

针对智能制造的预测性维护和系统部署

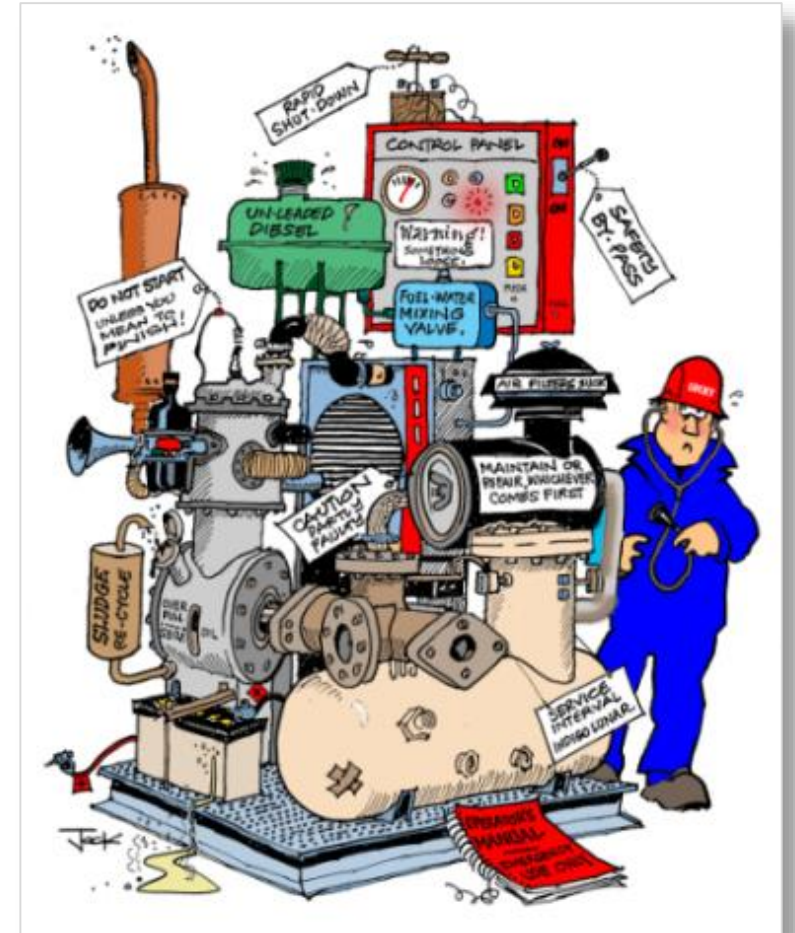
Jianping Chen

针对智能制造的预测性维护和系统部署

- 预测性维护介绍
- 预测性维护算法开发和工具箱
- 单机应用和生产部署

什么是预测性维护？

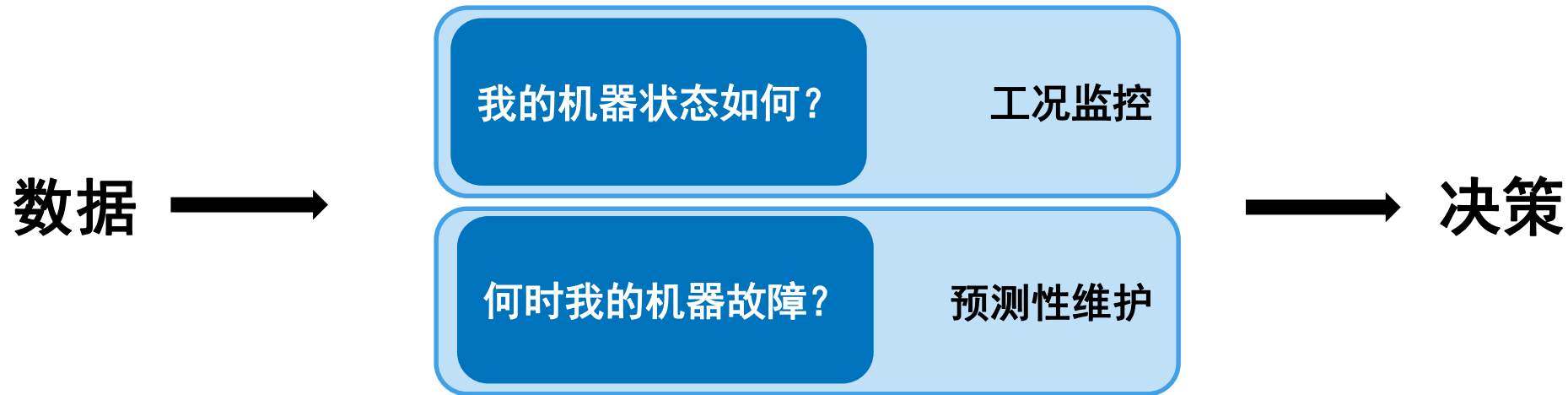
- 一种预测何时机器失效的预测技术
- 将即将发生的故障的信息发送给维护工程师，操作员和工厂经理
- 然后在最佳时间执行维护
- 这减少了不必要的维护并消除了意外停机



Source: Tensor Systems

预测性算法有啥用？

有助于根据大量复杂的数据做出维护决策



工况监控

监测机器传感器数据（振动，温度等）过程，以识别可能表明发生故障的重大变化

预测性维护

从传感器数据和历史数据中确定故障时间/剩余使用寿命（RUL）的技术，以便预测何时应进行维护

为什么预测性维护很重要？

- 提升操作效率

- 新的收入来源

- 竞争优势

Bill Ruh Retweeted
GE Digital @GE_Digital · Feb 1
 What does the future of the #IIoT look like? Our CEO @BillRuh_GE explains in this new interview: stratzb.to/gASk308yoP0



The Thought Leadership
 Bill Ruh
 strategy+business
 Bill Ruh, CEO

Siemens @Siemens
 Thanks to predictive maintenance the #Velaro E trains between Barcelona and Madrid run w/ 99.9% availability #GartnerSYM




ABB Global @ABBgroupnews
 A game changer that opens the door to predictive maintenance ow.ly/4nc2TT #IIoT #HM16



SAP IoT @SAP_IoT
 John Deere uses machine alerts using #telematics for predictive maintenance and to lower downtime of assets v3.co.uk/v3-uk/news/234 ... #IIoT



John Deere: Technology vendors need to feed agriculture's big data needs
 Farmers are hungry for IT solutions
v3.co.uk

Intel IoT @IntelIoT
 #DYK predictive maintenance can cut yield losses by 25%? Major benefits of #IIoT: intel.ly/2dg7Otm



Software Innovations @BoschSI · Jan 31
 How to develop a #DataAnalytics tool for #PredictiveMaintenance in 1 week? youtube.com/watch?v=9mas0b... #IIoT #Industry40



How to develop a data analytics tool in 1 week (Part 1)
 A team of data scientists, manufacturing & software experts at Bosch Software Innovations developed a data analytics tool for predictive maint...
youtube.com

Customer Example: Mondi

Predictive Maintenance

挑战

减少塑料生产中的浪费和机器停机时间

解决方案

使用 MATLAB 开发和部署基于机器学习的监控和预测性维护程序来预测机器故障

成果

- 八台设备每年解决 50,000 欧元
- 全面投产预计每年可以节约 > 200,000 欧元
- 在6个月内完成了原型开发

“We had the first tests within two months and a working prototype in six. The MATLAB code is easy to understand, so we can make changes rapidly when needed.” Dr Kohlert

- 生产软件 7/24 全天候运行

“There’s a misconception that MATLAB is only for research or development. We operate our machines nonstop, and we rely on our MATLAB based predictive maintenance software to run continuously and reliably in production.”



- International packaging and paper
- ~25k employees
- Revenues of €6.4 billion in 2014



One of Mondi’s plastic production machines, which deliver 18 million tons of plastic and thin film products annually.



MATLAB based HMI that enables equipment operators to receive warnings about potential failures before they occur

[Link to User Story](#)

Customer Example: Baker Hughes

Pump Health Monitoring System

挑战

- 多达20辆卡车在一个井场全天候运行
- 必须立即更换泵故障的卡车
- 准确的预测防止损坏并保持运行

解决方案

- 分析了搜集自10辆卡车，每秒50,000个样本的 **TB** 量级传感器数据
- 以**专有的二进制文件格式**读取和解析传感器数据
- 执行**FFT和频谱分析**，以过滤卡车，泵和流体的大量移动
- 最佳模型是使用阀门和阀座的压力、振动和定时传感器数据的神经网络模型

成果

- 节约**大于1千万**美金
- 开发时间缩短了十倍

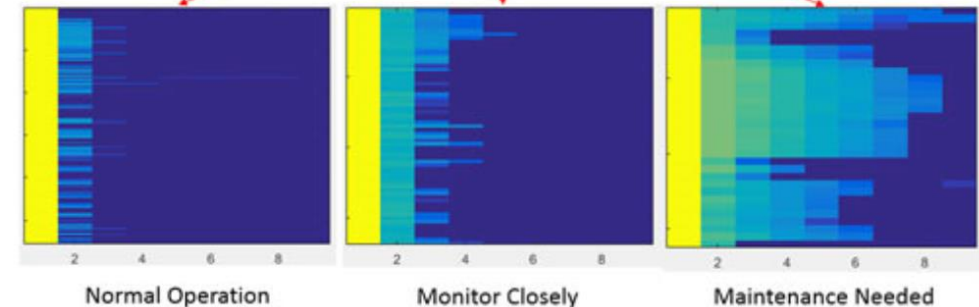
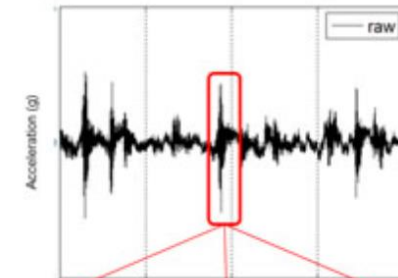


- one of the world's largest oil field services companies.
- ~34k employees



Positive displacement pumps inject a mixture of water and sand at high pressure into drilled wells.

