Elements of Machine Learning & Artificial Intelligence with application to E-drives

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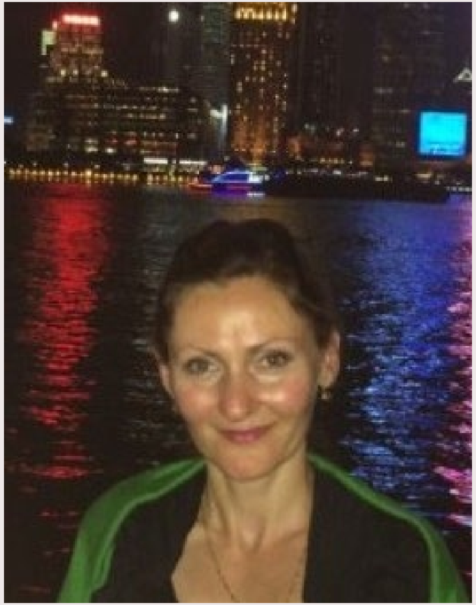


Can you give ML applications examples ?

IMAGE

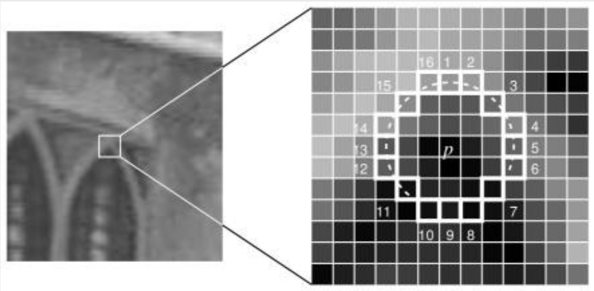
Object classification
Medical diagnosis / computer aided diagnosis
Automotive – self-driving cars (detect road objects)
Surveillance

TEXT

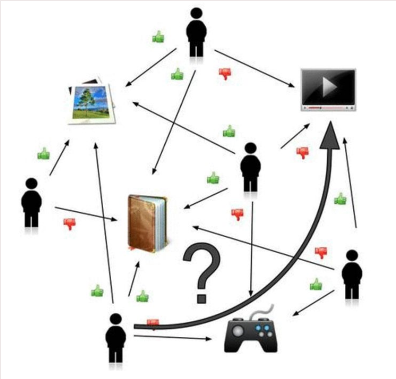
Sentiment analysis in movie reviews
Which word comes next
Automatic caption generation
Speech to text

FORECASTING

Sales
Recommender system (Netflix)
Fraudulent bank transactions

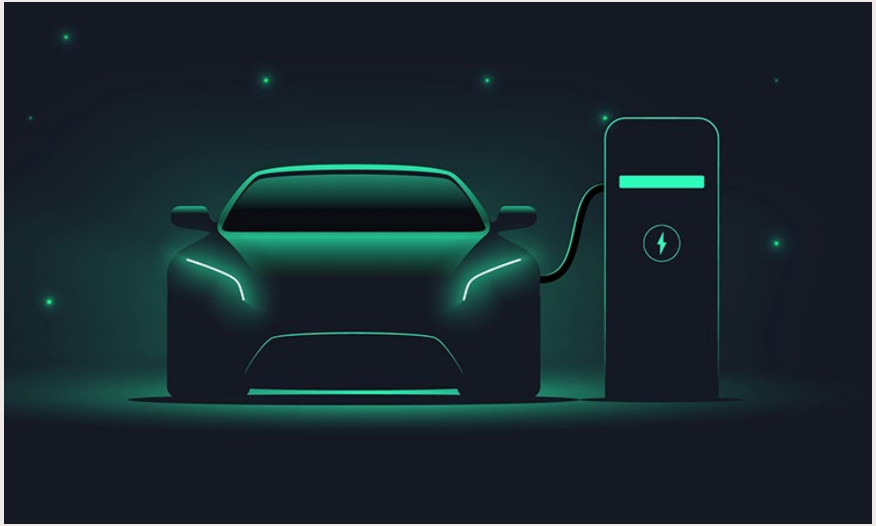


"an *emotional experience* that stays with you long after the credits roll. The powerful performances by DiCaprio and Winslet, combined with the film's ability to evoke a *wide range of emotions*, make it a timeless classic. I highly recommend "Titanic" for anyone who loves a film that can make you *laugh*, *cry*, and feel *deeply connected to its characters*."



