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KERNEL

Editorial

Snakebites kill and disable thousands in India each year, underscoring the need for increased awareness and research on antivenoms. A new centre coming up in the city aims to address this vital gap. Read more about it in this issue.

We also delve into the work of a scientist passionate about coding theory, signal processing and quantum information research.

We feature stories on a 3D printed glove that can help stroke patients, a record-breaking true random number generator, and a new strategy to make better and longer-lasting solid state batteries.

A QUEST FOR QUALITY ANTIVENOMS

Bamboo pit viper from Maharashtra (Photo: Kartik Sunagar)

NEW CENTRE AIMS TO FOSTER MUCH-NEEDED RESEARCH ON – AND AWARENESS ABOUT – THESE LIFE-SAVING CONCOCTIONS

"Animal venoms are absolutely fascinating," says Kartik Sunagar, Assistant Professor at the Centre for Ecological Sciences (CES), IISc. These protein cocktails produced by snakes and other creatures can both kill and save lives – in fact, antivenom is made from these lethal mixtures.

Kartik's Evolutionary Venomics lab at CES has been studying venomous animals, their evolutionary history and the make-up of their venoms for many years. The work that the lab has done in collaboration with others across the country has revealed several shortcomings of commercially available antivenoms in treating snakebites. They have also found that the toxicity levels in snake venom differ based on where the snakes are located – and can even vary within the same species and in the same individual over its lifespan.

Venom scientists like Kartik and others in India have long felt the need for comprehensive efforts to document this diversity in venoms and standardise the production of antivenoms. For example, the same antivenom is used across the country to treat bites, whether they are from a cobra or a krait, without any regard for the differences in the venom composition. Experts believe that there is an urgent need for antivenom manufacturers, public health officials

Continued on page 2

Continued from page 1

Architect view of the Centre (Image courtesy: Dayananda Sagar College of Architecture)

and policy makers to come together in order to develop region-specific antivenoms, especially for some of the neglected but dangerous species.

Those efforts have now received a shot in the arm with the establishment of a first-of-its-kind Antivenom Research and Development Centre in Bengaluru, with support from IISc, the Institute of Bioinformatics and Applied Biotechnology (IBAB), and the Government of Karnataka.

The Centre, which is coming up at Electronic City, is being built at an initial cost of Rs 7 crore. CN Ashwath Narayan, the Minister of IT-BT, Science and Technology, Government of Karnataka, laid the foundation stone for the Centre on 4 July 2022. In his inauguration speech, he pointed out how India is considered the global capital for snakebites and how there is a vast knowledge gap that exists in the field of venom research in the country.

Every year, 58,000 people die and 1,74,000 suffer permanent disabilities from snakebites, yet it remains the most neglected tropical disease. The antivenoms currently available in the market are largely ineffective as they are exclusively produced against the "big four" Indian snakes: the spectacled cobra, common krait, Russell's viper and saw-scaled viper. However, India is home to many other venomous snake species whose bites can also be fatal and/or crippling. "Our Indian snakes and other venomous animals are really amazing and completely unexplored," says Kartik. Currently used antivenoms are poorly designed and very few checks are in place to test the effectiveness of these drugs before they are released to the market.

To combat this problem, the new Centre will focus on carrying out research and improving the efficacy of antivenoms and related therapeutic drugs. Labs will be created where researchers from both IISc and IBAB can collaborate on research related to venoms and antivenoms. "This collaboration is extremely valuable and it will open up a lot of opportunities to initiate work in this area," says Subramanya Hosahalli, Director of IBAB. The centre will work with major Indian antivenom manufacturers and help them improve their products, as well as offer venom and antivenom testing services. "We are also going to establish a standard of certification for venom quality and antivenom products, which will be useful for the industry," adds Subramanya.

