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

Application Reference N°: 5845

1) Summary

The Summer School was a follow-up of a similar event held in Ljubljana two years earlier, in 2013. Due to positive responses, as well as effects of this first event from a handful to one a research group of respectable size connecting mof this first event, the scope and the format of the workshop this year was kept similar. The difference was in the selection of topics, with the aim to provide the interested students with a wide overview of computational topology and introduce new topics and current trends. As the first, also this workshop was aimed primarily at masters and beginning PhD students, but also advanced PhD's, postodcs and researchers in the field, as well as in neighbouring fields were among the participants. Altogether, 31 international and 26 local registered participants took part, and a number of unregistered local students or faculty attended part or all of the lectures. The workshop began and ended with invited lectures by two outstanding researchers from Ljubljana, Andrej Bauer from mathematics (specifically, mathematical foundations of computer science) and Blaž Zupan from computer science (specifically bioinformatics and machine learning), with the intention to widen the spectre of topics and bring in new ideas and initiatives. The core of the workshop was devoted to a series of five short courses, each introducing a relevant central topic of computational and applied topology. All courses had a strong emphasis on applications, as can be seen from the descriptions provided below. In the afternoon sessions there were two additional invited talks by two exceptional doctoral students connected to computational topology in Ljubljana (both girls), Sara Kališnik from Stanford and Marinka Žitnik from Ljubljana. Both had been invited speakers already in the 2013 event, and it was a pleasure to see the progress in their research after two years.

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 short courses, consisting of two 90 minute lectures each:

Combinatorial algebraic topology with applications to distributed computing (by **Dmitry Feichtner-Kozlov**): In these tutorial talks we will give a short introduction to the beautiful subject of combinatorial algebraic topology. We will take a specific view towards the modern applications to theoretical distributed computing. We will give a primer in distributed computing and show how a family of combinatorial simplicial complexes - so called protocol complexes - plays a crucial role in our understanding of boundaries of computation.

Computational Topology and Dynamics (by Konstantin **Mischaikow**): This tutorial focuses on Conley theory as a mathematically rigorous, robust, and computationally effective framework for applied dynamics. Of particular note is the fact that it provides a mathematical framework in which one can systematically discuss global nonlinear dynamics that is observable at a given resolutions in phase space and parameter space. The lectures will be broken into four parts. **1. Motivation**. We will discuss a new framework for dynamics that complements the classical framework of invariant sets, structural stability and bifurcation theory. A variety of examples arising from applications will be presented to motivate the need for this approach**. 2. Characterizing Dynamics**. We will provide a combinatorial description, based on posets and lattices, of global dynamics and describe how this combinatorial description leads to classical descriptions of dynamics in terms of Morse decompositions, attractors, and isolated invariant sets. **3. Conley Index**. We will describe the Conley index and indicate how can be used to understand existence and structures of dynamical systems. **4. Applications**. We will present an application of these ideas to show how they can be used to rigorously compute the global dynamics of regulatory networks over high dimensional parameter space.

Persistent Homology for Networks Science. (by **Francesco Vaccarino**): The statistical mechanical approach to complex networks is the dominant paradigm in describing natural and societal complex systems. The study of network properties, and their implications to dynamical processes, mostly focus on locally defined quantities of nodes and edges, such as node degrees, edge weights and –more recently– correlations between neighboring nodes. However, statistical methods become cumbersome when dealing with many-body properties and do not capture the precise mesoscopic structure of complex networks. Moreover, real-world networks usually display intricate patterns of redundant links with edge weights and node degrees usually ranging over various orders of magnitudes, which makes it very hard to extract the significant network structure from the background. In our lectures, we will give account of the way we attacked this problem via the calculation of the persistent homological features of complex weighted network, without the need to impose an ad-hoc metrical structure. Indeed, it is possible to define a filtration, which effectively returns the topological strata of the link-weight organization of a given network. We applied these techniques to a set of real-world networks, highlighting the presence of two classes distinguished by their homology. In particular, the properties of such mesoscopic structures divide weighted networks in two broad classes: one

characterized by small hierarchically nested holes, while the second displays larger and longer living inhomogeneities.

Motion planning and Topological Complexity (by **Lucile Vandembroucq**): Given a robot, a motion planning algorithm can be seen as a set of rules determining how the robot has to move from one state to another. Considering the space of all the states or configurations of the robot, a motion is just a path from a point to another in this configuration space. Based on this viewpoint, Michael Farber introduced in 2003 a topological invariant corresponding, roughly speaking, to the minimal number of rules needed to describe a motion planning algorithm on a given configuration space. This number, called Topological Complexity, gives a measure of the complexity of finding a motion planning algorithm and is one of the main ingredients of Farber's topological approach to robotics. This short course will be dedicated to the presentation of this notion and to the study of some of its properties.

