SigmaCamp Lectures

August 10-17, 2024

Lecture dates are subject to change

Contents

Saturday, August 10: Opening Lecture

The Language of Life: Decoding the Human Genome with AI
by *Olga Troyanskaya*

The human genome is 3 billion letters long and encodes the diversity of our cells and tissues, the process of our development, and of aging. The genome is full of puzzles - how does the same DNA sequence generate such different cells in the brain versus the skin? What genomic signals encode our predisposition to cancer? What is the impact of a specific letter change?

Answering these questions and decoding the human genome is similar to deciphering a book in a lost ancient language that uses a four-letter alphabet and is written with no punctuation or spaces. I will discuss how the explosion of AI models has led to breakthroughs in this field and the major open questions in this field. Challenges include interpreting the 98% of the genome that is noncoding (sometimes referred to as 'junk' DNA), detangling genomic signals regulating tissue-specific gene expression, mapping the resulting genetic circuits in disease-relevant cells, and, finally, connecting these mechanisms to specific disease outcomes in humans. I will introduce several of the state-of-the-art AI models addressing these challenges and their applications to autism and cancer.

About the lecturer: *Olga Troyanskaya is a Professor at the Department of Computer Science and the Lewis-Sigler Institute for Integrative Genomics, Princeton University, the Deputy Director for Genomics at the Center for Computational Biology of the Flatiron Institute of the Simons Foundation, and the Founder and Director of Princeton Precision Health. Dr. Troyanskaya's lab builds AI methods to decode genomes and diagnose and treat complex diseases. Her group pioneered Bayesian approaches for building networks to map tissue and cellular specificity to study pathway dysregulation in disease and for deep learning models to study regulatory genomes, enabling study of transcriptional and post-transcriptional variants and their role in cellular function, evolution, and diseases. Through developing AI-based integrative approaches, her lab focuses on studying the non-coding genome and modeling of complex molecular-level changes captured via diverse multi-omics techniques, including in specific clinical, treatment, and environmental contexts, enabling systems-level molecular views of human health and disease. Dr. Troyanskaya has committed to democratizing the use of her novel machine learning approaches with interactive, public interfaces for the biomedical community.*

Sunday, August 11

Marine Viruses: Tiny Biological Entities with Giant Global Impacts
by *Joaquín Martínez Martínez*

Did you know that there are more viruses in the ocean than stars in the known universe? Viruses are a diverse and dynamic component of marine ecosystems across all latitudes and depths in the ocean water column. Viruses are estimated to kill 20-30% of the marine microbes each day, but the consequences of viral infection in the ocean go beyond mortality alone. Unfortunately, for a long time, science failed to investigate viruses true ecological value. In order to reproduce and propagate, viruses rewire their host's metabolic machinery, virtually creating a new organism or "virocell" that behaves differently than healthy individuals. Viral impacts at the single-cell level cascade through populations, communities, and ecosystems, mediating and controlling many biological and chemical interactions among diverse organismal levels and serving as a leading edge of evolution. In this lecture, you will learn about ways in which viruses are an integral part of a balanced global ocean engine and how understanding marine viruses can lead to problem-solving research.

About the lecturer: *Spending every summer growing up on the Mediterranean coast in Spain led to Joaquín Martínez Martínez's passion for the ocean. Joaquín obtained a bachelor's degree in Marine Sciences at the University of Cádiz (Spain), a master's degree in marine microbial ecology at the University of Stirling (Scotland), and a Ph.D. in marine virus ecology at the University of Plymouth (England). Currently, he is a biological oceanographer at Bigelow Laboratory for Ocean Sciences in Maine. Joaquín's research is broadly focused on exploring microbial host-virus systems diversity and inter-relationships in marine environments, from coastal sites to deep-sea igneous crust. Viruses are the most abundant biological agents in the ocean, but they are still one of the most unexplored reservoirs of genetic and functional diversity. His overall goal is to understand the genetic basis of viral infections and how they affect life in the ocean. Joaquín is constantly awed by new discoveries that reveal the mighty impacts tiny viruses have in modulating life the way we know it.*

Patterns in Nature: Understanding Crystals and Quasicrystals
by *Michael Bershadsky*

This lecture will explore the mesmerizing realm of tilings, crystals, and their underlying symmetries. Crystals, with their periodic structures, have long been admired for their beauty and order. But what happens when we step beyond the boundaries of periodicity? Enter the enigmatic world of quasicrystals, the aperiodic cousins of ordinary crystals. Discover how quasicrystals, like the famous Penrose tiling, defy traditional symmetry and reveal hidden order dimensions. Learn how these extraordinary structures can be seen as "projections" from higher dimensions, offering a glimpse into a world where the usual rules of symmetry are transformed. Join us for a journey through the intricate patterns that govern the natural world and uncover the secrets of crystals and quasicrystals, which challenge our understanding of symmetry and order.