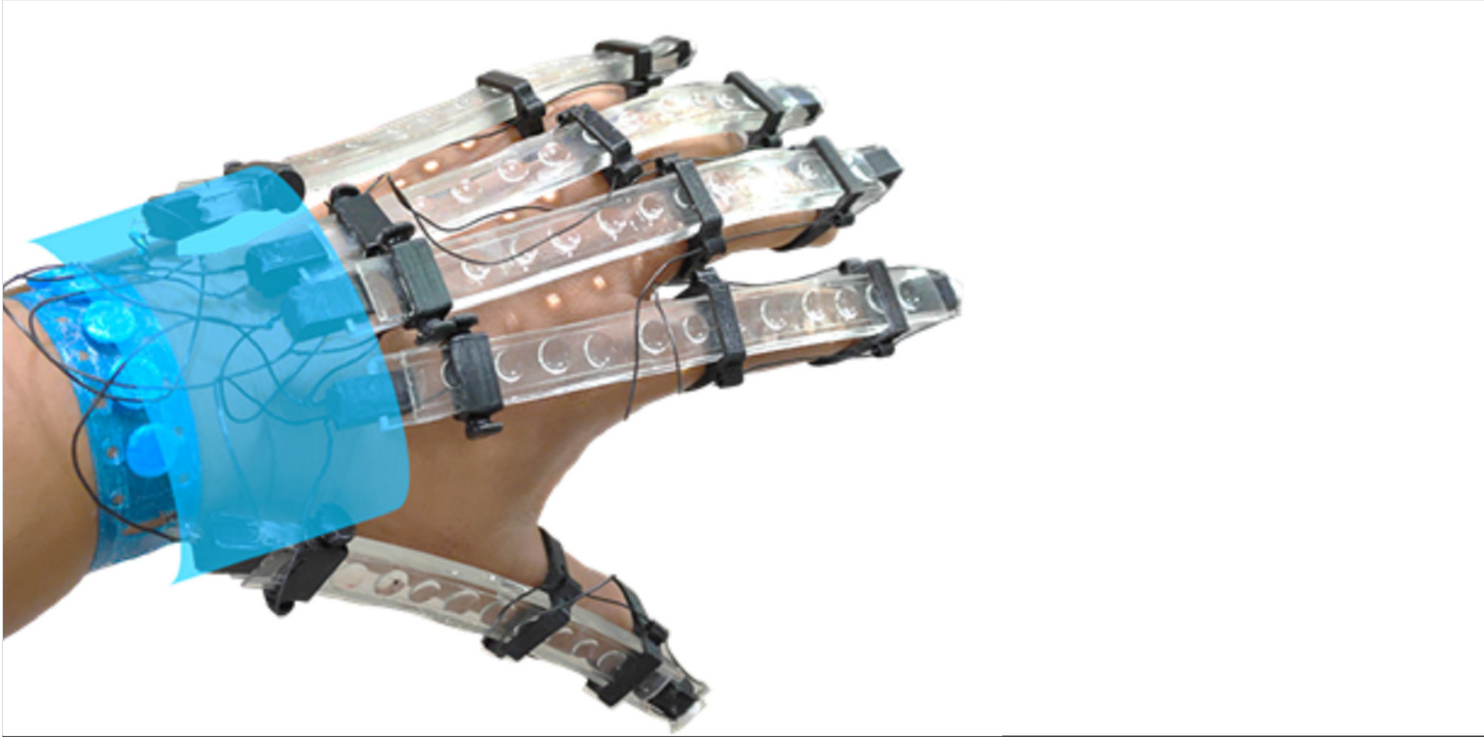
Education and outreach will be another important focus of the upcoming Centre. Both Kartik and Subramanya hope that such a Centre will inspire the next generation of herpetologists – scientists who study reptiles and amphibians – in India. The biggest attraction is expected to be a state-of-the-art serpentarium housing many species of snakes and other venomous animals like tarantulas, redback spiders, scorpions and endemic spider and centipede species, which will be open to the public, particularly the student community. "A kid can stand next to a vivarium and observe these enigmatic animals in near-natural habitats. They will also be able to watch through large glass windows the venom extraction process from a plethora of animals," explains Kartik.

