Research Newsletter of
the Indian Institute of Science

Issue 9, 2021

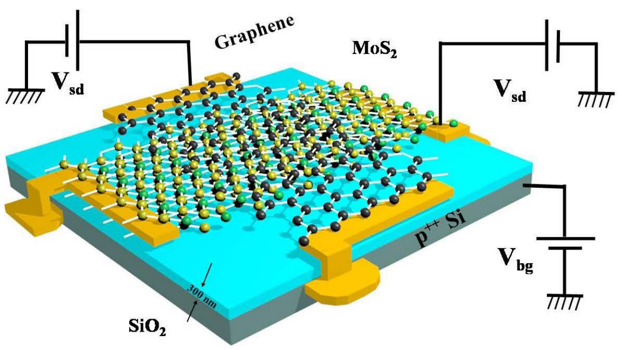
KERNEL

Editorial

Nanoscience has opened up tremendous opportunities in diverse fields. In the area of gas sensing, it is enabling researchers at IISc and elsewhere to build highly sensitive gas sensors and molecular memory devices, and ultimately an electronic nose that can sniff out different odours just like our own. Read more about these efforts in this issue.

We also feature an engineering lab that works on exciting developments in computer vision, developing algorithms that can extract meaningful information from images and videos, plus other stories related to recent research.

SENSING GASES AND NEW OPPORTUNITIES



Sensors as molecular memory (Image: Rahul Tripathi)

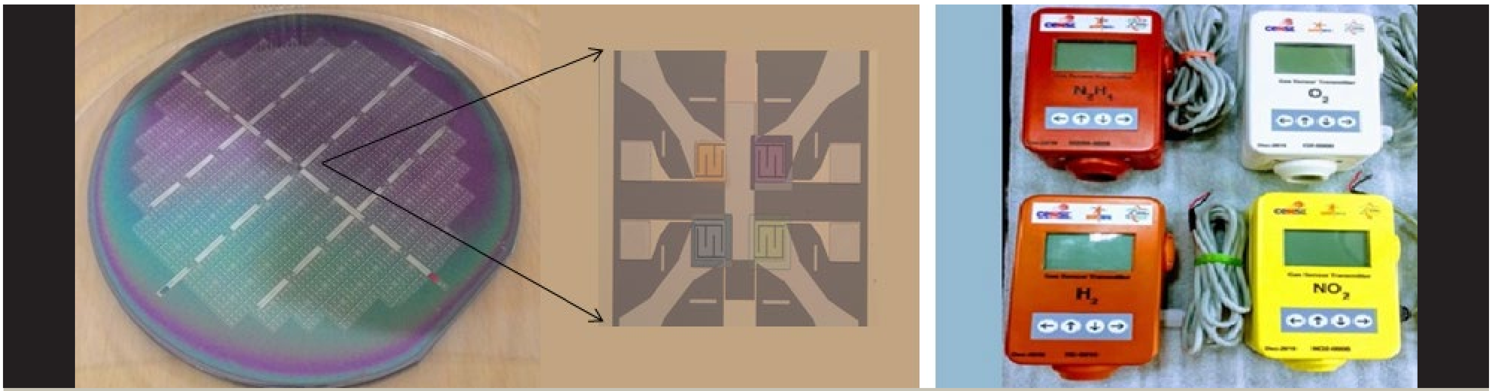
BY DESIGNING GAS SENSORS THAT INCORPORATE NANOMATERIALS, IISc RESEARCHERS ARE DEVELOPING SOLUTIONS TO PROBLEMS IN MANY FIELDS, INCLUDING SPACE RESEARCH

"Our eventual goal is to construct an electronic nose," reveals Navakanta Bhat, Professor, Centre for Nano Science and Engineering (CeNSE). He is referring to a yet-to-be developed electronic device whose sensors would be able to detect as many odours as a human nose. Not long ago, such a device would have been in the realm of science fiction. However, with the advent of nanoscience – the field that is currently revolutionising everything from sunscreen to computers to tennis equipment – electronic noses could soon become a reality.

Though such an electronic nose is yet to see the light of the day, nanoscience is dramatically altering the field of gas-sensing. For instance, nanomaterials-based gas sensors are becoming essential in monitoring toxic gases in the atmosphere as we attempt to combat air pollution. Additionally, gas sensors can now be used to find hidden explosives by sniffing out trace gases that form a part of their chemical signature. They are also finding applications in chemical industries which work with gases such as compressed natural gas, carbon monoxide and nitric oxide, to ensure that there is no

Continued on page 2

Continued from page 1



L: Silicon wafer with many sensor chips, each having 4 element sensor arrays. R: Fully packaged sensor systems for different gases (Photos: Chandra Shekhar Prajapati, Systems Lab & Gas Sensor Lab, CeNSE)

leakage from pipelines. Hydrogen sensors are now commonly used in space research to detect leakage as hydrogen is used as a fuel in rockets. Another potential application of gas sensors that is only just starting to capture the imagination of nanoscientists is in healthcare. With every breath, we let out thousands of organic molecules. If researchers can develop devices that measure the concentration of molecules associated with certain diseases, they could help doctors diagnose and determine the extent of these diseases.

