Pure Mathematics at the University of Adelaide: history, current themes and people

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THE UNIVERSITY
OF ADELAIDE
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Some history

1874: £20,000 from Walter W. Hughes and £20,000 from Thomas Elder to fund four professorships

From the 1878 calendar:

CHAPTER IV.—OF THE PROFESSORS AND LECTURERS.
1. There shall for the present be a Professor for each of the following groups of subjects, that is to say, for—
a. Classics and Comparative Philology and Literature.
b. English Language and Literature and Mental and Moral Philosophy.
c. Mathematics pure and applied.
d. Natural Science, especially Geology and Mineralogy ; the Professor to give lectures in Chemistry also.

From the 1887 calendar:

CHAPTER IV.—OF PROFESSORS AND LECTURERS.
1. There shall for the present be the following Professors, that is to say
a. The Hughes Professor of Classics and Comparative Philology and Literature.
b. The Hughes Professor of English Language and Literature and Mental and Moral Philosophy.
c. The Elder Professor of Pure and Applied Mathematics, who shall also give instruction in Physics.
d. The Elder Professor of Natural Science.
e. The Elder Professor of Anatomy, who shall also give instruction

History of the School

- ▶ 1899-1920 the *Elder Professorship* continued with mixed titles such as "Mathematics & Physics" (W. H. Bragg 1899-1910) or "Mathematics & Mechanics" (R. W. Chapman 1910-1920).

- ▶ Since 1920 again *Elder Professor of Mathematics*; held by pure mathematicians Eric Barnes (1959-74), Mathai Varghese (since 2013).

- ▶ The mathematics department was founded together with the Elder Professorship in 1877.

- ▶ 1973: Faculty of Mathematical Sciences with five Departments of pure and applied maths, computing science and statistics, and mathematical physics.

- ▶ 1987 mathematical physicists left to a new Department of Physics and Mathematical Physics within the Faculty of Science.

- ▶ Until 2022: School of Mathematical Sciences, comprising disciplines of applied mathematics (dynamics and stochastic), pure mathematics and statistics, as one of the schools in the Faculty of Engineering, Computer and Mathematical Sciences.

Pure mathematics at the School up to 1990's

▶ George Szekeres (Professor at Adelaide 1948-63): combinatorics, graph theory, numerical and complex analysis, general relativity.

▶ Algebra & number theory: Hans Schwerdtfeger (40's), Eric Barnes (50's-70's), Jane Pitman (60's-90's).

▶ Group theory & combinatorics: Marta Sved, Bob Clarke, David Parrott (80's-2000's).

▶ Geometric analysis: Jim Michael (1958-83) and his PhD student ('71) Leon Simon, later Professor at Stanford, won several prizes.

▶ Harmonic analysis & mathematical physics: Bill Moran ('76-'91), Alan Carey ('85-2001), later Director of MSI at ANU,

Geometry at Adelaide and the IGA

Heyday in the 1990's

- ▶ At peak 13 ARC Fellowships including 4 Professorial Fellows in pure maths,
- ▶ Alan Carey, Peter Bouwknegt (now both ANU) and Mathai Varghese in mathematical physics,
- ▶ Mike Eastwood & Rod Gover (now Auckland) invented tractor bundles in '92,
- ▶ Michael Murray invented bundle gerbes in '94.

Institute for Geometry and its Application (IGA)

- ▶ Founded on 7th November 1996 by Mike Eastwood, in recognition of the strong group of researchers in geometry and to promote research in geometry. Mike Eastwood is now adjunct professor.
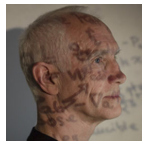
- ▶ Director since 2009: Mathai Varghese, currently 16 members, including adjunct and affiliate staff.
- ▶ The IGA organises workshops, instructional schools, lecture series and runs a regular seminar on Fridays.
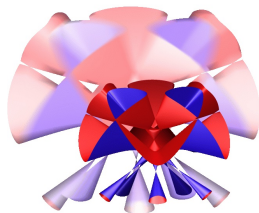
The common theme: geometry

▶ Geometry is based on very general concepts of *space*.
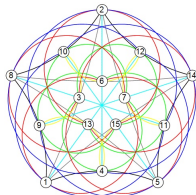▶ Depending on the level of structure, this can be, for example

