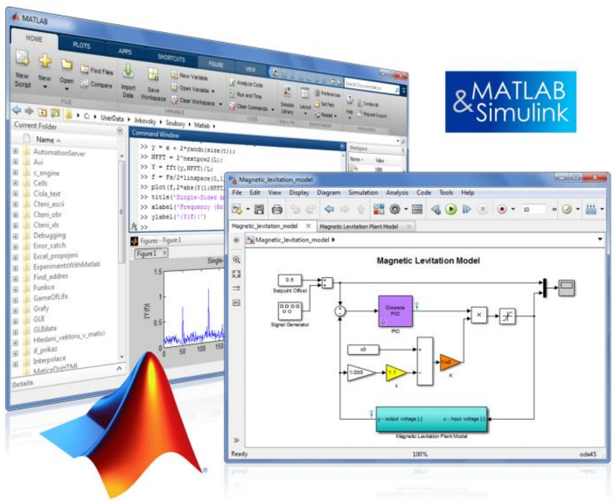
5.9.2019 Brno

TCC 2019

Prediktivní údržba v prostředí MATLAB



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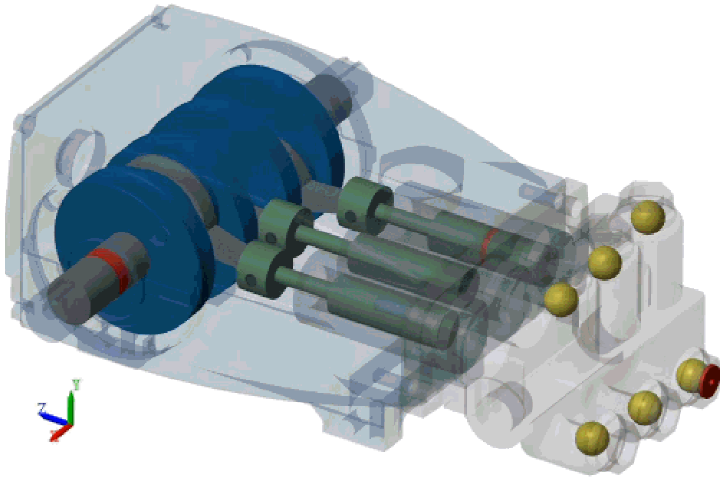
Types of Maintenance

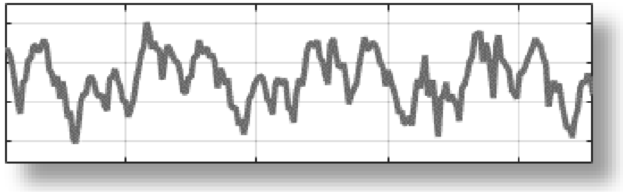
- **Reactive – Perform maintenance once there's a problem**
  - Example: replace car battery when it has a problem
  - Problem: unexpected failures can be expensive and potentially dangerous

- **Scheduled – Perform maintenance at a regular rate**
  - Example: change car's oil every 5,000 miles
  - Problem: unnecessary maintenance can be wasteful; may not eliminate all failures

- **Predictive – Forecast when problems will arise**
  - Example: certain GM car models forecast problems with the battery, fuel pump, and starter motor
  - Problem: difficult to make accurate forecasts for complex equipment

What is Predictive Maintenance?





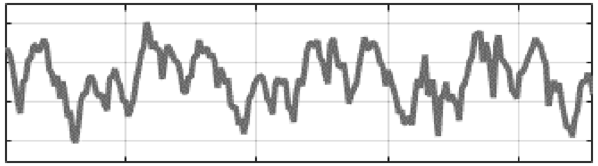
Translate

Turn off instant translation

English | Spanish | French | Pump - detected

English | Russian | Greek

Translate



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I need help.

Translate

Turn off instant translation

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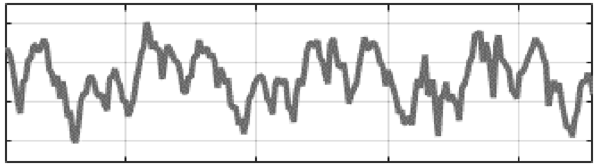
English | Russian | Greek | **Translate**



1/5000

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

Benefits of Predictive Maintenance

Increase “up time” and safety

Minimize maintenance costs

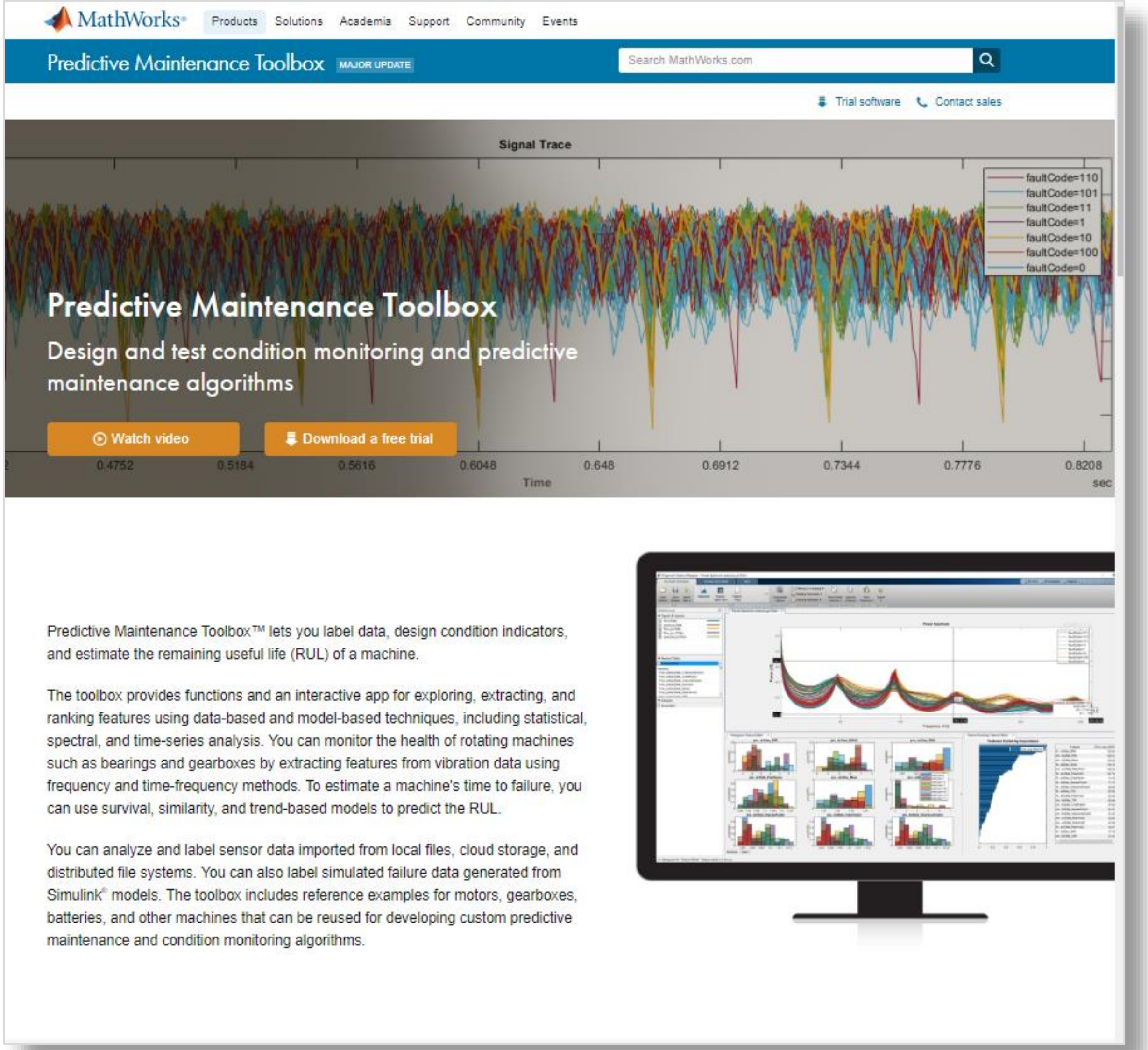
Optimize supply chain

Predictive Maintenance Algorithm
⇨ Answers These Questions

Is my machine operating normally?	Anomaly Detection	I need help.
Why is my machine behaving abnormally?	Condition Monitoring	One of my cylinders is blocked.
How much longer can I operate my machine ?	Remaining Useful Life Estimation	I will shut down your line in 15 hours.

Predictive Maintenance Toolbox for Developing Algorithms

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**

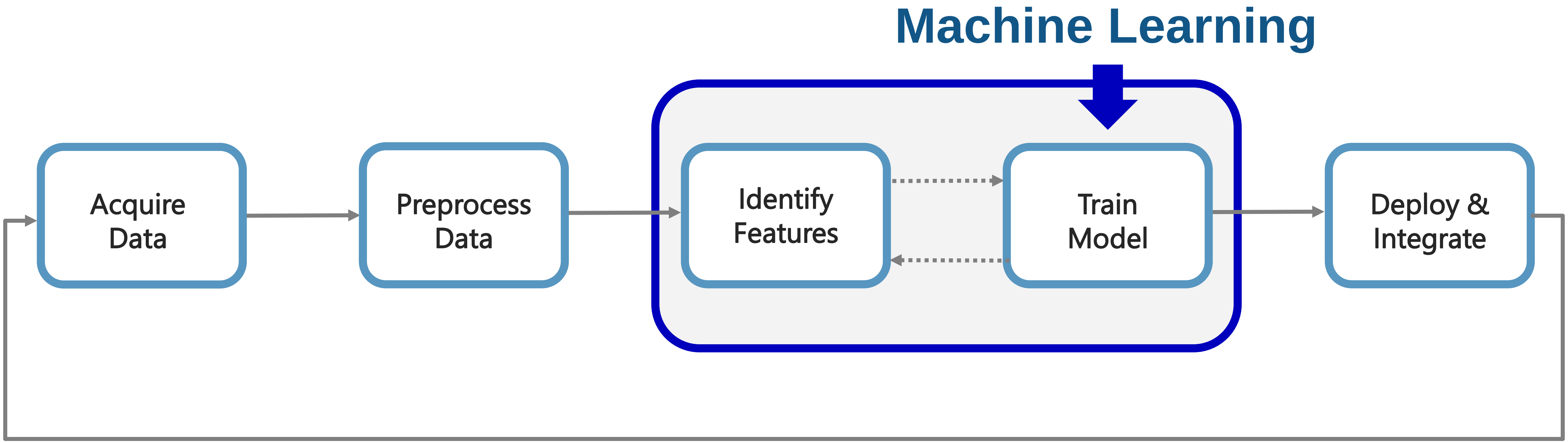


Approaches to Condition Monitoring and Predictive Maintenance

- ”Generic” Machine Learning (including Deep Learning)
  - E.g. Classification of failure types (bearing fault, burnt diode, seal leak)
  - E.g. Binary classification of machine state (normal/abnormal)
  - E.g. Classification of service urgency (high, medium, low)
  - E.g. Regression for remaining life estimation (15, 16, 17, 18, ... days)
  - Tools for this: Statistics and Machine Learning toolbox, Deep Learning toolbox

- Specialized models (in Predictive Maintenance toolbox)
  - Degradation models
  - Similarity models
  - Survival models
  - All of the above answer to ”how much longer will the machine work?”