Predictive Maintenance Alarm System



MATLAB based predictive maintenance alarm system

[Link to User Story](#)

维护类型

- 响应式 —— 有问题的时候执行一次维护
 - 例子：替换车辆蓄电池
 - 问题：不可预期的故障可能导致高昂的代价和潜在的危险
- 计划式 —— 按照固定的频率执行维护
 - 例子：汽车每 5,000 公里更换机油
 - 问题：不必要的维护导致浪费；不能完全消除故障
- 预测式 —— 问题发生之前预测性维护
 - 例子：某些 GM 的车型预测潜在的电池、油泵和启动电机故障
 - 问题：对复杂设备进行精确预测非常困难

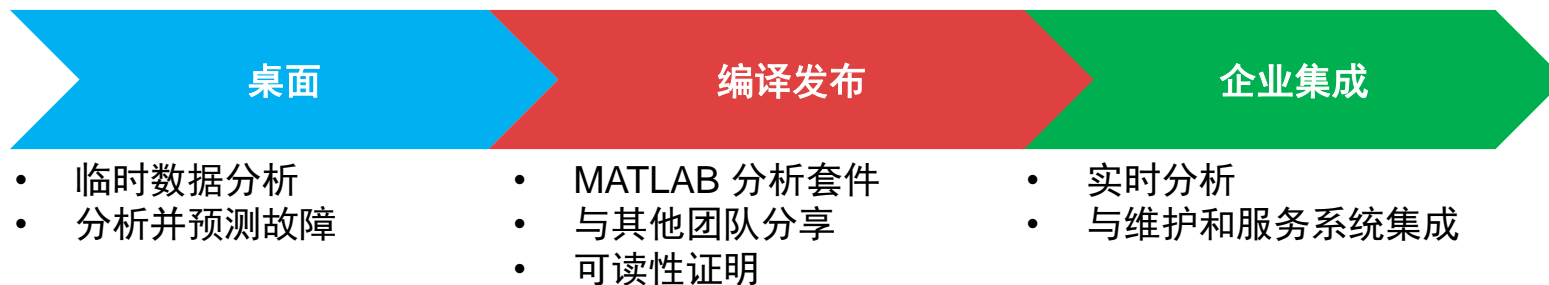
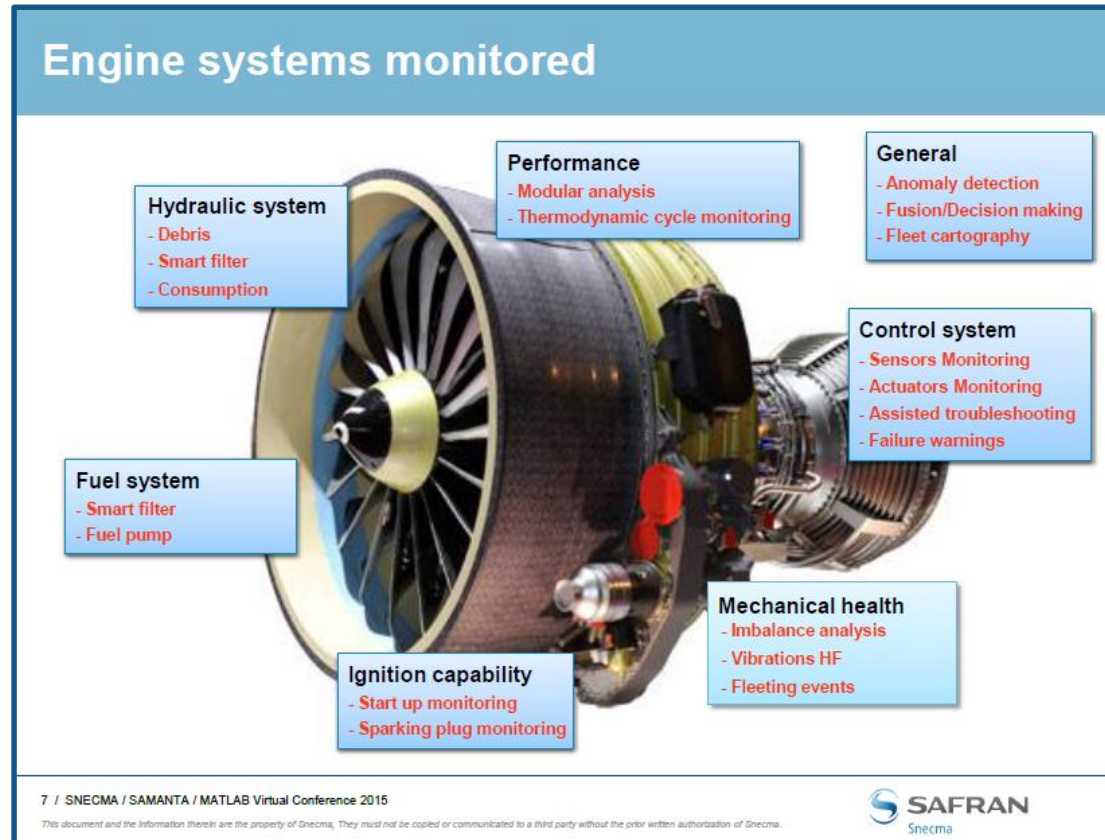
成功案例?

