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KERNEL

Editorial

With its powerful computational abilities, SahasraT, procured by IISc in 2015, has helped diverse teams at the Institute carry out cutting-edge research. In this issue of *Kernel,* read more about some of the areas where this supercomputer has been particularly helpful.

This issue also features a lab that works at the intersection of mechanics and biology, besides research highlights on mate-finding behaviour in crickets, a novel drop-on-demand printing technique and more.

RESEARCH IN THE FAST LANE

Photo courtesy: SERC

SAHASRAT, INDIA'S FIRST PETASCALE COMPUTER HOUSED AT IISc, IS POWERING DIVERSE RESEARCH PURSUITS ACROSS CAMPUS

When IISc brought home SahasraT in 2015, everyone on campus was excited, recalls Lakshmi J, Chief Research Scientist at the Supercomputer Education and Research Centre (SERC). It was India's fastest supercomputer, a veritable beast capable of carrying out a quadrillion (10^{15}) calculations per second. "Within three days of commissioning the machine, we were able to saturate 80% of the system resources in terms of the number of jobs executed," she says.

Now there are two supercomputers in India that are faster than SahasraT ("Pratyush" and "Mihir", specialised for climate and weather studies). IISc itself will add another supercomputer next year – under the National Supercomputing Mission, of which it is a lead partner. Yet SahasraT will still retain a unique position in India's academic landscape, says Sathish Vadhiyar, Chair of SERC. "The number of applications from different domains

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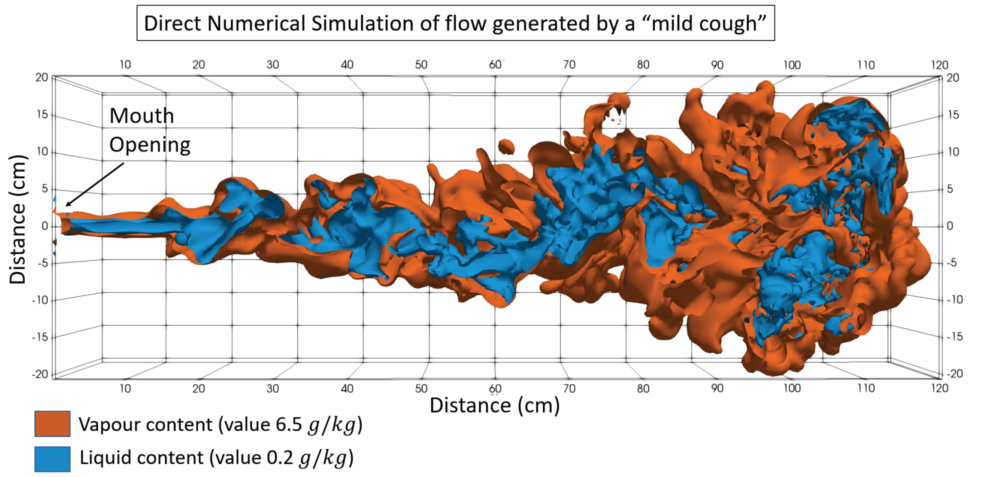
Simulating cough/sneeze flows to study droplet transmission for COVID-19 (Image courtesy: Sourabh Diwan et al.)



that SahasraT caters to is vast compared to these," he says. "It is a real 'general purpose' machine."

Supercomputers like SahasraT have thousands of processors – the "brains" of computers – working on different parts of the same problem in parallel. This cuts down the time needed to sift through large amounts of data tremendously. SahasraT has 33,000 processor cores arranged in clusters called nodes, which are in turn stacked on blades arranged in racks. It also has custom-built hardware and software that allow the different units to "talk" to each other without time lag, explains Lakshmi.

Over the past five years, SahasraT has enabled researchers from various departments to study a host of topics, from monsoons and materials to black holes and biomolecules. Prabal Maiti's lab in the Department of Physics, for example, is using SahasraT for at least four different projects, one of which is analysing DNA nanostructures for applications such as drug delivery. These structures are huge compared to carbon-based molecules, with over 300,000 atoms. Simulating how they behave or assemble can take years using conventional computers.