Workflow for Developing a Predictive Maintenance Algorithm



Predictive Maintenance Challenges

- Reduce the amount of data you need to store and transmit
- Explore approaches to feature extraction and predictive modeling
- Deliver the results of your analytics based on your audience
- Get started quickly…especially if you are an engineer

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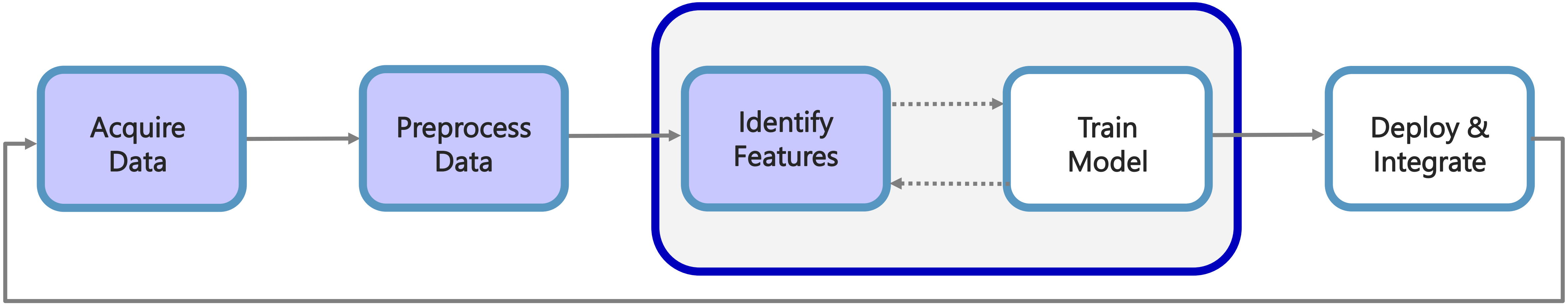


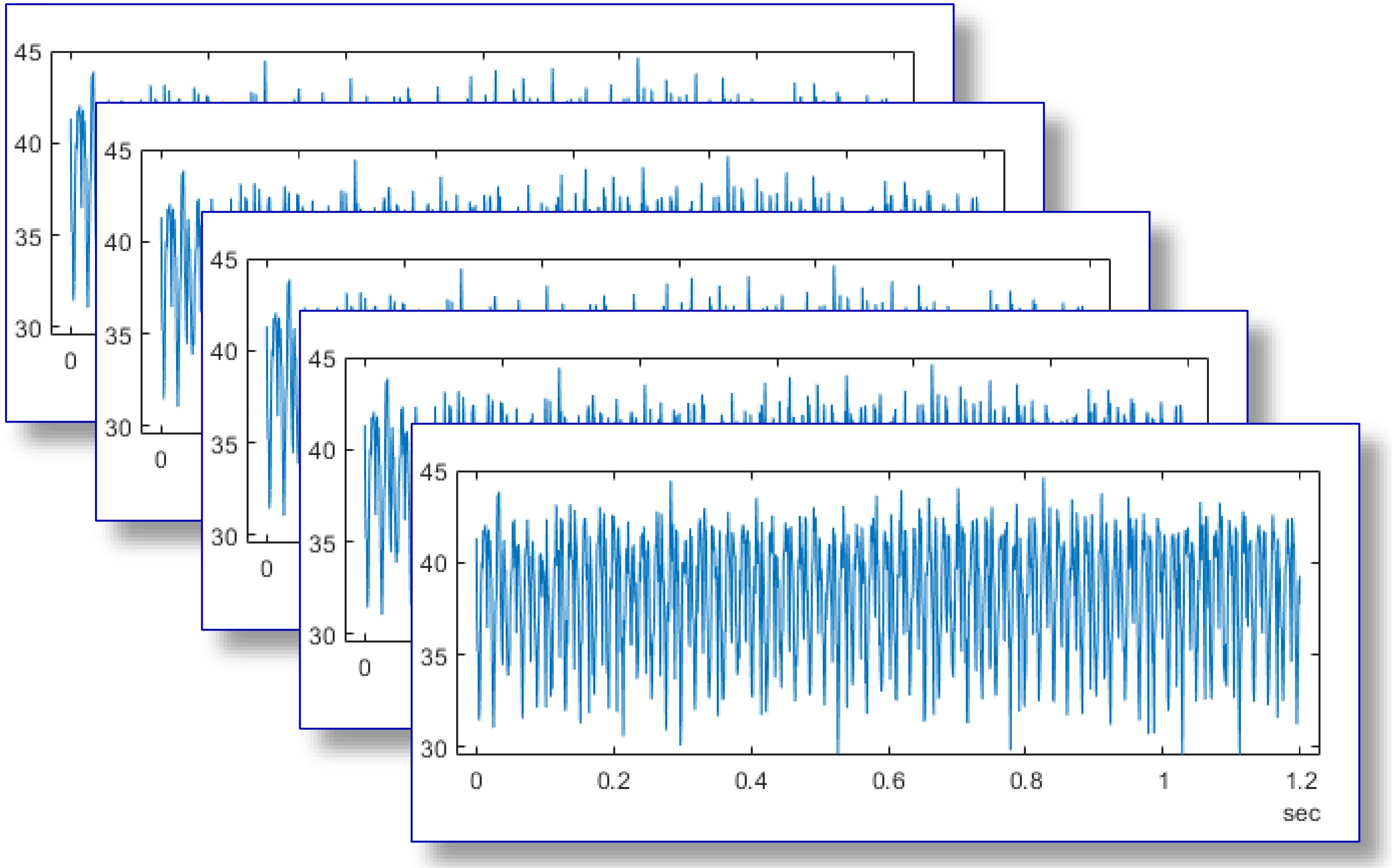
How do you make sense of the ALL the data being collected?

- **1 day ~ 1.3 GB**
- **20 sensors/pump ~26 GB/day**
- **3 pumps ~ 78 GB/day**

- **Satellite transmission**
  - **Speeds approx. 128-150 kbps**
  - **Cost $1,000/ 10GB of data**

- **Needle in a haystack problem**

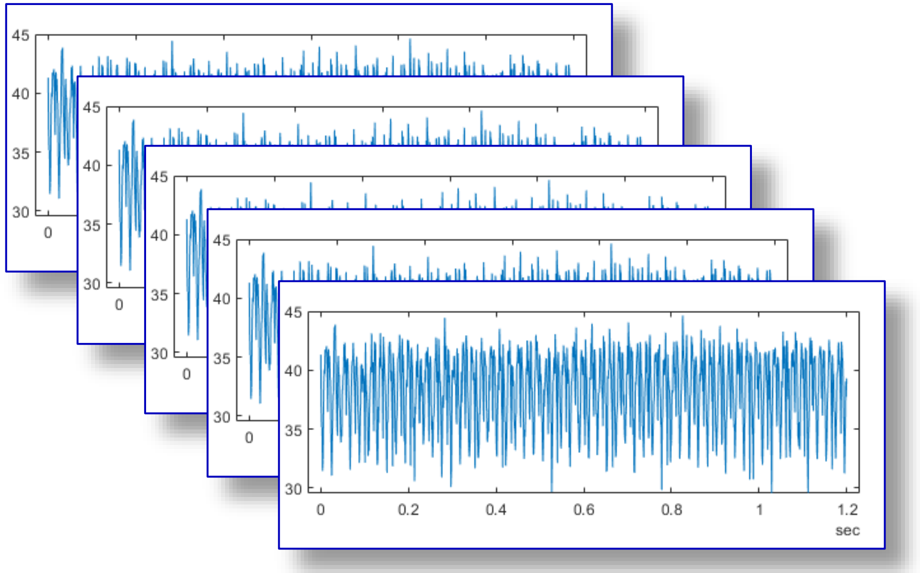
Pump flow sensor *1 sec ~ 1000 samples ~16kB*



