Laudatio für Matthew Kwan aus Anlass der Verleihung des ÖMG-Förderungspreises 2024

Matthew Kwan completed his PhD in 2018 at ETH Zürich with Benny Sudakov and after a few postdoc years at Stanford University he became an assistant professor at IST Austria in 2021.

He is an extraordinary talent working in the forefront of discrete mathematics and computer science. Within a few years since his PhD he has become a truly international leader in the field, having been awarded the top prize for junior researchers in discrete mathematics (the SIAM Dénes König prize), a stand-alone grant from the US National Science Foundation (quite unusual for a postdoc) and an ERC Starting Grant from the European Commission (only 4 years beyond his PhD, while his competitors were up to 7 years after PhD). He has solved a number of major open problems spanning many different areas of combinatorics, has made new connections between different areas of discrete mathematics and probability theory, and has introduced several powerful general methods. The most significant of these advances were made since Kwan arrived in Austria less than three years ago.

Let me comment on three research achievements that I particularly like.

1. Steiner triple systems. One of the highlights of Kwan's PhD was a single-author paper[1] (in *Proceedings of the London Mathematical Society*) developing the first general-purpose techniques for the statistical study of combinatorial designs. To give some context: combinatorial design theory is one of the most classical areas of discrete mathematics, pioneered by such luminaries as Euler, Fisher, Cayley, Sylvester, Hadamard, etc. Its objects of study are exquisitely regular set systems called *designs* (for example, the classical *Latin squares*), historically of interest for their fundamental connections to group theory, experimental design, and the study of error-correcting codes. Designs are very "fragile" objects: it is a highly nontrivial matter even to understand under which circumstances they exist, and notoriously difficult to say anything nontrivial about a *typical* design, drawn uniformly at random from the set of all possible designs with given parameters. Kwan developed a general method to compare random designs with certain random hypergraph processes, and used this to prove that (asymptotically) almost all *Steiner triple systems* have a *perfect matching*. (Steiner triple systems are the simplest nontrivial class of combinatorial designs, and the existence of perfect matchings is one of their most important properties).

After moving to Austria, together with three junior collaborators (two graduate students and a postdoc), Kwan[2] managed to leverage his insights in design theory to resolve one of the most important open problems in the field: a 50-year old

[1] M. Kwan, Proc. Lond. Math. Soc. (3) 121 (2020), no. 6, 1468–1495

[2] M. Kwan, A. Sah, M. Sawhney, M. Simkin, arXiv:2201.04554

conjecture of Paul Erdős on the existence of Steiner triple systems which have high *girth*. This is a structural property which implies that a Steiner triple system is in a certain sense "disordered", and is incompatible with the crystalline algebraic constructions that had pervaded the field since its inception. The proof of this theorem required significantly more sophisticated probabilistic tools than had previously been applied in this area, including a powerful general "weight system" framework for concentration of combinatorial random variables. This work has recently been accepted for the *Annals of Mathematics*, and has already inspired a range of further research (for example, the paper introduces a general class of "restricted random processes", which iteratively build a random hypergraph subject to certain constraints; related processes have since found applications in graph colouring, Ramsey theory and extremal hypergraph theory).

2. Ramsey graphs. *Ramsey's theorem* says that every n-vertex graph has a *homogeneous set* (clique or independent set) of size at least about $\log n$; we say that an n-vertex graph is a *Ramsey graph* if it has no homogeneous sets larger than $C \log n$ for some absolute constant C. Ramsey graphs are graphs which are in a certain sense "maximally disordered", and are of fundamental importance in combinatorics and theoretical computer science. In particular, there has been intensive study over the last 50 years on *structural properties* of Ramsey graphs (the list of people who worked in the area includes such leaders as Noga Alon, Béla Bollobás, Paul Erdős, Endre Szemerédi and Vojtěch Rödl).

During his PhD, Kwan and his advisor proved[3] the fundamental *Erdős–Faudree-Sós conjecture* in this area, which, roughly speaking, says that all Ramsey graphs must resemble typical outcomes of *random* graphs, from the point of view of their *subgraph statistics*. In doing so, Kwan introduced new ideas from probability theory (in particular, ideas from the theory of *anticoncentration*) to the study of Ramsey graphs. During his postdoctoral years, Kwan developed these ideas further with collaborator Lisa Sauermann[4] (a student at the time), proving new combinatorial anticoncentration inequalities suitable for application to Ramsey graphs.

