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Editorial

Machine learning is all the rage right now. But what exactly does it involve and why are many scientists at IISc actively working on it? Read more about it in this issue of *Kernel*.

In this issue, we also profile a scientist whose lab sifts through complex data to decipher the interconnections between the atmosphere and the oceans, and how they impact our lives.

We feature stories on blood-based biomarkers for late-stage brain tumours, novel insights into how certain quasiparticles move in two-layered graphene, and more.

BITS OF LEARNING

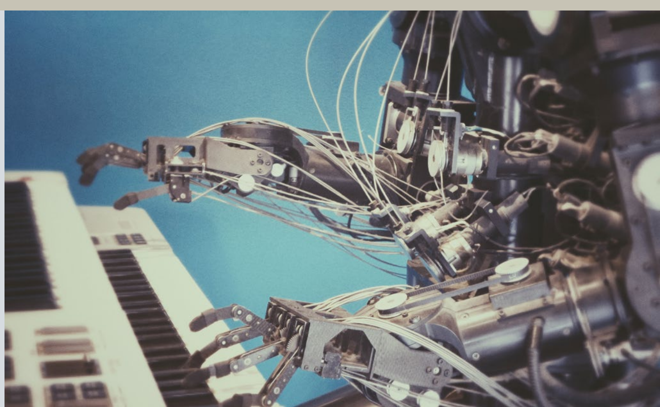

Image: Possessed Photography/Unsplash

MACHINE LEARNING CAN BE USED TO MAKE COMPUTERS LEARN LIKE HUMANS. RESEARCHERS AT IISc ARE APPLYING ITS PRINCIPLES IN FIELDS AS DIVERSE AS ROBOTICS AND LAW

When Google's AlphaFold burst onto the scene a few years ago with its ability to predict protein structures using only their amino acid sequences, it felt like the dawn of a new age in biology. It was yet another instance of machines having "learnt" to accomplish complex tasks that humans simply couldn't perform.

The technique used by AlphaFold, deep learning, is part of the broader discipline of machine learning. It has found numerous applications in several fields and attracted the attention of researchers from around the world, including IISc.

But what is machine learning? How is it different from conventional computer programming? "Everyone has a different take on machine learning," says Shishir Kolathaya, Assistant Professor at the Department of Computer Science and Automation (CSA) at IISc. "Machines learning to perform a seemingly complex task without human input is machine learning."

"It takes statistics and algorithms coming together for machine learning to take place," adds Ambedkar Dukkipati, Professor, CSA. "Humans have been making sense of statistics for a long time. Getting machines to do it was the next logical step."

On the other hand, Chiranjib Bhattacharyya, Professor and Chair of CSA, has a slightly

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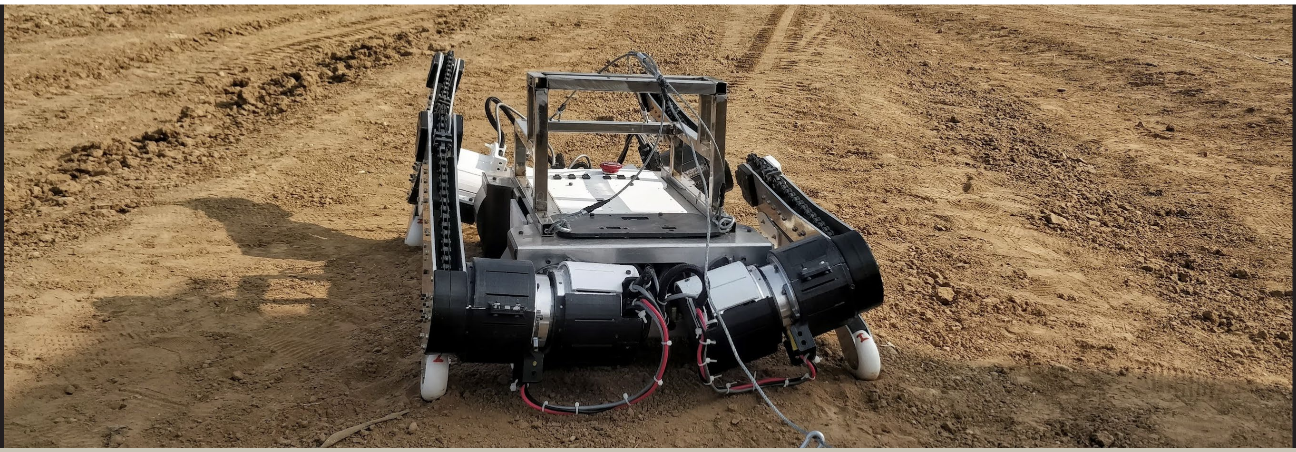


Stoch, the robot developed at RBCCPS (Photo courtesy: Shishir Kolathaya)

different explanation. "Machine learning is when machines learn from their environment," he says, a definition shared by AG Ramakrishnan, Professor at the Department of Electrical Engineering, who adds, smiling, "in a pale imitation of human children."