Another area of Maiti's research is HIV. A protein called gp41 helps the HIV particle fuse with the immune cell membrane. To understand this process and design drugs that can block it, Maiti's team is using a combination of atom-level and large-scale 3D simulations run on SahasraT. These involve solving math equations for millions of atoms to understand how exactly the atoms move and interact, and what forces act on them. "The force calculations are the heart of these simulations … they are [also] the most time-consuming part. Some of them run for months or years," he says. His lab is also developing dendrimer polymers which can help inhibit HIV infection.

In recent months, SahasraT has also been helping in the fight against COVID-19. A multi-institutional team (IISc, ICTS, JNCASR and KTH, Sweden) led by Sourabh Diwan at the Department of Aerospace Engineering is using it to analyse the dispersal of droplets released by a person coughing or speaking, by adapting a numerical code originally developed to study how cumulus cloud flows evolve.

Both cloud and respiratory flows are chaotic ("turbulent"), with droplets of different sizes behaving differently. The dynamics are governed by a set of partial differential equations which need to be solved computationally. To accurately replicate the turbulence in the flow, the researchers carry out a direct numerical simulation – a heavy-duty process involving 50,000-400,000 core hours using 2048-16,660 cores for a single run. "The immediate objective is to see how far the moist air travels, what is the effect of evaporation, how long these droplets linger in the air, and so on," says Diwan. "A long-term goal is to understand this flow more fundamentally."

SahasraT is also helping researchers like Bratati Kahali at the Centre for Brain Research to analyse the genomic sequences of 10,000 individuals from across India as part of the GenomeIndia initiative. Identifying genetic variations unique to Indians will help understand the genetic basis of many diseases. Early results from studies involving about 100 individuals show that there are more than a million variations that are completely novel in the Indian population and currently not accounted for in global databases, says Kahali.

Such studies are not feasible in a reasonable time using normal computers. Each DNA sequence has more than 3 billion base pairs or letters. The raw data for each experimental run for 24 individuals can take up 1.5 terabytes (TB) of storage space – 70 TB during analysis – and about 20 hours to analyse. "Whereas in SahasraT, I can parallelise it in such a manner that I can analyse 24 individuals' data in eight to ten hours," explains Kahali.

There are scores of similar projects that are ongoing, including simulating extreme weather events, modelling materials using machine learning, studying properties of glasses, insulators and semiconductors, and designing drugs using crystallography. In 2018, SERC organised a Grand Challenge which allowed three teams to utilise SahasraT's entire capacity for eight hours each. As part of this, an astrophysics team studied how particles in space aggregate to objects such as black holes.

These projects keep SahasraT running through the year; about 90% of the system's resources are almost always in use, says Vadhiyar. "Even on a Saturday evening, you will see that the machine is full and many jobs are waiting in the queue." To ensure that the machine keeps running without a pause, a dedicated team of engineers works continuously behind the scenes, helping IISc researchers execute their projects.

SERC also has more plans for this workhorse on the horizon. "We plan to set up teams that provide good visualisation services, high performance computing products, large scale scientific libraries and training courses," says Vadhiyar. "Overall, we would like SERC to act as a centre of excellence for the country."

- Ranjini Raghunath

A green lynx spider captures a female tree cricket (Photo: Viraj Torsekar)

TO MATE OR BE EATEN:

TREE CRICKET BEHAVIOUR IN THE PRESENCE OF A PREDATOR

IN THE PRESENCE OF PREDATORS, MALE TREE CRICKETS, BUT NOT FEMALES, CHANGE THEIR MATE-FINDING BEHAVIOUR, ACCORDING TO A NEW IISc STUDY

The cricket chirps that you hear on summer evenings are males calling to attract females of their species to mate with them. Female crickets do not call, and instead walk towards these calling males. What are the consequences of predation on their mate-finding behaviours and mating success?

These questions were addressed in tree crickets in a recent publication in the journal *Functional Ecology,* by researchers at the Centre for Ecological Sciences (CES) at IISc. They also investigated whether the chances of survival are affected if crickets altered their mate search behaviour.

The researchers experimentally manipulated the level of danger by maintaining different ratios of the number of predators – green lynx spiders – to crickets, in outdoor enclosures built in their natural habitat.

They then observed the crickets, and examined whether they changed their mate searching behaviour under different levels of threat, and noted their chances of survival. They also estimated the effects of these direct and indirect pressures on the mating success of the crickets.

