Tensors for Signals and Systems

Dates and time

11-01-2027
18-01-2027
25-01-2027
01-02-2027
from 13.45 – 16.00 hrs

Course location

Cursus- en vergadercentrum Domstad, Utrecht

ECTS

3 ECTS for attending lectures and successfully completing the homework assignment
1 ECTS for auditing the course

Lecturers

Kim Batselier, TU Delft
Martijn Boussé, Maastricht University
Philippe Dreesen, Maastricht University
Borbála Hunyadi, Maastricht University

Objective

This course introduces tensor-based methods for multidimensional signal processing, nonlinear system modeling, and machine learning. The course aims to provide participants with both the mathematical foundations and practical tools needed to work with structured low-rank tensor models arising in signals, systems, and data-driven applications. Particular emphasis is placed on interpretability, uniqueness, scalability, and structured low-rank representations of multidimensional signals and systems, including tensor-network formulations.

Contents

Lecture 1 – Tensor basics and decompositions

Tensor notation and terminology, tensor rank and multilinear rank, canonical polyadic decomposition, multilinear singular value decomposition, block-term decomposition, tensor train decomposition, tensor networks, uniqueness and identifiability, structured representations, computational aspects, and introduction to basic software toolboxes.

Lecture 2 – Tensor networks and machine learning

Tensor trains and tensor networks, low-rank tensor representations, dimensionality reduction, kernel machines, compression of neural-network architectures, and high-dimensional function representations. Applications in nonlinear system identification.

Lecture 3 – Tensors in signal processing and time-series analysis

Blind source separation and blind system identification, Hankel tensorizations, and time-series decomposition, coupled matrix-tensor decompositions. Applications in signal processing, including biomedical signals.

Lecture 4 – Tensor methods for nonlinear systems and decoupling

Decoupling of multivariate nonlinear functions, tensor decompositions for Volterra and polynomial system models. Applications in block-oriented nonlinear system identification.

Course materials

Core references

- Kolda, T. G., and Bader, B. W., "Tensor Decompositions and Applications," *SIAM Review*, vol. 51, no. 3, pp. 455–500, 2009.
- Cichocki, A., Mandic, D. P., De Lathauwer, L., Zhou, G., Zhao, Q., Caiafa, C. F., and Phan, A.-H., "Tensor Decompositions for Signal Processing Applications: From Two-Way to Multiway Component Analysis," *IEEE Signal Processing Magazine*, vol. 32, no. 2, pp. 145–163, 2015.
- Sidiropoulos, N. D., De Lathauwer, L., Fu, X., Huang, K., Papalexakis, E. E., and Faloutsos, C., "Tensor Decomposition for Signal Processing and Machine Learning," *IEEE Transactions on Signal Processing*, vol. 65, no. 13, pp. 3551–3582, 2017.
- Ballard, G., and Kolda, T. G., *Tensor Decompositions for Data Science*. Cambridge University Press, Cambridge, UK, 2025.

Prerequisites

Students are expected to be familiar with linear algebra, basic optimization, signals and systems, and elementary numerical methods. Prior exposure to machine learning or system identification is helpful but not required.

Homework assignments

Students will complete take-home homework projects consisting of theoretical exercises and computational experiments. The projects focus on tensor decompositions for multidimensional signal analysis and on tensor methods for nonlinear systems or machine learning applications.