After moving to Austria, Kwan began a much more thorough investigation into the connections between anticoncentration and Ramsey theory, together with Sauermann and two graduate students. His goal was to prove a longstanding conjecture on Ramsey graphs posed by Paul Erdős and Brendan McKay (roughly speaking, the conjecture is that in any Ramsey graph, for essentially any integer x less than the number of edges of the graph, one can find an induced subgraph with exactly x edges). This problem had been identified by Erdős about 30 years ago as being particularly important to the development of Ramsey theory: he even offered a special \$100 prize for its resolution! Kwan's efforts were rewarded: in a tour-de-force[5] bringing together ideas from many different areas of mathematics (including Fourier analysis, random matrix theory, the theory of Boolean functions, and low-rank approximation), he managed to prove a result vastly more general than the original Erdős–McKay conjecture. This work was recently published in the premier journal *Forum of Mathematics, Pi.*

3. Discrete random matrices. During his postdoctoral years, Kwan's interests in anticoncentration had begun to lead him towards discrete random matrix theory (historically, the theory of anticoncentration has been fundamentally intertwined with the study of singularity, rank and determinants of discrete random matrices). This is an area featuring contributions by such luminaries as Bourgain, Szemerédi and Tao.

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[3] M. Kwan, B. Sudakov, Trans. Amer. Math. Soc. 372 (2019), no. 8, 5571–5594

[4] M. Kwan, L. Sauermann, Discrete Anal. 2020

[5] M. Kwan, A. Sah, L. Sauermann, M. Sawhney, Forum Math. Pi 11 (2023)

Just before moving to Austria, Kwan made his first contributions to the area. In particular, together with Lisa Sauermann, he proved that for a random symmetric $n \times n$ matrix M_n (with essentially any nontrivial distribution for its entries), the order of magnitude of the permanent of M_n is $n^{n/2+o(n)}$ with high probability. Previously, essentially nothing was known about the permanent of a random symmetric matrix; this was described as "the still missing (final) piece of the picture" in Van Vu's survey on combinatorial random matrix theory[6] (based on his address at the 2014 International Congress of Mathematicians).

Since moving to Austria, discrete random matrix theory has become a key part of Kwan's research program. As his biggest accomplishment in this area, together with three graduate students[7], he managed to find a combinatorial description of the rank of a sparse random matrix. Specifically, consider a random binary matrix M_n, where every entry is independently equal to 1 with probability p_n and 0 with probability $1 - p_n$. If p_n decays sufficiently rapidly with n, then M_n is so sparse that it typically will not have full rank, but Kwan and his collaborators proved that with high probability the rank deficiency can be completely described in combinatorial terms (thereby giving a linear-time algorithm to compute the rank). This possibility was raised by Vu in his 2014 ICM address as a vague dream, but no significant progress could be made despite its importance (it has a number of implications, for example, it implies a central limit theorem for the rank of a sparse random matrix). Such a strongly combinatorial approach is revolutionary in random matrix theory, as it handles the very sparse regime that is inaccessible with traditional methods.

The three topics discussed above are by no means exhaustive. Kwan's productivity is absolutely extraordinary both in quality and quantity; less than six years after his PhD, including preprints, he has 48 articles (15 since arriving in Austria), in a variety of leading journals. Just to mention a few other breakthroughs, he developed[8] a new *iterative degree exposure* method to resolve an infamous conjecture of Füredi from the 1980s on partitions of random graphs (notably included on Ben Green's well-circulated list of 100 open problems), and he has some of the current state-of-the-art results[9] on *Rota's basis conjecture* in matroid theory. He has made connections[10] between stochastic geometry and the theory of *extended formulations* in combinatorial optimization, and very recently he resolved[11] the

[6] V. H. Vu, Proceedings of the International Congress of Mathematicians—Seoul 2014. Vol. IV, 489–508

[7] M. Glasgow, M. Kwan, A. Sah, M. Sawhney, arXiv:2303.05435

[8] A. Ferber, M. Kwan, B. Narayanan, A. Sah, M. Sawhney, Comm. Amer. Math. Soc. 2 (2022), 380–416

[9] M. Bucić, M. Kwan, A. Pokrovskiy, B. Sudakov, Int. Math. Res. Not. 2020, no. 21, 8007–8026

[10] M. Kwan, L. Sauermann, Y. Zhao, Trans. Amer. Math. Soc. 375 (2022), no. 6, 4209–4250

[11] M. Kwan, L. Sauermann, arXiv:2312.13826

so-called *quadratic Littlewood–Offord problem* on the boundary between additive combinatorics and probability theory. His work has been published in top journals such as *Forum of Mathematics Pi*, *Duke Mathematics Journal*, *Selecta Mathematica*, *Proceedings of the London Mathematical Society*, *Advances in Mathematics*, *Transactions of the American Mathematical Society*, *Journal of the London Mathematical Society*, and *International Mathematical Research Notices*. As measured by Google Scholar, he has over 600 citations (at least 350 since arriving in Austria).

In summary, Matt Kwan is a brilliant young talent whose results just within the last few years would trump the lifetime achievements of most senior mathematicians. His breadth within combinatorics as well as his technical versatility and the depth of his conceptual creativity make him stand out among all his peers worldwide. IST Austria is very proud to have attracted such an international rising star. Congratulation to Matt for the well deserved Prize of the Austrian Mathematical Society!

(László Erdős)