Hamedan University of Technology

Special Topics in the Industrial Applications of Machine Learning

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Fall 2025

Chapter 1: Introduction

Machine learning is transforming industries by turning data into actionable insights. This chapter provides an overview of ML concepts, industrial data, and the workflow from raw data to learning models.

In this chapter, we will cover:

- Course Overview
- What is Machine Learning? From ML to Deep Learning
- Industrial Data & Data Workflow
- Learning Objectives, Course Roadmap & Assessment
- Tools: Python, Packages, Frameworks, Datasets
- Resources: Theoretical references on the Internet
- Industrial Datasets: introduction and preliminary exploration

Chapter 1: Introduction

- Section 1: Industrial ML Overview
  Introduces students to ML concepts in an industrial context.
- Section 2: Course Outline
  Covers logistics, objectives, tools, and resources.
- Section 3: Industrial Datasets
  Presents datasets for later exercises and examples.

Course Overview

Welcome to "Special Topics in the Industrial Applications of Machine Learning"!

This course will introduce:

- Practical applications of ML and DL in industry
- Focus areas:
  -  Condition monitoring
  -  Fault detection and localization
  -  Predictive maintenance
  -  Process forecasting
- Processing and analyzing industrial sensor data: vibration, audio, voltage/current, images
- Building and evaluating ML models on real-world datasets
- Hands-on experience through labs and a final case-study project

What is Machine Learning?

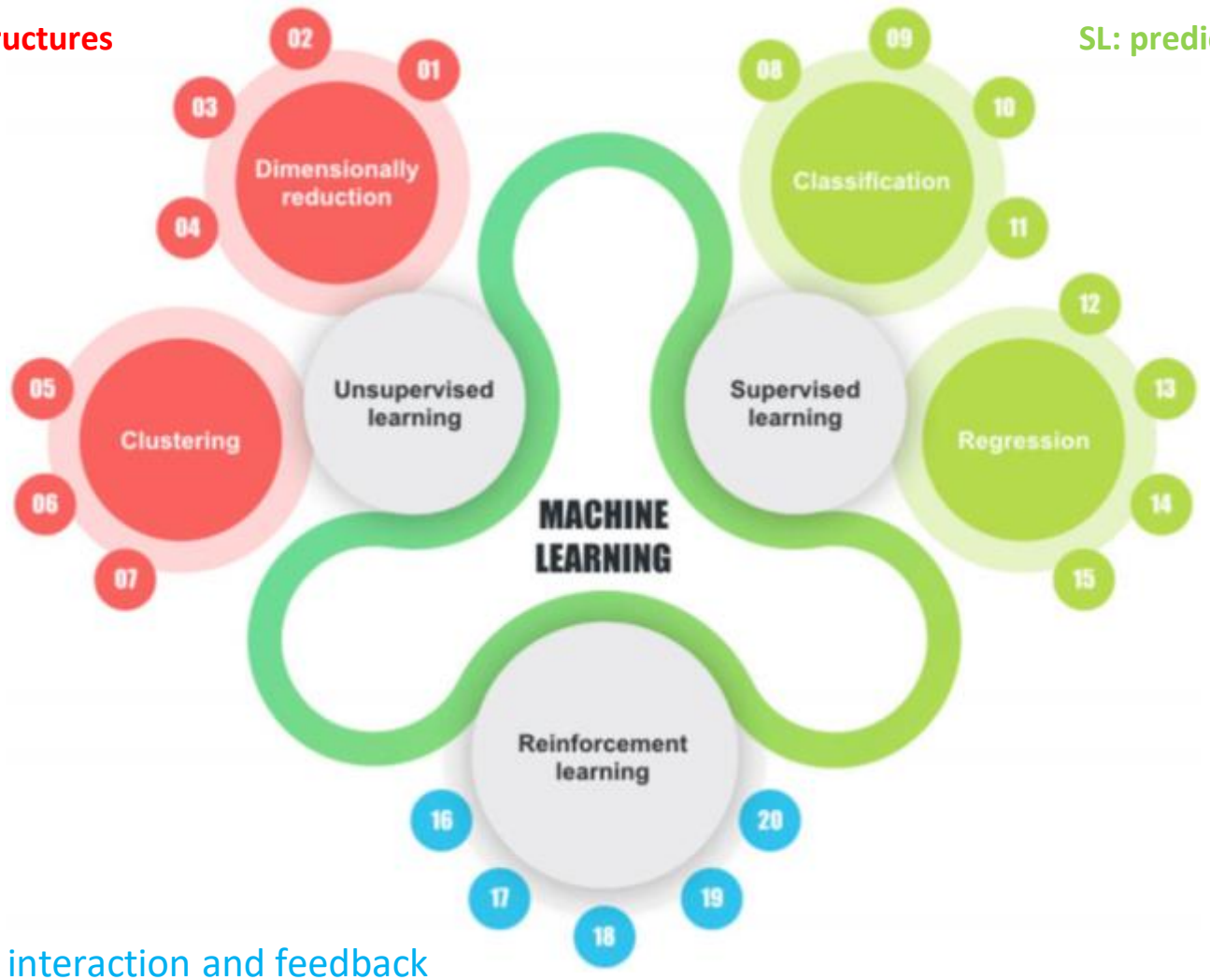
UL: find hidden structures

Algorithms:

1. PCA
2. LDA
3. t-SNE
4. Autoencoder
5. k-means
6. GMM
7. SOM

Applications:

1. Sensor fusion
2. Feature comp.
3. Fault features
4. Noise filter
5. Machine states
6. Fault grouping
7. Usage modes



SL: predict from labeled data

Algorithms:

8. SVM
9. Random Forest
10. k-NN
11. Neural Net
12. Linear Reg
13. SVR
14. Random Forest
15. Neural Net

Applications:

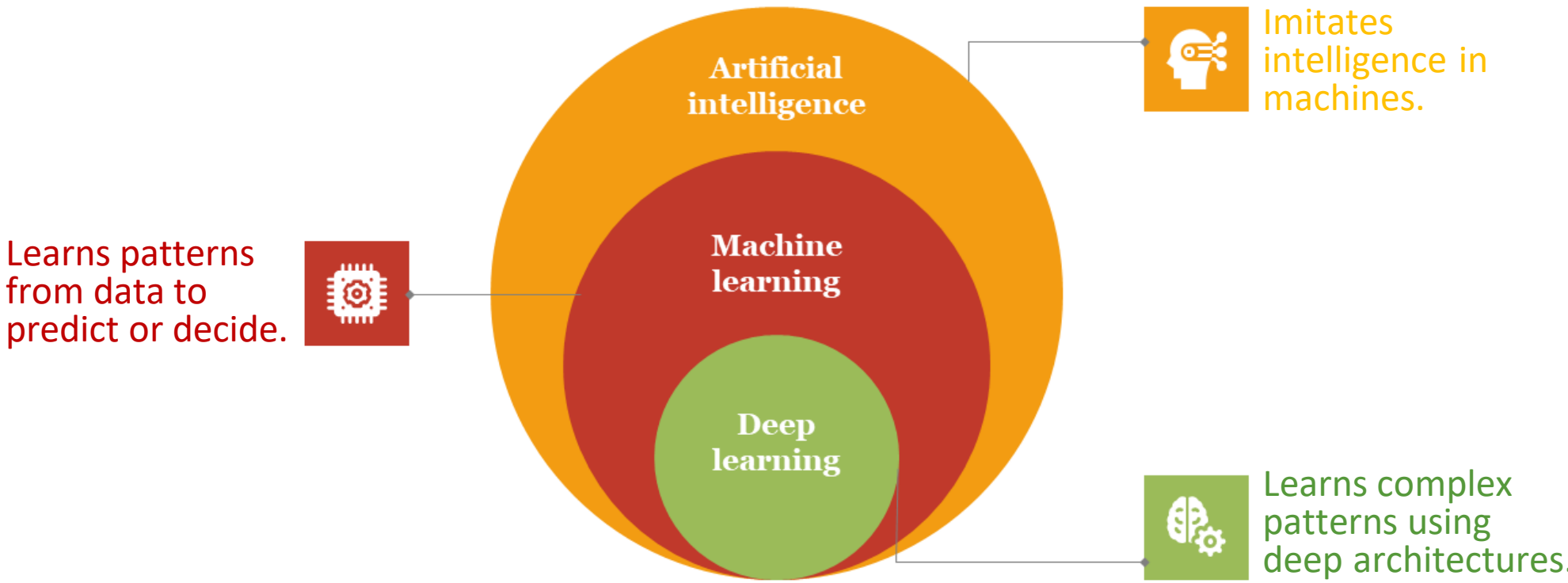
8. Fault detection
9. Quality check
10. Anomaly ID
11. Defect sorting
12. Load forecast
13. Remaining life
14. Energy use
15. Temperature rise

RL: learn by interaction and feedback

Algorithms: 16 learn by interaction and feedback. Q-learning 17. SARSA 18. DQN 19. PPO 20. A3C

Applications: 16. Predictive sched. 17. Control tuning 18. Energy optim. 19. Robot maint. 20. Process adapt.

From ML to Deep Learning



- Deep Learning:
  - Extracts features automatically from raw sensor data.
  - Captures complex temporal or multi-sensor patterns.
  - Useful for industrial tasks like fault detection and predictive maintenance.

