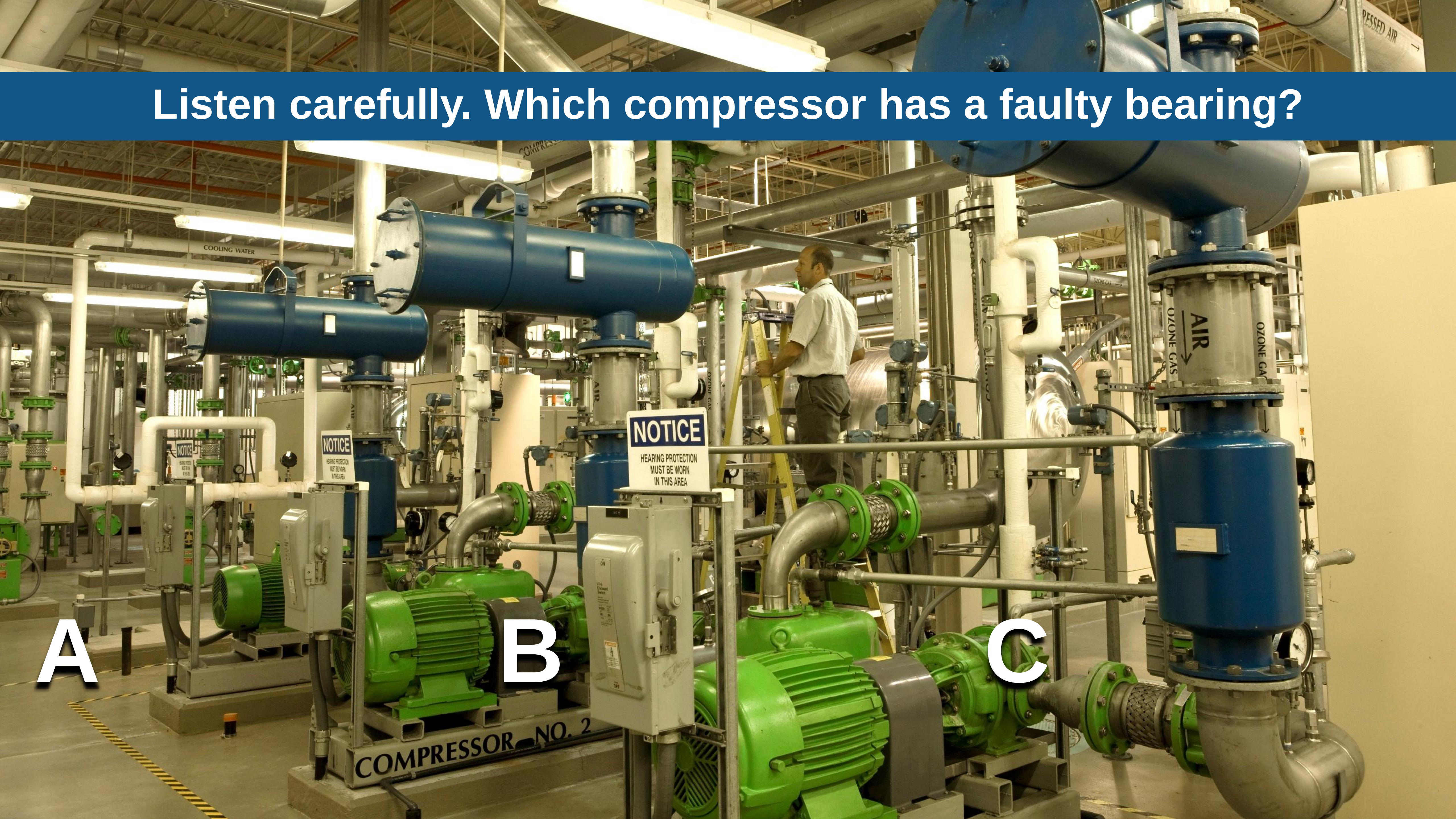
MATLAB EXPO 2021

Predictive Maintenance Using Deep Learning

Sudheer Nuggehalli *Rachel Johnson*

MathWorks®

Listen carefully. Which compressor has a faulty bearing?



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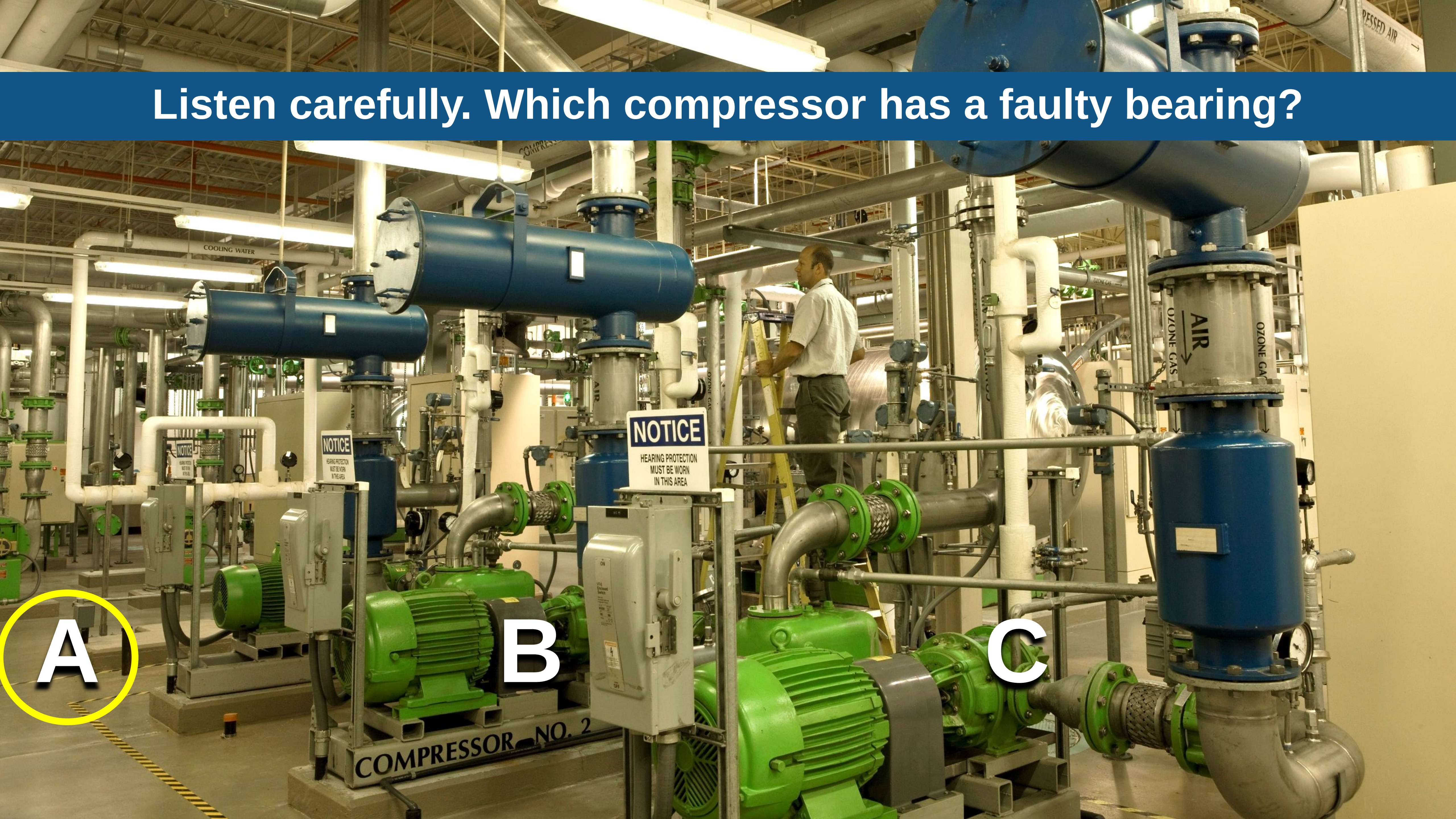