The Centre will also be a hub for key stakeholders like the forest department, clinicians, farmers and other members of local communities in snake habitats. They would have the opportunity to visit the Centre, study the snakes at the serpentarium, and gain hands-on experience in identifying and handling different species and administering first aid for snakebites, through targeted training programmes offered by the Centre. Kartik points out that clinicians themselves are not well trained in identifying snake species (or handling snakebites, in some cases) as most medical textbooks dedicate only half a page or one page to snakebites. "There are very few clinicians who are experts in treating and managing snakebites because that's not part of the main curriculum in medical education," says Subramanya.

Although antivenom research will be the ultimate focus, there are also plans to set up an incubation centre that will act as a springboard for startups that will prioritise venom research from a therapeutic perspective. Researchers at the Centre will also explore the curative benefits of venom for various other diseases – the kind of work that has never been done before in India, says Kartik. For example, captopril, a drug used to treat hypertension in the 1980s, was derived from the venom of the Brazilian viper, *Bothrops jararaca.* "Snakes have saved more lives than they have ever taken," he adds.

- Pratibha Gopalakrishna

Soft wearable glove for stroke rehabilitation (Photo: Mesoscopic Lab, Department of Physics, IISc)



3D PRINTED GLOVES FOR REHABILITATING STROKE PATIENTS

Stroke is India's third leading cause of death and the sixth leading cause of disability. Physiotherapy is one of the few treatments available for rehabilitating stroke victims and patients with physical injuries. However, physiotherapy can take days to months depending on the severity of the disability, making it challenging for patients as well as their carers.

To help such patients, researchers in the Department of Physics have developed a soft, wearable device that exploits the fundamental properties of light to sense a patient's limb or finger movements. The customisable 3D printed gloves can be remotely controlled, opening up the possibility of teleconsultation by physiotherapists.

"We wanted to develop something affordable, and available to a person at all times at their convenience. The product should be easy to use and must provide feedback," says Aveek Bid, Associate Professor at the Department of Physics, whose team has developed the device. He explains that quantifiable feedback – for example, the units of pressure applied while squeezing a ball or the degree of bending of a leg with a knee injury – is crucial for doctors to monitor the patient, even remotely. Such feedback can also motivate patients to perform better in every consecutive session.

Another challenge is that physiotherapy often requires daily hospital visits. Home visits by professionals or sophisticated devices to monitor patients remotely, although ideal, are not readily available and are expensive.

To address these challenges, the team has developed a mechanism by which customisable wearables like hand gloves can be designed, 3D printed, and controlled remotely. "The idea behind the device is that you wear something like a glove, the physiotherapist controls the device from a remote location through the internet, and makes your hands and fingers move," says Bid. The device can sense various hand and finger movements, and precisely detect parameters like pressure, bending angle and shape.

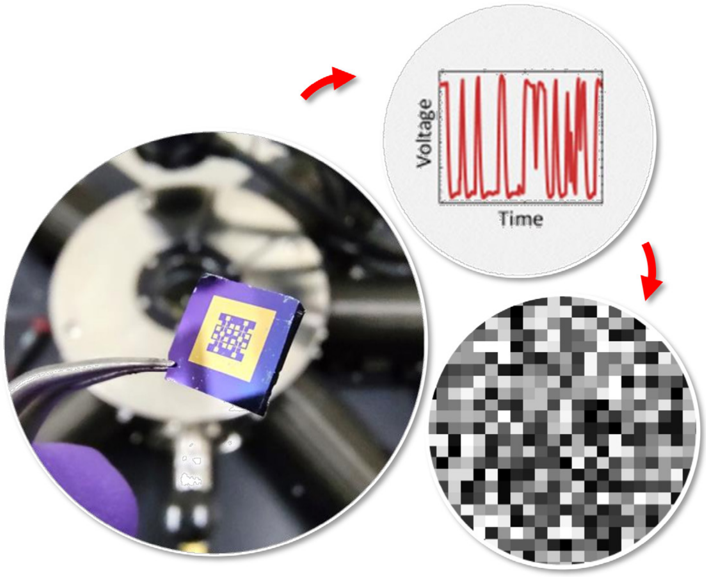
The technology that drives the device is based on the fundamental properties of light: refraction and reflection. A light source is placed at one end of a transparent rubbery material, and the other end has a light detector. Any movement in the finger or arm of the patient causes the flexible material to deform. The deformation alters the path of light, and thereby its properties. The device translates this change in light properties to a quantifiable unit. Since light travels across the entire length of the device, movement along any part of the patient's finger or arm can be accurately measured.

