Optimization for deep learning

Toulouse School of Economics

Ludovic De Matteis

Course Overview

Teacher

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- PhD Student in robotics at LAAS-CNRS
  - Research interests in optimization and optimal control
- Studies at Ecole Normale Superieure (ENS) Paris-Saclay
  - Master in Electrical Engineering
  - Master in Mathematics, Vision and Learning
  - Agrégation in Engineering - specialty in Computer Science

Course Overview

Planning

	Day	Time	Subject
1	13/10/2025	9:30 - 12:30	Basic definitions, Gradient Descent and Newton's method
2	27/10/2025	9:30 - 12:30	Practical - Gradient Descent and Newton's method
3	03/11/2025	9:30 - 12:30	Neural networks and stockastic gradient descent
4	10/11/2025	9:30 - 12:30	Practical - Neural Networks and digit recognition
5	17/11/2025	9:30 - 12:30	Alternative Neural Structures
6	24/11/2025	9:30 - 12:30	Practical - Alternative Neural structure, Adversial networks

Course Overview

Evaluation

- No final exam
- 3 pratical session
  - 1 report per session
  - 2 weeks delay to complete each report
  - 60% of the final grade
- 1 MCQ at the end of the course
  - 40% of the final grade

Lecture 1 -

On gradients and optimization algorithms

Summary

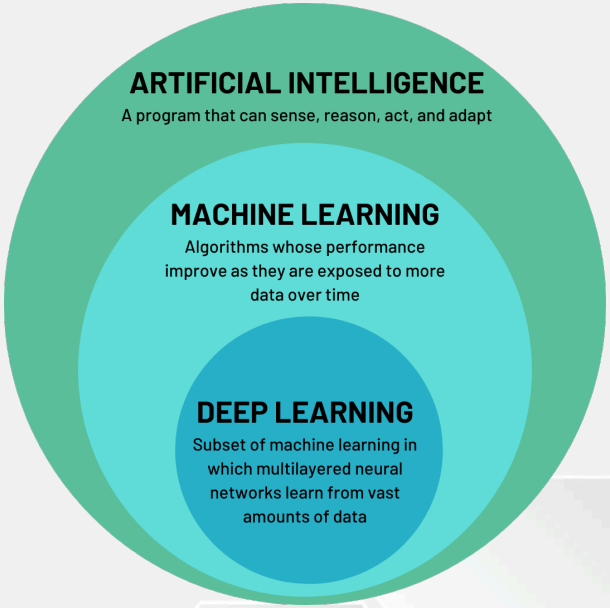
1. Motivation in Machine Learning
   - What is machine learning?
   - What is optimization?
   - Classical problems in machine learning
2. Derivatives and gradients
   - Reminder on derivatives
   - Optimality conditions
3. Gradient descent algorithm
   - Algorithm
   - Limitations
4. Newton's method
   - Comparison with gradient descent
   - Algorithm
   - Limitations

Motivation in Machine Learning

What is machine learning?

- Subfield of artificial intelligence that focuses on the development of algorithms that enable computers to perform specific tasks without explicit instructions.
- Systems learn from and make predictions or decisions based on data.

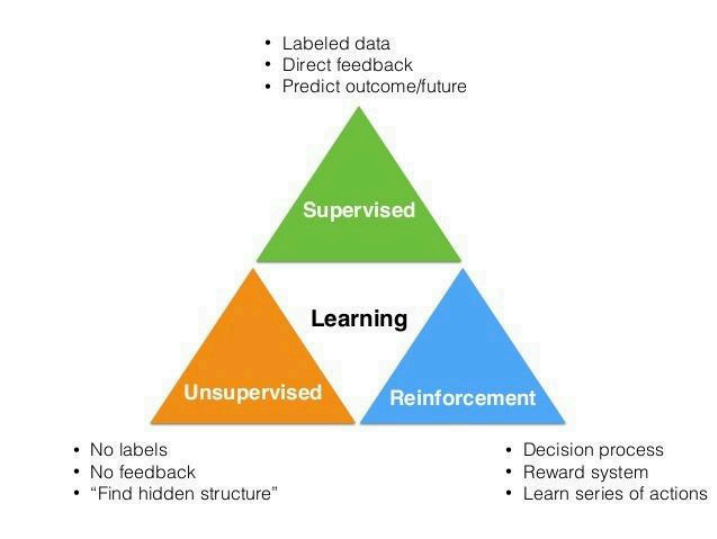
- The primary goal of machine learning is to enable computers to improve their performance on a task over time as they are exposed to more data.
- Widely used in various applications, including image and speech recognition, natural language processing, recommendation systems, robotics, finances...



Motivation in Machine Learning

What is machine learning?