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Key Takeaways for Predictive Maintenance

Small gains can yield big rewards.
Try different approaches, including deep learning.

You need AI *and* domain expertise.
MATLAB helps you do both.

MATLAB can automate your entire workflow

Journey 1:
Do you speak air compressor?

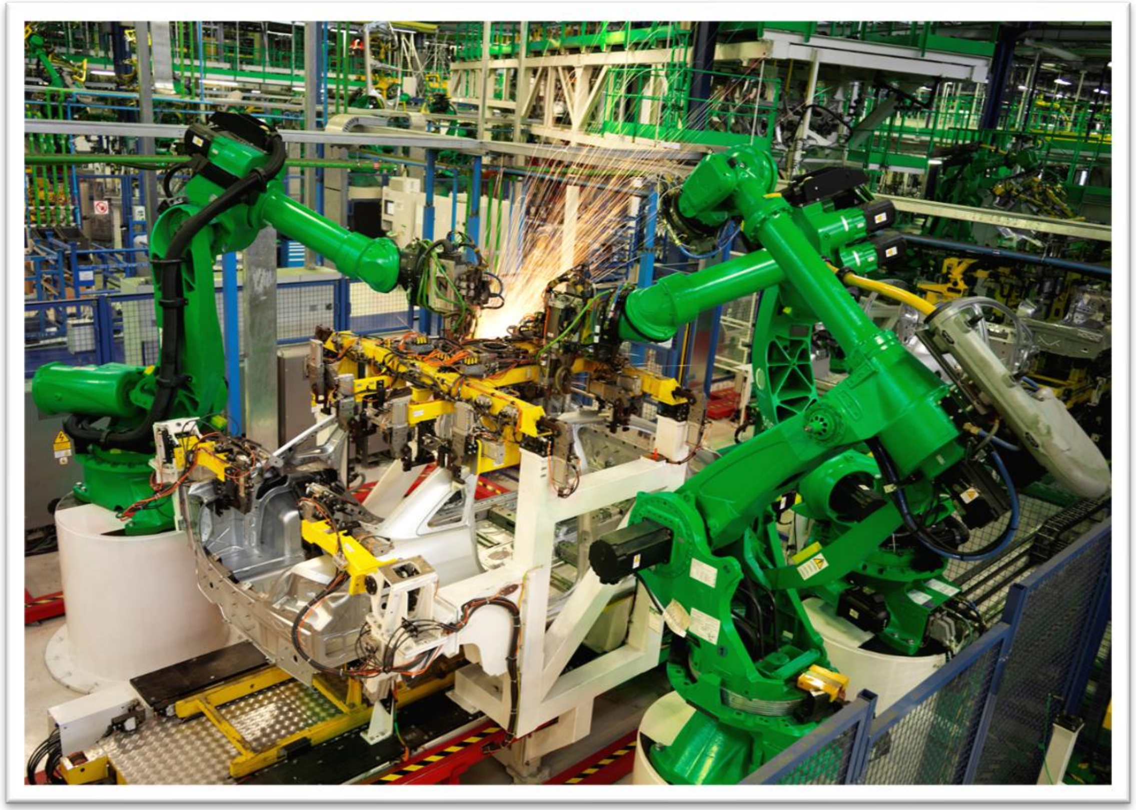
Fault Isolation with Acoustic Data

Journey 2:
Data, data, everywhere

Anomaly Detection with Vibration Data

Meet Rachel*

- Mechanical Engineer at Membrane Manufacturing**
- Responsible for a fleet of industrial machines
- New company AI initiative
- No deep learning experience



Membrane Manufacturing

*Rachel is an actor who works at MathWorks
**Not a real company

Predictive Maintenance Workflow

DATA PREPARATION

- Data access and preprocessing
- Simulation-based data generation
- Feature engineering

Predictive Maintenance Workflow

DATA PREPARATION		AI MODELING
Data access and preprocessing	⟷	Model design and tuning
Simulation-based data generation		Hardware-accelerated training
Feature engineering		Model exchange across frameworks

Predictive Maintenance Workflow

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AI MODELING

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DEPLOYMENT

- Embedded Devices
- Enterprise Systems
- Edge, cloud, desktop

ITERATION & REFINEMENT

Journey 1: Do you speak air compressor?

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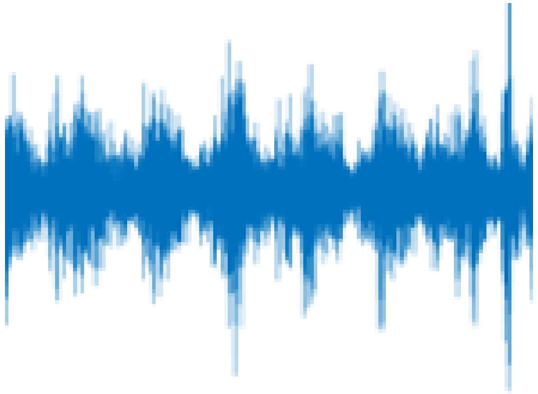
Goal | Data | Approach | Result

- **Fault detection:** Identify specific faults to enable maintenance staff to respond more quickly

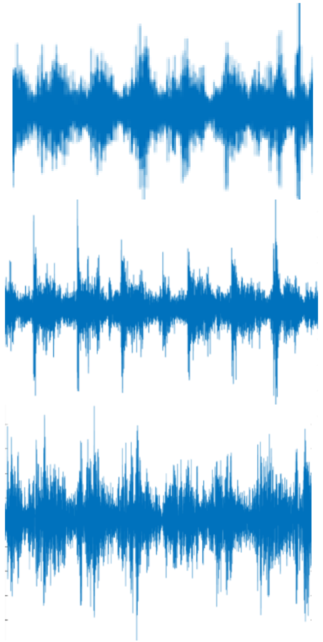


?

