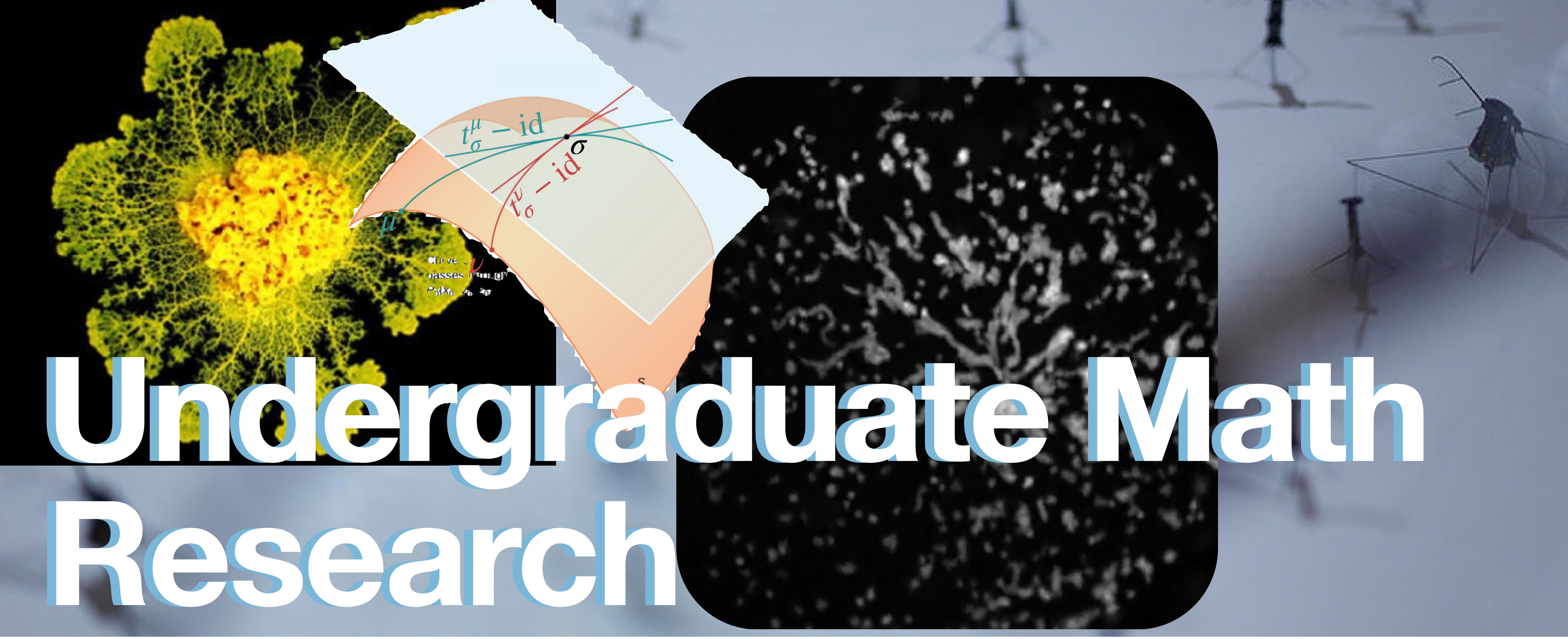

Undergraduate Math Research

Info Session

Monday, January 26th, 2026
University of California, Santa Barbara

Do you like pizza and/or math?

Scan this QR code to receive a copy of these slides and support future events like this!

Plan

Welcome and Introduction - Prof. Katy Craig (math)

Prof. Paul Atzberger (math)

Prof. Xiaolei Zhao (math)

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Prof. Katy Craig (math)

Directed Reading Program

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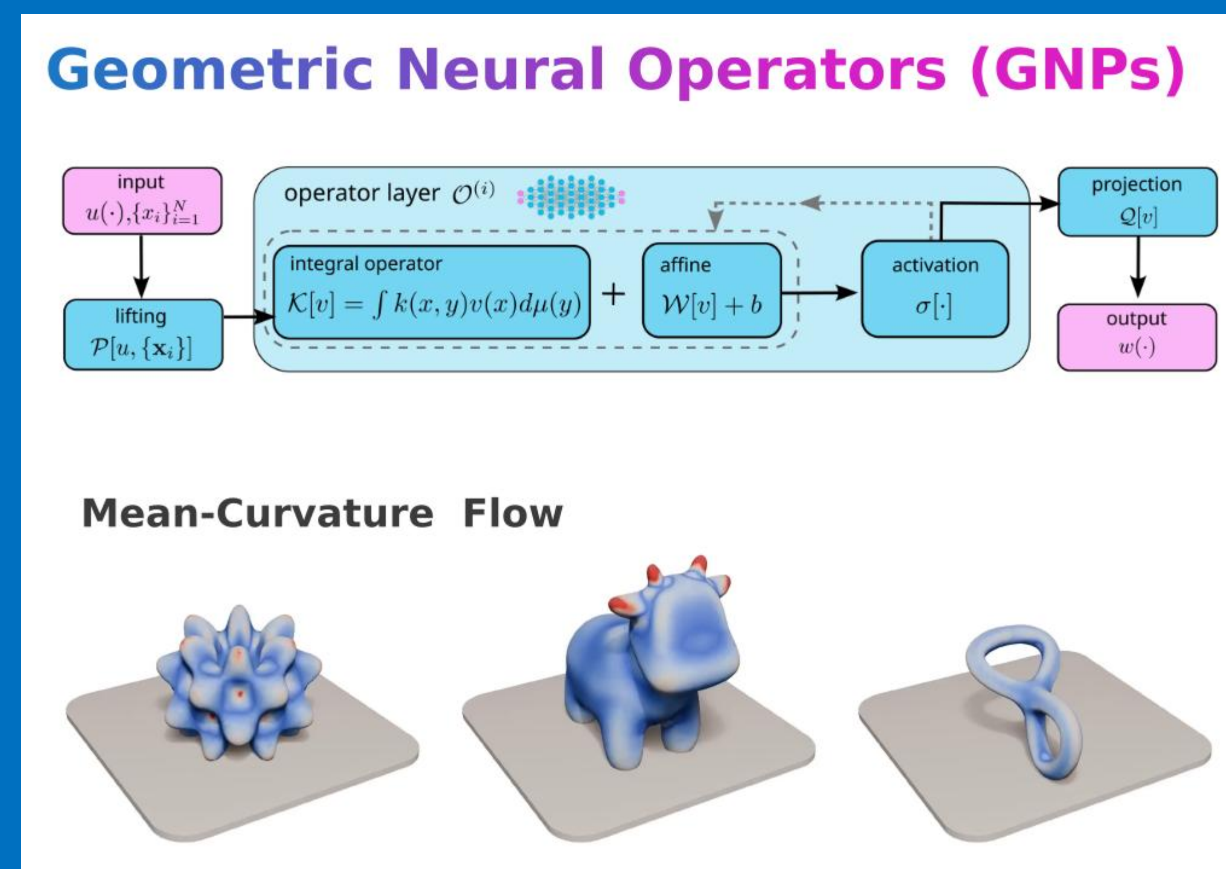
Atzberger Group

sign-up here

Applied Analysis:
- Differential Geometry
- Stochastic Analysis
- Numerical Methods

Machine Learning / AI:
- Geometric Deep Learning
- Adversarial Learning
- Scientific ML & Applications

Computational Mathematics
- Fluctuating Hydrodynamics (SPDEs)
- Statistical Mechanics of Soft Materials
- Biophysics Applications



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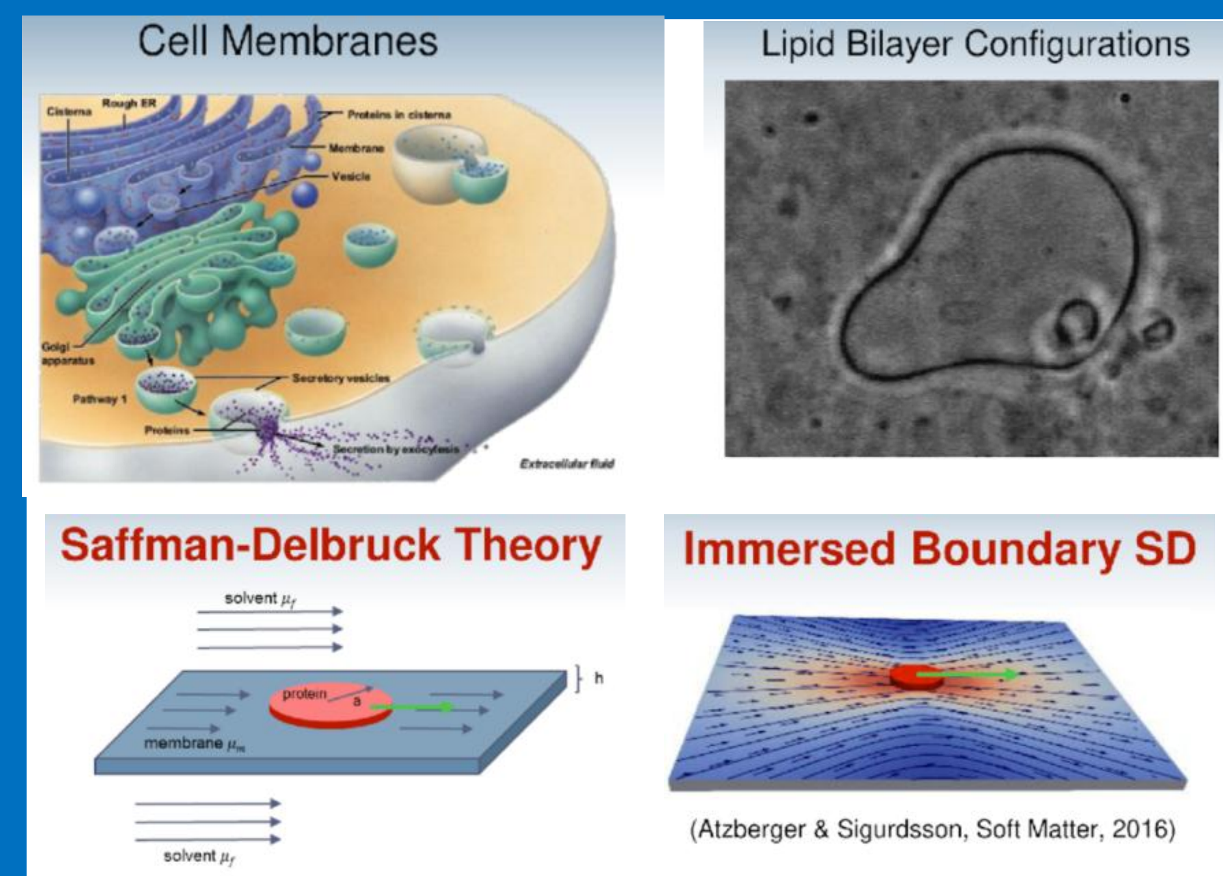