While the definitions of machine learning may vary depending on who you ask, all researchers agree on the fundamental principle underlying the discipline: machine learning uses algorithms that better themselves through experience and the use of data, unlike a conventional program whose code is formulated manually.

Shishir works with biped (two-legged) and quadruped (four-legged) robots. "Walking is such a simple task for humans," he explains. "We have mastered it over millions of years of evolution. But there are so many factors involved when you try to get a machine to do it."

It is a complex problem. Just getting robots to walk on flat surfaces is formidable, but to make robots of various sizes walk on different surfaces and gradients is a herculean task. "Machine learning, specifically deep learning, simplifies this task enormously," says Shishir, whose goal is to make robots and other objects perform tasks without human intervention. "In this way, we move towards making science fiction a reality."

Science fiction was also Chiranjib's motivation. "I used to read Satyajit Ray's *Professor Shonku* short stories," he recalls. His work focuses on the theory of machine learning. "We have been developing theories about unsupervised learning." One of the ways in which they wish to apply this research is in the area of autonomous navigation – more specifically through the technology of LiDAR, a light-based technology which is a critical component of self-driving cars.

But Chiranjib's greatest love is bringing together two different fields, machine learning and graph theory. "There was one result I was particularly proud of, which resulted in us discovering a new algorithm to solve the problem of finding cliques in a random graph. The algorithm allowed us to contribute back to graph theory."

Graph theory is also one of Ambedkar's areas of interest. "I got into machine learning because I was extremely interested in probability and abstract mathematics," he states. "Many people believe formal mathematical proofs are only important for theory. [But] a formally proven machine learning algorithm can give you much-needed guarantees in practical applications, especially where lives are at stake." This is particularly true for problems in one-shot and few-shot learning – making predictions using one or a few samples. "One-shot and few-shot learning is crucial for areas incapable of generating big data, such as diagnosing patients with rare diseases, where algorithms can only be trained with the limited data available," says Ambedkar.

Ambedkar's team has also gone on to design formally proven spectral graph algorithms for detecting communities in hypergraphs (constructs in graph theory connecting multiple related objects). This work has implications in detecting communities in a "fair" manner and may be useful in designing algorithms to help judges make decisions in courts.

Ramakrishnan's motivation, on the other hand, is explicitly utilitarian. "I am an engineer. I solve real-world problems," he states. "There are places where machine learning is the best tool for the job and I use it to its fullest extent."

One of his interests is linguistics, especially the study of Indian languages. "We work on complex linguistic problems, such as text-to-speech engines," he explains. "Indian languages introduce an element of complexity into the design of these engines. The way in which we use tenses, contexts, and the way in which we combine words in Indian languages, especially South Indian languages, is much more complicated than in English."

This complexity is apparent in the problem of speech recognition. One of Ramakrishnan's students has worked on applying deep learning to Kannada, Tamil, Hindi and English. "We had to think about innovative ways of breaking down words to sub-words, some of which make no grammatical sense," he says. "But the beauty of machine learning is that once the algorithms understand sub-words and their contexts, they can combine them to produce words they may never have been trained with."

All this makes machine learning sound like a tool for all ages and problems. However, there are issues to contend with. Safety, for instance, as Shishir points out. "We would rather that a robot identify a human as a human and nothing else, especially if that robot is a self-driving car."

Ramakrishnan concurs. "The case of the Amazon Echo speaker where Alexa, Amazon's AI assistant, told a young child to plug in a phone charger about halfway into a wall outlet, then touch a penny to the exposed prongs as a fun challenge tells us that there is still some way for machine learning to go."

