SigmaCamp Lectures

August 14-21, 2022

Lecture dates are subject to change

Contents

Sun, Aug 14: Opening Lecture

Quantum Money: "Information as Currency" Done Right
by ***Andrey Khesin***

From early coins to crypto, a key principle underscores anything that can be used as currency: telling real money apart from fake money. For a good currency, we need a verification procedure such that only the Mint would be able to produce money that is accepted by this procedure. This is why coins are stamped, bills have watermarks, and cryptocurrency has proof of work built into the protocol. However, coins and bills are not impossible to fake, and crypto is useless without its extremely large blockchain. There has never been a mathematically secure unit of currency. . . until now. Using the Shortest Vector Problem and the principles of quantum computing, we have designed a quantum algorithm that produces an unforgeable, verifiable quantum state: quantum money.

About the lecturer: *Andrey has been at SigmaCamp since the very beginning. He is working on my PhD in Math at MIT. He is always open to chat about math, physics, or computer science! At SigmaCamp, he usually runs the semilab "From A to B" and the Mafia evening club. Additionally, he greatly enjoys square dancing and contra. He tries to find time to play guitar, so if you want to jam together, let him know! His research is in quantum computing and quantum information theory. He is investigating what cool cryptographic primitives can be constructed with quantum computers. The most impressive one to date was proving that you can make quantum money.*

Monday, Aug 15

Continued Fractions
by *Nikita Nekrasov*

abstract -WIP

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.*

About the Laws of Nature
by *Mark Lukin*

What do we call "laws of nature"? Do they really exist, or are they just rules of thumb summarizing some of the observations people have made? Are they independent of each other or, perhaps, they form a coherent hierarchically organized system? Are the laws of nature invented by scientists or discovered? Using some examples from chemistry, mathematics and physics, we will try to answer these questions.

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 2022 with our campers.*

Can We Analyze Data While Respecting Privacy?
by *Adam Smith*

Huge collections of personal data are all over the place: tech companies, government agencies, and hospitals, and other organizations collect detailed information about many aspects of our lives. Society would benefit from opening those data sets up for research, but doing that in the most straightforward way would also be disastrous for people's privacy. Can we get the benefits of analyzing sensitive data without the privacy pitfalls? This lecture will explain some of the difficulties with sharing and learning from personal data, and some of the technical tools that computer scientists and statisticians have developed to address the issue. I'll show some ways to attack privacy, some ways to defend it, and also get you thinking of what "privacy" really means

About the lecturer: *Adam is a computer scientist at Boston University, where he is a founding member of the Faculty of Computing & Data Sciences. His areas of research include cryptography and information privacy. He is known, along with Cynthia Dwork, Frank McSherry, and Kobbi Nissim, as one of the co-inventors of differential privacy, for which he won the 2017 Gödel Prize.*

Symmetry Breaking, Superconductivity, and the Higgs Mechanism
by *Alex Frenkel*

Physicists love symmetry - it allows us to import abstract algebra's elegant machinery to simplify complicated problems and deduce powerful results and principles on scales ranging from the Planck length to the span of the universe. Moreover, much of the universe's fundamental interactions arrange themselves into a very symmetric form.

It turns out that symmetry can break. This happens in the rare event that the lowest-energy configuration of a system doesn't respect all of its symmetries: a pencil precariously balancing on its tip will choose a direction to fall, or a nebula moments away from collapse will choose a spot to create a protostar. Ten years ago the Large Hadron Collider unearthed overwhelming evidence for the Higgs Boson - a signature of symmetry breaking in the most fundamental description of the universe's interactions we have to date.

In this talk, I will touch on how physicists use group theory to think about symmetry, and how symmetry breaking leads to fascinating phenomena like superconductivity or endows otherwise massless particles (like the electron!) with mass via the Higgs mechanism.

