

CONTEMPORARY MATHEMATICS

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Geometry and Topology Down Under

A Conference in Honour of Hyam Rubinstein
11–22 July 2011
The University of Melbourne, Parkville, Australia

Craig D. Hodgson
William H. Jaco
Martin G. Scharlemann
Stephan Tillmann
Editors



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Providence, Rhode Island

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Preface

In July 2011, a two-week event, now known as the ‘Hyamfest’, was held at the University of Melbourne. It consisted of a workshop and a conference, both of which covered a broad range of topics in Geometry and Topology, including hyperbolic geometry, symplectic geometry and geometric topology.

These proceedings mirror the spirit of the event: They include research articles, expository articles and a set of Hyam Rubinstein’s favourite problems, again covering a broad range of topics. The editors would like to thank the authors for the work they have put into their contributions, and the referees for their commitment and efforts in their private task. The editors thank Christine Thivierge for her assistance in preparing this volume.

The workshop would not have been possible without the lecturers who put a lot of energy into preparing and delivering three inspiring lecture series, and their assistants who prepared problem sets and ran discussion sessions. The high standard of the talks at the conference contributed greatly to its success.

The event was sponsored by the Australian Mathematical Sciences Institute, the Australian Mathematical Society, the Clay Mathematics Institute and the National Science Foundation. The Department of Mathematics and Statistics at the University of Melbourne provided a wonderful conference environment, and staff at the Institute and the Department provided invaluable help and support.

The Editors
March 2013

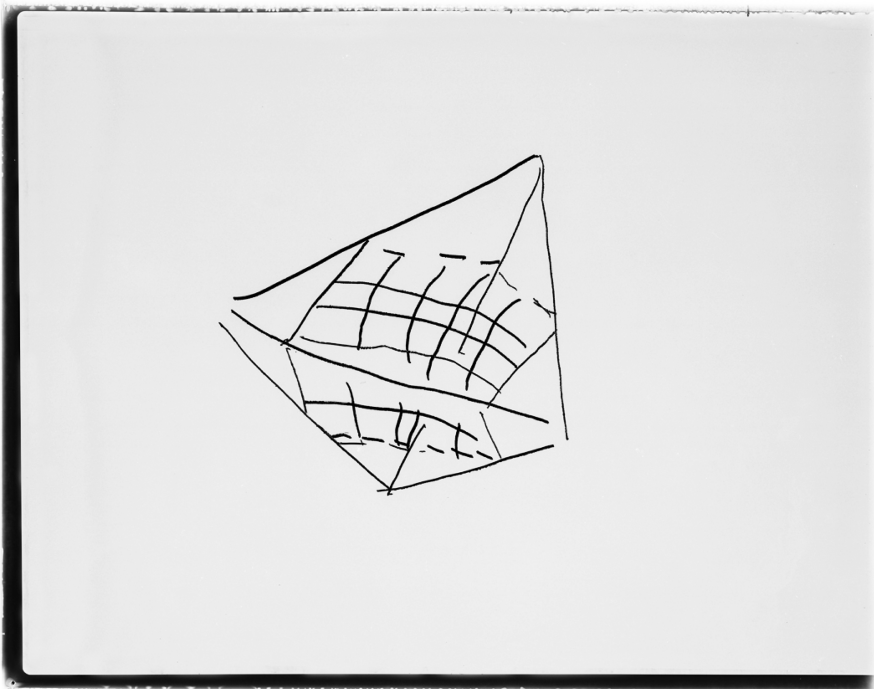


Photo: Tobias Titz

The Hyamfest

The conference and workshop *Geometry & Topology Down Under* consisted of two exciting weeks of lectures and research talks in the Department of Mathematics and Statistics at the University of Melbourne. The event brought together an impressive line-up of guests from the United States, Europe and Asia, and was attended by 115 students and researchers. It attracted experts and emerging researchers who reported on recent results and explored future directions in Geometry and Topology. The conference was held in honour of Hyam Rubinstein and celebrated his contributions to topology and his long-standing role as an advocate for the mathematical sciences.

The workshop (11-15 July) and conference (18-22 July) covered a broad range of topics in Geometry and Topology, including hyperbolic and symplectic geometry, Heegaard splittings and triangulations of 3-manifolds, and recent advances and applications in the study of graph manifolds. The organisers interpreted the topic of the workshop and conference broadly, so that the meeting had appeal to group theorists, analysts, differential geometers and low-dimensional topologists. The event was designed so that it was beneficial not only to the experts in the field but also to early career researchers and graduate students.