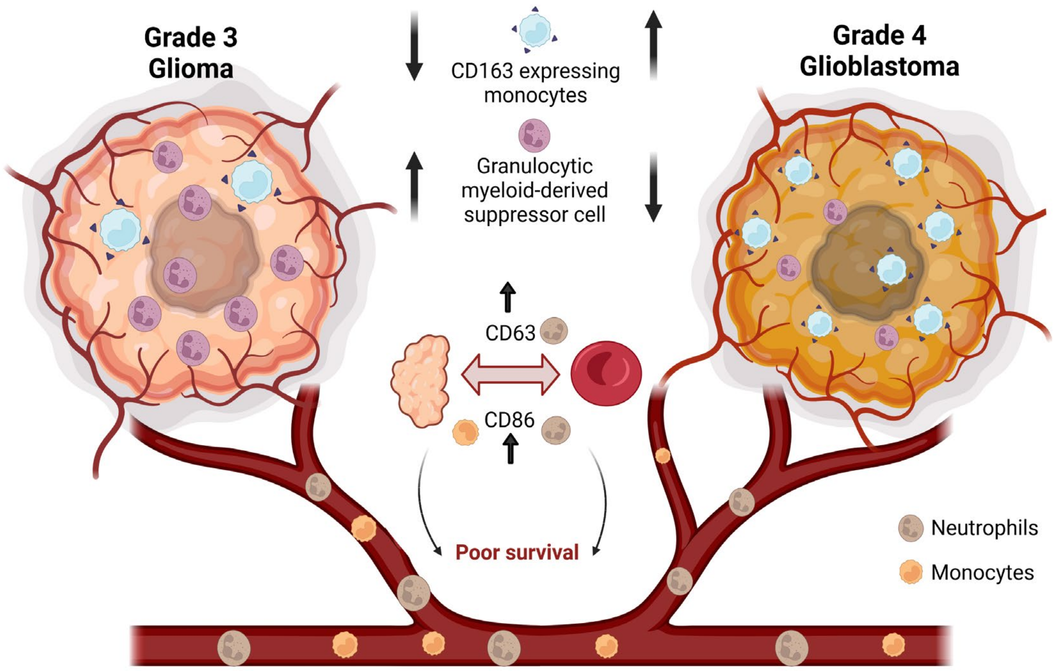
As machine learning becomes ubiquitous, there are other ethical challenges. "Many changes have to be made to a machine learning algorithm as it makes its way from the lab to the real world," says Chiranjib. Multinationals like Google and Facebook are the major drivers of this technology today. This isn't bad, Ambedkar believes, "but research institutions should reassert themselves. Machine learning should benefit everyone, not just those with the deepest pockets."

In the future, whether and how machine learning improves our well-being will depend on the intent of the humans designing and training the algorithms, according to Ramakrishnan. "At the end of the day, the algorithm is a tool. Just like with any other technology, what really matters is the nature of the person using it."

- Savyasachee Jha

A comparison of monocyte and neutrophil phenotype in grade four and grade three gliomas

Image: Jayashree V Raghavan, created on biorender.com



BLOOD-BASED BIOMARKERS FOR BRAIN TUMOURS

Potential blood-based biomarkers to predict disease progression and survival times in those with late-stage brain tumours have been identified by a team of researchers from IISc, the Mazumdar Shaw Centre for Translational Research and Mazumdar Shaw Medical Foundation.

The team analysed tumour and blood samples from individuals with gliomas – tumours that occur in the brain – to identify surface proteins on immune cells in the blood whose levels were closely linked to tumour progression. This study was published in *OncoImmunology.*

Late-stage gliomas such as grade three and grade four gliomas are harder to treat and the patient is likely to have a low chance of survival. "Our pilot study suggests that we can potentially use two blood-based biomarkers present on immune cells to identify patients who might not perform well with particular treatment strategies," says Siddharth Jhunjhunwala, Assistant Professor in the Centre for BioSystems Science and Engineering (BSSE), and senior author of the study. Such a blood-based testing methodology could help clinicians better understand disease progression and choose a more effective treatment regimen.

The team collected blood and tumour samples from patients with grade three and grade four gliomas, and compared the numbers of specific immune cells called monocytes and neutrophils in these samples.

"Because these are biosamples, they need to be preserved and processed very well without loss of cell viability," explains Jayashree V Raghavan, PhD student at BSSE and first author of the study. "We had to split up methodology between two institutes – here and at the lab at the Mazumdar Shaw Foundation. They would do all the processing and fixation to retain the viability of the cells, and then we would do the characterisation and immunostaining here."

