LONDON MATHEMATICAL SOCIETY
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NEWSLETTER

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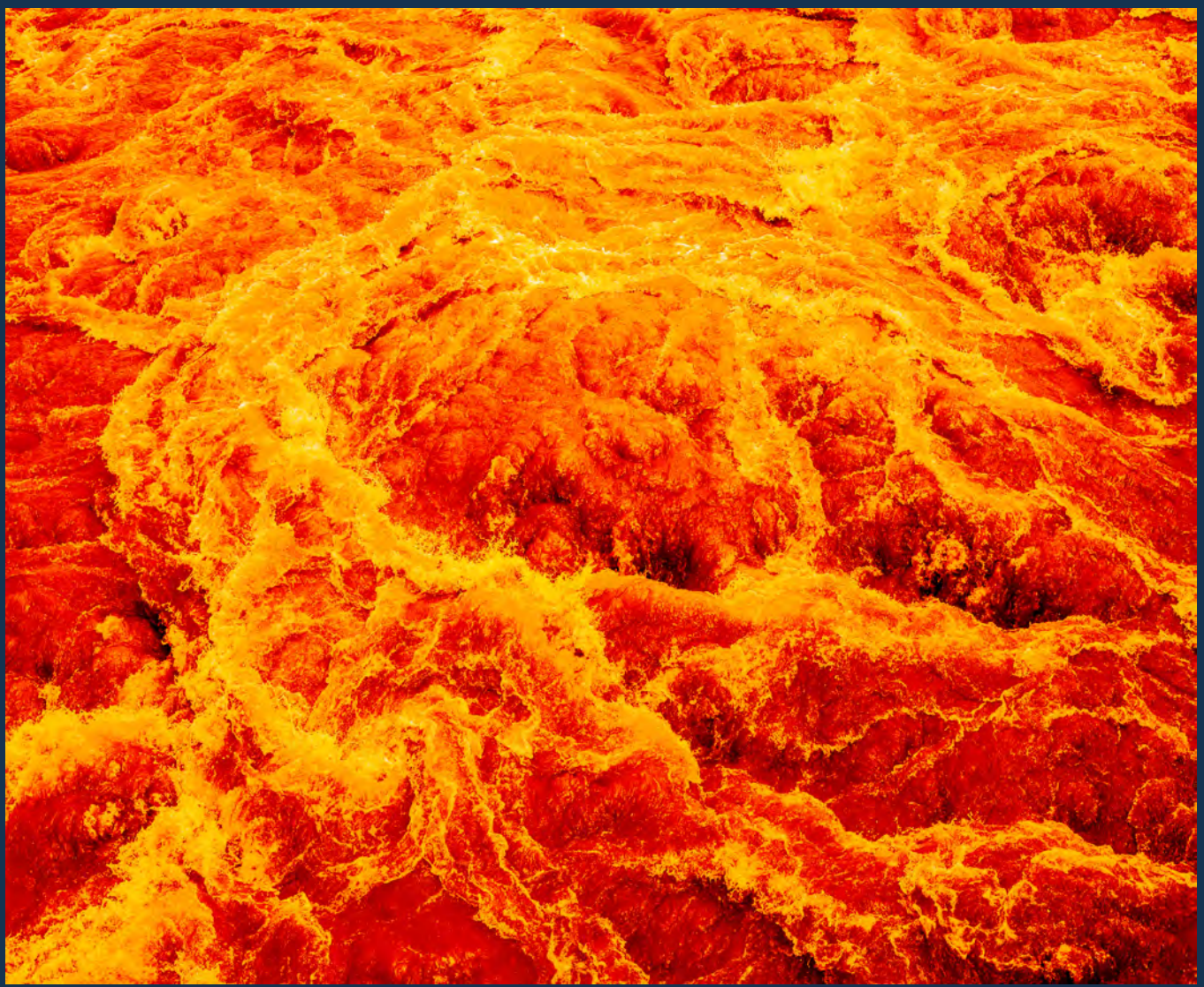

THE STATISTICS OF VOLCANIC SUPER-ERUPTIONS

HARDY–RAMANUJAN PARTITION FORMULA

INTERNATIONAL CONGRESS OF MATHEMATICIANS

EDITORIAL OFFICE

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COVER IMAGE

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See J. Rougier's article on volcanoes p27.

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NEWSLETTER WEBSITE

The Newsletter is freely available electronically at lms.ac.uk/publications/lms-newsletter.

MEMBERSHIP

Joining the LMS is a straightforward process. For membership details see lms.ac.uk/membership.

SUBMISSIONS

The Newsletter welcomes submissions of feature content, including mathematical articles, career related articles, and microtheses from members and non-members. Submission guidelines and LaTeX templates can be found at lms.ac.uk/publications/submit-to-the-lms-newsletter.

Feature content should be submitted to the editor-in-chief at iain.moffatt@rhul.ac.uk.

News items should be sent to newsletter@lms.ac.uk.

Notices of events should be prepared using the template at lms.ac.uk/publications/lms-newsletter and sent to calendar@lms.ac.uk.

For advertising rates and guidelines see lms.ac.uk/publications/advertise-in-the-lms-newsletter.

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Forthcoming LMS Events

The following events will take place in the next two months:

BCS-FACS Evening Seminar: 1 November, London (tinyurl.com/bcsfacs)

Computer Science Colloquium: 8 November, London (tinyurl.com/yc5e6gr3)

Graduate Student Meeting: 9 November, London (tinyurl.com/y8hafqjx)

AGM and Naylor Lecture: 9 November, London (tinyurl.com/y7q5dsgk)

South West & South Wales Regional Meeting and Workshop: 17 December, Exeter (tinyurl.com/ydymqdeq)

A full listing of forthcoming LMS events can be found on page 46.

Vacancies on LMS Committees

The detailed business of the LMS is run by about 23 committees and working groups, each usually having about 10 people. Altogether this comes to a large number of people, to whom the Society is extremely grateful for this vital work.

It is Council's responsibility to make the appointments to all these committees and to turn their membership over regularly, so that (a) the broadest possible spectrum of our membership is represented, and (b) the committees remain fresh and energetic. Of course, when forming a committee, account has to be taken of many things, such as maintaining subject and demographic balance, which means that on a given occasion otherwise very strong candidates may not always be able to be appointed.

So we are always looking for new people! See lms.ac.uk/about/committees for a list of committees.

If you are interested, or would like to recommend a colleague, please contact Katherine Wright at Katherine.Wright@lms.ac.uk in order that Council can maintain a good list of potential members of its various committees. It is not necessary to specify a particular committee. If you would like to know what is involved, you could in the first instance ask your LMS Departmental Representative.

Stephen Huggett
LMS General Secretary

Standing Orders of the Society

Readers may recall an article in the last issue of the Newsletter about proposals for changes to the Standing Orders of the Society. This note is to inform members of the dates of the consultation process. It will be possible to make and see comments through a blog on the LMS website, and also to make direct responses to the consultation by email.

The consultation will open at the beginning of November, and will close on 20 January 2019. This is in order that responses can be collated before Council's "retreat" at the beginning of February.

Details of the proposed changes, including the full text of the old and proposed new versions of the Standing Orders, will be circulated to members as soon as the consultation is open, along with information on how to access the blog and how to submit an email response.

Cecil King Memorial Foundation

The Cecil King Memorial Foundation and the London Mathematical Society are delighted to announce that the Cecil King Travel Scholarship 2018 has been awarded to Simon Crawford (University of Waterloo), who will undertake a period of research with S. Paul Smith and James Zhang at the University of Washington in 2019.

Simon Crawford writes: *During my PhD, my research focused on noncommutative ring theory and noncommutative geometry. I am very grateful to be awarded the Cecil King Travel Scholarship, which will allow me to travel to the University of Washington to work with S. Paul Smith. Paul has been a leading figure in noncommutative geometry since its inception and has a great deal of experience working with AS regular algebras, in particular the Sklyanin algebra. One of the projects I hope to work on will involve studying the singularities of algebras related to Sklyanin algebras, and his experience will be invaluable for this. James Zhang is another mathematician at Washington who has also made many fundamental contributions to my areas of interest. Recent work by James and his collaborators identified 'quantum' analogues of Kleinian singularities, and one of the results in my thesis showed that in many cases these rings are Morita equivalent to (respectively, isomorphic to) certain path algebras (respectively, corner rings of path algebras). I believe this is also true for the remaining cases and hope to prove this while at Washington, and James' perspective will be very helpful for this.*

The Cecil King Travel Scholarship was established in 2001 by the Cecil King Memorial Fund. Applications for the 2019 award are now open — further details on page 7.

IMU General Assembly, São Paolo

Prior to the ICM 2018 in Rio, the General Assembly of the IMU took place in São Paolo, Brazil, from 29 to 30 July. Bids were presented to the General Assembly from Paris and from St Petersburg for hosting the ICM 2022. The delegates decided that St Petersburg will host the 2022 International Congress of Mathematics. For details see icm2022.ru/en/. The ICM 2022 will be preceded by the IMU GA.

Isobel Falconer (St Andrews) was elected to the Executive Committee of the International Commission on History of Mathematics (ICHM), of which June Barrow-Green is Chair.

MATHEMATICS POLICY DIGEST

Global development challenges

EPSRC has released further information on tackling global development challenges through mathematical sciences and will launch two complementary Global Challenges Research Fund calls for proposals to tackle such challenges. One call will be for research proposals on empowering inclusion and building society, and the other will be for capacity building. Expressions of Interest should be submitted by 8 November 2018. Further details are available at tinyurl.com/yc2qjj9k.

UK Participation in Horizon 2020

The UK government has provided an overview of the UK's relationship with Horizon 2020. This is followed by a question and answer section, which clarifies the UK's eligibility to participate in Horizon 2020. More information is available at tinyurl.com/ybar6gh8.

Mathematics maintains its popularity at A-level

The rise of mathematics at A-level continues with another increase in the number of Mathematics entries across the UK in 2018. The number of students sitting the exam is up 2.5% on last year to 97,627. However, the figures for AS show a significant decrease. Figures released by the Joint Council for Qualifications show that

- A-level Further Mathematics entries decreased by 0.09% (to 16,157)
- AS Mathematics entries decreased by 49.5% (to 81,051)
- AS Further Mathematics entries decreased by 34.1% (to 18,426)

Dr Kevin Houston, LMS Education Secretary, commented: "It is great to see that mathematics is the most popular A-level subject and that so many students are attaining excellent grades. Our congratulations to the students and teachers who have worked so hard to make this happen. A worrying outcome of A-level reforms are the large drops in AS entries for Mathematics and Further Mathematics. Coupled with only a small number taking Core Mathematics, this means that there are far fewer students experiencing Mathematics beyond 16 when the UK should be ensuring that the opposite is true."

Algorithms in decision making

In May 2018 the House of Commons Science and Technology Select Committee published its report on *Algorithms in Decision Making*. The report called on the Centre for Data Ethics & Innovation — being set up by the government — to examine algorithm biases and transparency tools, determine the scope for individuals to be able to challenge the results of all significant algorithmic decisions which affect them and where appropriate to seek redress for the impacts of such decisions (tinyurl.com/ya4rwdgl). The government has published its response and has made a number of recommendations informed by the Select Committee report (tinyurl.com/ycdh6w83).

Dr John Johnston
Society Communications Officer

Note: items included in the Mathematics Policy Digest are not necessarily endorsed by the Editorial Board or the LMS.

EUROPEAN

EMS Council Meeting

The EMS Council convened on 23–24 June 2018 in Prague. It elected Volker Mehrmann as the new EMS President for 2019–22. Betül Tanbay was elected as new Vice-President, and Jorge Buescu joins the Executive Committee as a member-at-large. The Council approved the EMS budget and, among other decisions, introduced a system of life membership.

Finnish Mathematical Society

The Finnish Mathematical Society celebrates its 150th anniversary this year, making it one of the oldest still-functioning mathematical societies in the world. It will mark this milestone with a conference (30 Nov–2 Dec) in Helsinki on various fields important to Finnish mathematics. The meeting will feature a panel discussion on the interaction of mathematics and society, bringing together representatives of industry and the ministry of education and science. See tinyurl.com/ybq46mbr. A full article about the Finnish Mathematical Society is on page 32.

EMS Publishing

Highlights of the September edition of the EMS *Newsletter* include an interview with Abel Laureate Robert P. Langlands, a profile of BCAM (Basque Center for Applied Mathematics), and an introduction to the new *International Science Council*, a global voice for science — as well as the usual reviews, problems etc.: see tinyurl.com/y8nmzfe7. Other recent publications by the EMS Publishing House include Vladimir G. Maz'ya: *Boundary Behavior of Solutions to Elliptic Equations in General Domains*, and Timothée Marquis: *An Introduction to Kac–Moody Groups over Fields*. See ems-ph.org for details.

David Chillingworth
LMS/EMS Correspondent

Membership of the London Mathematical Society

The standing and usefulness of the Society depends upon the support of a strong membership, to provide the resources, expertise and participation in the running of the Society to support its many activities in publishing, grant-giving, conferences, public policy, influencing government, and mathematics education in schools. The Society's Council therefore hopes that all mathematicians on the staff of UK universities and other similar institutions will support mathematical research by joining the Society. It also very much encourages applications from mathematicians of comparable standing who are working or have worked in other occupations.

Benefits of LMS membership include access to the Verblunsky Members' Room, free online subscription to the Society's three main journals and complimentary use of the Society's Library at UCL, among other LMS member benefits (lms.ac.uk/membership/member-benefits).

If current members know of friends or colleagues who would like to join the Society, please do encourage them to complete the online application form (lms.ac.uk/membership/online-application).

Contact membership@lms.ac.uk for advice on becoming an LMS member.

Nominations for LMS Prizes 2019

The LMS would like to invite nominations for the following prizes in 2019, which are intended to recognise and celebrate achievements in and contributions to mathematics:

The **De Morgan Medal**, which is the Society's premier award and for which the only grounds are the candidate's contributions to mathematics; the **Senior Whitehead Prize**, for work in, influence on or service to mathematics and lecturing gifts; the **Naylor Prize and Lectureship in Applied Mathematics**, for work in, influence on, and contributions to, applied mathematics and/or the applications of mathematics, and lecturing gifts; the **Berwick Prize**, which is awarded to the author(s) of a definite piece of research published by the Society between 1 January 2011 and 31 December 2018; the **Whitehead Prizes**, for work in and influence on mathematics (up to six may be awarded); and the **Anne Bennett Prize**, for work in and influence on mathematics, particularly to women mathematicians.

Regulations and nominating forms can be found at tinyurl.com/lmsprizes2019. Please return nominating forms to Katherine Wright, Society Business Officer: prizes@lms.ac.uk.

The closing date for nominations is 25 January 2019. Any nominations received after that date will be considered in the next prize award round.

Nominations for Crighton Medal

The LMS and IMA invite nominations for the 2019 David Crighton Medal. The Crighton Medal is awarded to an eminent mathematician for services both to mathematics and to the mathematical community. Download a nomination form at tinyurl.com/crighton19. Nominations must be sent to prizes@ima.org.uk by 28 February 2019. Further information on the Crighton Medal can be found at lms.ac.uk/content/david-crighton-medal-award.

LMS Travel Grants for ECRs

The London Mathematical Society Travel Grant Scheme for Early Career Researchers is open to all UK-based Early Career Researchers (defined as Master's student, PhD/research student or anyone within five years of PhD completion, excluding academic career breaks). Grants of up to £500 are offered to support travel and accommodation either to attend a conference (in the UK or overseas) or to undertake a collaborative research visit.

Further details and an application form are available at tinyurl.com/y7b8ouo3. The next application deadline is 28 February 2019. Reports from two awardees of ECR travel grants can be found on page 13.

Cecil King Travel Scholarship: call for applications

The London Mathematical Society annually awards a £5,000 Cecil King Travel Scholarship in Mathematics, to a promising young mathematician. The Scholarship is to support a period of study or research abroad, typically for a period of three months, in any area of mathematics.

Applicants must be nationals of the UK or the Republic of Ireland and either be registered for or have completed a doctoral degree within 12 months of the closing date for applications. Applications from women, disabled and Black, Asian and Minority Ethnic (BAME) candidates are particularly encouraged, as these groups are under-represented in UK mathematics.

To apply, complete the application form at tinyurl.com/yarns982 and include a written proposal giving the host institution, describing the intended programme of study or research, and the benefits to be gained from the visit. The application deadline is 31 March 2019.

Shortlisted applicants will be invited to interview during which they will be expected to make a short presentation on their proposal. Interviews will take place at the University of Birmingham in May 2019.

Queries may be addressed to Elizabeth Fisher (ecr.grants@lms.ac.uk).

Owing to the low number of applications received in previous rounds, there has been a high chance of success in this scheme.

LMS Hardy Lectureship Tour 2020: nominations sought

The Society is seeking nominations for a Hardy Lecture Tour in 2020. The Hardy Lecturer visits the UK for a period of about two weeks, and gives the Hardy Lecture at a Society meeting, normally held in London in late June or early July. The Hardy Lecturer will also give at least six other lectures, on different topics, at other venues in the UK.