The device is highly sensitive – enough to respond to the touch of a butterfly, says team member Abhijit Chandra Roy, DST-Inspire Faculty at the Department of Physics and the brains behind the project. In addition, while existing devices can only detect the bending of a finger, the new device can even measure the degree of bending at every joint of the finger, he explains. The device can also capture and store data, and transmit it over the internet, facilitating remote monitoring by clinicians or physiotherapists.

The researchers say that the device has been tested for stability for over 10 months, and no loss of sensitivity or accuracy was found. Bid adds that the device has been entirely designed and manufactured in India, and is expected to cost less than Rs 1,000. A patent has been filed for the device and the researchers hope to launch it in the market soon.

– Mohammed Asheruddin

Fabricated electronic chip is loaded into the measurement setup, where the randomness of the electron trapping/detrapping is converted into binary output (Image: Nithin Abraham)



HOW RANDOMLY MOVING ELECTRONS CAN IMPROVE CYBER SECURITY

In October 2017, tech giant Yahoo! disclosed a data breach that had leaked sensitive information of over three billion user accounts, exposing them to identity theft. The company had to force all affected users to change passwords and re-encrypt their credentials. In recent years, there have been several instances of such security breaches that have left users vulnerable.

"Almost everything we do on the internet is encrypted for security. The strength of this encryption depends on the quality of random number generation," says Nithin Abraham, a PhD student at the Department of Electrical Communication Engineering (ECE). Abraham is a part of a team led by Kausik Majumdar, Associate Professor at ECE, which has developed a record-breaking true random number generator (TRNG), which can improve data encryption and provide better security for sensitive digital data such as credit card details, passwords and other personal information. The study describing this device has been published in the journal *ACS Nano.*

Encrypted information can be decoded only by authorised users who have access to a cryptographic 'key'. But the key needs to be unpredictable and, therefore, randomly generated to resist hacking. Cryptographic keys are typically generated in computers using pseudorandom number generators (PRNGs), which rely on mathematical formulae or pre-programmed tables to produce numbers that appear random but are not. In contrast, a TRNG extracts random numbers from inherently random physical processes, making it more secure.

In IISc's breakthrough TRNG device, these numbers are generated using the random motion of electrons. It consists of an artificial electron trap constructed by stacking atomically-thin layers of materials like black phosphorus and graphene. The current measured from the device increases when an electron is trapped, and decreases when it is released. Since electrons move in and out of the trap in a random manner, the measured current also changes arbitrarily. The timing of this change determines the generated random number. "You cannot predict exactly at what time the electron is going to enter the trap. So, there is an inherent randomness that is embedded in this process," explains Majumdar.

