MATSCIENCE LOCUS

IMSc Newsletter

July 2024 - February 2025

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It's with great pleasure that I introduce this inaugural print anthology of the IMSc newsletter. This collection is a wonderful reflection of the academic vibrancy and pioneering research that has always defined The Institute of Mathematical Sciences.

For over six decades, IMSc has proudly stood as a hub for fundamental inquiry in mathematics, theoretical physics, and computer and computational sciences. Just as central to our mission, our commitment to outreach is deep and abiding. We firmly believe that sharing our scientific knowledge is not just our duty, but a genuine privilege. This anthology embodies that belief, crafted to bring the cutting-edge work and insightful perspectives from our institute to a broader audience, with a special emphasis on inspiring young minds.

As you turn these pages, I truly hope you'll not only appreciate the depth and breadth of our research but also sense the sheer passion that drives our colleagues. May this anthology ignite curiosity, foster new understanding, and highlight the importance of scientific exploration. We're thrilled to share this initiative with you, and we eagerly anticipate continuing our journey of exploring our work and outreach for many years to come.

- V. Ravindran
Director, IMSc

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IMSc Outreach
Email: outreach@imsc.res.in

Newsletter webpage: https://www.imsc.res.in/outreach/newsletter/
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The Institute of Mathematical Sciences,
IV Cross Road, CIT Campus, Taramani, Chennai 600 113
Phone : 91-44-22543100

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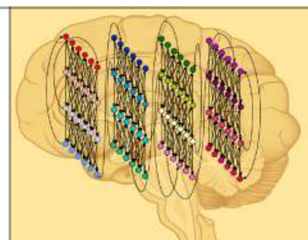
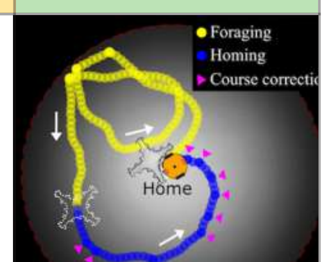
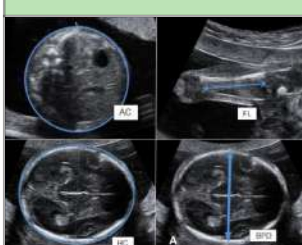
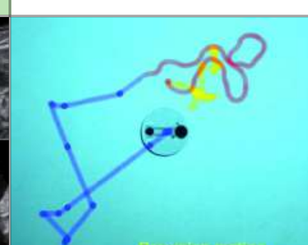
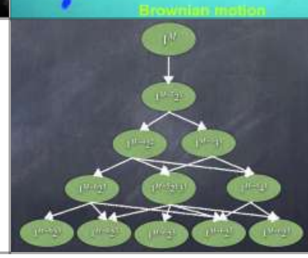
RESEARCH HIGHLIGHTS

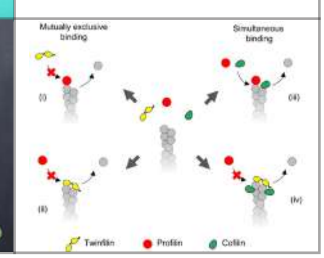








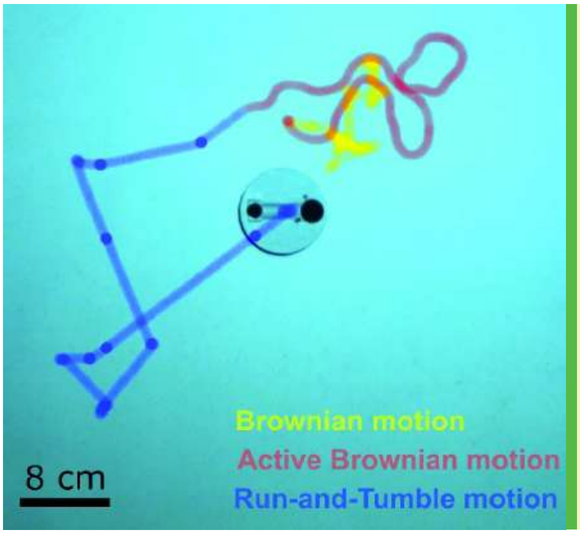




Akshay Sanjeev

Breathing life-like motion into a self-propelling robot

◆ *Bharti Dharapuram*



A recent study programmed a palm-sized robot to perform motions ranging from passive (Brownian) to active dynamics (Active Brownian and Run-and-Tumble). Shown in the image are the tracks of the robot reconstructed from overhead video footage, which was analyzed by the researchers.

Many bacteria use their energy to perform complex behaviours that allow them to move toward food while avoiding harmful repellents. The dynamics of such active systems are governed by rules in physics that can be adapted for human applications. A recent collaborative study tuned a palm-sized robot to perform a range of motions that can allow us to study active dynamics in the lab.

The research group behind the study includes Somnath Paramanick and Nitin Kumar from the Indian Institute of Technology (IIT) Bombay, Arnab Pal from the Institute of Mathematical Sciences, Chennai, and Harsh Soni from IIT Mandi.

Researchers programmed the robot to control the velocities of its two independently moving wheels and mounted it with sensors to detect light. Based on these signals, the robot can exhibit various dynamics, including those characteristic of living systems. The researchers showed that this robot switches between different kinds of motion, avoids obstacles and navigates towards a target by sensing a gradient in light.

Active entities consume energy to perform work and are ubiquitous in nature. These can be bacteria using flagella to propel themselves, a protein moving through a cell, or a bird flying in the sky. Scientists are interested in the dynamics of these self-propelling particles to understand emergent phenomena such as complex collective behaviour or self-evolved optimal navigational strategies. However, it is difficult to manipulate living systems in the lab, which can be a limiting step in understanding the underlying principles of such behaviour.

Therefore, when Kumar approached Pal with affordable and easily maneuverable robots, it presented many possibilities. Pal's research interests are in understanding search strategies across various scales. These range from repair proteins looking for DNA mutations to fix, homing pigeons traveling back to their nest, or a computer algorithm scanning a tree of possibilities in search of a solution. Pal and his colleagues were motivated to build a robust in-house system to study such behaviour using Kumar's robots.

"First, we wanted to see if it (the robot) actually performs different types of motion," Pal says. The researchers did this by programming the robot so that signals reaching its wheels could elicit different kinds of motion. "By adding stochasticity to the signals, we have been able to cover many different classes of stochastic processes," he says. They replicated Brownian motion seen in diffusion of gas molecules, run and tumble motion used by bacteria to align and move in a medium, and an active form of Brownian motion observed in the motion of Janus particles. After demonstrating a variety of passive and active dynamics, the researchers programmed the robots to switch between these movements using environmental cues. The robot efficiently navigated to a target by avoiding obstacles using infrared sensors and orienting itself based on differences in light intensity.

The next step would be to see whether this robust lab based system can offer valuable insights into the physics of homing – the incredible ability to navigate back to a home or a base from unfamiliar places, a behavior which is surprisingly ubiquitous across the animal kingdom, Pal says.

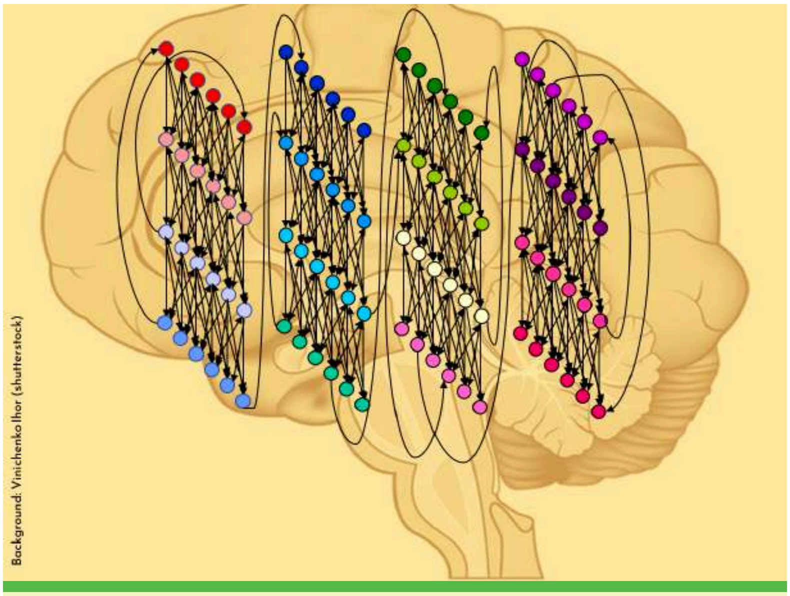
July 31, 2024

Reference: Paramanick, S., Pal, A., Soni, H., & Kumar, N. (2024). Programming tunable active dynamics in a self-propelled robot. The European Physical Journal E, 47(5), 34.

https://doi.org/10.1140/epje/s10189-024-00430-x

A blueprint for brains

◆ *Bharti Dharapuram*



Pathak et al's new study proposes a novel structural organization for the brain, schematically represented above. Here, densely connected brain regions are arranged into sequential layers with the greatest connectivity between regions in adjacent layers. This allows for an interplay between distributed and sequential modes of information processing.

Scientists have discovered that common design priciples underlie the connections within brains of varying complexity. This map of brain organization can help us understand the routes taken to process information, which allow organisms to respond to the world around them.

A recent study from the Complex Systems and Data Science (CSDS) research group at The Institute of Mathematical Sciences, Chennai has come up with a robust method to detect hierarchical organization in complex networks. Applying this metric to worm, macaque and human brain networks, the team discovered common patterns of brain organization. They found a signature of 'modular hierarchy', where the brain network is organized into individual well-connected groups, each of which is made up of layers with sequential connections. This common blueprint suggests that animal brains may process information in parallel, while also integrating outputs across them.

The brain can be seen as a network, known as a connectome. Its smallest unit (node) is a nerve cell or a brain region, and the connections between them (edges) are synapses or neural tracts between regions.

"Studying the brain as a network is a mathematical tool to find regular patterns in its seemingly entangled wiring," says Anand Pathak, the lead author of the study. The structure of this network can be described using two useful properties. *Modularity* is related to the grouping of nodes, where nodes within a group are more well-connected to each other than nodes in other groups. *Hierarchy* is another property where nodes or groups are arranged in a way that the output of one level serves as an input to the next. However, the measurement of this property in brain networks is often obscured by 'shortcuts' – connections between very different hierarchical levels, says Sitabhra Sinha, an author of the study who leads the CSDS research group.

To detect these structural properties, the team devised an index, which measures hierarchy as the extent of connectivity between adjacent layers in a network. They used a computer algorithm to search across various rearrangements of nodes and layers to find one that maximizes this index for a given network.

"We were surprised to discover that the networks did not just exhibit a hierarchical structure, but that these hierarchical levels were embedded within modules," says Shakti Menon, an author of the study. "Modular structure has been well studied in the brain but the fact that it is intertwined with the hierarchical structure is a fresh new insight," says Pathak. Another surprising aspect was that this template is shared between the worm *Caenorhabditis elegans* with about 300 nerve cells and macaque and human brains with billions of nerve cells, Pathak adds.

"A network that is modular in nature is optimized for distributed processing, while the flow is more sequential in a hierarchical network," says Menon. "Despite their vast differences in complexity, all of these brain networks are organized to reap the benefits of two very different types of information processing mechanisms." These insights support our current understanding and intuition about how the brain functions. From this study, we know that adjacent layers in a network hierarchy are, in fact, neighbouring regions in the brain. And their sequence of arrangement matches our current knowledge of how information flows in the brain.

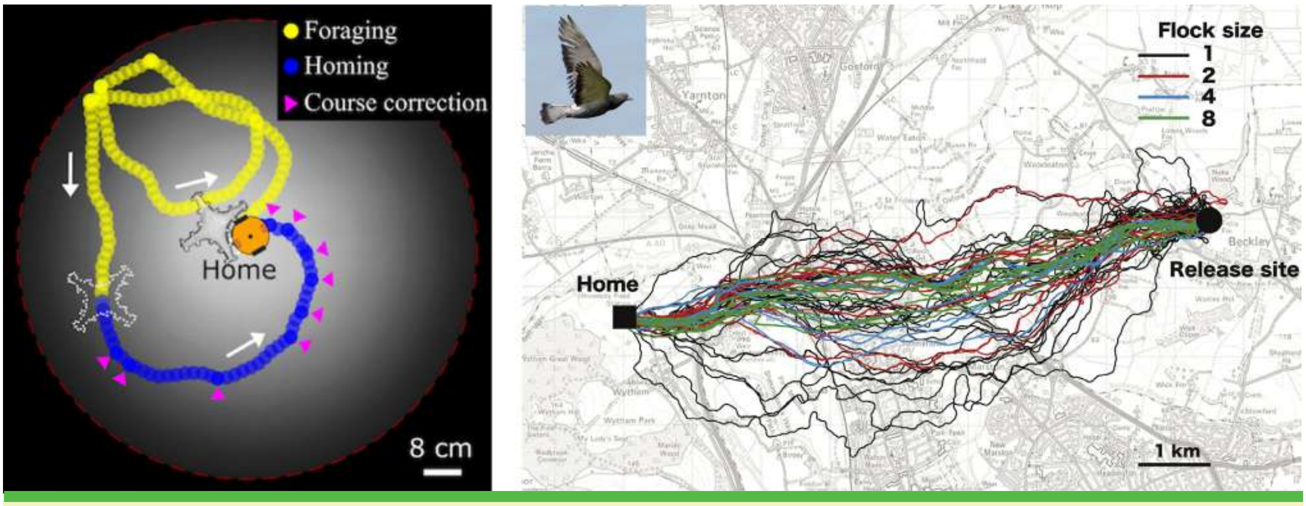
This method would be useful for understanding the structure of other complex networks with similar properties, says Sinha. For example, it can help us tease apart the different trophic tiers in complex food webs and understand the structure of animal social networks, he adds.

July 31, 2024

Reference: Pathak, A., Menon, S. N., & Sinha, S. (2024). A hierarchy index for networks in the brain reveals a complex entangled organizational structure. Proceedings of the National Academy of Sciences USA, 121(27), e2314291121. https://doi.org/10.1073/pnas.2314291121

Are we there yet? Uncovering universal principles of homing in the lab and nature

◆ *Bharti Dharapuram*



Researchers studied the statistical principles of homing by programming a foraging robot (left) in the lab to mimic the noise in the flight trajectories of homing pigeons (right; main image from Sasaki et al. (2022) under a CC BY-NC-ND license, inset image by David McCorquodale under a CC by 4.0 license).

Homing is ubiquitous in nature, where animals traveling in search of food, mates, or other resources find their way back home using environmental cues. Tracking the motion of a foraging robot in the lab, researchers have discovered that homing time does not increase beyond a critical level of noise in the search process. It is thus suggested that course corrections in the homing path do not necessarily increase the efficiency of homing beyond this criticality. This statistical basis of homing behaviour was described by a collaborative team of researchers using experiments, simulations, theory and animal tracking data.

Many animals show homing behaviour, where they reorient themselves to make course corrections in their path as they travel home. For example, a dung beetle rolling a ball of dung towards its destination performs a 'dance' on top of it to reorient itself in response to its surroundings. While scientists have probed the biological mechanisms driving homing behaviour, the statistical principles underlying its dynamics are not well understood. Since it is not possible to systematically vary parameters of animal motion in their natural habitat, lab-based robots offer an alternative tunable system to investigate homing dynamics. Additionally, movement trajectories of animals hold clues about how noise in the search paths influences the homing process. These approaches were used by researchers from the Indian Institute of Technology (IIT) Bombay, The Institute of Mathematical Sciences, Chennai (IMSc) and IIT Mandi to study the physics of homing.

The research team programmed a robot to perform active dynamics, where it leaves a home location to find a target object and returns home by sensing light intensity. "The beautiful thing about the robot is that it can be programmed to create a wide spectrum of stochastic motions. We engineered it to perform course correction, which is what homing animals do using environmental cues," says Arnab Pal from IMSc, an author of the study. An important aspect of their study was identifying orientation as the parameter to reset during course correction. "We wanted to understand the statistical properties of the time it takes to come back home with regard to the number of course corrections," Pal says. They found that homing time increases with randomness in the robot's orientation but remains constant beyond a critical value. This determines a critical frequency of course correction, beyond which homing efficiency does not improve. The researchers reproduced these findings using computer simulations of active Brownian particles, and explained them using a simple theoretical model from first principles.

Strikingly, the researchers were able to use these theoretical predictions to explain the real world flight trajectories of homing pigeons. "A single homing pigeon makes many mistakes but a flock with many individuals has less error," Pal says. They found that flock size influences how the orientation of the flight path varies through time, as predicted by their model. Varying the noise in the robot's wheels can mimic the behaviour of homing pigeons of different flock sizes. "There is a critical level of noise beyond which homing time does not change, which tells us that animals can only make mistakes until a certain limit," he adds.

Looking ahead, the research team wants to pursue many different ideas related to homing behaviour. "Along with our collaborators, we want to see how the robot responds to obstacles in its homing path," Pal says. While ecologists and statistical physicists often work in isolation, the research group's interest lies in the intersection and bridging the gap using tools ranging from physics to ecology. "The motivation is to study the navigation of foraging living entities and learning in homing paths in an attempt to reveal and explain universal statistical patterns."

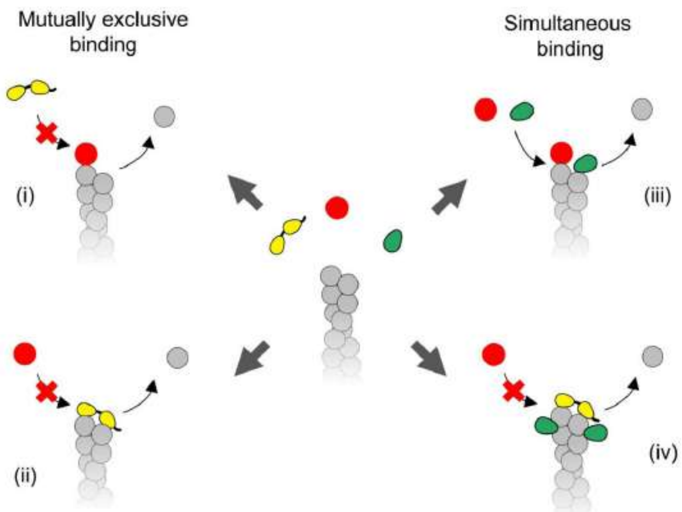
August 19, 2024

Reference: Paramanick, S., Biswas, A., Soni, H., Pal, A., & Kumar, N. (2024). Uncovering universal characteristics of homing paths using foraging robots. PRX Life, 2(3), 033007.

https://doi.org/10.1103/PRXLife.2.033007

Blending theory with experiments reveals multiplayer actin dynamics

◆ *Bharti Dharapuram*



Using cutting-edge experiments and theory, researchers have devised a model of multi-protein interactions (above) that regulate actin depolymerization. Image adapted from Arya, Choubey & Shekhar (2024) and shared under a CC by 4.0 license.

Actin is a protein that makes the scaffolding of our cells and organelles, helping them move and change shape. To do this, an actin filament changes in length by losing or stringing together subunits mediated by many regulatory proteins. While we know the regulatory function of single proteins, we do not fully understand how they collectively orchestrate actin dynamics.

Combining single-molecule experiments with theoretical models, researchers have developed a neat interaction map of proteins regulating actin depolymerization. Working with three regulatory proteins, they discovered previously unknown interactions and found that pairwise interactions explain their collective influence on actin disassembly. The study was carried out by the collaborative efforts of Ankita Arya and Shashank Shekhar from Emory University and Sandeep Choubey from The Institute of Mathematical Sciences, Chennai.

A cell responds to changes in its environment by breaking down and reassembling actin filaments to remodel its structural framework. Profilin, twinfilin and cofilin are three important regulatory proteins that mediate actin disassembly by binding to its barbed end. While we have an understanding of their one-way interactions with actin, traditional methods are limiting when studying their simultaneous transient interactions. In a new study, researchers used microfluidics and fluorescence imaging to make measurements of actin depolymerization rates by adding regulatory proteins both singly and together. They tested hypotheses about competitive or cooperative protein binding via an effective dialogue between theory and experiments.

The researchers found that profilin and cofilin can simultaneously bind to actin accelerating its depolymerization rate. Twinfilin competes with profilin for actin binding, while assisting cofilin in binding to the sides of an actin filament. Finally, they showed that these pairwise relationships can explain actin dynamics in the presence of all three regulatory proteins in a bottom-up manner.

“Our world-view is that you can understand living matter by using simple mathematical laws. We use ideas from statistical mechanics and statistics to understand these systems," says Choubey, explaining his motivation. The ideas for this study developed over conversations with Shekhar, whose research group uses lab experiments to understand the long-standing mystery of how cells control actin remodeling. "Actin is a nice model system because you can make high-throughput measurements of changes in the length of hundreds of filaments in a precise quantitative manner. Without these lab measurements, one really cannot test models," Choubey says.

They proposed simple models of competitive or cooperative interactions between regulatory proteins and tested predictions of actin depolymerization rates against experiments. "There is a dialogue between theory and experiments – you build a simple model, make a prediction and test it in experiments. If it doesn't match, you come back and modify your model. You can falsify models to get to the right mechanism," Choubey explains. "You can think of the modeling approach as a different microscope, an alternative method of observing what is happening within cells."

This approach proved useful as they found evidence that multi-component interactions with actin are often contrary to what is expected from single protein studies. They also found that pairwise interactions between regulatory proteins are enough to explain their collective role in actin depolymerization. "This bodes well for the future. If we can map out pairwise interactions, we may have a way to understand what happens at the cellular level," Choubey says.

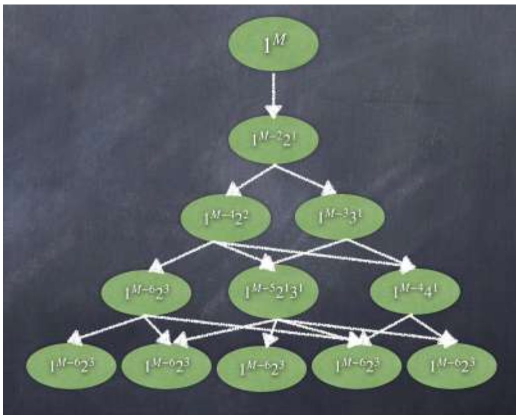
Looking ahead, the group is working on a generalized theoretical framework for interpreting such high-throughput datasets. "We want to develop a framework for precision measurements, which is like a theory of the experiment that you can test and falsify," Choubey says.

August 26, 2024

Reference: Arya, A., Choubey, S., & Shekhar, S. (2024). Actin filament barbed-end depolymerization by combined action of profilin, cofilin, and twinfilin. PRX Life, 2(3), 033002.
https://doi.org/10.1103/PRXLife.2.033002

A new framework to study rare events in aggregation

◆ *Bharti Dharapuram*



A new theoretical framework to study rare events in aggregation uses a model that specifies how clusters form and evolve when particles collide with each other.

Researchers have developed an analytical framework for studying rare events in aggregation, a phenomenon that drives the formation of clouds and coagulation of proteins. This work was carried out by R Rajesh and V Subashri from The Institute of Mathematical Sciences, Chennai and Oleg Zaboronski from the University of Warwick. Their findings can be used to study diverse phenomena in environment and climate, biology, and materials science.

Aggregation occurs when particles collide and coalesce to form clusters. Existing theory describes the mean number of clusters at a given time but does not predict the probability of their occurrence and evolution over time. The authors used a branch of probability theory dealing with rare events, known as large deviation theory, as the framework of their study. They modelled a collection of particles and how their mass distribution evolves over time due to aggregation events. They considered three scenarios, which differ in how the rate of collisions depends on the colliding masses. For each of these, they derived the probability of occurrence of rare events and their most probable path, verifying their predictions using simulations.

"Aggregation has been studied using a mean field rate equation called the Smoluchowski equation for a long time," Subashri says. In one of the scenarios where the equation has been applied, particles coalesce to form a gel that drastically changes the nature of their interactions. "The Smoluchowski equation predicts gelation, but does not capture these post-gelation dynamics," she adds, emphasizing an important gap addressed by their study.

"We start with a master equation for a probability distribution, which describes how particles enter a configuration and how they exit it," Subashri says about the analytical process. When the system is modelled several thousands of times it follows a typical path, but the group was interested in rare events that deviate from the usual. "It is hard to find the probability of rare events since there aren't many established methodologies to do it," she adds. The group used path integral methods to model these probabilities. "We had to do some modifications when gelation comes into the picture," she adds. Results from decades ago gave them the clues to make the necessary adjustments.

"This is a step forward because it provides a new method by which one can analyze aggregation," Subashri says. Their findings may allow us to study rare aggregation events, such as extreme climatic events and neurodegenerative diseases, with important human consequences. In such applications, we are modeling a physical system, which may not be that simple, Subashri cautions. "The current analytical framework provides us a guideline to proceed further."

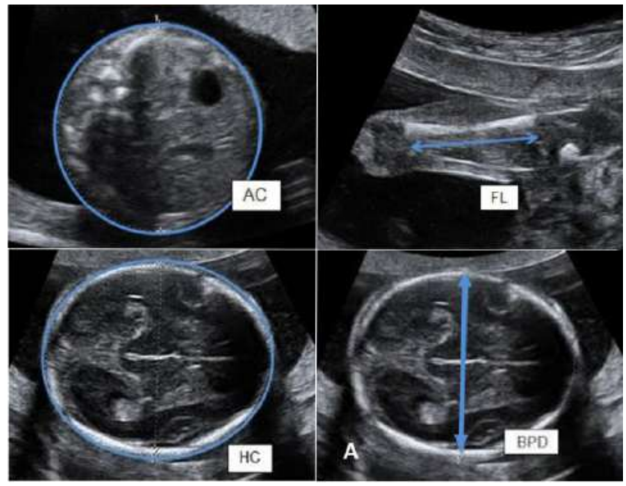
October 7, 2024

Reference: Rajesh, R., Subashri, V., & Zaboronski, O. (2024). Exact calculation of the probabilities of rare events in cluster-cluster aggregation. Physical Review Letters, 133(9), 097101. https://doi.org/10.1103/PhysRevLett.133.097101

A new model reveals the weight of a newborn from routine pregnancy scans

◆ *Bharti Dharapuram*

$$X = Ae^{-e^{-c(t-t_0)}}$$



Researchers have developed a model to predict foetal growth using the Gompertz formula (bottom left), which can be used to accurately estimate the weight of a baby at birth. The model uses four foetal measurements (panels on the right) from routine ultrasound scans as input. AC: abdominal circumference, FL: femur length, HC: head circumference, and BPD: biparietal diameter. Images from https://doi.org/10.1016/j.medici.2018.01.004 and https://doi.org/10.1007/s13224-021-01574-y shared under a CC by 4.0 license.

Routine ultrasounds of an expectant mother can now be used to predict the weight of her newborn baby using a growth model developed by a recent study. This allows for early interventions during pregnancy as weight deviations linked to risks of neonatal complications and stillbirth can be detected in advance.

Using measurements from at least three routine ultrasound scans across hundreds of pregnant women, the researchers modeled the growth of a foetus over time. They used this to estimate foetal measurements at term, which in turn were used to predict the weight of a baby at birth. Their model is simple and intuitive in capturing foetal growth and more accurate than existing models despite needing lesser data. In the future, this model can be incorporated into ultrasound machines and its predictions used in the clinical assessment of expectant mothers.

The study was carried out by Chandrani Kumari and Rahul Siddharthan of The Institute of Mathematical Sciences (IMSc), Chennai, in collaboration with Uma Ram, obstetrician and gynaecologist at the Seethapathy Clinic and Hospital, Chennai, Leelavati Narlikar from the Indian Institute of Science Education and Research (IISER), Pune, and Gautam Menon from Ashoka University, Sonepat NCR, formerly at IMSc.

During pregnancy, foetal development is monitored at regular checkpoints using ultrasound scans. These measure several linear dimensions of the foetus including abdominal circumference (AC), femur length (FL), head circumference HC), and biparietal diameter (BPD). “Monitoring foetal growth is an integral part of antenatal care because babies that are small or large for their gestational age are at an increased risk of complications,” explains Uma. Currently, foetal growth is assessed using charts, and birth weight can only be predicted using a scan within a week of delivery, which is not usual, she adds.

"We thought, can we model the growth of the foetus as a function of a few parameters," says Rahul, about the motivation of the study. The search for a suitable mathematical model led them to the Gompertz formula. "It models constrained growth and has previously been used to model tumour growth and foetus volume," says Chandrani.

The model contains three intuitive parameters, which describe the shape and scale of the relationship between foetal size and age. The researchers found that only the scale parameter needed to be fitted to each foetus, while the shape parameters could be treated as global. The researchers estimated these parameters from ultrasound scans of 774 pregnant women using four biometric measurements (AC, FL, HC, BPD) of a foetus taken at least thrice during pregnancy. Using the estimated scale parameter for an individual foetus in the Gompertz formula, the team predicted the foetal size measurements at term. Finally, they used these measurements to train a machine learning model to predict birth weight and verified their results using independent data from 365 pregnant women.

"While growth standards have been published by international organizations, we do not believe all women can be represented by one formula. Taking a step towards personalized medicine, this approach learns one parameter specific to a foetus, enabling us to make a more accurate prediction for that foetus", says Leelavati.

"We predict birth weight with a much smaller error compared to previous models," Rahul adds. The team was able to make accurate predictions of birth weight using routine ultrasound scans taken until only 24 and 35 weeks, which is an advantage over existing models, says Chandrani. "Being able to predict the birth weight and knowing if the fetus is maintaining or falling off its growth curve allows us to monitor them better and, additionally, time delivery," Uma says.

Leelavati points out that the anonymised data used in the study and the code for predictions are openly available for analysis by others, in line with open science principles. The authors plan to convert their work into an online calculator that can easily be used to predict birth weight. Going forward, they see the possibility of integrating their model into the software of ultrasound scanners to make birth weight predictions readily accessible. As foetal growth patterns can vary between individual mothers, populations, and environments, it would be exciting to extend their research to understand this diversity in the future. They also hope to study other aspects of gestation, gestational complications, and birth outcomes in future projects.