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sign-up here

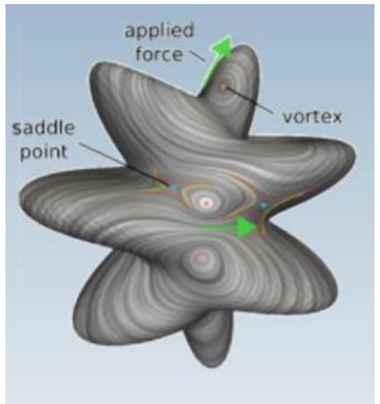
Surface Fluctuating Hydrodynamics (Inertial Regime)

Fluid

$$\rho \frac{d\mathbf{v}^\flat}{dt} = \mu_m\left(-\boldsymbol{\delta}\mathbf{d}\mathbf{v}^\flat + 2K\mathbf{v}^\flat\right) - \mathbf{d}p + \mathbf{t}^\flat + \Lambda\left[\gamma\left(\mathbf{V} - \Gamma\mathbf{v}^\flat\right)\right] + \mathbf{f}^\flat_{thm}$$
$$-\boldsymbol{\delta}\mathbf{v}^\flat = 0.$$

Microstructures

$$m\frac{d\mathbf{V}}{dt} = -\gamma\left(\mathbf{V} - \Gamma\mathbf{v}^\flat\right) - \nabla\phi + \mathbf{F}_{thm}$$
$$\frac{d\mathbf{X}}{dt} = \mathbf{V}.$$



Thermal Fluctuations

$$\langle \mathbf{f}_{thm}(t)\mathbf{f}_{thm}(s)^T\rangle = -2k_BT\mathcal{L}_{ff}\delta(t-s$$
$$\langle \mathbf{F}_{thm}(t)\mathbf{F}_{thm}(s)^T\rangle = 2k_BT\gamma\mathcal{I}\delta(t-s)$$
$$\langle \mathbf{F}_{thm}(t)\mathbf{f}_{thm}(s)^T\rangle = -2k_BT\gamma\Gamma\delta(t-s).$$

$$\mathcal{L}_{ff} = \mathcal{L}_f - \gamma\Lambda\Gamma$$
$$\mathcal{L}_f = \mu_m\left(-\boldsymbol{\delta}\mathbf{d} + 2K\right) + \mathcal{T}_f$$

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Introduction to Algebraic Geometry

Shapes, Equations, and Applications

Xiaolei Zhao

January 26, 2026

The Bridge Between Shape and Equation

What is Algebraic Geometry?

It is the study of geometric shapes defined by sets of algebraic equations.
It acts as a translation dictionary between:

Geometry (Visual)

- Curves, surfaces, and higher dimensions.
- Intuitive properties (holes, intersections).

Algebra (Formal)

- Polynomials and Rings.
- Calculation and formal manipulation.

The Central Idea: Zeros of Polynomials

- $y - x^2 = 0 \longrightarrow$ **Parabola**
- $x^2 + y^2 - 1 = 0 \longrightarrow$ **Circle**

The Toolkit and Vocabulary

- **1. Affine & Projective Varieties**
  - The fundamental shapes are called *Varieties*.
  - We often work in **Projective Space** (adding points at infinity) so that parallel lines meet, making the math more symmetric.
- **2. The Algebra-Geometry Duality**
  - **Ideals:** A collection of polynomials corresponds to a shape.
  - **Coordinate Rings:** We study functions on the shape to understand the shape itself.
- **3. The Modern Revolution (Schemes)**
  - Pioneered by Alexander Grothendieck.
  - Allows us to do geometry over integers, bridging the gap to **Number Theory**.

Why It Matters (Real-World Applications)

- **Cryptography (Digital Security)**
  - **Elliptic Curve Cryptography (ECC):** Modern encryption relies on the algebraic structure of curves defined by:

$$y^2 = x^3 + ax + b$$

  - Hard to reverse without a key, keeping data secure.
- **Theoretical Physics**
  - **String Theory:** Uses Calabi-Yau manifolds to model the hidden extra dimensions of the universe.
- **Robotics & Coding**
  - **Kinematics:** Robot movement ranges are calculated using algebraic varieties.
  - **Error Correction:** Used in satellite data transmission.

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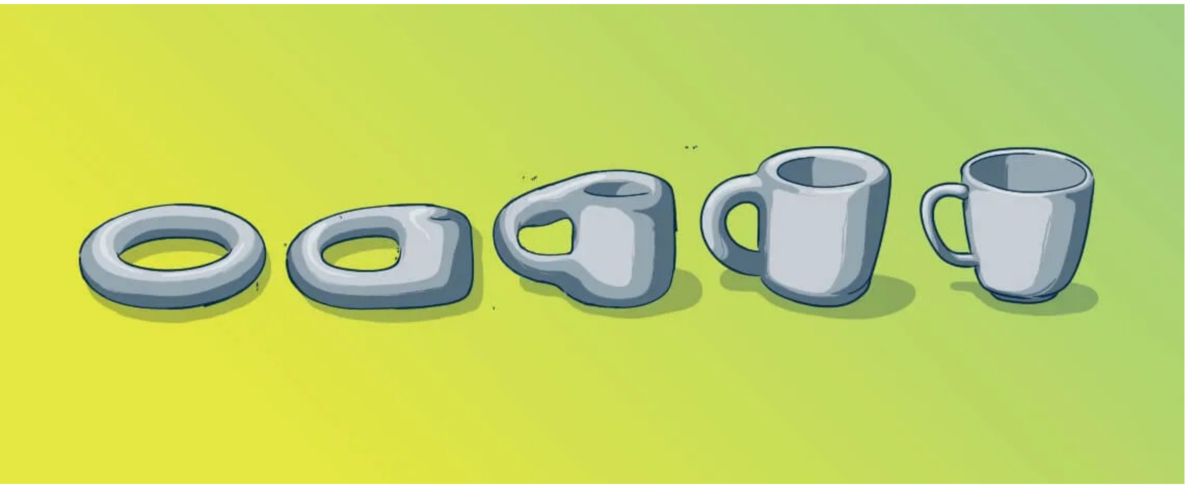
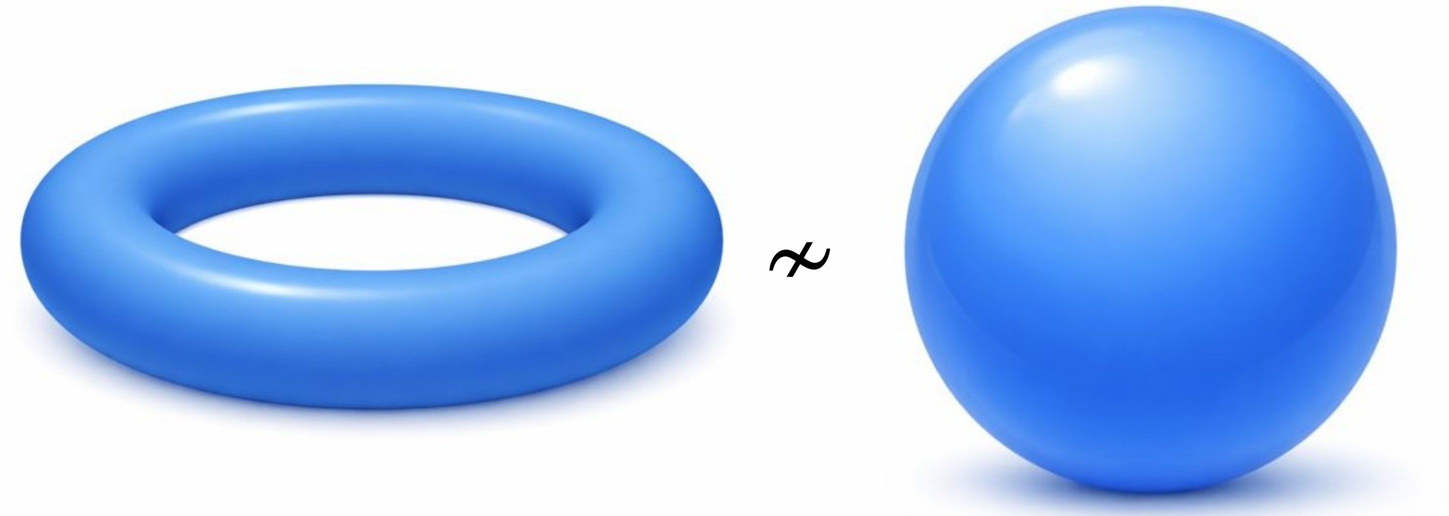
Research in Topology

Rhea Palak Bakshi
University of California, Santa Barbara

Information Session for Undergraduate Research
January 26, 2026

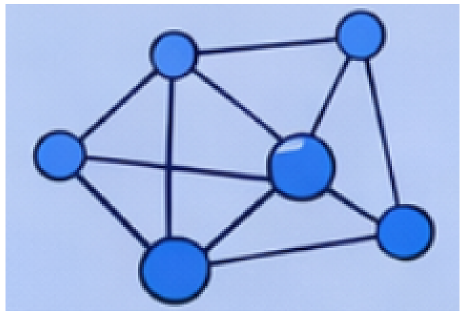




Topology

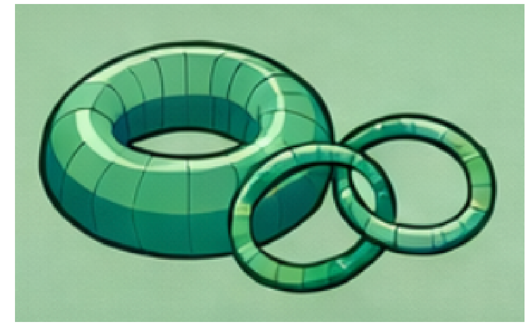
- Mathematical study of objects that are highly mouldable
- Branch of abstract math - exploration of properties of ‘geometric’ objects
- Think of it as geometry but no concept of distance
- Tells apart objects based on the number and kinds of holes in them