The researchers found that when the threat of predation increased, male crickets reduced calling, and moved towards other singing males they could hear around them. This directed movement indicates that they may be switching to a tactic known as "satellite" behaviour. These silent, satellite males hang around a caller, and attempt to mate with females who approach the singer.

This tactic has its benefits: they conserve energy by not calling, and are also less conspicuous to predators. But there is a cost: the chances of satellite males successfully mating is much lower than that of calling males. They lose out on mating opportunities but are more likely to survive to the next night, and try again to find a mate.

On the other hand, female crickets did not reduce their movements even when the risk of being eaten was high. This result was unexpected because males are expected to be the more risk-taking sex, according to Viraj Torsekar, former PhD student and the first author of the paper.

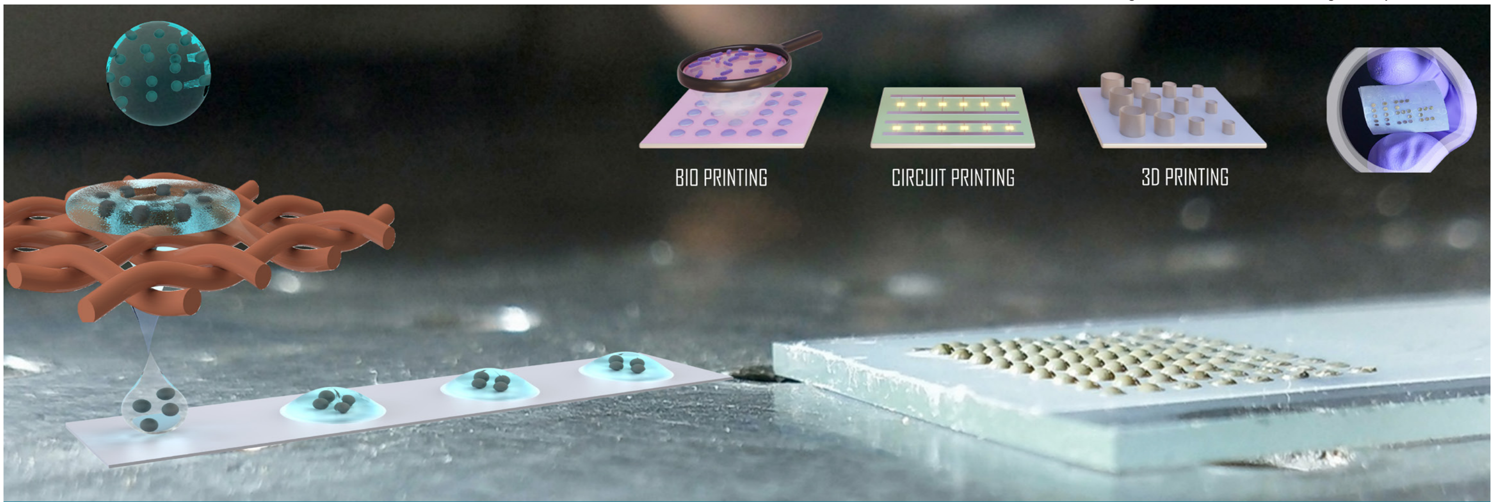
Torsekar adds that in many species of crickets, the female mounts the male during copulation and feeds on nutritious secretions from a gland on his back. And therefore, it would benefit the females to mate with multiple males to maximise this nutritional intake. Whether this added incentive plays a role in the females' continued movement even in the presence of predators, however, needs to be investigated.

The authors also found that increased predation risk reduced the chances of survival for both male and female crickets equally. This in turn reduced the number of times these individuals were able to mate, and could affect their reproductive fitness – the number of offspring an individual leaves behind – and the currency of success in nature.

"I think what is really novel and exciting about this study is that it examines both direct effects via mortality, and indirect effects via changes in behaviour, of predation on fitness, in both sexes, in very close to natural situations," says Rohini Balakrishnan, Professor at CES, and senior author of the paper.

