2015 Colloquia in Combinatorics

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Two consecutive one-day events hosted by QMUL and LSE

A full illustrated report of the event can be read <u>here</u>

Wednesday 13th May 2015

Thursday 14th May 2015



Anita Liebenau (University of Warwick, Warwick, UK) Ron Peled (Tel Aviv University, Tel Aviv, Israel) Alex Scott (University of Oxford, Oxford, UK) Olof Sisask (KTH, the Royal Institute of Technology, Stockholm, Sweden) Gregory Sorkin (London School of Economics and Political Sciences, London, UK) Stéphan Thomassé (Ecole Normale Supérieure de Lyon, Lyon, France) Venue: Maths Lecture Theatre, Mathematical Sciences Building, QMUL Contacts: Robert Johnson (r.johnson@gmul.ac.uk) and David Ellis (d.ellis@gmul.ac.uk)

Wednesday 13th May 2015

Thursday 14th May 2015



THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

Christina Goldschmidt (University of Oxford, Oxford, UK) Tim Gowers (University of Cambridge, Cambridge, UK) Will Perkins (University of Birmingham, Birmingham, UK) Alexey Pokrovskiy (Freie Universität Berlin, Berlin, Germany) Alexander Schrijver (University of Amsterdam, Amsterdam, Netherlands) Frank Vallentin (Universität zu Köln, Köln, Germany) Venue: New Theatre, East Building, LSE (room number: EAS.E171) Contact: Jozef Skokan (j.skokan@lse.ac.uk)

Supported by







To view the speakers and titles please click here.

To view full event programme please click here.

Those interested are welcome to attend for all or any part of the event. The two hosting institutions are less than half an hour apart by tube; it is hoped that many people will be able to attend for both days. There is no formal registration process and seats will be allocated each day on a first come, first served basis.

Queries should be sent to Rebecca Lumb.

Funding

Some funds are available to contribute to the **basic** travel expenses of research students who wish to attend the meetings. We would ask you to keep costs to a minimum, using public transport on **all** occasions and off-peak student travel tariffs wherever possible. Receipts for all journeys must be maintained as proof of travel. At this stage, we are unable to confirm the maximum amount available; please contact <u>Rebecca Lumb</u> for further information.

There are also some funds available from the London Mathematical Society for help with childcare costs. Further details can be found at http://www.lms.ac.uk/content/childcare-supplementary-grants.

Event Support

Support for this event by the London Mathematical Society and the British Combinatorial Committee is gratefully acknowledged by the organisers.

Event Poster

A poster advertising both days of the event is available to download <u>here</u>. Please do feel free to electronically distribute this to anyone who might be interested, append to local websites (linking back to this site using the URL <u>http://tiny.cc/Colloquia</u>) or print out to share on public notice boards.



THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

Wednesday 13 May 2015 Queen Mary, University of London

Maths Lecture Theatre, Mathematical Sciences Building Organisers: Robert Johnson and David Ellis

- Anita Liebenau (Warwick)
- Ron Peled (Tel Aviv)
- Alex Scott (Oxford)
- Olof Sisask (KTH)
- Gregory Sorkin (LSE)
- Stéphan Thomassé (Lyon)



Thursday 14 May 2015 London School of Economics

New Theatre, East Building Organiser: Jozef Skokan

- Christina Goldschmidt (Oxford)
- Tim Gowers (Cambridge)
- Will Perkins (Birmingham)
- Alexey Pokrovskiy (Berlin)
- Alexander Schrijver (Amsterdam)
- Frank Vallentin (Köln)

The programmes at both Queen Mary and LSE will start at 10.30am, with coffee from 10.00am

Anyone interested is welcome to attend. Some funds are available to contribute to the expenses of research students who wish to attend the meetings.

Further details can be obtained from http://tiny.cc/Colloquia or from Rebecca Lumb (r.c.lumb@lse.ac.uk).

Support for this event by the London Mathematical Society and the British Combinatorial Committee is gratefully acknowledged.



Two One-Day Colloquia in Combinatorics 13-14 May 2015 – London

http://tiny.cc/Colloquia



Wednesday 13 May 2015

The first day of the Colloquia in Combinatorics will be held at Queen Mary, University of London on Wednesday 13 May, starting at 10.30am. Coffee is available from 10.00 am in the Maths Building Foyer. All the talks will be held in the Maths Lecture Theatre, Mathematical Sciences Building, Mile End Campus, QMUL.

