

Introduction to optimization

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Course objectives

- By the end of this module, you will be able to answer the following questions:
 - What is optimization?
 - What are the applications of optimization?
 - Why should optimization be included in machine learning?

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What is optimization?

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Definition of optimization

- Discussion: what is optimization?

The process of finding the best possible solution to a problem within a set of constraints and objectives

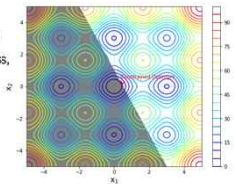
ChatGPT

Optimization, in general, refers to the process of finding the best solution or achieving the best outcome among a set of possible alternatives, given certain constraints or objectives. It involves systematically analyzing and improving a system or process to maximize efficiency, effectiveness, performance, or some other desirable criteria.

In mathematical terms, optimization often involves finding the minimum or maximum value of a function within a specified domain. This can be done using various techniques such as linear programming, nonlinear programming, dynamic programming, and heuristic methods.

In engineering, economics, operations research, and other fields, optimization is used to solve a wide range of problems, including resource allocation, production planning, scheduling, logistics, portfolio management, and more.

Overall, optimization aims to make the most out of available resources, time, and other factors to achieve the desired goals or objectives.



Egg crate function



Path finding

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Paradigm shift

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- Why do people get excited about optimization?



<https://www.youtube.com/watch?v=hN4EimFeyQM>

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Understanding the process of optimization

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- Let us look at one example to understand the process of optimization
 - Imagine that AKMU comes to Handong Global University (HGU) for the Fall festival
 - Your responsibility is to prepare a concert hall at the soccer field at HGU



<https://www.nocutnews.co.kr/news/4001443>



<https://www.handong.edu/square/inform/press/?mode=view&id=41350>

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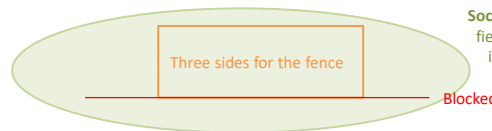


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Understanding the process of optimization

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- Suppose that you are specifically asked to maximize the area of the concert hall with the aim of having students in the concert hall as much as possible
 - You have 2,400 meters of fencing
 - You only need three sides for the fence
 - You want to use them to enclose some rectangular (or square) plot of the soccer field



Soccer field (assuming that the field is so large that it always includes the concert hall)

What will be the dimensions for the concert hall that will maximize its area?

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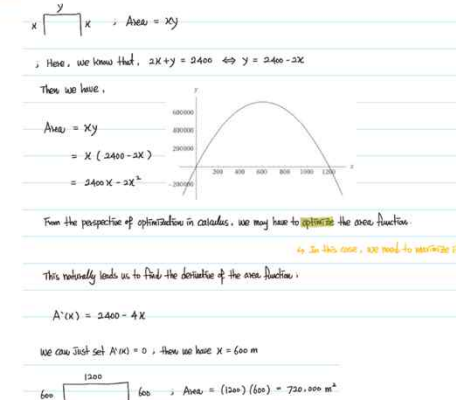


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Understanding the process of optimization

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- Solution:



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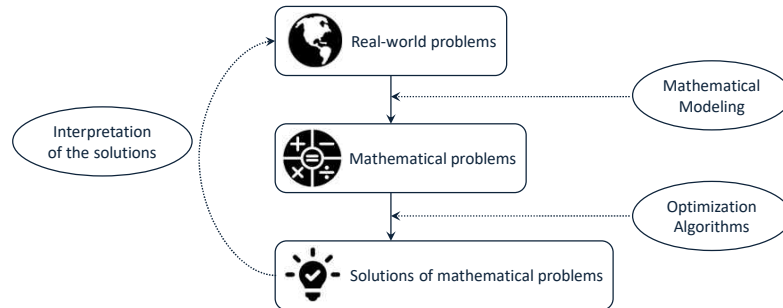


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Understanding the process of optimization

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- General steps of optimization



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What are the applications of optimization?

