



### Science Meeting – Scientific Report

The scientific report (WORD or PDF file - maximum of seven A4 pages) should be submitted online within two months of the event. It will be published on the ESF website.

Proposal Title:

### **Advanced course and research Workshop “Applied Algebraic Topology”**

Application Reference N°: 5533

1) Summary (up to one page)

The event consisted in:

- (I) An advanced lecture course “Applied Algebraic Topology” which was composed of the following 5 mini-courses delivered during the days June 26 - 28, 2014 :
  - *Topology of robot motion planning*, given by Alexander Dranishnikov (University of Florida);
  - *Topology of configuration spaces*, given by Dirk Schütz (University of Durham);
  - *Stochastic topology*, given by Roy Meshulam (Technion, Israeli Institute of Technology);
  - *Topological methods in combinatorics and in discrete mathematics*, given by Pavle Blagojević (Free University of Berlin);
  - *Sheaves and the topology of networks*, given by Robert Ghrist (University of Pennsylvania).

(II) A research workshop on Applied Algebraic Topology during the week June 30 – July 5, 2014.

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

## Scientific Content

Applied Algebraic Topology (AAT henceforth) is a new mathematical discipline studying problems of algebraic topology relevant to diverse applications in engineering and computer science. In broad terms, the scope of AAT currently includes, but is not restricted to, Topological Robotics, Stochastic topology, Topology of sensor networks, as well as Topological methods in combinatorics and in discrete mathematics. All these new research areas were presented at the CIEM event.

Historically, algebraic and differential topology were initiated to address problems of mathematical physics, dynamics and astronomy. The notion of a manifold, the concept of a simplicial complex, the homology and homotopy theories were created in order to model configuration spaces of mechanical and astronomical systems and to study their geometric and topological properties. Modern engineering suggests new classes of mathematical problems which require new mathematical tools. Modeling configuration spaces of very large systems (which appear in engineering, molecular biology, ecology and other disciplines) typically involves large number of parameters which cannot be measured without errors; therefore these parameters can be viewed as being random. This leads to the idea of Stochastic Topology, a new emerging mathematical discipline, which is able to give probabilistic predictions of topological properties of random manifolds and random simplicial complexes, produced by various probabilistic mechanisms. Stochastic topology uses a mixture of topological and probabilistic tools; it also employs techniques from combinatorial group theory and geometry. Stochastic topology was represented at our CIEM event, both at an advanced course and in lectures on the workshop.

A core subject on Topological Robotics is the use of topological methods to tackle the problem of building motion planning algorithms for autonomous systems (robots). This leads to a homotopy invariant  $TC(X)$ , very interesting on its own right, measuring the complexity of motion planning algorithms for systems having  $X$  as their configuration space. Research activity focusing on  $TC(X)$  is carried out by many mathematicians around the world, and some important results concerning  $TC(X)$  have been obtained; however many challenging questions remain open. One of the mini-courses and several lectures were devoted to this subject.

The study of various configuration spaces is another important research direction of AAT. Configuration spaces of mechanical linkages also appear in mathematical physics, geometry, statistical shape theory, representation theory. These results were presented, both in the advanced course and in the workshop.

The event also focused on the best and newest topological tools for applications in sensor networks, communications networks, and signal processing. Continuing technical innovations have made feasible the vision of distributed computers consisting of numerous cheap processing elements with limited local connectivity. Practical examples of such systems include environmental sensor networks, cell phones, and multi-agent robots. One pressing problem is how to perform system-wide analysis, assembling local information to infer or actuate global results. Recent advances have leveraged local-to-global principles from algebraic topology to provide robust algorithms for engineering systems. These include (1) homological methods for sensor networks; (2) topological complexity for robot motion planning; (3) simplicial complexes for planning in the presence of uncertainty; and (4) sheaf theory for network data aggregation and optimization.

Finally, modern topological combinatorics, which uses topological tools to solve problems of combinatorics, discrete mathematics and computer science, were largely presented at this event.

## Scientific Committee

Octav Cornea, University of Montreal,  
Alexander Dranishnikov, University of Florida,  
Michael Farber, University of Warwick,  
Aniceto Murillo, University of Málaga.

## Organizing Committee

Armando Costa, University of Warwick,  
Michael Farber, University of Warwick,  
Aniceto Murillo, University of Málaga.