Speaker (Institution)	Presentation title
Anita Liebenau	On the minimum degree of minimal Ramsey graphs
Ron Peled (Tel Aviv)	Probabilistic existence of regular combinatorial structures
Alex Scott (Oxford)	Colouring graphs without odd holes
Olof Sisask (Stockholm)	Quantitative continuity of convolutions in additive combinatorics
Gregory Sorkin (London)	VCG auction mechanism cost expectations and variances
Stéphan Thomassé (Lyon)	Decomposing 24-edge-connected graphs with high minimum degree into paths of fixed length



Thursday 14 May 2015

The second day of the Colloquia in Combinatorics will be held at The London School of Economics and Political Science on Thursday 14 May, starting at 10.30am. **. Coffee is available from 10.00 am Room EAS E304, East Building, LSE**. All talks will be held in the New Theatre, Room EAS.E171).East Building, LSE.

Speaker (Institution)	Presentation title
Christina	Scaling limits of Galton-Watson trees, and line-breaking constructions
Goldschmidt	
(Oxford)	
Tim Gowers	Communication complexity and interleaved products
(Cambridge)	
Will Perkins	Birthday inequalities, hard spheres, and independent sets
(Birmingham)	
Alexey Pokrovskiy	Connectedness in tournaments
(Berlin)	
Alexander Schrijver	Edge-colouring models
(Amsterdam)	
Frank Vallentin	New upper bounds for the density of translative packings of superspheres
(Köln)	

All interested parties are welcome to attend; there is no formal registration process and seats will be allocated each day on a first come, first served basis.

Support for this event from the **London Mathematical Society** and the **British Combinatorial Committee** is gratefully acknowledged by the organisers.



THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE



Queen Mary, University of London

The London School of Economics and Political Science

Two One-Day Colloquia in Combinatorics

13^{th} and 14^{th} May 2015



If attending both days, please keep this programme for day two



When tweeting about the Colloquia, please use the hashtag **#CC2015**

Follow us at: @LSEMaths @QMULMaths

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INFORMATION

Those interested are welcome to attend for all or any part of the event; it is hoped that many people will be able to attend for both days.

Some funds are available to contribute to the **basic** travel expenses of **research students** who attend the meetings. We ask you to keep costs to a minimum, using public transport on **all** occasions and off-peak student travel tariffs wherever possible. Receipts for all journeys must be maintained as proof of travel. At this stage, we are unable to confirm the maximum amount available. Expense claim forms are available at the event from the event organisers. Please contact Rebecca Lumb (r.c.lumb@lse.ac.uk) for further information.

Event organisers: Dr Robert Johnson (QMUL), Dr David Ellis (QMUL) and Dr Jozef Skokan (LSE).

SUPPORT

Support for this event from the London Mathematical Society (<u>www.lms.ac.uk</u>) and the British Combinatorial Committee (<u>https://britishcombinatorial.wordpress.com/</u>) is gratefully acknowledged.





WEDNESDAY 13th MAY 2015 Schedule

The first day of the Colloquia in Combinatorics will be held at Queen Mary, University of London on Wednesday 13th May, starting at 10.30am. Everyone interested is welcome to attend any part of the event. All the talks will be held in the Maths Lecture Theatre, Mathematical Sciences Building, Mile End Campus, QMUL.

Time	Speaker Presentation title				
10:00		Coffee (Maths Building Foyer)			
10:30	Stéphan Thomassé (Lyon)Decomposing 24-edge-connected graphs with high minimum degree into paths of fixed length				
11:20	Alex Scott (Oxford)Colouring graphs without odd holes				
12:10	Lunch (own arrangements – options on campus and nearby)				
13:30	Olof Sisask (Stockholm)Quantitative continuity of convolutions in additiv combinatorics				
14:20	Anita Liebenau (Warwick) On the minimum degree of minimal Ramsey gray				
15:10	Afternoon tea break (Maths Building Foyer)				
15:40	Ron Peled (Tel Aviv)	Probabilistic existence of regular combinatorial structures			
16:30	Gregory Sorkin (London)	VCG auction mechanism cost expectations and variances			
17:20		End			

Decomposing 24-edge-connected graphs with high minimum degree into paths of fixed length

Stéphan Thomassé

The Barát-Thomassen conjecture asserts that there is a function f such that for every fixed tree T with t edges, every graph which is f(t)-edge-connected with its number of edges divisible by t has a partition of its edges into copies of T. This has been proved in the case of paths of length 2^k by Thomassen, and recently shown to be true for all paths by Botler, Mota, Oshiro and Wakabayashi.