https://en.wikipedia.org/wiki/Recommender_system

Electric Vehicles

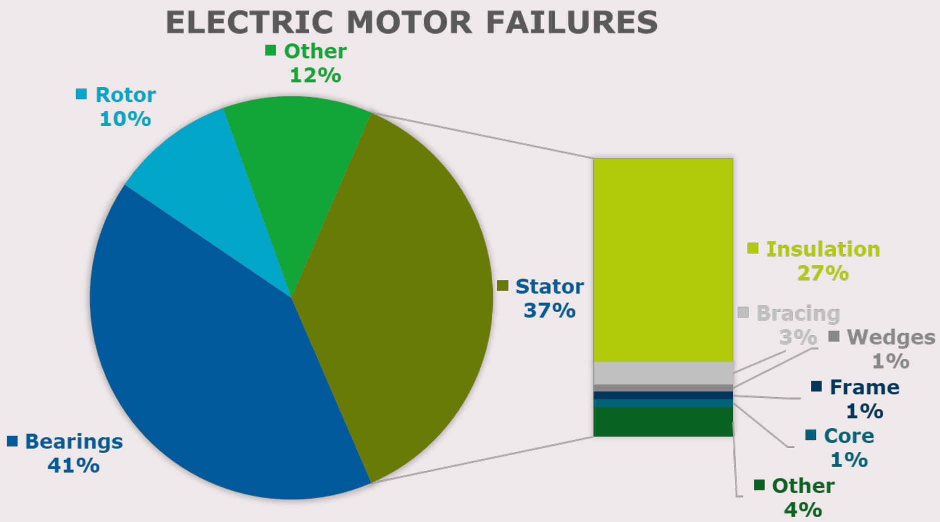


Performance
Durability
Electromagnetic compatibility
Noise-Vibration-Harshness
Design

Image Source: 'intelligenttransport.com'

Insulation failure in the stator accounts for 27%

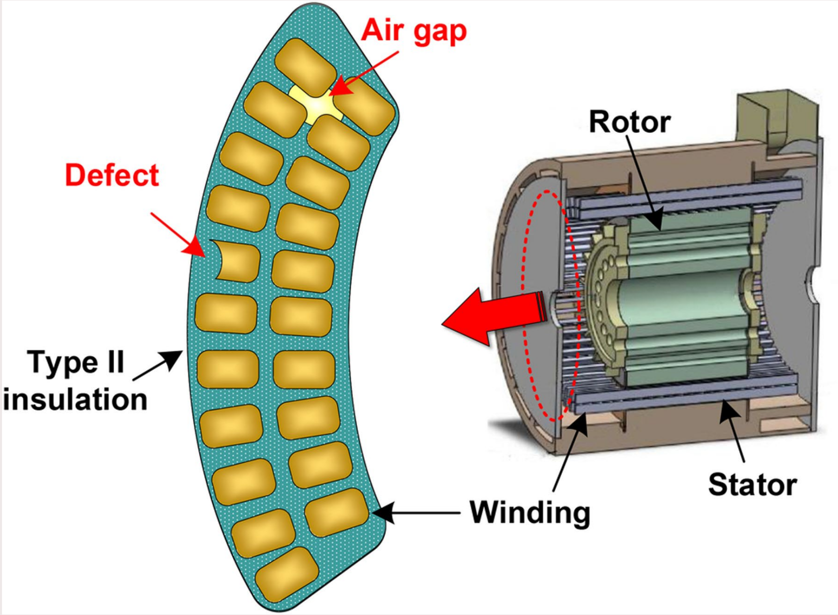
Condition monitoring of insulation layers in coils



Source: 'Report of large motor reliability survey of industrial and commercial installations, part I'

Machine Learning can be used for condition monitoring of windings

- Why is condition monitoring important?
- How can you do it?
- How can you sense deterioration of insulation?
- What kind of data you need to acquire?



Outline

- **What is Machine Learning ?**
- **Supervised Learning**
  - Regression
  - Classification
- **Unsupervised Learning**
  - Clustering
- **Reinforcement Learning**
- **Use-cases in electric vehicles**
  - Condition monitoring
  - Clustering of motors
  - Control
- **Machine Learning methodology (beyond model)**

Newton’s Law
Relation between force, mass and acceleration

$$\vec{F} = m\vec{a}$$

- Multiple observations
- Physics laws – symmetries, analytical description
- Small number of parameters

What if …

It would be almost impossible to write such a program "by hand" because of the

- ***high number of possibilities*** to consider (various object orientations, lighting conditions, occlusions, etc.)
- ***unstructured data*** (image identification - as opposed to structured, tabular data)
- tremendous ***amounts of data*** and ***computation resources*** / capacity

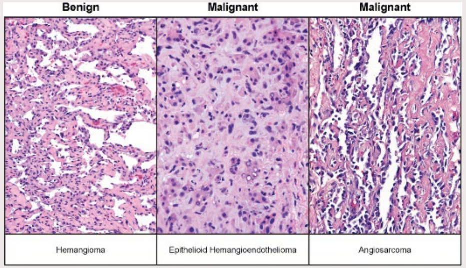
Use the *machine learning method:*

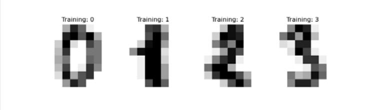
- instead of explicit instructions, computer receives annotated data (e.g. set of images labeled), and computer ***learns*** by itself to identify new images

What is *Machine Learning*?

- Face detection
- Digit recognition
- Classify disease cells in a tissue

Imitates humans

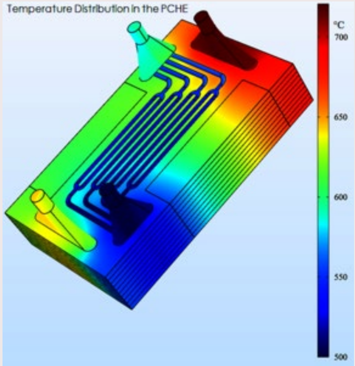


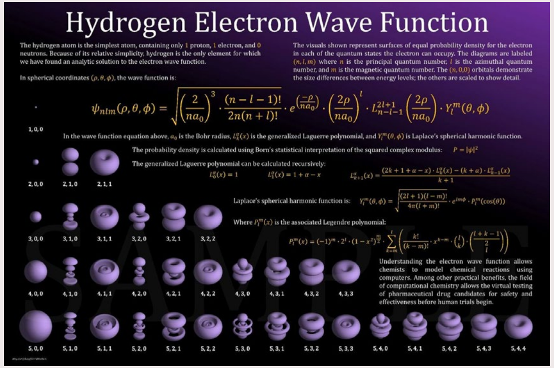


What is *Physical Modeling*?

