SigmaCamp Lectures

August 10-21, 2021

Lecture dates are subject to change

Contents

Wed, Aug 11: Opening Lecture

What Have We Learned From Covid?
by ***Alexei Tkachenko***

About the lecturer: *Alexei Tkachenko is a theoretical physicist at Brookhaven National Laboratory working on nanoscience and in the field called soft condensed matter. He studies problems that range from from living matter (DNA, proteins, membranes) to nanoparticles, plastics and even sand. He also teaches physics at School Nova.*

Thursday, Aug 12

How to Count Colorings?
by *Pavel Etingof (via Zoom)*

Suppose you want to color faces of a cube in two colors - red and blue. How many indistinguishable colorings (i.e., ones you cannot turn into each other by rotation) do you have? You may try the brute force approach – draw them all and then count, and if you are careful, you will succeed - there are 10. But what about three colors (red, blue and green)? Now this is pretty confusing, and if you are not extra careful, you are likely to make a mistake (the answer is 57). And if instead of a cube you have a dodecahedron, this becomes totally impossible - for three colors there are thousands of possibilities (the answer is 9099). The main challenge is to account for the symmetry – some colorings are very symmetric and others less so, which makes the process messy. Nevertheless, there is a technique, called Burnside's lemma, which allows you to count coloring precisely and efficiently without enumerating all possibilities (and you can do all the required calculations in your head!). Not surprisingly, this is based on a mathematical theory designed to study symmetry, called group theory. I will explain the basics of group theory, then derive Burnside's lemma, and then consider examples of its use, in particular obtaining the numbers 57 and 9099.
The lecture should be accessible to students with a good background in high school algebra ((pre)calculus is not required).

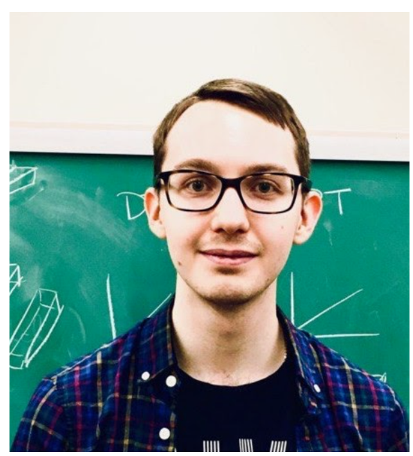
About the lecturer: *Pavel Etingof is Professor of Mathematics in the Mathematics Department at MIT. Pavel received his Ph.D. in mathematics from Yale University. His research interests are noncommutative algebra, representation theory, and mathematical physics. In mathematics, he mostly enjoys the interplay between different fields (such as algebra and analysis), and between classical and modern mathematics. He has led mathematics research programs for high school students at the Clay Mathematics Research Academy and the Research Science Institute (RSI) at MIT. He co-founded the MIT-PRIMES program and has served as its Chief Research Advisor since 2010. When Pavel isn't doing math, he enjoys mycology and can be found identifying, collecting, and cooking mushrooms for fun(gi).*

Physics of Space Flight
by ***Helmut Strey***

In this lecture, I will explore the physical principles that underly space flight. I will begin by discussing the scientific underpinning (or lack of) of popular science fiction franchises (Star Trek, Star Wars, etc.). We will then move to “real” space flight and explore concepts and limitations of space travel.
It is recommended that the students have taken HS physics since I am going to derive concepts using laws of physics.

About the lecturer: *Helmut Strey is the Director of the Laboratory for Micro- and Nanotechnologies (www.streylab.com) and Associate Professor in the Biomedical Engineering Department at Stony Brook University. Helmut Strey is a Biophysicist who is interested in developing micro- and nanotechnologies for applications in basic and applied research. Specifically, his lab is working on 1) microfluidic techniques for single-cell cancer genomics, 2) study of DNA dynamics in confined geometries to understand how gene regulation works, 3) developing wireless biosensors for home sleep studies. Helmut received the Dillon medal for research in Polymer Physics from the American Physical Society in 2003. He recently converted to Bayesianism and is passionate about making things, Soccer and Table Tennis.*

What is Quantum Information?
by ***Yakov Kononov***



So far, no one has managed to build a quantum computer. From the perspective of classical computations, quantum many-body systems solve a hard problem – find their groundstates and evolve them in time. Can we steal their methods? We will discuss the difference between classical and quantum information and related physics.