- *Samira Agnihotri*

Image: Microfluidic Devices and Heterogeneous Systems Lab, CeNSE



A LOW-COST, DROP-ON-DEMAND PRINTING TECHNIQUE

USING WATER-REPELLENT NANOWIRE MESHES INSTEAD OF TRADITIONAL NOZZLES WHOSE PORES CAN CLOG, A RESEARCH TEAM HAS DEVELOPED A VERSATILE PRINTING TECHNIQUE

Researchers at the Centre for Nano Science and Engineering (CeNSE) have developed a low-cost, drop-on-demand printing technique capable of generating a wide range of droplet sizes using a variety of inks. Apart from traditional printing, it could also potentially be useful for 3D printing of living cells, ceramic materials, electronic circuits and machine components.

Printers used currently – from inkjet printers to bio-printers that dispense living cells – have a nozzle with a small opening to eject droplets. However, particles in the ink or a cell suspension can clog the opening, which limits the amount of particles or cells that can be loaded initially. Therefore, the thickness of the layer that can be printed is also limited.

The new technique replaces the nozzle with a mesh covered with chemically treated nanowires that repel water. When a large droplet impacts on this mesh, it bounces back. However, a small part of the liquid is ejected through the mesh pore as a jet that breaks to create a micro-scale droplet, which is then printed onto a surface.

Because of the short contact time of the impacting droplet with the mesh (about 10 ms), the particles in the ink do not get a chance to clog the mesh pore, the researchers say. This allowed them to load the ink with larger quantities of nanoparticles, enabling printing of very thick lines in a single cycle. The mesh can also be easily cleaned and reused.

"The mesh costs only a small fraction of the nozzles that it replaces. This significantly reduces the operational cost when compared to conventional printing techniques," says Prosenjit Sen, Associate Professor in CeNSE and senior author of the study published in *Nature Communications.*

Sen and his lab have been working on developing nanostructured surfaces that can repel water. When large droplets hit such nanostructured meshes at high speeds, jets are ejected.

While studying this phenomenon, the researchers found that the velocity of the ejected jet was surprisingly higher than the velocity of the impacting droplet.

"This was the first hint that some mechanism was playing a role in focusing the kinetic energy," says Chandantaru Dey Modak, first author and PhD student at CeNSE. "At this point, we started asking the following questions: What is this focusing mechanism? Can this mechanism be exploited to reliably generate single microscale droplets?"

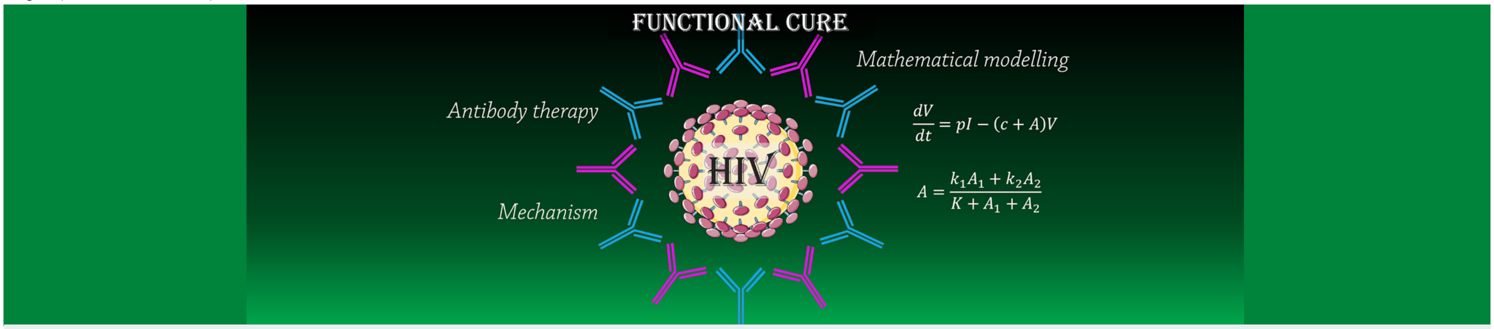
The team captured high-speed videos (50,000 to 80,000 frames per second) of these impacting droplets, and found that an air cavity was being formed at the droplet centre. During the recoil phase of the impact, this cavity collapsed, focusing all the kinetic energy into a single point, resulting in the generation of individual droplets. No "satellite" droplets – secondary droplets that result in unwanted scatter – were generated. The size of the droplets ejected could also be tweaked by adjusting the pore size of the mesh.

The researchers were able to demonstrate the use of this technique for various applications.