A nanomaterial is any substance that has at least one dimension in the nanoscale – which is a thousand times smaller than the microscopic scale and just about one billionth of a metre. S Venugopal, Associate Professor at the Department of Chemical Engineering, explains why the application of such materials is game-changing: "For gas-sensing applications, the use of metallic nanomaterials is mainly driven by their large surface area. Whenever you want to sense a gas, the molecules of the vapour need to interact with the solid or liquid phase of the sensor, and the extent of the interaction is determined by the interfacial area. As nanoparticles give us a very large interfacial area, they are ideal candidates for gas-sensing."

Venugopal's lab, in association with ISRO, is developing hydrogen gas sensors using metallic nanomaterials such as palladium. In the nanoscale range, palladium particles selectively absorb hydrogen gas to form palladium hydride, which causes them to swell up. This increase in volume makes them forge new electrical connections with neighbouring particles, resulting in a decrease in resistance. The change in resistance can be detected by a corresponding increase in electric current. His lab is currently optimising these sensors so that they work at room temperature, and also developing processes to manufacture these sensors on a large scale.

Navakanta's lab, on the other hand, is designing gas sensors that work on a chemiresistive principle – exploiting chemical reactions in nanomaterials to detect a change in resistance and thereby the type or quantity of gas. Some semiconductor nanostructures, such as metal oxides, undergo redox reactions when they encounter the target gas, which changes the resistance of the device. "Each metal oxide has an affinity for a particular gas, which allows it to selectively detect that gas," he says. By manipulating this property of metal oxides, his team has successfully constructed sensor arrays that incorporate several sensors on a single device, which can be used to detect a variety of gases in the environment. Presently, his team is working on making the sensor array even smaller. "The intent is to make these arrays smaller and smaller because, in the nanoscale range, the power consumption decreases, the sensitivity increases and the response time of the sensors is faster," he explains.

To miniaturise the sensor array, Navakanta's team synthesises nanotubes – structures that consist of metal nanowires (the core) encapsulated inside metal oxide rods (the shell), which are then connected to circuits for gas detection. In such structures, the properties of the sensor can be regulated by changing the core-to-shell thickness, which increases their sensitivity. Other than metal oxides, his lab also uses a certain class of compounds called transition metal chalcogenides, to design extremely thin nanosheets which display enhanced sensitivity and can work even at room temperatures (redox reactions generally occur at high temperatures in traditional sensors). These nanosheets are more efficient because the reactions do not require a heater which is typically used in such devices.

Another group led by Abha Misra, Associate Professor at the Department of Instrumentation and Applied Physics, is working on a new development in gas sensing. They are designing sensors as memory devices that "remember" their interaction with a particular gas and retain it as a molecular memory. "Gases are generally detected by virtue of electrons or charges that they exchange with the sensing material. If these charges can be trapped and retained, then a molecular memory can be created for a number of gases each time the device is reset," spells out Abha.

In these devices, a single sensor can detect a number of gases as the process does not depend on the material, but rather on the modulation and operation of the sensor. These sensors consist of a nanofilm (a few layers) of molybdenum disulphide, a semiconductor, along with a layer of graphene. Both of these layers are connected to two independent electrical sources, so that the external electrical field of the sensor can be suitably fine-tuned, thereby attracting a specific target gas. Apart from quantifying and detecting gases, these sensors can also be used as molecular switches for devices, and even as non-volatile memory devices to store data about gases.

While new applications for nanomaterial-based gas sensors are being found thick and fast, the ultimate goal of the field remains the development of an electronic nose, Navakanta points out. But building an electronic device that can mimic the human nose is a tall order because the human nose has an equivalent of about six million sensors and can detect over a trillion smells. However, the advent of Big Data and AI could be a big step forward in making such a device come true, he feels. "Once you have a million signals coming from a sensor it also becomes a data science problem," he says. "My PhD students are just beginning to explore the use of AI in sensor arrays."

- Anusha Rastogi

Photo: Akshay Jagatap et al

NOVEL COMPUTATIONAL MODEL TO PREDICT 'CHANGE BLINDNESS'

SUCCESSFUL CHANGE DETECTION MAY BE LINKED TO HOW SOME PEOPLE ARE BETTER AT SELECTIVELY FOCUSING ON SPECIFIC OBJECTS

Can you spot the difference in the two images above?

