Science Meeting – Scientific Report

Proposal Title: **Geometric and Topological Methods in Concurrency Theory 2015**

Application reference number: **ACAT-Science Meeting 5835**

1 Summary

This year's conference GETCO 2015 was the latest instance in a series of workshops and conferences on the interface of mathematics and computer science. GETCO focuses in particular on topological methods and tools that help to describe, to analyze, and to solve problems in concurrency theory and in distributed systems theory in theoretical computer science. On another thread, topics from topological data analysis and image analysis were taken up, with new methods (persistent homology etc) tailored towards the investigation of big data and complementing methods from statistics and machine learning.

Concurrency Theory is an area of theoretical computer science investigating the challenges represented by parallel architectures within an individual computer or within computer networks, in particular for the assessment of the correctness and/or safety of non-sequential distributed algorithms. A particular concurrency model, the so-called Higher Dimensional Automata, can mathematically be described by cubical complexes with a built-in direction reflecting the time flow. For a mathematical analysis of these models, one has to incorporate direction into tools and methods from algebraic topology. Directed Algebraic Topology tries to achieve this and to use fast (homology) algorithms to analyse the large models arising in practical applications.

Distributed Computing is another major area of computer science concerned with properties and limitations of software systems with components communicating and coordinating their actions in an asynchronous manner, using one of the standard communication models such as message passing or shared memory. Seminal work of Herlihy and co-authors (Gödel Prize 2004) has in many cases given limits for the solvability of tasks by analysing combinatorial topological properties of certain simplicial complexes (and relations between them) describing the tasks and the possible protocols that might achieve them.

Topological data analysis and shape analysis have developed tremendously since the turn of the century: The prinicipal tool, persistent homology has been studied over a range of years from a theoretical perspective. On that basis, sophisticated tools for the analysis of all sorts of samples and images (as discrete metric spaces) have been developed. The stability of methods and tools with respect to random effects from the enviroment is a key issue. Applications in many areas of science and technology (biology, medicine, cosmology, finance, engineering etc.) are meanwhile abundant.

The GETCO meeting took place at Aalborg University in Denmark and collected 41 participants from 14 countries: 33 Europeans, 7 from the Americas and one African researcher. 13 participants are graduate students or postdocs, the majority are principal investigators. Seven participants are female.

The programme consisted of 21 talks of around 40 minutes each that ended with short discussions that were often continued during coffee and lunch breaks and the social event on Thursday evening. Moreover, 7 participants presented ongoing research on posters during an afternoon poster session. The programme had been selected by a scientific committee consisting of Lisbeth Fajstrup (Aalborg), Dmitry Feichtner-Kozlov (Bremen), Éric Goubault (Ecole Polytechnique Palaiseau) and Martin Raussen (Aalborg). Secretary Amra Ibrisevic from the Department of Mathematical Sciences at Aalborg University gave excellent and efficient administrative support. Aalborg Unviversity kindly provided the costs for her assistance and for room expenses.

2   Description of the scientifc content of and discussions at the event

We give a brief overview over the talks presented at the conference. More details (abstracts of all talks and slides for many of them) can be found on the conference web site.

Topology and concurrency theory

Krzysztof Ziemiański (Warsaw) spoke about topological representations of executions of PV-programs (a particular class of Higher Dimensional Automata) in the form of minimal CW-complexes and compared those to other models.

    Thomas Kahl (Univ. Minhos) presented methods allowing to replace Higher Dimensional Automata by weakly equivalent ones of a very much reduced size by applying collapsing operations.

    Samuel Mimram (École Polytechnique Palaiseau) investigated programs using only mutexes which have a geometric semantics as precubial sets that satisfy a "cube axiom". This has the consequence that the resulting spaces are non-positively curved and that, in this case, directed homotopy coincides with ordinary homotopy.

    Emmanuel Haucourt (École Polytechnique Palaiseau) talked about compactifications of directed spaces and about how to construct particularly interesting directed spaces arising from a number of vector fields on a smooth manifold.

    Rick Jardine (Western Ontario) presented a theory of path categories and of path 2-categories for finite oriented cubical and simplicial complexes and a "2-category algorithm" for their computation, and he discussed complexity reduction methods.

    Sanjeevi Krishnan (Penn State) presented necessary and sufficient conditions for being able to evade from a sensor network in terms of ordered cohomology, a limit of a sheaf of positive cohomology semigroups. The main technical ingredient is a proof of positive Alexander duality (in homological degree 1).

    Rewriting methods use many techniques that are reminiscent of those in directed algebraic toology. Philippe Malbos (Lyon) talked about rewriting methods that allow the construction of coherent presentations of Artin monoids and of Plactic monoids.

