Vaibhav Karve, PhD

Senior Data Scientist
Data Science Directorate
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Research Interests

data science, computational graph theory, topology, boolean satisfiability, logic, algorithms, formal math, type theory interactive theorem proving

Education

PhD in Mathematics 2015-2021
University of Illinois at Urbana-Champaign

Integrated BS-MS in Mathematics 2010-2015
Indian Institute of Science Education and Research – Kolkata
Recipient of the *Director's gold medal*

Publications

- **V. Karve**, A.N. Hirani.
  GraphSAT – a decision problem connecting satisfiability and graph theory (2021), arXiv:1707.08557
- **V. Karve**, D. Yager, M. Abolhelm, D.B. Work, R.B. Sowers.
  Seasonal Disorder in Urban Traffic Patterns: a Low Rank Analysis,
  Journal of Big Data Analytics in Transportation (2021), doi.org/10.1007/s42421-021-00033-4
- **V. Karve**, A.N. Hirani.
  The complete set of minimal simple graphs that support unsatisfiable 2*-CNFs*
  Discrete Applied Mathematics (2020), doi.org/10.1016/j.dam.2019.12.017
- Y. Wu, G. Shindnes, **V. Karve**, D. Yager, D.B. Work, A. Chakraborty, R.B. Sowers.
  Congestion Barcodes: Exploring the Topology of Urban Congestion Using Persistent Homology (2017), arXiv:1707.08557

Developed Software

`graphsat`: A python package that recognizes clauses, Cnfs, graphs, hypergraphs, and multi-hypergraphs. The package implements local graph-rewriting, graph-satchecking, calculation of graph disjunctions, as well as checking of new reduction rules. It was created as a companion software to my PhD thesis. GitHub: /vaibhavkarve/graphsat. doi.org/10.5281/zenodo.4662169

`multihypergraph`: A python package for graph theory that supports looped- multi- and hyperedges. PyPI: /multihypergraph

`Model theory in lean`: A model theory implementation in the Lean theorem prover. Joint work with E. Blanchard, S. Harman, P. Hieronymi, N. Ravi, J. Schargorodsky, K. Thompson, N. Wulffraat, T. Xu, F. Zhao. GitHub: /vaibhavkarve/igl2020

Programming Skills

Languages
Python, Lean theorem prover, SageMath, Octave, ELisp, Bash, Make

Software

LaTeX, plain TeX, CoCalc, Docker, Emacs, Git, GitHub/GitLab, Jupyter, Gurobi (linear program solver), XPPaut (differential equation numerical solver)

Research Experience

[redacted] at SimSpace 2021-Present

PhD Thesis 2018-2021
Graphical structure of unsatisfiable Boolean formulae
Advisor: Dr. Anil Hirani
University of Illinois at Urbana-Champaign

- Fall 2020: funded by the David G. Bourgin fellowship.
- Defined a translation map from boolean 3-satisfiability instances into multi-hyper-graphs.
- Wrote a python package that computes CNFs (sentences in conjunctive normal form) as well as multi-hyper-graphs.
- Attempting a forbidden-graph characterization for 3-satisfiability.

Graduate Research Assistant Fall 2019
Forbidden graph characterization for 2-satisfiability
Advisor: Dr. Anil Hirani
University of Illinois at Urbana-Champaign

- Used forbidden-graph characterization to demonstrate a finite obstruction set for satisfiability.

Summer Graduate School July 2018
Invited to Representations of High Dimensional Data summer graduate school
Mathematical Sciences Research Institute (MSRI) in Berkeley, California

Graduate Research Assistant Summer 2017, Spring 2018
Non-negative matrix factorization of New York taxi traffic
Advisor: Dr. Richard Sowers and Dr. Daniel Work
University of Illinois at Urbana-Champaign

- Analyzed taxi traffic data from New York city with special focus towards compression and estimation.
- Used Sparse Non-negative Matrix Factorization to extract 50 of the most popular traffic trends in New York.
- Gained new insights into traffic dynamics, with a view towards aiding urban planning and extreme-event predictive algorithms.

NSF Program for Interdisciplinary and Industrial Internships at Illinois (PI4) Intern Summer 2016, Summer 2017
Recognizing patterns in New York taxi traffic
Advisor: Dr. Richard Sowers and Dr. Daniel Work
Funded by NSF, University of Illinois at Urbana-Champaign

- Analyzed taxi traffic data from New York city.
- Applied Persistent Homology tools to generate bar-codes that can characterize the traffic dataset.

MS thesis 2014-2015
Classification of Stable Exterior Forms
Advisor: Dr. Saugata Bandyopadhyay
Indian Institute of Science Education and Research – Kolkata

- A complete classification of all stable exterior forms was sought over both the real and complex fields. This involved finding the orbits, stabilizers and normal forms for each case, under the action of $GL(V)$ through pullback.

Canada Mitacs intern Summer 2014
Unitary Representations of Super-Conformal Algebra
Advisor: Dr. Hadi Salmasian
University of Ottawa

- Construction of the Super-Virasoro algebra, which arises as a $\mathbb{Z}_2$ gradation of the central extension of a Lie algebra of differential operators, called the Witt algebra, was studied. This algebra arises naturally from the calculations of string theory.
- The unitary representation for the Super-Conformal current algebra, seen as a semi-direct product of the Super-Virasoro and the Super-Loop algebras was found.

