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Immerse

THE IIT MADRAS RESEARCH MAGAZINE

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Edition 3

litmadras

THE FIFTH ESTATE

presents SHAASTRA 2015

Message from the Director

Prof. Bhaskar Ramamurthi, Director, IIT Madras

I join the *Immerse* team in their excitement and anticipation in bringing out this latest edition coinciding with Shaastra 2015. Research at IIT-M is humming, and what better way to pass on the healthy vibrations than a crisp edition of *Immerse*.

Research is now the preoccupation of around 550 faculty members, 3000+ MS and PhD research scholars, more than 800 project staff, and a good number of undergraduates as well, at IIT-M. It spans everything from basic curiosity-driven investigations to research directed at finding disruptive solutions to the daunting challenges facing India in water, energy, healthcare, transportation, housing and education.

The IIT-M Research Park, the first of its kind in the country, is a trailblazer in taking industry-academia collaborations to a new level. It is now expanding to three times its size. Our inter-disciplinary research centres, numbering more than a dozen, work closely with industry and start-ups to innovate new technologies that are affordable, frugal and sustainable.

The entrepreneurial bug has well and truly infected our research community at IIT-M. UG students throng the Centre for Innovation right from the first year, and a steady stream of UG and PG students as well as faculty members are launching new ventures through the IIT-M Incubation Cell and the various incubators.

I foresee unlimited opportunities ahead for all those who have been smitten by the charm of a career in research. This edition of *Immerse* gives but a glimpse of the myriad streams of research being pursued at IIT-M. I hope these peeks into the world of Research@IIT-M are tantalizing enough to draw readers to enter it, become part of it and draw on its wellsprings ■

CONTENTS

ELECTRICAL ENGINEERING

41

EVE IN QUANTUMLAND

ENGG. DESIGN DEPARTMENT

69

TI(Y)RELESS

HUMAN?T!ES & SOCIAL SCIENCES

53

EQUALITY IN DIFFERENCE

MATH$\sum_{i=0}^{\infty} m_i a^i$TICS DEPARTMENT

61

DARWIN MEETS NASH

MECHANICAL ENGINEERING

58

SEPARATE. SORT. REPEAT.

METALLURGY & MATERIALS

72

GAMES OF GREAT ENTROPY

OCEAN ENGINEERING

67

TAPPING INTO WAVE ENERGY

PHYSICS DEPARTMENT

44

THREE DEGREES ABOVE ZERO

DEPARTMENT LOGOS DESIGN:
PRAMOD 'PDF' KASI
DD/ME/2008

Contemporizing Research for Today's Context

Vinod P. Kumar, IIT Madras Alumnus, Technology Leader, GE Global Research

The needs of the current world are increasing at an ever faster rate and the demand from the research and academic community has never been greater. There are numerous world problems for which the solutions are not readily available - be it generating more energy including alternate sources of energy, curing health problems, transporting people and goods, communication which connects to the world, building infrastructure to cater to housing and various industries, supplying clean water for the growing population or providing a stable supply chain for food. If not addressed, these problems will become unmanageable disrupting our daily lives. And, India needs solutions to these problems more than ever, with the added complexity of cost constraints, lack of abundant natural resources, unavailability of land and pressure from societal norms. The solutions for these issues are not obvious and are not a natural extension of existing solutions; it requires a concerted effort on part of every scientist or researcher to develop breakthroughs and innovation which will alleviate these problems. Unlike popular opinion, pursuit of pure sciences is not separate from pursuing applied research, while in fact, they go hand in hand, one enriches itself from the other, and most often the right solutions owes its origin to both. Research today has to be contemporary and contextual, catering to the demands of today while making steady progress of knowledge. Here are few facets we need to consider and incorporate as we do our research to bring out fruitful outcomes to our problems:

Systems Thinking: All problems must be analyzed as a whole understanding its relationships. To get to the core of the problem, we need to drive clarity on its interdependencies and its relations to the constituents. These interdependencies can range from physical to abstract; navigating them to bring out the effective solution is key part of research.

Intersections: Though our streams of studies and research are traditionally delineated, such as mathematics, biology, electrical, mechanical, civil, etc., solutions to most research problems lie at the interface of multiple technical fields. It requires the research to exploit the intersection of several technical areas.

Adjacencies: Awareness of adjacencies in researching a technology space, like knowing our community, is critical. It is as simple as knowing what is happening in relevant areas, it enables us to leverage the outcomes of disparate fields to maximize the benefit of research.

Scalability: Developing solutions to scale that makes the right impact in the world is essential, without which the progress will not be sufficient to make it lasting and meaningful. While it takes enormous amount of effort to solve a scientific/technical problem and proving it in restricted settings such a research lab, it is more daunting to take it to the real world and make a difference. The scalability of solutions might entail research in itself to realize.

Frugality: Popularly known as Jugaad in India, our innovation to problems has to satisfy the constraints of cost, resources and time. As the world is trending to shortage of capacity in all aspects, it is not sufficient to assume there is access to plentiful resources. We should adopt the philosophy of frugality in our research and yet bring meaningful sustainable solutions to the problems.

Timeliness: Research in the past had the luxury of time. People spent their entire lifetime in pursuit of one problem. Though that trend will and should continue in certain disciplines, it is not appropriate for the problems at hand where we are a tipping point. There has to be a sense of urgency in our research – to develop and try out our findings in real environment – to fine-tune our solutions and find its way into the world.

Academic institutions and research organizations are no longer isolated islands of education, knowledge and research. They will have to play a stronger vital role going forward, creating mechanisms and structure to accelerate research and transition them to society. It is impossible to ignore the above mentioned facets as they are the realities we face today. To succeed in solving some of the toughest problems the humanity faces, we have no option but to contemporize research in science and technology.

IMMERSE

IIT Madras Magazine on Research in Science and Engineering

THE FIFTH ESTATE

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From the Editors

We live in a society exquisitely dependent on science and technology,
in which hardly anyone knows anything about science and technology.

Carl Sagan

When we began work on a research magazine last year, it didn't have a name. We had very vague ideas about not just the content, but our target audience, beyond that it had to, of course, be at a level accessible to every student at IIT Madras.

But we wanted to aim for more. Science stories that appear in mainstream media in India are unsatisfactory. Very few are well-written; most are obscured by jargon. Hardly any have an engaging narrative. The contrast with mainstream media abroad couldn't be greater, where apart from the newspapers which regularly carry science news, specialised science publications exist.

In India however, there is no quality science publication that fills the information vacuum about research at the best institutions. In an age when science and technology inform and drive so much of public policy, and when mis-information thrives, the dangers of a public uninformed about science are clear. Nowhere more so than in a country with a sixth of the world's population.

Elsewhere, we knew, the best universities have their own student-run science publications.

Why not try that here?

This is the third year of the IIT Madras research magazine, and the second year for *Immerse*. In this edition, we have a story from each of the 16 departments at IIT Madras. We have spared no effort in raising the quality of both the content and its presentation in this year's issue.

Through all this, we have been privileged to hear about the research from the researchers themselves. The satisfaction, and the occasional criticism, that they express upon reading what we have written, has been our sole reward. We are indebted to them for their time and efforts spent in explaining their research to us. Thank you.

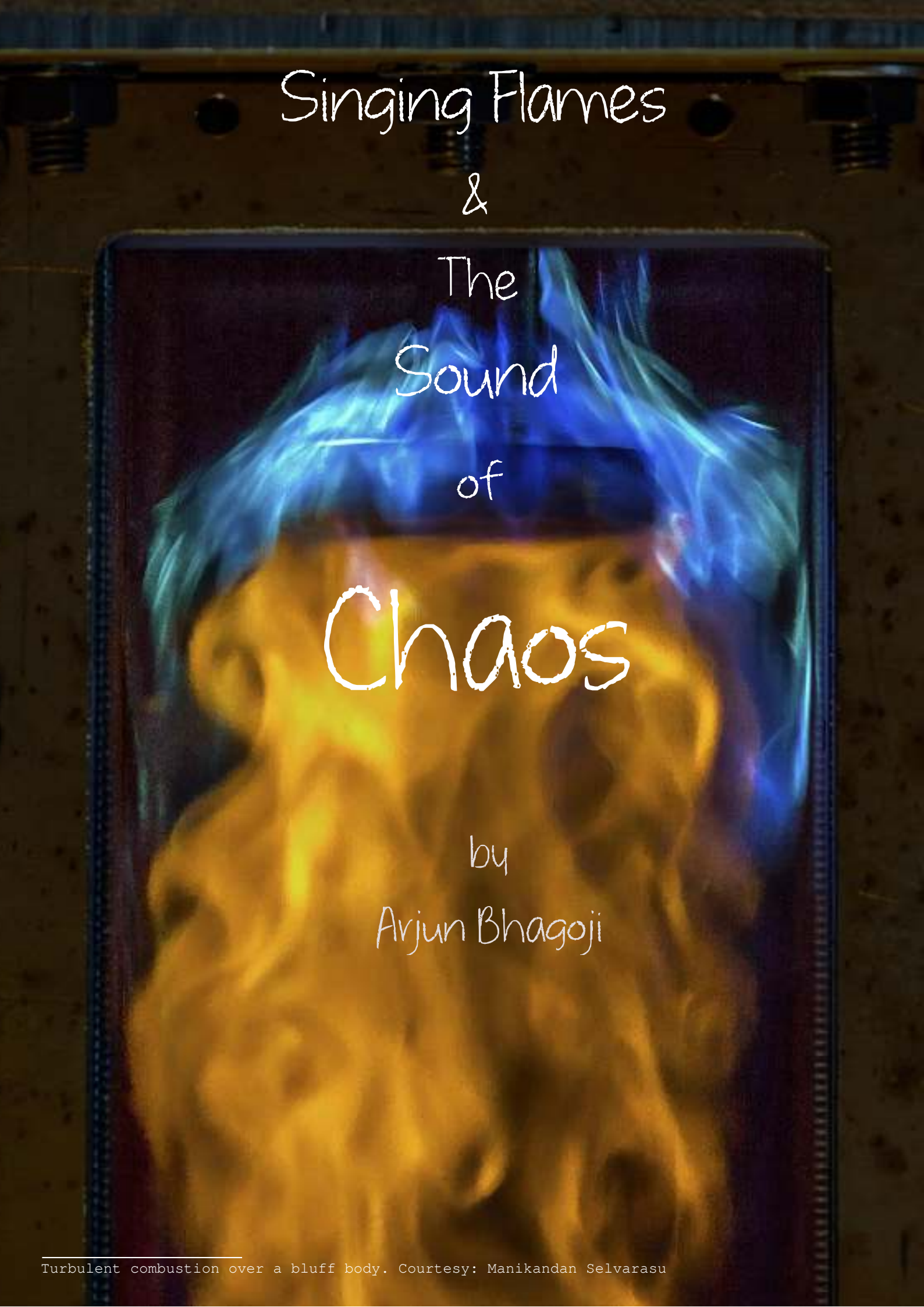
And yes, we did find our target audience. You could be the parent of a student here, or of an aspirant. You could be a visitor who chanced upon a copy on a coffee table or an alumnus. Or perhaps you just came across *Immerse* on Facebook. We want to reach you all.