Point-Set Topology



- Topological Spaces
- Continuous Maps
- Connected and Compact

Algebraic Topology

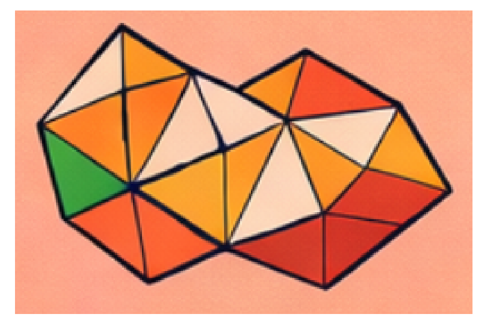


- Homotopy Groups
- Homology Groups
- Covering Spaces

Differential Topology

- Smooth Manifolds
- Intersection Theory
- Morse Theory

Piecewise-Linear Topology

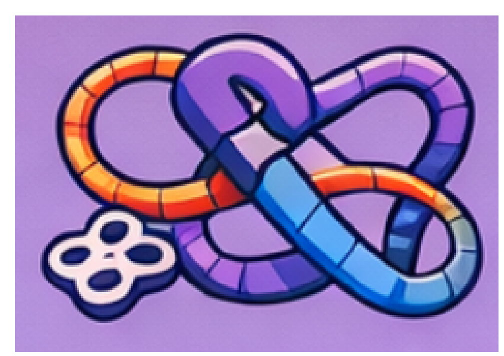


- PL Structures
- Simplicial Complexes
- Triangulations

Geometric Topology

- Knot Theory
- Low-Dimensional Topology
- Mapping Class Groups

Quantum Topology



- Skein Modules
- TQFTs and Anyons
- Hyperbolic Geometry

Algebraic Geometry

Hyperbolic Geometry

Mirror Symmetry

Quantum Cluster algebras

Temperley - Lieb algebras

Topological Quantum Field Theories

Skein Modules

Hecke algebras

Hopf algebras

Witten - Reshetikhin - Turaev Invariants

Representation Theory

Homological invariants

AJ Conjecture

Volume Conjecture

Research Opportunities With Me

Directed Reading Program

2025 3-Manifold Topology

Introduction to Knot Theory

Khovanov Homology

Skein Modules and Algebras

2026 Gram Determinants

Research Projects

2025 - 2026

Medial Quandles and Causality Detection

Summer Research (future)

2026

Problems in Combinatorial Knot Theory

Stephen Bigelow

Rhea Palak Bakshi

Quantum Algebra and Braid Groups

Quantum Topology and Knot Theory

John McCammond

Quinn Kolt

Geometric Group Theory and Combinatorics

Category Theory and Quantum Algebra

Tonie Scroggin

Alfredo Ramirez

Braid Varieties and Cluster Algebras

Low-Dimensional Topology

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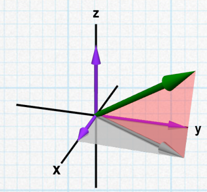
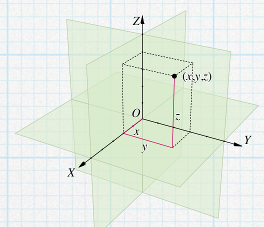
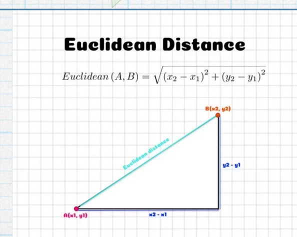
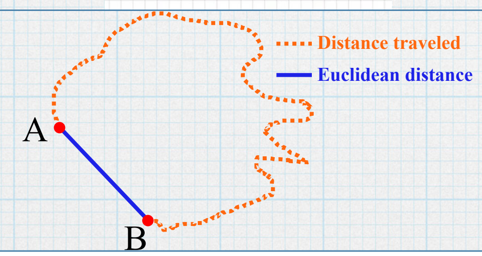
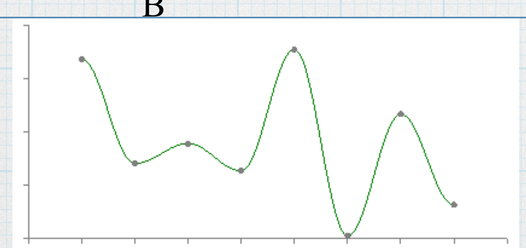
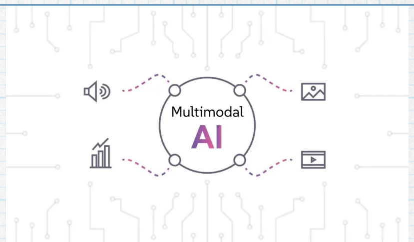
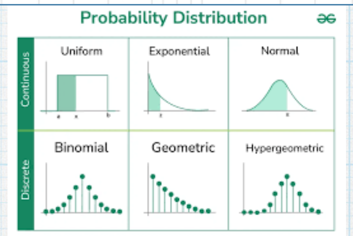
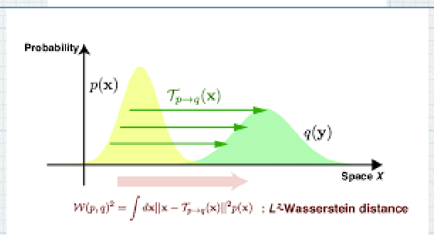
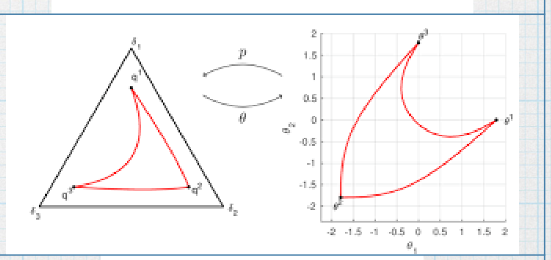
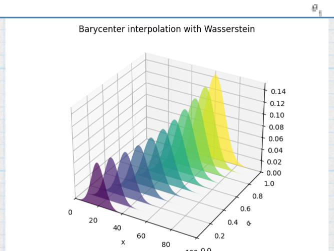
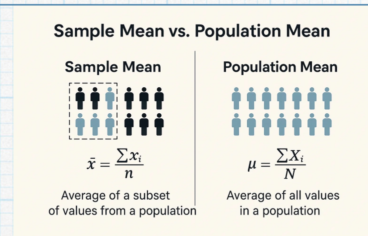
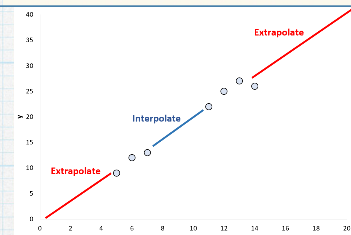
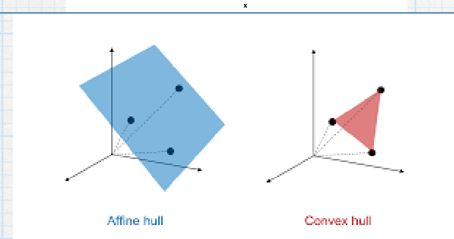
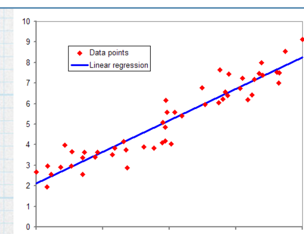
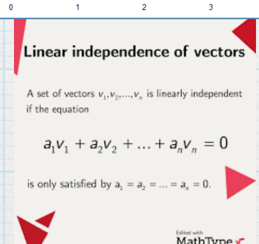
from Euclidean to Non-Euclidean

Points, Vectors	
$x = (x_1, x_1, \ldots, x_m)$	
Distances	
Path	
Interpolation	

Datasets,Texts, Musics...	
$P(a \leqslant X \leqslant b) = \int_a^b f(x)\mathrm{d}x$	
(Wasserstein) distances/ divergence	
Geodesics	
Interpolation	

from Euclidean

Mean	
Exterpolation	
Affine hull	
Regression	
Linear independence, dimensions	 Linear independence of vectors A set of vectors $v_1, v_2, \ldots, v_n$ is linearly independent if the equation $a_1v_1 + a_2v_2 + \ldots + a_nv_n = 0$ is only satisfied by $a_1 = a_2 = \ldots = a_n = 0$. MathType

to Non-Euclidean

Barycenter	
Exterpolation	knew so little
Signed Barycenter	See our work
Regression	Knew so little
Linear independence, dimensions	Completely new, and so much going-on!!!