- Calculate / Simulate temperature profile according to physics law (diffusion equation)

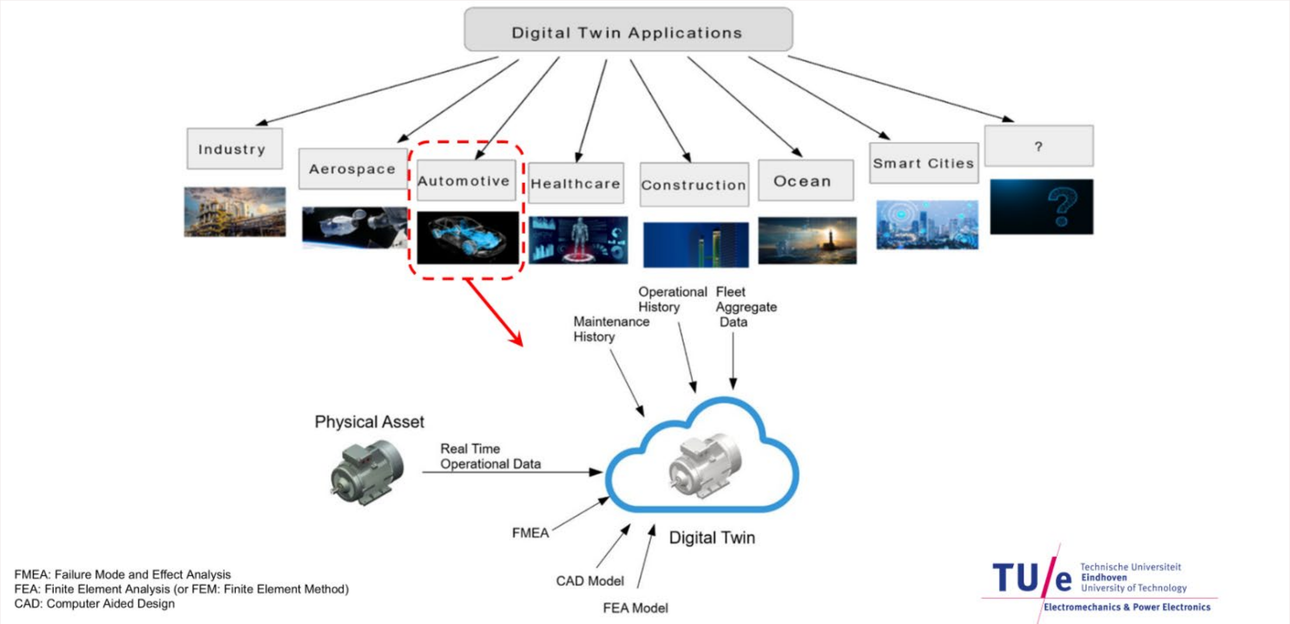
Explicit computing task



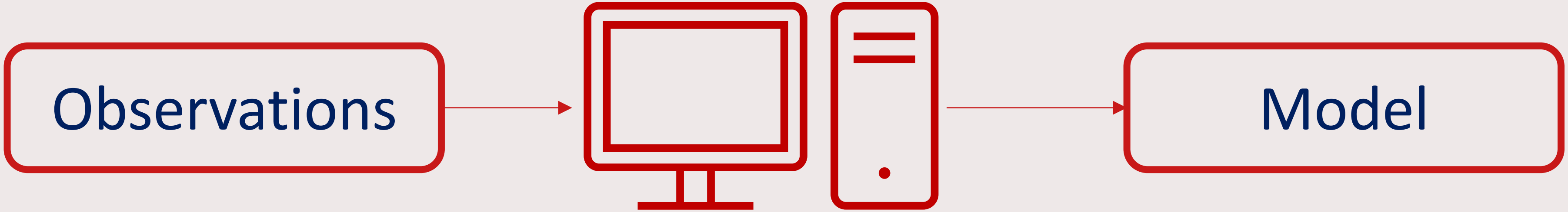


Kuhn, K.J., Cloutier, J.M., Boutin, R.D. et al. ”Soft tissue pathology for the radiologist: a tumor board primer with 2020 WHO classification update”, *Skeletal Radiol* **50**, 29–42 (2021).
https://scikit-learn.org/1.5/auto_examples/classification/plot_digits_classification.html ,
https://doi.org/10.1007/s00256-020-03567-w; https://www.comsol.com/paper/;
https://en.wikipedia.org/wiki/Atomic_orbital

Digital Twin combines physical models with data-driven solutions



How does Machine Learning work ?