In this talk, we propose an alternative proof of the path case with a weaker hypothesis: Namely, we prove that there is a function f such that every 24-edge-connected graph with minimum degree f(t) has an edge-partition into paths of length t whenever t divides the number of edges. The 24 bound cannot be replaced by 2, and we suspect that 3-edge connected and large minimum degree suffice. We will also present work in progress to reach the bound 8, and an approach which will (hopefully) attain the bound 3.

This is joint work with Julien Bensmail and Ararat Harutyunyan.

Colouring graphs without odd holes

Alex Scott

Gyarfás conjectured in 1985 that if G is a graph with no induced cycle of odd length at least 5, then the chromatic number of G is bounded by a function of its clique number. We prove this conjecture (joint work with Paul Seymour) and discuss some further results on induced cycles in graphs of large chromatic number (joint with Maria Chudnovsky and Paul Seymour).

Quantitative continuity of convolutions in additive combinatorics

Olof Sisask

Suppose A is a set of integers. If A is contained in $\{1, 2, ..., N\}$, how long an arithmetic progression must the sumset $A + A = \{a + ba, b \in A\}$ contain, in terms of the size of A? What about A + A + A? How large can A be if it itself does not contain any arithmetic progressions – solutions to x + y = 2z? What about other linear equations? Or suppose we know something about the sumset, say that |A + A| < K|A|, where K is a fixed constant and |A| is large. What can we say about A?

These are some central questions in additive combinatorics, and there has been substantial progress in the quantitative answers to each of them over the past few years. The aim of this talk is to describe some of this progress, which is due to many people, and to give an idea of one of the key results underlying it all, which we shall phrase as a continuity result for three-fold convolutions.

On the minimum degree of minimal Ramsey graphs

Anita Liebenau

We study graphs G that are r-Ramsey minimal for a graph H, that is, any rcolouring of the edges of G contains a monochromatic copy of H, but no proper subgraph of G has this property. Let $s_r(K_k)$ denote the smallest possible degree of a graph G that is r-Ramsey minimal for the clique on k vertices. Burr, Erdős and Lovász showed in 1976 that $s_2(K_k) = (k-1)^2$. This is in striking contrast to the fact that the known bounds for the Ramsey numbers are far apart.

We study the dependency of $s_r(K_k)$ on r and show that, under the condition that k is constant, $s_r(K_k)$ is roughly quadratic in r. It turns out that $s_r(K_k)$ is tightly connected to another extremal parameter: the Erdős-Rogers function $f_{k,k+1}(n)$, introduced by Erdős, Hajnal and Rogers, is the largest integer t such that any K_{k+1} -free graph on n vertices contains a subset of size t that is K_k -free.

This is joint work with Jacob Fox, Andrey Grinshpun, Tibor Szabó and Yury Person.

Probabilistic existence of regular combinatorial structures

Ron Peled

We show the existence of regular combinatorial objects which previously were not known to exist. Specifically, for a wide range of the underlying parameters, we show the existence of non-trivial orthogonal arrays, *t*-designs, and *t*-wise permutations. In all cases, the sizes of the objects are optimal up to polynomial overhead. The proof of existence is probabilistic. We show that a randomly chosen structure has the required properties with positive yet tiny probability. Our method allows also to give rather precise estimates on the number of objects of a given size and this is applied to count the number of orthogonal arrays, *t*-designs and regular hypergraphs. The main technical ingredient is a special local central limit theorem for suitable lattice random walks with finitely many steps.

This is joint work with Greg Kuperberg and Shachar Lovett.