Industrial Data & Data Workflow

Types of Industrial Data

Vibration

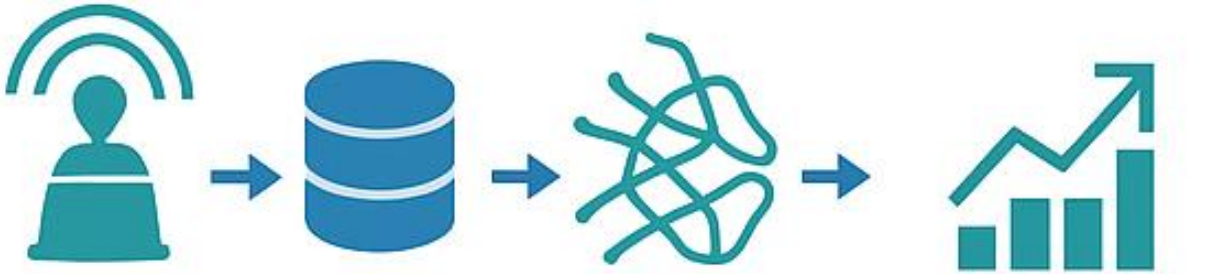
Current/
Voltage

Audio

Image

Temperature

From Data to Application



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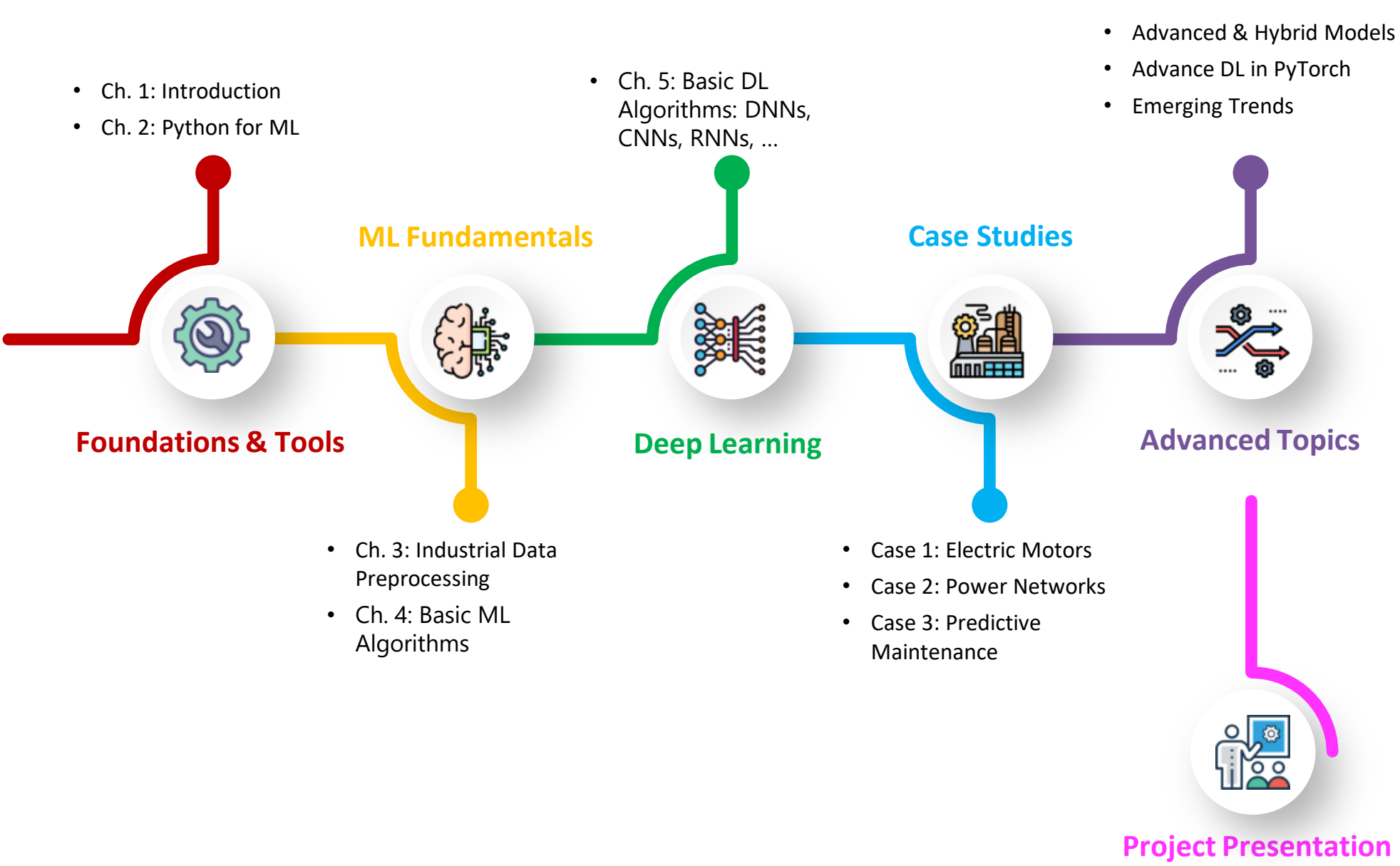
Learning Objectives

- **General:**
  - Understand complete industrial ML workflow
  - Analyze and preprocess sensor data (vibration, audio, voltage, images)
  - Select and apply ML/DL algorithms
  - Handle real-world data challenges

- **Specific:**
  - Python programming basics & libraries
  - Implement ML/DL models on real industrial datasets
  - Evaluate and improve model performance
  - Complete a final project