Solution: Feature Extraction

Reduce the amount of data you need to store and transmit

- **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

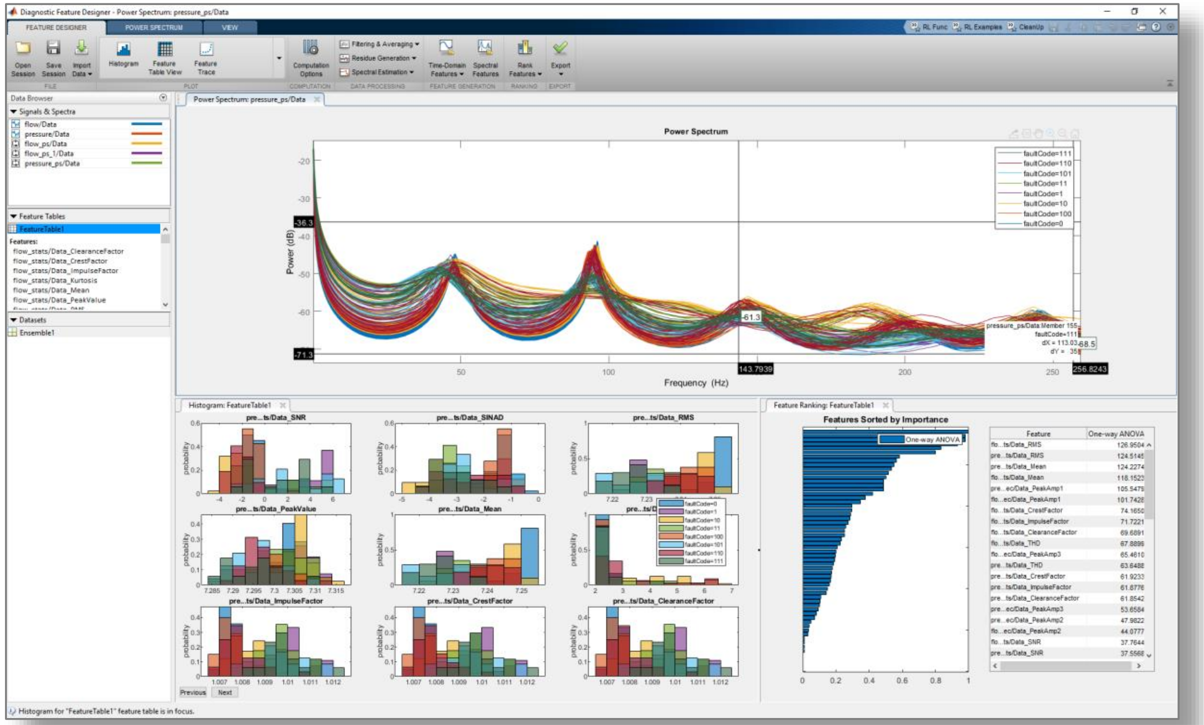


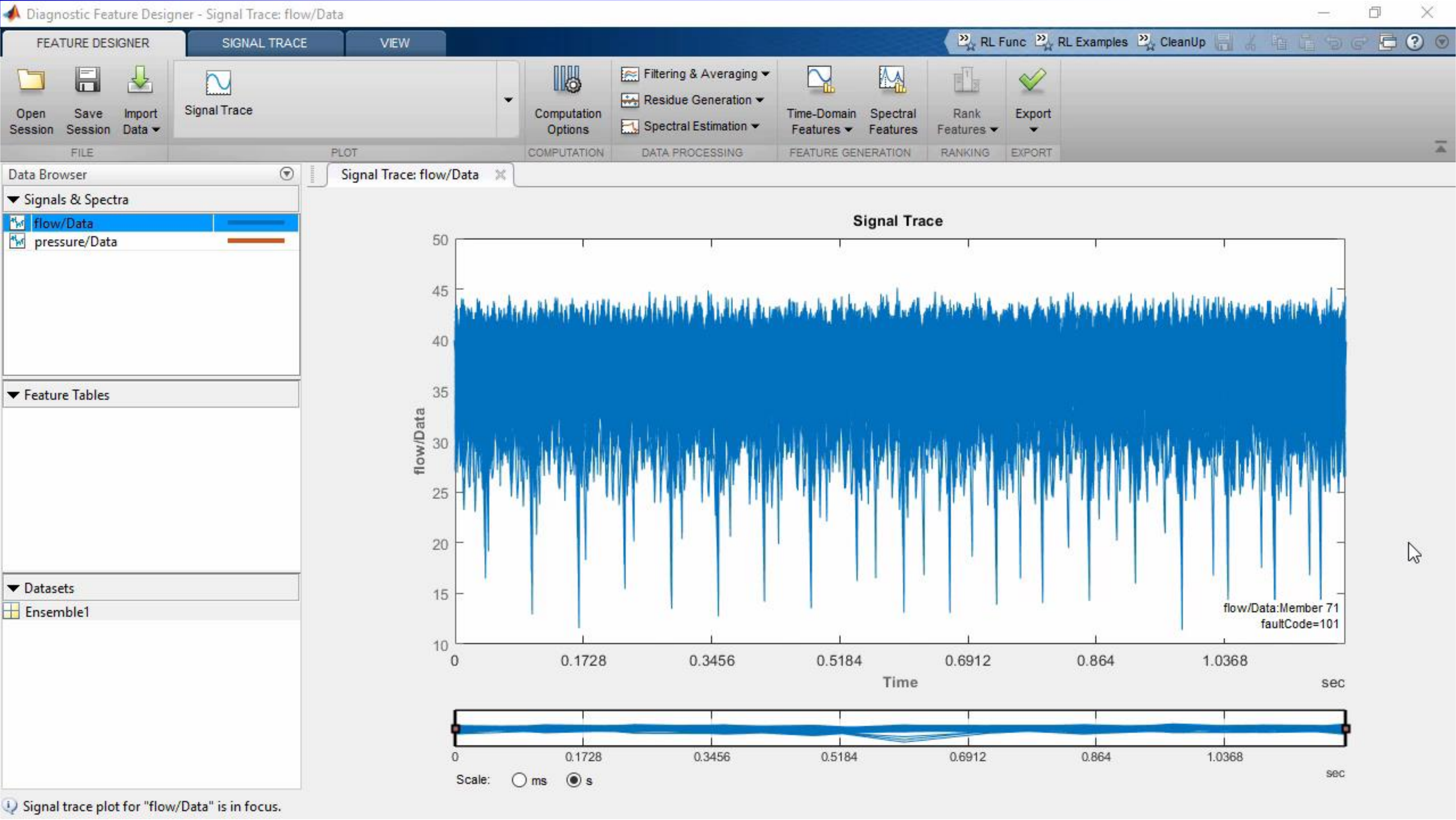
qMean	qVar	qSkewness	qKurtosis
38.4945	9.2306	-0.5728	2.4662
qPeak2P...	qCrest	qRMS	qMAD
15.2351	1.1553	38.6141	2.5562

Diagnostic Feature Designer App

Predictive Maintenance Toolbox R2019a

- **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**




Diagnostic Feature Designer - Signal Trace: flow/Data
FEATURE DESIGNER
SIGNAL TRACE
VIEW
RL Func
RL Examples
CleanUp
Open Session
Save Session
Import Data
Signal Trace
Computation Options
Filtering & Averaging
Residue Generation
Spectral Estimation
Time-Domain Features
Spectral Features
Rank Features
Export
FILE
PLOT
COMPUTATION
DATA PROCESSING
FEATURE GENERATION
RANKING
EXPORT
Data Browser
Signals & Spectra
flow/Data
pressure/Data
Feature Tables
Datasets
Ensemble1
Signal Trace: flow/Data
Signal Trace
flow/Data
Time
sec
flow/Data:Member 71
faultCode=101
0
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0.3456
0.5184
0.6912
0.864
1.0368
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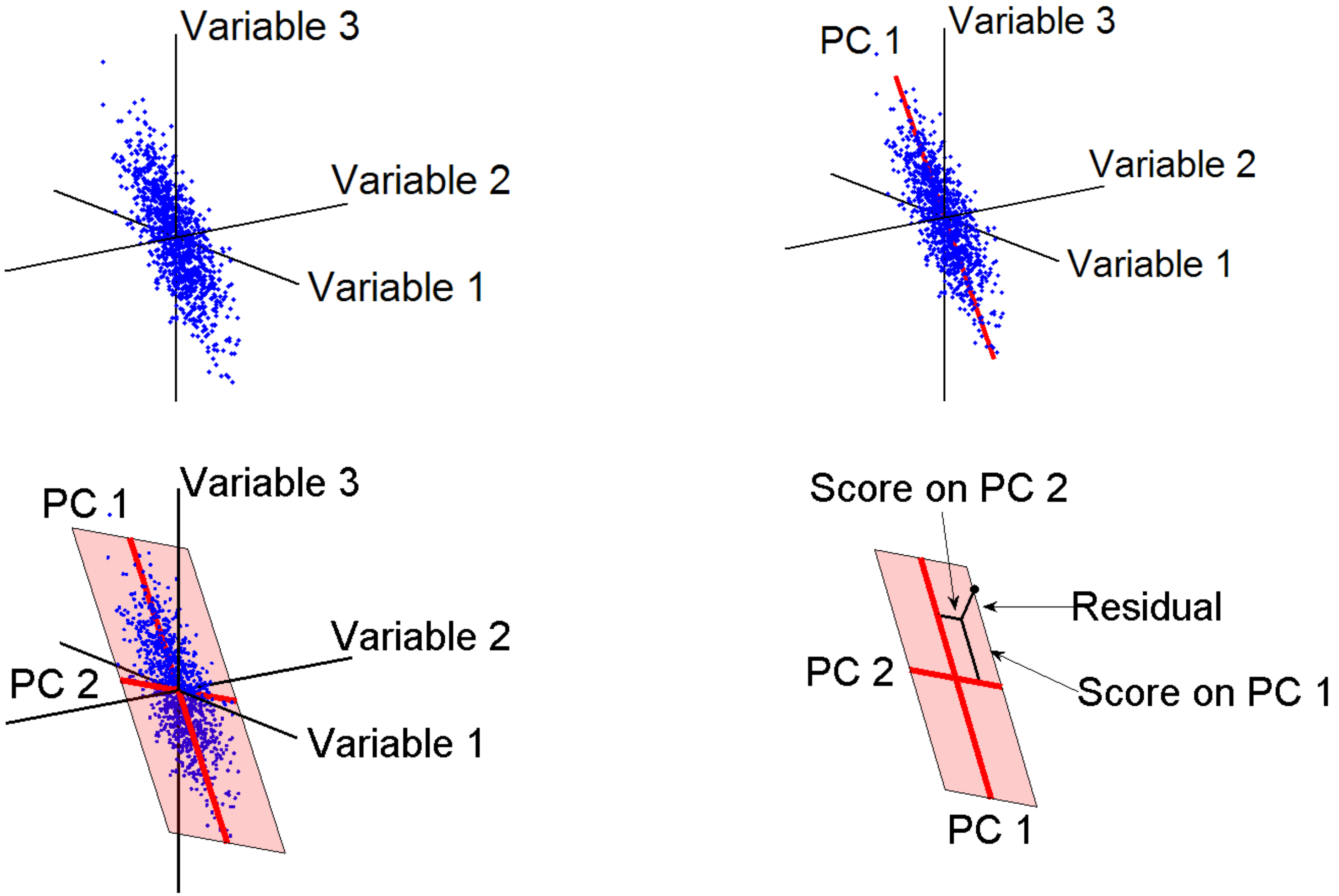
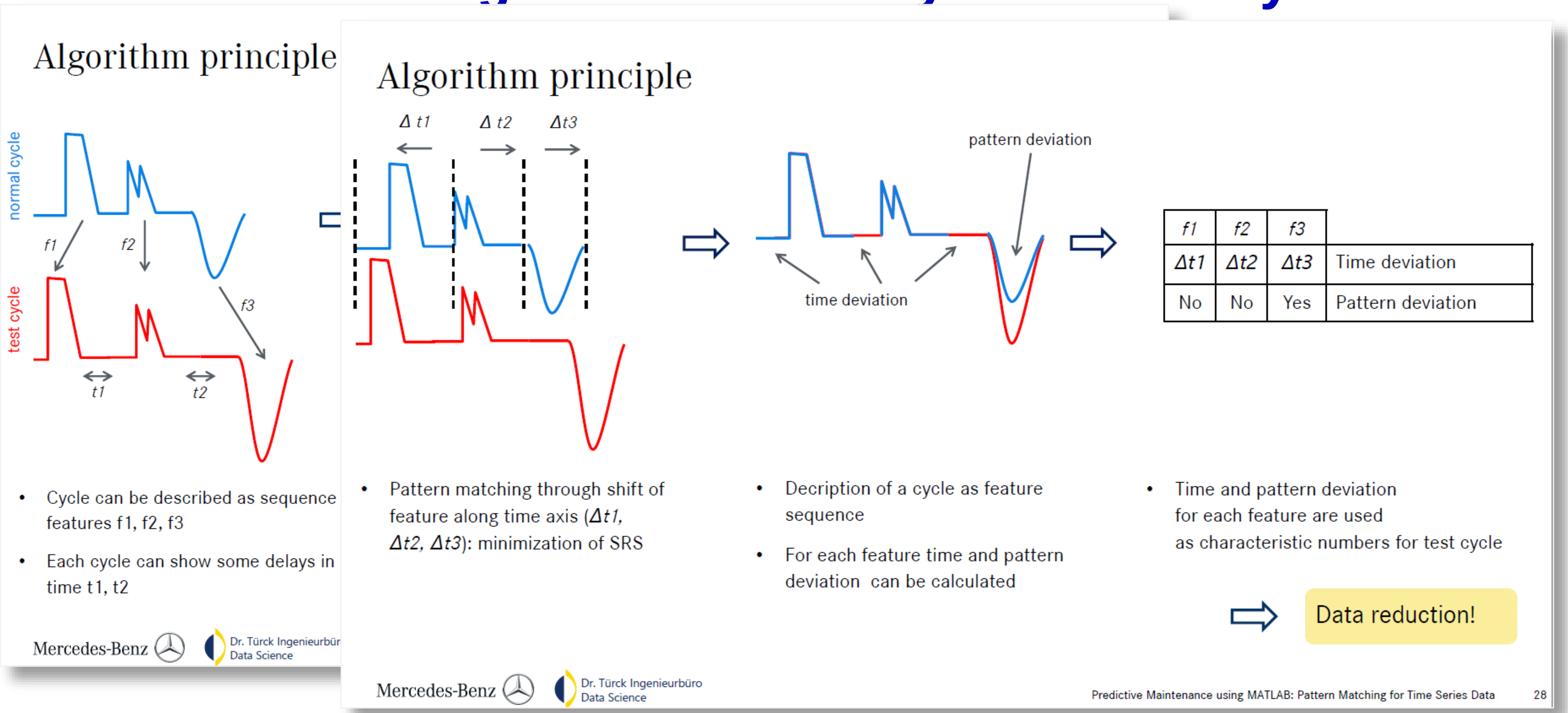
s
Signal trace plot for "flow/Data" is in focus.

Principal Components Analysis – what is it doing?



Daimler are Using MATLAB Today for Anomaly Detection



Algorithm principle

- Cycle can be described as sequence features f1, f2, f3
- Each cycle can show some delays in time t1, t2

Mercedes-Benz Dr. Türck Ingenieurbür Data Science

Algorithm principle

f1	f2	f3	
Δt1	Δt2	Δt3	Time deviation
No	No	Yes	Pattern deviation

- Pattern matching through shift of feature along time axis (*Δt1, Δt2, Δt3*): minimization of SRS
- Decription of a cycle as feature sequence
- For each feature time and pattern deviation can be calculated
- Time and pattern deviation for each feature are used as characteristic numbers for test cycle

⇨ Data reduction!