About the lecturer: *Michael Bershadsky got his PhD in physics from Princeton University in 1990. Immediately after this he came to Harvard University, where he was on the faculty at Physics Department until 2000. In 2000 he resigned from Harvard University and joined a private financial company. In January 2023 he resigned from the financial company. He is now studying biology.*

Quantum Entanglement: "Spooky Action at a Distance"
by *Sasha Abanov*

Join us for an exciting journey into the world of quantum physics, where things get really weird and fascinating! In this lecture, we'll explore the mysterious phenomenon of quantum entanglement, famously dubbed "spooky action at a distance" by Albert Einstein. We'll discuss Bell's theorem, a groundbreaking idea that challenges our understanding of reality itself. You'll get a glimpse into the strange and wonderful world of quantum mechanics. No prior knowledge is required — just bring your curiosity and imagination!

About the lecturer: *Sasha Abanov is a Professor in Department of Physics and Astronomy at Stony Brook University, NY. Sasha's research is in theoretical condensed matter physics and in mathematical physics. He is mainly interested in systems whose properties are defined by the laws of quantum physics. Some examples of such systems are superfluids, superconductors and Quantum Hall effect systems. Sasha enjoys teaching physics and mathematics at different levels. He has a lot of experience in teaching school students in various summer camps and math circles.*

Error Eror Error Correcting Codes
by *Sofya Raskhodnikova*

You want to send a message from Sigma to your parents, but you have been warned that the person who transcribes messages into emails to parents is prone to typos: a couple of letters of your message could be changed. How can you introduce redundancy to your message without making it too long? For example, if you want to say "Pick me up at 9am on the last day of Sigma next to the Art Barn," you can be worried that 9 in your message might turn into 6 and "Art" might turn into "Ant". You can repeat things multiple times, as in the title of this talk. However, this is also dangerous, since the person who types the messages might get mad at you that your message was so long, or even worse, your parents might think that you developed a verbal tic and come to pick you up earlier. In this lecture, we will explore how to add redundancy using *error-correcting codes*, a method used everywhere from the internet to satellites to hard drives in order to communicate and store information. We will also see that error-correcting codes can help us save a king from being poisoned and to accomplish group COVID-19 testing with fewer tests.

About the lecturer: *Sofya Raskhodnikova is a professor of Computer Science at Boston University. She received her undergraduate and graduate degrees in mathematics and computer science from MIT. Sofya works in the areas of randomized and approximation algorithms and also data privacy. These areas are part of theoretical computer science. Sofya has taught at Epsilon Camp and C.A.M.P. (Camp for Algorithmic and Mathematical Play). Her best memories of her childhood are from a math camp she attended in Belarus. As far as her hobbies go, recall that she works on privacy.*

Molecular Factories: A Study in Saddle Points
by *Tim Pinkhassik*

Chemists often invoke particular mechanisms of reactions, but how do they gather evidence for them? It is impractical and often even impossible to observe reactive intermediates, but chemists speak with confidence on the existence of dozens of species that they have never isolated to explain why a given reaction is fast or slow, gives certain products, or favors particular substrates. Chemists can make very confident predictions about the structure of a transition state—the key to discovering new reactions and improving existing ones—without ever having seen one. We will explore the experiments and physical principles underlying the study of mechanisms in chemistry through the lens of designing an organometallic catalyst.

About the lecturer: *Tim Pinkhassik is an undergraduate student at the University of California, Berkeley. He does catalysis research, and is particularly interested in discovering the mechanisms of how these reactions happen. At SigmaCamp, Tim runs the "Molecules that Save Lives" semilab, and can commonly be found in the Chem Circle.*

Monday, August 12

The Energy Machinery: Mitochondrial Bioenergetics and Cellular Respiration Explained
by ***Alexander Galkin***

This lecture provides an in-depth exploration of the fundamental mechanisms underlying cellular energy metabolism. We will learn how cells transform energy through the process of oxidative phosphorylation in mitochondria. We will examine how food is used to generate ATP and other energy currencies of the cell and also discuss how the energy from redox reactions drives the biosynthesis of ATP in mitochondria. By the end of this lecture, you will gain an understanding of the basics of bioenergetics, discover why cyanide is toxic, and learn what "barbasco" fishing in the Amazonia is.

About the lecturer: *Alexander received his PhD in Biochemistry at Moscow State University and completed postdoctoral studies at Frankfurt University and University College London. Dr. Galkin's research lab at the Brain and Mind Research Institute, Weill Cornell Medicine, focuses on studying the role of mitochondria-associated metabolic changes in tissue injury during cardiovascular diseases such as stroke, tissue ischemic damage, and neurodegeneration using various in vivo and in vitro models.*

The Unreasonable Effectiveness of Mathematics in the Natural Sciences: From Wigner to Modern Advances
by ***Yakov Kononov***

Join us for a lecture that explores the profound and enigmatic relationship between mathematics and the natural world. Inspired by Eugene Wigner's seminal essay, "The Unreasonable Effectiveness of Mathematics in the Natural Sciences," this talk delves into why mathematics, a creation of human thought independent of empirical observation, so effectively describes the laws of nature.

We will examine historical examples from Wigner, such as the use of complex numbers in quantum mechanics and group theory in particle physics, demonstrating how abstract mathematical concepts find practical applications. Additionally, the lecture will cover modern advances and discoveries that highlight the remarkable predictive power of mathematics in contemporary science.