Our brains have the remarkable ability to pay attention to details but may sometimes fail to notice even marked differences. This phenomenon of overlooking a visual change, or 'change blindness', has been studied by a research group at the Centre for Neuroscience (CNS) and the Department of Computer Science and Automation (CSA). They have developed a novel computational model of eye movement that can predict a person's ability to detect changes in their visual environment. The researchers believe that successful change detection may be linked to enhanced visual attention – how some people are better at selectively focusing on specific objects.

In the study, the team first checked for change blindness among 39 people by showing them an alternately flashing pair of images that have a minor difference between them. In the above image, for example, the difference lies in the size of the tyres on the extreme right.

"We expected some complex differences in eye movement patterns between subjects who could do the task well and those who could not. Instead, we found some very simple gaze-metrics that could predict the success of change detection," recounts Sridharan Devarajan, Associate Professor at CNS, and corresponding author of the paper. Successful change detection was found to be linked to two metrics: how long the subjects' gaze was fixated at a point, and the variability in the path taken by their gaze between two specific points ('saccade amplitude'). Subjects who fixated for longer at a particular spot, and whose eye movements were less variable were found to detect changes more effectively.

Based on these observations, the researchers developed a computational model that can predict how well a person might be able to detect changes in a sequence of similar images shown to them. The model also takes into consideration various biological parameters, constraints and human bias. "Since biological neurons are 'noisy', they do not encode the image precisely," Sridharan explains. He adds that there is a lot of variability in the way neurons encode – process and/or respond to – images in the brain, which can be captured by a mathematical representation called the Poisson process.

Other researchers have previously developed models that focus either only on eye movement or on change detection, but the model developed by the IISc team goes one step further and combines both.

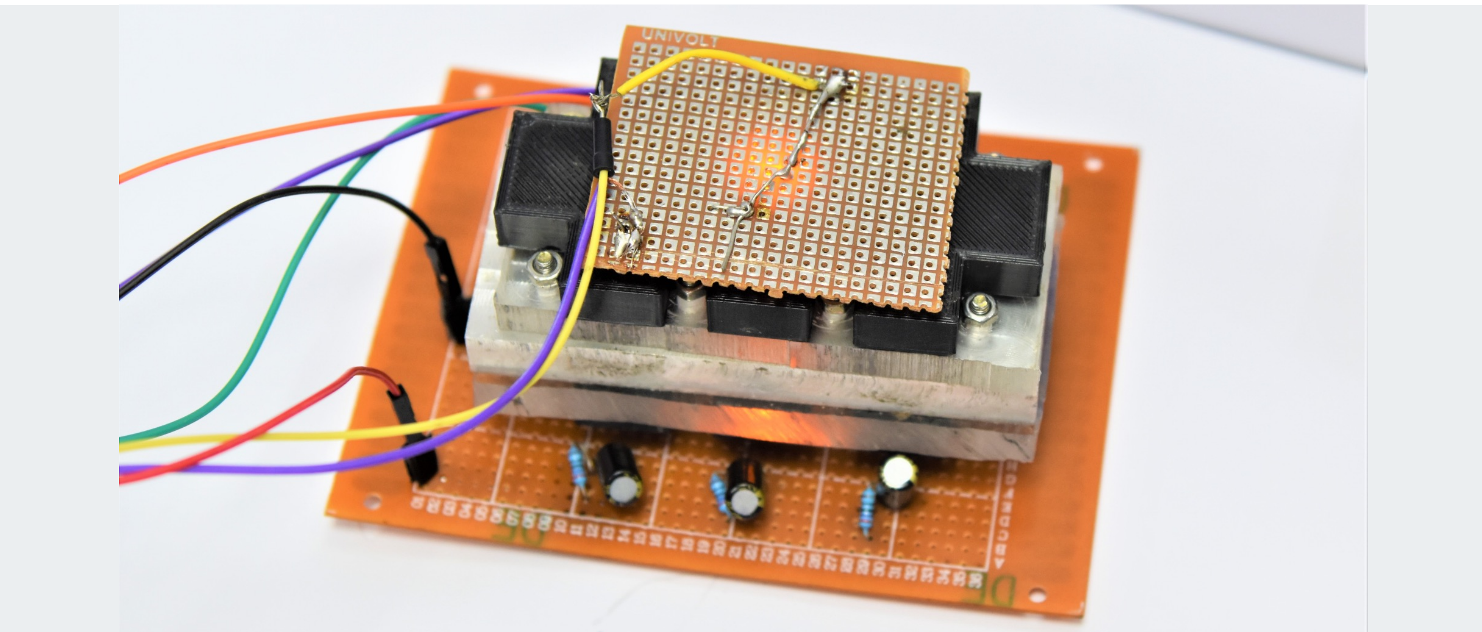
The researchers also tested their model against a state-of-the-art deep neural network called DeepGaze II, and found that their model performed better at predicting human gaze patterns in free-viewing conditions – when the subjects were casually viewing the images. While DeepGaze II could predict where a person will look if presented with an image, it did not work as well as the IISc-developed model at predicting the eye movement pattern of a person searching for a difference in the images.