Dataset (X)

Output / Labels (y)

(supervised learning)

Find model f_w (and parameters w), satisfying a loss function minimization condition

$$y_{predict} = f_w(X)$$

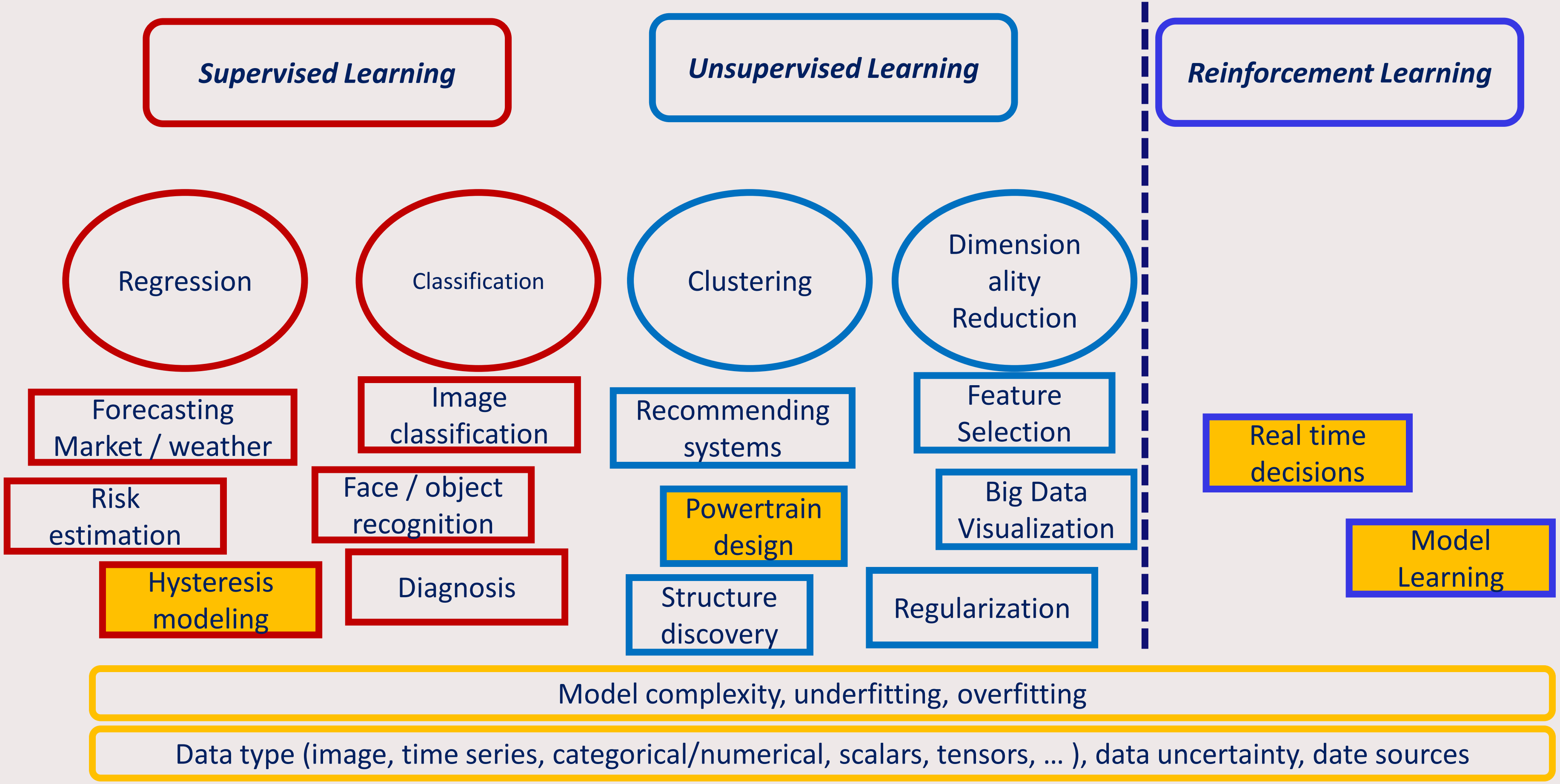
$$\mathcal{L}(X, y, \boldsymbol{w}) = ||y - f_w(X)||^2$$

Function f_w(x)

Regression / Classification

Key take aways

- Programming of computers using ***data instead of explicit instructions***
  - Make ***predictions***
  - ***Automate*** processes
- Does not replace traditional programming but ***complements*** it
- Allows for the use of ***large amounts*** of ***structured*** and/or ***unstructured data***
- Imitate the perception and ***intuition abilities of humans***


Supervised Learning
Unsupervised Learning
Reinforcement Learning
Regression
Classification
Clustering
Dimensionality Reduction
Forecasting Market / weather
Image classification
Recommending systems
Feature Selection
Real time decisions
Risk estimation
Face / object recognition
Powertrain design
Big Data Visualization
Model Learning
Hysteresis modeling
Diagnosis
Structure discovery
Regularization
Model complexity, underfitting, overfitting
Data type (image, time series, categorical/numerical, scalars, tensors, …), data uncertainty, date sources