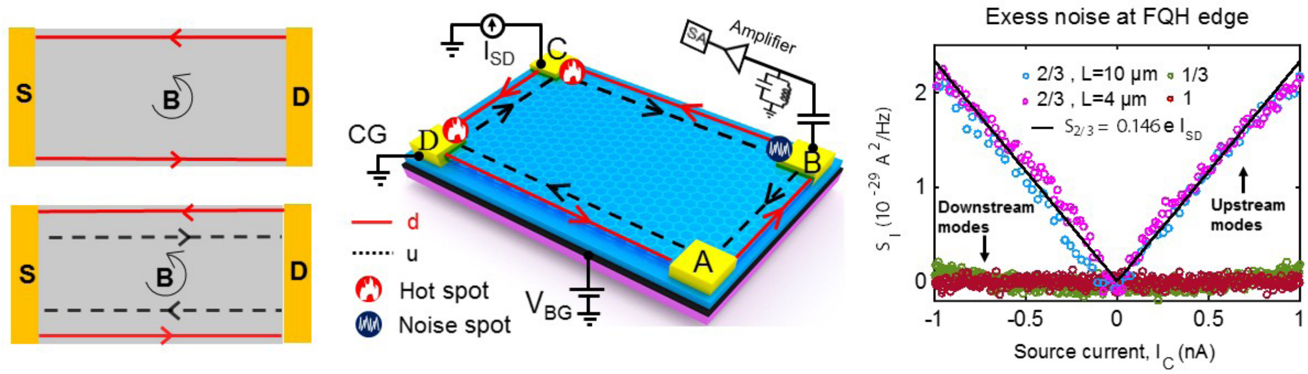
The team also looked for differences in the composition of surface proteins on these cells across the two grades of tumours. They found that a certain type of monocytes – the M2 monocytes – were present in larger numbers in the samples from grade four tumours. Previous studies have shown that high numbers of M2 monocytes are associated with a suppression of immune responses, and this finding could therefore help develop new treatment strategies. "Future studies could focus on developing therapies that reduce the numbers of M2 monocytes in the tumour microenvironment or alter their functionality," says Jhunjhunwala.

The researchers also found that levels of two surface proteins on neutrophils and monocytes, CD86 and CD63, were closely related in both the blood and tumour samples. The presence of high levels of these proteins on immune cells in other tumours has previously been associated with poor prognosis, or low chances of survival, Jhunjhunwala points out. "What our study showed is that you do not need to look at these markers only in the tumours, you might be able to look at these just from the blood, and the clinician can make an assessment," he says.

Jhunjhunwala cautions, however, that further testing and validation on a larger scale is necessary before this can be taken from the lab to the clinic. "We would like to expand our cohort and test [for] only these two markers now, in individuals with stage three and stage four brain tumours, and follow their survival times."

- Karthika Kaveri Maiappan

Image courtesy: Kumar et al



TRACKING QUANTUM PHENOMENA IN 2D GRAPHENE

In recent years, a phenomenon called the quantum Hall effect has emerged as a platform for hosting exotic features called quasiparticles, with properties that could lead to exciting applications in areas like quantum computing. When a strong magnetic field is applied to a 2D material or gas, the electrons at the interface – unlike the ones within the bulk – are free to move along the edges in what are called edge modes or channels – somewhat similar to highway lanes. This edge movement, which is the essence of the quantum Hall effect, can lead to many interesting properties depending on the material and conditions.

For conventional electrons, the current flows only in one direction dictated by the magnetic field ('downstream'). However, physicists have predicted that some materials can have counter-propagating channels where some quasiparticles can also travel in the opposite ('upstream') direction. Although these upstream channels are of great interest to scientists because they can host a variety of new kinds of quasiparticles, they have been extremely difficult to identify because they do not carry any electrical current.

In a new study, researchers from IISc and international collaborators provide "smoking gun" evidence for the presence of upstream modes along which certain neutral quasiparticles move in two-layered graphene. To detect these modes, the team used a novel method employing electrical noise – fluctuations in the output signal caused by heat dissipation.

"Though the upstream excitations are charge-neutral, they can carry heat energy and produce a noise spot along the upstream direction," explains Anindya Das, Associate Professor in the Department of Physics and corresponding author of the study published in *Nature Communications.*

Quasiparticles are largely excitations that arise when elementary particles like electrons interact among each other or with matter around them. They are not truly particles but have similar properties like mass and charge. The simplest example is a 'hole' – a vacancy where an electron is missing in a given energy state in a semiconductor. It has an opposite charge to the electron and can move inside a material just like the electron does. Pairs of electrons and holes can also form quasiparticles which can propagate along the edge of the material.

In previous studies, the researchers have shown that it might be possible to detect emergent quasiparticles like Majorana fermions in graphene; the hope is to harness such quasiparticles to eventually build fault-tolerant quantum computers. For identifying and studying such particles, detecting upstream modes which can host them is critical.

In the current study, when the researchers applied an electrical potential to the edge of two-layered graphene, they found that heat was transported only in the upstream channels and dissipated at certain 'hotspots' in that direction. At these spots, the heat generated electrical noise that could be picked up by an electrical resonance circuit and spectrum analyser.

The authors also found that the movement of these quasiparticles in the upstream channels was 'ballistic' – heat energy flowed from one hotspot to another without any loss – unlike the 'diffusive' transport observed earlier in gallium-arsenide based systems. Such a ballistic movement is also indicative of the presence of exotic states and features that could help build energy-efficient and fault-free quantum components in the future, according to the authors.

