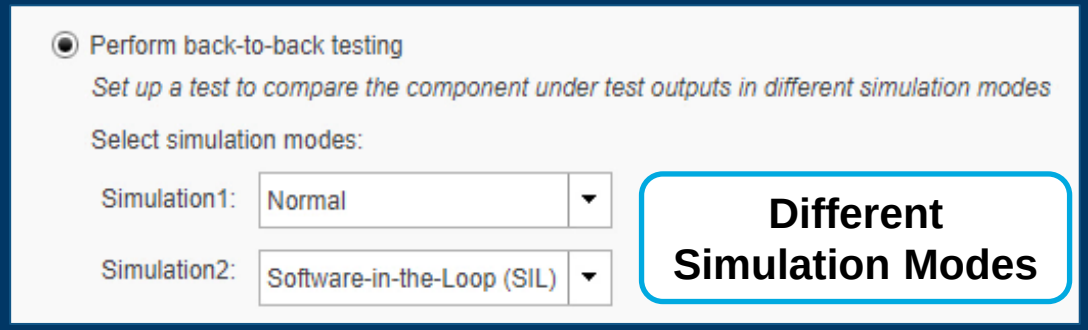
vs.

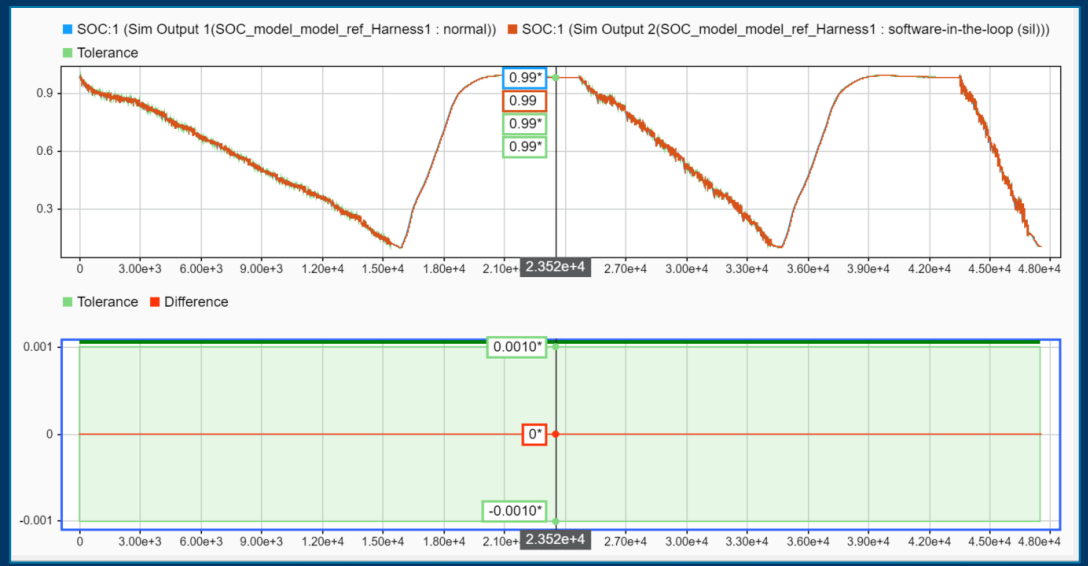
Simulation Output

Prediction results

Perform back-to-back testing on model behavior





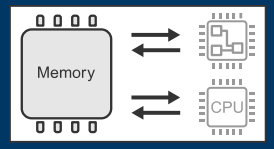


Test **equivalence of model behavior** from desktop simulations to SIL/PIL/HIL

Questions and concerns we need to answer to build confidence

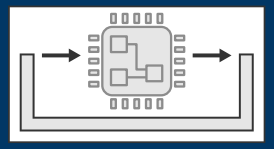
AI Modeling

System-level Simulation



Memory and Execution Time

Verification and Validation

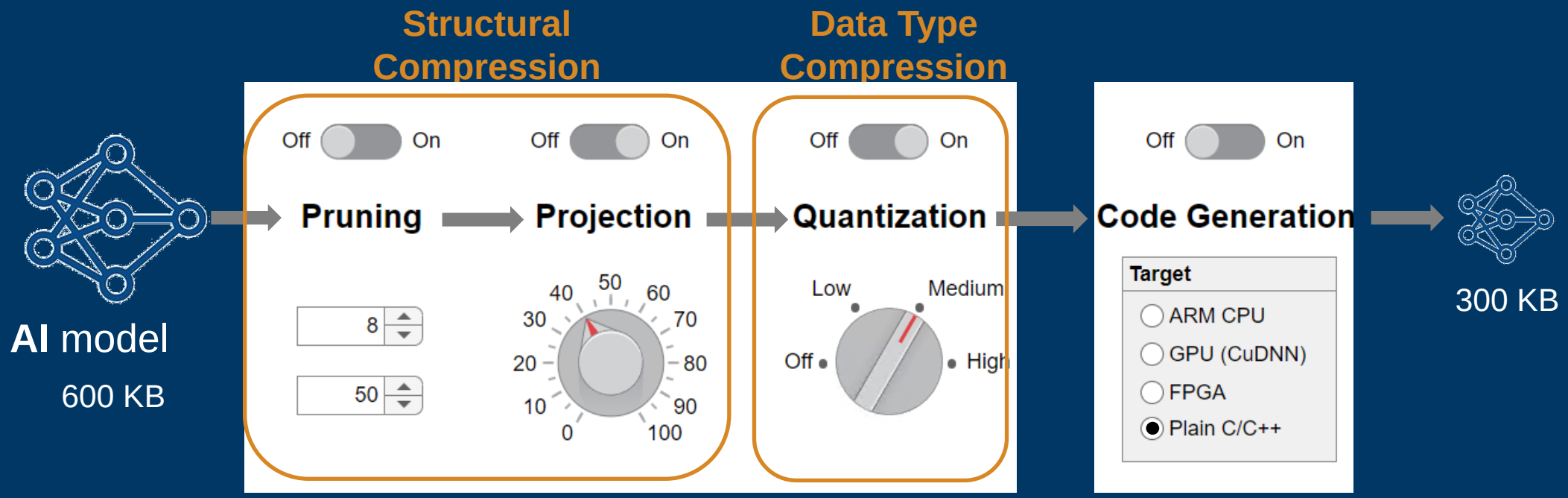


Testing on Hardware

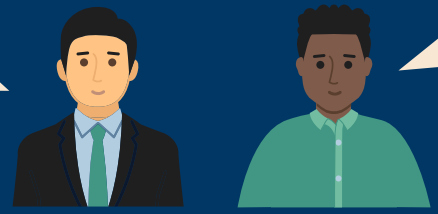
5 keys to building confidence

1. Access and explore state of art AI models
2. System-level testing to assess impact of adding AI component

Reduce model footprint and accelerate inference of DL models for deployment to the edge



*"my model is 40MB, I needed it to be **less than 10MB to fit**."*



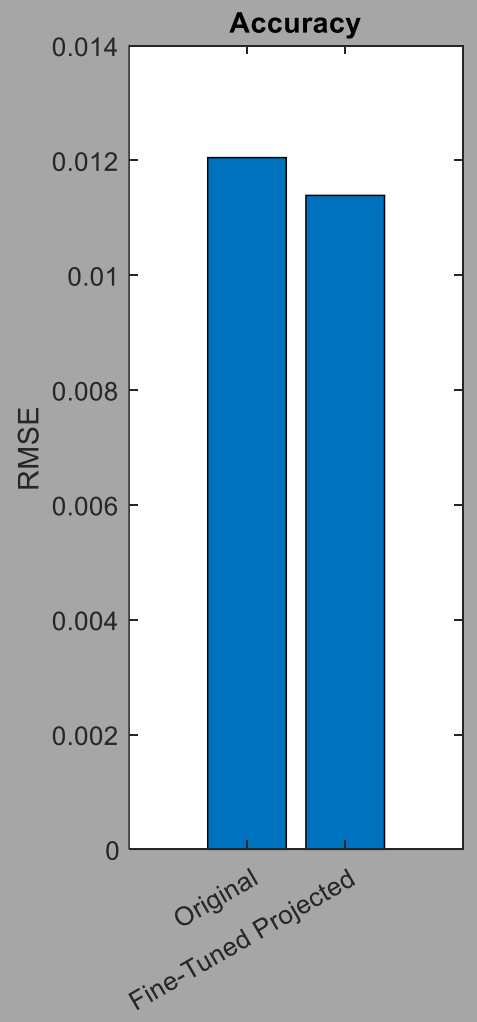
*"model is 600kb and want to **reduce it to 300kb**. If I'm not fitting it in, I don't have a working solution"*

