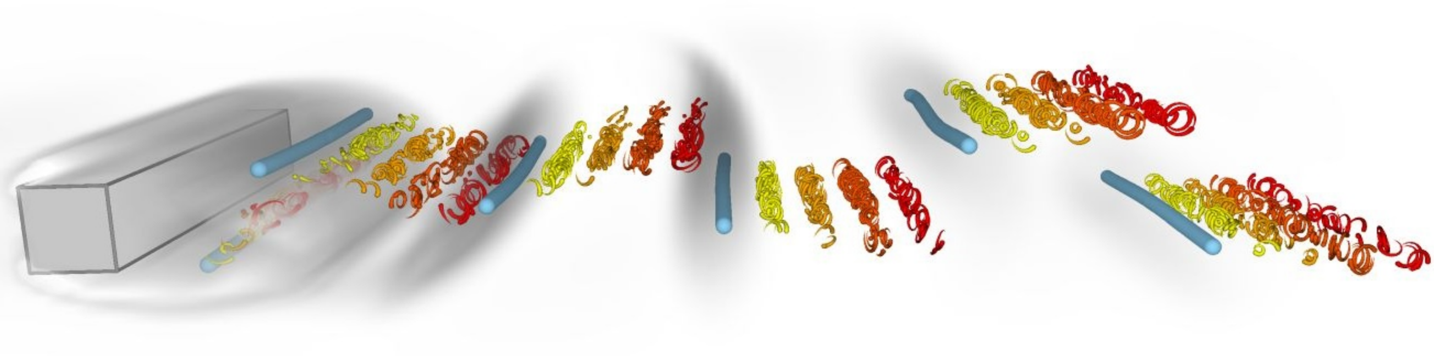
MSc Thesis: Tensor Decompositions for Vector Fields

University of Zurich[UZH]



Introduction

Vector fields are a common data structure in the field of scientific visualization. Typical applications include flow simulations in rivers, airflow computations around airplanes, or wind simulations in meteorology. The storage and visualization of such large-scale vector fields pose a significant challenge. With the increasing precision of sensors and the growing power of modern simulation tools, data sizes continue to increase, often exceeding the memory capacity of standard workstations. This makes the visualization and analysis of these datasets computationally demanding.

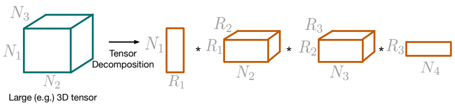


Figure 1: Exemplary illustration of a tensor train decomposition of a large 3D tensor

A possible solution to this challenge is to compress the data for storage and reconstruct it for visual exploration and analysis. Among various approaches, *tensor decompositions*, such as the Tucker decomposition [1] and the Tensor Train decomposition [2] (Figure 1), have proven to be powerful tools for lossy compression of large 3D datasets. In these methods, a 3D volume is interpreted as a higher-order tensor, which is then factorized into a set of smaller, lower-dimensional tensors. This representation enables efficient, controllable compression and flexible reconstruction of selected data regions. Furthermore, due to their linear structure, tensor formats allow certain analyses to be performed directly in the compressed domainå without requiring full reconstruction of the data.

In this project, our aim is to explore how tensor decompositions can be applied to **compress large 3D vector fields** while preserving their essential **structural features**. Beyond data reduction, a central question is how much of the topology of the field can be maintained after compression and reconstruction. We are also interested in developing visualization techniques that exploit the tensor representation enabling efficient and possibly partial reconstruction for visual analysis.

Topological and structural features that are of particular interest include:

- vortex core lines,
- ridge and valley lines,
- streamlines,
- and possibly other structures.

Assignment

Depending on the scope and project type, the following tasks may be part of the project:

- Implement or adapt an algorithm to compute the tensor decomposition of 3D vector fields.
- Investigate and compare different tensor decomposition techniques regarding their suitability for vector field compression.
- Develop algorithms for efficient reconstruction of the decomposed vector field.
- Define and implement metrics to assess the accuracy of reconstruction and feature preservation.
- Visually compare features of the original and reconstructed vector fields, using vector field features such as vortex core lines, ridge lines, and streamlines.
- Explore efficient feature extraction methods that take advantage of the linear structure of tensor decompositions and avoid full data reconstruction.

Project Type

Master thesis

Requirements

Interest in scientific visualization. Good understanding of linear algebra. Basic knowledge of visualization.

Supervision

Prof. Dr. Renato Pajarola
Clara Hartmann (Assistant)

Workload

- 40% Theory
- 30% Implementation
- 30% Testing and evaluation

Contact

Write an Email to hartmann@ifi.uzh.ch

References

[1] Ledyard R Tucker. Some mathematical notes on three-mode factor analysis. *Psychometrika*, 31(3):279–311, 1966.

[2] Ivan V. Oseledets. Tensor-train decomposition. *SIAM Journal on Scientific Computing*, 33(5):2295–2317, September 2011.

VISUALIZATIONAND MULTIMEDIALAB

Professor Dr. Renato Pajarola
Visualization and Multimedia Lab
Department of Informatics
University of Zurich