The philosophical implications of this effectiveness prompt us to consider whether it reflects a deeper truth about the universe or is a characteristic of human cognition. This lecture is intended for everyone—mathematicians, scientists, and those simply curious about the world—offering deep insights and provoking thoughtful reflection.

About the lecturer: *Yakov Kononov is a distinguished expert in mathematical physics. He holds degrees from the Moscow Institute of Physics and Technology, the Independent University of Moscow, and the Higher School of Economics. Dr. Kononov earned his PhD from Columbia University and subsequently served as a Gibbs Assistant Professor at Yale University. In 2023, he transitioned to the financial industry, where he currently applies his extensive skills and expertise.*

Understanding Basketball with Physics
by ***Boris Barron***

Professional sports organizations, such as the NBA, are collecting precise player-tracking data; data which consists of centimeter-precision of player locations dozens of times per second, every game. However, what can we actually do with this data? In this talk, using a physics-inspired approach known as density-functional fluctuation theory (DFFT), we will discuss how we can predict where a player is likely to be from the locations of other players, identify which defensive players are standing in good positions to prevent 2-point or 3-point outcomes, and determine how strongly specific offensive players attract the opposing team—the first advanced quantification of the concept of 'player gravity'. This data-driven approach will not require us to know anything intricate about basketball. Rather, by observing fluctuations in data, we will be able to infer important aspects of the game. Arguably, basketball is more interesting through analysis than gameplay.

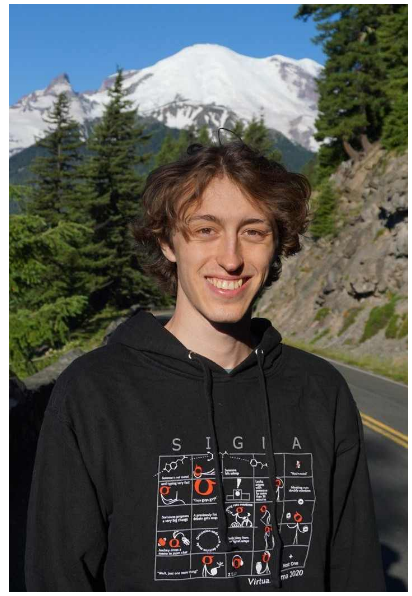
About the lecturer: *Boris received his PhD in Physics from Cornell University and is currently a research scientist at the Max Planck Institute for Demographic Research (MPIDR) in Germany. His recent research focuses on collective systems—complex systems that cannot be fully understood through observation—and often employs elements of information theory. Originally a dance major, Boris has also majored in biophysics, mathematical physics, "just" physics, and is perhaps currently best described as a computational demographer. With degrees from three different countries, none of which he or his parents are from, Germany is the fifth country that he calls home.*

Lattices: From Geometry to Cryptography
by ***Oded Regev***

Lattices are periodic arrangements of points in space that have attracted the attention of mathematicians for over two centuries. They have recently also become an object of great interest in computer science due to their remarkable applications in cryptography. I will describe some of the progress in the field, starting from Minkowski and ending in recent NIST standards for post-quantum cryptography. The talk should be broadly accessible and does not assume any prerequisites. It will include a fun live demo, showing how to encrypt messages using only pen and paper in a way that even quantum computers cannot break.

About the lecturer: *Oded received his Ph.D. in computer science and is currently a computer science Silver Professor at the Courant Institute of New York University. During his postdoctoral studies, he got interested in quantum computation and high-dimensional geometry, which have been the focus of his research ever since. He is also very interested in machine learning and RNA biology, and runs a wet lab.*

Cogs on a Mission: Language Cognition
by *Alexander Suponya*



Do you ever feel your brain churn when you switch from English to your heritage language to speak to your parents on the phone? Have you ever watched a baby speak for the first time? What is going through the minds of that deaf family using sign language to communicate on the train? Finally, a timeless question: what causes people to think and communicate differently? Using linguistics and cognitive science, let's uncover the secrets behind that fancy meat computer writing the script of our lives beneath our skulls.

About the lecturer: *Alexander Suponya is a 6th year Sigma counselor pursuing his M.S. in biomedical engineering at Rutgers University. Alexander's current research in the Adam J. Gormley Lab uses neural networks to optimize biomaterial design. He has also researched neural plasticity in the auditory cortex, retinal autophagy in mice, qPCR primer design, small molecule drug discovery and electroactive polymers. Alexander is the founder and former president of the Rutgers Linguistics Club and has previously given Sigma lectures on GPT-3 and brain implants.*

Tuesday, August 13

Quantum Computing
by *Peter Shor*

Almost since its discovery, quantum mechanics has been recognized as a weird theory. However, for the first 30 years of its existence, nobody realized that this weirdness could be used for anything. We have now discovered several applications for this weirdness, including an algorithm for factoring large integers into primes using a quantum computer that is much faster than any prime factorization algorithm for classical computers. We will discuss the weirdness of quantum computing and give a sketch of how the factorization algorithm works.