Fine tune using projection-based model compression techniques

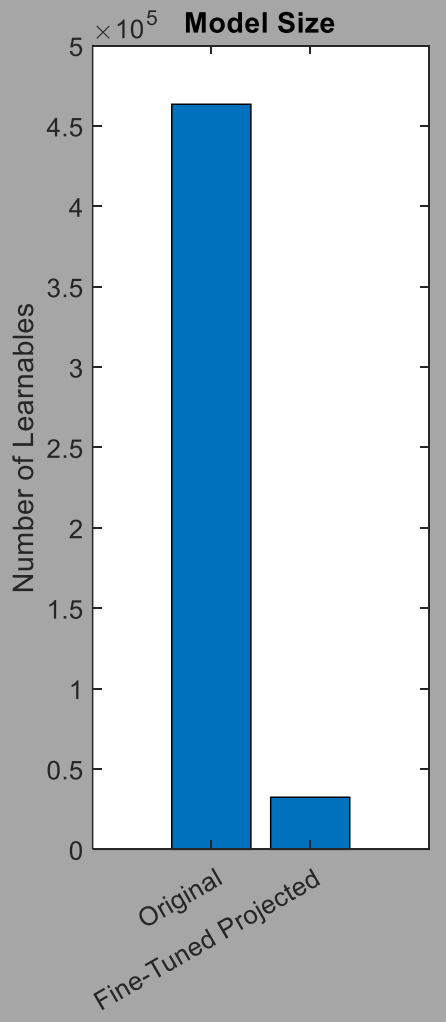
463.4k	7	0	0
total learnables	layers	warnings	errors

32.3k	7	0	0
total learnables	layers	warnings	errors

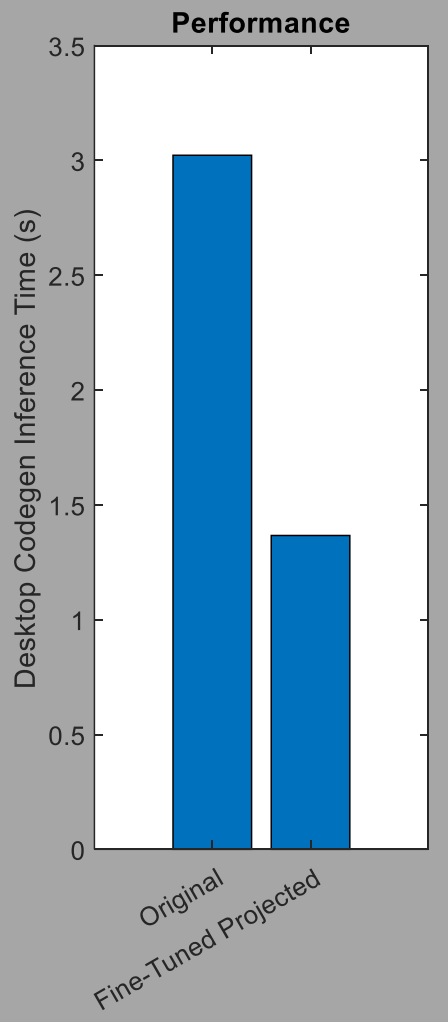
Similar Accuracy



93% Smaller



Faster



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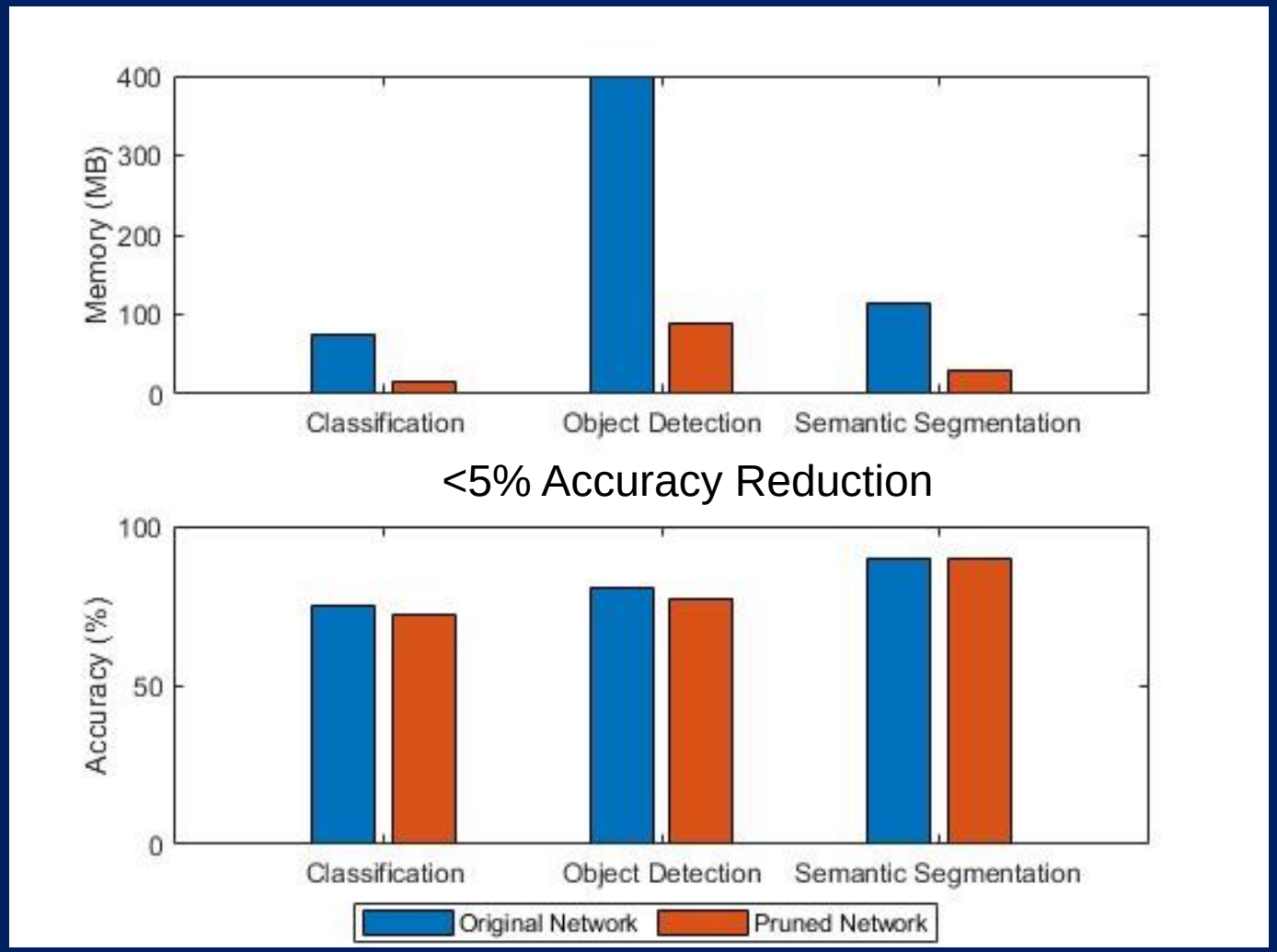
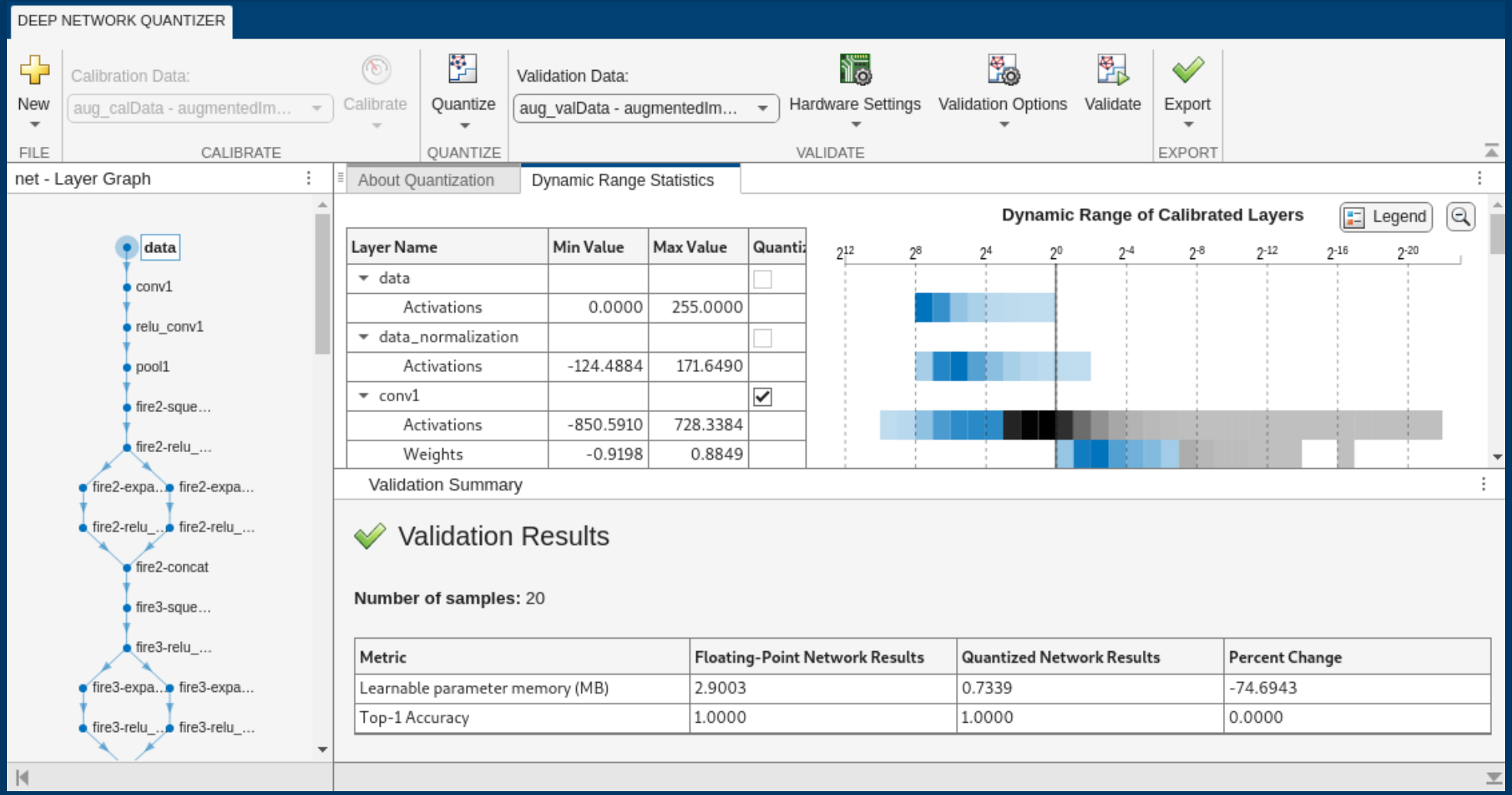
Apply pruning to a variety of AI model types to reduce memory footprint