- Ranjini Raghunath

Image: Jyotirmoy Paul

TRACKING THE MOVEMENT OF THE INDIAN PLATE SINCE THE LAST MASS EXTINCTION

Scientists have speculated that a supervolcano erupted about 65 million years ago (65 Ma), which drastically affected the Earth's climate, resulting in the fifth mass extinction. The eruption of magma onto the planet surface occurred just underneath the then Indian plate, in a location known as Réunion (presently in the southern Indian Ocean). Scientists have suggested that the volcanism probably created India's Deccan plateau and affected the dynamics of the Indian plate in many ways.

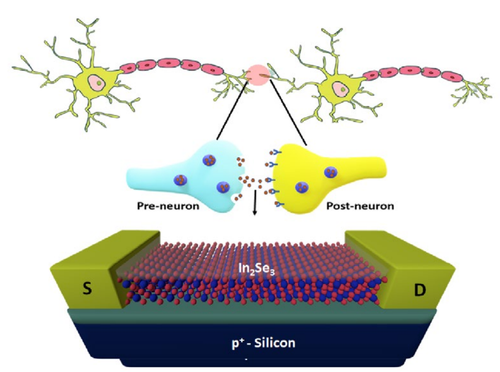
Using numerical models of mantle convection, Jyotirmoy Paul and Attreyee Ghosh from the Centre for Earth Sciences show that due to the Réunion plume eruption, about 130 km of the Indian continental lithosphere might have eroded away, making it an unusually thin plate compared to other continental plates. In addition, the plume material could have lubricated the boundary between the Indian plate and the underlying mantle.

As a result, the Indian plate could slide over the mantle very quickly, achieving the highest velocity ever by any plate (~20 cm/year) since 65 Ma.

This could be a potential reason for the massive impact between the Indian and the Eurasian plates, ultimately forming the world's tallest mountain chain – the Himalayas.

- Jyotirmoy Paul

Image courtesy: Neha Mohta



INDIUM SELENIDE-BASED TRANSISTOR AS AN ARTIFICIAL NEURONAL SYNAPSE

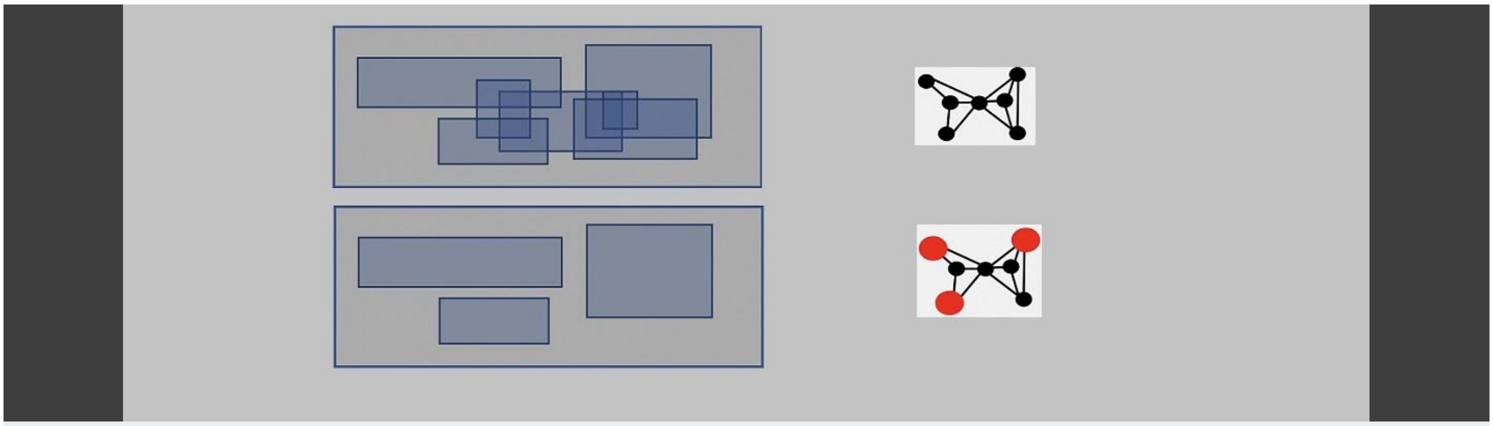
Artificial Neural Networks (ANNs) – a system of interconnected electric circuits or algorithms that communicate with one another just like the neurons in our brain – are gaining popularity for their ability to perform complex tasks, especially in pattern recognition. However, existing devices that mimic neurons and synapses – the junctions between two interacting neurons – operate at high voltages and show variable conductivity, making it difficult to construct efficient ANNs.

To address these concerns, researchers at IISc have developed an Indium Selenide-based transistor that was found to mimic several characteristics of a biological synapse. The team, led by Digbijoy Nath at the Centre for Nano Science and Engineering (CeNSE), fabricated a transistor out of multi-layered indium selenide, and tested its response to sequential voltage pulses, similar to the electric signals in the neurons.

