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North America

Building a Cloud-Based Digital Twin for an EV Battery Pack

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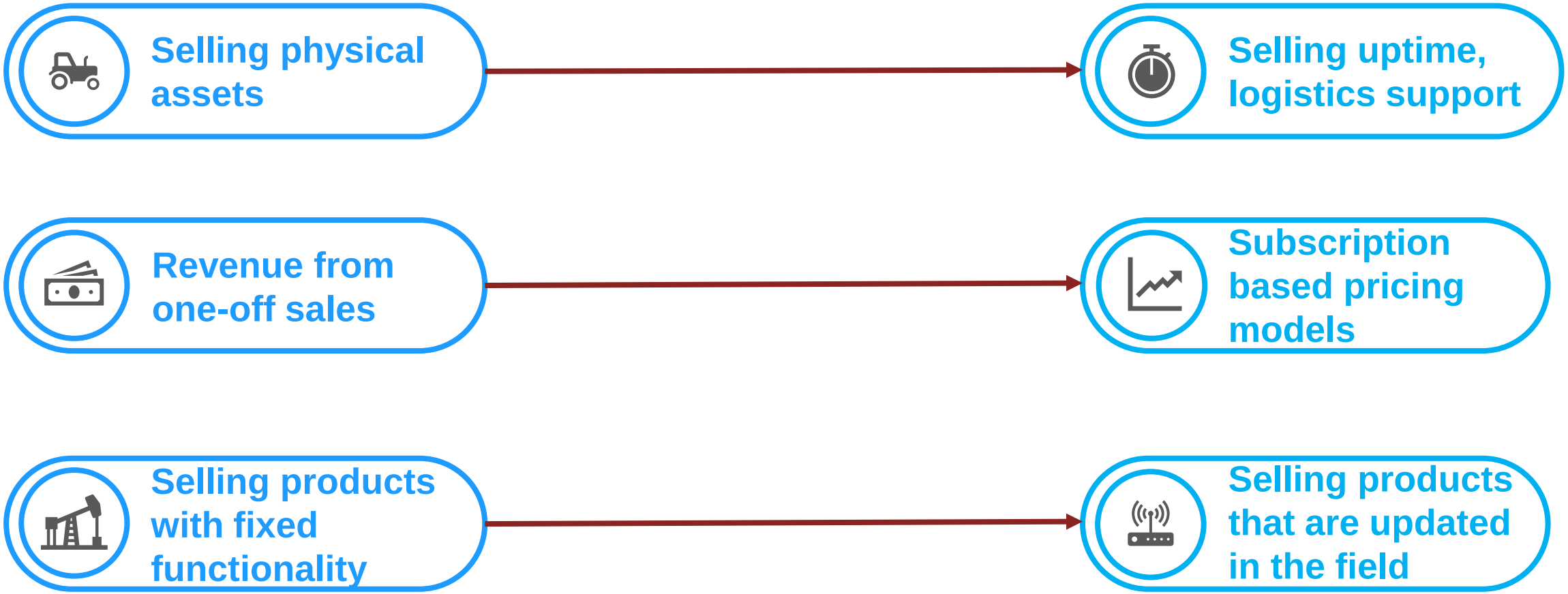
Digital Twin is a major trend and a new way of thinking in the era of Digital Transformation



Digital Twin adoption is a journey that involves people, process, and technology

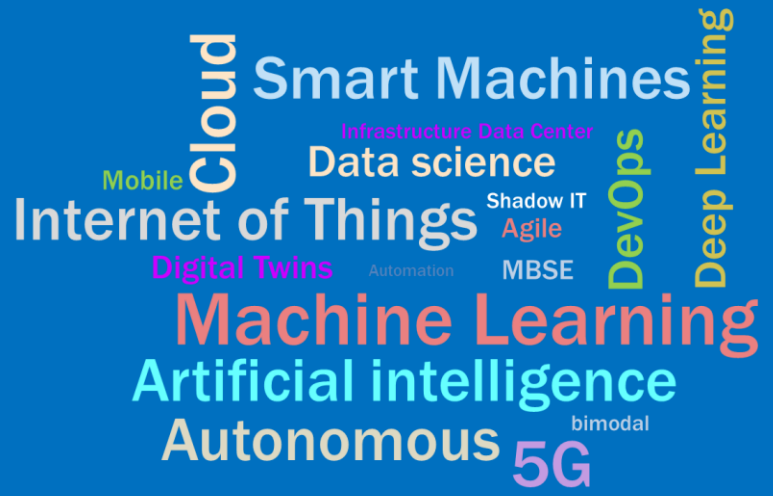
Selling physical assets

Revenue from one-off sales

Selling products with fixed functionality

Digital Products and Services

- Fleet Management
- Predictive Maintenance
- Smart Machine Optimization
- Anomaly Detection



Selling uptime, logistics support

Subscription based pricing models

Selling products that are updated in the field

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Building a Cloud-Based Digital Twin for an EV Battery Pack