In the future, the researchers also plan to incorporate artificial neural networks with "memory" into the model – to more realistically mimic the way our brains retain recollections of past events to detect changes.

The authors say that the insights into understanding change blindness provided by their model could help scientists better understand visual attention and its limitations. Some examples of areas where such insights can be applied include diagnosing neurodevelopmental disorders like autism, improving road safety while driving or enhancing the reliability of eyewitness testimonies.

- Anoushka Dasgupta

Photo: G Sai Santosh



MODULAR DEVICE FOR EXTRA-TERRESTRIAL EXPERIMENTS

A SELF-CONTAINED LAB-ON-CHIP PLATFORM FOR STUDYING HOW BACTERIA COULD GROW AND DIVIDE IN OUTER SPACE

Understanding how microbes behave in extreme environments could provide valuable insights for human space missions such as 'Gaganyaan', India's first crewed spacecraft set to be launched in 2022. To aid such explorations, researchers at IISc and ISRO have developed a modular, self-contained device to cultivate microorganisms, allowing scientists to carry out biological experiments in outer space.

In a study published in *Acta Astronautica,* the team showed how the device can be used to activate and track the growth of a bacterium called *Sporosarcina pasteurii* over several days, with minimal human involvement.

In recent years, scientists have been exploring the use of lab-on-chip platforms – which combines many analyses into a single integrated chip – for such experiments. But there are additional challenges to designing such platforms for outer space when compared to the lab.

"It has to be completely self-contained," points out Koushik Viswanathan, Assistant Professor in the Department of Mechanical Engineering and a senior author of the study. "Besides, you can't simply expect the same operating conditions as you would in a normal laboratory setting … and you can't have something that guzzles 500W, for example."

The device developed by the IISc and ISRO team uses an LED and photodiode sensor combination to track bacterial growth by measuring the optical density or scattering of light, similar to spectrophotometers used in the lab. It also has separate compartments for different experiments. Each compartment or 'cassette' consists of a chamber where bacteria – suspended as spores in a sucrose solution – and a nutrient medium can be mixed to kickstart growth, by flicking on a switch remotely. Data from each cassette is collected and stored independently. Three cassettes are clubbed into a single cartridge, which consumes just under 1W of power. The researchers envision that a full payload that could go in a spacecraft will contain four such cartridges capable of carrying out 12 independent experiments.

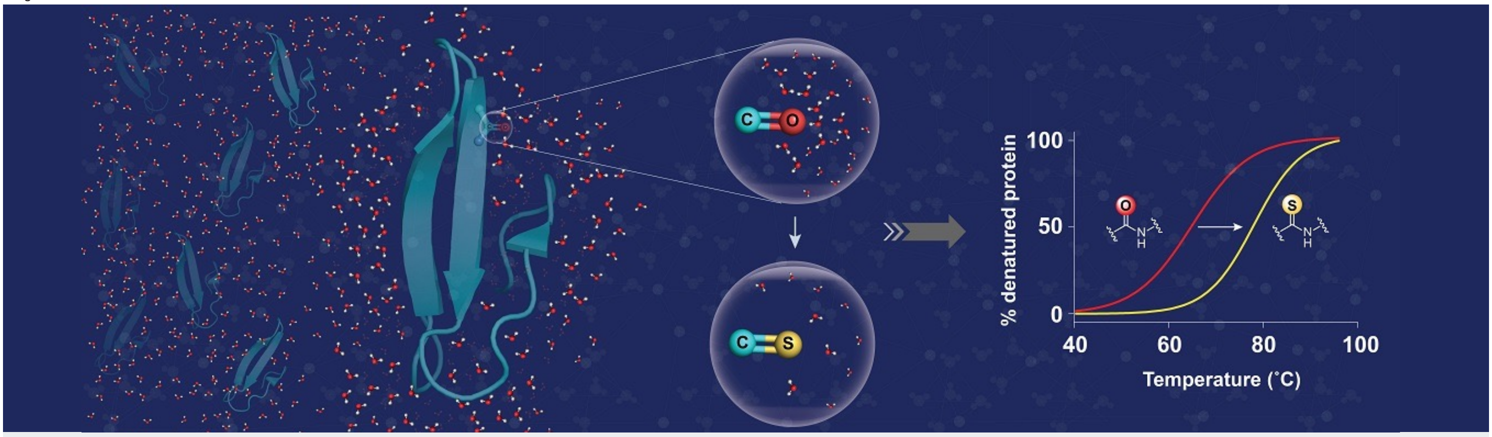
The team also had to ensure that the device was leak-proof and unaffected by any change in orientation. "This is a non-traditional environment for the bacteria to grow. It is totally sealed and has a very small volume. We had to see whether we would get consistent [growth] results in this smaller volume," says Aloke Kumar, Associate Professor in the Department of Mechanical Engineering, and another senior author. "We also had to make sure that the LED going on and off doesn't generate much heat, which can change the bacterial growth characteristics." Using an electron microscope, the researchers were able to confirm that the spores grew and multiplied into rod-shaped bacteria inside the device, as they would have under normal conditions in the lab.

