

Teoria e metodi dell'ottimizzazione

Laurea Magistrale in Matematica - a.a. 2021/22

Basic data

Title: Teoria e metodi dell'ottimizzazione [TMO]

Semester I - 6 CFU (42 h)

Webpage: <http://pages.di.unipi.it/biggi/dida/tmo.html>

Instructor: Giancarlo Bigi (giancarlo.bigi@unipi.it)

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Topics: nonlinear optimization/programming (finite dimension)

Prerequisites: linear algebra, basics of topology, multivariate calculus

Material: lecture notes + detailed references

Exam: oral test or seminar&report

Nothing at all takes place in the universe in which
some rule of maximum or minimum does not appear (L.Euler, 1744)

Our mathematical optimization framework

find minima and/or maxima of $f: \mathbb{R}^n \rightarrow \mathbb{R}$ over some $X \subseteq \mathbb{R}^n$

- $X = \mathbb{R}^n \rightarrow$ *unconstrained optimization*
- X any (convex) subset of $\mathbb{R}^n \rightarrow$ *constrained optimization* 
- X explicitly described by algebraic inequalities and/or equalities
- f smooth and/or convex

(nonlinearities in f and/or in [the description of] X)

Optimization: a bit of history

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Optimization rooted in ancient times

problems of geometrical nature [Euclid (300bc), Zenodorus, Apollonius (200bc)]

Calculus paved the way to pioneers

P.de Fermat (1629), G.W.von Leibniz (1684), I.Newton (1671)

L.Euler (1755), J.L.Lagrange (1797)

C.F.Gauss (1794), A.M.Legendre (1805), A.L.Cauchy (1847)

Insights from economics

diminishing returns [T.R.Malthus, D.Ricardo et al. (1815)] → convexity

individual utility maximization [A.A.Cournot (1838), L.Walras (1874)] → games

First textbook in 1917 (by H.Hancock)

Springer encyclopedia in 2009: 4646 (two-column) pages!

TMO contents: a magic blend

Mixing (variable doses):



TMO contents: a magic blend

Mixing (variable doses):

– Theory

- convex analysis
- optimality conditions
- duality

– Algorithms

- unconstrained optimization
- nonlinear least squares
- constrained optimization

– Applications

a never ending list in so many areas

([artificial intelligence](#), data analysis and statistics, computer graphics, physics, chemistry, signal processing, telecommunications, robotics, transportation, logistics, biology, life sciences, finance, economics and social sciences, etc.)

plus strong ties with numerical analysis, calculus of variations, control theory ...

The great watershed in optimization

Infact the great watershed in optimization isn't between linearity and nonlinearity, but **convexity** and **nonconvexity**

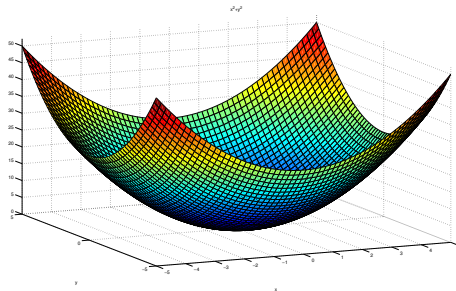
(R.T.Rockafellar, SIAM Review 1993)



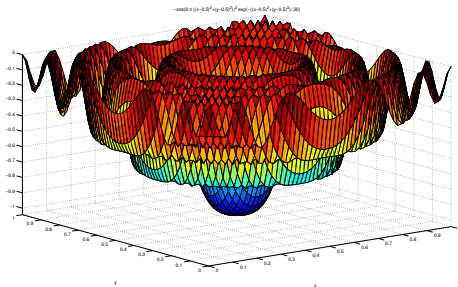
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local minimum $\equiv$ global minimum



**plenty of local minima
a unique global minimum**

A sample of applications

– Transportation

traffic over networks and road pricing

– Economics and finance

oligopolistic and spatial price markets

portfolio selection and risk management

growth models and analysis of economic indicators

– Physics and chemistry

configuration of molecules

estimate of physical parameters

laws of reflection

– Computer science

point pattern matching

supervised classification

– Information technology and telecommunications

signal reconstruction

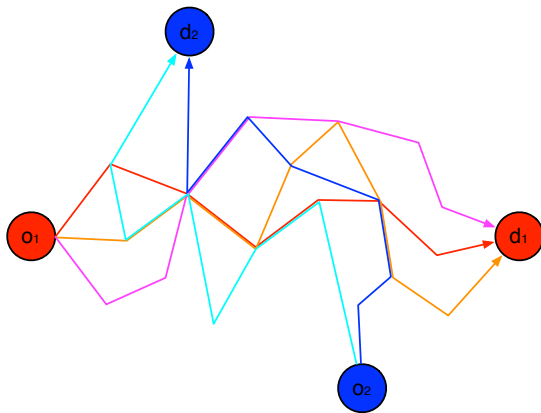
power allocation in radio systems and cloud computing

Traffic over a transportation network

Predict the steady distribution of traffic over a network (N, A)

Origin–Destination pairs: $s \in OD \subseteq N \times N$ with a traffic demand $d_s > 0$

The travel time on each arc $a \in A$ depends on the total flow on a



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Optimization point of view

the management of the network is centralized
(a unique decision-maker)

minimize $\left\{ \begin{array}{l} \text{the total travel time} \\ \text{or} \\ \text{the maximum travel time of } OD \text{ pairs} \\ \text{or} \\ \text{.....} \end{array} \right.$

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Multi-agent point of view

- no central management

- each user aims at minimizing its own travel time

- (the outcome for each one depends also on the choices of the others)

- game theory comes into play

 - concepts of equilibria [J.F.Nash (1950), G.J.Wardrop (1952)]