Course guide
250COD014 - 250COD014 - Data-Assisted Engineering and Reduced Order Modelling

Last modified: 15/06/2026

Unit in charge: Barcelona School of Civil Engineering
Teaching unit: 751 - DECA - Department of Civil and Environmental Engineering.

Degree: MASTER'S DEGREE IN COMPUTATIONAL AND DATA-ASSISTED ENGINEERING (Syllabus 2026). (Optional subject).

Academic year: 2026 **ECTS Credits:** 5.0 **Languages:** English

LECTURER

Coordinating lecturer: PAVEL RYZHAKOV, SERGIO ZLOTNIK

Others: RICCARDO ROSSI, ALIREZA SHAMEKHI

TEACHING METHODOLOGY

It will be specified on the course page.

LEARNING OBJECTIVES OF THE SUBJECT

Students will acquire knowledge of data analysis techniques, as well as a priori and a posteriori model reduction methods. They will apply different Reduced Order Modeling (ROM) techniques to data-driven problems and to computational mechanics applications.

Learning Outcomes / Competences
Ability to develop and use reduced-order models for engineering applications.
Ability to implement different ROM techniques computationally.
Ability to select the most appropriate ROM technique for a given problem.

STUDY LOAD

Type	Hours	Percentage
Self study	80,0	64.00
Hours large group	45,0	36.00

Total learning time: 125 h

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

CONTENTS

Math preliminaries

Description:
Vector spaces and vector and matrix norms. Rank and span. Eigenvalues and eigenvectors. Types of matrices and their properties (symmetry, orthogonality, and orthonormality).

Specific objectives:
This section provides a review of the linear algebra concepts required to understand data characterization and analysis techniques, as well as reduced-order modeling techniques. In addition, advanced concepts, such as features, norms, and measures commonly used in the field of reduced-order modeling, will be introduced. These concepts go beyond the material typically covered in undergraduate linear algebra courses.

Related activities:
Hands-on computer session focused on dataset characterization and the computation of relevant metrics.

Full-or-part-time: 8h
Theory classes: 2h
Guided activities: 1h
Self study : 5h

Modal Analysis and its relation to ROM

Description:
content english

Specific objectives:
This topic introduces modal analysis as an a priori reduced-order modeling technique and compares it with data-driven approaches such as POD. The similarities, differences, and practical application of modal analysis to the modeling of linear structural systems are presented.

Related activities:
Understand the principles of modal analysis and its relationship with ROM techniques, and learn how modal bases can be used to reduce the computational complexity of linear structural models.

Full-or-part-time: 5h
Theory classes: 1h
Self study : 4h

Data and SVD (Intro and advanced topics)

Description:
This section introduces different types of data and their matrix-based representation. Data will be considered in a broad sense, including experimental measurements, images, numerical simulations, and other information sources. Different data matrix structures, including tall-and-skinny and short-and-fat matrices, will be discussed together with their computational implications.

The concepts of cross-correlations and self-correlations will be introduced as key tools for data analysis. Principal Component Analysis (PCA) and Singular Value Decomposition (SVD) will be presented as fundamental techniques for identifying patterns, low-dimensional structures, and
dominant features in complex datasets.
This topic will be subivided into two large blocs (theory and basic properties, and practical applications=

The use of SVD for solving overdetermined and underdetermined linear systems through the computation of pseudoinverses will also be covered, together with its application to linear regression problems and the treatment of incomplete datasets (gappy data).

Specific objectives:
Understand different matrix-based representations of data arising from experiments, numerical simulations, images, and other information sources.
Analyze the structure and correlations within datasets using tools such as correlation matrices, self-correlations, and cross-correlations.
Apply PCA and SVD techniques to identify dominant patterns, perform dimensionality reduction, and extract the most relevant features from data.
Use SVD to compute pseudoinverses, solve overdetermined and underdetermined linear systems, and address linear regression and gappy data problems.

Related activities:
Theory classes, tutorial and first homework.

Full-or-part-time: 16h
Theory classes: 4h
Guided activities: 2h
Self study : 10h

Aposteriori reduction via Proper Orthogonal Decomposition

Description:
This section introduces Proper Orthogonal Decomposition (POD) as an extension of SVD to problems governed by partial differential equations (PDEs). Dimensionality reduction will be presented as a powerful tool for representing the spatio-temporal behavior of complex systems through low-dimensional approximations.

The concepts of variable separation and modal basis representations of spatial fields will be introduced, together with the construction of reduced-order models through Galerkin projection onto orthonormal basis functions. Different strategies for selecting and constructing reduced bases will also be discussed. Finally, POD-based reduced-order modeling will be applied to structural finite element (FEM) models.

Specific objectives:
Understand the fundamentals of POD and its connection to SVD for PDEs.
Build reduced-order models using modal bases and Galerkin projection.
Apply POD techniques to structural FEM models.