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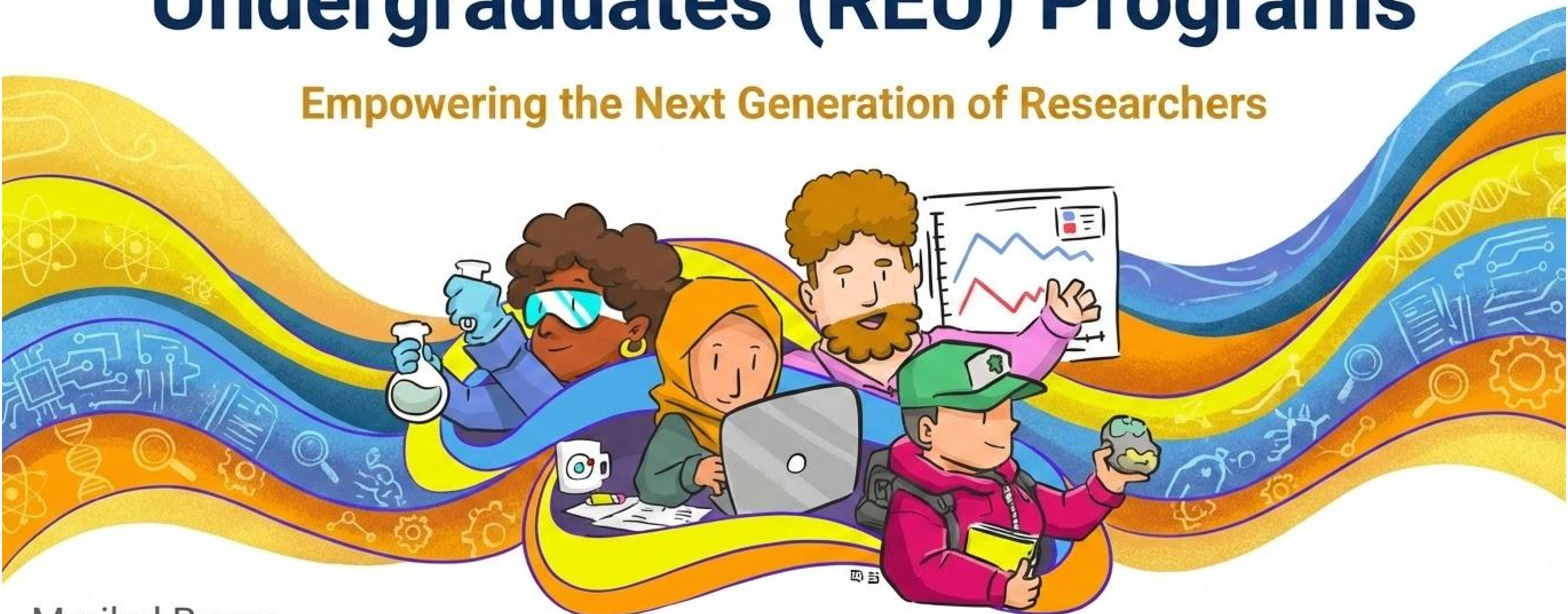
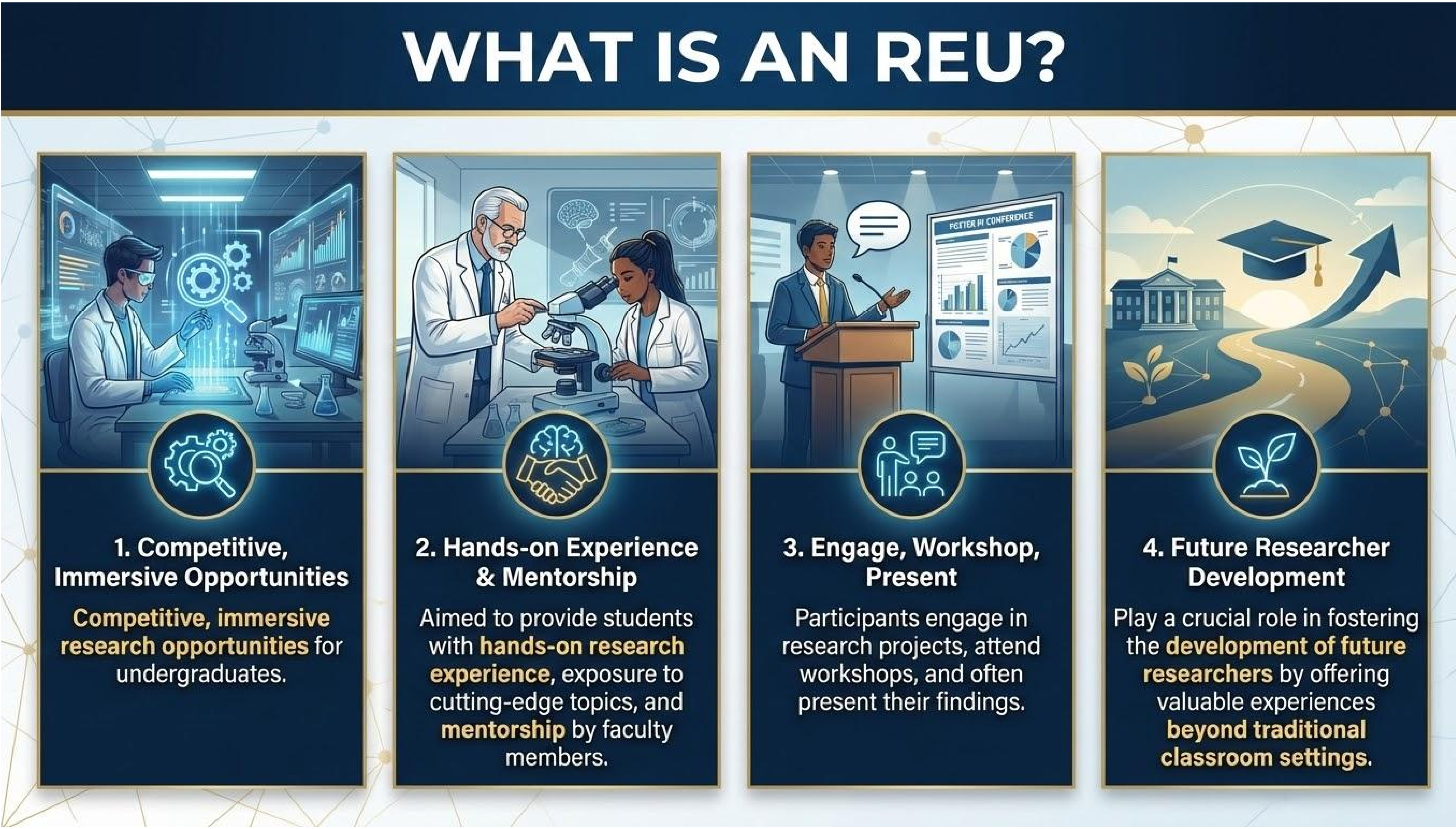
Exploring Research Experience for Undergraduates (REU) Programs

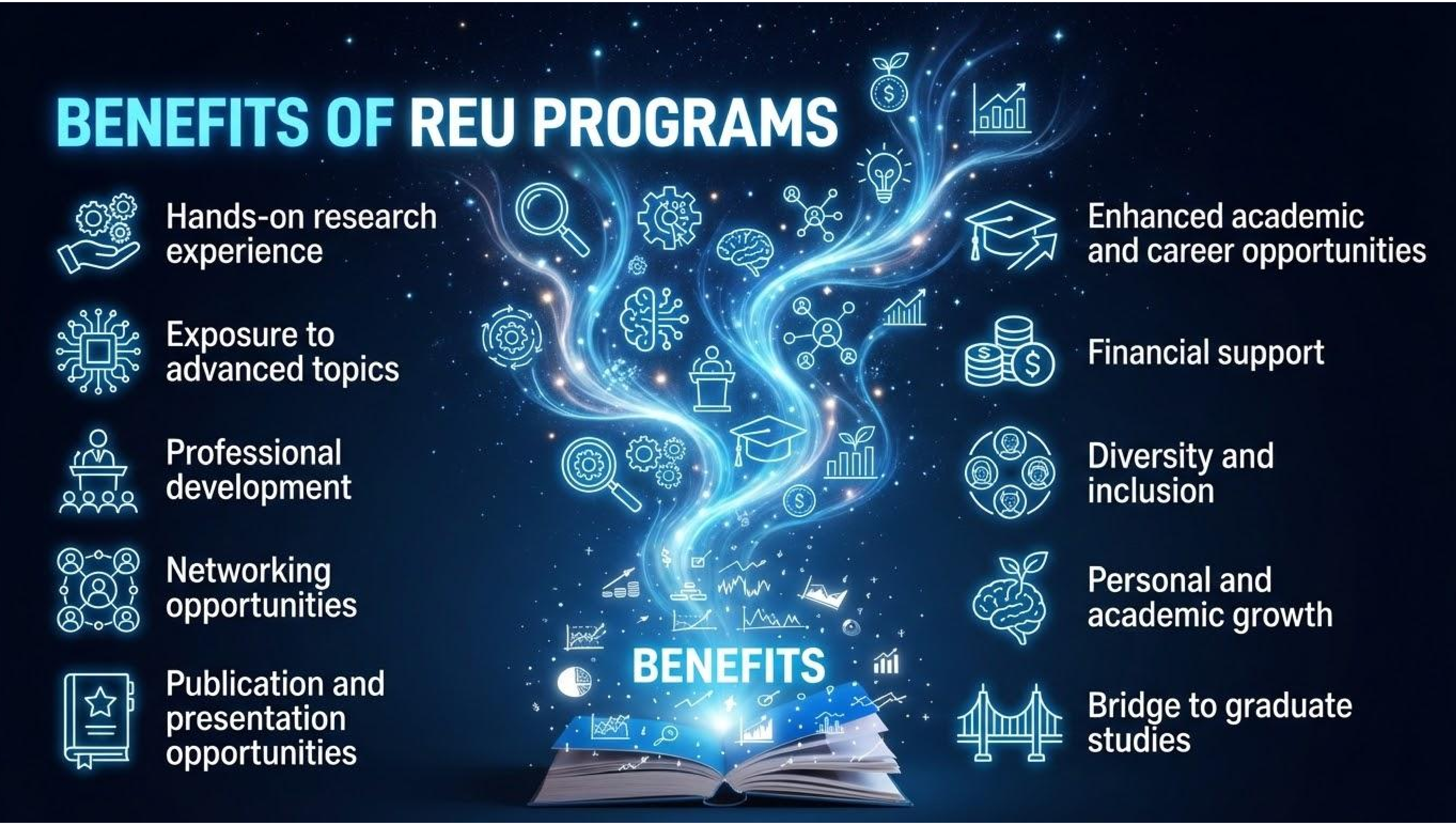
Empowering the Next Generation of Researchers