Journey 1: Do you speak air compressor?

Goal | **Data** | Approach | Result

- Acoustic time series data from sensors
- Labeled faults from maintenance logs



1. Healthy
2. Leakage Inlet Valve fault
3. Leakage Outlet Valve fault
4. Non-Return Valve fault
5. Piston Ring fault
6. Flywheel fault
7. Rider Belt fault
8. Bearing fault

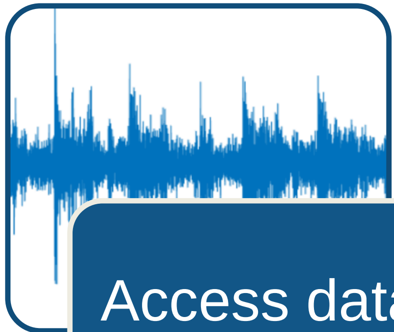
Journey 1: Do you speak air compressor?

Goal | Data | **Approach** | Result

Method	Validation Accuracy
Ensemble Bagged Trees	88%
Deep Neural Network	?

Journey 1: Do you speak air compressor?

Goal | **Data** | **Approach** | **Result**



Access data with datastore

```
audioFeatureExtractor('SampleRate
Window',hamming(windowLength,'peric
OverlapLength',overlapLength,...
spectralCentroid',true, ...
spectralCrest',true, ...
spectralDecrease',true, ...
spectralEntropy',true,...
spectralFlatness',true,...
spectr
spect
spect
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```
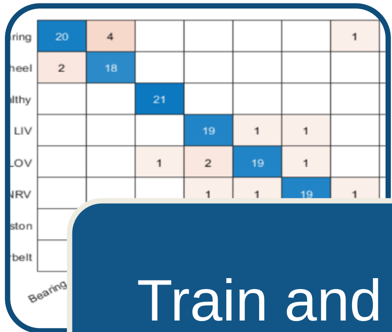

Extract features with Audio Toolbox



Train and validate LSTM