Course Roadmap

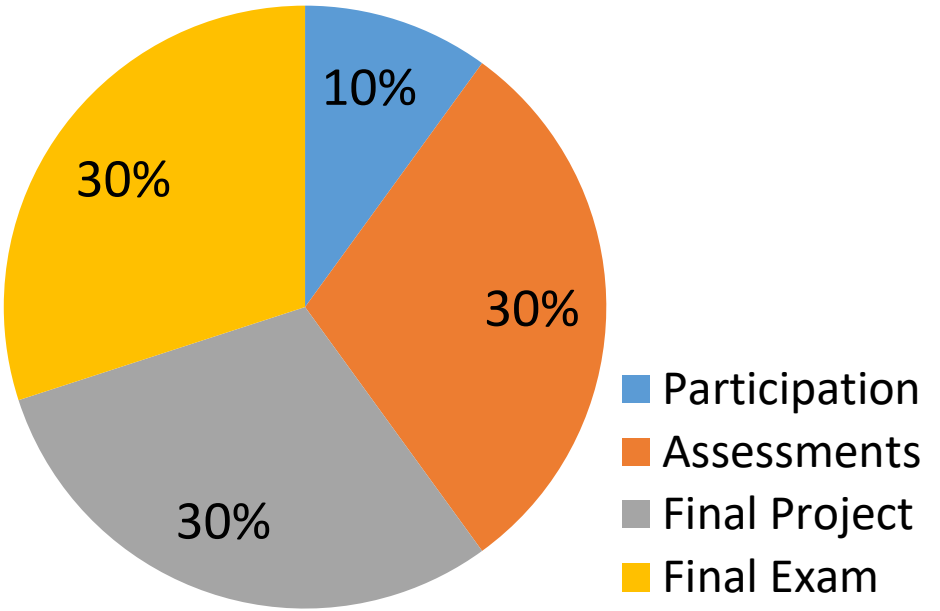


Teaching & Assessment

Teaching Approach

- Weekly lectures
- Weekly labs
- Hands-on assignments (real data)
- Case studies (industrial)
- Continuous support (Q&A, feedback)

Assessment



Extra Credit (+10%) for advanced project extensions

Tools

1. Programming Environment

- **Language:** Python
- **IDEs:** Jupyter Notebook, Spyder
- **Optional:** Google Colab (cloud-based)

2. Libraries

- **Data Science:** NumPy, Pandas, Matplotlib
- **Machine Learning:** Scikit-learn
- **Deep Learning:** TensorFlow + Keras, Pytorch

3. Datasets

- **Industrial case-study datasets:** Main focus in labs
- **Public datasets:** UCI, Kaggle for practice
- **Synthetic/simulated datasets:** Only when needed

Resources

Python Programming

- Python in Persian: Online book (Farsi): PythonPersian.com
- Practical Python Full Course (Farsi, YouTube): Watch Here
- Python Tutorials: Beginner-friendly playlist (Farsi, YouTube): Playlist Link
- Python for Everybody: Dr. Charles Severance (English, Coursera): Coursera Link

Deep Learning

- Practical Deep Learning Tutorials (Farsi, YouTube): Playlist Link
- Deep Learning Tutorial (Farsi, YouTube): Farsi Deep Learning Channel
- Deep Learning with TensorFlow: Full Course (Farsi): DataYad
- Deep Learning with PyTorch: Full Course (Farsi): Howsam
- Deep Learning Specialization: Andrew Ng (English, Coursera): Coursera Link

Condition Monitoring

- Machine Learning for Predictive Maintenance (English, Udemy): Course Link
- Condition Monitoring & Fault Diagnosis with ML (English, YouTube): Playlist Link
- Predictive Maintenance using Vibration & ML (English, YouTube): Watch Here
- AI for Predictive Maintenance in Industry (English, Coursera): Coursera Link

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Industrial Datasets (Part 1)

- **CWRU Bearing Data Center**: Vibration data of bearings under various conditions.
- **Paderborn University**: Motor vibration and current signals.
- **Electric Motor Temperature (UCI)**: Simulated electric motor data including temperature, current, and voltage.
- **MaFaulDa**: Vibration and acoustic signals from rotating machinery.
- **Electrical Fault detection and classification**: A collection of line currents and voltages for different fault conditions.
- **Electrical Grid Load Data**: Consumer load data for short- and medium-term forecasting.
- **Electrical Grid Stability Simulated Data**: Simulated data for power grid stability analysis.
- **Power Plant (UCI)**: Operational data from a power plant for performance prediction.
- **TE Process Simulation (Tennessee Eastman)**: Chemical process control dataset.
- **Air Quality**: Sensor readings for air quality monitoring.
- **Storm EVent ImageRy (SEVIR)**: Collection of spatially and temporally aligned satellite imagery, radar mosaics, and lightning detections.
- **SECOM Manufacturing**: Semiconductor production line sensor data.