Interdisciplinary meetings and funding for grand challenges can help encourage future collaborations between clinical researchers and academics, Uma says. Availability of open data from large studies and increasing the pool of journals and reviewers with cross-speciality expertise can bolster such efforts, she adds.

October 17, 2024

Reference: Kumari, C., Menon, G. I., Narlikar, L., Ram, U., & Siddharthan, R. (2024). Accurate birth weight prediction from fetal biometry using the Gompertz model. European Journal of Obstetrics & Gynecology and Reproductive Biology: X, 24, 100344.

https://doi.org/10.1016/j.eurox.2024.100344

EVENTS


Aysha Mahira

Auctions, matches, bandits and other games

◆ *Bharti Dharapuram*

Participants and resource-people at the ACM summer school on 'An Invitation to Algorithmic Game Theory'.

A two-week ACM (Association for Computing Machinery) school on 'An Invitation to Algorithmic Game Theory' was organized at The Institute of Mathematical Sciences (IMSc), Chennai from 1st to 14th July 2024. With support from ACM India, IMSc and Google, the summer school introduced students to algorithms in game theory.

The summer school was attended by over 40 participants from across the country, with about three-quarters of them represented by Bachelors and Integrated Masters students. The goal was to have students from diverse educational backgrounds including state universities and private engineering colleges, says Sushmita Gupta, a faculty at IMSc who coordinated the event.

Algorithmic game theory emerged with the dawn of the Internet marketplace, when the need to execute millions of auctions every second required a marriage of game theory and efficient algorithm design, says Sushmita. It deals with games between players who make strategic choices about their moves based on available information to achieve some objective.

Algorithmic game theory allows us to frame problems using game design and analyze the costs and benefits of strategies across various players to efficiently identify an optimal solution. These problems can fall within competitive or cooperative contexts where the objective is to maximize value measured as financial gain or social welfare. Equilibrium concepts help us assess outcomes and their persistence under various game plays.

At the summer school, instructors walked participants through a wide array of problems peppered with real-world applications. "The goal was to give an intentionally scattered sampling of canonical and widely studied questions that are the bread and butter of game theory," says Sushmita.

Swaprava Nath from IIT Bombay introduced the problem of auctions to allocate resources while optimizing for profit and the value held by bidders. Sushmita illustrated this using the landmark AdWords algorithm, which helps search engines maximize revenue by matching advertisers to search words. Shweta Jain from IIT Ropar continued with the example of internet advertising to describe the multi-armed bandit problem. Here, a naive player makes a choice by sampling multiple options and learns about rewards through exploration.

Chandrashekar Lakshminarayanan from IIT Madras provided an overview of Artificial Intelligence and its applications in two-player strategy games such as chess and Go.

Aparna Taneja's team at Google's AI for Social Good applied the multi-armed bandit problem to decide which recipients received an intervention to improve the engagement in a maternal health program. Arun Sai Suggala and Dheeraj M Nagaraj from Google Research spoke about real-word applications of the multi-armed bandit problem across multiple users in a collaborative framework. Palash Dey from IIT Kharagpur discussed algorithms for stable matching of partners based on their preference, which has a rich body of theory and human applications. Pallavi Jain from IIT Jodhpur spoke about ways of dividing items between people under various notions of fairness. Sushmita returned to discuss congestion games, where the goal is to find ways of routing traffic through a road network to minimize overall travel time.

C Ramya from IMSc spoke about computational complexity, which is an important constraint in algorithmic game theory. This is because one cannot take an infinite amount of time to solve a problem, leading to considerations about finding a solution in reasonable time.

B Srivathsan from Chennai Mathematical Institute spoke about games on graphs, which is a powerful mathematical framework to study questions in logic, verification and automata theory.

"The summer school was more of an invitation to higher studies. Our ardent hope is that it expanded the horizons of students and informed them about a fascinating topic. We wanted them to feel that higher studies can be interesting and worth exploring, be it in algorithmic game theory or something entirely different," says Sushmita about the motivation behind the event. "It is like eating something delicious and remembering the feeling that you enjoyed it."

"Each day was a new flavour of game theory that I never thought existed," says Bhavik Dodda, a third year Integrated Masters student from Sardar Vallabhbhai National Institute of Technology, Surat. "I am part of the ACM student chapter at my college where I got to know about the summer school," he says. Back from the summer school, he was inspired to use a matching algorithm to resolve mismatches between roommates in their recent hostel room allotments. "It did work and that was fun!" he says.

"Through the summer school, I came to know that algorithmic game theory is a very practical area where I can use my knowledge about algorithms and complexity," says Harsh Sharma, a second year Bachelors student from the Chennai Mathematical

Institute. “The lectures didn’t require many prerequisites and we were exposed to many open problems to give us an idea about how it feels to do research in this field,” he adds.“I have been interested in algorithmic game theory for a while now, but haven’t done a proper course in it and wanted to learn more,” says Krishnashree JB, who is about to finish her Masters degree from PSG College of Technology, Coimbatore. “I am currently working on stable matching and wanted to know about other work in the field, which would help in my career,” Krishnashree says.

“I am from a biology background and I’ve mostly done biology courses,” says Authisha Thirumani Selvam, a fourth year undergraduate student from Indian Institute of Science Education and Research, Pune. “I was also very interested in math but everyone studying it seemed much smarter and I avoided math courses,” she adds. A recent interest in computational social choice drew her to applying to the school. “The summer school was very inviting and didn’t scare me off. It was very intuitive and I really liked that,” she says.

“These programs are much needed, especially for people who are not from well-known institutions,” Sushmita says. They can help undergraduate students who are really bright and have great potential but fall through the cracks due to a lack of guidance. “This program is, honestly, a form of outreach to catch students early. Every student can and should aspire to such opportunities no matter what their current circumstances,” she says earnestly. “IMSc is reaching out to a lot of people through such events and everybody is welcome to participate in them.”

July 31, 2024

School's out! Teachers on a maths and science adventure

◆ *Bharti Dharapuram*

Participants and resource-people at the recent Vigyan Pratibha workshop at IMSc.

The Institute of Mathematical Sciences (IMSc), Chennai hosted a five-day Vigyan Pratibha workshop for science and mathematics teachers between 10th to 14th July 2024. The 43 teachers attending the workshop represented central government schools (Kendriya Vidyala, Jawahar Navodaya Vidyalaya and Atomic Energy Central School) across Tamil Nadu and Kerala.

Vigyan Pratibha is a project by the Homi Bhabha Centre for Science Education (HBCSE), Mumbai. The program develops learning resources and offers training to encourage talent in science and mathematics among 8th to 10th Standard students from diverse backgrounds. The project uses learning units to deeply engage students in discovering knowledge by observing, analyzing and discussing common phenomena around them.

IMSc is the nodal centre of the project in southern India and regularly organizes workshops for teachers, and makes school visits to help them implement learning units in their classrooms.

In the recent workshop, resource people from various institutions converged at IMSc to introduce teachers to learning units and spoke about various themes in science, mathematics and pedagogy. "We pick learning units that work well and where we've got a good response from teachers. There are also ones that we are trying out with them for feedback," says Varuni P who coordinated the event along with Manikandan (Mani) Sambasivam from the IMSc outreach team. Graduate students and faculty at IMSc also give talks at the workshop. "Some sessions are in the form of lesson plans that teachers can do with their students but some are also just interesting problems and topics for teachers to think about," she says.

Mani and Varuni engaged teachers in a conversation around pedagogical content knowledge, which deals with understanding the different ways in which students think about and interpret information. D Uthra from DG Vaishnav College, Chennai mapped the different kinds of questions one can possibly ask and how these shape our observations and thinking.

There were sessions about finding patterns, critical thinking and making inferences. G Arunkumar from Indian Institute of Technology (IIT) Madras introduced mathematical thinking using patterns in square numbers to make conjectures, find proofs and arrive at generalizations. Viswanath Sankaran from IMSc spoke about the different ways of partitioning a number, the curious associations between them and the process of proposing theorems. A fantastical quest in Fermi questions to estimate intangible quantities using back of the envelope calculations was led by Jayasree Subramanian from IIT Palakkad.

There were many activities involving games and hands-on activities. V Sathish Kumar from IMSc introduced a card game called "set" where the goal is to quickly spot sets of cards based on rules about their patterns. While having good fun, teachers learnt about the mathematics behind the game play drawing from combinatorics and logic. Varuni encouraged teachers to explore ways of arranging square patches of different sizes to assemble a larger sized quilt, introducing the mathematical problem of tiling. V Madhurima from the Central University of Tamil Nadu, Thiruvarur used the fable of the thirsty crow to illustrate the measurement of volumes and packing. To demonstrate the properties of materials and their interactions, Mani encouraged participants to test different kinds of cleaning agents to bring back the shine to tarnished copper vessels.

AV Balasubramanian from the Centre for Indian Knowledge Systems, Chennai spoke about the ecological importance of sustainable agriculture and the immense regional diversity of grains in India. His talk ended with a lively discussion where teachers shared their personal experiences about food and farming.

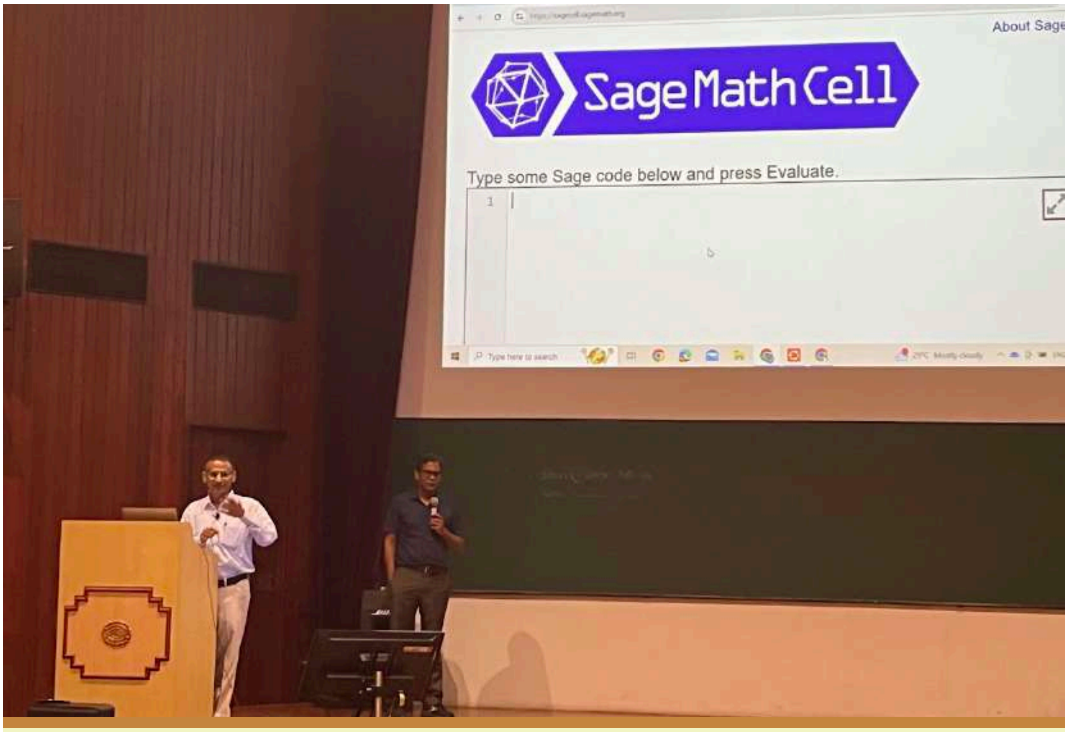
"Sometimes it [the training] is directly applicable in our classroom but at other times these experiences lead us to finding new ways to teach," says Parveen, school teacher from an Atomic Energy Central School.

"It is an ignition for us to carry things forward," adds Balbir Singh Narooka from a Jawahar Navodaya Vidyalaya. However, there can be challenges with limited availability of time in class and adapting teaching methods to changes in curriculum, feel a few teachers from Kerala."Once the teachers come in they tend to hold back, but relax after a day or so and feel free to discuss a lot of science and maths. This transformation is really nice to see and happens every time," says Mani. "They are comfortable enough to say that something is not going to work," Varuni adds. "Many of these teachers will come back for a second workshop in November where we will do a few more learning units and get their feedback once they've tried the material in class," she says.

July 31, 2024

IMSc hosts Sage Days 126

◆ *Bharti Dharapuram*



Ajit Kumar and Amri introduce participants to Sage Math on Day 1 of Sage Days 126.

The Institute of Mathematical Sciences, Chennai (IMSc) hosted Sage Days 126 between 31st August to 2nd September 2024. Sage Math (Sage) is a free open-source software based in Python, which is a powerful tool for learning, teaching and research in various topics of basic and advanced maths. Sage Days is an event that travels around the world to bring together new and existing users with Sage contributors. Sage Days 126 started with an introduction to Sage and its use as a tool in education followed by its applications in specific fields of maths.

"Sage is a Computer Algebra System that has a lot of capability for teaching and has many pedagogical benefits," says Ajit Kumar from the Institute for Chemical Technology, Mumbai. He teaches a popular NPTEL course on 'Computational mathematics with SageMath' for students and teachers. "Sage offers a nice progression from learning a programming language to performing advanced scientific computation," he says. Students learn new concepts and the complex connections between them in the process of writing code, something that Ajit has extensively used in his teaching. "You could learn about mathematical structures in theory, but when you manipulate many examples using Sage, it leads to a better understanding," says Amritanshu Prasad (Amri) from IMSc. "When you have to compute something it forces you to really think about what it is that you are computing and the parameters involved in its definition."

For second year Bachelors students from the Central University of Tamil Nadu, Thiruvarur, Sage Days 126 is their first exposure to coding in mathematics. It is an introduction before they are taught Python and start using CoCalc (the implementation of Sage) as a part of their course work. M Shriya, currently a Masters student at Kings College, London, was introduced to Sage when working on her thesis with Amri during her Masters from BITS Pilani. “I learnt what it takes to contribute to Sage during Sage Days 114 in 2022. As a part of my thesis, I developed the vector partitions module in Sage-Combinat,” she says. “Sage helps you visualize maths concepts and is very good for people who are good at coding but cannot understand pure math,” she says. Shriya is currently developing new classes on Chow rings of Matroids in Sage as a Google Summer of Code project with Travis Scrimshaw from Hokkaido University.

“The first time I heard of Sage was from Amri,” says Viswanath Sankaran from IMSc. “He was an early adopter and he began telling everyone about it.” Amri himself started using Sage after hearing about it at a talk, and later invited Karl-Dieter Crisman from Gordon College to present lectures on Sage at IMSc. In the following years, the interest in Sage at IMSc gained momentum when Travis Scrimshaw gave another series of talks. This led to the organization of Sage Days 60, the first such event held at IMSc, which brought together many leading researchers and developers. “Around that time I ported a lot of my code into Sage. It has a lot of niche functionalities since it is developed by the community, for example, in combinatorics related to representation theory,” Viswanath says. “I use Sage all the time for my research, I would be crippled without it,” Amri says.

“It is not much appreciated that mathematics has an experimental side to it,” Amri says. “At the end of the day we have to write a proof, but to discover results we do experiments to guess at formulae and relationships. Sage has a lot of power to run these experiments,” he adds. “More and more people are realizing that this is very helpful.”

September 05, 2024

IMSc opens its doors for a celebration of maths and science

◆ *Bharti Dharapuram*

The Institute of Mathematical Sciences, Chennai held its Open Day on 24th August 2024, where school students listened to talks about maths and science, participated in demonstrations, played fun games and took back popular science books to read. We also had visitors from the general public across all age groups who rekindled their curiosity for science through simple but delightful experiments The activities, hosted by researchers, staff and faculty at IMSc, were spread across themes in maths, physics, computer science and biology.

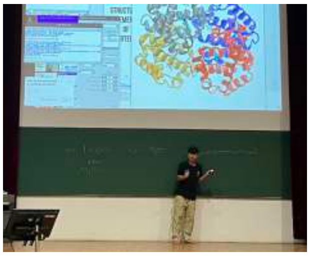
July 31, 2024

Talks

Shri Hari Gopalakrishna spoke about the evidence of dark matter from the discrepancies in the rotation curves of the galaxies, and the different methods used to detect dark matter.

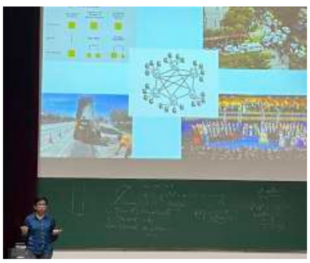
Sunil Kumar Pasupulati spoke about prime numbers, theorems and conjectures related to them and their applications.

Demonstrations



Roni Saiba spoke about the protein folding problem, where a single protein sequence can fold into a complex three dimensional structure.

Rahul Gupta spoke about how different curves intersect with one another.

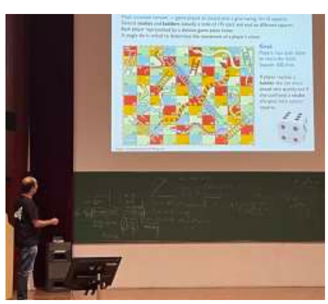


Sushmita Gupta spoke about how Game Theory deals with various 'games' that we come across in our everyday life.

Izhar Ashraf spoke about the challenges of studying history and the robust computational methods to ensure reproducibility.

Manika Gupta spoke about the union-closed family of sets conjecture.

Sitabhra Sinha spoke about Snakes and Ladders as a Markov Process, where a system shifts from one state to another as a sequence of chance events.



An audience of school children and the general public attend the talk series during the IMSc Open Day.

Photo credit: Siva Perumal K. (IMSc Media) and Bharti Dharapuram

Science at the Sabha 2025

◆ *Bharti Dharapuram*

Annagiri Sumana from IISER Kolkata: 'Challenges of relocation: Case study of ants'

The Institute of Mathematical Sciences (IMSc), Chennai held the eighth edition of its annual public event 'Science at the Sabha' on 9th February 2025 at the Music Academy, Chennai. This year, it was attended by close to 600 members of the general public who heard talks from four eminent scientists across Indian institutes on topics from ecology to mathematics. The four-course offering gave the audience a taste of research ranging from the challenges of nest relocation in ants, a deceptively simple open problem in number theory, the two sides of Artificial Intelligence, and disordered systems from man-made to natural materials.

The flagship event hosted by IMSc has been an annual affair since 2016 except for a two-year pause during the pandemic. The format was conceived by former faculty members Gautam Menon (now at Ashoka University) and KN Raghavan (retired from IMSc and now at Krea University) as an occasion where the public could catch glimpses of the science done in Indian institutions. "In other countries, there are specific days dedicated to science where people can walk in at events," Raghavan says. "There is no dearth of science institutions in Chennai but we don't know what they do," he adds, highlighting the lack of public science events in India. The venue of Music Academy, a cultural landmark where most editions of Science at the Sabha have taken place, was also a conscious choice. "We didn't want it to be in a scientific institution," he says. "It was a deliberate decision for scientists to come out of their shells."

This year, the event opened with a talk by Annagiri Sumana, a Professor at the Indian Institute of Science Education and Research (IISER) Kolkata. She spoke about the difficulties of moving house with family, bag and baggage. But in ants, which are among the most diverse and abundant animals inhabiting Earth for over a hundred million years. She described her group's research studying the challenges of nest relocation in the ant species, *Diacamma indicum*. "We have individual records of all of the ants in the nest," Sumana said,

UK Anandavardhanan from IIT Bombay: 'A gentle invitation to number theory'

about marking each ant in a colony to observe its behaviour to answer research questions. She walked the audience through her team's various experiments and explained their findings. They found that leader ants accompany other members of a colony to a new nest site by guiding each individual using physical contact. The adult ants easily carry the young ones with them as they relocate, solve problems cooperatively and the leaders efficiently navigate to find a new nest site in an unknown terrain.

This was followed by a talk by UK Anandavardhanan, a Professor at the Indian Institute of Technology (IIT) Bombay. He illustrated the enigma of open problems in mathematics that are easy to state but difficult to prove using the congruent number problem. He led the audience through natural numbers (counting numbers), rational numbers (fraction of two natural numbers) and right-angled triangles. An enthusiastic audience prompted him with answers along the way.

He defined a congruent number as one that can be expressed as the area of a right-angled triangle whose sides have rational numbers as their lengths. The problem has to do with identifying numbers that are congruent and those that are not. He gave us glimpses of the different ways in which mathematicians have approached the problem, often building on the audience's collective intuition for patterns. "Taking a problem and putting it into a new perspective can present new insights," he said, discussing one possible route to solving this centuries-old problem. "There has been great progress towards the problem, but we are far from fully solving it," he said.

The third installment at the event was by Richa Singh, a Professor at IIT Jodhpur. She presented case studies highlighting the positive and negative aspects of Artificial Intelligence (AI) drawing from her lab's research. She spoke about face-recognition models developed by her research group that helped identify over a hundred victims of the Balasore train accident. She also gave examples of algorithms developed by her lab that have helped law enforcement solve cases.

Speaking about the negative side of AI, she pointed out that concerns usually arise when AI tools are used with malintent or when the technology is inaccurate. She gave examples of how deepfakes can be used to victimise people or spread misinformation and how biases in data used to train AI models can lead to poor performance. "It is important to understand nuances of cultural, geographic and demographic sensitivities," she stressed.

Richa Singh from IIT Jodhpur: 'Shadows and Light: The thrilling odyssey of trusted AI'

Pinaki Chaudhuri from IMSc Chennai: 'In a disordered world'

Pinaki Chaudhuri, a faculty member at IMSc Chennai, spoke about disordered systems and their properties, drawing examples from familiar materials and phenomena. He started by pointing out how we think of solids, liquids and gases as lying along a spectrum of ordered to disordered matter. However, some solids, such as glass, can have a disordered structure of molecular arrangement that gives rise to unique properties. These structures arise due to interactions between particles and the energetic costs of their rearrangements, which are studied using computer models. Pinaki discussed the mechanical properties of fracture and flow in disordered solids such as metallic glass, ketchup and tar. "It can help us identify weak spots, predict the precursors of structural failure and even prevent failure," he said. Zooming out, he discussed how phenomena such as avalanches, cellular traffic and even crowd behaviour in a music concert can be studied through the lens of disordered systems.

Apart from the talks, a poster series showcasing new research from IMSc across the disciplines of maths, computer science, physics and biology caught public attention in this year's Sabha. In previous years, some of the themes for the poster series included 'Indian Women in Science' and 'Science, Education and Public Service in Chennai' and 'Climate Change'.

Each year, the event is attended by hundreds of people. "In the past, we have had eminent Indian scientists from a range of fields from astronomy to molecular biology talk about current scientific advances," says Varuni P, from the IMSc Outreach office.

"Questions from the audience, especially children, in the earlier editions, have displayed great levels of curiosity and wonder for science," says her colleague Manikandan Sambasivam. Even this year, the audience posed many interesting questions: How can one come up with a conjecture in mathematics? Why do ants steal young ones from their neighbouring colonies? What about the environmental costs of running AI models? How can packing problems help us design auditorium seating for optimal occupation and evacuation?

Answering an audience question, the expertise of various speakers blended together when discussing how studying ant behaviour has given us ideas about drone formations and swarms, and how it is a rich source of several computer algorithms.

"It all comes together," said Meena Mahajan, an IMSc faculty anchoring the event, about the deep connections between the various disciplines. She concluded:

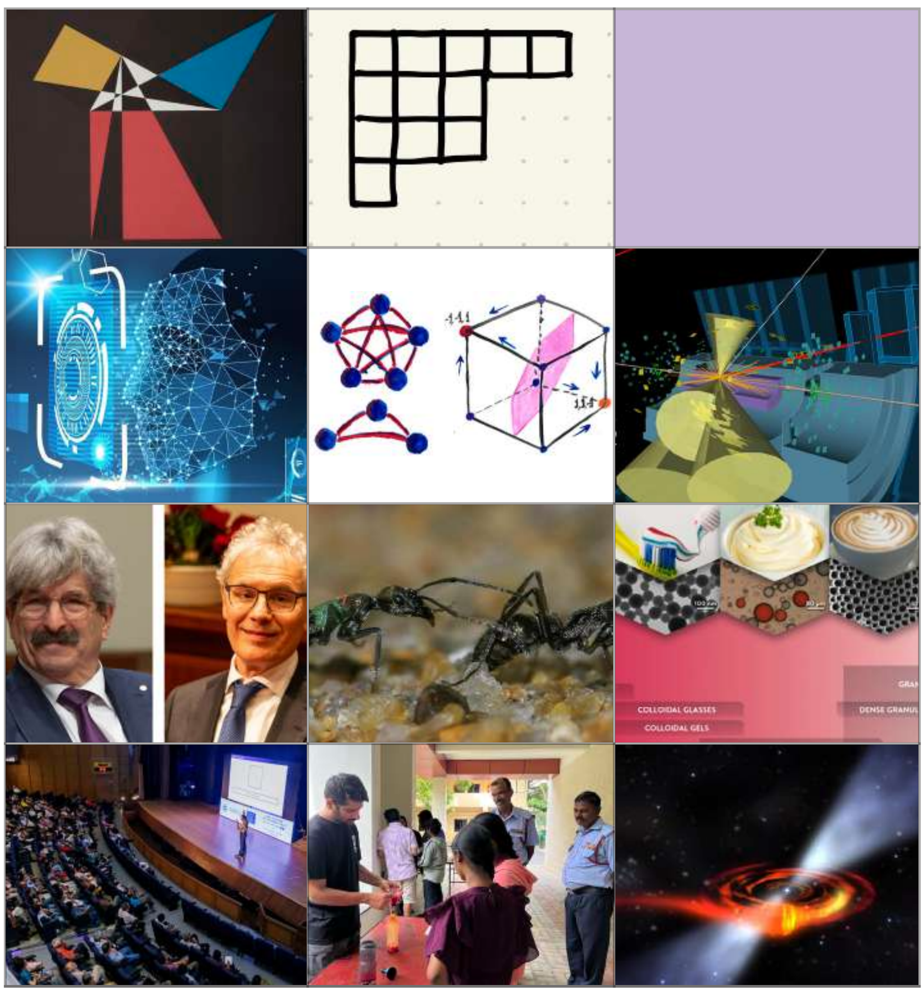
> “ This is how science moves forward...

Science at the Sabha 2025 talks are available to watch online on the Matscience YouTube channel ([*https://www.youtube.com/@matsciencechannel*](https://www.youtube.com/@matsciencechannel)*)*

■ **September 05, 2024**


IMSc Media

FEATURES




Bharti Dharapuram

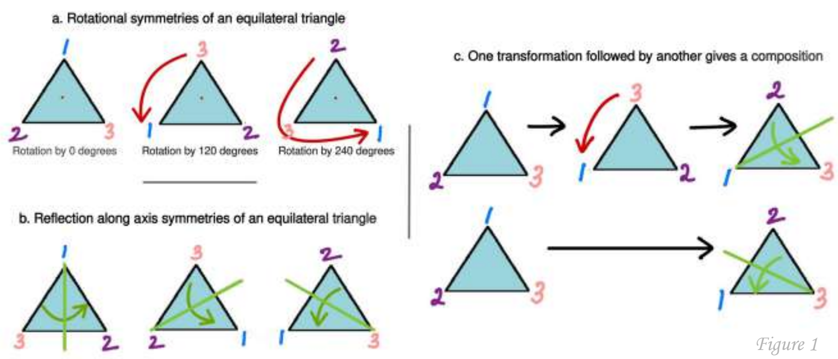
A trapdoor to another mathematical realm

◆ *Bharti Dharapuram and Amritanshu Prasad*

"These things don't happen very often, I still remember seeing that picture and this really clear pattern," Amri recalls about an image that led to an unexpected insight into a four-decade-old equation, "It was a memorable day as a mathematician."

Amritanshu Prasad (Amri), a faculty at The Institute of Mathematical Sciences, Chennai was working with Arvind Ayyer (Indian Institute of Science Bangalore) and Steven Spallone (Indian Institute of Science Education and Research, Pune) to look into the properties of matrix representations of symmetric groups in early 2016.

A group is an abstraction of the set of symmetries of a structure. Mathematicians may consider symmetries of graphs (or networks), physicists may look at symmetries of space-time, while chemists may be interested in the symmetries of a molecule.They can be regarded as transformations of the structure that keep its essential properties intact. For example, an equilateral triangle has six symmetries; three reflections, and three rotations (Figure 1). Groups come with a composition (or product law). Following one transformation by a second one results in a new transformation called the composition. To study such transformations tractably, mathematicians use matrices to represent the transformations in a group. In a representation, the composition of transformations becomes matrix multiplication. Each group can have many different representations, whose understanding can lead to deep insights into the structure of the group. The atomic building blocks of representation are the irreducible ones.



The different kinds of actions that preserve the symmetry of a geometric object, a triangle in this case, constitute a symmetric group (left). These actions can combine to replicate another action from the group (right). Image adapted from http://mathonline.wikidot.com and shared under a CC by 3.0 license.

> **"A group is an abstraction of the set of symmetries of a structure. Mathematicians may consider symmetries of networks, physicists may look at symmetries of spacetime, while chemists may be interested in the symmetries of a molecule.**

The group of symmetries of n identical objects is called the symmetric group. Its irreducible representations were classified by Frobenius, Schur and Young more than 100 years ago. Amri and his collaborators were curious about representations of symmetric groups using matrices with an odd number of rows and columns.

Frobenius, Schur and Young had established that the irreducible representations of symmetric groups are indexed by integer partitions. An integer partition is a way of breaking down a positive integer into smaller ones: for example, the integer 4 can be broken down in five ways, namely 4, 3+1, 2+2, 2+1+1, and 1+1+1+1. We do not distinguish between the partitions 3+1 and 1+3, as their parts are the same. Thus an integer partition can be regarded as a finite sequence of positive integers, arranged in weakly decreasing order. For example, 5+3+3+1 is the integer partition of 12.