"Now that we know this proof-of-concept works, we have already embarked on the next step – getting a flight model [of the device] ready," says Koushik. This would include optimising the physical space that the device can take up and its performance under stresses such as vibration and acceleration due to gravity.

The device can also be adapted for studying other organisms such as worms, and for non-biological experiments, the researchers say. "The whole idea was to develop a model platform for Indian researchers," explains Aloke. "Now that ISRO is embarking on an ambitious human space mission, it has to come up with its own solutions, made at home."

- Ranjini Raghunath

Image: Bhavesh Khatri



SULPHUR INCREASES PROTEIN STABILITY BY REPELLING WATER

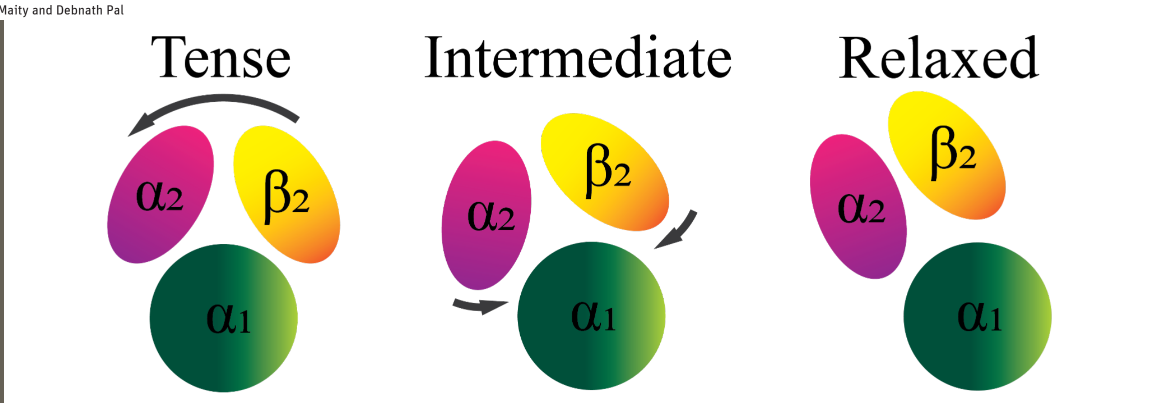
For decades, the diversity in shape, size, and function of proteins has intrigued researchers who have tried to understand the forces that dictate protein structure and stability. Stability under thermal stress is an important factor in protein design; by altering the amino acid side chains, the stability of a protein can be changed.

Now, researchers led by Jayanta Chatterjee at the Molecular Biophysics Unit report that the thermal stability of proteins can also be brought about by chemical modification of the polypeptide backbone. The backbone of a protein is composed of amide bonds, which are well solvated by (complexed with) the surrounding water. By replacing the oxygen atom of a single amide bond with sulphur, the researchers could significantly lower the solvation or interaction of the thioamide bond with water. This creates a lipophilic microenvironment that acts in synergy with neighbouring amino acids to significantly increase the protein's stability.

The results not only highlight the utility of this single atom substitution to increase protein stability, but also the critical role of surrounding water in influencing protein stability. The marked desolvation of amide bonds also makes this tool attractive for the design of membrane-permeable peptide drugs.

- *Bhavesh Khatri and Jayanta Chatterjee*

Image courtesy: Dibyajyoti Maity and Debnath Pal



NOVEL INSIGHTS INTO FORMATION AND STRUCTURE OF HAEMOGLOBIN IN SICKLE CELL ANAEMIA

In sickle cell anaemia, the shape of red blood cells gets distorted due to the aggregation of mutant haemoglobin into fibrils inside the cells when the concentration of oxygen in the blood is low, and the haemoglobin molecule becomes tensed.

