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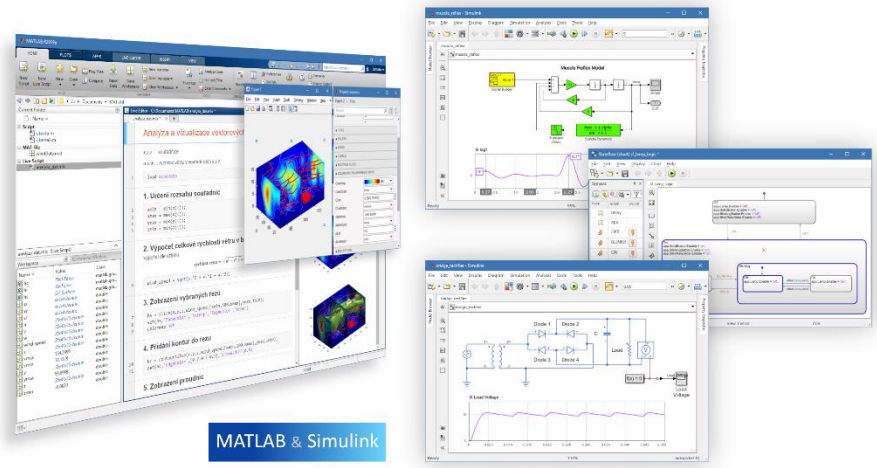
TCC 2020

Machine learning - od učení k implementaci

Condition Monitoring a Predictive Maintenance



Jaroslav Jirkovský
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www.mathworks.com

There are two ways to get a computer to do what you want

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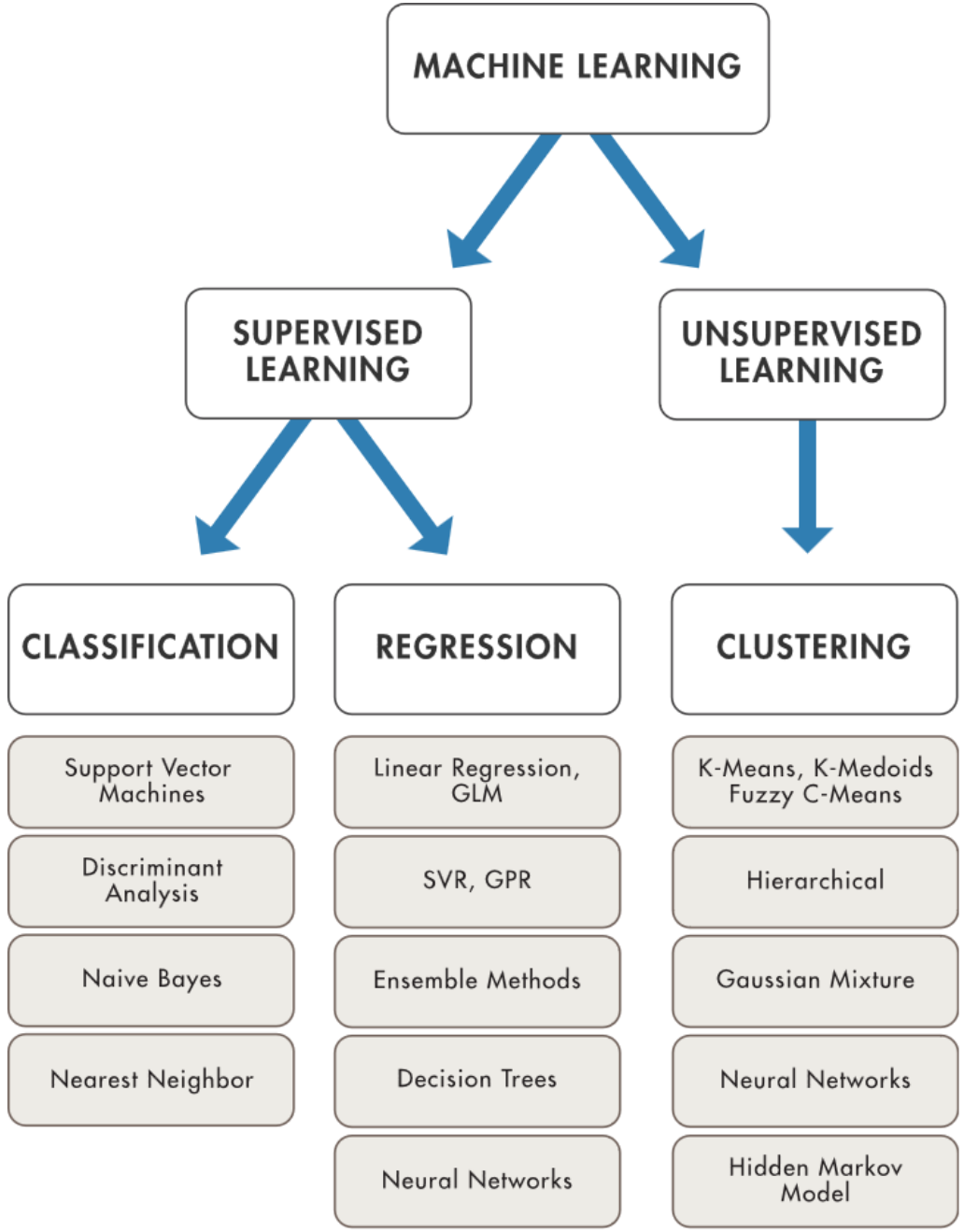
Artificial Intelligence

Machine Learning

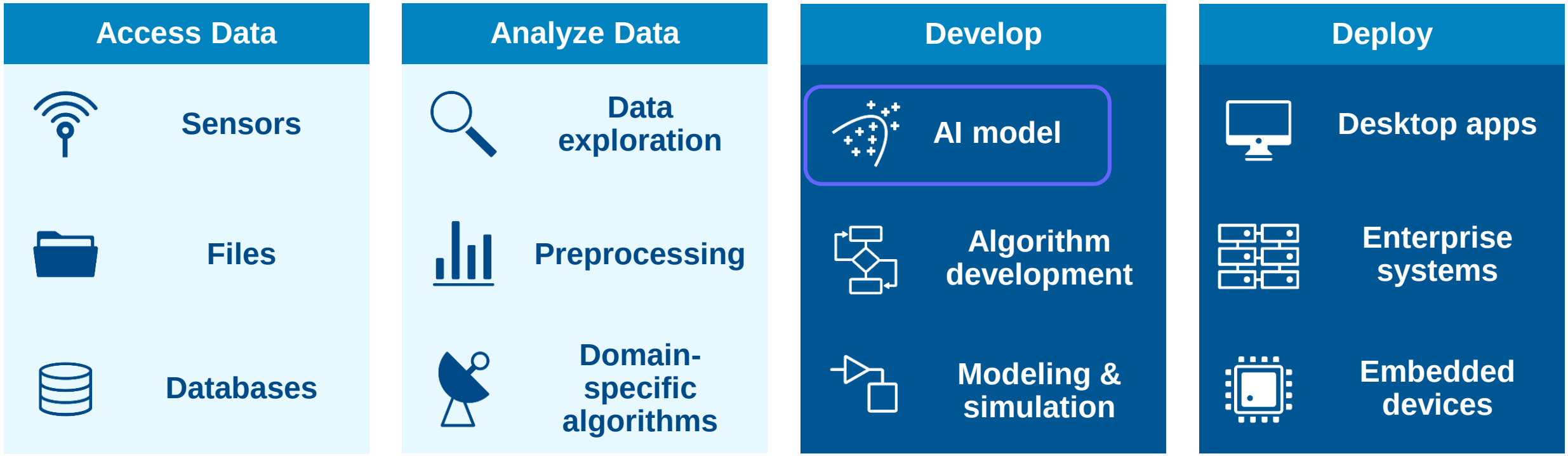
Machine Learning

- **Different Types of Learning:**



AI is Just One Part of System Development Workflow

with MATLAB and Simulink




KUKA
KUKA
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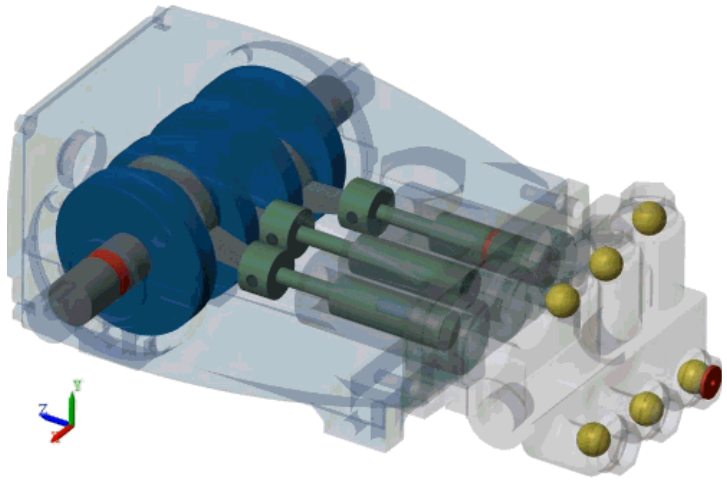
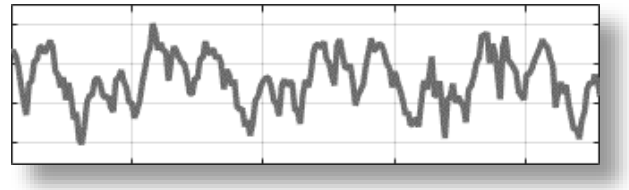
AI for Condition Monitoring and Predictive Maintenance

- *Measure the wear of each robot*
- *Predict* and fix failures before they happen
- AI handles uncertainty and variability

What is Condition Monitoring and Predictive Maintenance?





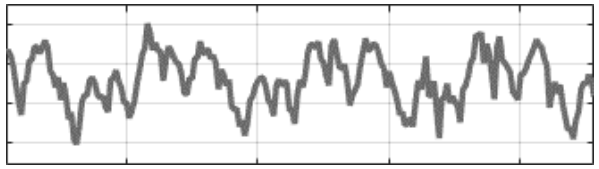
Translate

Turn off instant translation

English | Spanish | French | Pump - detected

English | Russian | Greek

Translate



1/5000

I need help.