Maribel Bueno

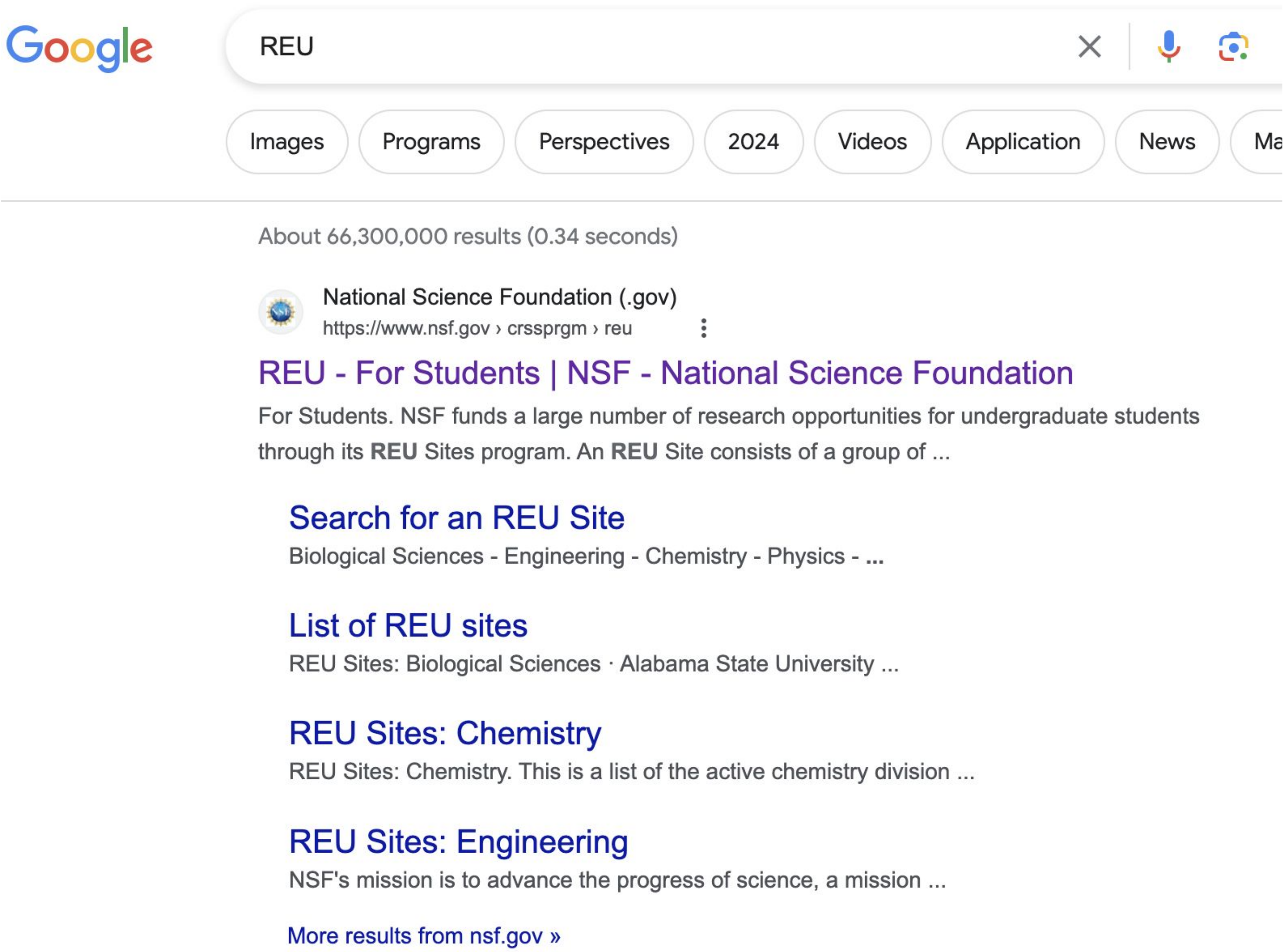
Illustration by COLDEX REU student Kyle Suen

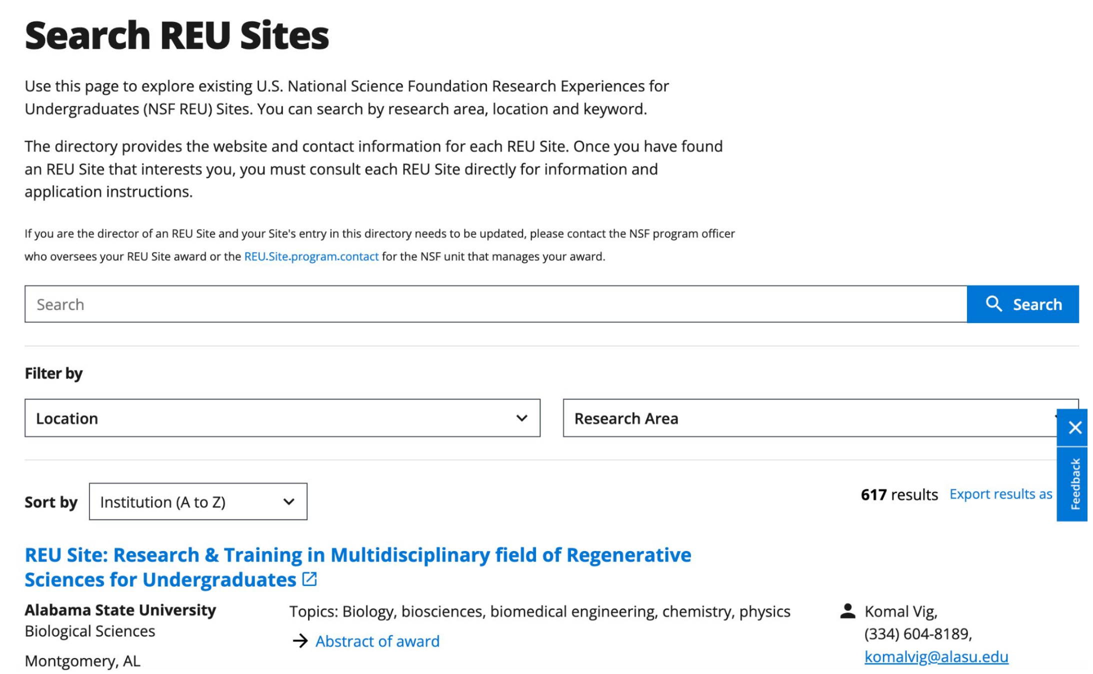

WHAT IS AN REU?
1. Competitive, Immersive Opportunities
Competitive, immersive research opportunities for undergraduates.
2. Hands-on Experience & Mentorship
Aimed to provide students with hands-on research experience, exposure to cutting-edge topics, and mentorship by faculty members.
3. Engage, Workshop, Present
Participants engage in research projects, attend workshops, and often present their findings.
4. Future Researcher Development
Play a crucial role in fostering the development of future researchers by offering valuable experiences beyond traditional classroom settings.


BENEFITS OF REU PROGRAMS
Hands-on research experience
Exposure to advanced topics
Professional development
Networking opportunities
Publication and presentation opportunities
BENEFITS
Enhanced academic and career opportunities
Financial support
Diversity and inclusion
Personal and academic growth
Bridge to graduate studies


ELIGIBILITY AND APPLICATION PROCESS
ELIGIBILITY:
• Must be a US citizen or permanent resident. Some accept international students.
• Undergraduates not graduating seniors.
• Cannot work during the duration of the program.
• May be able to take 1 class concurrently.
• GPA requirement.
APPLICATION PROCESS
1. Search for programs.
2. Application materials: Send CV, 2 letters of recommendation, copy of transcripts, letter of intent, application form.
3. Sometimes interviews.
4. Deadlines in February-March.
5. Notification of acceptance.
6. Acceptance and commitment.

HOW TO FIND REU PROGRAMS





Site Information	Site Location	Contact Information	Additional Information
Arizona State University REU Site: Quantitative Research for the Life and Social Sciences (QRLSS)	Tempe, Arizona	**Primary:** Sherry Woodley sherry.woodley@asu.edu	**Research Topics/Keywords:** Main Field: Mathematical Sciences Sub-Fields: Biological and Social Sciences Abstract of Award
California State University, Chico REU Site: Research Experience in Mathematics for Undergraduates and Teachers	Chico, California	**Primary:** Kevin McGown (530) 898-4083 kmcgown@csuchico.edu	**Research Topics/Keywords:** Main field and sub-fields of the research: Mathematics: Statistics, Number Theory, Aperiodic order, Topology, Commutative algebra, Graph theory **Comments:** Renewal of previously funded REU Site (NSF award number 1559788) Abstract of Award
California State University, San Bernardino REU Site: Investigations in Geometry and Knot Theory	San Bernardino, California	**Primary:** Corey Dunn (909) 537-5368 cmdunn@csusb.edu **Secondary:** Rolland Trapp	**Research Topics/Keywords:** Differential geometry, knot theory **Comments:** Renewal for 1758020 Abstract of Award
Clarkson University REU Site: Mathematical Biology Team Science (MBioTS) Research for Undergraduates (REU) Program at Clarkson University	Potsdam, New York	**Primary:** James Greene (315) 268-4074 jgreene@clarkson.edu **Secondary:** Susan Bailey	**Research Topics/Keywords:** Mathematical Biology, Dynamical Systems, Applied Topology, Control Theory, Uncertainty Quantification, Machine Learning, Cell Biology, Evolution, Toxicology Abstract of Award
Cornell University RTG: Dynamics, Probability, and Partial Differential Equations in Pure and Applied Mathematics Mathematics	Ithaca, New York	**Primary:** Alex Vladimirsky (607) 255-9871 vladimirsky@cornell.edu	**Research Topics/Keywords:** Optimality & uncertainty in control problems and games; periodic non-intersecting random walks and random matrices; nonintegrable constraints in mechanics Abstract of Award

INDIANA REU PROGRAM - EXAMPLE

Each participant will receive a **$5,000 research stipend.**

The 2026 REU program will be held virtually from June 8 – July 31, 2026. All meetings and interactions will be held on Zoom, but students will have the opportunity to travel to Indianapolis for an in-person conference in late July.

Complete applications are due February 13, 2026. Please see project descriptions and the application below.

For additional information about the 2026 REU program, please contact Dr. Julia Arciero at jarciero@iu.edu.

Projects for the 2026 REU Program

1. Mathematical modeling of heart transplantation (Advisor: Dr. Julia Arciero)
2. Modeling forces in cell migration (Advisor: Dr. Jared Barber)
3. Modeling cellular and membrane dynamics (Advisor: Dr. Horia Petrache)
4. Modeling survival thresholds in biological populations (Advisor: Dr. Sebastian Sensale)

Additional project details

Project 1: Mathematical modeling of heart transplantation +

Project 2: Modeling forces in cell migration +

Project 3: Modeling cellular and membrane dynamics +

Project 4: Modeling survival thresholds in biological populations +

PROGRAM COMPONENTS

CORE RESEARCH & MENTORSHIP

- Research projects.
- Mentorship.
- Evaluation and feedback.