Equivariant methods in computational geometry (by **Rade Živaljević**): The lectures will illustrate the role of equivariant topological methods in solving combinatorial or discrete geometric problems that have proven to be of relevance for computational geometry and computational mathematics in general. The applications follow the versatile configuration space/test map scheme, a two-step procedure for converting a problem into a form amenable to topological methods. Step 1: The problem should give us a clue how to define a "natural" configuration space X and how to rephrase the question in terms of zeros or coincidences of the associated test maps. Step 2: Standard topological techniques like equivariant obstruction theory are used to solve the rephrased illustrate the design and the analysis of concrete configuration spaces (simplicial, cell, and manifold complexes), including the complexes that arise in problems of Tverberg type ((generalized) chessboard complexes), and equipartitions of measures.

The opening and closing talks extended into other related fields. **Andrej Bauer** introduced homotopy type theory which connects seemingly unrelated topics from computer science and mathematics to give a new understanding of type theory and the role of homotopy theory in foundations of mathematics. **Blaž Zupan** concluded the workshop with an attractive introduction to an open-source visual programming data mining toolbox called Orange, developed in the Bioinformatics lab at the Faculty of Computer and Information Science, which was hosting the event.

Two additional 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 on parametric persistence with applications to sensor networks were given. The afternoon session included 9 contributed talks with topics ranging from applications of algebraic topology to combinatorics, discrete and algebraic Morse theory, knots and 3-manifolds, various aspects of persistence, and others.

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

The five short course offered at the summer school covered a broad scope of currently very active parts of computational topology. Also this time, we are happy to report that we have succeeded in attracting exceptional 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 courses ranged from introductory tutorials in topics which were new to most of the participants (as for example the excellent introductions to distributed computing and to topological robotics) to courses that initially started at a relatively basic level but concluded with up to date specialized topics (like for example the excellent introduction to completely new ways of viewing dynamical systems, or interplay between topology and network science). This added to the scientific interest of the event.

The contributed talks presented new interesting research. In general, the discussion was lively and we believe that new promising contacts were established and interesting new ideas shared. The masters students that were present found, according to our information, most of the lectures manageable and motivating. We hope that some of them will continue to work in computational topology at the PhD level.

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, June 22, 2015
09:00 - 9:30	Registration (Room P 22 at Večna pot 113, Faculty of Computer and Information Science)
09:30 - 10:30	Andrej Bauer (Opening talk): Homotopy Type Theory: who needs it?
10:30 - 11:00	Coffee Break
11:00 - 12:30	Konstantin Mischaikow: Computational Topology and Dynamics I
12:30 - 14:00	Lunch Break
14:00 - 15:30	Francesco Vaccarino: Persistent Homology for Networks Science I
15:30 - 16:00	Coffee Break
16:00 - 16:20	Duško Jojić: Multiple Chessboard Complexes
16:20 - 16:40	Joao Miguel Nogueira: Essential Tangles and their Decompositions of Knots
16:40 - 17:00	Joao Pita Costa: The Topos Foundation of Persistence
17:00 - 17:20	Abhishek Jayantilal Rathod: MIn Morse: Approximability and Applications
17:20 - 17:40	Leon Lampret: (Co)homology of Lie Algebras via Algebraic Morse Theory

	Tuesday, June 23, 2015
09:00 - 10:30	Rade Živaljevic: Equivariant Methods in Computational Geometry I
10:30 - 11:00	Coffee Break
11:00 - 12:30	Francesco Vaccarino: Persistent Homology for Networks Science II
12:30 - 14:00	Lunch Break
14:00 - 15:30	Dmitry Feichtner-Kozlov: Combinatorial Algebraic Topology with Applications to Distributed Computing I
15:30 - 16:00	Coffee Break
16:00 - 16:45	Sara Kališnik: Parametrized Homology & Parametrized Alexander Duality Theorem
16:50 - 17:00	Break
17:00 - 17:20	Marc Ethier: Reconstructing the Dynamics of a Self-Map through Persistence
17:20 - 17:40	Dejan Govc: Some Results on the Unimodal Category
17:40 - 18:00	Nela Milošević: Associating Simplicial Complexes to Commutative Rings
18:00 - 18:20	Frank Weilandt: The Discrete Conley Index as the Homotopy Type of a Space

	Wednesday, June 24, 2015
09:00 - 10:30	Lucile Vandembroucq: Motion Planning and Topological Complexity I
10:30 - 11:00	Coffee Break
11:00 - 12:30	Konstantin Mischaikow: Computational Topology and Dynamics II
12:30 - 14:00	Lunch Break
14:00 - 15:30	Dmitry Feichtner-Kozlov: Combinatorial Algebraic Topology with Applications to Distributed Computing II
15:30 - 16:00	Coffee Break
16:00 - 16:45	Marinka Žitnik: Compressive Data Fusion and Persistent Homology
18:30 -	Social event

	Thursday, June 25, 2015
09:00 - 10:30	Rade Živaljevic: Equivariant Methods in Computational Geometry II
10:30 - 11:00	Coffee Break
11:00 - 12:30	Lucile Vandembroucq: Motion planning and Topological Complexity II
12:30 - 14:00	Lunch Break
14:00 - 15:00	Concluding talk: Blaž Zupan: Orange, Data Mining Fruitful and Fun
15:30 -	Hike with picnic