This is but a glimpse of the research at IIT Madras. Immerse yourself ■

To produce a mighty book, you must choose a mighty theme.

Herman Melville

Singing Flames & The Sound of Chaos



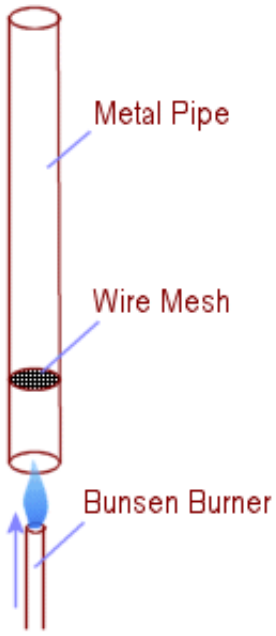
by

Arjun Bhagoji

Turbulent combustion over a bluff body. Courtesy: Manikandan Selvarasu

Chaos. It is, as Edward Lorenz so aptly defined it, "when the present determines the future, but the approximate present does not approximately determine the future." A large number of systems that we encounter routinely such as radio circuits, weather and population models and even celestial systems of bodies exhibit chaotic behaviour. That is, these systems display a sensitive dependence on how they were set off in motion. In recent years, Professor R. I. Sujith of the Aerospace Engineering Department at IIT Madras has been using chaos theory and techniques involving nonlinear system analysis to effect what can be termed a revolution of sorts in the study of thermoacoustic systems.

Acoustic waves, commonly known as sound waves, have the distinct feature that the back and forth motion of packets of air that produces the sound happens along the same direction as the wave motion. The oscillation of air packets creates variations in pressure along the path of the wave. The sound produced by such a varying pressure field can be amplified on interaction with local inhomogeneities in temperature and density. A simple example is a Rjike tube, which in its basic form consists of a source of unsteady heat release (such as a flame) that produces sound inside a confining chamber that allows for the transmission and reflection of generated sound waves. Aircraft engines, gas turbines and industrial burners are all examples of such 'thermoacoustic' systems.



A Rjike tube. Courtesy: Sudhir P, CC-BY-SA-3.0

Sudden excitation of large-amplitude pressure oscillations is a routine problem in thermoacoustic systems. Fluctuations in the flame produce sound waves that get reflected back at the boundaries of the confinement towards the flame location, resulting in further flame fluctuations that create sound waves, and so on. Thus, the conversion of unsteady heat release rate to sound creates a positive feedback and an increase in the amplitude of pressure oscillations; this phenomenon is termed thermoacoustic instability. This is similar to the feedback effect observed when we place a microphone near a speaker, which very quickly leads to a loud, shrieking noise. Thermoacoustic oscillations can, at times, be violent enough to cause wear and tear and sometimes even complete breakage of machine parts.

Thermoacoustic instabilities are hence a huge problem for the propulsion and power-generation industries. In gas turbines used for power production, the instability is typically detected using pressure transducers after it has already occurred. Once an instability is detected, the turbines have to be shut down and restarted, which easily takes about an hour. Contracts between the turbine manufacturers and the power companies often require the manufacturers to bear the cost of such shutdowns.

Thermoacoustic instabilities result in annual losses of billions of dollars for the power industry.

The situation is more critical when such instabilities arise in an aircraft's or a rocket's engine where the option to shut down the engine in mid-air is non-existent and severe vibrations or breakage of the engine can prove to be fatal. For such engines, extensive tests have to be run on-ground. However, a substantial number of these engines, especially for rockets, gets destroyed while testing.

Now, the key questions are: can we predict the onset of instability and prevent damage to engines and gas turbines? Also, is there a way to study these instabilities appropriately in a laboratory environment and apply the knowledge to engine and gas turbine design? Prof. Sujith has been attempting to answer these questions since he came back to his alma mater in 1995. In a small building behind the Aerospace Department, Prof. Sujith and his students have tackled, and to a large extent

Prof. Sujith's group at IIT Madras. Courtesy: Luca Agrati

answered, fundamental questions about thermoacoustic instabilities with equipment that they have devised themselves for the most part.

A few years back, Prof. Sujith was studying acoustically enhanced waste incineration as well as basic problems on sound propagation. Waste incineration is one among a few scenarios where thermoacoustic instabilities are useful. This is because when combustors make a lot of sound, it helps mix and incinerate the waste efficiently. Prof. Sujith wanted to excite low frequency sound to improve incineration; however, the combustor that he used produced sound only at high frequencies, and was stable at low frequencies. To circumvent this difficulty, he devised a strategy wherein the combustor was started at high frequencies and thereafter the flameholder position was quickly adjusted to get the combustor to work at low frequencies.

The effectiveness of this trick fascinated Prof. Sujith and he set out to find out why his method worked. What he discovered has led to a paradigm shift in the way thermoacoustic instabilities are viewed and analyzed. Traditionally, a linear stability analysis of eigenmodes was used to diagnose the stability of the system. An eigenmode is a vibrational mode of an oscillatory system, and in this case, the oscillations are in the air packets that vibrate in the engine. When the eigenmodes of the system are orthogonal (which in this context implies that vibrations at different frequencies do not interfere with each other), the stability of the individual eigenmodes determine the stability of the system. Prof. Sujith, working with Koushik Balasubramanian, then a Dual Degree Masters student, found that for thermoacoustic systems, eigenmodes are not orthogonal and can therefore interact with each other. The trick earlier with the flame worked precisely because of such an interaction between the modes at low and high frequencies.

The concept of instability due to non-orthogonal eigenmodes can be understood visually, if we regard the eigenmodes of the system as vectors in 2D space. Then, if the eigenvectors are orthogonal (that is, at right angles), as either or both are reduced, the resultant sum of the two vectors also reduces in magnitude. On the other hand, if the two vectors are not orthogonal, then decreas-

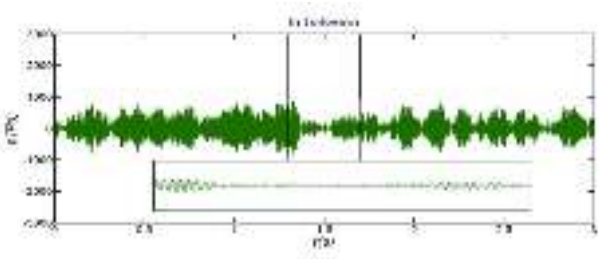
Prof. Sujith with the turbulent combustion chamber built by Gireeshkumaran Thampi, a current Ph.D student in the lab. Courtesy: Luca Agrati

ing one can momentarily cause the resultant to increase. In the case of a thermoacoustic system, this temporary increase can destabilize the system by kick-starting a nonlinear instability. Hence, the traditional controllers for thermoacoustic systems that rely on linear stability analysis and the assumption of orthogonality are bound to fail. This was the first major step that Prof. Sujith took in changing the way thermoacoustic instabilities are viewed, bringing the thermoacoustic community's attention to the group working at IIT Madras.

Another traditional assumption was that large-amplitude pressure oscillations, termed limit cycles, result when the acoustic power generated by the flame matches the losses in the system. These limit cycles can actually be visualized as closed contours in the phase space of the system, which is simply a plot of the variation of a system parameter as a function of other system parameters. For thermoacoustic systems, the measured pressure signal near the confined flame and time-delayed versions of the same pressure signal can be used as the relevant system parameters to create the phase space, thanks to a mathematical theorem known as Takens' delay embedding theorem.

Lipika Kabiraj, a former Ph.D student of Prof. Sujith's, conducted experiments on a ducted flame to study the transition to limit cycle pressure oscillations upon changing the position of the flame. The flow through the duct was kept laminar, which simply means that the fluid or gas packets move in parallel layers, with no disruption between the layers. One can contrast such a flow pattern with a turbulent flow where there is rapid and thorough mixing between the layers. She observed that the thermoacoustic instability is not made up of just single frequency oscillations, but also contains several interesting non-linear dynamical states such as quasi-periodicity, intermittency and chaos. This finding led Prof. Sujith and his group to realize that thermoacoustic phenomena are essentially nonlinear and therefore have to be studied from the point of view of dynamical systems theory. The obvious logical next step was to look for such states in a turbulent thermoacoustic system, which is the flow situation one is more likely to

encounter in engines deployed in the field.



Intermittent bursts occurring prior to the onset of thermoacoustic instability. Courtesy: Vineeth Nair and R. I. Sujith