Industrial Datasets (Part 2)

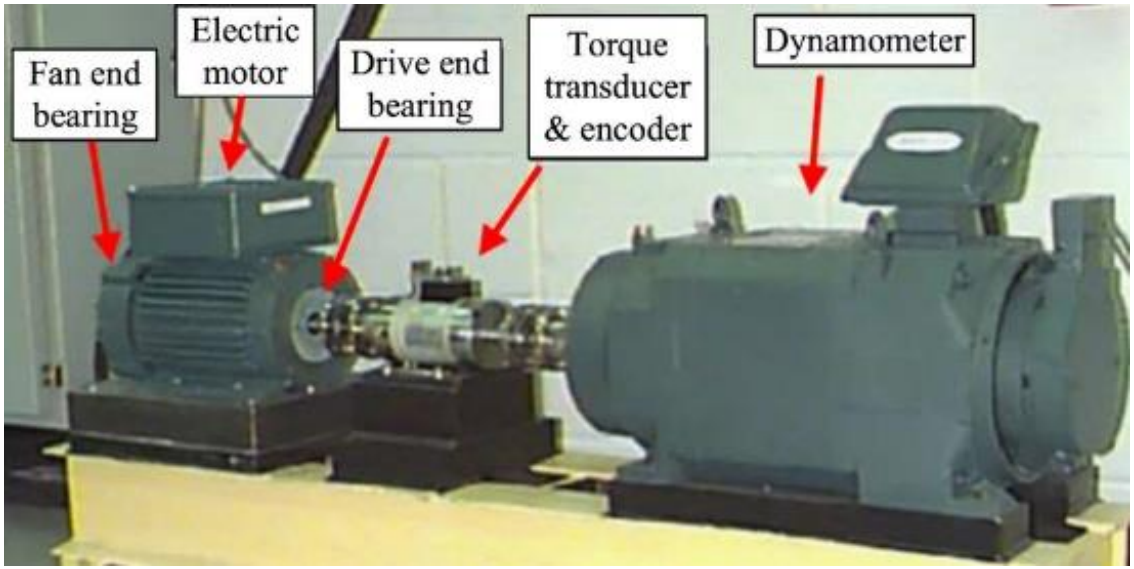
- **Wafer Map Defect**: Wafer maps labeled with defect types.
- **Concrete Compressive Strength**: Concrete compressive strength measurements.
- **Gas Sensor Array Drift**: Gas sensor readings under temperature and humidity variations.
- **Steel Plates Faults**: Numerical features for steel plate defect classification.
- **Alarm Logs in Packaging Industry (ALPI)**: A sequence of alarms logged by packaging equipment in an industrial environment
- **HydSys:** Predictive Maintenance Of Hydraulics System
- **PPD**: Production Plant Data for Condition Monitoring
- **UFD:** Ultrasonic flowmeter diagnostics Data Set

- **Some additional industrial datasets can be found at:**
  - Predictive Maintenance Collection on GitHub
  - Awesome Industrial Datasets List
  - NASA Prognostics Center of Excellence Data Set Repository
- **Kaggle:** A popular platform for datasets, competitions, and notebooks, including many industrial and predictive maintenance datasets.

Selected Datasets: CWRU

CWRU Bearing Data Center [Download dataset]

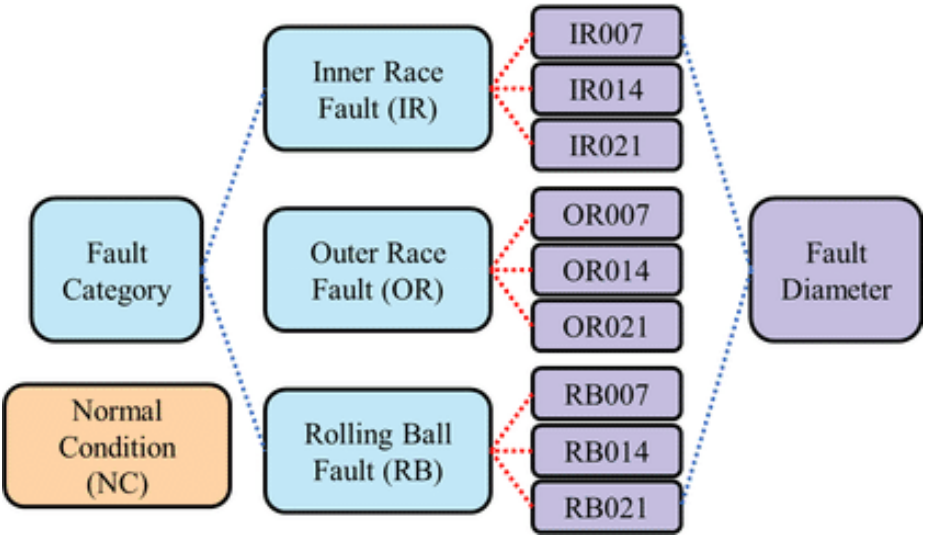
- Standard benchmark for **vibration** & condition monitoring
- Contains vibration signals from **bearings** under different conditions:
  Normal, Inner race fault, Outer race fault, and Ball fault

