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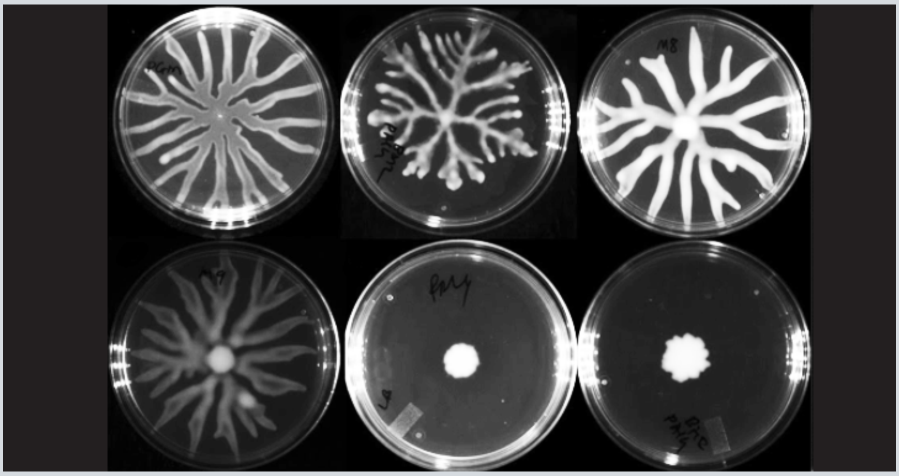
KERNEL

Editorial

Like humans, bacteria too can form close-knit groups, a behaviour usually seen when they are under duress. In this issue of *Kernel,* read more about sociality in bacteria: the different kinds of aggregations, how they are formed, and why scientists are keen on studying them.

Also featured in this issue is an electrical engineering lab developing tools and technologies related to human speech, besides stories on a software platform for smart video tracking and a device for measuring evaporation.

WHEN BACTERIA BAND TOGETHER



Swarming patterns in *Pseudomonas aeruginosa* bacteria in different concentrations of media (Photo courtesy: Varsha Singh lab)

To humans, bacteria appear to lead mundane lives. These single-celled prokaryotes – so called because their cells lack a distinct nucleus and other structures – absorb nutrients from their environment, grow, and multiply on their own. But how do such relatively rudimentary organisms perform complex tasks like turn milk into yoghurt or cause diseases? The answer, at least in part, lies in the ability of several bacteria to form tightly-knit social groups in certain situations, a behaviour that has attracted the attention of many biologists, including some from IISc. Their research has led to exciting discoveries about how and why bacteria form different types of collectives.

Social bacteria

The study of social behaviour in bacteria began in 1683, when Dutch scientist Antonie van Leeuwenhoek, the world's first microscopist, discovered a bacterial commune by studying plaque scraped off his own teeth. But it wasn't until the 1970s that research on bacterial sociality gained traction

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GFP positive *Salmonella* Typhimurium in strings (Image courtesy: Alan Varghese, Dipankar Nandi lab)

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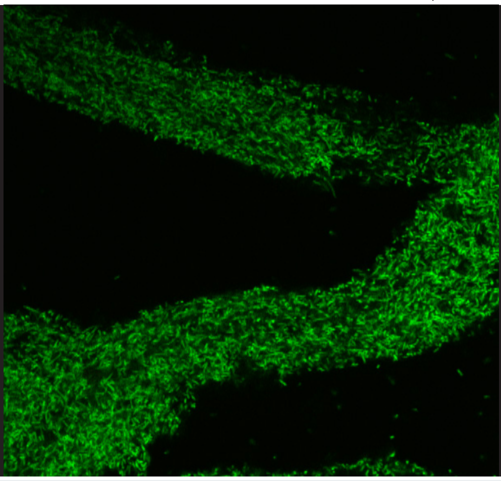


when Danish researcher Niels Høiby showed that individuals of a bacterial species called *Pseudomonas aeruginosa* tend to aggregate in the lungs of patients with chronic cystic fibrosis infections. Since then, such aggregations, referred to as biofilms, have been shown to be involved in several bacterial infections in humans, and have also been documented in many other habitats.

A biofilm is formed when members of a species, or sometimes multiple species, join forces and become embedded in a slimy matrix. Bacteria produce biofilms often in response to stressful environmental conditions like a lack of moisture or nutrients, or the presence of toxins like antibiotics or disinfectants, according to Dipankar Nandi, Professor in the Department of Biochemistry at IISc. Biofilm bacteria work together to secrete the components of the slime, which protects them from unfriendly environmental conditions. They also cooperate with each other to share nutrients and remove metabolic waste.

