UNIVERSITÀ
DEGLI STUDI
DI BERGAMO

Dipartimento
di Ingegneria Gestionale,
dell'Informazione e della Produzione

Lesson 13.

Fault diagnosis I

Introduction

DATA SCIENCE AND AUTOMATION COURSE

MASTER DEGREE SMART TECHNOLOGY ENGINEERING

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Outline

1. Introduction and motivation
2. Terminology
3. Taxonomy
4. Defining a predictive maintenance problem

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1. **Introduction and motivation**
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Introduction and motivation

Intelligent **fault diagnosis** is one of the cornerstone of the industry 4.0 paradigm

- Maintenance costs represent an important part of a production industry total costs
- Optimizing the interventions, reducing the dead times, can drastically improve the production and reduce the costs

Common maintenance strategies are:

- **Reactive maintenance** (run-to-failure): use the component until it breaks
- **Preventive maintenance** (time-based): do maintenance at regular time instants
- **Predictive maintenance** (condition-based): do maintenance on the basis of measured data and algorithms

Data sources

In order to develop an algorithmic solution, it is mandatory to have **data** on the problem

- **Measurements** made during the machine functioning
- Information about **mean time to failure** of the component and working conditions

The usefulness of a certain **measure** and **technique** depends on the **fault type**

- **Vibration analysis:** mechanical faults, rotating components
- **Thermography:** emitted infrared energy, proportional to the surface temperature
- **Tribology analysis:** of lubricant oil, wear particle analysis
- **Ultrasound analysis:** high frequency vibrations ($\geq 30\ \mathrm{kHz}$), leak detection
- **Other:** electro-magnetic tests, visual inspection,…

Data sources

Public datasets for predictive maintenance include:

- **Gearbox Fault Detection Dataset:** Dataset for fault detection in a transmission system using accelerometer data and information regarding bearing geometry. https://c3.nasa.gov/dashlink/resources/997/

- **Robot Execution Failures Dataset:** Force measurements and twisting moment to detect faults in robots; it is composed of 463 samples and 30 features. https://archive.ics.uci.edu/ml/datasets/Robot+Execution+Failures

- **IDA2016Challenge Data Set:** Dataset for the detection of faults in the air pressure systems of a truck: it is composed of 76000 samples and 171 features. https://archive.ics.uci.edu/ml/datasets/IDA2016Challenge

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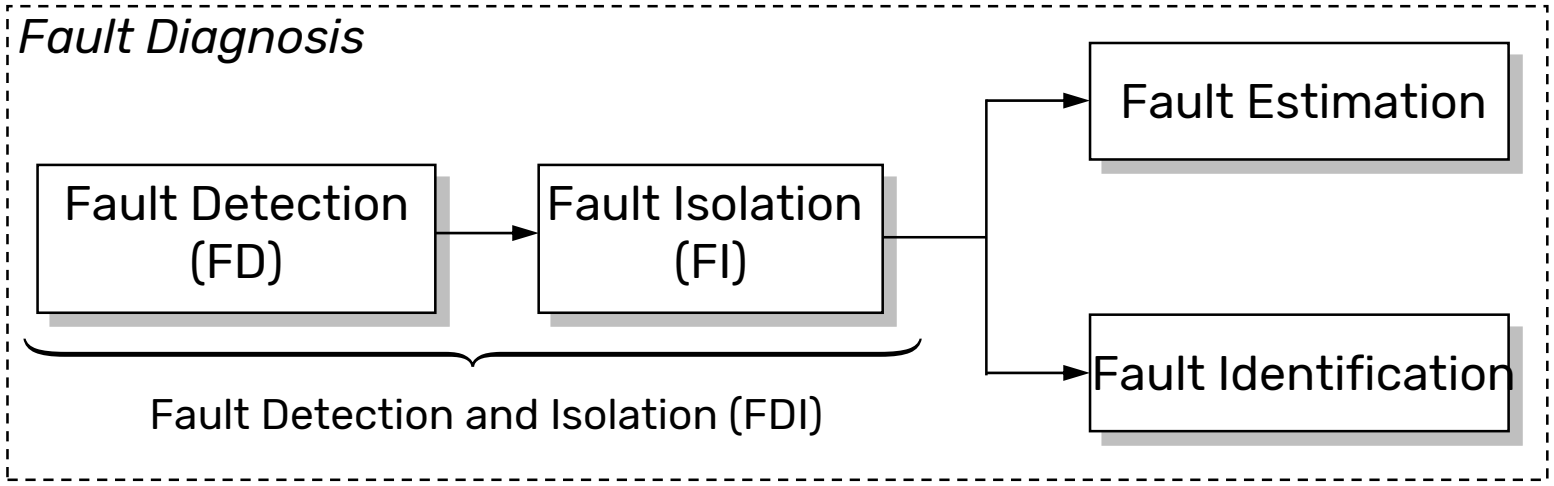
Terminology