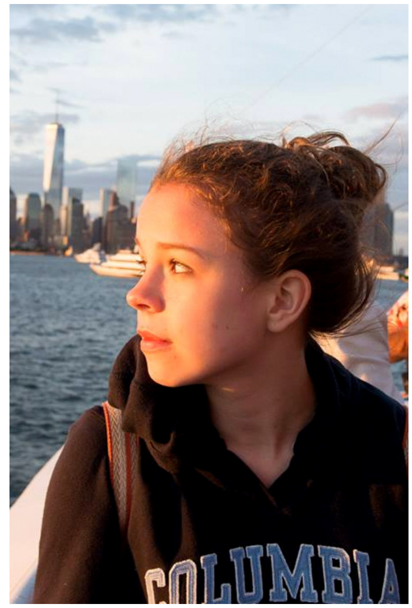
About the lecturer: *Peter Shor is a professor of Applied Mathematics at MIT. He discovered the quantum factoring algorithm in 1994, when he was working at Bell Labs. Before this discovery, he worked on algorithms for digital computers and on combinatorics. Since then, he has worked mainly on algorithms for quantum computers and related problems — quantum information theory, quantum error-correcting codes, and quantum complexity theory.*

What is the Science behind Climate Change?
by *Zohar Komargodski*

Climate change is one of the most pressing issues of our time, impacting ecosystems, economies, and communities worldwide. This talk will be about the physics principles that are crucial to understand in order to discuss this topic. We will cover some basic physics of light and atoms and explain greenhouse gases and the greenhouse effect. We will discuss the observed and projected impacts of climate change, such as rising temperatures, shifting weather patterns, and sea level rise. Then we will touch upon very complicated physics topics that are crucial but not understood yet. My goal is to equip attendees with the knowledge needed to engage in informed discussions and actions.

About the lecturer: *Zohar Komargodski is a Physics Professor at the Simons Center for Geometry and Physics. He received his PhD from the Weizmann Institute in Physics in 2008, after which he served as a postdoctoral fellow at the Institute for Advanced Study. His research studies in theoretical particle physics include a variety of topics such as Quantum Field Theory, Conformal Symmetry, Supersymmetry, Quantum Gravity, and Particle Physics Phenomenology.*

Investigating Unculturable Microbes: Marine Microbial Ecology of Oxygen Minimum Zones
by *Natasha Butkevich*



While humans need oxygen to survive, there are some clever organisms that either don't mind its absence or actually struggle when oxygen is around. Some of these lifeforms live in oxygen minimum zones, which are curious regions of the ocean characterized by minimal dissolved oxygen concentrations. But how do organisms survive without oxygen, what purpose do they serve, and how do scientists study them when they don't really want to be grown in a lab? This lecture will delve into the fundamentals of microbial metabolism, examining the unique ecological niches and alternative metabolic pathways that predominate in oxygen minimum zones. We will also explore the methods used by microbial oceanographers to investigate these elusive microorganisms, both during expeditions at sea and on land. Understanding these processes is critical for advancing our knowledge of marine ecosystems and their role in global biogeochemical cycles.

About the lecturer: *Natasha earned her bachelor's degree from Cornell University in 2020, focusing on microbiology. She is currently pursuing a Ph.D. at the School of Marine and Atmospheric Sciences at Stony Brook University. Her research integrates stable isotope probing, Raman microspectroscopy, and fluorescence in-situ hybridization to elucidate the connection between microbial identity and function in the Eastern Tropical North Pacific Oxygen Minimum Zone (OMZ). Natasha teaches the Unseen World of the Sea semilab at SigmaCamp. Beyond her academic endeavors, Natasha has a long-standing passion for ballroom dancing, a pursuit she began as an undergraduate and has continued alongside her Ph.D. studies. Recently, she has also rekindled her interest in ballet. In her free time, Natasha enjoys creating artwork, with plans to share her projects on Instagram in the future.*

On Darwin, Democracy and Racism
by *Mark Lukin*

It is usually believed that racism is an archaic worldview, something opposite to more modern, democratic views. From this, one could conclude that ancient and primitive human societies were the most racist, which is not supported by historical and ethnographic data. In this lecture, I will show that racism is a much more recent phenomenon than is commonly believed, that it was a side effect of the democratization of society, limited in both time and space, and doomed to disappear in the foreseeable future.

About the lecturer: *Mark Lukin is a researcher at Stony Brook University, NY. The focus of Mark Lukin's scientific interests is nucleic acids (DNA and RNA), the molecules responsible for the storage and transfer of hereditary information in living organisms. How does DNA get copied? What happens when DNA molecules break? To answer these, as well as many other questions, Mark needs to prepare artificial (modified) nucleic acids and their building blocks, the crazy compounds that normally do not exist in nature. The only way to obtain them is to do a chemical synthesis, the thing Mark likes the most. Besides that, Mark loves music, history, Greek philosophy, and science fiction. When he was young, he loved to do simple but spectacular chemical experiments. Recently, he realized he still loves to do that.*

Tax Avoidance 101: Policy, Planning, and Catching Al Capone
by *Stephen Nye*

Tax is one of the most influential, and least noticed, forces which guide economic decisions great and small. From Mergers & Acquisitions to Private Equity practices all the way down to the choices made by the average American homeowner or employee, compliance with and utilization of the tax system is a crucial concern.

