

# Vaibhav Karve, PhD

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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:2105.11390](https://arxiv.org/abs/2105.11390)
- **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](https://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](https://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](https://arxiv.org/abs/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](https://github.com/vaibhavkarve/graphsat). [doi.org/10.5281/zenodo.4662169](https://doi.org/10.5281/zenodo.4662169)

**multihypergraph**: A python package for graph theory that supports looped- multi- and hyperedges. PyPI: [/multihypergraph](https://pypi.org/project/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](https://github.com/vaibhavkarve/igl2020)

## PROGRAMMING SKILLS

### Languages

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

### Software

ℒ<sub>TEX</sub>, plain T<sub>EX</sub>, CoCalc, Docker, Emacs, Git, GitHub/GitLab, Jupyter, Gurobi (linear program solver), XPPaut (differential equation numerical solver)

## RESEARCH EXPERIENCE

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**Project ██████ at SimSpace Corporation** 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

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### Graduate Teaching Assistant – *Merit Program for Emerging Scholars*

Fall 2016, Spring 2017, Fall 2017

Calculus I, II, III and Differential Equations

Fall 2018, Spring 2021

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](https://github.com/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](https://github.com/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 9<sup>th</sup> through 12<sup>th</sup> 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**

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**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 &amp; Technology, Government of India

**AWARDS**

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**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**

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**Dramatics**

2010-2015

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