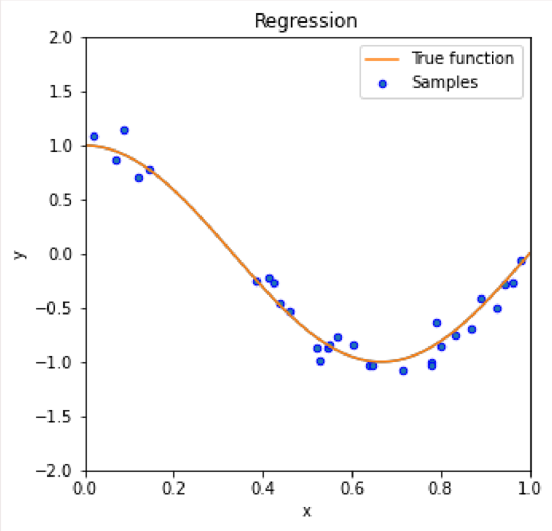
Machine learning methods: supervised learning

Electrical Vehicles use-cases

Condition monitoring failures
Regression

Powertrain
Clustering

Control
Reinforcement learning

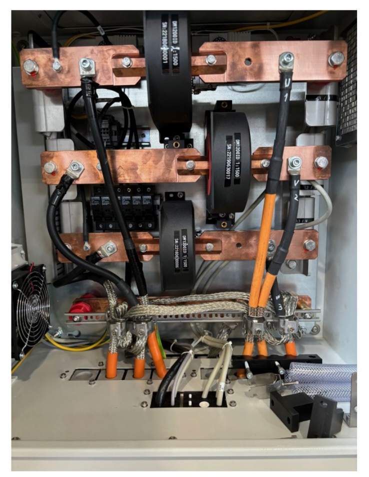


$$y_{predict} = f_{\boldsymbol{w}}(X)$$

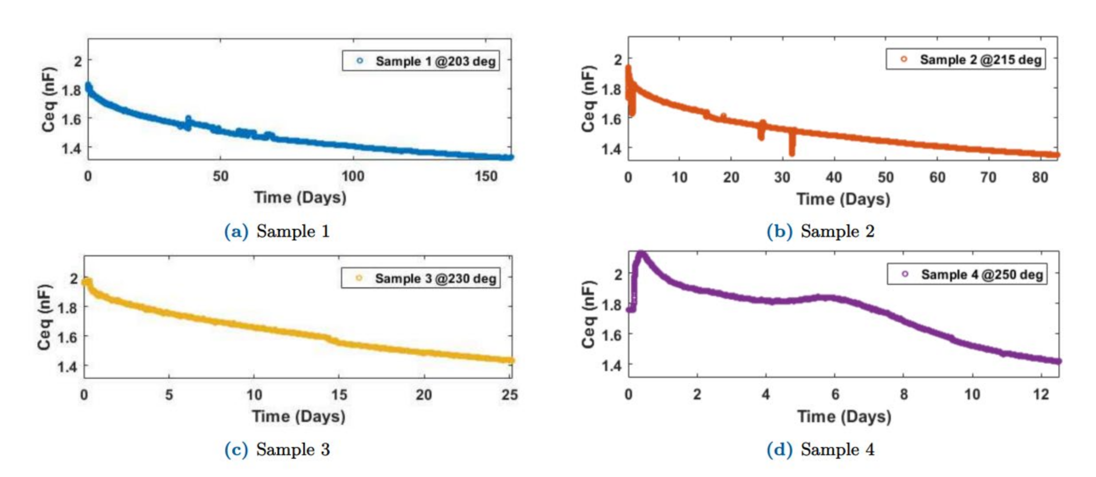
$$\mathcal{L}(X, y, \boldsymbol{w}) = ||y - f_{\boldsymbol{w}}(X)||^2$$

Indirect monitoring sensing by current sensors, voltage sensors, temperature sensors

The voltage and current measurement box



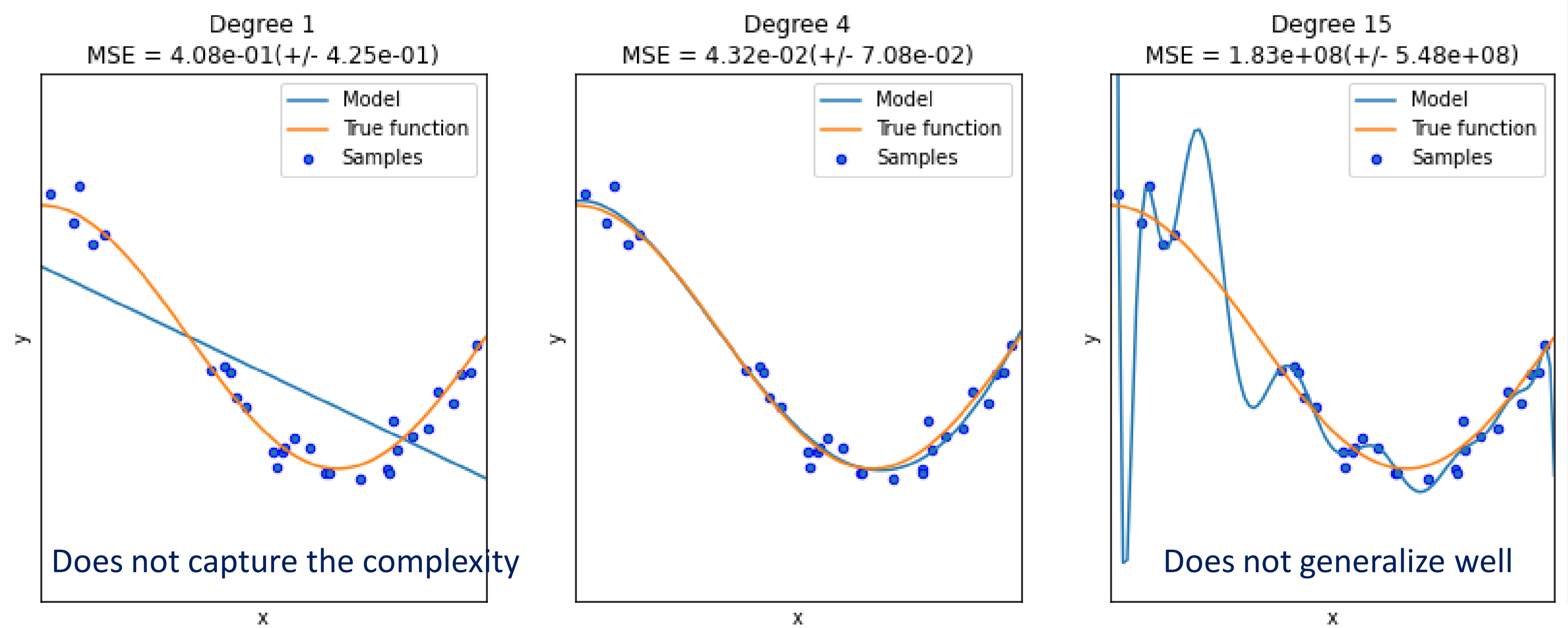
Condition monitoring by phase to ground capacitance