Safran 发动机监看检测解决方案

- 监控系统
 - 检测故障指标
 - 预测维护时间
 - 确认组件

- 提升飞机可用性
 - 及时出发和到达
 - 计划和优化维护
 - 减少发动机停工时间

- 降低维护费用
 - 问题辅助定位
 - 减少二次受损



涡轮发动机的预测性维护

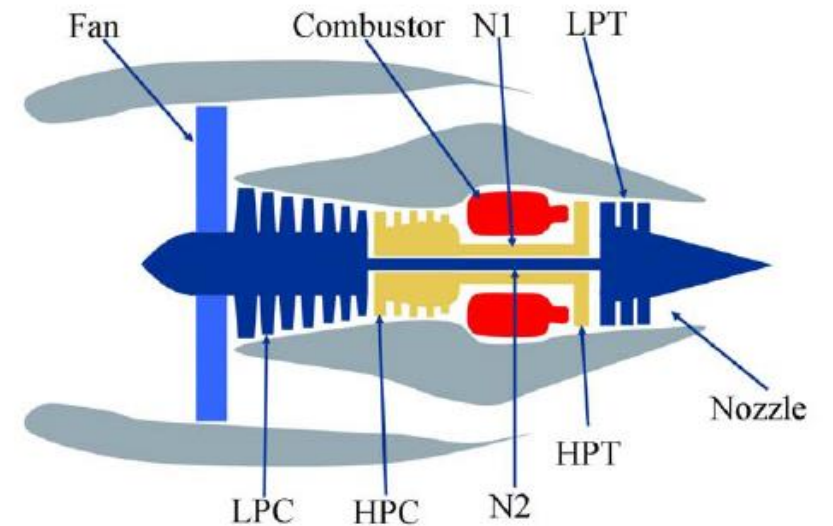
同一型号的 100 台发动机的传感数据

预测并修正故障

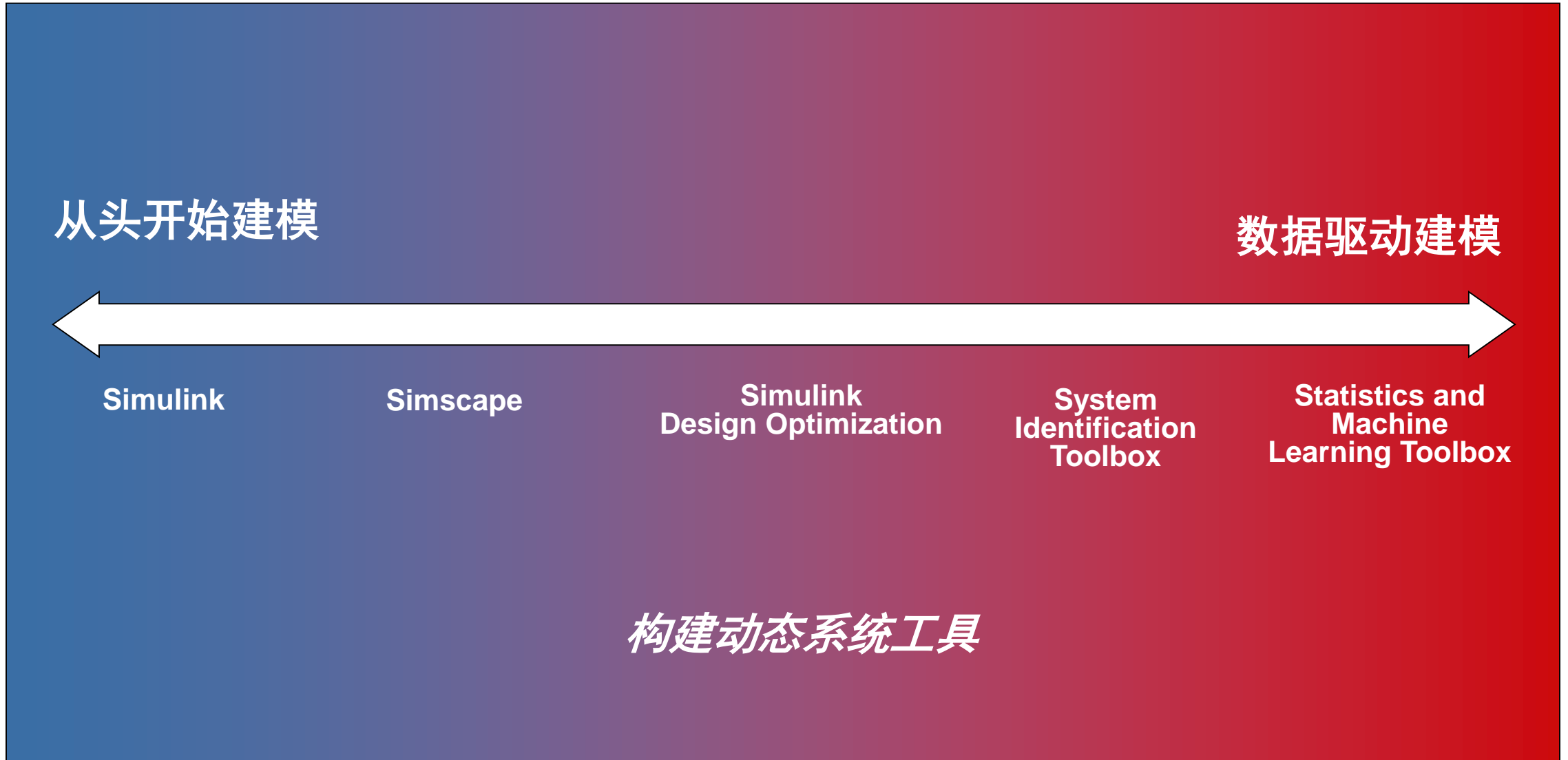
- 导入和分析历史传感数据
- 训练模型预测故障发生的时间
- 在真实传感数据中部署模型
- 在实际中预测故障

Data provided by NASA PCoE

<http://ti.arc.nasa.gov/tech/dash/pcoe/prognostic-data-repository/>



建模方法



涡轮发动机的预测性维护

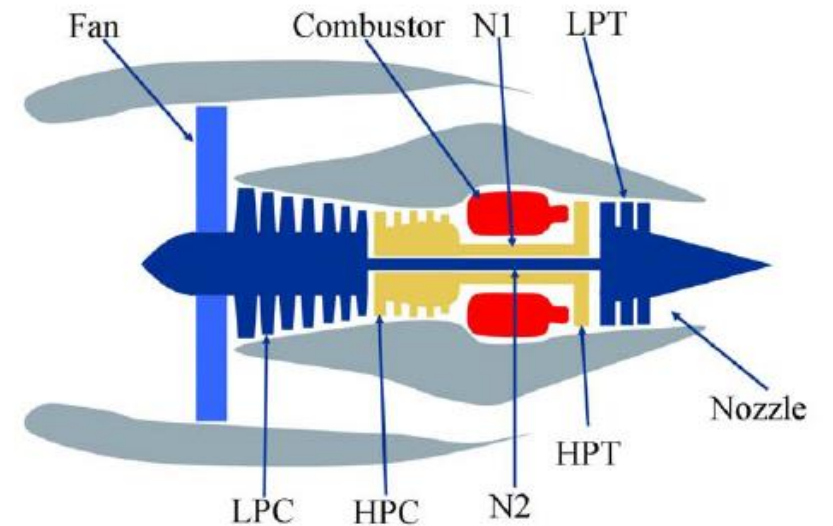
同一型号的 100 台发动机的传感数据

场景 1：没有故障数据

- 例行维护
- 没有故障发生
- 维修人员告诉我们，大多数发动机可以运行更长的时间
- 在**没有具体错误**的时候，我们能够更加聪明地安排维护么？

Data provided by NASA PCoE

<http://ti.arc.nasa.gov/tech/dash/pcoe/prognostic-data-repository/>



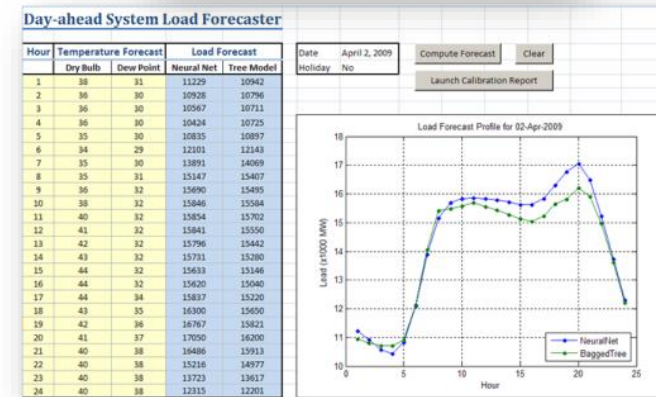
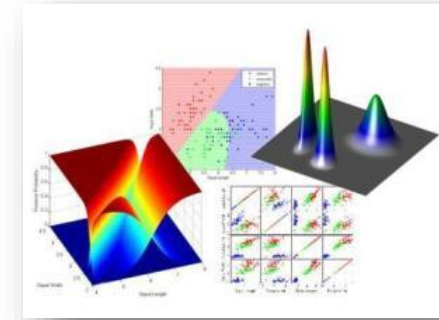
机器学习

■ 特点

- 很多变量
- 系统过于复杂，很难用公式表达
(比如，黑盒建模)

■ 例子

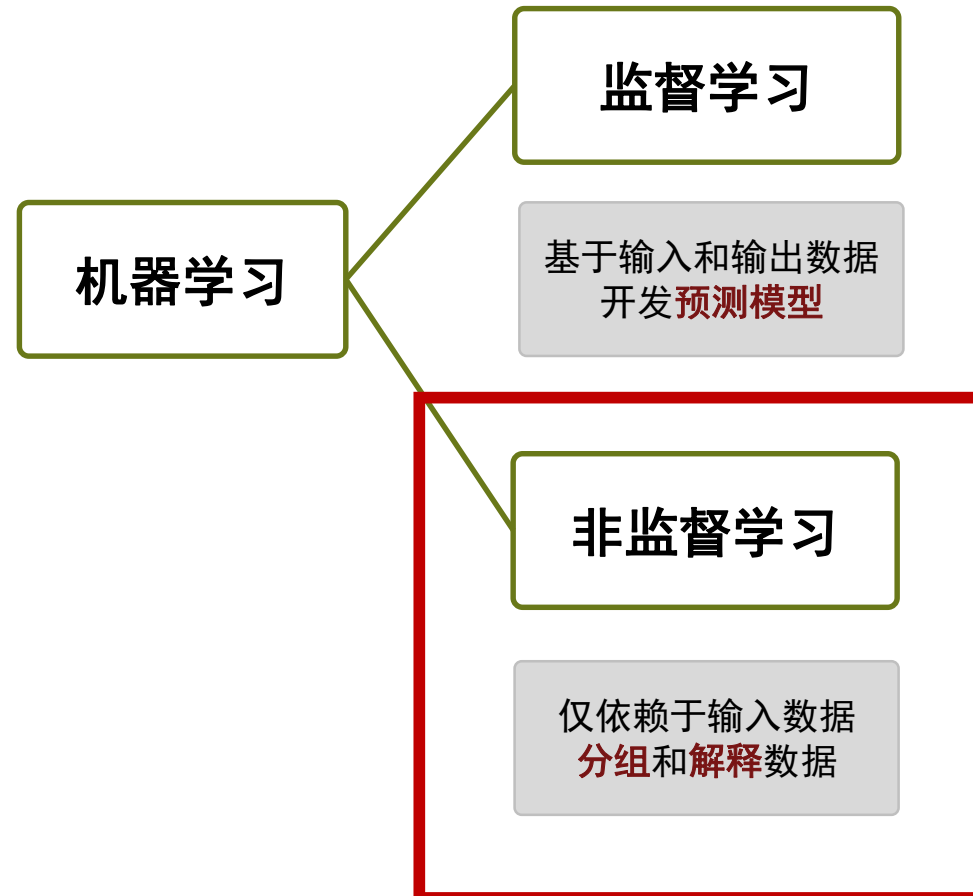
- 模式识别 (语音、图像)
- 金融算法 (信用评估、算法交易)
- 能源预测 (负荷、价格)
- 生物学 (肿瘤预测、药物研发)
- 工程学 (流量分析、预测性维护)