Will Wilson, MathWorks

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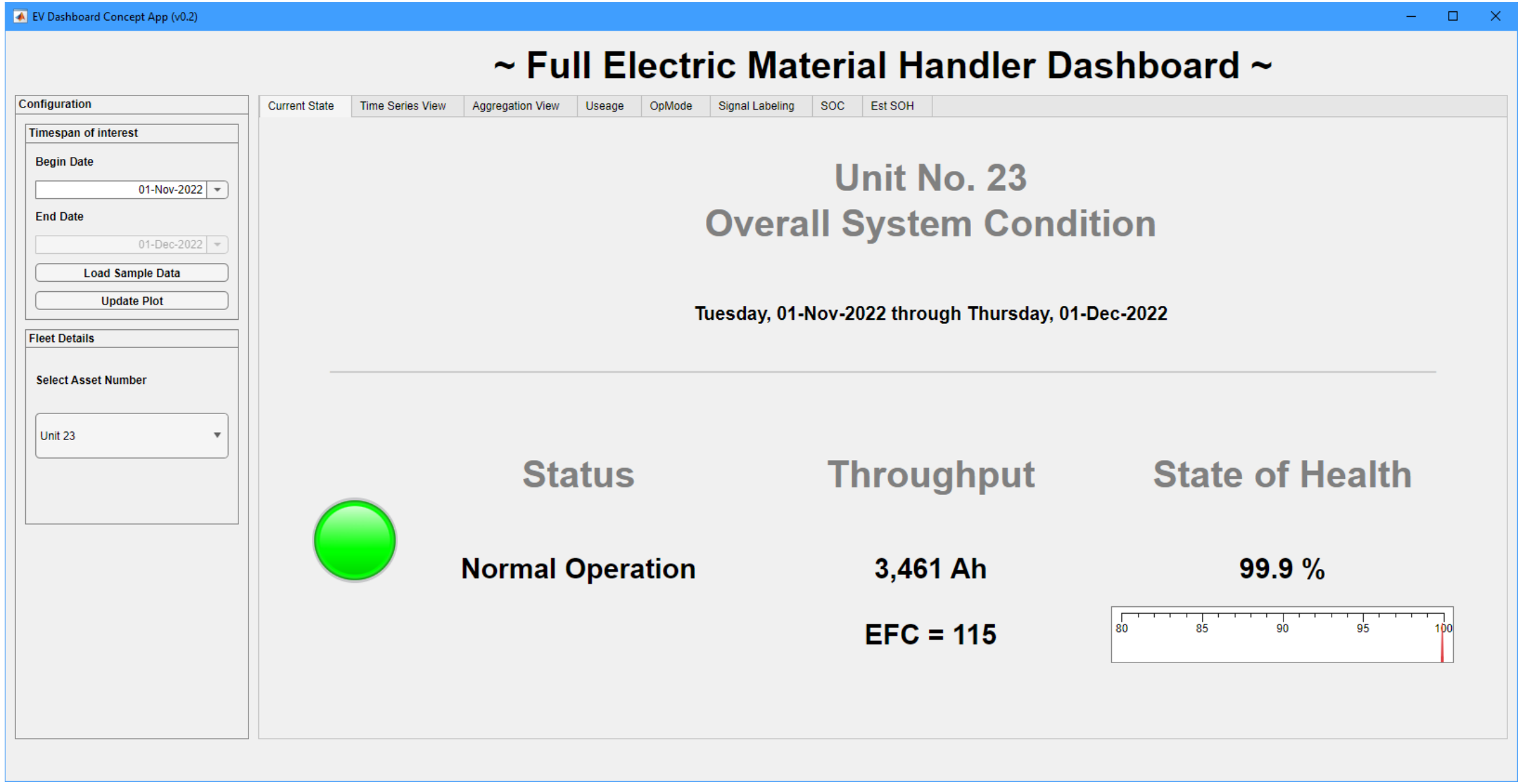
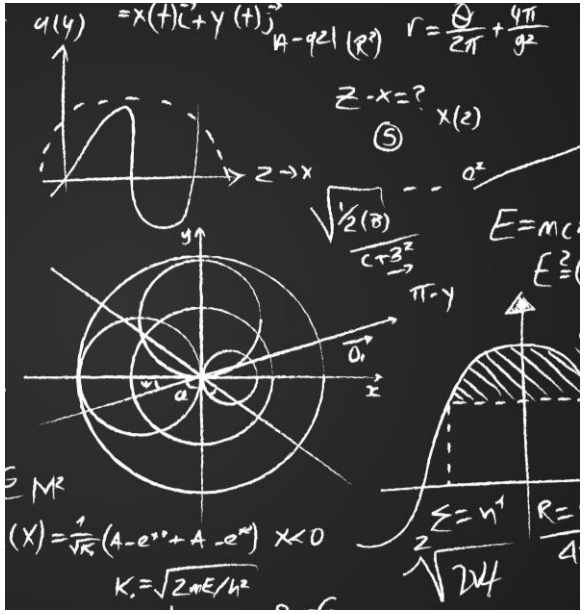
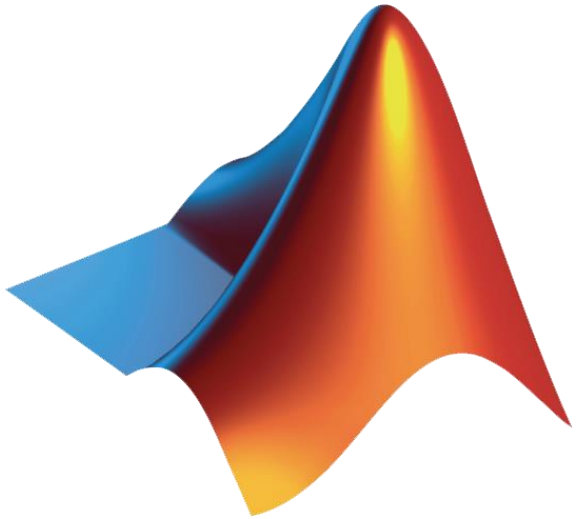
System performance dashboard