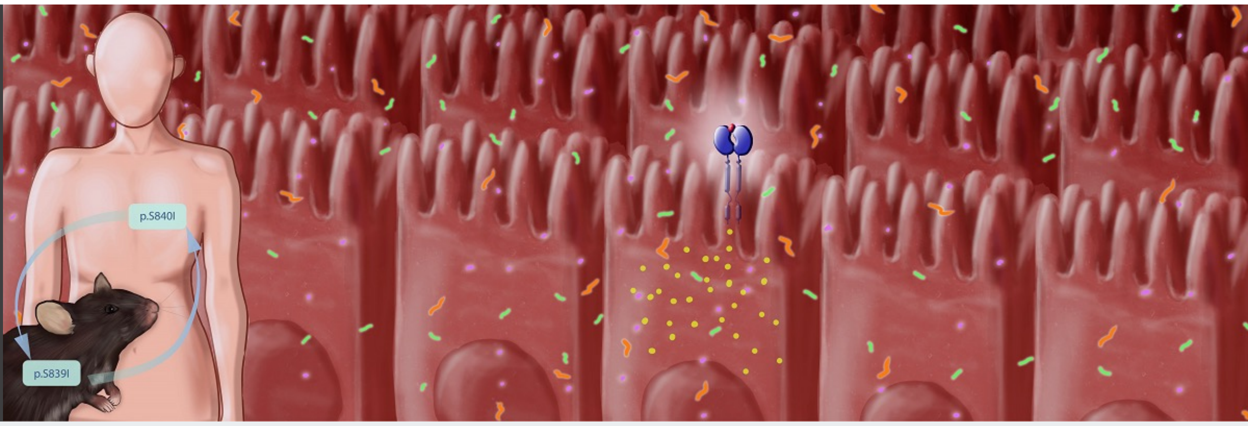
A new study by Dibyajyoti Maity and Debnath Pal at the Department of Computational and Data Sciences has shed light on the mechanism behind this aggregation, using molecular dynamics simulations. Haemoglobin is made up of two dimers, each of which has two subunits (α and β). The team has shown that the angle between the two dimers is a characteristic feature of the two states (tensed and relaxed) of the molecule, and demonstrated that both normal and mutant haemoglobin undergo tensed-to-relaxed transition, irrespective of the presence or absence of oxygen when starting from the tensed state. They also predict that an intermediate state between the tensed and relaxed states facilitates the transitions.

The mutation responsible for sickle cell anaemia causes a molecule called valine to replace glutamate.

The study also determined that in the mutated form of haemoglobin, it is the absence of glutamate rather than the presence of valine that plays a greater role in the formation of fibrils in sickle cells.

- *Arpit Omprakash*

Image: Tejeswini Padma



A NOVEL MOUSE MODEL FOR CHRONIC DIARRHOEA

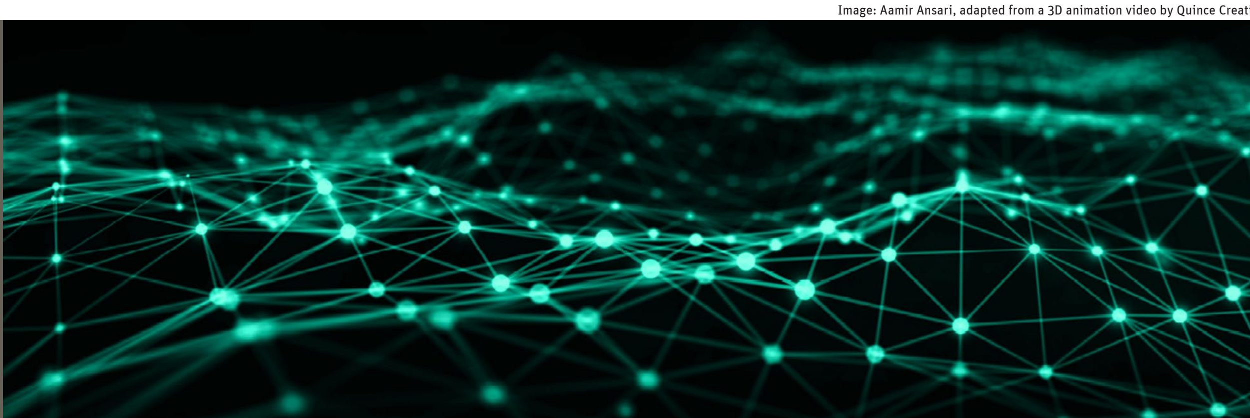
Although treatments and preventative measures for acute diarrhoea are widely available, the long-term consequences of recurrent and chronic diarrhoea, prevalent in developing countries such as India, are not well understood.