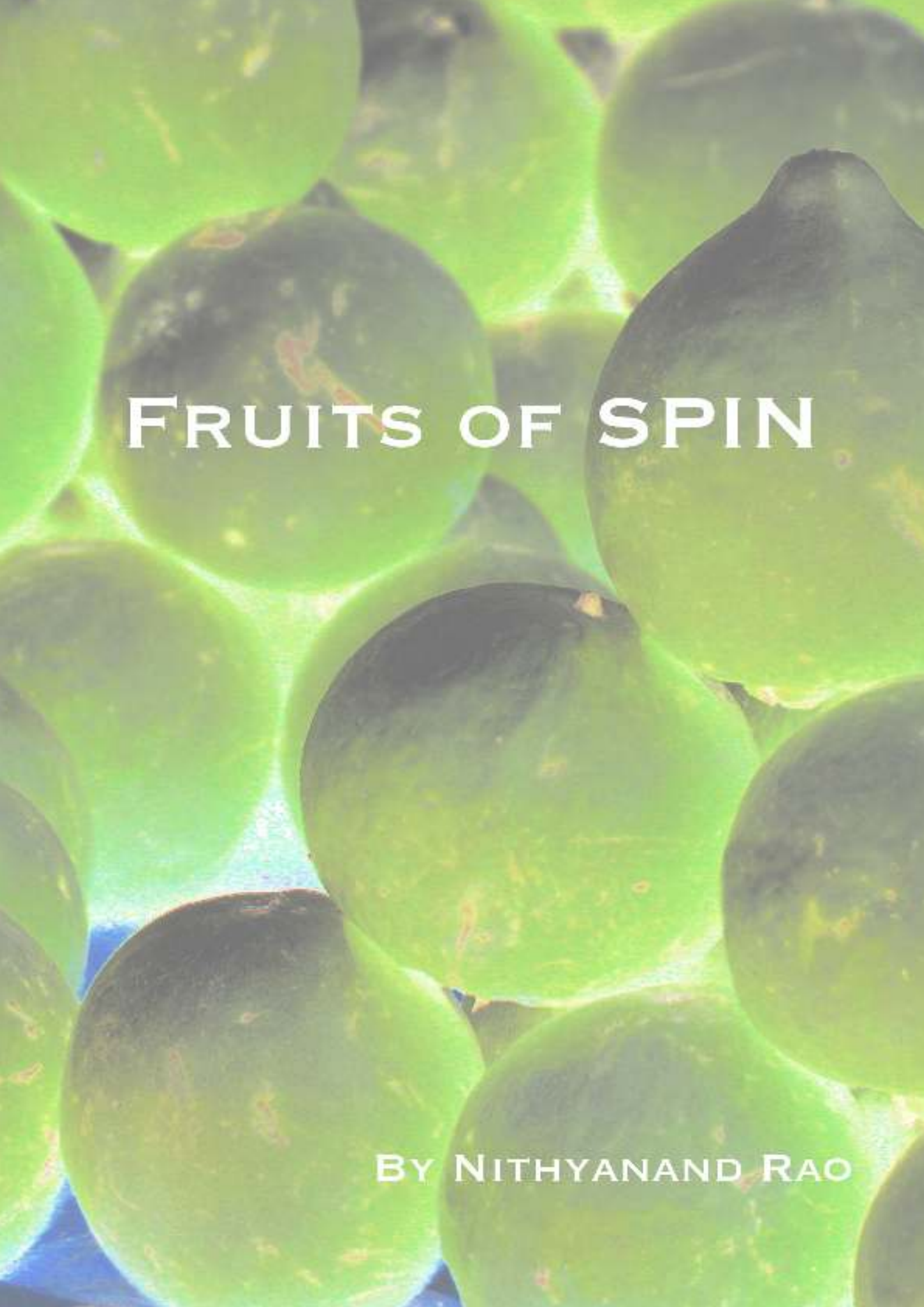
When a combustion chamber with a turbulent flow passing through it is mechanically stable; that is, without vibrations, the interaction of the flame, the flow-field and the acoustics results in a muted hum, a sound that is referred to as combustion noise. Noise in a system, by definition, is random behaviour that cannot be accounted for or written down in terms of deterministic equations. Distinguishing between chaos and random behaviour is notoriously difficult in practice. What Prof. Sujith and one of his former Ph.D. students Vineeth Nair found is that the so-called 'combustion noise' was a result of chaotic dynamics. They observed that when the proportion of fuel that burns with a fixed amount of air is altered, large-amplitude pressure fluctuations are created in the combustion chamber. This sudden transition and its critical sensitivity on continuously varying system parameters like the amount of air used for burning makes prediction of an instability notoriously difficult and its prevention next to impossible, especially in systems that require immediate control action such as a military aircraft engine.

So, the group began looking for precursors to instability, that would allow an engineer in the field to take precautionary measures and sustain the combustor in a state of stable operation. As they were performing the experiments in their lab at IIT Madras, using earmuffs against the deafening sound of the combustors, Prof. Sujith noticed that the students performing the experiment were able to intuitively predict when the system was about to become unstable. After listening to the sound produced by the combustors for a few experiments, he realized that even he could predict the onset of instability. There was a distinctive burst sound that occurred every now and then, in seemingly no partuicular pattern just before the instability. When the operating conditions were varied in a controlled manner towards instability, the combustor was first stable, where it produced the low humming sound. Then, as instability is approached, there were the bursts, until eventually the combustor entered regimes of unstable operation, as indicated by a sharp loud tone.

On analyzing the data from the time just before the instability, they realised that the bursts correspond to a type of behaviour known as intermittency in the language of dynamical system theory. Thus, the old paradigm for instability in combustors, which was simply stable → unstable was replaced by a new one, chaos → intermittency → periodic oscillations.

In technical jargon, a chaotic time signal is a fractal in time; that is, it has patterns that appear the same at different time scales. This property of fractal signals is known as self-similarity. Since the combustor dynamics was chaotic for mechanically stable operation, Prof. Sujith and Vineeth looked for a fractal structure in the data sets. However, the complexity of the system led to the surprising result that the pressure fluctuations of different amplitudes scale differently with time; that is, there is a spectrum of self-similar patterns, a feature known as multifractality, that can be observed by scaling the data differently. Thus, they realized that, measurements from the combustor have a rich multifractal structure at stable operation which finally collapses to a single point at instability, indicating that there is now only a single dominant time scale of relevance to the system. The good news is that this collapse happens in a gradual manner, unlike the pressure amplitudes that rise abruptly only at instability. The loss of multifractality thus allows one to predict an instability before it occurs, giving adequate time to deploy strategies to make the combustor operation stable, thereby avoiding the regime of instability altogether.

Prof. Sujith and his group are now working towards an understanding of the physics underlying the observed intermittent behavior. They are also exploring the occurrence of intermittent bursts in other fluid-based systems such as aeroelastic, aeroacoustic and even biological systems. They are looking for connections between all these systems, to see if there are some universal underlying principles. The type of investigations Prof. Sujith's group has carried out using simple, yet insightful experiments and the immense impact their work has had on the power industry can serve as an inspiration for researchers around the country ■


FRUITS OF SPIN
BY NITHYANAND RAO

It's no secret. Buy a mango that looks perfectly ripe, especially off-season, and you'll very likely be taking home not so much the king of fruits, but an impostor.

Carbide, the vendor might reluctantly admit, blaming it on his supplier.

What really happens when carbide is used to artificially ripen fruits?

Prof. Chandrakumar's research group at the MRI/MRS Centre of Department of Chemistry, IIT Madras, set out to investigate this using a technique that relies on the same quantum-mechanical phenomenon as the brain scanners used in hospitals.

When a fruit ripens, it softens, changes colour, and smells different. And it's sweeter. All this is due to the molecular changes happening inside. In some fruits the plant hormone ethylene, a gas, is produced naturally. It calls upon various other hormones which collectively lead to, among other things, a decrease in acidity and an increase in the sugar to acid ratio.

If fruits are harvested when ripe, they would have a short shelf life. Which is why artificial ripening appears attractive. Carbides are a class of compounds commonly used for this purpose because they generate acetylene, also a gas, which mimics the behaviour of ethylene. However, the most commonly used among them, calcium carbide, is often contaminated with hazardous elements like arsenic and phosphorus. For this reason, its use for artificial ripening is banned in India.

A ripening fruit can, of course, be studied by extracting its juice. But there's a better, non-destructive way.

Nuclear magnetic resonance (NMR) is a phenomenon that magnetic resonance imaging (MRI) machines in hospitals use for non-invasive scanning. Spectroscopy – the study of matter by exploiting its interaction with electromagnetic radiation – based on NMR is widely used for probing molecular structure. Prof. Chandrakumar realized that a form of NMR spectroscopy, called volume-localized spectroscopy, offered a non-destructive and reliable method to study natural and artificial ripening at the molecular level.

The phenomenon of magnetic resonance arises from several fundamental principles of physics. One of them, angular momentum, is a property that rotating objects have. But elementary particles have an intrinsic spin angular momentum which is a purely quantum-mechanical property; it has no analogue in classical mechanics. For a given type of particle, the magnitude of spin is a constant.

If a nucleus has an even number of protons, they pair up to cancel each other's spin; the same applies for an even number of neutrons. In such cases, the net spin of the nucleus becomes zero. If there's an odd number of either, or both, of them, the nucleus will have a net spin. The direction of this nuclear spin, unlike its magnitude, can be manipulated using an external magnetic field, an effect which depends on the exact number of neutrons and protons.

To see what happens, consider the nucleus of a hydrogen atom, a single proton, which behaves as a tiny bar magnet of its own pointing in the direction associated with its spin. When an external magnetic field is applied, the direction of this proton magnet rotates about the field direction, tracing out a cone. Known as precession, the frequency of this rotation is called Larmor frequency, which depends on the strength of the external magnetic field as well as a quantity called the gyromagnetic ratio, which is a constant for a given nucleus.

The result is that the net magnetism of the sample aligns either parallel or anti-parallel to the external field, being a resultant of the magnetism of the individual protons which have a component in one of these two directions. The energy difference between these two states is determined by the Larmor frequency. The lower-energy, parallel, state has slightly more nuclei, but they can jump to the higher-energy, anti-parallel, state if radiation at the Larmor frequency is applied, a phenomenon called resonance.

"When the frequency of the electromagnetic radiation nearly matches the energy level separation, you have the possibility to flip the spin. But the crucial point there is that the two energy levels are a quantum-mechanical consequence of the fact that spins can have only a certain finite number of allowed stable orientations in an external field. Unlike a classical compass needle," says Prof. Chandrakumar.

The radiation used to excite the nuclei can be applied

continuously, or can be in bursts, called pulses, each lasting between one microsecond to a few milliseconds, depending on the experiment. When a proton absorbs this energy, it enters a state which is neither the ground state nor the excited state – a superposition of the two states.

For this to happen though, the radiation has to have its magnetic field component oscillating perpendicular to the applied magnetic field. "If not, under standard NMR conditions, we cannot excite the system at all," says Prof. Chandrakumar. The duration of the pulse matters too. The product of the amplitude of the magnetic field component of the radiation and the duration of the pulse determines the angle through which the bulk magnetization flips. In the present experiment, it's 90 degrees.

Before the radiation is switched on, the nuclear spins have an equilibrium distribution – all the magnetization is parallel to the external field; none perpendicular to it. Applying radiation at resonant frequency, as a 90 degree pulse, results in the opposite situation. Then, the radiation is switched off.

"There is going to be a spontaneous return of the system to equilibrium non-radiatively," says Prof. Chandrakumar. This process is called relaxation. And relaxation takes time. "If excitation needed, say, 1 microsecond to 10 milliseconds...relaxations would need hundreds of milliseconds to tens of seconds. So it's a much slower process."

The bulk magnetization, which is now perpendicular to the field direction, precesses around the latter, inducing a voltage in a coil surrounding the sample. This is how the NMR signal is detected.

"The NMR spectrum, therefore, is not an absorption or an emission spectrum like in other spectroscopic methods"

"It is an induction signal," says Prof. Chandrakumar. "You have this dynamo on bicycles. So it's exactly the dynamo effect as far as the detection is concerned."

What makes NMR such a good probe of molecular structure is the fact that the Larmor frequency depends on the strength of the magnetic field at the position of the nucleus, which is, in general, different from the strength of the applied field. This difference arises because the negatively charged electron generates a small field opposing the applied field. This changes the magnetic field strength experienced by the nucleus and causes a shift in its Larmor frequency. Known as chemical shift, this effect depends on the distribution of electrons around the nuclei being probed as well as the strength of the applied field. "Chemical shifts indicate structural features in the molecule. If you're looking at a proton NMR, then [you can see] if this proton NMR belongs to a methyl group or an aromatic ring or something else," says Prof. Chandrakumar.