I. Tsyokhla, A. Griffo, and J. Wang, “Online condition monitoring for diagnosis and prognosis of insulation degradation of inverter-fed machines,” IEEE Transactions on Industrial Electronics, vol. 66, no. 10, pp. 8126–8135, 2019.

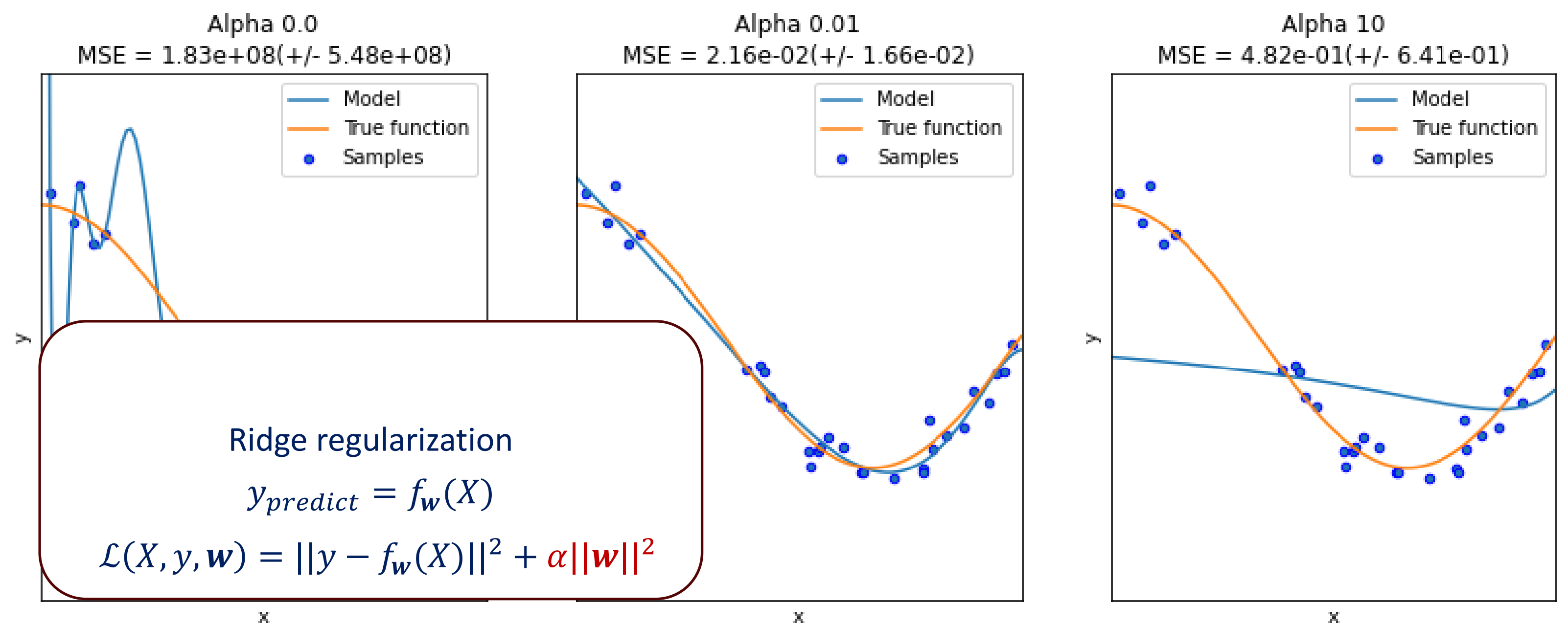
Model complexity may lead to *underfitting* or *overfitting*

Underfitting (degree 1) “Reasonable” fit (degree 4) Overfitting (degree 15)