Nandi's lab also recently discovered a new mode of cooperation in bacteria. Alan Varghese, a former undergraduate researcher in his lab, was studying how *Salmonella* Typhimurium – which causes gastroenteritis in humans – responds when it is deprived of iron. During the course of his research, he stumbled upon "string-like structures" formed by these bacteria, which turned out to be a novel collective. According to Nandi, since this kind of multicellular aggregation is new to science, it was important for his team to characterise its structure in detail, and also demonstrate how they are different from classical biofilms (this bacterium also forms biofilms but under different conditions). Their discovery has just been reported in the journal *Frontiers in Microbiology.*

A former Junior Research Fellow in Nandi's lab, Samay Pande is now Assistant Professor in the Department of Microbiology and Cell Biology at IISc. For his postdoctoral research at the Institute of Integrative Biology, ETH Zurich, in Switzerland, he investigated social interactions in *Myxococcus xanthus,* a predatory soil bacterium. When starved, these bacteria aggregate into mounds, become spores and form a multicellular fruiting body. Upon encountering nutrients again, they germinate and start their lives afresh.

In a recent study published in *Current Biology,* Pande and his colleagues have demonstrated that spores of this bacterium secrete a diffusible "public good" molecule required for germination. The study also captures the flipside of sociality: conflict. In a mixed-strain fruiting body, spores belonging to a particular strain do not produce and contribute to the common pool of another important molecule needed for germination. This, according to the authors, constitutes cheating because the benefits of being in a collective accrued by these freeloaders come at a cost to other group members.

Varsha Singh, Associate Professor in the Department of Molecular Reproduction, Development and Genetics, studies another intriguing cooperative behaviour in bacteria called swarming. With the help of appendages called flagella, groups of some species move in unison in a moist medium when the situation demands. "For instance, we know that *P. aeruginosa* engages in swarming when a specific nutrient is limiting, such as iron or phosphate," says Singh, who wrote a review article on the phenomenon in the *Journal of the Indian Institute of Science* in 2020 along with Rahul Jose, an undergraduate student in her lab. Another paper co-authored by Singh, also published last year in *Physical Review E,* has shown that these bacteria can also swarm away from a patch of antibiotic.

Talking bacteria

Before bacteria transform themselves from their solitary forms to their social avatars, they need to communicate with each other about whether and when to make this coordinated switch. Biologists have discovered that in order to achieve this lifestyle change, bacteria talk to each other in a chemical language. And the most popular form of chemical communication is called quorum sensing, which is seen in several bacteria, including in *P. aeruginosa.*

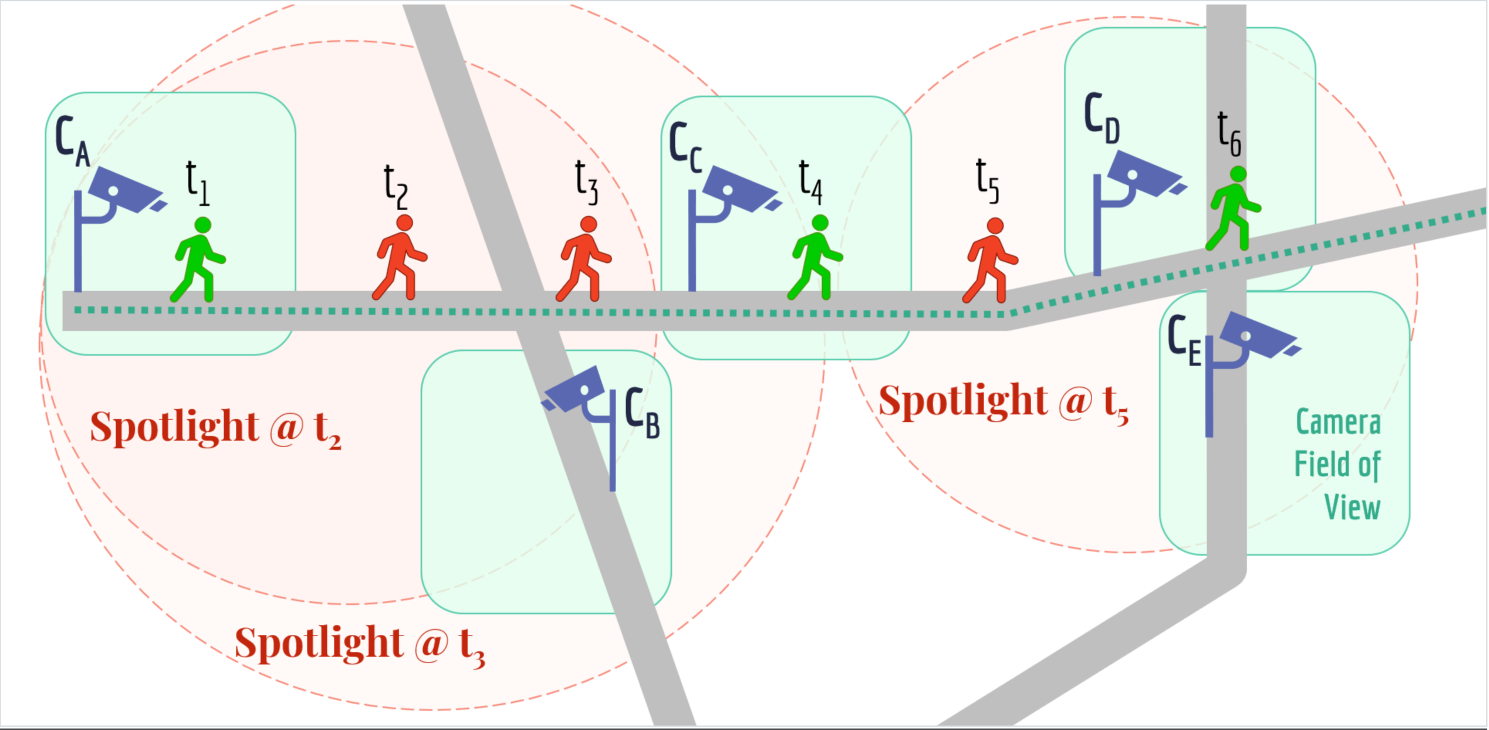
"They use a molecular signal or quorum signal to count one another. When the signal reaches a certain threshold, bacteria as a population switch their behaviour," explains Singh. She reveals that quorum sensing in swarming *P. aeruginosa* is achieved with the help of a chemical called C4-homoserine lactone (C4-HSL), which can easily diffuse across the population. "When C4-HSL levels reach a threshold, the population can make a surfactant which is necessary for swarming," she adds.