"Using drop impact printing, we could print 3D pillars of different sizes, an electronic circuit for semiconductor device applications, and bio-based droplet arrays for cell culture," says Modak. "The capability to print a wide range of droplet sizes while using different kinds of inks for different applications makes this technique unique."

- Ranjini Raghunath

Image: Rajat Desikan and Rubesh Raja



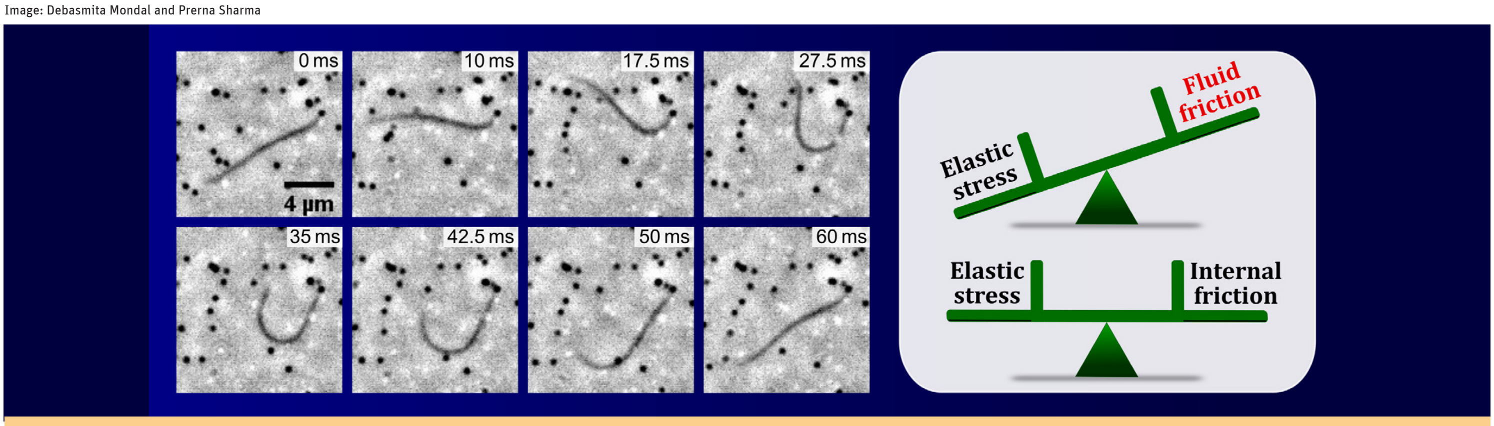
A PROMISING ALTERNATIVE TO LIFELONG HIV TREATMENT REGIME

AIDS is a chronic, life-threatening condition caused by HIV, which is known for its ability to evade the host's immune system effectively. There is no known cure or vaccine. A lifelong treatment with antiretroviral therapy (ART) is usually necessary in the event of the infection being reignited. However, a study done in macaques found that the probability of such an event occurring was significantly reduced through early immunisation with HIV antibodies (bNAb therapy).

Researchers in the Department of Chemical Engineering have now constructed a novel math model of HIV infection following immunisation with bNAb antibodies. It suggests that long-lasting reduction of viral load is switched on by interventions like ART or bNAb therapy. It also predicts that early bNAb therapy enhances stimulation of the host's immune cells, and helps in mounting a better defense compared to ART. The researchers say that their model is the first quantitative description of HIV dynamics under bNAb therapy, and that it unravels the mechanism underlying the response described in the macaque study. The study adds to the evidence that bNAb therapy may be a promising alternative to ART.

- Rohini Murugan

Image: Debasmita Mondal and Prerna Sharma



WHAT GOVERNS STABLE CILIARY OSCILLATIONS?

Cilia are whip-like appendages used by cells and tissues to move, and are indispensable for cellular and developmental processes ranging from the clearing of mucus in the lungs to the movement of sperm towards the egg. They are "active" filaments that spontaneously oscillate by continuously consuming chemical energy and dissipating it through periodic motion. For stable oscillations, the active energy input must be balanced by sufficient dissipation.