The schedule is decided by the Programme Secretary in consultation with the Hardy Lecturer, and will be designed to allow as many UK mathematicians as possible to benefit from the Hardy Lecturer's presence in the UK.

The holder of the Hardy Lectureship shall be a mathematician who has not been normally resident in the United Kingdom of Great Britain and Northern Ireland for a period of at least five years, at the time of the award. Grounds for the award of the Lectureship include:

- the achievements of the Hardy Lecturer, including work in, influence on, and general service to mathematics, lecturing gifts, and breadth of mathematical interests;
- the overall benefit the UK mathematical community might derive from the visit;
- the possibility of bringing to the UK a mathematician who might otherwise visit rarely or never.

The Hardy Lectureship is not restricted to mathematicians working in any specific area of mathematics. Previous lecturers include: 2018 Lauren Williams (UC Berkeley), 2016 Jacob Lurie (Harvard), 2015 Nalini Joshi (Sydney), 2014 Percy Deift (NYU).

The London Mathematical Society will fund: the honorarium (£2,000 paid directly to the Hardy Lecturer); travel expenses, including travel to/from the UK and within the UK, up to £2,500; accommodation expenses up to £1,500; and a contribution to the host department to hold a dinner for the Hardy Lecturer up to £100 per institution.

The host department(s) will be expected to provide a partial contribution towards accommodation costs, office accommodation and the academic support normally offered to a distinguished visitor.

Nominations must have the support of the host department(s), and should be sent by the Head of Department to the Programme Secretary (lmsmeetings@lms.ac.uk). The closing date for proposals is 31 January 2019. For further details and guidance on how to submit a nomination, please visit the Society's website: lms.ac.uk/events/lectures/hardy-lectureship.

LMS Mathematical Symposia: call for proposals

The LMS Mathematical Symposia (currently the LMS–Durham Symposia) began in 1974, and have historically been held at the University of Durham, from 1974 to the present date. The Symposia are a well-established and recognised series of international research meetings, which provide an excellent opportunity to explore an area of research in depth, to learn of new developments, and to instigate links between different branches.

The format is expected to allow substantial time for interaction and research. The meetings are by invitation only and held in July/August each year, lasting five days, with 50-70 participants, roughly half of whom will come from the UK. Traditionally, two or three such meetings are held in July/August.

Post-2020, the Symposia will be open to be hosted by other institutions. The Research Grants Committee invites proposals from institutions interested in hosting the LMS Mathematical Symposia in August 2020 and onwards. Host institutions will be responsible for providing the infrastructure of the Symposia.

The Research Grants Committee is looking to replicate the model of the current LMS–Durham Symposia, in that we wish to find a host institution, and will subsequently release a call for proposals for organisers to choose a symposium topic and run the event. It is expected that the Symposia will change institutions every 2–5 years, allowing all institutions an opportunity to host the prestigious event.

Proposals should include: the mathematical case for hosting the LMS Mathematical Symposia at your institution (not more than one page); short CVs of the proposed organisers (not more than one paragraph each), including examples of other events they have run; details of the administrative arrangements, including arrangements for dealing with any relevant visa or work-permit issues; a brief description of the proposed location and accommodation.

The Committee will meet in January 2019, February 2019 and June 2019 and welcomes expressions of interest at all meetings.

For further details about the Durham Symposia in its current iteration, visit tinyurl.com/ya6lqwyb. Queries may be addressed to the Chair of the Research Grants Committee, Dr Francis Clarke, or the LMS Grants and Membership Administrator, Anthony Byrne (grants@lms.ac.uk).

LMS Undergraduate Research Bursaries in Mathematics 2019

The Undergraduate Research Bursary scheme provides an opportunity for students in their intermediate years to explore the potential of becoming a researcher. The award provides £180/£190 per week to support a student undertaking a six to eight week research project over summer 2019, under the direction of a project supervisor.

Students must be registered at a UK institution for the majority of their undergraduate degree, and may only take up the award during the summer vacation between the intermediate years of their course. Students in the final year of their degree intending to undertake a taught Masters degree immediately following their undergraduate degree may also apply. Applications must be made by the project supervisor on behalf of the student.

For further information and to download the application form, visit tinyurl.com/ya5stelx. Queries may also be addressed to George Ross (urb@lms.ac.uk). The closing date for receipt of applications is 5 pm Friday 1 February 2019.

LMS Invited Lectures Series 2020: call for proposals

The annual LMS Invited Lectures Series consists of meetings held in the UK at which a single speaker gives a course of about ten expository lectures, examining some subject in depth, over a five day period (Monday to Friday) during a university vacation. The meetings are residential and open to all interested.

The LMS Invited Lecturer is offered a £1,250 honorarium for giving the course plus full expenses. A £4,000 grant is given to the host department to support attendance at the lectures.

Proposals for the Invited Lectures 2020

Any member who would like to suggest a topic and lecturer and is prepared to organise the meeting at their own institution or a suitable conference centre can submit a proposal. For further details, visit the Society's website: www.lms.ac.uk/content/invited-lecturer-proposals. The deadline for proposals is 1 February 2019.

LMS Invited Lecturer 2019

The LMS Invited Lecture Series 2019 on advanced topics in life insurance mathematics will be given by Professor Søren Asmussen (Aarhus University) at the ICMS in Edinburgh from 20 to 24 May 2019.

Recent previous Invited Lecturers

2018: A. Owen (Stanford University) From the Foundations of Simulation to Quasi Monte Carlo, Warwick University; 2017: J. Agler (UC San Diego) Function Theory by Hilbert Space Methods, Newcastle University.

Enquiries about the Invited Lectures may be addressed to the LMS Programme Secretary (lmsmeetings@lms.ac.uk).

LMS Research Schools 2020: call for proposals

Up to £15,000 of funding is available for an LMS Research School which provides training for research students in any contemporary area of mathematics. The LMS Research Schools support participation of research students from both the UK and abroad. The lecturers are expected to be international leaders in their field. The LMS Research Schools are often partially funded by the Heilbronn Institute for Mathematical Research (heilbronn.ac.uk/).

Information about the submission of proposals can be found at: lms.ac.uk/events/lms-research-schools along with a list of previously supported Research Schools. Applicants are strongly encouraged to discuss their ideas for Research Schools with the Chair of the Early Career Research Committee, Professor Chris Parker (research.schools@lms.ac.uk) before submitting proposals.

Proposals should be submitted to Elizabeth Fisher (research.schools@lms.ac.uk) by 31 January 2019.

To extend the international reach of the Research School, prospective organisers may also wish to consider applying to the Clay Mathematics Institute (CMI) for additional funding under the CMI's Enhancement and Partnership Program. Further information about this program can be found at: tinyurl.com/y72byonb.

Prospective organisers are advised to discuss applications to this program as early as possible by contacting the CMI President (president@claymath.org).

Holgate Session Leaders

Members are reminded that the LMS currently has vacancies for Holgate Session Leaders. See details at tinyurl.com/yc9hsek7. To apply, send a CV and letter outlining (a) what you could offer as a Holgate Session Leader, and (b) what you believe the Holgate sessions could offer as an educational experience, to education@lms.ac.uk.

EMS–Simons for Africa Program

The next deadline of the *EMS–Simons for Africa* program is 15 November 2018 for research visits in all areas of pure and applied mathematics and statistics, for fellows based in Africa. This programme is run by the EMS Committee for Developing Countries, with the support of the Simons Foundation. To submit an application, visit tinyurl.com/ycefz6mw.

ISLP Poster Competition 2018–19

The International Statistical Literacy Project (ISLP) team has announced the International Poster Competition for 2018–19 for school children and undergraduates. The competition invites candidates to design a statistical poster. The posters should reflect or illustrate usage analysis, interpretation and communication of statistics or statistical information. The competition is open to teams of two to five students. Registration and entry is free. Deadline for registration is 1 February 2019. To register, email Margaret.MacDougall@ed.ac.uk. Overall winners are to be announced and their posters displayed at the 62nd World Statistics Congress of the International Statistical Institute during August 2019. Further information can be found at tinyurl.com/ybugyygw.

International Day of Mathematics and Logo Competition

The International Mathematical Union (IMU) is leading a project to have UNESCO proclaim 14 March as the International Day of Mathematics (IDM). If approved by UNESCO the first celebration of the IDM is expected to be on 14 March 2020.

The IMU is now inviting bids for the IDM logo. The deadline for submission of logos to the competition is 31 December 2018. More information about the logo competition, together with a call for bids to host the IDM website, can be found at tinyurl.com/yb52k579.

The Mathematical Gazette

The Mathematical Association, founded in 1871, is the oldest national society for teachers. Several of its Presidents have also served the LMS (including Sylvester, Whitehead, Hardy, Mary Cartwright, Atiyah, and Zeeman). Its main journal, *The Mathematical Gazette*, is a serious mathematics journal for serious mathematics teachers - and others (tinyurl.com/y9nm9zqg). The Editor, Dr Gerry Leversha (G.Leversha@btinternet.com), would welcome direct approaches from LMS members who would be interested in joining the Gazette's panel of potential referees.

VISITS

Visit of Alexander Tylyshchak

Dr Alexander Tylyshchak (Department of Algebra, Uzhgorod National University, Ukraine) will be visiting Dr Joe Gildea at the University of Chester from 1 to 15 November 2018. Dr Tylyshchak's current research focuses on Representation Theory, Theory of Linear Groups and Algebraic Coding Theory. For further information contact Dr Joe Gildea (j.gildea@chester.ac.uk). This visit is supported by an LMS Scheme 5 grant.

Visit of Wafaa Batat

Dr Wafaa Batat (Ecole Polytechnique d'Oran) will visit Stuart Hall at the University of Newcastle from 3 to 21 December 2018. Dr Batat works in the field of submanifold geometry, particularly submanifolds of Lie groups and other manifolds with large symmetry groups. She has also worked on finding examples of special geometries on these spaces such as Einstein metrics and Ricci solitons. The visit is supported by an LMS Scheme 5 grant.

Annual LMS Subscription 2018–19: reminder

Members are reminded that their annual subscription, including payment for publications, for the period November 2018 – October 2019, becomes due on 1 November 2018 and should be paid no later than 1 December 2018. In September, the Society sent a reminder to all members to renew their subscription for 2018-19. If you have not received a reminder, please email membership@lms.ac.uk.

Members can now view and pay their membership subscriptions online via the Society's website at lms.ac.uk/user. Further information about subscription rates for 2018-19 and a subscription form may also be found on the Society's website: lms.ac.uk/content/paying-your-subscription.

The Society encourages payment by direct debit. If you do not already pay by this method and would like to set up a direct debit (this requires a UK bank account), please set up a direct debit to the Society with GoCardless.com via your online membership record: lms.ac.uk/user.

The Society also accepts payment by cheque and credit or debit card. Please note card payments are now accepted online only and can be made via your online membership record: lms.ac.uk/user.

Benefits of LMS membership include free online access to selected Society journals, a complimentary bimonthly LMS Newsletter, use of the Verblunsky Members' Room at De Morgan House in Russell Square and much more: lms.ac.uk/membership/member-benefits.

Elizabeth Fisher
Membership & Engagement Officer

REPORTS OF THE LMS

Report: LMS meeting at ICM 2018

2018 LMS Honorary Member Maria Esteban, with 2017 Honorary Member Étienne Ghys

At the recent ICM in Rio, a special LMS meeting took place at 6 pm on Tuesday 7 August 2018, taking advantage of so many members being present at the same time and place. It was followed by a reception an hour later, open to both members and non-members, although the latter was by invitation only.

The meeting, chaired by the President Caroline Series, was centred around a lecture *From Gambling to Random Modelling* by Professor Marta Sanz-Solé of the University of Barcelona, and a former President of the European Mathematical Society.

She presented a fascinating history of the development of different strands which went into the modern theory of stochastic analysis, focussing in particular on the works of Ito (1915–2008). As readers may recall, Ito was the first recipient of the Gauss Prize awarded at the ICM 2006 in Madrid. Stochastic analysis is a somewhat applied topic with which most pure mathematicians may not be very familiar, and hence the lecture was a welcome addition to general culture. The lecture took as point of departure the classical theory of Markov chains and invoked results and ideas of other distinguished Russians such as

Kolmogorov. It was well received but there was not really much time for questions, although Sir Michael Atiyah managed to get into a lively discussion with the speaker.

Concluding the meeting members were invited, in fact strongly encouraged, to sign the legendary Members' Book of the LMS, thereby joining the signatures of notables of the past such as Maxwell and Poincaré. The book has a long pedigree, and had been transported all the way to Rio to make the ritual possible.

Peter Scholze and Sir Michael Atiyah

At the meeting the number of members jumped by at least two as two Honorary Members of the LMS had been elected earlier in the year: the Rio Fields Medallist Peter Scholze (Bonn), and Maria Esteban (Paris), well known for her many contributions to industrial and applied mathematics. Scholze was unfortunately not present as he had left Rio already on the previous Sunday, but at the reception a ceremony was held at which Maria Esteban was presented with her certificate.

While the meeting took place in one of the lecture rooms, the reception took place on the top floor of the Grand Mercure Hotel in the grounds of the Congress. The actual venue is known as the Ibistro Ballroom, and had actually served as the venue for many other similar receptions during the Congress. It came equipped with a bar and a large balcony from which one had a striking view of the nearby lagoon and could imagine the main city of Rio further east, because the Congress took place at the very periphery of the widespread urban conglomeration where incidentally also the Olympics of 2016 was held.

Drinks and various titbits were being served by waiters discreetly balancing trays among crowding mathematicians. Needless to say, the reception turned out to be attended by more people than the actual meeting. Professor Atiyah was seated at the centre surrounded by people eager to have a word or two or at least to have a selfie taken with him.

Wiley, being one of the LMS's major publishers, had kindly sponsored the reception. The mingling continued for hours, and mathematicians not only had the opportunity to talk with each other, but also to meet representatives of Wiley and CUP and discuss publishing projects. It could be regretted that there was perhaps more alcohol served than food, and the reception continued in full flow until the bar was closed for the night.

Ulf Persson
Chalmers University of Technology
Gothenburg, Sweden

Report: Noether Celebration (LMS–IMA Joint Meeting)

Cheryl Praeger (University of Western Australia) *Emmy Noether, Symmetry, and Women in Mathematics*

The London Mathematical Society's Noether meeting, jointly organised with the Institute of Mathematics and its Applications, which took place on 11 September 2018, was an excellent occasion to celebrate the life, work, and legacy of Emmy Noether.

The first talk by Reinhard Siegmund-Schultze from the University of Agder focussed on the discrimination that Noether faced early on in her academic career owing to her gender and background. (See his article in Issue 476 of the *Newsletter*.) Siegmund-Schultze showed, among other things, using correspondence between noted mathematicians of the

period, that there was a fair bit of conservative sexist resistance against appointing Noether to the post of Privatdozent (this was the name of the academic post she deserved to occupy). There were some fascinating comments made by mathematicians such as David Hilbert, which Siegmund-Schultze quoted, that favoured Noether's promotion to said academic post and ridiculed the merit or lack thereof of the arguments against that.

Katherine Brading's talk, which followed Siegmund-Schultze's talk, discussed some of the puzzles and motivations behind a couple of Noether's famous results. She talked about Hilbert's famous assertion related to some of Einstein's results and showed how Noether's results were, in a way, answering a question that Hilbert had posed.

Elizabeth Mansfield's talk was probably a bit more mathematical than the first two talks — it discussed Noether's conservation laws in a mathematical setting and had a very fascinating result involving the rocks at Stonehenge.

Norbert Schappacher's talk, which followed, did an excellent job at discussing the philosophical and conceptual underpinnings of Noether's mathematical work, and also pointed out how often German–English mistranslations have hurt the historical record on such matters.

Norbert Schappacher (IRM/UFR de mathématique et d'informatique) *On Emmy Noether's conceptual mathematics*

The final talk of the meeting was given by Cheryl Praeger from the University of Western Australia. She laid out a general outline of Noether's mathematical legacy, talked about the discrimination that she faced in her mathematical life, and made some important yet cheerful points about how far the mathematical community has come in terms of representation of women in different mathematical associations, societies and unions over the years, as well as how far it still has to go.

Rudradip Biswas
PhD student in Mathematics
University of Manchester

Reports: LMS Travel Grants for Early Career Researchers

The London Mathematical Society Travel Grant Scheme for Early Career Researchers is open to all UK-based Early Career Researchers. See page 7 for details on how to apply. These are the reports of two awardees of ECR travel grants.

James Tuite (Open University): Support from an LMS Early Career Researcher Travel Grant allowed me to attend the Japanese Conference on Combinatorics and its Applications in Sendai from 20 to 24 May 2018. The conference was organised by the University of Tsukuba and took place at Sendai International Forum.

My primary research topic is extremal graph theory, in particular the degree/diameter and degree/girth problems and their relatives. The purpose of my trip to the conference was to present a talk on recent progress in the study of extremal mixed graphs, including new bounds on the orders of such networks and results on the regularity properties of extremal graphs. The talk was part of the symposium Graph Structure, organised by Professor Kenta Ozeki of Yokohama National University.