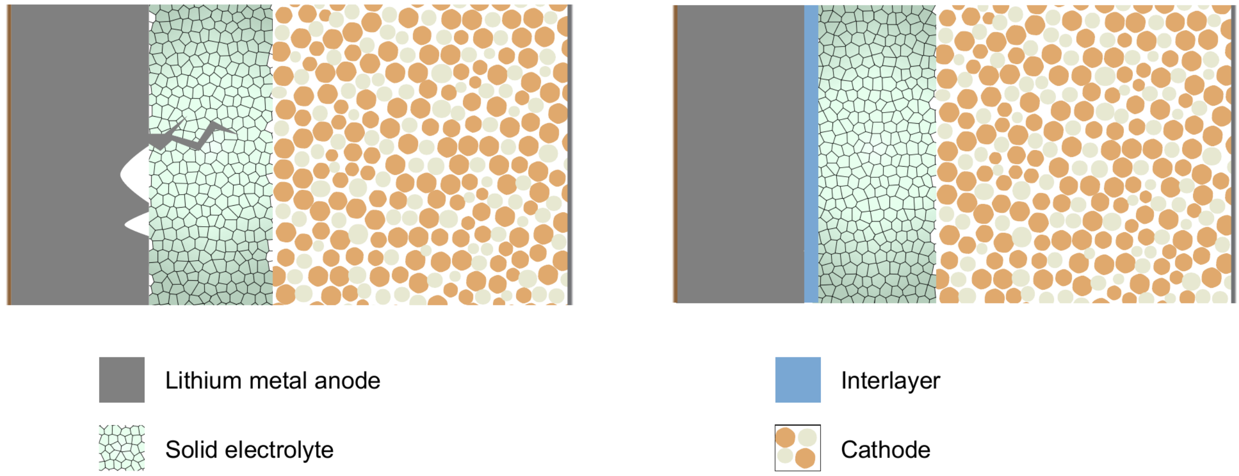
The performance of the device on the standard tests for cryptographic applications designed by the US National Institute of Standards and Technology (NIST) has exceeded Majumdar's own expectations. "When the idea first struck me, I knew it would be a good random number generator, but I didn't expect it to have a record-high min-entropy," he says.

Min-entropy is a parameter used to measure the performance of TRNGs. Its value ranges from 0 (completely predictable) to 1 (completely random). The device from Majumdar's lab showed a record-high min-entropy of 0.98, a significant improvement over previously reported values, which were around 0.89. "Ours is by far the highest reported min-entropy among TRNGs," says Abraham.

The team's electronic TRNG is also more compact than its clunkier counterparts that are based on optical phenomena, says Abraham. "Since our device is purely electronic, millions of such devices can be created on a single chip," adds Majumdar. He and his group plan to improve the device by making it faster and developing a new fabrication process that would enable the mass production of these chips.

– Rohith KMS

Schematic representing a Li-metal solid-state battery with voids and discontinuities that drive dendrite growth, which can be reduced using an appropriate interlayer (Image: Vikalp Raj)



NOVEL STRATEGY TO MAKE FAST-CHARGING SOLID-STATE BATTERIES

Researchers at the Solid State and Structural Chemistry Unit (SSCU) and their collaborators have discovered how next-generation solid-state batteries fail, and devised a novel strategy to make these batteries last longer and charge faster.

Lithium-ion batteries – the kind that you might find in your smartphone or laptop – contain a liquid electrolyte sandwiched between a positively charged electrode (cathode) and a negatively charged electrode (anode), usually made of graphite. When the battery is charging and discharging, lithium ions shuttle between the anode and cathode in opposite directions. These batteries have a major safety issue – the liquid electrolyte can catch fire at high temperatures.

A promising alternative is solid-state batteries that replace the liquid with a solid ceramic electrolyte and swap graphite with metallic lithium. Ceramic electrolytes perform even better at higher temperatures, which is especially useful in tropical countries like India. Lithium is also lighter and stores more charge than graphite, which can significantly cut down the battery cost.