Agenda



Background and Common Understanding



Digital Twin Project

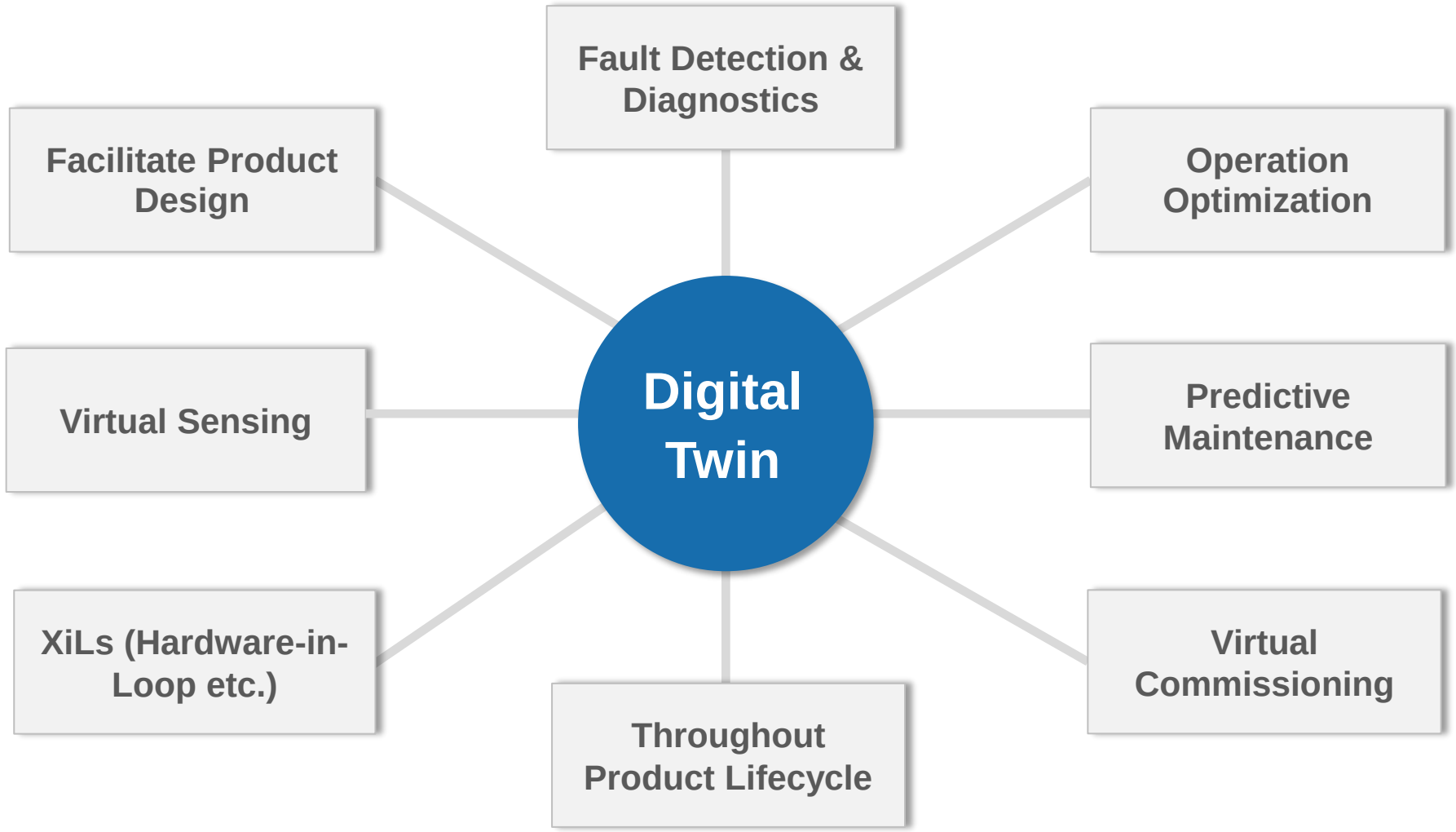
Resources and Next Steps

Let's get on the same page about the definition of "Digital Twin"

*A "**Digital Twin**" is a representation of an asset that calculates system states **to support decision making** through integrated, systematic use of data and models*

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

Digital Twin Use Cases



The traditional data analytics workflow is a good framework to discuss this type of project

Access and Explore Data

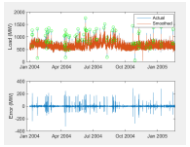
Files

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

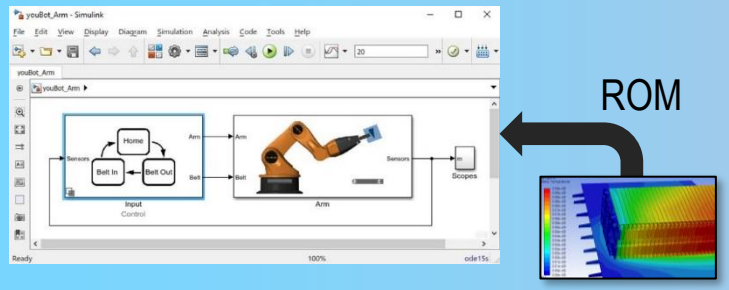
Digital Twin Model

Cloud Based Dashboard

Modeling approaches

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

Physics-Based



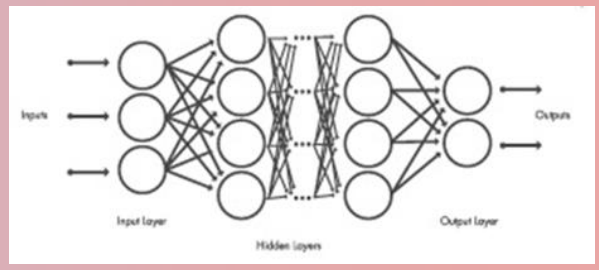
- Dynamic models of systems/components
- Electrical, mechanical, algorithms, etc.
- Can integrate models from other tools, e.g., FEM