Apart from offering valuable insights into group behaviour, studying social bacteria is helping researchers explore how to make human-friendly bacteria more effective, and hostile bacteria less harmful. For instance, Samriddhi Thakur, another former undergraduate student in Nandi's lab, has shown that biofilm formation in *Salmonella* could be inhibited by coumarin, a chemical that plants make to defend themselves against herbivores.

Understanding bacterial interactions in cooperatives could also address larger evolutionary questions, such as how multicellularity itself may have originated, a prospect that many biologists like Pande find exciting. "We can test social evolution hypotheses more cleanly and precisely in microbial systems," he says.

- Karthik Ramaswamy

Image: Yogesh Simmhan



A SOFTWARE PLATFORM FOR "SMART" VIDEO TRACKING

Researchers at IISc have developed a novel software platform from which apps and algorithms can intelligently track and analyse video feeds from cameras spread across cities. Such analysis is not only useful for tracking missing persons or objects, but also for "smart city" initiatives like automated traffic control.

Thousands of video cameras have been set up across cities worldwide. Machine learning models can scour through the feeds from these cameras for a specific purpose – tracking a stolen car, for example. These models cannot work by themselves; they have to run on a software platform or "environment" (somewhat similar to a computer's operating system). But existing platforms are usually set in stone, and don't offer much flexibility to modify the model as the situation changes, or test new models over the same camera network.

"There has been a lot of research on increasing the accuracy of these models, but sufficient attention hasn't been paid to how you make [the model] work as part of a larger operation," says Yogesh Simmhan, Associate Professor at the Department of Computational and Data Sciences.

To address this gap, Simmhan's lab has developed a software platform called *Anveshak.* It can not only run these tracking models efficiently, but also plug in advanced computer vision tools and intelligently adjust different parameters – such as a camera network's search radius – in real time.

In a recently published paper, his team shows how *Anveshak* can be used to track an object (like a stolen car) across a 1,000-camera network. A key feature of the platform is that it allows a tracking model or algorithm to focus only on feeds from certain cameras along an expected route, and tune out other feeds. It can also automatically increase or decrease the search radius or "spotlight" based on the object's last known position.