The output characteristics of the device were able to capture essential features of the synapse. The researchers also used the device's responses to build a computer model which simulated an ANN. When they trained the ANN with a database of handwritten numbers, it was able to recognise 93% of numbers correctly. This device shows promise in constructing more complex neural networks for pattern recognition.

- Karthika Kaveri Maiappan

Image courtesy: Arindam Khan



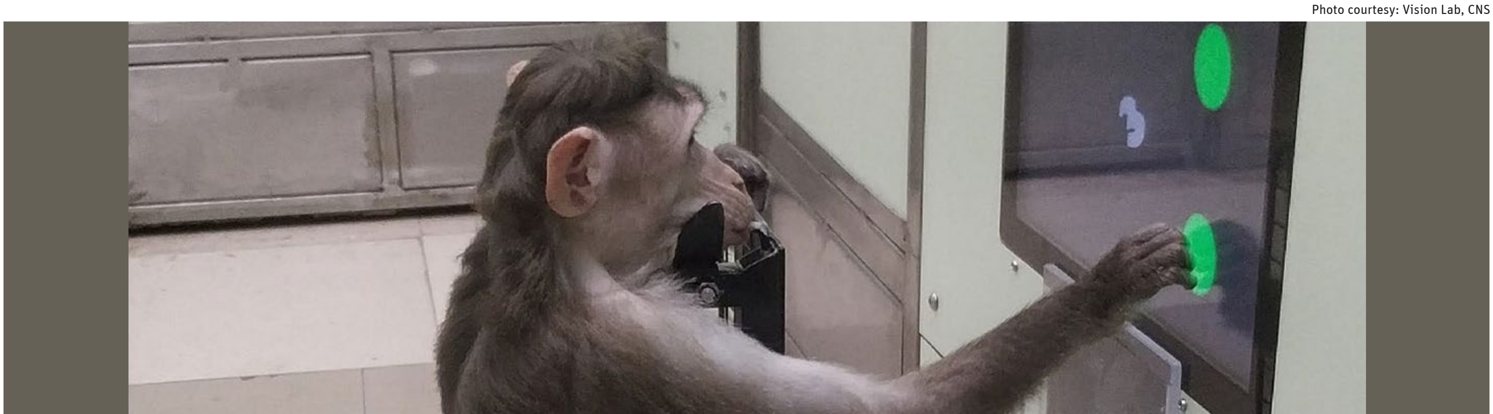
BREAKTHROUGH RESULT IN COMPUTATIONAL GEOMETRY

Maximum Independent Set of Rectangles (MISR) is a fundamental problem in fields such as computational geometry, approximation algorithms, and combinatorial optimisation. In this problem, given a set of (possibly overlapping) rectangles on a plane, one needs to find the maximum number of non-overlapping rectangles. MISR finds numerous applications in practice, such as in map labeling, data mining, and resource allocation. It also has rich connections with many important problems in theoretical computer science and discrete geometry. However, it is intractable to find the optimal solution for this problem. So, researchers are trying to find efficient and approximate solutions that are close to optimal.

Recently, Arindam Khan from the Department of Computer Science and Automation, undergraduate intern Madhusudhan Reddy, and international collaborators made progress on this notoriously hard problem by developing an algorithm that finds a solution that is at least one-third of the optimal solution.

In a follow-up study, they have further improved the result and showed an efficient algorithm that finds a solution (almost) half of the optimal solution. The work has led to the development of new mathematical techniques and extends the present techniques to their limits.

Photo courtesy: Vision Lab, CNS



STUDYING ANIMAL VISION IN A NATURALISTIC ENVIRONMENT

Researchers led by SP Arun at the Center for Neuroscience have developed a novel lab environment mimicking a natural setting to study cognition in freely moving monkeys. The setup consists, among other things, of a naturalistic group housing chamber and a behaviour room where the monkeys could perform tasks on a touchscreen workstation. The monkeys were trained to voluntarily position their heads on a chinrest to learn and perform complex cognitive tasks. One of the tasks was to determine if two images shown one after the other were the same.

The researchers were able to track eye movements while the monkeys carried out the task, without forcefully restraining them, using cameras and infrared illuminators placed above and below the workstation.

The researchers also let an untrained monkey into the behaviour room with a trained monkey, to see if it could learn the task by simply observing the trained monkey. Surprisingly, it learned the task much faster than the researchers' own training methods. The design, therefore, provides a unique environment where scientists can also study novel social interactions while the monkeys are learning, which is currently not possible with traditional methods.