## Structure

As stated above the event consisted in an “Advanced Course” and a “Workshop”.

The “Advanced Course” took place during the days June 26 – 28, 2014. It was articulated into 5 different mini-courses which were carefully chosen to cover the main topics of the event. These mini-courses, together with the corresponding lecturers were:

- *Topology of robot motion planning*, given by Alexander Dranishnikov (University of Florida);
- *Topology of configuration spaces*, given by Dirk Schütz (University of Durham);
- *Stochastic topology*, given by Roy Meshulam (Technion, Israeli Institute of Technology);
- *Topological methods in combinatorics and in discrete mathematics*, given by Pavle Blagojević (Free University of Berlin);
- *Sheaves and the topology of networks*, given by Robert Ghrist (University of Pennsylvania).

The “Workshop” took place during the following week, June 30 – July 4, 2014, and was devoted to the presentation of the latest achievements on the covered topics.

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

The main goals achieved at these event are:

- To survey the main achievements and the main open problems of applied algebraic topology; The workshop provided an excellent opportunity for researchers from diverse backgrounds to learn new mathematics and new applications. Apart from the scheduled lectures, it was noticeable the exchange of ideas, problems, techniques, and motivations in informal discussions.
- To encourage participation of young researchers and facilitate among them the dissemination of the main ideas of AAT. The advanced course preceding the workshop helped a great deal in facilitating the introduction and interactions of the young researchers to the proposed subjects.
- To provide forum and stimulating discussions between world leading researchers in the field through collaboration and cooperation.

- To make the mathematical community aware of the possibility of applying well developed techniques of algebraic topology to problems arising in engineering, physics, molecular biology, statistics and other disciplines.
- The interaction of young topology researchers as well as established topologists with interests in using topological methods in applied sciences.

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

Annex 4a: Programme of the meeting

**ADVANCED COURSES SCHEDULE**

	26 Jun	27 Jun	28 Jun
9:15	Registration and Opening	(A)	(A)
9:30			
10:00	(D)	Coffee Break	Coffee Break
10:20			
10:30	(C)	(C)	(C)
10:50			
11:00	(B)	(B)	(B)
11:30			
11:50	(E)	(E)	(A)
12:00			
12:20	(D)	(D)	(E)
12:30			
12:50	Lunch	Lunch	Lunch
13:00			
13:20	(E)	(A)	(A)
13:30			
15:30	(D)	(D)	(E)
16:00			
16:20	(D)	(D)	(E)
16:30			
16:50	(D)	(D)	(E)
17:00			
17:20-17:50	(D)		

**COURSES**

- (A) Topology of robot motion planning, by Alexander Dranishnikov;  
 (B) Topology of configuration spaces, by Dirk Schütz;  
 (C) Stochastic topology, by Roy Meshulam;  
 (D) Topological methods in combinatorics and in discrete mathematics, by Pavle Blagojević;  
 (E) Sheaves and the topology of networks, by Robert Ghrist.

## WORKSHOP SCHEDULE

	30 Jun	1 Jul	2 Jul	3 Jul	4 Jul
9:00-9:30	Opening and Registration				
9:30-10:15	R. Ghrist	A. Dranishnikov	R. Meshulam	P. Blagojevic	D. Schütz
10:15-10:30	Break	Break	Break	Break	Break
10:30-11:15	M. Grant	E. Babson	J. González	T. Nowik	R. Zivaljevic
11:15-11:30	Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
11:30-12:15	P. Pavesic	J. García Calcines	M. Golasinski	S. Yuzvinsky	M. Kahle
12:15-12:30	Break	Break		Break	Break
12:30-1:15	G. Khimshiashvili	V. Kurlin		L. Vandembroucq	R. González Díaz
1:15-4:00	Lunch	Lunch		Lunch	
4:00-4:45		H. Wagner		M. Adamaszek	
		S. Parsa		A. Haase	
4:45-5:00		Break		Break	
		B. Di Fabio		I. Basabe	
5:00-6:10		M. Amann		F. Belchi	
		M. J. Pereira		F. Frick	
6:10-7:00		Poster Session			