Regularization methods can help to avoid overfitting

No penalization | Gradual penalization | Too hard penalization



Ridge regularization

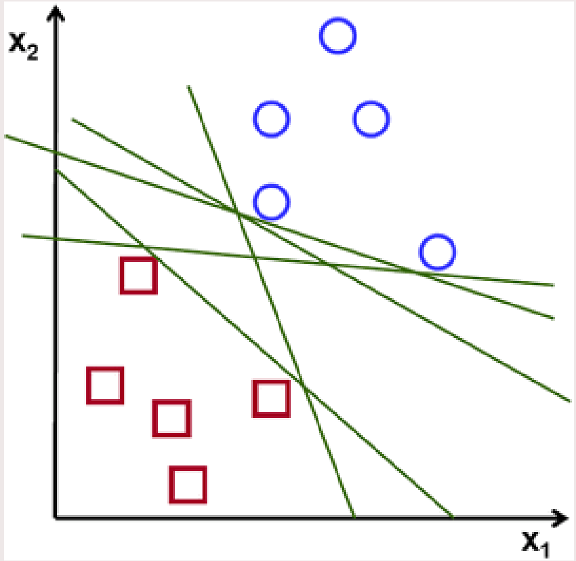
$$y_{predict} = f_w(X)$$

$$\mathcal{L}(X, y, \boldsymbol{w}) = ||y - f_w(X)||^2 + \alpha||\boldsymbol{w}||^2$$

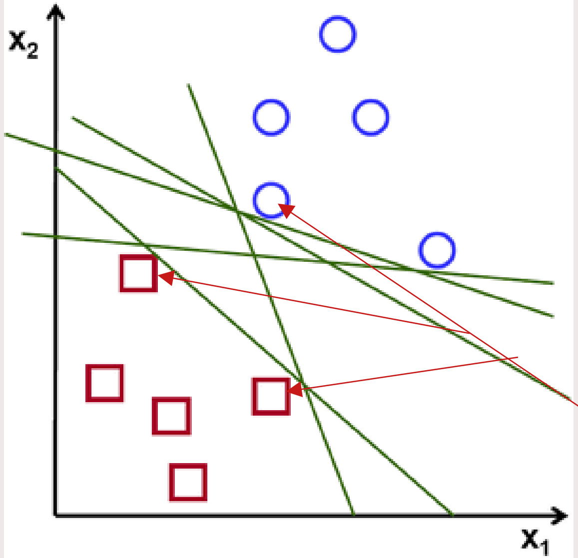
Classification

Some examples

- Image classification (dog, cat, …)
- Topic classification (science, history, art, …)
- Classification of vehicles depending on **mass** (x1) and **power consumption** (x2) to determine the **insurance category** (label)
    - ***Given a new vehicle, which category it belongs to?***



Example classification methods: Support Vector Machines



Support Vector Machines : find line (or hyperplane) that maximizes the separation between the two classes (the ***decision boundary***)

$$f(\boldsymbol{x}) = \boldsymbol{w}^T\boldsymbol{x} - \boldsymbol{b_0} = 0$$

This translates in minimizing:

$$\mathcal{L} = ||\boldsymbol{w}||^2$$

Subject to:

$$l_i(\boldsymbol{w}^T\boldsymbol{x} - \boldsymbol{b_0}) > 1 \quad \forall\, i \in \{0, 1, \dots\} \text{ classes}$$

Support vectors

Note: This is a linear case, but can be generalized to non-linear case

Assessing performance on classification: *confusion matrix*

Predicted / True	Label 1 true	Label 2 true	Label 3 true	Label 4 true
Label 1 predicted	97	7	3	5
Label 2 predicted	0	86	8	2
Label 3 predicted	5	0	93	1
Label 4 predicted	3	2	4	89

Specificity and **Sensitivity**

$$\textbf{Specificity} = \frac{true\ negatives}{true\ negatives + false\ positives}$$

$$\textbf{Sensitivity} = \frac{true\ positives}{true\ positives + false\ negatives}$$

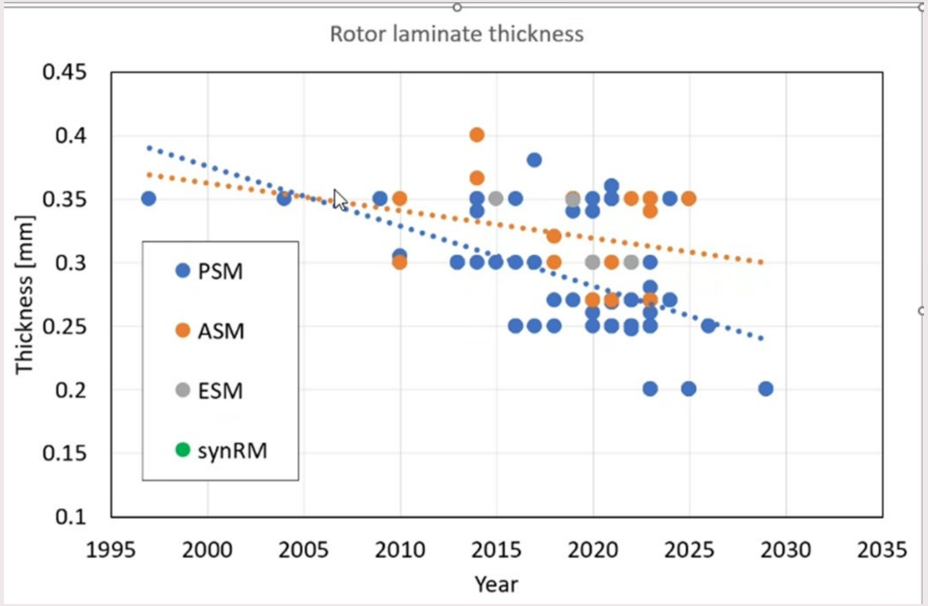
Machine learning methods: *un*supervised learning

