MathWorks
# AUTOMOTIVE CONFERENCE 2022
North America

## Building a cloud-based digital twin for an EV battery pack

*Will Wilson, Javier Gazzarri , Shyam Keshavmurthy, MathWorks*

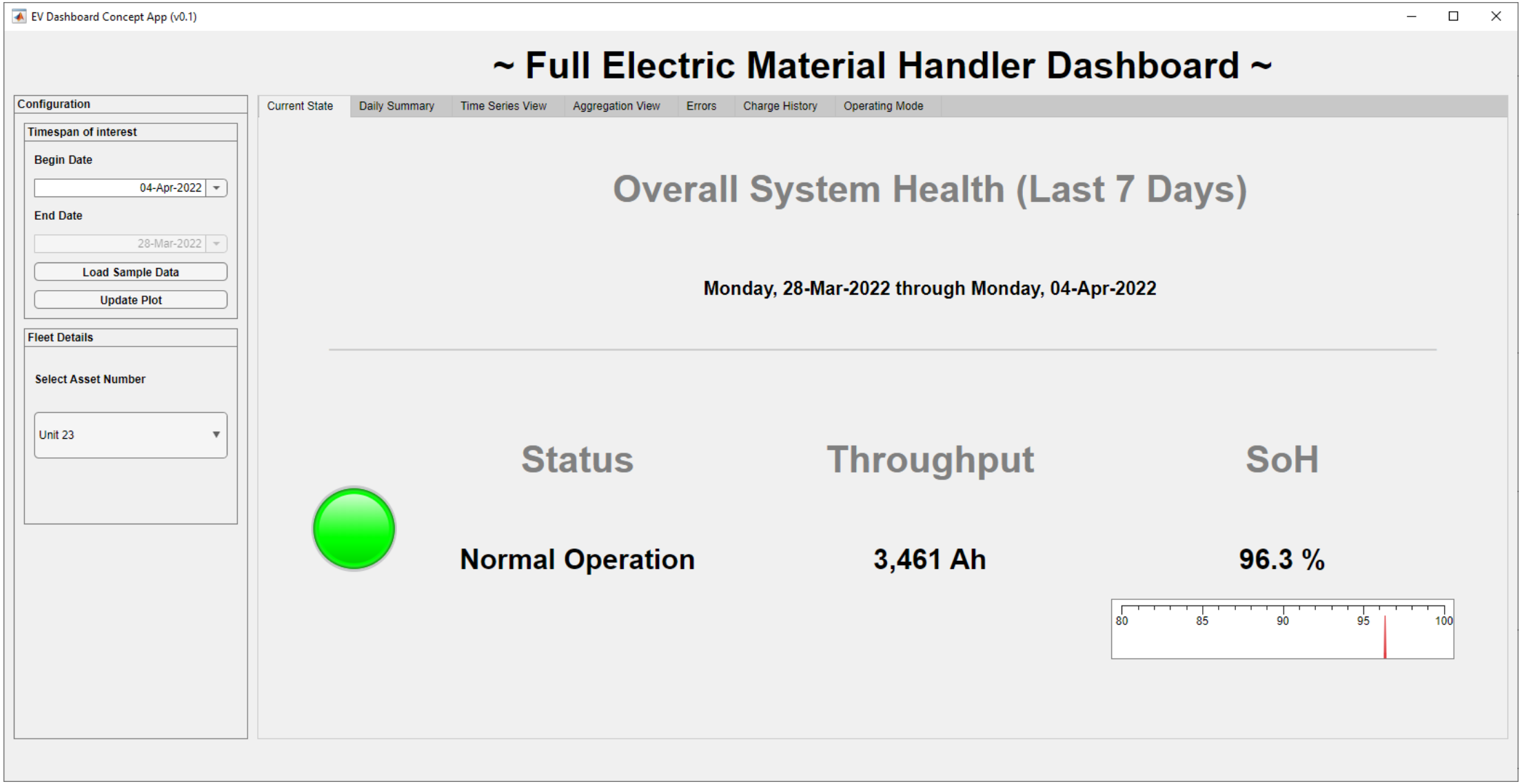


MathWorks

# Agenda

- Level setting & common understanding
- Digital Twin project
- Next steps and future state
- Resources & Collateral

# Demo - System Performance Dashboard



# Digital Twin?

## A definition

*"A digital twin is an **up-to-date representation, a model, of an actual physical asset in operation**. It **reflects the current asset condition** and includes relevant historical data about the asset.*

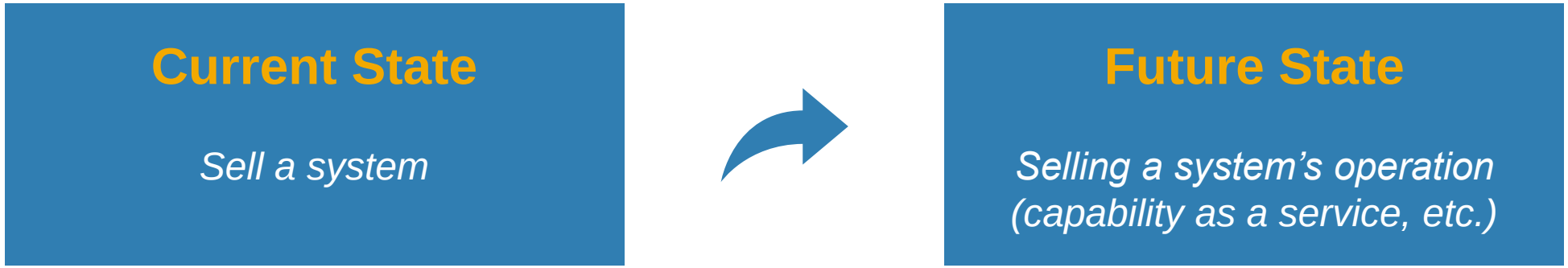
*Digital twins can be **used to evaluate the current condition of the asset**, and more importantly, **predict future behavior, refine the control, or optimize operation**."*