```
d extractFeatures_init

onfig.linearSpectrum.N
or (int i = 0; i < 257
  config.OneSidedSpectr
+ 1U);
  config.linearSpectrum
rt>(
  co
tic
```

Generate C code for edge deployment

Air Compressor Data Classification

Part 1: Data Preparation

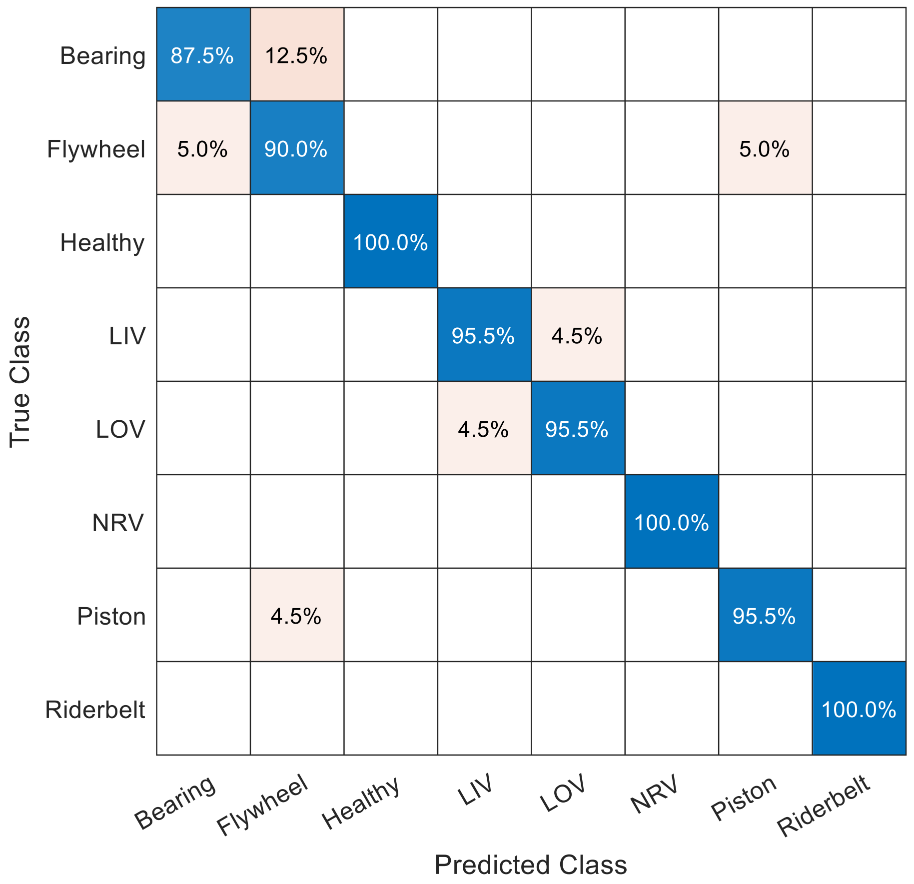
Table of Contents

Journey 1: Do you speak air compressor?

Goal | Data | Approach | **Result**

- Successfully identified faults with 95% validation accuracy

Method	Validation Accuracy
Ensemble Bagged Trees	88%
Deep Neural Network	95%



Journey 1: Do you speak air compressor?

Goal | **Data** | **Approach** | **Result**

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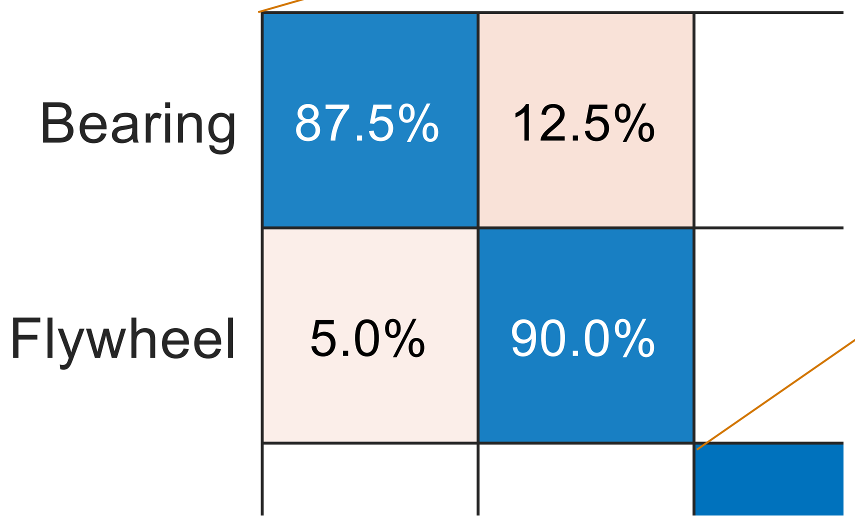

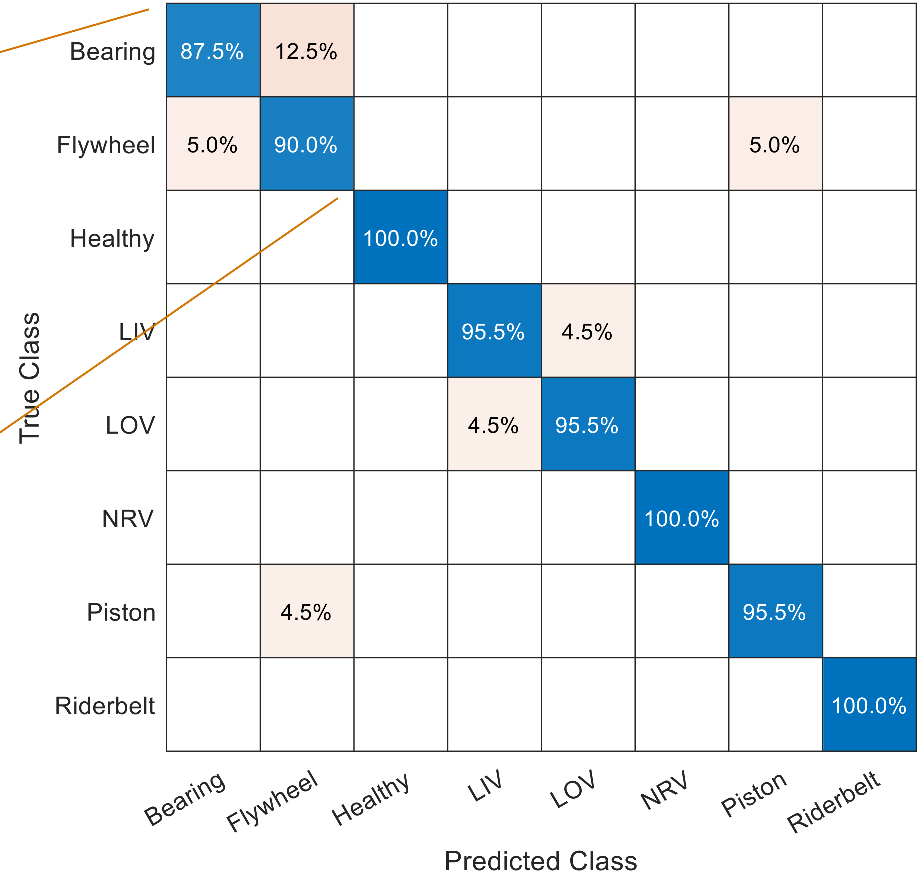

Journey 1: Do you speak air compressor?

Goal | Data | Approach | **Result**

Poll: How could we improve the results?

- ❑ Collect more data
- ❑ Tune network hyperparameters
- ❑ Try a different feature set
- ❑ Try a different algorithm
- ❑ Buy more GPUs

Journey 1: Do you speak air compressor?

Goal | Data | Approach | **Result**

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Journey 1: Do you speak air compressor?

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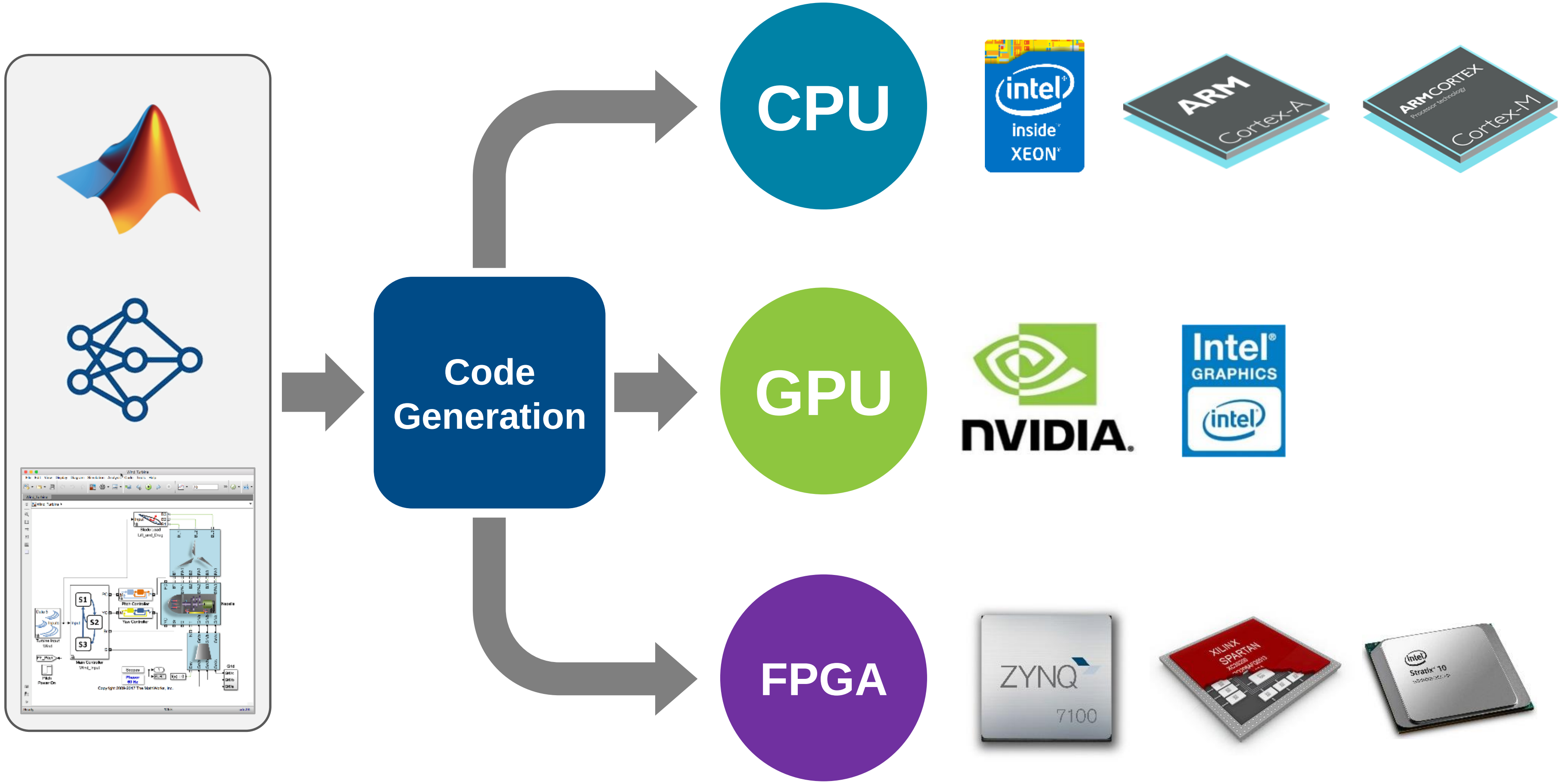

Journey 1: Do you speak air compressor?