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

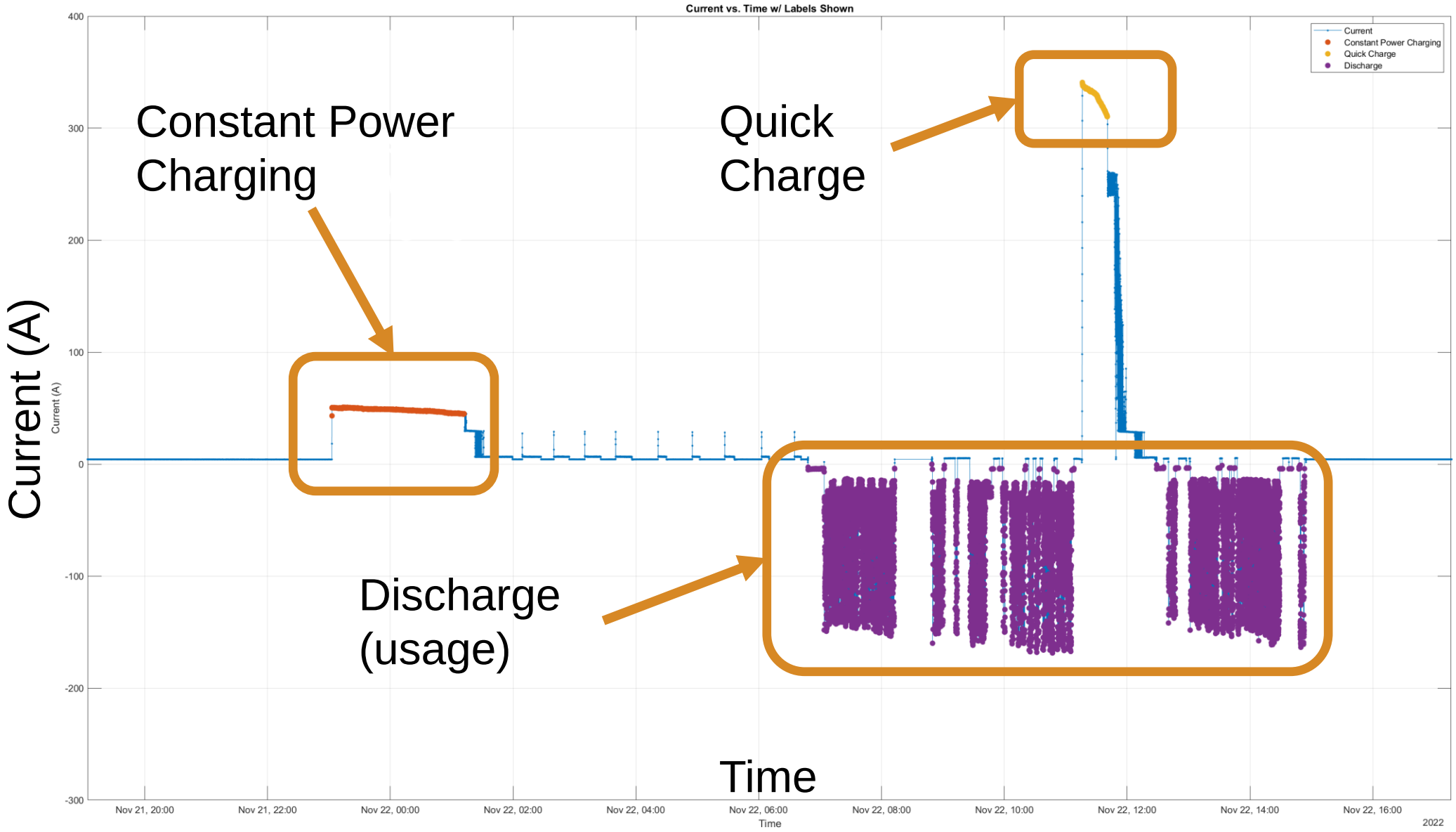
AI-Based



- 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?

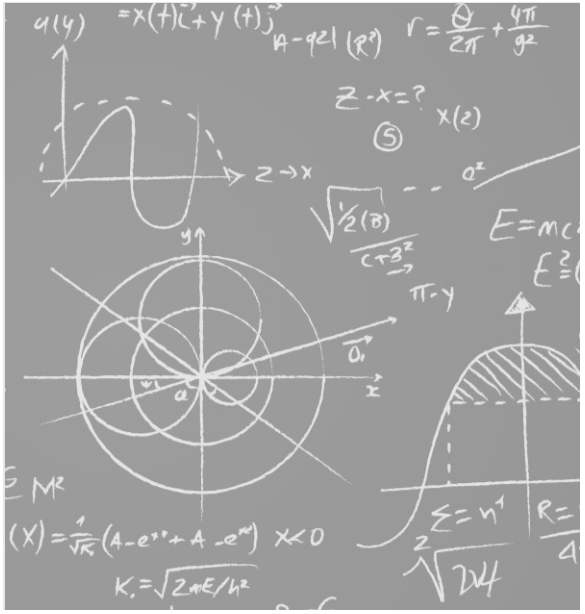
The ability to label your data is critically important



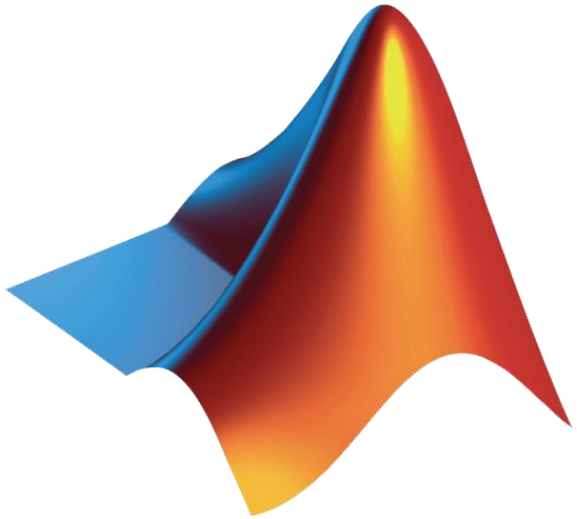
Labeled signal segments can be curated for future use

```
LabledSegments =

  26×4 table

        EventType              StartTime              EndTime            TotalTime
    ___________________    ____________________    ____________________    _________

    "ConstPwrCharge"       21-Nov-2022 23:03:02    22-Nov-2022 01:12:22    02:09:20
    "ConstPwrCharge"       22-Nov-2022 23:03:33    23-Nov-2022 01:45:01    02:41:28
    "QuickCharge"          21-Nov-2022 11:08:12    21-Nov-2022 11:33:09    00:24:57
    "QuickCharge"          22-Nov-2022 11:16:12    22-Nov-2022 11:40:36    00:24:24
    "QuickCharge"          23-Nov-2022 10:57:50    23-Nov-2022 11:23:13    00:25:23

           :                      :                       :                      :

    "Discharge"            23-Nov-2022 09:31:54    23-Nov-2022 10:39:29    01:07:35
    "Discharge"            23-Nov-2022 10:54:42    23-Nov-2022 10:55:57    00:01:15
    "Discharge"            23-Nov-2022 12:43:57    23-Nov-2022 12:52:48    00:08:51
    "Discharge"            23-Nov-2022 13:02:28    23-Nov-2022 14:13:45    01:11:17
    "Discharge"            23-Nov-2022 14:35:44    23-Nov-2022 14:53:16    00:17:32
```

Agenda



Background and Common Understanding



Digital Twin Project

Resources and Next Steps

Project goal and scope

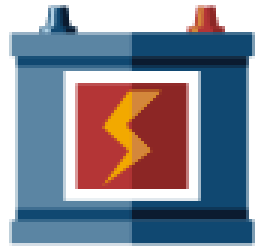
Demonstrate how an EV battery pack digital twin could be developed and deployed

Goal

Given ~ 1.5 years of raw vehicle log data stored in the cloud, build a digital twin of an EV battery pack of a Full Electric Material Handler in order to understand (and estimate) system behavior.