This lecture will teach a brief history of the United States government taking our money, cover crucial topics in understanding what they will or will not take, and will build towards an analysis of some of the most common ways to keep money out of the hands of the IRS. Along the way, it will touch on tax policy concerns and explain why the government takes what it does, how it does, and the broader macroeconomic concerns that inform the decisions and build the foundation of political platforms. It will also tell the story of the IRS' greatest accomplishment: the final defeat of the murderous gangster Al Capone.

About the lecturer: *Stephen Nye is a 3rd year Law Student at New York University, focusing his studies on the tax planning and ramifications of complex business transaction. He has accepted an offer to begin his legal career at Kirkland & Ellis LLP, the most profitable law firm in the United States. His interests include history, Air & Missile Defense, and picking up heavy things just to put them back down.*

Wednesday, August 14

Quest for Biological Immortality: The Need, The Fraud, & The Roadmap
by *Leon Peshkin*

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In Slavic folklore, Koschei the Immortal was bony, thin and lean. Was his condition caused by severe calorie restriction (CR)? Did Vampires realize young blood keeps them younger via GDF11? What exactly is the molecular mechanism of rejuvenation in embryos and how to properly prepare the embryo extracts at home? In this lecture we will review the tales, the fakes and the hard science behind thousands of years of human attempts to delay, cancel or reverse the damage of aging. We will examine the exceptional longevity of selected species across the tree of life and try to crack their secrets. We will study nature's own clocks and consider ways to adjust and halt the pace of their ticking. We will focus exclusively on engineering and laboratory science and leave the moral, environmental and philosophical implications for a separate discussion.

About the lecturer: *Leon came into Systems Biology with a PhD in Artificial Intelligence to help advance probabilistic modeling and data analysis in biological and medical research. Today, his passion lies in understanding the root causes of aging and unlocking nature's mechanisms for longevity and the reversal of age-induced damage, which naturally occurs in an embryo - germline reset. The interface between embryology and aging, the onset of cell differentiation and eventual de-differentiation, is the focus of his work on model organisms, e.g., Xenopus. His group has introduced a scalable platform for intervention testing in Daphnia as a way to obtain data amenable to Machine Learning.*

Bayes' Rule and Conspiracy Theories: Getting Cancer, Canned, Conned, and COVID
by *Andrey Boris Khesin*

How do we know the moon landing happened? What did society get wrong with "stranger danger"? Why does Nigeria have so many princes looking to give away their money? Extraordinary claims require extraordinary evidence, but how do we evaluate the strength of our evidence? All of these questions can be answered using one of the simplest and most powerful equations in mathematics: Bayes' Theorem. Knowing this simple rule can help in every aspect of life, from interpreting outcomes of medical tests, to not falling for conspiracy theories, to avoiding scams that sound too good to be true. In this talk, we'll cover everything about how Bayes' theorem answers why a moon landing conspiracy would have fallen apart immediately, how Microsoft Word cost many CBS producers their jobs, what to teach your younger siblings about seeking help, and how to win at Mafia.

About the lecturer: *Andrey has been at SigmaCamp since the very beginning. He is working on his PhD in Math at MIT, studying quantum computing and quantum information theory. His research has included everything from quantum compilers, to quantum money, to non-local games. His hobbies include solving puzzles and playing board games; some of his favourites are Terraforming Mars and Spirit Island. Additionally, he greatly enjoys contradancing and square dancing. At SigmaCamp and SigmaCamp Next, he runs the Chaos Theory and Game Theory semilabs.*

The Successes and Failures of String Theory
by *Alex Frenkel*

For an abstract field of physics, String Theory has become surprisingly controversial. Both pop science fans and experts in quantum gravity have claimed that 'string theory is dead.' The reasons for these claims range from string theory being unverifiable to the lack of supersymmetry or the existence of a positive cosmological constant. The goal of this lecture is to unpack this claim, and argue the reasons for why string theory might or might not be worth studying. I will go over exactly what got string theory to this point – why it initially became incredibly hyped up following a series of 'string revolutions', how it over-promised and under-delivered in the run-up to the launch of the LHC, and what the future of string theory and quantum gravity may be from here.

About the lecturer: *Alex is a graduate student studying string theory and holography. He splits his time between Stanford University and the University of Cambridge.*

What Makes It Great: Famous Examples of Data Visualization
by *Alexander Brook*

Graphs, charts, and plots are everywhere, from news articles to your homework to scientific papers. We will look at some landmark examples of data visualization, talk about their context, try to figure out their purpose, and answer the question: what makes them great?