https://www.mathworks.com/discovery/digital-twin.html

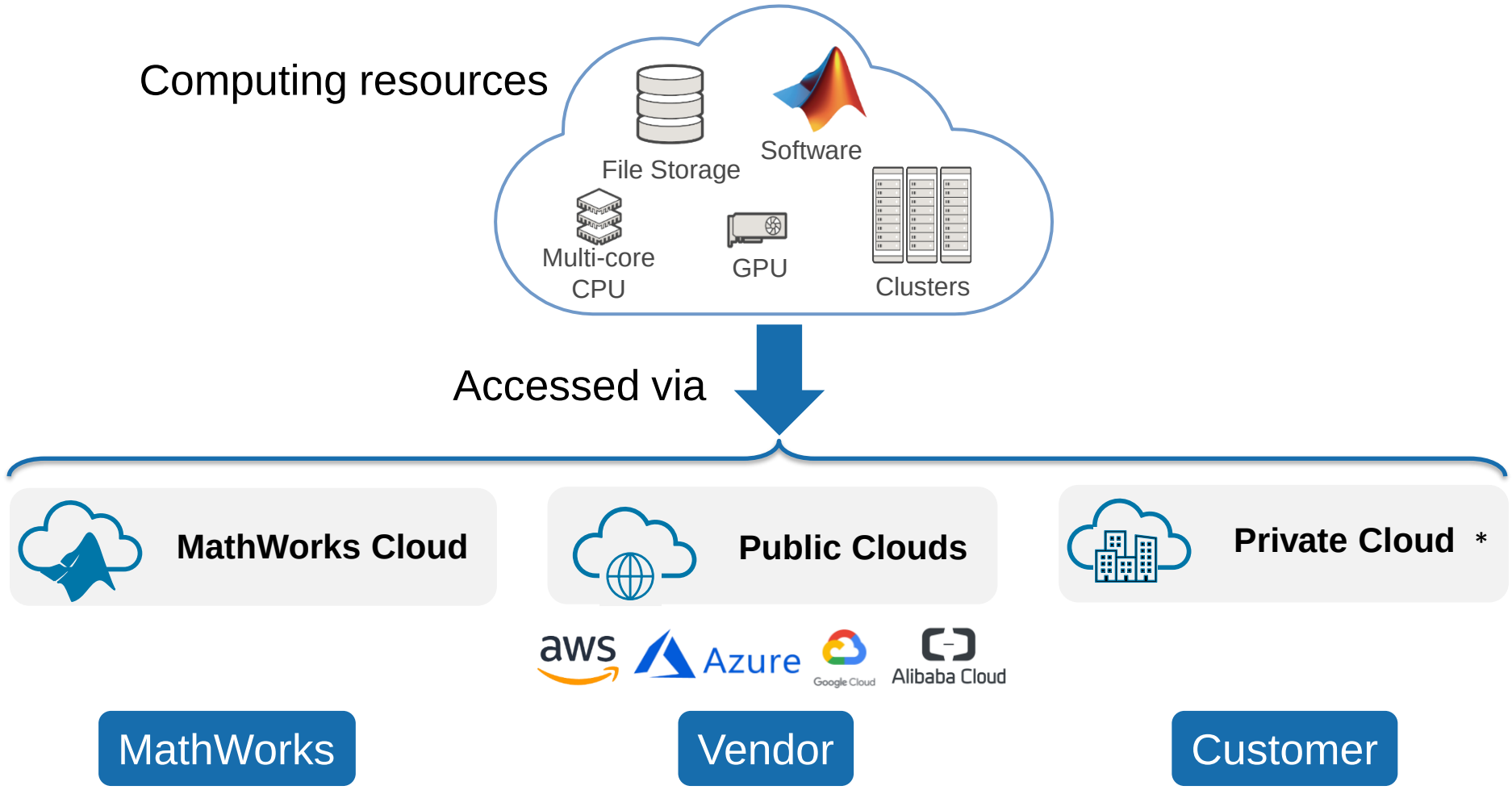
# Why Digital Twin?

## Business value & motivating factors

- **Do things better**: Optimize your customer's experience
  - Anomaly detection
  - Predictive maintenance
  - Asset performance management
  - Operations optimization
  - Fleet management
  - Feedback to design
- **Do new things**: Evolve business models and opportunities



# Run MATLAB and Simulink where you need to




[Learn More]

*Private accounts can be setup in AWS or Azure with limited access

# Agenda

- Level setting & common understanding
- Digital Twin project
- Next steps and future state
- Resources & Collateral

# Project Goals and Scope

Demonstrate how an EV battery pack digital twin could be developed and deployed

## Goal

Build a cloud-based digital twin for an EV battery pack of a Full Electric Material Handler

## Scope

This project is focused on deploying analytics and a digital twin model to a cloud-based dashboard.  Future work could include deploying some of the analytics onto hardware running directly on machines in the field (battery state of health estimation for example).