Scope

This project focused on developing a data engineering pipeline, creating a simple digital twin model, and informing the end user of things like estimated battery state of health, system usage, etc. via a MATLAB WebApp dashboard.

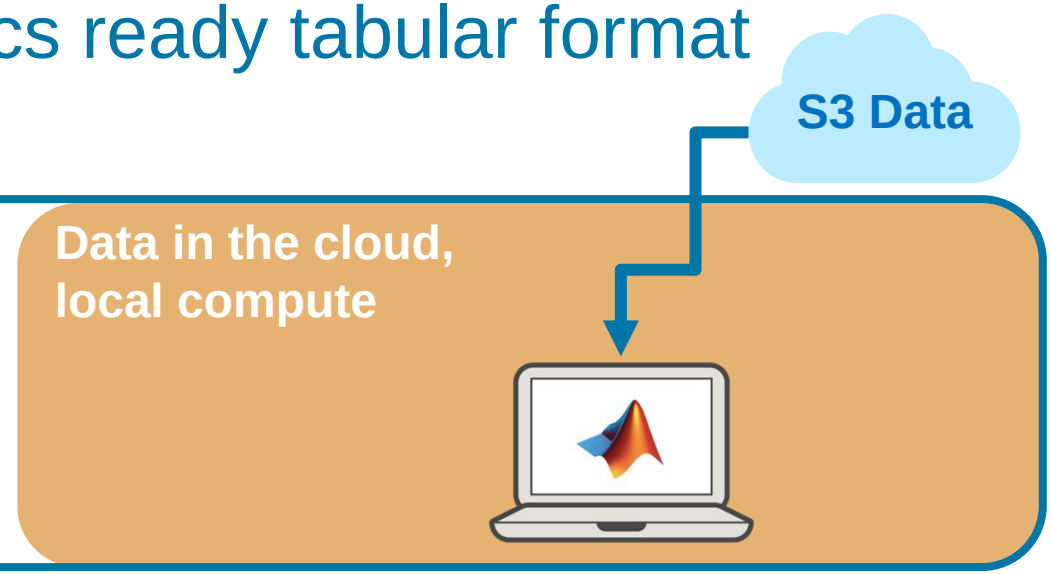


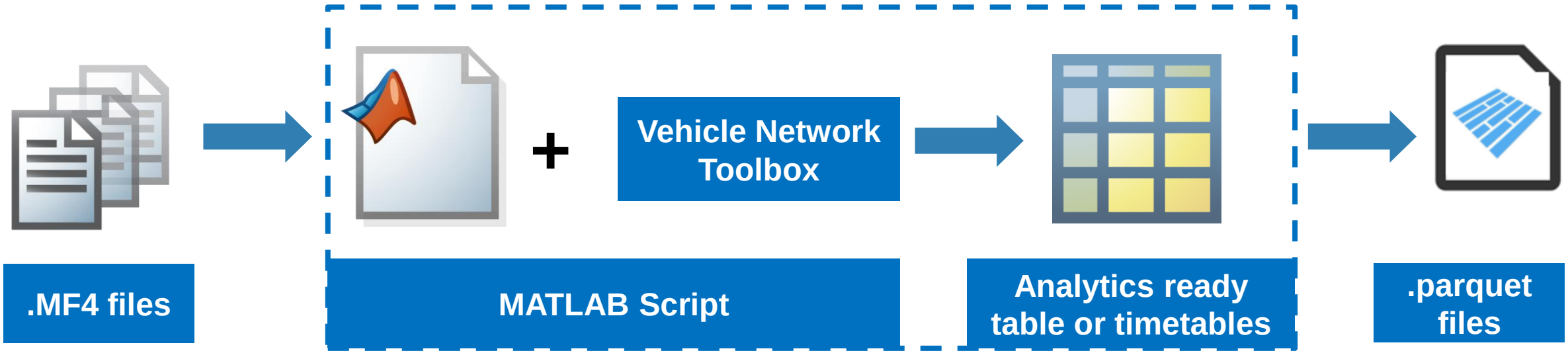
Anode material:
Lithium Titanate

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

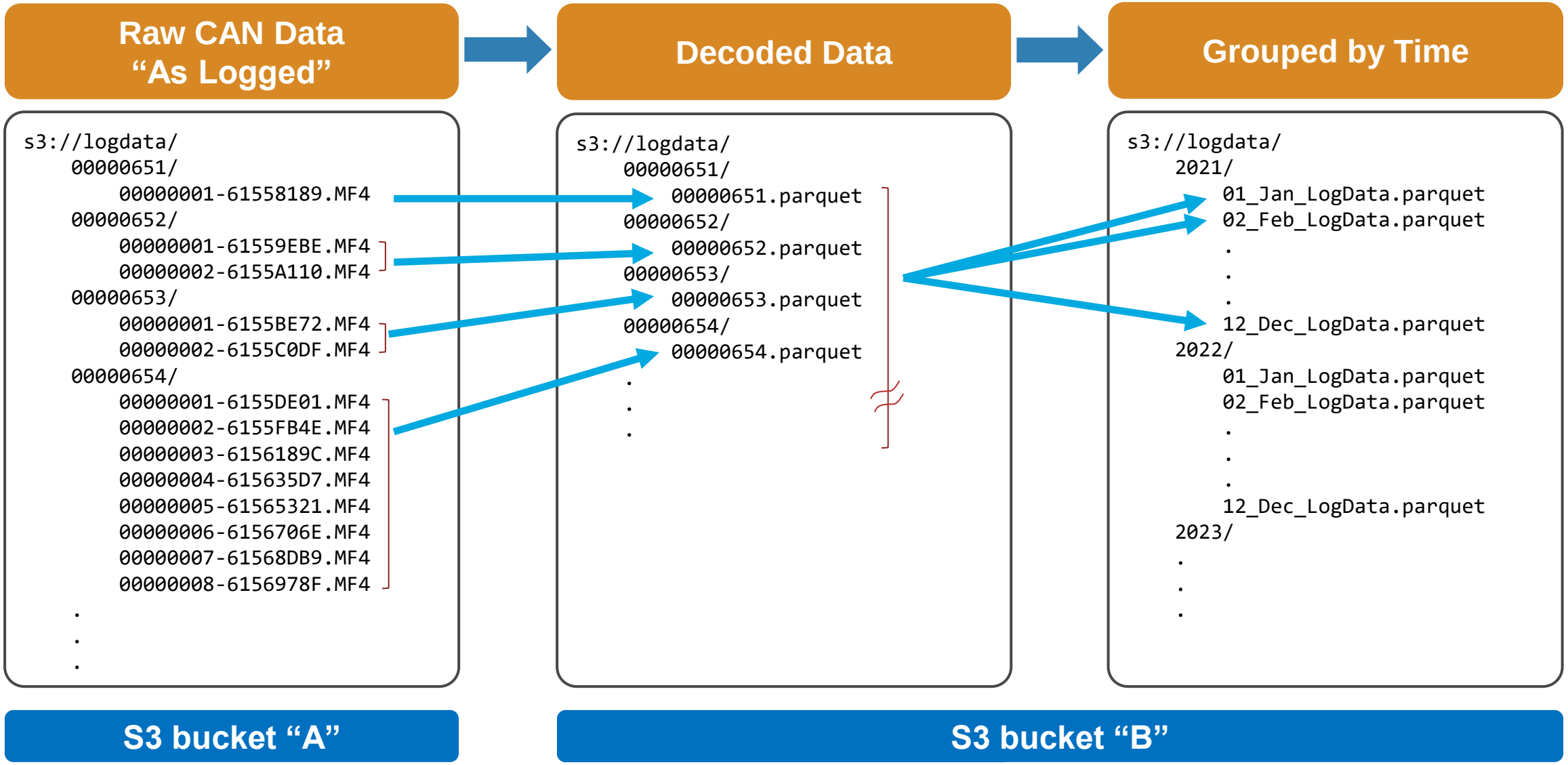
MATLAB was used to convert raw CAN data in .MF4 files into an analytics ready tabular format

- Understand the problem by accessing a few files
  - Scope the problem / understand the challenges





Data Engineering workflow and evolution



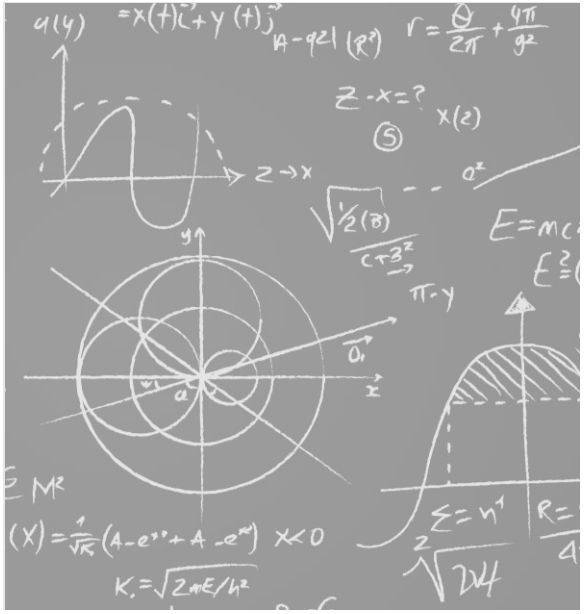
Digital Twin Project