The conference included talks on the latest research in combinatorics, particularly in Japan, the USA and China, but with many other delegates from Europe and Asia. Topics of particular interest to me included rainbow connectivity, spectral theory, transversals of Latin squares, coding theory and Hamiltonicity and pancyclicity. The presentations and conversations with other mathematicians helped to broaden my

mathematical horizons and led to interesting connections between our different disciplines. This resulted in interesting new research problems and collaborations. The conference was a great success and I thank both the organisers and the LMS for their generous support.

Matthew Garrod (Imperial College London): A large and growing field within applied mathematics is network science. Network science applies techniques from domains such as graph theory, statistics, physics and machine learning to mathematically model and analyse large interconnected systems such as online social networks and biological networks. One of the largest international conferences within this field is NetSci, the 2018 edition of which was hosted in Paris from the 11 to 15 June 2018. The week-long conference included both independent sessions concerning topics such as Controlling Complex Networks and Statistical Inference for Network Models as well as keynote talks by distinguished researchers within the field and multiple poster sessions.

On 18 June, I presented a poster entitled *How Informative are Node Coordinates in Geometric Networks?* which contained a summary of some of my recent PhD research. The attendees of NetSci 2018 came from a wide variety of disciplines ranging from more mathematical or theoretical domains to scientists working in applied domains such as ecology or economics. As a consequence, presenting a poster was a unique challenge as it required having explanations of my work ranging from more entry level introductions to more mathematically sophisticated discussions.

Report: ICFT 22

ICFT 22, the annual UK Meeting on Integrable and Conformal Field Theory and Related Topics, took place 1 – 2 June 2018 at Cardiff University. The meeting, supported by an LMS Conference grant, served the dual purpose of reporting on new results and giving young researchers a chance to make themselves known. This year saw a particularly large representation of young speakers and a strong female representation with three of the eight speakers being female.

The first day, 1 June, had integrability as its theme with talks by Kasia Rejzner (York), Julia Cen (City University of London), Yoh Tanimoto (Tor Vergata) and Junpeng Cao (Chinese Academy of Sciences) with topics ranging from algebraic quantum field theory and operator algebraic constructions to solitons and the Bethe ansatz.

The second day, 2 June, focused on conformal field theories with talks by Ana Ros Camacho (Utrecht), Thomas Gemueden (ETH Zurich), Sam Fearn (Durham) and Cornelius Schmidt-Colinet (Munich) with talks on matrix factorisations, orbifolds of lattice vertex algebras, Mathieu Moonshine and renormalisation group interfaces. Due to particularly splendid weather, many discussions were continued in a nearby park after the meeting concluded.

Gandalf Lechner and Simon Wood
Cardiff University

Records of Proceedings at LMS meetings
Ordinary Meeting: 7 August 2018

The meeting was held during the International Congress of Mathematicians (ICM) 2018 at the Riocentro Conference Centre, Rio de Janeiro. Over 80 members and visitors were present for all or part of the meeting. The meeting began at 6.00 pm with the President, Professor Caroline Series, FRS, in the Chair. No applicants were elected to Membership.

The President introduced a lecture given by Professor Marta Sanz-Solé (University of Barcelona) on *From Gambling to Random Processing*. The President then invited Professor Sanz-Solé to randomly choose the winner of the LMS Buzzwire Competition from the names of 15 delegates who had completed the challenge. The winner was awarded a Fibonacci Spiral Clock.

After the meeting, a reception was held in the Ibistro Ballroom of the Grand Mercure Barra di Tijuca. The President welcomed members and guests. The President proposed a vote of thanks to the organising committee of the International Congress of Mathematicians 2018.

The President announced that the Society had elected Professor Peter Scholze and Professor Maria J. Esteban to Honorary Membership in 2018. The President then presented Professor Maria Esteban (CNRS/Paris Dauphine University) with her Certificate of Election. Professor Esteban expressed her thanks to the President and to the Society. The President then invited Professor Esteban to sign the Members' Book and be formally admitted to the Society. The President then invited Professor Etienne Ghys, who was elected to Honorary Membership in 2017, to sign the Members' Book. The President also announced that Professor Scholze had been presented with his certificate of Honorary Membership on Saturday 4 August during the International Congress of Mathematicians.

17 further members signed the book and were admitted to the Society.

Records of Proceedings at LMS meetings
Ordinary Meeting: 11 September 2018

The meeting was held at De Morgan House in London as a joint Meeting with the Institute of Mathematics and its Applications (IMA). Over 65 members and visitors were present for all or part of the meeting. The meeting began at 11.00 am with the President, Professor Caroline Series FRS, in the Chair. No members were elected to Membership at this meeting. Three members signed the book and were admitted to the Society.

Professor Series handed over to the President of the IMA, Professor Alistair Fitt, for the welcome from the IMA. Professor Fitt then handed over to Professor June Barrow-Green (Open University) who introduced the first lecture given by Professor Reinhard Siegmund-Schultze (University of Adger) titled *Some basic biographical facts about Emmy Noether (1882-1935), in particular on the discrimination against her as a woman*.

Professor Barrow-Green introduced the second lecture given by Professor Katherine Brading (Duke University) on *The puzzle that led to Noether's theorems*. After lunch, Professor Sara Lombardo (Loughborough University) introduced the third lecture by Professor Elizabeth Mansfield (University of Kent) on *Noether's Theorem, one hundred years later*. Professor Lombardo then introduced the fourth lecture given by Professor Norbert Schappacher (IRMA/UFR de mathématique et d'informatique) on *On Emmy Noether's conceptual mathematics*. After tea, Professor Alice Rogers (King's College, London) introduced the final lecture, which was given by Professor Cheryl Praeger (University of Western Australia) on *Emmy Noether, Symmetry, and Women in Mathematics*.

At the end of the meeting, the IMA President, Professor Fitt, thanked the speakers on behalf of the IMA. Professor Fitt then handed over to the LMS President, Professor Series, who thanked the speakers on behalf of the LMS and closed the meeting.

A reception was held at De Morgan House and a Joint Society Dinner was hosted by the IMA and the LMS at Pizza Express, Southampton Row.

Postcard from the International Congress of Mathematicians

MARIANNE FREIBERGER AND RACHEL THOMAS

Thousands of mathematicians gather every four years at the International Congress of Mathematicians to share and celebrate mathematics. This year it was in Rio de Janeiro, Brazil from 1 to 9 August — the first time it had been held in the southern hemisphere. We are the editors of *Plus* magazine, and were in Rio to report on the Congress in collaboration with the London Mathematical Society and the Institute of Applied Mathematics and its Applications.

Tuesday 31 July

After flying into Brazil in the dark, we woke to sun streaming over the spectacular mountainous islands rising behind the Riocentro conference centre. We were at the International Conference of Mathematicians (ICM) in Rio de Janeiro.

The job of the first day, the day before the conference officially began, was to ignore the jetlag and get the lay of the land. Palm trees and paths paved with white and black pebbles ran between the large blocky pavilions that comprised the conference centre. The open air lobby of the main ICM pavilion was bordered by a spectacular pond with exotic plants and flowers. It was lovely to be in touch with the sounds, smells and weather of Rio from the heart of the conference.

Once we'd done the necessary groundwork we joined many other delegates at the welcome reception in the mezzanine of the lobby. As well as a chance to reconnect with old friends, the music, caparinhas and food set the mood nicely for the conference and the excitement to come.

Wednesday 1 August

9am Wednesday saw around 4000 mathematicians eagerly waiting in the amphitheatre for the opening ceremony. We found out later the Brazilian organising team had made a superhuman effort to recreate the sets, seating and stage for the opening ceremony, after they lost all their preparations in a fire in another pavilion just 48 hours before.

The room was bathed in green light and echoed with the sounds of the jungle. Photographs of nature and traditional crafts were projected across the background, evoking mathematical shapes and structures. There was a hum of excitement as thousands of mathematicians waited to hear who had won the main prizes announced at the ICM, particularly the Fields medals.

The ceremony started with recognition of the traditional cultures of Brazil, and the promise of the future legacy of the ICM for mathematics in the country. After these opening remarks the winners of the first prizes were announced — the Carl Friedrich Gauss Prize went to David Donoho, the Chern Medal to Masaki Kashiwara, and the Leelavati prize to Ali Nesin — the medals would be awarded later in the conference. Then we reached the main event: the Fields medals were awarded to Caucher Birkar, Alessio Figalli, Peter Scholze and Akshay Venkatesh (see pages 20 – 23); and the Rolf Nevanlinna prize to Constantinos Daskalakis.

The opening ceremony

The announcements were accompanied by videos produced by the Simons Foundation, which gave a sense of the person and their mathematics. People outside of mathematics might be surprised to dis-

cover what a moving moment it is finding out who these people are and why they have been recognised. In the evening the Brazilian Mathematical Society invited all Congress participants to celebrate with music, drinks and food.

Thursday 2 August

Students celebrating Olympiad success

Day two and the conference began to widen out. We were treated to an excellent plenary from Simon Donaldson giving an overview of differential geometry, from his "crib review" of Riemannian geometry up to recent results. The talk turned out to be an excellent primer for many of the other talks, particularly by some of the Fields medallists.

Another plenary, by Sylvia Serfaty, on systems of points with Coulomb interactions, was a highlight and an excellent example of how mathematics can link areas together. The problem originally came from physics but now links to other fields in mathematics like number theory and statistical physics. Serfaty gave a broad view of the mathematics from the origin of the problem to its impact and implications.

The day was also a special one for over 500 students from the Brazilian Mathematics Olympiad of Public Schools. After the excitement of attending the opening ceremony the previous day, they were awarded their gold medals by some of the current and former Fields medallists. Alessio Figalli said: "I was really moved by seeing so many students from all around Brazil coming to the ICM to receive the award. Having a chance to meet them was a very rewarding experience. I hope that many of them will succeed in becoming professional mathematicians."

Friday 3 August

We were all getting into the swing of things by Friday morning. One of the draws for many is the frequent and easy interactions with fellow mathematicians from all over the world. Chatting with someone over breakfast from India or Sydney, meeting people during the break from Cameroon, chatting at a reception with delegates from Nigeria and Campuchea. The ICM increasingly aims to encourage delegates from all over the world, something the Brazilian hosts had boosted with their Open Arms travel grants to mathematicians from the developing world. "I find that really generous in [the ICM's] intent, to reach, mathematically, to everywhere in the world," said Nalini Joshi, an Australian mathematician who has just been elected Vice President of the International Mathematical Union (IMU).

Another feature of the ICMs is a series of public lectures which primarily target local audiences, particularly students and teachers. Friday saw Ingrid Daubechies, former President of the IMU, talk about the role of maths in restoring art, including examples of recreating Italian frescoes from just the few pieces that remained after damage during the war. It was a fascinating story of the impact of mathematics told compellingly by someone involved in the development of both the theory and application.

Saturday 4 August

Peter Scholze

One of Saturday's highlights was Lai-Sang Young's lecture on dynamical systems, described by many as a masterclass in how to give a plenary. She presented a broad picture of how her subject had developed,

explaining her work in a way that drew the audience along with her.

Saturday also gave LMS members the opportunity to meet the Fields Medallists Peter Scholze and Caucher Birkar. Scholze was presented with his honorary membership of the LMS by Caroline Series. Members had the opportunity to congratulate Birkar in the evening, where he had a long and animated conversation with Sir Michael Atiyah.

Saturday was also significant for Birkar as he became the only person ever to be presented with the Fields medal twice! Birkar's briefcase, containing his Fields medal, had been stolen from his seat as he stood to receive congratulations in the moments after the ceremony. This was obviously a very unfortunate and stressful moment for both Birkar and for the Brazilian organisers. But Birkar's gracious speech on receiving his replacement medal was a moving and very positive resolution.

Birkar started with a cheerful point: as well as making him more famous the theft also resulted in many more people being aware of the Fields medals (as the theft was widely reported in the media). And he put the event into perspective: "In the beginning it was a shock, it happened so fast," Birkar said. "But very soon I recovered. In the grand scheme of things this is a really, really small thing. I have seen much worse things in my life, and if I was discouraged by such small things I wouldn't be here today."

Sunday 5 August

The congress dinner

For many, Sunday was the chance to recover from the night before. The conference dinner had been an enjoyable and particularly Brazilian experience with a Samba group turning it into Mardi Gras. Sunday was a scheduled day off in the middle of the conference and many took the opportunity to explore the spectacular city of Rio de Janeiro. Mountains were climbed, beaches were enjoyed and chop (draught beer) was drunk overlooking the sea.

Monday 6 August

Monday saw a rarity — a plenary given by two mathematicians. Peter Kronheimer and Thomas Mrowska delivered a plenary on knot theory, beautifully illustrated by wonderful graphics and carrying their audience along with them. Their final, gripping, slide, modestly explained how an as-yet-unproved conjecture offered an avenue to a non-computer-assisted proof of the four-colour theorem.

Monday also saw the last of the Fields medal lectures by Venkatesh, Scholze, Figalli and Birkar. They gave a view across vast swathes of mathematics in their plenaries and it was particularly interesting to spot the concepts interwoven between the different areas of their work.

Tuesday 7 August

We were particularly looking forward to Tuesday's lecture by David Donoho, winner of the Gauss Prize. He had said in his interview with us that he had a message he thought would be useful for the gathered mathematicians to hear. "It's about an important application area and a kind of a triumph for mathematics." His talk explained how the mathematics improving MRIs had gone from the blackboard (including the work of Fields Medallist, Terry Tao) to the bedside in just over a decade.

The lecture consisted of a talk within a talk: the presentation Donoho gave to the US Congress about the benefits mathematics for patients and taxpayers. The plenary was also a deeply personal story, showing the impact mathematics can have on people's lives — how it can "do work for human good" — including those of Donoho's immediate family. The development of compressed sensing has meant that when you next have an MRI the time you have to lie still in the claustrophobic machine will be greatly re-

duced, with no reduction in the quality of the image produced.

Tuesday evening saw the chance for LMS members to sign the famous Members' Book, including Maria Esteban who was also awarded an Honorary Membership in 2018. The lecture of Marta Sanz-Solé was followed by a reception at the top of the conference centre hotel.

Participants at one of the receptions

Wednesday 8 and Thursday 9 August

The final prize lecture of the conference was by Ali Nesin, the winner of the Leelavati prize, along with help from his friend and colleague, the architect Sevan Nisanyan. Nesin explained the inspiring story of creating a mathematical haven from nothing, which you can read about on page 24. The scale of this project, in philosophy, practicality and political and personal challenge, was immense and the lecture concluded with a standing ovation.

The ICM is a chance to meet people and hear about work from around the world, a chance to broaden your mathematical culture. This tradition will continue in the 2022 ICM to be held in St Petersburg, Russia. Stanislav Smirnov, one of the organisers, said they hope to extend Rio's work encouraging mathematicians from developing countries to participate. Although you might think that in this age of email and skype we all have wider access to our mathematical colleagues, nothing beats personal interaction and face-to-face communication. The Russian organisers hope, at the 2022 ICM, to give delegates even more opportunities to talk and collaborate with each other.

The chance to connect with people and the celebration of mathematics as a social, collaborative enterprise seems to have been the overwhelming highlight for everyone we met at the ICM. Even the celebration of excellence of the prize winners recognised this. "Maths is really a very social discipline — none of these amazing stars could exist in isolation," said Jack Thorne. It's a chance to come together with other mathematicians, meet old friends and make new ones, make connections and start potential collaborations. It's vital for the health of mathematics. "The ICM gives me a strong sense of the international mathematical community," said one attendee. "It makes me proud to be a mathematician."

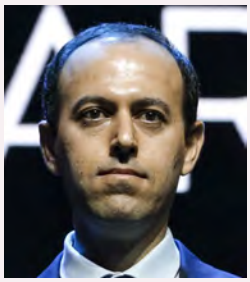
Thanks to many delegates who spoke to us about their experiences at the conference, particularly Stephen Huggett, June Barrow-Green, Cheryl Praeger, Nalini Joshi, Jack Thorne, Alessio Figalli, David Donoho, Clément Mouhot, Ivan Smith, Maria Esteban.

Marianne Freiberger and Rachel Thomas

Marianne Freiberger and Rachel Thomas are the editors of *Plus* magazine (plus.maths.org), a free online maths magazine for the general public. *Plus* is part of the the Millennium Mathematics Project, based at the University of Cambridge. Marianne and Rachel have written and edited several popular science books.

After studying semigroup theory at the University of Western Australia, Rachel was a maths consultant working for government and industry. Marianne did her PhD in complex dynamics at Queen Mary, University of London. Together they believe they can find the maths in anything, including the Archers.

Fields medal: Caucher Birkar



Caucher Birkar received a Fields medal for his contributions to algebraic geometry, in particular to the effort to classify algebraic varieties. Much of Birkar's work focuses on complex projective varieties. In particular, he has made spectacular breakthroughs regarding a classification scheme known as the minimal model programme (MMP).

Inspiration for this comes from varieties of complex dimension one and goes back to the work of Bernhard Riemann. Every such variety can be associated to a compact Riemann surface, and compact Riemann surfaces come in three types: those with positive curvature, zero curvature, and negative curvature.