Pruning
~4x Memory Reduction

Equivalent Accuracry

Quantize deep networks to 8-bit scaled integer data types

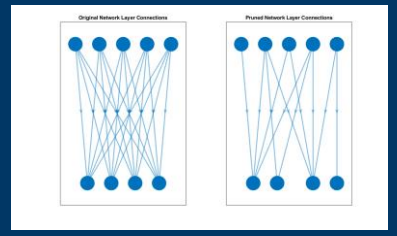


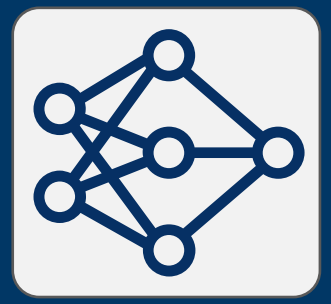
Deploy compressed model using automatic code generation

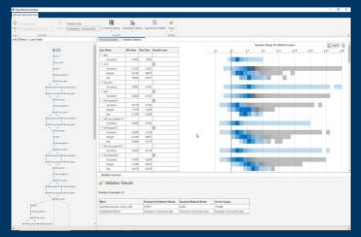
Model compression (pruning, projection and quantization)

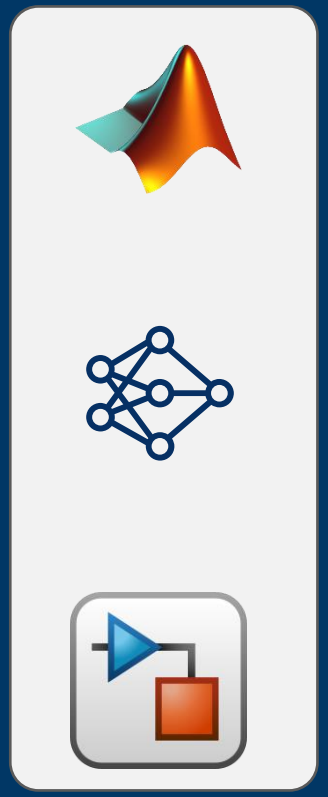
Generate code for AI model + pre- and post-processing

Performant multi-processor deployment









Code Generation

CPU

Any CPU
No Library needed

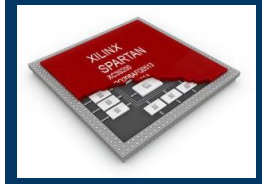
oneDNN
Library

ARM Compute
Library

GPU

µC

FPGA



Perform trade-off analysis between AI and traditional techniques

Kalman Filter

AI Model

	EKF Extended Kalman Filter	Tree Fine Regression Tree	FFN 1-hidden layer Feedforward Network	LSTM Stacked Long Short-Term Memory Network	LSTM* * Compressed Stacked Long Short-Term Memory Network
Preprocessing effort	🔵	🟡	🟡	🔵	🔵
Training Speed	N/A	🔵	🟡	🔴	🔴
Interpretability	🔵	🔵	🔴	🔴	🔴
Inference Speed	🟡	🔵	🔵🔵	🔴	🟡
Model Size	🔵	🟡	🔵	🔴	🔵
Accuracy (RSME)	🔵	🟡	🔵	🔵🔵	🔵🔵

Results are specific to this Battery SOC Estimation example

Much Better 🔵🔵 Better 🔵 Okay 🟡 Worse 🔴

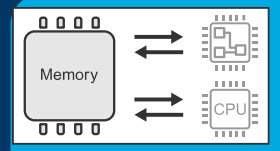
Trade-Off Analysis of Different Models

(Non-AI vs. Different AI Models)

Questions and concerns we need to answer to build confidence

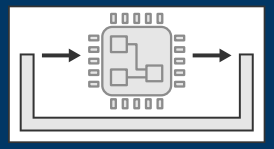
AI Modeling

System-level Simulation



Memory and Execution Time

Verification and Validation



Testing on Hardware

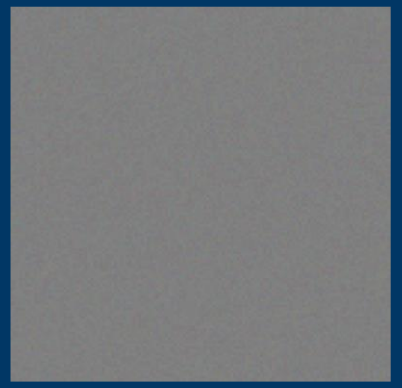
5 keys to building confidence

1. Access and explore state of art AI models
2. System-level testing to assess impact of adding AI component
3. Model compression, trade-off studies, and leverage automatic code generation

Neural networks can misclassify inputs due to small imperceptible changes

Bicycle

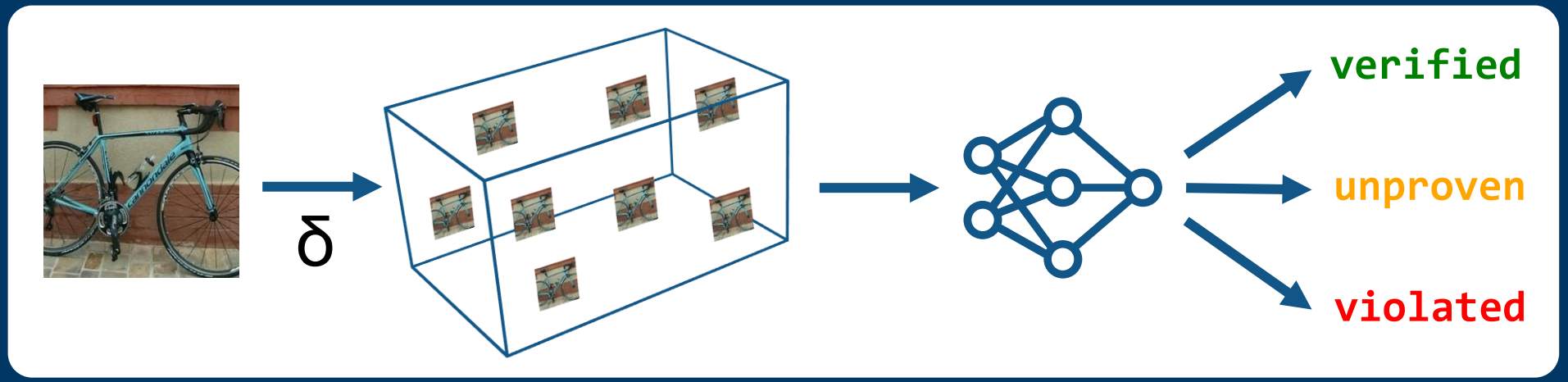
+ δ



=

Pole

Neural network verification provides formal evidence that your model behaves as intended