(making sense of our data)

How does the “cloud” play into any of this?

- Logger data uploaded to an S3 bucket
  - External decision
- Dashboard can be hosted on the cloud
  - See reference architectures on GitHub
- Data Engineering Pipeline is cloud based
  - Take advantage of additional (parallel compute) & data locality
- Enables connecting to other systems and software applications
  - databases, cloud services, etc.

Agenda



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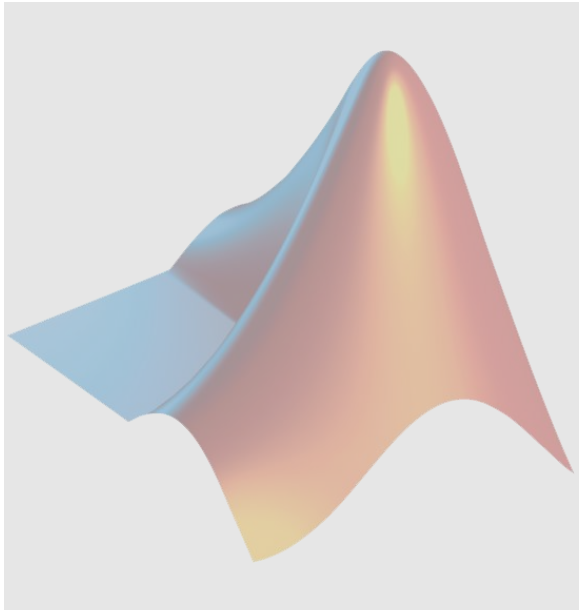

Digital Twin Project

Resources and Next Steps

Attend an upcoming webinar on 4-May-2023

mathworks.com/company/events/webinars/upcoming/devops-with-matlab-a-predictive-maintenance-system-for-streaming-data-3979653.html