Topology and Distributed Systems

Sergio Rajsbaum (UNAM Mexico) gave an introduction to the use of methods from combinatorial topology for the analysis of problems concerning the algorithmic solvability of issues in a distributed environment, including many eye-opening examples.

    Armando Castañeda (UNAM Mexico) discussed methods to compute independent sets of a graph in an asynchronous crash-prone environment and proposed a wait-free distributed algorithm in the case of the largest possible number of processes that can solve the task.

    Thomas Nowak (ENS Paris) gave particularly simple proofs for three classical impossibility results in distributed computing through the analysis of point-set topology properties of execution spaces, with a particular focus on te binary consensus problem.

    Petr Kuznetsov (Telecom Paris Tech) gave topological characterizations of task solvability in adversarial shared-memory models by models of distributed computation as subsets of the runs of the iterated immediate snapshot model.

    Damien Imbs (Bremen) compared the power to decide consensus tasks in various settings (shared memory, iterated immediate snapshot, use of x-consensus models) and showed

that more sophisticated models in general do not allow for solving more tasks.

Topological Data Analysis and Image Analysis

Pawel Dłotko (Inria) gave a survey talk on challenges in the development of persistent homology techniques, in particular for the computation of level sets of a function as used in mesh generation and for the manipulation of large families of persistence diagrams.

Ulrich Bauer (TU München) described how a morphism between persistence modules produces a matching of the corresponding persistence barcodes and gave a lucid new proof of the algebraic stability theorem using the barcodes of the kernel and the cokernel of the morphism.

Steve Oudot (Inria) shed new light on the diamond principle in persistence theory of zigzag morphism by applying reflection operations from the representation theory of quivers. An application to the computation of persistence for zigzags was outlined.

Hubert Wagner (IST Austria) introduced similarity measures for families of text documents as used in text mining and discussed how these can be applied in a topological analysis using persistent homology.

Marian Mrozek (Krakow) presented an extension of Robin Forman's Morse theory to combinatorial multi-vector fields with applications to Conley index theory.

Neza Mramor-Kosta (Ljubljana) talked about perfect discrete Morse functions on cell complexes with a minimal number of critical elements allowing for efficient algorithms for computing topological invariants.

Claudia Landi (Modena) described the computation of discrete Morse matchings and how one might generalize the set-up and the algorithmics from one-dimensional to multidimensional filtrations

Primoz Skraba (Ljubljana) discussed a sheaf approach to find global features in data from consistent local models and how this may be useful in the investigation of local topological invariants of stratified spaces.

Patrizio Frosini (Bologna) described how to use persistent homology in order to achieve lower bounds for a pseudo-distance between vector functions up to a given transformation group and how to apply the results to shape comparison.

Poster session

Seven young researchers presented their recent research during a poster session on Wednesday afternoon; among them

- Deborah O. Ajayi (Ibadan), Vector Fields on Certain Incomplete Real Flag Manifolds

- Natalia Garcia Colin (INFOTEC Mexico), A combinatorial characterization of triangulations of surfaces through their intersection matrices

- Jérémy Dubut (ENS Cachan), Natural homology

- Grzegorz Jabłoński (Krakow), Persistent homology of eigenvectors and generalized eigenvectors

- Maria José Jimenez (Sevilla), Topological analysis of volume reconstructions for activity recognition

- Nina Otter (Oxford), A roadmap for the computation of persistent homology

3 Assessment of the results and impact of the event on the future directions of the field

The meeting can be perceived as one in a sequence of events under the ACAT programme assembling researchers within different domains of applied algebraic topology allowing them to exchange research results and ideas and to forge a common identity among people working in the field, notably within Europe. Many lively discussions involving people from various sub-communities showed the usefulness of such gatherings. In fact, some preparatory steps for a HORIZON 2020 application involving researchers from all three fields described above were taken on the side of the conference.

The GETCO meeting had a particular focus on topological methods applied to problems in theoretical Computer Science, more specifically, questions within concurrency theory and within distributed systems theory. Speakers presented their latest results and ideas within each of these areas; in both cases combinatorial algebraic topology plays a key role. There were many discussions on how to "join forces", to compare methods and results, even in a formal setting. This will certainly be an important direction for future research.

On a more concrete level, several participants showed interest in having their work submitted to a proceedings volume of the conference. The organizers are currently working on finding the best platform for such a volume.