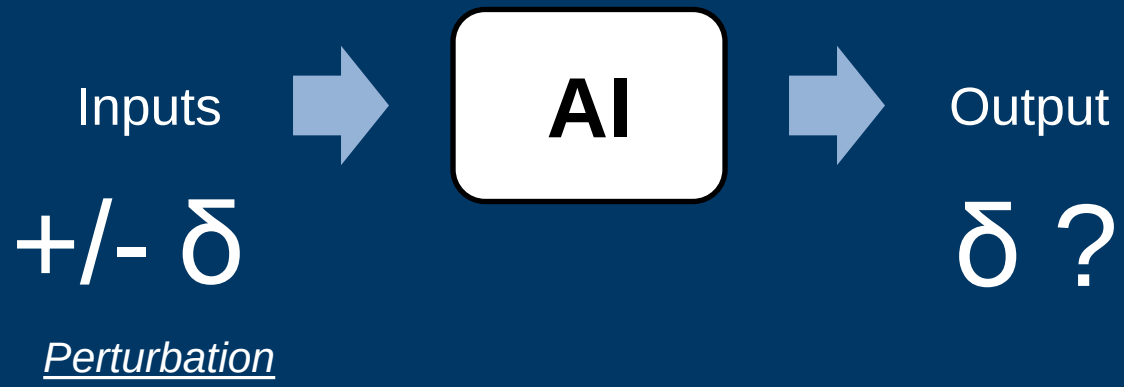
Deep Learning Toolbox Verification Library

by MathWorks Deep Learning Toolbox Team STAFF

Verify and test robustness of deep learning networks

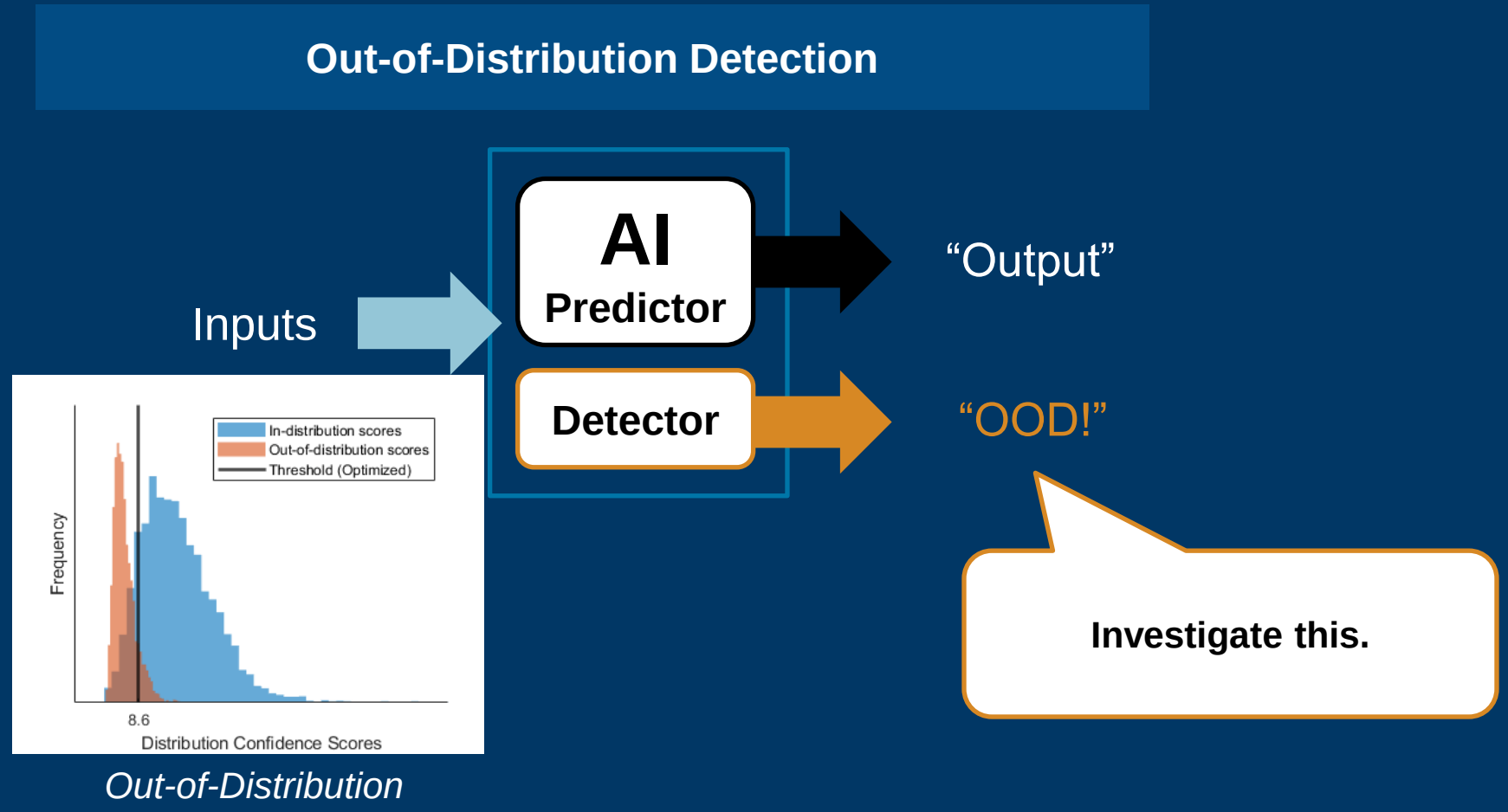
Perform formal verification to test robustness

Robustness against Input Perturbation




```
dlX = dlarray(X,'BC');
XLower = dlX-perturbation;
XUpper = dlX+perturbation;
dlnet = dlnetwork(trainedNetwork.Layers(1:end-1));
[YLower,YUpper] = estimateNetworkOutputBounds(dlnet,XLower,XUpper);
YLower = extractdata(YLower)';
YUpper = extractdata(YUpper)';
maxDeviation = max([abs(YLower-Y_pred);abs(YUpper-Y_pred)]);
```

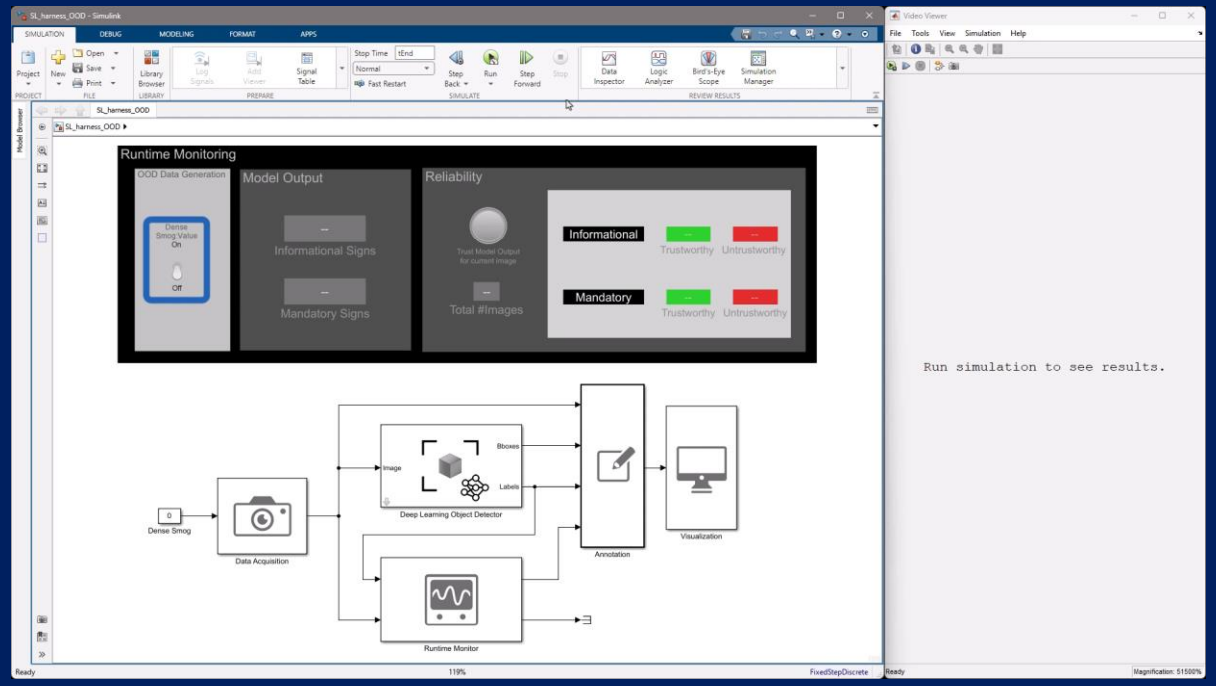
Check for out of distribution values to ensure safety