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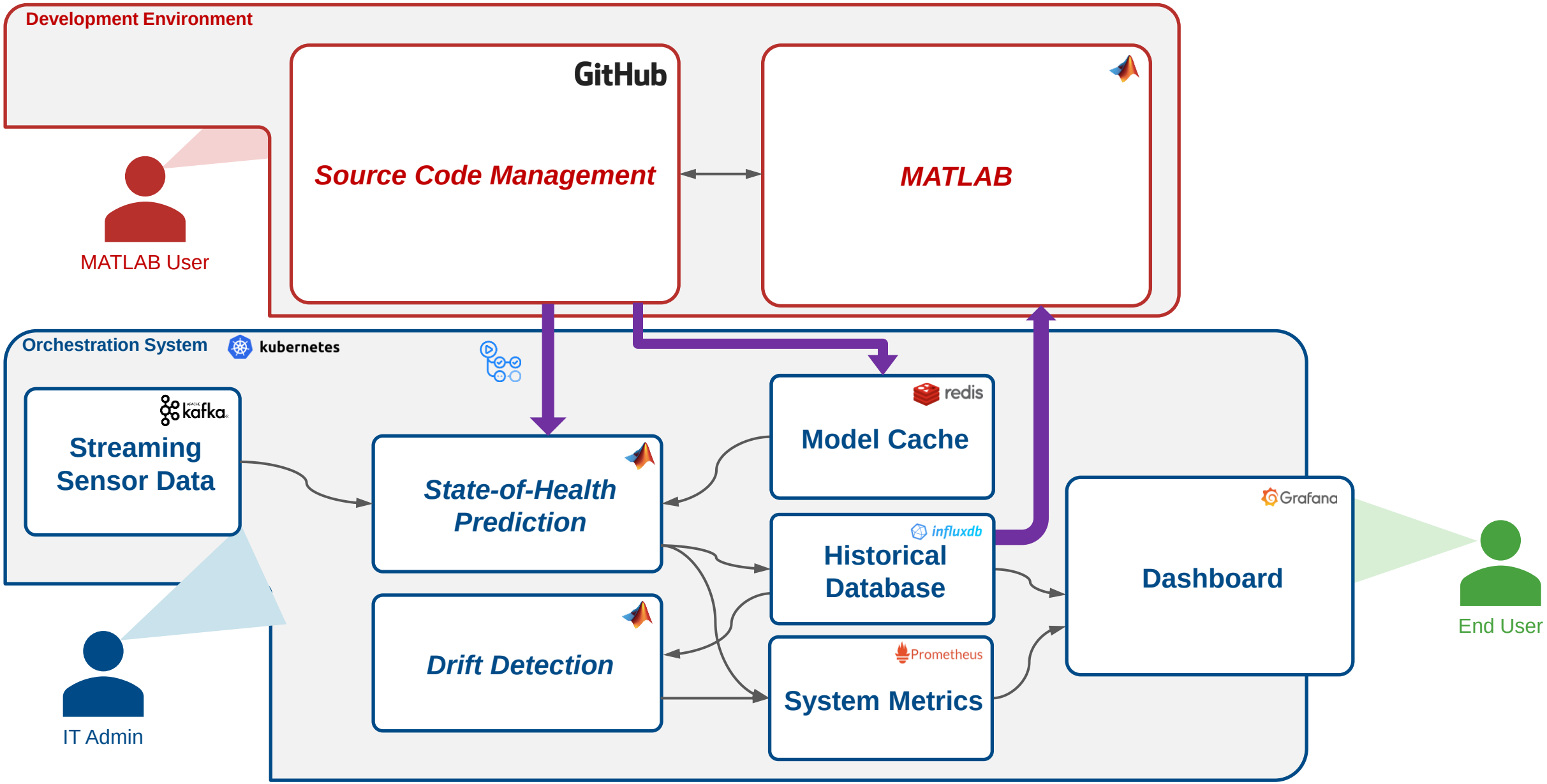
Live Events

DevOps with MATLAB: A Predictive Maintenance System for Streaming Data

Start Time	End Time
4 May 2023, 5:30 AM EDT	4 May 2023, 6:30 AM EDT
4 May 2023, 9:00 AM EDT	4 May 2023, 10:00 AM EDT
4 May 2023, 2:00 PM EDT	4 May 2023, 3:00 PM EDT

[Link]

Webinar will get into these concepts



Simscape Battery

mathworks.com/products/simscape-battery.html#:~:text=Simscape%20Battery™%20provides%20design.across%20normal%20and%20fault%20conditions.

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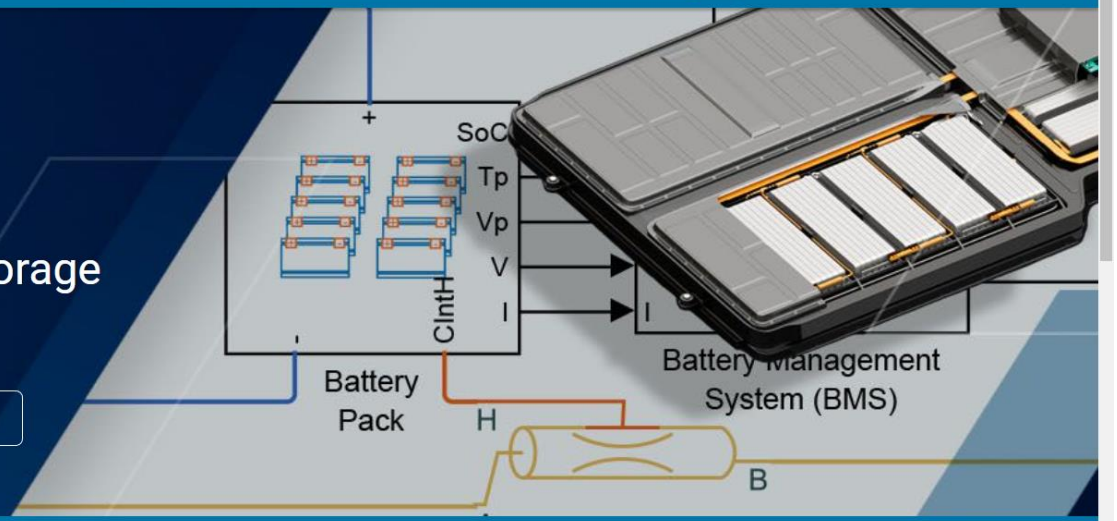
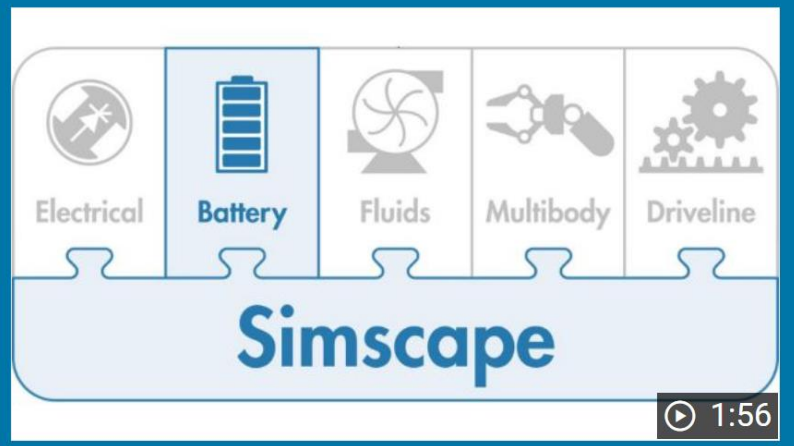


Simscape Battery™ provides design tools and parameterized models for designing battery systems. You can create digital twins, run virtual tests of battery pack architectures, design battery management systems, and evaluate battery system behavior across normal and fault conditions.