In the first week, short courses were given by Danny Calegari on *Ergodic Theory of Groups*, Walter Neumann on *Invariants of hyperbolic 3-manifolds* and Leonid Polterovich on *Function theory on symplectic manifolds*. The short courses introduced honours and postgraduate students, as well as early-career or established researchers, to a broad range of methods and results. Each lecturer gave a 75-minute lecture each day. Discussion sessions, which were led by vibrant, early-career researchers, were held each afternoon. The lectures were of exceptionally high standard, and special notes and exercises were designed for the participants. All lectures have been recorded and are, in addition to a wealth of other material, available on the conference website: www.ms.unimelb.edu.au/~hyamfest.

The conference in the second week featured a line-up of 23 international experts who reported on a variety of new results. For instance, Ian Agol gave a proof of Simon's conjecture, David Gabai reported on recent progress on the topology of ending lamination space, Walter Neumann talked about a new geometric decomposition for complex surface singularities, Yi Ni showed that Khovanov homology with an extra module structure detects unlinks, and Gang Tian described a new symplectic curvature flow. Moreover, each day featured a "What is...?" talk in the spirit of the Notices of the AMS just before lunch. These talks were positively received by both junior and senior researchers.

In conjunction with the conference, a free public lecture was given by Danny Calegari on 19 July. The public lecture attracted media attention, and many members of the public attended the lecture.

The organisers were thrilled by the geographical distribution of the 115 registered participants, more than half of whom travelled to Melbourne from overseas. There were 55 participants from Australia, 36 from the USA, 12 from Japan, and the remaining ones from Canada, China, France, Hungary, Israel, Korea, Mexico, Singapore and the UK. Moreover, 26 of the 55 Australian participants travelled from interstate.

The organisers feel that the event has helped to develop and strengthen collaborations between different research groups within Australia and between groups in Australia and overseas, and to inspire young scientists, graduate and undergraduate students to engage in exploring the many exciting research problems in this area of mathematics.

The organisers are grateful for generous funding by the Australian Mathematical Sciences Institute (AMSI), the Australian Mathematical Society (AustMS), the Clay Mathematics Institute and the National Science Foundation (NSF), which made this exciting event possible. The organisers thank the staff at AMSI for their help and support, and the Department of Mathematics and Statistics at the University of Melbourne for hosting this event and providing a wonderful conference environment.

Organising Committee

James Carlson (Clay Mathematics Institute)
Loretta Bartolini (Oklahoma State University)
Danny Calegari (California Institute of Technology)
Craig Hodgson (University of Melbourne)
William Jaco (Oklahoma State University)
Amnon Neeman (Australian National University)
Paul Norbury (University of Melbourne)
Arun Ram (University of Melbourne)
Stephan Tillmann (University of Queensland)
Penny Wightwick (University of Melbourne)
Nick Wormald (University of Waterloo)

Courses at the Hyamfest

Ergodic Theory of Hyperbolic Groups

Lecturer: Danny Calegari

Assistant: Alden Walker

An introduction to the use of dynamical and probabilistic methods in geometric group theory, especially as applied to hyperbolic groups. I hope to discuss (central) limit theorems for random geodesics and random walks, behaviour of characteristic functions (e.g. (stable) commutator length, w-length, etc.) under random homomorphisms, and a few other topics if time permits.

Invariants of Hyperbolic 3-Manifolds

Lecturer: Walter Neumann

Assistant: Christian Zickert

This short course will concentrate on number-theoretic invariants and number theoretic methods in the study of 3-manifolds. The first lecture will be a brief introduction to algebraic number theory, followed by four lectures on 3-manifolds, concentrating mostly on hyperbolic 3-manifolds.

Function Theory on Symplectic Manifolds

Lecturer: Leonid Polterovich

Assistant: Daniel Rosen

Function spaces associated to a symplectic manifold exhibit unexpected properties and interesting structures, giving rise to an alternative intuition and new tools in symplectic topology. These phenomena are detected by modern symplectic methods such as Floer theory and are closely related to algebraic and geometric properties of groups of Hamiltonian diffeomorphisms. I shall discuss these developments, their applications as well as links to other areas such as group quasi-morphisms and quantum-classical correspondence. All necessary symplectic preliminaries will be explained.

Notes, problem sets and video recordings of the lectures are available at:

<http://www.ms.unimelb.edu.au/~hyamfest/workshop.php>

Talks at the Hyamfest

“What is...?” talks

Mohammed Abouzaid (Clay Mathematics Institute/MIT)

... a Weinstein manifold?