In the early 20th century a group of Italian mathematicians turned their attention to smooth complex projective varieties of dimension two. As is the case for one dimension, their classification involves three types of varieties. They are Mori–Fano fibre spaces, made from Fano varieties, Calabi–Yau fibre spaces, made from Calabi–Yau varieties, and varieties of general type. The approach uses a series of "surgery type" operations — contracting a special kind of curve to a point — to turn a two-dimensional variety into a simple variety belonging to one of these three types.

An important concept in the classification context is that of birational maps. Loosely speaking, a birational map between two varieties can turn a blind eye to small subsets of the varieties that might otherwise prove awkward, and therefore provide a flexible way of relating varieties to each other. The surgery type operation developed by the Italian group always yields a variety that is birationally equivalent to the one that was operated on. Therefore, every smooth two-dimensional complex projective variety is birationally equivalent to a variety of one of the three simple types.

In dimension three and greater, the aim is still to relate each projective variety to a simpler one belonging to one of three types. But the technique developed by the Italians doesn't work: the curves that could be contracted on two-dimensional varieties don't exist in higher dimensions. The minimal model problem (MMP) was developed to generalise the Italian scheme. The aim is to show that any smooth complex projective variety either has a minimal model (simple relative) which is of the Calabi–Yau fibre space type or the general type, or that there's a variety birationally equivalent to it, which admits a Fano fibration.

One stumbling block to establishing the MMP is that there are smooth complex projective varieties that have no smooth minimal model: varieties with singularities could not be avoided. During the 1970s and early 1980s, however, it became clear that certain singularities were a price worth paying for the overall simplicity that could be gained, and that it was still feasible to put the MMP into practice. Thus, varieties with these singularities were allowed into the picture.

A surgical operation used to deal with singularities, called a *flip*, presents a major problem, however. It is generally not clear that the required flips always exist, and even if they do, whether sequences of flips always terminate to give a minimal model. For complex projective varieties of dimension three these problems were overcome in the 1980s. But in higher dimensions many obstacles still existed.

It's in this area that Birkar has made groundbreaking contributions. For example, in a paper published in 2010 he proved, together with Paolo Cascini, Christopher Hacon, and James McKernan, a result which implies the existence of flips in dimensions greater than two and the existence of minimal models for varieties of general type in arbitrary dimension. The paper ventured into territory people previously thought was inaccessible, and introduced tools that are now widely used.

In 2016 Birkar also proved that Fano varieties form a bounded family, another spectacular result with important implications for the MMP in which they play a central part. This boundedness, so Birkar's citation states, "will be crucial as a paradigm for the full MMP". As of now, a full proof that the MMP works in all dimensions remains elusive, though Birkar's contributions to the area are bound to lead the way.

Fields medal: Alessio Figalli

Alessio Figalli has been awarded the Fields medal for "his contributions to the theory of optimal transport and his applications in partial differential equations, metric geometry and probability".

Optimal transport theory is about transporting resources from one place to another in the most efficient way — you want to find a transport map that minimises some cost function.

The first thorough mathematical treatment of optimal transport problems arrived in the late eighteenth century with the work of the French civil engineer Gaspard Monge. Monge's mathematical formulation involves minimising an integral over cost functions with respect to certain probability measures. Solving such a problem is difficult due to a high degree of non-linearity, and because the problem might be ill-posed. It wasn't until the 1940s that significant progress in the area was made by Leonid Kantorovich, using measure theory and functional analysis. During the 1980s further important developments followed.

Figalli has been lauded for a wide range of theoretical results in optimal transport theory. Despite being a "pure mathematician 100%" two particularly interesting examples of his work are inspired by physical problems. One of these examples comes from the field of meteorology. To model large-scale atmospheric flows, meteorologists use the semi-geostrophic equations. These can be derived from the Euler equations of fluid flow, and are valid on scales at which the rotation of the Earth dominates atmospheric flows. (The term "geostrophic" describes a balance of the Coriolis force, caused by the Earth's rotation, and the pressure gradient force.)

The semi-geostrophic equations can be used, for example, to describe the formation of atmospheric fronts, but useful solutions aren't easy to come by: solutions may not exist, or they may be unphysical. The link to optimal transport theory lies in the fact that nature is a great optimiser. Clouds, for example, move so as to dissipate as little kinetic energy as possible. This means that the motion of infinitesimal particles imagined to make up a cloud can be described as an optimal transport process.

Mathematically, the cost function in this optimal transport problem is the square of distance travelled (proportional to kinetic energy). For such cost functions optimal transport maps exist, are unique, and are related to the well-known Monge–Ampère equation. Figalli's groundbreaking contribution to the area, in collaboration with Guido De Philippis, was a new understanding of solutions to the Monge–Ampère equation, which allowed the optimal transport set-up to be applied to the semi-geostrophic equations. Together with Luigi Ambrosio and Maria Colombo, the pair then also proved the global existence of solutions to the semi-geostrophic equations in three-dimensional convex domains.

The other interesting result inspired by applications, which we alluded to above, involves an isoperimetric problem. As is well-known, soap bubbles assume a spherical shape in order to minimise their surface energy. The same goes for crystals: they "choose" a shape that has the least surface energy for their volume. The question Figalli considered is how the shape of the crystal changes when you add energy to it, for example by heating it up.

Together with Francesco Maggi and Aldo Pratelli, Figalli considered how individual particles making up the crystal would move in response to the extra energy, turning the process of shape-changing into an optimal transport problem. The three were able to prove a surprisingly neat and general result: the shape of the crystal can change by at most the square root of the energy added.

Figalli has been honoured not only for the depth of his results, but also their breadth. His webpage at the ETH in Zurich lists a total of twelve research areas, and, although aged only 34, he already has around 150 publications to his name.

You can see a video interview with Figalli at (tinyurl.com/y7m77oog) and read a more detailed but still accessible account of Figalli's work on the IMU website (tinyurl.com/y9t8scto).

Fields medal: Peter Scholze

Peter Scholze has been awarded the Fields medal for "transforming arithmetic algebraic geometry over p-adic fields through his introduction of perfectoid spaces, with application to Galois representations and for the development of new cohomology theories."

Perfectoid spaces are testament to the vibrancy of mathematics. They were introduced by Scholze in 2011 and have revolutionised algebraic and arithmetic geometry. They have allowed Scholze and others to resolve important open problems and provided a bridge between the areas of topology, Galois theory and p-adic geometry.

Scholze was inspired to create perfectoids as he wanted to answer questions about equations over different types of fields. (It can be easier to tackle problems for fields with positive characteristic than for fields with characteristic 0. The characteristic of a field is the smallest number of times you must add the multiplicative identity to itself to get the additive identity.) For an example of this, consider varieties: sets of solutions of collections of polynomial equations. When these polynomials are over real numbers, the variety can often be easily visualised as a space. For example the polynomial $ax^2+by^2 = cz^2$ is the surface of a cone. But varieties taken over different fields, such as those with positive characteristic, result in more abstract spaces. During the 1960s Alexander Grothendieck established that there was a connection between varieties over fields of positive characteristic p, and the Galois group of their defining polynomials.

In particular, Scholze wanted to solve problems in fields with p-adic arithmetic, which have characteristic 0. In these infinite fields the p represents a prime number that defines a new measure of closeness. Two numbers are close not if they are close in value, but if their difference is divisible by a power of the prime number p. The higher the power, the closer the two numbers are. This concept is useful in areas such as number theory where you want to solve equations involving congruences modulo some prime number p.

In the 1960s Alexander Grothendieck conjectured there was a p-adic version of Hodge theory. The original version of this drew together singular cohomology — information about the number of holes in a space — and de Rham cohomology — which concerns the analytic structure of the space. The British mathematician W.V.D. Hodge proved that for varieties over complex numbers, singular and de Rham cohomologies are equivalent, and offer different ways of obtaining the same information about the space. Perfectoids are infinitely winding, fractal-like objects that bridge p-adic arithmetic and geometry. They are spaces with étale cohomology — an algebraic version of singular cohomology — in which p-adic arithmetic can be used to understand the geometry and topology of the spaces, providing just the right setting for p-adic Hodge theory. They enable "tilting" the p-adic numbers, with characteristic 0, to fields of characteristic p, so that the tools of Galois theory that are available for fields of characteristic p can be transported to the setting of p-adic numbers.

Perfectoid spaces have already had a great impact on mathematics in a very short time. Scholze has used them to prove Deligne's weight-monodromy conjecture in important new cases. They were also pivotal in his proof of the existence of Galois representations attached to the cohomology of locally symmetric spaces. Scholze's work is opening up new avenues for research and might even shed light on some deeper unifying aspects of mathematics.

The development of perfectoids also demonstrates the role of mathematics as a language, and the importance of having the right language for what you are trying to do. "The key issue for me is finding the right definitions, finding the right notions that really capture the essence of some mathematical phenomenon," says Scholze. "I often have some vague vision of what I want to understand but I'm often missing the words to really say that. But then sometimes I read some other paper and there's this definition that really clicks, and suddenly I can say what I always wanted to say." Scholze is expanding the language of mathematics and allowing us to tell new, beautiful and perhaps surprising mathematical stories.

Fields medal: Akshay Venkatesh

Akshay Venkatesh has been awarded the Fields medal for his "synthesis of analytic number theory, homogeneous dynamics, topology, and representation theory".

Most of Venkatesh's career has involved exploring the borders of number theory with other areas of mathematics. He has brought together concepts and tools from different areas with great impact on solving open problems and pointing the way to future progress. This ability is illustrated by his resolution of the subconvexity problem in number theory.

The subconvexity problem essentially concerns the size of L-functions. L-functions are generalisations of Riemann's ζ-function and are pivotal objects in number theory today. The Riemann hypothesis conjectures that the points at which the ζ-function vanishes all lie along the critical line formed by points in the complex plane with real part equal to a half. The subconvexity problem is concerned with tightening the upper bound on the size of L-functions along a critical line.

The problem had been of some interest since Weyl's work a century ago, but has been the focus of more intense work in the last 10 to 15 years due to its applications, including links between number theory and chaos in quantum systems. Venkatesh, in part jointly with Philippe Michel, resolved the subconvexity problem in 2010. The result generalised all previous work on bounds for the problem and also brought together approaches from representation theory and dynamical systems, proving significant new results in these areas along the way to a final proof.

Another example of Venkatesh's ability to bridge areas, this time number theory and topology, is his work with Jordan Ellenberg and Craig Westerland on Cohen–Lenstra heuristics. These are surprising heuristic results, developed in 1984 by Henri Cohen and Hendrik Lenstra, about how class numbers (which indicates how close a ring is to unique factorisation) vary over all possible rings. The heuristics seemed to work, but no one had insight as to why until the work of Venkatesh and his coauthors in 2016. They achieved their results by connecting topology and number theory: first proving a new result in topology about the homological stability of Hurwitz spaces, and then translating this understanding back to number theory to prove that the predictions of some of the Cohen–Lenstra heuristics were valid.

Venkatesh delivered a striking Fields medal lecture at the ICM, covering ongoing work formed, as he put it, from "conjectures based on conjectures". These bold conjectures relate to the Langlands program and the connections between topology, analysis, algebra and number theory. A famous example of one these connections appeared in Andrew Wiles' proof of Fermat's Last Theorem.

Wiles' proof, with crucial input from Richard Taylor, relied on a method that connects elliptic curves with modular forms — illustrating the connection between geometry and analysis predicted by the Langlands program. The Taylor–Wiles method applied in the restricted setting of Shimura varieties, but a recent result from Venkatesh generalises these to non-Shimura varieties.

The conjectures Venkatesh spoke of in his lecture involve topological objects called locally symmetric spaces which, Venkatesh and his coauthors have shown, exhibit unexpected symmetries. They have made progress proving special cases of these conjectures, and checking numerical predictions that arise. The mathematical community expects that proofs of these conjectures, and the tools and connections that will result along the way, will be a vital step to completing the Langlands program.

Venkatesh has been incredibly successful in making surprising and rich connections between different areas of mathematics, but he doesn't hide the fact that it has taken a lot of hard work: "A lot of the time when you do math, you're stuck. But at the same time there are these moments where you feel privileged that you get to work with it. And you have this sensation of transcendence. You feel like you've been part of something really meaningful."

You can see a video interview with Venkatesh at (tinyurl.com/y9pbxj92) and read an account of his work on the IMU website (tinyurl.com/y83k25fm).

Leelavati prize: Ali Nesin

Ali Nesin received the Leelavati Prize for his "tireless work in creating and developing the 'Mathematics Village' as an exceptional, peaceful place for education, research and the exploration of mathematics for a wide range of people." The award is named after the 12th Century mathematical treatise *Leelavati* and is for outstanding contributions for increasing public awareness of mathematics.

When Nesin's father, the renowned writer Aziz Nesin, died in 1995, Nesin returned to his homeland of Turkey to work as the director of the Nesin Foundation. He also became head of the mathematics department at Istanbul Bilgi University, working to create a department that would offer education on a comparable level to international institutions. But Nesin soon realised that the students arriving at the university were not ready for such an education.

After running a series of summer workshops to address this, Nesin began to dream of something better. The Mathematical Village was launched in 2007 when over 100 students, mostly from Bilgi University, attended the first summer school. Since then it has welcomed thousands of high-school and university students, who stay for two weeks at a time and pay a small fee to cover their food and accommodation, but no students are refused on a financial basis. It is a beautiful, peaceful environment, with amphitheatres, open-air lecture rooms, Turkish baths and a two-storey library decorated with geometric mosaics.

University students are taught (in English) by mathematicians visiting from all over the world. These mathematicians volunteer to lecture to the students, and are provided with food and lodging in return. "I went there initially because it had been strongly recommended to me by friends, and I was curious. Then I went back because I had enjoyed it so much!" says Stephen Huggett, from the University of Plymouth, who visited to teach undergraduate and postgraduate students.

Nesin created this mathematical paradise despite significant economic and political challenges. He was unable to get official permission to build the Village. The local authorities said this was because educational institutions required the permission of the government, despite the fact that the Mathematics Village is a nonprofit organisation that doesn't award any educational qualifications or degrees.

A lecture room at the Mathematics Village (Photo: Stephen Huggett)

A possible reason for the official resistance is that Ali Nesin's father was a prominent atheist, a controversial belief in religiously conservative Turkey. The architect of the Mathematics Village, Sevan Nisanyan, who is also a prominent atheist, faced 19 separate court cases because he refused to stop building the village. He was jailed for its illegal construction in 2014. "It was established against the bureaucracy of the state, an act that we took major risk for and suffered major consequences for," said Nisanyan. He escaped jail in 2017 and is living in Greece. Hundreds of other intellectuals across Turkey have also been arrested, and hundreds or thousands of scholars have fled Turkey.

But despite all this, on the hillside near Izmir, Nesin has created a haven for mathematical learning, creativity and joy. There is only an invitation to enjoy doing mathematics. And Nesin has given many hundreds of people — from high school students to research mathematicians — a chance to do just that. "The mathematics village is for the future artists, scientists, politicians and creators of Turkey and the world. We welcome all." said Nesin.

You can find out more, including how to contribute, at www.nesinkoyleri.org/eng/

The Centenary of the Hardy–Ramanujan Partition Formula: The LMS Connection

ADRIAN RICE

This year marks one hundred years since the publication of one of the most remarkable and surprising results in the history of number theory: Hardy and Ramanujan's asymptotic formula for the unrestricted partition function. We explore how the LMS played a small but vital role in the formula's creation.

Many mathematicians will be familiar with the famous Hardy–Ramanujan formula for the unrestricted partition function. If $p(n)$ represents the number of ways a positive integer n can be written as a sum of positive integers, in which the order is irrelevant, then

$$p(n) = \sum_{q=1}^{[\alpha\sqrt{n}]} A_q(n)\phi(n) + O\left(n^{-1/4}\right),$$

where

$$A_q(n) = \sum_{p=1}^{q} \omega_{p,q} e^{-2n\pi pi/q},$$

and

$$\phi(n) = \frac{\sqrt{q}}{2\pi\sqrt{2}}\left[\frac{d}{dz}\left(\frac{\exp\left(a\lambda_z/q\right)}{\lambda_z}\right)\right]_{z=n},$$

with $z \in \mathbb{C}$, $p, q \in \mathbb{Z}^+$, $(p,q) = 1$, $a = \pi\sqrt{2/3}$, $\lambda_z = \sqrt{z - \frac{1}{24}}$, and $\omega_{p,q}$ a certain $24q$-th root of unity.

Today of course, it is more likely that the refinement proved by Rademacher in 1937 [2] would be used:

$$p(n) = \sum_{q=1}^{\infty} A_q(n)\frac{\sqrt{q}}{\pi\sqrt{2}}\left[\frac{d}{dz}\left(\frac{\sinh\left(a\lambda_z/q\right)}{\lambda_z}\right)\right]_{z=n},$$

a convergent series which gives the exact value of $p(n)$ for *any* positive integer n. Regardless of which version is used, few mathematicians are probably aware that this year marks the centenary of the formula's original publication. This centenary is celebrated in a paper recently published in the *American Mathematical Monthly*, [3], which traces the mathematical story of this spectacular result. But one further detail with which even fewer people would be familiar is the small but crucial role the LMS played in the development of this remarkable formula.