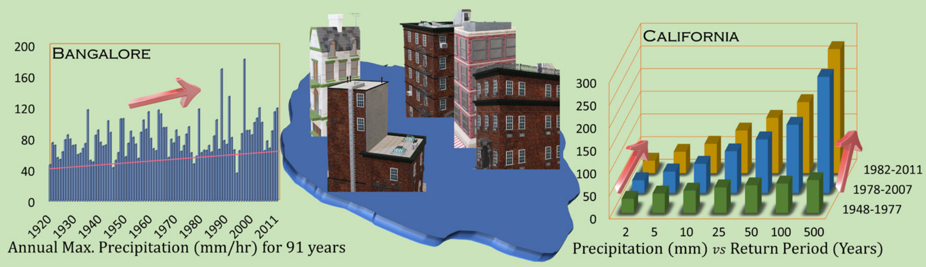
Scientists have so far believed that ciliary "beating" or oscillation is governed by external fluid friction.

However, in a new study, researchers from the Department of Physics show that external fluid friction is not sufficient to balance the passive elastic stresses generated within the filament. It is actually "internal friction", arising from slow structural rearrangements within the filament, which may be responsible for stable oscillations.

This counter-intuitive result emerged from experiments using a novel method developed to study cilia isolated from the green algae *Chlamydomonas.*

The study also settles a long-standing debate on the influence of external factors on the collective behaviour of cilia.

Image: Chandra Rupa R et al.



HAS URBANISATION LED TO INCREASED PRECIPITATION IN CITIES?

Increased population in urban areas has led to a rise in the number of unplanned cities, and an increased vulnerability to extreme weather events. Examining historical patterns in precipitation and temperature can help predict future climate change, and develop strategies to tackle natural disasters.

Researchers from the Interdisciplinary Centre for Water Research at IISc and the University of Saskatchewan, Canada, have performed a detailed statistical analysis of changes in temperature and precipitation over 30 years in seven cities. It revealed an increase in yearly average temperature, yet a decrease in diurnal temperature in all the cities. The precipitation depth – the amount of rainfall that can accumulate in a given area – has increased in the recent past for most of the cities, the study found.

The team also showed that short-duration precipitation events have become more frequent recently, and that overall, the precipitation depth has increased considerably in the evenings.

Understanding the impact of urbanisation on local rainfall patterns can help to design stable infrastructure in cities, and aid in risk assessment and efficient operation of infrastructure particularly during calamities like flooding.

- Shatarupa Sarkar

Image courtesy: Equine biotech/Utpal Tatu

AN INDIGENOUS ICMR-APPROVED COVID-19 DIAGNOSTIC KIT

Equine Biotech, a startup incubated at IISc, has developed an indigenous diagnostic kit called “Global diagnostic kit” for accurate and affordable diagnosis of COVID-19.

The test kit, based on Reverse Transcriptase Polymerase Chain Reaction (RT-PCR), the gold standard for COVID-19 diagnosis, has been approved for use in authorised COVID-19 diagnostic labs by the Indian Council of Medical Research (ICMR).

The test takes about 1.5 hours to confirm the presence of SARS-CoV-2 in patient samples. It is also easy to use and has 100% specificity, according to the founders. The company is currently seeking to licence its new COVID-19 test kit and work with med-tech companies and other industries for mass producing, marketing and distribution of these kits.

Equine Biotech has 30 years of experience working on infectious diseases, including zoonotic diseases.

The company is founded on the concept of ‘One Health’, which encompasses human as well as animal health and wellness. It has previously developed diagnostic tests for screening livestock, especially cattle and horses, for blood parasitic diseases such as trypanosomiasis, trichomoniasis, theileriosis and babesiosis.

- Ranjini Raghunath

Photo: KG Haridasan

USING MECHANICS TO ENGINEER TISSUES

NAMRATA GUNDIAH'S LAB BLENDS BIOLOGY WITH MECHANICS TO ANSWER FASCINATING QUESTIONS ABOUT HUMAN HEALTH AND BIO-INSPIRED MATERIALS

"Understanding biology is really fun," says Namrata Gundiah, an engineer working at the intersection of mechanics and biology. Gundiah is an Associate Professor and DST Ramanujan Fellow, and heads the "Biomechanics laboratory" at IISc's Department of Mechanical Engineering. "All the techniques in my lab are in mechanics that we apply to problems in biology – this is the niche of our group," she explains.

Gundiah chuckles as she says, "From a science perspective, [my colleagues] still don't know where to put me in, the mechanics or biology part." Her lab at IISc is an eclectic mix of engineers and biologists who study both biomechanics and mechanobiology. Biomechanics is the study of the structure, function and motion of biological systems ranging from tissues to organisms, whereas mechanobiology focuses on how cells perceive and adapt to dynamically changing mechanical cues.