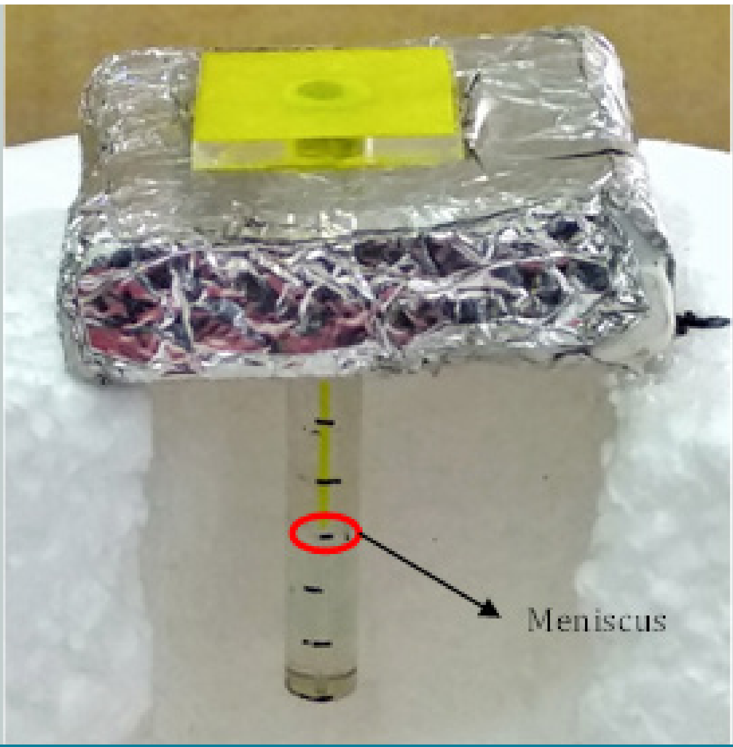
The platform also enables the tracking to continue uninterrupted even if the resources – the type and number of computers that analyse the feeds – are limited. "In the field, the amount of computing power you have is not really negotiable on the fly. The devices are static. You have to do the best you can with what is available," explains Simmhan. For example, if the search radius needs to be increased and the computer becomes overwhelmed, the platform will automatically start dropping the video quality to save on bandwidth, while continuing to track the object.

In 2019, as part of a winning entry for the IEEE TCSC SCALE Challenge award, Simmhan's lab showed how *Anveshak* could potentially be used to control traffic signals and automatically open up "green routes" for ambulances to move faster. The platform used a machine learning model to track an ambulance on a simulated Bengaluru road network with about 4,000 cameras. It also employed a "spotlight tracking algorithm" to automatically restrict which feeds needed to be analysed based on where the ambulance was expected to go.

Simmhan's lab is also working on incorporating privacy restrictions within the platform. "We can decide what are the kinds of analyses that we are comfortable running. We could say, for example, that we would allow analytics that track vehicles, but not analytics that track people, or analytics that track adults but not children," he says. They are also working on ways to use *Anveshak* to track multiple objects at the same time.

- Ranjini Raghunath

Evaporimeter tested in the lab (Photo courtesy: Navneet Kumar)



AN EFFICIENT WAY TO MEASURE EVAPORATION

An IISc team has developed a new device that could measure the rate of evaporation of a local area within a couple of minutes. The device is a more efficient and inexpensive way to measure evaporation when compared with existing methods. "Our method allows you to get a much more realistic measure of transpiration from plants and evaporation from soils," says Jaywant H Arakeri, Professor in the Department of Mechanical Engineering, and senior author of the study published in the *Journal of Hydrology.*

Evaporation is the process by which water turns from liquid to a gaseous state. Apart from being an integral process in the water cycle, evaporation also plays a major role in regulating water loss in plants through a process called transpiration. Measuring the evaporation rate is useful for farmers to gauge water requirements for their fields and in weather stations to characterise the local atmospheric condition. It is also widely used by botanists to study the dynamics underlying transpiration by plants.

Currently, pan evaporimeters are the most commonly used devices to measure evaporation rates. They resemble large pans that are filled with water. The change in water level over a day gives the evaporation rate from that area for that day.

"The disadvantages [of existing methods] are that the evaporation rates are for one whole day, and over a large area (1 square metre). And one needs an open ground to place the device. But we have a simple method of directly measuring evaporation from a small surface – at the order of a couple of centimetres, and over a short period of time," Arakeri explains.

The proposed device consists of a filter paper connected to a capillary tube that takes water from a reservoir to the filter paper, thereby wetting it and thus mimicking an evaporating water surface. By measuring the distance travelled by the lower meniscus in the capillary tube over a couple of minutes, the evaporation rate is estimated. The innovation lies in being able to measure the very small amount (about 1 microlitre) of water that is lost in evaporation from the surface in a minute.

Since the evaporation rate is affected by a number of factors such as temperature, wind velocity, and humidity, this device could show the evaporation rate within a niche environment. "It gives you an idea of evaporation rate even from a small leaf. For example, if this device is kept near a paddy plant, we could get a better measure of the evaporation rate that a particular leaf of that plant might be experiencing," explains Arakeri.

