Research Networking Programmes

# Science Meeting – Scientific Report

**Scientific report (one single document in WORD or PDF file) should be submitted online within two months of the event. It should not exceed seven A4 pages.**

***Proposal Title**:* Summer school on computational topology and topological data analysis

***Application Reference N°:*** 4682

## 1) Summary

The Summer school was aimed primarily at masters and beginning PhD students which are still undecided as to the specific topic of their future research. Altogether, 32 international and 27 local registered participants took part, and a number of unregistered local students or faculty attended part or all of the lectures. The core of the workshop was a series of five short courses each consisting on central topics in computational topology: topological modeling of data with applications to computer vision, algorithms on graphs, persistent homology, discrete Morse theory and topological robotics. The opening and concluding talks, given by prominent Slovenian researchers in areas close to the field of computational topology were intended primarily as motivation for new directions of research where new ideas, interesting problems and applications could be found. The afternoon sessions were partly devoted to student talks, and partly to project work. Overall, the atmosphere was very productive, and the students, as well as other participants were eager to follow the lectures and actively participate with questions, as well as in the projects.

## 2) Description of the scientific content of and discussions at the event (up to four pages)

The scientific content of the summer school was concentrated on the following five central topics of computational topology, presented in the form of short courses consisting of two 90 minute lectures each:

- **Mathematics, Shape, Computer Vision** (by **Massimo Ferri**, Università di Bologna, Italy): An excursus of many aspects of mathematics – in particular of geometry and topology – which are applied in the fields of

shape analysis and computer vision.Mathematical subjects to be touched: gradients, critical points, transforms, distances, transformation groups, persistent homology. Applicationsto contour extraction, alignment detection, shape from X, shape retrieval and automatic diagnosis were described

- **Basic algorithms for surface-embedded graphs** (by **Jeff Erickson**, University of Illinois at Urbana-Champaign, USA): For many classical algorithmic graph problems, faster algorithms are known for graphs that have additional structure. This short course will survey some important algorithmic techniques for graphs that can be drawn in the plane or other surfaces without crossing edges. The course will introduce several fundamental mathematical tools, including Euler's formula, rotation systems, duality, tree-cotree decompositions, the combinatorial Gauss-Bonnet theorem, homotopy, homology, covering spaces, balanced separators, and treewidth, as well as applications of these tools for computing minimum spanning trees, shortest paths, minimum cuts, and approximation solutions for several NP-hard problems.
- **Discrete Morse theory** (by **Bruno Benedetti**, Freie Unversität Berlin, Germany): Morse theory studies smooth surfaces or manifolds by looking at generic real-valued functions defined on them. Morse theory was developed in 1927 by Marston Morse; it represents "the most important single contribution to mathematics by an American mathematician", according to Fields laureate Steven Smale. Discrete Morse theory is a way to simplify a triangulated surface/manifold (or even an arbitrary simplicial complex) maintaining some of its topological properties, like homotopy and homology groups. The theory was developed by Forman in 1998, and unlike the smooth counterpart, it is quite elementary.
  In this short course, we plan to cover (1) basic definitions, (2) relations between smooth and discrete Morse vectors, (3) obstructions from elementary knot theory and (4) computational approaches.
- **Persistent Homology** (by **Ulrich Bauer**, Institute of Science and Technology of Austria): Persistent homology is an algebraic tool for measuring topological features of shapes and functions. Given a filtration of a topological space (a nested sequence of subspaces), it determines the lifespan of homological features (connected components, tunnels, voids) within the filtration.The course covered the fundamental ideas of persistent homology, fundamental results such as the stability of persistence diagrams, and motivating applications such as homology inference of shapes from point clouds and topological simplification of scalar functions.
- **Topological robotics** (by **Danica Kragić** and **Florian Pokorny,** KTH Royal Institute of Technology, Sweden): The course consisted of two parts, a more technical and a more mathematical side of the subject:
  - **Data analysis in integration of perception and action**:
    A robot system needs to autonomously acquire new knowledge through interaction with the environment. The knowledge can be acquired only if suitable perception-action capabilities are present: a robotic system has to be able to detect, attend to and manipulate objects in the environment as well as interact with people and other robots. We present our work in the area of vision based sensing and control with specific objectives on attention, segmentation, multisensory control and learning with a focus on what and how to represent to achieve intelligent behaviour in

robots. the first from the technological and the second from the mathematical point of view.

- **Topological Concepts and Robotic Manipulation**: The manipulation of complicated or deformable objects poses a challenge to current robotic systems. We will discuss recent efforts undertaken at KTH which attempt to adapt ideas from topology for applications in robotic grasping and machine learning. We will present some of the research questions and challenges that one faces when using topological ideas in the real world, and we will discuss how approximately shortest homology generators, winding numbers and Gauss linking integrals can be used in robotics.