One could use NMR to study bulk objects, such as a fruit. The chosen one for this study, was sweet lime.

A set of three sweet limes was artificially ripened by keeping them in a desiccator containing calcium carbide, while another set of three was allowed to naturally ripen. Over the course of a month, NMR spectra of the two sets were taken to see how their molecular constituents changed. "When we pick a suitable region of the fruit where we know from the image there's enough fleshy part, we can get a high-resolution NMR spectrum. We're trying to get the molecular imprint of what is happening in a natural process, without interfering with it," says Prof. Chandrakumar.

An obvious constituent of any fruit is water. So the NMR signal from the hydrogen nuclei – protons – in water molecules has to be suppressed selectively to prevent it from swamping the signals from protons in other compounds. Once this is done, the NMR spectrum of the naturally-ripened sweet lime shows several peaks that are characteristic of the molecules involved.

The horizontal axis of an NMR spectrum represents the resonance frequency of various nuclei, but not in the usual units of hertz. This is because the extent of the shielding effect of the electrons, and hence the resonance frequency of various nuclei, depends on the strength of the applied magnetic field. To remove this dependence, the difference between the resonance frequency of the nuclei and that of a standard is calculated relative to the standard. This is the number, called the chemical shift, which appears on the horizontal axis and has the dimensionless units of parts per million (ppm).

The most prominent peaks in the sweet lime NMR spectrum are from the hydrogen nuclei of the different sugars present, mainly sucrose, glucose and fructose.

Tracking how these peaks change over time reveals the change in total sugar concentration as the fruit ripens.

The characteristic peaks from sucrose and glucose appear at one end of the spectrum. At the other end are the broadly spread smaller peaks from citric acid. These two regions of the NMR spectrum can be used to calculate the sugar to acid ratio, which provides a measure of the extent of ripening.

"We track the sugar to acid ratio, typically, as a function of ripening"

This ratio, for the most part, increases as the fruit ripens. Sucrose and glucose also have other peaks which lie to the right of their characteristic peaks (in the main sugar region), which can also be used to calculate this ratio. This gives specific information about the concentrations of these two sugars.

That was for the naturally-ripened sweet limes. For the ones artificially ripened using calcium carbide, the sugar to acid ratio increases, then decreases and ends up below the initial value. As in natural ripening, the skin of the fruit turns yellow, but this happens faster for the artificially-ripened ones. At the molecular level, this is manifested as a faster increase in the ethanol content, the peaks of which are more prominent than those in the NMR spectra of the naturally-ripened fruits. Acetylene is what does the trick.

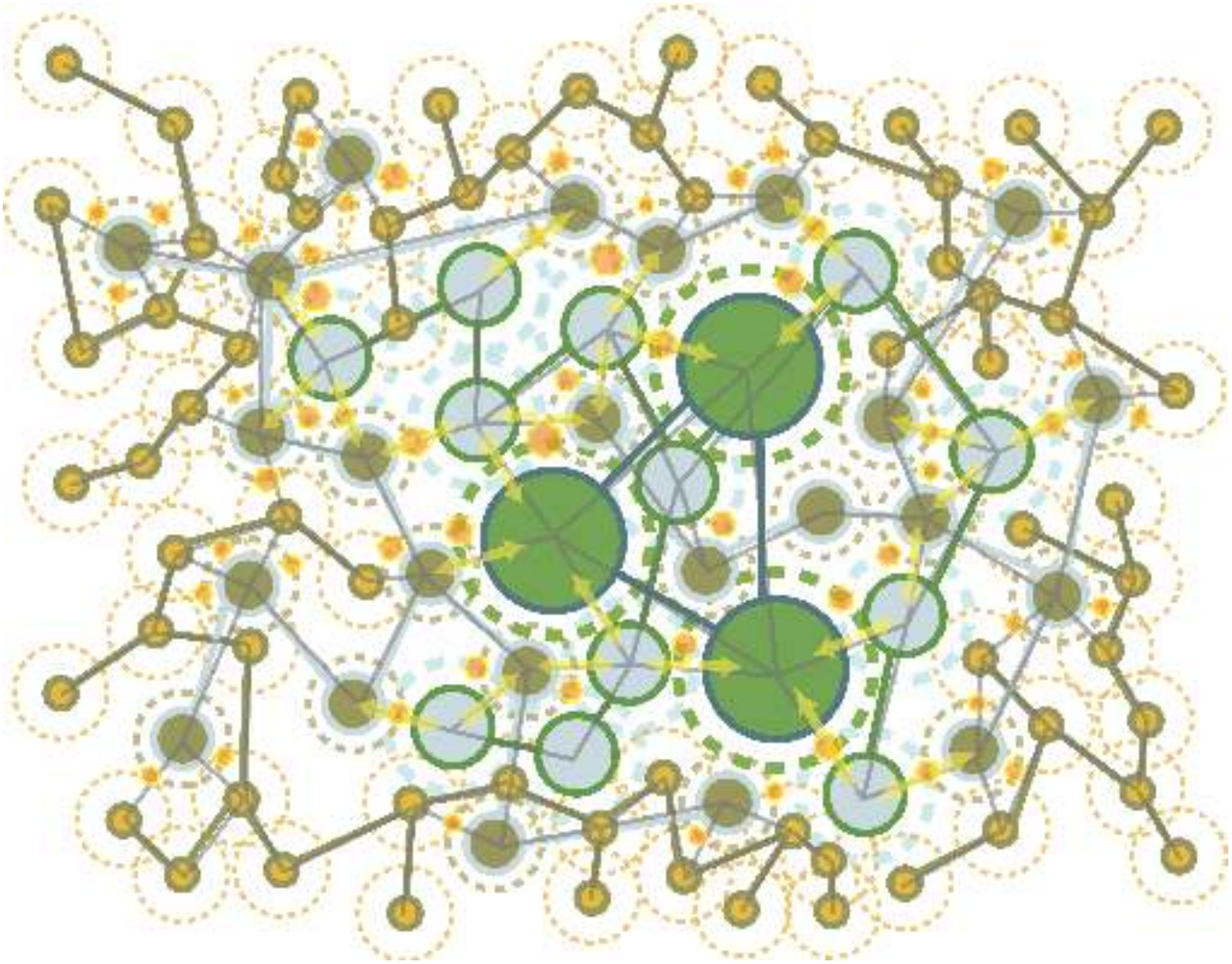
These experiments reveal only the relative concentrations of what's inside the fruit. Their absolute concentrations were determined by comparing the NMR spectra of the fruit with that of a model solution containing the same constituents whose concentrations – both relative and absolute – are known.

This study was done by Abhishek Banerjee, Christy George who were Ph.D. students working with Prof. Chandrakumar at the time along with Sathyamoorthy Bharathwaj, who was an M.Sc. student.

One of Prof. Chandrakumar's current Ph.D. students, Amey Kirwai, is studying the guava's ripening process, which is different from that of sweet lime, using NMR signals from phosphorus nuclei instead of hydrogen. "He's looking at the phosphorus reservoir in terms of sugar phosphate, adenosine triphosphate and diphosphate and so on, and trying to track the ripening under various conditions – such as in the presence and absence of oxygen – of a fruit like guava, which is a fruit crop of great relevance in India and other tropical climes," says Prof. Chandrakumar.

All this using a completely non-invasive and non-destructive method. What next?

"There have been some discussions on fruit quality control with a research institution and a major food retail chain. Though the technique is expensive, it gives you a quick non-invasive method for tracking, at a molecular level, anything that is to be learned about the food material. So, people who are interested in the shelf life of foodstuffs find this kind of approach would be valuable," says Prof. Chandrakumar ■



Can smart grids solve India's energy crisis?

Each circle represents a node/building in the smart grid which has the capacity to produce its own energy, with different colours representing different types of nodes. The arrows represent energy and data exchange, with energy-excess nodes providing energy to energy-deficient nodes. Courtesy: Zachary Veach via Flickr. CC-BY-NC-SA 2.0.

Smart Power

By Aroon Narayanan

When Nikola Tesla, in the early 1880s, conceived of the first AC induction motor, he showed remarkable foresight in predicting the incredible versatility of a power distribution system based on the principle of alternating current. The AC power grid that he thus helped develop, has undergone many major upheavals since then, with technology always striving to maximise efficiency and responsiveness, while minimising losses and expenses.

Perhaps the transformation with the potential to be the most far-reaching, is the most recent one – the idea of a smart grid. Researchers at IIT Madras led by Prof. Sivalingam, working with IBM Research, have proposed new protocols and algorithms that exploit the capabilities of the smart grid to make it more efficient and reliable.

Akin to transformations inspired by artificial intelligence underway in every sector today, the power grid is now conceived not as a static, unidirectional entity, but as a dynamic, bidirectional entity that facilitates increasing interaction between demand and supply. These modernised versions of the power grids of yesteryear, called smart grids, are a giant leap forward in the sphere of intelligent management of vital resources. They are designed to recognize and react in a highly self-sufficient manner to a host of data that the hardware in the system provides, such as power usage statistics, loading variations – variations in how many devices are connected to the grid – and supply constraints.

The possibilities opened up by having such a system are seemingly endless. Smart meters will become commonplace. These meters will show not just the total power consumed but also break it down into how much was consumed in different time frames – which are set depending on power supply/demand fluctuations and can be specific hours, days or weeks – and which socket consumed how much, and so on. Power production at high demand requires greater manpower and resources to ensure that the excessive demand does not cause grid breakdown. Based on the data from the meters, the power companies will be able to provide variable tariffs, depending on when in the day, month, or year the demand is high.

Also, power plants are currently always switched on, since it is not possible to predict when demand will rise. This leads to unnecessary wastage of limited resources such as coal. The companies, by analyzing past power usage patterns, would be able to decide when it would be safe to switch off their generators.

The consumers, on the other hand, will have complete control on how they should adjust their power consumption patterns to minimize expenses. For example, households could run washing machines and other power-hungry equipment during that time of the day when the tariff is set low. Power Grid Chairman and Managing Director R. N. Nayak estimates that the deployment of the smart grid in India would bring about 15-20% energy savings overall, which can make an enormous amount of difference, given how large a portion of the country still languishes in the dark with blackouts and brownouts.

The IEEE Standards Association ranks India as the third largest market for smart grid investments.

The social benefits of implementing the smart grid are enormous. India has prodigious potential in solar energy and it is now possible for villages to take up solar power production on their own.With the deployment of the smart grid, residents of these villages can even become producers by selling the excess power they generate. If their power production falls short, they can always draw power from the grid. It is this versatility of the smart grid that led various state power corporations in India to incubate smart grid projects, with a total of over a dozen projects currently sanctioned.

Globally, the smart grid and allied research areas have expansive scope and have been taken up by top

universities. At IIT Madras, Prof. Krishna Sivalingam, of the Computer Science and Engineering department, and his team of three post-graduate students – Kavin, Dhananjay and Karthick – took up challenges related to smart grids in collaboration with IBM Research India Labs.