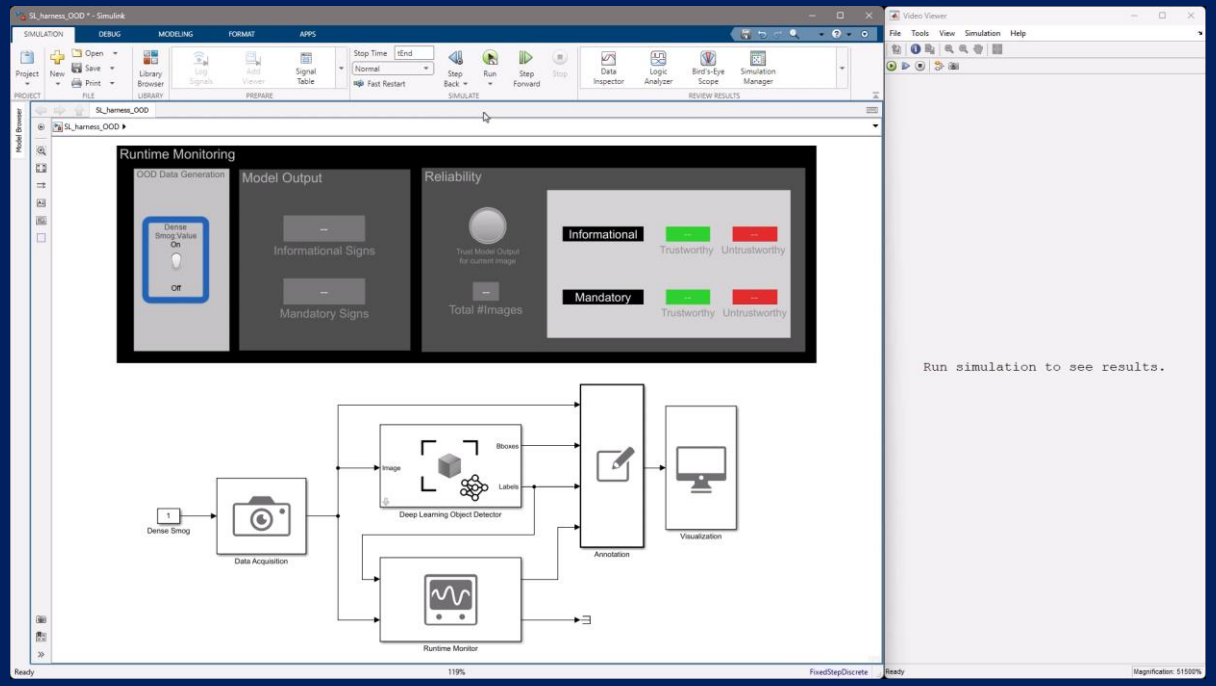
Out-of-Distribution

Integrate and test your AI model with Simulink with a Runtime Monitoring System

In-distribution ✓



Out-of-distribution ✗



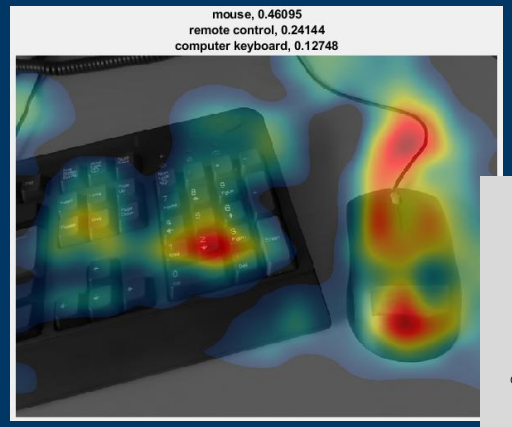
Explain & Visualize how a Model Works

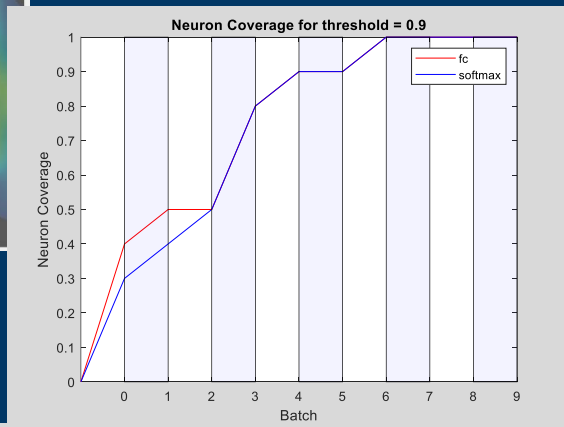
There are visualization techniques to investigate and explain model predictions.

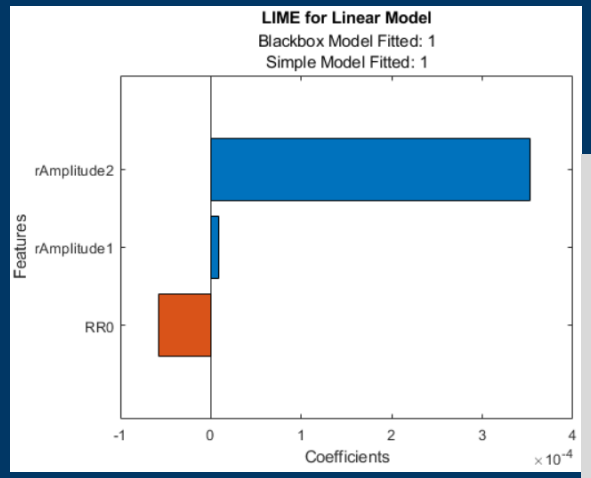
Which features did a model use to make a prediction?

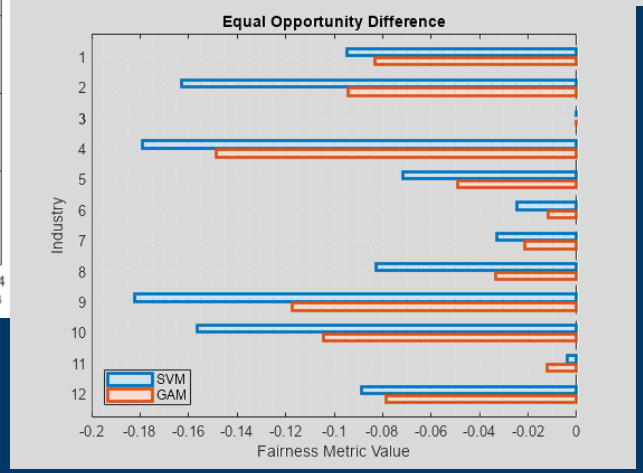
What are the main features found in each of the layers?

Class Activation Mapping	R2019a
Occlusion	R2019b
Local Interpretable Model-agnostic Explanation (LIME)	R2020b
GRAD-CAM, Shapley Values	R2021a
GRAD-CAM for 1-D	R2022b
Fairness Metrics, Neuron Coverage	R2022b
Bias mitigation using fairness thresholder for binary classification	R2023a
Fairness metrics comparisons	R2023a
Multi-point Shapley values/plots	R2024a
Explain object detectors using D-RISE	R2024a









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There is an increased focus in government **regulation and certification** efforts

Automotive

COMMITTEE DRAFT

ISO/CD PAS 8800

Road Vehicles — Safety and artificial intelligence

Under development

A draft is being reviewed by the committee.

Aerospace

WIP 2023-06-26

SAE INTERNATIONAL EUROCAE

Process Standard for Development and Certification/Approval of Aeronautical Safety-Related Products Implementing AI ARP6983

This document discusses guidelines for the development of Aircraft Systems leveraging AI capabilities, taking into account the overall aircraft operating environment and functions. This includes validation of requirements and verification of the design implementation for certification and product assurance and guidelines with the assessment of safety. It provides practices for showing compliance with the regulations and serves to assist a company in developing and meeting its own internal standards by considering the guidelines herein.

Medical Devices

← Software as a Medical Device (SaMD)

Artificial Intelligence and Machine Learning in Software as a Medical Device

May 13, 2024 update: 191 Artificial Intelligence and Machine Learning (AI/ML)-Enabled Medical Devices were added to the list below. With this update, the FDA has authorized 882 AI/ML-enabled medical devices. Of those newly added to the list, 151 are devices with final decision dates between August 1, 2023, and March 31, 2024, and 40 are devices from prior periods identified through a further refinement of methods used to generate this list.