"Unfortunately, when you add lithium, it forms these filaments that grow into the solid electrolyte, and short out the anode and cathode," explains Naga Phani Aetukuri, Assistant Professor in SSCU and corresponding author of the study published in *Nature Materials.*

To investigate this phenomenon, Aetukuri's PhD student, Vikalp Raj, artificially induced dendrite formation by repeatedly charging hundreds of battery cells, slicing out thin sections of the lithium-electrolyte interface, and peering at them under a scanning electron microscope. When they looked closely at these sections, the team realised that something was happening long before the dendrites formed – microscopic voids were developing in the lithium anode during discharge. The team also computed that the currents concentrated at the edges of these microscopic voids were about 10,000 times larger than the average currents across the battery cell, which was likely creating stress on the solid electrolyte and accelerating the dendrite formation.

"This means that now our task to make very good batteries is very simple," says Aetukuri. "All that we need is to ensure that the voids don't form."
To achieve this, the researchers introduced an ultrathin layer of a refractory metal – a metal that is resistant to heat and wear – between the lithium anode and solid electrolyte. "The refractory metal layer shields the solid electrolyte from the stress and redistributes the current to an extent," says Aetukuri. He and his team collaborated with researchers at Carnegie Mellon University in the US, who carried out computational analysis which clearly showed that the refractory metal layer indeed delayed the growth of microscopic lithium voids.

Applying extreme pressure that can push lithium against the solid electrolyte can prevent voids and delay dendrite formation too, but that may not be practical for everyday applications. Other researchers have also proposed the idea of using metals like aluminium that alloy or mix well with lithium at the interface. But over time, this metal layer blends with lithium, becoming indistinguishable, and does not prevent dendrite formation. Raj explains how their technique differs: "If you use a metal like tungsten or molybdenum that doesn't alloy with lithium, the performance which you get from the cell is even better."

The researchers say that these findings are a critical step forward towards making commercial solid-state batteries a reality. Their strategy can also be extended to other types of batteries that contain metals like sodium, zinc and magnesium.

- Ranjini Raghunath

Photo courtesy: Rohini Balakrishnan

PREDICTING FIELD CRICKET CALL FREQUENCIES

Crickets produce sounds by rubbing a specialised structure called ‘plectrum’ on the margin of one forewing against a file of ‘pegs’ on the other. These sounds get amplified by a resonant structure on the wing called the harp.

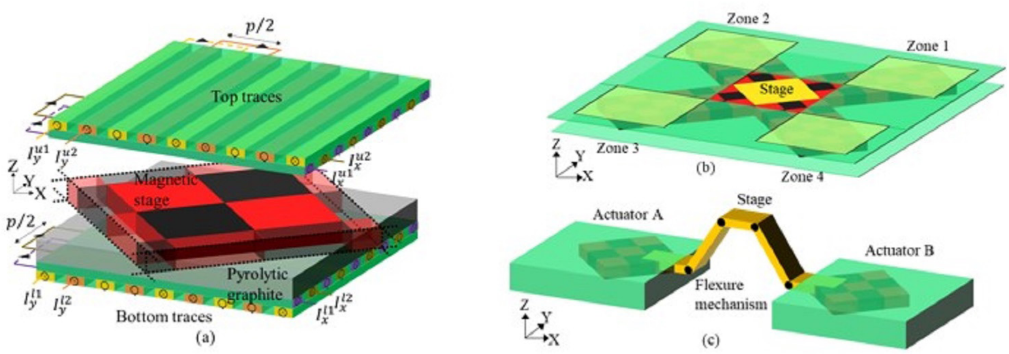
A new approach has now been used to predict the acoustic features of calls of different cricket species, in a study led by Rohini Balakrishnan from the Centre for Ecological Sciences, and Vamsy Godthi and Rudra Pratap from the Centre for Nano Science and Engineering. The team used a numerical technique called finite element modeling to study the complex geometry of cricket wings. Focusing on the harp’s geometry, and using the cricket *Gryllus bimaculatus* as the baseline, they successfully predicted the call frequencies of eight other field cricket species.