Translate

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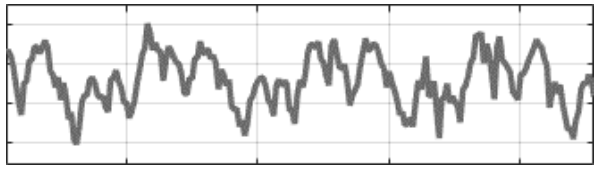


1/5000

I need help. One of my cylinders is blocked. I will shut down your production line in 15 hours.

Predictive Maintenance Algorithm

⇨ Answers These Questions

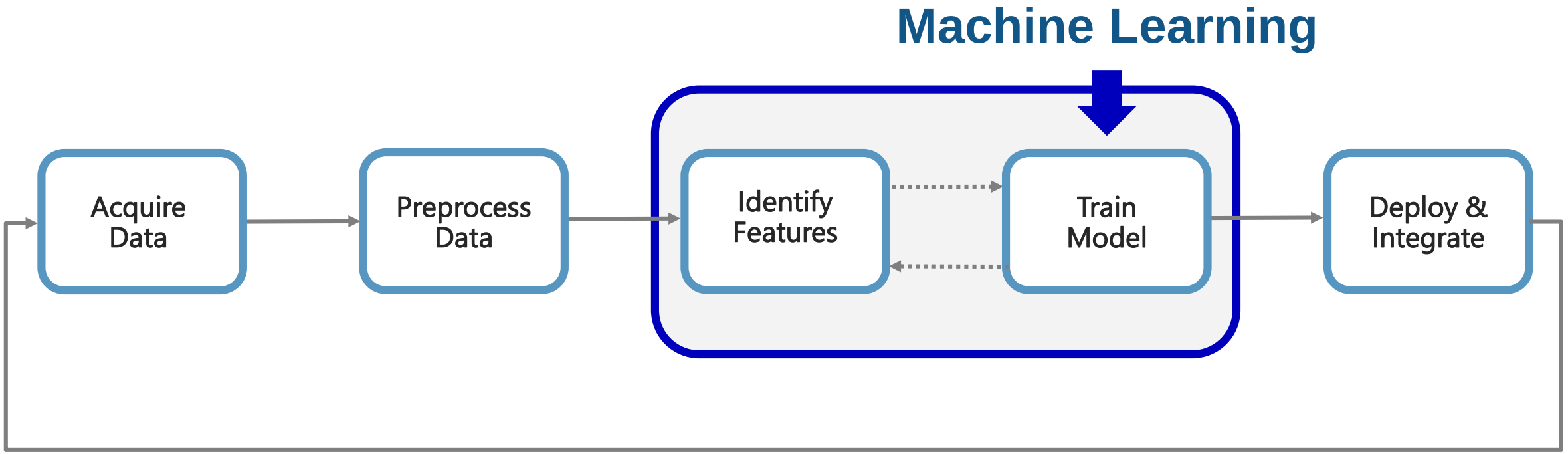
Is my machine operating normally?	Anomaly Detection
Why is my machine behaving abnormally?	Condition Monitoring
How much longer can I operate my machine ?	Remaining Useful Life Estimation

I need help.

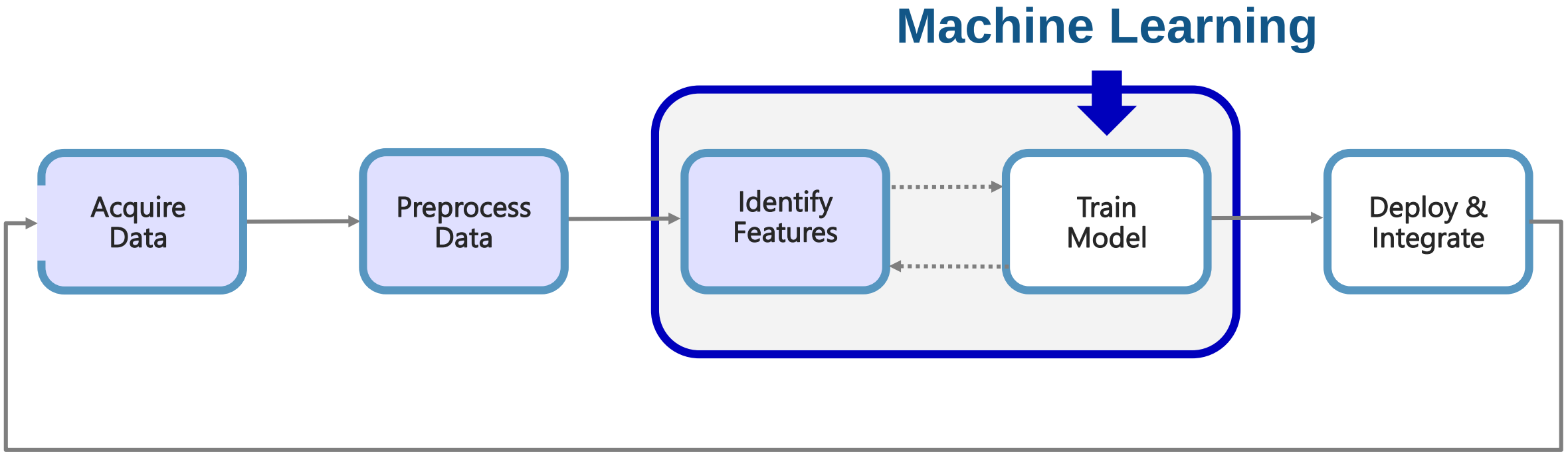
One of my cylinders is blocked.

I will shut down your line in 15 hours.

Workflow for Developing a AI (PdM) Algorithm



Workflow for Developing a AI (PdM) Algorithm



Why extract features and what are they?

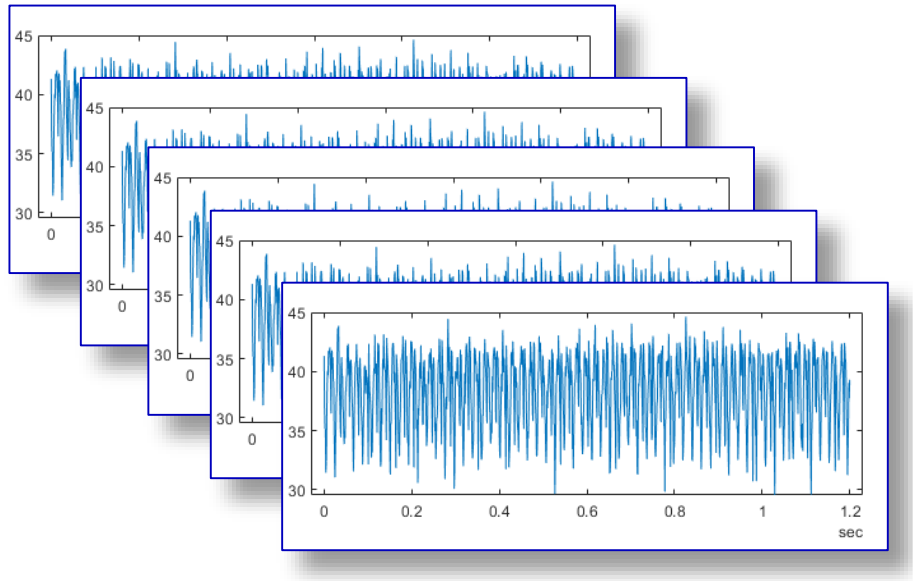
- **Working with raw data**
  - might not describe the system dynamics in the best possible way
  - unfeasible to develop machine learning models with all of the raw data

- **Transform the data into smaller set of descriptive *features***
  - describe the dynamics better
  - usually also reduce the amount of data!

- **Example: classifying speech to male/female**
  - Instead of using the raw waveform, calculate/extract the power on ten spectrum bands
    → vector of ten values instead of potentially millions of samples
  - This often requires *domain knowledge* (what are the good features?)

Feature Extraction

- How do you extract features?
  - Signal processing methods
  - Statistics & model-based methods
- Which features should you extract?
  - Depends on the data available
  - Depends on the hardware available
- How do I deal with streaming data?
  - Determine buffer size
  - Extract features over a moving buffer window



qMean	qVar	qSkewness	qKurtosis
38.4945	9.2306	-0.5728	2.4662
qPeak2P...	qCrest	qRMS	qMAD
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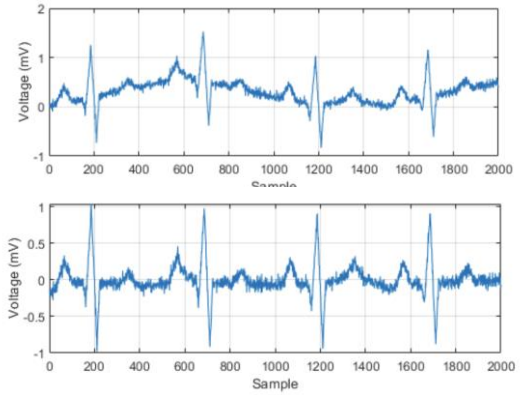
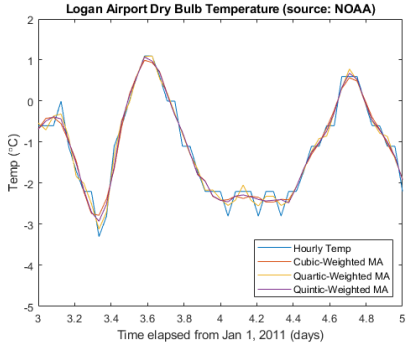
Statistics + Signal Processing