Annex 4b: Full list of speakers and participants

Invited Speakers:

Andrej Bauer, University of Ljubljana, Slovenia
Dmitry Feichtner-Kozlov, University of Bremen, Germany
Sara Kališnik, Stanford University, USA
Konstantin Mischaikow, Rutgers University, USA
Francesco Vaccarino, Politecnico di Torino, Italy
Lucile Vandembroucq, Universidade do Minho, Portugal
Blaž Zupan, University of Ljubljana, Slovenia
Rade Živaljevic, Serbian Academy of Sciences and Arts, Serbia
Marinka Žitnik, University of Ljubljana, Slovenia

Contributed talks:

Joao Pita Costa, Josef Stefan Institute, Slovenia
Marc Ethier, Jagellonian University, Poland
Dejan Govc, University of Ljubljana, Slovenia
Duško Jojić,
Leon Lampret, University of Ljubljana
Nela Milošević, University of Donja Gorica, Montenegro,
Joao Miguel Nogueira
Abhishek Jayantilal Rathod
Frank Weilandt,

Complete list of registered participants

Abhishek Jayantilal Rathod (Indian Institute of Science)
Aleksandra Franc (Faculty of Computer and Information Science, University of Ljubljana)
Aleš Vavpetič (Univerza v Ljubljani)
Andrea Guidolin (Polytechnic of Turin / University of Turin (Italy))
Andrej Bauer (University of Ljubljana, Slovenia)
Arnur Nigmetov (Max-Planck Institut für Informatik)
Barbara Di Fabio (ARCES, University of Bologna)
Beatrice Bertani (Alma Mater Studiorum - University of Bologna)
Biserka Cvetkovska (Faculty of computer and information science, Ljubljana)
Blaž Sovdat (University of Ljubljana)
Blaž Zupan (University of Ljubljana, Slovenia)
Damir Franetic (Univerza v Ljubljani, Faculty of Computer and Information Science)
Darko Pevec (University of Ljubljana)
Declan McPartlin (Faculty of Computer Science Ljubljana)
Dejan Govc (Institute of Mathematics, Physics and Mechanics & Institute Jožef Stefan, Ljubljana, Slovenia)
Dmitry Feichtner-Kozlov (University of Bremen, Germany)
Duško Jojić (Faculty of Science, University of Banja Luka, Bosnia and Herzegovina)
Ezio Catelli (Università di Bologna)
Francesco Vaccarino (Politecnico di Torino - ISI Foundation)
Frank Weilandt (Jagiellonian University, Krakow)
Giulio Lo Monaco (Alma Mater Studiorum - University of Bologna)

Gregor Jerše (Faculty of Computer and Information Science, University of Ljubljana)
Grossi Annalisa (alma mater studiorum. Unibo. Bologna)
Jaka Smrekar (Faculty of Mathematics and Physics, University of Ljubljana, Slovenia)
Joao Miguel Nogueira (University of Coimbra)
Joao Pita Costa (Jozef Stefan Institute Ljubljana)
Konstantin Mischaikow (Rutgers University, USA)
Leon Lampret (FMF and IMFM)
Luca Grementieri (Alma Mater Studiorum - University of Bologna)
Lucile Vandembroucq (Universidade do Minho, Portugal)
Luis Rei (Jozef Stefan Institute Ljubljana)
Marc Ethier (Jagiellonian University)
Marija Jelic (University of Belgrade, Faculty of Mathematics)
Marija Đurđević (Faculty of Computer and Information Science, University of Ljubljana)
Marinka Žitnik (University of Ljubljana)
Martin Stražar (University of Ljubljana, Faculty of Computer and Information Science)
Matevž Jekovec (University of Ljubljana, Faculty of Computer and Information Science)
Mehmetcik Pamuk (Middle East Technical University)
Nela Milošević (University of Donja Gorica, Montenegro)
Neža Mramor (Faculty of Computer and Information Science, University of Ljubljana)
Neža Žager Korenjak (University of Ljubljana)
Petar Pavešic (Fakulteta za matematiko in fiziko, University of Ljubljana)
Peter Lendero (University of Ljubljana)
Petra Poklukar (Fakulteta za matematiko in fiziko, Univerza v Ljubljani)
Primož Škraba (Jozef Stefan Institute Ljubljana)
Quercioli Nicola (Alma Mater Studiorum, Unibo, Bologna)
Rade Živaljevic (Mathematical Institute of the Serbian Academy of Sciences and Arts)
Riccardo D. Jadanza (ISI Foundation)
Roberta Perissinotti Bisoni (University of Bologna)
Sabina Oražem (Slovenia)
Sara Kališnik (Stanford University, USA)
Sašo Strle (Univerza v Ljubljani, Fakulteta za matematiko in fiziko)
Semra Pamuk (Middle East Technical University)
Soroosh Nazem (Politecnico di Torino)
Timotijević Marinko (Serbia)
Turkmen Ornek (Middle East Technical University)
Špela Poklukar (University of Ljubljana)

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 at least a part of them.