The device would be useful to scientists studying the physiological process of transpiration in plants because of its ability to measure the evaporation rate over small areas and over short periods of time. Stomatal responses can also now be addressed, in a better and more controlled way, using this device. The authors also suggest that it could be used in oceans to study changing evaporation patterns in the open sea and in weather stations to estimate evaporation rates in the atmosphere, an important parameter that is currently not measured.

The next step is to make the device commercially available. "We are looking for interested companies to take it up to make it into a product. Meanwhile, we have been doing some experiments in the polyhouse [a kind of greenhouse used to grow crops in a controlled environment], and we also want to try it out in the field," says Arakeri.

- Rohini Murugan

Photo: Swapnil Pawar

AGGRESSION BETWEEN LIZARD SPECIES CAN SHAPE COMMUNICATION

Males of two fan-throated lizard species – *Sitana laticeps* and *Sarada darwini* – court females and behave aggressively in front of rival males by rapidly flagging their dewlaps, fan-shaped appendages below their throats.

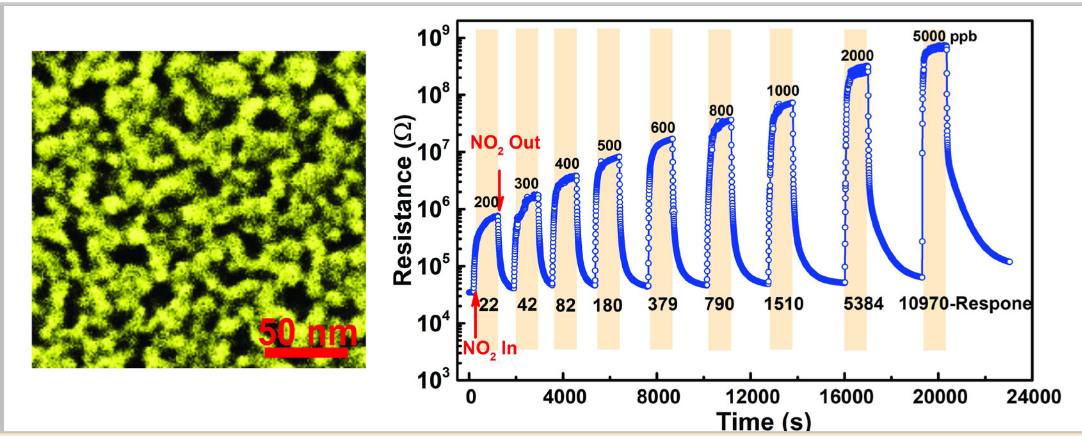
In a small grassland patch in Maharashtra, these species overlap with each other. Males of both species look different but females look almost identical. Males, therefore, find it difficult to distinguish between mates of their own and other species. This apparent confusion triggers aggression between these species that can escalate to chasing and even physical combat, which is particularly dangerous for the smaller *Sitana laticeps.*

To avoid aggression, males of the *Sitana laticeps* species have modified their sexual signals and learnt to distinguish between rivals of their own and other species, finds a new study from Maria Thaker's lab in the Centre for Ecological Sciences.

In areas where the two species co-exist, *Sitana laticeps* males have smaller dewlaps and show reduced courtship and aggression. These shifts make them look a little more like females, reducing unwanted attention from the aggressive males of the other species.

- Maria Thaker and Amod Zambre

Image: N Devabharathi



PRINTED GAS SENSOR TO DETECT TOXIC NITROGEN DIOXIDE

A fully inkjet-printed gas sensor to detect very low levels of nitrogen dioxide, a toxic gas, has been developed by researchers in the Department of Materials Engineering and Materials Research Centre led by Subho Dasgupta. The sensor is based on thin films of mesoporous tin oxide.

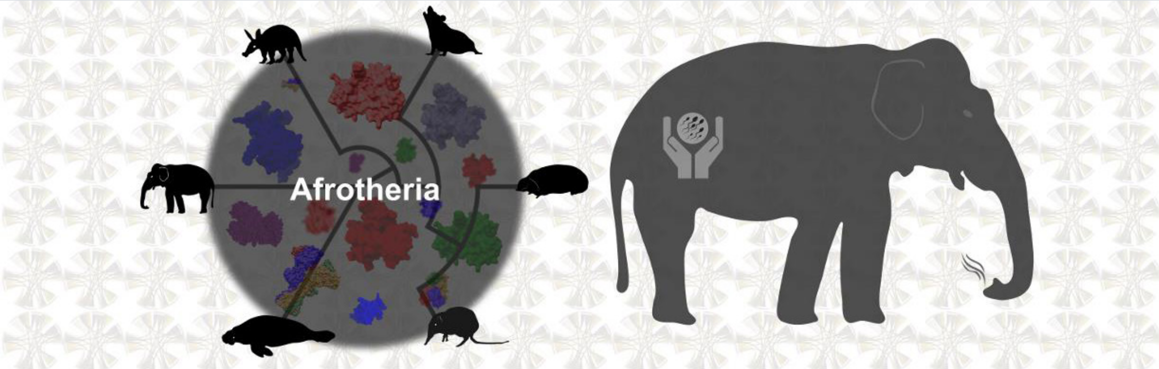
To create the "ink" for printing, they combined a tin oxide precursor (metal halide) with a tri-block copolymer and an additional organic compound called xylene that helps in increasing the pore size. They used an inkjet printer to print this ink onto a substrate, and allowed it to self-assemble into layers of crystalline tin oxide with well-connected pores 15-20 nm in size. The printed sensor has a large surface area to efficiently adsorb and desorb nitrogen dioxide. It also allows fast movement of electrons within its crystalline tin oxide ligaments, resulting in enhanced sensing.