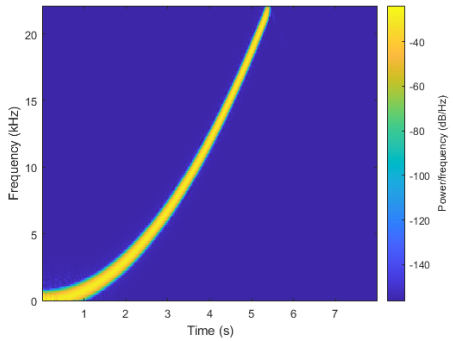
Data Preprocessing



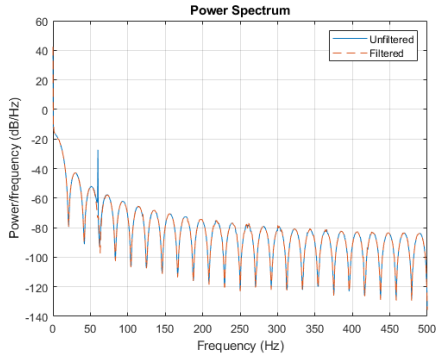
Detrending



Smoothing

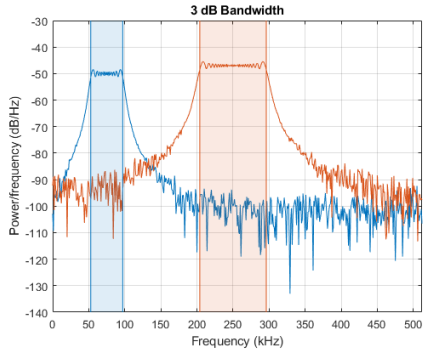


Resampling

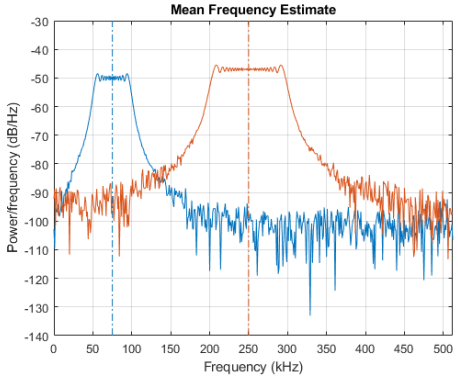


Filtering

Feature Engineering



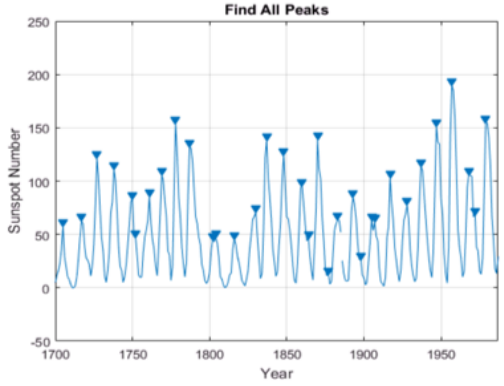
Bandwidth measurements



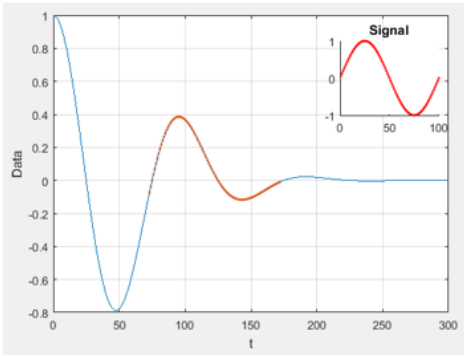
Spectral statistics

Frequency domain

Time domain



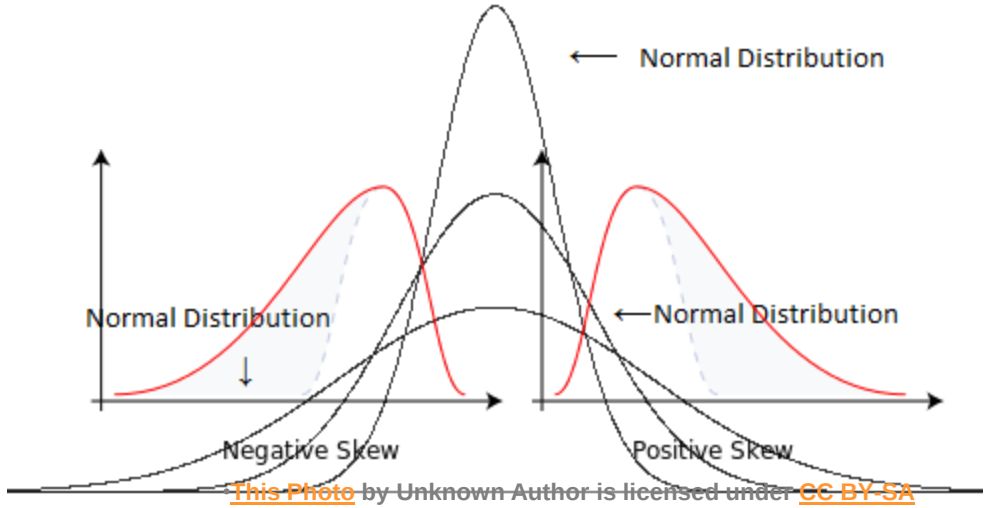
Find peaks



Find signal patterns

Common time-domain signal features

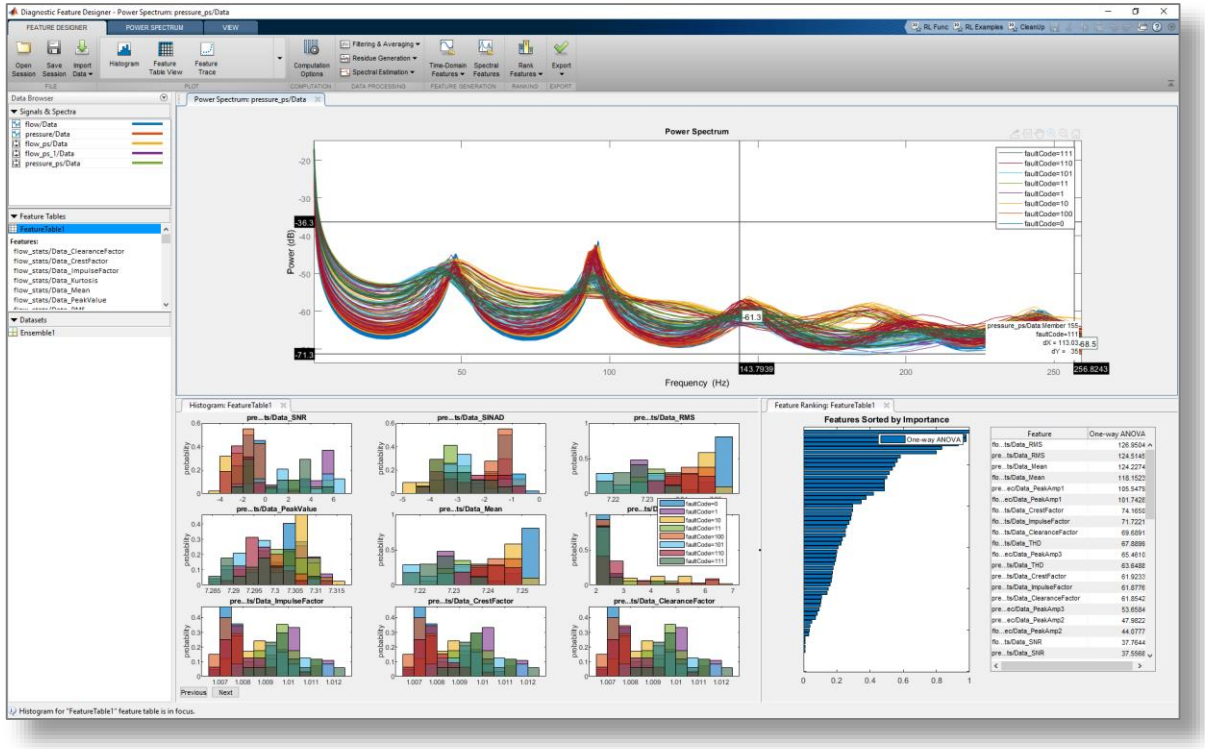
- **Kurtosis**
- **Skewness**
- **Peak-to-peak, RMS, Mean, Variance, etc.**



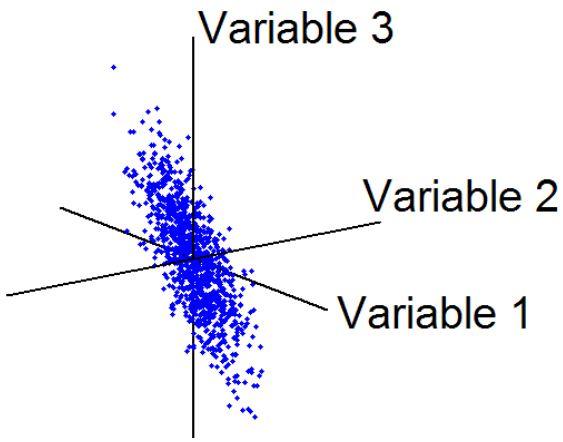
Diagnostic Feature Designer App

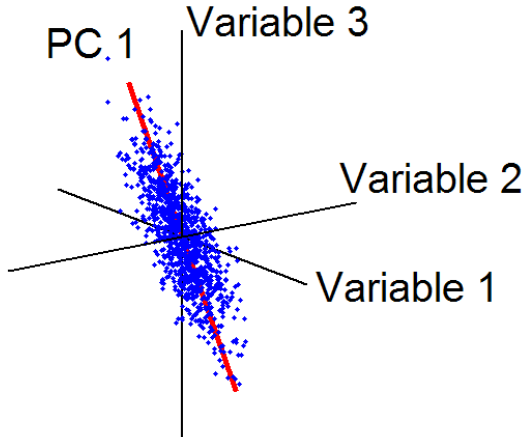
(Predictive Maintenance Toolbox)