About the lecturer: *Yakov obtained a PhD degree from Columbia University under the supervision of Andrei Okounkov. Currently he is an assistant professor at Yale. His main research area is mathematical physics, in particular various mathematical structures arising in quantum field theory and string theory. Besides mathematics, Yakov loves music and playing piano.*

Basics of Nuclear Energy and How Atomic Bombs Work
by *Zohar Komargodski (via Zoom)*

I will explain the basic physics of nuclear energy, and the technologies used in making atomic bombs and nuclear reactors. I will also explain why nuclear physics does not admit a simple "periodic table" like the elements do.

About the lecturer: *Zohar Komargodski is a Professor at Simons Center for Geometry and Physics, Stony Brook University. Zohar studied at the Weizmann Institute in Israel, where he received his PhD in 2008. Later he joined the Institute for Advanced Study in Princeton. In 2011 Zohar returned to the Weizmann Institute, and in 2017 joined the Simons Center for Geometry and Physics. His research is on Quantum Field Theory, which has applications on a wide variety of fields in physics, including Particle Physics and Condensed Matter Physics.*

Friday, Aug 13

Melting Crystals, Quantum Foam, And Celestial Mechanics
by ***Nikita Nekrasov***

Newton's law of gravitation provides an explanation of Kepler's law of planetary motion. It also predicts the planets shouldn't move according to Kepler's laws, following much more intricate trajectories instead, due to their mutual attraction. We shall discuss this problem and relate it to a game of soccer on a toroidal football field. In a mysterious way, the celestial mechanics investigation will carry us to the soup of boiling black holes and melting crystals to the ultimate questions of the origins and fate of spacetime and Universe in string theory.

About the lecturer: *Nikita is a Professor at the Simons Center for Geometry and Physics at Stony Brook University. He thinks about the laws of Nature and natural laws and why they are not always the same. He likes to compute complicated sums which explains his attachment to SigmaCamp for many years.*

Explosives
by ***Eugene Pinkhassik***

Explosives are both dangerous and fascinating. In our conversation, we will mostly talk about chemical explosives. While a wide variety of substances store a tremendous amount of potential energy, some of them can release this energy suddenly, resulting in powerful explosions. What are the common attributes of explosive materials? Why perfectly safe household items become powerful explosives? Why are some explosives too dangerous for practical use? How are explosives detected at the airport? We will talk about these and other related questions and may sneak in a coupe of practical demonstrations — volunteers will be needed!

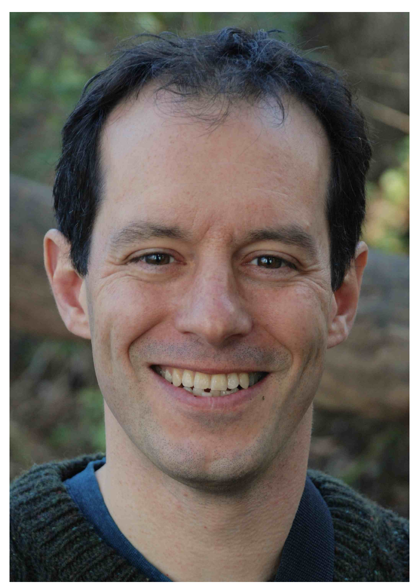
About the lecturer: *Eugene Pinkhassik graduated from Kazan State University in Russia and obtained his PhD in Chemistry in the Institute of Chemical Technology in Prague, Czech Republic. After a visiting scientist stay in Parma, Italy and a postdoctoral fellowship at the University of Colorado, Boulder, 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.*

Building Math From Scratch: From Euclid to Bourbaki
by ***Alexander Kirillov***

One frequently hears that mathematics can be built from the ground up, deriving all of it from just a few basic axioms or postulates. Truth, however, is slightly more complicated than that. Do we really all agree with the laws of logic? How one chooses our basic postulates and how can we be certain that we didn't miss any? And is there really only one mathematics or everyone is free to create their own world?
In this lecture, we will talk about history of such axiomatic constructions of math — from Euclid's *Elements* and Aristotle syllogisms to the great vision of David Hilbert in early 20th centry and mortal blow of Gödel's incompleteness theorem, and then on to the latest such attempt undertaken by a retired French general Nicolas Bourbaki, whose *Éléments de mathématique* runs to over 10 000 pages and is on the bookshelf of almost any professional mathematician.