Integer partitions are among the most intriguing objects that come up in enumerative mathematics. Mathematicians have long sought a nice formula for the number of integer partitions, and sophisticated techniques following the work of Euler, Ramanujan and Rademacher allow us to easily show that the number of integer partitions of 1000 is 24061467864032622473692149727991, a number so large that it defies intuition. Even so, many subtle questions about integer partitions continue to intrigue mathematicians today.

> **“As the integer becomes large, an exponential increase in the number of partitions makes them challenging to track.**

Let’s pause to see integer partitions and play around with them. A useful visualization of an integer partition is a Young diagram introduced in 1900 by the British mathematician Alfred Young. In this diagram, a partition is drawn as a left-justified array, where rows are arranged in descending order of parts represented as boxes in each row. For example, the Young diagram of 5+3+3+1 is:

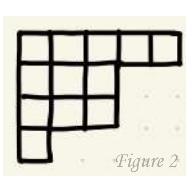


Figure 2

One integer partition is said to cover another, if adding a box to one Young diagram results in the Young diagram of the other. For example, the integer partition 5+3+3+1 covers both 4+3+3+1 and 4+3+2+1.

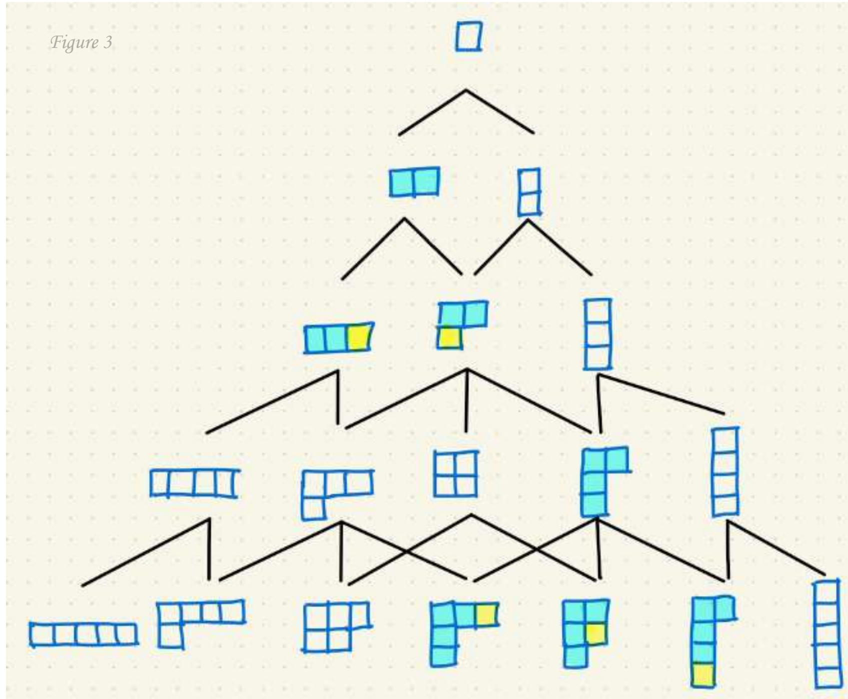


Figure 3

Young’s graph depicts how the different integer partitions of a given number, depicted as a specific arrangement of boxes, are related to each other. The permutations of these boxes in a given diagram are related to actions in a symmetric group.

This gives rise to a network of connections between partitions of different integers, where each row displays the Young diagrams for that row number (Figure 3).

The network, called Young’s graph, grows very quickly.

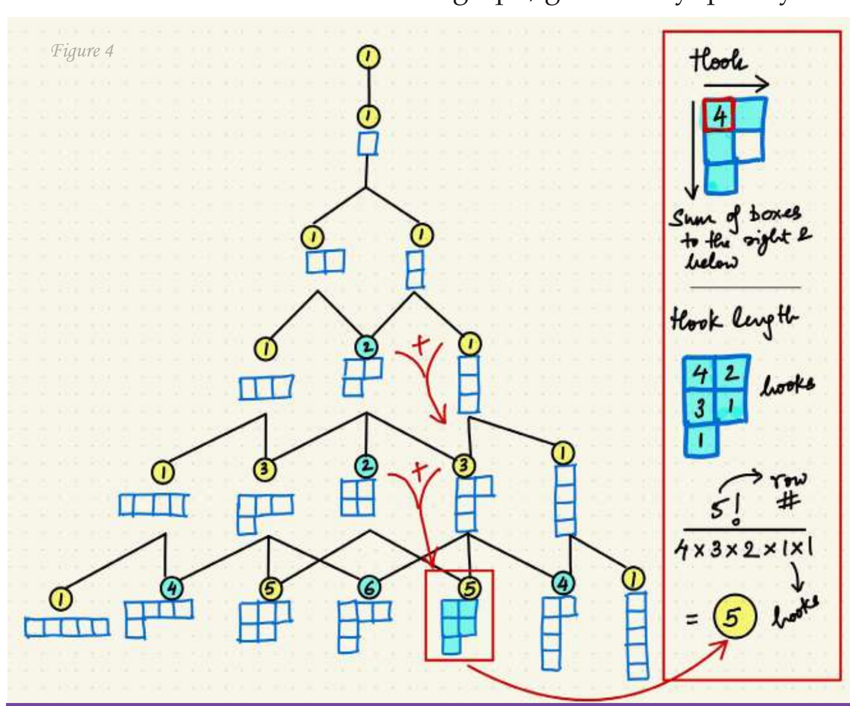


Figure 4

One can assign a number to the nodes in a Young’s graph by summing the numbers associated with their parents. This is derived using the elegant Hook length formula (inset) that gives important properties of symmetric groups.

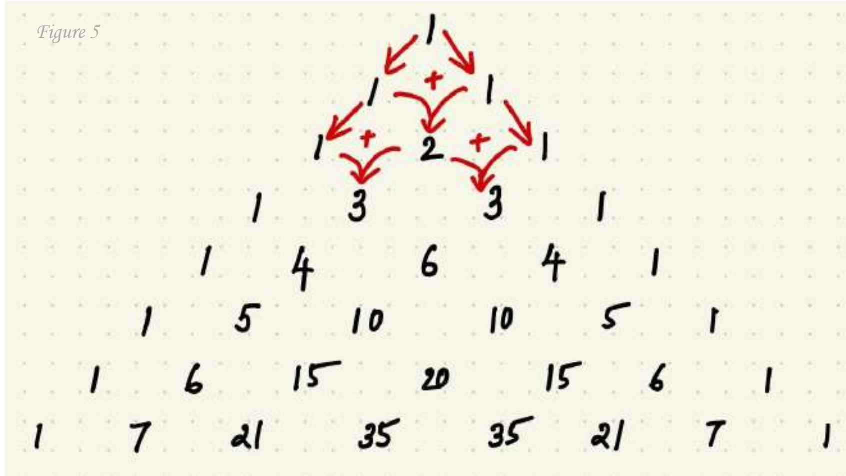
"Describing this growth was one of the beautiful results of Hardy and Ramanujan. They showed that it grows exponentially in the square root of n (the integer being partitioned)," Amri says about the famous partition function.

> **"Fractals are patterns that show self-similarity across scales. A well-known example is Pascal's triangle where, starting from 1, the numbers in a row of a triangular array are derived by summing up adjacent numbers in the previous row.**

Using this map of integer partitions, one can calculate the number of ways of arriving at a specific Young diagram by sequentially adding one box at a time. This can be done by adding the numbers associated with the partitions that are covered by a given Young diagram and following this through Young's graph.

However, as the integer becomes large, an exponential increase in the number of partitions makes them challenging to track. This is where the elegant Hook length formula, discovered in 1953 by the North American mathematicians Frame, Robinson and Thrall, comes in handy (Figure 4). "It is sort of miraculous that it works," says Amri.

Amri and collaborators walked through these steps because the Hook length formula gives the dimensions of the irreducible representations of a symmetric group. In other words, the size of an atomic matrix



Pascal's triangle is obtained by summing up adjacent numbers in a row to give rise to the next row of values and has interesting mathematical properties.

representing the symmetric group – the object of their interest. "It is a fairly elementary set-up where you draw these pictures and put numbers in them, but it has a lot of mathematical significance," Amri says about the Young's graph linking integer partitions. "It is a rich source of very interesting mathematics."

Once they calculated Hook lengths and placed them on the Young's graph, they drew a line connecting all the odd values. And the image they saw took them completely by surprise. It was the key that opened the doors to a relationship between symmetric groups and the enchanting world of fractals.

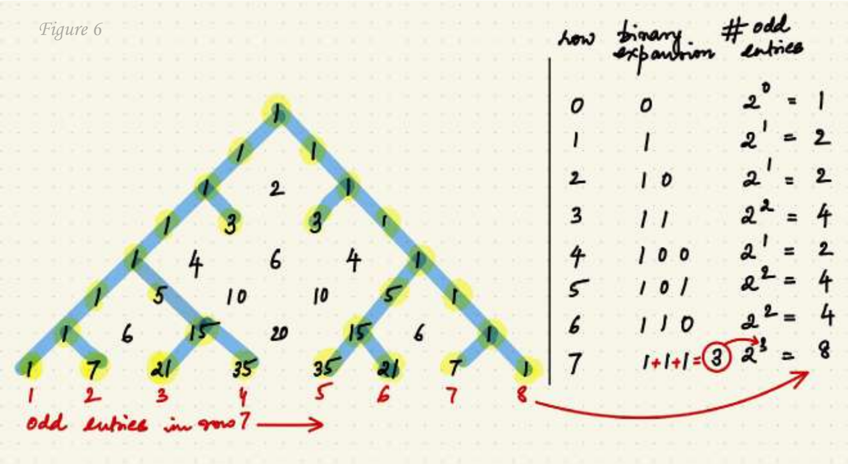
Fractals are patterns that show self-similarity across scales. Imagine viewing an image and zooming in for the same image to come into view again and again at different levels of magnification. Fractals usually arise in geometry, but sometimes they can also arise from enumerative problems. Amri likes to call such fractals combinatorial fractals. A well-known example is the Pascal's triangle where, starting from 1, the numbers in a row of a triangular array are derived by summing up adjacent numbers in the previous row (Figure 5). It has many important applications – it gives the coefficients of the expansion of $(x + y)^n$ and the number of ways of obtaining k combinations of n objects.

Something interesting happens when we start tracking odd numbers across the Pascal's triangle. One starts seeing repeating triangles, which reset at powers of 2 with larger triangles appearing as the tree expands. The lines enclosing a triangle arise from each odd number having a unique odd parent in the previous level and either one or two odd daughters in the next level.

The number of odd instances in a row is always a power of 2, whose exponent can be easily calculated by summing up the binary expansion of the row number (Figure 6).

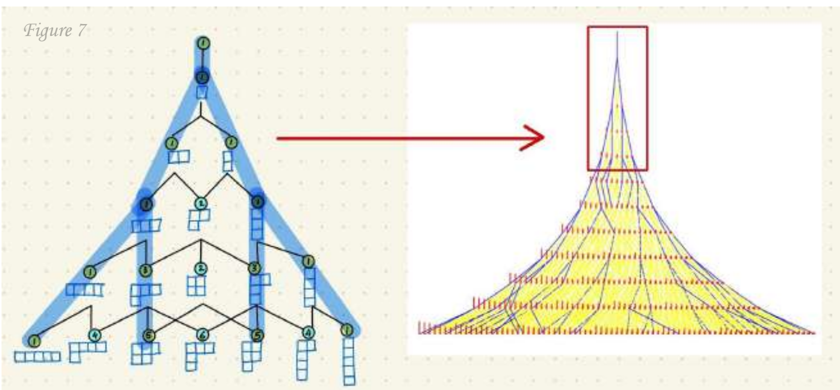
Amri's image revealed an unexpected connection between Young's graph and Pascal's triangle. "I was fooling around on my computer and

Figure 6



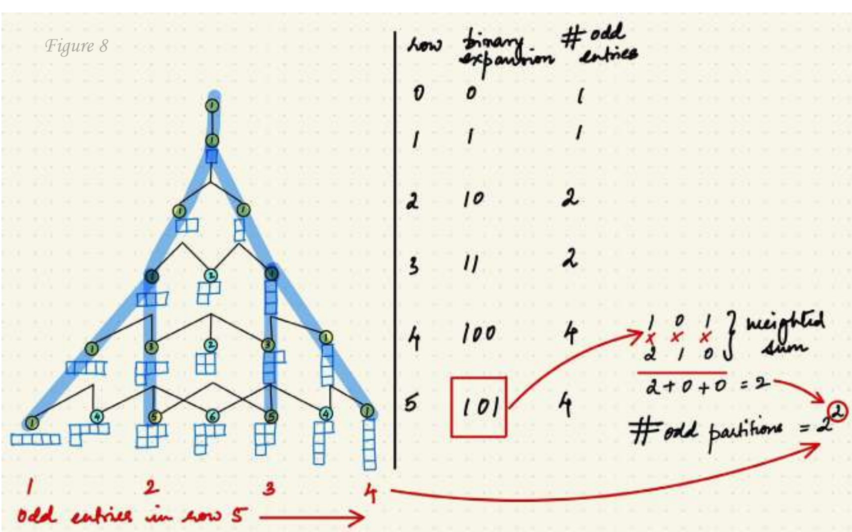
Tracing lines through the odd values in a Pascal's triangle reveals a fractal (left), where the number of odd entries in any row can be simply calculated by summing up its binary expansion (right).

Figure 7



Tracing the odd partitions in a Young's graph reveals a fractal structure.

Figure 8



The similarity of the fractal in the Young's graph and a Pascal's triangle allows us to calculate the number of odd partitions in any row.

plotting things," recalls Amri. "I was thinking maybe it (irreducible representations of a symmetric group) has something to do with Young's graph, so I wrote a small computer program in Sage and plotted it," he adds. "I was completely shocked because I saw this tree with these repeating patterns just like in a Pascal's triangle (Figure 7)."

Since we know how to find the number of odd entries in the Pascal's triangle, the same can be adapted for this sister fractal that Amri chanced upon. The number of odd partitions in a row is the weighted sum of the binary expansion of the row number.

The group relied on this fractal perspective to derive the proof for the number of odd partitions in a Young's graph. "Once we knew that the fractal nature was there, it was not so difficult to prove it. What others may have missed was the visual insight," he says.

"We didn't know at that time, but there was a well-known formula due to Macdonald, which gives how many odd guys there are in each row," Amri says. Way back in 1971, the British mathematician Ian

> **" I saw this tree with these repeating patterns just like in a Pascal's triangle," he adds. "What others may have missed was the visual insight,**

Macdonald had given a proof for this formula using very different methods.

"Macdonald's formula was there but that it arises from this fractal structure was not known," Amri says, illustrating how disparate fields of mathematics offer alternate routes of reaching the same insight.

"This wasn't even the problem we set out to solve, it was an easier version of that problem," he laughs, talking about their accidental proof.

October 10, 2024

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Bharti thanks Viswanath Sankaran for introducing this work and for discussions related to symmetric groups and their irreducible representations.

On the trail of Euclid's Elements

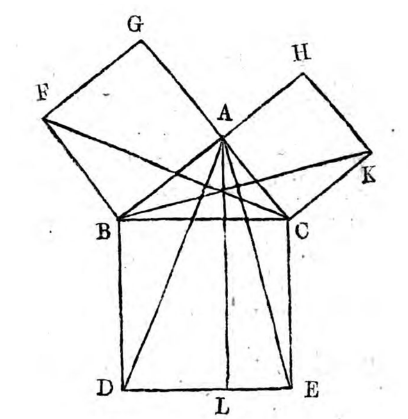
Manikandan Sambasivam

Crockett Johnson, Proof of the Pythagorean Theorem (1965) National Museum of American History, Washington, D.C

More than two millennia after *Elements* was written by the Greek mathematician Euclid, it made its appearance in Tamil. It was translated by a Christian missionary named Henry Bower and published by the Church Mission Press in Palayamkottai in 1861. A couple of months ago, we shared the first book in this translation on the IMSc website.

The original *Elements* consists of thirteen books covering geometry, number theory, and logical deduction. It systematically presents definitions, postulates, and propositions, providing rigorous proofs for theorems. Its influence on our way of thinking did not stop just with science and mathematics, but has impacted language, religion and art.

Many years ago, my interest in popular science and maths led me to Thomas Heath's English translation of *Elements*. However, I didn't engage with the text enough to appreciate its historical importance, and my interest faded over time. This was until last year, when the book came into my field of view again. I was incessantly looking for the right Tamil words for scientific and mathematical terms while translating Vigyan Pratibha educational material for school students along with Uthra Dorairajan from DG Vaishnav College, Chennai.

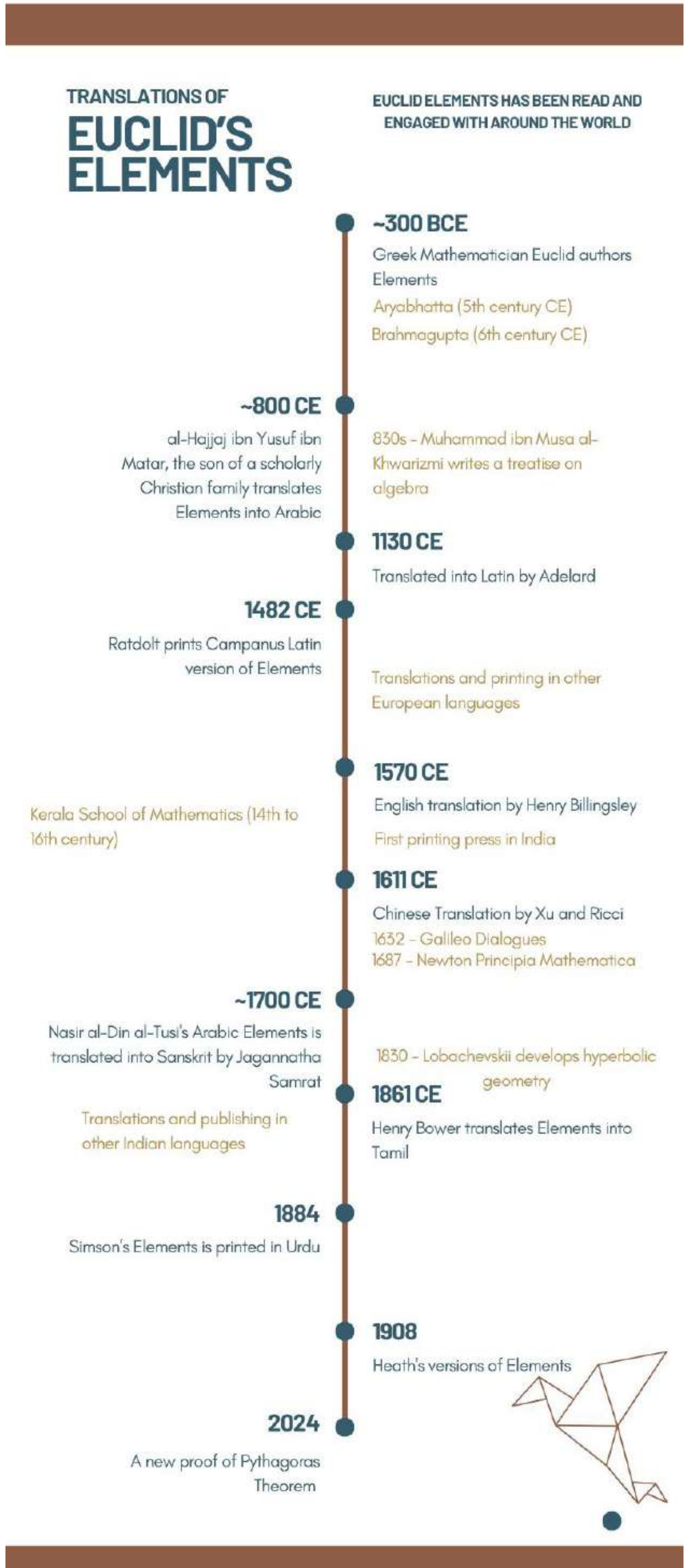


Euclid's proof of the Pythagorean theorem. Artist Crockett Johnson's painting was inspired from this proof, and is among the first in his series of geometric paintings.

Somewhere along the way, I remembered Euclid's *Elements* and started wondering if it had been translated into Tamil. An online search didn't yield many results, usual archival sources returned empty and I couldn't find anything in libraries or bookstores. But I was fortunate to be at IMSc, a great place to mine information about this seminal work that has inspired mathematical thought and spawned many translations.

> **"The original *Elements* consists of thirteen books covering geometry, number theory, and logical deduction.**

The history and journey of *Elements* has been recorded beautifully in Benjamin Wardhaugh's book 'Encounters with Euclid: How an Ancient Greek Geometry Text Shaped the World'. When Euclid's *Elements* first came into print in the 16th century, the German printer Erhard Ratdolt was forced to adopt new printing techniques to accommodate its many geometric figures. In the 17th century, Baruch Spinoza, an influential Dutch philosopher, used Euclid's style of reasoning to write his book 'Ethics Demonstrated in Geometrical Order'. Instead of points, lines and angles, Spinoza dealt with God, mind, emotions, human bondage and freedom. Abraham Lincoln was deeply influenced by *Elements* and is said to have studied its first six volumes. In Steven Spielberg's biographical film, we see Daniel Day-Lewis as Lincoln charismatically justifying equality through the self-evident and common notions of Euclid (Things equal to the same thing are also equal to one another - Common Notion 1, Book One). More recently, the American cartoonist and illustrator Crockett Johnson, found inspiration in *Elements* among other books to create over a hundred geometric paintings



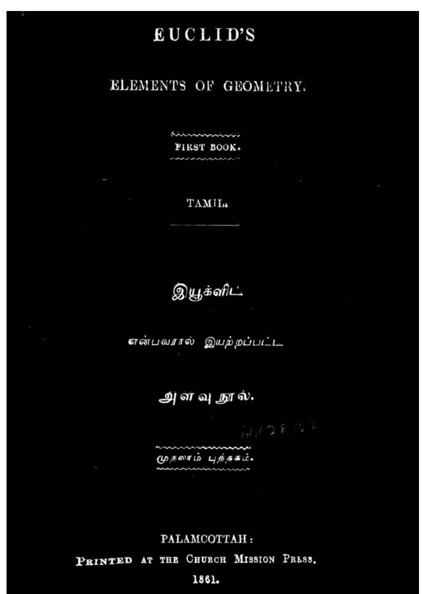
in an amalgamation of art and science.

Elements has been translated numerous times, driving movements that influenced mathematical thought and generated new ideas across the world. In the 8th and 9th centuries, it was among the classic texts in various languages that were translated in the intellectual epicenter of Baghdad. There have been multiple translations of the books into Arabic.The polymath Omar Khayyam even explained the difficulties in its postulates. In a relay of recitation and translation, a Latin version was generated from Arabic via Spanish in 12th century England.

“ *Elements* has been translated numerous times, driving movements that influenced mathematical thought and generated new ideas across the world.

In a similar change of hands across languages, Xu Guangqi and Matteo Ricci worked on the Chinese translation of *Elements* in 17th century China. In his diaries, Ricci points to challenges in translation arising from differences in grammar between the east and west, and highlights the importance of the text as a crash course in logic. In 18th century India, Jagannatha Samrat translated the text into Sanskrit and there are said to be versions of it in Urdu, Marathi, Hindi, Oriya among other Indian languages.

In search of a translation in Tamil, I spoke to several maths researchers at IMSc who guessed that there must be one but didn't know for sure. I found a concrete lead when R Ramanujam, a former faculty in Computer Science, said that *Elements* was indeed translated into Tamil in the nineteenth century. With this information, I approached our librarian Maruthu Pandiyan and asked for help in locating a copy. He contacted many physical libraries in Chennai and Tamil Nadu to no avail, and found only a mention in the Jaffna library. He eventually located a digital copy in the British Library. I was really excited to have found the translation from 160 years ago that seems to have been lost from our collective memory. I started putting up the text on the IMSc website and took about four months to complete the task. The Tamil vocabulary used wasn't very different from today with the exception of some words and spellings.



EUCLID'S

ELEMENTS OF GEOMETRY.

FIRST BOOK.

TAMIL.

இயூக்ளிட்

என்பவரால் இயற்றப்பட்ட

அளவு நூல்.

முதலாம் புத்தகம்.

PALAMCOTTAH:
PRINTED AT THE CHURCH MISSION PRESS.
1861.

Henry Bower's translation of the first book of Euclid's Elements into Tamil.

“ *Elements* is an expression of our mathematical thought and is invaluable to read in one's native language.

We have found and shared only the first book in Euclid's treatise, but I hope that we can find the rest of them. *Elements* is an expression of our mathematical thought and is invaluable to read in one's native language, like the translations of literary and religious texts that we make our own.

With modern tools at our disposal, it is much easier to translate seminal scientific and mathematical texts into various languages and is a mission worth our time. We may have far surpassed the mathematics described in the *Elements*, but it is an important chapter in the history of mathematics, which holds insights about the path of reasoning and generation of new scientific ideas.

October 10, 2024

Pulsars, served three ways

◆ *Bharti Dharapuram*

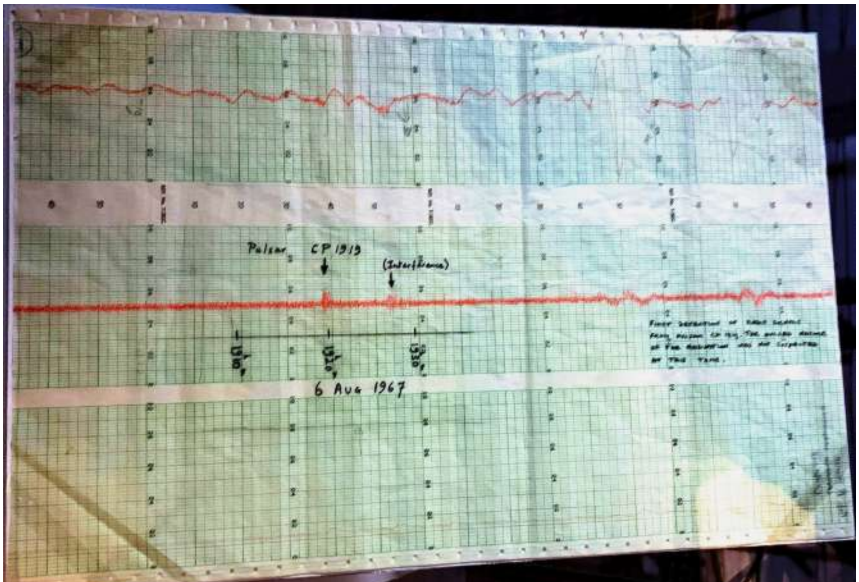


Chart recording with the radio signal from the first pulsar to be discovered by Jocelyn Bell Burnell in 1967. Image by Billthom shared under a CC by 4.0 license.

The discovery

"Nobody knew what a pulsar was until I discovered the first two," says Jocelyn Bell Burnell in a 2021 documentary. As a PhD student with Antony Hewish at Cambridge University, she helped build a radio telescope at the Mullard Radio Astronomy Observatory. One day in 1967, looking through the telescope's recording charts, she saw regularly spaced peaks in its tracks that she couldn't explain. These strings of signals, 1.3 seconds apart, came from a specific region in the sky and led Burnell to the first pulsar to be ever discovered.

A pulsar is a neutron star, one of the final stages in a star's life cycle, where a star moderately heavier than the sun collapses upon itself into a volume tens of kilometres across. It spins really fast, sending out a strong beam of electromagnetic radiation along its magnetic axis.

> **"A pulsar is a neutron star that spins really fast, sending out a strong beam of electromagnetic radiation along its magnetic axis.**

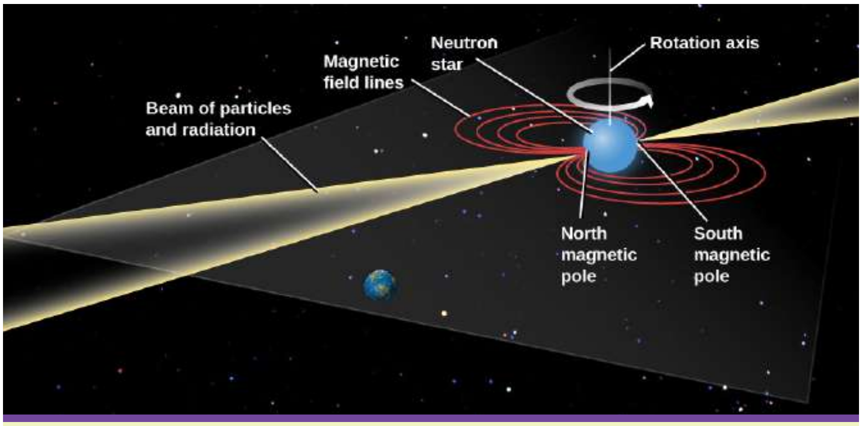
This becomes visible when the radiation points towards us as it sweeps across space in the course of the pulsar's rotation. This is like being illuminated by a lighthouse beacon when it rotates to face us again and again. Similarly, the electromagnetic beam emanating from a pulsar is seen at regular intervals by a telescope in its line of view, keeping time of the pulsar's rotation. The first pulsar that Burnell observed, named CP 1919, made a rotation every 1.3 seconds.

"It's incredibly hard to get people to believe you've discovered something amazing if you've got only one. I knew that finding more would be the clincher," Burnell says. Her discovery of the second pulsar later in the same year laid to rest apprehensions that the pulses came from background noise, instrumental anomalies, or more alarmingly, little green men from another planet.

In 1974, Hewish – Burnell's advisor, won the Nobel Prize in Physics for the discovery of pulsars, along with Martin Ryle. In 2018, Burnell won the Breakthrough Prize in Fundamental Physics for her discovery of pulsars and donated the prize money to the Institute of Physics UK to support minority students.

The dance

In the same year as Hewish and Ryle won the Nobel Prize, Joseph H Taylor from the University of Massachusetts, Amherst and his PhD student, Russell A Hulse, were puzzled by irregularities in the ticks of another pulsar. It was recorded



A pulsar is a neutron star, which emits beams of electromagnetic radiation from its magnetic axis, which is different from its axis of rotation. This beam of radiation becomes visible when it sweeps across earth in the course of the pulsar's rotation. Image shared from https://pressbooks.online.ucf.edu under a CC by 4.0 license.

at the Arecibo Observatory in Puerto Rico, where a massive dish captured radiowaves, reflecting it to receivers which amplified these signals from the cosmos. Based on the Doppler shift in the signal, they deduced that the pulsar was spinning once every 59 milliseconds, it had an invisible partner, and the pair danced around each other in elliptical orbits.