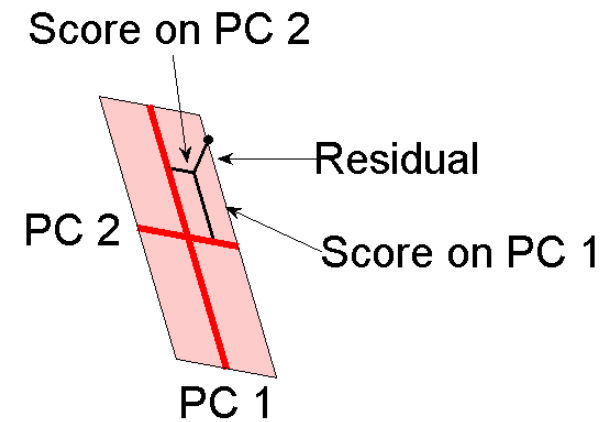
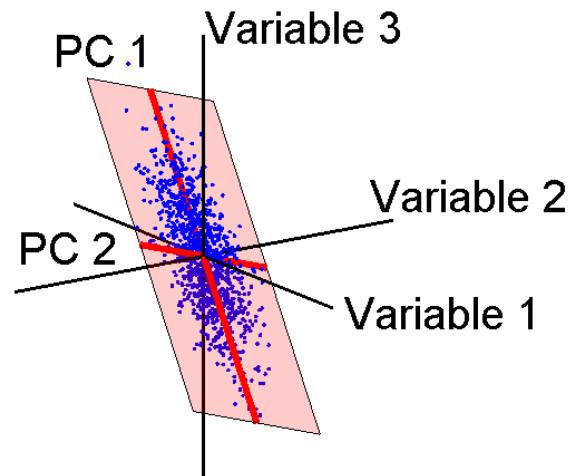
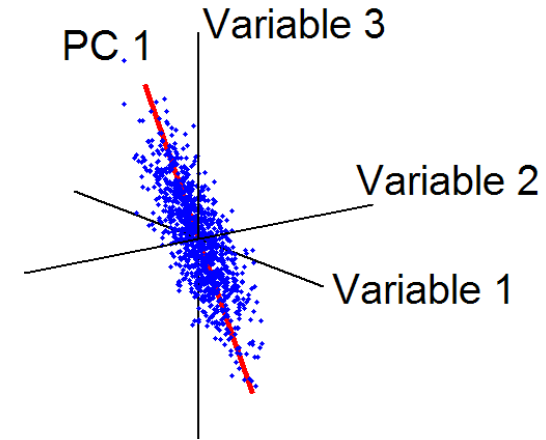
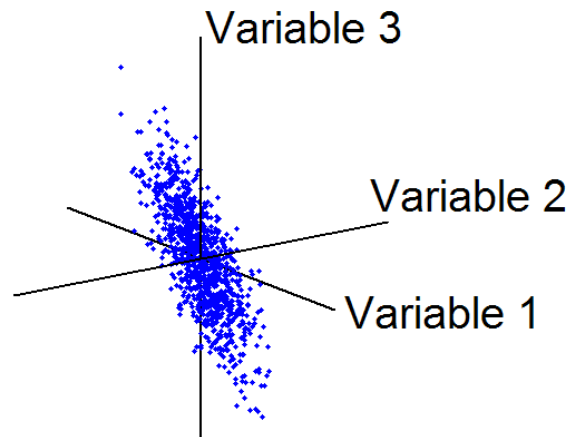
AAA	93.68%	5.55%	0.59%	0.18%	0.00%	0.00%	0.00%	0.00%
AA	2.44%	92.60%	4.03%	0.73%	0.15%	0.00%	0.00%	0.06%
A	0.14%	4.18%	91.02%	3.90%	0.60%	0.08%	0.00%	0.08%
BBB	0.03%	0.23%	7.49%	87.86%	3.78%	0.39%	0.06%	0.16%
BB	0.03%	0.12%	0.73%	8.27%	86.74%	3.28%	0.18%	0.64%
B	0.00%	0.00%	0.11%	0.82%	9.64%	85.37%	2.41%	1.64%
CCC	0.00%	0.00%	0.00%	0.37%	1.84%	6.24%	81.88%	9.67%
D	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	AAA	AA	A	BBB	BB	B	CCC	D