About the lecturer: *Alexander Kirillov is a professor in the Math Department of Stony Brook University. His research is in representation theory, quantum invariants of knots and low-dimensional manifolds, and Topological Field Theory. He has been working with high school children, teaching math circles and gifted classes, since his own high school graduation. In addition to math, he also enjoys hiking, volleyball, and robotics — he is the coach of Islandbots robotics club.*

How to Agree with Your Friends
When You Don't Know Who Your Friends Really Are
by ***Adam Smith***



How can a group of people or computers who don't trust each other agree on something when all they can do is talk to each other one-on-one? We'll see a few protocols for this problem, variants of which are called "consensus" or the "Byzantine generals problem". We'll touch on issues from the nature of time — can a network really be synchronized? — to how computers elect their own leaders.

About the lecturer: *Adam Smith is a professor of computer science at Boston University. He obtained his Ph.D. from MIT in 2004, and was a faculty member at Penn State from 2007 to 2017. His research interests lie in data privacy and cryptography, and their connections to machine learning, statistics, information theory, and quantum computing. He recently discovered that the key to staying sane in a pandemic is kayaking.*

Why Some Materials Shrink When Heated?
by *Igor Zaliznyak (via Zoom)*

Our common experience is that most solids expand when heated. This behavior has simple explanation. Because it costs less energy to move two atoms apart than bring them closer together, as microscopic atomic vibrations grow in magnitude with the increasing temperature storing the energy of the supplied heat, atoms, on the average, move apart and solid expands. Technologically, such thermal expansion presents significant problem for structures and precision mechanisms that operate at variable temperature. Hence, it is important to find materials that do not expand, or even shrink upon heating – this would allow custom-tailoring thermal expansion to fit technological needs. While such behavior - called negative thermal expansion – is common in soft matter: polymers and rubber, it is rare in solid ceramics that is needed for applications. Surprisingly, however, some solids do possess negative thermal expansion property, and it has the same nature as that of soft matter. In this lecture, I will explain how the mechanism of negative thermal expansion works and how we figured this out with the help of a former Sigma camper.

About the lecturer: *Dr. I. Zaliznyak is a physicist at Brookhaven National Laboratory, where he studies microscopic quantum properties of matter using neutron particles. Among others, these include exotic quantum states of electrons in metals, such as superconductivity, magnetism, and superfluidity in quantum liquids. Dr. Zaliznyak obtained his Ph. D. degree at the P. Kapitza Institute for Physical Problems, Moscow, in 1993. He also teaches math at SchoolNova.*

Saturday, Aug 14

What is Topology? Or How To Divide a Ham And Cheese Sandwich
by *Misha Grinberg (via Zoom)*

Topology is a branch of mathematics that deals with the consequences of the idea of continuity, or continuous dependence. In this lecture, we will introduce this subject by discussing the following result. Let A, B, and C be three bounded shapes (or solids) in three-dimensional space. Then there exists a plane which divides each of A, B, and C into two shapes of equal volume. We will appeal to the innate topological intuition of the audience to outline a proof of this result.

About the lecturer: *Originally from Ukraine, Misha Grinberg obtained his PhD in mathematics from Harvard University in 1997, specializing in geometry and topology. Since then, his career has oscillated between pure and financial mathematics. After stints teaching at MIT and Northwestern University, he spent 15 years as a researcher at Renaissance Technologies. More recently, he has pursued his early interests in geometry and topology as an independent scholar. Misha is interested in the topology of singular spaces and maps, often in situations arising from linear algebra and group theory.*

Recent Progress in Anti-SARS-CoV2 Chemotherapy Development
by *Mark Lukin*

Antiviral chemotherapy utilizes small molecules that block some core process of viral replication, thereby stopping the infection. Unlike vaccination, this approach can be applied to the treatment of already infected individuals and is generally more versatile than vaccination. Unfortunately, the development of antiviral drugs is less straightforward and more time consuming than the development of vaccines. Many research groups are currently working on the development of chemotherapy for COVID-19, and I will tell you about some of the most recent.