The subject of partitions had occupied the attention of several early LMS members in the 19th century. These included Presidents such as Augustus De Morgan, Arthur Cayley, and especially James Joseph Sylvester, who introduced the use of combinatorial and graph-theoretic methods to the subject. A slightly later 19th-century LMS member and President who devoted many years to partitions was former army officer Major Percy MacMahon.

Unusually for a prominent British mathematician — then and now — MacMahon had never studied mathematics at university, receiving his mathematical training as a cadet at the Royal Military Academy in Woolwich. This resulted in a more pragmatic, computational approach to much of his mathematics, a style which by the turn of the 20th century appeared somewhat old-fashioned compared to the more analytic methods of younger contemporaries such as Hardy and Littlewood.

Perhaps sensing this, MacMahon used his 1896 LMS presidential address to bemoan the relative neglect of partitions by British mathematicians at the time:

> The theory requires further elucidation and development, and it is to be hoped that workers in our science will now, after a period of forty years, give it some attention.

Although he had to wait a further twenty years, that attention was duly given by G. H. Hardy and Srinivasa Ramanujan in their monumental work on partitions, presented at an LMS meeting on 18 January 1917 and published in a groundbreaking paper entitled *Asymptotic formulae in combinatory analysis* the following year, [1].

Hardy and Ramanujan had spent much of 1916 building an increasingly sophisticated formula for the par-

tition function, incorporating techniques from complex analysis and the theory of modular forms. After several modifications, by late in the year, they had arrived at the following form:

$$p(n) = \sum_{q=1}^{m} A_q(n)\phi(n) + O\left(e^{\delta\sqrt{n}}\right),$$

where $\delta < \pi\sqrt{2/3}$.

It was here that Hardy's connections within the LMS came into play. "At this point" he later recalled, "we might have stopped had it not been for Major MacMahon's love of calculation". At Hardy's request, MacMahon single-handedly calculated every value of $p(n)$ for $n = 1$ to 200, using the recurrence relation

$$p(n) - p(n-1) - p(n-2) + p(n-5) + p(n-7) - p(n-12) - p(n-15) + \cdots = 0.$$

a process that apparently took over a month. MacMahon's computations provided crucial numerical corroboration of the validity of Hardy and Ramanujan's formula: "We expected a good result, with an error of perhaps one or two figures, but we had never dared to hope for such a result as we found." For example, the first six terms of their formula gave $p(100) = 190,569,291.996$, whereas MacMahon's precise number was $p(100) = 190,569,292$. Most astonishingly, the first eight terms of their formula gave $p(200) = 3,972,999,029,388.004$, while MacMahon's calculations revealed that $p(200) = 3,972,999,029,388$.

It was because of MacMahon's input, as Hardy later wrote, that he and Ramanujan "were inevitably led to ask whether the formula could not be used to calculate $p(n)$ *exactly* for any large n." In order to do this, in their formula, they now made m a function of n, specifically, the integer part of $\alpha\sqrt{n}$, where α is an arbitrary positive constant. The result was an error term with order of magnitude of at most $n^{-1/4}$ and an asymptotic formula of unprecedented accuracy. It is perhaps not surprising that, as Hardy and Ramanujan acknowledged in their paper:

> To Major MacMahon in particular we owe many thanks for the amount of trouble he has taken over very tedious calculations. It is certain that, without the encouragement given by the results of these calculations, we should never have attempted to prove theoretical results at all comparable in precision with those which we have enunciated.

That paper is now exactly 100 years old and, like Rademacher's subsequent improvement of their formula, it was published in the *Proceedings of the LMS*. But it was not just via this venue of publication that the LMS helped to bring this result to the wider world. As Hardy and Ramanujan acknowledged, their formula could not have reached its final form without MacMahon's vital input — and this input was facilitated in part by the LMS. Although Hardy and MacMahon's approaches to mathematics were completely different, their mutual membership and regular attendance of LMS meetings (and in particular, their service on the LMS Council) led to social contact, respect for each other's work and, ultimately, to MacMahon's offer of valuable help.

So, how much credit can be given to the LMS for the Hardy-Ramanujan formula? Obviously, Hardy and Ramanujan's joint work on partitions would have occurred with or without the LMS. But it was the LMS, the venue of their paper's initial presentation, which ensured the vital input of MacMahon, and the place of its eventual publication. Without these crucial factors, the exact form of Hardy and Ramanujan's paper, the precision of the results it contained, and the influence it was able to exert might all have been very different. The LMS thus served as a small but useful catalyst for one of the most significant results in early 20th-century British mathematics.

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Adrian Rice

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‘Apocalyptic volcanic super eruption that could DESTROY civilisation is much closer than we thought, say experts’

JONATHAN ROUGIER

A volcanic ‘super-eruption’ is capable of returning humanity to a pre-civilization state. I describe the challenges of estimating the global magnitude/frequency relationship for large explosive eruptions, and some of the wider issues that arise. I also describe what happened when the popular press picked up on our research.

Introduction

The magnitude (M) scale for volcanic eruptions is quite innocuous, with large eruptions occupying the range from 4 to 9. But, like the Richter scale for earthquakes, the M scale is $\log_{10}$:

$$M = \log_{10}(\text{ejected mass in kg}) - 7$$

so that $M = 5$ is a gigatonne of mass, and $M = 8$ is 1000 gigatonnes. If gigatonnes of mass erupts explosively, then its injection into the upper atmosphere can cause regional and even global effects. Explosive eruptions at $M = 8$ or above are known as ‘super-eruptions’, and their impact is continental-scale, in terms of ash deposition; and global-scale, in terms of decade-long weather perturbations caused by sulfuric acid aerosols, sometimes termed ‘volcanic winter’ [7].

Over the last few decades the world’s economy has developed in a quiescent environment under the stimulus of growth and profit, rather than resilience. The resulting globe-spanning dependencies make us particularly vulnerable to hazards with a global footprint. Eminent volcanologist (and co-author) Stephen Sparks gives a sobering assessment of the outcome of a super-eruption on today’s world:

> Together with changing patterns of wet and dry conditions, huge food shortages and global economic collapse seem inevitable. It is hard to see more than a small fraction of the current world’s population surviving such hostile conditions.[1]

Thus our recently-published estimate of the global magnitude/frequency relationship for large explosive eruptions [6] had an end-of-civilization angle.

In this article I will explain the challenges of estimating the magnitude/frequency relationship from the historical record, present our results, outline some ongoing work about more practical considerations, and describe what happened when we published our paper.

The historical record

The historical record of large explosive eruptions is inferred from the ash (technically, ‘tephra’) layers which are deposited on the surface of the land and ocean, and then interred, to be rediscovered in exposed outcrops and core samples. This inference is very imprecise, and the two obvious things to watch out for are rounding of the magnitude estimates (reflecting, perhaps, a psychological aversion to unwarranted precision), and under-recording, which will vary by location, time, and magnitude. Our data were taken from the LaMEVE database [1], containing eruptions with $M \geq 4$. We updated the database during the analysis, to reduce some artefacts, and revise some of the magnitude estimates, especially the large ones.

The presence of rounding in the database is easily established by plotting the frequencies of the magnitude estimates by their values: there is piling-up on the integer values (see Figure 1). We were unable to eliminate this piling-up by widening the bins from 0.1 to 0.25 or 0.5. Therefore we addressed the rounding problem by grouping magnitudes into unit-width bins centered at the integers: $[4.5, 5.5)$, $[5.5, 6.5)$ etc. This was a different practice to some other groups, who created bins by rounding down the magnitudes: $[4.0, 5.0)$, $[5.0, 6.0)$, etc. The LaMEVE database starts at $M = 4$, and so we had to drop those eruptions with $4 \leq M < 4.5$ from our analysis.

[1] tinyurl.com/y7zfba8e.

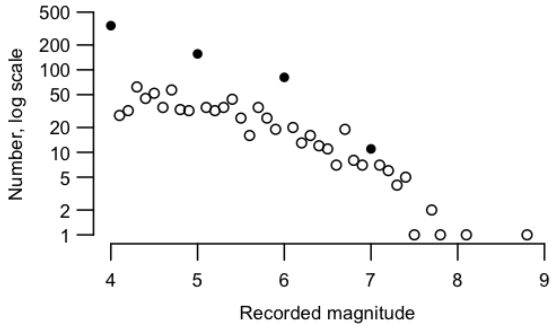

Figure 1. Rounding: the recorded magnitudes pile up on the integer values (note the logarithmic vertical scale).

Under-recording in the database is much more challenging. We had documented the widescale and substantial under-recording in two previous papers [4, 5]. The challenge is that the recording probability, like the frequency, varies by magnitude: the two processes are confounded. We tried various approaches to modelling the global recording probability explicitly as a function of time and magnitude, but nothing really worked.

In the end, we decided that we would have to use the record going back 100 thousand years (ka) to identify the recent period where the recording probability was effectively 1, for each magnitude bin, and then base our estimate only on this recent period. Using only a small fraction of the available records increases the uncertainty in our estimates, but, from a conservative point of view, this is preferrable to making strong assumptions about the under-recording process.

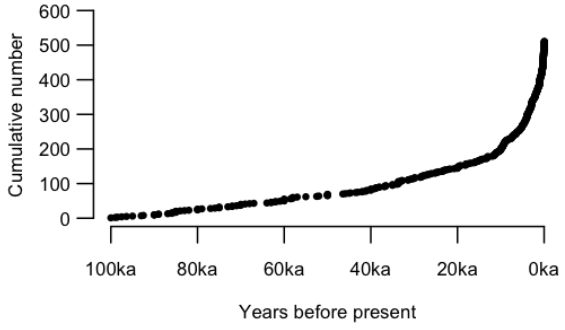

Figure 2. Under-recording for $M \in [4.5, 5.5)$. In our model, we treat the rate of eruptions at a specified magnitude as effectively constant. Convexity indicates that the recording probability is falling going backwards in time.

We plotted the cumulative number of eruptions in the database as a function of time, for each bin (see Figure 2). Working backwards from today, for which the recording probability is 1, we identified, by eye, the first upward bend, elbow, or gap (see Figure 3).

It is not necessary to be really accurate in dating the first bend, because the crucial issue is that the average recording probability since the date is close to 1.

The date of 1600 CE for the bin $[4.5, 5.5)$ (see Figure 3) is consistent with our previous work, and with the narrative evidence, which associates improvements in recording with the colonial expansion of western European countries in the late 16th century [8]. In the end we used 1600 CE for the bin $[4.5, 5.5)$ (82 recorded eruptions), 500 CE for $[5.5, 6.5)$ (28 eruptions), and 300 BCE for $[6.5, 7.5)$ (13 eruptions). We used the full 100 ka for $M \geq 7.5$, comprising 4 eruptions in $[7.5, 8.5)$, and 1, Toba in Indonesia, a massive $M = 9.1$.

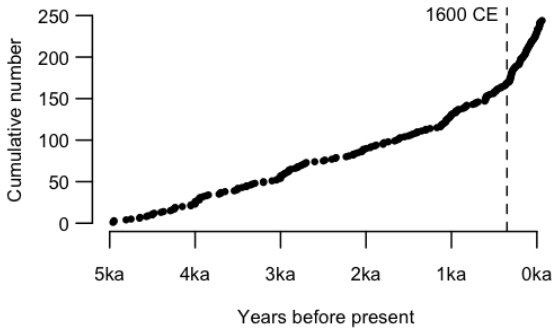

Figure 3. Under-recording for $M \in [4.5, 5.5)$. Zooming in on the recent past to find the first upward bend, elbow, or gap. We chose the value 1600 CE by eye.

Results

Our statistical model asserts that that, globally, large explosive eruption times follow a Poisson process, and that the eruption magnitudes are independent of the history of the process; i.e., a marked Poisson process [2]; see "Poisson processes" below for more details. The Poisson process model at the global scale is much weaker than a Poisson process model for each volcano; the latter is harder to defend because the magma chamber under a volcano would typically need some time to recharge between large explosive eruptions. Our model is homogeneous in time, although in the paper we discuss the effect of ice loading and unloading in the northern hemisphere, through the most recent ice-age.

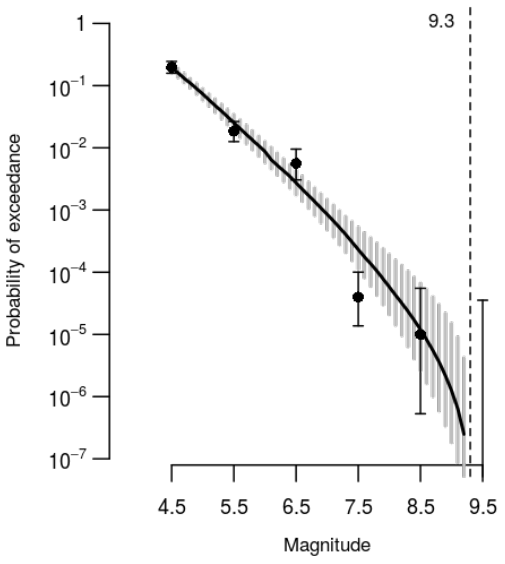

Figure 4. Exceedance probability: the probability of at least one explosive eruption of at least the specified magnitude, happening somewhere on earth in the next year. The dots and error bars represent bin-based maximum likelihood point estimates and 95% uncertainty intervals, aligned with the lower bound on each bin. The solid line represents a parametric fit with pointwise 95% uncertainty intervals.

We presented our results as an exceedance probability curve (see Figure 4). The smooth curve involves an additional parametric model for the distribution of magnitudes, plus some further adjustments. We truncated the magnitude at $M = 9.3$, although we showed that the choice of this upper bound did not substantially affect the exceedance probability at $M = 8$. We also allowed for the possibility that up to three eruptions recorded as $[6.5, 7.5)$ should have been recorded as $[7.5, 8.5)$, and that the number of eruptions recorded as $[7.5, 8.5)$ is a lower-bound, as suggested by the figure. A simple comparison suggests that the number of missing eruptions in the bin $[7.5, 8.5)$ over the last 100 ka is between 5 and 8.

It is common to present very small exceedance probabilities as their reciprocal, termed the 'return period': see "Poisson processes" for the origin of this term. Our estimated return period for $M = 8$ is 17 ka, with a 95% uncertainty interval of 5 ka to 50 ka. The previous interval was 45 ka to 715 ka [3]. Therefore our estimate represents a substantial downward revision of the return period for super-eruptions, indicating that super-eruptions are a much larger societal risk than previously thought, although still small in absolute terms.

Poisson processes

We use the simplest form of marked point process, in which large explosive eruptions follow a Poisson process with rate λ (units of '/year') and magnitudes ('marks') are IID with distribution function F. If we define the bins with a sequence of fence-posts $m_1, \ldots, m_{k+1}$, such that $\int_{m_1}^{m_{k+1}} \mathrm{d}F(x) = 1$, then the eruptions which fall in magnitude bin i follow a Poisson process with rate

$$\mu_i := \lambda \int_{m_i}^{m_{i+1}} \mathrm{d}F(x).$$

The Poisson distribution can then be used to derive the Maximum Likelihood point estimate for μ_i, which is simply the number of eruptions divided by the duration of the interval, and also a 95% confidence interval.

Denote the exceedance probability for $M = m$ as $\bar{P}(m)$. Then

$$\begin{aligned}\bar{P}(m_i) &= 1 - \exp\left\{-\lambda \int_{m_i}^{\infty} \mathrm{d}F(x)\right\} \\ &= 1 - \exp\left\{-\sum_{j=i}^{k} \mu_j\right\} \approx \mu_i,\end{aligned}$$

which is a good approximation when $1 \gg \mu_1$ and $\mu_j \gg \mu_{j+1}$. This is why we show the bin-based estimates superimposed on the exceedance probability function.

It is conventional to define the 'return period' for $M = m$ as $R(m) := \bar{P}(m)^{-1}$, which has units of 'years'. Let T_m be the time in years between eruptions of magnitude at least m. Then

$$\mathbb{E}(T_m) = \left\{\lambda \int_{m}^{\infty} \mathrm{d}F(x)\right\}^{-1} \approx \bar{P}(m)^{-1},$$

where the equality follows from the Poisson process, which has Exponentially-distributed waiting times, and the approximation is good for $\bar{P}(m) \ll 1$. Hence the name 'return period'. The return period is also approximately the expectation of the time from now until the next eruption of magnitude at least m, assuming that the model continues into the future.

Ongoing work

We currently have two strands arising out of this research. The first is to move towards local volcanic risk assessment. There may not be very much we can do to prevent or mitigate a super-eruption, but large eruptions, which are much more frequent, can still be devastating for communities and even countries, and careful planning is a crucial part of disaster risk reduction. Initially, we would like to estimate the probability that a particular volcano will have a large explosive eruption ($M \geq 4$) over a specified period into the future, such as 30 years.

