HMMT November Education Events

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Education Events | **November 14, 2021**

Schedule

Time (EST)	Education Room 1	Education Room 2	Education Room 3	Education Room 4
11:00 AM - 12:00 PM	Math Careers Talk **Laura P. Schaposnik** *A Mathematician's Path*			
1:00 PM - 2:00 PM	**Debbie Marks, Mafalda Figueiredo Dias, Jonathan Frazer** *Statistical physics and deep learning for predicting the effect of human genetic variation*	**Georg Gerber** *Using Statistical Machine Learning to Harness the Microbes within Us to Treat Disease*	**Sean Li** $y^2 = x^3 - 11$	
2:00 PM - 3:00 PM	**Henry Cohn** *Self-reference and Paradox*	**Joscha Legewie** *Sociology in the Age of Big Data*	**Jacob Barandes** *Symmetries and Symmetry-breaking in the Universe*	**Laura Cui** *Quantum Entanglement, Statistical Physics, and the Arrow of Time*
3:00 PM - 4:00 PM	**Ariel Amir** *How Mathematics can Aid Biology: Evolution, Fluctuations and Hitting the Jackpot*	**Ramy Arnaout** *Counting, Entropy, and Diversity*	**Mira Bernstein** *A little exercise in epistemic logic and a tribute to John Conway*	

November Education Events

Time: 1:00 - 2:00 PM

Debbie Marks, Mafalda Figueiredo Dias, Jonathan Frazer

Statistical physics and deep learning for predicting the effect of human genetic variation.

1:00 - 2:00 PM | Education Room 1

Protein sequences across diverse organisms are the result of millions of years of evolutionary experiments. By modelling the distribution of these sequences we can capture the patterns of amino acids which are important throughout evolution to maintain protein function and fitness. In this talk we will discuss how applying probabilistic modelling to this problem, from old school statistical physics to the latest deep learning advancements, can reveal the 3-dimensional structure of proteins and predict the impact of genetic variation on human health.

Debbie Marks is a mathematician and computational biologist with a track record of using novel algorithms and statistics to successfully address unsolved biological problems. She has a passion for interpreting genetic variation in a way that impacts biomedical applications. Her lab at Harvard is interested in developing methods in deep learning to address a wide range of biological challenges including predicting the effects of genetic variation and sequence design for biosynthetic applications.

Mafalda Figueiredo Dias is a theoretical physicist who recently became interested in computational biology. Before joining Debbie's lab she worked at the border between cosmology and string theory, developing computational tools and studying complex models as a way to learn about the first instants of the Universe. She now develops new statistical models to address the link between biological sequence and function, for both proteins and whole genomes.

Johnny Frazer's background is in theoretical physics. His previous work included developing computational tools for testing theories of the very early universe, as well as pioneering the use of information theory and probabilistic modelling for studying cosmic inflation in string theory. His love of high-dimensional probability and information theory has now brought him to the data-rich world of genomics.

Technicality/Prerequisites: None.

Georg Gerber

Using Statistical Machine Learning to Harness the Microbes within Us to Treat Disease

1:00 - 2:00 PM | Education Room 2

Your body has as many microbial cells as human cells. These trillions of organisms, deemed the human microbiome, form health-essential ecosystems throughout your body. Conversely, disruption of the microbiome has been implicated in a variety of major human diseases including infections, arthritis, food allergy, cancer, heart disease, neurological diseases, and obesity/diabetes. The human microbiome is inherently dynamic, due to interactions among microbes, with our bodies, and with the environment. With recent advances in experimental techniques, it is possible to generate immense, high- dimensional datasets measuring changes in the microbiome over time. Analyzing these datasets is important for understanding the role of the microbiome in health and disease, and ultimately designing therapies to treat human ailments. Given the scale and complexity of these datasets, advanced computational techniques are essential. In this talk, I will provide an introduction to the microbiome, and then describe some novel computational methods that we have developed that combine probabilistic models and machine learning to analyze microbiomes over time. I will also touch on the need for interpretability and modeling uncertainty in machine learning applications.