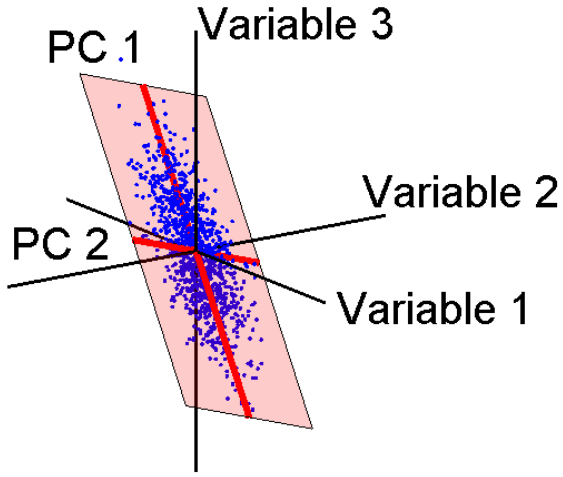
- **Extract, visualize, and rank features from sensor data**
- **Use both statistical and dynamic modeling methods**
- **Work with out-of-memory data**
- **Explore and discover techniques without writing MATLAB code**

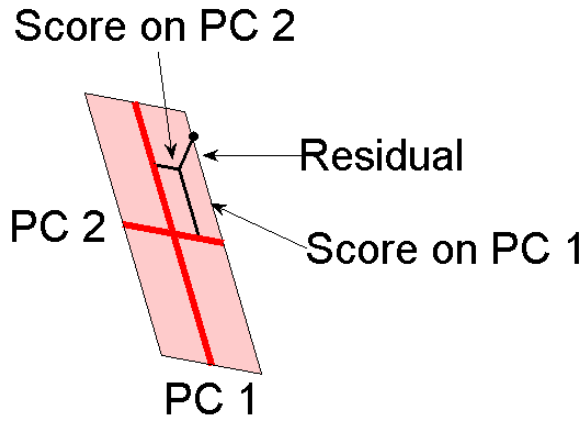


Principal Components Analysis – what is it doing?









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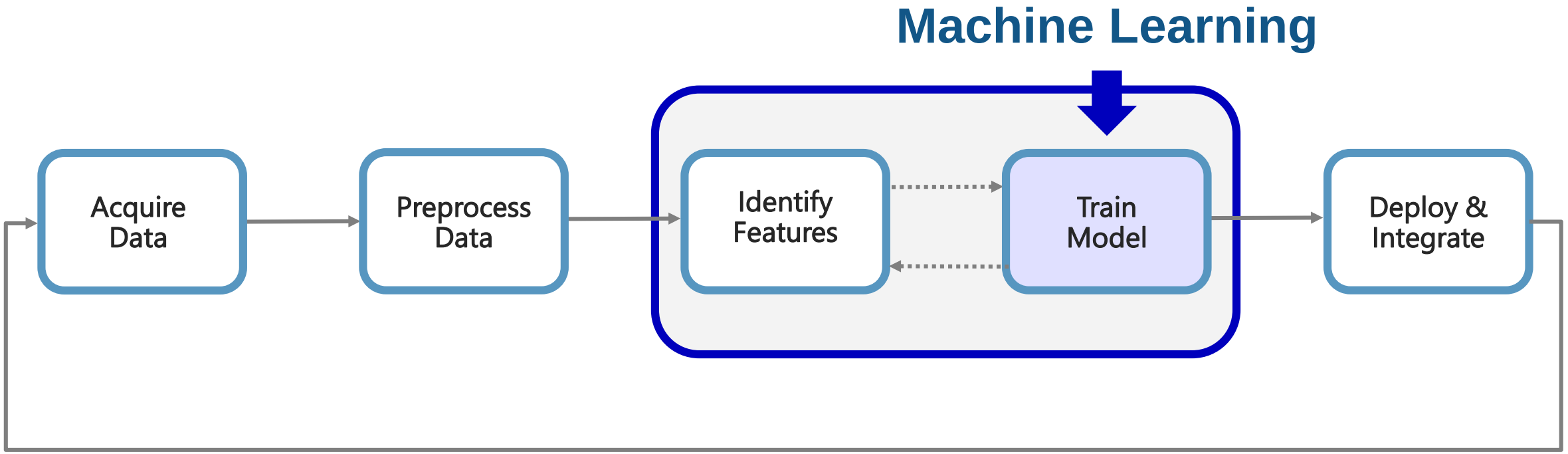
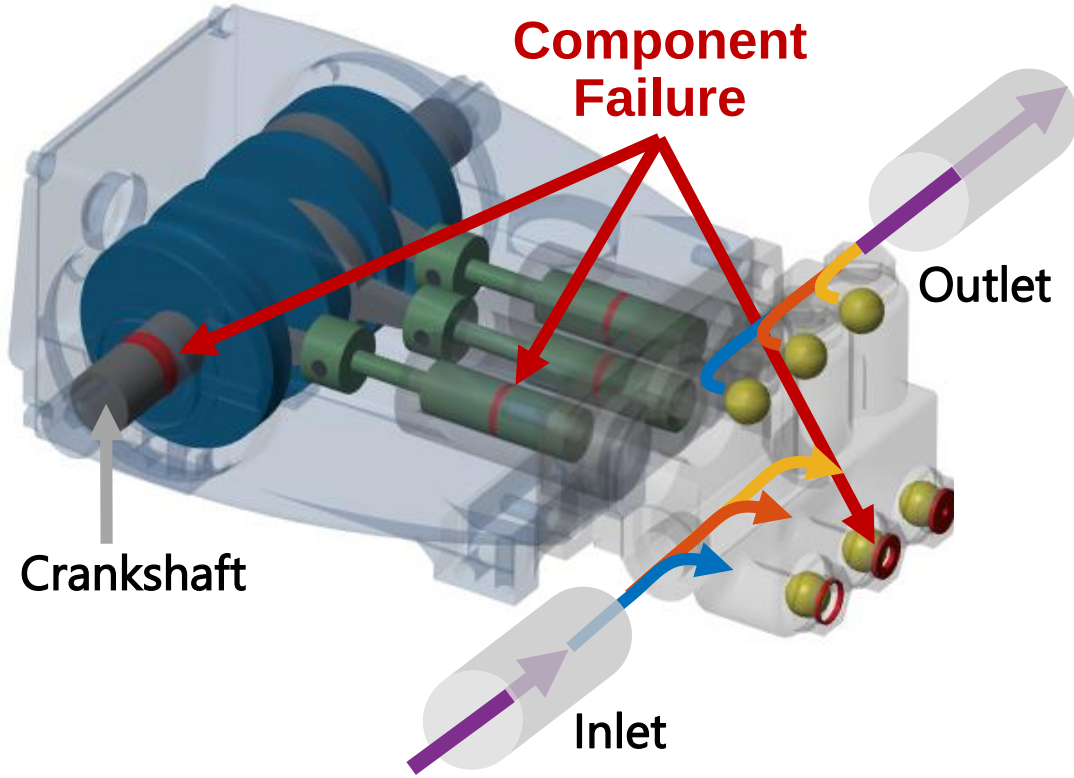


Fault Classification Algorithms Allow You to Identify the Root Cause of Anomalous Behavior

- **Three-phase pump commonly used for drilling and servicing oil wells**
  - Three plungers try to ensure a uniform flow
- **Condition monitoring to detect:**
  - Seal leak
  - Inlet blockage
  - Bearing degradation



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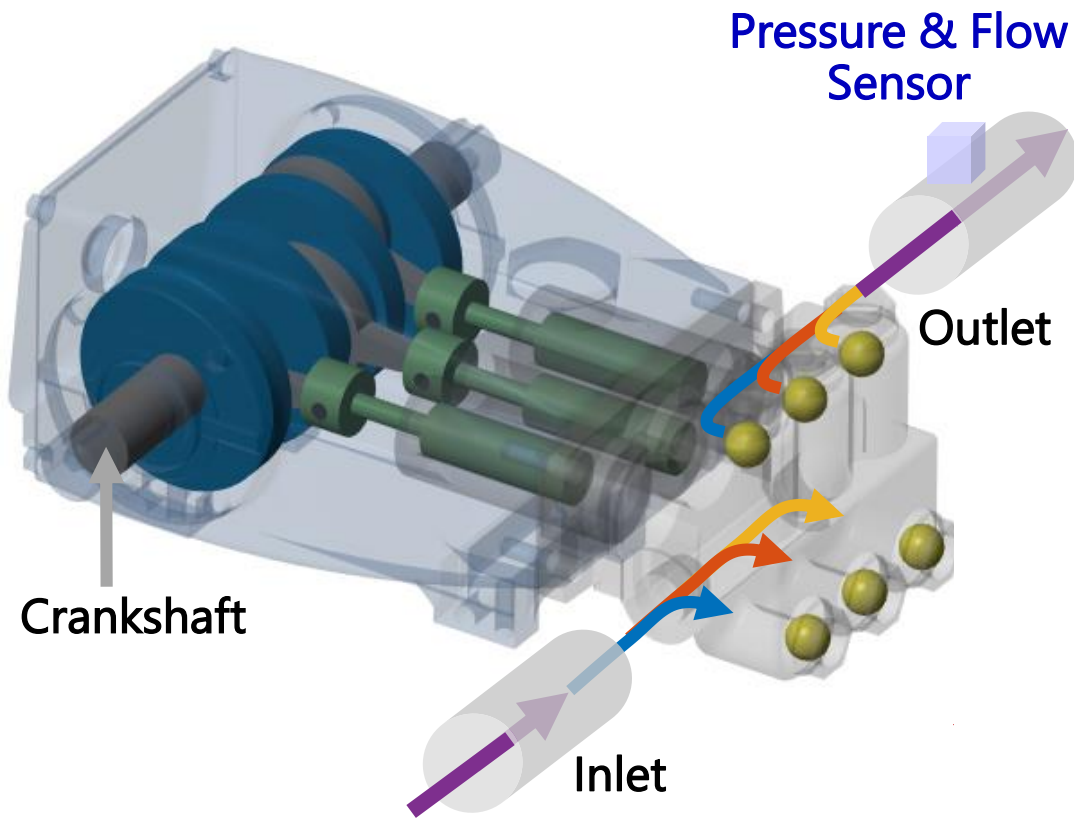