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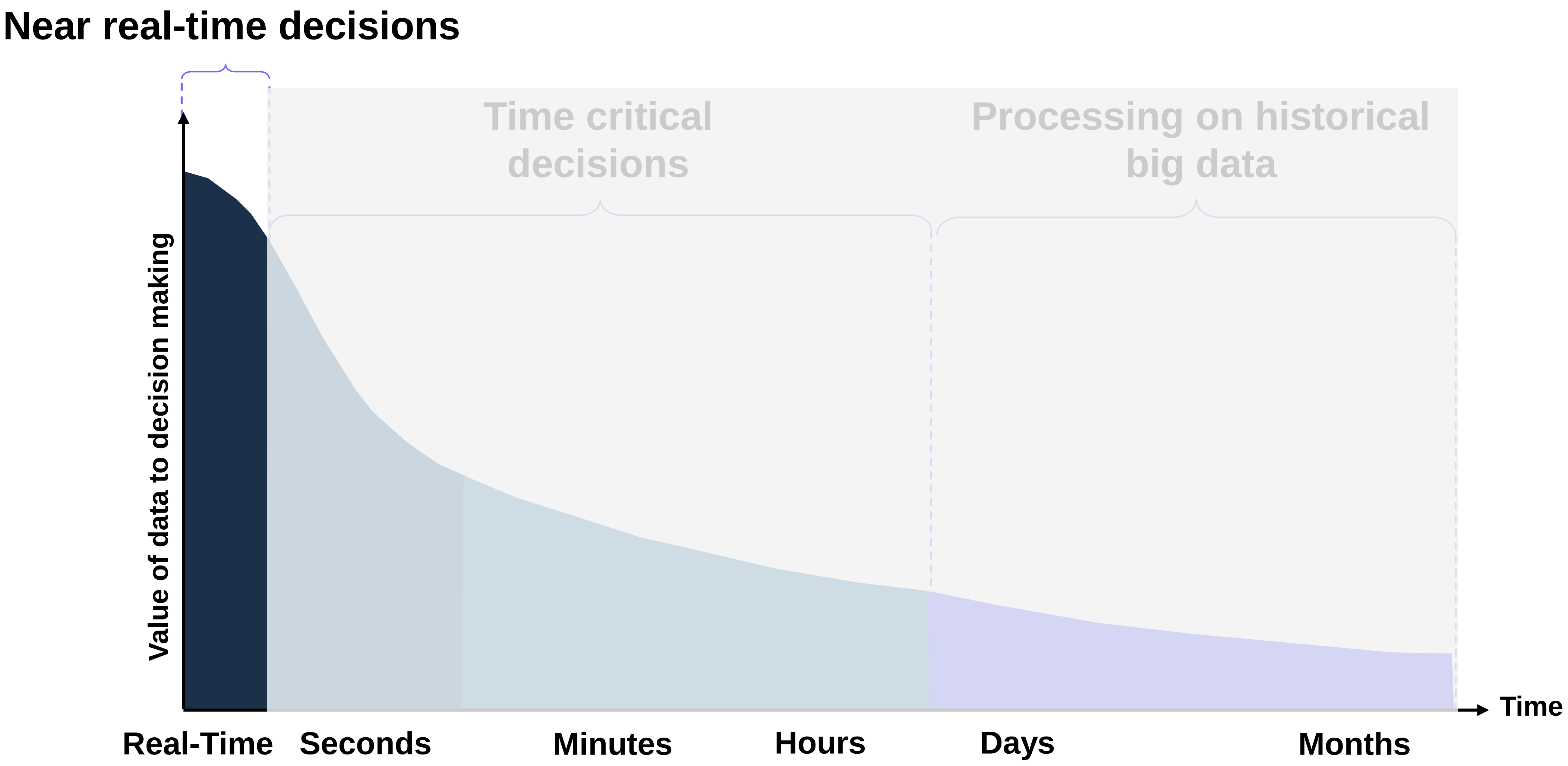
Data reduction of time series by a factor of 250x without a significant loss of information

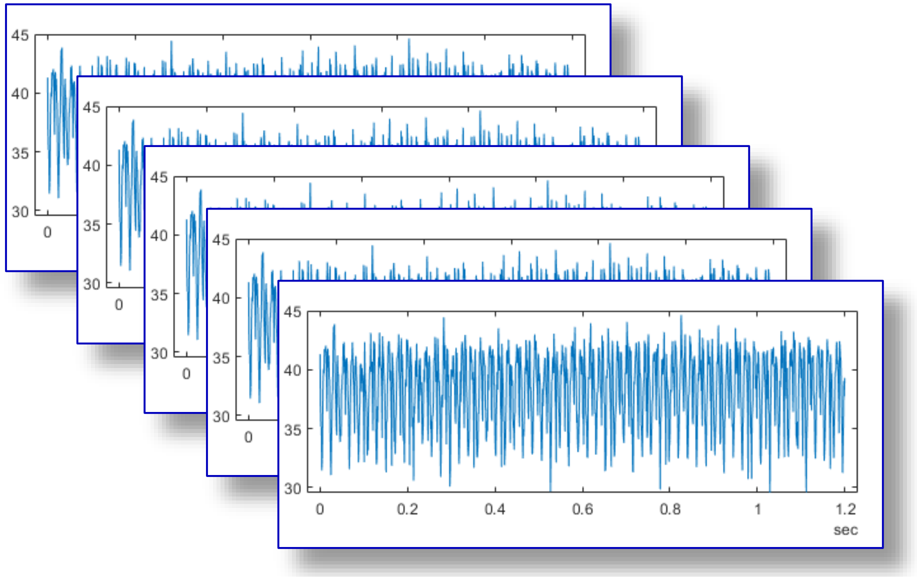
When is Your Data Most Valuable?



Solution: 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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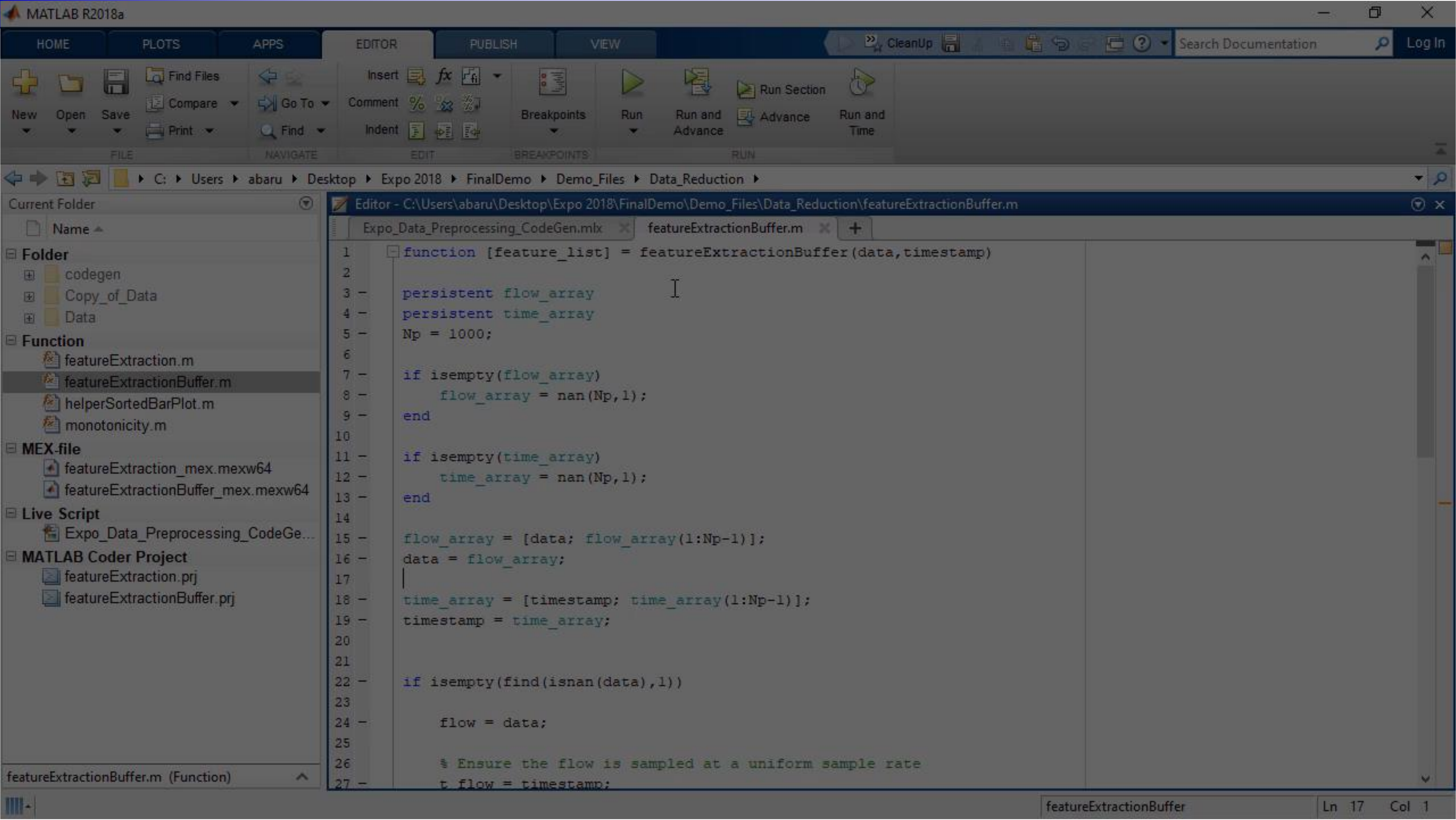
MATLAB R2018a
HOME
PLOTS
APPS
EDITOR
PUBLISH
VIEW
Search Documentation
Log In
New
Open
Save
Find Files
Compare
Print
Go To
Find
Insert
Comment
Indent
Breakpoints
Run
Run and Advance
Run Section
Advance
Run and Time
FILE
NAVIGATE
EDIT
BREAKPOINTS
RUN
C: ▸ Users ▸ abaru ▸ Desktop ▸ Expo 2018 ▸ FinalDemo ▸ Demo_Files ▸ Data_Reduction ▸
Current Folder
Name
Folder
codegen
Copy_of_Data
Data
Function
featureExtraction.m
featureExtractionBuffer.m
helperSortedBarPlot.m
monotonicity.m
MEX-file
featureExtraction_mex.mexw64
featureExtractionBuffer_mex.mexw64
Live Script
Expo_Data_Preprocessing_CodeGe...
MATLAB Coder Project
featureExtraction.prj
featureExtractionBuffer.prj
featureExtractionBuffer.m (Function)
Editor - C:\Users\abaru\Desktop\Expo 2018\FinalDemo\Demo_Files\Data_Reduction\featureExtractionBuffer.m
Expo_Data_Preprocessing_CodeGen.mlx
featureExtractionBuffer.m
function [feature_list] = featureExtractionBuffer(data,timestamp)
persistent flow_array
persistent time_array
Np = 1000;
if isempty(flow_array)
flow_array = nan(Np,1);
end
if isempty(time_array)
time_array = nan(Np,1);
end
flow_array = [data; flow_array(1:Np-1)];
data = flow_array;
time_array = [timestamp; time_array(1:Np-1)];
timestamp = time_array;
if isempty(find(isnan(data),1))
flow = data;
% Ensure the flow is sampled at a uniform sample rate
t_flow = timestamp;
featureExtractionBuffer
Ln 17
Col 1