The difficulty is that the historical record for a specific volcano is very short, in geological terms, and compromised by mis- and under-recording. Augmenting the record by pooling similar volcanoes understates the uncertainty, by imposing the condition that these volcanoes are effectively identical, when they are not. Instead, we plan to treat a set of volcanoes as 'similar but not identical', using the statistical modelling approach of exchangeability.

The second strand is to explore the consequences of a super-eruption return period of about 20 thousand years for other aspects of societal risk management. Initially we are considering the regulation of nuclear facilities. For discussion: if a volcanic super-eruption is going to wipe out a considerable portion of the world's population every 20 thousand years, then why are we managing the probability of 100 fatalities in an accident at a nuclear facility down to once every 10 million years?

This question is a caricature, but it highlights the issue that unmanageable natural hazards provide a 'backstop' for manageable hazards. The regulation of nuclear facilities is very complicated, and we would not claim to be able to set the appropriate amount of regulation according to other societal risks. But we would like to make the argument that the substantial downward revision of the return period for super-eruptions provides a reason to reconsider regulatory thresholds for nuclear sites.

Publication and public interest

Our research on large eruptions and super-eruptions caught the imagination of the public press. Here's what happened. We received help from the University of Bristol press office in writing an attractive press release, and also from the journal, *Earth and Planetary Science Letters*, to synchronize the public availability of our paper with the embargo on the press release. The only thing we could not do was provide a photograph of a super-eruption: the last one happened over 20 thousand years ago (Taupo in New Zealand's North Island, $M = 8.1$). The press office offered us several stock photographs of large explosive eruptions, but these understate the magnitude of a super-eruption by several orders of magnitude. In the end we settled on a NASA image of the Toba caldera.

Figure 5. The Toba caldera: the site of a massive super-eruption 75,000 years ago. Image credit: NASA/METI/AIST/Japan Space Systems, and U.S./Japan ASTER Science Team.

The press release[2] went out on Monday, and the paper was made available online on Wednesday, so journalists had two working days to contact me for more details. Volcanoes were in the news, because of the activity at Mount Agung in Bali, Indonesia. I got five or six detailed enquiries, by email. Two radio stations lined up interviews for their news shows, but in both cases I was bumped for other stories.

On Wednesday I tracked the uptake of our press release in the media, using the search term 'super-eruption' in Google News. I think the first outlet to publish was *End Times Headlines*, for which civilization-ending volcanic eruptions are catnip. The *Daily Mail* followed shortly after, with 'Apocalyptic volcanic super eruption that could DESTROY civilisation is much closer than we thought, say experts'. *The Sun* referred to me as a 'boffin'. Most of the major papers covered the story, and many stuck closely to the press release. The *Sunday Times* was the winner

[2] tinyurl.com/y86gnb4f.

of 'Most fanciful visualization of a super-eruption', which pictured the earth as a thin shell containing boiling magma, all the way down to the core.

My favourite article was 'Volcanologist Who Shifted Date of Next Super-Eruption Is Surprisingly Chill' in the online magazine *Inverse*. [3] Peter Hess, who wrote the article, had contacted me before publication with several interesting questions, and he picked up on one of the messages in the press release, that super-eruptions show that our tenure as a civilization here on earth is quite precarious. The reason that I was "surprisingly chill" about super-eruptions was, as he put it, "Something else will probably kill us first, seeing as the global climate is warming, antibiotic-resistant bacteria are thriving, and nuclear war is a greater threat than ever." He might also have mentioned flu-like pandemic or a massive solar storm.

The biggest challenge in presenting our results to a general audience is the idea that our model, a Poisson process, is memoryless. If the last super-eruption was over 20 thousand years ago, and the return period is 17 thousand years, then it is quite reasonable to suppose that we are overdue. In the press release we deflected this supposition by writing "But it is important to appreciate that the absence of super-eruptions in the last 20 thousand years does not imply that one is overdue. Nature is not that regular."

In talks, a popular question is where the next super-eruption will be. This is not really predictable, but if I had to pick one location then it would be Yellowstone in North America, which has had six very large eruptions ($M \geq 6$) in the last 1.3 million years, including two super-eruptions. Another question is whether there will be any warning: my colleagues tell me not necessarily. If you had a few days' warning and knew where the eruption was going to be, you could improve your chances by moving to the opposite side of the earth, although maybe not by very much unless you were already a skilled survivalist.

Acknowledgements. I would like to acknowledge my research collaborators Steve Sparks, Kathy Cashman, Sarah Brown, Neil Chapman, and Natalia Deligne, for their encouragement and their expertise; and the EPSRC, NERC and the Leverhulme Trust for funding.

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Jonathan Rougier

Jonathan Rougier is Professor of Statistical Science in the School of Mathematics, University of Bristol. He specializes in uncertainty and risk assessment, particularly in Earth and Environmental Sciences. He was co-editor of *Risk and Uncertainty Assessment for Natural Hazards* (CUP, 2013), but has not got rich from the royalties.

[3] tinyurl.com/ycfmvtdd. Of course, I am not a volcanologist, and technically we did not shift the date of the next super-eruption, but shortened the return period.

Reciprocal Societies: The Finnish Mathematical Society

The Finnish Mathematical Society (FMS) celebrates its 150 year anniversary this November. This makes it one of the oldest still functioning mathematical societies in the world. At the time of its founding, there was only one Finnish university, the University of Helsinki, but today mathematics research is undertaken in at least ten different universities in Finland. The Society currently has around 300 members.

Finnish Mathematics Days participants in Joensuu 2018

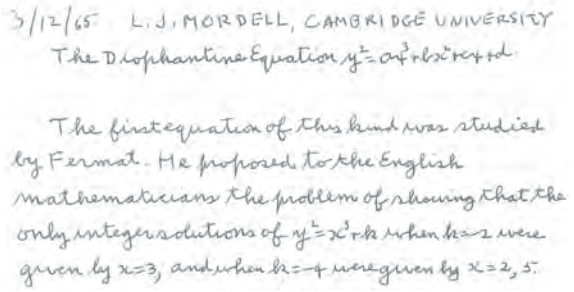
Many well-known Finnish mathematicians have been involved with the FMS, such as Ernst Lindelöf, founder of the famous Finnish complex analysis school in the early 1900's. He acted as the secretary, and also as the President for more than four decades. (Now a President may serve a term of at most 5 years.)

The official meeting of the FMS takes place annually. In addition to making decisions and voting on various matters, the meeting features an invited talk that is often given by a newly appointed professor. Every second year the FMS arranges a meeting, the *Finnish Mathematical Days*, for all Finnish mathematicians. The venue of the meeting rotates between different departments around Finland. This year it was in Joensuu, and the next meeting will take place in Oulu in 2020.

The FMS publishes, together with the Finnish Physical Society, a bulletin *Arkhimedes* in Finnish with six volumes per year. Jointly with other Nordic Societies, it is responsible for the journal *Mathematica Scadinavica*.

The Society awards annually the Lindelöf Prize for the best Master's Thesis in Mathematics in Finland, and from next year will do the same for the best Doctoral Thesis. The Mathematics Prize of the Society is awarded every second year for the wider promotion of mathematics. This year's prize was awarded to Kirsi Peltonen for her work for creating projects that increase communication between the arts and mathematics. The FMS also organises mathematics competitions in Finnish schools and training for teams participating in the IMO.

The FMS supports visits of foreign mathematicians by organising the *FMS Lectures*, an activity that has been fruitful for Finnish mathematics for many years. The lectures can take place in any mathematics department in Finland. Books of abstracts provide a historical record of the lectures.


3/12/65 L.J. MORDELL, CAMBRIDGE UNIVERSITY
The Diophantine Equation $y^2 = ax^3 + bx^2 + cx + d$.

The first equation of this kind was studied by Fermat. He proposed to the English mathematicians the problem of showing that the only integer solutions of $y^2 = x^3 + k$ when $k = 2$ were given by $x = 3$, and when $k = -4$ were given by $x = 2, 5$.

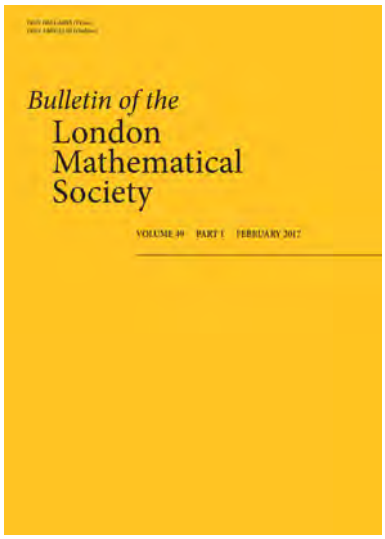
Beginning of the handwritten abstract of an FMS Lecture given by L.J. Mordell in Helsinki 3.12.1965.

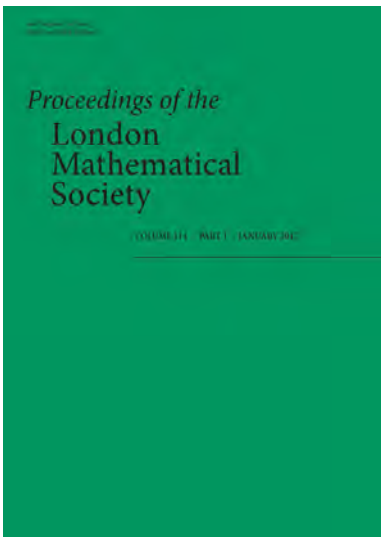
The FMS also takes its turn in organizing the *Nordic Congress of Mathematicians*, which is arranged together with its Nordic sibling societies. The last such meeting was held in Stockholm in March 2016, and the next one will take place at Aalto University in 2020. It also helps to organize some special events and conferences, such as the *Meeting of Young Mathematicians in Finland 2015*, which brought together young scholars in mathematics. The largest special undertaking by far was hosting the ICM in 1978 in Helsinki.

Eero Saksman
President of the Finnish Mathematical Society

Editor's note: the LMS and the FMS have a reciprocity agreement meaning members of either society may benefit from discounted membership of the other.

Read the latest content from the Journals of the London Mathematical Society





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Microthesis: Growth in Virtually Abelian Groups

Alex Evetts

Growth functions of finitely generated groups, and their associated power series, give a useful classification of groups. Moreover, they have far-reaching implications for the algebraic properties of the underlying group, and to classical decision problems. In my PhD project I am studying the rationality of various growth series.

The growth of a group

How can we compare the 'sizes' of finitely generated infinite groups? They are all countably infinite, so we cannot distinguish them by cardinality. Instead, we define the length of an element to be the length of a smallest word in the generators that represents that element. A 'smallest word' for some element in this sense is called a *geodesic*. Then we can look at all of the elements whose length is n. We will write $\sigma_{G,S}(n)$ for the number of elements of length n in a group G, generated by a finite subset S, and we call this the *growth function* of G. It measures how 'fast' a group gets large as n increases.

Growth is a useful way of classifying finitely generated groups. Asymptotically, the growth function does not depend on the choice of finite generating set. It also has deep connections to the algebraic properties of the group: a group has a polynomial growth function if and only if it has a nilpotent subgroup of finite index (being nilpotent is an algebraic concept that is a generalisation of being abelian).

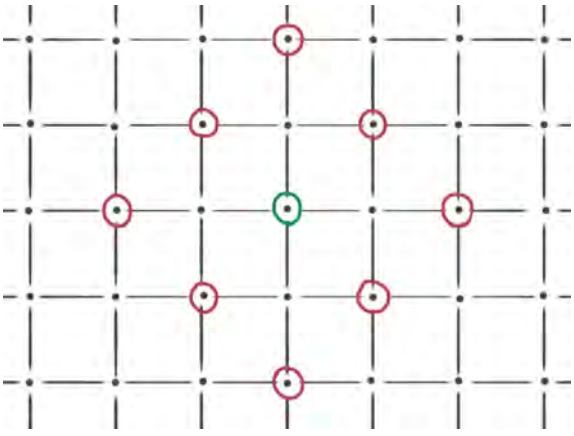
Growth also has a natural geometric interpretation. The *Cayley graph* of a group G has a vertex v_g for every element $g \in G$, and an edge connecting v_g to v_h whenever there is some $s \in S$ with $gs = h$. This edge is labelled by the generator s. A path in the Cayley graph spells out a word in the generators: just read off the edge labels in turn. We call a path a geodesic if it is a shortest route between its endpoints (where we count each edge as 1 unit of distance). A path is a geodesic if and only if it corresponds to a geodesic word. The growth function $\sigma_{G,S}(n)$ counts the number of vertices that can be reached by a geodesic path of length n.

Rational growth

The *growth series* of a group G with respect to a generating set S is the formal power series

$$\sum_{n=0}^{\infty} \sigma_{G,S}(n)\, z^n.$$

A natural question to consider about such an object is under what conditions it can be written as a rational function, that is, the ratio of two polynomials with integer coefficients. For example, the group $\mathbb{Z}^2$ generated by $S = \{(1,0),(0,1)\}$ has growth function $\sigma_{\mathbb{Z}^2,S}(n) = 4n$ (for $n \geq 1$), and corresponding growth series $1 + \sum_{n\geq 1} 4nz^n = \frac{1+2z+z^2}{(1-z)^2}$.



A portion of the Cayley graph of $\mathbb{Z}^2$, with the identity marked in green, and the elements of length 2 marked in red.

Being able to demonstrate rational growth has deep consequences. A power series being rational is equivalent to the existence of a linear recurrence relation

defining the coefficients. So if a group has a generating set that yields a rational growth series, then algorithms can be constructed to build up the group in a structured way. In particular, one can build the Cayley graph of the group, and therefore decide algorithmically whether or not a word in the generators represents the group identity. This is known as the *word problem*.

It has been known since the early 1980s that virtually abelian groups (those with an abelian subgroup of finite index) and hyperbolic groups (whose Cayley graphs have non-positive curvature in a precise sense) have rational growth with respect to any choice of generating set. Recently Duchin and Shapiro have proved that the integer Heisenberg group also has this property. The significance of these results comes from the fact that they hold for any choice of generating set S. This need not be the case in general. Stoll showed in 1996 that there exist groups whose growth series are rational with respect to one generating set and irrational with respect to another.

Polyhedral sets and patterns

Benson [1] introduced a framework with which to study virtually abelian groups. If we give $\mathbb{N}^m$ the Manhattan (or taxicab) metric (where the length of a vector is the sum of the coordinates), then we can measure the growth of any subset $W \subset \mathbb{N}^m$. There is a large class of such subsets called *polyhedral sets*, defined as the sets enclosed by affine hyperplanes, which have rational growth series. The strategy for group growth is then to find a set of geodesic representatives for the group elements, that are in one-to-one, length-preserving correspondence with a polyhedral set (or union of such sets) in $\mathbb{N}^m$ for some m. Since these sets grow rationally, the group itself will have rational growth series.

If G is virtually abelian, it has a free abelian normal subgroup of finite index, say $\mathbb{Z}^n$. If S is an inverse-closed generating set, we can write $S = X \cup Y$ where X denotes those generators contained in $\mathbb{Z}^n$, and Y denotes the others. Words $y_1 y_2 \cdots y_k$ where each $y_i \in Y$ are called *patterns*. For a fixed pattern $\pi = y_1 y_2 \cdots y_k$, we can look at words of the form

$$x_1^{w_1} \cdots x_r^{w_r} y_1 x_1^{w_{r+1}} \cdots x_r^{w_{kr}} y_k x_1^{w_{kr+1}} \cdots x_r^{w_{kr+r}}.$$

Call the set of all such words W^π. Since S is inverse-closed, we only need non-negative powers $w_i \geq 0$, so there is a bijection between W^π and $\mathbb{N}^{kr+r}$. It turns out that for each pattern, we can find a set of unique geodesics in W^π that corresponds to a polyhedral set in $\mathbb{N}^{kr+r}$, and therefore grows rationally, yielding rational growth of the group.

Conjugacy growth series

My work [2] uses the framework outlined above to investigate non-standard growth series in virtually abelian groups. In particular, I have proved that the *conjugacy growth series* of any virtually abelian group is a rational function; that is, the growth series resulting from counting the number of conjugacy classes which can be reached by a geodesic path of length n in the Cayley graph.

Every conjugacy class in a virtually abelian group can be expressed as either a finite set of elements, or a finite union of cosets of certain subgroups. A generalised version of Benson's result then produces, for each conjugacy class, a finite tuple of candidates for a geodesic representative for that class.

The proof then hinges on the fact that if we have a set of k-tuples of words for some $k > 0$, then we can find a language of words consisting of a choice of shortest word for each tuple, which corresponds to a polyhedral set in some $\mathbb{N}^m$. Thus we produce a language of geodesic words for the conjugacy classes which grows rationally.

FURTHER READING

[1] M. Benson, Growth series of finite extensions of $\mathbf{Z}^n$ are rational, Invent. Math. 73 (1983) 251–269.
[2] A. Evetts, Rational Growth in Virtually Abelian Groups, preprint (2018), arXiv:1808.06371.

Alex Evetts

Alex is a PhD student at Heriot-Watt University, supervised by Laura Ciobanu. His interests lie in geometric and combinatorial group theory, focussing on questions of growth, and the application of formal language theory to groups. When he isn't doing mathematics, he can usually be found up a hill, or playing the trombone.

