Shuo Pang

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Research Interests

Proof complexity, circuit complexity, combinatorial optimization

Positions

Postdoc, University of Copenhagen — November 1, 2022–Present
Host: Jakob Nordström

Education

Ph.D. in Mathematics, University of Chicago — June 4, 2022
Dissertation: *Some Results in Proof Complexity and SAT Solving*
Adviser: Alexander Razborov

B.S. in Mathematics, Peking University — July 30, 2016
Thesis: *A Survey on Fermat's Last Theorem in the First Case*
Thesis adviser: Qingchun Tian

Publications

- *Graph Colouring Is Hard on Average for Polynomial Calculus and Nullstellensatz* — 2023
  Joint with Jonas Conneryd, Susanna de Rezende, Jakob Norström, and Kilian Risse.
  To appear in Proceedings of the 64th Annual IEEE Symposium on Foundations of Computer Science (FOCS23).

  Description. This work proves that Polynomial Calculus, hence also Nullstellensatz, requires linear degree to refute the 3-colorability of sparse random graphs and random regular graphs. This gives optimal, exponential size lower bounds via the known size-degree relation.

  The proof constructs an Alekhnovich-Razborov pseudo-reduction operator, based on the Romero-Tunçel technique which was originally designed for large-girth graphs. We extend this technique to rid of the large-girth assumption, and this enables us to deal with general sparse expanders in an elegant and simple way.

- *Some Results in Proof Complexity and SAT Solving* — 2022
  PhD dissertation, UChicago open access

  Description. The dissertation encloses the three main results of my PhD study on Resolution-Clique, SoS-Clique, and CDCL Solvers, with a gentle introduction to the shared underlying theme.

- *SoS Lower Bound for Exact Planted Clique* — 2021
  Proceedings of the 36th Computational Complexity Conference (CCC21). Submitted to journal.

  Description. This work proves Sum-of-Squares (SoS) degree lower bounds for the exact Planted Clique problem on random graphs $G(n, \frac{1}{2})$, where 'exact' means the SoS algorithms (our adversary) can reason with polynomial identities generated by the full set of axioms, including $\sum_{i=1}^{n} x_i = \omega$ which describes the size of the imaginary clique. Our degree lower bound is $d = \Omega(\frac{\epsilon^2 \log n}{\log \log n})$ as long as $\omega = O(n^{\frac{1}{2}-\epsilon})$, which settles the problem left open from the pseudo-calibration paper [Barak-Hopkins-Kelner-Kothari-Moitra-Potechin16] almost optimally in both parameters d and ω.

The main drive behind the work is developing further the average-case lower bound techniques for SoS. Our design of the pseudo-expectation $\widetilde{E}$ is different from the pseudo-calibration method, and the PSDness analysis is, on a high level, Johnson schemes [Feige-Krauthgamer03] plus graphical matrices [BHKKMP16] combined into use. This combination is carried out through somewhat intricate combinatorial transforms and the use of special Hankel matrices, a realization made possible by the specialty of $\widetilde{E}$ in the first place.

- *On Cdcl-Based Proof Systems With the Ordered Decision Strategy* 2019
  Joint with Nathan Mull and Alexander Razborov
  Proceedings of the 23rd Theory and Applications of Satisfiability Testing (SAT20). SIAM Journal on Computing (SICOMP), Volume 51, Issue 4, 2022.

  Description. In this work, we prove that conflict-driven clause learning (CDCL) SAT-solvers with the *ordered decision strategy* and *DECISION learning scheme*, are equivalent to ordered resolution. We also prove that if replacing this learning scheme with its opposite, which stops backtracking right after the first non-conflict clause, then the solvers become equivalent to general resolution. This is among the first theoretical studies of the interplay between specific decision strategies and clause learning.

  For both results, we allow nondeterminism in the solver's ability to perform unit propagation, conflict analysis, and restarts, in a way similar to previous works in the literature. To aid the presentation of our results, and possibly future research, we define a model and language for discussing CDCL-based proof systems that allow for succinct and precise theorem statements.

- *Large Clique Is Hard on Average for Resolution* 2019
  Proceedings of the 16th International Computer Science Symposium in Russia (CSR21)

  Description. This work proves a $2^{\Omega\left(k^{1-o(1)}\right)}$ resolution size lower bounds for the k-Clique problem on suitable random graphs where $k < n^{1/3}$. This complements the result in [Beame-Impagliazzo-Subharwal07] which is for the range $k > n^{5/6}$. The proof here uses the classical bottleneck counting/random restriction framework plus a variant of clause width. This width variant is defined from neighborhood density, a concept introduced and studied in [Beyesdorff-Galesi-Lauria13, Atserias-Bonacina-De Rezende-Lauria-Nordström-Razborov18].

Academic Service & Activity

- Paper Refereeing: Computational Complexity (2020, 2021), SIAM Journal on Discrete Mathematics (2023), STOC19, 23, CCC21, SAT23
- *SAT Extended Reunion*, Simons Institute at UC Berkeley. Invited visiting scientist. US 2023
  - Invited talk on Polynomial Calculus and Colouring
- *MIAO Seminar*, University of Copenhagen (UCPH). DK 2022
  - Invited talk on Sum-of-Squares and Exact Clique
- *Banff International Research Station (BIRS) Complexity Workshop.* CA 2020
  - Invited talk on Resolution and Clique
- UCPH and Lund University. Invited academic visit. SE & DK 2019
  - BARC Talk at UCPH on Resolution and Clique
  - MIAO Seminar talk at Lund University on CDCL Solvers
- *Complexity Theory Workshop*, Clay Math Institute, Oxford. Student attendee UK 2018

- REU *"On Bott Periodicity"* at Peking University, advised by Prof. Houhong Fan. CHN 2014

Teaching Experience

- As Instructor

  At Chicago: 2018–21

  Calculus I, MATH 15100 (f19)
  Calculus II, MATH 15200 (f18, w20, f21)
  Calculus III, MATH 15300 (w19, s19, s20, f20, w21)
  f/w/s: fall/winter/spring quarter.
  Lecturing 2.5 hr/week, office hour and problem session 3 hr/week, 10 weeks.

- As co-Instructor

  - *Computability and Complexity (CoCo)* at UCPH, with Jakob Nordström 2023

- As TA

  At Chicago: 2017–18

  Honors Calculus 3, MATH 16300, with Sarah Ziesler (f17)
  Point Set Topology, MATH 26200, with Kurt Vinhage (w18)
  Complex Variables, MATH 27000, with Danny Calegari (f18)

Honors

- Fellowships

  - *S. McCormick Research Fellowship*, UChicago 2016–17

- Math contests

  - S.-T. Yau College Student Math Contest, 2015
    1st place in team contest, 3rd in individual geometry & topology.
  - The Chinese Mathematics Competitions (CMC) in math major, first prize. 2014
  - High school:
    China Mathematics Olympiad (CMO), silver. 2012
    China Western Mathematics Olympiad (CWMO), gold. 2010
    China Northern Mathematics Olympiad (CNMO), first prize. 2010

- Etc.

  Chinese Physics Olympiad (CPhO) provincial round, first prize. 2011

Reference

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