# Data Analytics Workflow

**Access and Explore Data**

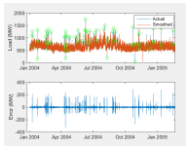
**Files**

**Databases**

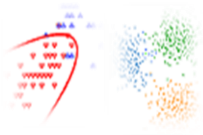
**Sensors**

**Preprocess Data**

**Working with Messy Data**



**Data Reduction/ Transformation**



**Feature Extraction**

**Develop Predictive Models**

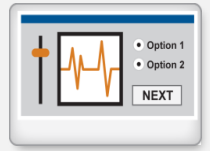
**Model Creation e.g. Machine Learning**


**Parameter Optimization**

**Model Validation**

**Integrate Analytics with Systems**

**Desktop Apps**




**Enterprise Scale Systems**


**Embedded Devices and Hardware**

# Prepare raw data for modeling

## Extract, Transform, and Load (ETL) Workflow Considerations

Access and Explore Data → **Preprocess Data** → Develop Predictive Models → Integrate Analytics with Systems

### Extract

**Raw .MF4 Files**

**File Types**

*MDF (.MF4)*
*.blf*
*.parquet*
*.mat*
*custom binary*
*text*

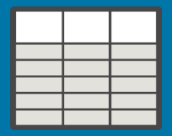
### Transform

**Finalize & Sort**

**Decode raw CAN messages**

**Time align signal data**

**Enforce Common Schema**



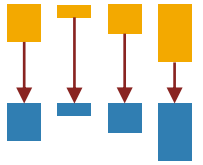
### Load

**Write Resultant Data**

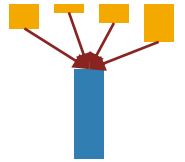
***.parquet***
*.mat*
*text*

**Write Mode**

*One-to-one*

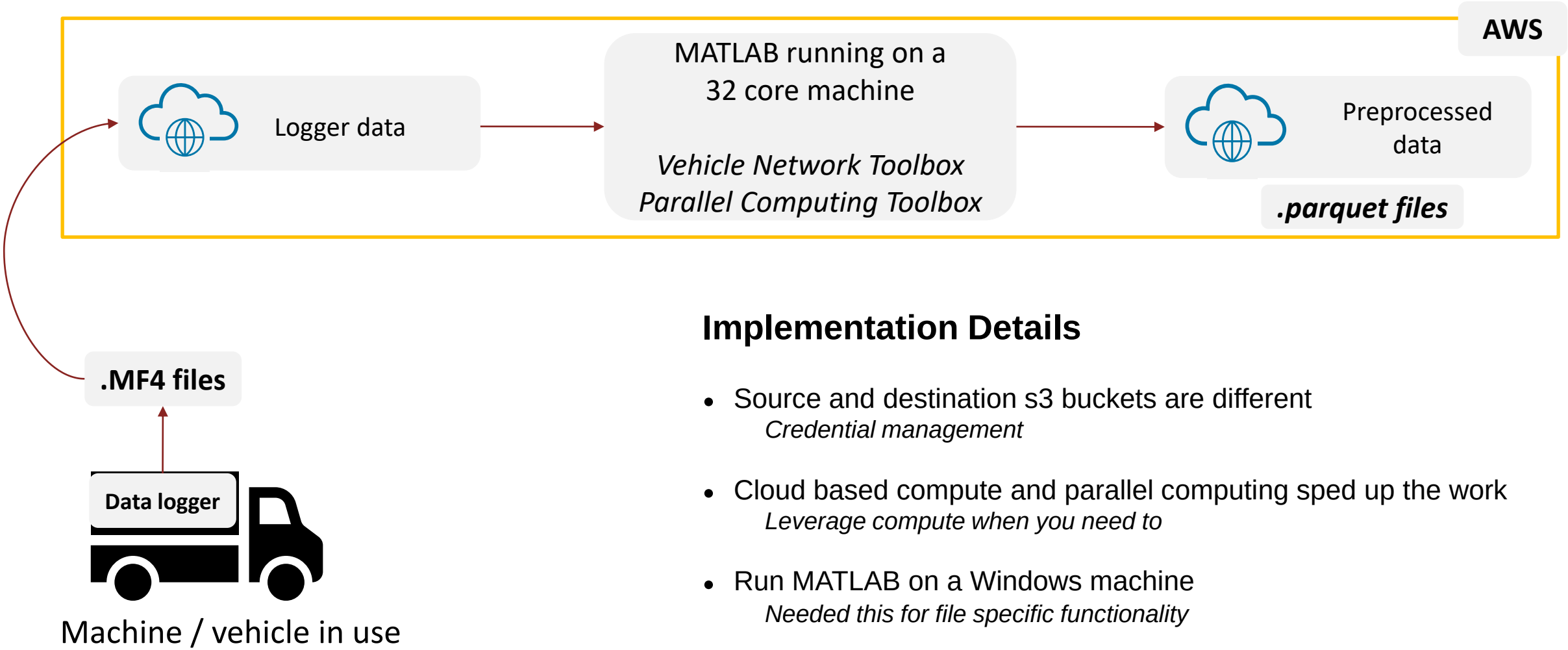


*Many-to-fewer*



# Raw Log Files

## Cloud based data preprocessing pipeline




### Implementation Details

- Source and destination s3 buckets are different
  *Credential management*
- Cloud based compute and parallel computing sped up the work
  *Leverage compute when you need to*
- Run MATLAB on a Windows machine
  *Needed this for file specific functionality*

# Data Analytics

## Using log data to answer usage-based questions

- Does the system perform as advertised?
  - **Operation**: must operate for 3-4 hours in the morning and 3-4 hours in the afternoon
  - **Charging**: battery must fully charge in 30 min (at lunch time)