VCG auction mechanism cost expectations and variances

Gregory Sorkin

We consider Vickrey-Clarke-Groves (VCG) auctions for a very general combinatorial structure, in an average-case setting where item costs are independent random variables. When the costs have uniform (0, 1) distribution, we prove that the expected VCG cost is at least double the expected nominal cost, and exactly double when the desired structure is a basis of a bridgeless matroid. In the matroid case we further show that, conditioned upon the VCG cost, the expectation of the nominal cost is exactly half the VCG cost, and we show several results on variances and covariances among the nominal cost, the VCG cost, and related quantities, as well as considering other distributions. As an application, we find the asymptotic variance of the VCG cost of the minimum spanning tree in a complete graph with random edge costs.



PLACES TO EAT: in and around QMUL

Baghdad Café – Authentic Iraqi and Arabic food, Burdett Road Drapers Bar and Kitchen – wide range to suit all dietary requirements, Bancroft Road Drunken Monkey – Asian fusion, Westfield Way Greedy Cow – gastropub food, Grove Road Half Moon Pub – Wetherspoons serving standard pub food, Mile End Road Morgan Arms – Up-market pub food, Morgan Street Mucci's – Italian trattoria, Library Square Nandos – Portuguese Chicken, Mile End Road Pride of Asia – Bangladeshi restaurant with all-you-can-eat buffet, Mile End Road The Curve – international food to eat-in or take away, Westfield Way



Mile End Campus

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(i) Information

Visitors who require further information or assistance please go to the Main Reception in the Queens' Building. Smoking is prohibited on campus. These premises are alarmed and monitored by CCTV, please call Security on 020 7882 5000 for more information. Library/bookshop Fitness centre Bar (Coffee place (T) Eatery P Staff car park Bicycle parking **BL** Bicycle lockers (£) Cash machine

New Graduate Centre construction site 18

Currently no through route between Geography Square and Bancroft Road.





THE LONDON SCHOOL THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE POLITICAL SCIENCE

THURSDAY 14th MAY 2015 **Schedule**

The second day of the Colloquia in Combinatorics will be held at The London School of Economics and Political Science on Thursday 14th May, starting at 10.30am. Everyone interested is welcome to attend any part of the event. The talks will be held in the New Theatre (room number: EAS.E171), East Building, LSE; refreshments breaks will be taken in EAS.E304, East Building, LSE; reception will be held in the Shaw Library, Sixth Floor Old Building, LSE.

Time	Speaker Presentation title					
10:00		Coffee (room EAS.E304)				
10:30	Will Perkins (Birmingham)Birthday inequalities, hard spheres, and independent sets					
11:20	Alexander Schrijver (Amsterdam)	Jexander Schrijver Amsterdam)Edge-colouring models				
12:10	Lunch (own	Lunch (own arrangements – options on campus and nearby)				
13:30	Frank Vallentin (Köln)New upper bounds for the density of translative packings of superspheres					
14:20	Christina Goldschmidt (Oxford)	Scaling limits of Galton-Watson trees, and line- breaking constructions				
15:10	Afternoon tea break (room EAS.E304)					
15:40	Alexey Pokrovskiy (Berlin)	Connectedness in tournaments				
16:30	Tim Gowers (Cambridge)	Biggs Lecture: Communication complexity and interleaved products				
17:30	Reception (Shaw Library, Sixth Floor Old Building)					

Birthday inequalities, hard spheres, and independent sets

Will Perkins

I will discuss two related models from statistical physics and combinatorics: the hard sphere model of random non-overlapping spheres in Euclidean space and the hardcore model of a random independent set in the *d*-dimensional integer lattice. I will present a new method for bounding the partition function in both models, and show applications including a surprising fact about spheres in 24 dimensions.

Edge-colouring models

Alexander Schrijver

Several graph invariants can be described as 'partition functions' (in the sense of de la Harpe and Jones), and their duals based on edge-colouring models. We give characterizations of such invariants, and of related invariants for knots and chord diagrams, where Lie algebras come in.

The talk will be introductory and does not assume any specific knowledge in this area.

New upper bounds for the density of translative packings of superspheres

Frank Vallentin

In this talk I will present new upper bounds for the maximum density of translative packings of superspheres in three dimensions (unit balls for the l^p -norm). This will give some strong indications that the lattice packings experimentally found in 2009 by Jiao, Stillinger, and Torquato are indeed optimal among all translative packings. For this we apply the linear programming bound of Cohn and Elkies which originally was designed for the classical problem of packings of round spheres. The proof of our new upper bounds is computational and rigorous. Our main technical contribution is the use of invariant theory of pseudo-reflection groups in polynomial optimization.

