2025年度共同利用研究報告書

2025年10月09日

所属・職名 Institute of Mathematics for Industry, Kyushu University.・Assistant Professor

Keunsu Kim

		整理番号	2025a006	
1.研究計画題目	Topological Data Analysis and Industrial Mathematics			
2.新規・継続	新規			
3.種別	若手・学生研究			
4.種目	研究集会（Ｉ）			
5.開催方法	対面開催			
6.研究代表者	氏名	Keunsu Kim		
	所属部局名	Institute of Mathematics for Industry, Kyushu University.	職名	Assistant Professor
7.研究実施期間	2025年08月05日(火曜日)～2025年08月08日(金曜日)			
8.キーワード	Topological Data Analysis, Industrial Mathematics			
9.参加者人数	49人			

10.本研究で得られた成果の概要

The Topological Data Analysis and Industrial Mathematics (TDA-IM) workshop was held at Nishijin Plaza, Kyushu University, with around 60 participants from universities, industry, and research institutes in Japan, Korea, and abroad attending in person. The workshop showcased recent research on the diverse applications of Topological Data Analysis (TDA). Case studies and discussions highlighted its use in urban engineering, life sciences, and materials science. The Math. Research Institute Calc for Industry addressed fundamental challenges inherent in the business model of industrial mathematics, and further talks explored advances in mathematical theory. The workshop clearly demonstrated both the practical applicability of TDA and its potential for development within industrial mathematics. Participants shared a strong consensus on the importance of expanding academic exchange between Japan and Korea, and discussions also laid the groundwork for future collaborations, including joint research, co-authored publications, and researcher exchange programs.

Report of Results

Workshop Title: Topological Data Analysis and Industrial Mathematics (TDA-IM)
Date: August 5–8, 2025
Venue: Nishijin Plaza, Kyushu University
Participants: Approximately 60 participants, including researchers and students from universities, research institutes, and industry in Japan, Korea, and abroad

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1. Overview of the Workshop

This workshop was held under the theme of **Topological Data Analysis (TDA)**, a new mathematical approach increasingly recognized in data science. TDA provides a framework for extracting and quantifying hidden topological structures in complex data, and is simultaneously progressing in theoretical development and practical application across diverse domains. The workshop brought together mathematical researchers and industrial practitioners to share recent advances in TDA and to discuss its application potential, while also addressing fundamental issues of the business model of industrial mathematics and its future prospects.

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2. Major Presentations and Discussions

(1) Applications of TDA

- **Urban engineering and civil engineering**: New methods applying TDA to non-destructive testing and ground-penetrating radar image analysis were introduced. These approaches demonstrated the potential to detect defects and anomalies with higher precision than conventional techniques.
- **Life sciences**: A new analytical framework for single-cell RNA-seq data was presented. In particular, combinatorial Hodge decomposition was applied to reconstruct cell differentiation processes as potential energy landscapes, thereby showing the possibility of mathematically interpreting the dynamics of gene expression.
- **Materials science**: Research focused on elucidating the relationship between nanostructures of amorphous silicon and its thermal conductivity using TDA. Molecular dynamics simulations were used to generate atomic configurations, from which thermal conductivity and

persistence diagrams were computed. Statistical analyses identified local structures correlated with conductivity, and it was revealed that deformations of pentagonal atomic structures play a critical role in altering conductivity. The physical mechanism underlying this change was also explained through vibrational mode analysis.

(2) Network Science and Industrial Mathematics

- A new link prediction method based on persistent homology for graph and network data was reported. Compared with conventional graph neural network (GNN)–based approaches, this method achieved comparable performance on benchmark datasets while offering greater interpretability and transparency.
- The Math. Research Institute Calc for Industry highlighted the “midstream dilemma” of industrial mathematics, referring to structural difficulties in translating business challenges into mathematical models. Although mathematical expertise is valued, it often fails to directly translate into tangible business outcomes. The need for a sustainable business model for industrial mathematics was emphasized.

(3) Mathematical Theory

- Several presentations reported on theoretical advances that strengthen the foundations of TDA. Topics included Topological Nonnegative Matrix Factorization (Top-NMF), persistent Laplacians, and topological regularization methods. These approaches were introduced as frameworks that enhance interpretability and numerical stability in data analysis, and the interplay between theory and applications stimulated the discovery of new mathematical problems.