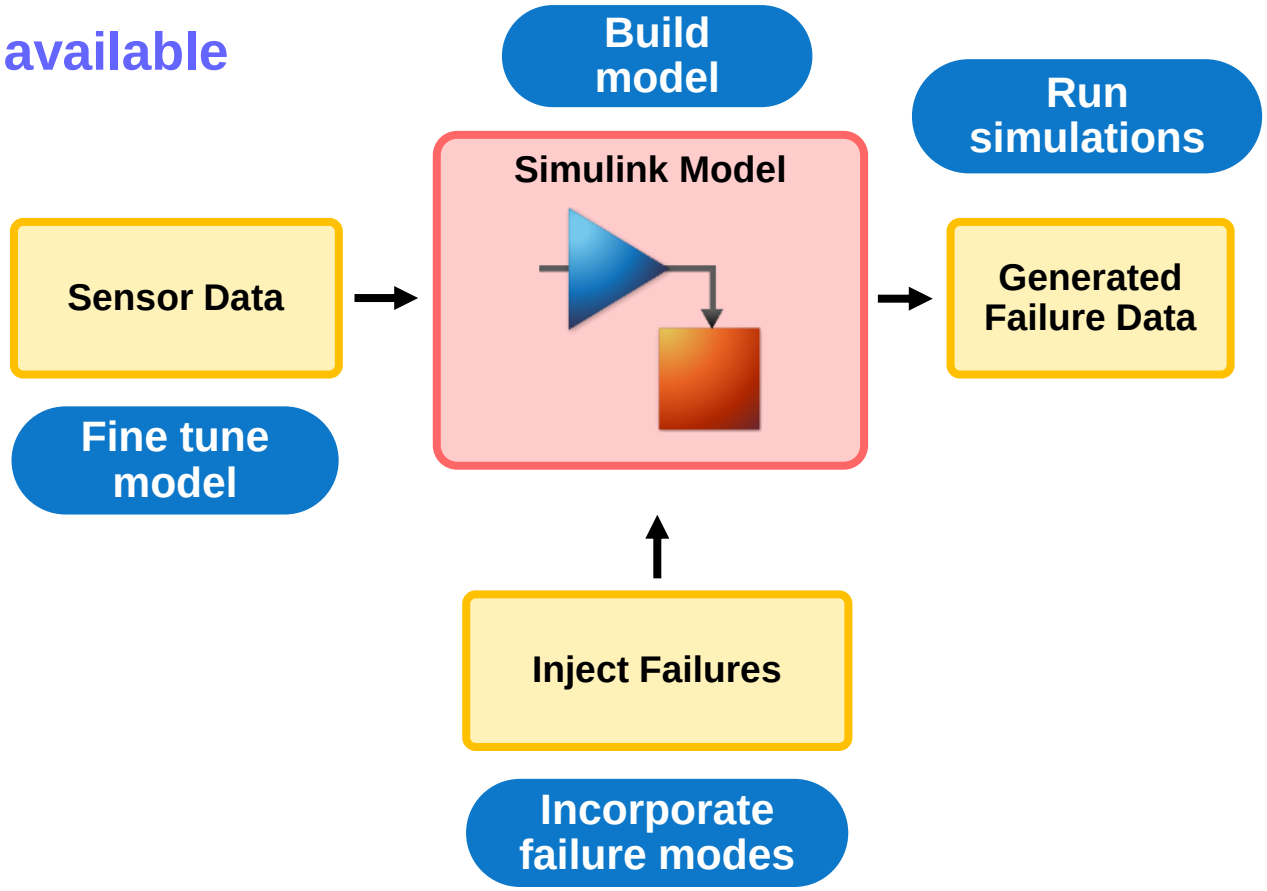
- **Identify fault present in system using only pressure and flow sensor data**

Example: Analyze Features for Pump Diagnostics

- https://www.mathworks.com/help/predmaint/ug/analyze-and-select-features-for-pump-diagnostics.html

Generate Synthetic Failure Data from Simulink Models if Real Failure Data is Unavailable

- **Model failure modes**
  - Work with domain experts and the data available
  - Vary model parameters/components
- **Customize a generic model to a specific machine**
  - Fine tune models based on real data
  - Validate performance of tuned model



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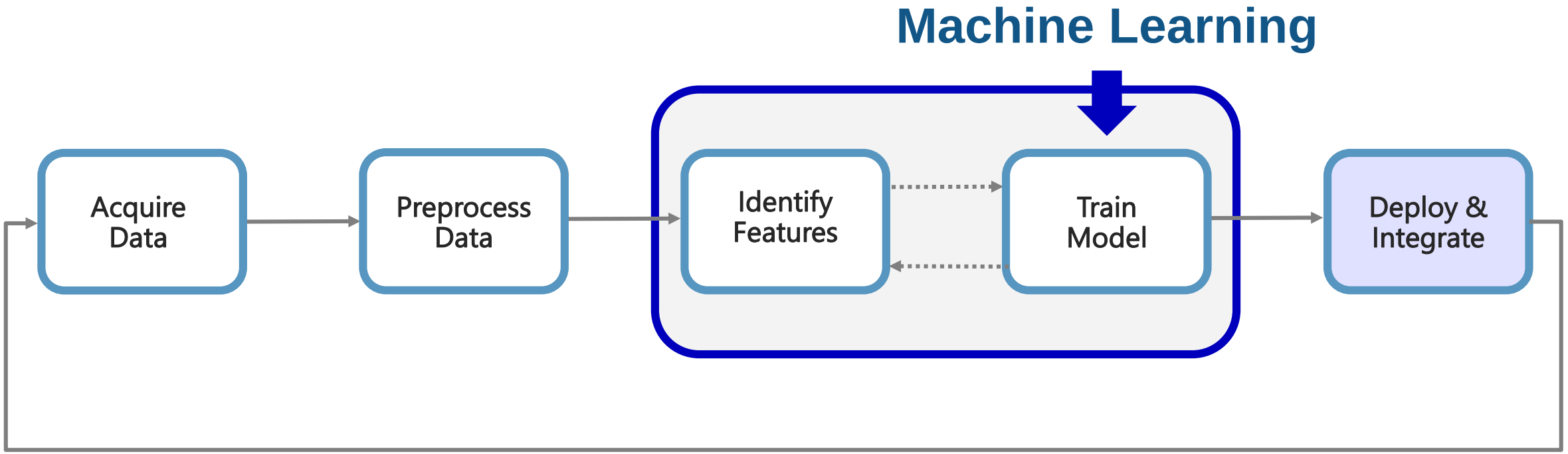
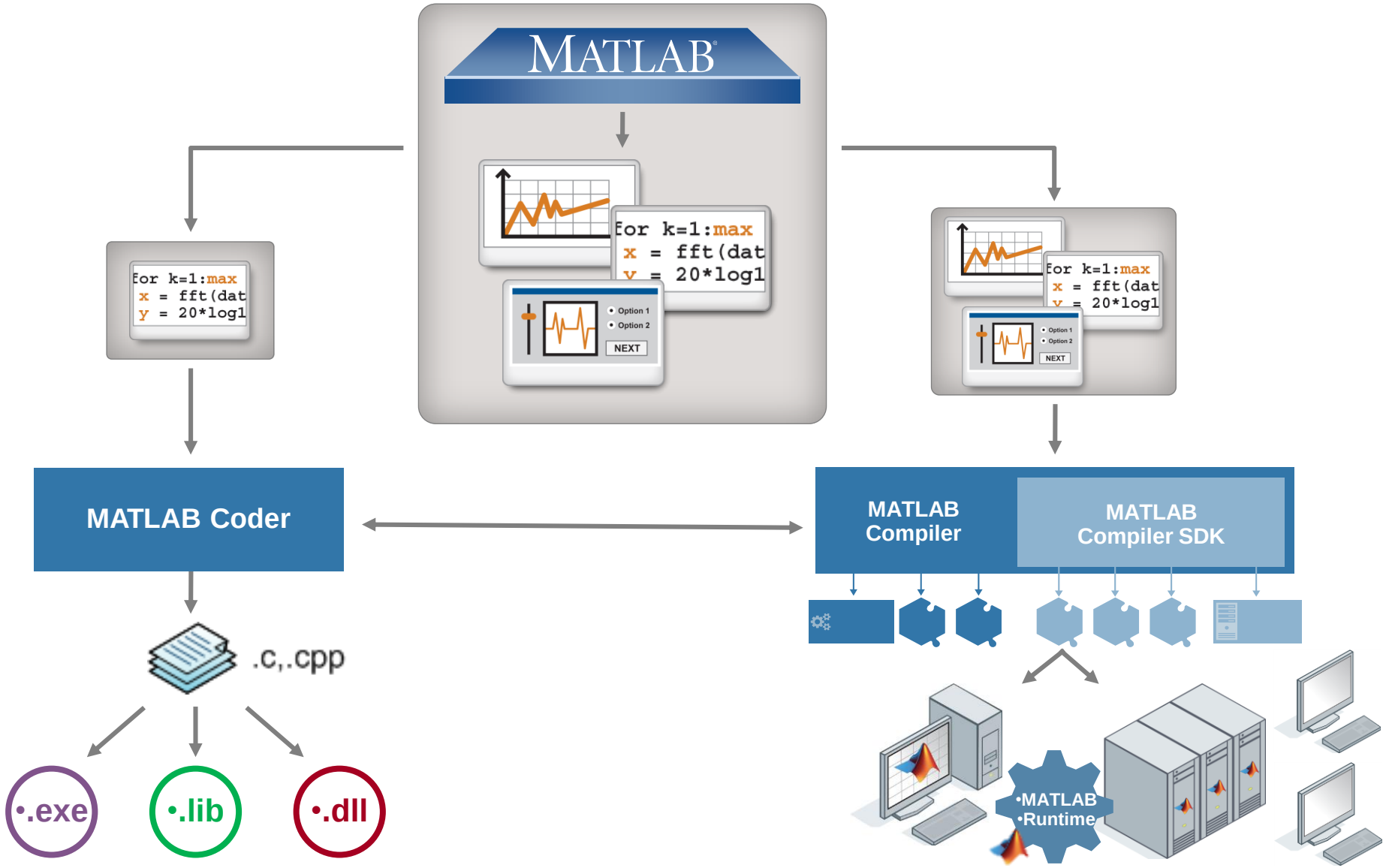