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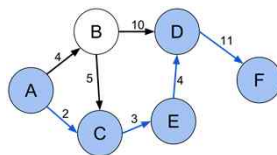
Applications of optimization

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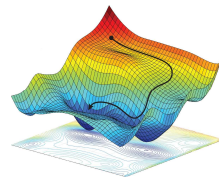
- Leveraging optimization algorithms can assist us in solving various real-world problems:



Traveling Salesman Problem ^[1]



Shortest Path Problem ^[2]



Optimization Problem ^[3]

^[1] https://www.localsolver.com/docs/8_5/example/tour/tsp.html
^[2] https://en.wikipedia.org/wiki/Shortest_path_problem
^[3] <https://towardsdatascience.com/on-optimization-of-deep-neural-networks-21de9e83e1>

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Research experiences

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Problem Definition

- Airline pilots perform some in-flight re-planning activities manually

Proposed Solution

- Data-driven approach using machine learning to optimize flight route

Honeywell

Problem Definition

- Boeing has experienced cost growth due to delays in manufacturing

Proposed Solution

- Supervised learning approach to improve demand/supply forecasting

BOEING

Problem Definition

- Chick-Fil-A has one of the longest drive-through waiting times

Proposed Solution

- Computer vision-based optimization approach to improve service

Chick-fil-A

Problem Definition

- American Airlines has wanted to improve operational efficiency

Proposed Solution

- Modeling and simulation approach to analyze various initiatives

American Airlines

Problem Definition

- Samsung software developers spend considerable time writing codes

Proposed Solution

- Machine learning-based code auto-completion tool development

SAMSUNG

Problem Definition

- No airspace infrastructure for UAM operations in South Korea exists

Proposed Solution

- Data-driven approach to construct UAM airspace infrastructure

HYUNDAI

Problem Definition

- Noise is linked to health issues for communities near an airport

Proposed Solution

- Advanced design methods-based approach to minimize airport noise

KAC GIMPO

Problem Definition

- CJ Logistics wants to make the best decision for a new hub location

Proposed Solution

- Surrogate-based optimization approach to support decision making

CJ LOGISTICS

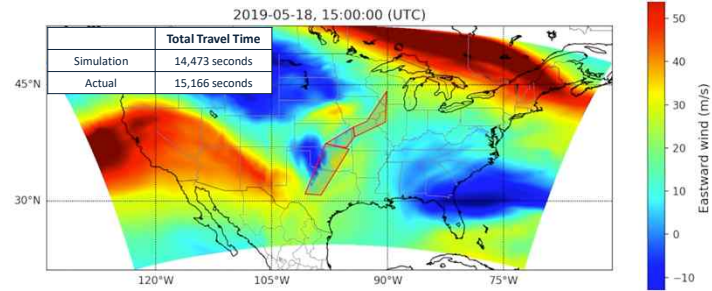


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Case 1 – Flight path optimization

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- Ph.D. research – Georgia Institute of Technology



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Case 2 – Departure procedure optimization

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- Sponsored research – Federal Aviation Administration



Dashed lines: Optimum
Straight lines: Baseline



Airline: Korean Air
Aircraft: Boeing 737-800
Departure: Gimpo → Arrival: Jeju

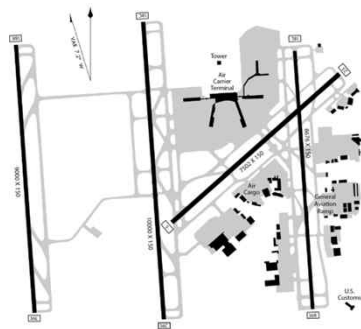


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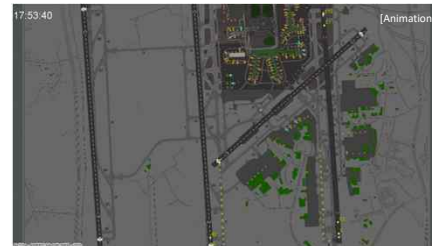
Case 3 – Airport operation optimization

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- Industry research – American Airlines



Credited by Operations Planning and Performance team at American Airlines



Airport Modeling and Simulation

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Why should optimization be included in machine learning?