This was the discovery of the first binary pulsar, PSR 1913 + 16, where the visible pulsar travels at 300 km per second around its silent companion, a neutron star (a non-pulsar whose electromagnetic beam is not falling on earth).

Six decades before this discovery, Einstein's general theory of relativity predicted that massive accelerating bodies emit gravitational waves. These ripples of energy arise from the source and travel through space at the speed of light, distorting space-time along the way. Binary pulsars with their enormous mass and velocity lose energy as gravitational waves. This shrinks their orbit over time, bringing them closer as they spiral faster and faster into each other. These changes in the orbital period are reflected in changes in the time between pulses detected by a radio telescope. Taylor and colleagues observed the binary pulsar over four years and found that its orbital period is decaying at a rate predicted by theory, providing indirect evidence for the presence of gravitational waves.

Taylor and Hulse won a Nobel Prize in 1993 for their discovery of the binary pulsar, which had served as a natural laboratory for studying gravitational waves. Two decades later, direct evidence for gravitational waves was detected from a violent collision of two black holes over a billion light years away. In a collaborative project involving researchers across countries, the Laser Interferometer Gravitational-wave Observatory (LIGO) in the USA captured the feeble whispers of this massive cosmic event. In 2017, Rainer Weiss, Barry C Barish and Kip S Thorne from LIGO/Virgo (gravitational wave detector of the European Gravitational Observatory) won a Nobel Prize for building the detector and finding evidence of gravitational waves. However, this was just the tip of the iceberg - gravitational waves in other frequencies remained elusive.

> **"Binary pulsars with their enormous mass and velocity can provide indirect evidence for the presence of gravitational waves.**

The array

In 1982, Shrinivas Kulkarni from the University of California, Berkeley, was another graduate student peering at the skies at the Arecibo Observatory. This time around, the blips that he recorded were more frenzied than ever before, pointing to a new pulsar that spun around its axis at an incredible 641 times per second (~ 0.0016 seconds per rotation). Kulkarni, along with his advisor Donald Backer's research group at Berkeley, had discovered the first millisecond pulsar. Later work showed that the millisecond pulsar evolves when a regular pulsar draws matter from a nearby companion giving an enormous boost to its rotation. These super-spinners are precision timekeepers, making them excellent probes of ripples in space-time.

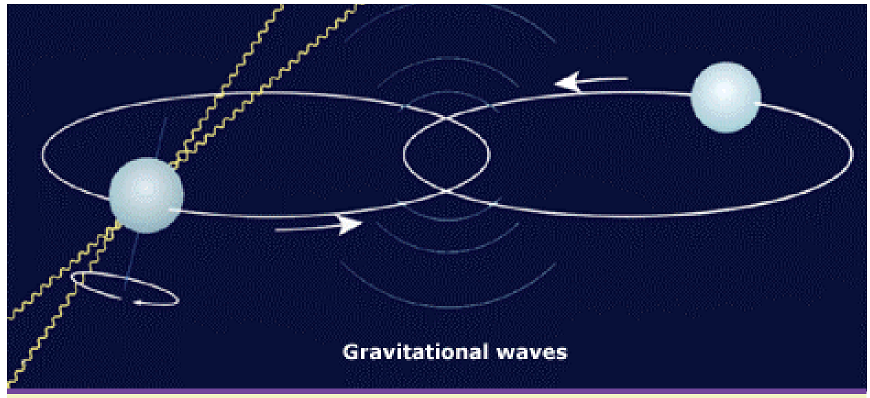
When a gravitational wave passes through, it perturbs space-time affecting the time at which a millisecond pulsar's signal arrives on earth.

Observing a constellation of millisecond pulsars spread across the sky, it is possible to measure very small deviations in their signals over background noise.

> "**A millisecond pulsar evolves when a regular pulsar draws matter from a nearby companion giving an enormous boost to its rotation. These super-spinners are precision timekeepers, making them excellent probes of ripples in space-time.**

Since these millisecond pulsars are separated by thousands of light years, they act as enormous receivers of low-frequency gravitational waves arising from the merger of supermassive blackholes."There are many pairs of supermassive blackholes in the universe that are dancing around each other on their way to merger and emitting gravitational waves," says Manjari Bagchi, an astrophysicist at The Institute of Mathematical Sciences, Chennai. "The superposition of gravitational waves emitted by individual pairs results in the existence of these ripples in every direction, known as stochastic or background gravitational waves. Stochastic gravitational waves can also be created by the cosmological properties of the very early universe," she adds.

Cosmic-scale experiments to measure gravitational waves need researchers from across the globe to come together in massive collaborative efforts. The International Pulsar Timing Array is a consortium of groups from Europe, North America, India, Japan and Australia, that has its eyes on a hundred millisecond pulsars whose signals may potentially surf gravitational waves.



In a binary pulsar, two pulsars orbit around their center of mass emitting energy in the form of gravitational waves. As they lose energy, their orbits become smaller over time and they accelerate to spiral into each other. Image from https://pressbooks.howardcc.edu shared under a CC by 4.0 license.

Within this, the Indian Pulsar Timing Array (InPTA) is a Indo-Japanese collaboration that has been observing around 25 millisecond pulsars over the last few years. It uses the upgraded Giant Metrewave Radio Telescope (uGMRT) at Narayangaon near Pune.

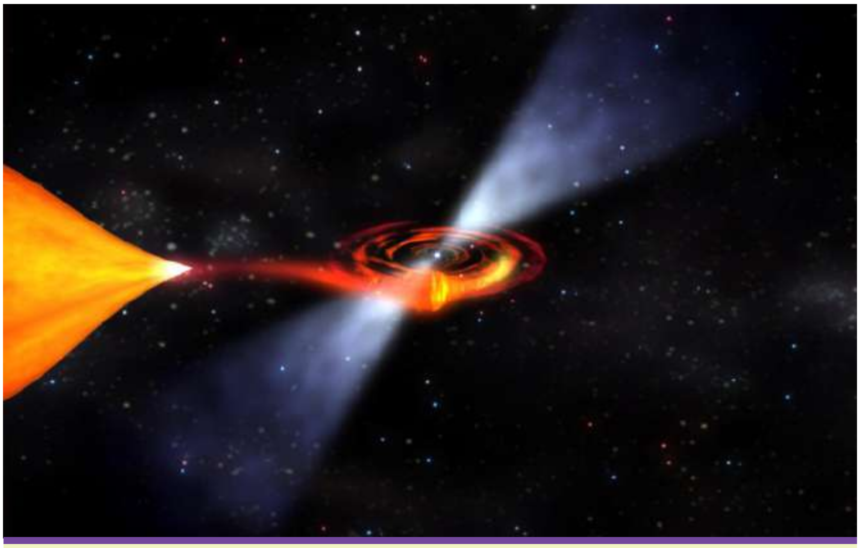
An aerial view of the Arecibo Observatory in Puerto Rico showing the reflector dish in a natural sinkhole. It was built in 1963 and was among the largest single-aperture telescopes for many decades before collapsing in 2020. Image by H. Schweiker/ WIYN and NOAO/AURA/NSF shared under a CC by 4.0 license.

Last year, InPTA along with the European Pulsar Timing Array (EPTA) detected evidence for nano-Hertz stochastic gravitational waves, which was also reported by the North American and Australian groups.

> "**The Indian Pulsar Timing Array is a Indo-Japan collaboration that has been observing around 25 millisecond pulsars over the last few years.**

The road ahead

"Pulsar Timing Array experiments have not reached the end of their journey yet. Scientists are now aiming to detect gravitational waves from mergers of individual pairs of blackholes," says Manjari. Scientists also want to find out what fraction of the stochastic gravitational waves arise from the origin of the universe and the fraction of astrophysical origin, she adds. There is an ongoing merger



When an old pulsar (right, with electromagnetic beams) draws matter from a nearby star (left), it resurrects into a millisecond pulsar, which spins hundreds of times per second. It keeps time very precisely, making it an ideal instrument to detect gravitational waves. Image by Dana Berry (Skyworks Digital) for NASA.

“Pulsar Timing Array experiments are now aiming to detect gravitational waves from mergers of individual pairs of blackholes.

of gravitational wave data across global observatories to better detect signatures of gravitational waves. “The Indian group aims to search for gravitational waves using Indian data only. The results and the data will be made public soon!,” Manjari says.

October 7, 2024

From magnets to the mind: How Hopfield and Hinton bridged physics to AI

◆ *Sitabhra Sinha*

Almost everyone, whatever their expertise (or lack of it), seems to have an opinion – or at least questions – as to why the prize ostensibly meant for "the most important discovery or invention in the field of physics" - the exact wording in Alfred Nobel's will instituting these prizes - should be given for "artificial intelligence" (as the media seems to have portrayed it). In fact, the spectacle reminds one strongly of the furore attending the award of the 2016 prize in Literature to the songwright Bob Dylan, that was accompanied by "raucous cheering, disbelieving emojis and graceless carping" (in the words of Amit Chaudhuri writing in The Guardian).

Indeed, the similarities seem to go deeper. In neither case, there was much disagreement about the importance of the body of work that was recognized. Dylan's worldwide fame could hardly increase any further by awarding him a prize, even a Nobel – so the controversy was about whether his songs (or as some disparagingly put them, "pop songs") can be classified as "literature". Similarly, Hopfield and Hinton, while not a household name like Dylan, are well known and respected figures in the international scientific community whose contributions have been long recognized by their peers, for instance, by awarding Hopfield the extremely prestigious Boltzmann medal in 2022, which is given for the most outstanding achievements in statistical physics. Earlier winners of the medal, like Kenneth Wilson and Giorgio Parisi, have also gone on to win the Nobel prize in physics subsequently. So, the puzzlement among the public (and even among some scientists who really ought to know better, one of whom made the ridiculous claim that it was given because Nobel hadn't made any provision for prizes in computer science) seems to be primarily about how this work falls within the ambit of "physics".

> **"Apart from the boundaries between physics and, say, engineering, being somewhat arbitrary, the prize seems to be a nod towards science finally breaking down the millenia-old division between physical (or "inanimate") and living systems.**

A possible answer is that, apart from the boundaries between physics and, say, engineering, being somewhat arbitrary (in any case, they did not exist as separate fields even a couple of centuries back), the prize seems to be a nod towards science finally breaking down the millenia old division between physical (or "inanimate") and living systems. We can trace the beginning of this enterprise – at least for our purpose – to the 1940s, when by one those curious coincidences of history, scientists began asking if the mathematical physics approach that had been so successful in revealing the subatomic world through the quantum revolution, could also reveal what is life, as well as, how the brain works. During these years, physicists such as Niels Bohr and Erwin Schrödinger were grappling with the question of the mechanism by which the cell encodes information that is inherited from one generation to the next – an initiative that within a few years would lead to the discovery of DNA by the physicist Francis Crick working with James Watson. Around the same time, in Chicago, a neurophysiologist Warren McCulloch working together with a gifted young mathematician Walter Pitts (who was so precocious that he had been invited at the age of 12 to study mathematical logic at Cambridge by Bertrand Russell) published a paper that viewed neurons as effectively just ON-OFF switches. By making the neurons flip from OFF to ON states or back on receiving signals from other neurons connected to them, McCulloch and Pitts showed that one can build logic circuits that can in principle do any complex operation one can think of.

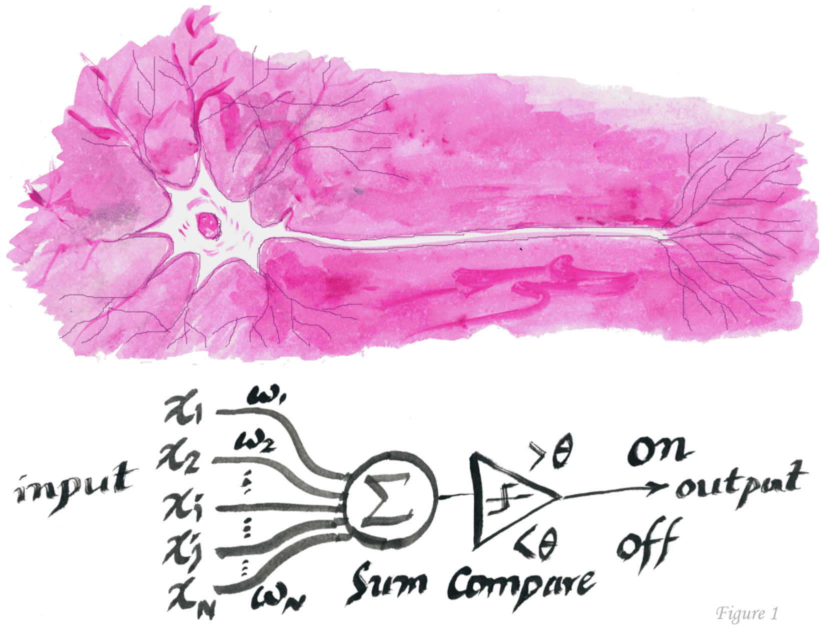


Figure 1

A schematic diagram of a representative biological neuron (top compared with the operating principle of the McCulloch-Pitts model of a neuron (bottom), which is essentially a binary switch (i.e., having only two states, viz., ON or active – denoted by 1, and OFF or inactive – denoted by 0). Just as the dendrites emanating from the neuronal cell body allow it to obtain information about the activation status of neighboring neurons (i.e., whether they are firing action potentials or not), with the signals from different neurons having differential influence in terms of their ability to evoke a response, the McCulloch-Pitts neuron receives as input the binary states (x_i, i = 1, …, N, which can only take values 0 or 1) of all its N "pre-synaptic" neurons, that are then weighted by the corresponding synaptic strength (w_i for neuron i). These inputs are then summed and compared against an intrinsic threshold. If the weighted sum exceeds the threshold, the neuron fires an action potential (i.e., it turns ON) and the signal is conveyed down the axon to its post-synaptic neurons; else it remains quiescent (OFF).

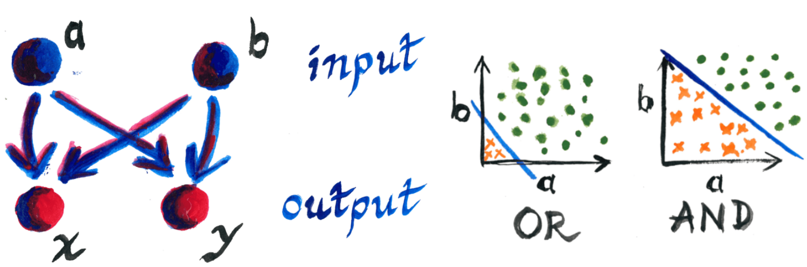


Figure 2

Simple neuronal circuits can be constructed to implement various logical operations on input signals. As pointed out by McCulloch and Pitts, a network comprising 2 input neurons (whose activity states are denoted as a and b) that are stimulated – or not – by incoming stimuli, that provide synaptic connections to the output neurons x and y (left) can function as either an OR logic gate or an AND logic gate, by varying the connection weights and thresholds. The input-output diagram of each gate is indicated (center: OR, right: AND) with the axes representing the activity (low or high) of the input neurons and the symbols, dots (ON) and crosses (OFF) representing the state of any of the output neurons. For OR gate, high activity in any of the input neurons results in the output neuron switching to the ON state, while for the AND gate, only when both input neurons are highly activated, does the output neuron turn ON.

Immediately after the war, the theoretical breakthrough of McCulloch and Pitts led to Frank Rosenblatt using this idea to come up with early machines that could recognize simple images – but the general problem of how to actually design the circuits required to implement any given problem remained unsolved. As it happened, the clue for how to do this was already there for anyone who knew where to look. In 1949, the neuropsychologist Donald Hebb came up with a deceptively simple hypothesis of how the brain "learns", which can be stated simply as "neurons that fire together, wire together". Thus, if two neurons consistently fire to do a particular task, they will connect more strongly with each other, thereby making it even more likely that in the future they will fire together – or in other words, when a network of artificial neurons are shown a series of patterns repeatedly, that corresponds to some of the neurons firing while others remain silent, they will "learn" to settle to such patterns by altering their mutual connections – thereby "memorizing" the patterns shown.

In fact, in 1974, William Little, a member of the Physics Department at Stanford University, published a model where he showed how implementing Hebb's rule can generate short-term and long-term memory in a network of switch-like neurons. The stage was now set for John J Hopfield's landmark paper of 1982 in which he went beyond Little's work by deviating a little from biological realism

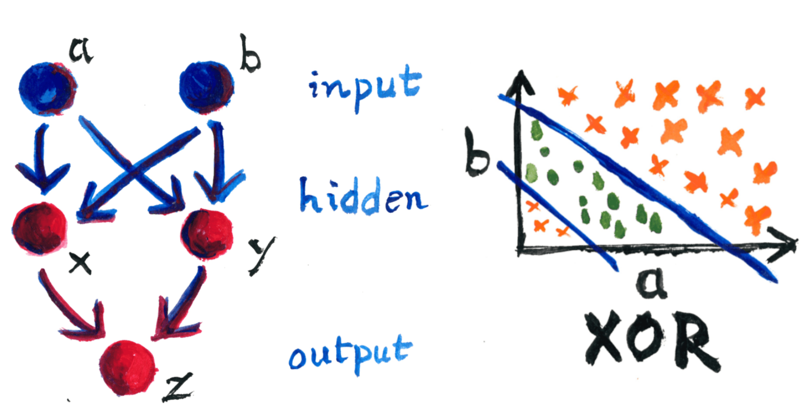


Figure 3

By introducing an additional layer (so-called "hidden" because the neurons in this layer are neither directly accessible to external stimuli nor is their response immediately observable unlike the output layer) between the input and the output layers (left), the network becomes capable of implementing arbitrarily complex logical operations. In particular, it can implement XOR logic, whose input-output diagram is shown above (right), where the output neuron can switch to ON state (indicated by dots) if and only if only one of the input neurons is highly active. Otherwise, if both input neurons are either highly active or are inactive, the output shows no activity (crosses).

– something the physicist Daniel Amit termed "a brilliant step backwards". Specifically, Hopfield assumed that if a neuron A is connected to neuron B with some strength *W*, B is also connected to A with the same strength *W*. This simple assumption allows one to associate an energy with each brain state, defined as a particular configuration of neurons that are on ("firing") while others are off ("quiescent"). To give an example, consider swinging a pendulum held in your hand. If you give it an initial jerk, you are supplying some energy which makes it swing from side to side – thus the initial state has high energy. If you now hold your hand still, over time the forces of friction will make the energy dissipate into the surroundings and the pendulum will gradually come to rest in a vertical orientation. Similarly, in the neural network model of Hopfield, the arbitrary state from which the "brain" starts is at a high energy state that over time will gradually come to rest in the closest available minimum-energy state that is actually the memory learnt by Hebb's rule. Hopfield further showed that by mapping the language of ON/OFF neurons to tiny magnetic spins that are oriented either UP or DOWN, this description of the brain is essentially equivalent to random magnets (technically called "spin glasses") that physicists have been studying for some time.

" Hopfield assumed that if a neuron A is connected to neuron B with some strength *W*, B is also connected to A with the same strength. This simple assumption allows one to associate an energy with each brain state, defined as a particular configuration of neurons that are on ("firing") while others are off ("quiescent").

" One could think of an energy landscape for the brain with the memory states corresponding to the valleys (low energy states) that were separated from all other memory states by high energy "ridges", such that each memory had a basin of attraction around it that corresponded all sensory stimuli that eventually resulted in recalling that memory.

The advantage of transforming the problem of neural networks into one of random magnets was that one could now think of an energy landscape for the brain with the memory states corresponding to the "valleys" (low energy states) that were separated from all other memory states by high energy "ridges", such that each memory had a basin of attraction around it that corresponded all sensory stimuli that eventually resulted in recalling that memory

Thus, Hopfield gave a very simple physical explanation for associative memory – the process by which when we, for example, smell freshly baked bread, it can give rise to a Proustian chain of thoughts that make us remember an event in our childhood when we used walk past the local bakery in the arms of our mother (say). As shown by the Hopfield model, this is no more or less than the brain state starting initially in a high energy state (smelling the bread) gradually flowing down to the neighbouring lowest energy state (the memory of our childhood).

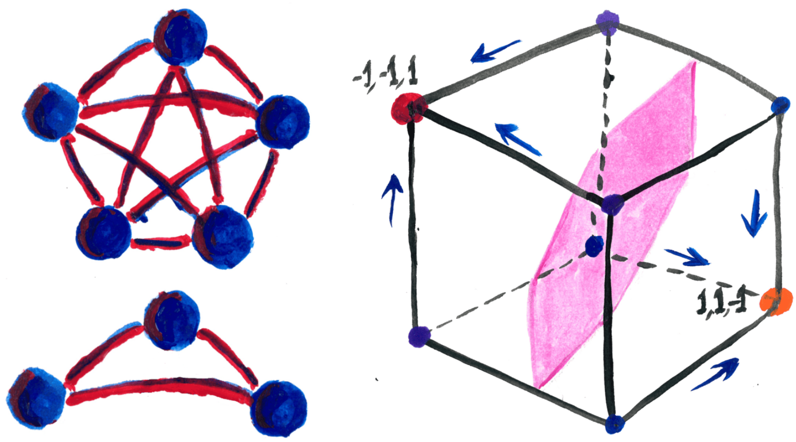


Figure 4

The neural network model for human-like associative memory proposed by Hopfield in 1982 assumes that every neuron is connected to every other in the network of N neurons being considered – schematically shown for N=5 (left top) and N=3 (left bottom). The connections between neurons are undirected as Hopfield's learning rule (based on Hebb's principle) ensures that the connection weights are symmetric – i.e., if neuron i connects to neuron j with synaptic strength W_{ij}, and neuron j connects to neuron i with synaptic strength W_{ji}, then $W_{ij} = W_{ji}$ for all $i \neq j$. Each state of the network can be defined as a sequence of the spin orientations S_i that represent the ON/OFF status of each neuron (i=1,…, N) in the network, i.e., $\{S_1, S_2, \ldots S_N\}$. It's easy to see that there are a total of 2N possible network states, from {–1, –1, …, –1} to {1, 1, …,1}. The dynamics, i.e., time-evolution from one network state to another, is shown for a N=3 Hopfield network. The synaptic strengths, calculated according to Hopfield's learning rule, ensure that the state ξ={1,1,–1} is an attractor – i.e., the network has memorized a single pattern ξ (right). Small variations from this state will flow back to the state as shown above. Larger variations will flow to the complementary state ξ′= –ξ={–1, –1,1} obtained by "flipping" all the spin states in ξ and which, therefore, is the other attractor of the network dynamics. The colored plane separates the basins of attraction of the two attractors.

> **"By dividing the neurons of the network into "visible" (whose states encode the memorized pattern) and "hidden" (which perform computations but are not directly accessible for input or output), and by allowing probabilistic evolution of the states (to take into account the inherent fluctuations in the biological process going on inside the brain), Hinton came up with the Boltzmann machine model.**

Connecting memory storage and recall in the brain to energy landscapes, almost overnight made physicists working in statistical physics enter brain science in droves – a process that was dubbed the "Hopfield revolution" – where they solved problems that previously couldn't even be quantified, like how does memory capacity change with network size (measured in terms of the number of neurons *N* comprising it).

Hopfield's model however had severe limitations in terms of how closely it followed the biological architecture of the brain. In particular, the brain has a clearly hierarchical structure, as sensory neurons respond to external stimuli, which then activate layers of interneurons one after another, before eventually causing motor neurons to activate muscles. Geoffrey Hinton working with collaborators such as Terrence Sejnowski, realized that not all neurons need be involved in the reception of stimuli and/or readout of memory. Thus, by dividing the neurons of the network into "visible" (whose states encode the memorized pattern) and "hidden" (which perform computations but are not directly accessible for input or output), and by allowing probabilistic evolution of the states (to take into account the inherent fluctuations in the biological process going on inside the brain), Hinton came up with the Boltzmann machine model named after Ludwig Boltzmann, the founder of statistical physics.

Subsequently, Hinton combined a layered architecture, where connections exist only between successive layers (inspired by the hierarchical structure of brains) with the energy landscape framework of Hopfield, to develop Restricted Boltzmann Machines. The rest as they say is history, as it allowed networks with arbitrary numbers of layers to be trained by altering their connection weights to perform any given function. The resulting birth of the deep learning paradigm is – as we are all well aware – radically transforming society through the AI revolution.

But just as a journey of a thousand miles begins with a single step, the impressive advances in machine learning

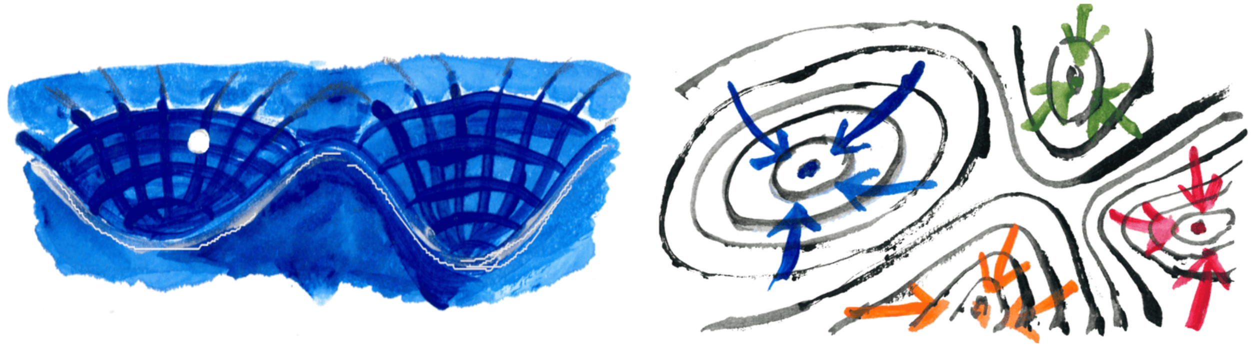


Figure 5

For a Hopfield network with a single stored pattern, there are only two attractors (as seen in Figure 4) which also happen to be the energy minima for the system seen as a globally connected network of binary state spins (i.e., a spin can at any time only be in one of two possible orientations, viz., 1 or –1 – such spins are often referred to as Ising spins in the physics literature). This can be shown in terms of an analogy with a landscape comprising two deep valleys separated by ridges (left), the state of the system corresponding to the white ball that is rolling downhill in whichever valley it is located in. The energy-landscape description of the model network is thus identical to a ferromagnetic system – e.g., a magnetized piece of iron – under a suitable mapping of spin states (known technically as a gauge transformation). If more than one pattern is stored as a memory, then other attractors appear – represented as valleys in the contour diagram (right) that shows an analogy with a physical landscape. The system state will converge to the nearest energy minimum, shown in the analogy through arrows that represent flow of a ball down to a valley bottom starting from different initial conditions, the state at which the system ends up varying depending on which basin of attraction the initial state of the system was located.

owes its existence to Hopfield stepping back a bit from the biology to simplify the problem of learning and recall, that allowed him to bring to bear the well-developed machinery of statistical physics of spin models and random magnets and thus bridge the apparently widely separated fields of neuroscience, physics and machine learning. More broadly, Hopfield and Hinton's work raises the question whether living systems are really in any way significantly different from physical systems or whether this perceived distinction is just a holdover from a belief in existence of some special "vital force" being responsible for life and consciousness. Would we in our lifetime see the first sentient AI emerging, possibly uttering the words "I compute, therefore I am"?

This is a revised, augmented version of an article by the author that appeared in Deccan Herald newspaper on October 16, 2024.

December 22, 2024

Places that take science to the public

◆ *Drishti Jain, Asian College of Journalism*

"Come sit here in the centre, we will be able to see the full frame," a man said to his five-year old son. The duo reclined their chairs to get a good look at the overhead dome in Chennai's BM Birla Planetarium. Scrawled across it were the words: 'The Search for Life in the Universe.' It was pitch dark except for the bright stars dotting the sky.

"This star is 8500 light years away," boomed the narrator's voice across the theatre. The little boy's eyes widened in wonder and he frowned as the star came closer and closer.

The Periyar Science and Technology Centre houses the BM Birla Planetarium, which has eight galleries with over 500 exhibits on display. It is one of many places in Chennai with outreach programs that make science and mathematics accessible to students, teachers, and the general public. Since it opened its doors in the late eighties, it has seen many generations of citizens. "I used to come here when I was a kid," the little boy's father said as he was exiting the show.

Outside, visitors queued along an iron railing to get their 3D glasses to 'Meet the Dinos', a show about extinct dinosaurs told through vivid storytelling. In the queue was Mridula Vasudev on a college trip with her classmates from RMK College of Engineering and Technology in the city. "Science is very interesting and has the capability of fascinating young minds. More places like this should be accessible to the public," she said.

The Periyar Science and Technology Centre, Chennai was established by the Government of Tamil Nadu over forty years ago for science education and outreach among the general public. (Photo: Drishti)

> **"The Periyar Science and Technology Centre is one of many places in Chennai that make science and mathematics accessible to students, teachers, and the general public.**

The library allows people to participate in the many demonstrations that it houses. One of the rooms echoes with rustic notes of people running a steel rod across other suspended ones, to learn how rods of different lengths produce different sound frequencies. In another exhibit, a 3D cutout of a scientist narrates the history of calculus to visitors.

"They are eager about the space and are learning a lot," said Shantani, a school teacher from Shri Natesan Vidyasala who was shepherding her Class IV students around the galleries. "When they have seen the experiment performed live, it makes it easy for us to communicate and explain things to them in their mother tongue."

A gallery showcasing the life and work of the mathematician Srinivasa Ramanujan at the Centre. (Photo: Drishti)

An exhibit showing the anatomy of a shark heart at the Solomon Victor Heart Museum. (Photo: Drishti)

Through a narrow passage in front of the library is The Solomon Victor Heart Museum, where hearts of various animals are suspended in glass jars allowing visitors to see their anatomical details.