This is joint work with Maria Dostert, Cristobál Guzmán, and Fernando Mário de Oliveira Filho.

Scaling limits of Galton-Watson trees, and line-breaking constructions

Christina Goldschmidt

Consider a Galton-Watson branching process with a critical offspring distribution, conditioned to have total progeny n. The family trees of such processes constitute a natural collection of models for random trees, which includes various standard combinatorial trees such as uniform random labelled trees and uniform binary planar trees. Since 1990, a beautiful theory of scaling limits for these objects has been developed. It turns out that there is a good way to rescale distances in the tree so that, in the limit as n tends to infinity, one obtains a compact limit object. The family of possible limiting objects, which are essentially "tree-like" path metric spaces, is now known as the stable trees.

I will give a survey of some of this theory, and then talk about joint work with Bénédicte Haas (Paris-Dauphine), in which we give a new almost sure construction of the stable trees, via a surprisingly elementary line-breaking procedure.

Connectedness in tournaments

Alexey Pokrovskiy

Thomassen conjectured that there is a function f(k) such that every strongly f(k)-connected tournament contains k edge-disjoint Hamiltonian cycles. This conjecture was recently proved by Kühn, Lapinskas, Osthus, and Patel who showed that $f(k) < O(k^2 log^2 k)$ and conjectured that there is a constant C such that $f(k) < Ck^2$. A proof of this conjecture will be presented. The proof uses the method of "linkage structures" introduced by Kühn, Lapinskas, Osthus, and Patel, which is a fairly general method for studying highly connected tournaments.

As a second application of this method we'll show that every 452k-connected tournament is k-linked, solving another conjecture of Kühn, Lapinskas, Osthus, and Patel.

"The Norman Biggs Lecture"

Communication complexity and interleaved products

Tim Gowers

Communication complexity is a concept of great importance in theoretical computer science. It concerns situations where a number of people have partial information about a function and they want to evaluate it while exchanging as few bits as possible.

I shall discuss recent joint work with Emanuele Viola. Motivated by an application in communication complexity, we proved a theorem that says that if G is the group $SL_2(q)$ for large q, A and B are arbitrary dense subsets of G^2 , and (a_1, a_2) and (b_1, b_2) are chosen randomly from A and B, respectively, then the product $a_1b_1a_2b_2$ is very close to being uniformly distributed. I shall also talk about a multiparty generalization of this result, which has further applications to communication complexity and required us to prove a group-theoretic result of independent interest.



THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

PLACES TO EAT: in and around LSE

Close by:

All Bar One – Kingsway Belgo – Kingsway Bill's – Kingsway Café Amici – Kingsway Café Nero – Kingsway Costa – Kingsway EAT – Kingsway Paul – Kingsway Pret a Manger – Kingsway Sainsburys – Kingsway Starbucks – Kingsway Subway – Kingsway The Delaunay – Aldwych Viet Eat – Kingsway

On campus:

The Bean Counter – 32 Lincoln's Inn Fields Café 54 – Mezzanine floor, New Academic Building Daily Grind Coffee Shop – Tower One reception Fields Bar and Kitchen – Lincoln's Inn Fields Fourth Floor Café Bar – Old Building Fourth Floor Restaurant – Old Building George IV Pub – Portugal Street LSE Garrick – Columbia House Plaza Café – John Watkins Plaza Three Tuns Bar – Saw Swee Hock Student Centre