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Fusing optimization and machine learning

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- Discussion
 - Do you think that we are going to replace optimization with machine learning or machine learning by optimization?

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Fusing optimization and machine learning

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- Prof. Pascal Van Hentenryck
 - School of Industrial and Systems Engineering, Georgia Institute of Technology



You will see many cooperations between machine learning and optimization. So, we are not replacing optimization with machine learning.

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Fusing optimization and machine learning

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- Why optimization should be included in machine learning?
 - Case 1. Maximizing likelihood
 - The Expectation-Maximization (EM) algorithm is an iterative method to find the maximum likelihood estimation of parameters in a statistical model (e.g., GMM)
 - Case 2. Minimizing an error function
 - The Multi-Layer Perceptron (MLP) model leverages the gradient descent algorithm to update weight parameters in a way that an error function is minimized
 - Case 3. Finding an optimal hyperparameter
 - The Support Vector Machine (SVM) model requires to specify two hyperparameters. A grid search method is one of the approaches to optimize the hyperparameters
 - ...

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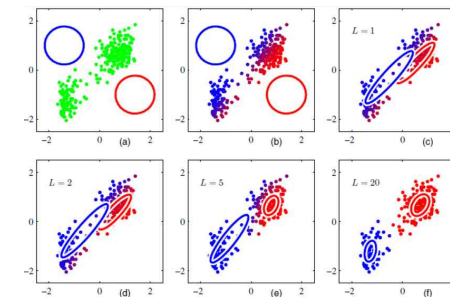


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Fusing optimization and machine learning

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- The Expectation-Maximization (EM) algorithm is an iterative method to find the **maximum** likelihood estimation of parameters in a statistical model (e.g., GMM)



https://www.researchgate.net/figure/illustration-of-the-EM-algorithm-GMM-on-the-Old-Faithful-data-set_fig4_310644322

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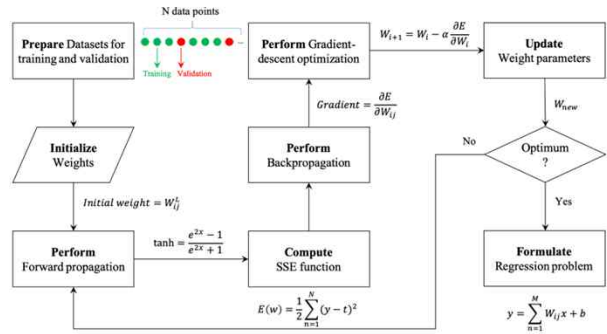


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Fusing optimization and machine learning

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- The Multi-Layer Perceptron (MLP) model leverages a gradient descent algorithm to update weight parameters in a way that an error function is **minimized**



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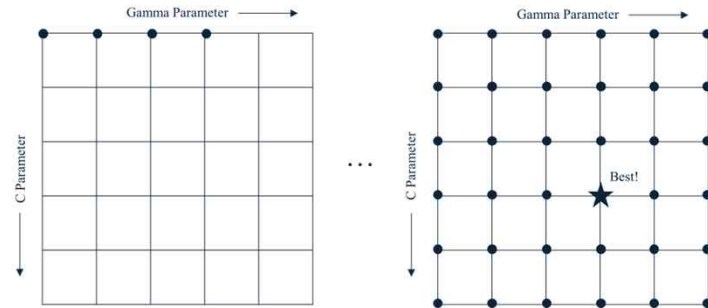


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Fusing optimization and machine learning

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- The Support Vector Machine (SVM) model requires to specify two hyperparameters
- A grid search method is one of the approaches to **optimize** the hyperparameters



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Course summary

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- Throughout this module, you have learned:
 - What is optimization?
 - What are the applications of optimization?
 - Why should optimization be included in machine learning?

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THANK YOU

For more information, please reach out to Prof. Junghyun Kim at
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