European Parliament

2019-2024

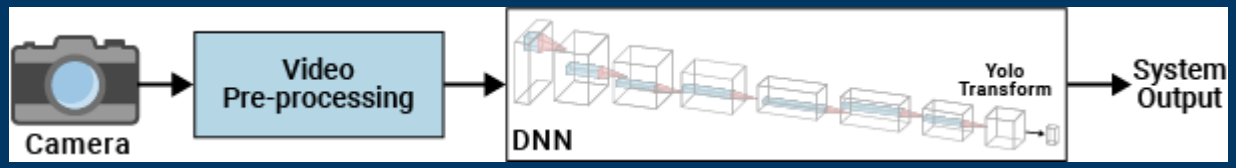
TEXTS ADOPTED

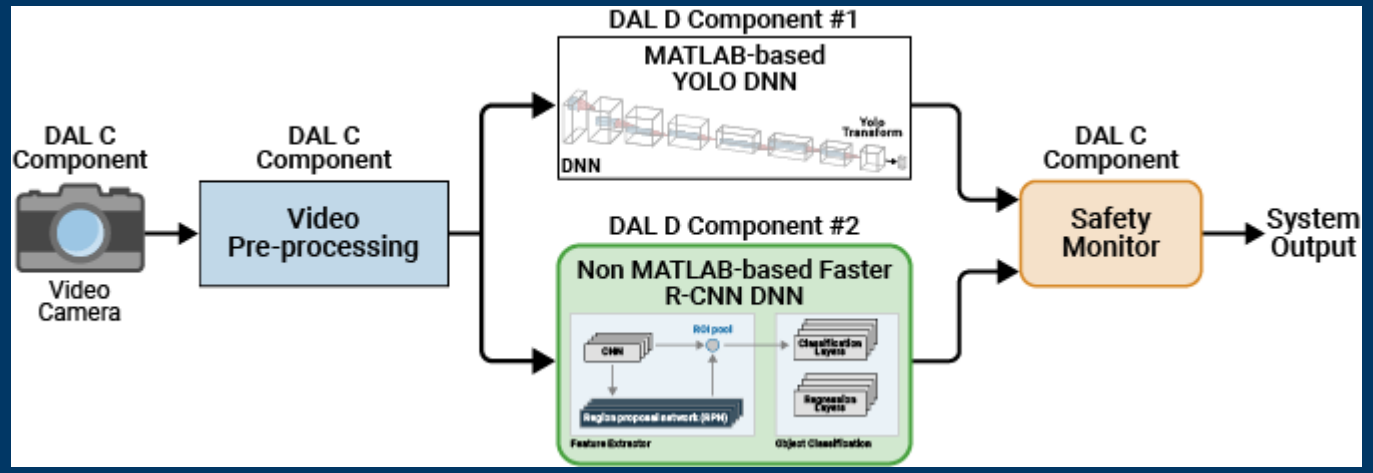
P9_TA(2024)0138

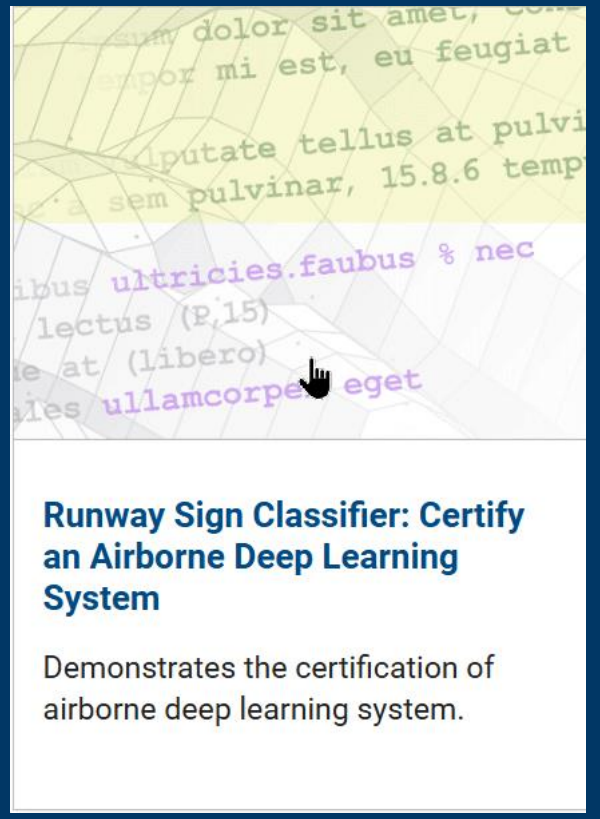
Artificial Intelligence Act

European Parliament legislative resolution of 13 March 2024 on the proposal for a regulation of the European Parliament and of the Council on laying down harmonised rules on Artificial Intelligence (Artificial Intelligence Act) and amending certain Union Legislative Acts (COM(2021)0206 – C9-0146/2021 – 2021/0106(COD))

Published first reference application on developing system with AI component to comply with DO-178







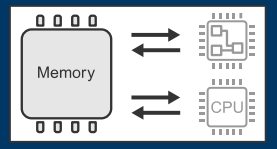
Runway Sign Classifier: Certify an Airborne Deep Learning System

Demonstrates the certification of airborne deep learning system.

Questions and concerns we need to answer to build confidence

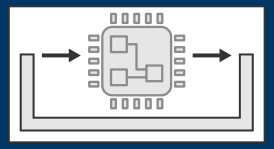
AI Modeling

System-level Simulation



Memory and Execution Time

Verification and Validation



Testing on Hardware

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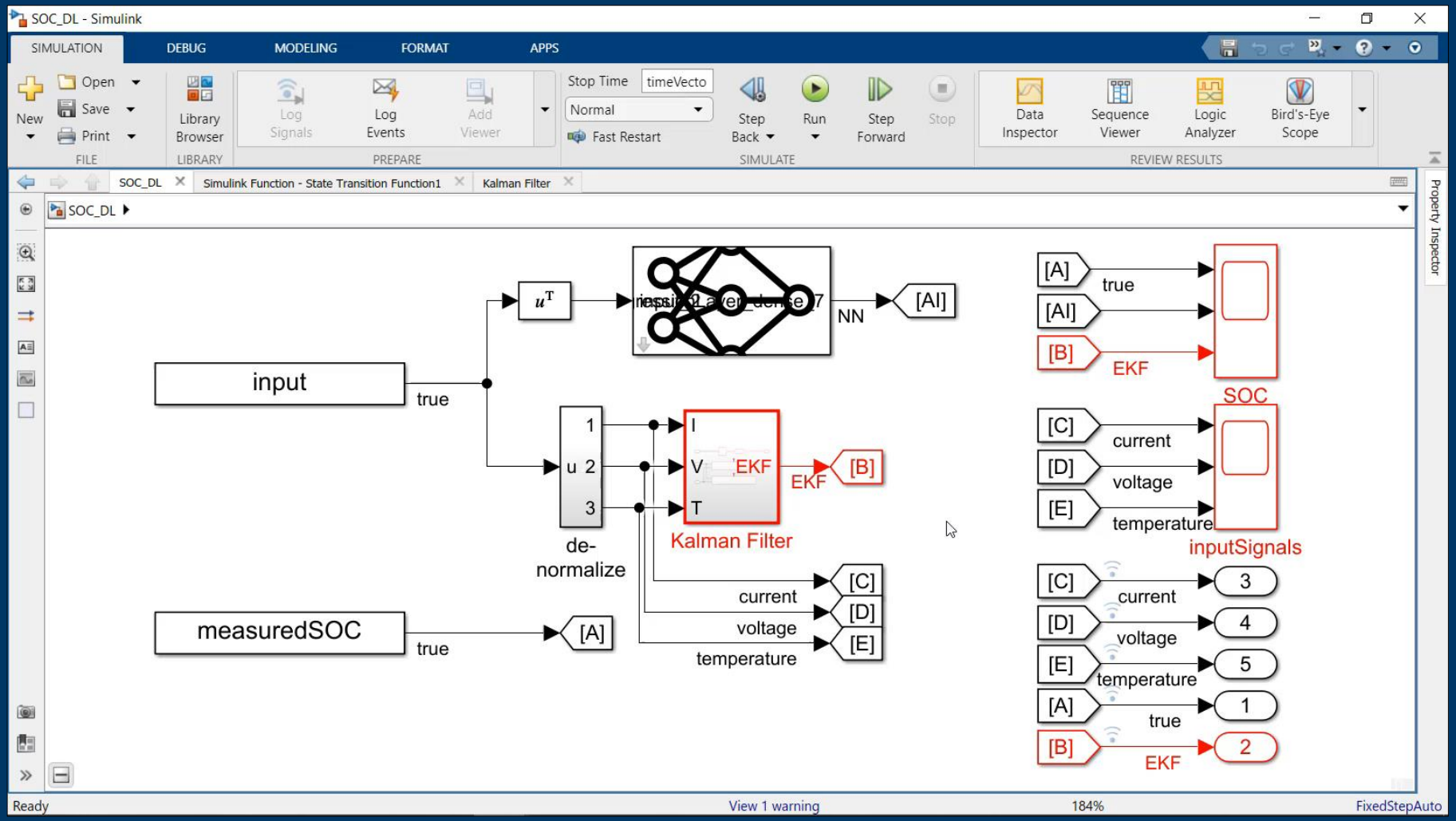
3. Model compression, trade-off studies, and leverage automatic code generation
4. Verify robustness and test for out of distribution