Goal | Data | Approach | **Result**

- What's Next?

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Deploying AI to Embedded and Production Systems

Journey 2: Data, data, everywhere…

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Goal | Data | Approach | Result

- **Anomaly Detection:** Detect when the machine deviates from normal operation.
- Avoid surprises. Address anomalies before catastrophic failure occurs.

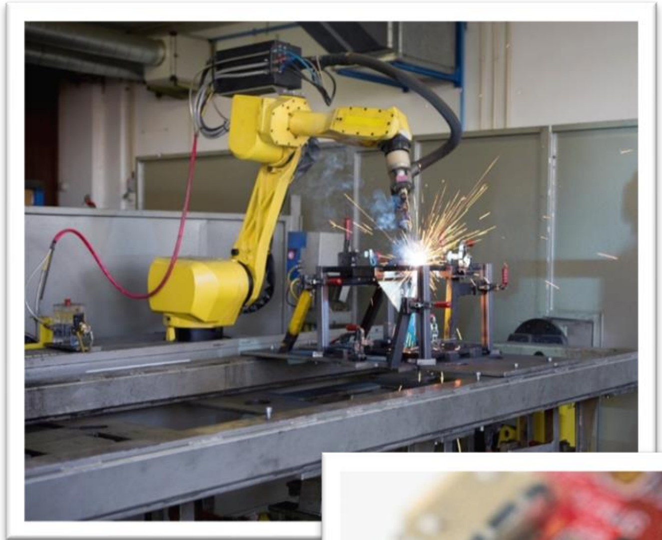
Currently

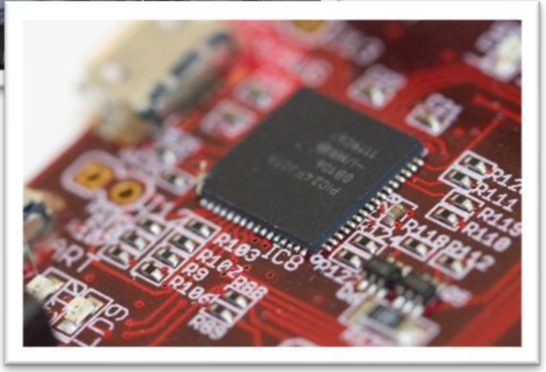
- Routine monthly maintenance
- Not many failures
- But when failures do happen…

Journey 2: Data, data, everywhere…

Goal | **Data** | Approach | Result

- Vibration data from 3-axis accelerometers
- Labeled “before” and “after” maintenance
  - “After” data = Normal ✓
  - “Before” data = Not sure **?**
- Some data tagged as “abnormal” by maintenance crews





Journey 2: Data, data, everywhere…

Goal | **Data** | **Approach** | **Result**

Method	Validation Accuracy
K-Means Clustering	85%
Autoencoder	?

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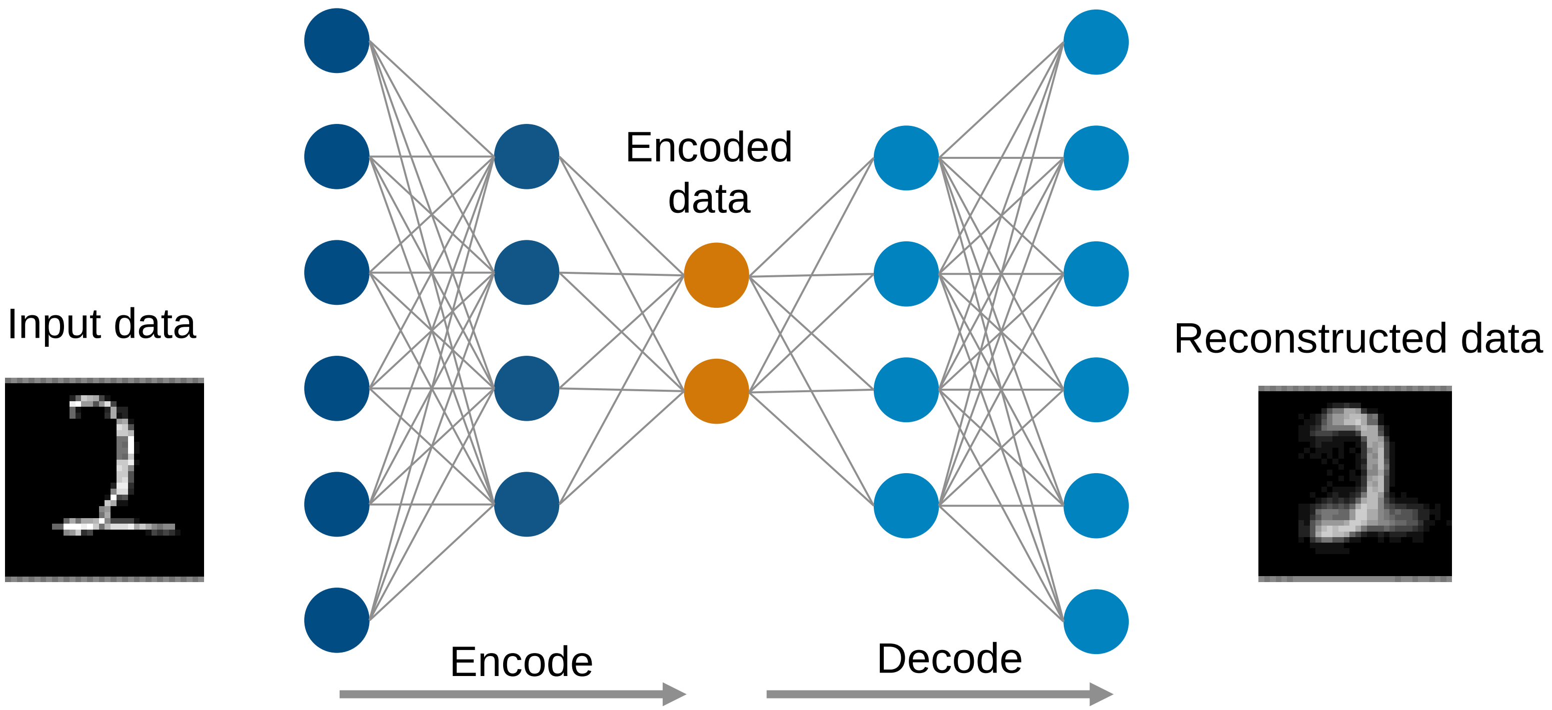
Journey 2: Data, data, everywhere…

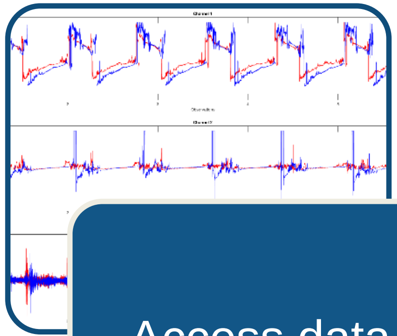
Goal | Data | **Approach** | Result

Autoencoder

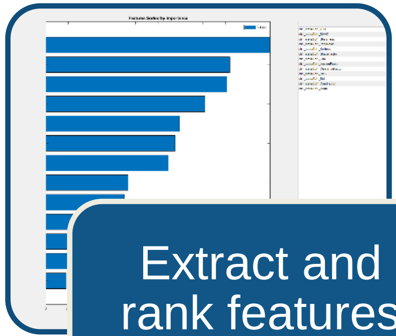