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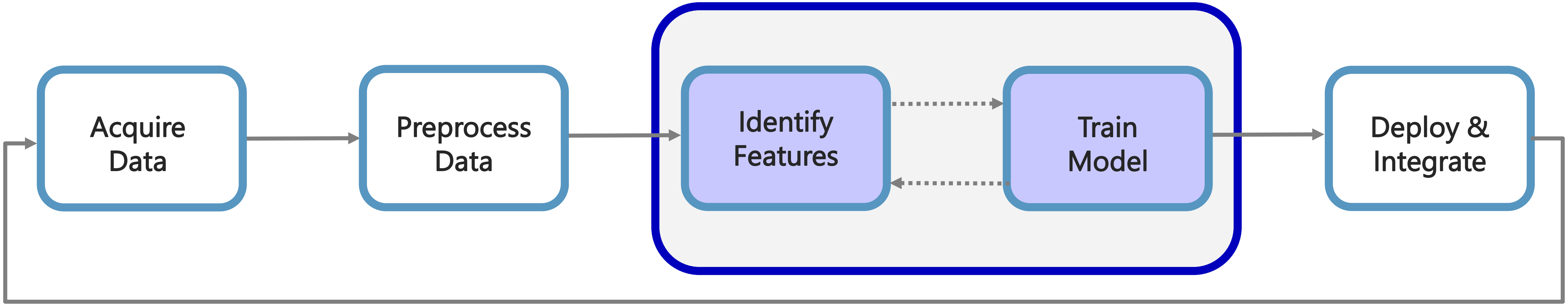
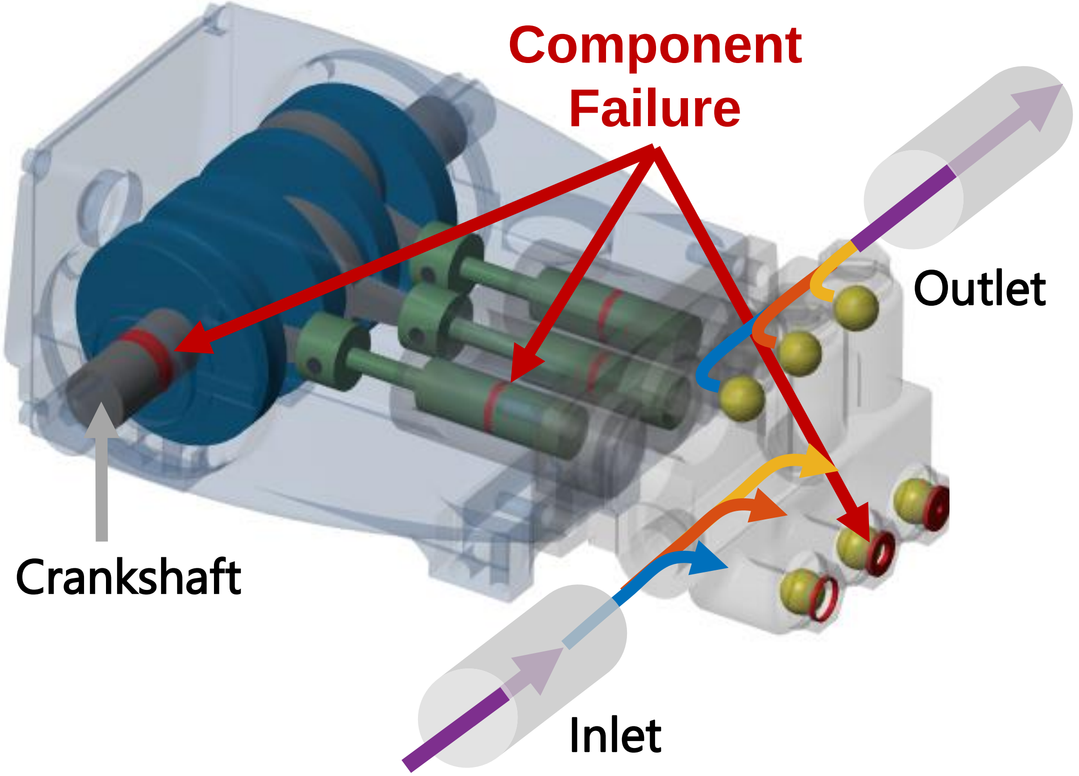


Fault Classification Algorithms Allow You to Identify the Root Cause of Anomalous Behavior

- **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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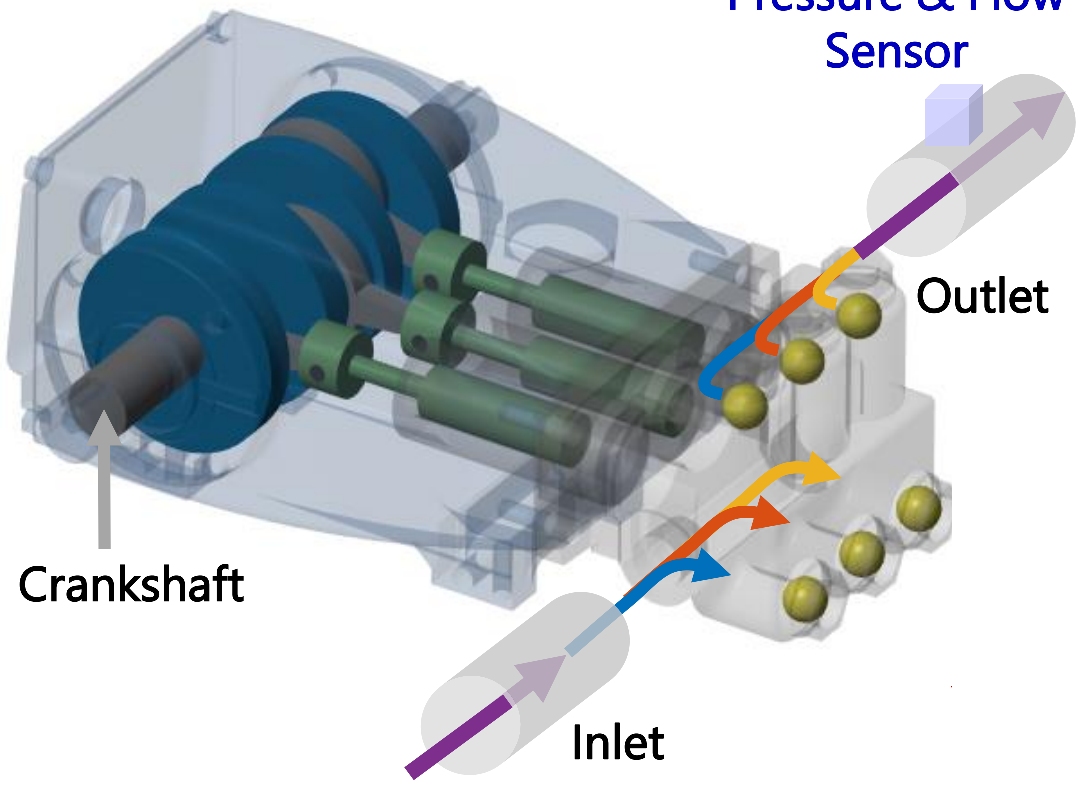
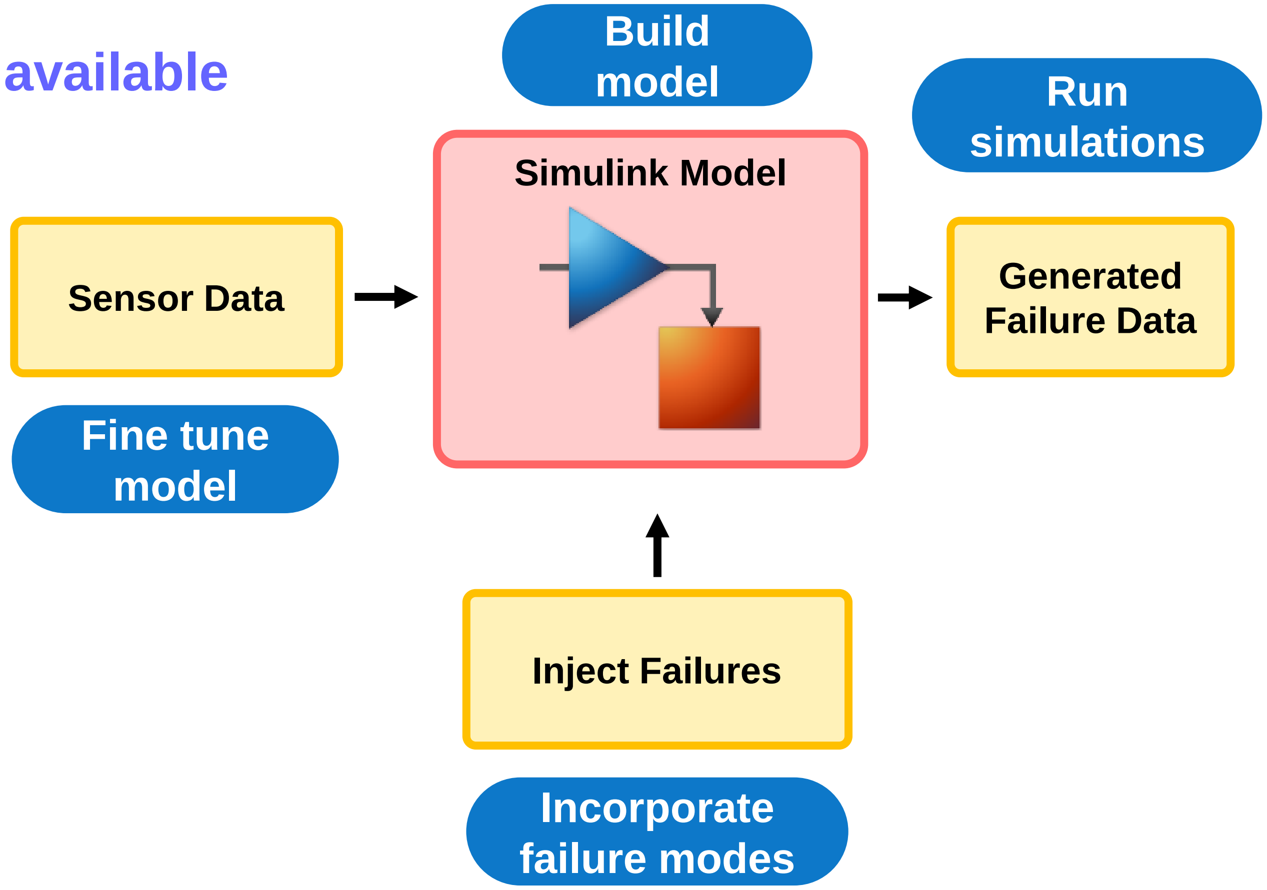
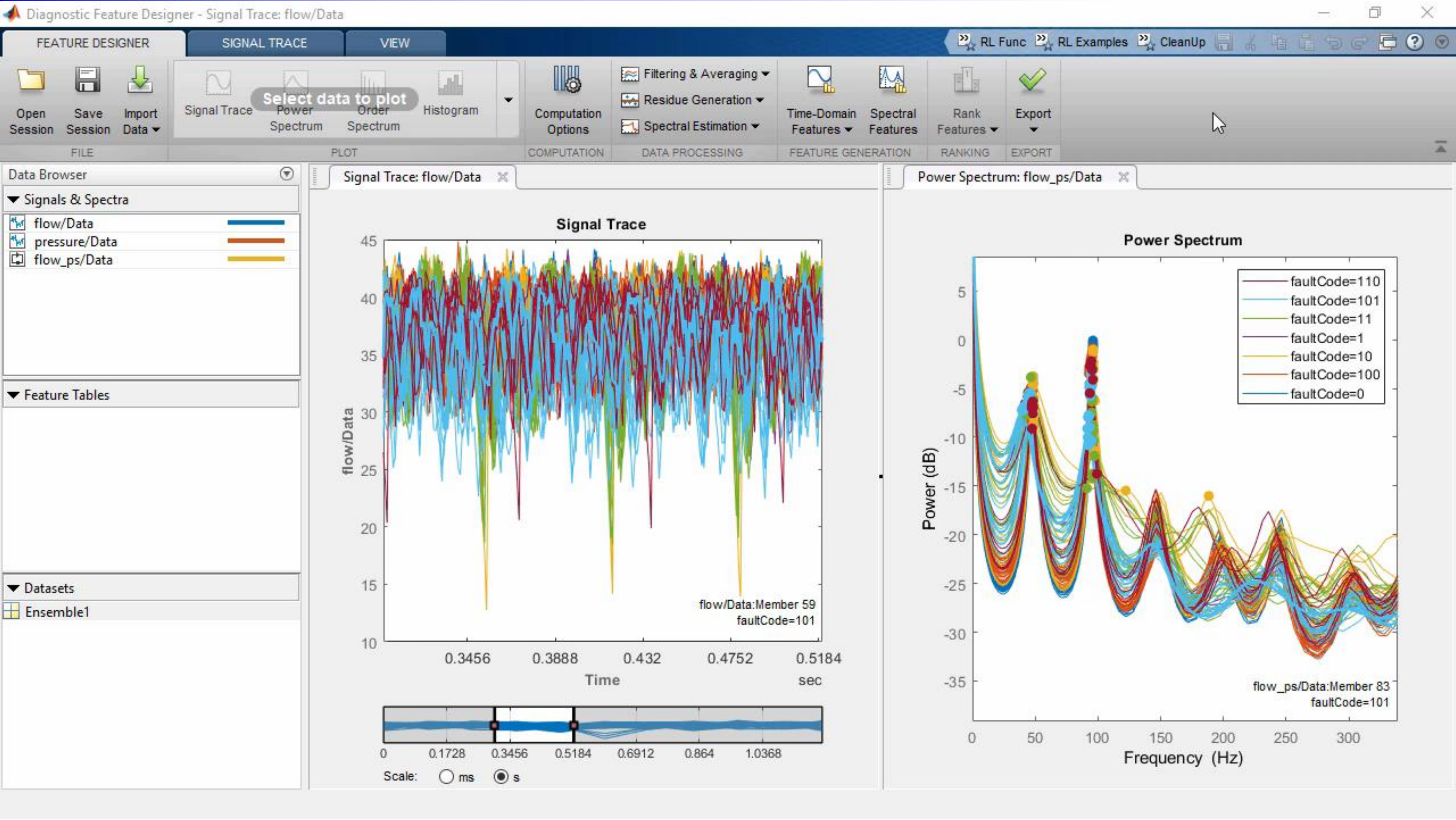