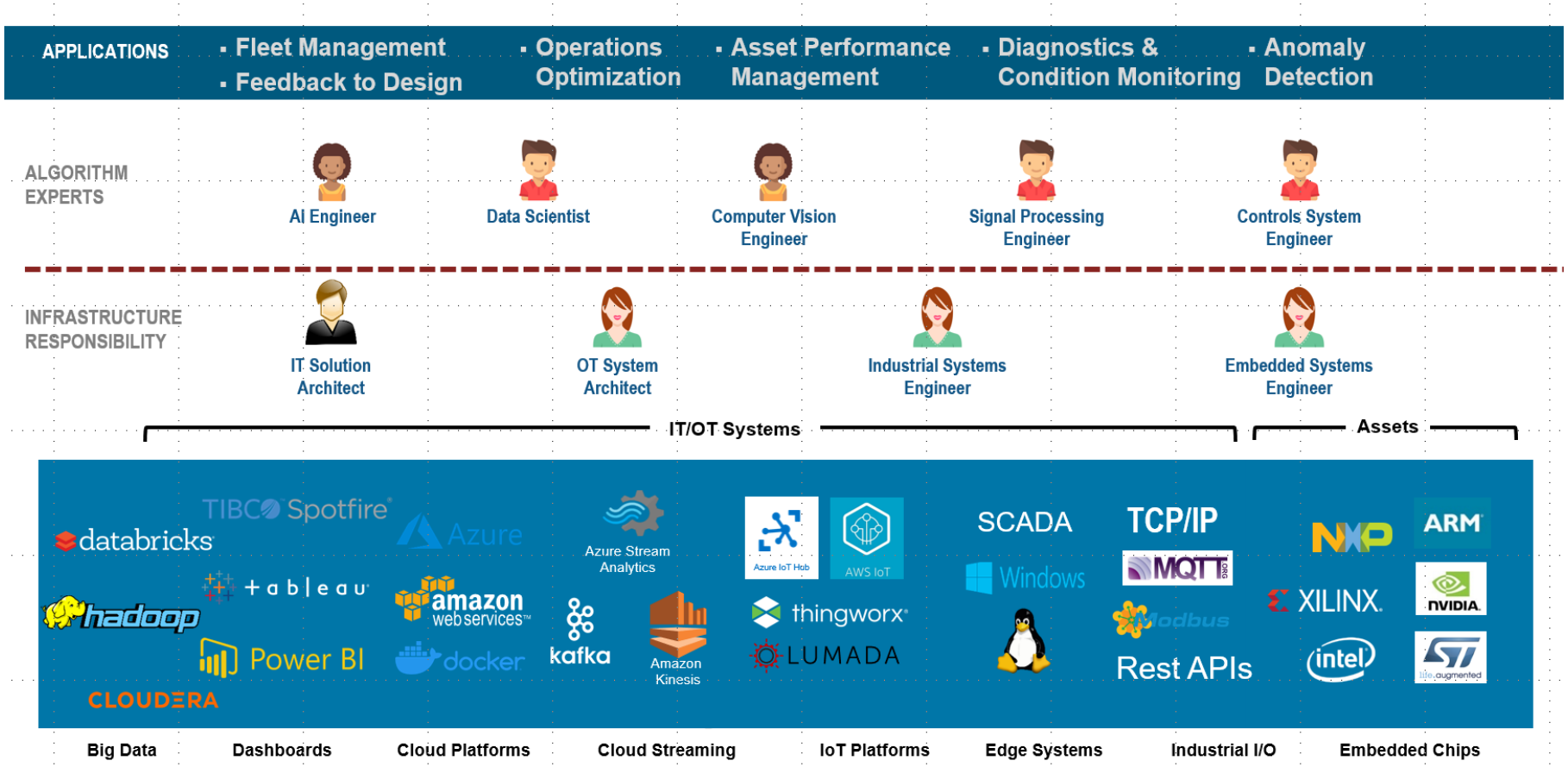
- What is the effect of ambient temperature on the system?
  - Ambient temp ranges from -10 to 35°C over the year.  How does this affect system performance?

- What is the actual duty cycle based on operational data?
  - Power used during operation vs. charging
  - Total number of charge / discharge cycles
  - etc.

# Collaborate!

## Strategize, develop, test, iterate

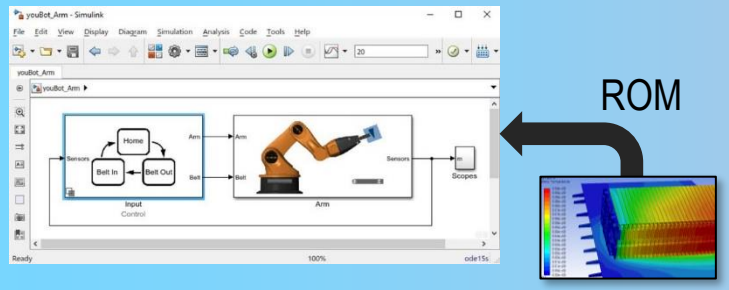
Access and Explore Data → Preprocess Data → **Develop Predictive Models** → Integrate Analytics with Systems



# Modeling Approach

## Choosing a model strategy is a function of what you **have** and what you **know**

### Physics-Based



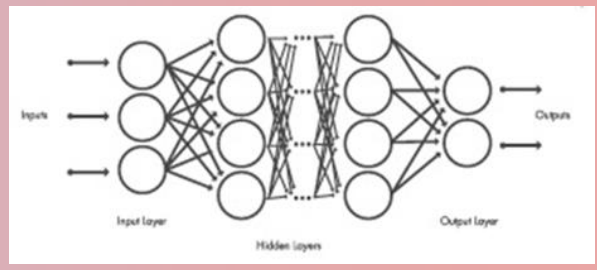

- Dynamic models of systems/components
- Electrical, mechanical, algorithms, etc.
- Can integrate models from other tools, e.g., FEM