Journey 2: Data, data, everywhere…

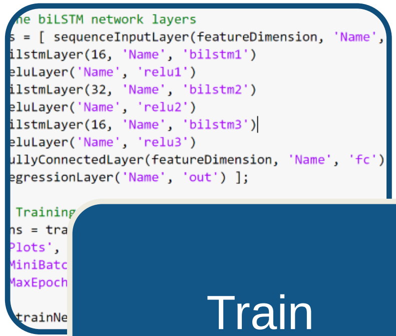
Goal | **Data** | **Approach** | **Result**



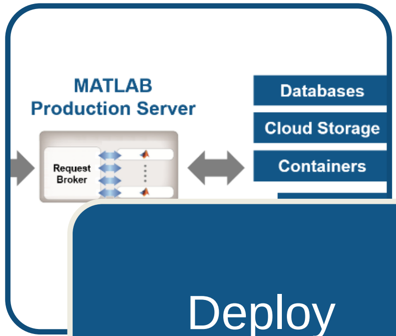
Access data from files



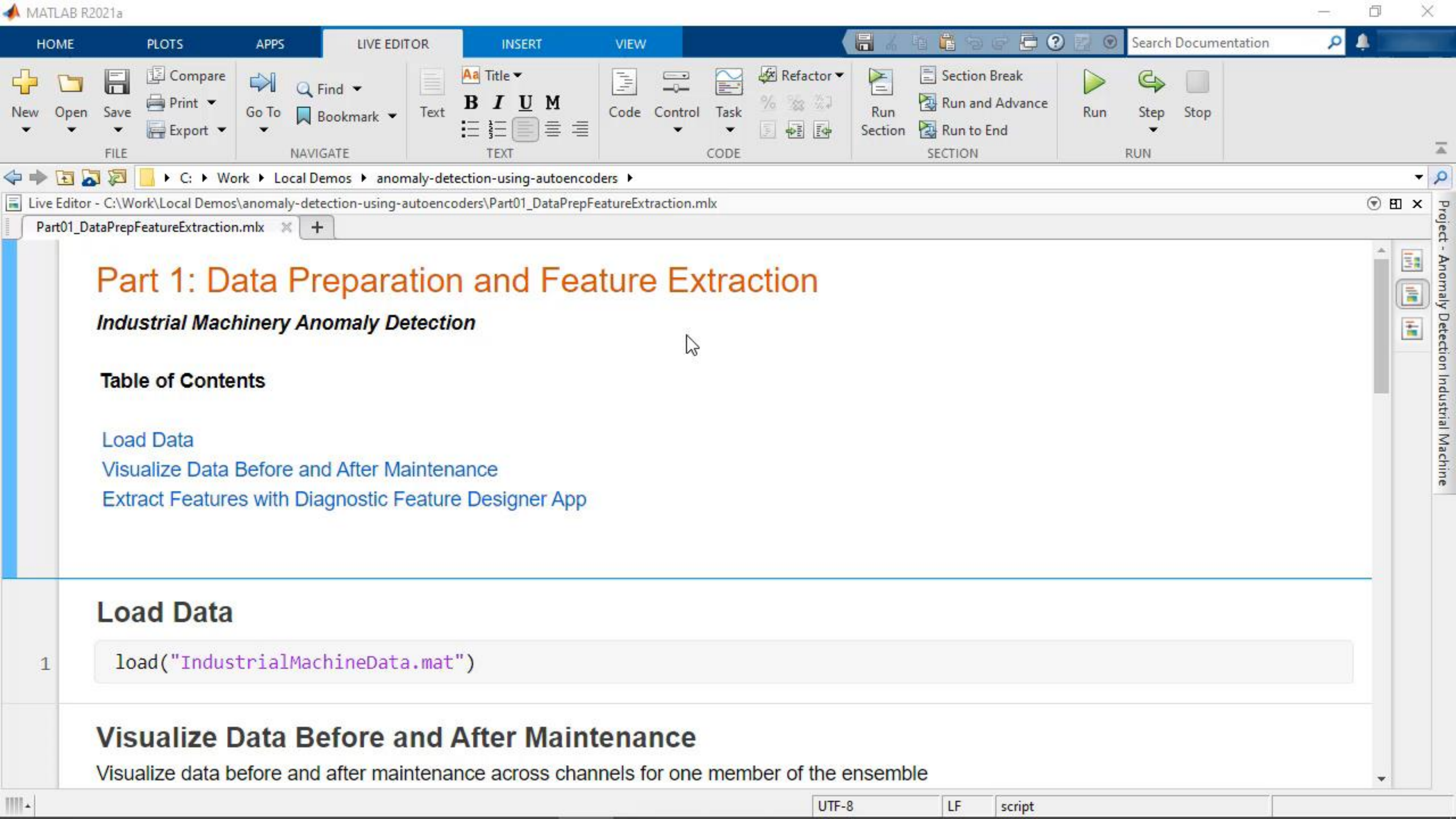
Extract and rank features with Diagnostic Feature Designer App



Train autoencoder on normal data



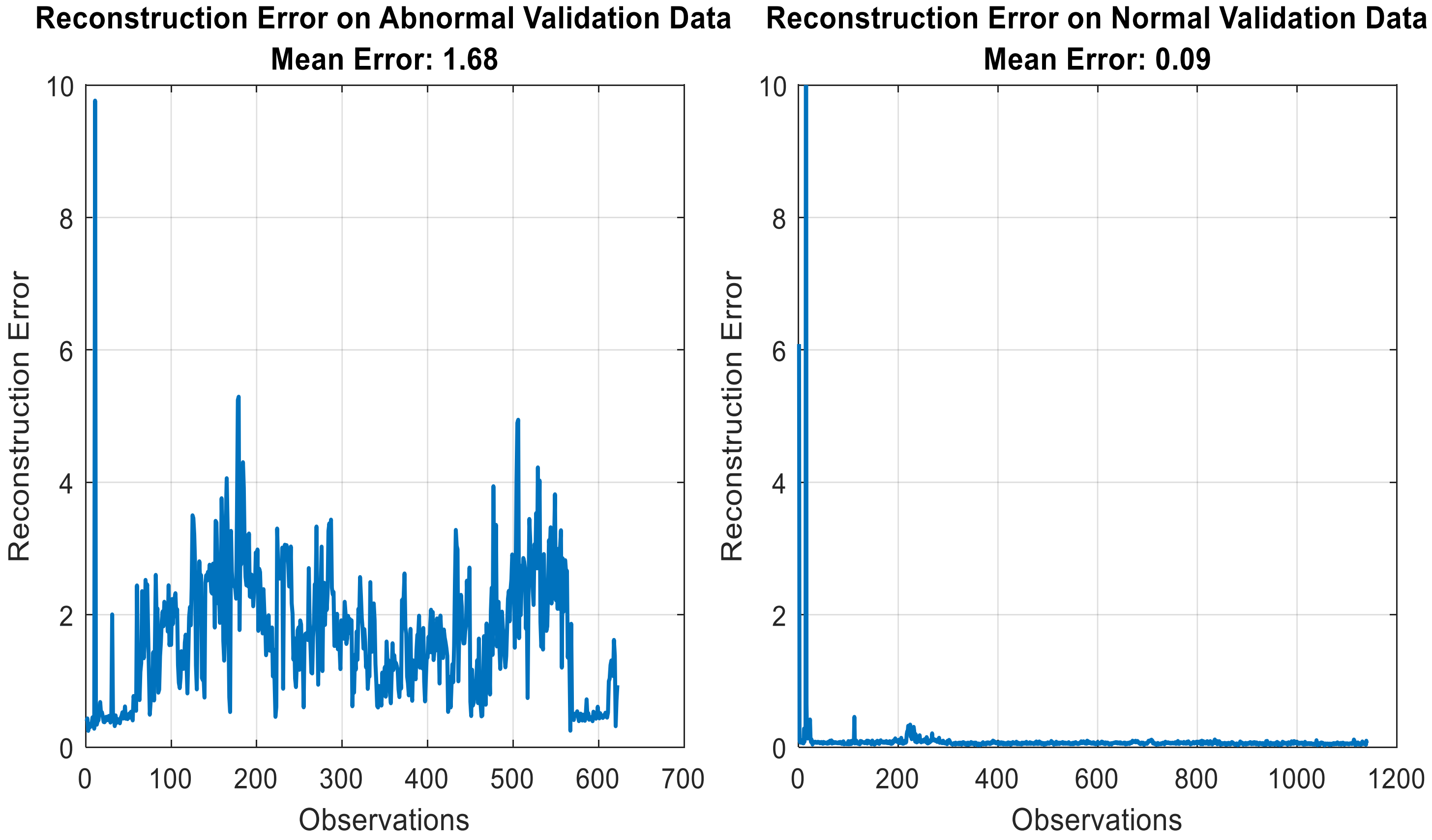
Deploy algorithms to the cloud


MATLAB R2021a
HOME
PLOTS
APPS
LIVE EDITOR
INSERT
VIEW
Search Documentation
New
Open
Save
Compare
Print
Export
FILE
Go To
Find
Bookmark
NAVIGATE
Text
Title
TEXT
Code
Control
Task
Refactor
CODE
Run Section
Section Break
Run and Advance
Run to End
SECTION
Run
Step
Stop
RUN
C: ▸ Work ▸ Local Demos ▸ anomaly-detection-using-autoencoders ▸
Live Editor - C:\Work\Local Demos\anomaly-detection-using-autoencoders\Part01_DataPrepFeatureExtraction.mlx
Part01_DataPrepFeatureExtraction.mlx
Part 1: Data Preparation and Feature Extraction
Industrial Machinery Anomaly Detection
Table of Contents
Load Data
Visualize Data Before and After Maintenance
Extract Features with Diagnostic Feature Designer App
Load Data
1 load("IndustrialMachineData.mat")
Visualize Data Before and After Maintenance
Visualize data before and after maintenance across channels for one member of the ensemble