The primary objective of a smart grid's deployment is that it must provide increased efficiency and reliability in the delivery of electricity at a reasonable cost in an automated and sustainable manner. The complete requirements are specified as Quality of Service (QoS) parameters, which are derived from the grid's properties. At any given point in time, the grid will have a large number of properties using which it can be characterized. For example, on the supply side, the grid will be operating at a specific frequency, generating a specific amount of power from a specific number of centers. Similarly, on the demand side of the network, consumers will be connecting different loads – household appliances or commercial machines – to the grid at different power factors. (The power factor is a measure of what percentage of the supplied power is consumed by the load.) All this data must be collected, stored and analyzed to provide an efficient distribution scheme. This is made possible by deploying advanced Wide Area Monitoring Network systems, which was the major theme of the team's research.

These systems rely extensively on data generated by Phasor Measurement Units (PMUs), or Synchrophasors. All electrical variables such as power, voltage and current, are commonly represented as phasors, which are vectors in the Cartesian coordinates rotating at some frequency. The frequency of the voltage phasor is the same as the frequency of the electricity that we receive in our homes (50 hertz in India). Similarly, the phasor data contains further properties of power generation which can be used for extensive analysis.

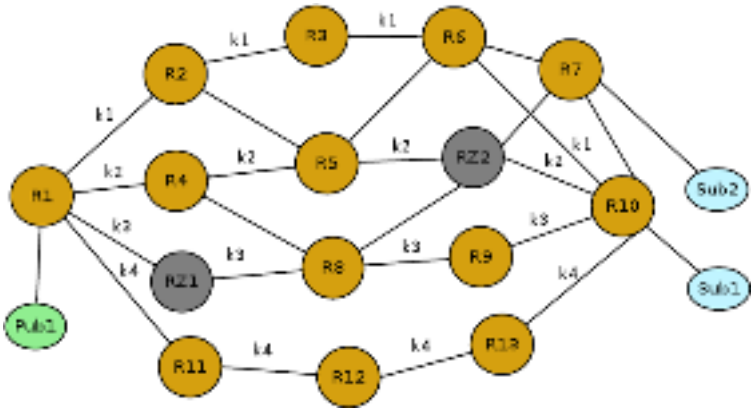
The team's first paper on the topic was submitted in 2012, in which they proposed a network architecture to better process the data generated by the PMUs. The Internet, which we are so used to now, is an example of a network – an immensely interconnected web of nodes, each representing either a supplier or a consumer. The network requires basic underlying protocols that define its configurations and specify how it is to be used to function coherently. This set of protocols is called a network architecture. For a smart grid, North American SynchroPhasor Initiative, or NASPI, specifies a framework which architectures should adhere to in order to support all the functions of a smart grid.

The Internet functions by interaction between one source and one destination facilitated by a network. This paradigm, called unicast, is a physical property of the network, and its data-handling devices, called routers, but the overlying applications can be modified to provide a multicast; that is, make available the same data to multiple destinations. For example, Facebook is an overlying software application programmed to mimic a multicast on the underlying network.

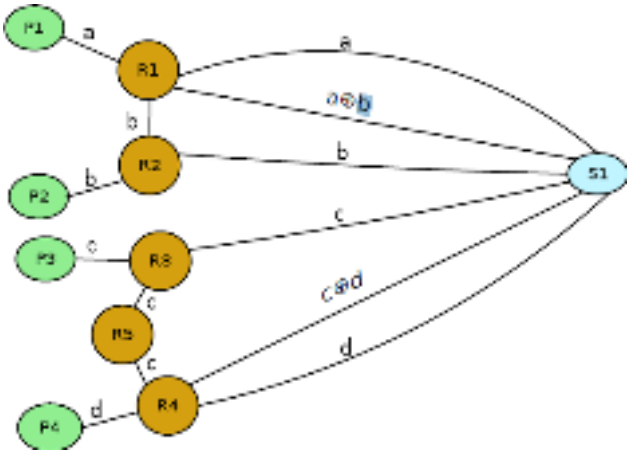
Similarly, publish-subscribe paradigms (shown in the figure), where multiple destinations request access from multiple publishers of data, also can be developed on overlays; that is, using overlying applications. This is how RSS feeds, which have become highly popular, function. Current smart grid architectures also utilize the publish-subscribe paradigm, with the PMUs publishing data which can be requested by subscribers, but using multicast overlays. This means that the underlying network still functions physically on unicast. Prof. Sivalingam's team proposed that the underlying network and routers themselves be modified to provide multicast support, which they proved would improve QoS parameters by reducing delay in data transmission.

A second piece of research by the team focused on algorithms that ensured the reliability of the data sent over the network. This is vital because some of the data sent over the network finds applications in sensitive areas such as feedback control – regulating power production based on feedback – and state estimation, where the system's current state is analyzed. This data is highly critical and its loss or errors in its actual values can have far-reaching consequences. For example, underestimating the frequency of the produced power can lead to the system increasing the frequency at the production plant above acceptable limits, which in turn could adversely affect the functioning of devices connected by the consumers.

Over the Internet, reliability is typically ensured by sending the same data packets over multiple paths. This method, although highly reliable, takes up a lot of bandwidth. The team proposed three algorithms which utilized the resources better. The number of paths available on the network, chosen on the basis of accuracy requirements and network constraints, is denoted by N. The first method, called Single Link Fault Tolerance (SLFT), divides one packet of data into $N-1$ sub-packets



The publish-subscribe paradigm. P/Pub represents a Publisher, R represents a router and S/Sub represents a subscriber. Courtesy: Prof. Sivalingam and his team.



Network Coding for Monitoring Grid. P/Pub represents a Publisher, R represents a router and S/Sub represents a subscriber. Courtesy: Prof. Sivalingam and his team.

and then creates a parity packet, whose components are used to check for errors in transmissions. Here, the component is obtained by performing an exclusive-OR function – which is a logical operation that outputs true only when exactly one of the two inputs is true – over all the sub-packets. The parity packet itself is $N-1$ times smaller than the original packet, so this algorithm reduces the bandwidth required by a factor of $N-1$. As a downside, this algorithm works only for large packets of data. Also, it is resilient to failure only on one of the N links (hence the name) and can fail if more than one link fails.

The second algorithm, called Double Link Fault Tolerance (DLFT), is an extension of SLFT. Here, the packet is divided into N sub-packets and instead of one, there are two parity packets. These sub packets are sent over N paths, with three of these sent over the best path. This algorithm reduces bandwidth requirement by a factor of $N/3$, which is acceptable for $N > 3$. A drawback to this method is that it introduces differential delay – the best-path packets arrive at the receiver at a different time than the others. On the other hand, it fails only if the number of failed links is greater than two.

The third algorithm proposed by the team, named Network Coding for Monitoring Grid, presents a slightly more complex method using publishers and routers (refer to figure). Dr. Sivalingam's team found that the algorithm is resilient to only single link failures, but is more efficient and easier to implement than both SLFT and DLFT. Overall, bandwidth requirement was shown to be reduced by $30-82$ percent and data reliability was increased in some cases by up to 100 percent.

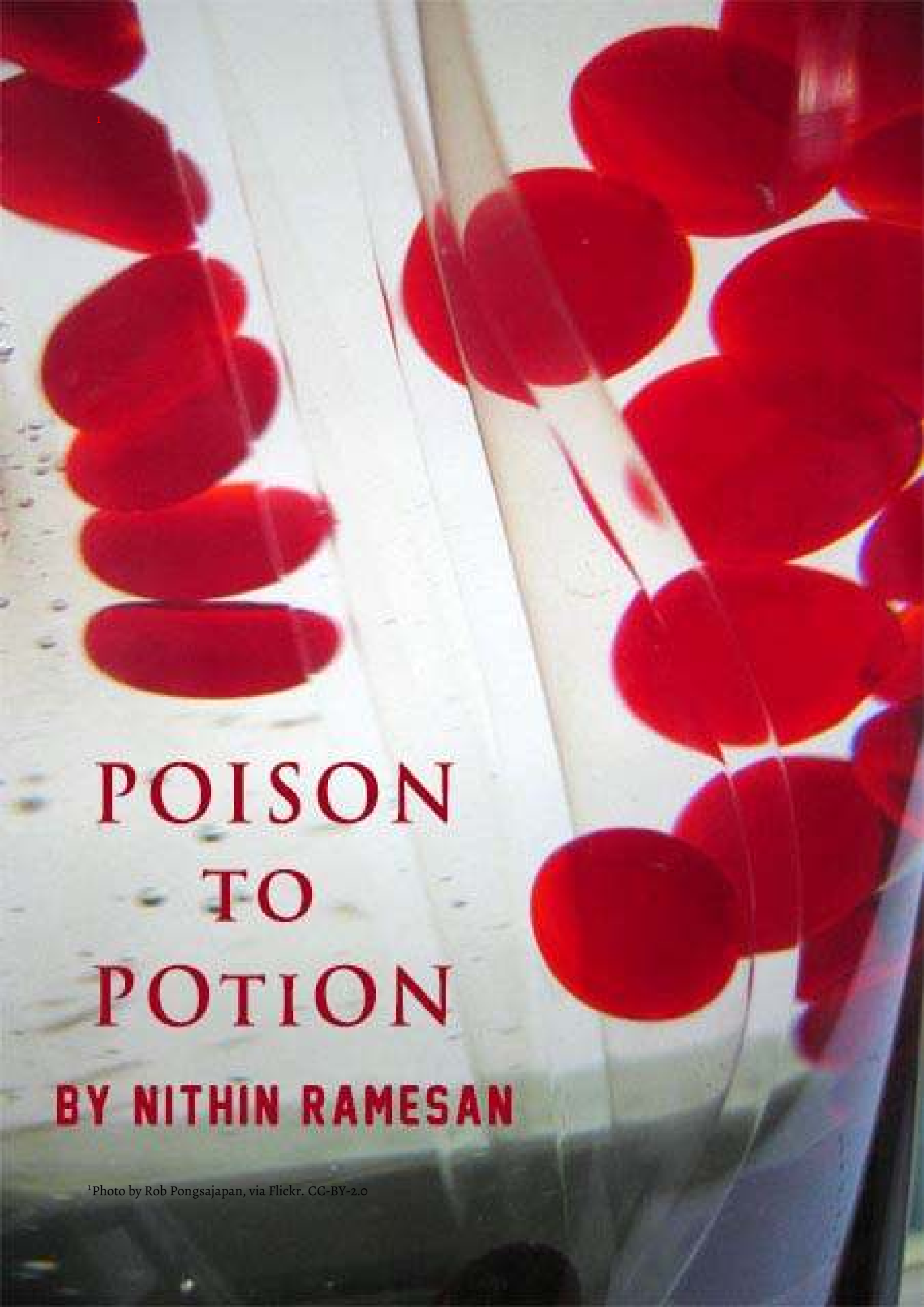
The third paper that the team submitted dealt with developing an effective method of combining two simulation frameworks required to computationally analyze a smart grid – the power system simulation and the communication network simulation.