About the lecturer: *Alexander Brook is a biostatistician at Beth Israel Deaconess Medical Center. He has a PhD in Applied Mathematics, and used to work in computer vision. Currently, his job is to work with clinical researchers to help them design their research, collect and analyze their data, and report the results.*

Astrochemistry - From Shaping the Universe to the Search for Life
by *Victor Paiva*

Astrochemistry sits at the exciting intersection of chemistry and astronomy, exploring how these two sciences come together to unveil the mysteries of the universe. Join us for a lecture where we will discuss the creation of elements, the techniques used to probe distant celestial objects, and the chemical processes occurring in space. We will also delve into the conditions necessary for life as we know it and how we can search for these conditions beyond Earth.

About the lecturer: *Victor has a M.Sc. in physical chemistry and is an enthusiast of academic competitions, in which he competed at international level as a student. Currently, he is a chemistry teacher at Colegio Etapa, in Brazil, and an academic advisor for Chemistry Olympiads. He was the Brazilian team leader in three International Junior Science Olympiads and two Iberoamerican Chemistry Olympiads, and personally trained students that collectively won 37 international medals. Besides chemistry and teaching, Victor is also a cat aficionado. Don't hesitate to ask him about his cats.*

Thursday, August 15

It's All Modeling: What do Cells, Social Networks, and Weather Prediction Have in Common?
by *Olga Troyanskaya*

We've all heard about social networks. In this lecture, we will discuss what networks have to do with biology and how they are related to social networks. We will learn about machine learning/AI methods for building biological networks and for discriminative predictions and about what these methods have to do with discovering what genes and proteins do in biological circuits. We will also discuss what this all has to do with genomics and disease.

About the lecturer: *Olga Troyanskya is a Professor at the Department of Computer Science and the Lewis-Sigler Institute for Integrative Genomics, Princeton University, the Deputy Director for Genomics at the Center for Computational Biology of the Flatiron Institute of the Simons Foundation, and the Founder and Director of Princeton Precision Health. Dr. Troyanskaya's lab builds AI methods to decode genomes and diagnose and treat complex diseases. Her group pioneered Bayesian approaches for building networks to map tissue and cellular specificity to study pathway dysregulation in disease and for deep learning models to study regulatory genomes, enabling study of transcriptional and post-transcriptional variants and their role in cellular function, evolution, and diseases. Through developing AI-based integrative approaches, her lab focuses on studying the non-coding genome and modeling of complex molecular-level changes captured via diverse multi-omics techniques, including in specific clinical, treatment, and environmental contexts, enabling systems-level molecular views of human health and disease. Dr. Troyanskaya has committed to democratizing the use of her novel machine learning approaches with interactive, public interfaces for the biomedical community. Dr. Troyanskaya received her Ph.D. from Stanford University in 2003, is a member of the National Advisory Council for Human Genome Research and is an Association for Computing Machinery fellow. She is a recipient of the Sloan Research Fellowship, the National Science Foundation CAREER award, the Ira Herskowitz Award from The Genetics Society of America and the Overton Prize in computational biology.*

(Re)constructing Networks
by ***Krerley Oliveira***

A graph is a set of vertices connected by a set of edges. Despite this simple notion, it is fundamental in today's world, modeling, for example, the spread of a disease. In this case, people are the vertices, and the edges are determined by the connections between people, such as living in the same house. The disease may spread in a simple way: for each neighbor of an infected person, we flip a coin with a probability p of landing heads. If the coin lands heads, the neighbor gets the disease. Each person becomes healthy (or dies!) the next day. Thus, the disease spreads like a special type of graph called a tree.

An important question is, knowing all the vertices and edges, a percentage of infected people, and the probability p of a person infecting another, how we can determine the people who are most likely to have been infected. This relates to a part of complex network theory called "network reconstruction" and has several concrete applications.

We will discuss how (to try) to do this with simulations and why this is generally difficult. The main tool to be used is an algorithm called the "Monte Carlo Markov Chain," elected as one of the most important and influential of the 20th century.

We will also tell the story of how this problem appeared in our lives, through work helping a small and beautiful town in the interior of Brazil called Maragogi, with a population of 30,000, to combat the most important epidemic of this century, starting in March 2020 and continuing to this day.

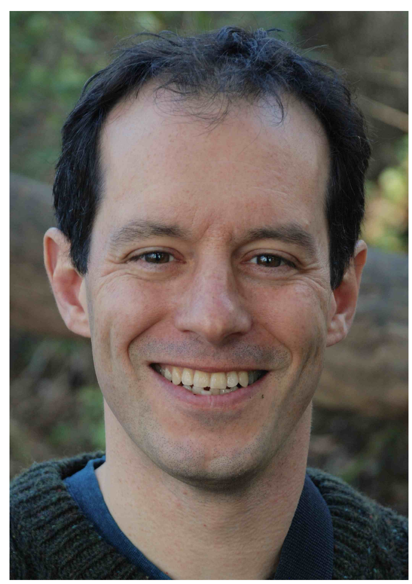
About the lecturer: *Krerley Oliveira holds a BA, Master's and PhD in Mathematics specializing in Dynamical Systems and Ergodic Theory. He was elected an affiliated member of the Brazilian Academy of Sciences, founded the graduate program on Mathematics at the Federal University of Alagoas and mentored numerous students. He also played a pivotal role in the Mathematics Olympiad Program in Alagoas, nurturing young mathematical talents since 2003. With a background from math competitions, including leading the Brazilian Team at the IMO 2017, Krerley's expertise is widely recognized. Currently, they are spearheading research projects in Natural Language Processing and Computer Vision applied to justice, public purchases, analysis of medical records and the fight against corruption. These projects are sponsored by the Justice Court of Alagoas, TCE-SP and WHO. Outside the realm of mathematics and research, Krerley possesses a passion for triathlon. He has participated in 12 Ironman races and secured three drafts for the Brazilian national age group team at triathlon world championships.*