机器学习概览

学习类型

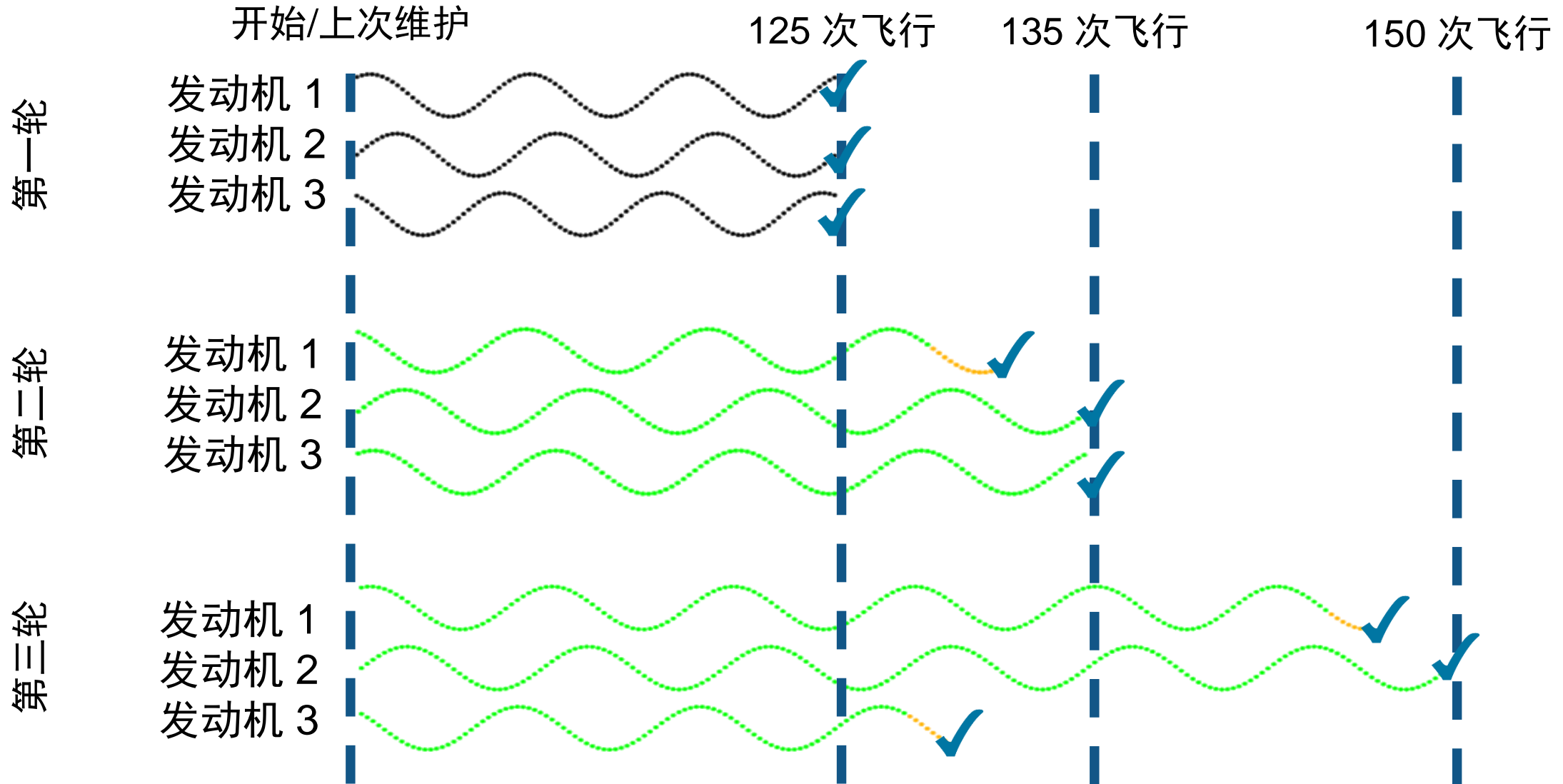


主成分分析



非监督学习的实现

✓ 维护



涡轮发动机的预测性维护

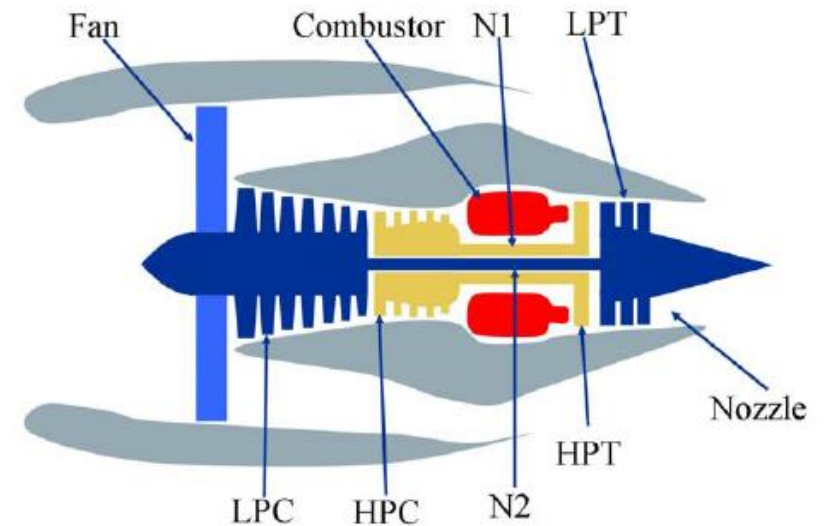
同一型号的 100 台发动机的传感数据

场景 2：拥有故障数据

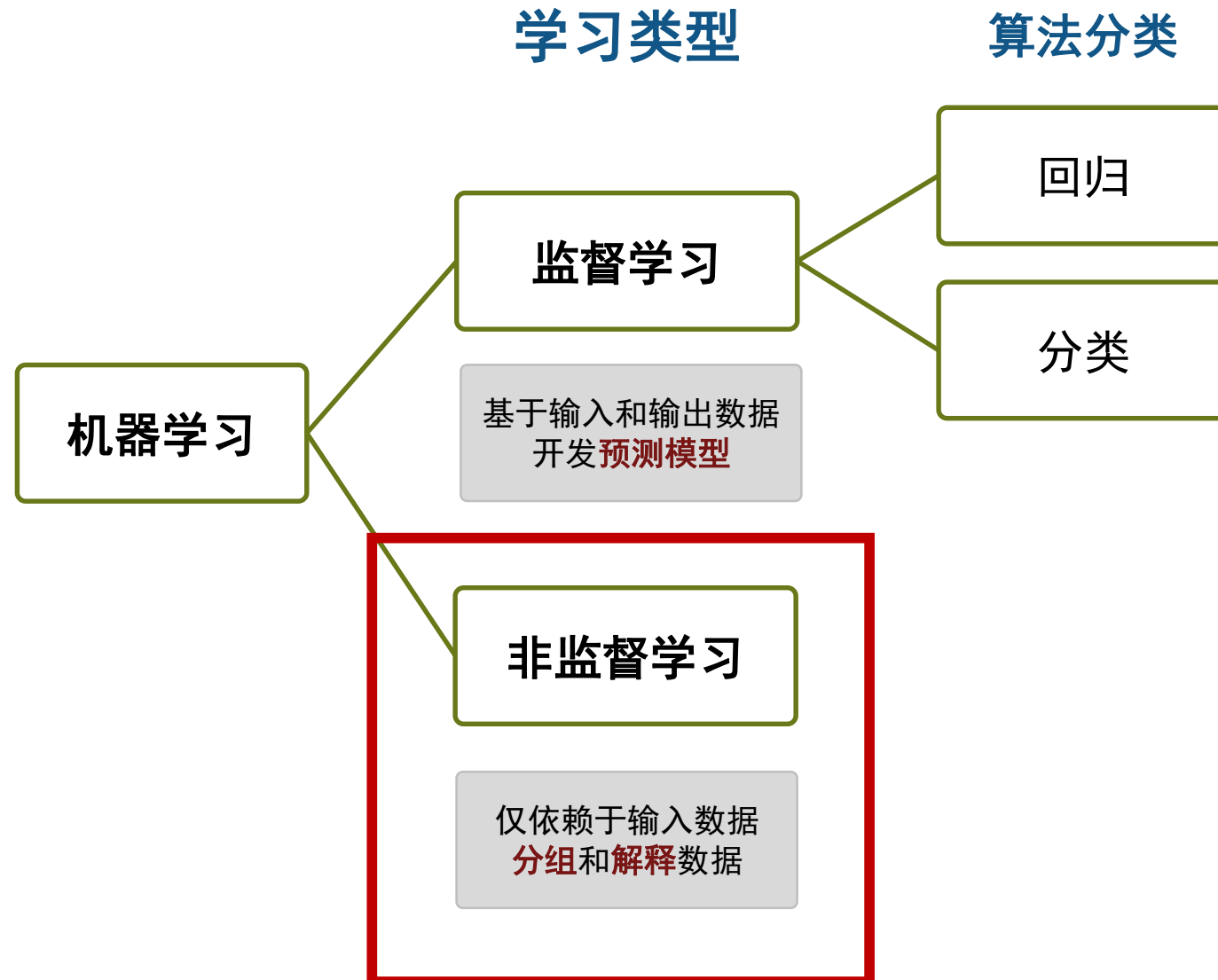
- 例行维护
- 仍然发生故障 (可能是刻意所为)
- 查找故障记录，并收集故障事件之前的数据
- 我们能够**多久**才可能发生预测故障？