Project - Anomaly Detection Industrial Machine
UTF-8
LF
script

Journey 2: Data, data, everywhere…

Goal | **Data** | **Approach** | **Result**

Method	Validation Accuracy
K-Means Clustering	85%
Autoencoder	99%



Journey 2: Data, data, everywhere…

Goal | Data | Approach | Result

- What's Next?

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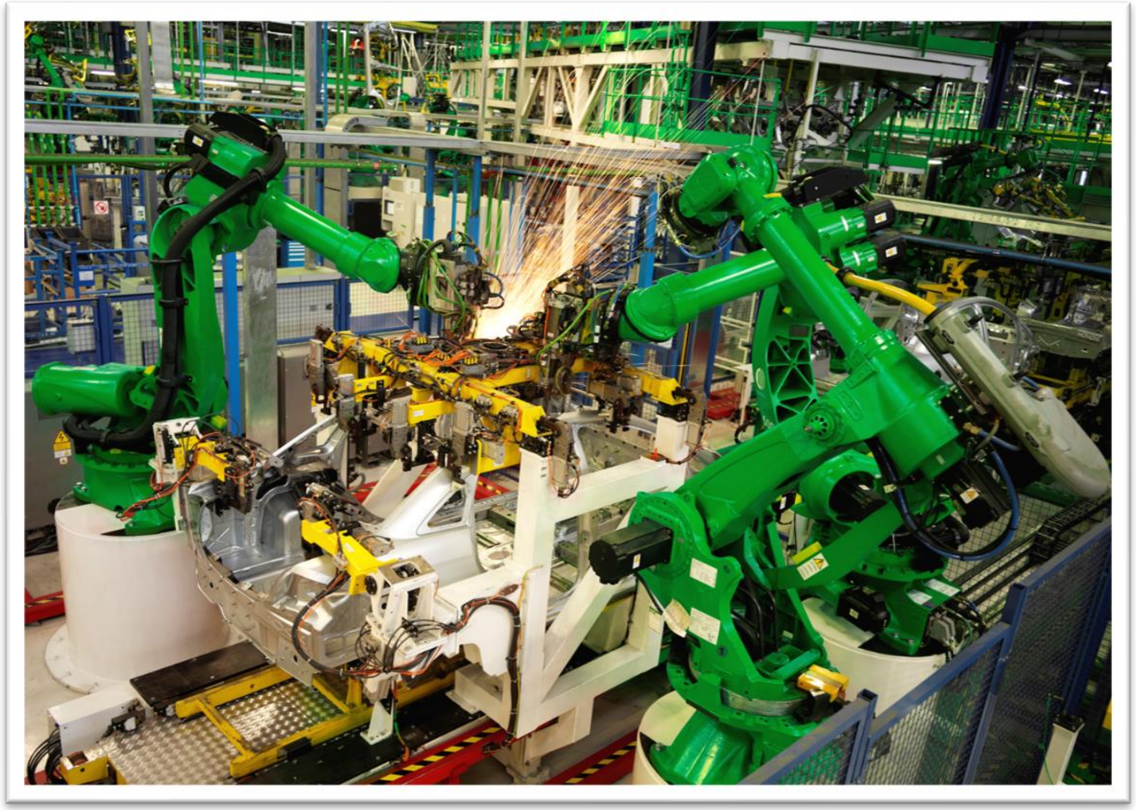
DevOps for Software and Systems:
Putting Algorithms and Models in Operation

Six months later…

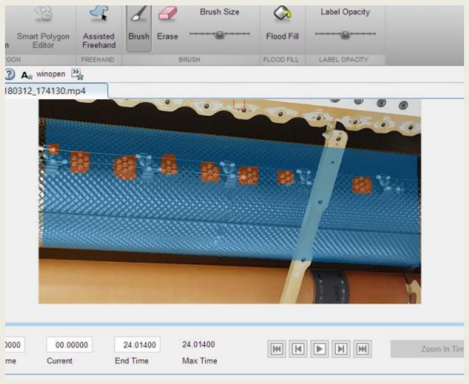
Six Months Later

- Increased uptime by 10%
- Want to expand to entire fleet, multiple locations
- Next project: Predict Remaining Useful Life (RUL)
- Got a promotion! ☺

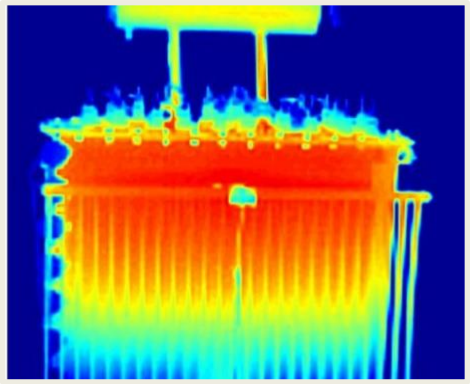


Membrane Manufacturing

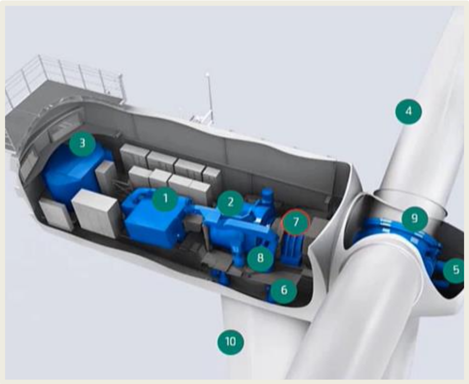
Companies are succeeding with MATLAB for Predictive Maintenance



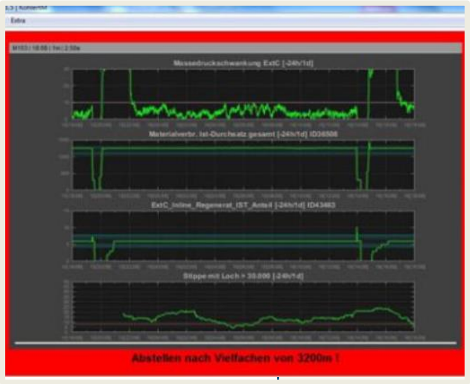
Airbus detects defects in aircraft pipes with semantic segmentation



Siemens develops health monitoring system for distribution transformers



RWE Renewables detects anomalies in wind turbine bearings using neural networks



Mondi develops and deploys algorithms to predict plastic production machine failures

LG Energy Solution used Deep Learning for Predictive Maintenance on industrial cutter