Related activities:
Theory class, tutorial

Full-or-part-time: 8h
Theory classes: 2h
Practical classes: 1h
Self study : 5h

Non-linear problems and hyper-reduction

Description:
This lecture introduces the main challenges associated with reduced-order modeling of non-linear systems, highlighting the limitations and computational bottlenecks of standard POD-based approaches when applied to non-linear operators. To address these issues, the concept of hyper-reduction is presented, with a focus on two widely used techniques: the Discrete Empirical Interpolation Method (DEIM) and the Empirical Cubature Method (ECM). Their theoretical foundations, implementation principles, and role in enabling efficient non-linear ROMs are discussed.

Specific objectives:
Familiarize the students with the Discrete Empirical Interpolation Method (DEIM) and the Empirical Cubature Method (ECM)

Full-or-part-time: 8h
Theory classes: 2h
Practical classes: 1h
Self study : 5h

Advanced Topics in Reduced-Order Modeling and Data-Driven Methods

Description:
This topic explores advanced techniques at the intersection of reduced-order modeling and data-driven approaches. Building upon the challenges posed by non-linear systems, it introduces machine learning methods for non-linear dimensionality reduction, with a focus on autoencoders and manifold learning techniques. The use of Uniform Manifold Approximation and Projection (UMAP) for data visualization, clustering, and low-dimensional representation of complex solution spaces is also presented, highlighting its potential in ROM workflows.

Specific objectives:
Understand advanced ROM strategies for non-linear systems and learn how data-driven techniques such as autoencoders and UMAP can be used for dimensionality reduction, feature extraction, and the analysis of complex solution spaces.

Full-or-part-time: 8h
Theory classes: 2h
Practical classes: 1h
Self study : 5h

Defense of the work, part 1

Description:
The students will have to present, defend and discuss their works related to the first part of the course (aposteriori ROM). They will be also asked questions to test their knowledge of the basics.

Specific objectives:
Test students knowledge, strengthen their scientific communication skills.

Full-or-part-time: 9h
Guided activities: 3h
Self study : 6h

Proper Generalized Decomposition: Intrusive Formulation and High-Dimensional Problems

Description:
This topic introduces Proper Generalized Decomposition (PGD) as an a posteriori reduced-order modeling technique. The fundamental concepts of separated representations are presented, together with their application to the efficient solution of high-dimensional linear problems using intrusive formulations.

Specific objectives:
Understand the basic principles of PGD and learn how separated representations can efficiently address high-dimensional computational problems.

Full-or-part-time: 8h
Theory classes: 2h
Practical classes: 1h
Self study : 5h

Proper Generalized Decomposition

Description:
This topic extends the PGD framework to non-intrusive settings, showing how reduced representations can be constructed from existing computational data. Applications to linear systems and data compression are presented.

Specific objectives:
Learn the principles of non-intrusive PGD and its application to efficient data representation and compression.

Full-or-part-time: 8h
Theory classes: 2h
Practical classes: 1h
Self study : 5h

Proper Generalized Decomposition 2

Description:
This topic explores arithmetic operations on PGD-separated representations, covering both basic and advanced operations and demonstrating their use in practical computational applications.

Specific objectives:
Understand how mathematical operations can be performed directly on PGD representations and applied to engineering problems.

Full-or-part-time: 8h
Theory classes: 2h
Guided activities: 1h
Self study : 5h

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

Reduced Basis

Description:
This topic introduces reduced basis methods, focusing on the construction of efficient reduced spaces through greedy algorithms and their application to parametric computational problems.h

Specific objectives:
Learn how reduced bases are constructed and how they can be used to accelerate numerical simulations.

Full-or-part-time: 8h
Theory classes: 2h
Practical classes: 1h
Self study : 5h

Data-Based Surrogates

Description:
This topic presents data-driven surrogate modeling techniques, including Principal Component Analysis (PCA) for dimensionality reduction and Gaussian Process Regression (Kriging) for prediction and approximation.

Specific objectives:
Understand the fundamentals of data-based surrogate models and their use for efficient prediction and analysis.

Full-or-part-time: 9h
Theory classes: 2h
Guided activities: 1h
Self study : 6h

Defense of the work, part 2

Description:
The students will have to present, defend and discuss their works related to the second part of the course (apriori ROM). They will be also asked questions to test their knowledge of the basics.

Specific objectives:
To test students knowledge and strengthen their scientific communication skills.

Full-or-part-time: 9h
Guided activities: 3h
Self study : 6h

GRADING SYSTEM

TASKS + ORAL EXAMINATION

BIBLIOGRAPHY

Basic:
- Brunton, Steven L.; Kutz, J. Nathan. Data-driven science and engineering: machine learning, dynamical systems, and control. 2nd ed. Cambridge: Cambridge University Press, 2022. ISBN 9781009098489.
- Benner, Peter; Ohlberger, Mario; Cohen, Albert; Willcox, Karen. Model Reduction and Approximation: Theory and Algorithms [on line]. SIAM, 2017 [Consultation: 16/06/2026]. Available on: https://epubs-siam-org.recursos.biblioteca.upc.edu/doi/book/10.1137/1.9781611974829. ISBN 9781611974829.