Integrate Analytics with Your Enterprise Systems

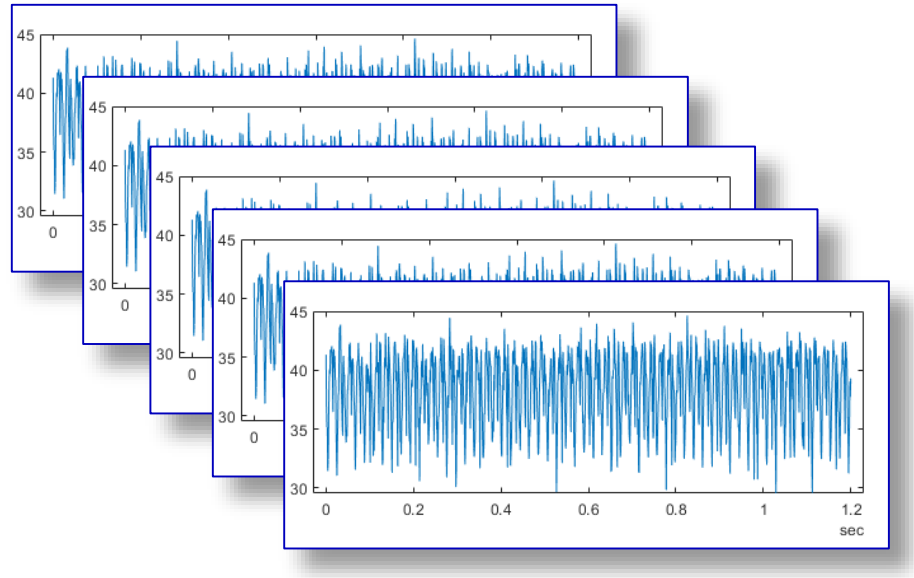
MATLAB Compiler and MATLAB Coder



Feature Extraction at the Edge

Reduce the amount of data you need to store and transmit

- **Design your feature extraction algorithm in MATLAB, then automatically convert MATLAB to C/C++**
  - Eliminate chance for coding-errors
  - Implement new versions quicker
  - Maintain only one source (MATLAB)
  - Process data in real-time



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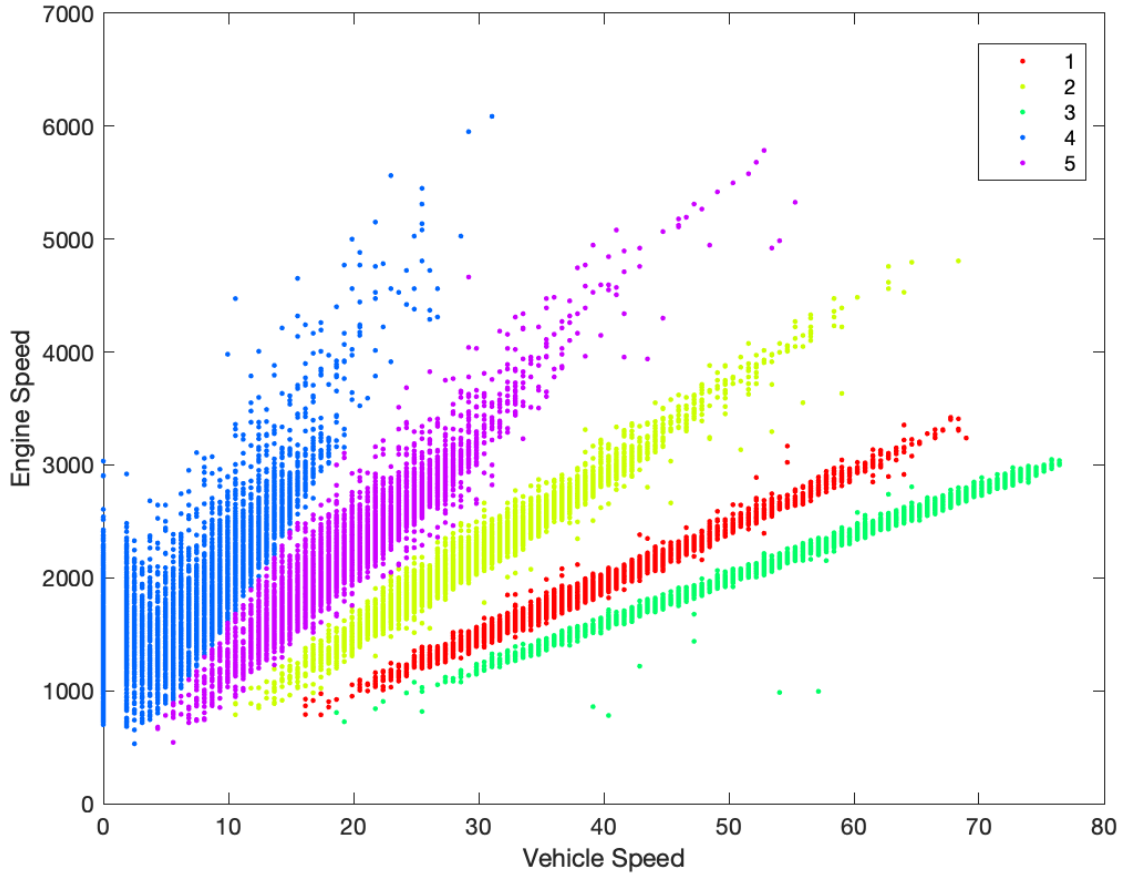
15.2351	1.1553	38.6141	2.5562