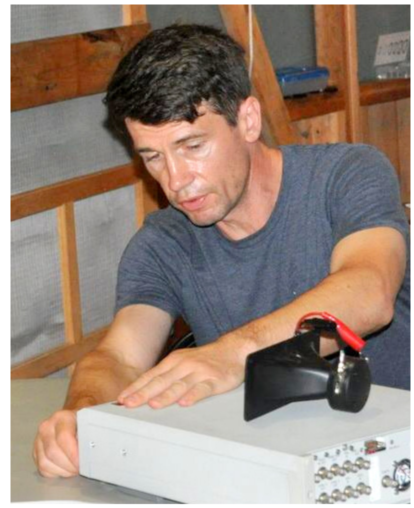
About the lecturer: *Mark Lukin is a Research Assistant Professor in Pharmacology Department of Stony Brook University, NY. The focus of Mark Lukin's scientific interest are nucleic acids (DNA and RNA) — the molecules responsible for storage and transfer of hereditary information in living organisms. 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. He plans to do some of those experiments in SigmaCamp 2021 with our campers.*

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 is 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.*

How to Measure Time
by *Boris Podobedov*



We live in ever shorter time increments, guided by clocks that tick invisibly with immaculate precision, and yet, simultaneously, we have the capacity to imagine and record histories that are thousands or millions of years old, to trace chains of cause and effect that span dozens of generations. Compared to our ancestors, our time horizons have expanded in both directions, from the microsecond to the millennium, which is arguably one of the key traits that make us modern humans. We can now glance at our phone and instantly get the time that is accurate to within a split second, but we must appreciate that the answer was, in a sense, at least five hundred years in the making. From Galileo's altar's lamp to Niels Bohr's cesium, from the chronometer to Sputnik, there were incredible technological and scientific breakthroughs that have improved our ability to measure time, and even our understanding of what time really is. In this lecture we will review the most exciting of these discoveries.

About the lecturer: *Boris is an accelerator physicist at Brookhaven National Laboratory (BNL). He got his PhD from the Stanford University Department of Applied Physics. His expertise is designing, building, and operating 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. Having spent two decades working with light source accelerators at BNL and elsewhere, Boris recently joined the Electron-Ion Collider project at Brookhaven, which will be building the most powerful collider-accelerator in the US.*

Sunday, Aug 15

Coming up For Air: Fish Air-breathing Biomechanics And Evolution
by *Elska Kaczmarek (via Zoom)*

One of the most surprising things about lungs is that they first evolved in fish swimming around over four hundred million years ago, long before fish began venturing onto land. The evolution of lungs was game-changing—it gave fish access to a source of oxygen and a source of buoyancy that were previously unavailable and lowered the barriers to terrestriality. Nearly all land and aquatic vertebrates alive today descended from the first air-breathing fish, indicating its evolutionary success. And there are still air-breathing fish that are alive today. Among land vertebrates, there have been diverse innovations in the mechanics of ventilation.
We will discuss how to read phylogenetic trees, the origin and evolutionary history of air-breathing, and the biomechanics of air-breathing behaviors in fishes, turtles, lizards, mammals, and birds.

About the lecturer: *Elska Kaczmarek is a PhD student in Ecology, Evolution, and Organismal Biology at Brown University. Her dissertation research is focused on air-breathing fish with the goal of better understanding how ancient fish first developed this unusual ability. She uses X-ray videos and CT scans to collect 3D kinematic data of the air-breathing behaviors of living fishes (including knifefish, polypterus, and lungfish). She is also studying non-air-breathing fish to explore whether gulping air to regulate buoyancy may actually be a strong candidate for the original "breathing" behavior.*

Cryptocurrency – From Bitcoin Pizza to Dogecoin
by *Nestor Tkachenko*

In today's world we have people paying $6.6 million for a video of an animated Donald Trump, markets dedicated to pyramid schemes, and middle schoolers becoming overnight millionaires through currencies based on memes. All this is due to the emerging technology of blockchain which is beginning to penetrate the mainstream. Join us to dive into the basics and more advanced aspects of cryptocurrency, and participate in a discussion about its future.

About the lecturer: *Nestor recently left Harvard to start a venture backed company called Rito, working to create an operating system for food through robotics. He previously studied Physics and was a Siemens and Regeneron STS research finalist for his research on magnetically levitating cars, also working to develop a device that allows paraplegics to walk through electronic muscle stimulation.*
Prior to starting Rito, Nestor worked on incubating companies and leading seed investments in emerging tech at venture capital firm 8VC. While at 8VC he explored frontier companies in many industries, including the semiconductor, robotics, and crypto space.