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

**Adamaszek, Michal**

University of Bremen, Germany

**Amann, Manuel**

Karlsruhe Institute of Technology, Germany

**Babson, Eric**

University of California Davis, USA

**Belchi, Francisco**

University of Málaga, Spain

**Besabe, Ibai**

University of Florida, USA

**Blagojevic, Pavle**

Free University of Berlin, Germany

**Blanco, Mónica**

University of Cantabria, Spain

**Borat, Ayse**

Zirve University, Turkey

**Buijs, Urtzi**

Catholique University of Louvain, Belgium

**Carrasquel Vera, José**

Catholique University of Louvain, Belgium

**Costa, Armindo**

University of Warwick, UK

**Costoya, Cristina**

University of La Coruña, Spain

**Di Fabio, Barbara**

University of Bologna, Italy

**Dranishnikov, Alexander**

University of Florida, USA

**Ethier, Marc**

Jagiellonian University, Poland

<b>Farber, Michael</b>	University of Warwick, UK
<b>Ferrucci, Emilio</b>	University of Bonn, Germany
<b>Frick, Florian</b>	Technical University of Berlin, Germany
<b>García Calcines, José</b>	University of La Laguna, Spain
<b>Garvín, Antonio</b>	University of Málaga, Spain
<b>Gavira, Alberto</b>	UAB, Spain
<b>Giraldo, Antonio</b>	Politechnic University of Madrid, Spain
<b>Golasinski, Marek</b>	Nicolaus Copernicus University, Poland
<b>Goldfarb, Boris</b>	SUNY at Albany, USA
<b>Goldfarb, Danny</b>	Niskayuna High School, USA
<b>González, Jesús</b>	CINVESTAV, Mexico
<b>González Díaz, Rocío</b>	University of Sevilla, Spain
<b>Grant, Mark</b>	Newcastle University, UK
<b>Ghrist, Robert</b>	University of Pennsylvania, USA
<b>Gutiérrez, Bárbara</b>	CINVESTAV, Mexico
<b>Hasse, Albert</b>	Free University of Berlin, Germany
<b>Jablonski, Grzegorz</b>	Jagiellonian University, Poland
<b>Kahle, Matthew</b>	Ohio State University, USA
<b>Kaluba, Marek</b>	Adam Mickiewicz University, Poland
<b>Khimshiashvili, Giorgi</b>	Iliia State University, Georgia
<b>Klockiewicz, Bazyli</b>	Mickiewicz University, Poland
<b>Krcal, Marek</b>	IST, Austria
<b>Kurlin, Vitaliy</b>	Durham University, UK
<b>Luna, Germán</b>	University of Calgary, Canada
<b>Macias, Enrique</b>	University of Santiago de Compostela, Spain
<b>Malen, Greg</b>	Ohio State University, USA
<b>Manfredi, Enrico</b>	University of Bologna, Italy
<b>Meshulam, Roy</b>	Technion, Israel
<b>Murillo, Aniceto</b>	University of Málaga, Spain
<b>Nowik, Tahl</b>	Bar-Ilan University, Israel
<b>Pan, Weiwei</b>	Saint Mary's College of California, USA
<b>Paoli, Simona</b>	University of Leicester, UK
<b>Parsa, Salman</b>	Duke University, USA/IST Austria
<b>Pavesic, Petar</b>	University of Ljubljana, Slovenia
<b>Pereira, María José</b>	University of La Coruña, Spain
<b>Rieser, Antonio</b>	Technion, Israel
<b>Romero, Francisco</b>	Complutense University, Spain
<b>Schütz, Dirk</b>	University Durham, UK
<b>Sierra Murillo, Salvador</b>	Free Univesity of Berlin, Germany
<b>Thumann, Werner</b>	Karlsruhe Institute of Technology, Germany
<b>Turgay, Deniz</b>	Swansea University, UK
<b>Vandembroucq, Lucile</b>	University of Minho, Portugal
<b>Vilches, José Antonio</b>	University of Sevilla, Spain
<b>Viruel, Antonio</b>	University of Málaga, Spain
<b>Wagner, Hubert</b>	Jagiellonian University, Poland
<b>Weilandt, Frank</b>	Jagiellonian University, Poland
<b>Wintner, Mose</b>	University of Southern California, USA
<b>Yuzvinsky, Sergey</b>	University of Oregon, USA
<b>Zivaljevic, Rade</b>	Mathematical Institute SANU, Serbia