Ian Agol (University of California, Berkeley)

... drilling and filling?

Danny Calegari (California Institute of Technology)

... a martingale?

Joel Hass (University of California, Davis)

... an almost normal surface?

Software demonstrations

Ben Burton (The University of Queensland)

Regina

Marc Culler (UIC) and Nathan Dunfield (UICU)

SnapPy

Research talks

Mohammed Abouzaid (Clay Mathematics Institute/MIT)

Symplectic topology and higher dimensional analogues of ribbon graphs

Ian Agol (UC Berkeley)

Presentation length and Simon's conjecture

Michel Boileau (Université Paul Sabatier)

Graph manifolds which are integral homology 3-spheres and taut foliations

Marc Culler (University of Illinois at Chicago)

Character varieties, fields, and spectograms of 3-manifolds

Nathan Dunfield (UIUC)

The Least Spanning Area of a Knot and the Optimal Bounding Chain Problem

David Gabai (Princeton University)

On the topology of ending laminations space

Cameron Gordon (University of Texas at Austin)

L-spaces and left-orderability

Kazuo Habiro (Kyoto University)

Quantum fundamental groups of 3-manifolds

Joel Hass (University of California, Davis)

Level n normal surfaces

Craig Hodgson (The University of Melbourne)

Veering triangulations admit strict angle structures

- William Jaco (Oklahoma State University)
Constructing annular-efficient triangulations
- Thang Le (Georgia Institute of Technology)
Homology growth, volume, and Mahler measure
- Feng Luo (Rutgers University)
Variational principles and rigidity theorems on triangulated surfaces
- Darryl McCullough (University of Oklahoma)
Diffeomorphisms and Heegaard splittings of 3-manifolds
- Yoav Moriah (Technion)
Heegaard splittings with large subsurface distances
- Walter Neumann (Barnard College, Columbia University)
Bilipschitz geometry of complex surface singularities
- Yi Ni (Caltech)
Khovanov module and the detection of unlinks
- Leonid Polterovich (Chicago/Tel Aviv)
Lagrangian knots and symplectic quasi-measures
- Martin Scharlemann (University of California, Santa Barbara)
New examples of manifolds with multiple genus 2 Heegaard splittings
- Abigail Thompson (University of California, Davis)
3-manifolds with distance two Heegaard splittings
- Gang Tian (Beijing University and Princeton University)
Symplectic curvature flow
- Genevieve Walsh (Tufts University)
Right-angled Coxeter groups, triangulations of spheres, and hyperbolic orbifolds
- Shicheng Wang (Peking University)
Graph manifolds have virtually positive Seifert volume

List of Participants

Mohammed Abouzaid
MIT/Clay

Robert Ackermann
UC Santa Barbara

Ian Agol
UC Berkeley

Michael Albanese
University of Adelaide

Christopher Atkinson
Temple University

Jose Ayala Hoffmann
The University of Melbourne

Jeffrey Steven Bailes
The University of Melbourne

Lashi Bandara ANU

Christopher Banks
University of Newcastle

Loretta Bartolini
Oklahoma State University

Burzin Bhavnagri
The University of Melbourne

John Bland
University of Toronto

Michel Boileau
Universite Paul Sabatier

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Flinders University

Benjamin Burton
The University of Queensland

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CalTech

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University of Sydney

William Cavendish
Princeton University

Young Chai
Sungkyunkwan University

Sangbum Cho
Hanyang University

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ANU

Alexander Coward
UC Davis

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Nathan Dunfield
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Matthew Kotros
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NTU Singapore

Thang Le
Georgia Institute of Technology

Sangyop Lee
Chung-Ang University

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California Institute of Technology

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Rutgers

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CUNY College of Staten Island

Hidetoshi Masai
Tokyo Institute of Technology

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ANU

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Samuel Mellick
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Amnon Neeman ANU	Callum Sleigh The University of Melbourne
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Yi Ni CalTech	Matthew Spong The University of Queensland
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Omar Ortiz The University of Melbourne	Masakazu Teragaito Hiroshima University
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Yoshikazu Yamaguchi
Tokyo Institute of Technology

Xi Yao
The University of Queensland

George Yiannakopoulos
DSTO

Christian Zickert
University of Maryland

Alexander Zupan
University of Iowa



Photo: Tobias Titz

Biographical Sketch of Hyam Rubinstein

J. (Joachim) Hyam Rubinstein is a Professor in the Department of Mathematics and Statistics at the University of Melbourne in Melbourne, Australia. He was born in 1948 in Melbourne and is the third of six children, all boys. Hyam and his brothers were strongly influenced by their mother, who encouraged her sons to study science and mathematics. All of the brothers were mathematically minded and keen on chess. Hyam received highest recognition for academics and mathematics, in particular, before becoming a teenager, winning the John Braithwaite Scholarship in 1959. He entered Melbourne Boys' High School and at age 17 years, topped the State list of matriculation exhibition winners: topping the general exhibition, with exhibitions in calculus, applied mathematics, and physics, and winning the B.H.P. Matriculation Prize. He completed Melbourne Boys' High School taking the prize for pure mathematics, physics, and chemistry in his last year of school.