- The aim of **fault diagnosis** is to discover **anomalous behaviours** in **physical** plants

1. **Fault detection:** detect if there is an anomaly
2. **Fault isolation:** detect the faulty component
3. **Fault identification:** characterize the type, size, nature of the fault
4. **Fault estimation:** estimate the fault signal



Terminology

Condition monitoring (CM) refers to the **continued oversight** of the progression of the degradation of a system or a component

The differences with fault diagnosis (FD) is not so sharp, but, in general:

- FD produces a **discrete output**, CM produces a **continuous output**
- FD is usually a **more structured** approach which is applicable **component-wise**
- CM deals with a more **system-wise** evaluation, for which simple procedures can be applied

Fault estimation methods, when applicable, lead to effective condition monitoring

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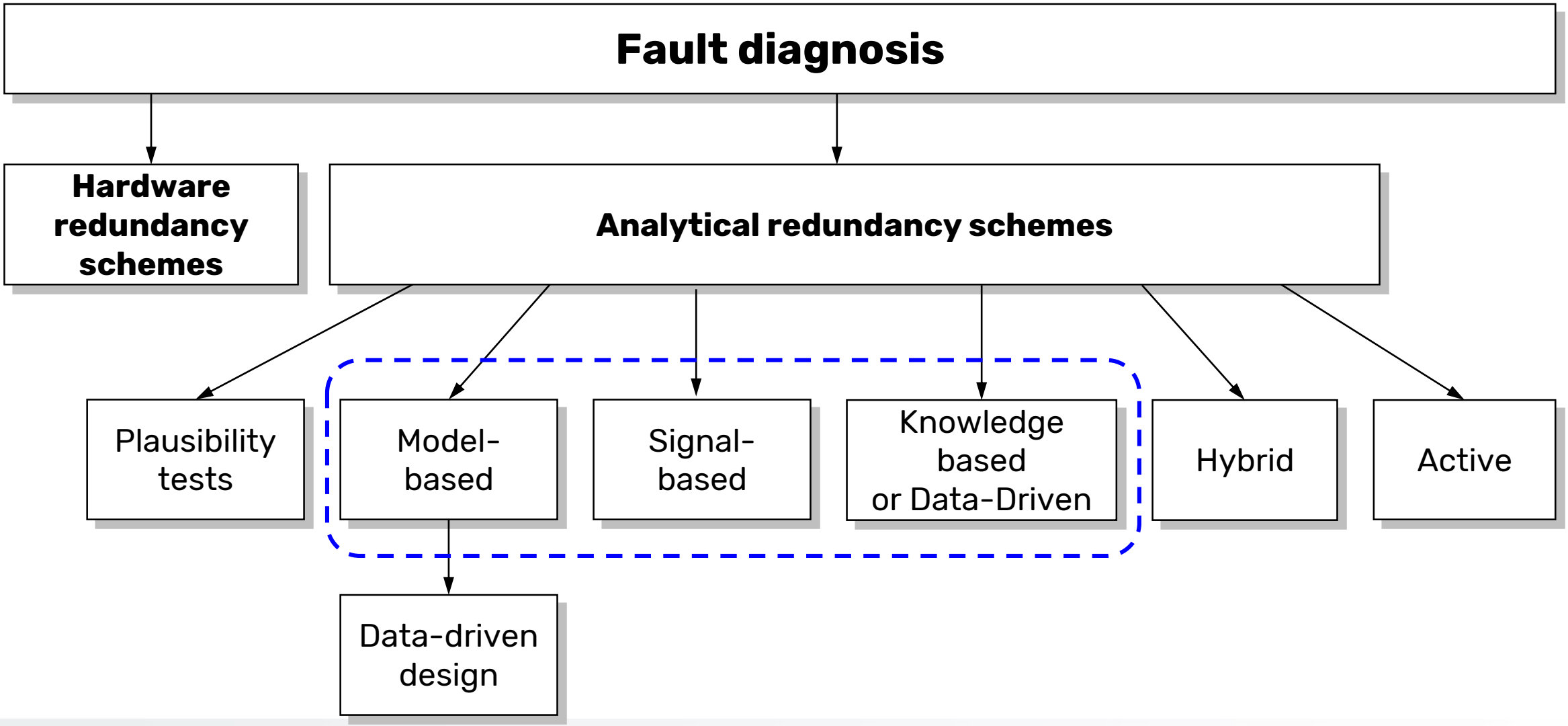
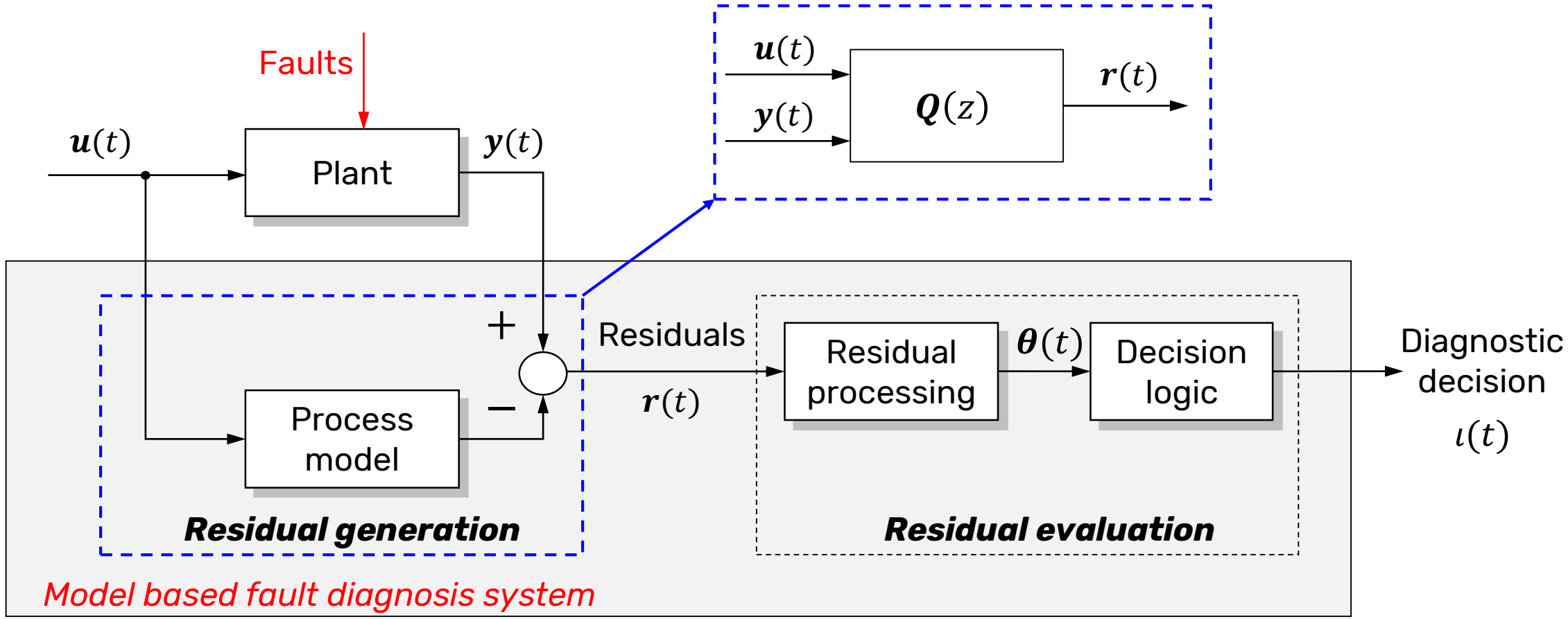
Taxonomy