The power system represents the generation and consumption part of the grid, where electrical parameters are determined. The communication network simulates the nodes through which these parameters are passed, depending on where and when they are needed.

Both the power system and the communication network simulators work well individually, but require synchronization to prevent errors in combined functioning because they differ fundamentally in their data processing – the power system works in the continuous time domain while the communication network works in the discrete time domain. The power system's data plots a continuous curve on a graph while the communication network's data is discontinuous, since it has data only at discrete points in time. Hence, effective data exchange between the two, which is vital to the grid's functioning, can only be achieved by synchronizing time.

To this effect, the team proposed a co-simulation framework for the leading software simulation programs used in communication and power systems, Open Distribution System Simulator (OpenDSS) and OMNet++ respectively. They then implemented the same by developing a software based on the framework. The software is openly available on Sourceforge.

This project by Prof. Sivalingam's team is symbolic of how science works – small, definite steps of progress are made by researchers in the hope that their work will be carried forward, just like they carry forward someone else's work. The smart grid initiative can still only be seen as a glass less than half full, but the few drops that Prof. Sivalingam's group has added will go a long way in helping fill up the vessel ■



POISON TO POTION

BY NITHIN RAMESAN

[1]Photo by Rob Pongsajapan, via Flickr. CC-BY-2.0

All the side effects of chemotherapy arise from the drugs targeting normal as well as cancerous cells. If the targeting mechanisms were improved, wouldn't the side effects decrease?

BT

Cancer, characterized by abnormal cell growth in the body, has varied manifestations. Leukemia is one of them, affecting the bone marrow, which, being a major site of blood cell production, results in a large number of abnormal white blood cells entering the bloodstream. The most effective way of treating leukemia at present is chemotherapy, either by itself – with all its adverse side effects – or together with bone marrow or stem cell transplants.

Professor Rama S. Verma, and his team at the Department of Biotechnology, IIT Madras, are researching a novel treatment that uses a new class of molecules called immunotoxins, that could eliminate the side effects that cancer patients have to endure during their treatment.

Leukemia is a cancer of the blood, and is therefore distributed throughout the body. As a result, radiation therapy is not a feasible method of treatment – it can only target localized tumors. Hence, treatment of both these forms of leukemia is traditionally via chemotherapy. As cancer is basically unchecked and rapid cell division, the drugs used in chemotherapy target these cells by interrupting the process of cell division – or mitosis – and killing the cells in the process.

Unfortunately, other cells, such as those in bone marrow – which is where red and white blood cells are produced – hair follicles and the lining of the digestive tract, also divide at high rates. Consequently, the side-effects of chemotherapy include a decreased production of white blood cells (and a corresponding decrease in immunity), anemia (because of a decrease in production of red blood cells), hair loss, nausea, and inflammation of the digestive tract. More permanent effects may also occur, including infertility, nerve damage and cognitive impairment. Although fraught with so many side-effects, chemotherapy is still the mainstream treatment simply because it is the only effective method of treatment there is.

All the side effects of chemotherapy arise from the drugs targeting normal as well as cancerous cells. If the targeting mechanisms were improved, wouldn't the side effects decrease? It was this line of thought that inspired research on immunotoxins.

Immunotoxins are artificial proteins that consist of a toxin protein attached to a cell-selective targeting protein. They belong to a class of molecules called chimeric proteins, drawing a comparison between their hybrid nature and the ancient Greek monster said to have a lion's head, a goat's body and a snake for its tail.

The membranes of cells in our bodies have numerous chemical structures, called receptors, embedded in them. Hormones and other chemicals that are naturally secreted in the body, target and bind to these receptors all the time as part of the body's natural processes. Each hormone binds only to a single receptor, like a lock and key. This receptor-specific binding is carried out by a part of the chemical, the targeting portion. If a receptor that is more prominently present in cancerous cells can be found, then engineering an immunotoxin to target only tumour cells, with very few normal cells being affected, becomes feasible. "The basic principle behind immunotoxins is that cancer cells overexpress some receptor molecules. We can then use these overexpressed molecules as targets," says Prof. Verma.

I ask Prof. Verma what inspired him to work on immunotoxins, and more generally, work in the field of biochemistry. His face splits into a smile as he begins to reminisce. "I was always interested in medicine and biology. However, I didn't clear the entrance exam we had in U.P. for medical school, and hence I did my B. Sc. in biology. I then specialized in biochemistry during my Master's and Ph.D., as it was related closely with medicine." After working in the USA for 13 years, including stints at the University of Pennsylvania, the National Cancer Institute and Indiana University, Prof. Verma returned to India and joined the industry, where he headed R& D. "I had read journals and other literature, and I found immunotoxins very interesting. But the industry didn't want me to work on those compounds. They were more concerned with compounds whose patents were expir-

Prof. R S Verma

"The basic principle behind immunotoxins is that cancer cells overexpress some receptor molecules. We can then use these overexpressed molecules as targets"

ing, so that they could synthesize similar compounds and file for patents themselves," says Prof. Verma.

In search of opportunities to work on research problems that interested him, Prof. Verma then joined IIT Madras. "I applied for a grant, got it immediately, and started to work on the immunotoxins."

But where do we get immunotoxins from? The toxin part of the immunotoxin is traditionally derived from one of many sources – plant (ricin, for example), bacteria (diphtheria), fungus or yeast. While immunotoxins have been around for four decades, what puts them at the cutting edge of research now is the choice of toxin molecules – instead of animal - or plant-based toxins, toxins produced by the human body itself are being used.

Human toxins are being researched because when plant or animal-derived toxins are used, our immune system recognizes that they are not part of our body. It then reacts the same way it does to any foreign chemical introduced into the bloodstream – it produces antibodies that neutralize the toxin, thus reducing the efficacy of the treatment. "They are, after all, foreign chemicals being introduced into the bloodstream," says Prof. Verma.

If the toxins were from our own body, no immune response would be triggered, and the potency of the treatment would not decrease. But what exactly are these toxins that our body produces?

Programmed cell death, a natural part of the working of our bodies, is known as apoptosis, as opposed to necrosis, which is cell death due to trauma sustained by the cell. Between 50 and 70 billion cells die everyday due to apoptosis in the average human adult.

Apoptosis occurs when certain pathways are blocked in the normal functioning of the cell. And this is where Prof. Verma saw an opportunity. "The toxins we use are the chemicals that cause natural cell death, or apoptosis, in our bodies," he says. With the aim of creating a compound that "minimally touches and affects normal cells, these chemicals were isolated, cloned and tagged with the targeting molecules. Prof. Verma and his team have synthesized seven new immunotoxins, with variations in the targeting portion.

The biggest challenge he faced on the research front was manufacturing the human proteins in bacteria. The combined molecule – the targeting portion and the toxin – is produced in genetically reengineered bacteria. The recipe that every cell uses to manufacture proteins, is DNA. Different portions in a strand of DNA

correspond to different proteins. The beginning and end of each portion is denoted by a codon, a triplet of nucleotides, the building blocks of DNA. Ribosomes typically use cDNA (complementary DNA) – a copy of DNA that is synthesized from the original DNA present in the nucleus, to manufacture proteins. To produce chimeric proteins, the stop codon is removed from the cDNA corresponding to the first protein, and the cDNA corresponding to the second is chemically attached to it. When reinserted into a bacterial cell for protein manufacture, the chimeric protein will be produced in clumps, called inclusion bodies.

The extraction of proteins from these inclusion bodies involves two steps – extracting the inclusion bodies from the bacteria, and dissolving them to get a solution of the immunotoxins. "The proteins often get denatured, or deformed in the process. If the shape of the protein changes, it can no longer bind to the cell receptors. Reactivating them was a tedious process," says Prof. Verma.

Humanized immunotoxins were not used before because knowledge of human DNA was not sufficient to map out which portions of it governed the production of the necessary toxins. It was not until the 1990s, when the human genome was mapped extensively, that their use became feasible.

When asked about the major obstacles he faced outside of the lab, Prof Verma has an immediate and emphatic answer: "Funding. Very few labs in India are working on immunotoxins, so it's hard to convince the powers-that-be that I'm working on something novel and with immense scope. Further, IITs don't have research funds on par with those in universities outside India, so I have to work with what I get. It can get very hard to manage."

The next step, he says, is clinical studies – producing the immunotoxins in large amounts, and testing it on animals, in order to determine the maximum dosage of each immunotoxin that can be administered without causing harm. "We look at the absorption, distribution, metabolism, and excretion of the drug in the animal, and the extrapolate the amount required for a human," he says. Prof. Verma and his team are waiting for another grant to be cleared so that they can begin mass production and clinical trials, which he expects will take 2-3 years to complete. "We'll do patient samples – we draw blood from patients with chronic myeloid leukemia and acute myeloid leukemia – and test the immunotoxins on those," he says ■