Shahid, a first-year engineering student from Mohamed Sathak College of Arts & Science, Chennai, and his classmate made three rounds around the Polar Satellite Launch Vehicle (PSLV)-4 model in astonishment. "Our college has brought us here as a part of our industrial visit," says Shahid, whose class is on a mandated tour for a fortnight, where they learn by visiting places outside the classroom. "I think it's a very good initiative."

"I scored seven out of ten," said V Muthukumaran, a friend of Shahid's after taking the space quiz at the India in Space gallery. He has eagerly waited to visit the planetarium for two years. "I want to become a Physics lecturer, and my visit today has enhanced my knowledge about the Davisson–Germer Experiment which we're taught in books but have never seen. This will help me prepare for my public exams," he said.

"Students are made to rote learn, score marks and come to the science field without any practical knowledge," says Aashiq Muhammad, who has just finished school and was stopping by the Periyar Centre on his way to the Anna Centenary Library. "This is very wrong," he says emphatically. "Exposure to practical science can even help the nation make advancements in the army," he says near the Defence Research and Development Organisation (DRDO) gallery.

A teacher among the managing staff at the Planetarium said that they hold regular classes for college students to make gadgets over a course of 3-4 weeks. “This year, we invited many schools and colleges in Chennai to celebrate the first National Space Day through essay writing, model making and painting competitions. These types of outreach programs help students study science and pursue a research career.”

“ A few kilometers down the road from the BM Birla Planetarium, The Institute of Mathematical Sciences in Taramani was holding its Open Day. Many government schools were invited, where students and teachers learned scientific phenomena using simple experiments.

A few kilometers down the road from the BM Birla Planetarium, The Institute of Mathematical Sciences (IMSc) in Taramani was holding its Open Day. Many government schools were invited, where students and teachers learned scientific phenomena using simple experiments. Over forty exhibits were displayed across the campus by PhD students, interns, postdoctoral researchers and faculty.

“I loved this journey today,” said Dharshini, a class 11th student of Rani Lady Meyyammai Girls Higher Secondary School, Chennai.

Models of various spacecraft missions of the Indian Space Research Organisation on display at the Centre. (Photo: Drishti)

The Institute of Mathematical Sciences, Chennai was founded over sixty years ago and carries out fundamental research in the fields of Mathematics, Theoretical Physics, Theoretical Computer Science and Computational Biology. (Photo: Bharti)

A demonstration of the Pythagorean cup illustrating the siphoning effect. (Photo: Bharti)

you keep pouring in more than the required quantity, it will overflow," he said, explaining the siphoning effect. The students let out a combined "Oooh" in chorus after the experiment ended, amazed by the mechanism they just heard.

"This is the second time we're conducting the Open Day over the last few weeks. The students are not forced to come here unlike in their school, which makes a huge difference," said Aniruddha. "They are curious, going around with the spark of learning science."

"We experienced things which we are going to learn about in 11th and 12th standard, which will also help me in preparing for NEET [National Eligibility cum Entrance Test]."

Several tables were laid out on either side of the public library in IMSc, where students in small groups went from one table to the next discussing what they had learnt and meticulously took notes.

"This is a greedy cup," said Aniruddha, a PhD student, which made everyone around him burst into laughter. "If

IMSc students creating Lissajous patterns using sand pendulums. (Photo: Siva)

Visitors looked at a range of materials using different kinds of microscopes (Photo: Hareesh)

At the next exhibit, students were busy with the Sand Lissajous demonstration. The experiment was carried out using a large bottle filled with sand. It hung upside down from the ceiling and was fixed with two adjustable strings, which allowed the suspended bottle to move in two different directions as a pendulum. When the bottle was released the sand flowing from it created complex and beautiful patterns.

Bharti, who was teaching students how to use a microscope said, “Many school children said they don’t have basic instruments like microscopes in their school The idea is to make them use various types of microscopes, including the Foldscope where the frame is made of paper and can be easily assembled by anyone.”

“One may never study about a woman scientist in school, but when you come here, you find that it isn’t the case and this motivates girls to enter this space.

“The outreach programs of every institute can allow children to find some kind of spark within,” said TV Venkateswaran, a faculty at the Indian Institute of Science Education and Research, Mohali visiting IMSc. People often have a fixed image of a scientist - they may immediately think of APJ Abdul Kalam or Einstein, he says. “One may never study about a woman scientist in school, but when you come here, you find that it isn’t the case and this motivates girls to enter this space.”

After the sunset, the students sat on the side of the garden and discussed their day. “Did you see the water prism,” a girl asked her friend while sipping tea. “Yes, yes! I did. That was the most beautiful one,” she replied excitedly.

December 16, 2024

Anatomy of a proton and its exotic cousins

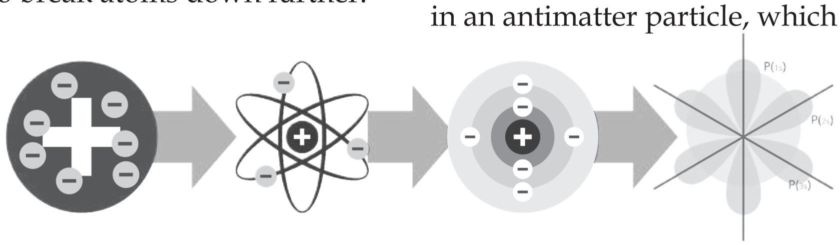
◆ *Bharti Dharapuram*

When in school, we learned that atoms are made up of three kinds of subatomic particles - electrons, protons and neutrons. We imagined tiny negatively charged electrons as excitable entities that were always zipping around, restrained by positively charged protons that kept things together, while neutrons, cohabiting with protons in the nucleus, passively looked on. However, this cartoon version of the atom sweeps over an incredible complexity of interactions. After more than a century of research in quantum physics, we have a more nuanced understanding of the anatomy of an atom and continue to explore its landscape.

While the concept of an atom as the fundamental unit of matter was prevalent for hundreds of years, the discovery of electrons at the turn of the twentieth century showed that it was possible to break atoms down further. Various models of an atom were proposed, from Joseph John Thomson’s model of electrons embedded in a positively charged pudding to Erwin Schrödinger’s model where electrons are an effervescent cloud surrounding the nucleus. In the 1970s, the Standard Model of particle physics broke down subatomic particles even further to come up with an assorted box of elementary particles. Those making up matter are known as fermions and others that impart mass or carry force are called bosons.

“The Standard Model of particle physics breaks down subatomic particles to come up with an assorted box of elementary particles.

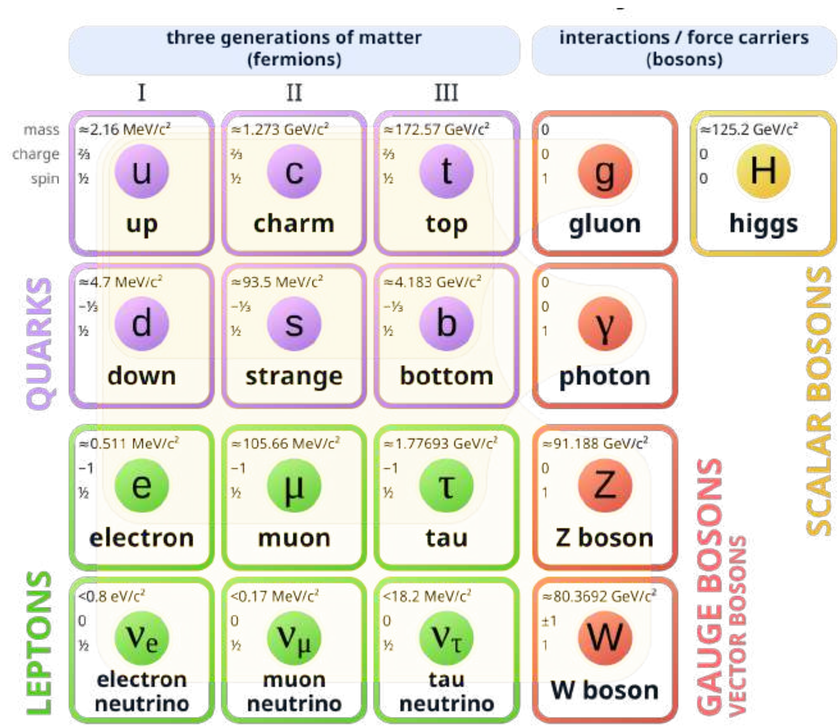
Fermions, the elementary particles making up matter, are of two types, quarks and leptons. They have an alter ego in an antimatter particle, which



Atomic models through the ages. From left to right: JJ Thomson’s plum pudding model, Ernest Rutherford’s nuclear model, Niels Bohr’s planetary model and Erwin Schrödinger’s quantum model. Image by Ville Takanen shared under a CC by 3.0 license.

has the same mass but other contrasting properties. Two types of quarks, named up and down, make up protons and neutrons, which are among six different kinds or 'flavours' of quarks. Composites of quarks are more generally called hadrons. Baryons are a subclass of hadrons made up of an odd number of (anti)quarks. The two lightest members of the baryon family (represented as qqq, where q is a quark and qqq is a triplet of quarks) are the proton, which consists of two up quarks and one down quark, and the neutron, comprising of one up quark and two down quarks. Mesons, made up of a quark-antiquark pair ($q\bar{q}$, where $\bar{q}$ is an antiquark), form the other class of hadrons, which are unstable and usually observed in particle collision experiments.

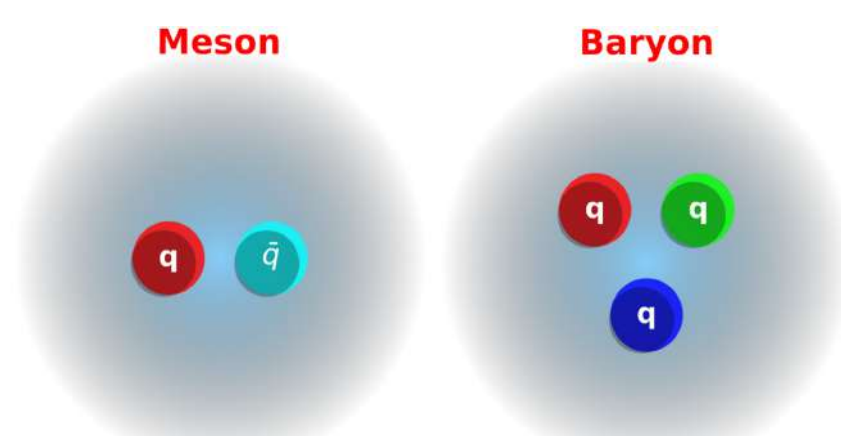
Quarks have a fractional electric charge, and depending on how they are combined, may impart a resultant charge to the hadrons they are part of. For example, a proton gets one unit of positive charge since it is made up of two up quarks, each with a two-thirds positive charge, and a down quark with a one-third negative charge.



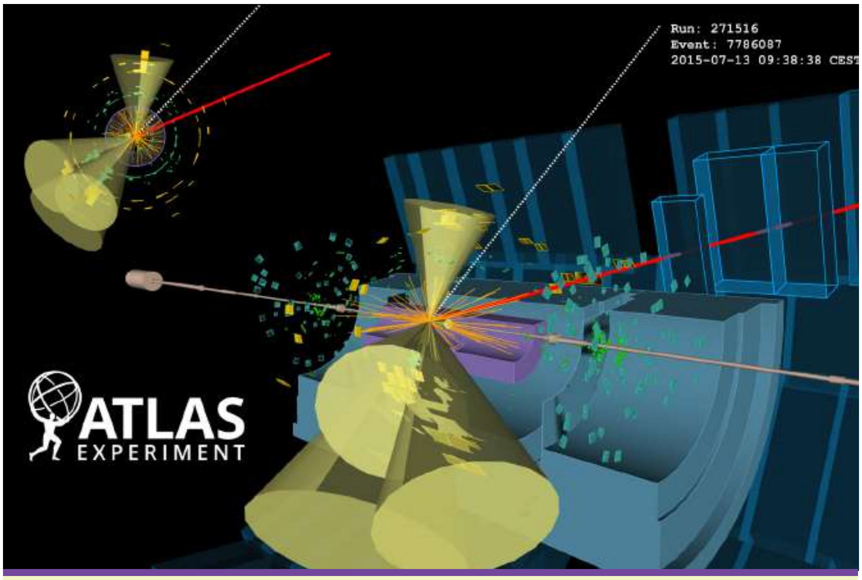
The Standard Model of elementary particles.

Up and down quarks are the building blocks of most matter around us. There are two more quark pairs (charm-strange, top-bottom) analogous to up-down except for each pair's progressively increasing mass, and rarity. Leptons, such as electrons and neutrinos, are much lighter matter particles, which have two additional analogous generations of lepton-pairs (muon-muon neutrino, tau-tau neutrino) much like quarks.

The force determining how quarks within protons and protons within a nucleus stick together despite repelling electric forces, is known as the strong force. Quantum ChromoDynamics (QCD) is a well-accepted theory of strong force that explains how elementary particles within hadrons interact with each other. QCD argues that apart from the electric charge, a quark carries another kind of charge called 'colour' charge, which can be either red, green or blue. This has nothing to do with colours in the visible spectrum, but is used to describe a specific property of quarks, which makes them sensitive to the strong force. The three constituent quarks within each proton or neutron belong to three different colours to render the resulting composite colourless. A quark's



Ordinary hadrons are composed of a quark-antiquark pair (meson) or a triplet of quarks (baryon). Image by Bhabani Sankar Tripathy.



Reconstruction of particle tracks detected from high energy proton collision experiments at the Large Hadron Collider. Image by ATLAS Collaboration, CERN.

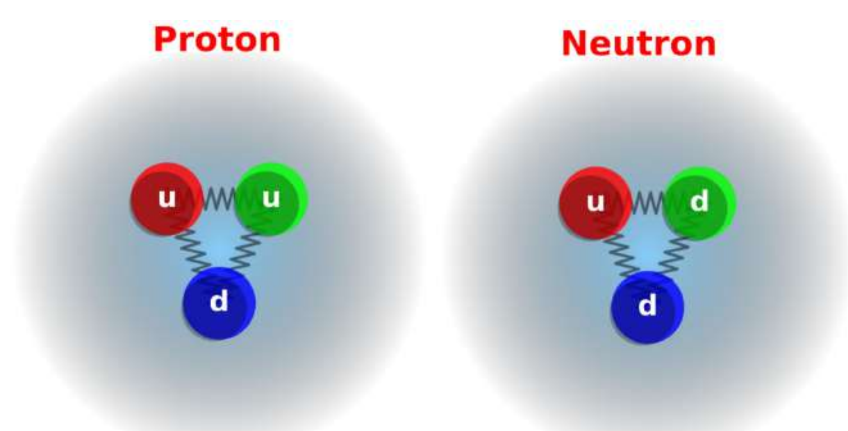
property of colour makes it responsive to the strong force, where quarks of different colours are held together by force-carrying particles called gluons. Gluons in strong force are equivalent to photons in electromagnetic force, with the exception that gluons carry a colour charge, while photons do not carry an electric charge.

> “ **A quark is one of the elementary particles making up matter whose composites are called hadrons, such as protons and neutrons.**

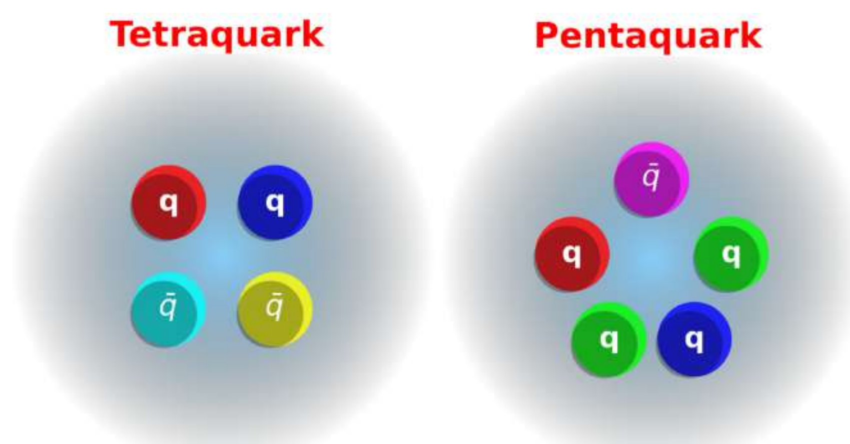
The strength of the strong force increases with distance, such that it can be considered very small at distances less than one-tenths of a femtometer (10^{-16} meters), but is large at greater distances. The strong force gets its name because its strength is many orders of magnitude greater than the other fundamental forces (gravitation, electromagnetism, weak interaction). When quarks are pulled apart to large distances, the energy expended in separating them is high enough to give rise to a new quark-antiquark pair that bunks with the existing one. Quarks, therefore, cannot be isolated and are never observed alone.

The presence of a colour charge on gluons mediating the strong force, and the relationship of strong force with distance makes it unique among the fundamental forces. These properties make it impossible to study strong interactions at large distances by solving equations to find exact solutions. Instead, researchers use computationally intensive numerical simulations such as Lattice Quantum ChromoDynamics (Lattice QCD). In this framework, space-time is discretized into a grid on which the theory of QCD is defined and quark-gluon interactions are monitored using Markov Chain Monte Carlo simulations. The input parameters to these calculations are related to quark mass and coupling strength. These virtual numerical experiments provide predictions that can be tested against real-world experimental observations.

In particle collision experiments, such as in the Large Hadron Collider (LHC) at CERN - the European Organization for Nuclear Research in Switzerland, Belle II at KEK - The High Energy Accelerator Research Organization in Japan, and Beijing Spectrometer III in



Quarks and gluons are the building blocks of protons and neutrons. Within these, three differently coloured quarks interact using strong forces mediated by gluons. Image by Bhabani Sankar Tripathy.

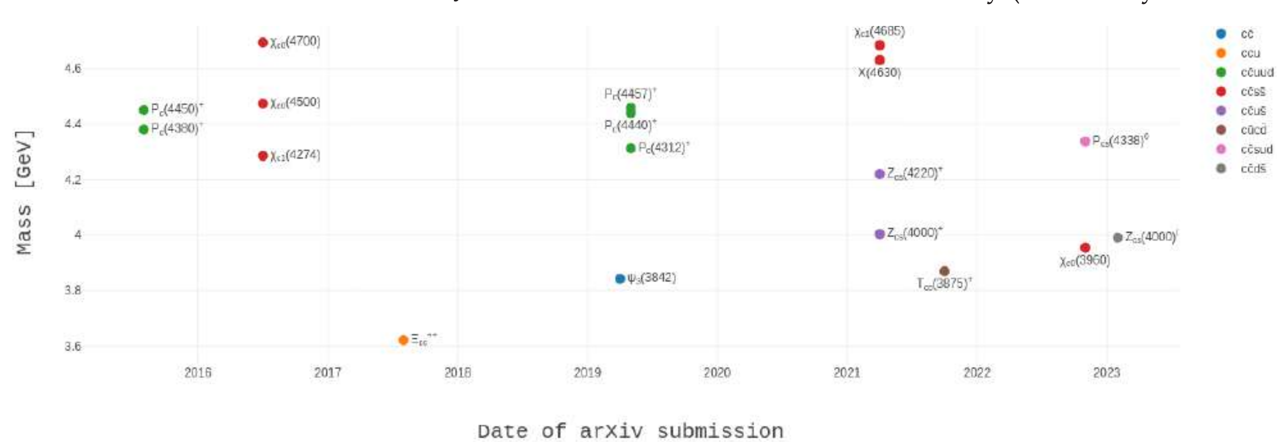


Exotic hadrons are fleeting complex composites of quarks discovered in particle collision experiments, which can be investigated using Lattice QCD simulations. Image by Bhabani Sankar Tripathy.

the Beijing Electron–Positron Collider II at the Institute of High Energy Physics in China, particles are smashed at very high velocities to offer clues about the interactions between elementary particles. Scientists use theoretical predictions to interpret the data emerging from these experiments.

Until 2003, experiments around the globe uncovered the existence of a handful of hadrons, most of which fit into the simplest picture of baryons (*qqq*) and mesons (*qq*). Since then, experimental facilities have been discovering exotic hadrons - complex quark composites with a fleeting existence (10^{-23} seconds), which challenge this traditional picture. "*X(3872)* was the first exotic hadron to be discovered at Belle II, whose origin remains an open question till today," says M. Padmanath who leads the hadron physics group at The Institute of Mathematical Sciences (IMSc), Chennai. Another discovery that has spiked recent scientific interest is the T_{cc} tetraquark reported by the LHCb collaboration, suggested to be made of two charm quarks and an up and a down antiquark, he adds. LHCb and Belle II continue to investigate documented exotic hadrons and discover novel ones, while emerging facilities, such as the Electron-Ion Collider at the Brookhaven National Laboratory, can give us a detailed picture of quark-gluon interactions and allow us to test theoretical predictions of exotic hadrons. "Lattice QCD simulations play an important role in gathering evidence for the existence of these composite particles and the conditions under which they come to be," Padmanath explains.

"Our research explores exotic hadron features such as tetraquarks, pentaquarks and hexaquarks using lattice QCD simulations," says Padmanath. "We collaborate with global researchers and utilize powerful High-Performance Computing facilities in India (Indian Lattice Gauge Theory Initiative at the Tata Institute of Fundamental Research Mumbai, IMSc), Germany (University of



Exotic hadrons detected in the Large Hadron Collider beauty experiment at CERN. Here, the mass of each exotic hadron (in giga-electron volt) is plotted against its year of discovery. The colour codes indicate the quark composition of a hadron. In the figure legend: u - up, d - down, c - charm, s - strange, and the corresponding antiquarks are represented by bars over the symbols. Image by the Quarkonium Working Group Exotics hub.

Regensburg, Gauss Centre for Supercomputing and the John von Neumann Institute for Computing in Jülich) and Slovenia (Vega IIS) to study hadronic interactions at the femtoscale (10^{-15} meters)”.

“Since 2003, experimental facilities have been discovering exotic hadrons - complex quark composites with a fleeting existence. Research at IMSc explores these features using lattice Quantum Chromodynamics simulations.

Their recent work, in collaboration with German and Slovenian scientists, involved virtual numerical scattering experiments of mesons to recreate the tetraquark and study its properties [1, 2]. They also predicted the existence of a new heavy di-baryon D_{6b} [3] and a heavy tetraquark T_{bc} [4] along with scientists from TIFR Mumbai. “Looking ahead, we plan to perform advanced calculations to deepen our understanding of quark-level interactions within hadrons and their implications in subnuclear physics and beyond,” says Padmanath.

January 22, 2025

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Exotic hadrons bend the rules, Frank Close, CERN Courier, 2017

Early birds and the worm

◆ *Roni Saiba*

All multicellular animals begin their lives as a single cell, the zygote. The zygote undergoes controlled divisions to give rise to the whole organism. However, every cell in an individual contains the same genetic material encoded by its DNA (deoxyribonucleic acid) sequence but can have widely different functions. How does each cell decide its fate? How do cells in the skin develop and behave differently from cells in the kidneys? The overarching answer to this question is gene regulation.

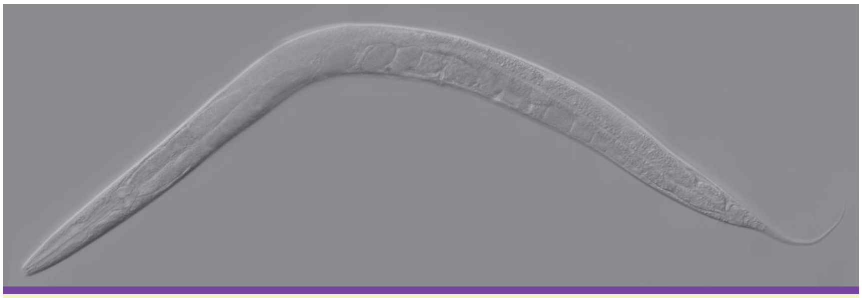
Genes within the DNA sequence encode proteins that play an important role in cell structure and function. The gene sequence is used to make a complementary mRNA sequence (messenger ribonucleic acid) during transcription, which acts as the template for protein synthesis during translation. Gene regulation is the process by which genes required (not required) for a cell's function can be turned on (off). For a long time, proteins were known to be key factors in gene regulation. Proteins called transcription factors bind to DNA and regulate its function by promoting or stopping transcription. However, other regulatory mechanisms are active after mRNA is synthesized, which fall under post-transcriptional regulation. The 2024 Nobel Prize in Physiology and Medicine was awarded to Gary Ruvkun from the University of Harvard and Victor Ambros from the University of Massachusetts for "the discovery of microRNA and its role in post-transcriptional gene regulation."

Gary Ruvkun and Victor Ambros won the 2024 Nobel Prize in Physiology/Medicine "for the discovery of microRNA and its role in post-transcriptional gene regulation". Image on the left by John Sears is adapted from the source and shared under a CC by 4.0 license. Image on the right by Arthur Petron is adapted and shared under a CC by 4.0 license.

"There are other regulatory mechanisms apart from proteins that fall under post-transcriptional regulation.

Ruvkun and Ambros carried out their research on a millimeter-long worm called *Caenorhabditis elegans*. This worm was developed as a model organism in biology by Sydney Brenner, a Nobel Prize winner himself, who also happens to be the academic grandparent of Ruvkun and Ambros. The duo were working as post-docs in the lab of H Robert Horvitz at the Massachusetts Institute of Technology when they discovered a pair of genes, *lin-14* and *lin-4*, which seemed to be involved in gene regulation. Development in *C. elegans* larvae is divided into four stages named L1 to L4. Mutations in these genes lead to heterochronic defects where specific cell types appear earlier as compared to the normal course of development. When *lin-4* is not functional, worms do not develop a vulva as they repeat the L1 stage and accumulate internal eggs. On the other hand, if *lin-14* is not functional, specific cell types start developing precociously, hampering the worm's growth. A gain of function mutation in *lin-14* causes the same effect as a loss of function mutation in *lin-4*, suggesting that *lin-4* regulates the function of the *lin-14* gene.

At the time Ambros and Ruvkun were carrying out their research, transcription factors were considered the primary regulators of gene expression. However, there also were hypotheses and observations regarding the role of RNA in gene expression. Roy J Britten and Eric H Davidson hypothesized the possible role



Ruvkun and Ambros used Caenorhabditis elegans as a model system to study mutations in a pair of interacting genes called lin-14 and lin-4 that influence development. Image by Zeynep F. Altun from source shared under a CC by 2.5 license.

of RNA in gene regulation in 1969, and plant molecular biologists demonstrated that two mRNA strands transcribed from either direction of a DNA sequence bind together to affect transcription. The novelty of Ambros's and Ruvkun's research was to demonstrate the presence of such a process in animals and identify its exact mechanism.

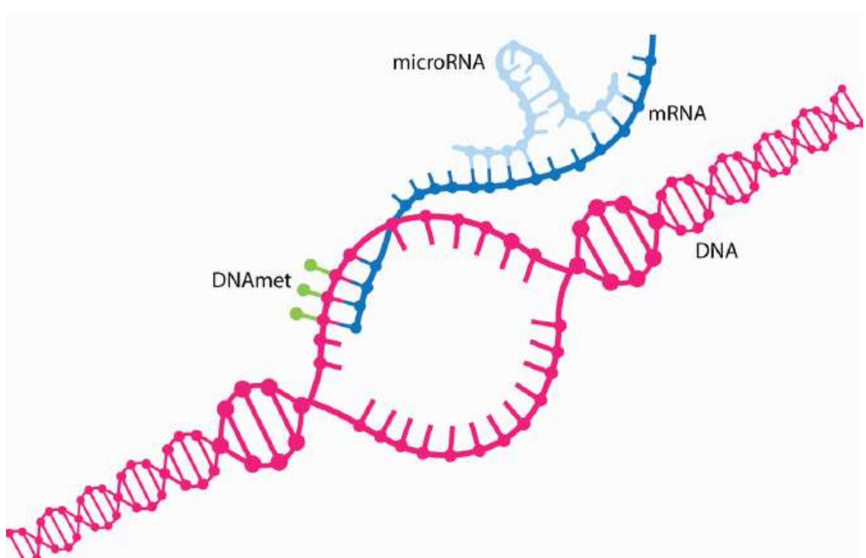
> **"The novelty of Ambros's and Ruvkun's research was to demonstrate the exact mechanism of RNA based gene regulation in animals.**

After their postdoctoral stint at the Horvitz lab, Ambros and Ruvkun established independent labs of their own. Ruvkun settled at Harvard University and chose to study *lin-14* as the target of his research. His group made multiple *lin-14* mutants and painstakingly found their location on the *C. elegans* genetic map. Once this was done, they noticed an interesting pattern. All the gain of function mutations mapped to an untranslated region in the tail end of the *lin-14* mRNA. Ambros also joined Harvard University and was working on *lin-4*, the regulator of *lin-14*, which came with its challenges. In the pre-genomics era, it was a herculean task to map *lin-4* since it occupies a tiny region of the genome only about a 100 nucleotides long. Its length was puzzling because such a short sequence could not possibly code for a protein. How was it achieving its function then?

The eureka moment happened during a phone call between Ambros and Ruvkun on 11 June 1992. When discussing their findings, they observed that a 22-nucleotide-long portion of the *lin4* RNA, called microRNA, is partially complementary to the untranslated tail end of *lin-14*. Et voilà! After transcription, complementary regions of the two mRNA molecules must be binding together preventing protein synthesis in *lin-14*, thus regulating its expression. They independently published their findings in the same issue of the journal Cell in 1993.

> **"Their findings garnered attention when Ruvkun's group identified another regulatory pair of microRNAs conserved across evolutionary lineages.**

Back then, the reception of their now seminal work was lukewarm at best. Most molecular biologists studying animals did not seem to care for a pathway found in a mere worm and plant molecular biologists were trying to understand their own RNA-based observations. Ambros was denied tenure at Harvard,



microRNA binds to complementary regions of mRNA preventing its translation into protein. This pathway of post-transcriptional gene regulation was discovered by Gary Ruvkun and Victor Ambros in the worm Caenorhabditis elegans. Image by KajsaMollersen, shared under a CC by 4.0 license.

after which he worked at Dartmouth College before settling at the University of Massachusetts.