The sensor was able to detect even trace amounts of nitrogen dioxide – as low as 20 parts per billion. It also provided stronger response than most currently available gas sensors in the market or the ones that the researchers developed at the lab scale.

The use of an inkjet printing technique also makes it easier to scale up the process to produce inexpensive gas sensors for a wide range of applications.

- Ranjini Raghunath

Image: Yazhini Arangasamy



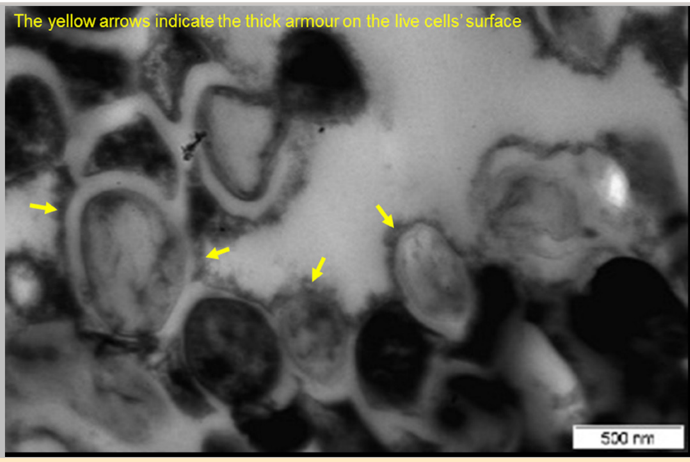
COMPARISON OF AFROTHERIAN PROTEINS: STRENGTH IN NUMBERS

A new study by N Srinivasan's lab in the Molecular Biophysics Unit has probed the proteomes – the entire set of functional proteins – of a group of mammals collectively referred to as Afrotheria. Afrotheria includes animals currently living in or originally from Africa, ranging from small insectivorous shrews and golden moles to elephants. The authors found that a large number of ribosomal proteins and olfactory receptors – linked to stress regulation and a heightened sense of smell respectively – were hallmarks of Afrotherian proteomes.

The authors also report that although Afrotherian proteomes are almost 99% similar, comparisons on a finer scale reveal that elephants have branched out extensively from their Afrotherian relatives. The number of copies of individual proteins and their combinations may have contributed to differences between them. In addition, their study highlights that elephants have an unusually high number of sperm-protecting proteins. This may be because for animals like the elephant with low reproductive rates and fewer offspring, it is critical to produce high quality eggs and sperm. The presence of more copies of these proteins may boost sperm protection and the success rate of reproduction.

- Yazhini Arangasamy

Image courtesy: P AjitKumar



AN ARMOUR PROTECTS AND PRIMES TB BACTERIA AGAINST AN ANTIBIOTIC

The bacterium that causes tuberculosis (TB) is notorious for gaining resistance to antibiotics, which makes treatment of the disease difficult. A new study by P AjitKumar and colleagues from the Department of Microbiology and Cell Biology shows that when TB bacteria encounter the common anti-TB drug rifampicin, a small proportion of the bacterial cells develop a thick, armour-like capsule. This armour reduces the entry of the drug, thereby preventing the build-up of lethal levels within the cells. This strategy ensures the survival of these cells despite the continued presence of lethal levels of the drug outside.

The team also discovered that this capsule consists of certain types of carbohydrate molecules that make it difficult for rifampicin to enter the cells. The small amount of rifampicin that manages to enter the cells triggers a stress reaction, which in turn causes mutations in the bacterial DNA. In the subsequent generations, those bacterial cells that have gained rifampicin-resistant mutations escape antibiotic-mediated death. These mutant bacteria grow and divide to generate new populations of cells that are entirely rifampicin-resistant and therefore survive in the presence of lethal doses of the drug.