The Science Behind Particle Accelerators
by *Boris Podobedov*

A particle accelerator is a machine that accelerates charged particles to very high energies while containing them in well-defined beams. With the fundamental concepts behind their design pioneered about 100 years ago, there are now over 30,000 accelerators worldwide and their number and capabilities keep growing. Today's accelerators include anything from small machines used in hospitals or in the semiconductor industry to the 100-km circumference circular collider now being considered as a successor of the famous Large Hadron Collider in Switzerland. This lecture will explain how accelerators operate and what makes them so useful. It will also highlight scientific and engineering challenges faced by the design teams of the most advanced accelerators in the world.

About the lecturer: *Boris is an accelerator physicist at Brookhaven National Laboratory. His expertise is to design, build, and operate large particle accelerators. These are mostly used as colliders for high energy and nuclear physics research, or serve as light sources that provide powerful X-ray beams to researchers in many different fields of science. As you might guess, Boris' job has a lot to do with all aspects of electricity and magnetism, and this is exactly the topic of the Semilab he is teaching at Sigma.*

The Mystery of Memorization in Machine Learning
by *Adam Smith*



Modern machine learning models excel at prediction tasks. When given enough data to train on, they can now solve problems that, until a few years, ago, were thought of as out of reach for computers—from writing large-scale software to identifying flower varieties in a photo. One of the odd features of these modern models is their propensity to "memorize" parts of the data on which they are trained. That is, these models will often spit back out specific images or blocks of text that are nearly identical to images or text in their training data. In this lecture, I'll start with surprising examples of memorization and explain what we know about *why* it happens. Memorization is deeply connected to the rapid increases in *size* of the models we train and use these days. I'll talk about some of those connections as well as the implications for other questions, like how compatible modern models are with privacy concerns.

About the lecturer: *Adam Smith is a professor of computer science at Boston University. His research interests lie in data privacy and cryptography, and their connections to machine learning, statistics, information theory, and quantum computing. He is best known for the co-invention of differential privacy.*

Biomimicry: Inventions Inspired by Nature
by ***Polina Zavyalova***

What do bullet trains, Velcro, pain-free needles, and some evolutionary computer algorithms have in common? Turns out that all of these have been inspired by observing and studying the living world! Biomimicry - also called biomimetics - is the field of emulation of systems and elements of nature for the purpose of solving complex human problems. For example, the inventions above are inspired by kingfishers, burdock, mosquitos, and large groups of birds and insects. In this lecture, we will explore the nature-inspired design process that leads to antibacterial surfaces, the strongest materials, energy-saving building designs, and much more. Come learn a new approach to innovation in engineering, medicine, computer science, and architecture!

About the lecturer: *Polina is a fifth-year PhD student in electrical and computer engineering at the University of Toronto. She received her BSc in Physics in 2019, which was also her first year at SigmaCamp. Her current research revolves around using ultrafast laser fabrication techniques to make compact astronomical instruments for detection of gases in exoplanet atmospheres. She is broadly interested in novel sensing and metrology applications. At SigmaCamp, she teaches the Cosmology semilab.*

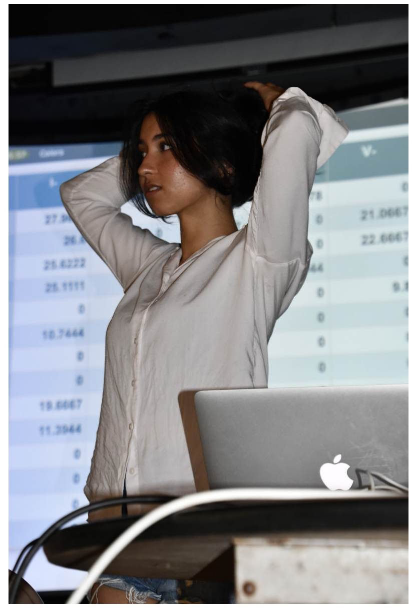
Friday, August 16

Cellular Robots: Using Synthetic Biology to Program Living Cell Therapies by ***Wendell Lim***

We are beginning to understand the principles of how the complex behaviors of living cells are wired by molecular/genetic circuits. I will describe how we can use this understanding to genetically program sophisticated immune cell "robots" to treat complex diseases such as cancer, autoimmunity and degeneration. These cells can be programmed to precisely recognize disease tissue and to launch highly precise and targeted responses that can be far more effective compare to traditional molecular drugs.