Georg Gerber is a computer scientist, microbiologist and physician who heads a research lab focused on creating novel machine learning methods and high-throughput experimental systems to understand the role of the microbiota in human diseases and applying these findings to develop new diagnostic tests and therapeutic interventions to improve patient care. He also serves as Chief of the Division of Computational Pathology and co-directs the MA Host- Microbiome Center. Dr. Gerber holds a PhD in Computer Science from MIT (statistical machine learning) and an MD from Harvard Medical School. Prior to his academic career, he was an executive in the film and computer graphics industry.

Technicality/Prerequisites: Some knowledge of topics including basic biology, dynamical systems, computer science, and machine learning would be helpful, but isn't essential.

Time: 1:00 - 2:00 PM

Sean Li

$y^2 = x^3 - 11$

1:00 - 2:00 PM | Education Room 4

Given an equation, we like to ask for its integer solutions; these are called Diophantine problems. These problems tend to look easy, but sometimes end up being very, very hard (e.g., $a^n + b^n = c^n$). In this talk, we discuss the innocent equation which comprises the title of the talk. After seeing how typical elementary methods fail, we'll survey two high-level ways to nuke the problem. Psst, some surprise algebraic number theory and elliptic curves await!

Sean Li is a freshman at MIT studying mathematics and computer science. He is one of the November HMMT Problem Czars! He loves to teach and write problems, especially in algebra and combinatorics. In his free time, he likes to dance, go on walks, and ferment in Hayden Library.

Technicality/Prerequisites: The talk consists of elementary motivation, followed by a technical overview. Knowledge of groups and rings is helpful but is definitely not required.

Time: 2:00 - 3:00 PM

Henry Cohn

Self-reference and Paradox

2:00 - 3:00 PM | Education Room 1

True or false: "this sentence is false"? If it's true, then it's true that it's false (since it asserts its own falsehood), so it must be false. But if it's false, then it's false that it's false, so it must be true. Neither possibility is self-consistent, which makes it a trick question, but one that leaves us with an unsettling possibility. If that sentence can't be considered true or false, isn't logic ruined forever?

What are we to make of this example? We'll take a look at this paradox and others, and we'll think about what they tell us about the deeper nature of mathematics. No special background is required, just an eagerness to have logic make sense even when we push it to its limits.

Henry Cohn is a senior principal researcher (and one of three founding members) at Microsoft Research New England in Cambridge, Massachusetts and an adjunct professor in the MIT Department of Mathematics. Previously he was head of the cryptography group at Microsoft Research Redmond, and before that, he was in the theory group.

Technicality/Prerequisites: None.

Time: 2:00 - 3:00 PM

Joscha Legewie

Sociology in the Age of Big Data

2:00 - 3:00 PM | Education Room 2

This lecture introduces students to how "big data" and the digital age transform our understanding of the social world. The lecture explores how the digital age changes sociological research and showcases the application of statistics and data science to important social problems such as racial bias, partner & friendship choice, public opinion and polarization and urban inequality.

Joscha Legewie is John L. Loeb Associate Professor of the Social Sciences at Harvard University. His work is motivated by a theoretical interest in the social, spatial, and temporal processes that lead to inequality. As part of this research, he is working on various projects that examine the effect of policing on educational outcomes and health of minority youth using large-scale administrative data.

Technicality/Prerequisites: None.

Laura Cui

Quantum Entanglement, Statistical Physics, and the Arrow of Time

2:00 - 3:00 PM | Education Room 4

Maybe you've heard about this thing called entanglement or "spooky action at a distance". Or maybe you've found yourself wishing you could go back in time and keep your dog from eating your homework. In this talk we'll define what entanglement really is, ask how information can even be quantum anyways, and see how it all ties together with the direction of time.

Laura Cui is an undergraduate at MIT studying physics and math, and is curious about problems in quantum information and fundamental physics. When not thinking about math, Laura can be found painting, taking walks along the river, or appreciating a cup of milk tea.

Technicality/Prerequisites: Familiarity with basics of probability. Experience with vectors and linear algebra will also be helpful.

Jacob Barandes

Symmetries and Symmetry-breaking in the Universe

1:00 - 2:00 PM | Education Room 3

Symmetry plays a central role in modern physics. Symmetries can show up in physics in several conceptually distinct ways: there can be symmetries of physical objects, but also symmetries of underlying equations, and these different kinds of symmetries have different consequences. Symmetries are also important in physics because they can be broken – as indeed they must be, because the real world around us is very asymmetrical. In this talk, we'll explore these ideas by working through several examples involving simple polynomials. This will be a highly participatory talk, so be sure you have a pencil and paper (or their electronic equivalents)!