Their findings garnered attention when Ruvkun's group subsequently identified another regulatory pair, *let-7* microRNA and *lin-41*, conserved across evolutionary lineages. In the meantime, Ambros's lab showed that *lin-4* microRNA also regulates another gene called *lin-28*, suggesting a paradigm of microRNA regulation networks that are phylogenetically conserved. Following the theme of post-transcription gene regulation, Andrew Z Fire and Craig C Mello discovered RNA interference, by which double-stranded RNA is involved in gene silencing, and won the 2006 Nobel Prize in Physiology and Medicine.

The puzzle of RNA-based regulation remains to be completely solved and there may be more prizes on the horizon for researchers finding the next missing piece.

January 22, 2025

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The Great Ant Migration: A tiny world in motion

◆ *Shivani Lamba, Asian College of Journalism*

Annagiri Sumana, a Professor of Biological Sciences at IISER Kolkata presented the first talk at Science at the Sabha 2025 about the challenges of relocation in ants. (Photo: IMSc Media)

The tiniest smidgen of sugar falls on the floor, and soon a trail of organisms appears. Who are these black and red-colored creatures? Ants. They not only forage but are often shifting houses—carrying their food and family along. For us humans, relocating our house is often an exhausting and overwhelming process. But why do ants relocate, and how do they manage it?

At the eighth edition of Science at the Sabha, Annagiri Sumana, a Professor at the Indian Institute of Science Education and Research (IISER) Kolkata, opened a window to the world of ants and answered these questions drawing from her lab's research. This annual public event organized by The Institute of Mathematical Sciences, Chennai had four talks from various disciplines.

Breaking myths about ants

Most people believe there are only two types of ants: black and red. Red ants are known for their painful bites, while black ants are considered harmless. However, this is a misconception.

The world is home to over 12,000 species of ants—higher than the total number of mammals or birds on Earth. These ants come in a variety of colors, from shades of brown to even green. They are found almost everywhere in the world, except in polar regions where the extreme cold prevents their survival. Despite their small size, ants have a massive influence on ecosystems, playing crucial roles in soil aeration, pollination, seed dispersal, plant protection, and nutrient cycling.

Ants as guards and farmers

Some ants even have specialized relationships with plants. Certain species feed on the sugary secretions of

Two individuals of the ant species Diacamma indicum demonstrating a tandem run. The follower maintains physical contact with a tandem leader who efficiently navigates to a new location. (Photo: Sumana Annagiri)

plants and, in return, protect them from herbivorous insects. This mutualistic relationship benefits both ants and plants, forming an essential part of many ecosystems. Another fascinating fact about ants is their ability to farm. Some species cultivate fungus gardens, much like human farmers grow crops. These ants cut leaves into tiny pieces, chew them, and place them in designated chambers where the fungus grows. The worker ants then feed on the spores produced by the fungus.

> **"The world is home to over 12,000 species of ants—higher than the total number of mammals or birds on Earth. Despite their small size, ants have a massive influence on ecosystems.**

Do all ants make trails?

A common sight in homes and gardens is a line of ants marching toward a food source. But do all ants form these trails? Surprisingly, no. While many species use pheromone trails to guide colony members toward food, several hundred species do not. These ants forage alone, carrying food back to the nest individually.

Studying ant behaviour

Each ant colony has a strict hierarchy. The queen is the sole reproductive individual, while worker ants perform various tasks such as foraging, defense, and brood care. There are further divisions within the workers—some have strong mandibles and act as soldiers, while others tend to the young.

To study ants, researchers like Sumana mark individuals with paint, with unique colour codes for each member of the colony. This allows scientists to track each individual and study their role within the colony. Observing these individually identified ants provides insights into division of labour, communication, and decision-making within their intricate societies.

Why do ants relocate?

Relocation can be exhausting. Packing, planning, and moving from one place to another takes effort. But what about ants? They also relocate—when their home is damaged, there is competition from neighbours, or when resources are running low.

> **"Sumana's research has found that some ants use tandem running to lead their colony members to a new nest location by efficiently navigating in an unknown terrain.**

Where do ants live? Just as birds live in nests and humans build homes from mud and brick, some ant species create underground nests with intricate tunnel systems akin to a "compact studio apartment". Sumana spoke about her lab's research on one such ant species known as *Diacamma indicum*. They may form colonies of a few tens to over two hundred ants, consisting of the queen, workers and soldiers. Like humans, ants spend a significant amount of time inside their homes.

Transporting one's offspring: Do all organisms do it?

When humans relocate, they always take their children along. But can all organisms carry their offspring from one location to another? The answer is no. Many species leave their young behind, unable to transport them. But ants? They take everything—including their fragile brood—during relocation.

Ant colonies consist of various life stages—eggs, larvae, and pupae, all of which require special care. The colony is the most invested in the pupa stage, which will soon transform into an adult.

The larvae are fragile, and the eggs are the most delicate. Yet, ants manage to transport them carefully, ensuring the survival of the next generation.

How do ants relocate?

Relocating a colony is not an easy task, especially when transporting fragile young. Sumana's research has found that ants of the species *Diacamma indicum* use tandem running to lead their colony members to a new nest location. Tandem leaders are very efficient in navigating unknown terrain and can find some of the shortest routes between the old and the new nest site. During a tandem run, much like holding hands, a follower ant maintains physical contact with a tandem leader as the latter guides it to a new location. Once the site is chosen, workers transport eggs, larvae and pupae.

The followers carefully carry the brood with them, manoeuvring their large load through tiny spaces with help from others. They also watch out for brood thieves—ants from neighbouring colonies out to steal their young ones. Whether escaping a flood, avoiding competitors or seeking better shelter and resources, ants execute relocation in an organized and efficient manner, within six hours on average.

> **"Observing these individually identified ants provides insights into division of labour, communication, and decision-making within their intricate societies.**

Lessons from ants

Ants, despite their size, exhibit remarkable problem-solving abilities and adaptability. Their relocation strategies and cooperative behaviour offer valuable lessons in teamwork and efficiency. The next time you see a line of ants carrying their belongings, remember—they may be executing a big move, a miniature version of what humans experience.

Edited by Bharti Dharapuram

Sumana's talk is available to watch online on the Matscience YouTube channel.

Shivani Lamba can be contacted at shivanilamba108@gmail.com.

March 4, 2025

A gentle invitation to Number Theory

◆ *Janaki Pande, Asian College of Journalism*

UK Anandavardhanan, a Professor of Mathematics at IIT Bombay, presents a talk on number theory to the general public at Science at the Sabha 2025. (Photo: IMSc Media)

The building blocks

Anyone who has sat through maths classes in school will be familiar with natural numbers, rational numbers, and right-angled triangles. Though seemingly unrelated, these basic concepts are all one needs to understand one of number theory's ancient unsolved problems, namely, the Congruent Number Problem.

For those whose school days are a distant blur, a natural number is any whole number except 0 (for example, 1, 2, 3 and so on to infinity). A positive rational number is a fraction made up of two natural numbers (for example, 1/2, 5/7, 19/25). A right-angled triangle can be thought of as one half of a rectangle sliced diagonally.

> **"A natural number is called a 'congruent number' if it can be expressed as an area of a triangle whose sides are rational numbers.**

Under the scrutiny of curious mathematicians, interesting patterns and questions emerge from these basic concepts. These problems are sometimes easy to state, yet their answers are the subject of years of research. The Congruent Number Problem is one such puzzle that was first mentioned in an equivalent form in a 10th century Persian manuscript. Since then, it has surfaced in the notebooks of mathematical legends like Fibonacci and Fermat.

On a warm Sunday afternoon at the Music Academy in Chennai, the Congruent Number Problem is evoked again before a gathering of the general public including young children.

In a hall that often resonates with classical melodies, UK Anandavardhanan, a Professor in mathematics at the Indian Institute of Technology (IIT) Bombay begins his lecture, 'A Gentle Invitation into Number Theory'. It is a part of the eighth edition of the Science at the Sabha, a public outreach event organised by the Institute of Mathematical Sciences (IMSc), Chennai.

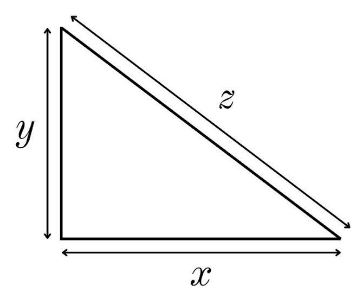
The Congruent Number Problem

"We have all heard of right-angled triangles," says Anandavardhanan. "Can someone tell me what the Pythagorean theorem is?"

A young boy in the crowd answers that it relates to a right-angled triangle, where the squares of the two shorter sides add up to the square of the longer side (for example, $3^2+4^2=5^2$). Anandavardhanan elaborates that the area of such a triangle can be calculated by multiplying its base by height and dividing this by two.

Coming to the crux of the problem, Anandavardhanan explains that a natural number is called a 'congruent number' if it can be expressed as an area of a right-angled triangle whose sides are rational numbers.

In the figure below, n is a congruent number if x, y and z



Area of a triangle:

$$n = \frac{xy}{2}$$

Pythagorean theorem:

$$x^2 + y^2 = z^2$$

The building blocks of the Congruent Number Problem are right-angled triangles, natural numbers and rational numbers. In the image above, n is a congruent number if x, y and z are rational numbers.

are rational numbers. While the concept of a congruent number might have been easy to grasp, the challenge lies in proving whether any given number is congruent or not.

Observations and advances

"Maths is also an experimental science, it's all about pen and paper and deep thinking," continues Anandavardhanan, as the first 50 congruent numbers appear on the screen. To mathematicians, these numbers are raw material for making observations, finding patterns and coming up with conjectures.

Transitioning into the second phase of the lecture, he gives his audience a glimpse into this process of mathematics research. 6 is a congruent number because it is the area of a triangle with sides as the rational numbers 3, 4 and 5 ($3^2 + 4^2 = 9 + 16 = 25 = 5^2$ and (3 x 4)/2 = 6). 5 is also a congruent number–it is the area of a right-angled triangle with sides as the fractions 9/6, 40/6, 41/6, which are also rational numbers. This makes us wonder if some numbers, like six, are more "easily congruent" than others.

The search for congruent numbers its not as easy as it may seem. Anandavardhanan points out that proving that 1, 2 and 3 are not congruent took centuries of research. After the initial mention of congruent numbers in Persian manuscripts, the Italian mathematician Fibonacci claimed that 1 and no other squares could be congruent numbers. This was proved by Fermat four centuries later. Fermat's method also proves that 2 is not congruent. It took many more decades of research to prove that 3 is not a congruent number.

Another observation is that if we scale a triangle associated with a congruent number by a natural number, it is possible to generate more congruent numbers. Scaling the sides of a triangle by a number increases the triangle's area by the square of that number. For example, if we take a triangle (say, with sides 3, 4, 5 and area 6) and double its sides (6, 8, 10), its area increases four times (24). Therefore, if the area of the initial triangle is a congruent number, the area of a triangle scaled by a natural number is the previous area multiplied by a perfect square, which is also a congruent number.

This narrows down the search for congruent numbers to 'square-free numbers', numbers whose prime factors do not repeat. For example, 24 can be written as 2 x 2 x 2 x 2 x 3, which is not a square-free number because 2 repeats itself. On the other hand, 6, which is 2 x 3, is a square-free number. If a square-free number is proved to be congruent, then multiples of that number by a perfect square will also be congruent.

> **"The search for congruent numbers is not as easy as it may seem. Proving that 1, 2 and 3 are not congruent took centuries of research.**

Over the years, the Congruent Number Problem has seen many developments often separated by decades of research. At present, it finds its way into modern mathematics through the world of elliptic curves and modular forms. The most recent development

5, 6, 7, 13, 14, 15, 20, 21, 22, 23, 24, 28, 29, 30, 31, 34, 37, 38, 39, 41, 45, 46, 47, 52, 53, 54, 55, 56, 60, 61, 62, 63, 65, 69, 70, 71, 77, 78, 79, 80, 84, 85, 86, 87, 88, 92, 93, 94, 95, 96, ...

The first 50 congruent numbers. (Source: A003273 - OEIS shared under a CC by 4.0 license)

"Maths is also an experimental science, it's all about pen and paper and deep thinking," says Anandavardhanan. (Photo: IMSc Media)

related to elliptic curves is a conjecture by Birch and Swinnerton-Dyer, which was categorised as a Millenium Prize Problem in 2000. It is among the seven mathematical problems selected by the Clay Mathematics Institute, for a $1 million award. Any progress towards settling the Birch and Swinnerton-Dyer conjecture, in particular, advances our understanding of the Congruent Number Problem.

The chase continues, for an elegant solution that will be able to determine whether a given natural number n is congruent or not.

The thrill of the chase

For many adults, maths remains confined to the classroom, the exam, the powdery remnants of chalk that float to the ground after blackboards are dusted off. "What is taught as maths in schools is not really what people like him do," says Rahul Siddhartan, a faculty member at IMSc, about Anandavardhanan's work.

Once you are out of the competitive system at school, and into a life of research, there is no hurry, Anandavardhanan explains. "You can take your time, meditate about ideas, and rethink things slowly," he adds. To him, mathematics is about adding rigour to approaching questions. It is about looking at proofs, observing what works, and the excitement of possibly applying it to another seemingly disconnected problem.

Even among the academics in the audience, the Congruent Number Problem may have been new to many. In the scientific landscape, every subject and sub-field leads to profound but often isolated depths of research. Anuran Pal, a PhD student at IMSc, says, "Once you are past the barriers of studies and exams, there is a lot of freedom." Scientists follow rigorous methods of inquiry and there are no forbidden questions or limits to their curiosity.

" Over the years, the Congruent Number Problem has seen many developments often separated by decades of research.

Researchers exist in a space where questions abound and the chase for answers never ceases. Sometimes, in events like these, they step out of their silos, to share, however briefly and simply, the problems that consume their days. Yet, as with the Congruent Number Problem, even if their research question seems easy to convey and grasp, the answers remain elusive, awaiting future exploration and breakthroughs.

Edited by Bharti Dharapuram

Anandavardhanan's talk is available to watch online on the Matscience YouTube channel.

Janaki Pande can be contacted at janakipan02@gmail.com.

March 4, 2025

Shadows and Light: The thrilling odyssey of trusted AI

◆ *Keerthivas S, Asian College of Journalism*

On a pleasant Sunday evening, the Music Academy in the heart of Chennai hosted the 8th edition of its annual public event "Science at the Sabha". The event was conducted by The Institute of Mathematical Sciences (IMSc), Chennai. The place was alive and teeming with visitors, as members of the general public made their way to hear a four-part science discourse.

The audience in the auditorium was a diverse mix of people. There was a chatter of excited school kids, probably having their initial taste of a science talk, accompanied by their parents. There were also academics scattered among members of the general public.

At 4:00 pm the lights were dimmed as the stage lit up indicating the start of the event. The first couple of hours rolled by as Annagiri Sumana gave a fascinating talk on nest relocation in ants followed by UK Anandavardhanan's talk on congruent numbers, which saw enthusiastic responses from young members of the audience.

After a break for High Tea, there was a buzz amongst the audience as the stage dimmed and a burst of brilliant blue filled the stage before the third talk began. Richa Singh, a Professor of Computer Science and Engineering at the Indian Institute of Technology (IIT) Jodhpur, strode onto the stage to deliver her talk on "Shadows and Light: The Thrilling Odyssey of Trusted AI".

Richa Singh, a Professor of Computer Science and Engineering from IIT Jodhpur, spoke about the positive and negative aspects of Artificial Intelligence using case studies from her group's research. (Photo: IMSc Media)

"Face-recognition AI models developed by Richa Singh's research group were helpful in identifying victims of the 2023 Odisha train accident.

She first introduced foundation models in machine learning, which are of two types:

- Discriminative models - These models classify data into different categories.
- Generative models - These models generate new content (language, audio, visual, multimodal) similar to training data.

Richa spoke in detail about Generative AI (GenAI), such as ChatGPT and other Large Language Models (LLMs), which generates new content by learning patterns from large amounts of pre-existing data. Different types of data ranging from text, audio, images and videos can be created using these models, marking a significant leap in the capabilities of AI.

She described the GenAI paradox associated with the positives and negatives of AI. She pointed out the positives of GenAI to be -

- Creativity and productivity - Enhancing creativity by constantly churning out new ideas and increasing productivity.
- Democratizing access - Making information and technology more accessible to people, especially the marginalized or disadvantaged.
- Social good application

Richa's group has developed face recognition models that can identify victims of accidents, and improved models of deepfake detection that reduce bias. (Image by Richa Singh/TechScape: IIT Jodhpur)

Richa discussed a few case studies to demonstrate the beneficial aspects of AI. When her group started their research on face recognition with people with facial injuries, with up to 50-70% disfigurement, the existing models fared very poorly. So Richa's group developed models with much better accuracy in matching images of people with facial injuries with their earlier photographs without injuries.

> **"GenAI is not a magic wand: handle with care.**

Her group was able to put this model to use to identify victims of the 2023 Odisha train collision which claimed the lives of hundreds of people. Using face-recognition AI models developed by her research group, over 120 unclaimed bodies, often with facial injuries, were matched with photos in a database of identification documents within 18 hours.

In another example, Richa highlighted how her research group assisted law enforcement by using an AI model to generate a realistic image of a suspect from a police sketch. These examples showcase the power of AI in helping government agencies.

Richa elaborated on the negative aspects of AI including -

- Bias and fairness concerns - Bias can find its way into GenAI via skewed real-world training data that mirrors existing societal inequities and discrimination.
- Potential for misuse - Usage of AI with malintent to harm people. For example, the creation of deepfakes that could victimize people or spread of misinformation among the public.
- Opacity and explainability issues - The lack of transparency about the inner workings and decisions made by an AI model, which generates its output.

Illustrating the difficulty of recognising deepfakes, Richa played a few audio recordings and asked the audience to identify the fake and real voices. Using case studies from her group's work on deepfake detection, she highlighted misuse of AI tools to spread misinformation and victimize vulnerable sections of the public.

> **"Richa highlighted how the misuse of AI tools can spread misinformation and victimize vulnerable sections of the public.**

She discussed how AI models developed by other countries perform poorly with Indian data because of biases in model training. One example was the low accuracy of deepfake detection with Indian voices. This is because AI models do not recognize the diversity in Indian accents since their training data predominantly come from western countries.

Richa also spoke about how negation prompts to GenAI fail to give the desired results. These prompts deal with descriptions of the elements one wants to exclude from the output, which as her group discovered, gives unexpected results. They are currently working on improving the performance of AI models with negation prompts.

Richa concluded her talk with the simple yet powerful quote "GenAI is not a magic wand: handle with care", cautioning the audience about harnessing the powers of GenAI judiciously.

Edited by Bharti Dharapuram

Richa's talk is available to watch online on the Matscience YouTube channel.

Keerthivas S can be contacted at skeerthivas@gmail.com.

■ **March 4, 2025**

How disorder rules the world

◆ *Shumaila Firoz, Asian College of Journalism*

Pinaki Chaudhuri from IMSc Chennai spoke about disordered systems across scales, from molecular arrangements in disordered materials to biological and natural phenomena. (Photo: IMSc Media)

There is a comforting illusion that the world is built upon order. Despite this perception of organization, there is substantial disorder in the physical world that often goes unnoticed. The study of disordered systems even won the 2021 Nobel Prize in Physics, awarded to Giorgio Parisi "for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales".

Pinaki Chaudhuri, a faculty at The Institute of Mathematical Sciences (IMSc), Chennai recently presented a popular talk on disordered systems at Science at the Sabha 2025. He shed light on the pervasiveness of disorder in the natural world from materials that are hard to classify to complex systems like crowds and natural disasters. Blending scientific rigour and accessibility, he spoke about the unusual properties and complex behaviour of disordered systems, leaving a deep appreciation of such phenomena.

Rebel materials

Nature has many examples of structured arrangements, such as crystalline materials with an ordered arrangement of atoms or molecules. Disordered materials like glass defy this regular structure, existing in a state that is unlike a typical solid. Glass holds its shape, does not flow at room temperature and breaks into smaller fragments when struck. In contrast to crystalline solids, glass has a random arrangement of molecules. Such materials called amorphous solids seem to exist between solid and liquid states, refusing to classify neatly. What makes materials with such a random arrangement have solid-like properties remains a mystery.

The packing of underlying components to fill up space shapes the properties of such materials. In disordered materials, these components can settle into different arrangements even from the same starting conditions. Researchers use computer models to study how these components interact with each other to give rise to various packing arrangements having different energy states.

> **"The 2021 Nobel Prize in Physics was awarded to Giorgio Parisi "for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales"**

Disordered solids come in various forms and size-scales. They range from metallic glasses with high endurance strength where atoms are disordered at less than a nanometer scale, to granular solids like sand, where particles are visible to the naked eye. Based on the size-scale of their components, they can occur as hard or soft amorphous solids.

> **"The mechanical properties of disordered systems are a balance between flow and failure. Disordered systems show unpredictable behaviour as they have many components with complex interactions.**

Flow and failure

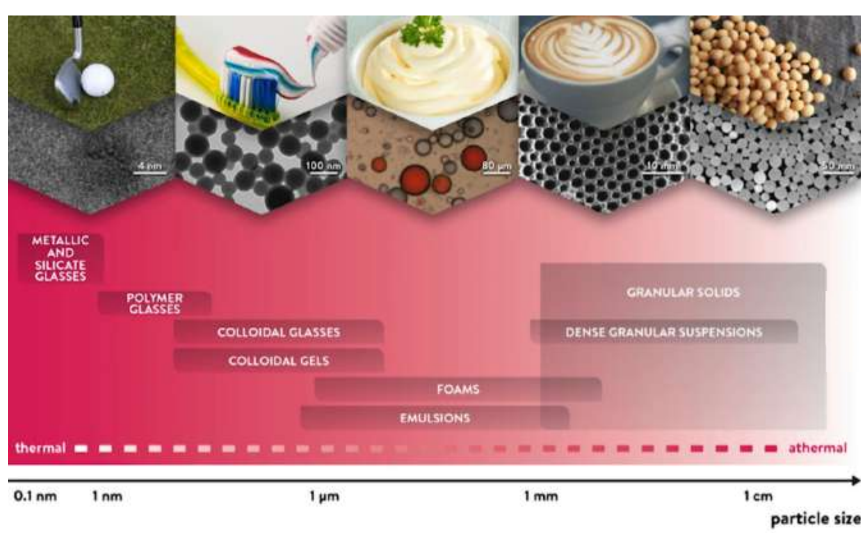
Disordered solids have unique properties that are different from traditional rigid materials. Examples of soft disordered solids are a pile of grains, sand castles, ketchup, toothpaste and tar. These maintain their shape until an external force causes them to flow. This transition occurs at the yield stress, which describes the minimum force required to make a material flow like a liquid. A pile of grains behaves like a solid when stable, but can flow like a liquid with a slight disturbance. Toothpaste remains in the tube until you squeeze it, after which it flows onto your toothbrush.

The mechanical properties of disordered systems are a balance between flow and failure. Disordered systems are characterized by unpredictable behaviour as they have many components that interact with each other in complex ways. This is an important challenge while working with materials as it is difficult to predict when they may fail in response to varying pressure, temperature and stress. Avalanches and landslides are other examples of disordered solids breaking, which can have devastating human consequences. Researchers are interested in understanding how and where fracture starts, which can be used to predict and prevent failure. This can be used to design better materials and structures and predict catastrophic events.

> **"From the organization of natural structures to the traffic systems that we navigate daily, disorder is everywhere, shaping the way materials, organisms, and even human societies function.**

Traffic snarls to tumour cells

Another property of disordered systems is jamming, for example, the sudden clogging of a funnel when rice grains stop flowing abruptly after having smoothly passed through it. This phenomenon, a quick transition from a flowing state to a rigid one, occurs due to the tight packing of components in a constrained space. Other contexts in which jamming is relevant are traffic snarls, stampedes, transport of macromolecules within cells, the spread of tumour cells, etc. This has implications



Disordered materials have a random arrangement of molecules and exist in a state in between solids and liquids. They come in various forms and size-scales ranging from metallic glasses to granular solids like sand. (Image by Pinaki Chaudhuri) for materials science, urban planning, health care and even disaster management.

An unconventional view of the world

Disordered systems help us recognize that the world is not as neatly structured as our school textbooks might suggest, but is rather complex. From the organization of natural structures to the traffic systems that we navigate daily, disorder is everywhere, shaping the way materials, organisms, and even human societies function. As research progresses, our understanding of these disordered systems may reveal new insights into some of nature's most complex and unpredictable behaviours, and even social organization.

It is a field that refuses to fit into conventional categories, much like the materials and systems it seeks to understand.

Edited by Bharti Dharapuram

Pinaki's talk is available to watch online on the Matscience YouTube channel.

Shumaila Firoz can be contacted at shumailafiroz4668@gmail.com.

March 4, 2025

INTERVIEWS

Aysha Mahira

Shweta Jain: At the intersection of game theory and machine learning

◆ *Bharti Dharapuram*

Shweta Jain is an Assistant Professor at the Department of Computer Science and Engineering, Indian Institute of Technology (IIT) Ropar. She completed her Masters and PhD from the Department of Computer Science and Automation at the Indian Institute of Science (IISc), Bangalore. Bharti Dharapuram caught up with her at the ACM (Association for Computing Machinery) school on 'An Invitation to Algorithmic Game Theory' hosted at IMSc, Chennai where she taught several lectures.

Shweta Jain

What are your broad research interests?

I work at the intersection of game theory and machine learning. A lot of interesting problems involve solution techniques from both these fields. The field of ML-AI (Machine Learning and Artificial Intelligence) is evolving at a rapid pace. What excites me is how theoretical analysis can help towards finding efficient solutions to its practical applications. An aspect of game theory is that it is a perfect information model. Players understand valuation, utility model, choices made by others, and based on these one can run analyses and derive equilibrium strategies. Game theory says that if people are rational and intelligent, they will behave in a certain way. However, if you consider a situation where the world is not perfect, one wouldn't know this information beforehand, then my research intends to find out how agents behave in such situations.

> **"An aspect of game theory is that it is a perfect information model. However, if you consider a situation where the world is not perfect, one wouldn't know this information beforehand. My research intends to find out how agents behave in such situations.**

In my talk at the summer school, I spoke about the multi-armed bandit mechanism, which combines multi-armed bandits from reinforcement learning with auction theory. In this problem, a social planner and agents realize the reward of an action only after that action is taken. The question that we are trying to ask is, eventually, when everyone starts gathering more information about the rewards while exploring the actions, how does the strategic choice of the agents change over time?

What are some of the applications of your research?

One application is the sponsor search auction – Google gets paid whenever somebody clicks on an advertisement, and they want to learn the click probability of these ads. At the same time, they also want to learn how much advertisers value a particular advertising slot on the website, which is an auction problem. Another interesting application is the combination of congestion games with imperfect information. There could be multiple routes from my office to home, and I can only get to know which route is better when I actually take that route. This is a multi-agent problem because the cost of that route depends upon what routes others are taking.

Another example that I talked about in my lecture is demand response. Imagine that you want to reduce the peak load in a smart grid scenario. One practical way to do that is to charge people based on how much power they consume and also based on the peak time. A different perspective is to formulate the problem from a mechanism design perspective and design a game to incentivize consumers to reduce their load during peak hours. This is an exciting application because the demands are stochastic, and you are learning over a period of time while also trying to come up with a game to shift the peak demand.

> **"A primary challenge was that I had a two-body problem. We were not particularly in favour of working at two different places, so our focus was to find a job at the same place and support our daughter.**

What are the challenges that you have faced in your academic journey?

A primary challenge was that I had a two-body problem – my husband did his PhD in mechanical engineering at IISc and was also looking for a job. We were not particularly in favour of working at two different places, so our focus was to find a job at the same place and support our daughter. Every institute has its own requirements and expectations, so this was particularly challenging and an issue that a lot of people are facing. Academic institutes should start looking into this if they want good people to join them. I also had to do a lot of interviews, and sometimes, the process was really slow. I enjoyed doing interviews, talking to people, and traveling, though. It helped me make many friends across different IITs.

What is your advice for PhD students entering the job market?

I wanted to be an academician right from the beginning, not just because of research but because I have a huge passion for teaching. We wanted to be in India to be closer to family, so we never considered going abroad. I gave some interviews for industry jobs after my PhD, but I don't think it was meant for me. The only downside of academia is its salary structure compared to industry. Otherwise, you have the freedom to choose your problems and shape your research. It is great if you are in academia and working in collaboration with industry – you have the freedom to choose among challenging problems and decide how to solve them. This is my personal perspective because a lot of people do enjoy an industry job. There are pros and cons to both, and I would say it is a personal choice. And a student should list his/her priorities before entering the job market.

What are your thoughts on representation of women in ML-AI research?

It is low, but I have seen an increasing trend over the years.

> **"The representation [of women in ML-AI research] is increasing but not at the pace it should. However, these days, I am seeing a good representation of women in PhD programs, which is encouraging.**

Even among the computer science faculty at my institute, there are only four female faculty out of twenty-three. During my Masters from IISc in 2008-2010, there were only three women in an entire batch of about fifty. The representation is increasing but not at the pace it should. The drop-off is significant if you consider a family's expectations of marriage for women. I could only do my PhD after marriage because I was fortunate to find someone who was also interested in research and was supportive. That doesn't happen to everybody. However, these days, I am seeing a good representation of women in PhD programs, which is encouraging. Every conference has women-specific workshops or committees and we are discussing women in science. Women are coming together, collaborating and talking, which is nice.

July 31, 2024

Olaf Beyersdorff: A researcher with a recurrent academic home in Chennai

◆ *Bharti Dharapuram*

Olaf Beyersdorff is a Professor of Theoretical Computer Science at the Friedrich Schiller University Jena who works on proof complexity. He first came to IMSc as a PhD student and has continued to collaborate with researchers here ever since, introducing many of his own students to the campus. While on a recent visit, we caught up with him to chat about his research interests and his enduring association with IMSc.

