Model reduction techniques

ECTS: 6

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UNIVERSITY WHERE THE COORDINATOR IS: UPM

HAVE YOU GIVEN PERMISSION TO RECORD YOUR CLASSES? Yes

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UNIVERSITY WHERE THE LECTURER IS: UPM

HAVE YOU GIVEN PERMISSION TO RECORD YOUR CLASSES? Yes

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UNIVERSITY WHERE THE LECTURER IS: UPM

HAVE YOU GIVEN PERMISSION TO RECORD YOUR CLASSES? Yes

SUBJECT CONTENTS:

1. General introduction to the course

Reduced order models, classification and goals; acceleration in numerical simulations. Projection based models and data-driven models. Large databases post-processing and description, patterns identification. Spatial patterns and symmetries. Spatio-temporal periodic and quasi-periodic patterns. Standing and traveling waves. Some examples of scientific and industrial applications. Patterns formations in non-linear systems: Ginzburg-Landau equation and thermal convection systems. Benchmark fluid dynamic problems: flow past cylinders, backward facing step. Fluid dynamics in industrial problems: flows in urban environments, underground reservoir flows, flight test data and the analysis of aeroelastic frequencies.

2. Interpolation, proper ortogonal decomposition (POD) and singular value decomposition (SVD)

POD and SVD, comparing the two methodologies in two-dimensional databases. Analysis of large databases. Difficulties to extend SVD; canonical decomposition and tensor rank. Tucker's method and high order singular value decomposition. Using these techniques for database compression, interpolation and repair (Sirovich method). Reduced order models based on SVD and HOSVD. Additional techniques: Kriging interpolation and sampling techniques such as DEIM, Q-DEIM and LUPOD. Some examples and applications.

3. Reduced order models based on the projection of a physical model

Reduced order model obtained using physical model projections. Galerkin projection and some other projection techniques; modelling the non-lineal terms. Pre-processing reduced order models to solve evolution problems based on projection techniques. Adaptive reduced order models based on projection techniques. Some examples and applications.

4. Reduced order models based on the identification of spatio-temporal patterns

Limitations on some techniques based of the Fourier decomposition of a signal, such as FFT, PSD and Laskar. Dynamic mode decomposition (DMD) and some extensions such as optimized DMD. Koopman observability theory and DMD.

Spatial and spectral complexities; limitation of the previous methods. Higher order DMD (HODMD) and iterative HODMD; data extrapolation and cleaning noisy experimental databases. Spatio-temporal Koopman decomposition (STKD). Spatio-temporal patterns extraction and identification of standing and traveling waves. Data-driven reduced order models based on the previous techniques. Some examples and applications.

METHODOLOGY

Lectures will combine the essential ideas of the previous techniques with their practical applications. For such aim, simple examples will be introduced in class and some small projects will be developed using some tools provided to the students (using for instance MATLAB or Python codes able to call full models with the idea of speeding up their resolution). Codes of all the tools and techniques introduced in the course will be provided as well.

The criterion to evaluate the students in the form ‘continuous evaluation’ will divide the students in groups up to four people. The students will solve three problems along the course, related to contents developed in 2, 3 and 4.

LANGUAGE: Spanish/English depending on the audience

IS IT COMPULSARY TO ATTEND CLASSES? Remote classroom connected via Telecom.

BIBLIOGRAPHY

T.G. Kolda, B.W. Bader; Tensor decompositions and applications. SIAM Review, 51 (2009) pp. 455-500.

J.N. Kutz; Data-driven Modeling & Scientific Computation. Oxford University Press, 2003.

A. Quarteroni, A. Manzoni, F. Negri; Reduced Basis Methods for Partial Differential Equations. An Introduction. Springer, 2016.

P.J. Schmid; Dynamic mode decomposition of numerical and experimental data. Journal of Fluid Mechanics, 656 (2010) pp. 5-28.

G. Strang. Introduction to Linear Algebra. Wellesley-Cambridge Press. 5th Edition 2016.

ADDITIONAL BIBLIOGRAPHY

P. Benner, S. Gugercin, K. Willcox; A survey of projection-based model reduction methods for parametric dynamical systems. SIAM Review 57(4) (2015) 483-531.

T. Bui-Thanh; Proper orthogonal decomposition extensions and their applications in steady aerodynamics. MSc thesis. Massachusetts Institute of Technology (2003).

A. Chatterjee; An introduction to the proper orthogonal decomposition. Current. Science, 78 (2000) pp. 808-817

R. Everson, L. Sirovich; Karhunen–Loeve procedure for gappy data J. Opt. Soc. Am. A, 12 (1995), pp. 1657-1664

J.N. Kutz, S.L Brunton, B.W. Brunton, J.L. Proctor; Dynamic Mode Decomposition. SIAM, 2016.

S. LeClainche, J.M. Vega; Analyzing Nonlinear Dynamics via Data-Driven Dynamic Mode Decomposition-Like Methods. Complexity (2018) article ID 6920783.

B.R. Noack, M. Morzynski, G. Tadmor (Eds); Reduced-Order Modelling for Flow Control. Springer, 2011.

A. Quarteroni, G. Rozza (Eds.); Reduced Order Methods for Modeling and Computational Reduction. Springer, 2014.

SKILLS

Basic and general skills**:**

CG1 Having the knowledge that provides a basis or opportunity for originality when developing and/or applying ideas, often within a research context and knowing how to translate industrial needs in terms of R&D in the field of Industrial Mathematics.

CG2 – Be able to apply the acquired knowledge and abilities to solve problems in new or unfamiliar environments within broader contexts, including the ability to integrate multidisciplinary R&D in the business environments.

CG3 – Have the ability to communicate the conclusions reached together with the knowledge and reasons that support them to specialist and non-specialist audiences in a clear and unambiguous way.

CG4 – Have the appropriate learning skills to be able to continue studying in a way that will largely be selfdirected or autonomous and also to be able to successfully undertake doctoral studies.

Specific skills:

CE1 – Acquire a basic knowledge in an area of Engineering/Applied Science, as a starting point for an adequate mathematical modelling by using well-established contexts or in new or unfamiliar environments within broader and multidisciplinary contexts.

CE2 – Model specific ingredients and make the appropriate simplifications in a model to facilitate their numerical treatment, maintaining the degree of accuracy, according to previous requirements.

CE5 – Be able to validate and interpret the obtained results, comparing them with visualizations, experimental measurements and/or functional requirements of the corresponding physical engineering system.

Specialization on “Mathematical Modelling”:

CM2: Know how to model elements and complex systems or not very common fields which lead to well posed formulated problems.

WILL YOU BE USING A VIRTUAL PLATFORM? Yes, Moodle platform at UPM.

WILL YOU BE USING ANY SPECIFIC SOFTWARE?

Yes. Some programming environment (such as MATLAB, GNU/Octave or Python) and some simulation tools will be used. In any case, access to all the needed software will be provided in the course.

CRITERIA FOR THE FIRSTT ASSESMENT OPPORTUNITY:

Group report plus oral presentation of the project by one of the team members, followed by a maximum of fifteen minutes of questions and answers.

The project done during the subject lead the student to study different problemes and look for information for them. This allows to evaluate general skills CG1, CG2 and

CG5 as well as specific skills CE1, CE2, CE5 and CM2. The presentation of the project allows to evaluate general skill CG4.

CRITERIA FOR THE SECOND ASSESMENT OPPORTUNITY:

Same as in the first assesment opportunity.