Data provided by NASA PCoE

<http://ti.arc.nasa.gov/tech/dash/pcoe/prognostic-data-repository/>



Overview – Machine Learning



使用历史数据预测故障发生的时间

开始/上次维护

● 开始记录

✘ 故障

✓ 维护

历史数据

发动机 1

发动机 2

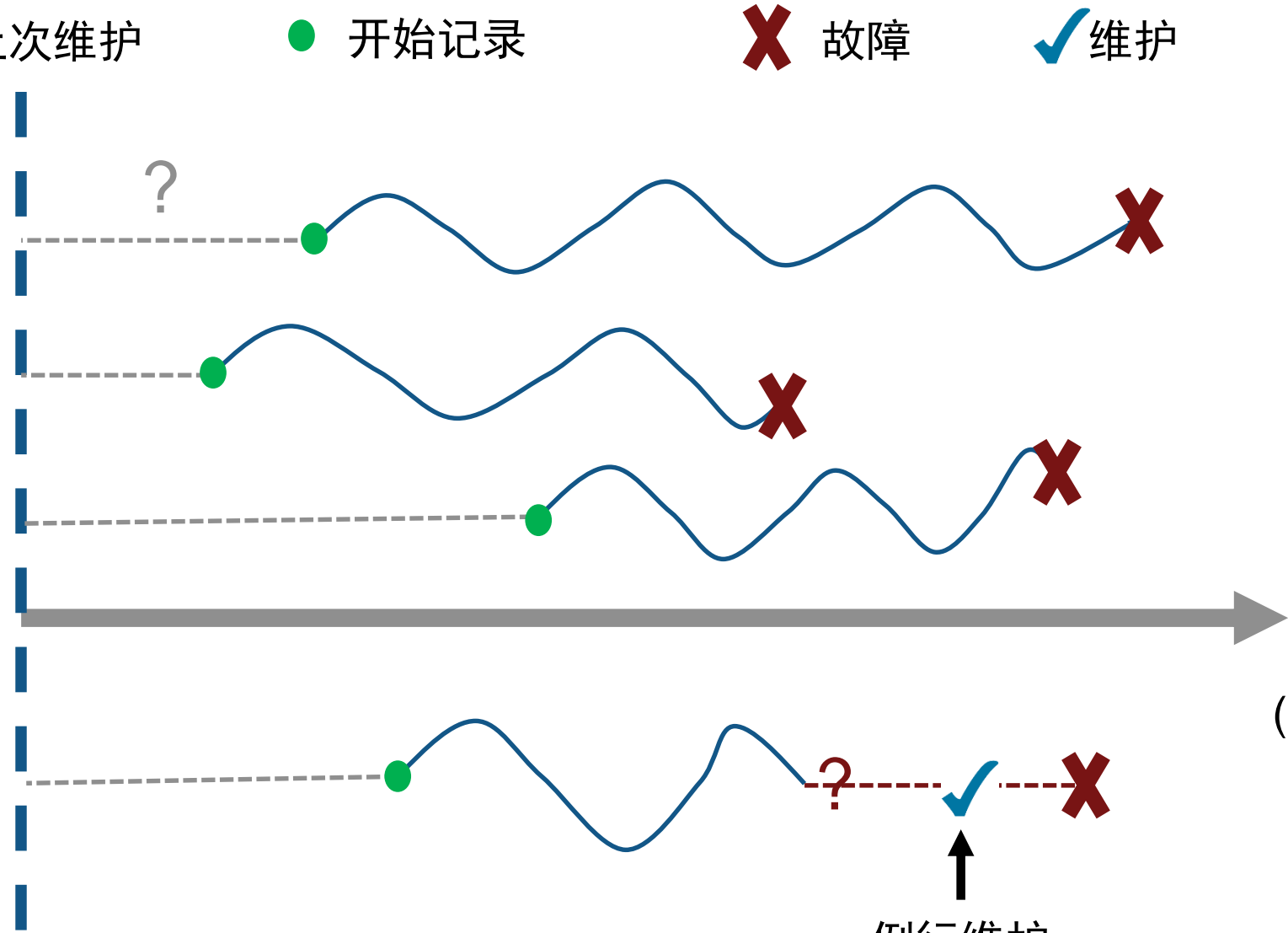
发动机 100

当前

发动机 X

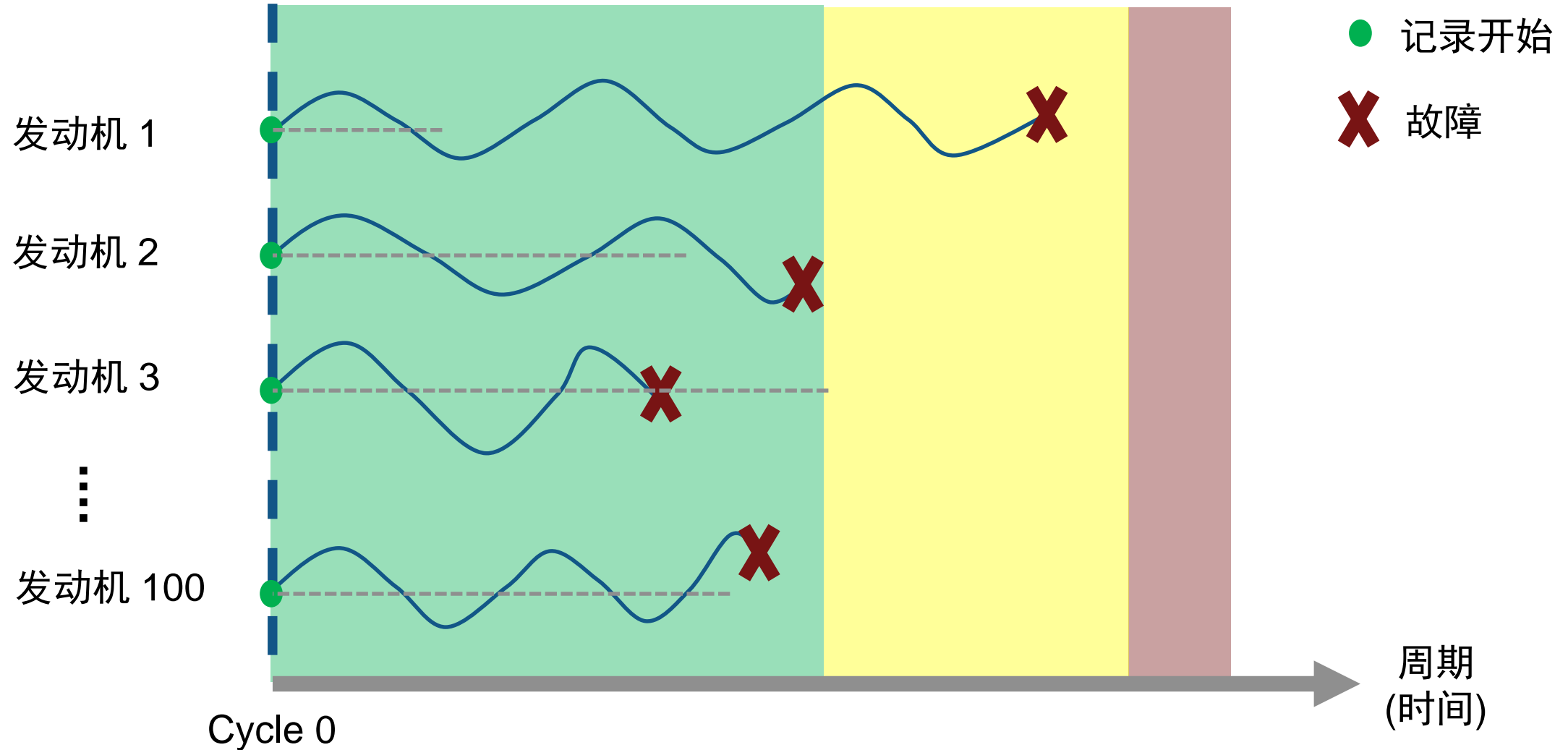
周期
(时间)

例行维护



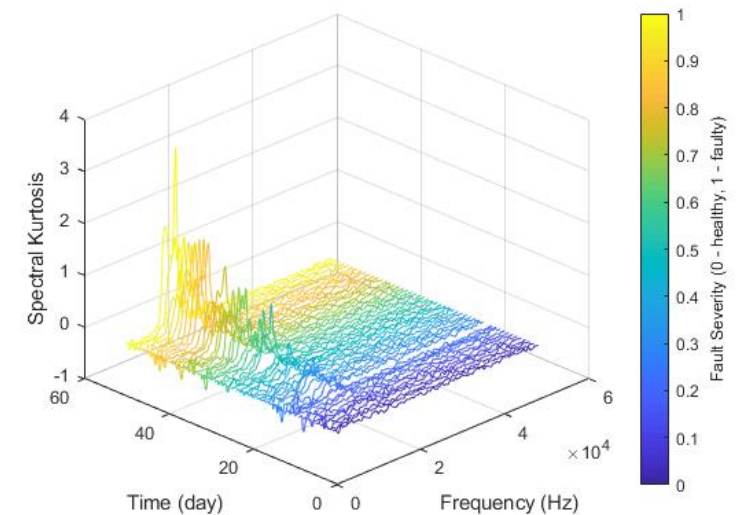
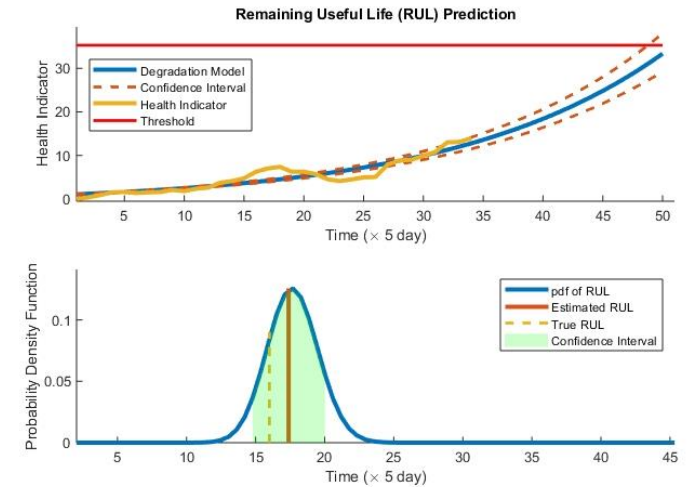
预处理和输入数据分类

开始记录数据



预测性维护工具箱的主要功能

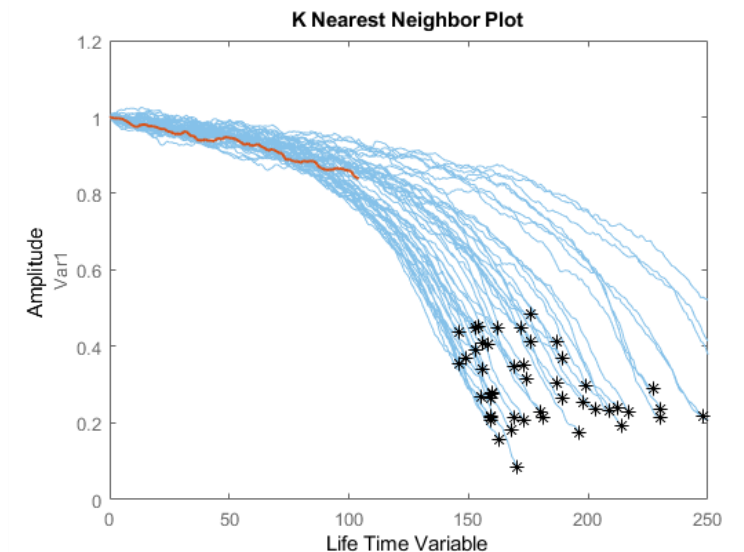
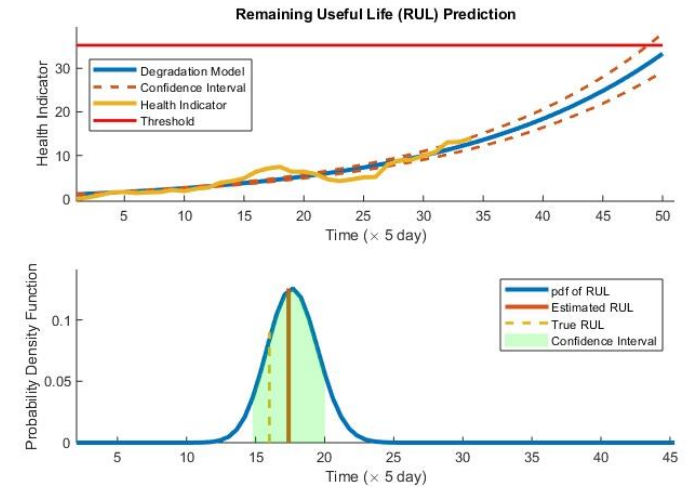
- 生存模型、相似性、时间序列模型用于剩余使用寿命 (RUL) 估计
- 时域、频域和时频特征提取方法，用于设计工况指标
- 组织从本地文件、Amazon S3™、Windows Azure® Blob 存储和 Hadoop® 分布式文件系统导入传感器数据
- 组织从Simulink® 模型导入的仿真仿真数据
- 为电机，变速箱，电池和其他机器开发预测性维护算法的参考设计