Multi-Dimensional Weirdness, Watermelon Scams, And Why $\pi e > 8$ Is My Favourite Inequality
by *Andrey Khesin*

One of the most unpleasant parts of buying groceries is that the watermelons are three-dimensional. In fact, the more dimensions that our watermelons have, the more we're paying for tasteless green rind instead of that sweet, delicious middle. We'll cover some curiosities of the world of higher dimensions. For instance in many dimensions most of the world's area is near the equator, most directions are orthogonal, and a sphere between some spheres in a box can be much bigger than the box itself! Come and see these mind-blowing examples for yourself and see why the last one is only true because $\pi e > 8$

About the lecturer: *Andrey has been at SigmaCamp since the very beginning. He is currently working on his PhD in Math at MIT. He is always open to chat about math, physics, or computer science! At SigmaCamp, Andrey usually runs the semilab "From A to B", the oobleck workshop, and the Mafia and Hanabi evening clubs. Additionally, he greatly enjoys square dancing and contra. He will try to find time to play guitar, so if you want to jam together, let him know!*
Andrey's research is in quantum computing and quantum information theory. He is investigating how efficiently can classical computers simulate quantum computation and how much does having access to entanglement help spatially-separated parties trying to measure simultaneously to determine an unknown quantum state

Current Experimental Platforms for Quantum Computing
by ***Alec Douglas***

Quantum computing has recently been throughout the news promising cryptographic revolution, advances in chemical simulation and pharmaceutical computation, optimization problems, and novel material development, such as batteries and superconductors. However, quantum computing as an idea has been around since the 80s, and a scientific goal since 1994.
Why has quantum computing been so hard to achieve? What modern advances have created the surge in interest around quantum computing? How is each competitor approaching the problem?
We will provide a brief overview of what quantum computing is, as well as the general difficulties involved in building a quantum computer. We will then have an in depth look at the most promising modern platforms. We will go over different physical mechanisms, advantages and disadvantages, as well as their current place in the race.
I will cover platforms such as:
Superconducting Qubits (Google, IBM, Intel)
Trapped Ions (Honywell, IonQ)
Neutral Atoms (Pasqual, QuEra)
And More!

About the lecturer: *Alec Douglas is an incoming Harvard Physics graduate student. He plans to focus on the interface of atoms and light, which forms the basis of most modern quantum computing platforms. Alec just finished his undergraduate at Harvard College, where he studied physics. He worked on Quantum Metrology (the study of how to improve sensors using quantum effects) using Nitrogen Vacancy (NV) centers. These are atomic scale defects in a diamond crystal that exhibit unusually robust quantum dynamics due to the stability of the diamond. In addition they can be initialized in a well defined state using optical light. Therefore NV centers can be used to explore quantum dynamics of many quantum bits to long times. Alec worked on new metrological sequences, as well as developing methods for simulating other quantum systems in NV centers using external control magnetic fields.*

Tuesday, Aug 17

Gravity, Holography, and Black Hole Information
by ***Alex Frenkel***

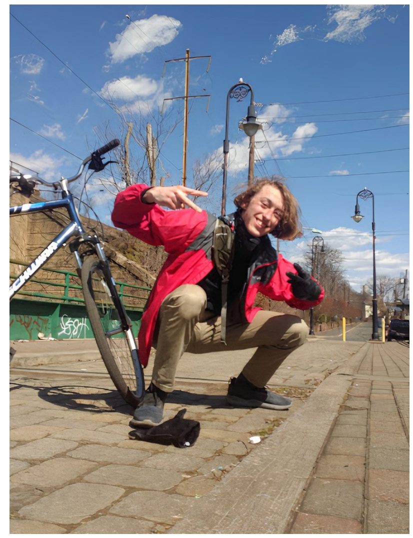
Since the introduction of quantum theory and quantum field theory in the 1930s, physicists have sought a "quantum theory of gravity" - a systematic understanding of how non-deterministic notions of probability and probability amplitudes from quantum mechanics apply to the fluctuating geometry of space and time.

While it's difficult to get any experimental results to guide our search (for example, it might require a particle collider the size of our solar system) there are a few particular puzzles we can latch onto, similarly to how the puzzle of light speed being identical in every reference frame led directly to Einstein's breakthroughs in special and general relativity. One particular puzzle is the "Information Paradox" - in 1974 Hawking showed that black holes evaporate and eventually disappear by emitting particles containing perfectly random white noise. We know with fairly high certainty that black holes exist (we now have pictures!), and we know that in any quantum theory information is conserved. So if I throw my diary into a black hole, what happens to the information contained inside of it when the black hole fully evaporates?