Olaf Beyersdorff

What is the broad area of your research?

The area that we work in is called proof complexity, which is a branch of theoretical computer science. Proof complexity is a special facet of complexity (or computational complexity), which started about fifty to sixty years ago as a theoretical endeavour to understand the complexity of proofs for mathematical statements. It is a meeting point of a couple of disciplines fundamental to theoretical computer science, namely, logic, algorithms and complexity.

Imagine that we have a mathematical statement, which we know is true and, therefore, has a valid proof. We specify this theorem and want to understand how complex or long the proof needs to be. In order to make that a rigorous question, we need to define a formal proof system – a language in which to write down the proof succinctly and formally. Once we have these two things at hand [a theorem and a formal proof system], one can ask - 'What is the shortest proof of the theorem in that formal system?' This is the basic question that we are interested in, and the field has a long tradition of investigating many proof systems.

“Proof complexity is a special facet of computational complexity, which started as a theoretical endeavour to understand the complexity of proofs for mathematical statements. It is a meeting point of logic, algorithms and complexity.

A surprising discovery over the last 20 years has been that proof complexity has close connections to another area called solving. It is an area where practitioners try to solve complex computational problems that arise in many areas such as software verification, hardware verification and model checking. These problems often don't have good algorithmic solutions, but existing algorithms try to solve them as efficiently as possible. While they do not always succeed to give an answer, they do so in many industrial instances. And we don't really understand why. Proof complexity comes into the picture here, because it provides the main theoretical framework to try and answer this question.

“The ongoing visit is at least the second academic generation of collaborations with IMSc. My first visit was 23 years ago when I was a young PhD student.

We have been looking at proof complexity of Quantified Boolean Formulas (QBF), which is an extension of satisfiability (SAT) testing. This area has seen a lot of development in the past 20 years and we have been contributing to its theoretical foundations over the last decade. This includes defining the number of proof systems for QBF, defining a number of interesting formulas, looking at proving precise bounds on the size of the proofs, etc.

Can you tell us about your long association with IMSc?

The ongoing visit is at least the second academic generation of collaborations with IMSc. My first visit was 23 years ago when I was a young PhD student with Johannes Köbler at Humboldt University, Berlin. He has a long-standing collaboration with V Arvind from IMSc [retired theoretical computer science faculty and former Director] and still visits on a very regular basis.

This was on graph isomorphism, an interesting problem in computational complexity that doesn't neatly fit into any one of the standard complexity classes. I vividly remember that both Johannes and Arvind involved their PhD students in the collaboration.

My next stage was at Leibniz University in Hannover with Heribert Vollmer who happened to have an [Indo-German] DAAD-DST project; there have been multiple iterations of this program over the years. He had a project with Meena Mahajan, IMSc. faculty, on algebraic circuit complexity, and I was very happy to return to IMSc. It is one of the best exchanges that we've had, and quite fruitful in terms of publications that emerged. And this time something quite beautiful happened - I got Meena interested in proof complexity.

> **"IMSc is a recurring home in my academic life. What I really appreciate is that IMSc seems like a haven for research where they focus on the right things.**

This wasn't one of her research topics before, she is an expert in complexity and algorithms, in particular, algebraic complexity. At first, we started looking into algebraic aspects of proof complexity, in a specific class of proof systems called NC0 proof systems, where verification of proofs is done by very restricted resources. A couple of years later when I moved to the University of Leeds, we continued our collaboration, and I consider it one of my biggest successes that I got her interested in QBF proof complexity.

This is the third generation of my own PhD students that I have involved in the project, first from Leeds and now from the University of Jena. I don't exactly remember how many generations of PhD students I got to know at IMSc, but it was quite many. Meena is one of my most frequent collaborators, and it is great that our expertise is complementary. We not only meet in Chennai but regularly organize seminars together and meet in cities around the world. There is usually a series of visits where we discuss ideas and new directions, and try to get some work done, following it up when we return to our own institutions.

IMSc is a recurring home in my academic life. It is a very special place in having one of the best and largest theoretical computer science groups internationally. What I really appreciate is that IMSc seems like a haven for research where they focus on the right things.

What is your advice for young researchers?

I think it is good to be open-minded. I've been to a number of places - my career goes through Berlin, Hanover, Sapienza University in Rome, Leeds and Jena. I think it is good to see how things are done in different places and how different systems work, because you gain diverse perspectives. It is good to collaborate, to meet new people, and to introduce them to your research area and what you are doing. I have had a couple of changes of direction in what I have looked into and it was influenced by the people I met. You need to have your own agenda but also be open to listening to what other people have to say. I think that is quite important.

> **"I didn't know much when I first came to India, but I have been quite fascinated about it culturally and historically ever since. I've been to many Carnatic concerts during the music season and really enjoyed the music scene.**

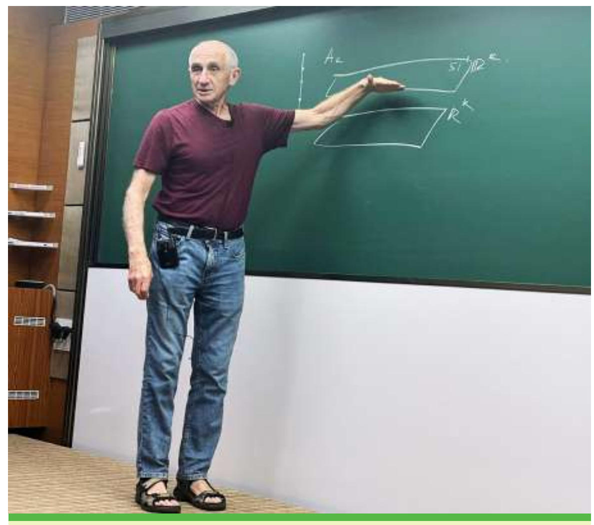
What other fun things are you involved in when you visit Chennai?

I didn't know much when I first came to India, but I have been quite fascinated about it culturally and historically ever since. While visiting Chennai in December, I've been to many Carnatic concerts during the music season and really enjoyed the music scene. I am quite into Western classical music and I find this parallel musical cosmos very interesting. It was striking at first, it felt like coming from the moon and seeing this other musical universe that is so rich and different. I find it interesting that rasikas are real experts in Carnatic music but may not know much about Western music, and vice versa for people trained in Western music. I have been to Kalakshetra several times and seen performances. India has fascinated me a lot culturally, I must say.

October 10, 2024

Yakov Eliashberg: Unfolding insights from a life in mathematics

◆ *Bharti Dharapuram*



Yakov Eliashberg

Yakov Eliashberg is the Herald L. and Caroline L. Ritch Professor of Mathematics at Stanford University, whose research spans the fields of symplectic and contact topology. As the inaugural speaker of The TNQ Distinguished Lectures in Mathematics, he delivered a lecture on 'The Strange and Wonderful World of Symplectic Geometry' at the Indian Institute of Technology Madras on 26 September 2024. As a part of the TNQ Numbers & Shapes program, he also taught a five-day workshop on symplectic topology, hosted at The Institute of Mathematical Sciences, Chennai between 23-27 September 2024. During his visit, Bharti Dharapuram met with him for a conversation about symplectic geometry, mathematics and his journey.

Mathematics and mathematicians

Author's note: *Symplectic geometry finds its origins in Hamiltonian mechanics. Here, the motion of a particle is described by a curve in a coordinate system known as phase space. Every point in a phase space is defined by position and momentum, combinations of which describe all possible states any particle can assume. Given an initial state, a particle's motion is described by a curve in the phase space such that the area of the parallelogram enclosed by its position and velocity vectors in a specific coordinate direction remains constant over time. In this case, the property of area preservation emerges from Hamilton's equations of motion, which constrains the paths a particle can take from the set* *of all possible trajectories. This property of area preservation in specific coordinate directions is known as symplectic structure. Mathematicians study properties of symplectic structures and transformations which preserve it.*

Symplectic geometry, put simply

Symplectic geometry is a geometric structure discovered in attempts to formulate equations of mechanics. In the 19th century, great polymaths (Lagrange, Jacobi, Hamilton) were trying to derive better formulations for Newton's laws of mechanics. At the time, two approaches - the Lagrangian and Hamiltonian formalisms, came about. These ways of stating mechanical problems and writing equations still exist today and depending on the purpose, one might be better than the other. In some sense, the approach of Hamilton is more geometric.

It describes a mechanical system by what is called its phase space. A point in the phase space determines not only the position of the system but also its velocity or momentum. You can think of the development of a dynamical system as a curve in this space. Every point in this space gives you the system's initial position, and the Hamiltonian function, which is the energy of the system expressed through velocity or momentum, gives you its dynamics. Early work showed that this flow of the system given by the Hamiltonian function preserves many interesting geometric features. For instance, it preserves volume, but Poincaré observed that it preserves much more. It preserves something called symplectic structure, which is a geometry based on area rather than distance. This is in two-dimensions, but symplectic structure can be generalised to higher dimensions.

Poincaré was interested in celestial mechanics and probably was the first to realise that mechanical equations for most real-life problems are not integrable, in the sense that you cannot just write down a formula and find a solution. Even with powerful computers you cannot answer many of these interesting questions. Even if you compute a numerical trajectory, you don't know if the trajectory follows periodic motion and if the periodic orbit is stable or not. For instance, it is still an open problem if the motion of the solar system is periodic - but we are kind of safe for the next billion years!

> **"We act in this mathematical world exactly the way an explorer would in the real world. We go there, we try to see what is possible and sometimes discover that there is a prohibition. We then try to change our approach subject to newly discovered constraints.**

What mathematicians do

There is, I think, a misconception among the general public about what mathematicians do. I don't know how it is in India, but in the United States when you read an article about some great mathematical discovery, the newspapers say "this mathematician solved a puzzle". It is made to look like some kind of entertainment for adults. There are many interesting and famous classical problems we would like to solve and what do mathematicians do in order to solve these? We create new worlds. For example, to study symplectic geometry we created the symplectic world. When we come to this world, we do not know what is possible and are exploring. We go there, we try to see what is possible and sometimes discover that there is a prohibition, there is a law of nature which says that a certain construction is not possible. We then try to change our approach to see what is possible, subject to newly discovered constraints. We act in this mathematical world exactly the way an explorer would in the real world.

I think it is extremely rare [that mathematicians work in complete isolation]. Mathematics is collective work, which is very important. Even if there are great people who appear to achieve results in isolation, most of them wouldn't be able to do it without a lot of background work done by the whole mathematical community. I think most reasonable people can become good mathematicians, no doubt. Of course, nobody is guaranteed to make a great discovery, even if they are a genius. But everybody can do some useful and important work, and there is enough important work for everybody. Of course, it is also important to have some fantastic people who appear a few times in a century.

Problems and solutions

There are good questions that you can ask and there are not so good questions. In my view, finding good questions is at least as important as solving them. This, of course, requires experience. Usually, there is a problem and in many cases, the goal of solving it is very far. In science, there is an extremely important thing called arguing by analogy. It is important not to be very narrow in your field but to have a broader understanding in mathematics, and to know many subjects, so you can bring ideas from one to another.

[Imagine] you have a problem and a preliminary idea of what you expect will happen and you try to prove it. In many cases what you are trying to do may be wrong, but it is not obvious. It looks like you are coming very close to finding the solution but somehow something always goes wrong. Sometimes persistence does pay dividends, but in most cases it is a sign that maybe things are not right. It is important to be open-minded, maybe you can completely change your mind to see if the opposite route would work.

When I was a student in Leningrad University, my advisor was Vladimir Abramovich Rokhlin, who was a very good mathematician. I learned a lot from him but also from a senior student, Mikhail Gromov, who was a fantastic mathematician. He greatly influenced all my views of mathematics. There was a problem related to symplectic geometry [Arnold's conjecture, generalizing Poincaré's last geometric theorem] that we were both thinking about. It was completely unclear what kind of outcome it could have. It could be A , or B, the complete opposite. In the beginning, both of us thought that B was the answer, so for a while, I tried to prove B, but there were always some mistakes. At one moment I realised that probably just the opposite was true. Therefore, I started to think about it and thought about it for many years before finding the solution. It was an effort spread over at least six to seven years.

> **“In my view, finding good questions is at least as important as solving them. It is important not to be very narrow in your field but to have a broader understanding in mathematics, and to know many subjects, so you can bring ideas from one to another.**

Drawing Indian students to geometry

In general, I think [mathematics] research in India has traditionally been restricted to certain areas. For example, number theory, probably thanks to Ramanujan, is extremely popular. There are fantastic number theorists in India. When I first came here around ten years ago—it was my first time in Chennai—I met with Dishant Pancholi, and MS Raghunathan, a great mathematician whose work is close to geometry. We discussed that it would be great to do something to develop geometry and topology in India, and I am happy to see that it is happening now.

Reflections on his past

Author's note: Yakov Eliashberg was born in Saint Petersburg (Leningrad at the time), and as a young child took serious interest in playing the violin, dreaming of becoming a professional musician. Alongside this, he was inspired to learn mathematics from the system of olympiads and math circles that were prevalent in the Soviet Union, mentored by some great teachers. At a critical juncture in school that shaped his future, he chose to study science and mathematics over professional violin. He went on to finish his doctorate from Leningrad University and found a position at the Syktyvkar State University where he taught mathematics for a few years. With a rising wave of antisemitism, he quit his job to try to emigrate in the footsteps of family and friends who had left abroad. When he was denied permission, he worked as a substitute teacher and computer programmer for many years before he was allowed to emigrate to the US, where he resumed mathematics research. Since 1989, he has held a position as a professor of mathematics at Stanford University.

Playing the violin

I continued playing the violin for a while in the US but stopped at some point. It is difficult for everyone to understand, but I had the following very strange problem. I always had an extremely good pitch, what you would call a perfect pitch. But sometimes a blessing can become a problem - because this sense of a perfect pitch at some point shifted by almost a single tone in my ears. Whatever I heard had this shift, which made it extremely difficult for me to play in ensembles. I had to correct for it while playing, and for me, it was like playing something wrong.

> **"I was very lucky when I emigrated. But I was prepared that it may be difficult for me [to return to doing mathematics]. I really didn't know whether I would be able to restart and effectively function as a mathematician. I am happy that I managed.**

Math circles in the Soviet Union

The whole system of olympiads and math circles was extremely well-organised and there were a lot of really great people participating there. When we were at university, many students went to schools and organised mathematics circles. It was loosely organised but, I think, it was extremely important. I was running this circle for a couple of years when I was at university and I know at least two or three extremely good mathematicians who came from this school. But there were extremes in this movement. For instance, the system had some people who were oriented towards training students to win prizes, which can be unpleasant. I was luckily not participating in this. A prize is fine as a stimulus, but when it is the only goal it becomes like a professional sport and defeats the purpose.

To be reborn as a mathematician

I was essentially out of mathematics for maybe seven to eight years in the Soviet Union. I needed to do something to earn money for living. I was trying to do mathematics but was too tired with the other things I was doing, which were also mentally taxing. I was invited as a speaker at the International Congress of Mathematicians, Berkeley [August 1986] and, of course, I was not allowed to go. But after this meeting, a Berkeley mathematician - Alan Weinstein, one of the founding fathers of symplectic geometry, organized a special year-long program on symplectic geometry at the Mathematical Sciences Research Institute (MSRI). He sent me an invitation to the Soviet Union. I considered it a joke because there seemed to be no chances for me to go there. But suddenly, I was allowed to go. I had an invitation, I got the permission and I had the opportunity to spend a year at this research institute and do mathematics. That, I think, was extremely important. I was very lucky when I emigrated and came to the States. But I was prepared that it may be difficult for me [to return to doing mathematics]. I really didn't know whether I would be able to restart and effectively function as a mathematician. I am happy that I managed.

January 26, 2025

The author thanks Dishant Pancholi and Sushmita Venugopalan for discussions related to symplectic geometry that greatly helped in writing the introduction.

Further reading:

Interview of Yakov Eliashberg, Allyn Jackson, Celebratio Mathematica, 2024. https://celebratio.org/Eliashberg_Y/article/1166/

Podcast featuring interview of Yakov Eliashberg by Ramaseshan Ramachandran, produced by Maed in India for the TNQ Distinguished Lectures series, 2024. https://pod.link/1740737148/a8229fa65d9e9aafed82043

The TNQ Distinguished Lectures in Mathematics, TNQ Foundation, 2024. https://www.tnqdistinguishedlectures.org/about-speaker/yakov-eliashberg.html

How physics found a geometric structure for math to play with, Kevin Hartnett, Quanta magazine, 2020. https://www.quantamagazine.org/how-physics-gifted-math-with-a-newgeometry-20200729/

CAMPUS COMMUNITY


Varuni Prabhakar

Long conversations (not all) about short stories

◆ *Bharti Dharapuram*

A recent meeting of the reading club at the library.

An email announcing the first meeting of the IMSc reading club went out in November last year amid a flurry of excitement. There was a lot of planning, the organisers printed posters and spammed people with invitations. But cyclone Michaung struck, throwing cold water on their plans. Even while wading in knee-deep water, people kept asking if the reading club meeting was on, says Hareesh, a PhD student and one of the club's many organisers. This eagerness, shining through the occasional cynicism, has kept the club rolling since its debut in January. It is a place where books are sometimes an excuse to meet people, share stories and have a good chuckle.

The reading club meets once every two weeks, where the discussion is loosely based around a theme. It is difficult to find one book that everyone likes, so this format works better as anyone can pitch in. The first meeting invited people to talk about a book they would recommend to others and the hype drew in more than twenty faculty and students. But there was an air of formality about it, which has faded in the following meetings, brightening the conversation among a smaller group of people.

'Short stories' was the theme of the meeting that I attended, where people were encouraged to bring a copy of a book they wanted to talk about. Seven of us sat around the long table on the second floor of the library, where the meetings usually take place. "Initially we thought it would be hard to get access to that space, but when we spoke to the librarian, he was more than happy to bring in some activity," Hareesh says.

We pretty much threw the theme out of the window right from the beginning. There were conversations about the books we are reading, genres and authors we love and hate, our inability to read, and our determination to not like books we haven't read. There was even a friendly introduction to magic realism and postmodern literature, with hilarious anecdotes going around. We did bounce the ball back to the theme every now and then, talking about short stories by classic Russian authors, Saki, Ted Chiang's science fiction, Jhumpa Lahiri and RK Narayan, wondering if people aren't writing as many short stories these days. We also talked about writing in Indian languages, where there was excitement about Satyajit Ray's Professor Shonku, and the incredible life of the Marathi author Achyut Godbole. This happens very often, conversations soar and expand to discussions around books and reading, comics, movies or life in general. A courageous few make notes and diligently document the references that come up in the unwieldy conversation.

The last meeting had no theme to it. Was it anarchy, I ask. "It was actually amazing," Hareesh replies. "It started with a detective novel and then went to many topics like graphic novels, comics, superhero movies," he says. "I think the last 15 minutes of almost every meeting is people talking about random things - it is almost like a therapy session."

The friendly neighbourhood reading club is always looking for new themes to discuss and ideas for other interesting sessions to organise. If you have any ideas, write to **hareeshj@imsc.res.in** or **nmitra@imsc.res.in**, drop by the next meeting and jump into the conversation.

July 31, 2024

Remembering Kiddo (2008 - 2024)

Bharti Dharapuram

Photo: Shanmuga Priya

When I came to IMSc a few months ago, I was mildly shocked to see someone lying in wait as I opened the door to enter the new building. Elderly and dignified, she shuffled past, barely noticing my presence. I was worried that she may be lost but she walked away resolutely, seeming to know where she wanted to be. Little did I know that Kiddo had spent almost seventeen long years at IMSc, seeing generations of students come and go as the emeritus pet on campus. Over the last few weeks, I spoke to some of them who recollected memories of her.

Kiddo was a pup in 2008 when she was brought to IMSc with a broken leg after a road accident outside campus. A few students got her treated by a vet who recommended that she be kept indoors till her leg healed. The students approached Nick Gill, a postdoc, and his partner since they lived in a flatlet on campus. "We were very happy to have her to stay - my partner and I both love animals. We were already friends with Butch so we were happy for Kiddo to join the family," Nick says. Kiddo lived with them for a few days till her cast came off. "We called her "tiddles" because she was "a tiddler", a small quite scrawny pup when we first met her," he says.

"She was very loving and not at all scary," says Madhushree Basu, who met Kiddo soon after she joined IMSc as a PhD student. "The first memory I have is of

Gopala Krishna K [former IMSc student] coming from the hostel side with Kiddo." Many students helped raise Kiddo, some of whom were Ramachandra Phawade, Rohan Poojary, Sowmyajit and Alok Laddha. "It actually took a village," Madhushree says. "When Alok went to IMSc to give a talk recently, Kiddo came into the lecture room looking for him." There were many dogs on campus back then, Blackie and Kiddo on either side of the campus and a couple of visiting street dogs. "She was not a very 'happening' dog", Madhushree jokes. She recounts Kiddo's brief phase of bravery when she chased crows and troublesome monkeys along with Chikku, another campus canine. But it was short-lived. Kiddo's was a largely chill and calm life, says Madhushree.

Nick Gill, a postdoc at IMSc, and his partner took Kiddo (right) in when she came to the campus with an injured leg. They called her Tiddler, who was their dog friend along with Butch. "She must have been renamed as Kiddo. I don't know how that renaming happened," Nick says. (Photo: Nick)

Pinaki Banerjee remembers Kiddo being largely indifferent to his presence while he was on campus between 2011-2017. "It was my girlfriend Rusa, now my wife, who mostly took care of her," he says. They shared this responsibility with their senior Rohan Poojary, who had been feeding Kiddo for many years. "She didn't care much about anything, just like the research scholars at IMSc," Pinaki laughs. But one day he twisted his ankle while playing tennis and fell on the court. "Kiddo, who never entered the tennis court, came and circled me. That was the first and last time I saw her inside the tennis court." This made Pinaki wonder if she actually cared. After he graduated and moved out of campus, Pinaki vividly remembers her affectionately coming to him and hanging about him whenever he visited.

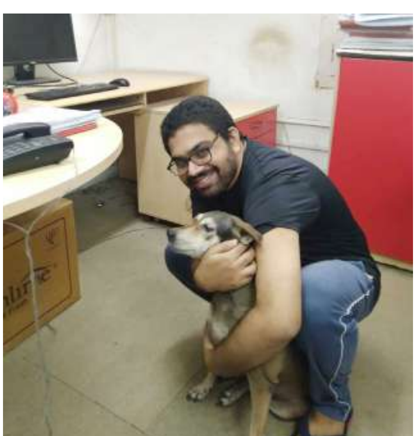
Aaloka and Alok with Kiddo at IMSc. (Photo: Varuni)

"When I first came to IMSc in 2016, I was not very attached to dogs," says Semanti Dutta, who started taking care of Kiddo following Pinaki and Rusa, and another student

Pinaki and Rusa with Kiddo in the main building. "She was an institute dog so there were a lot of people who were always around her," Pinaki says. (Photo: Pinaki)

Kiddo dozing off near the canteen. (Photo: Pinaki)

Prashanth Raman, who was very fond of animals. "She was a very well-trained dog," but could be shrewd on occasion, like when Semanti gave her some unappealing vegetarian food and Kiddo pretended to fall terribly ill. "We got really worried, but we gave her milk and biscuits and she was fine in a moment," Semanti laughs. She mentions how different Kiddo's reaction was whenever Alok would visit the campus. "She looked so happy, I have never seen her like that with anyone else." Semanti remembers bringing treats for Kiddo from her trips home. "I used to treat her like a friend," says Semanti. "She was an integral part of my IMSc life."



Sruthy, Anupam and Kiddo, were among the very few who stayed on campus during the pandemic. "I wrote my thesis during Covid so our full focus was on Kiddo." Sruthy says. (Photo: Anupam)

Sujoy Mahato's first memory of Kiddo was during his PhD interview at IMSc, when he saw a dog with a big belly near the guest house. "I thought she might be pregnant, but when I went back to join IMSc I realised she was like that only," Sujoy chuckles. "The academic journey can be very stressful, you miss home and people. Whenever I felt that way I went and spent time with her, which made things better." Sujoy recollects meeting Kiddo after many months of the COVID-19 lockdown. "For two to three minutes she didn't recognise me, which was very heartbreaking. Then she came and sniffed me for some time and was so excited when she recognised me."

Kiddo was terrified of fireworks and Sujoy knew where to find her when they went off. "I would open the door to my office and she would be sitting outside", he says. "She would come in and sit there for hours."

For Sruthy Murali and Anupam A H, Kiddo was a much-loved companion during the COVID-19 lockdown in 2020. "We were staying in a flatlet on campus and Kiddo used to stay with us. Only we were there along with another family. We have very memorable moments from the time," Sruthy says. "She was our main motivation and source of happiness during those months. She was our main entertainment," she says. Kiddo accompanied them to the office every day, sometimes in pouring rain, giving Sruthy company as she wrote her PhD thesis isolated from the world. "I acknowledged Kiddo in my thesis," Sruthy says warmly.

"Kiddo was everywhere, you would always see her,"

Shanmuga Priya was among the last generation of students to care for Kiddo. "She couldn't walk properly, but when she would see me in the morning, she would try to run," Shanmuga Priya says. (Photo: Shanmuga Priya)

Kiddo spent a lot of time with Sujoy, Semanti and Anupam Sarkar. "She was shy, she wouldn't bark much," Semanti says. (Photo: Sujoy)

says Anupam Sarkar. While he did not have a deep affection for dogs, he felt attached to Kiddo when he started feeding her. Anupam says she didn't need any extra care until her condition started deteriorating around 2021-22. Like many of us, when she became pudgy after the COVID lockdown, Anupam devised an ingenious exercise routine. "I would let her smell a chew stick and walk around in circles and she would follow me," he laughs. "She is the calmest dog I have ever seen."

Shanmuga Priya B, was not really a dog lover but took Kiddo to the hospital when she once fell ill, caring for her ever since. Kiddo was once terrified when Shanmuga Priya took her to the hospital and people struggled to hold her down when she had to be given injections. Kiddo was an octogenarian by human standards and her eyesight and sense of smell were failing. "I usually whistle a tune when I give her food. And when I did that she instantly became calm. She knew someone familiar was beside her," Shanmuga Priya recollects. Kiddo was a regular presence at her office. "My office mates allowed her to stay there - they loved her very much." "I didn't see her as a dog," Shanmuga Priya says, for whom she was more like family. "She looked so beautiful."

Through Kiddo's many health issues due to her advanced age, Shanmuga Priya was her steadfast companion. And many on campus jumped in to help. The canteen staff provided food for a couple of years, Anirban Mukhopadhyay funded her food over the last few months and the housekeeping staff cleaned up after Kiddo. Many pooled in funds for her many hospital visits.

Kiddo passed away on 5th November 2024 in front of the Ramanujan Auditorium at IMSc - the campus where she spent her entire life and was very dearly loved.

Collated by Bharti Dharapuram

December 16, 2024

An inordinate fondness for plants

◆ *Bharti Dharapuram and Manikandan Sambasivam*

"I have been gardening for the past 27 years. What I know is through experience," says R Mahendran, who, along with his team looks after the many plants on campus.

"I don't have much education, I have only studied until the fifth standard," Mahendran says.

Hailing from Thiruthuraipoondi near Thanjavur, he moved to Chennai along with his family for livelihood. "When I came to the city in 1998, I was new to gardening," he says. He found employment in the estate of a wealthy businessman where an early incident taught him an important lesson. "One afternoon, a senior gardener was leaving to work and I asked him to explain what he was going to do," he recounts. "You shouldn't be asking these things," came a sharp retort. Chastised, Mahendran followed the gardener, observing closely as he went about planting cuttings and later replicated his actions. "Cuttings should be planted at a slight angle and not straight down. Roots emerge from the node and not the base of the stem," he demonstrates with a plucked stem. "The end can rot because of water stagnation if there isn't enough aeration. If the bark peels in the planted end, the cutting is unlikely to survive and grow," he explains.

"I still have retained this information in my memory." Learning happens by observing and actively doing is the lesson that he learnt. "This is how I learnt things, nobody taught them to me."

"I was a worker at IIT Madras for 12 years, and I have been a supervisor at IMSc now for almost 15 years," Mahendran says. He comes to work early, cycling from his house near Kotturpuram while the traffic signals are turned off before the morning rush. He oversees planting saplings, propagating stem cuttings, germinating seeds, pruning trees and shrubs and maintaining the lawns. "I

Mahendran propagates a variety of seedlings and cuttings in his small nursery.

try to do everything, I work alongside the other gardening staff. It is only then that they will be inspired to take interest in the work," he says. His team also organises potted plants along corridors and offices in the main building, and they make special arrangements for important events. "Twice a week or so, we place these pots in the open because they need sunlight, and then return them back to their place. If we don't do this they start shriveling within two weeks and start shedding beyond three," he says. "It is not enough to put a plant in a pot and just let it be. One has to change the soil once in six months or turn it and mix in manure," he adds.

Mahendran's day ends around 4:30 pm, when he cycles back home before the daylight fades. "I am 69 years old and my eyes get strained in the dark."

Monsoons can be particularly challenging for Mahendran's team, where they attend to fallen trees and branches around campus. "A lot of plants are lost during the rainy season. Last year [2023], there was severe inundation and many plants died. It is difficult to restart after such heavy rainfall events, but we try to address the situation immediately," he says. The lockdowns during COVID-19 presented unprecedented challenges. "People weren't let into the institute gate during COVID, they asked me not to come. But plants can't speak for themselves, can they?" he says. "I was present here throughout. Others were asked not to come and I was the only one. Plants are like children to me, I can't see them die." Based in his room, a blue shed next to the canteen overlooking his small nursery, Mahendran used to make tea and kasayam for the few people from the institute who dropped in for a visit.

" Learning happens by observing and actively doing is the lesson that Mahendran learnt early on.

Outside the same room, he fondly shows Mani and I around the nursery where he tends to saplings of about a dozen different plants.

"I germinate many seeds to bring up saplings in case we decide to plant these in the future," he says. He points to *Syngonium*, palms, money plants, jaadi malli, mango,

Mahendran was among the very few people on campus during the COVID-19 lockdown. He made tea and kasayam for the few people on campus who dropped by his room.