### Data-Driven

```
% Predicted state and covariance
x_prd = A * x_est;
p_prd = A * p_est * A' + Q;

% Estimation
S = H * p_prd' * H' + R;
H = H * p_prd';
klm_gain = (S \ B)';

% Estimated state and covariance
x_est = x_prd + klm_gain * (z - H * x_prd);
p_est = p_prd - klm_gain * H * p_prd;

% Compute the estimated measurements
y = H * x_est;
```

- Kalman estimator
- System identification
- Regression

### AI-Based

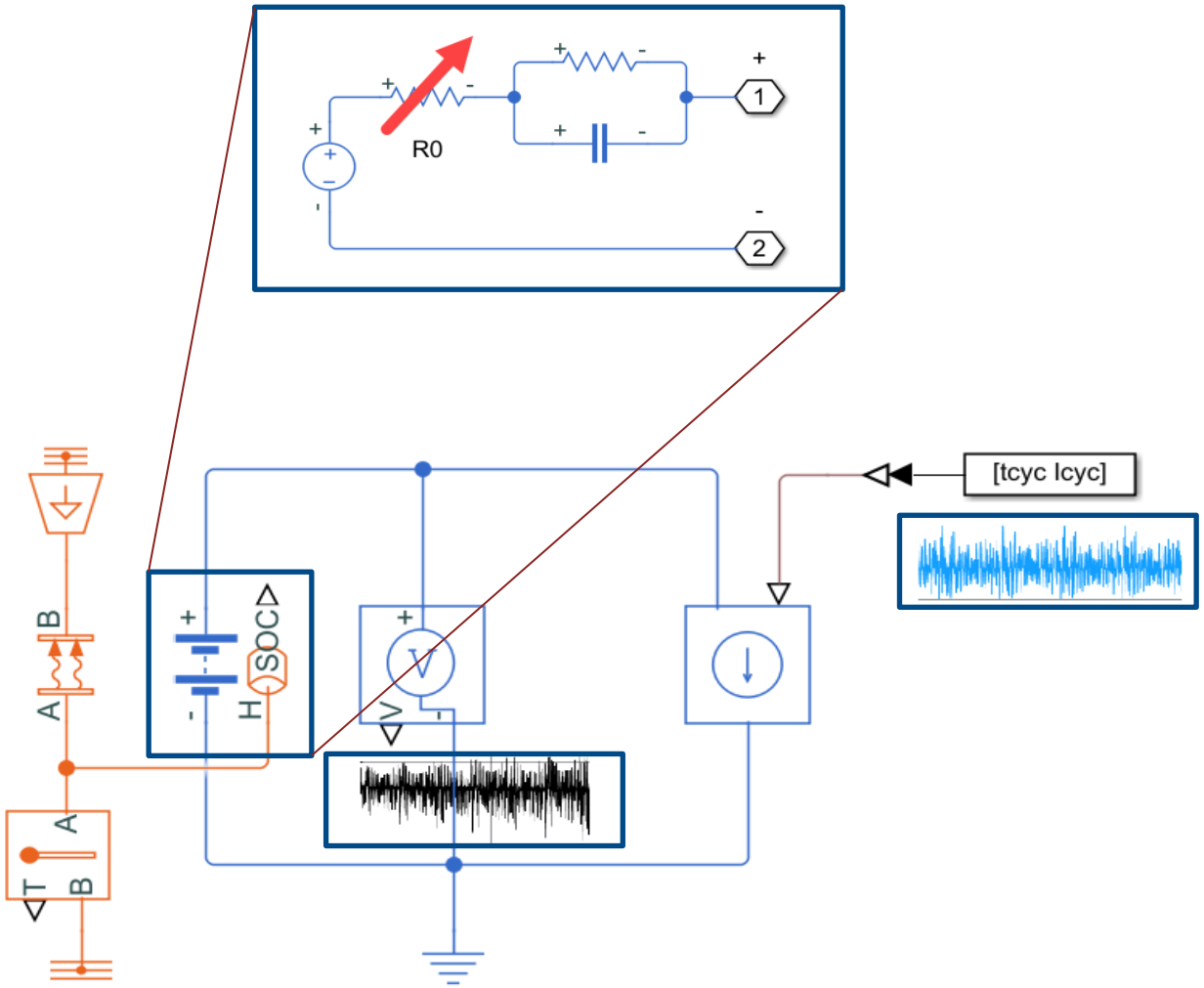



- Machine Learning
- Deep Learning
- Reinforcement Learning.

- Factors in selecting model strategy
  - What does your application need?
  - Do you have knowledge of system's physics (or only historical data)?
  - Who has the expertise needed to build the model?