• topological spaces in topology
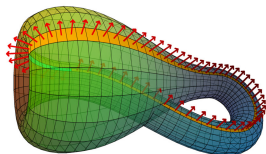
• manifolds in differential geometry


• algebraic varieties in algebraic geometry
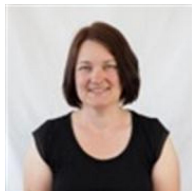

• projective spaces in finite geometry

Geometry and applications

- ▶ differential equations with independent variables from these spaces:
  - ▶ analyse the set of solutions and their behaviour ↝ dynamics,
  - ▶ conditions on the space under which there are solutions.
- ▶ distinguishing features of the shape ↝ topological and geometric invariants,
- ▶ geometric structures such as symmetries or metric quantities (distances, volume, angles),
- ▶ existence of certain maps between the spaces that allow do describe complicated spaces by simpler ones,
- ▶ applications in mathematical physics, e.g. wave equation, Einstein equations in general relativity, Maxwell's equation in electromagnetism, Yang-Mills equation in particle physics, Dirac equation in quantum mechanics,
- ▶ models for the universe in general relativity, or as configuration space of physical objects or quantities, such as particles or fields, for example in electromagnetism, quantum field theory, or string theory.

David Baraglia

- ▶ Differential and algebraic geometry, moduli spaces, geometric Langlands program,
- ▶ gauge theory, Higgs bundles, with applications to mathematical physics (quantum field theory and string theory).
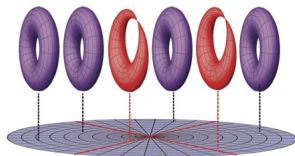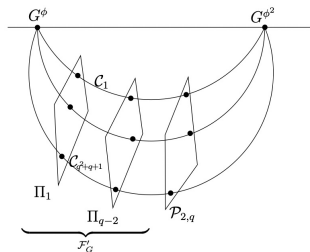

- ▶ PhD from the University of Oxford.
- ▶ David held two ARC Postdoctoral Fellowships at the ANU and at Adelaide.
- ▶ International collaborations:
  - ▶ University of Tokio,
  - ▶ University of Auckland.

Sue Barwick

- ▶ Finite geometry, projective geometry,
- ▶ applications to cryptography.

- ▶ PhD from University of London.
- ▶ International collaborations:
  - ▶ Royal Holloway, University of London,
  - ▶ Clemson University, U.S.A,

Finnur Lárusson

- ▶ Complex geometry and analysis, Oka theory,
- ▶ complex dynamics, contact geometry,
- ▶ theory of minimal surfaces,
- ▶ homotopy theory, geometric invariant theory.

- ▶ PhD from the University of Chicago,
- ▶ currently Head of School.
- ▶ International collaborations:
  - ▶ University of Ljubljana
  - ▶ University of Bern
  - ▶ University of Rome II "Tor Vergata"
  - ▶ University of Granada
  - ▶ Brandeis University

Thomas Leistner
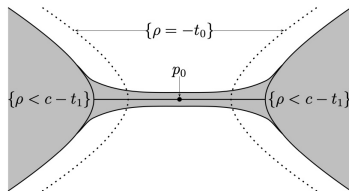
- ▶ Differential geometry: semi-Riemannian and conformal geometry, space-time geometry, spin geometry,
- ▶ holonomy groups, Lie groups, homogeneous spaces.

- ▶ PhD from Humboldt University Berlin.
- ▶ International collaborations:
  - ▶ University of Hamburg
  - ▶ Polish Academy of Sciences and University of Warsaw
  - ▶ University of Auckland
  - ▶ University of Turin
  - ▶ Utah State University

Danny Stevenson and Ray Vozzo
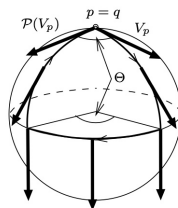
- ▶ Differential geometry, higher geometry, algebraic topology, category theory and homotopy theory,
- ▶ both PhD from Adelaide
- ▶ Danny is currently Director of Teaching,
- ▶ Ray is a Teaching Fellow and also works on methods in mathematical education.
- ▶ International collaborations:
  - ▶ University of Auckland
  - ▶ Herriot-Watt University

Mathai Varghese

- ▶ Differential geometry, geometric analysis, index theory,
- ▶ noncommutative geometry, spectral theory of elliptic operators
- ▶ mathematics of string theory and condensed matter physics: (fractional) quantum Hall effect, topological insulators and topological semimetals.