- **Identify fault present in system using only pressure and flow sensor data**

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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Residue Generation
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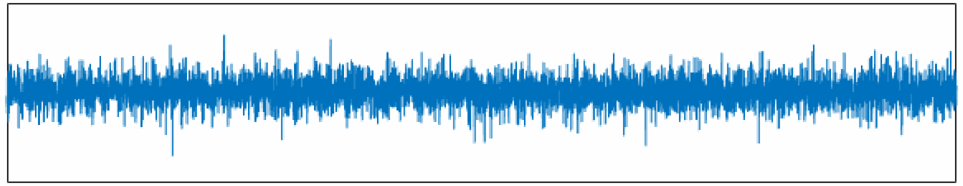
DATA PROCESSING
Time-Domain Features
Spectral Features
FEATURE GENERATION
Rank Features
RANKING
Export
EXPORT
Data Browser
Signals & Spectra
flow/Data
pressure/Data
flow_ps/Data
Feature Tables
Datasets
Ensemble1
Signal Trace: flow/Data
Signal Trace
flow/Data
Time
sec
flow/Data:Member 59
faultCode=101
Scale:
ms
s
Power Spectrum: flow_ps/Data
Power Spectrum
Power (dB)
Frequency (Hz)
faultCode=110
faultCode=101
faultCode=11
faultCode=1
faultCode=10
faultCode=100
faultCode=0
flow_ps/Data:Member 83
faultCode=101

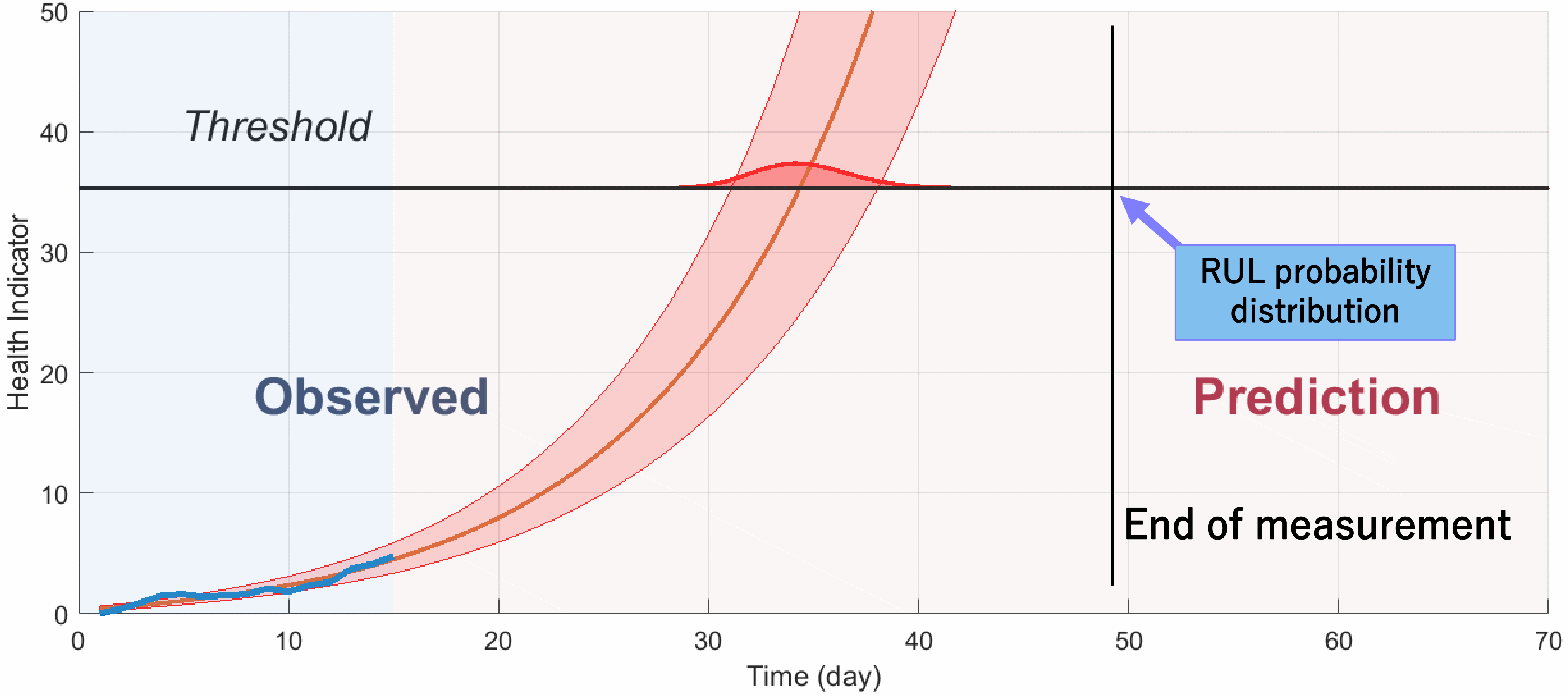
Estimate Remaining Useful Live (RUL)

to Determine When You Should Perform Maintenance



RUL: 459 hours

(95%CI: 374-558 hours)



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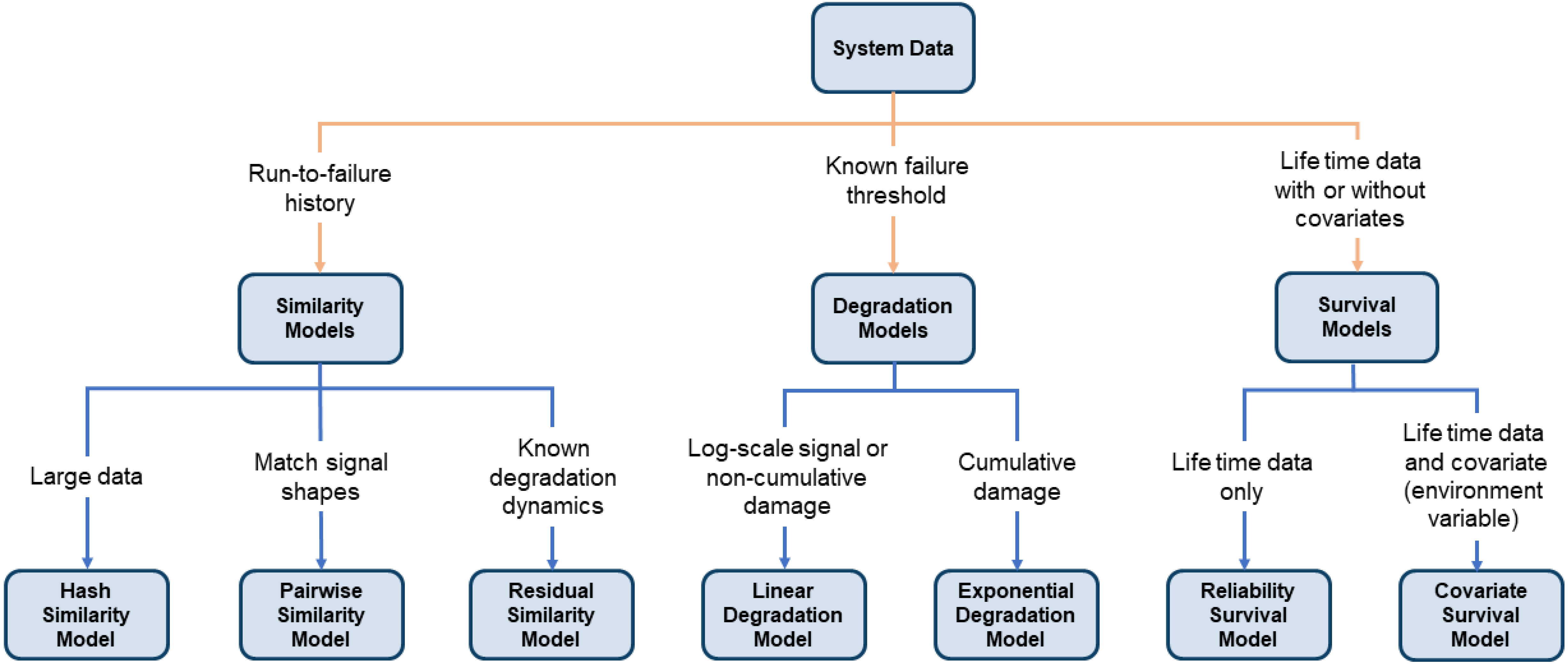