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3. Achievements and Significance

The workshop demonstrated that TDA can contribute concretely to solving practical problems in urban engineering, life sciences, materials science, and network analysis. By addressing both practical challenges in industrial mathematics and theoretical directions in TDA, the workshop served as a platform connecting academic research with industrial needs.

Poster sessions and presentations by young researchers further facilitated the exchange of research outcomes, contributing to the formation of new research networks and fostering the next generation of talent. Thus, the workshop played

a dual role as a forum for both academic exchange and educational collaboration.

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4. Future Prospects

Participants strongly agreed on the importance of further expanding international academic exchange, particularly between Japan and Korea. Specific plans were discussed for:

- Promoting joint research projects,
- Publishing joint papers, and
- Establishing researcher exchange programs.

The workshop highlighted both the theoretical achievements of TDA and its potential for industrial applications, reaffirming the essential role of mathematics in addressing complex societal and industrial challenges. These outcomes are consistent with the objectives of the IMI Joint Usage/Research Center at Kyushu University.

若手・学生研究-研究集会（Ⅰ）

Topological Data Analysis and Industrial Mathematics

Aug. 5 (Tuesday) ~ Aug. 8 (Friday), 2025

Nishijin Plaza, Fukuoka, Japan

Day 1 (Aug 5, Tue)

14:00 - 14:20
Registration

14:20 - 14:30
Opening Remark

14:30 - 15:30
Suyoung CHOI (Ajou University) - Plenary Talk
Topological Data Analysis for Non-Destructive Testing in Civil Engineering

15:30 - 16:00
Coffee Break

16:00 - 16:40
Yusuke IMOTO (Kyoto University)
RNA Landscape Analysis via Combinatorial Hodge Decomposition

16:50 - 17:30
Junwon YOU (POSTECH)
PHLP: Interpretable Link Prediction via Persistent Homology and Its Extension to Knowledge Graph Completion

Day 2 (Aug 6, Wed)

10:00 – 10:40
Tetsuji TANIGUCHI (Hiroshima Institute of Technology / Math. Research Institute Calc for Industry)
Potential of Mathematics for Industry, and the Dilemma in the Midstream

10:50 – 11:15
Raiki YOSHIMURA (Nagoya University)
A Data-Driven Framework for Predicting Liver Failure Dynamics and Living Donor Transplant Prognosis

11:15 – 11:40
Eunwoo HEO (POSTECH)
Quantifying the Topological Structure of Graphs: The Total Persistence Difference

11:40 – 12:00
Photo

12:00 – 14:00
Lunch Break

14:00 – 14:40
Sungrim Seirin-LEE (Kyoto University)
Pathological State Inference System based on Mathematical Model and TDA for Personalized Treatment in Dermatology

14:50 – 15:30
Emerson ESCOLAR (Kobe University)
A topological analysis of the space of recipes

15:30 - 16:00
Coffee Break

16:00 - 16:40
Tomoki UDA (University of Toyama)
Ellipse Cloud: Anisotropy-Aware Persistent Homology

16:50 - 17:30
Keunsu KIM (Kyushu University)
Nonnegative Matrix Factorization with Topological Regularization

17:30 -
Banquet
The banquet is supported by POSTECH MINDS (PI: Prof. Jae-Hun Jung).

Day 3 (Aug 7, Thu)

10:00 - 10:40
Ippei OBAYASHI (Okayama University)
Applications of Persistent homology to materials science, and persistent homology software HomCloud

10:50 - 11:15
Daiki TATEMATSU (Nagoya University)
Understanding depression during the COVID-19 pandemic as topographical maps

11:15 - 11:40
Seongjin CHOI (POSTECH)
Symmetric Simplicial Lifting for Hypergraph Learning

11:40 – 12:00
Poster pre-persentation

12:00 – 14:00
Lunch Break

14:00 – 15:00
Tea Performance

15:00 – 16:30
Poster Session

Day 4 (Aug 8, Fri)

10:00 – 10:40
Jisu KIM (Seoul National University)
Topological Data Analysis for Feature Extraction and Model Evaluation

10:50 – 11:15
Dongwoo GANG (Seoul National University)
Persistent Vector Bundles and Stiefel-Whitney Classes in Data Analysis

11:15 – 11:40
Sebastian Elias GRAIFF ZURITA (Kyoto University)
Geometric properties of curves in ensemble forecasting

11:50 – 12:30
Shamisen Performance and Closing

Speakers and Titles

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