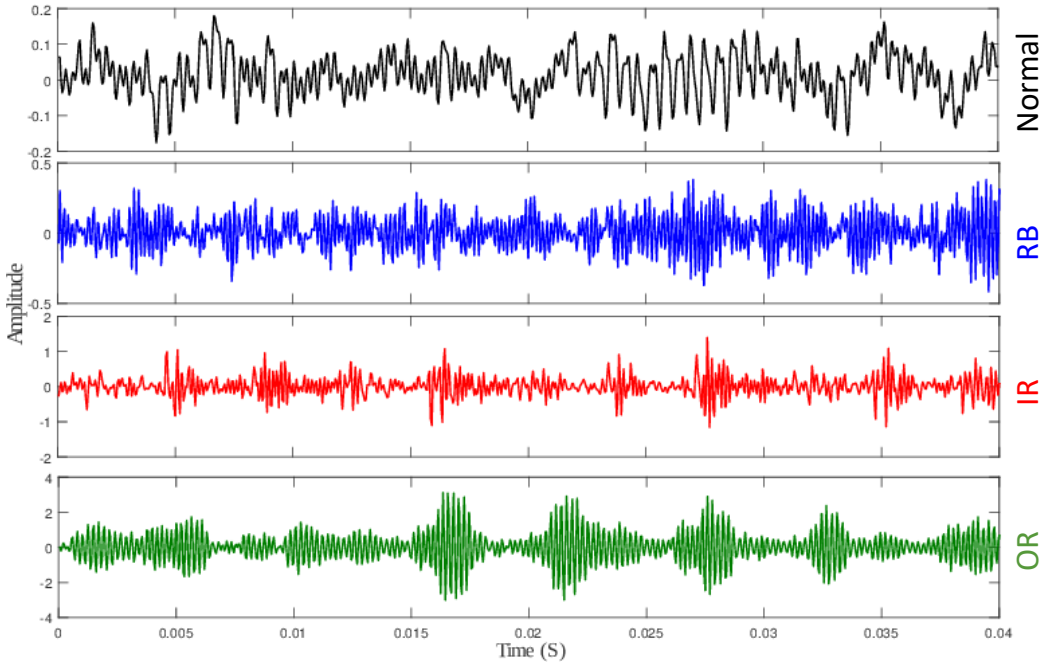


- **Fault sizes:** 0.007, 0.014, 0.021 in
- **Motor loads:** 0–3 hp
- **Sensors:** Drive End (DE) & Fan End (FE) accelerometers
- **Sampling rates:** 12 kHz, 48 kHz

Selected Datasets: CWRU

- File format: .mat (MATLAB)
- Signal inside file: 1D array (e.g., 'X097_DE_time')
- Sampling rate: 12 kHz (or 48 kHz)
- Duration: ~2 s (~24,000 samples) per recording
- Load: 0–3 hp (not shown in tree)
- Labels for ML: fault type, fault size, load