Researchers led by Sandhya S Visweswariah at the Department of Molecular Reproduction, Development and Genetics have now developed a novel transgenic mouse model harbouring a rare human mutation initially described in a Norwegian family with a history of congenital diarrhoea. The mutation is present in the gene encoding receptor guanylyl cyclase-C (GC-C), the protein receptor for diarrhoea-causing heat-stable enterotoxins secreted by enterotoxigenic *E.coli.* These mice with an activating mutation in GC-C displayed symptoms of diarrhoea such as enhanced faecal water and sodium content, higher frequency of bowel movements, and altered gut motility. Intriguingly, mutant mice showed an altered gut microbiome and expression of genes associated with inflammatory bowel diseases (IBD).

Preclinical models for diarrhoea are not well established. Therefore, this mouse model provides the first tool to understand the consequences of chronic diarrhoea on the overall health and functioning of the gut. It will also provide an opportunity to test clinical regimes for the treatment and prevention of diarrhoea and IBD in the future.

- Shashi Kiran, Vishwas Mishra & Avipsa Bose

Image: Aamir Ansari, adapted from a 3D animation video by Quince Creative (quincemedia.com)



PREDICTING THE STRUCTURE OF MICROBIAL COMMUNITIES

Our body is home to a large number of microbes on which our health depends. Disruption of the gut microbiome, which can happen with the use of antibiotics, affects not only our digestion but also our mental health. It is important, therefore, to understand how microbial communities survive, and devise ways of restoring them if they are perturbed.

In a recent study, researchers led by Narendra Dixit in the Department of Chemical Engineering and the Centre for BioSystems Science and Engineering have developed a new method to efficiently predict the compositions of microbial communities. The study was performed in collaboration with Unilever R&D.

A major challenge in such prediction has been the large number of interactions between the microbes present, which determine the compositions of microbial communities but remain difficult to unravel. In the new method, the researchers developed a way to subsume a majority of the interactions into a few, effective interactions, which were easy to unravel and, at the same time, facilitated accurate prediction of community compositions. The method dramatically reduces the effort in deciphering the interactions and enables the study of much larger microbial communities than currently feasible.

- Narendra Dixit

Photo courtesy: Soma Biswas

SEEING THE WORLD THROUGH THE EYES OF A COMPUTER

SOMA BISWAS' LAB DEVELOPS ALGORITHMS TO EXTRACT MEANINGFUL INFORMATION FROM IMAGES AND VIDEOS

During her Master's degree at IIT Kanpur, Soma realised for the first time that she enjoyed research, problem solving and independent thinking. At the same time, she also mentored undergraduates as a Teaching Assistant and discovered her love for mentoring and working with students. "You're not really teaching them … but you discuss with them and I enjoyed doing that."

These experiences coupled with her fascination for computers led Soma to join the University of Maryland, College Park as a graduate student. Later, after working at the University of Notre Dame and GE Research, she finally joined the Department of Electrical Engineering at IISc as an Assistant Professor. Curiosity about what happens to all the images and videos captured by surveillance cameras led her to the field of Computer Vision, and research on face recognition and surveillance technologies. She was fascinated, she says, "by how a simple camera placed somewhere can essentially do something that an expert [in the job] can."

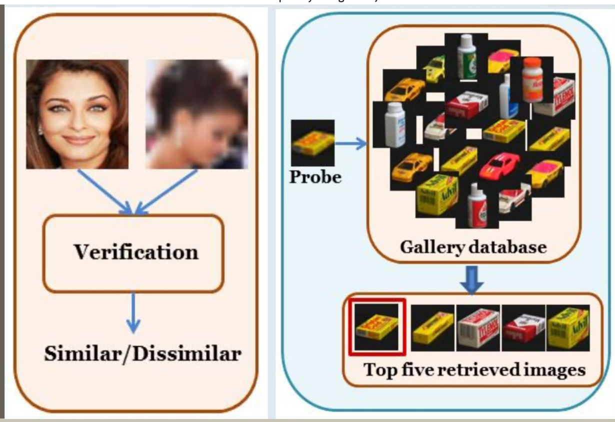
Computer vision deals with developing algorithms and artificial intelligent systems that can derive meaningful information from images, videos, and other visual data. With the recent development of Deep Learning approaches, there has been a boom in the research and development of practical applications of computer vision. We now have algorithms and software that can recognise human handwriting, detect objects, describe images, create tags, and much more.