The opening talk and the concluding talk were on closely related topics with connections to the main topics of the summer school:

- **Beyond planarity of graphs (**by **Bojan Mohar,** Simon Fraser University, Canada, and Institute of mathematics, physics and mechanics, Ljubljana, Slovenia): where Importance of planar graphs and some more general classes of graphs in mathematics, computer science and applications were discussed.
- **Qualitative analysis, modeling and simulation of dynamic systems** (by **Ivan Bratko**, Faculty of Computer and information science, University of Ljubljana): Typically, dynamic systems are modelled and analysed quantitatively, for example with differential equations, and system simulation is carried out numerically. In contrast to this, qualitative reasoning and modelling is an area of Artificial Intelligence where modelling, reasoning and simulation are done qualitatively, without numbers. In such an approach, the velocity of a car may be “high”, or “low”, etc., and it may be increasing or decreasing. In this lecture, an approach to qualitative modelling and simulation based on qualitative differential equations will be introduced. It will be shown how a qualitative model of a systems can be automatically learned from observed quantitative behaviours of the system. The techniques will be illustrated by applications to robot learning, and to reconstructing human operator’s skill of controlling a crane.

In addition, two invited PhD student talks (by **Marinka Žitnik** from University of Ljubljana, Faculty of Computer and Information Science on applications of topological methods to machine learning and **Sara Kališnik** from Stanford University and University of Ljubljana, Faculty of Mathematics and Physics on applications to tumor classification) were given. Also, three contributed talks were given in the afternoon session on relevant topics.

A part of the afternoon sessions was devoted to project work. The organizers and some of the speakers (M. Ferri) presented several projects for the students to work on, in particular on applications of persistent homology to specific data sets for classification problems in two and three dimensions as well as problems in sensor networks including the analysis of time-varying sensor measurements using existing topological tools, and implementations of topological tools for image analysis. Finally, several students performed experiments looking for non-trivial topology in WiFi signals representing non-trivial topology in physical space (i.e. buildings as obstacles). Up until now, two complete project reports have

been handed in by students from Ljubljana (who have earned credits towards their masters diploma) along with three reports to be submitted shortly.

The afternoon contributed talks were on closely related topics to the central topics of the summer school. In addition, projects were presented for students to work on, which were mostly on applications of discrete Morse theory and persistent homology to data and in particular to images.

All lectures were videotaped and will be available online in the scope of VideoLectures and on the home page. We are also happy to have attracted very motivated and interested students.

**3) Assessment of the results and impact of the event on the future directions of the field (up to two pages)**

We are very happy to have succeeded in attracting invited speakers who are distinguished experts in their fields. The lectures were on a very high level from the point of view of scientific merit, motivation for students and overall presentation.

The students were mostly at the PhD level, and the majority already had a strong background in computational topology (or some other closely related field like computationally geometry, algebraic topology, topological algorithms, or similar). As a result, most of the lectures that initially started at a relatively basic level, concluded with up to date specialized topics, which added to the scientific interest of the event. Also some masters students were present that, according to our information, found most of the lectures manageable and motivating. We hope that some of them will continue to work in computational topology at the PhD level.

Several new directions, in particular of applications of computational topology to machine learning, qualitative data analysis and robotics were opened, and new connections between participants (also specializing in different fields) were established. In the Slovenian community there are, in addition to a wider awareness of computational topology and its possible applications to various fields, some quite specific immediate results are: two completed projects of Slovenian masters students, one on Topological tools applied to classification of digits in the MNIST data set and one on Implementations of edge detection algorithms, have already been handed in and we are expecting a few more in the next few weeks, a postdoc visit from Ljubljana to Stockholm with the objective of combining results from topological complexity with topics from robotics which are studied by the group at KTH, a new PhD student with a strong background in computational topology from his masters studies employed as a young researcher by the artificial intelligence lab in Ljubljana with the goal of applying discrete Morse theory and other topological methods to qualitative data analysis.

We are also happy to report, that the participants showed a high degree of motivation and interest in the topics presented, the attendance at the lectures was very high, the discussion was lively and interesting. Also, the participants were from different parts of the world, mostly from Europe but also from other countries and a number of new connections have been formed which will lead to enhanced research in these fields, in particular among young mathematicians.