	Student Services Centre Ground floor, Old Building Graham Wallas Room OLD 5.25, Old Building Hong Kong Theatre	Ground floot, Clement House New Theatre EAS E171, East Building Ground floor, Old Building Shaw Library Sixth floor, Old Building	Sheikh Zayed Theatre New Academic Building Thai Theatre New Academic Building	New Academic Building The Venue Basement, SAW	Vera Anstey Room Between ground and first floor, Old Building (Step free access is not available to this venue)	3 Tuns Ground floor, SAW Bean Counter Basement, 32 Lincoln's Inn Fields	Café 54 Ground floor, New Academic Building Daily Grind Tower 1/2 Reception Denning Learning Cafe	First floor, SAW Fourth Floor Café Bar Old Building Fourth Floor Restaurant Old Building George IV buth Between LCH and KGS	Portugal Street LSE Garrick Ground floor, Columbia House Mezzanine Café New Academic Building Plaza Café John Watkins Plaza Senior Common Room	and Dining Room Fifth floor, Old Building Student Common Room Ground floor, King's Chambers Weston Café Sixth floor, SAW
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Accessib	 Disabled lift Disabled parking (blue badge) Accessible toilets 	Disabled access from Sum Disabled access from Sum Disabled access	Portable ramp for 20 Kingsway (KS) located in entrance foyer. Please call for Security staff to set up the ram	After 6.30pm, please call Security 020 7955 6200 to ensure that any access doors are open.	95A 95 Aldwych Aldwych ALD Aldwych House Aldwyci	CMK Clare Market Houghton CMK Clare Market Houghton CLM Clement House Aldwych Research Lab Lower Grou	COL Columbia House Aldwy CON Connaught House Aldw COW Cowdray House Portuge	EASEast Building HoughtonKGSKing's Chambers PortugKSW20 Kingsway32132 Lincoln's Inn Fields	44L 44 Lincoln's Inn Fields (n 50L 50 Lincoln's Inn Fields Pc LCH Lincoln Chambers Ports LAK Lakatos Building Portugi	LRBLionel Robbins BuildingNABNew Academic BuildingNABNew Academic BuildingOLDOld Building Houghton 5PARParish Hall Sheffield StreeterPEAPeacock Theatre Portuge

November 2014



2015 Colloquia in Combinatorics

The 2014/15 Colloquia followed the successful format established in the past: six invited talks were delivered on each of the two days. The meeting went according to plan, and our expectations were fully met. Most participants attended both days. The conference attracts both excellent speakers and a large audience, with participants coming not only from the UK but also from continental Europe.



The Queen Mary day started with an engaging talk by Stéphan Thomassé about Barát-Thomassen conjecture. In the following talk, Alex Scott talked about resolution to a beautiful conjecture of Gyarfás from 1985 that a graph without an induced odd cycle longer than three has chromatic number bounded by a function of its clique number. The programme continued with three talks by promising young mathematicians: Olof Sissak discussed recent progress for some central questions (such as how large a set of integers can be if it contains no solutions to a given linear equation) in additive combinatorics, Anita Liebenau talked about the structure of Ramsey-minimal graphs, and Ron Peled

showed how to use the probabilistic method to show the existence of regular combinatorial objects (such as orthogonal arrays, t-designs, and t-wise permutations) which previously were not known to exist. The day's programme ended with a lecture by Gregory Sorkin in which he discussed Vickrey-Clarke-Groves auctions (a type of sealedbid auction of multiple items that assigns the items in a socially optimal manner) for general combinatorial structures. Will Perkins opened the LSE day, talking about a new method for bounding the partition function in two models from statistical physics and also showed some of its applications in combinatorics. Afterwards, Alexander Schrijver discussed how partition functions and their duals can describe certain graph invariants, and how to use Lie algebras to describe these invariants. Then, Frank Vallentin gave a beautiful talk about one of the oldest problems in mathematics: 'How much of space can be filled with pairwise non-overlapping copies of a given solid?'. The talk started with historical perspective, continued with modern applications of geometric packing



problems, and ended with new methodology developed to find new upper bounds for the maximum density of translative packings of superspheres in three dimensions. In the afternoon, Christina Goldschmidt surveyed the newly developed theory of scaling limits of Galton-Watson trees. This was followed by Alexey Pokrovskiy who presented his solutions to two conjectures of Kühn, Lapinskas, Osthus, and Patel about highly connected tournaments. The meeting culminated in the traditional Norman Biggs lecture, given by Tim Gowers. Tim delivered an engaging and stimulating lecture in which he discussed how an interesting question in communication complexity quickly transforms to a seemingly unrelated problem in algebra, and then solves it.









PROFESSOR TIM GOWERS

NORMAN BIGGS SPEAKER: PROFESSOR TIM GOWERS



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New upper bounds for the density of translative packings of superspheres



LSE

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