A deep learning algorithm or model "learns" a lot like humans. Taking the example of object classification, when a child sees a bird for the first time, it asks its parent what that is. The parent says that it's a bird. The next time a child sees a different bird, it again asks its parent, and this continues a few more times until the child has "understood" what a bird is and no longer asks its parent when it sees one. Next, when the child sees an airplane for the first time, it once again asks its parent. Soon, the child learns to classify things like birds and airplanes as flying objects. When a deep learning model "learns" something, the researcher acts as its parent, giving feedback on each image. The model incorporates the feedback so that it can classify similar images correctly next time. Repeating this loop over enough data produces a model that can work really well on unseen images of the same category which the researcher feeds to the model.

Deep learning has been a game-changer in the field of computer vision. Given enough data, these models can be trained to learn and perform virtually any task. However, getting these voluminous amounts of data is not always possible. The primary focus of Soma's lab at IISc has been to develop algorithms that can learn using minimal data. One such direction is development of zero-shot or few-shot algorithms, which, after training, require none or only a few labeled examples of each new domain/class to recognise them seamlessly.

Another related problem that the lab works on is domain adaptation. As humans, we can recognise a given object day or night, or even across seasons. But to a computer, every image is just a bunch of pixel values and recognising the same object in different ambient conditions (different lighting or weather conditions or at different times of the day or year) is a great challenge. "You can't really keep on capturing data and then training [the model] for all possible environmental conditions. So you would want your algorithms to generalise to different conditions or domains," Soma explains. In an ongoing project on domain adaptation, the lab is trying to generalise an existing algorithm to determine whether a manufactured part in an automobile manufacturing plant is defective from just scanning its image. This generalisation is necessary as the conditions across different manufacturing plants of the same company are not uniform, giving rise to images taken in

L: Detecting whether images (some with poor resolution) taken in different conditions are same or not. R: Poor quality images objects obtained from surveillance cameras need to be matched with images stored in the database. (Images: Soma Biswas)



different conditions – different lighting or camera angles, for example.

Apart from the variety of conditions, there are also different kinds of modalities that a computer has to deal with. According to Soma, recent work from her lab on Cross-Modal Retrieval has made quite a stir in the community. This line of work bridges the gap between the representations of the two modalities and generalises well to other unseen data classes. These approaches can be deployed in various practical applications such as searching for products on e-commerce platforms. The lab has addressed several challenging and lesser explored directions, such as scenarios where the available labels are noisy and where several of the training data do not have annotations. Along the same lines, the lab has also worked on the problem of sketch-based image retrieval, where relevant images can be retrieved using just a rough hand-drawn sketch query. This is especially useful nowadays because of the proliferation of touchscreen devices. Based on the above principles and models, the lab has taken up a new project to detect fake news using data from multiple modalities.

The lab also works on novelty detection and continual learning. In order for algorithms to successfully work after deployment, they need to clearly understand what they know and do not know. When most existing algorithms encounter the image of a new object, they tend to wrongly classify it as something they know. "We need algorithms that can detect if something is new," Soma points out. The model must first identify new information before incorporating it, to increase its accuracy. "Learning never stops; as humans, we don't stop at a certain age when we see something new," she says. Incorporating newfound knowledge and continually increasing the knowledge base of models is another interesting direction that the lab is working on.

In future, Soma wants to work on medical and satellite data, as the data-efficient models that she is currently developing will most likely be useful in such fields where collecting annotated data is really difficult. She also talks about how most of the algorithms out there are practically black boxes. Thus, it is difficult to understand when they work and when they suddenly fail. Developing AI solutions that can give understandable explanations for their output is something that is required in the field of medical sciences, as important decisions that are taken based on AI have to be well defended. She aims to develop algorithms that are, above all, reliable and explainable. Then, anyone working with such an algorithm can have the confidence to trust its predictions and in cases where the algorithm is unsure, it will let the user know.

Soma, now Associate Professor, says that the field is ever-changing and rapidly growing. She mentions that it is very important for a researcher to work on something they are passionate about. "Research has its ups and downs; you can't work for a particular paper or recognition. You have to work and enjoy your work just for the sake of it. Everything else comes as a byproduct of it."

- Arpit Omprakash

Students working in Soma Biswas' lab (Photo courtesy: Soma Biswas)

Office of Communications (OoC)
Indian Institute of Science (IISc)
Bengaluru - 560012
kernel.ooc@iisc.ac.in | office.ooc@iisc.ac.in
https://kernel.iisc.ac.in/

भारतीय विज्ञान संस्थान

EDITORIAL TEAM
Deepika S
Karthik Ramaswamy
Narmada Khare
Ranjini Raghunath (Coordinator)
Samira Agnihotri

DESIGN
TheFool.in