- Sunreeta Bhattacharya (with inputs from authors)

Photo courtesy: SPIRE lab

SPEAK, AND YE SHALL BE HEARD!

PRASANTA KUMAR GHOSH AND HIS TEAM DECODE THE INTRICACIES OF HUMAN SPEECH

Gone are the days when electrical engineering just meant long trails of wires and beeping machines. In the age of *Siri* and *Alexa,* the field has grown to encompass diverse domains. One such area of research is the study of human speech. Researchers working in this area collect, process and interpret not just sound, but also other cues from a speaker. This has been the focus of the SPIRE lab at the Department of Electrical Engineering (EE).

Headed by Prasanta Kumar Ghosh, Associate Professor, the lab is keenly interested in the orchestra of organs that generate the majority of sounds in our body – the respiratory and the vocal systems. These organs not only enable us to speak, but the sounds and cues from them also contain tremendous information about their health. Combine these vocal signals with facial expressions and body movements when we talk, and the result is a rich set of data that allows scientists to ask and answer some challenging research questions.

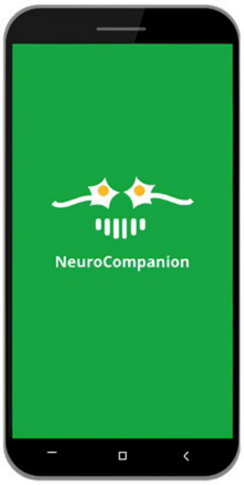
One of the challenges in speech research is evaluating one's English pronunciation, particularly when the speaker is from India, a country with a diversity of languages. For example, as Prasanta points out, a Gujarati and Kannadiga speaking the same English sentence will sound different. "This is because of the influence of the accent of their mother tongues, and you can tell that I am a Bengali the same way," he says. Since English is a must for most jobs, ideally the speaker should have a neutral accent so that customers can understand what they are saying. Often, some training is needed to reduce the influence of native language accents, he adds. "English Gyani", a software tool being developed in the SPIRE lab, aims to do just that. Using automated speech recognition algorithms, it acts as a personalised tutor that provides interactive feedback to the user, based on their voice recordings.

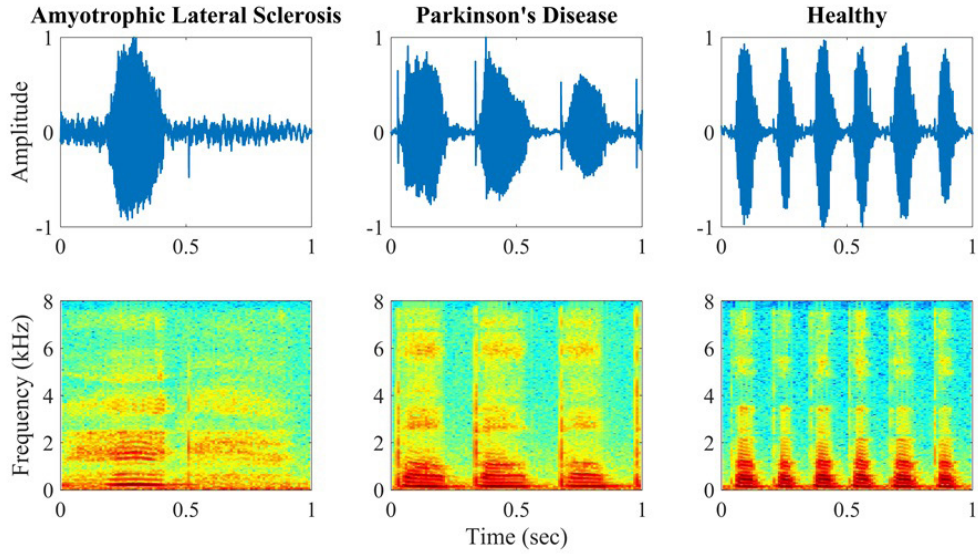
Another major research focus is tracking the movements of body parts involved in articulating speech – the jaws, lips, teeth and tongue. For this, the researchers use a specialised device called the Electromagnetic Articulograph. Special sensors placed on these body parts record where and how they move during speech. This data can assist doctors to detect, diagnose and monitor several neurodegenerative disorders including Amyotrophic Lateral Sclerosis (ALS) and Parkinson's Disease (PD), in which struggling to speak is a typical sign of disease progression. Towards this goal, they have recently launched an app called "Neurocompanion", which enables the telemonitoring of patients using their voice recordings. This research is being conducted in collaboration with the National Institute of Mental Health and Neurosciences (NIMHANS), funded by the Department of Science and Technology, Government of India.