There have been fascinating recent breakthroughs motivated by this problem, in the context of an idea that emerged in the late 1990's dubbed "holographic gravity" - similarly to how our notion of a hologram is a picture that *appears* 3D while being formed by a 2D array of lights, physicists have been able to show that a gravitational system that *appears* D dimensional can emerge from a $D-1$ dimensional quantum system without any gravity. In this talk, I will show the beautiful fractal nature information theory takes on in the context of holographic gravity, and fundamentally new things it has taught us about the resolution of the information paradox and the nature of quantum gravity more broadly.

About the lecturer: *Alex is a second year Ph.D. Student and NSF GRFP fellow at Stanford University, after graduating from UC Berkeley in 2019. His primary research interest is quantum gravity, of which the black hole information problem is an important facet, and specifically the recent idea of geometry emerging as correlation and entanglement in a quantum system. More broadly, he is interested in the structure of quantum states, phase transitions, and systems out of equilibrium.*

Uncanny Valley: When Will Robots Learn To Speak Our Language?
by *Alexander Suponya*



As we ponder the inevitability of a robot apocalypse, scientists are actively developing ways in which computers can help analyze human speech and writing with the help of natural language processing and big data. Using deep learning algorithms like GPT-3 and other digital tools, almost any computer user can generate articles and stories which, on a surface level, appear to have been written by a human being. Will there ever be a robot Shakespeare? Or instead, a robotic Dr. Watson — one who can help explain how people use language among themselves?

About the lecturer: *Alexander is a third-year SigmaCamp counselor and a rising sophomore studying biomedical engineering and computer science at Rutgers University. He has worked at Sigma as a T.A. for Prof. Andrei Antonenko's Constructing a Language semilab in 2019, and is committed to maintaining SigmaCamp's linguistics content. A NACLO veteran and avid conlanging enthusiast, Alexander is working to revive the pure Linguistics club at Rutgers, and will be helping Dr. Christiane Fellbaum on revamping her WordNet semantics project. Outside of linguistics, Alexander is researching the effects of histone modification on neural plasticity in the auditory cortex, and is learning Mandarin and Cantonese.*

Mind-Altering Substances: Chemistry and Physiology
by ***Tim Pinkhassik***

We have all heard of psychoactive substances, and most of us have used them: caffeine is an extremely popular stimulant. Mankind has known of these substances for millenia, and more than a few religions use these substances as a sacrament. But what are these mysterious chemicals? What makes them different than other bioactive molecules? Who was Alexander Shulgin, and has the CIA's MK Ultra program really ended? We will explore several classes of substances and elucidate their mechanism of action, as well as look toward their potential beneficial applications and many dangerous consequences.

About the lecturer: *Tim has been coming to Sigma Camp since 2016; this is his first year as a counselor and he is really excited about it! He is mainly interested in synthetic organic chemistry and supramolecular chemistry. He is also interested in electrical engineering and physics. Tim is on school's debate team and runs school chemistry club. He also loves science fiction and is really interested in history.*

Growing Hearts in a Dish - Far Future or Reality?
by ***Arina Nikitina***

The concept of regenerative medicine - treating damaged tissues with cells reprogrammed from patient's own skin - has been around for decades, but we still use human donors for transplantation, instead of growing a new heart from scratch. In this lecture you will learn about the main problem of regenerative medicine and the current state of the field. I will also explain how adult cells can be "reset" to their embryo-like state and how these reset cells can be grown into any tissue type, including brain, liver, heart, pancreas and many more. As a bonus I will show footage of beating heart cells grown in my lab!

About the lecturer: *Arina Nikitina is a PhD student studying bioinformatics at Georgia Tech. Her research is focused on metabolism of induced pluripotent stem cells and the changes it undergoes once cells commit to the cardiac phenotype. To answer this question she uses mass spectrometry imaging and computer vision algorithms, so her time is split between growing cells in a wet lab and programming in Python. In her free time she plays guitar in the streets of Atlanta, leads her own YouTube vlog and does ballroom dancing.*

Wednesday, Aug 18

Bernouilli Calculus
by *Alex Kontorovich (via Zoom)*

Johann Bernoulli, one of the world's first "AP Calc" students, learned the subject from its co-inventor, Gottfried Wilhelm von Leibniz, and passed it down to his prized pupil, one Leonhard Euler. But somewhere along the way, Johann discovered a rather unusual method for producing certain fascinating formulas that look, at least at first, like black magic. We will discuss some of these incantations, and see where they lead