## 4) Annexes 4a) and 4b): Programme of the meeting and full list of speakers and participants

### Annex 4a: **Programme & Schedule**

The abstracts are available here.

| | **Monday** |
|---|---|
| **09:00 - 9:30** | Registration (Room 2.02 at Jadranska 21, Faculty of Mathematics and Physics) |
| **09:30 - 10:30** | Bojan Mohar: Beyond Planarity of Graphs (Opening talk) |
| **10:30 - 11:00** | Coffee Break |
| **11:00 - 12:30** | Massimo Ferri: Mathematics, Shape, Computer Vision |
| **12:30 - 14:00** | Lunch Break |
| **14:00 - 15:30** | Jeff Erickson: Basic algorithms for surface-embedded graphs |
| **15:30 - 16:00** | Coffee Break |
| **16:00 - 18:00** | Project work |

| | **Tuesday** |
|---|---|
| **09:00 - 10:30** | Bruno Benedetti: Discrete Morse theory |
| **10:30 - 11:00** | Coffee Break |
| **11:00 - 12:30** | Ulrich Bauer: Persistent Homology |
| **12:30 - 14:00** | Lunch Break |
| **14:00 - 15:30** | Jeff Erickson: Basic algorithms for surface-embedded graphs |
| **15:30 - 16:00** | Coffee Break |
| **16:00 - 16:45** | Marinka Žitnik: Topological Methods in Machine Learning |
| **16:45 - 17:15** | Student talks: Miguel Marañón |
| **17:15 - 18:00** | Project work |

| | **Wednesday** |
|---|---|
| **09:00 - 10:30** | Massimo Ferri: Mathematics, Shape, Computer Vision |
| **10:30 - 11:00** | Coffee Break |
| **11:00 - 12:30** | Bruno Benedetti: Discrete Morse theory |
| **12:30 - 14:00** | Lunch Break |
| **14:00 - 15:30** | Ulrich Bauer: Persistent Homology |
| **15:30 - 16:00** | Coffee Break |
| **16:00 - 16:45** | Sara Kališnik: The Classification of Hepatic Lesions Using Multidimensional Persistent Homology |
| **16:45 - 17:15** | Student talks: Joao Pita Costa |
| **17:15 - 17:45** | Student talks: Luyen Le |

| | **Thursday** |
|---|---|
| **09:00 - 10:30** | Danica Kragić: Data analysis in integration of perception and action |
| **10:30 - 11:00** | Coffee Break |
| **11:00 - 12:30** | Florian Pokorny: Topological Concepts and Robotic Manipulation |
| **12:30 - 14:00** | Lunch Break |
| **14:00 - 15:00** | Ivan Bratko: Qualitative analysis, modelling and simulation of dynamic systems (Concluding talk) |
| **15:00 - 15:30** | Coffee Break |
| **18:00 -** | Evening in Ljubljana |

| | **Friday** |
|---|---|
| **9:00 - evening** | Project work, Departure |

## Annex 4b: Full list of speakers and participants

**Speakers:**

**Ulrich Bauer**, Institute of Science and Technology of Austria
**Bruno Benedetti**, Freie Unversität Berlin, Germany
**Ivan Bratko**, University of Ljubljana
**Jeff Erickson**, University of Illinois at Urbana-Champaign, USA
**Massimo Ferri**, Università di Bologna, Italy
**Sara Kališnik**, Stanford University and University of Ljubljana
**Danica Kragić,** KTH Royal Institute of Technology, Sweden
**Bojan Mohar**, Simon Fraser University, Canada, and IMFM, Slovenia
**Florian Pokorny**, KTH Royal Institute of Technology, Sweden
**Marinka Žitnik**, UL FRI, Slovenia
**Joao Pita Costa**, Jožef Stefan Institute, Slovenia
**Luyen Le**, National University of Ireland, Galway, Ireland
**Miguel Marañón**, Universidad de La Rioja, Spain

**List of registered participants**

Luis Miguel Anguas Márquez
Marinka Žitnik
Ulrich Bauer
Mattia Giuseppe Bergomi
Davide Bolognini
Bruno Benedetti
Adam Burchardt
Ivan Bratko
Marco Castronovo
Tomasz Dwojak
Sergio Cabello Justo
Jeff Erickson
Massimo Ferri
Ulderico Fugacci
Dejan Govc
Gjorgji Grgovski
Luis Haug
Barbara Ikica
Hanife Isal
Grzegorz Jablonski
Miha Jejčič
Aleksandra Franc
Mateusz Juda
Sara Kališnik
Marek Kaluba
Gregor Jerše
Danica Kragić
Marko Lalović
Leon Lampret
Peter Lendero
Van Luyen Le

Ivo List
Miguel Marañón
Neža Mramor Kosta
Alexandra Moraru
Jan Kralj
Miha Nedeljko
Chris Palmer
Alice Patania
Bojan Mohar
Piotr Piekart
Joao  Pita Costa
Maja Podbevšek
Petar Pavešić
Ciro Polizzi
Nelson Silva
Jasna Skrbec
Florian Pokorny
Luka Stopar
Jaka Smrekar
Domen Šoberl
Primož Škraba
Andrea Villa
Žiga Virk
Jurij Volčič
Hubert Wagner
Frank Weilandt
Aleš Vavpetič
Damir Franetič

**Complete information is available at**
**http://acat2013.fmf.uni-lj.si/participants/**

**The lectures were open to the public and in addition to these, a number of mathematicians and computer scientists from Ljubljana attended a part or all of them.**