- Arpit Omprakash

Photo courtesy: Jai Sukhatme

Jai Sukhatme (third from left) with current and former students (L-R) Aditya, Pradeep, Suhas, Sambrita, Abu and Nihar

AN OCEAN OF OPPORTUNITIES

JAI SUKHATME'S LAB INVESTIGATES THE INTERCONNECTIONS BETWEEN OCEAN AND SKY

Science fiction author Arthur C Clarke once said, "How inappropriate to call this planet Earth, when it is clearly Ocean." These oceans, which make up two-thirds of our world, are the focus of a whole new field of research – Oceanic and Atmospheric Sciences – which seeks to harness our existing knowledge of physics and geology to understand the phenomena that affect and regulate the oceans and atmosphere.

Jai Sukhatme, Associate Professor at the Centre for Atmospheric and Oceanic Sciences (CAOS) at IISc studies the dynamics of atmospheric and oceanic flows – everything from atmospheric circulation and upper ocean turbulence, to the intricate connections that these processes forge with one another, thereby impacting climatic conditions in far-flung places. His work centres around geophysical fluid dynamics – studying the movement of fluids in naturally occurring flows, such the atmosphere or the ocean – primarily in the tropical regions.

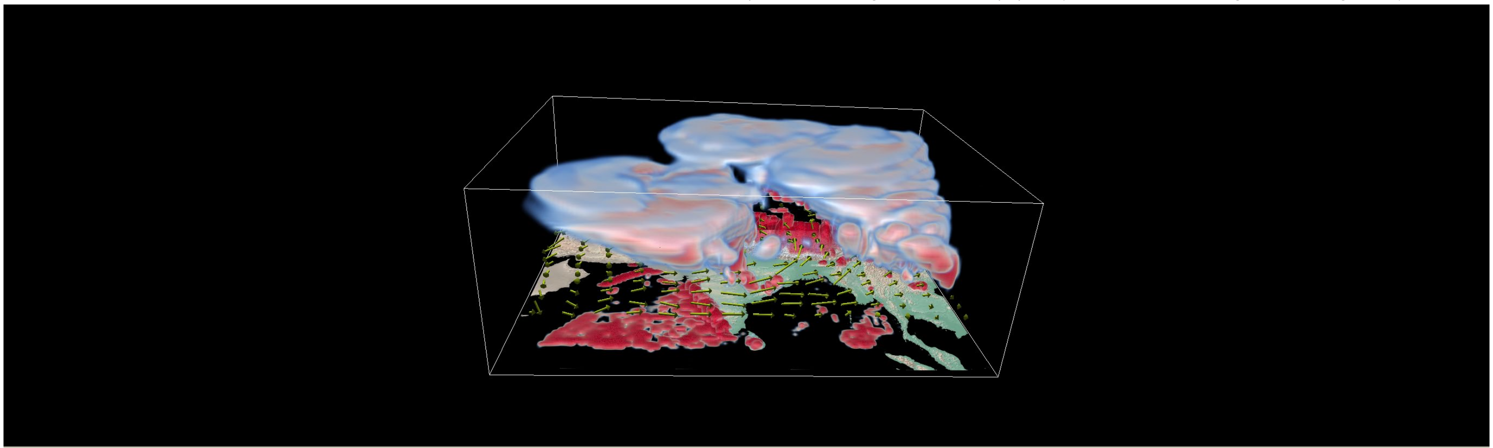
Fresh out of a BTech in Engineering Physics from IIT Bombay, Jai realised that he was interested in physics but did not gravitate towards any one field in particular. At that time, he came across a project in geophysics which sparked his interest in the subject, and he tried out a few classes in atmospheric science and dynamics. This led to a master's degree from the University of California, Davis and what would prove to be a lifelong interest in atmospheric and ocean sciences. During his PhD at the University of Chicago, he studied surface quasi-geostrophic turbulence, a simplified model of the flow of fluids in the ocean and atmosphere. In particular, he used a variety of statistical methods to understand the movement of stratified fluids – mainly, air and water – which have varying densities along the vertical direction, and this entrenched his interest in the subject.

Jai explains that atmospheric and oceanic scientists apply several methods ranging from numerical modelling to statistics to understand natural processes such as wind currents and oceanic tides, and to analyse their impact on climatic conditions, like the monsoon. Frequently, atmospheric scientists also rely on obtaining data from satellites, such as rain, humidity and surface temperature of oceans.