4 Annexes: Programme of the meeting and full list of speakers and participants

Tuesday, April 7, 2015

11:00-11:45	Registration (Niels Jernes Vej 14, room 4.117)
11:45-12:45	Lunch break (NOVI canteen, Niels Jernes Vej 10)
12:45	Opening
13:00-13:40	Krzysztof Ziemianski: *Spaces of directed paths on semi-cubical sets*
13:50-14:30	Philippe Malbos: *Oriented Syzygies for Monoids*
14:30-15:00	Coffee break
15:00-15:40	Ulrich Bauer: *Induced Matchings and the Algebraic Stability of Persistence Barcodes*
15:50-16:30	Pawel Dlotko: *''Applied computational topology, where we should go now?''*

Wednesday, April 8, 2015

09:00-09:40	Sergio Rajsbaum: *Introduction to distributed computing analysis using combinatorial topology*
09:50-10:30	Armando Castañeda: *Computing independent set in an asynchronou distributed fault-tolerant environment*
10:30-11:00	Coffee break
11:00-11:40	Rick Jardine: *Path categories and algorithms*
11:50-12:30	Sanjeevi Krishnan: *Dynamic Sensor Networks (joint work with Rob Ghrist)*
12:30-14:00	Lunch break (NOVI canteen, Niels Jernes Vej 10)
14:00-14:40	Neza Mramor: *On perfect discrete Morse functions*
14:50-15:30	Primoz Skraba: *Sheaves and Global Sections*
15:30-17:00	Poster session & reception

Thursday, April 9, 2015

09:00-09:40	Marian Mrozek: *Morse-Forman-Conley theory for combinatorial multivector fields*
09:50-10:30	Hubert Wagner: *Generalized similarity measure for texts*
10:30-10:50	Coffee break
10:50-11:30	Steve Oudot: *Reflections in quiver and persistence theories*
11:30-13:00	Lunch break (NOVI canteen, Niels Jernes Vej 10)
13:00-13:40	Emmanuel Haucourt: *Directions from Vector Fields*
13:50-14:30	Damien Imbs: Untangling Partial Agreement: Iterated x-Consensus Simulations
15:30-18:30	Excursion - guided tour (Danish Distillers)
18:30-	Conference dinner ([Prinses Juliana](#))

Friday, April 10, 2015

09:00-09:40   Claudia Landi: *Reducing Complexes in Multidimensional Persistent Homology*

09:50-10:30   Patrizio Frosini: *Geometric shape comparison via G-invariant non-expansive operators and*
              G- invariant persistent homology

10:30-11:00   Coffee break

11:00-11:40   Petr Kuznetsov: *"Generalized Asynchronous Computability Theorem"*

11:50-12:30   Thomas Nowak: *Point-Set Topology for Impossibility Results in Distributed Computing*

12:30-14:00   Lunch break (NOVI canteen, Niels Jernes Vej 10)

14:00-14:40   Samuel Mimram: *Dihomotopy and the cube property*

14:50-15:30   Thomas Kahl: *"Reduction of higher-dimensional automata"*

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Participants:

Armando Castaneda	Intituto de Matemáticas, UNAM, Mexico
Claudia Landi	Università di Modena e Reggio Emilia, Italy
Damien Imbs	University of Bremen, Germany
Daniele Toller	University of Camerino, Italy
Deborah Olayide	University of Ibadan, Nigeria
Dmitry Feichtner-Kozlov	University of Bremen, Germany
Emmanuel Haucourt	LIX, École Polytchnique, France
Eric Finster	LIX, École Polytchnique, France
Eric Goubault	LIX, Ecole Polytchnique
Fabian Romero	Intituto de Matemáticas, UNAM, Mexico
Grzegorz Jablonski	Jagiellonian University, Poland
Hubert Wagner	IST Austria
Iver Ottosen	Aalborg University, Denmark
Jan Felix Senge	University of Bremen, Germany
Jan-Philipp Litza	University of Bremen, Germany
Jeremy Dubut	LSV, ENS Cachan, France
Jose-Carlos Gomez-Larrañaga	CIMAT, Mexico
Krzysztof Ziemianski	University of Warsaw, Polen
Lisbeth Fajstrup	Aalborg University, Denmark
Maria Jose Jimenez	University of Seville, Spain
Marian Mrozek	Jagiellonian University, Poland
Martin Raussen	Aalborg University, Denmark
Natalia Garcia-Colin	INFOTEC, Mexico
Neza Mramor	University of Ljubljana, Slovenia
Nicolas Ninin	CEA List,Ecole Polytechnique, France
Nina Otter	University of Oxford, UK
Patrizio Frosini	University of Bologna, Italy
Pawel Dlotko	University of Pennsylvania, USA
Petr Kuznetsov	Telecom ParisTech - INFRES, France
Philippe Malbos	Université Claude Bernard Lyon 1, France
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