Jacob Barandes does research at the intersection of physics and philosophy. His main areas of study include the foundations of quantum mechanics, the classical limit, field theory, general relativity, thermodynamics, and formal methods in mathematical physics. He is also interested in the philosophy of probability, the philosophy of time, the philosophy of mind, the history of physics, and logic.

Technicality/Prerequisites: None.

Time: 3:00 - 4:00 PM

Ariel Amir

How Mathematics can Aid Biology: Evolution, Fluctuations and Hitting the Jackpot

3:00 - 4:00 PM | Education Room 1

After presenting a brief background on microbial growth, I will describe a spectacular example of the success of applying mathematics to an important problem in biology, dating back to the 1940's - the first demonstration that it is random mutations that lead organisms to evolve (highly relevant today in the case of COVID evolution!). In this case Luria and Delbruck (a biologist and physicist, respectively) teamed up to analyze the fluctuations in the numbers of bacteria surviving a viral attack. The irreproducibility of the result ends up being its most important aspect - when properly addressed within the context of a mathematical model.

Ariel Amir grew up in Israel and received his B.S. from Hebrew University and his M.S. and Ph.D. from Israel's Weizmann Institute of Science. In 2011, he came to Harvard University as a Junior Fellow, and in 2014 he joined the Harvard Paulson School as Assistant Professor of Applied Mathematics and Applied Physics.

Technicality/Prerequisites: Basic knowledge of probability (mean, variance).

Ramy Arnaout

Counting, Entropy, and Diversity

3:00 - 4:00 PM | Education Room 2

The first step toward understanding a complex system usually involves counting. It turns out that Shannon entropy (information theory/computer science), the Gini coefficient (economics), Simpson's index (ecology) are all ways to count and are intimately related through the umbrella concept of diversity. This talk will go into some of the key concepts, components, and parameters that relate diversity to these different ways of counting, and what all of this is or may be good for, in science and in the real world.

Ramy Arnaout spent a lot of time trying to figure out how to not spend a lot of time searching science. He holds an MD from Harvard Medical School, where he was a Soros Fellow, a DPhil (PhD) in mathematical biology from Oxford University, where he was a Marshall Scholar, and an SB in biology from MIT, where he still plays pickup basketball. Since residency, he has been a clinical pathologist and systems biologist, all in and around Boston, MA.

Technicality/Prerequisites: None.

Time: 3:00 - 4:00 PM

Mira Bernstein

A little exercise in epistemic logic and a tribute to John Conway.

3:00 - 4:00 PM | Education Room 3

The legendary mathematician John Horton Conway passed away in May 2020 from COVID-19. Just before his death, the American Mathematical Monthly published a short paper that Conway had written back in the 1970's, called "A Headache-Causing Problem". The authors listed on the paper are ``Conway (J.H.), Paterson (M.S.), and Moscow (U.S.S.R)" -- yes, you read that correctly. The abstract (short summary) of the paper is: "After disproving the celebrated Conway-Paterson-Moscow theorem [1], we prove that theorem and make an application to a well-known number-theoretic problem." The reference [1] is to the paper itself; the number-theoretic problem is Fermat's Last Theorem.

As you can tell, this paper is joke piled upon joke -- but the math is real and quite elegant. It concerns a logic game that involves thinking about what other people are thinking. The "headache" comes from the fact that both the proof and the disproof of the main theorem seem correct, and it is hard to see the flaw in either argument. The paper doesn't give away the answer -- you have to figure it out for yourself.

In this talk, I will tell you the story of this funny little paper (the first mathematical publication by a city!) and introduce you to the Headache-Causing Problem. Hopefully, by the end of the hour, we can vanquish the headache together.

Mira Bernstein received her PhD in algebraic geometry in 1999 and has taught at UC Berkeley, Stanford, and Wellesley College. She left academia in 2008; since then, her work has focused on using mathematics and statistics to solve social problems -- from exploring the effects of extending health insurance to low-income populations to using mathematics to fight gerrymandering. Mira is also very active in mathematics education.

Technicality/Prerequisites: This will be a technical talk with lots of student interaction. The only prerequisites are (1) knowing how to add small natural numbers; (2) a willingness to tolerate a (temporary) mathematical headache.