Fault diagnosis
Hardware redundancy schemes
Analytical redundancy schemes
Plausibility tests
Model-based
Signal-based
Knowledge based or Data-Driven
Hybrid
Active
Data-driven design

Model-based fault diagnosis

A model of the system is developed to design a **residual generator** $\boldsymbol{Q}(z)$



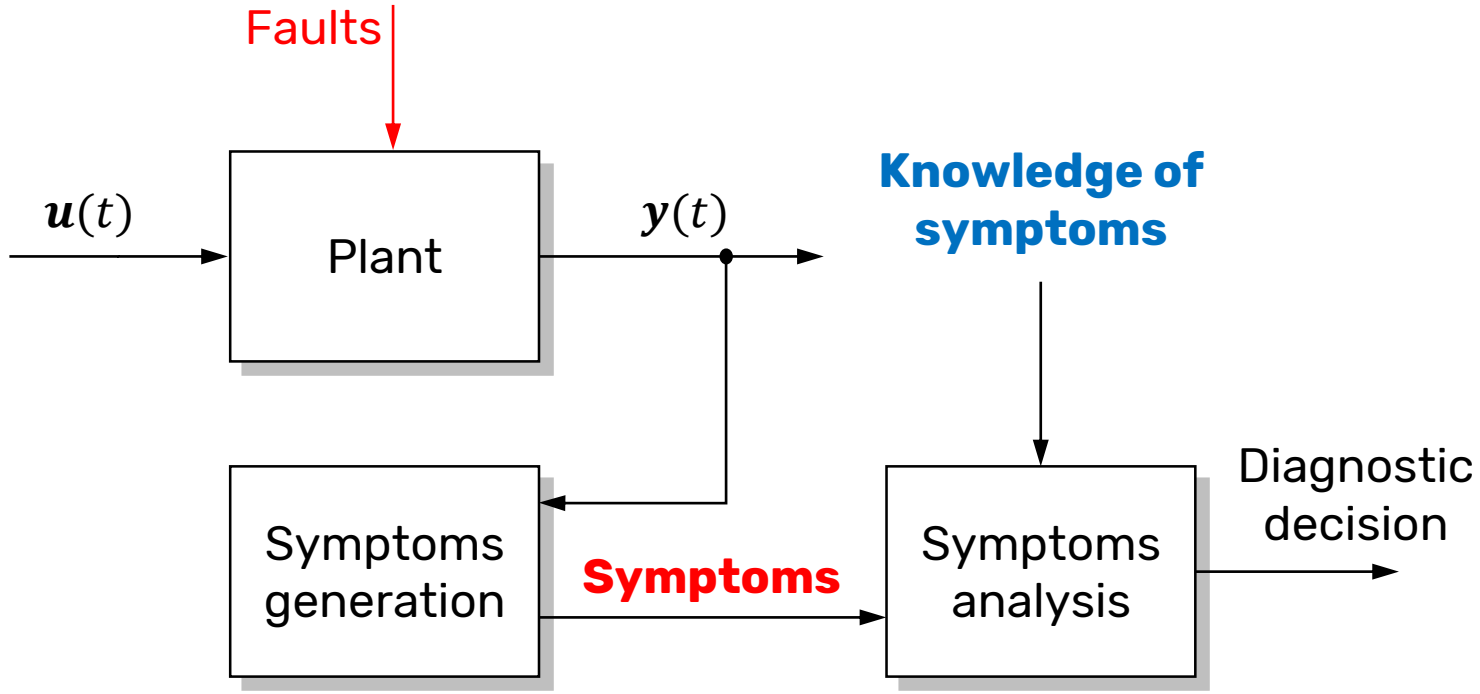
Signal-based fault diagnosis

Certain process signals carry information about the faults to be detected

- From them, **fault symptoms** are computed…
- …and compared with **prior knowledge about the faults**

Examples are:

- Diagnosis of rotating components defects
- Stator\rotor current faults



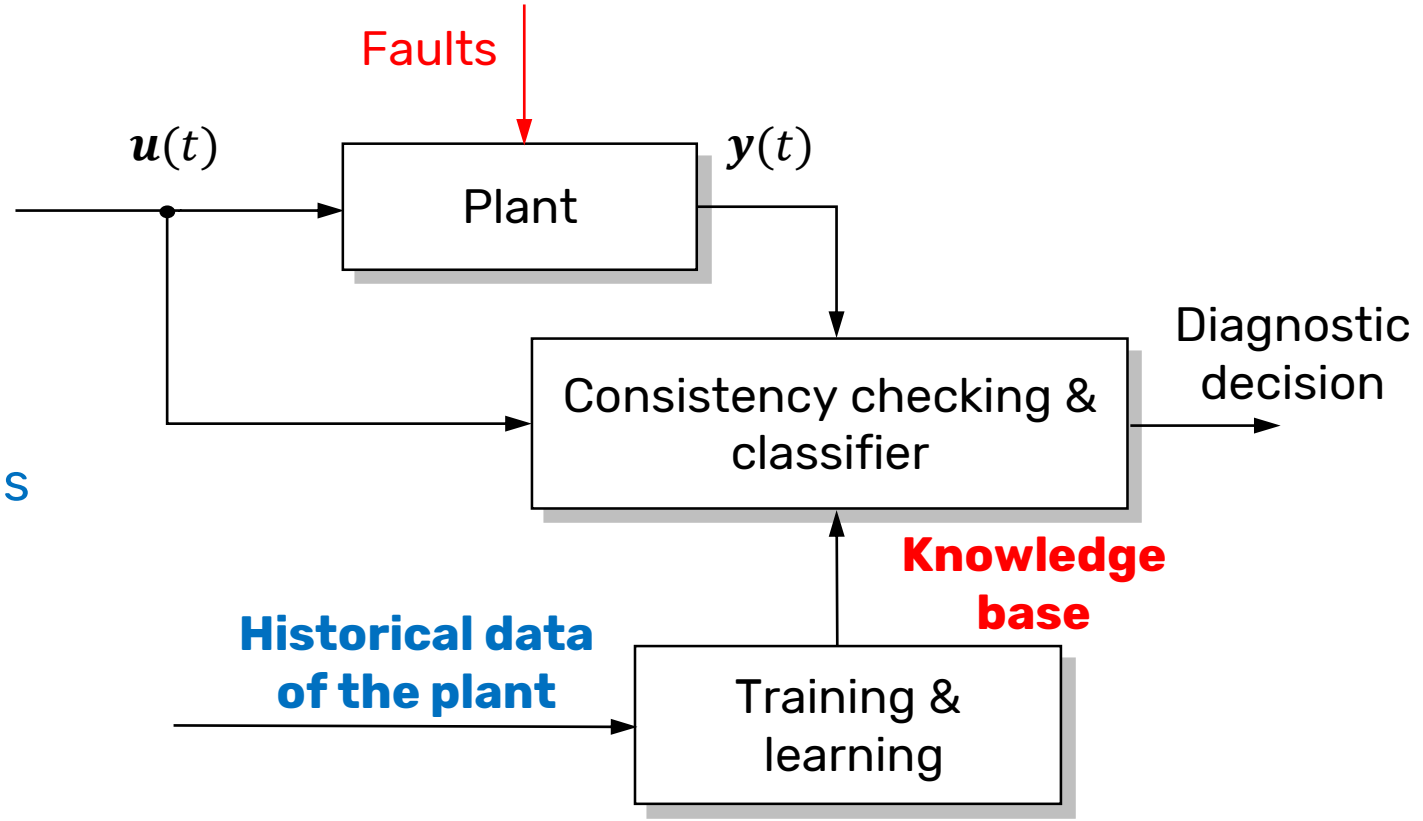
Knowledge-based fault diagnosis

Great amount of historical data available:

- There is **not a prior knowledge** about the faults, and it has to be **extracted from data**
- **Training vs testing** phases

Common approaches are:

- Machine learning classifiers
- Statistical Process monitoring methods (control charts, PCA indicators,…)