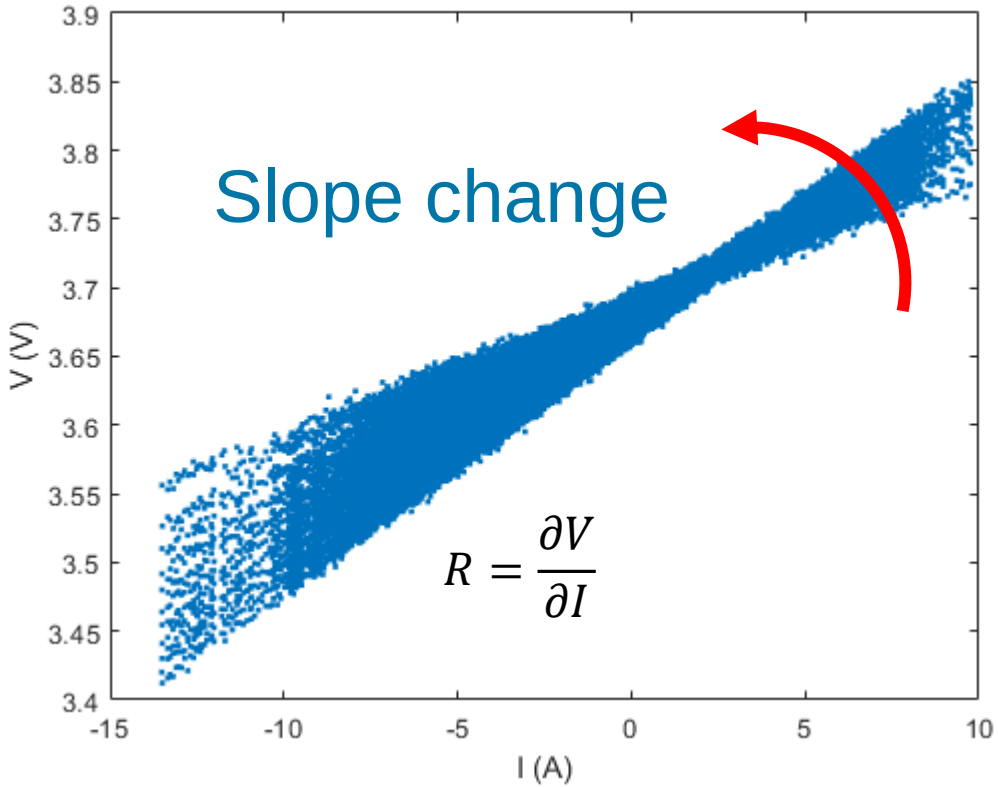
# Simulate to Set Expectations

## As internal resistance increases, what should we see?




## Internal Resistance - $R = \frac{\partial V}{\partial I}$

## Synthetic Data



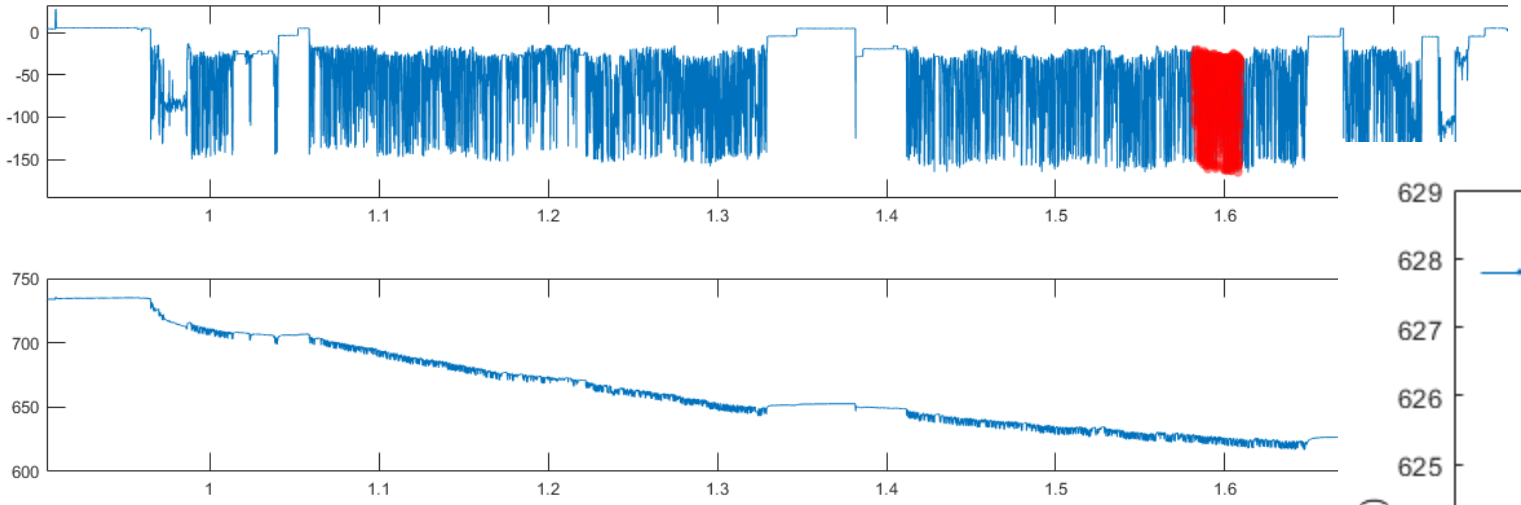
# Incrementally fit data based on voltage values