While Jai's lab relies on extensive collaborations to procure the data they need, it specialises in the analysis of this data to deepen our knowledge of the basic physical science that underlies any given phenomenon. An interesting discovery from his lab revolves around surface kinetic energy in the Bay of Bengal, in collaboration with Debasis Sengupta, Professor and current Chair of CAOS. In an expedition to the Bay of Bengal, Debasis's team deployed instruments to collect data about ocean currents, and these data sets were then examined by Jai's group. In the ocean, the velocity of currents manifests in two ways – as waves, or as vortices. Jai's lab was able to identify the contributions of both waves and vortices to the kinetic energy (which depends on velocity) of ocean currents. Their finding is not only important for understanding the distribution of kinetic energy in the Bay of Bengal, it also goes toward explaining how the energy that enters the seas from the atmosphere is disseminated, and how the energy balance is maintained.

Piecing together the factors that regulate a region's climate is nothing short of a jigsaw puzzle. This is because variations in climate often tend to be related across thousands of kilometres and are called teleconnections. Jai's lab works on characterising these teleconnections and remote influences to understand how tropical weather conditions might be affected by phenomena that originated elsewhere. One of his PhD students, for instance, created a moist model which had waves in the tropics reaching out to the midlatitudes, and then doubling back to the equatorial regions. Similarly, his work with V Venugopal, Associate Professor at CAOS, identified a teleconnection originating from the Atlantic basin, which played a role in disrupting the Indian monsoon. Not only is this compelling from a weather prediction perspective, it also demonstrates the complex connections that link the atmosphere to the ocean, and the interconnectedness of regions that are very far from each other.

Simulation of clouds, circulation (mid-level) and water vapour (low-level) during formation of mid-tropospheric cyclone over western India using WRF model (Image courtesy: Jai Sukhatme)



Atmospheric scientists often rely on thought experiments and simulations to understand the changes that have occurred in climatic conditions over time. In this context, Jai's lab looks at uniform surface sea temperatures – a hypothetical scenario which contrasts with the normal pattern of temperature increasing from the colder poles to warmer tropics. Removing this gradient opens up the possibility of studying several potential changes, such as the disappearance of the Hadley cell – the name given to the overall pattern of circulation of wind currents in the tropical atmosphere. It also has major implications for our current scheme of energy movement from the tropics to the poles. Jai explains that delving into such imaginary models allows scientists to expand their traditional outlook on natural phenomena and understand the extent of the impact a specific process would have on another. For instance, this study allowed Jai's lab to work on the factors that stabilise and promote the formation of the Hadley cell, and to further make sense of the convoluted mesh that tropical atmospheric and oceanic processes form with one another.

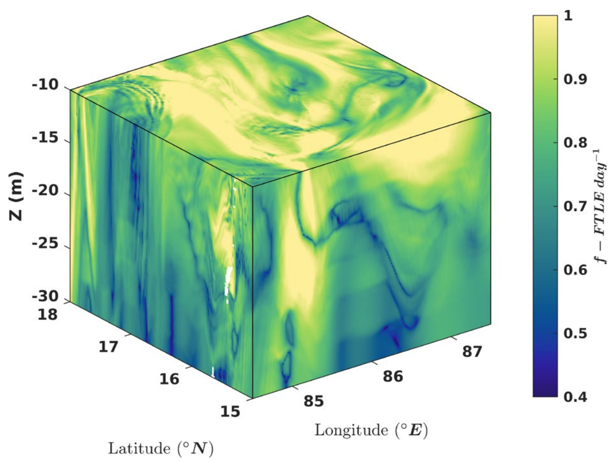
Another fascinating foray of his lab has been into processes that are likely to be affected because of a warming climate. His lab studies zonal mean winds, which circulate in the same latitude in a direction parallel to the equator. Wind currents are usually associated with a specific momentum over a given area in a given time ('momentum fluxes') that play an essential role in regulating the type of atmospheric flow in a region. Through modelling and data analysis, Jai's team has found that the momentum budget in the tropics rests on a fragile balance between the Hadley cell and a variety of waves. Much like the gradual but consistent melting of ice caps, all the pieces of this momentum budget will be affected as the temperature rises in the tropics.

Jai also elaborates on the prospects that have opened up in the field in the past decade. There are several new industries that are working on renewable energy prediction, quantifying risk associated with floods or hurricanes as well as gauging the impact of weather on transport, agriculture or other industries. "The recent generation of big data in atmospheric sciences as well as more sophisticated tools in data analytics such as machine learning have resulted in people realising that you could probably exploit this data to learn more about one's environment," he explains.

Jai admits that public interest in climate change has helped bring ocean and atmospheric research into the limelight in recent years, but at the same time, he feels that it would be gratifying if basic research in the field also received a similar stimulus. "A lot of the research we do is driven by curiosity to get a fundamental understanding of the kind of variability we see in the atmosphere."

- Anusha Rastogi

Finite Time Lyapunov Exponents that are measures of mixing in a high resolution simulation of the Bay of Bengal (Image courtesy: Jai Sukhatme)



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