剩余使用寿命 (RUL) 估计

使用历史数据和传感器数据预测RUL和故障时间

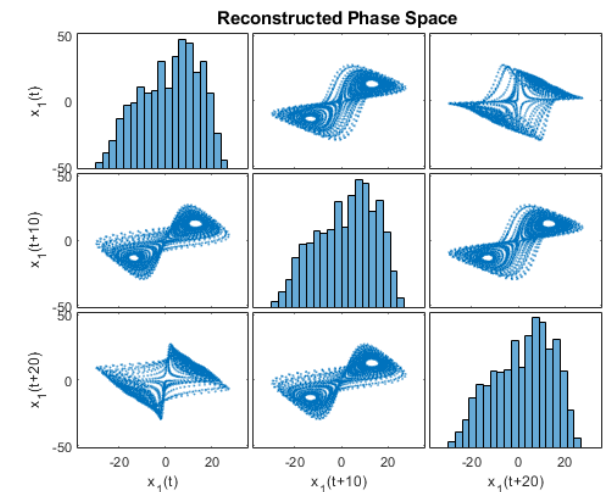
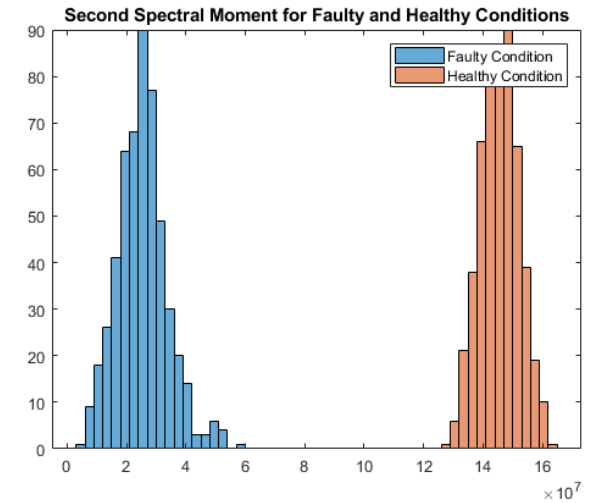
- 只有机器故障时刻的数据 → 生存分析法
- 拥有机器完整的生命周期的数据 → 基于相似性的方法
- 有关于安全临界阈值的任何信息 → 退化方法



工况指标的设计

使用基于信号和基于模型的方法提取特征，估计机器的健康度

- 通过计算时间-频率时刻来捕获时动态（例如振动数据）
- 使用相空间重构方法检测非线性系统中的突变
- 其他可用的方法包括统计，频谱分析，时间序列建模和模态分析



数据组织和标记

管理不同操作和失效条件下搜集的多个数据集

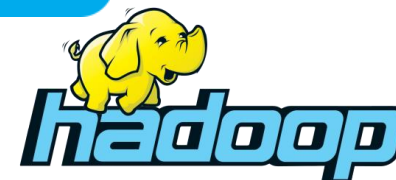
- 使用 ensemble 对象访问存储于本地、云端、和HDFS上的文件
- 使用 ensemble 对象管理和标记不同的数据成分为“独立”或“依赖”变量

```
fileLocation = fullfile('.', 'RollingElementBearingFaultDiagnosis-Data', 'train_data');
fileExtension = '.mat';
ensembleData = fileEnsembleDatastore(fileLocation, fileExtension);
ensembleData = initializeEnsemble(ensembleData);
ensembleDataTable = tall(ensembleData)
```

ensembleDataTable =

M×10 tall table

Vibration_Data	sr	rate	load	BPF0	BPFI	FTF	BSF	Label
[146484×1 double]	48828	25	0	81.125	118.88	14.838	63.91	"Inner Race Fault"
[146484×1 double]	48828	25	50	81.125	118.88	14.838	63.91	"Inner Race Fault"
[146484×1 double]	48828	25	100	81.125	118.88	14.838	63.91	"Inner Race Fault"
[146484×1 double]	48828	25	150	81.125	118.88	14.838	63.91	"Inner Race Fault"
[146484×1 double]	48828	25	200	81.125	118.88	14.838	63.91	"Inner Race Fault"
[585936×1 double]	97656	25	270	81.125	118.88	14.838	63.91	"Outer Race Fault"
[585936×1 double]	97656	25	270	81.125	118.88	14.838	63.91	"Outer Race Fault"
[146484×1 double]	48828	25	25	81.125	118.88	14.838	63.91	"Outer Race Fault"
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:



从 Simulink 中产生故障数据

使用真实机器故障的仿真模型所得的仿真数据训练算法

- 使用 Simulink 和 Simscape 构建机器模型，抓取不同的故障模式
- 运行在不同的故障条件下多个仿真
- 使用预测性维护工具箱提供的 ensemble 对象管理和标记仿真数据

The screenshot displays the MATLAB Live Editor interface for a Simulink model named 'FailureDataTransmissionSimulink.mlx'. The interface is divided into several panes:

- Current Folder:** Shows a folder named 'SimulationData' containing 10 MAT files (Transmission_Casing_log_1.mat to _10.mat) and a 'Live Script' named 'FailureDataTransmissionSimulink.mlx'.
- Live Script:** Contains MATLAB code for setting up and running simulations.


```

      Setup simulations in Simulink model
      mdl = 'Transmission_Casing';
      open(mdl);
      toothFaultValues = -2:0.2:-0.2; % 10 ToothFaultGain values
      for ct = numel(toothFaultValues):-1:1
          simin(ct) = Simulink.SimulationInput(mdl);
          simin(ct) = setVariable(simin(ct), 'toothFaultGain', toothFaultValues(ct));
      end

      Run simulations and store data
      location = fullfile(pwd, 'SimulationData');
      [status,E] = generateSimulationEnsemble(simin,location);

      Create ensemble to manage data
      ensemble = simulationEnsembleDatastore(location);
      ensembleData = tall(ensemble)
      
```
- Command Window:** Shows the execution of the 'ensemble' command, resulting in a 'simulationEnsembleDatastore' object with properties:


```

      >> ensemble
      ensemble =
      simulationEnsembleDatastore with properties:
          DataVariables: {4x1 string}
          IndependentVariables: {0x0 string}
          ConditionVariables: {0x0 string}
          SelectedVariables: {4x1 string}
          NumMembers: 10
          LastMemberRead: {0x0 string}
      
```
- Output Window:** Displays the output of the 'tall' function, showing a 4x4 table of tall tables:

SimulationInput	SimulationMetadata	Tacho	Vibration
[1x1 Simulink.SimulationInput]	[1x1 Simulink.SimulationMetadata]	[20202x1 timetable]	[20202x1 timetable]
[1x1 Simulink.SimulationInput]	[1x1 Simulink.SimulationMetadata]	[20211x1 timetable]	[20211x1 timetable]
[1x1 Simulink.SimulationInput]	[1x1 Simulink.SimulationMetadata]	[20202x1 timetable]	[20202x1 timetable]
[1x1 Simulink.SimulationInput]	[1x1 Simulink.SimulationMetadata]	[20212x1 timetable]	[20212x1 timetable]
[1x1 Simulink.SimulationInput]	[1x1 Simulink.SimulationMetadata]	[20202x1 timetable]	[20202x1 timetable]
[1x1 Simulink.SimulationInput]	[1x1 Simulink.SimulationMetadata]	[20216x1 timetable]	[20216x1 timetable]
[1x1 Simulink.SimulationInput]	[1x1 Simulink.SimulationMetadata]	[20204x1 timetable]	[20204x1 timetable]
[1x1 Simulink.SimulationInput]	[1x1 Simulink.SimulationMetadata]	[20213x1 timetable]	[20213x1 timetable]
:	:	:	:
:	:	:	:

算法开发的参考设计

启动工况监控和预测性维护开发

- 指导您完成预处理数据，提取特征以及构建分类器和预测模型的工作流程
- 演示各种信号处理，机器学习和动态建模技术的用法
- 重用为算法的模板

Fault Detection

Prognostics

Similarity-Remaining Estimation

Fault Diagnosis

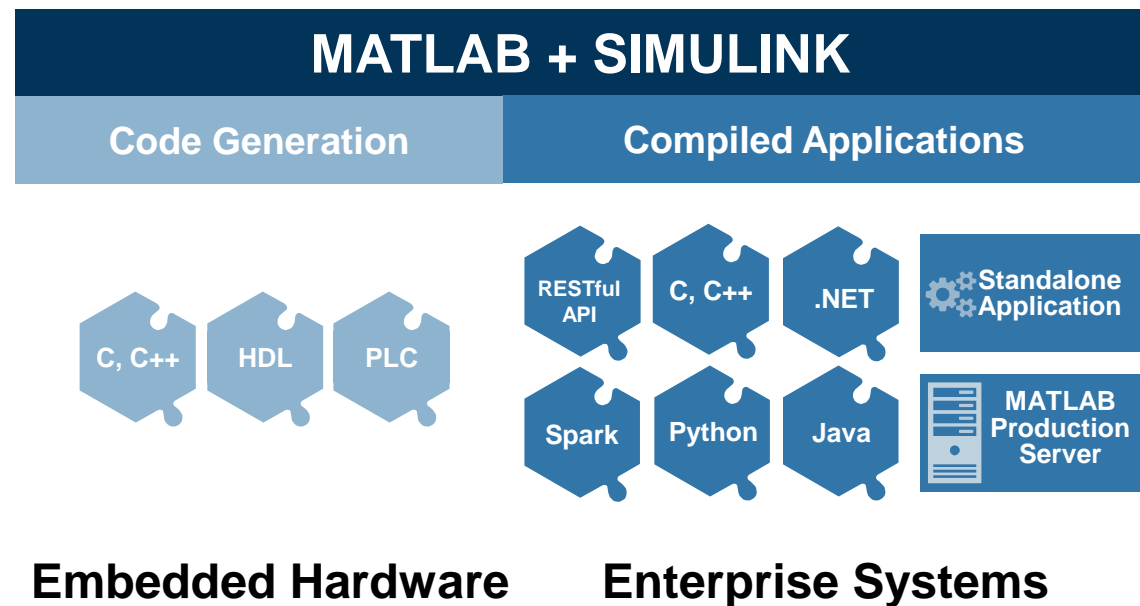
Rolling Element Bearing Fault Diagnosis

Fault Diagnosis of Centrifugal Pumps using Steady State Experiments

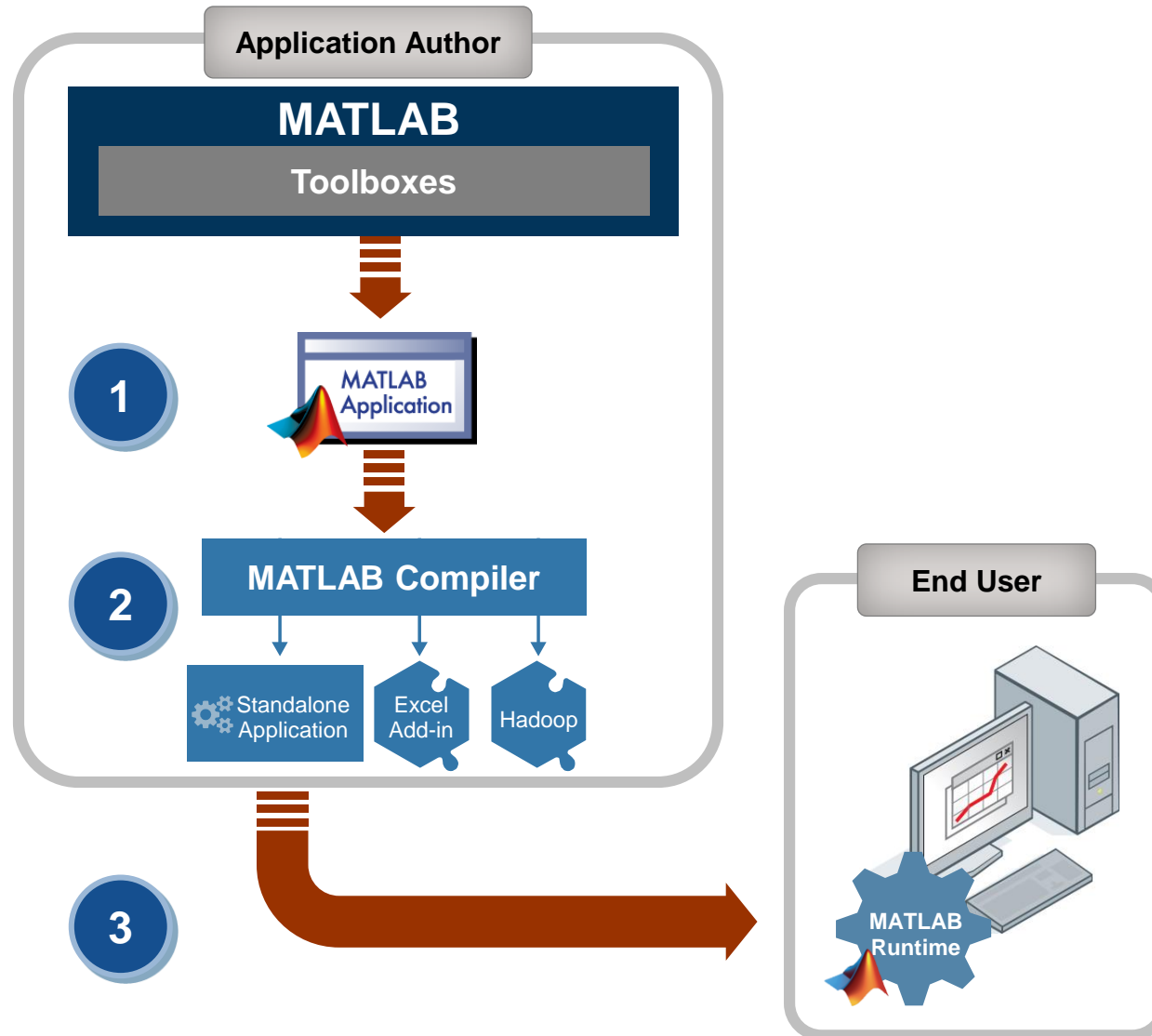
Fault Diagnosis of Centrifugal Pumps using Residual Analysis

应用发布

- 将模型运行在云上或嵌入式设备上
- 运行在生成环境中
- 集成到企业应用系统或云平台中



单机应用发布

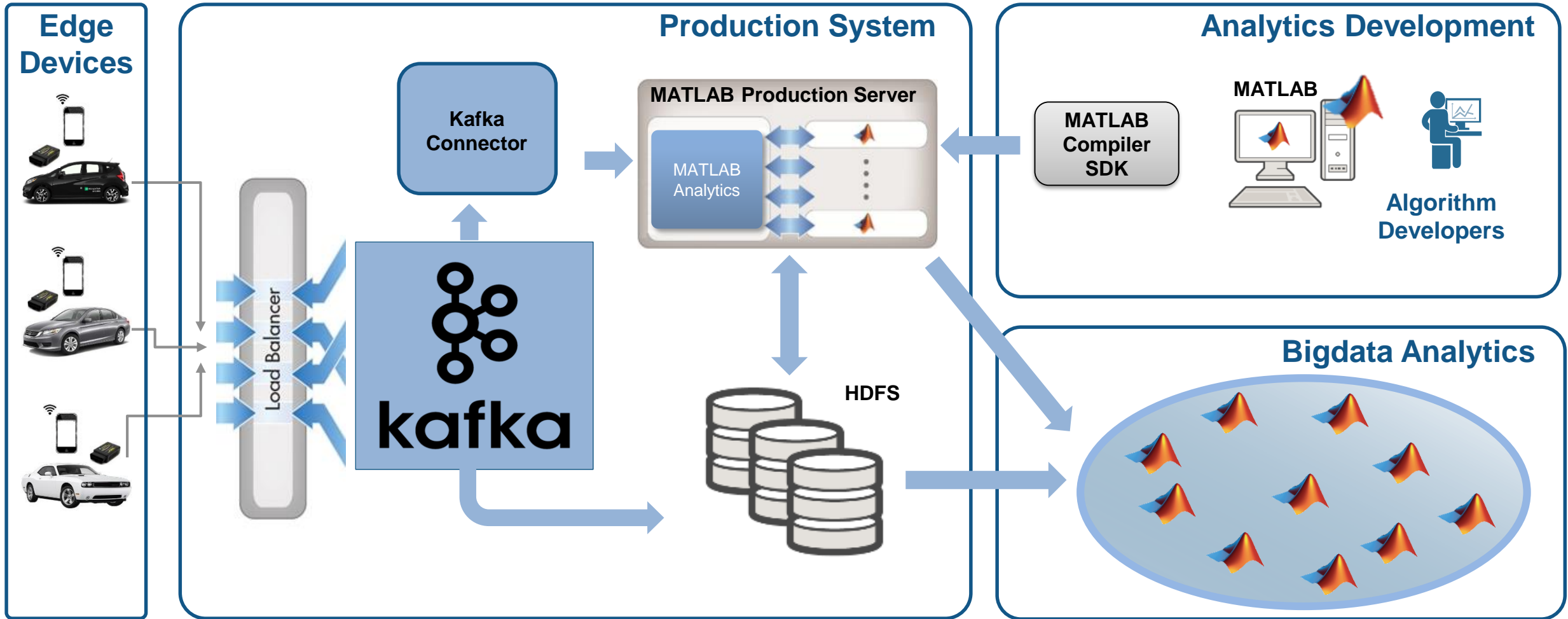


The image shows the MATLAB software interface. The top menu bar includes HOME, PLOTS, APPS, and SHORTCUTS. Below the menu bar is a toolbar with various icons for file operations, workspace management, and code execution. The current folder is displayed as \\mathworks\public \> Chetan_Rawal \> Videos \> mlCompiler \> Video1_AppCompilerStandalones \> AcousticsDemo. The file explorer shows a list of files and folders, with ImpulseResponseAnalysis.m selected. The Command Window displays the following code:

```
>> guide ImpulseResponseAnalysis
>> ImpulseResponseAnalysis
fx >> |
```

The Command Window also shows a message: "New to MATLAB? Watch this [Video](#), see [Examples](#), or read [Getting Started](#)."

流处理数据架构



针对智能制造的预测性维护和系统部署

- 预测性维护介绍
- 预测性维护算法开发和工具箱
- 单机应用和生产部署