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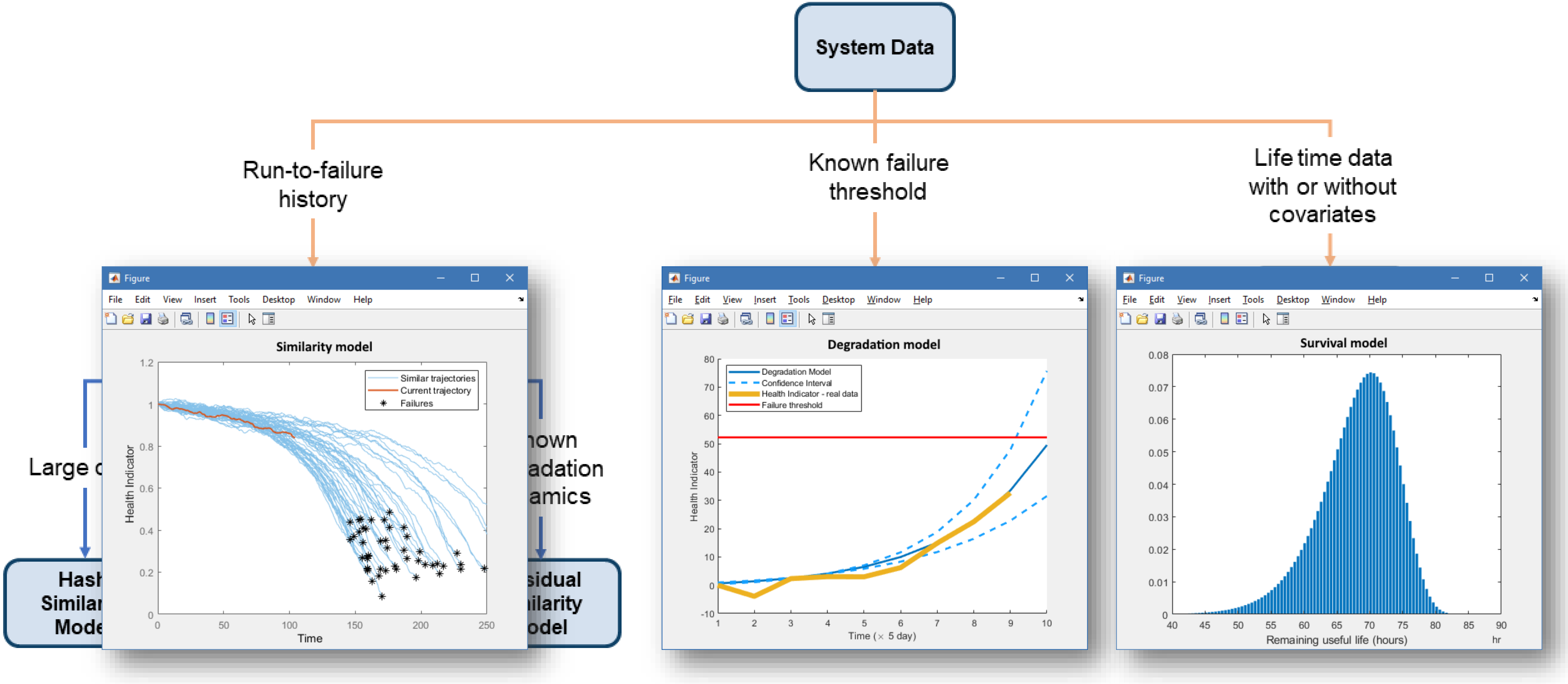

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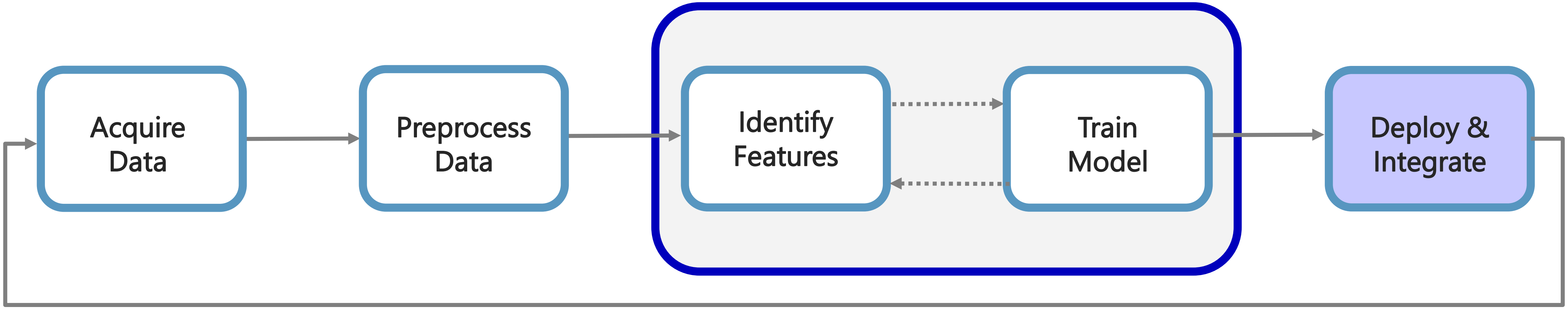
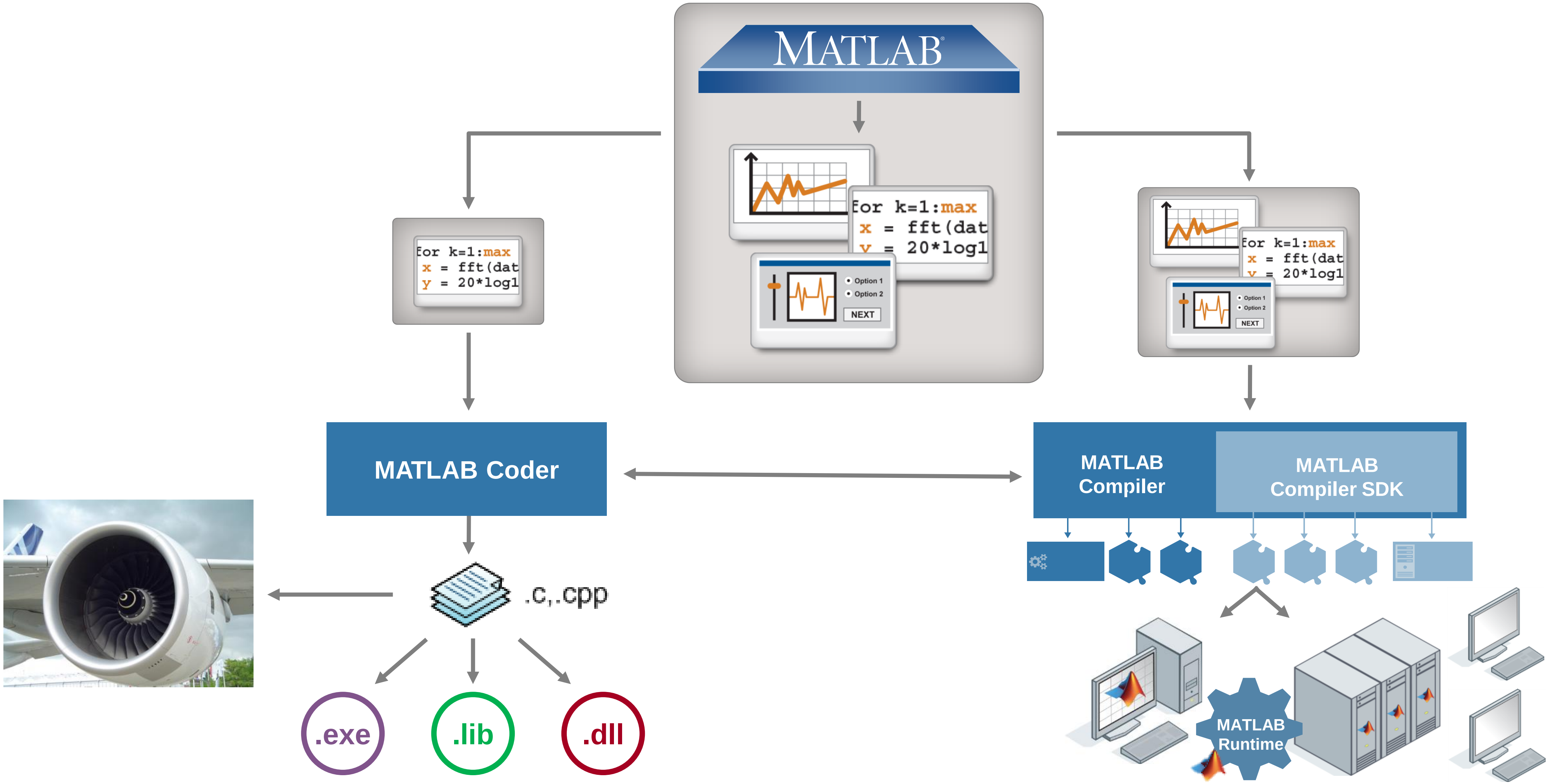
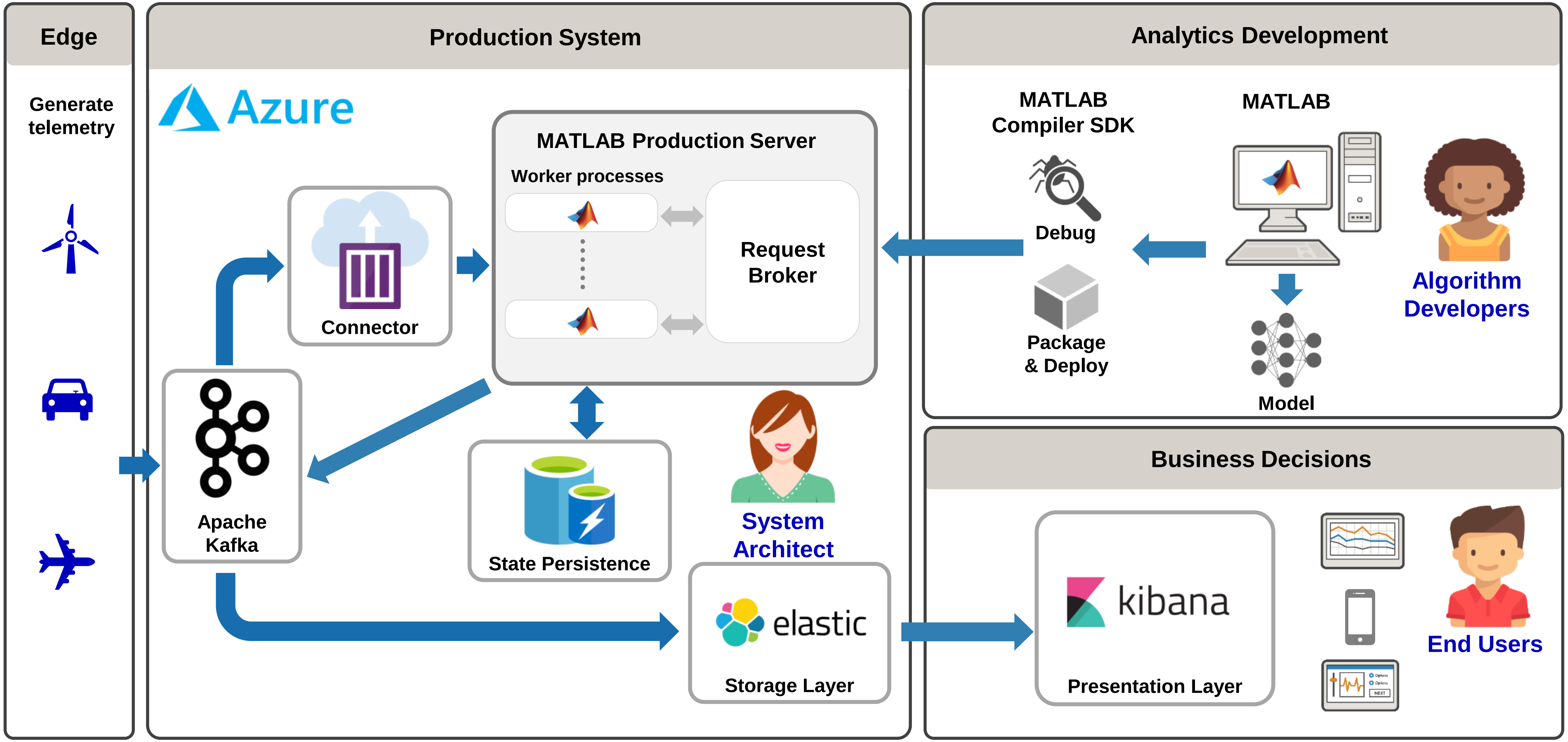