Heilbronn Research Fellowships

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Research areas of interest include, but are not restricted to, Algebra, Algebraic Geometry, Combinatorics, Computational Statistics, Data Science, Number Theory, Probability, and Quantum Information. These areas are interpreted broadly: Fellows have previously been appointed with backgrounds in most areas of Pure Mathematics and Statistics, and in several areas of Mathematical/Theoretical Physics.

For more information about the application procedure, and the Fellowships on offer this year, please visit our website: **http://heilbronn.ac.uk/opportunities/.**

For more information about the Heilbronn Institute, see **http://heilbronn.ac.uk.**

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There is a salary supplement of £3.5K pa, in recognition of the distinctive nature of these Fellowships. Payment of this supplement is conditional on a finished thesis having been accepted in final form, because we expect Heilbronn Fellows to hold PhDs before working at the Heilbronn Institute. In addition, a fund of at least £2.5K pa to pay for research expenses will be available to each Fellow.

The Fellowship will be for three years, with a preferred start date in October 2019, though another date may be possible by prior agreement.

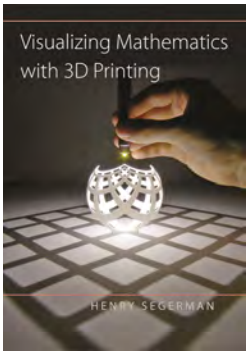
The Heilbronn Institute is a supporter of the LMS Good Practice Scheme aimed at advancing women's careers in mathematics and we particularly welcome applications from women for this post. Candidates interested in learning more about the working environment at the Institute prior to application are welcome to contact the Associate Chair, Dr Tim Burness, at **assoc-chair-himr@bristol.ac.uk.**

The application deadline is 11.59pm on Thursday the 11th of November 2018.

Visualizing Mathematics with 3D Printing

by Henry Segerman, Johns Hopkins University Press, 2016, hardback, pp200.
£52, US$ 70, ISBN 978-1-4214-2035-6.

Review by Mairi Walker



With so many popular maths books covering topics in geometry and topology, it can be difficult for a new one to stand out. But a standout book is exactly what Segerman has produced with *Visualising mathematics with 3D printing*. Although this book covers relatively common topics, it does so not just with the help of two-dimensional images, but with 3D printed models — or, for those without the money to buy the models, or access to a 3D printer, interactive 3D visualisations, available online free of charge. The reader can explore polytopes, knots and surfaces with the advantage of being able to handle the objects themselves.

The book opens with a chapter on symmetry, and the *comma symmetry sphere* — a sphere, patterned with 'comma' shapes, on which one comma can be moved to any other by a unique symmetry — is presented as an intuitive, visual way of representing the symmetry group of a 3D object. This topic is the first demonstration of the power of Segerman's visualisations: Being able to move and rotate an object for yourself is invaluable when studying its symmetries. From here, the classification of the possible symmetries of 3D objects is outlined, and we move nicely into the second chapter, which looks at polyhedra. After neatly classifying regular polyhedra, Archimedean solids are introduced, and symmetries of polyhedra are discussed. The text is full of visual examples, including fine art sculptures as well as 3D-printed objects, all carefully chosen to illustrate key concepts, or provoke mathematical curiosity.

The rest of the book continues in a similar style, with 3D visualisations allowing the reader to interact with topics such as four-dimensional space, tilings, curvature, knots and surfaces. The book is carefully structured, with each chapter building on material from previous ones. Although the book is written in a friendly and conversational style, it is not devoid of advanced mathematics, and Segerman takes many opportunities to point to further reading, and mention open problems, such as the question of which polyhedra tile three-dimensional space. The book finishes with a *Menagerie* chapter, giving a whistle-stop tour of several other topics, from fractals to mechanised 3D printed mathematical curiosities. This is followed by a commentary on the figures, and information on how the models were made.

Being critical, I did find the book heavy going in some places, and I often found myself looking back at previous chapters to remind myself of notation, definitions and examples. I found that some chapters, particularly the chapter on knots, lacked a clear narrative, and perhaps lacked substance too. Although the online visualisations are excellent, there were several places where having a physical 3D printed model would have been beneficial, and unfortunately these aren't cheap.

Despite these downsides, I think this book is a valuable resource for a wide range of people. If you are interested in an accessible and well-written outline of a broad range of topics in geometry, which dips into the maths involved and provides plenty of context and visual stimuli, then there is a wealth of interesting material to be found in this book. For those with an interest in maths education or outreach, it really shows the potential of 3D printing for teaching and communicating concepts in geometry. Ideas from the book could form a basis for teaching at a range of levels, from first encounters with symmetry in primary school, through secondary school

masterclasses, up to undergraduate level courses on symmetry, geometry and topology. I, for one, am looking forward to seeing what Segerman does next.

As a final note, many of the images in this book will be familiar to you if you were fortunate enough to visit the *Brilliant Geometry: The art of mathematical projection* exhibition of Segerman's 3D printed mathematical objects (Summerhall, Edinburgh 12th May to 4th June 2017). This book is an excellent companion to the exhibition, placing the content in a broader context, and giving further information on the topics covered.

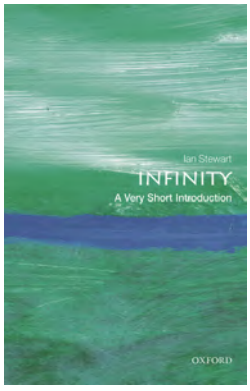
Mairi Walker

Mairi Walker currently works at the University of Warwick and was formerly the Mathematics Engagement Officer at the University of Edinburgh. She is an active member of the UK Mathematics Trust. Outside of work she is a keen swimmer and runner, and dreams of one day cycling around the world.

Infinity: A Very Short Introduction

by Ian Stewart, Oxford University Press, 2017, paperback, pp160. £7.99, ISBN 978-0-1987-5523-6.

Review by Colin Turner



The *Very Short Introduction* (VSI) series by Oxford University Press attempts to take a moderately deep dive into various subjects in slimline volumes. Professor Stewart addresses the apparent paradox of tackling the subject of the infinite in such a small volume right at the start, along with the observation that the topic of infinity has long provided such paradoxes. This particular VSI aims to tackle infinity as found in numbers, geometry, art, theology, philosophy and more, and so it is a tightly packed volume indeed.

Infinity is a concept that is, at least now, embraced in mathematics, but also reaches into physics, philosophy, theology and language in significant measure. In this book, Ian Stewart sets off almost immediately into the mathematical interpretations and concepts of infinity, starting with examples that are likely to be accessible to a wide range of readers, but also touching on some that will cause more mathematically advanced readers to consider them carefully and which may be challenging to less mathematically literate readers.

These examples are of the paradoxical issues surrounding infinity; all but one of these is explicitly mathematical, some geometrical, others more algebraic; by the end of the first short chapter we have visited David Hilbert's famous hotel and explored some of the implications for the arithmetic of the infinite.

The second chapter then moves into a more detailed exploration of the consequences of the infinite in numbers, and in particular explores the infinite, non-repeating decimal representations of irrational numbers and the continuity of the real numbers.

Stewart then explores the history of the infinite in the third chapter, and how it weaved through early Greek philosophy and the classic paradoxes of Zeno, and how for the Greeks issues of infinity were closely tied to their thoughts and theories about motion, and indeed whether motion was in fact possible or

an illusion. Some time is spent with Aristotle, and how he dismissed the idea of an "actual" infinity in favour of a "potential" infinity. We then move through with both Locke and Kant to the beginning of more modern philosophical analyses of the infinite. Some time is taken to explore the philosophy of the infinite in Christian theology, particularly through Thomas Aquinas, a philosopher heavily influenced by Aristotle and how he used the infinite in his "proof" of God.

Stewart also explores how, in the modern era, mathematicians take the infinite very much as a normal and integral part of mathematics, with little concern about the distinction of actual and potential infinities that were the great concern of the philosophy of the ancient world.

We dive, then, from the infinitely large to the infinitely small in the fourth chapter where the seeds of calculus and analysis are to be seen, and the philosophical objections of Bishop Berkeley to the use of infinitesimals. It is interesting to note that these and other concerns about the theoretical underpinnings of calculus were largely ignored in the face of its obvious utility, until others tried to explore these foundations more deeply. Stewart takes us through this work through Cauchy and eventually to the work of Bolzano and Weierstrass who finally introduced the ε and δ notation that has undoubtedly delighted many undergraduates since and ushered in the start of analysis proper. Stewart then dips into an examination of non-standard analysis, a topic that at least I was never knowingly exposed to in my formal studies; it was intriguing to read of these numbers with "standard" and "infinitesimal" parts.

There follows a chapter on the geometrically infinite, which in particular looks at the role of the infinite in art, but which again after an informal discussion dips into the mathematics of what is going on. The chapter after this focuses on infinities that arise in physics, particularly in optics, Newtonian and relativistic gravity, moving on then to discuss the size of the known universe and its curvature. These two chapters are both short and may require some unpacking by readers with less background knowledge.

The final chapter is mostly dedicated to work of Cantor and his systemization of modern mathematical thinking around the concept of the infinite. Here we meet the distinctions between the finite, countably infinite and uncountably infinite, transfinite cardinals and transfinite ordinals. But even here we find the objections of some philosophers, in this case Wittgenstein. This is interesting to read in an era where Cantor's formulations are considered uncontroversial and part and parcel of the "paradise" of Hilbert's modern mathematics in the same way that the past controversies of complex numbers are of little interest to modern mathematicians.

The approach taken to infinity in the book is unapologetically pure mathematical in its spirit, and I suppose this may make the work a little less accessible for some readers, particularly those who are not prepared to think through some of the sections, perhaps with a pen and paper. The *Very Short Introduction to Mathematics*, from the same series, by Timothy Gowers similarly tackles a cross section of challenging examples from the discipline in a relatively small space.

In September 2016, the BBC aired an interesting series on Radio 4 *The History of the Infinite* (this is still happily available online for those interested, at least for those in the UK). In this series, Adrian Moore began discussing the original Greek antipathy to the idea in early philosophy, and then how the idea emerged through Aristotelian philosophy and Christian theology. It was after this that Moore decided to tackle the more serious implications of the infinitely small and big in mathematics, before emerging back through physics into more philosophical territory.

I suspect this route, sandwiching the more complicated mathematical treatment between philosophy more related to human experience could be more palatable to a general reader.

The Very Short Introduction to Infinity is nevertheless a fascinating and joyful exploration of the topic, accessible to the committed and careful novice, but with enough detail and asides to delight formally mathematically trained readers.

Colin Turner

Colin Turner is Professor of Engineering Education at Ulster University, rather surprisingly following his PhD in pure mathematics. He is still working out what to do when he grows up. In the meantime he teaches engineering mathematics and software and undertakes research in algorithms in cardiovascular medicine.

Report of British Science Festival, 2018

Hull and the Humber, 11–14 September

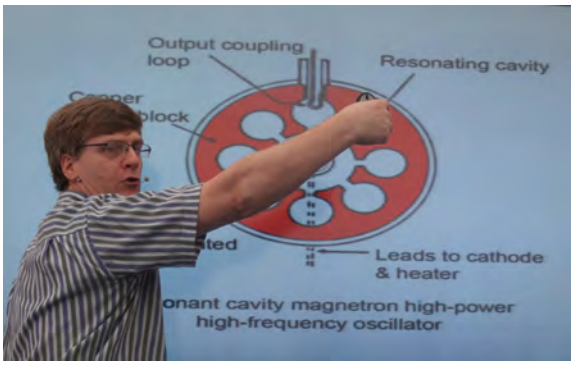
Report by Peter Giblin, Treasurer for the Mathematical Sciences Section of the British Science Association

The British Science Festival (britishsciencefestival.org) was hosted this year by the University of Hull, with over 100 events taking place on the campus of the University during the afternoon and in the city centre during the evening.

The mathematical sciences were well represented at the Festival, and what follows are just some of the highlights.

The 2018 President of the Mathematical Sciences Section is Jen Rogers, Director of Statistical Consultancy Services at the University of Oxford and a member of Maths Inspiration. Her lecture, *Do you look before you leap?* probed the absurdities of some media coverage of statistical issues — bacon sandwiches increase the risk of pancreatic cancer by an appalling 20% — well, what they don't say is the risk rises from 5 in every 400 to 6 in every 400. And besides, eating bacon sandwiches may be associated with a lack of fruit or exercise, who knows? Jen also picked apart some 'survey' results: a certain airline claims 92% of its customers are satisfied with the service they receive — well, the survey only allowed answers from Excellent to OK so there is no room to express dissatisfaction. She discussed regression to the mean, confidence intervals and utility matrices. Jen finished with a safe bet: in an audience of around 70 she bet 50 to 1 that two people would have the same month and day for their birthday, and an audience member ventured £1! A quick probability calculation showed how safe the bet was.

Colin Wright spoke about *Under and over the radar: a modern view*. Besides his extensive work in promotion of maths worldwide, Colin is a director of the port security and coastal surveillance company Denbridge Marine Ltd. Colin emphasized that maths underlies everything in his talk, but concentrated on the workings of radar, the interpretation of radar signals and 'hiding' from radar detection. A mirror surface can deflect the radar signal and render even a large vessel invisible. Many variants of radar are in use: doppler radar by the police to monitor speed, low power solid state radar in a car to warn of imminent collision, and continuous wave radar, also employing doppler techniques, to make the radar immune to slow moving and stationary clutter.



Colin Wright

Laura Bonnett, a postdoctoral fellow in Biostatistics at the University of Liverpool, gave the Rosalind Franklin Award Lecture in mathematical and physical sciences: *In the driving seat: what's the risk with epilepsy?*. Given that a person has a seizure while driving, how long should elapse before he or she is permitted to drive again? Until recently the DVLA used 'expert opinion' to place the time as one year, without any evidence base. The socially acceptable risk is determined as 20%, which is the probability of a newly qualified driver having an accident within 12 months. Using statistical techniques Laura was able to show that to achieve this risk a wait of 6 months was enough. An important message from the lecture was that one should always challenge policies which are not evidence based.

Stuart Davidson (National Physical Laboratory) gave a lecture called *Defining weight in a Parisian vault*. The Bureau International des Poids et Mesures is holding a convocation in November 2018 to agree new definitions of the base SI units, with implementation the following May. Stuart gave a historical survey of 'weights and measures', explaining why the most intractable SI unit to define precisely is the kilogram. The 'electrical kilogram', which will relate the SI unit of mass to the Planck constant, was first proposed in the 1970s by Bryan Kibble at NPL using what is now called a 'Kibble balance'. The apparatus has since been greatly refined to produce results with an uncer-

tainty of < 2 in 10^8 and NPL is working on producing next-generation balances which will be much lower cost and easier to use.

Katie Steckles, well-known as a presenter of maths talks and workshops in schools and for the media, organized a whole evening MathsJam event (see mathsjam.com) at a pub in the centre of Hull. She, Colin Wright and Mark Lorch (Professor of Science Communication at the University of Hull) gave demonstrations, and members of the public sat around at tables, eating, drinking and (more importantly) doing maths in a convivial atmosphere.

Sandra Vaiciulyte gave a talk entitled *What would you leave behind?* Recent wildfires in the South of Europe and California, USA illustrate how rapidly growing cities and nature challenge one another and, most of all, human safety. Helping preparations are sophisticated evacuation models, predicting population movement during wildfires. The Fire Safety Engineering Group at the University of Greenwich is working on an urban-scale evacuation model and have successfully simulated the Swinley forest fire in the UK in 2011. Sandra's research is bringing together two sciences, psychology and mathematics, quantifying human cognitive and emotional responses, and consequent decision making, in emergency situations.

Next year's Festival will be from 10 to 13 September and hosted by the University of Warwick and the city of Coventry.

Peter Giblin

Peter Giblin OBE is Emeritus Professor of Mathematics at the University of Liverpool where his research interests are in singularity theory and its application to computer vision and differential geometry. In his spare time he serves on several committees, including the mathematical sciences section of the British Science Association, and enjoys taking part in outreach to schools.

Obituary of Member

Robert Francis Churchhouse: 1927 – 2018

Professor Robert Francis Churchhouse, CBE, KSG, who was elected a member of the London Mathematical Society on 16 November 1967, died on 27 August 2018, aged 90.

John Churchhouse writes: Robert Francis (Bob) Churchhouse was born in 1927 to a working class Catholic family living in Collyhurst, one of the poorest parts Manchester at the time. Bob attended Saint Clare's R.C. primary school in Blackley. Bob graduated to Saint Bede's College in 1939 where he progressed well but with no specific mathematical bias. This was to change in December 1942 when, whilst ill and bored at home, he devoured a textbook on trigonometry completing all of the examples and this would firmly set his future academic and career course.

Bob won the Cartwright scholarship to Manchester University to study Mathematics, graduated with a first class honours, then went on to do a PhD in Number Theory at Trinity Hall, Cambridge under the supervision of Professor Louis Mordell. His time at Cambridge brought him into contact with several ex-Bletchley mathematicians and so, in retrospect, it was not surprising that his mathematical skills were put to work at GCHQ.