"We are intrigued by form and function, an idea started by D'Arcy Thompson just over 100 years ago. We are excited to see how mechanics and mathematics can be used to explain the different shapes and patterns in nature," adds Gundiah. She is the first woman to be a tenured faculty member at the Department of Mechanical Engineering, which is celebrating its 75th anniversary this year.

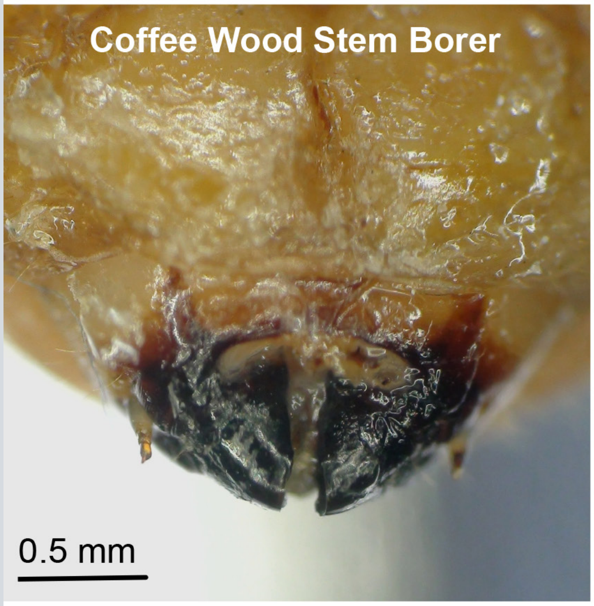
Two decades ago, as a graduate student at the University of California, Berkeley, Gundiah grew interested in certain proteins in arteries and the skin that undergo large deformations. These proteins are amorphous and exhibit rubber-like behaviour, which she describes as "exciting for someone trained in mechanics". Degradation of such proteins can lead to aneurysms, caused by weakening of human arterial walls. An understanding of the growth of these structures during development and progression is hence important. Her interest in rubber-like materials continues at IISc, where she investigates the anomalies in structural proteins present in tissues that undergo dynamic stretch.

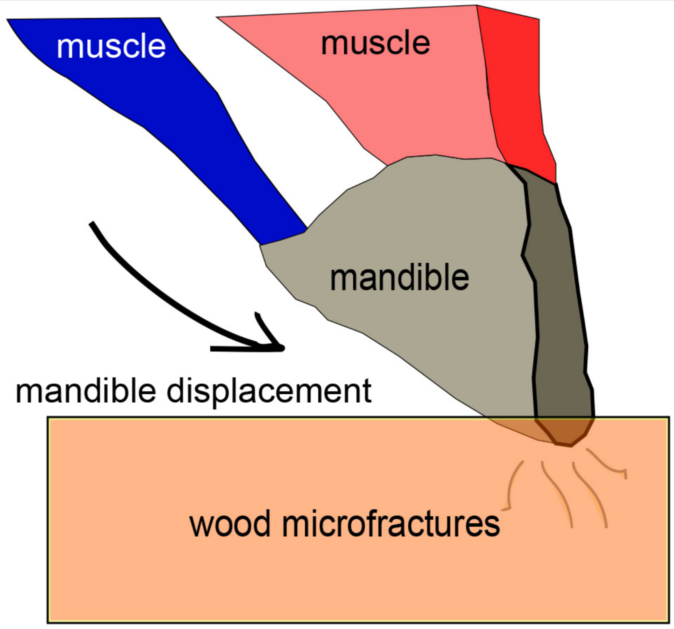
Tissues in our body exhibit both anisotropic and viscoelastic properties. The anisotropy results in materials exhibiting different properties along each direction, and viscoelasticity enables the materials to exhibit both viscous and elastic properties under deformation. Viscous materials exhibit time-dependent responses whereas elastic materials react instantaneously when stretched and return to their original state upon removal of the loads. Delineating the individual and coupled roles of these factors in tissue behaviours is hence an exciting research direction for her group.