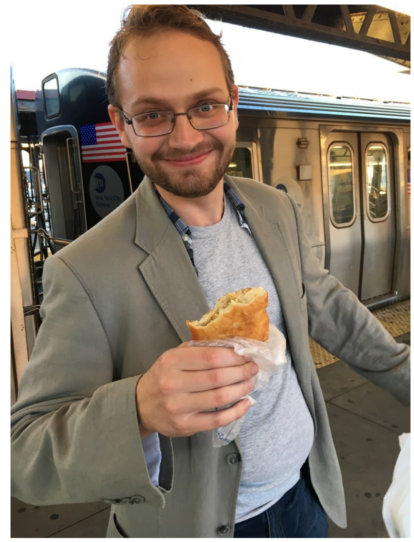
About the lecturer: *Alex Kontorovich is a Professor of Mathematics at Rutgers University, and the 2020-21 Distinguished Visiting Professor at the National Museum of Mathematics. He received his PhD from Columbia in 2007, and held positions at Brown, Stony Brook, the Institute for Advanced Study in Princeton, and Yale, before moving to Rutgers.*

The Physics of Spying – the Cold War And Beyond
by *Gil Refael (via Zoom)*

Simple physics played a big role in the struggle between the superpowers of the 20th century. My talk recount some of the major stories, principles and personalities, from the Fermi back-of-the-envelope perspective. We will touch upon low-tech bugs to stealth planes and submarines. Security clearance not required.

About the lecturer: *Gil Refael grew up in the Tel Aviv area in Israel. He represented Israel in the 1994 International Physics Olympiad, and won a bronze medal (14th place), and a gold medal for the theory part. He studied physics and math at Tel Aviv University (graduated 1997), and continued to study physics at Harvard University, graduating with a PhD in 2003. After two years as a postdoc at the KITP in UCSB, he joined the faculty at Caltech. Gil's research concentrates on the physics of many body electrons systems and quantum computation. His interest in physics problems is channeled to the 'Caltech Physics League' (ph50) class he teaches at Caltech. His research is generously supported by the Simons Foundation and the Packard Foundation. He currently holds the Taylor W. Lawrence Chair of Theoretical Physics.*

Do Neural Networks Dream of DNA?
by *Artem Krantsevich*



Artificial Neural Networks achieved a lot of success and attracted a lot of attention in the last years. Today they can perform cool and impressive tasks like generating photorealistic images or enjoyable music, and at the same time they lead to very practical results like predicting protein folding. But how much agency (if any) should be attributed to the method, capable of tackling such sophisticated challenges? Is it nothing more than a statistical tool or something close to an actual Artificial Intelligence? In this lecture I will discuss how my experience using Deep Learning for my research shaped my perception of Neural Networks, and will argue that developing and applying Deep Learning models might be more about communication, than about math or programming.

About the lecturer: *Artem is a Postdoc in the Applied Math & Statistics Department of Stony Brook University, NY. Pure mathematician by training, Artem did his PhD in Computational Biology and currently he uses mathematical methods to analyze DNA mutations created as a part of immune response. One of his main ongoing projects is developing (and understanding!) Neural Networks to predict potential mutations at the level surpassing current human knowledge. He views Neural Networks as his colleagues, who are extremely talented in finding mathematical patterns, but at the same time have extremely poor communication skills. So, understanding how (and what) Neural Networks "think" about DNA is a substantial part of Artem's work.*

From Cells to Populations: the Biologically Ambiguous Nature of What It Means to be an Organism

by *Lilianne Mujica-Parodi*

In biology, we commonly think of protagonists as operating solely at the level of the organism, which is made of its constituent incomplete parts, and together produce populations. While there are no novels (to my knowledge) about the adventures of a left kneecap, in reality, the distinction between what is a whole–versus just a part–is much less clear than one might think. For example, there are populations (like ant colonies) that are thought to operate as one organism. Likewise, there are cells (like neurons and astrocytes) that also appear to interact as organisms. In this talk, we explore the question of what it means to be an organism, from the perspectives of biology, behavior (e.g., "collective intelligence"), and modeling.