Integrate Analytics with Your Enterprise Systems

MATLAB Compiler and MATLAB Coder



Predictive Maintenance Architecture on Azure



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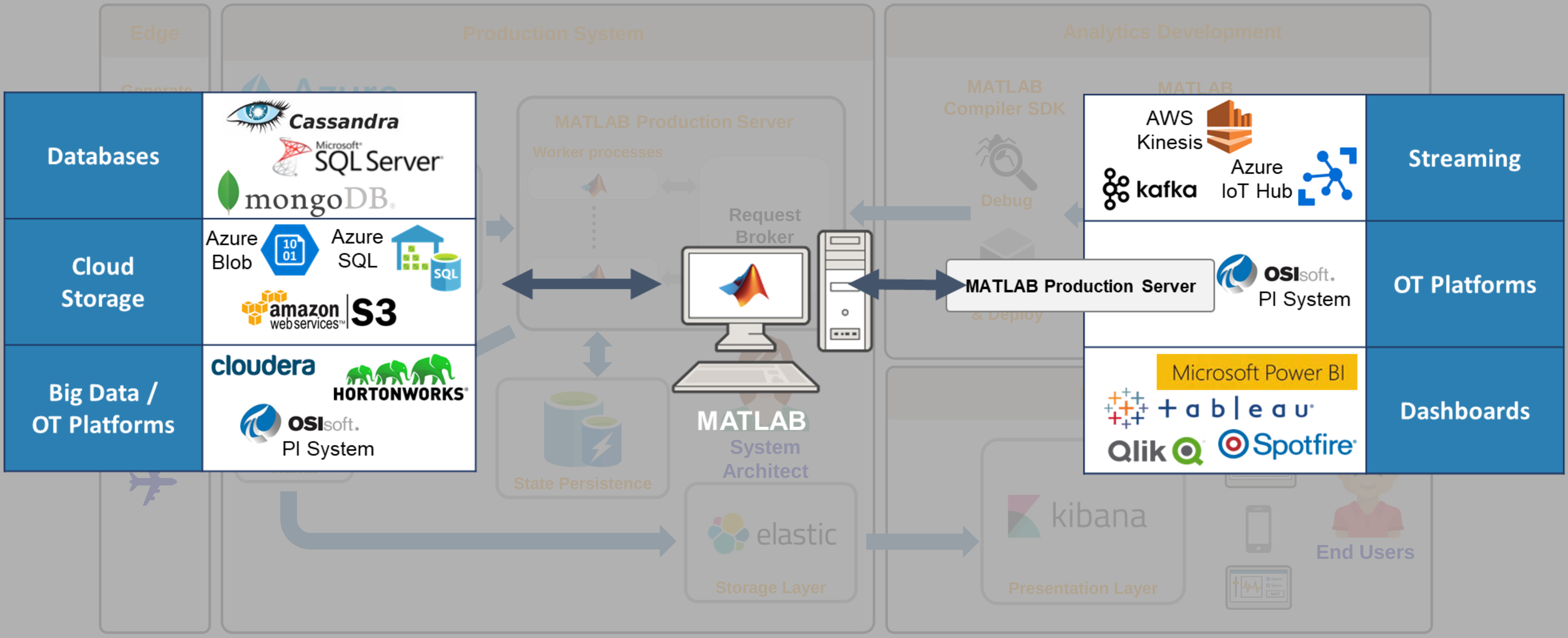

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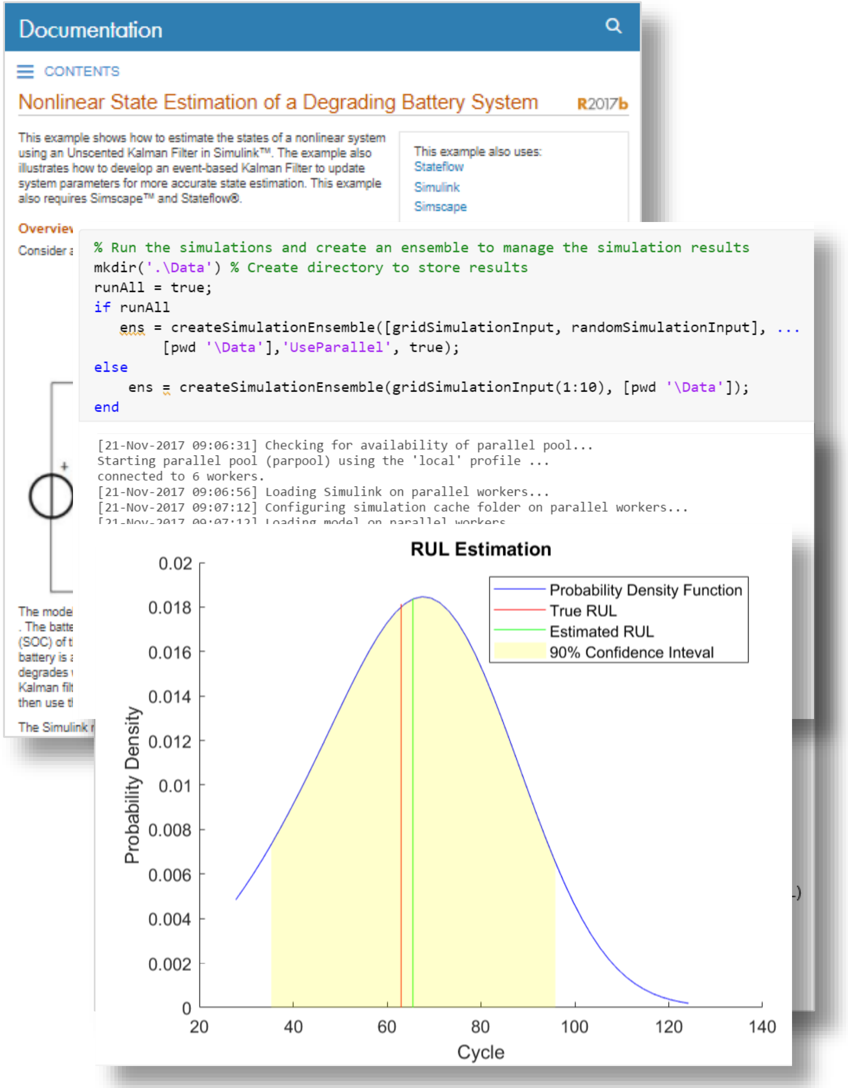
How can the Predictive Maintenance Toolbox help you?

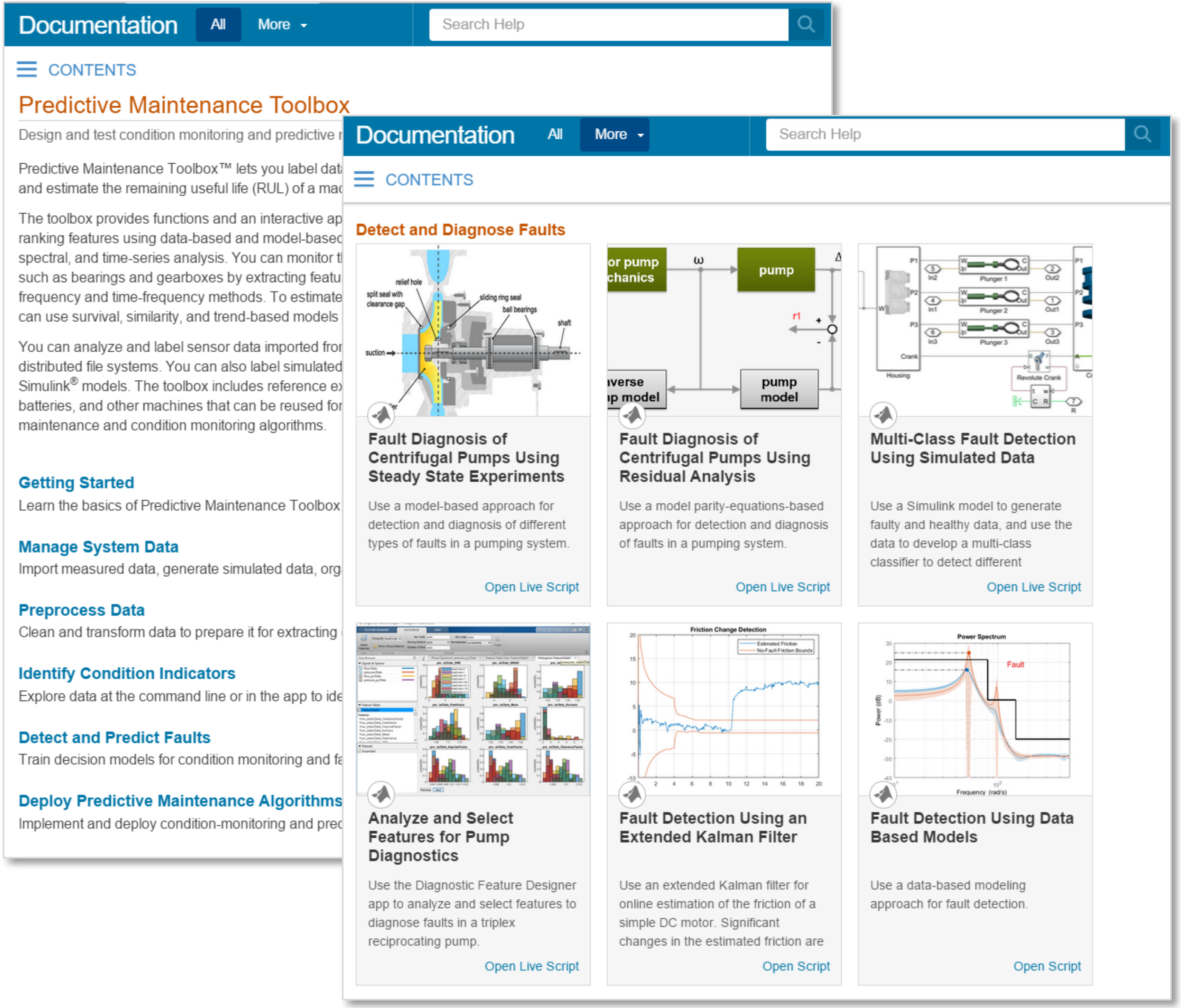
- **How do I get started with developing algorithms?**
  - Reference examples
  - Workflow-based documentation
- **How do I manage data and what if I don't have any data?**
  - Command line functions to organize data
  - Examples showing Simulink models generating failure data
- **How do I choose condition indicators / estimate the RUL?**
  - Functions provided for estimating RUL
  - Functions for computing condition indicators



HUMUSOFT

MATLAB can help you get started TODAY

- **Examples**
- **Documentation**
- **Tutorials & Workshops**
- **Consulting**
- **Tech Talk Series**



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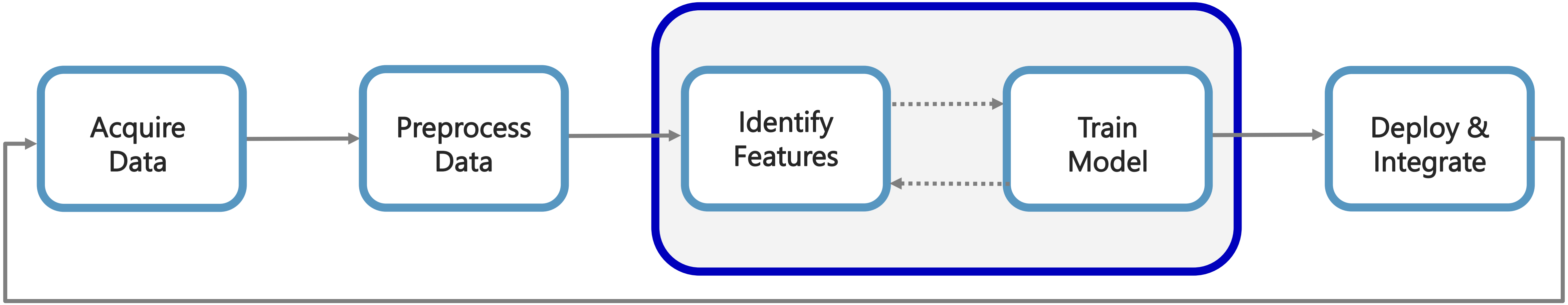

Děkuji za pozornost