Challenge

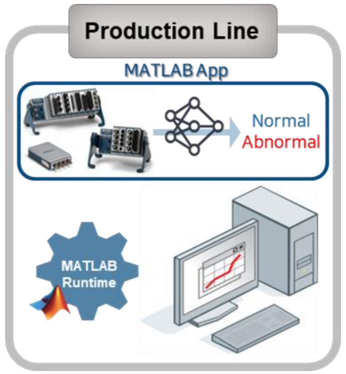
Maintenance of equipment in the factory also depends on the site engineer’s opinion, and sometimes those are a bit conservative

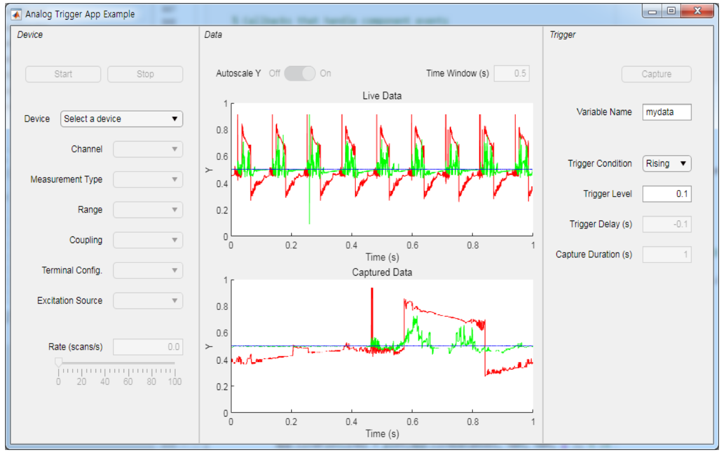
Solution

Developed a condition monitoring system and deployed standalone executable which can acquire raw data from NI device directly, make a prediction and display the result in GUI

Advantages of using MATLAB and Simulink

- Interactive Apps for generating features and training various AI models
- Capabilities of entire workflow from data acquisition to deployment
- Leveraged MathWorks engineer’s support for fast prototyping





Condition monitoring system using Deep Learning

> *“3 advantages of MATLAB that lead our project to success: App-based AI development workflow, compatibility with 3rd party hardware and short test cycle with rapid prototyping.”*
>
> *Junghoon Lee,* ***LG Energy Solution***

>> MATLAB for deep learning

Key Takeaways for Predictive Maintenance

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Try different approaches, including deep learning.

You need AI *and* domain expertise.
MATLAB helps you do both.

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2021

Thank you

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