About the lecturer: *Alex is a third 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.*

Tuesday, Aug 16

TBA
by ***Oleg Gang***

abstract

About the lecturer: *about*

Mathematics of Voting: Does Ideal Democracy Exists?
by ***Alexander Kirillov***

abstract

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.*

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 United States 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.*

Entropy: How to Quantify Uncertainty
by *Boris Barron*

Information theory is perhaps the most beautiful area of mathematics that many never get to encounter. Is it not remarkable that the 'quantification of uncertainty ' has a unique form? That instead of philosophical discussions of 'simplicity' (e.g., Occam's razor) it can be considered rigorously? Information theory provides an approachable way to arrive at entropy and has many applications from machine learning to demography. In this lecture, we will explore information theory concepts from first principles with a focus on building intuition.

About the lecturer: *Boris is working on his PhD in Physics (with a minor in Policy Analysis) at Cornell University. He has a BSc in Biophysics from York University (2017) and MSc in Mathematical and Theoretical Physics from the University of Oxford (2018). He has broad research interests and is presently working on building data-driven models for residential segregation. Throughout his PhD he has been supported by the NSERC PGS-D.*

Wednesday, Aug 17

Can We Hear a Volume?
by ***Yakov Kononov***

abstract

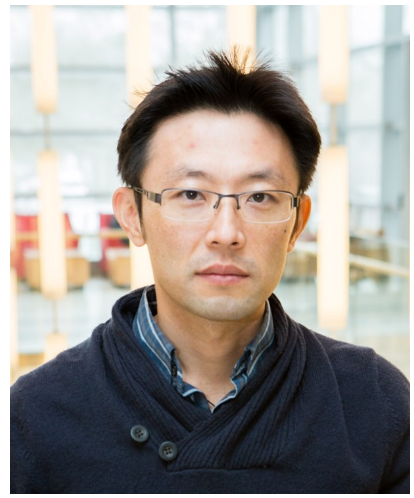
About the lecturer: *Yakov obtained a PhD degree from Columbia University under the supervision of Andrei Okounkov. Currently he is an assistant professor at Yale. His main research area is mathematical physics, in particular various mathematical structures arising in quantum field theory and string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

Relativity Theory: 100 Years After Einstein
by ***Misha Bershadsky***

abstract

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 until 2000. In 2000 he resigned from Harvard University and joined a private company.*

Unmanned Planes: How One Trains AI For Aerial Dogfights?
by *Jaime Ide*



Autonomous vehicles will revolutionize the way transportation will be done in the future, going from the ground to the skies, from the east to the west. Artificial intelligence (AI) is a key technology in this revolution, and it will allow computer vision, predictive modeling, and decision-making on these vehicles. In this lecture, I will talk about AI algorithms capable of piloting an F-16 in simulated air-to-air combat (dogfight) and defeating a graduate of the US Air Force's (USAF) F-16 Weapons Instructor Course in match play. Moreover, I will describe how concepts from brain sciences can inspire new solutions to train autonomous agents more efficiently.

About the lecturer: *Jaime Ide is a Mechatronic engineer that became a Computational Neuroscientist and Data Scientist. He got his Ph.D. in Artificial Intelligence from the University of Sao Paulo, Brazil (2005), and received his training in MR imaging at the University of Pennsylvania (2007-2008) and Yale University (2008-2010). Currently, he is an Artificial Intelligence (AI) Research Engineer at Lockheed Martin, developing and applying AI and Machine Learning methods in unmanned aircraft and cognitive systems. Broadly, he is interested in the application of Bayesian methods, computational modeling, and machine learning in cognitive neuroscience, neuroimaging, and decision-making, as well as in real-world predictive and reinforcement learning problems. He is passionate about robotics, chess, and table tennis.*

How Smart Can a Brain In a Dish Get?
by *Arina Nikitina*

Scientists are becoming better at engineering various tissues in a dish, however these organs are mostly really small due to vascularization problems and thus are called organoids. Organoids capture the real organ function and structure, but can be maintained separately from the body and used for drug testing and studying the original organ development. As such, recently brain organoids became a popular model for studying neurodegenerative diseases such as Parkinson's, Alzheimer's and Huntington's. Come to my lecture to learn about how long can these organoids survive in a dish and how similar to a real human brain can they get!