The ratio of harp thickness to area emerged as an accurate predictor of call frequency. The call frequencies of all cricket species are all tonal and lie between 2-9 kHz, in spite of 200 million years of evolution.

Such models can be used on museum specimens to predict the call frequencies of cricket species that have not been recorded in the wild. The approach can be extended to study the sounds of other animals and insects as well.

- Praveen Jayakumar

Image courtesy: GR Jayanth



COMPACT NANOPOSITIONING STAGES WITH LARGE RANGE AND MULTIPLE DEGREES OF FREEDOM

Precision positioning stages are often central to science and technology at the micrometer and nanometer length scales in diverse fields such as microscopy, robotics, automation and metrology. These stages are used to hold in place, or move in a specified manner, a piece of equipment or a sample. Therefore, compact multi-degree-of-freedom stages with large dynamic range are especially desirable. However, most positioning technologies demand large compromises to be made on one or more of these fronts.

In a recent study published in *Nature Communications,* KS Vikrant and GR Jayanth from the Department of Instrumentation and Applied Physics report a new type of compact, diamagnetically-levitated positioning stages that achieve large-range, six degrees-of-freedom (DOF) positioning with nanometre-scale precision.

Compared to other diamagnetically-levitated stages reported in literature, the proposed stages in this paper achieve between one to two orders of magnitude improvement in a variety of parameters including payload carrying capability, positioning stability, and precision.

These stages offer a combination of range, resolution, and low volume that other state-of-the-art positioning technologies cannot individually achieve. This opens up new possibilities for applications in micro and nanorobotics, scanning probe microscopy and optical alignment.

Shayan Garani (Photo courtesy: PNSIL team)

INTO THE REALM OF A PUZZLE SOLVER

FROM SIGNAL PROCESSING TO QUANTUM ENTANGLEMENT, SHAYAN GARANI'S INTERESTS ENCOMPASS A DIVERSE RANGE OF COMPLEX PROBLEMS

"The cube is a sort of [quantum computer] memory, where the vertices are qubits, and the faces are stabilisers," says Shayan Srinivasa Garani, Associate Professor at the Department of Electronic Systems Engineering, when asked about the inspiration for his lab logo. Sitting across a large wooden desk stacked with papers, patents, and awards for research in diverse fields, he adds, "A coded quantum memory has been my dream."

The Physical Nano-memories, Signal and Information processing Laboratory (PNSIL), led by Shayan works on solving problems in diverse areas, from signal processing and machine learning to tackling quantum information problems.

A major focus of PNSIL since it was set up has been solving problems in error correction. Information systems and signals in modern electronic devices are prone to errors during transmission and storage. To overcome these errors, computer scientists devised techniques in which by replacing certain symbols of information with other (and a larger number of) symbols, the signals can be corrected, making them robust against errors. The set of symbols are called codewords and this process of replacement is called encoding. Different encoding schemes have different properties and advantages. One of PNSIL's main efforts is to study and analyse the mathematical properties of these codes, design better codes for various applications, and design efficient encoding and decoding architectures.

Shayan's tryst with coding theory goes back many years before he started PNSIL. After completing his Master's degree at the University of Florida, he briefly worked in a telecommunication company before undertaking his doctoral studies at the Georgia Institute of Technology. A significant chunk of his doctoral research involved studying and solving problems related to non-binary 2D constrained codes. When he joined the industry after his PhD, he was involved in developing what are called Low-Density Parity Check (LDPC) codes for deployment in magnetic hard disks and solid-state drives.

LDPC codes are also known as Gallager codes, named after Robert G Gallager, who developed them in 1960. LDPC codes are known to be capacity-achieving, which means that the speed of information transfer in some transmission channels – like an optical fibre – is as fast as mathematically predicted for that channel.