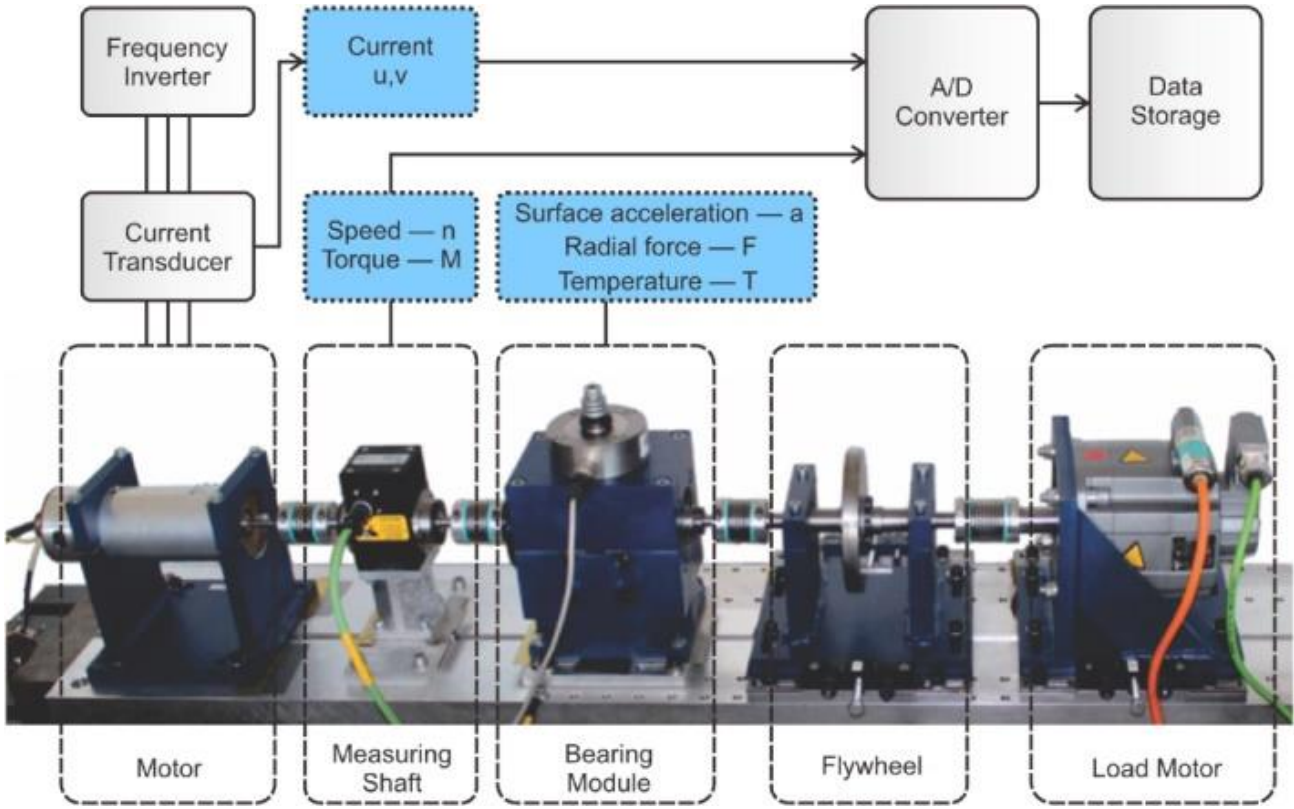




Selected Datasets: Paderborn

Paderborn University Bearing Dataset [Download dataset]

- **Purpose**: Benchmark dataset for bearing fault diagnosis (vibration & motor current signals)
- **Fault Types**:
  - Inner ring (IR)
  - outer ring (OR)
- **Operating Conditions**:
  - Speed: 600–1600 RPM
  - Load torque: 0.7 Nm
  - Radial force: 1000 N
- **Sensors & Sampling:**
  - Accelerometers @ 8 kHz
  - motor current @ 16 kHz

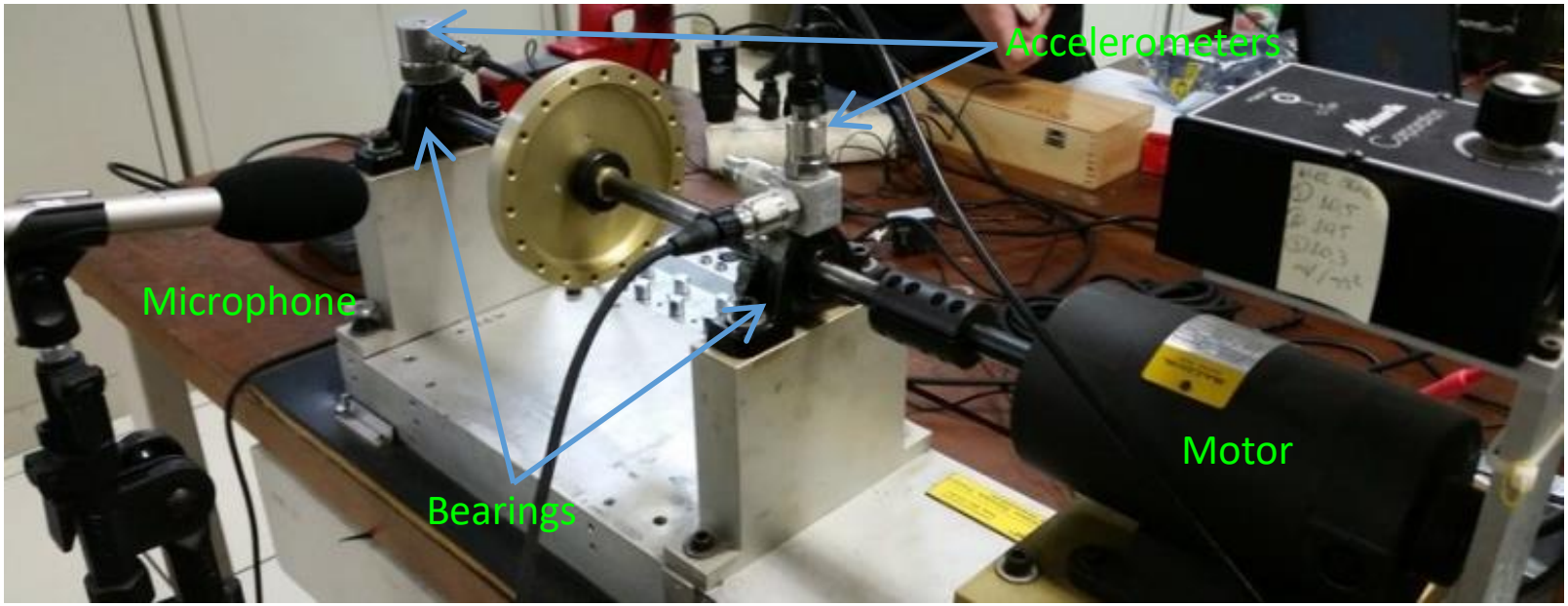


- **File Format**: .mat files; 1D arrays
- **Data for ML**: Fault type, fault location, fault severity