The main interest of her lab at IISc has been in fibrosis. Collagen, although an important structural protein in the body, sometimes accumulates excessively on the tissues, leading to fibrosis – which results in remodelling of tissues and leads to dysfunction. Myocardial fibrosis, which affects the heart, may also lead to heart failure. To understand how material properties of tissues evolve in fibrosis, the group uses techniques from mechanics to explore the contributions of material symmetries in non-linear tissue mechanics and links those to underlying changes in the way cells interact with their environment.

Another area that interests Gundiah's lab is to quantify how cells stick to each other and to the underlying substrate, and how they migrate under different

Quantifying mandible tip hardness and fracture processes in chip generation for insights into wood cutting by insects (Image: Lakshminath Kundanati and Namrata Gundiah)





cues. The properties of tissues are affected by the cells and the extracellular matrix, which is a complex 3D network of proteins and carbohydrates secreted by cells into their surroundings. Cells in the tissues are exquisitely sensitive to their environment and are constantly subjected to a vast repertoire of mechanical and biochemical cues.

Gundiah's lab has developed techniques to quantify the forces exerted by cells on substrates during adhesion and migration in response to shear stress, cyclic stretch and confinement. Cell migration is also important in understanding processes like wound healing, development, and cancer progression. The group has fabricated micron-sized pillar array detectors, with included ridges, which enable them to direct cell migration and calculate traction forces exerted by cells.

Apart from tissue mechanics, the group has interests in natural biomaterials and in bio-inspired structures. "I love insects!" says Gundiah when talking about her recent work on how coffee wood stem beetle larvae cut through wood to generate wood chips that they ingest. Substrate piercing, cutting and steering of probes by insects through materials is ubiquitous in nature. A better understanding of these processes may help in the design of bio-inspired cutting tools.

Another interesting work from the group is inspired by soft-bodied animals like caterpillars that can carry load, maintain posture, and negotiate difficult and complex terrain. These animals have muscle fibres oriented at specific angles in the body that enable movement.

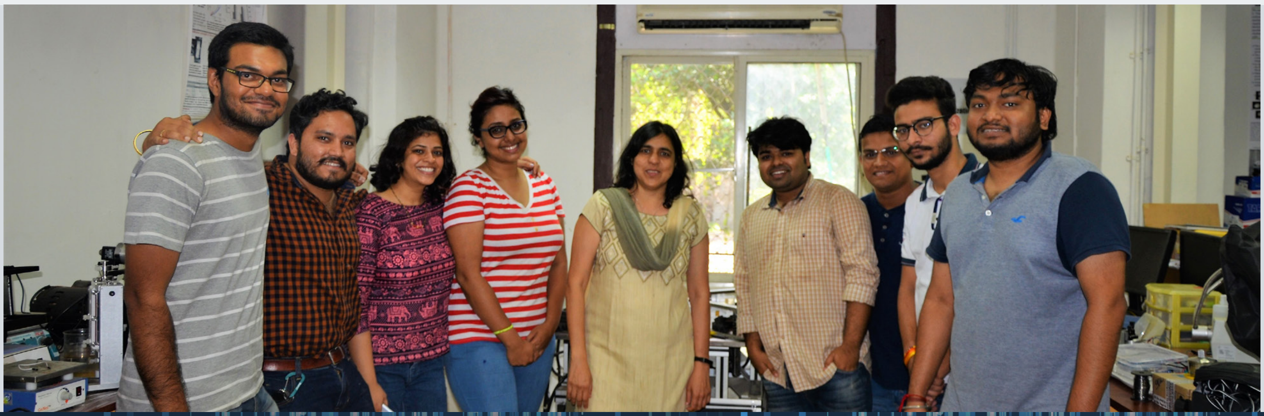
Designing materials inspired by such animals, with an ability to change their shape and stiffness under external loads, has important applications in soft robotics.

For her work, Gundiah often collaborates with experts in vastly different fields. "I find it very rewarding to work with people coming from different backgrounds," she says.

When asked about her plans for further research, Gundiah says, "The whole idea of fibrosis is a question that will occupy me for another decade." She feels that fibrosis is a rich and diverse area with several complex problems that remain to be resolved. "I have established links from the cellular level to the tissue level," she says, "Integrating these links into a coherent picture is a challenging task that we are presently working towards."

– *Gouri Patil*

Namrata Gundiah with her team in the lab (Photo: Rahul Biswas)



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