- Three main classes of machine learning:
  - **Supervised learning**: The model is trained on a labeled dataset, where the input data is paired with the correct output. The goal is to learn a mapping from inputs to outputs.
  - **Unsupervised learning**: The model is trained on an unlabeled dataset, where the input data does not have corresponding output labels. The goal is to discover patterns or structures in the data.
  - **Reinforcement learning**: The model learns to make decisions by interacting with an environment. It receives feedback in the form of rewards based on its actions and aims to maximize cumulative rewards over time.



Motivation in Machine Learning

What is optimization?

- Optimization is the process of finding the best solution to a problem from a set of possible solutions, often by minimizing or maximizing a specific objective function.
- It can be written (in the case a minimization as)

$$\inf_{x \in \mathcal{X}} f(x)$$

where $f : \mathcal{X} \to \mathbb{R}$ is the **objective function**, x are the **decision variables** and $\mathcal{X}$ is the **set of feasible points**.

- In machine learning, optimization is used to find the best parameters for a model to minimize a loss function that measures the difference between the model's predictions and the actual data.

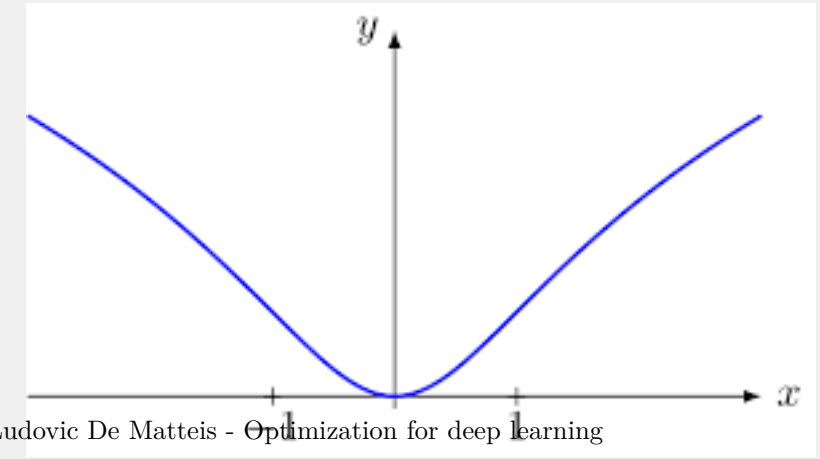
Motivation in Machine Learning

What is optimization?

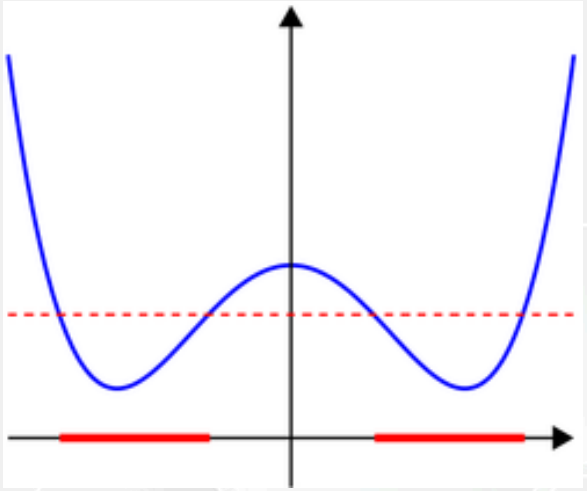
- The best decision variable is called the **optimal solution** and is denoted x^*.
- We define the set of **global minimizers** of the function f as

$$\arg\min_{x \in \mathbb{R}^n} f(x) \stackrel{\text{def}}{=} \{x_0 \in \mathbb{R}^n \mid \forall x \in \mathbb{R}^n, f(x_0) \leq f(x)\}$$

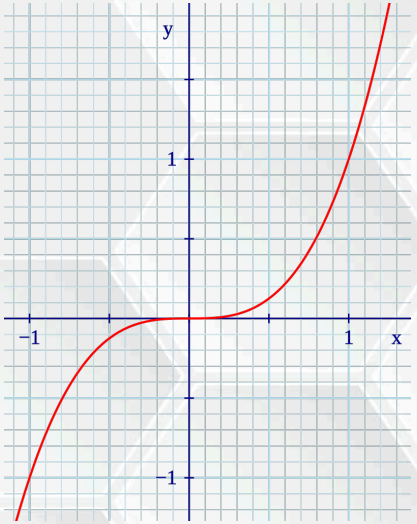
- The global minimizer of a function does not necessarily exists and if it does i can be non unique.



(a) Unique Minimizer



(b) Multiple Minimizer



(c) Zero Minimizer

Motivation in Machine Learning

Classical problems in machine learning

Regression

Motivation in Machine Learning

Classical problems in machine learning

Classification