- ▶ Sir Thomas Elder Professor of Mathematics,
- ▶ current Australian Laureate Fellow,
- ▶ several professorial ARC Fellowships in the past,
- ▶ Fellow of the Australian Academy of Science and the South Australian Royal Society,
- ▶ PhD from MIT,
- ▶ numerous international collaborations.
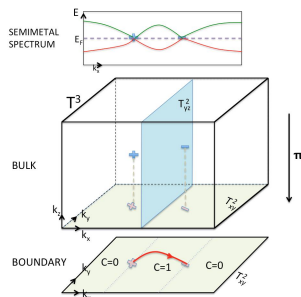
Recent MPhil graduates in pure maths

- ▶ Tyson Klingner (Baraglia, Villonen), Fulbright PhD Scholarship
- ▶ Alexander Lai De Olivera (Larusson, Stevenson) PhD at ANU
- ▶ Tim Moy (Leistner, Eastwood), PhD at University of Cambridge
- ▶ Tom Munn (Leistner, Eastwood), PhD at Lund University
- ▶ Stuart Teisseire (Leistner, Eastwood), PhD at University of Auckland
- ▶ Ahnaf Tajwar Tahabub (Varghese, Baraglia), Fulbright PhD Scholarship
- ▶ David Brook (Varghese, Hochs), PhD at Pennsylvania State University
- ▶ Haripriya Sridharan (Larusson, Leistner), PhD at Adelaide and Melbourne
- ▶ Ben Moore (Eastwood, Leistner), 2020 University Master by Research Medal, PhD at University of Warwick
- ▶ Kim Becker (Murray, Stevenson), 2019 University Master by Research Medal, PhD at Oxford University
- ▶ John McCarthy (Varghese, Baraglia), 2018 University Master by Research Medal, PhD at Imperial College London
- ▶ Michael Hallam (Varghese, Baraglia), PhD at Oxford University
- ▶ Kelli Francis-Staite (Murray, Leistner), 2015 Rhodes PhD Scholarship

Pure maths courses we teach

3rd year:

- ▶ Groups & Rings, Field & Modules
- ▶ Complex Analysis, Topology & Analysis, Integration & Analysis

Honours/Masters:

- ▶ Differential Geometry
- ▶ Lie groups and Lie algebras
- ▶ Algebraic Topology
- ▶ Functional Analysis
- ▶ Category Theory

Pure mathematics and machine learning?[1]

- ▶ Measure theory and functional analysis are at the foundations of ML.

- ▶ Topology: topology of data set changes when it passes through a neural network, better learning when topological complexity decreases.
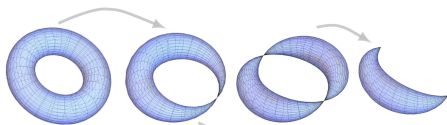

FIGURE 22. Donut to croissant: torus → pinched torus → doubly-pinched torus → sphere. Betti numbers: $(1, 2, 1) \to (1, 1, 1) \to (1, 1, 2) \to (1, 0, 1)$.

[Naitzat, Zhitnikov & Lim, Topology of Deep Neural Networks, *Journal of Machine Learning Research* 21 (2020).

- ▶ Topology, machine learning and mathematical physics come together when neural networks are used to detect phase changes in topological insulators. [Zhang, Shen & Zhai, Machine Learning Topological Invariants with Neural Networks, *Phys. Rev. Lett.* 120, 066401 (2018)]

- ▶ This is not a one-way-street: machine learning has been used in algebraic geometry [G. Williamson et al.] and knot theory [M. Lackenby et al.]. See also "Advancing mathematics by guiding human intuition with AI" in *Nature*, 600, 70–74 (2021).

[1] Thanks to Hemanth Saratchandran at AIML, former postdoc at the IGA