Hyam then entered Monash University where he majored in pure mathematics and statistics and earned B.Sc. Honours (First Class) in 1969. He followed an older brother to University of California-Berkeley to do graduate work in mathematics. At Berkeley, Hyam was influenced by the work of John Stallings in geometric topology and became a student of Stallings. He completed his thesis and earned his Ph.D. in 1974. While at Berkeley, he was supported by an IBM Fellowship and received three distinctions in the qualifying exams. Hyam was by this time married to his wife Sue and they decided to return to Australia upon the completion of his doctorate. He accepted a postdoctoral appointment at the University of Melbourne. At the end of his postdoctoral appointment, he received a contract to stay at Melbourne University and teach, a position from which he was promoted in the last year to senior lecturer and he received tenure. In 1982, he was appointed to a Chair of Mathematics and became a professor at the University of Melbourne.

During the period prior to Hyam becoming Chair, his predecessor, Leon Simon, influenced both the Department and Hyam. Through Leon's encouragement, Hyam and Jon Pitts started a collaboration that led to the introduction into 3-manifold topology of sweep outs and minimax methods from geometric analysis. Hyam's tremendous breadth and understanding of mathematics and his generous sharing of ideas has led to many fruitful collaborations. The early work with Pitts carried forth in a collaboration on PL minimal surface theory with William Jaco; later Hyam introduced a polyhedral version of sweep outs and discovered almost normal surfaces. The latter provided the methods for Hyam to solve the 3-sphere recognition problem. Hyam had a long and productive collaboration with Iain Aitchison on polyhedral differential geometry and another with Marty Scharlemann on the general structure and methods for comparisons of Heegaard splittings. He returned to a collaboration with Jaco, both of whom enjoy triangulations and algorithms

in low-dimensional topology, as well as very good red wine. Hyam has expanded his interest into a number of collaborations with young mathematicians, including Ben Burton, Craig Hodgson and Stephan Tillmann, connecting the geometry and topology of 3-manifolds. In the late 80s, Hyam began a collaboration with Doreen Thomas on shortest networks, leading to the solution of the Steiner ratio conjecture and the development of a group working in the design of access to underground mines. This group now provides consultation around the world on shortest networks in 3-dimensional space and has produced impressive software introducing their new algorithms to many applications. Hyam also has an enjoyable collaboration with his son Ben on machine learning. This collaboration brings geometry and topology into the science of machine learning, which is Ben's specialty.

Hyam has earned exceptional recognition. He is a Fellow of the Australian Academy of Sciences, a Fellow of the American Mathematical Society, and a Fellow of the Australian Mathematical Society. He was awarded the Australian Academy's Hannan Medal for exceptional mathematical research and the Australian Mathematical Society's George Szekeres Medal for outstanding contributions to the mathematical sciences. He served as president of the Australian Mathematical Society, Chair of the National Committee for the Mathematical Sciences, and Chair of the Working Party of the National Strategic Review of Mathematical Sciences Research in Australia.

"Geometry and Topology Down Under" is a tribute to Hyam's contributions to the algorithmic theory of 3-manifolds, Heegaard splittings, PL minimal surfaces, sweep outs, almost normal surfaces, efficient triangulations, and shortest networks. It also recognizes his influential role throughout a period of exciting and expansive development in the study and understanding of low-dimensional topology and 3-manifolds.

This book contains the proceedings of the conference Geometry & Topology Down Under, held July 11–22, 2011, at the University of Melbourne, Parkville, Australia, in honour of Hyam Rubinstein.

The main topic of the book is low-dimensional geometry and topology. It includes both survey articles based on courses presented at the conferences and research articles devoted to important questions in low-dimensional geometry. Together, these contributions show how methods from different fields of mathematics contribute to the study of 3-manifolds and Gromov hyperbolic groups. It also contains a list of favorite problems by Hyam Rubinstein.

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