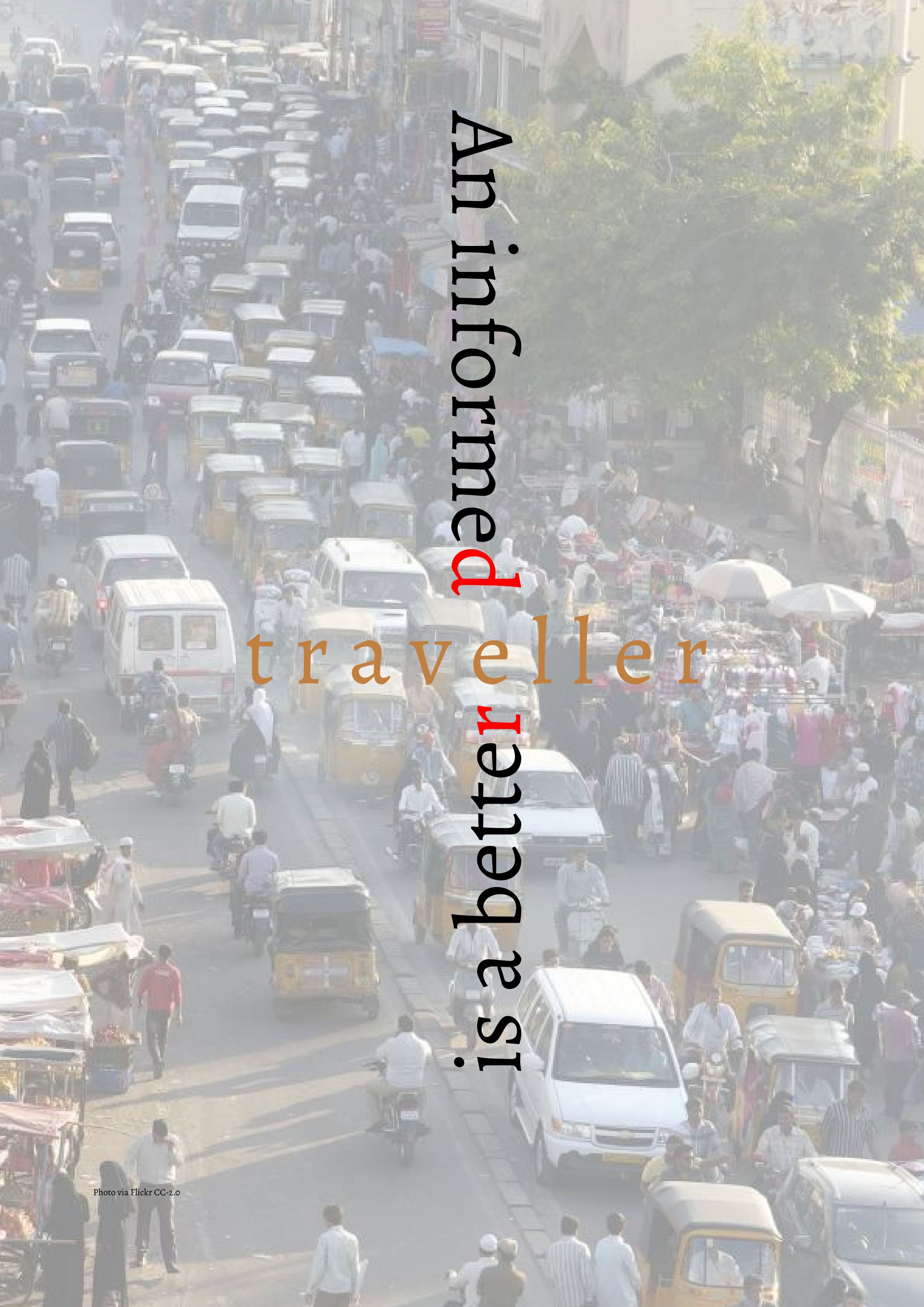


Photo via Flickr CC-2.0

Are we there yet?

By Ananth Sundararaman

For any country, its infrastructure is a matter of pride. From roadways and railways, to airports and other smart-city initiatives, in the last few years India has witnessed a phenomenal change in the transportation sector, leading to world-class facilities being developed across various parts of the country. Indian cities are expanding their boundaries and becoming increasingly populous, with a growing need for a good transportation network to ease the process of development and urbanisation. Although our country's network of roads is one of the largest in the world, second only to that in the USA, the quality of roads in major Indian cities has not kept up with the growing demand for good quality infrastructure. Problems associated with traffic congestion in cities are well known and numerous, making travelling at peak hours a frustrating experience. This seems to arise from the fact that road capacity has not improved on par with the increase in traffic. Streets bustling with vehicles, pedestrians, and the occasional sight of stray animals have become a common sight and reflect a lack of planning when it comes to designing our roads.

The Intelligent Transportation Systems (ITS) Laboratory and Traffic Monitoring Centre at IIT Madras, sponsored by the Ministry of Urban Development (MoUD) under the Centre of Excellence Programme, was inaugurated in 2011 to understand, and develop solutions to, this problem. It is here that Dr. Lelitha Vanjakshi, a professor in the Transportation Division at the Department of Civil Engineering, is currently working on two projects to demonstrate the applications of ITS in India.

A good transportation system is at the backbone of any country's economy. We sometimes take this for granted, but virtually almost all goods and services have to be transported from one part of the country to another. We need a good system combining the use of vehicles, railways and infrastructure like roads and bridges to facilitate safe, quick and hassle-free movement of passengers and cargo.

Over the past decade, India has seen unprecedented growth in the number of vehicles making use of this infrastructure, which is now being pushed to the limits of its capacity. Apart from introducing new infrastructure and expanding older ones, we also need to think about bringing down the cost of maintenance of this transportation system so that it becomes a viable investment for the future by lasting longer. In this era of information revolution, we can record, manage and analyse transportation operations in real time and implement new technologies for efficient and intelligent use of our transportation systems. For instance, drivers in Japan today rely on the use of route guidance systems to pilot them through their vast network of roads with timely voice instructions.

ITS includes application of advanced technologies to the transportation sector to gather, organize, analyze and share information with the users of these systems for efficient and safe travel. ITS offers various services aimed at providing provide a hassle-free travelling experience, including car navigation, traffic signal control systems, variable message sign-boards for the public transportation services to the more advanced automatic number plate recognition and speed cameras for security purposes. Such a system hopes to integrate information about traffic, such as the number and type of vehicles using a road at any given point during the day, with various modes of transportation within the city and make it available to users so that they can make an efficient and coordinated use of the transportation network of our cities. This technology, if implemented correctly, has the potential to unclog the transportation network for cars, trucks, buses and even trains. The future could soon see a whole range of electronic devices and systems put in place to make the journey safer and speedier even for the traveller looking to move between parts of the city limits.

The first project involves predicting , the arrival times for our city's MTC buses, a task that faces many challenges, considering that their operation is subject to a variety of external conditions ranging from weather, unforeseen public events like rallies and uncertainty in traffic. This has led to the deployment of real-time GPS tracking systems, on a few select bus routes, to estimate the average time taken for buses to travel between adja-

cent stops.

"An informed traveller is a better traveller," says Akhilesh Koppineni (BT/CE/2011), an alumnus of IIT-M who is currently involved in the development of the algorithm that does the backend analysis of collected data. He had started working on this in 2009, his sophomore year, after he decided to install GPS trackers on a few campus shuttle buses, and analyse whether a pattern could be arrived at for the travel time in these buses. Moving ahead to make this the inspiration for his B. Tech project on MTC bus time arrivals, he went on to work on similar lines in different companies after graduation, and even published his own work in this area. After the establishment of the CoEUT in 2011, he has come back to his alma mater after nearly three years of work experience and is continuing research on what he had started.

With this idea, the project team comprising both final year students apart from M. Tech and Research Scholars and dedicated staff, deployed Information Dissemination Units, or kiosks, in the MTC bus stops along select routes that display the predicted time of arrival for these buses and their current position, based on a travel time prediction model that they developed in the ITS Lab by fitting MTC buses with a GPS tracking system. This system of tracking has been implemented on an initial pool of 100 buses covering about 25 routes along the Rajiv Gandhi Salai.

"Geotagg", a startup by alumni including Akhilesh is based out of the IIT-M Research Park and a similar setup in the Bus-Tracking App for the shuttle buses inside the institute. As their effort to place kiosks with information screens at each bus stop within the institute could not be accomplished due to financial constraints, except for one at the main gate, they decided to make it a Web and Android application to track buses at IIT Madras, Akhilesh informs. Geotagg further aims at doing a similar setup of Android and web based Application for the

Monitor array displaying live feeds. Courtesy: Ananth Sundararaman

Variable Message Sign board. Courtesy: Ananth Sundararaman

MTC buses in Chennai, and hopes to release it by the end of November.

The algorithm that has been developed to do the analysis for the MTC buses takes into account factors such as distribution of times taken for previous trips taken for the route, speed of the buses from the GPS tracking systems, and also traffic conditions depending on the time of the day.
Just two previous bus arrival times are enough for this model to predict the time of arrival for the next bus. So far, it has been successful in achieving a 3-5 minute offset between the actual time of arrival and the predicted time. It now has a patent pending for its unique implementation in conditions native to Chennai, something that would definitely give a boost to research in this area.

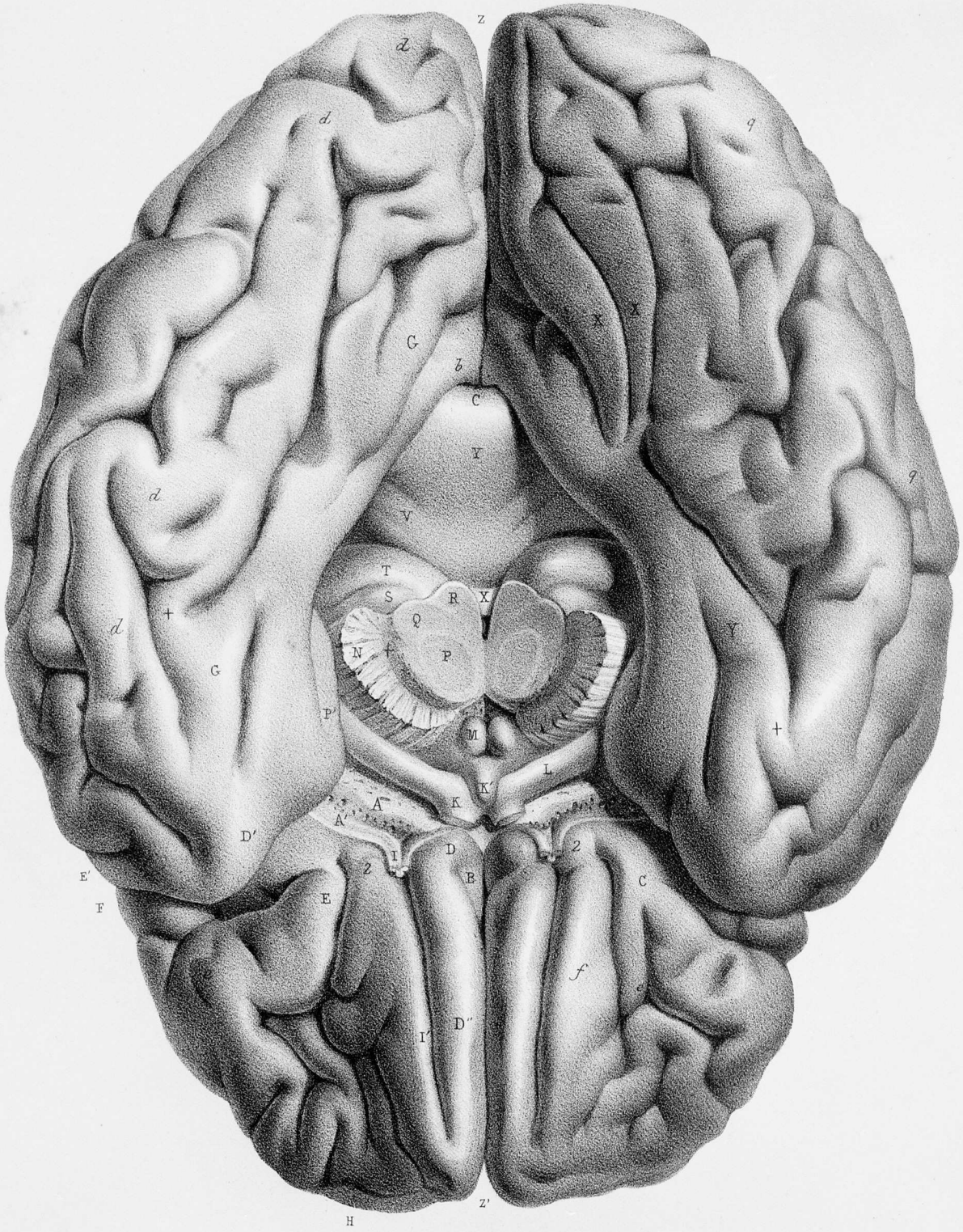
While the first project is limited to Chennai, the second one is a part of the Advanced Traveller Information System (ATIS) for Indian cities sponsored by the Department of Electronic And Information Technology (DeitY), Government of India. It is concerned with the demonstration of the scope of ATIS by implementing this system along the chosen test bed along the IT corridor of Chennai, on a 16-km-long network of roads including parts of OMR, Taramani Road, Velachery Main Road, Velachery Bypass Road, Sardar Patel Road, and Taluk Office Road.