Bob loved his 11 years at GCHQ, working on fascinating problems with very talented people and using the latest computing technology, but a desire to pursue an academic career and publish his work led him to move to the fledgling Atlas Laboratory, Harwell in 1963. Bob was the Head of Programming and pursued research interests in Information Retrieval, Computer-Aided Mathematics and Optical Character Recognition.

Following a study of the Möbius Function on the Atlas Computer, Bob and Jack Good evidenced that the Mertens Hypothesis was almost certainly false (which has since been proved) and the Riemann Hypothesis almost certainly true. Another computer study led him to the discovery of congruence properties of the binary partition function. A third study confirmed a discovery by J. Brillhart of a cubic with extremely large partial quotients (including one of about 16 million) in the continued fraction of its real root. Bob and S.T.E. Muir showed that the explanation of this result lay in the fact that the cubic was linked to the modular equation associated with the elliptic modular function involving the square root of –163. Since the quadratic number field invoking this square root is the last having class number one, no other cubics with even larger partial quotients exist.

In 1970, whilst on a visit to the South of France, Bob received a call out of the blue from the Principal of University College, Cardiff about a new position to set up a department of Computing Mathematics as well as run the University's own Computer Centre. Bob and the family duly moved to Cardiff in 1971 where he set up a thriving department as well as going on to be Dean of Students and Deputy Principal for Science and Engineering.

In 1965, Bob was asked to serve on the Flowers Committee responsible for the provision of computers to Universities and Research Councils and was subsequently asked to serve on the follow up Computer Board. Bob chaired the Computer Board from 1979–82 and was subsequently awarded a CBE for his services.

In 1996, aged 68, Bob retired from the university and was made an Emeritus Professor. Periodically, Bob would sit on GCHQ promotion boards and during this time GCHQ loaned him Enigma and Hagelin cipher machines (shown in the photo above). Bob subsequently gave over 80 lectures around the world on the Enigma machine and its impact on key WW2 battles. In 2002 Cambridge University Press published Bob's book entitled *Codes and Ciphers* charting the use and development of codes and ciphers from Roman times through machines like Enigma to the current day internet.

Outside of his work life, Bob loved literature and music and was a very keen follower of cricket. He is survived by his beloved wife Julia, his three sons, eight grandchildren and one great-grandson.

BCS-FACS Evening Seminar 2018

Location: De Morgan House, London
Date: 1 November 2018
Website: tinyurl.com/bcsfacs

This event is organised by the LMS and the BCS Specialist Group for practioners in Formal Aspects of Computing Science. Bill Roscoe (Oxford) will talk on *Verifying CSP and its offspring*. To register interest, email lmscomputerscience@lms.ac.uk.

LMS Computer Science Colloquium

Location: De Morgan House, London
Date: 8 November 2018
Website: tinyurl.com/cscolloquium18

Aimed at PhD students and post-docs, the theme of this event will be 'Quantum Computing: Unique Mathematical Perspectives'. See the website for details of speakers and to register. Funds are available to help with travel costs. Free attendance for students; £5 for all others (payable on the day).

LMS Meeting

LMS Graduate Student Meeting

9 November 2018, 9.30 am – 2.30 pm, BMA House, Tavistock Square, London WC1H 7JP

Website: lms.ac.uk/events/meeting/agm

This is a free event aimed at a general mathematical audience. The meeting will include student presentations of their current work, with a prize awarded for the best student talk. It will be followed by the LMS AGM, and a wine reception at De Morgan House. Travel grants of up to £50 are available for students who attend both the Graduate Student Meeting and the AGM; email lmsmeetings@lms.ac.uk for details.

LMS Meeting

Annual General Meeting of the LMS

9 November 2018; 3.00 – 6.00 pm, BMA House, Tavistock Square, London, WC1H 7JP

Website: lms.ac.uk/events/meeting/agm

Manuel de Pino (Bath): *Singularity Formation and Bubbling in Nonlinear Diffusions*
John R. King (Nottingham), Naylor Lecture: *Blow-up Phenomena in Reaction Diffusion*

These lectures are aimed at a general mathematical audience. All interested, whether LMS members or not, are most welcome to attend this event.

The meeting will include the presentation of certificates to all 2018 LMS prize winners and the announcement of the annual LMS election results.

The meeting will be followed by a reception, which will be held at De Morgan House, 57-58 Russell Square, London WC1B 4HS.

The Society's Annual Dinner will be held after the reception at 7.30 pm at the Montague on the Gardens, 15 Montague St, Bloomsbury, London WC1B 5BJ. The cost of the dinner will be £58.00, including drinks. To reserve a place at the dinner, email AnnualDinner_RSVP@lms.ac.uk. For further details about the AGM, contact Elizabeth Fisher (lmsmeetings@lms.ac.uk).

Knowledge Exchange in the Mathematical Sciences Conference

Location: Aston University
Date: 3–4 December 2018
Website: tinyurl.com/ybc7lsq2

This IMA conference is for all engaged in knowledge exchange of mathematics research to and from academia, industry, government and society. Early bird fees are available until 16 November, after which fees will increase by £20.

Functor Categories for Groups

Location: Lancaster University
Date: 7 December 2018
Website: tinyurl.com/y7wcpmn6

This meeting will focus on the interplay of graphs and groups, and how each of these structures can be used in the study of the other. Limited funding is available for PhD students, allocated on a first come first served basis. To register, email Nadia Mazza (n.mazza@lancaster.ac.uk).

LMS Meeting

LMS South West & South Wales Regional Meeting

17 December 2018; 2.00 pm Exeter University

Website: tinyurl.com/ydymqdeq

The meeting forms part of a workshop on *Number Fields and Function Fields: Two Parallel Worlds*, 18–20 December 2018. Funding for travel expenses is available for Society members and research students. See the website for further details, to register and to reserve a place at the dinner. The cost of the dinner will be approximately £35, including drinks.

Calcium Signalling

Location: School of Mathematics, Cardiff
Date: 23 January 2019

This workshop, *Calcium Signalling in Fertilisation, Embryogenesis and Development: Modelling and Experiments*, will bring together junior and senior researchers from across the UK. For details and to register email (KaouriK@cardiff.ac.uk) by 7 January.

Electricity Systems of the Future

Location: Isaac Newton Institute, Cambridge
Date: 18–22 March 2019
Website: tinyurl.com/yadhhlys

This workshop, *Electricity Systems of the Future: Incentives, Regulation and Analysis for Efficient Investment*, will focus on economic mechanisms to incentivise investment in technologies and systems to yield socially optimal outcomes. Application deadline: 9 December 2018.

2018 Christopher Zeeman Medal presentation and lecture

Location: Royal Society, London
Date: 5 March 2019

The 2018 Christopher Zeeman Medal will be presented to Dr Hannah Fry on 5 March 2019 at the Royal Society. The presentation will be followed by a talk by Dr Fry, and a reception.

British Mathematical Colloquium 2019

Location: Lancaster University
Date: 8–11 April 2019
Website: tinyurl.com/yb5t6vts

Plenary speakers: Michel Broué, Alice Guionnet, Kathryn Hess-Bellwald, Gil Kalai, Nicolas Monod and Yuval Peres. Workshops will be in Algebra, Analysis, Combinatorics, Geometry, Probability and Mathematics Education. Supported by the Heilbronn Institute and an LMS Conference grant; organised in partnership with the Clay Mathematics Institute.

Mathematics of Operational Research

Location: Aston University, Birmingham
Date: 25–26 April 2019
Website: tinyurl.com/y95ypjh7

This Institute of Mathematics and Operational Research conference will aim to draw together the considerable community of researchers and practitioners who develop new mathematics of relevance to and which underpin applications in OR.

Measurability, Ergodic Theory and Combinatorics

Location: University of Warwick
Date: 8–12 July 2019
Website: tinyurl.com/metc2019

The meeting will focus on connections between combinatorics and other fields such as descriptive set theory, ergodic theory, measured group theory and orbit equivalence. The deadlines for financial aid and registration are respectively 1 April and 6 June 2019. Supported by an LMS Conference grant.

MAFELAP 2019

Location: Brunel University London
Date: 17–21 June 2019
Website: tinyurl.com/ycfv5zqw

This conference will consist of plenary lectures, mini-symposia and parallel sessions. To propose a mini-symposium please send an email to mafelap-mini-symposia@brunel.ac.uk with your name, those of any intended co-organizers, and a tentative title.

British Combinatorial Conference 2019

Location: University of Birmingham
Date: 29 July–2 August 2019
Website: tinyurl.com/y826pqjt

This conference covers research in all areas of combinatorics and its applications. Support for PhD students, early career researchers, and some researchers from developing countries is available. To express interest in attending, email bcc2019@contacts.bham.ac.uk.

Society Meetings and Events

November 2018

1 BCS–FACS Evening Seminar, London
8 LMS Computer Science Colloquium, London
9 LMS Graduate Student Meeting, London
9 Society Meeting and AGM, London

December 2018

17 LMS South West & South Wales Regional Meeting, Exeter

March 2019

5 Christopher Zeeman Medal Presentation and Lecture, Royal Society, London
21 Hirst Lecture and Society Meeting, De Morgan House, London

April 2019

29–3 May LMS-CMI Research School, *PDEs in Mathematical Biology — Modelling and Analysis*, ICMS, Edinburgh

May 2019

20–24 LMS Invited Lecture Series 2019, Professor Søren Asmussen (Aarhus University), ICMS, Edinburgh

June 2019

28 General Meeting of the Society and Aitken Lecture, London

July 2019

1–5 LMS Research School: *Random Structures: from the Discrete to the Continuous*, Bath
8–12 LMS Research School, *Mathematics of Climate*, Reading

Calendar of Events

This calendar lists Society meetings and other mathematical events. Further information may be obtained from the appropriate LMS Newsletter whose number is given in brackets. A fuller list is given on the Society's website (www.lms.ac.uk/content/calendar). Please send updates and corrections to calendar@lms.ac.uk.

November 2018

1 BCS-FACS Evening Seminar, London (479)
6–7 Women in Mathematics: Opportunities for the Future 2018, University of Bristol
8 LMS Computer Science Colloquium, London (479)
8–9 Young Researchers in Algebraic Number Theory, University of Sheffield (478)
9 Graduate Student Meeting, London (479)
9 Society Meeting and AGM, London (479)
13 The Mathematics of Climate Change, Gresham College Lecture, Chris Budd, Museum of London
16 Trends in Persistent Homology, Queen's University Belfast (478)
27 Careers Open Day, The Repertory Theatre, Birmingham (478)
28 Blackett Memorial Lecture, The Royal Society, London (478)
30 Integrable Day 2018, Loughborough University

December 2018

3–4 Knowledge Exchange in the Mathematical Sciences Conference, Aston University (479)
3–7 Manifolds Workshop, INI, Cambridge (477)
5–11 Topology and Applications, Cochin, India (477)

7 Functor Categories for Groups, Lancaster University (479)
10–11 Mathematical Challenges of Big Data IMA Conference, London (478)
10–12 Mathematical Sciences and Technology 2018, Hotel Equatorial Penang, Malaysia
10–14 Conclusions and Future Directions Workshop, INI, Cambridge (477)
11–14 Advances in Applied Algebraic Geometry, University of Bristol (478)
13–14 Finite Dimensional Algebras, Homotopy Theory, and Geometry, University of Glasgow (478)
14–15 XIV Brunel-Bielefeld Workshop on Random Matrix Theory and Applications, Brunel University London (478)
17 LMS South West & South Wales Regional Meeting, Exeter (479)

January 2019

7–10 Variational Problems in Geometry and Mathematical Physics, University of Leeds (478)
8 Can Maths Tell Us Where We Are?, Gresham College Lecture, Chris Budd, Museum of London
14–17 Operators, Operator Families and Asymptotics II, University of Bath (478)
16–18 British Postgraduate Model Theory Conference 2019, University of Manchester (478)
23 Calcium Signalling in Fertilisation, Embryogenesis and Development: Modelling and Experiments, Cardiff (479)

February 2019

12 Maths In The City; What Will Our Future Cities Look Like?, Gresham College Lecture, Chris Budd, Museum of London

March 2019

5 Christopher Zeeman Medal Presentation and Lecture, Royal Society, London (479)
12 How Will We Teach Maths in the Future?, Gresham College Lecture, Chris Budd, Museum of London
21 Hirst Lecture and Society Meeting, De Morgan House, London
18–22 Electricity Systems of the Future: Incentives, Regulation and Analysis for Efficient Investment, INI, Cambridge (479)

April 2019

8-11 British Mathematical Colloquium 2019, Lancaster University (479)
10 LMS Meeting at the BMC, Lancaster
25–26 Mathematics of Operational Research, Aston University, Birmingham (479)
29–3 May LMS–CMI Research School, *PDEs in Mathematical Biology — Modelling and Analysis,* ICMS, Edinburgh
30 500 Years of Mathematics, Gresham College Lecture, Chris Budd, Museum of London

May 2019

20–24 LMS Invited Lecture Series, Søren Asmussen (Aarhus University), ICMS, Edinburgh (477)

June 2019

17–21 MAFELAP 2019, Brunel University London (479)
28 General Meeting of the Society and Aitken Lecture, London

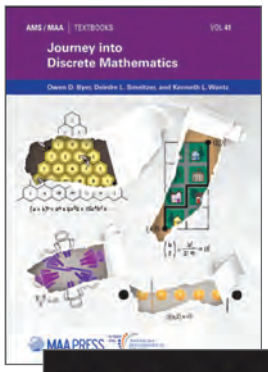
July 2019

1–5 LMS Research School: *Random Structures: from the Discrete to the Continuous,* Bath
8–12 Measurability, Ergodic Theory and Combinatorics, University of Warwick (479)
8–12 LMS Research School, *Mathematics of Climate,* Reading
15–19 International Congress on Industrial and Applied Mathematics, Valencia
29–2 Aug British Combinatorial Conference 2019, University of Birmingham (479)

August 2019

4–9 Theory and Practice: an Interface or a Great Divide? Maynooth University (476)

AMS American Mathematical Society



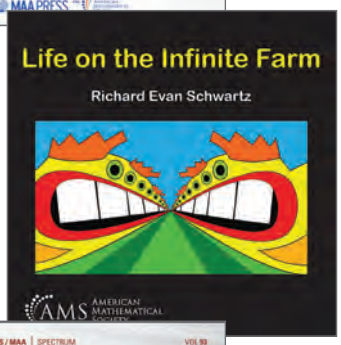
JOURNEY INTO DISCRETE MATHEMATICS

Owen D. Byer, Eastern Mennonite University, Deirdre L. Smeltzer, Eastern Mennonite University & Kenneth L. Wantz, Regent University

Designed for use on a first course in mathematical abstraction for early-career undergraduate mathematics majors. The important ideas of discrete mathematics are included - logic, sets, proof writing, relations, counting, number theory, and graph theory - in a manner that promotes development of a mathematical mindset.

MAA Textbooks, Vol. 41
MAA Press

Dec 2018 389pp 9781470446963 Hardback £71.95

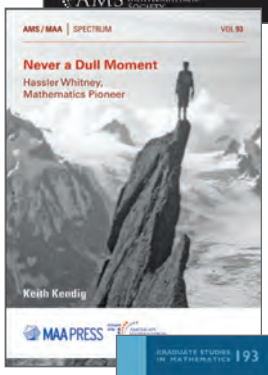


LIFE ON THE INFINITE FARM

Richard Evan Schwartz, Brown University

Mathematician and award-winning children's book author Richard Schwartz teaches about infinity and curved space through stories of whimsical farm animals. Children as young as five will enjoy the lighthearted illustrations and the fanciful approach to infinity. Older students will appreciate the more advanced ideas and geometric references.

Oct 2018 176pp 9781470447366 Paperback £24.50



NEVER A DULL MOMENT

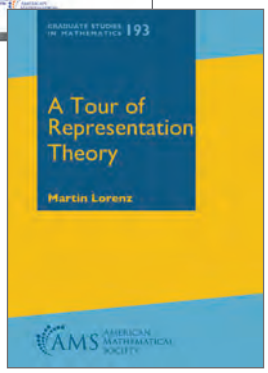
Hassler Whitney, Mathematics Pioneer

Keith Kendig, Cleveland State University

Hassler Whitney was a giant of twentieth-century mathematics. This biography paints a picture of him and includes dozens of revealing anecdotes. Mathematically, he had a rare detector that went off whenever he spotted a piece of mathematical gold, and he would then draw countless pictures, gradually forging a path from hunch to proof. This geometric path is seldom reflected in the rigor of his formal papers, but thanks to a close friendship and many conversations over decades, author Kendig was able to see how he actually worked.

Spectrum, Vol. 93
MAA Press

Nov 2018 381pp 9781470448288 Paperback £57.50



A TOUR OF REPRESENTATION THEORY

Martin Lorenz, Temple University

Offers an introduction to four different flavours of representation theory: representations of algebras, groups, Lie algebras, and Hopf algebras. A separate part of the book is devoted to each of these areas and they are all treated in sufficient depth to enable the reader to pursue research in representation theory.

Graduate Studies in Mathematics, Vol. 193

Oct 2018 654pp 9781470436803 Hardback £90.50

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