IISER research intern 2011-2013
Mathematical Modeling of Calcium Ion Oscillations due to Membrane Fluxes in Pancreatic Cells
Advisor: Dr. Pranay Goel
Indian Institute of Science Education and Research – Pune

- A minimal model was developed, as a variation of the class-1 Li-Rinzel model to explain the anomalously *slower* oscillations observed in pancreatic cells. The numerical integration software XPPaut was employed for solving the differential equations involved and generating the bifurcation diagrams needed.
- The model was able to reproduce all experimental data on the reaction of these cells to CPA, oleate and EGTA accurately.
- This work was in collaboration with Dr. Arthur Sherman and Dr. Les Satin.

IISER research intern Summer 2012
Mathematical Modeling of One-Carbon and Glutathione Cycle
Advisor: Dr. Pranay Goel
Indian Institute of Science Education and Research – Pune

- The literature on existing models of the glutathione cycle was studied and the equations were successfully simplified, making them more tractable for any future work on this system.

Teaching and Mentoring

Graduate Teaching Assistant – *Merit Program for Emerging Scholars* Fall 2016, Spring 2017, Fall 2017, Fall 2018, Spring 2021
Calculus I, II, III and Differential Equations
University of Illinois at Urbana-Champaign

- The Merit Program for Emerging Scholars targets students with high potential who are members of groups, such as ethnic minorities and women, who tend to be underrepresented in the areas of science, mathematics and engineering.
- Taught in active-learning formats.

Teaching Assistant April 23-25, 2021
INMAS 2021: Workshop on Modeling and Optimization (online)
Workshop instructor: Alexander Estes

- INMAS provides high quality training and internship experiences that broaden career opportunities for students in the Mathematical Sciences by bringing powerful computational and modeling tools to bear on industry's most pressing problems.
- The workshop introduced optimization models and methods for solving linear programming and mixed integer linear programming using the Gurobi optimization solver.

Illinois Geometry Lab Mentor Spring 2021, Fall 2020, 2016-2017
University of Illinois at Urbana-Champaign

- The Illinois Geometry Lab at UIUC aims to enhance and support undergraduate research within the department and to engage local, state and national communities through outreach.
- 2020: Led a team of undergraduates in a research project titled *Theorem proving in Lean*. The project aims to formalize model theory in Lean.
  GitHub: /vaibhavkarve/igl2020
- 2016-2017: Led a team of undergraduates in a research project that visualized urban traffic patterns temporally and spatially, using matrix factorization algorithms as well as persistent homology.

IGL–UniHigh Summer Research PI Summer 2020
Interactive theorem proving in Lean: formalizing Euclidean and Hilbertian geometry
Illinois Geometry Lab, University of Illinois at Urbana-Champaign

- Led a 5 week summer research project with high-school seniors.
- We formalized Euclid's and Hilbert's axioms in the Lean interactive theorem prover. GitHub: /vaibhavkarve/leanteach2020.

Graduate Teaching Assistant Spring 2019, Spring 2020
Computational Mathematics
University of Illinois at Urbana-Champaign
- Conceptualized and designed the course with Dr. Anil Hirani.
- Course utilizes innovative teaching platforms like CoCalc to teach programming in Python and SageMath to undergraduates.
- Topics covered include network and graph algorithms, topological data analysis, computer algebra and cryptography algorithms.

Graduate Teaching Assistant Fall 2015, Spring 2016
Calculus III
University of Illinois at Urbana-Champaign
- Taught in active-learning, discussion-based formats.

Summer Illinois Math Camp – instructor and course designer Summer 2017
Classical Constructions: Learn to draw algebra
University of Illinois at Urbana-Champaign
- Designed and taught a week-long course for 9th through 12th grade students.
- Course description: What can we do with a compass and a straightedge? These simple tools can be used to create shapes, do arithmetic and prove fun facts about geometry. This course taught students geometry as the ancient Greeks saw it, using only tools that were available then.

Undergraduate Teaching Assistant 2013-2014
Real Analysis, Calculus I and II
Indian Institute of Science Education and Research – Kolkata

Fellowships

David G. Bourgin Mathematics Fellowship Fall 2020
Department of Mathematics, University of Illinois at Urbana-Champaign

Gene H. Golub Summer Research Fellowship Summer 2019
Department of Mathematics, University of Illinois at Urbana-Champaign

Innovation in Science Pursuit for Inspired Research (INSPIRE) Fellowship 2010-2015
Awarded by Department of Science & Technology, Government of India

Awards

Departmental TA Instructional Award 2019
Department of Mathematics, University of Illinois at Urbana-Champaign

Honorable Mention – Image of Research Competition 2019
Graduate College, University of Illinois at Urbana-Champaign
Awarded for visualizing Kaprekar's process

Listed on *Teachers Ranked as Excellent* Fall 2015, Spring 2016, Fall 2016, Spring 2017, Fall 2017
Center for Innovation in Teaching and Learning, University of Illinois at Urbana-Champaign Fall 2018, Spring 2019, Spring 2020, Spring 2021

IGL Research Award* Fall 2016
Illinois Geometry Lab, Department of Mathematics, University of Illinois at Urbana-Champaign
*awarded to Manhattan Traffic IGL research team

People's Choice Award 2016

Research Live! Competition, University of Illinois at Urbana-Champaign

Director's Gold Medal 2015
Indian Institute of Science Education and Research – Kolkata

Co-Curriculars

Dramatics 2010-2015
Active member of the dramatics club at IISER Kolkata, having conceptualized, scripted, acted in and directed over a dozen plays.