SKILL & KNOWLEDGE BUILDING

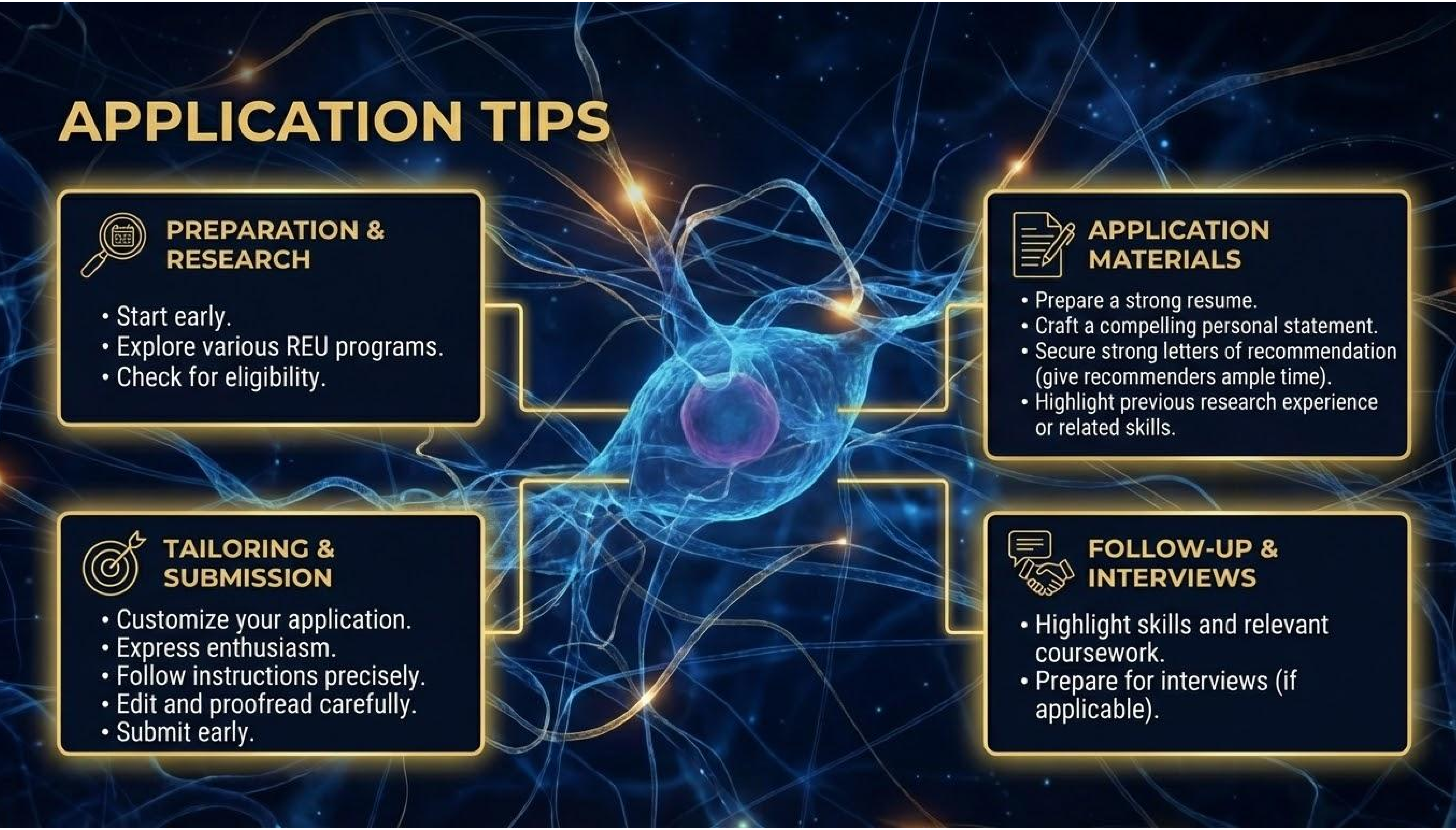
- Workshops and seminars.
- Professional development.
- Graduate school information.

COMMUNITY & NETWORKING

- Peer interactions.
- Networking opportunities.
- Field trips (optional).

DISSEMINATION & OUTPUT

- Presentations.
- Research symposium/conference.
- Publication opportunities.


APPLICATION TIPS
PREPARATION & RESEARCH
• Start early.
• Explore various REU programs.
• Check for eligibility.
APPLICATION MATERIALS
• Prepare a strong resume.
• Craft a compelling personal statement.
• Secure strong letters of recommendation (give recommenders ample time).
• Highlight previous research experience or related skills.
TAILORING & SUBMISSION
• Customize your application.
• Express enthusiasm.
• Follow instructions precisely.
• Edit and proofread carefully.
• Submit early.
FOLLOW-UP & INTERVIEWS
• Highlight skills and relevant coursework.
• Prepare for interviews (if applicable).

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Fast Phase Prediction of Charged Polymer Blends by White-Box Machine Learning Surrogates

Clayton Ellis
PhD student Department of Statistics and Applied Probability

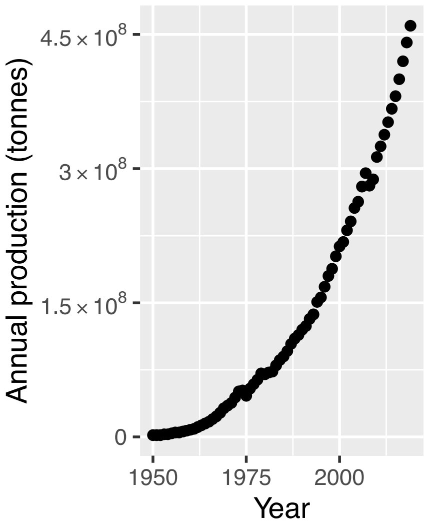
in collaboration with
Xinyi Fang, Chris Balzer, Timothy Quah, Scott Shell, Glenn Fredrickson and Mengyang Gu

UC Santa Barbara MRL Materials Research Laboratory

NSF Materials Research Science and Engineering Center [DMR–2308708]

Saving the World with Recycling

- The amount of plastic waste is increasing and we need better ways to recycle it
- Using electric charge, we can mix polymers that normally don't mix but make up a lot of waste
- Simulation methods, such as Self-consistent field theory (SCFT) and random phase approximation (RPA) are **fast compared to experiments**, but they can still be **slow as input design is large**.



Summary of our results:

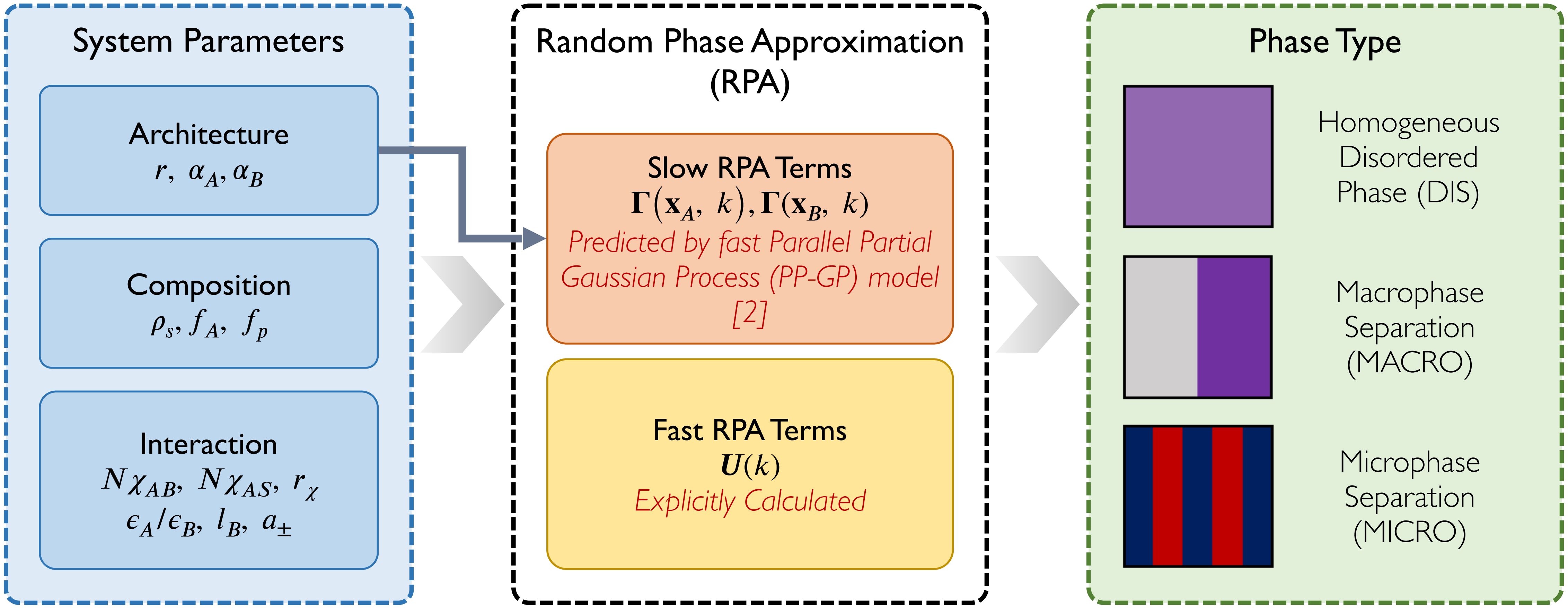
➢We develop a predictive model to emulate RPA which achieve **>99% accuracy** with only around **20 training samples**, while other predictive model needs 10^2-10^3 samples to be 80% accurate

➢We achieve this by focusing on emulating the part of the RPA dependent only on the polymer architectures; once this is emulated, the computation is around **100x times faster**

"Hey ChatGPT, generate an image to save the world of plastic by recycling"

[1] Ellis, C., Fang, X., Balzer, C., Quah, T., Shell, M. S., Fredrickson, G. H., & Gu, M. (2025). Fast phase prediction of charged polymer blends by white-box machine learning surrogates. *Macromolecules*.