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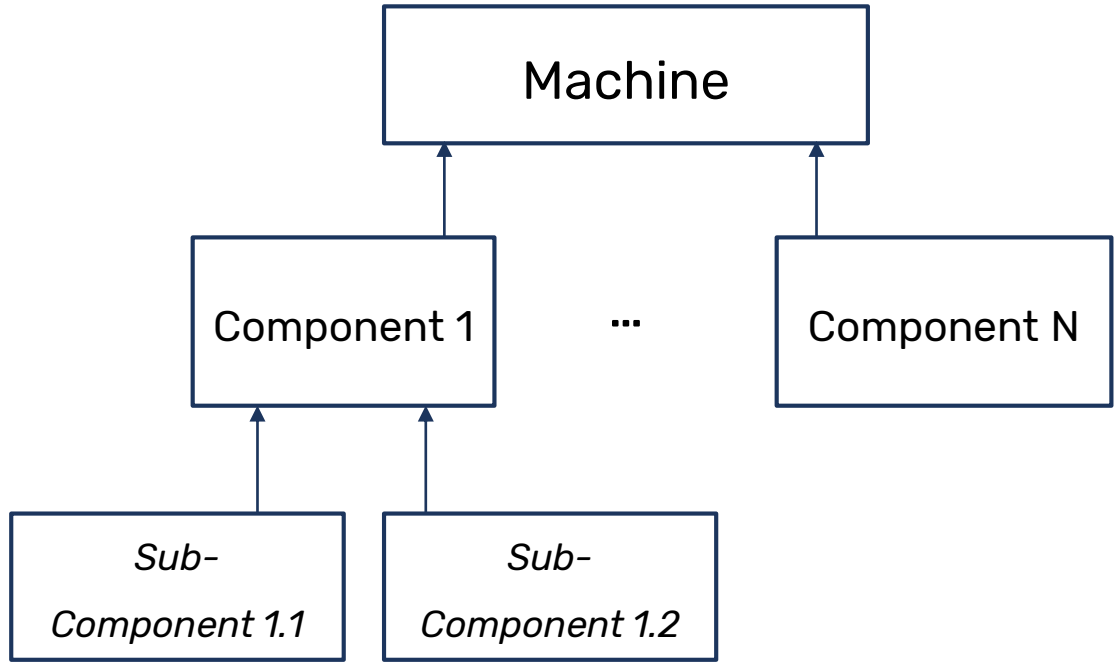
Defining a predictive maintence problem

Suppose you want to develop a **predictive maintenance** algorithm on a machine, made up of several **components**.

- **AIM:** to understand when the machine is degrading

What do we have to consider?

1. Problem definition
2. Data acquisition
3. Development of the solution



Defining a predictive maintence problem

1. PROBLEM DEFINITION (PURPOSE OF THE ALGORITHM)

- **What answer do I want to get from the algorithm?**
  - ✓ Fault detection & isolation ➔ fault \ not fault, location of the fault
  - ✓ Condition monitoring ➔ monotonic indicator of machine health status
- **What are the critical components?**
  - ✓ FMECA / FTA – criticality, frequency of failure
  - ✓ Exchange of information with the maintenance department
- **Do I have all the information that I need?**
  - ✓ Faults history, physical quantities related to machine operation

Defining a predictive maintence problem

2. DATA ACQUISITION

- **Test plan**
  - ✓ Typical operation of the machine or in its working range
  - ✓ Tests in **Healthy state** - Test in **faulty state** (fault injection or endurance?)
- **Measurements acquisition**
  - ✓ Additional sensors? They must be acquired with specific hardware: which one?
  - ✓ Syncronize data from multiple data sources
  - ✓ Amount of data to be stored
  - ✓ Always check at the end of the day (even during) what has been acquired ☺

Defining a predictive maintence problem

3. DEVELOPMENT OF THE SOLUTION

- **Chosen technique**
  - ✓ **Model-based:** based on a mathematical model of the machine or component
  - ✓ **Signal-based:** based on a symptom of failure visible within a signal
  - ✓ **Data-driven:** based only on the observed data (machine learning). I suppose that there is symptom of faults inside the data, but I have to discover it
    - ❑ **Supervised model:** estimate the relation from data (A) and condition (B), A→B
    - ❑ **Unsupervised model:** anomaly detection methods