About the lecturer: *Wendell Lim is a Professor of Cellular & Molecular Pharmacology and Biochemistry & Biophysics at the University of California San Francisco. He is the director of the UCSF Cell Design Institute. He works in the areas of systems and synthetic biology to understand how complex cellular behaviors are wired. He is also applying these approaches to engineering immune cell therapies that can treat complex diseases such as cancer.*

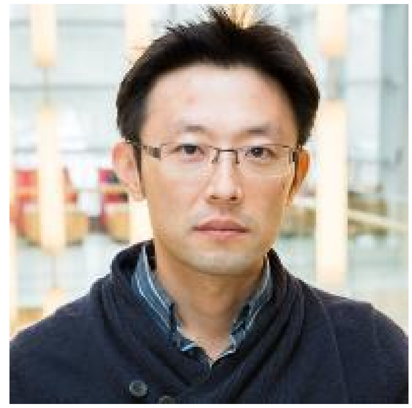
The Million Dollar Question: Beyond Polynomial Boundaries
by *Tarika Mane*



Our world is full of problems that we must solve, whether that be sorting a list of ages, finding a sequence of amino acids, or creating an optimal map for voting districts. Some of these are more complex than others, requiring additional time and resources to find the solution. Determining how complex they are is a fundamental interface between mathematics and computer science - this field is known as complexity theory! As we examine such problems, we can group them by how complex they are and derive general results based on their complexity class. In complexity theory, we often wonder if a problem can be solved "quickly" and if the solution of a problem can be verified "quickly". In this lecture, we will travel through the fundamental concepts that form the field of complexity theory, leading us to one of the most famous unsolved problems in theoretical computer science and mathematics known as "P vs NP", currently worth a million dollars. The solution to this problem can have profound consequences such as breaking down modern cryptography systems or enhancing biotechnology through efficient protein structure prediction.

About the lecturer: *Tarika Mane is currently in finance as a quantitative strategist at Goldman Sachs, creating pricing and predictive models as well as working on optimization problems with large scale datasets. In particular, she has recently built out pricing curves and created new baskets for ETFs for the US and Brazil short markets. She received her bachelor's in mathematics and master's in computer science from the University of Chicago and enjoys solving puzzles and playing logic games. Due to this, she has spent all her years as a counselor helping out with the tournament and Problem of the Month.*

Coordination without Communication: The Challenge of AI Teaming
by *Jaime Ide*



Ever wonder how teams work together without knowing everything about each other? Imagine a group of independent computer programs, called "autonomous agents," trying to achieve a goal together. Normally, they'd need complete information about their environment to succeed, but what if some details are hidden? This research tackles that challenge! We present a new approach called Multi-Agent Reinforcement Learning with Epistemic Priors (MARL-EP). MARL-EP is basically a fancy way of saying it's a special training program for these agents. It helps them act like detectives, using the clues they have about the situation and their teammates' possible actions to guess what's happening "behind the scenes." This allows them to achieve a high level of teamwork, even with limited information!

About the lecturer: *Jaime Ide is an AI Research Engineer at Lockheed Martin, developing AI and Machine Learning for unmanned aircraft and cognitive systems. A Ph.D. in AI and training in brain imaging allow him to combine his engineering background with neuroscience research. His interests include using AI to understand the brain, decision-making, and robotic control. Outside of work, he enjoys robotics, chess, and table tennis.*

Cryptocurrencies - Basic Principles Explained
by *Julia Kempe*

In this lecture, we will delve into some of the history and the underlying principles of cryptocurrencies and aim to understand how decentralized payment schemes could work. We will illustrate what terms like "proof of work", "distributed ledger" and "blockchain" mean and how they are used. We will also address some of the recent hype, boom and bust. Note: A very close cousin of this lecture was given last year, so do not attend if you attended in 2023.

About the lecturer: *Julia has a PhD in Mathematics and Computer Science and MS degrees in Math and Physics. In the first decade of her research activity she has worked in quantum computation and information, studying algorithms for quantum computers. She has then worked nearly a decade in finance before returning to academia, where she is now working at the interface of data science, machine learning and science.*

Nanobots
by ***Eugene Pinkhassik***

This lecture will give a personal account of the main research program in our laboratory, making nanoscale devices with unusual properties that address global challenges. You will hear three stories describing construction, properties, and applications of functional devices made with nanocapsules. The first story will describe the biologically inspired method for the creation of hollow nanocapsules that act as shells in nanobots. The second story will unravel unusual properties of these nanocapsules. Finally, the third story will highlight current and future applications enabled by superior properties of nanocapsules.

About the lecturer: *Eugene Pinkhassik graduated from Kazan University in Russia and obtained his PhD in Chemistry in the University of Chemistry and Technology in Prague, Czech Republic. After a visiting scientist stay in Parma, Italy and a postdoctoral fellowship at the University of Colorado, Boulder, he began an independent faculty career. He is currently an Associate Professor at the University of Connecticut. His research interests focus on making nanomaterials and nanodevices with new and superior properties to address current problems in energy-related technologies, medical imaging and treatment, and environmental sensing.*