Workflow for Phase Generation



High-dimensional parameter space describes broad class of charged copolymer blends

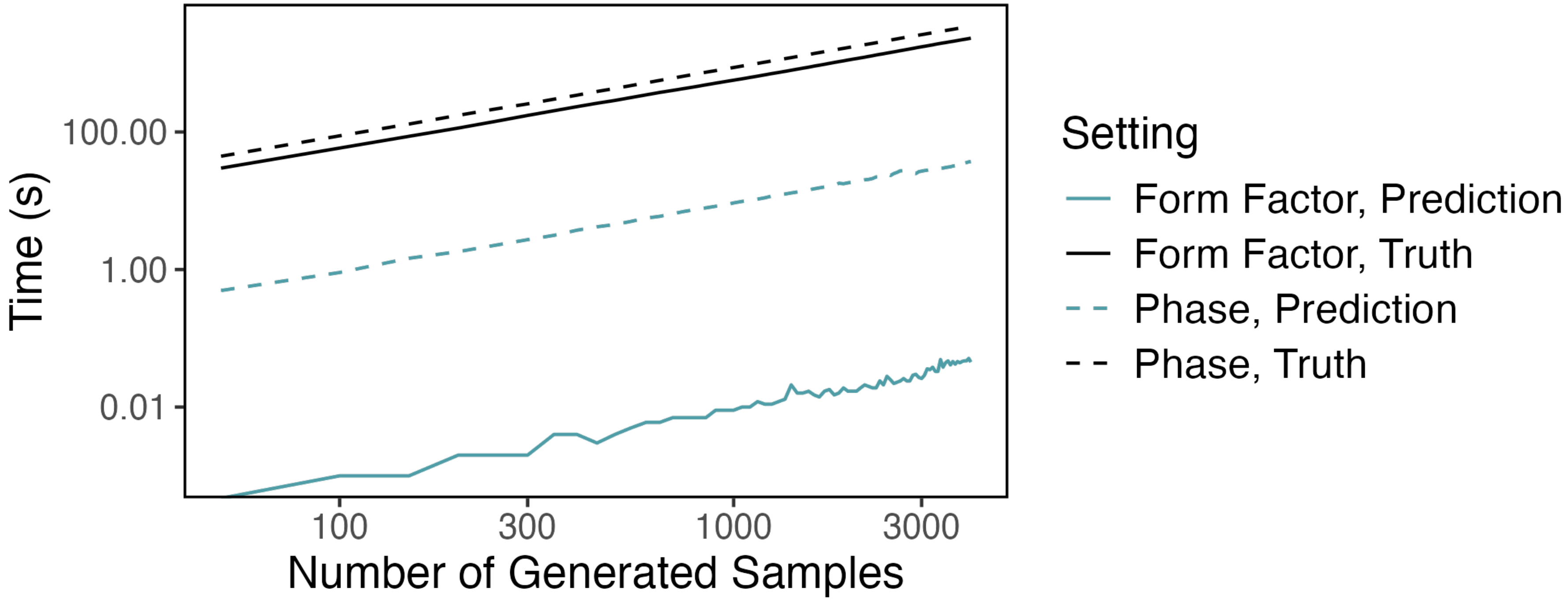
Ascertaining phase behavior requires numerical evaluations of both easy and difficult to compute quantities

The RPA simulation allows for the classification of phase behavior as a disordered, microphase or macrophase separated state

[2] Gu, M., & Berger, James O (2016). Parallel Partial Gaussian Process Emulation for Computer Models with Massive Output. Annals of Applied Statistics.10(3) 1317-1347

Comparison with Direct Simulation and Alternative Methods

Time ↓:
- For computation of form factor entries: **50,000-70,000 times faster**
- For phase determination: **~100 times faster**
- For computational complexity: **Linear in observations/grids** rather than **quadratic in bead counts**



Accuracy ↑:
- **Over 99%** prediction accuracy with only **50 training points**
- **25-30% better** than classical models with **500 training points**

1

Thank You!

Xinyi Fang

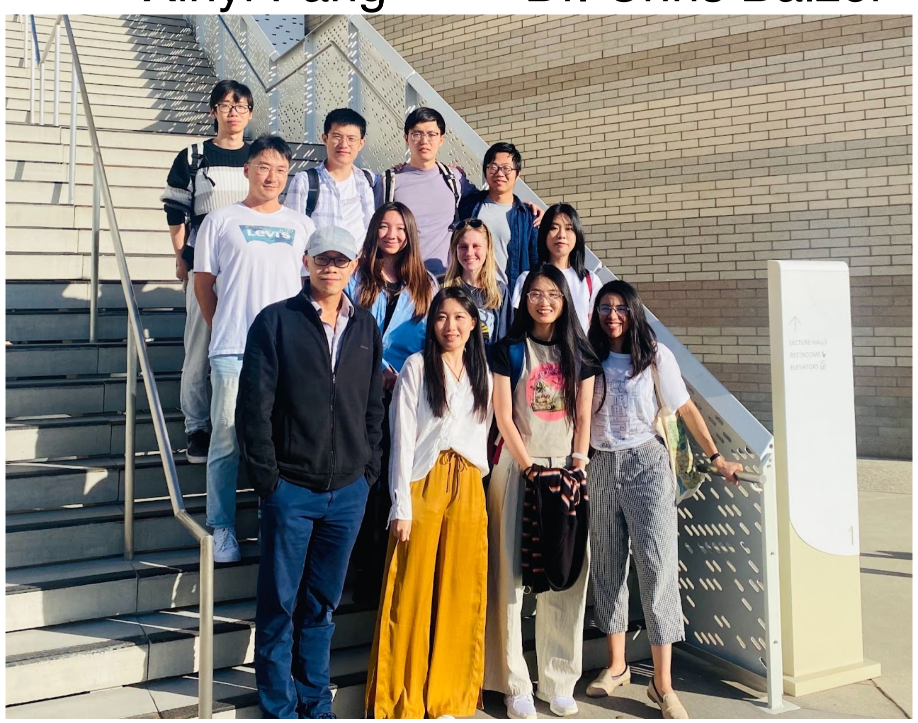
Dr. Chris Balzer

Dr. Timothy Quah

Dr. Scott Shell

Dr. Glenn Fredrickson

Dr. Mengyang Gu



National Science Foundation
MRSEC
Materials Research Science and Engineering Centers

UC Santa Barbara MRL
Materials Research Laboratory
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https://sites.google.com/site/michaelmengyanggu/members

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About Me (Max Emerick)

- Originally from Seattle, Washington
- Bachelor's at Cal Poly, Master's at UCSB
- Now in 4th year of PhD
- Studying mechanical engineering
- In my free time, I like to surf, hike, mountain bike, rock climb, etc.

My Research

- Broadly: dynamical systems and control theory
- Study systems modeled by differential equations: $\frac{d}{dt}x(t) = f\left(x(t), u(t)\right)$
- Try to understand behavior and modify by designing $u(t)$
- Specifically: continuum limits of large-scale systems
  - Robotic swarms, interacting particle systems, large networks, etc.
- Use tools from optimization, differential geometry, and PDEs

Research Process

- Meet every week or two weeks
- Start by talking about interests, find overlaps, share papers
- Select a problem or subproblem
- Work on problem together
- Depending on progress, possibly publish a paper

Get in Touch

- Talk to me after the session
- Email: memerick@ucsb.edu
- Personal Website: https://maxemerick.github.io/

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The vibe of quantum algebra

Tensor categories and Hopf algebras

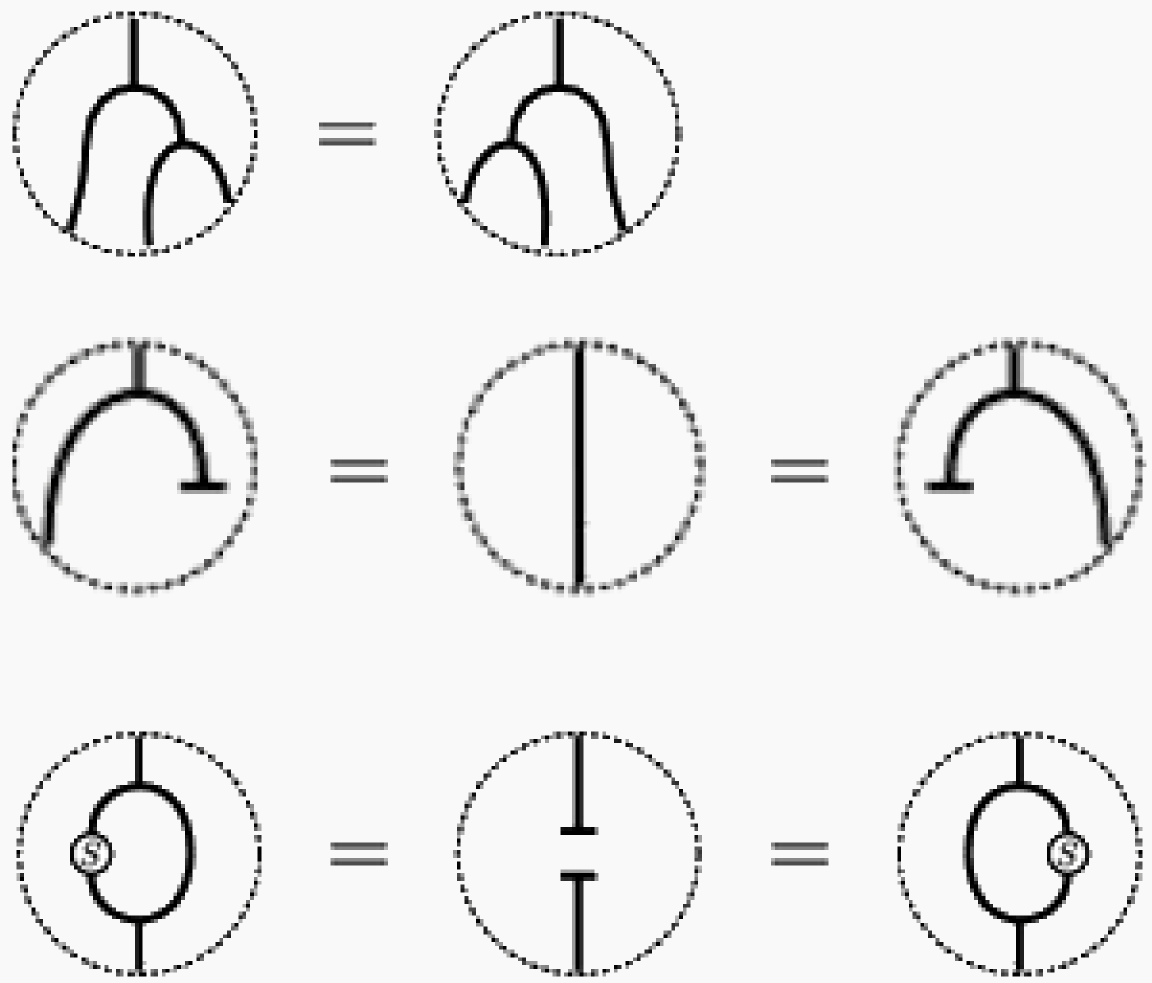
Quinn T. Kolt (she/her)
PhD Candidate

Info Session on Undergraduate Research
January 26, 2026

University of California, Santa Barbara (UCSB)
Department of Mathematics

Group axioms

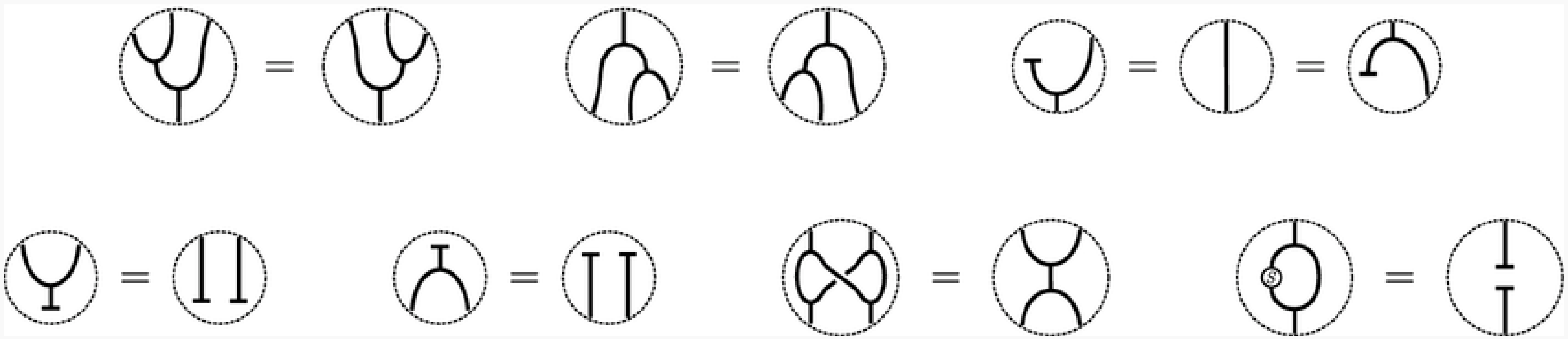
A *group* is a set G with multiplication $\curlywedge : G \times G \to G$, unit $\perp : \{*\} \to G$, and inverse $S : G \to G$ such that



where $\curlyvee : G \to G \times G$ is the comultiplication map $g \mapsto (g, g)$ and $\top : G \to \{*\}$ is the counit map $g \mapsto *$.