The SPIRE lab also collaborates with the All India Institute of Speech and Hearing (AIISH) at Mysore, in developing tools for several types of voice therapies. One goal is to quantify the extent of damage to the voice box, using data from high-speed videos of the vocal fold vibrations while a person speaks. Another is to develop a tool to help people with severely damaged or absent voice boxes, by converting their whisper-like speech into normal-sounding speech.

Prasanta's interest in pursuing a career in this area was seeded when he was a Master's student at IISc. "Here, I got a flavour for doing research for the first time. And the teachers were really great, in terms of not just teaching, but helping us to see beyond what was taught in class," he says. In particular, TV Sreenivas from the Department of Electrical

Speech waveforms and spectrograms linked to each person uttering the syllable 'pa' in succession: an ALS patient, a PD patient and a healthy person (Image courtesy: SPIRE lab)





Communication Engineering and YV Venkatesh from EE at IISc inspired him greatly, he adds.

After IISc, brief stints as a researcher at Microsoft and IBM helped him choose academia over industry. "Everything else was great [in the industry], but what was lacking was the freedom to define my own research path. In a company, I can't really create my own tree of research, with all of the branches that I'm interested in. I wanted to create a research environment where I can solve problems that are impactful for society," he says.

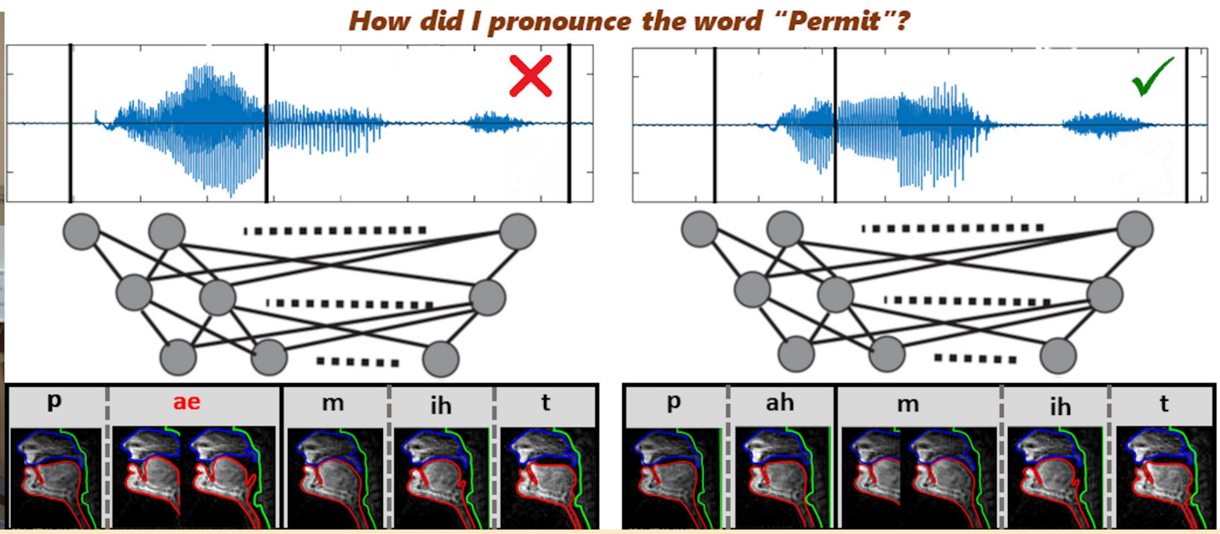
Prasanta has also received recognition as a teacher, including the Centre for Excellence in Teaching award from the EE department at the University of Southern California (USC) where he did his PhD, and the Professor Priti Shankar Teaching Award from IISc in 2017. He believes that the goal of teaching should be to train students to develop the ability to weave new ideas out of the concepts that they are taught. His teaching strategies are strongly influenced by those of Bart Kosko, who taught him at USC. He also encourages his students to give talks at other institutions, or intern at companies to get a feel for the work culture there.

Prasanta strongly believes that to mature as a researcher, students should be involved in pursuing a variety of questions. "The depth and breadth of research ... that's important. While the breadth helps a student to gain and share knowledge across different problems, the depth helps him or her to dig deeper into their own research," he says. For that purpose, he ensures that each student is involved part-time in other projects as well. This also helps build a social network within the lab; if a student is stuck on a particular topic, they are in touch with their colleagues through meetings for various other projects that they are involved in, and don't feel isolated or depressed, Prasanta explains.

"Pre-pandemic, we went on a lot of lab outings – had lunch outside and did other activities together. That connects all of us as a family, and helps us to grow socially as well," he says. "Otherwise, we will all become like robots."

- *Samira Agnihotri*

An electromagnetic articulograph used to collect data from various body parts for speech research (Photo courtesy: SPIRE lab)



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