About the lecturer: *This is going to be my fifth time being a counselor at Sigma. I love this place; although sometimes I can seem moody - don't worry, it's just my normal face. I am a graduate student at Georgia Tech's Bioinformatics PhD program. Back in Russia I taught math to students in grades 5 - 11. Aside from my work and studies, I love music; every year at Sigma I try to find like-minded people to perform as a rock-band at the Talent Show!*

Thursday, Aug 18

Making and Breaking Systems: Mathematical Ideas in the Visual Art
by *Masha Ryskin*

The presentation will address themes common to both art and mathematics. The talk will begin with historical and contemporary examples of the use of mathematical concepts in visual art, both as a means of representation and as independent themes, followed by a discussion of the artistic process. I will talk about my work as well as the work of my collaborator, Serge Marchetta, who will join me to describe his geometry-based projects

About the lecturer: *Masha Ryskin is a Russian-born multidisciplinary artist based in Providence. She received an academic art education in Moscow, Russia, followed by a BFA in Printmaking from RISD and an MFA from the University of Michigan. She is currently an Associate Professor at Rhode Island School of Design.*
Ryskin works in a variety of media, including drawing and painting, printmaking and installation. Her work, exhibited nationally and internationally, is concerned with a sense of place as a metaphor for memory, history and the passage of time. She has participated in a number of artist residencies, both in the US and abroad, and received many grants and fellowships, including a Fulbright Fellowship to Oslo, Norway.
In addition to her individual practice, Ryskin frequently collaborates with other artists, musicians and dancers and works as a designer. Her work has been reviewed and published in a variety of publications, including The New York Times.

Are All Infinities the Same?
by ***Sofya Raskhodnikova***

Are there more integers or real numbers? computational problems or computer programs? We will learn how to compare sizes of infinite sets and find out about problems that cannot be solved by computers, no matter how sophisticated computers get.

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.*

TBA
by ***Richard Granger***

abstract

About the lecturer: *Richard Granger received his Bachelor's and Ph.D. from MIT and Yale. He is a Professor at Dartmouth with joint appointments in the Department of Psychological and Brain Sciences, the Thayer School of Engineering, and the Cognitive Science Program; he directs Dartmouth's interdisciplinary Brain Engineering Laboratory (brainengineering.org), with publications and patents ranging from computation and robotics to cognitive and basic neuroscience. He advises multiple technology corporations and government research agencies, is co-inventor of FDA-approved devices and drugs in clinical trials, and has been the principal architect of a series of advanced computational systems for military, commercial and medical applications.*

How do Mind Altering Substances Work?
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 is an undergraduate student at University of California, Berkeley. He has been coming to Sigma Camp since 2016. He really enjoys chemistry, and is am also interested in electrical engineering. Tim's undergraduate research is in organometallic chemistry, particularly in the chemistry of iridium catalysis. In his free time, he plays piano, guitar, and balalaika. He also enjoy cooking.*

Superconductivity: Exotic Macroscopic Properties from Simple Models
by ***Alec Douglas***

5 Nobel prizes have been awarded for the study of superconductivity: 1913, 1972, 1973, 1987, and 2003. Yet we still don't have superconductors in our homes. What makes superconductivity so challenging to study, why don't we have it commercially, and what directions are people looking now? I will go over a brief history of superconductivity, introduce the underlying physical mechanisms, and demonstrate superconductors' exotic properties, such as levitation, experimentally.

About the lecturer: *Alec is a Harvard Physics Graduate student. His PhD work is related to simulating exotic materials, such as high temperature superconductors by trapping and observing the collective behavior of many atoms tapped by light. In particular we can simulate the behavior of insulating materials by mapping the behavior of electrons hopping around in a crystal of atoms to atoms hopping around in crystals made of light.*
When he is not in the lab, Alec enjoys biking, rock climbing, video and board games.

Friday, Aug 19

TBA
by *Olga Trostyanskaya*

abstract

About the lecturer: *about*

How Albus Dumbledore's Philosopher's Stone Gave Rise to Modern Chemistry
by *Mark Lukin*

This will be a new version of the old lecture that I gave during 2012 SigmaCamp. I will tell about history of Alchemy, and about its gradual transformation into modern Chemistry.