Battery Pack Model Builder is a design tool that lets you interactively evaluate different battery pack architectures. The tool automates the creation of simulation models that match the desired pack topology and includes cooling plate connections so electrical and thermal responses can be evaluated.

Parameterized models of battery packs and battery management systems demonstrate operations, including cell balancing and state of charge estimation. You can use these examples to determine cell

Show more



What is Simscape Battery?

Invest in yourself with focused training

Upcoming 2023 training related to what you saw today

MATLAB Fundamentals

June 6-8 / July 10-13

Building Interactive Applications in MATLAB

May 4 / August 16

Battery Modeling and Algorithm Development with Simulink

June 21-22 / August 9-10

MATLAB for Data Processing and Visualization

May 3 / October 17

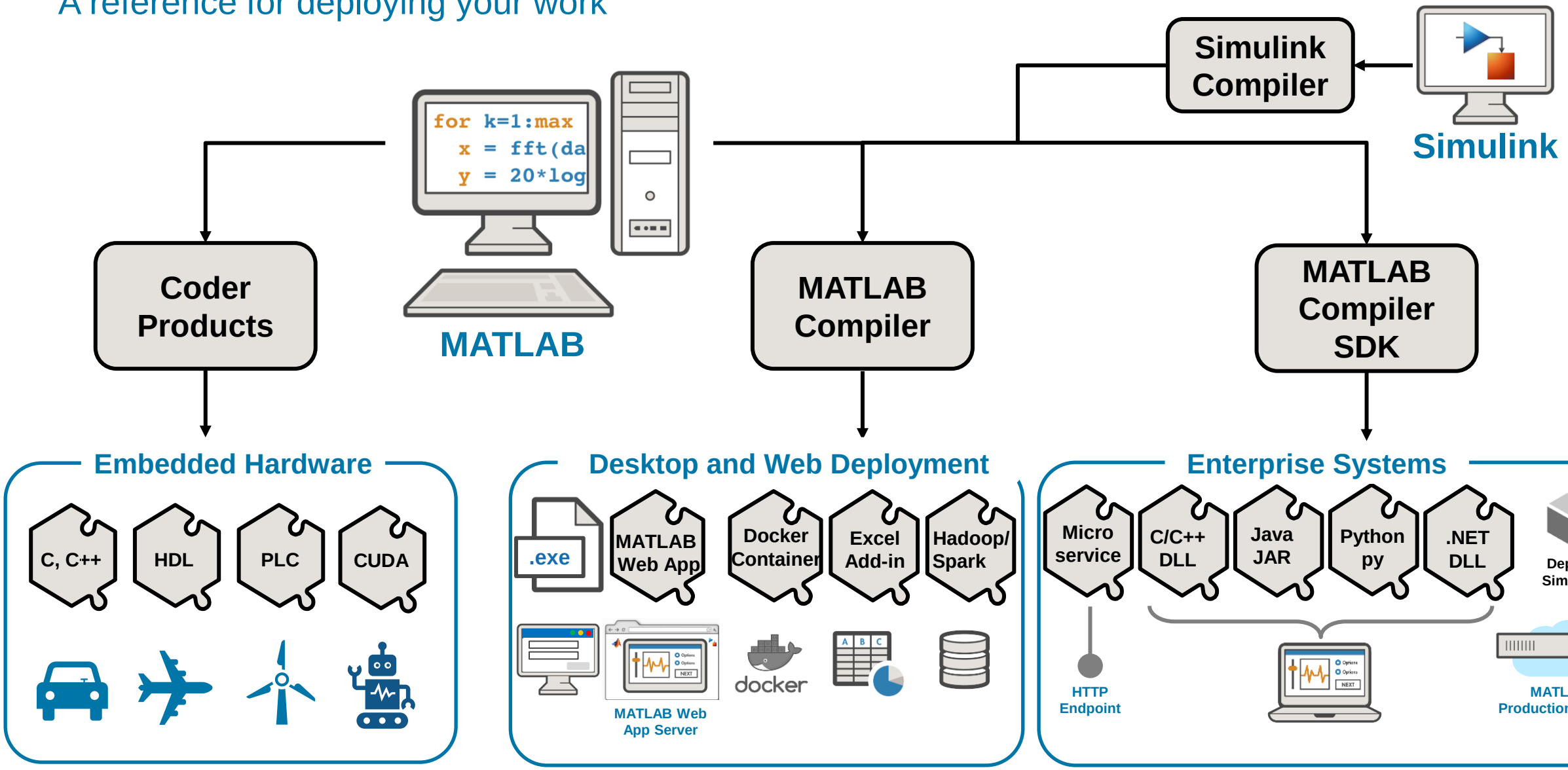
Predictive Maintenance with MATLAB

October 25-26

For complete offerings, visit mathworks.com/training

Talk to us about operationalizing your work

A reference for deploying your work



In summary

- **Digital Twin** is a **major trend**
  - It is a new way of thinking and working in the era of **Digital Transformation**
- **Digital Twin adoption** is a **journey**
  - It takes **People, Process and Technology** to have a sustainable, broad success
- Forwarding thinking companies are building up their **Digital Twin Capabilities** and generating **incremental values** through individual projects with positive ROI

MathWorks is here to help you succeed in Digital Twin applications

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Thank you

wwilson@mathworks.com

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