Session 10: Linear regression

Optimization and Computational Linear Algebra for Data Science

Léo Miolane

Contents

- 1. Ordinary least squares
- 2. Penalized linear regression
- 3. Matrix norms

Introduction

- We have n « feature vectors » $a_1, \ldots, a_n \in \mathbb{R}^d$.
- Each point a_i comes with a « target variable » $y_i \in \mathbb{R}$.

Solving Ax = y is a bad idea

The system Ax = y may have:

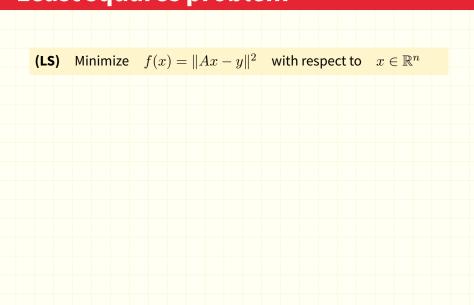
No solution.

Infinitely many solutions.

Ordinary least squares

Ordinary least squares 4/1

Least squares problem



The Moore-Penrose pseudo-inverse

Definition

Let $A=U\Sigma V^\mathsf{T}$ be the SVD of A. The matrix $A^\dagger \stackrel{\mathrm{def}}{=} V\Sigma' U^\mathsf{T}$ is called the (Moore-Penrose) pseudo-inverse of A, where Σ' is the $d\times n$ matrix given by

$$\Sigma'_{i,i} = \begin{cases} 1/\Sigma_{i,i} & \text{if } \Sigma_{i,i} \neq 0, \\ 0 & \text{otherwise,} \end{cases}$$

and $\Sigma'_{i,j} = 0$ for $i \neq j$.

Solving $A^{\mathsf{T}}Ax = A^{\mathsf{T}}y$

Claim: The vector $x^{LS} \stackrel{\text{def}}{=} A^{\dagger}y$ is a solution of $A^{\mathsf{T}}Ax = A^{\mathsf{T}}y$

Theorem

The set of the minimizers of $f(x) = \|Ax - y\|^2$ is

$$A^{\dagger}y + \operatorname{Ker}(A) = \left\{ x^{\operatorname{LS}} + v \,\middle|\, v \in \operatorname{Ker}(A) \right\}.$$

Ordinary least squares

Penalized least squares

Penalized least squares 8/17

Ridge regression

Ridge regression consists in adding a « ℓ_2 penalty » :

(Ridge) Minimize
$$f(x) = \|Ax - y\|^2 + \lambda \|x\|^2$$
 w.r.t. $x \in \mathbb{R}^n$

for some fixed $\lambda > 0$.

Lasso

Penalized least squares

The Lasso adds a « ℓ_1 penalty »:

(Lasso) Minimize $f(x) = ||Ax - y||^2 + \lambda ||x||_1$ w.r.t. $x \in \mathbb{R}^n$

for some fixed $\lambda > 0$.

10/17

Intuition behind feature selection

Lemma

Let x^{Lasso} be a minimizer of the Lasso cost function and let $r=\|x^{\mathrm{Lasso}}\|_1$. Then x^{Lasso} is a solution to the constrained optimization problem:

Penalized least squares 11/17

Intuition behind feature selection																			

12/17

Penalized least squares

Matrix norms

Matrix norms 13/17

Frobenius norm

Definition

The Frobenius norm of a matrix $A \in \mathbb{R}^{n \times m}$ is defined as

$$||A||_F = \sqrt{\sum_{i=1}^n \sum_{j=1}^m A_{i,j}^2}$$

Proposition

$$||A||_F = \sqrt{\sum_{i=1}^{\min(n,m)} \sigma_i(A)^2}$$

The spectral norm

Definition

The spectral norm of a matrix $A \in \mathbb{R}^{n \times m}$ is defined as

$$||A||_{Sp} = \max_{||x||=1} ||Ax||.$$

Proposition

$$||A||_{\mathrm{Sp}} = \sigma_1(A).$$

The nuclear norm

Definition

The nuclear norm of a matrix $A \in \mathbb{R}^{n \times m}$ is defined as

$$||A||_{\star} = \sum_{i=1}^{\min(n,m)} \sigma_i(A).$$

ŀ	\ pi	pl	ic	at	tic	or	1 t	:0	n	1a	ti	rix	K	CO	n	1p	le	et	io	n	

17/17

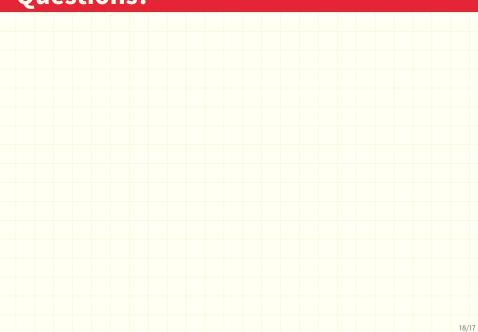
Matrix norms

ŀ	\ pi	pl	ic	at	tic	or	1 t	:0	n	1a	ti	rix	K	CO	n	1p	l	et	io	n	

17/17

Matrix norms

Questions?



Questions?