Examples of Successful Machine Learning Applications

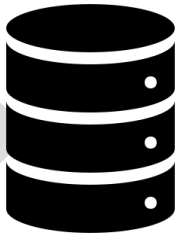
Manufacturing Analytics

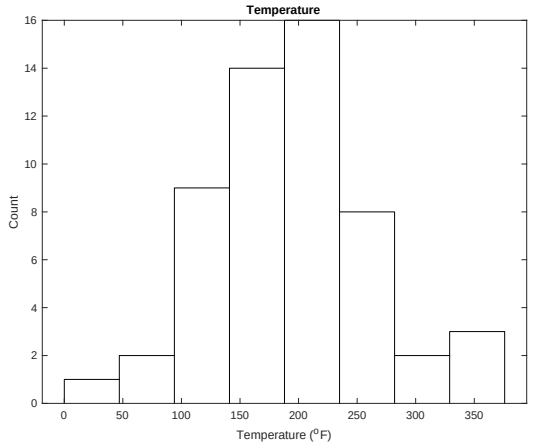
Fleet Data Analytics

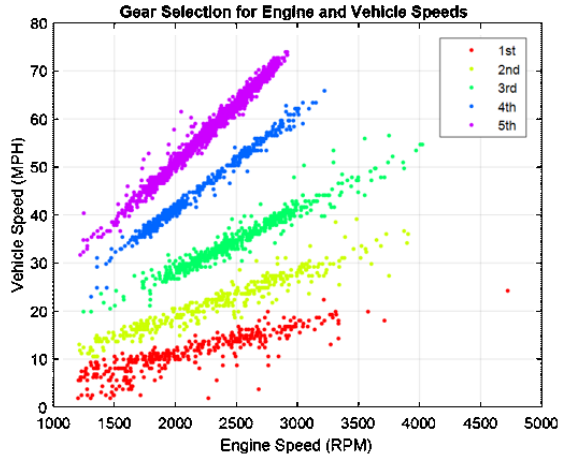
Energy Forecasting



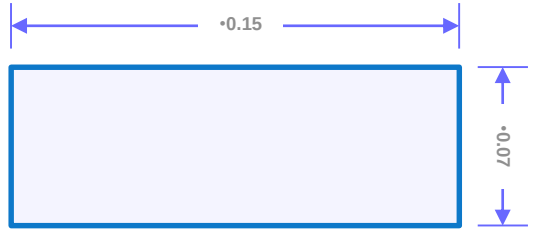
Fleet Data Analytics



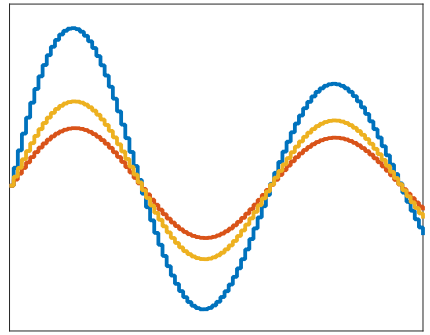




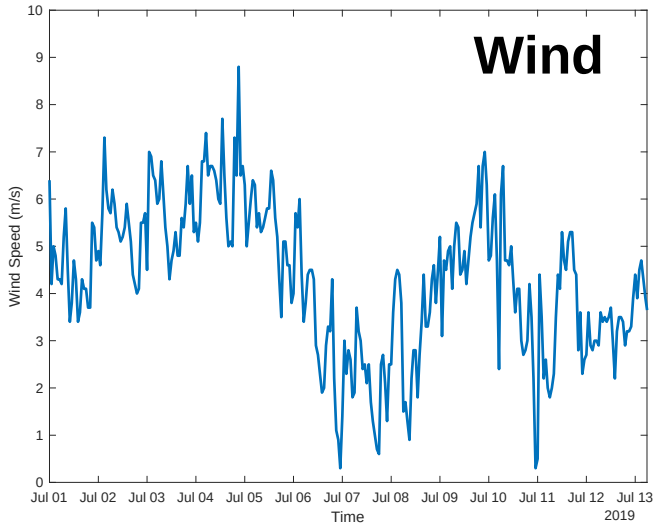
Design Decisions

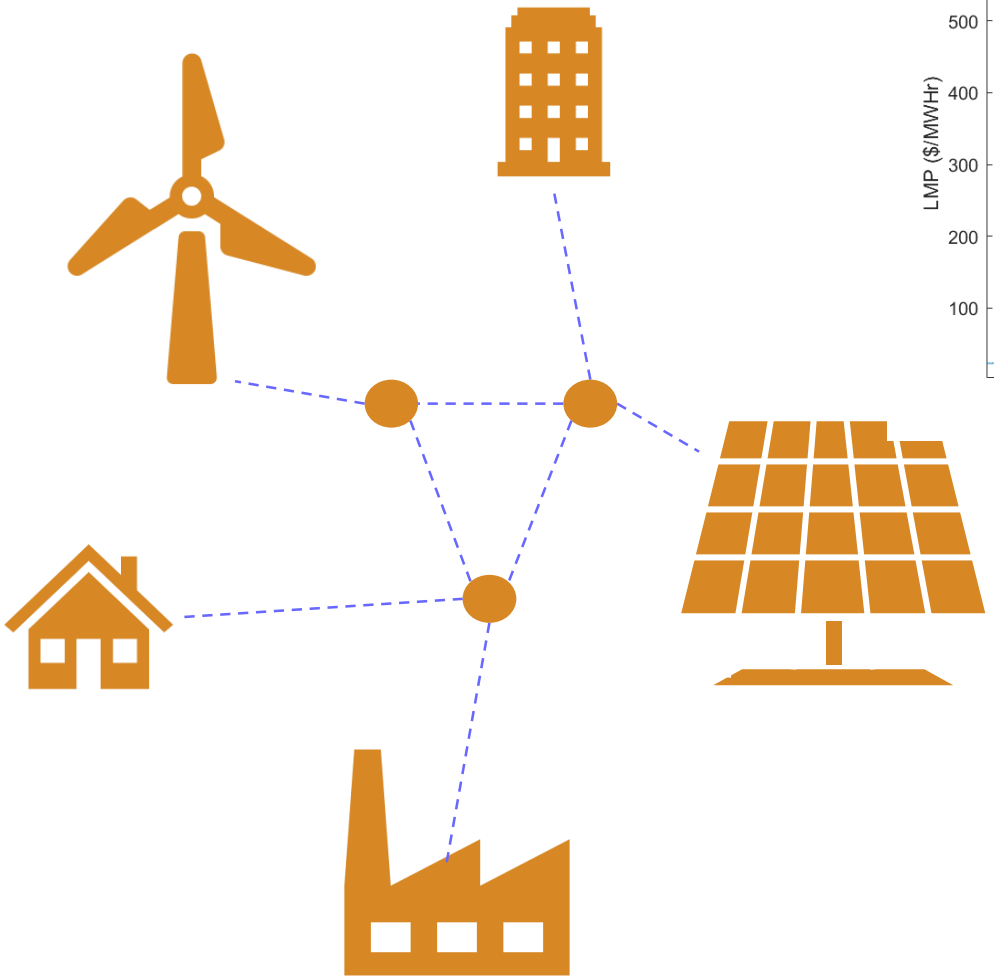


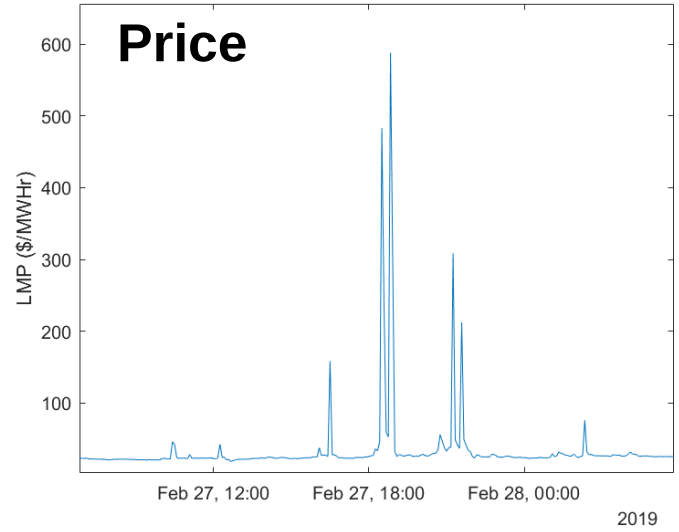
Test Plans

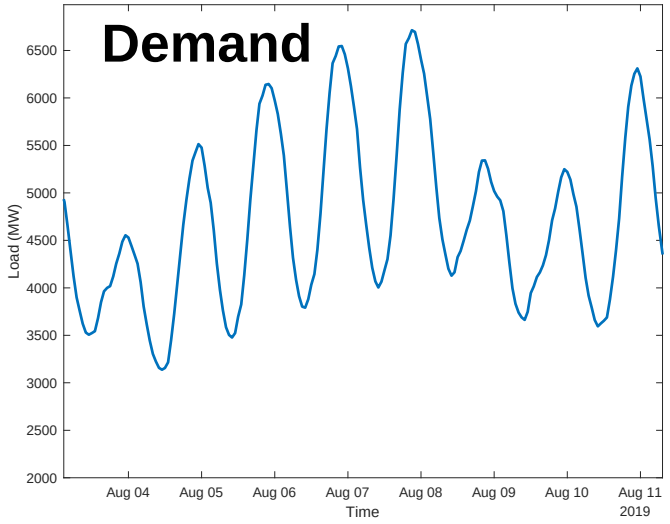


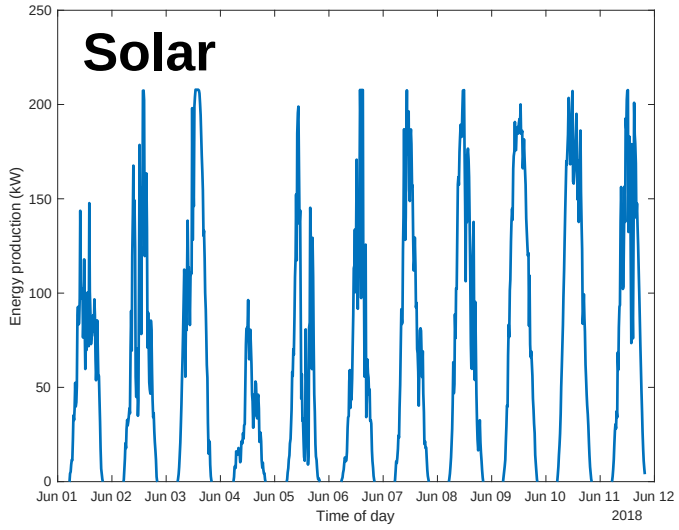
The Need for Energy Forecasts











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Machine Learning + X

Fleet Analytics

Equipment Expertise

Design Specs
Operating Modes
Operating Conditions

Machine Learning

Statistical Analysis
Unsupervised Learning

Energy Forecasting

Electrical Grid Expertise

Seasonality
Weather Effects
Generator Characteristics

Machine Learning

Time Series Modeling
Regression

Manufacturing Analytics

Manufacturing Expertise

Process Equipment
Process Variables
Performance Metrics

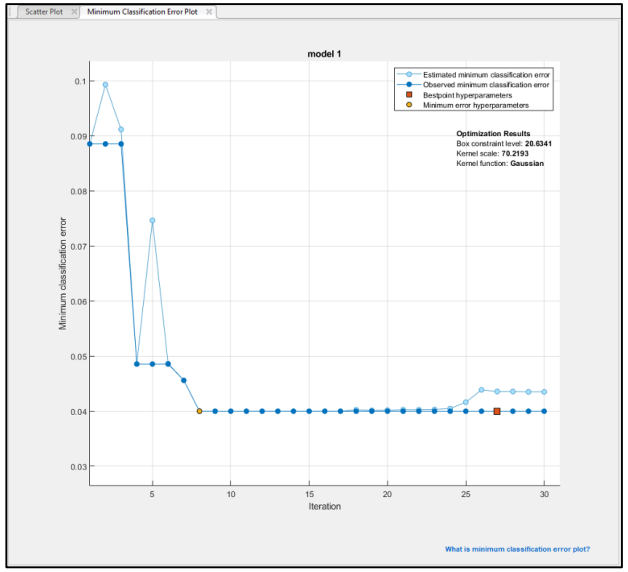
Machine Learning

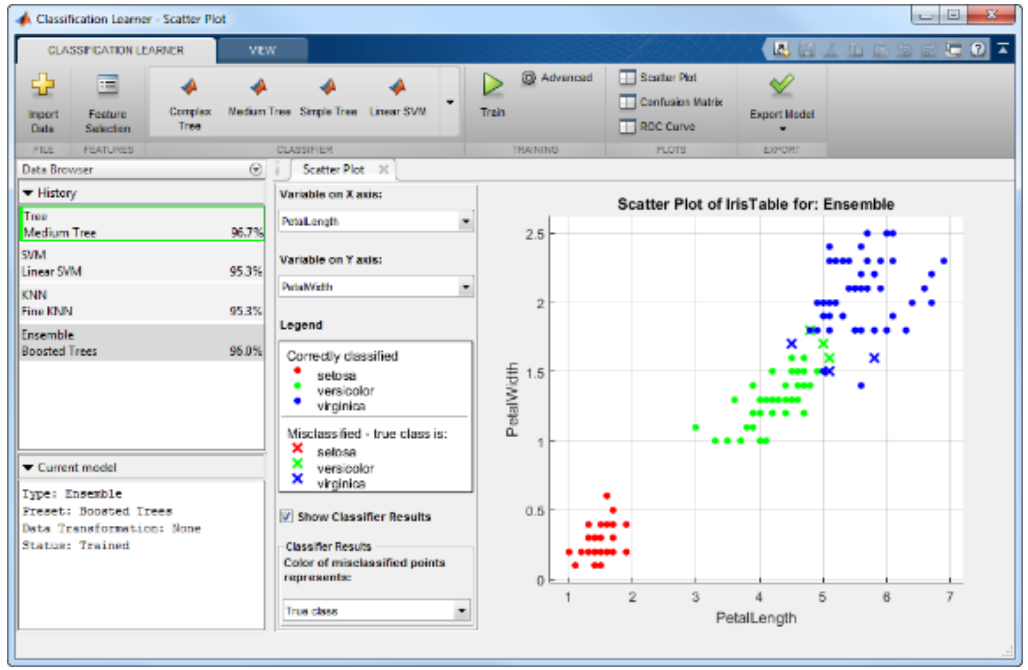
Anomaly Detection
Regression
Classification