Generate Library-Free C/C++ Code for AI Models



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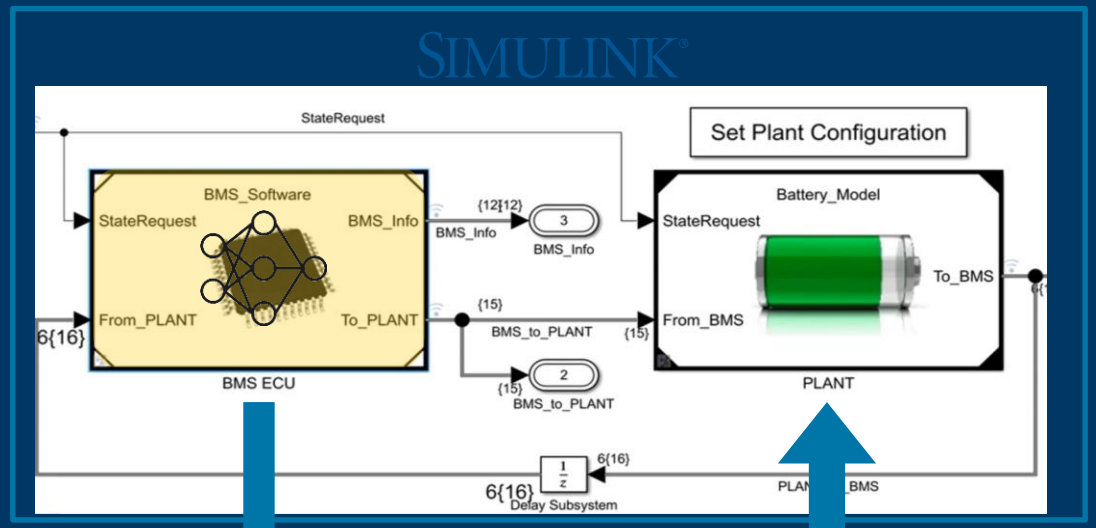
Processor-in-the-Loop Testing on ARM Cortex-M7 Processor



Code generation from algorithm

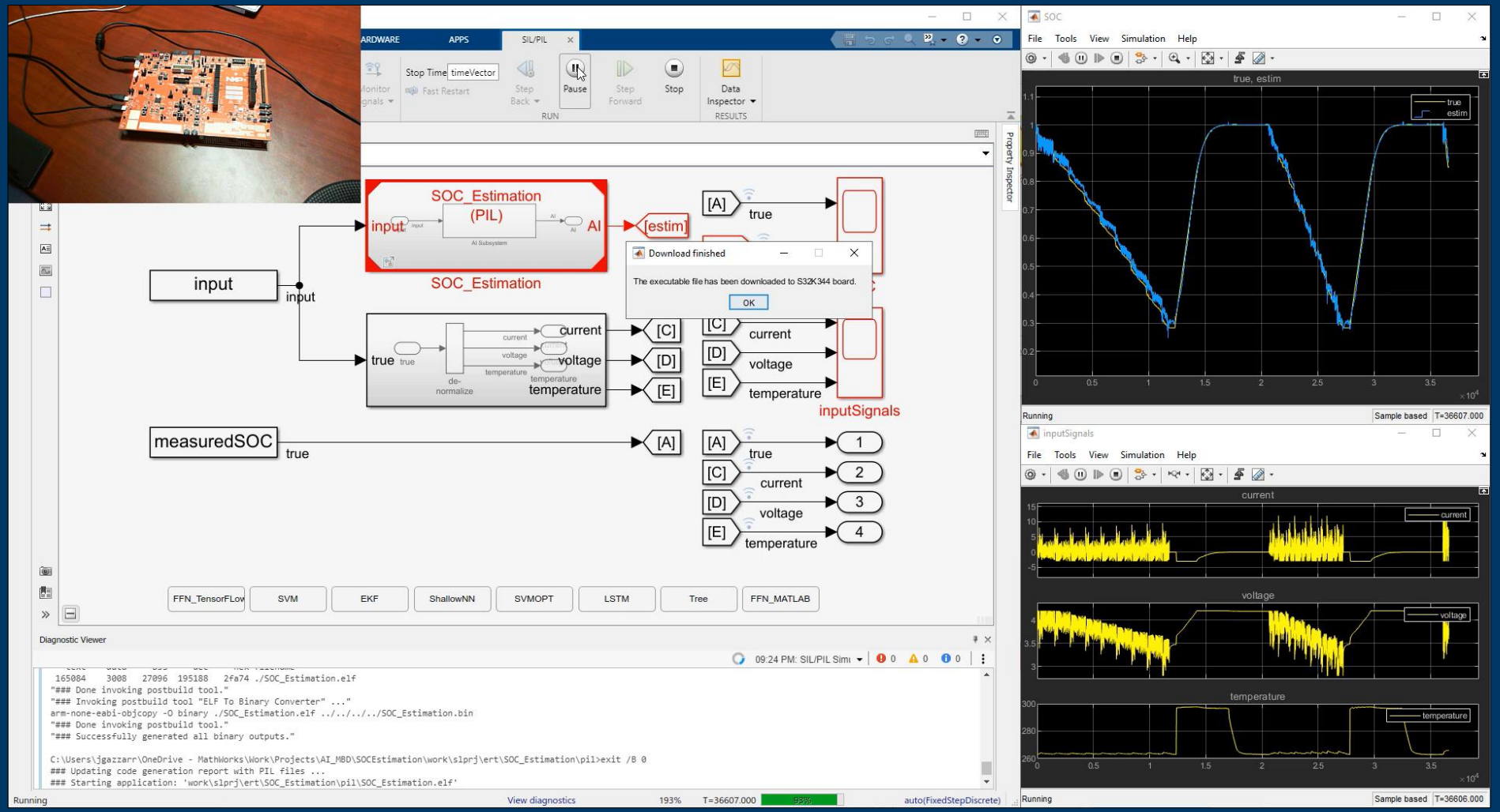
Deployed code communicates with simulated plant

NXP S32K344 board

Arm® Cortex®-M

42

Processor-in-the-Loop Testing on ARM Cortex-M7 Processor



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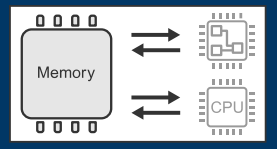
Questions and concerns we need to answer to build confidence

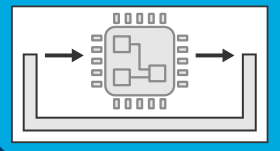
AI Modeling

System-level Simulation



Memory and Execution Time

Verification and Validation



Testing on Hardware

5 keys to building confidence

1. Access and explore state of art AI models
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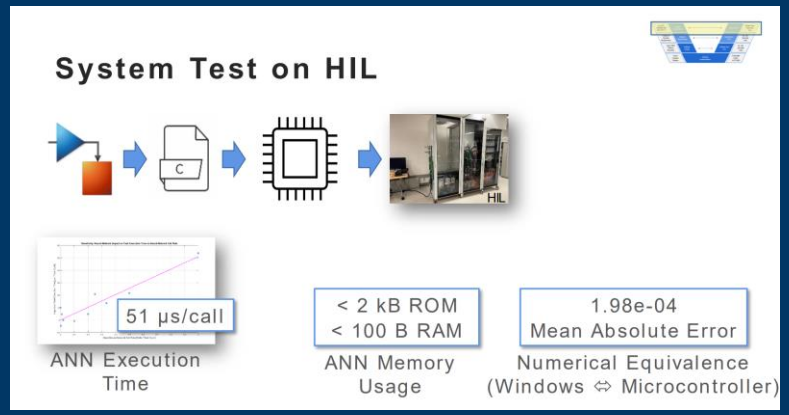
3. Model compression, trade-off studies, and leverage automatic code generation
4. Verify robustness and test for out of distribution
5. Perform PIL and HIL testing