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 2022 with our campers.*

AD: the Secret Sauce Behind All Machine Learning
by *Helmut Strey*

abstract

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.*

Levitating Cars - the Future of Transportation
by *Nestor Tkachenko*

For years we've been hearing exciting ideas for transportation, from the Hyperloop and Maglevs to flying cars, but most have fallen short due to energy and cost concerns. In this lecture we discuss Eddy current levitation, a technology with the potential to provide a cheap and efficient mode of transit with the possibility of revolutionizing transportation forever with flying cars. This lecture will discuss how existing and proposed technologies are falling short given urban engineering considerations. We will also do a deep dive into the physics behind the commercial viability of Eddy current levitation, explore what a future with this technology looks like, and possibly even have a live demonstration.

About the lecturer: *Hello, I'm Nestor and I'm very excited to return to in-person Sigma as a counselor again! My primary work is as a professional Dogecoin investor, but on the side I'm a founder of a food robotics startup called Rito which I dropped out of Harvard to start. I also love philosophy, iced lattes, and hot takes.*
I am personally very interested in physics, technology, and entrepreneurship. I do everything from building burrito-making robots and creating levitating vehicles, to shocking people to make them dance.
I love meeting new people and enjoy understanding how others think, and always appreciate interesting discussions on any topic, from questions of morality to cultural trends, so feel free to talk to me about anything!

Saturday, Aug 20

Living on Mars on Earth and on Earth on Mars
by ***Marina Polonskaia***

"The next important step in the evolution of life is that humankind develops a space-based civilization, ultimately becoming a multi-planet species. I think it is incredibly important that humanity is out there exploring the Solar System and that we have a self-sustaining base on Mars." (Elon Musk)
How do we build a space colony? Can we re-create nature? Can humans handle a trip to Mars? Will we ever be able to live permanently in space or on other planets? Or, our trips to Mars should and will remain the job of robots?
We will discuss the history and future of the man-made closed ecological systems created to sustain human life, including Biosphere 2, MELiSSA, and the BIOS-1, BIOS-2, and BIOS-3 projects.

About the lecturer: *Marina Polonskaia received her B.S. in Physics and Physics education and M.S. and Ph.D. in Biophysics from Krasnoyarsk, Russia. Her postdoctoral training was in Molecular biology and Oncology in UIC (University of Illinois at Chicago). Later she worked as a research scientist at HMS (Harvard Medical School) and SBU (Stony Brook University). Since 2004 Marina is running an academic enrichment program for k-12 students, SchoolNova. She has extensive experience in teaching biology to students during summer months in Russia and USA. She was among the group of people who opened SigmaCamp back in 2012 and have been a full-time faculty or visiting lecturer almost every year since.*

What is Life?
by *Aleksey Tkachenko*

Erwin Schroedinger was one of the founding fathers of Quantum Mechanics, famous for his hypothetical cat. In the middle of World War II, in 1943, he gave a lecture "What is Life?". I borrowed both his title and some of his ideas and will talk about life from point of view of a physicist. I will ask, but not necessarily answer a number of questions about the life, universe and everything:
How is the living world different from the rest of the physical world?
How could life emerge?
And, last but not least: What is the purpose of life?

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. At SigmaCamp, Alexei is responsible for the tastiest of all the semilabs, called "Thermal Physics in the Kitchen".*

Arctic Circle Theorem and Limit Shapes
by *Sasha Abanov*

In how many ways can one densely tile a chessboard by dominos of the size 2×1?
Starting with this problem, well-known in physics and combinatorics, we will discuss a limit shape phenomenon — the appearance of a most probable macroscopic state in random systems. This state is usually characterized by a well-defined geometric boundary separating frozen and liquid spatial regions. We will talk about the Arctic Circle Theorem — a beautiful result in the domino tiling problem and will see how one can think about the limit shape problem as of the optimal motion of a quantum fluid.

About the lecturer: *Sasha is a Professor in Department of Physics and Astronomy and a Deputy Director of the Simons Center for Geometry and Physics 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.*

Poisons
by *Eugene Pinkhassik*

abstract

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.*