Hopf algebra axioms

A *Hopf algebra* is a vector space H with linear multiplication $\curlywedge : H \otimes H \to H$, unit $\perp : F \to H$, comultiplication $\curlyvee : H \to H \otimes H$, counit $\top : H \to F$, and antipode $S : H \to H$ such that



(horizontal reflections not shown)

where $X : H \otimes H \to H \otimes H$ is the braiding map $h \otimes k \mapsto k \otimes h$.

Note: all of these are satisfied for groups, so groups are Hopf algebras in Set!

How do I learn more?

Books on quantum algebra:

- Kassel-Quantum Groups
- EGNO-Tensor categories (difficult to read but amazing reference)
- https://people.math.osu.edu/penneys.2/UQSL/UQSL.html

Who does research in this area?

- Professors in this department:
  - Stephen Bigelow
  - Zhenghan Wang
- I am accepting students (quinn@math.ucsb.edu)!

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Research - Katy Craig

systems of interacting agents

partial differential equations

optimal transport

optimization

Current/previous undergraduate students:

Emily Lopez
(Minnesota)

Ben Faktor
(UCLA)

Haoqing Yu
(Cornell)

Vidushi Mittal
(UC Davis)

Ashwin Anand
(Current)

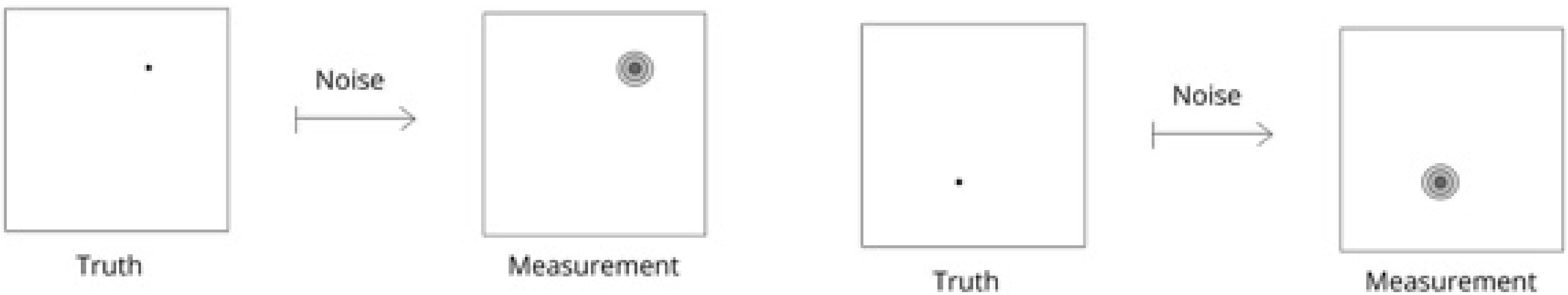
My website: https://web.math.ucsb.edu/~kcraig

Information for prospective students:
https://web.math.ucsb.edu/~kcraig/math/ProspectiveStudents.html

A current project (with Ben Faktor)

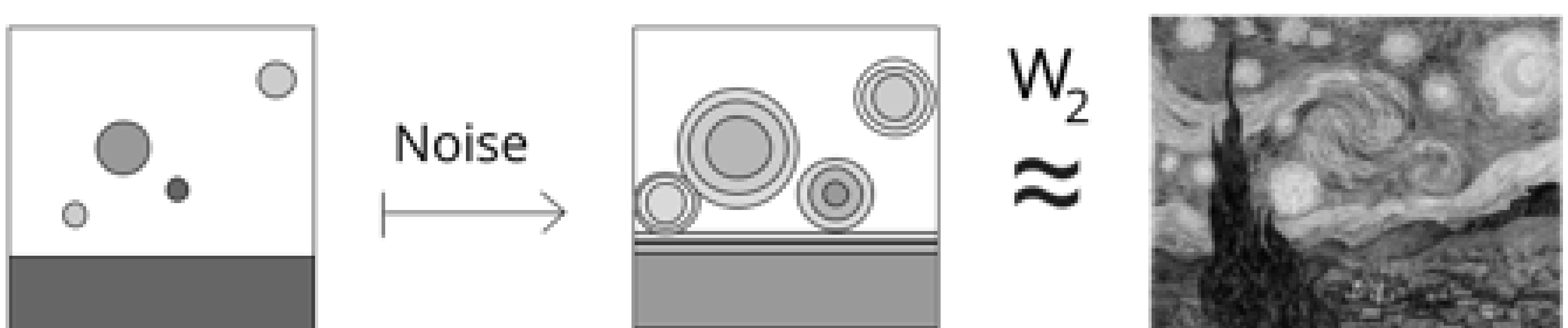
Given are a fixed measurement

and a noise model:



etc.

Question: Which image's noisification is closest?



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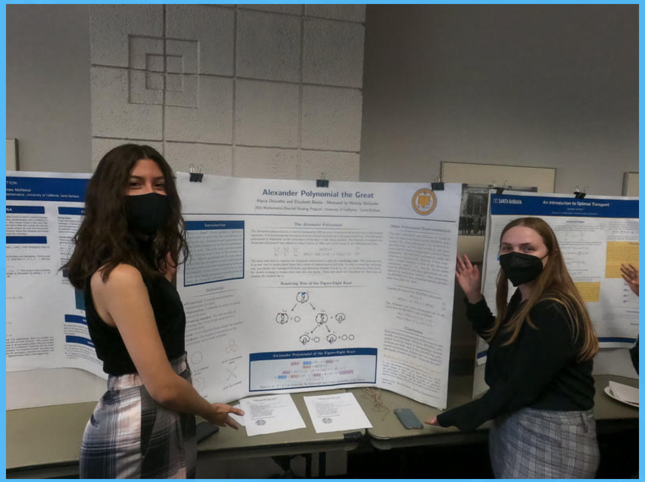
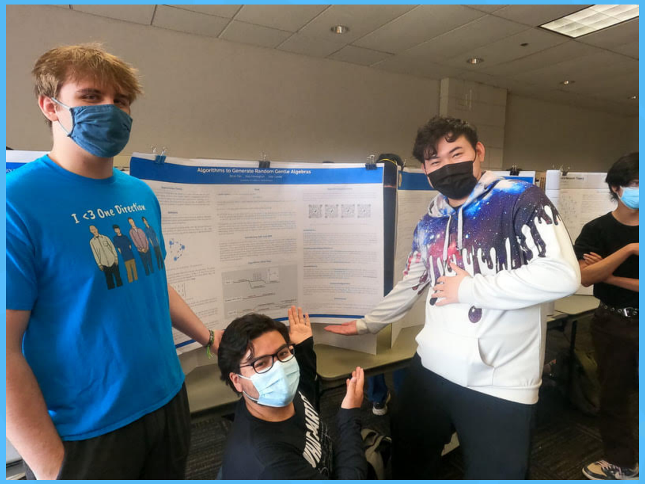
Directed Reading Program

Directed Reading Program

What is the Directed Reading Program?

- One-on-one or small group mentoring
- Work with graduate students and junior faculty
- Join math-related events throughout the year





Directed Reading Program

What do I do in the DRP?

- Winter and Spring Quarter: Read interesting math with a mentor!
- Panel discussions:
  - Beyond a Bachelor's, Graduate School Panel
  - Mathematical Career Panel
  - Presenting Mathematics Effectively Workshop
- Universal Cover workshops
- Public poster session on campus!

Directed Reading Program

What are some current projects?

- Fluid dynamics
- Representation theory
- Quantum computing
- Analytic number theory
- Rational homotopy theory
- Cryptography and CS
- Hopf algebras
- Quantum topology
- Geometric group theory
- Computational differential geometry
- Complex geometry
- Elliptic curves
- Mathematical music theory
- Machine learning
- Category theory
- Mathematical physics

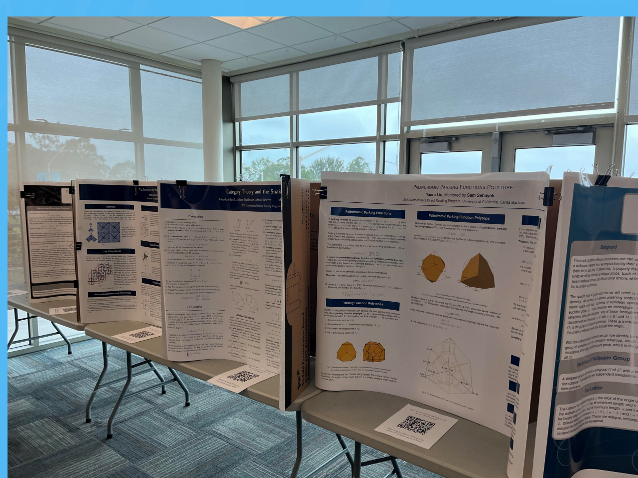
Directed Reading Program

How to Apply

Applications open in early Fall quarter.

Pairings are decided late November.

Check for DRP emails or visit the website!



ucsbdrp.org

Thank you!

Do you like pizza and/or math?

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