LDPC codes have been well-studied since their introduction. Shayan was initially disinterested in them as he felt that most problems were already solved. It was only when his advisor and colleagues pointed out various problems in their practical implementation and the many puzzles yet to be solved that he was intrigued once again. Now he considers LDPC codes as one of his favourite classical coding schemes. In recent years, his lab has published various studies on hardware implementations of LDPC codes, developed 2D LDPC codes along with efficient 2D signal processing algorithms for next-generation storage systems. He is also venturing into LDPC codes for the transmission of quantum information.

When Shayan joined IISc, he was keen on pursuing the many puzzles in quantum information research, an area that had fascinated him for many years. He was first exposed to quantum information at a talk by Umesh Vazirani, a renowned computer scientist, in 2004. Quantum information technologies promise secure communication systems and speedups in solving various problems that are considered 'tough' to solve with classical computers. Quantum technologies are now just behind the horizon, and PNSIL works on various problems and new algorithms that assist in making these technologies a reality.

Entanglement also fascinates Shayan. It is a phenomenon where two physically separate entities, like atoms or photons, Research discussions in PNSIL (Photo courtesy: PNSIL team)

become linked even if they are very far apart, and inexplicably start influencing each other's behaviour at the quantum level. Such far-flung connections could open up the possibility of quick and seamless transmission of both classical and quantum information over long distances.

A quantum channel, like an optical fibre, is used to transmit quantum information. As a coding theoretician, it was natural for him to explore the potential of entanglement in designing codewords for the transmission of quantum information. To reduce errors, this information is encoded using quantum error correction codes (QECCs), similar to classical error correction. His lab has developed comprehensive theoretical frameworks and efficient encoding architectures for entanglement-assisted versions of QECCs. Shayan and his students have also proposed novel methods to encode quantum information distributed amongst multiple users and recover lost information. He has also begun exploring and tackling problems in quantum neural networks, combining his interests in machine learning and quantum information.

Another major focus of the lab is solving theoretical problems in machine learning and neural networks, particularly in mimicking the way in which the human brain stores memories, building upon results from his Master's thesis.

"Have you noticed that when you recite poems, learn slokas, or even prove theorems, you may [initially] have a missing link? But when you get the missing link, boom! You suddenly remember," he explains. Called temporal plasticity, this ability to store and recall patterns, helps us anticipate what comes next depending on what information is already stored in our brain. Shayan explains this using an analogy: Imagine that you are in a kitchen. There are cooking tools and there are vegetables. Both are related and there is a sort of clustering in your brain of the items based on their interrelations. When you are cooking, there is a sequence of actions and items involved, and over time, this clustering evolves as the actions are performed. Earlier, there were well-established frameworks only for spatial clustering. Shayan's lab has provided the necessary theoretical framework to understand the temporal evolution of this information in the brain and implemented these schemes in the form of neural networks on computers.

Aside from his research and teaching, Shayan tends to his garden in his free time. He is also a trained and practising Carnatic vocalist, and sometimes has jamming sessions with his students. It is of no surprise, therefore, that he has worked on music theory and processing too – he has presented papers on related topics at conferences. His lab has been exploring fundamental questions like what is music? What is a raaga? Should music be thought of as discrete or continuous? How can sound waveforms and gamakams be synthesised? He hopes that his contributions will help musicians better understand and analyse music.

Shayan says that he has always been very curious about every field. "You must be drawn to hard problems and have the endurance to work on them," he says when asked about what students should focus on. Having a lab with diverse students – from undergraduates to postdocs who have studied distinctive fields like physics, electrical engineering, and mathematics – has enabled him to work on a broad spectrum of problems that have piqued his interest.

"You can have many ideas. Still, unless you have a group of students to work with and get solutions on paper, they are just going to remain in your mind," he adds. "Nothing can beat that smile on your face when you solve a puzzle, and it is laid out correctly and is picture-perfect, and you can claim that no one else in the world has done that, [but] you've done that."

- Praveen Jayakumar

Shayan Garani with lab members at IISc in 2022 (Photo courtesy: PNSIL team)

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