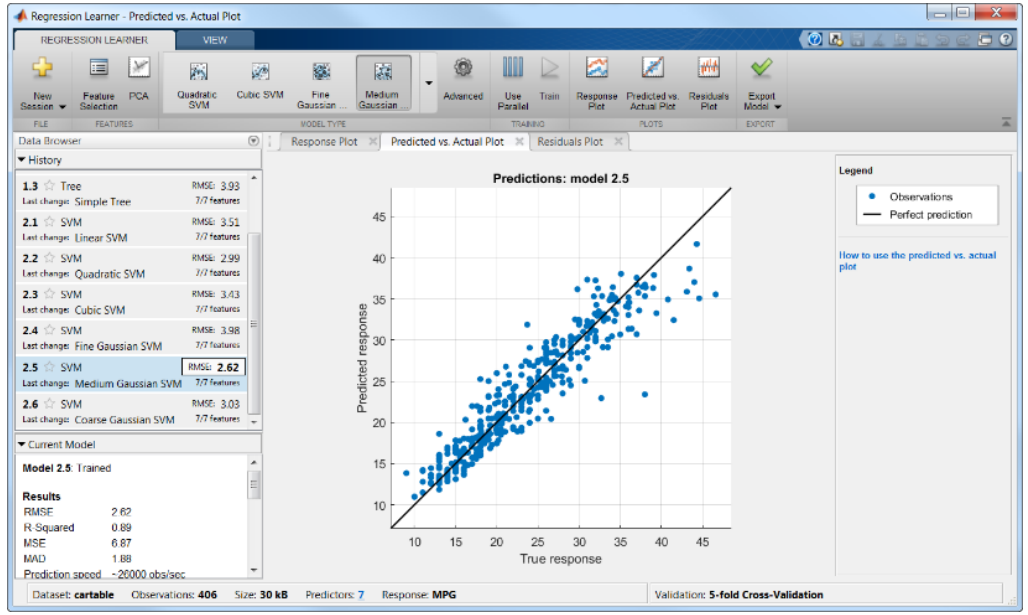
Machine Learning apps

- Try out many models
- Compare results
- Get to a reasonable model without worrying about the details

Hyperparameter optimization in apps







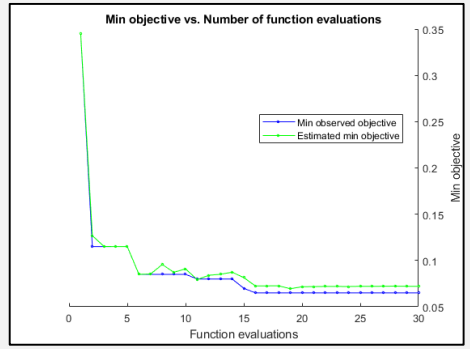
AutoML

- **Build many machine learning models**
- **Find a good model without becoming an expert**

`fitcauto`

Model Selection

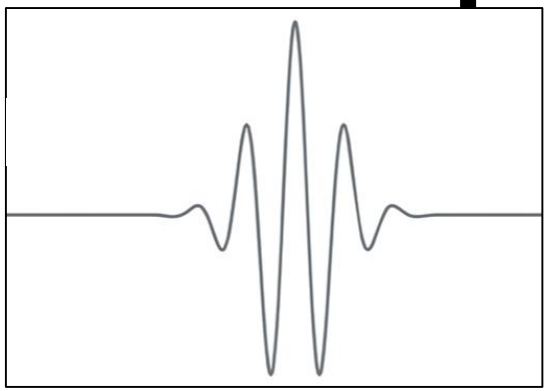
Hyper-parameter Optimization

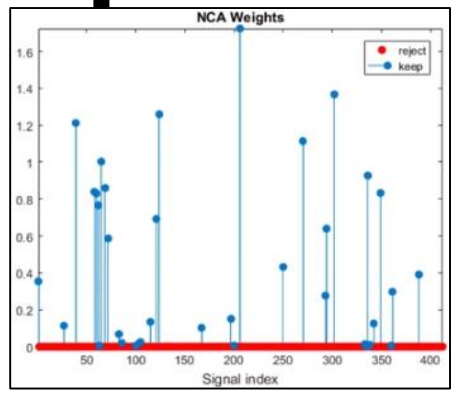


Decision Tree?
SVM?
KNN?
Ensemble?
…?

Import Data → **Preprocess Data** → **Extract Features** → **Train Model** → **Deploy & Integrate**

Wavelet Scattering

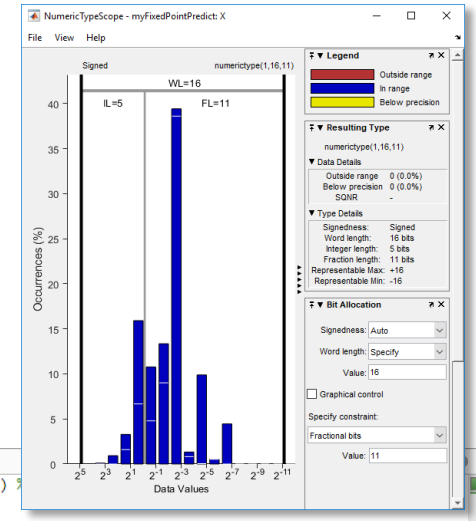




Feature Selection

Automatic C/C++ Code Generation

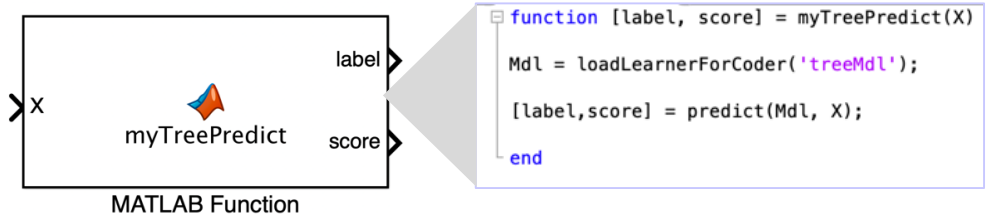
- **Prediction for most Classification and Regression models**
- **Update deployed models without regenerating code**
  - SVM, Decision Trees, Linear Models
- **Fixed-Point support**
  - SVM, Decision Trees, Ensemble of Trees
  - Shallow Neural Network (through Simulink)
- **Integrate with Simulink models as MATLAB Function Block**




```
Function: myFixedPointPredict
1 function [label, score] = myFixedPointPredict(X,T)
2 Mdl = loadLearnerForCoder('myMdl','DataType',T);
3 [label,score] = predict(Mdl,X);
4 end
```

ALL MESSAGES (0) | VARIABLES

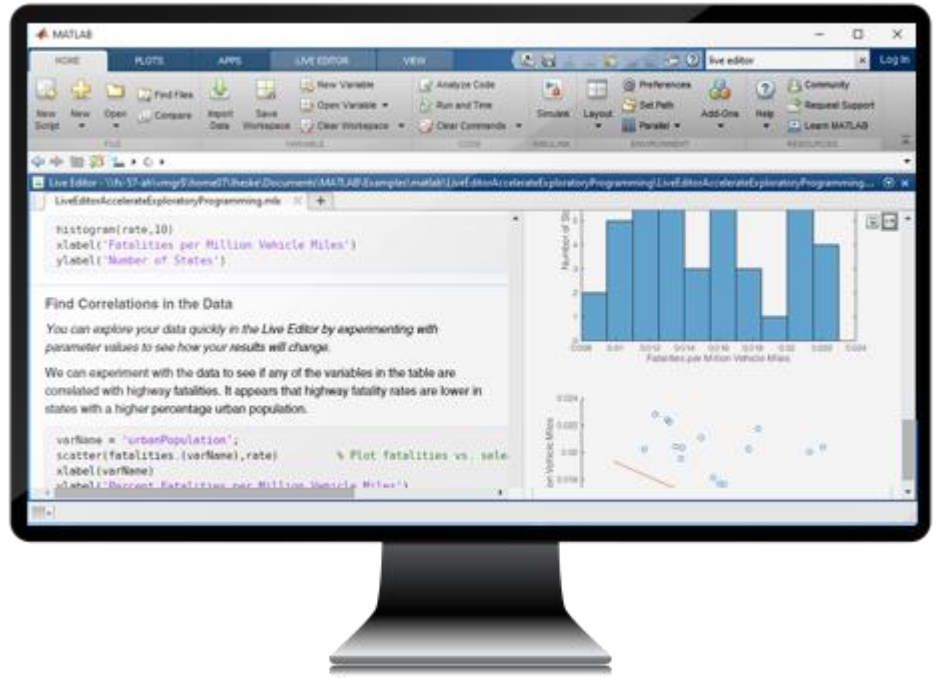
Name	Type	Size	Class	DT Mode	Signed	WL	FL	Percer of Curre Range	Alway Whole Numb	Sim Min	Sim Max
label	Outpu	:32561 × 1	logical	-	-	-	-	-	Yes	0	1
score	Outpu	:32561 × 2	embedded.fi	-	Signed	16	14	93	No	-1.856	1.8560
T	Input	1 × 1	struct	-	-	-	-		No	-	-
XDataType		0 × 0	embedded.fi	-	Signed	16	11		No	-	-
ScoreDataType		0 × 0	embedded.fi	-	Signed	16	14		No	-	-
InnerProductDataType		0 × 0	embedded.fi	-	Signed	16	6		No	-	-
X	Input	:32561 × 5	embedded.fi	-	Signed	16	11	87	No	-3.354	13.865
Mdl	Local	1 × 1	classreg.learning.cod	-	-	-	-		No	-	-



Integrate MATLAB with Other Languages

Jak začít s prostředím MATLAB?

- **On-line kurzy zdarma**
  - MATLAB Onramp, Simulink Onramp, Stateflow Onramp
  - Deep Learning Onramp, Machine Learning Onramp
  - časová náročnost: 2 hodiny
  - https://matlabacademy.mathworks.com/



Děkuji za pozornost