## Bin data by SoC

selection

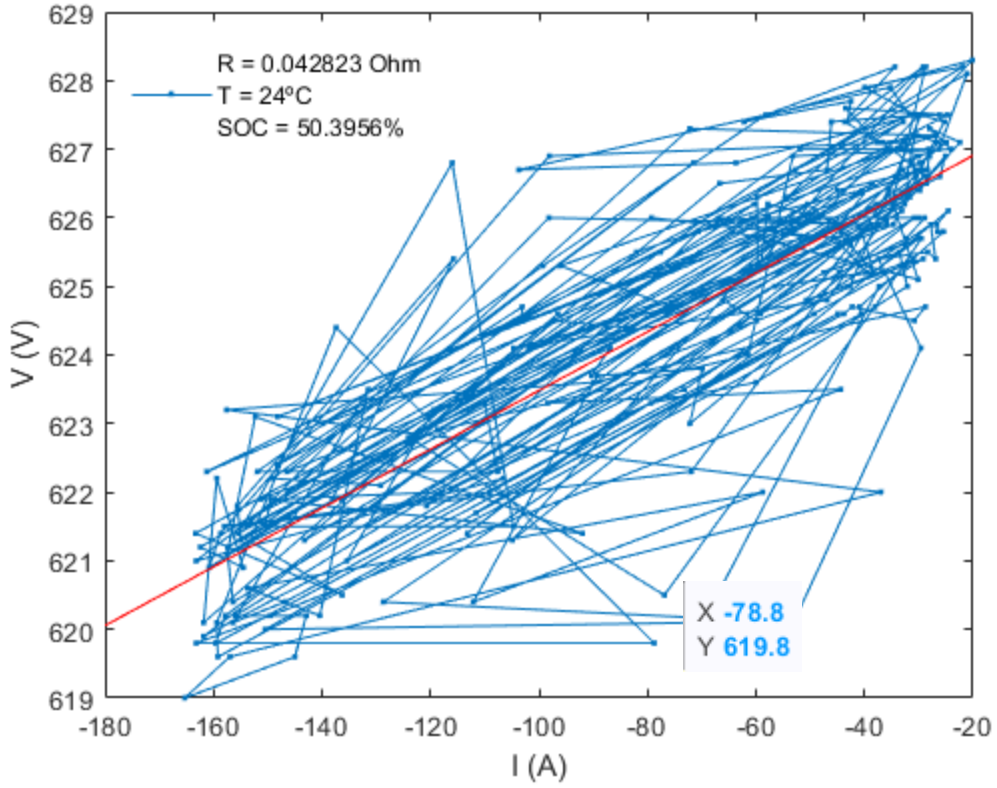
I(A)

V(V)




Internal Resistance - $R = \frac{\partial V}{\partial I}$

Discharge



# Initial results on a subset of data

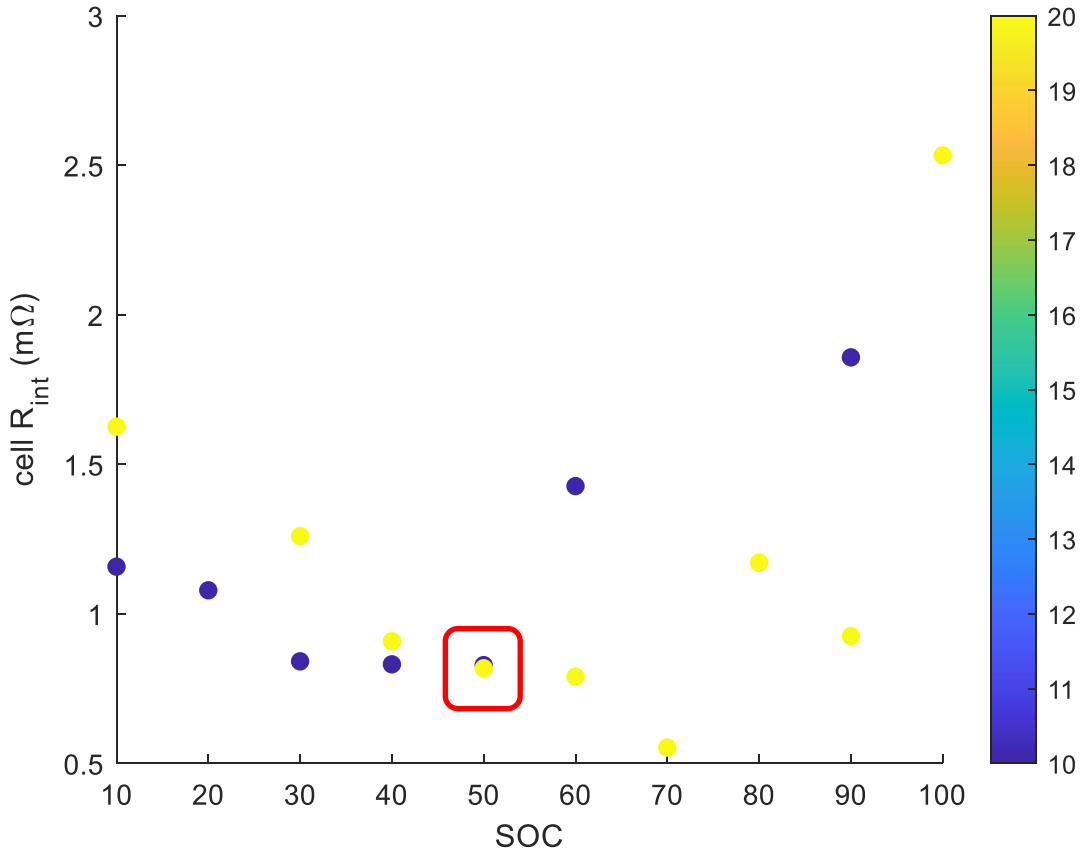
## Internal resistance as a function of SoC and Temperature

Internal Resistance - $R = \frac{\partial V}{\partial I}$

Discharge

Convert from pack to cell

$\times \frac{Np}{Ns}$




| | |
|---|---|
| Internal discharge impedance (10 sec DC pulse, 50% SOC, 25°C) | 0.71 mΩ |

# Agenda

- Level setting & common understanding
- Project update
- Next steps and future state
- Resources & Collateral

# Next Steps for Modeling Work

## Strategy and planned next steps

- Understand system behavior over time
  - How does internal resistance change over time?
  - Can we detect degradation in power output over time?
- Battery cell performance parameters
  - Internal resistance so far (power), capacity next (energy)
  - Combine internal resistance and capacity learnings into a SoH story
- Feature Engineering + AI modeling & Automation
  - Cloud based parallel computing (“Thinking out loud on the cluster”)

# Future State: AI SoH predictor model

APPLICATIONS

- Fleet Management
- Feedback to Design
- Operations Optimization
- Asset Performance Management
- Diagnostics & Condition Monitoring
- **SoH estimator**