Selected Datasets: MaFaulDa

Machinery Fault Database (MaFaulDa) [Download dataset]

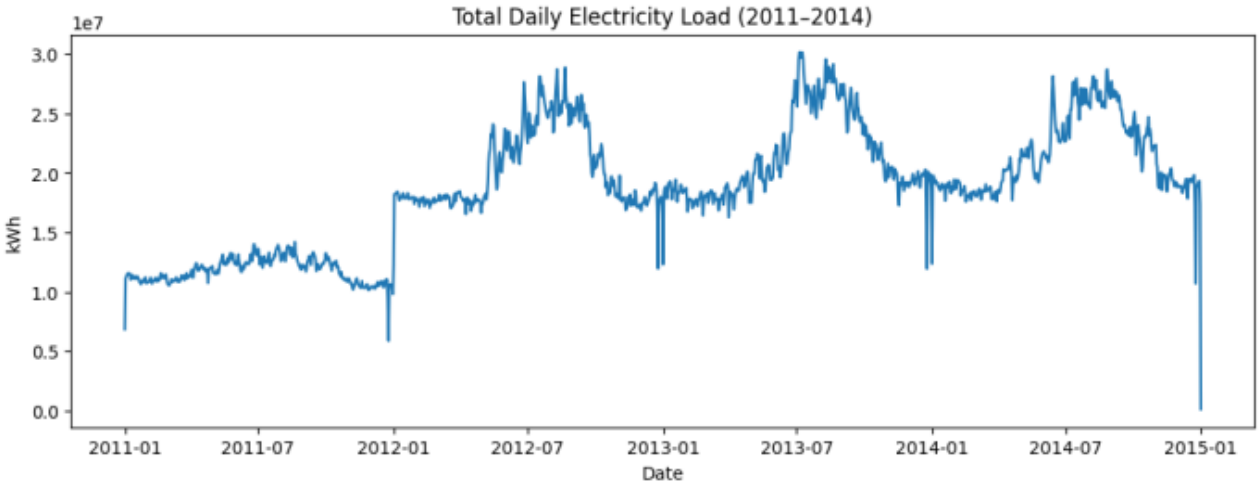
- **Domain**: Fault diagnosis in rotating machinery (lab simulator)
- **Signals**: 6 vibration channels (two triaxial accelerometers), tachometer, microphone
- **Faults**: Imbalance, misalignment (horizontal/vertical), bearing faults (inner/outer, underhang/overhang)
- **ML Tasks**: Fault detection, classification, diagnosis

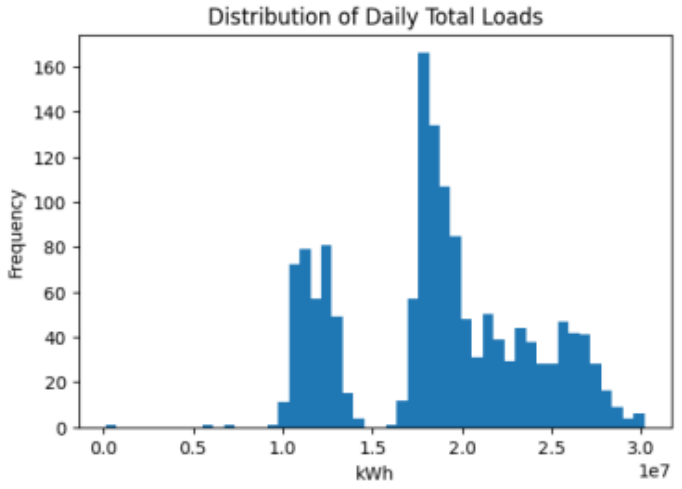


Selected Datasets: Electricity Load

Electricity Load Diagrams (2011–2014) [Download dataset]

- Source: **UCI Machine Learning Repository**
- Measures electricity consumption of **370 customers in Portugal**
- Time period: **2011–2014**
- Sampling: **every 15 minutes (~96 samples/day per customer)**
- Customers belong to **residential, industrial, and commercial categories**
- Commonly used for **time-series forecasting, anomaly detection, and clustering**
- **Format:** CSV file, one column per customer plus timestamp





Chapter 2: Introduction to Python for ML

Python is a leading ML language with powerful libraries. This chapter covers Python basics and hands-on industrial datasets.

In this chapter, we will cover:

- Python Basics
  - Introducing Python & Tools
  - Python Basics
  - Data Computations with NumPy
  - Data Manipulations with Pandas
- Data Visualization
  - Exploring Industrial Datasets
  - Exploring CWRU Bearing Dataset
  - Exploring Paderborn Bearing Dataset
  - Exploring MaFaulDa Machinery Fault Dataset
  - Exploring Electricity Load Diagrams