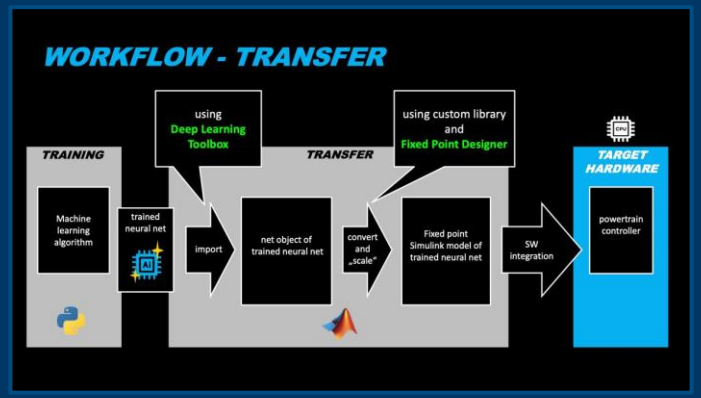
Learn about other automotive uses of AI virtual sensors

Gotion



Battery pack SOC estimation with neural network

Mercedes-Benz



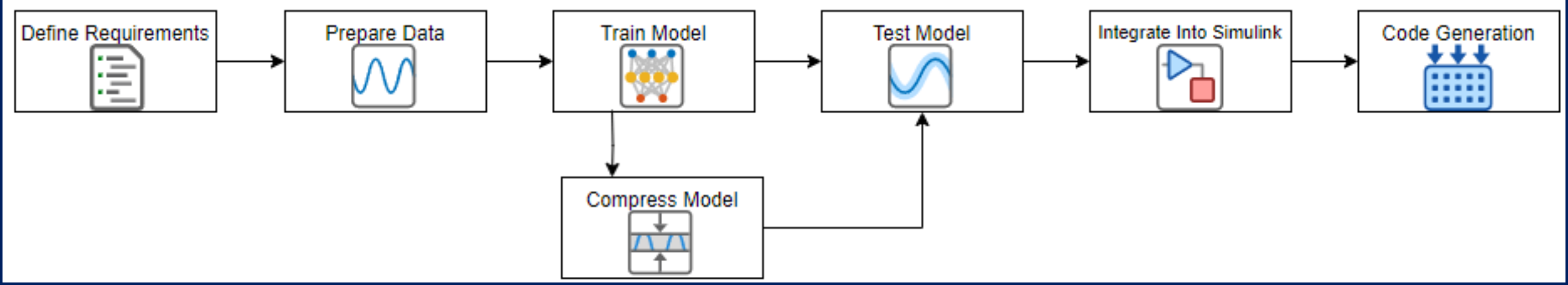
Engine piston pressure estimation with deep neural network

45

5 keys to building confidence through design for AI-driven systems

1. Access and **explore state of art models**
2. **System-level simulation** to test impact of adding AI component
3. Model **compression**, **trade-off studies**, and leverage automatic **code generation**
4. Verify **robustness** and test for **out of distribution**
5. Perform **PIL and HIL** testing

Get started quickly with end-end reference examples



This example shows how to perform these steps:

1. Define Requirements for Battery State of Charge Estimation
2. Prepare Data for Battery State of Charge Estimation Using Deep Learning
3. Train Deep Learning Network for Battery State of Charge Estimation
4. Compress Deep Learning Network for Battery State of Charge Estimation
5. Test Deep Learning Network for Battery State of Charge Estimation
6. Integrate AI Model into Simulink for Battery State of Charge Estimation
7. Generate Code for Battery State of Charge Estimation Using Deep Learning

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How Generative AI will Impact Engineering Workflows

Augment Existing Workflows

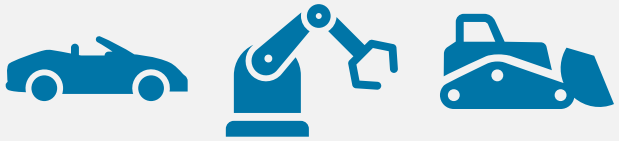
- Learn while doing
- Create code, analyses, models, etc. using NLP
- Check, verify, validate

Empower MATLAB and Simulink Users to Build

- Access popular models for text, images, video, etc.
- Build custom transformer models
- Easy from options from platforms like Hugging Face

Generative AI in Engineered Systems

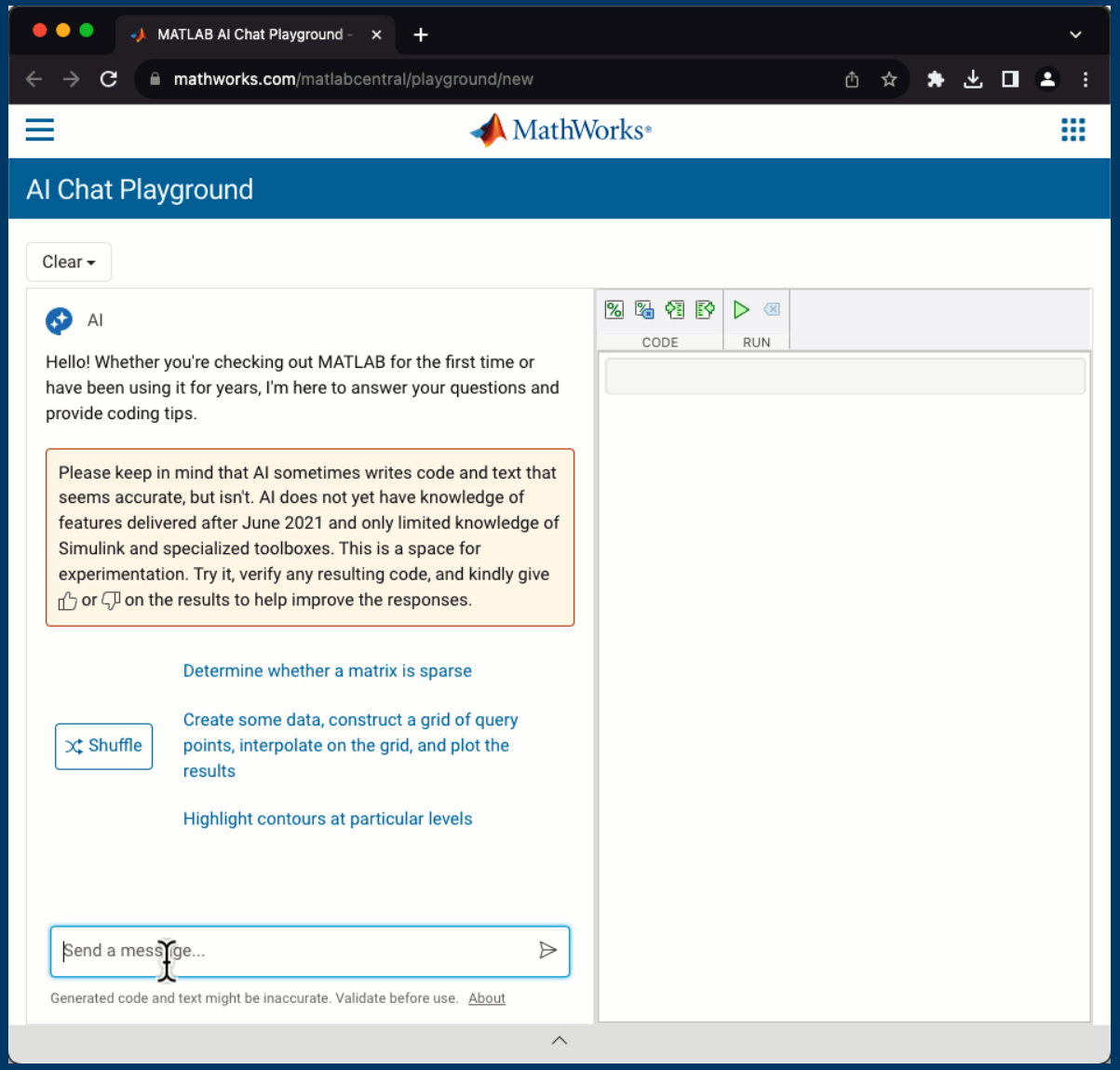
- Apply LLM innovations to time-series sensor data
- Real-time and near-real-time systems
- Safety-critical



Now, Near-term → Future

MATLAB AI Chat Playground

- Experiment with an AI assistant alongside MATLAB
- Generate first-draft MATLAB code or ask questions
- Powered by the ChatGPT API's



https://www.mathworks.com/matlabcentral/playground/

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Use Large Language Models with MATLAB

- GitHub Repo: llms-with-matlab within matlab-deep-learning
- Connect to models via the OpenAI™ API and the Azure® OpenAI Service
- Connect to local and remote models hosted with Ollama
- Examples of chatbots, text summarization, retrieval augmented generation, image generation

Let us catch up after session to discuss MathWorks investments

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Please join our other AI sessions today

MathWorks
AUTOMOTIVE CONFERENCE 2024

Thank you

MathWorks®