ALGORITHM EXPERTS

Data Scientist

1. Train ML model using data
2. Deploy trained model MATLAB

INFRASTRUCTURE RESPONSIBILITY

IT Solution Architect

OT System Architect

Industrial Systems Engineer

Embedded Systems Engineer

IT/OT Systems

TIBCO Spotfire, databricks, Azure, Azure Stream Analytics, tableau, hadoop, amazon web services, Power BI, docker, kafka, Amazon Kinesis, CLOUDERA, MATLAB

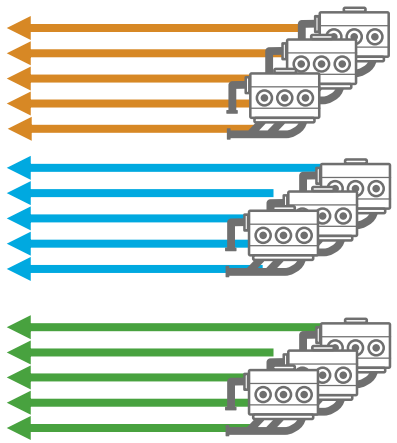
Edge

Loggers

Smart gateway

Linux Server

Assets

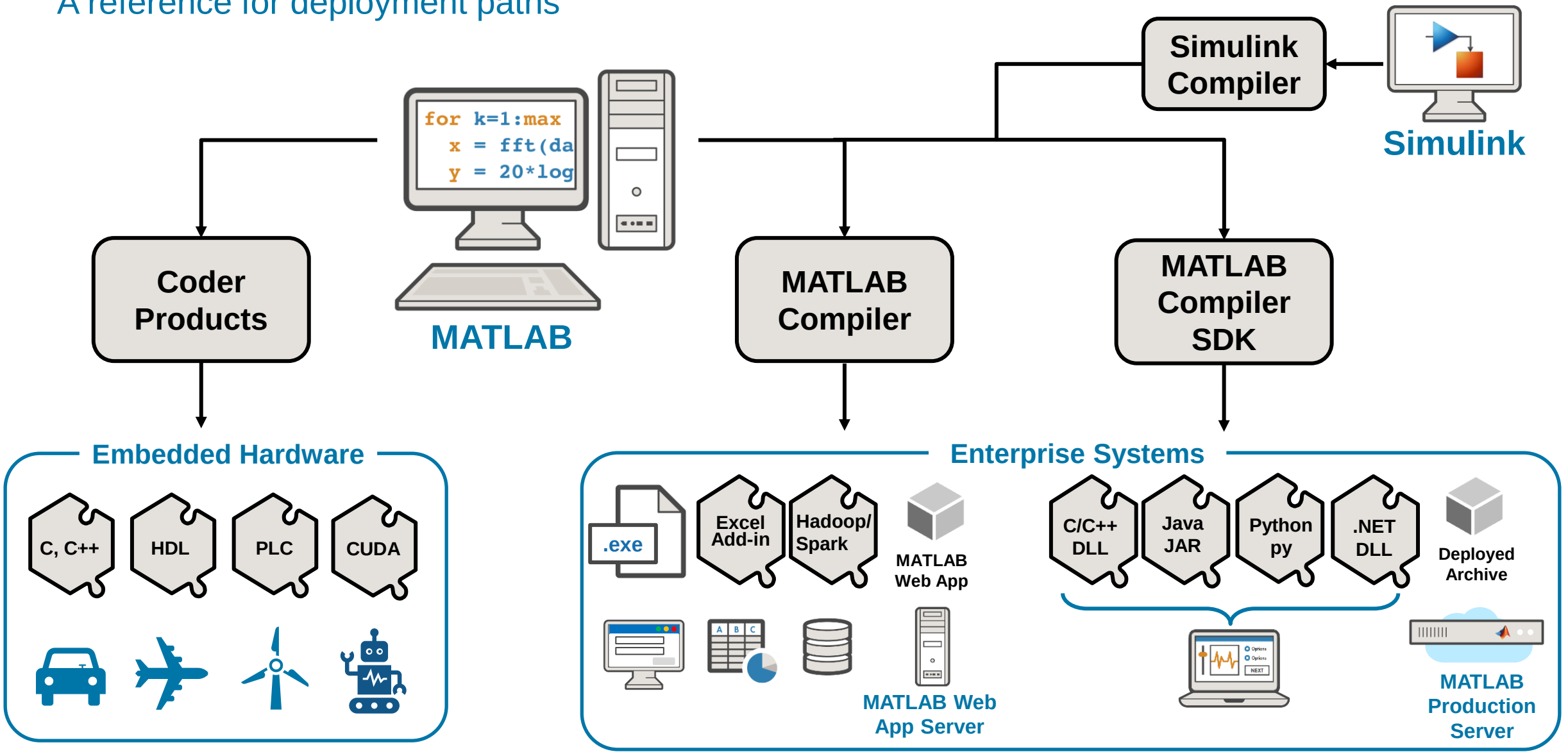


# Agenda

- Level setting & common understanding
- Project update
- Next steps and future state
- Resources & Collateral

# Operationalizing your MATLAB Analytics

## A reference for deployment paths



# Resources & Collateral

## Video Links

- Predictive Maintenance Series
  - Introduction
  - Feature Extraction for Identifying Condition Indicators
  - Remaining Useful Life
  - Diagnostic Feature Designer
  - Digital Twin
- Relevant Topics
  - Digital Twin Parameter Tuning
  - What is Predictive Maintenance Toolbox?
  - Predictive Maintenance Using Deep Learning
  - Deploying AI on PLCs
  - Federated Learning w/ Physical Models

MathWorks
# AUTOMOTIVE CONFERENCE 2022
North America

## Thank you