Gardening staff planting grass in a patch of lawn near the hostel complex.

pirandai, banana and a few saplings of the cannonball tree, whose seeds, he says, are particularly difficult to germinate.

> **“Monsoons can be particularly challenging for Mahendran’s team, where they attend to fallen trees and branches around campus. The lockdowns during COVID-19 presented unprecedented challenges.**

He shows us the compound wall at the back where he leaves food everyday, which crows and squirrels drop by to eat at noon. Mynas, babblers, koels and woodpeckers come to visit, and mongooses stop to drink water that he leaves outside. “This tree is a malai vembu,” he says, pointing to a young tree outside the canteen which resembles a neem tree. “It needs a lot of sunlight to grow. It was leaning heavily on one side and it is doing better now after we supported it.” He walks us to the garden patch next to the guest house where they have planted a series of largely native aromatic plants that attract many insects, including butterflies that dawdle lazily in the afternoon. They do not spray chemicals to keep away pests, he says. He takes us down a path from his room by the side of the canteen and shows us large peepal and banyan trees that take us by surprise. “The saplings growing in the walls are because of birds dropping their seeds,” he says, pointing to the stubborn shoots sprouting from concrete.

He is wary of growing large trees on campus - rain-trees that lack in strength what they have in size, peepal, tamarind, mango and neem trees that can damage walls and cause leaks in buildings. He seems to worry about them. He approves of pongam though. “It is good for everything.”

“I like all plants. I like working towards maintaining them. One needs to carefully consider where to plant a sapling so that it will survive, how long it needs to grow and how it will fare in the future. I keep thinking about what would be nice to do and do it without waiting for someone to ask,” he says. “There is always an element of chance when you plant anything. You need to plant with faith that

A peepal tree growing amidst the flatlets on campus.

A group photo including all the gardening staff taken during a tree planting drive to celebrate 50 years of IMSc in 2013.

it will do well. Not everyone can farm, not everyone can garden. It comes organically to some people and needs conviction.” Mahendran beams while showing us a photo from 13 years ago, where all the gardening staff are gathered together outside the main gate. It was taken when his team planted avenue trees on the road outside campus to commemorate IMSc’s 50th anniversary.

“I don’t expect any awards. I am answerable to the institute for the gardening work that they budget for and trust me to execute,” he says earnestly. “It is only because I like the work that I have been able to keep at it for the last 15 years.”

Mahendran is deep in conversation about propagating cuttings, when we hear impatient cawing outside. He wraps up the conversation quickly. It is time to feed the crows.

January 22, 2025


Hareesh J

Book reviews

GUT by Giulia Enders

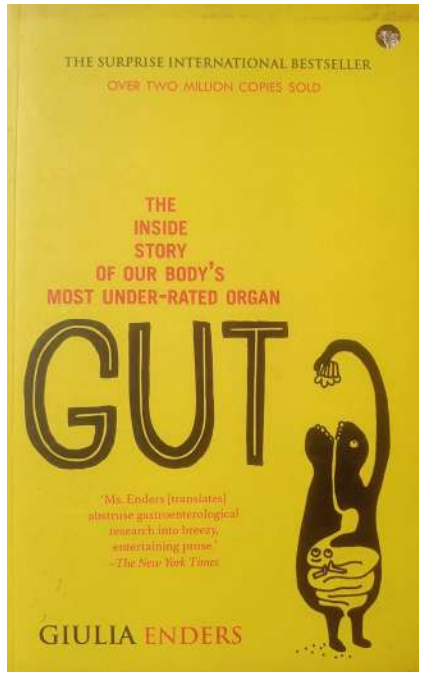
◆ *Shakti N. Menon*

'Everyone is whizzpopping, if that's what you call it,' Sophie said. 'Kings and Queens are whizzpopping. Presidents are whizzpopping. Glamorous film stars are whizzpopping. Little babies are whizzpopping. But where I come from, it is not polite to talk about it.'

- Roald Dahl, The BFG

Before we go any further, I have to tell you this: I hear these little voices, and they tell me what to do. I can see your eyes dart in bewilderment, so let me explain. You must know that your body contains countless biological machines. They're of different shapes and sizes, and they coordinate in an exquisite manner to keep you alive. But although the machines in your body are largely similar to those in anyone else's, human behaviour is notoriously unpredictable.

You're likely to find that two people will respond to exactly the same circumstances in vastly different ways. Machines don't strategize - they just do what they're designed to do. Our bodies are just meaty marionettes, and your strings are not pulled in the same manner as mine. What exactly is it in you that makes you behave differently from me? Your eyes are a bit more relaxed, but your nose still shrivels in confusion. At this point you decide that I must be



talking about the brain, and the neurons within. You wonder, with trepidation, if I hear voices in my head. No, the machines actually speak to my other brain. Trillions of them.

In her extraordinary first book, Giulia Enders shines a spotlight on one of the least-appreciated, and surprisingly under-examined, parts of our body, which is responsible for a lot more that we give it credit for. I can't recall the last time I read something so tightly packed with scientific information, while also being humorous and thoroughly enjoyable. In addition to providing a comprehensive overview of every step involved in digestion, the book introduces us to some tiny friends who are dedicated to making our lives better.

Our digestive tracts are little ecosystems, containing around a 100 trillion bacteria, most of which play essential roles in digestion. It is also possible that some of them might make you less depressed, while others could make you fat! There is still active research on the extent to which your gut flora can impact your body, but they cannot do so without the enteric nervous system (ENS), which spans the gut. The ENS, colloquially known as the second brain, is unexpectedly sophisticated, and it sends signals to the parts of our brain responsible for "self-awareness, emotion, morality, fear, memory, and motivation", thereby playing a key role in shaping our experiences. One of the tenets central to everything that we believe in is that human beings are individuals, capable of independently making decisions. It boggles the mind to imagine that perhaps some of our putatively autonomous decisions may in fact be made in collaboration with things living inside us. Enders convincingly argues that "[o]ur self is created in our head and our gut".

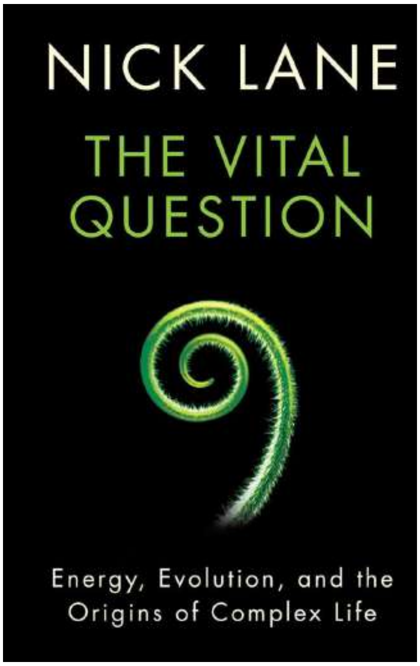
Unsurprisingly, this book is filled with facts that I was completely unaware of; for example, that saliva contains a painkiller stronger than morphine. That the appendix, long believed to be mostly useless, "acts as a storehouse of all the best, most helpful bacteria". That the composition of everyone's saliva is slightly different, and that it can hence be used to test for diseases. That there are broadly three different types of guts (enterotypes), based on the family of bacteria that is dominantly found. I was also intrigued by the fascinating insight that balancing your diet also means balancing your amino acids! And as someone who suffers greatly from travel sickness, it was illuminating to learn that it is likely due to a mismatch between the signals received by the brain, similar to those symptoms experienced as a result of alcohol poisoning, for instance.

Gut is a rare science-themed book I would enthusiastically recommend to a casual reader, simply for its arresting style ("The first thing a sea squirt does after setting up home is to eat its own brain"!). Enders' text is beautifully complemented by the absolutely delightful illustrations (by her sister, Jill), which depict the inherently weird and wonderful facets of the digestive process. I'm fairly confident that you don't treat your gut with anywhere near the level of respect that it deserves, or have an appreciation for the complexity of the tasks it carries out. The first step towards rectifying that would be to read (and then re-read) this book!

December 16, 2024

THE VITAL QUESTION by Nick Lane

Anuran Pal



*I*s Earth the only planet that harbours life? According to the British biochemist Nick Lane, "Suitable conditions for the origin of life might be present, right now, on some 40 billion planets in the Milky Way alone". By "life" he means prokaryotes, single-celled organisms devoid of a nucleus, which were the first living beings to appear on Earth. But what makes life on our planet remarkable is the abundance of complex eukaryotic life forms. The key is our beloved organelle, the mitochondrion, the powerhouse of the cell, or as the author calls it, "the thermodynamic epicentre of the cell".

In his fifth book, Lane proposes a possible trajectory for realising complex life on the planet. He sets the stage by examining the evidential history of life on Earth and discusses past attempts to answer the question of its origin. He introduces the universal driver of life - chemiosmosis, in the simple form of proton gradients across membranes. Lane coherently transitions from the geochemistry of deep hydrothermal vent micropores four billion years ago to the biochemistry of primordial prokaryotes, laying a compelling narrative for the origin of chemiosmosis. However, the metabolic versatility of prokaryotes cannot generate the energy required for morphologically complex eukaryotes.
Using Fermi estimates, he demonstrates the gigantic gap in energy between a typical prokaryote and an ancestral eukaryote, which he refers to as "the black hole at the heart of biology" at the start of the book. To tackle this, Lane walks us through the formation of mitochondria through endosymbiosis. In the process, he lays down hypothetical explanations for empirical observations like the hybrid nuclear membrane, introns, sex and death, among other peculiarities of eukaryotic life. Towards the end of the book, he speculates on the role of mitochondrial and nuclear DNA coadaptation in the origin of speciation, imagines how

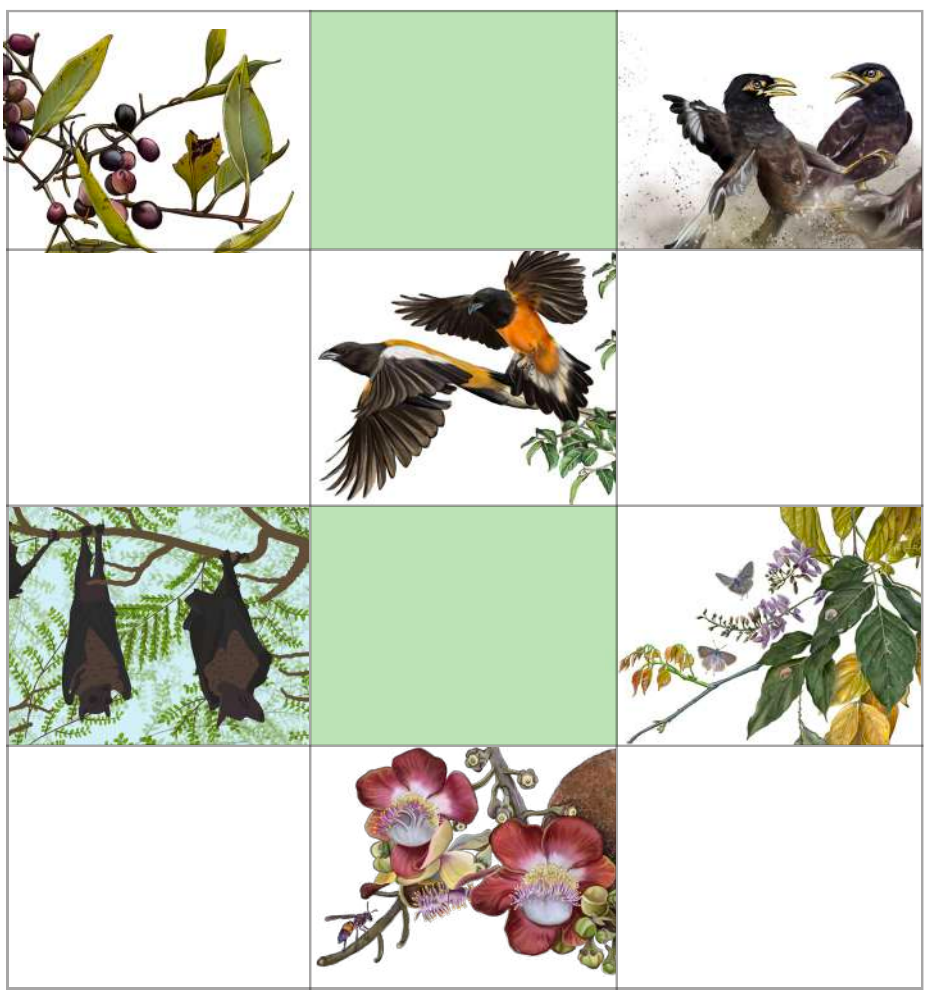
greater aerobic capacity may link to extended lifespans, and remarks that "incorporating energy into evolution is long overdue".

The book is a convincing narrative of biotic complexity from abiotic origins. The author lays a logical groundwork explaining the origin of metabolism and eukaryotic complexity but leaves aside the origin of replication. By standing on the shoulders of giants and filling in the gaps with his contributions and testable hypotheses, Lane shows that physical laws constrain chemical reactions, which transform into life under the right conditions. He uses jargon when necessary, with the occasional reminder of its meaning and a comprehensive glossary at the end of the book for forgetful individuals like me. This makes the book easy to read and surprisingly self-contained in its 368 pages. With 37 grayscale figures and corresponding descriptive labels, he creates a visual picture wherever possible. Lane avoids unnecessary digressions in his prose-style writing and masterfully weaves a captivating story accessible to a general audience.

I will recommend this book to anyone interested in (the origin of) life. Lane's lucid writing makes cutting-edge science accessible to a vast audience, where he covers large ground without sacrificing accuracy. For the scientifically inclined, the book also contains a rich bibliography that is thematically arranged. *The Vital Question* makes several conceptual connections across scientific disciplines while attempting to uncover the origin of life. At the outset, this appears to be a formidable task, but Lane's efforts make for an enlightening read and many of the bold ideas he proposes may hold the keys for future research.

January 23, 2025

CAMPUS BIODIVERSITY




Aysha Mahira

Our exotic neighbour who smells great and throws pollen parties

◆ *Bharti Dharapuram*

The cannonball tree, named after its characteristic fruit, produces spectacular fragrant flowers that attract many insects, like the lesser banded hornet here, which feed on its pollen.
Artist: Ravi Jambhekar

The cannonball tree (*Couroupita guianensis*, Tamil - Nagalingam, Hindi - Nagalinga/Tope gola) is native to South and Central America and belongs to the family Lecythidaceae, which consists of species commonly found in the Amazonian forests. It has many striking flowers on long stalks emerging directly from the tree trunk, a feature known as cauliflory. The strong fragrance of these flowers attracts insect parties that come for a feast of pollen. The tree shows a unique adaptation where the stigma sits at the center of the flower inside a huddle of fertile stamens carrying viable pollen. This arena is hooded by drooping rows of sterile stamens with pollen that do not germinate, which attract pollinators like the carpenter bee. While collecting this pollen to feed larvae, the head and back of the bee gets accidently dusted with viable pollen. These pollen are transferred to other flowers on the bee's foraging route, thus fertilizing them. Fertilized flowers produce large woody fruit resembling cannon balls, whose foul-smelling pulp is eaten by mammals in the tree's native range, who disperse its seeds over long distances.

July 31, 2024

A delicious branch of a spectacular evolutionary radiation

◆ *Bharti Dharapuram*

Jamun or naaval, is a member of one of the largest tree radiations in the world. It is a host plant for moths and butterflies, like the hungry Tussock moth caterpillar advancing towards its leaves in the image above. Artist: Ravi Jambhekar

The jamun tree belongs to Myrtaceae, a plant family that originated in Gondwana, a landmass combining South America, Africa, Arabia, Antarctica, Australia and the Indian subcontinent. The myrtle family is distributed across the world with many species producing aromatic oils (eucalyptus, clove) and fleshy fruit (guava, jamun). This family hosts *Syzygium*, the largest plant genus in the world, with over a thousand species distributed across tropical and subtropical Africa, India and Southeast Asia. (A genus is a higher hierarchical level in the biological classification of organisms and many species may be subsumed within it. For example, jamun – *Syzygium cumini*, and clove – *Syzygium aromaticum*, are two different species within the genus *Syzygium*.)

Syzygium originated in the Australia-New Guinea region around 50 million years ago and expanded in its geographic range through multiple dispersal events, many of them jumps between islands. Recent evidence shows that these stepwise dispersals isolated populations, which diverged from each other leading to speciation events. The rapidity of this process gave rise to a plethora of species over a short period of time, many of which are tricky to tell apart based only on their appearance. *Syzygium* flowers host many insects and its fruit attract birds, mammals and even reptiles.

Syzygium cumini is native to the Indian subcontinent and produces clusters of small white fragrant flowers in spring and early summer that are pollinated by bees and other insects. Its fruit go through shades of green, pink and purple as they ripen, where its mature delicious dark purple fruit are eaten by birds and small mammals. The tree has beautiful glossy dark green leaves worthy of poetry. One can explore when it flowers, fruits and sheds leaves across locations in India using citizen science data collected by SeasonWatch.

In his book 'Trees of Delhi', Pradip Krishen talks about two kinds of jamun. He says that botanists are unsure about the distinction, but jamun sellers in Delhi attest to their existence. Krishen refers to *Syzygium cumini* as 'jamun', which has smaller and more round fruit, and calls *Syzygium nervosum* 'rai jamun', which has larger and more elongated fruit.

One can see the naaval tree near the dish behind the IMSc main building (the terrace has a great view of its canopy) and by the road right outside the campus.

August 30, 2024

Artist: *Sheryl Mathew*

A handsome, rather noisy bird in our backyard

◆ *Bharti Dharapuram*

The rufous treepie belongs to the crow family and is a smart looking noisy bird that is commonly seen and heard on campus To the right is a magizham or a bullet wood tree, which produces small white flowers with a strong and lasting fragrance. Artist: Ravi Jambhekar

The rufous treepie (*Dendrocitta vagabunda*) belongs to the family Corvidae along with crows and magpies, and is found in the Indian subcontinent, with a distribution extending up to Cambodia. It is a handsome bird with a sooty black head and neck, an orangish-brown body, and a graduated long white tail dipped in black. It is a rather noisy bird with a wide range of calls, including "ko-tree" or "krowwiiii kroo", and short repetitive screeches. It is found singly, in pairs or small groups in scrub, gardens, human habitation, and wooded areas. It is an omnivore that forages at different heights in a tree stand, feeding on fruits, seeds, nectar, insects, small reptiles, which is also known to scavenge and remove ectoparasites from deer. It is often seen in mixed-species flocks, which are parties of different kinds of birds that move together and forage. It is among the four species of treepies found in India, all belonging to the genus *Dendrocitta*. The grey treepie replaces the rufous treepie at higher elevations, the white-bellied treepie is found in the forests of the Western Ghats, and the Andaman treepie is endemic (only found there and nowhere else) to the Andaman islands. On campus, the rufous treepie is often heard and seen among the trees surrounding Ramanujan auditorium and the library.

Magizham, bakul, or maulsari (*Mimusops elengi*) is a smallish leafy evergreen tree native to the Indo-Malaya and Australia, which is commonly planted in gardens and avenues. It has small white star-shaped flowers with many petals, with a strong sweet fragrance that lasts long after the flowers fall to the ground. It has glossy green oval leaves with wavy margins and pointed ends, and berries which are reddish orange when ripe. It is a host plant for the caterpillars of Common Red Flash and Common Crow, while the Dark Cerulean feeds on its nectar. There are many magizham trees on campus - on the path leading to the substation from the main building, outside the hostels, and lining the road left of the main gate.

October 10, 2024

Hanging out with the flying foxes

◆ *Bharti Dharapuram*

The Indian Flying Fox is widely distributed in the Indian subcontinent and is one of the largest bats found in this region, which plays an important role in seed dispersal and pollination.
Artist: Radha Sunder

The Indian Flying Fox (*Pteropus medius*; formerly *Pteropus giganteus*) belongs to the family *Pteropodidae*, with 170 species of bats distributed across tropical Africa, Asia, Australia and islands in the Indo-Pacific. Members of this family are some of the largest among bats. They have big eyes and a keen sense of smell, which they use to forage on fruits and nectar, unlike insectivorous bats that use echolocation to navigate and find prey. Within this family of fruit bats, the genus *Pteropus* (flying foxes) represents sixty species that are predominantly found in islands and coastal regions. The Indian Flying Fox is among the very few species in this group with a widespread distribution spanning the Indian subcontinent. With a wingspan of up to 1.5 meters, it is one of the largest bats found in India.

Flying foxes started diversifying around 6-7 million years ago, their large flight distances allowing them to colonize faraway islands in the Indian and Pacific Oceans. The subsequent geographic isolation on these islands may have given rise to new species. While we understand the recent evolutionary history of bats in general, pressing questions about the origin of their striking adaptations remain to be answered. This is because of gaps in their paleontological record with an absence of fossils representing the transition of bats to flight and echolocation. Researchers hypothesize that tree- or rock-dwelling ancestors of bats may have started gliding before the evolution of powered flight in these curious mammals.

Given their ability to fly over long distances, fruit bats are ecologically important as pollinators and seed dispersers that can help in the regeneration of forests. At dusk, they emerge from the trees where they rest in colonies, known as roosting sites, and a recent study tracking individual bats found that they can travel more than 40 km in one night. They feed on the flowers and fruit of dozens of different tree species and select foraging sites based on the surrounding tree cover. The small but numerous fruits of *Ficus* such as banyan/aalamaram (*Ficus benghalensis*) and peepal/arasamaram (*Ficus religiosa*) are important food sources for the species. While it is thought that they return to the same roosting site after foraging, males may move between multiple roosting sites during the breeding season. The number of individual bats on a roosting tree is related to its width, canopy size and height. In northern Tamil Nadu, large colonies are seen roosting in trees of *Ficus* species along with tamarind/puliyamaram (*Tamarindus indica*) and mahua/kaattu-iluppai (*Madhuca longifolia* var. *latifolia*).

Fruit bats are natural hosts for viruses, which can cause zoonotic diseases when there is a spillover of the pathogen to humans. Such transfer may happen when several factors, including ecology, pathogen dynamics, behaviour and host biology - "barriers to spillover infections", coincide in time and space. A recent study reported the importance of fruit bats to the local dispersal of clumps of seeds in cashew and areca plantations in the Western Ghats. Plantation workers collect these dropped fruits and seeds, which can be processed easily, and view bats as beneficial to farming. Researchers advocate for (often simple) strategies to prevent zoonotic transmission in scenarios where people live near fruit bats and call for research and monitoring of bat colonies to detect future outbreaks.

On the IMSc campus, a colony of the Indian Flying Fox can be seen roosting on trees in the lawn east of the main building. While they rest during the day, they are occasionally heard chattering and seen fanning their wings and moving across branches in the canopy.

December 16, 2024

At home and abroad

◆ *Bharti Dharapuram*

Violent battles often erupt between occupants of nesting sites and the couple that wish to evict them. Each partner grapples with its opposite number and contestants drop to the ground secured in each other's claws. Bills are jabbed ruthlessly at the opponent. Finally, the defeated couple leaves to search for another site." - Common Myna fact-sheet, Australian Museum. Artist: Ravi Jambhekar

The Indian myna (*Acridotheres tristis*, also known as common myna), belongs to the family Sturnidae and is distributed across Asia. Birds in this family are commonly known as starlings - medium-sized perching birds with a wide repertoire of calls that form large social groups. Some other starlings found in India are the hill myna, jungle myna, Brahminy starling, pied starling and the rosy starling (a winter migrant).

Mynas are gregarious birds, where tens to hundreds of individuals roost throughout the year, often with other species such as crows and rose-ringed parakeets. Such gatherings of birds, which sleep together in the same place, are not incidental as they are seen even when alternate roosting sites are available. Roosting behaviour is commonly seen in birds found in open habitats and those foraging in flocks. It might help them share information about food resources or protect them against predators.

Among the starlings in India, the common hill myna (*Gracula religiosa*) has the widest call repertoire. They have four basic call types and an individual may have anywhere from five to twelve patterns of vocalisations. They learn these as they are growing into an adult, influenced by the calls of other individuals around them. Common hill mynas can distinguish between individuals based on their calls even when the call types are the same. Their vocal repertoires vary with distance and different populations can have their own dialects. Due to their wide variety of calls and the ability to mimic sounds in captivity, they are traded as pets, threatening their populations in the wild.

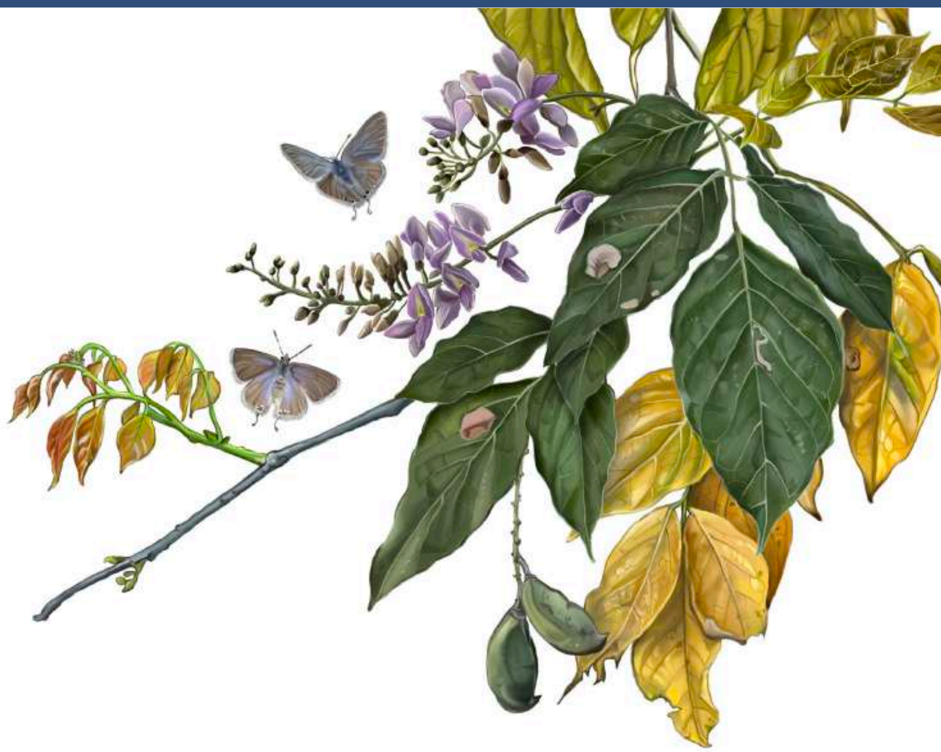
The Indian myna was introduced in Australia in the 1860s to control insects and has emerged as a major pest. “The introduction and liberation of exotic birds was practised with considerable assiduity both in Sydney and Melbourne. The legacy of such misguided enthusiasm is seen today in the presence of numerous starlings, sparrows, goldfinches, and other birds that inhabit, for the most part, the settled areas of Australia,” says an article from 1948. Using genetic data, researchers have found that mynas introduced in Melbourne likely arose from a population in Maharashtra, which then invaded New Zealand.

The Indian myna is listed among the world’s hundred worst invasives - species which are introduced outside their native range and cause ecological harm in the new environment. Its introduction is associated with a drop in populations of native birds through competition for nesting sites and breeding territories. They are seen to have aggressive interactions with native bird species around tree cavities that they use as nesting sites. A recent study identified certain genetic variants that are common across multiple invasive populations of the Indian myna. The region of the genome carrying these variants is also thought to be involved in the association of house sparrows with humans and may help these birds adapt to novel diets.

January 23, 2025

A tree with an explosive secret

◆ *Bharti Dharapuram*



The versatile pungam tree survives in a wide range of environments and has immense socioeconomic value. It is a host plant to many butterflies, like the pea blues (Lampides boeticus) seen here, and its flowers run a covert operation. Artist: Ravi Jambhekar

Pongamia pinnata (pea family - Fabaceae), pungam in Tamil and karanj in Hindi, is a medium-sized tree native to the Indian subcontinent with a range extending to Southeast Asia and northern Australia. Commonly known as the Indian Beech Tree or the Pongame Oil Tree, it has been introduced to many areas outside its native range It survives in a wide range of environments, tolerating drought, heat, harsh sunlight, fire, wind, inundation and salinity. The species is associated with mangroves and naturally occurs along coastlines and rivers. It is a preferred tree species in afforestation efforts and is commonly planted along city avenues for shade and as a windbreaker in landscaping.

The pungam tree produces a flush of reddish-hued young leaves that turn dark green on maturing. The older leaves often fall prey to herbivory by insects, scarred by blotches, snaky mines and galls. It has a brief shedding phase in early spring, making it an almost evergreen tree. The tree is a host to a coterie of butterflies with imaginative names such as Awls, Sunbeams, Ceruleans, Pea Blue and even a Sailer. The larvae of these butterflies chomp through pungam leaves to complete their life cycle and metamorphose into adults.

The tree produces small fragrant flowers in shades of white, pink and purple with dark maroon collars. These flowers are less than a centimeter long, clustered in pretty inflorescences that appear in spring and summer.

Pungam flowers are largely pollinated by bees and wasps, which set off the most adorable explosion. Each pungam flower has a large petal with a nectar guide, that is hooded over four folded petals. Two of these inner petals, called keel petals, conceal a bundle of stamens that are held in tension. When an insect steps on these petals seeking nectar deep within the flower, the movement trips a violent 'keel explosion'. Much like a landmine going off, this explosion sprays the underside of the insect with a cloud of pollen. These pollen are carried to other flowers by the foraging insects, which leads to their fertilization.

The seeds of pungam occur in pointed oval pods and are extraordinarily rich in oil, which has been extracted as lamp-oil, lubricant and an insect repellant, and is being explored as a source of biodiesel. Various parts of the tree are also important in traditional and folk medicine across cultures, and used to treat a range of diseases. The leaves are great for composting and the wood is used as fuel and for making tools.

On campus, pungam trees can be found in the patch of lawn overlooking the parking shed near the hostel side entrance.

March 4, 2025


MAGNETIC LEVITATION
IMSc Media