Electrical Vehicles use-cases

Condition monitoring failures
Regression

Powertrain / Component
Clustering

Control
Reinforcement learning



Machine learning methods: reinforcement learning

Electrical Vehicles use-cases

Condition monitoring failures
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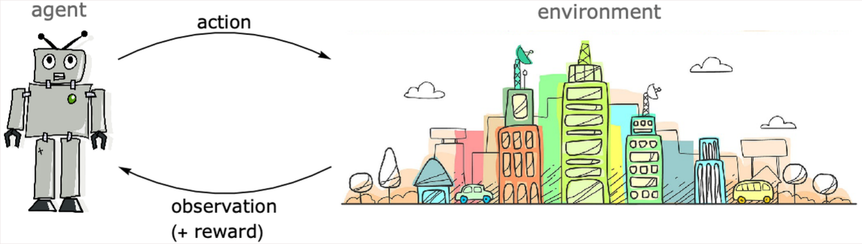
Reinforcement learning

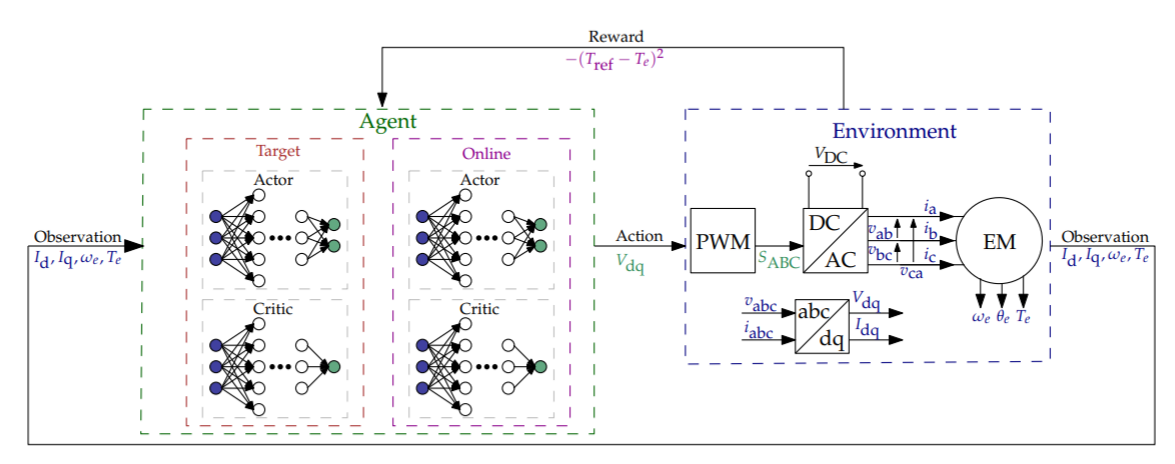


Reinforcement learning: learning from interacting with an external system called the *environment*.

Etienne Bernard, *Introduction to Machine Learning*, https://www.wolfram.com/language/introduction-machine-learning/

Reinforcement learning applied to *torque control*

Recent advancement in deep neural network can be applied to further optimize control
- Online learning
- High dimensional data



Deep Deterministic Policy Gradient (DDPG)

Source: J. Escárate Muñoz, E. Ilhan Caarls

The model is often just a few lines of your code …

Machine Learning workflow

Problem formulation

- Classification ?
- Regression ?
- Reinforcement Learning ?

Data curation

- Annotations
- Missing data
- Data accuracy
- Anomaly detection
- Feature extraction / selection
- Filling data
- Normalization

Data augmentation / ???

- Does the data capture variability
- Physics knowledge

Model selection

- Which architecture – hyperparameters tunning
- Complexity
- Cost function / Business value
- Physics knowledge

Training, validation, testing

- Performance measure
- Generalization
- Overfitting?
- Underfitting?
- Collinearity
- Under-/Over-determined
- Solution interpretation

Deployment and MLOps

- Data drift (changes in data)
- Model drift (changes in model assumptions)
- Hyper-parameters
- Monitoring

Useful links

Wolfram
Machine Learning

OpenCV

Python
Sklearn

Matlab
Statistics and Machine Learning Toolbox

[1] Etienne Bernard, *Introduction to Machine Learning*, https://www.wolfram.com/language/introduction-machine-learning/

[2] Kevin P. Murphy, *Machine Learning, A Probabilistic Perspective*, ISBN: 9780262018029, Pub date: August 24, 2012, Publisher: The MIT Pres

[3] Daphne Koller and Nir Friedman, *Probabilistic Graphical Models, Principles and Techniques*, ISBN: 9780262013192, Pub date: July 31, 2009, Publisher: The MIT Press