About the lecturer: *Lilianne R. Mujica-Parodi is Director of the Laboratory for Computational Neurodiagnostics, and Professor in Stony Brook University's Department of Biomedical Engineering. She also holds academic appointments in the Laufer Center for Physical and Quantitative Biology, Program in Neuroscience, and Departments of Neurology, Psychiatry, and Physics. In addition, she is Research Staff Scientist and Lecturer in the Department of Radiology at Massachusetts General Hospital and Harvard Medical School (Athinoula A. Martinos Center for Biomedical Imaging). Dr. Mujica-Parodi received her undergraduate and graduate degrees from Georgetown University and Columbia University, respectively, studying mathematical logic and foundations of physics. After her Ph.D. (Niles G. Whiting Fellow), she completed an NIH Training Fellowship in Clinical Neuroscience at Columbia University's College of Physicians and Surgeons. She was subsequently promoted to Assistant Professor there, where she performed research until being recruited by Stony Brook University. She is the recipient of the National Science Foundation's Career Award, the White House's Presidential Early Career Award in Science and Engineering, and the Fulbright Distinguished Scholar Award. Dr. Mujica-Parodi's research extends control systems engineering and dynamical systems to human neuroimaging (fMRI, M/EEG, NIRS, ECOG, MRS, PET), with applications to neurological and psychiatric disorders.*

Thursday, Aug 19

Small Things Cause Big Problems: the Story of a Short Insertion in the COVID-19 Genome
by *Igor Rogozin (via Zoom)*

Many new and unique features of the novel coronavirus SARS-CoV-2 have contributed to its pathogenicity since its apparent origin in 2019, while the rapid analysis and understanding of various functional features of this virus has been crucial in devising vaccines to thwart the resultant COVID-19 pandemic. One of these features is a unique new 4 amino acid insertion in the SARS-CoV-2 Spike protein. This protein promotes entry into human cells. The nucleotide composition of this sequence are dramatically different from the rest of the SARS-CoV-2 genome. In this lecture, we will discuss theoretical and experimental studies suggesting that this insert, comprised of a combination of overlapping functional signals, has allowed SARS-CoV-2 to infect its new host (human) more readily.
This lecture is intended for students who have taken a Biology class in high school.

About the lecturer: *Igor Rogozin has been working on various aspects of molecular evolution and comparative genomics as a research scientist at the National Center for Biotechnology Information NLM, National Institutes of Health (USA). He is also an Adjunct Lecturer in the Foundation for Advanced Education in the Science.*

On an Absolute Truth, a (im)possibility Of Agreeing To Disagree, And Scientific Thinking
by *Mark Lukin*

In our new, tolerant world, all opinions must be respected. Does this mean that every statement is just an opinion, and that different points of view can exist on any issue? Is it true that it is normal for people to agree to disagree? How does all this affect science, which, according to the good old paradigm, seeks to find universal truth? How is a scientific debate different from, for example, a judicial debate? What is the real reason for the execution of Gordano Bruno? What can and what cannot be the subject of scientific research? Are science and religion mutually exclusive?

About the lecturer: *Mark Lukin is a Research Assistant Professor in Pharmacology Department of Stony Brook University, NY. The focus of Mark Lukin's scientific interest are nucleic acids (DNA and RNA) — the molecules responsible for 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. He plans to do some of those experiments in SigmaCamp 2021 with our campers.*

Benford's Law
by *Alexei Borodin*

If one looks at population numbers of all the towns in the United States then one sees that the leftmost digit of those numbers is "1" about 30% of the time and "9" less than 5% of the time. The same happens with electricity bills, length of rivers, and street addresses. This observation is known as Bendford's law.
In this lecture we will investigate this law and explain why it works. We will also discuss how it can be used, for example for detecting fraud in financial documents.
The lecture expects that the students are familiar with high school algebra and logarithms.

About the lecturer: *Alexei Borodin received his Ph.D. in mathematics from the University of Pennsylvania in 2001. He was a professor at Caltech in 2003-2010, and since 2010 he is a professor of mathematics at MIT.*
Alexei enjoys working on problems on the interface of algebra and probability.

What is String Theory & Why Is It Interesting?
by *Martin Rocek (via Zoom)*

I'll try to explain what string theory is and what it's current status is. I will not assume any background in physics.

About the lecturer: *Martin Rocek is am a professor of theoretical physics at the C.N. Yang Institute for Theoretical Physics at Stony Brook. He studies supersymmetry and its mathematical implications; string theory uses supersymmetry a great deal.*