Initiated in 2011 by faculty members R. Sivanandan,

Karthik K. Srinivasan, Lelitha Vanajakshi and Gitakrishnan Ramadurai, the project has neared completion, and is now looking to improve services and progress towards large scale integration in traffic systems of Indian cities. Information about traffic and delay time to reach their destinations is displayed to the users through Variable Message Sign (VMS) boards which have been installed at important junctions and sections of the arterial roads on the selected 16-km stretch of road and also through the RTIS website (`http://rtis.iitm.ac.in`). Users can also access the website to view options of selecting their origin, destination and mode of travel, and the system will suggest routes for travel with the distance and estimated duration. The website also features colour-coded maps depicting speed and congestion levels on the various roads within the network, as well as traffic delays (in minutes) at various junctions and roads, live traffic images from the 32 video cameras monitoring the traffic, and an interactive map interface showing location alerts for traffic disruptions such as accidents, incidents, processions, and road work.

One of the salient activities of the team at CoEUT involves evaluating and developing sensors for real time traffic monitoring and traffic data collection. Traffic parameters are extracted from the video using automated video processing solutions such as GRIP, Trazer and Trafficam Collect-R. GRIP is an image processing software that is being developed in-house to extract classified vehicle count from live and recorded videos. The vehicles moving across the virtual detection zone are counted and categorized into four different classes – two-wheeler, auto-rickshaw, light and heavy motor vehicles based on their width. Trazer is a commercially available video analytics specifically developed for Indian conditions, and generates data on classified count for four different classes and their respective speeds and projected occupancies for every one minute. Trafficam Collect-R is a virtual loop based video sensor with embedded hardware. It processes the images on the field and communicates the traffic parameters to the lab. These include classified count, speed, occupancy, speed and headway separately for different classes. These sensors along with a few others, are being tested in the IT hub of the city along these selected roads. The team also collaborates with some of these sensor manufacturers to calibrate and improve their performance to work better under Indian conditions.

ITS is still in its infancy in India, with decision-makers, key planners and agencies yet to understand its potential. The investments in this sector by the Ministry of Urban Development and DeitY done are of significant importance and should be stepped up in the forthcoming years, as this is a problem that will affect the near future at current rates of growth and development of our cities. IIT-M stands at the forefront of research and development of indigenous technology in this area that caters specifically to Indian conditions, and in demonstrating the scope of this technology and its benefits. It is hence vital that we start paying attention to the way we travel and begin exploring options of using ITS in India, so as to improve deteriorating conditions of traffic congestion in India ■



Dessiné d'après nature par F. Bion

Lith. d'Artus, rue de la Harpe 50

Memories in gray and...

By Ranjani Srinivasan

Dementia, a neurodegenerative disorder, is a silent killer. It progressively affects various aspects of one's daily life and eventually imposes a bedridden state on the afflicted. Alzheimer's disease is one of the most common kinds of dementia, affecting an estimated four million people in India.

A person afflicted by Alzheimer's may not remember having had breakfast, and in the same afternoon, may forget their own identity. Nightmarish as this prospect is, we do not yet have a cure for Alzheimer's. A cure can mean very different things at different stages of evolution of medical science; halting the disease and postponing its onset are also equally important. Today, the ability to predict the onset of Alzheimer's is of great interest to researchers and clinicians, with the hope that we may be able to equip impending victims of Alzheimer's to face the first few years of affliction.

Early diagnosis is, therefore, important. Ranjan Piyush, for his M.S. thesis in the Biomedical Engineering Group of the Department of Applied Mechanics, under the guidance of Prof. S. Ramakrishnan, investigated a possible methodology that may eventually help in early diagnosis of Alzheimer's.

Although first identified in 1907, we are still far from understanding what causes Alzheimer's and how to treat it. The structure and function of various regions of the brain and the strength of their inter-linking connections are areas of intense interdisciplinary research. Our understanding of neuroscience has for long been about identifying chunks of the brain or "modules" that are relevant to a certain function.

Today, the tracts, the fibres that connect these modules, have come to be recognized as important. Diffusion Tensor Imaging, or DTI, is an imaging technique that illuminates these connecting tracts and helps us analyze their strength.

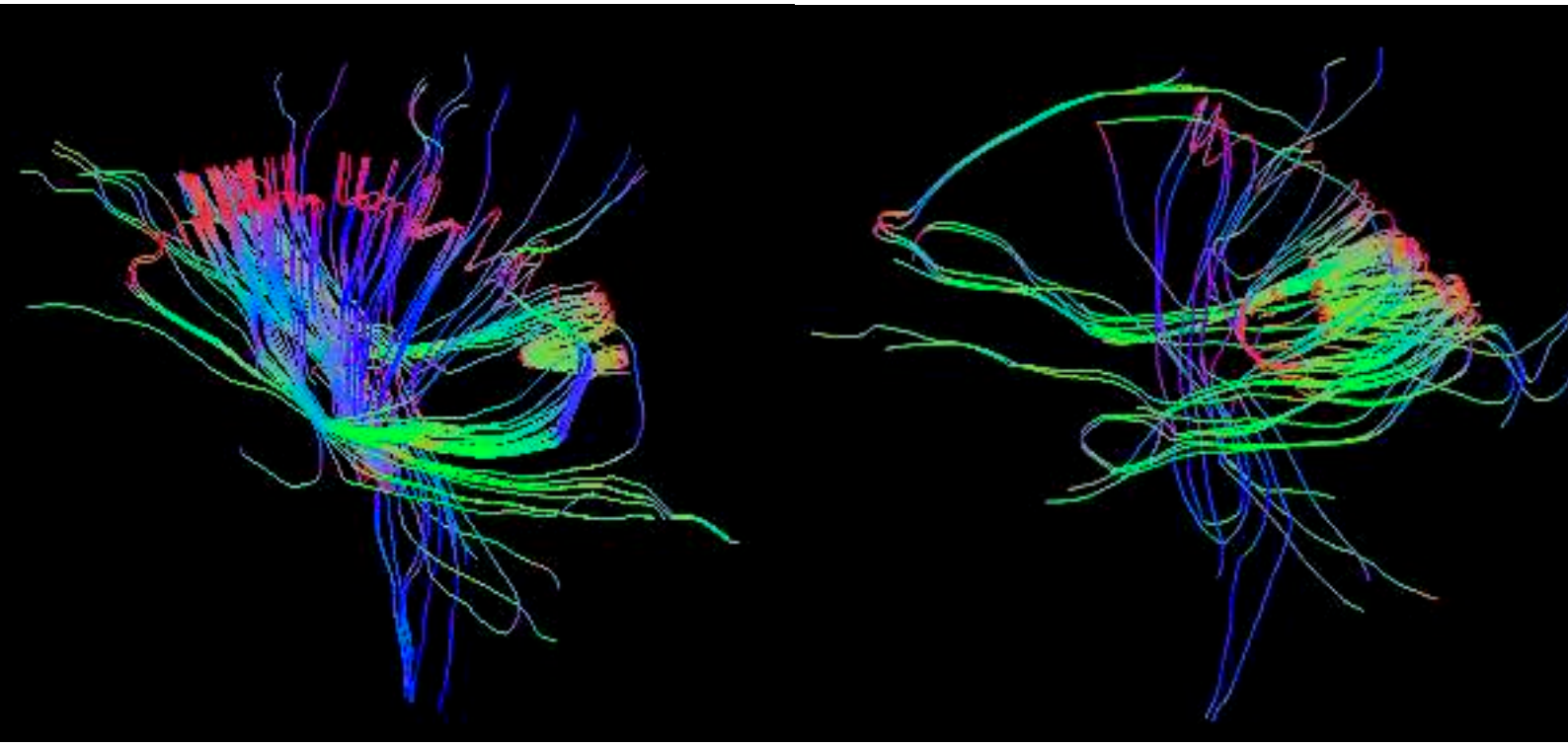
When we talk of tickling our gray cells, we are actually referring to the gray matter, which lies on the outer layer of the brain, and is typically associated with cognition, memory and high-level processing. It is composed of cell-bodies of nerve cells, the neurons, that indeed appear gray.

But there is much more to our brains than just the gray regions. A significant volume is occupied by the white matter, composed of axons – spindly fibres along which signals travel – that connect various chunks of the brain. It has a white hue due to the presence of an insulating protein called myelin, which helps prevent leakage and dissipation of the signals. Myelin also enables the signal to travel almost a hundred times faster than it would otherwise.

The white matter of the brain has for long been neglected, but researchers now realize that damage to it, or its sub-optimal functioning, is associated with many neurological conditions like dyslexia, schizophrenia and bipolar disorder, to name a few. Alzheimer's too is suspected to be closely linked to sub-optimal functioning of the white matter.

Quality of the connections is one of the foremost features of the white matter and DTI is currently the only tool that is in vivo – it can be employed on living, whole organisms, as opposed to one on dead animals or in laboratory petri-dishes. DTI helps us assess the strength of these connections. Cognitive, emotional and social functions of the brain are thought to be deeply associated with the quality of connections. An understanding of these communication networks, and more importantly, how certain abnormal or sub-optimal connections are linked to particular conditions, is a huge challenge in today's neuroscience research.

Quantitative analysis of DTI images reveals some of the properties of these tracts in the brain. DTI, a modified form of magnetic resonance imaging (MRI), uses the gradient of the magnetic field to probabilistically estimate the diffusion of water molecules in a tissue. We get a vector (technically, a tensor) map of diffusion in various directions, which is dynamic, as the amount – both the magnitude and direction – of diffusion changes



Diffusion Tensor Imaging of the brain. The image on the left shows a healthy brain and the one on the right shows an Alzheimer's affected brain. Courtesy: Prof. S Ramakrishnan and Ranjan Piyush

in time. This dynamic map is processed to yield the connecting tract-integrity.

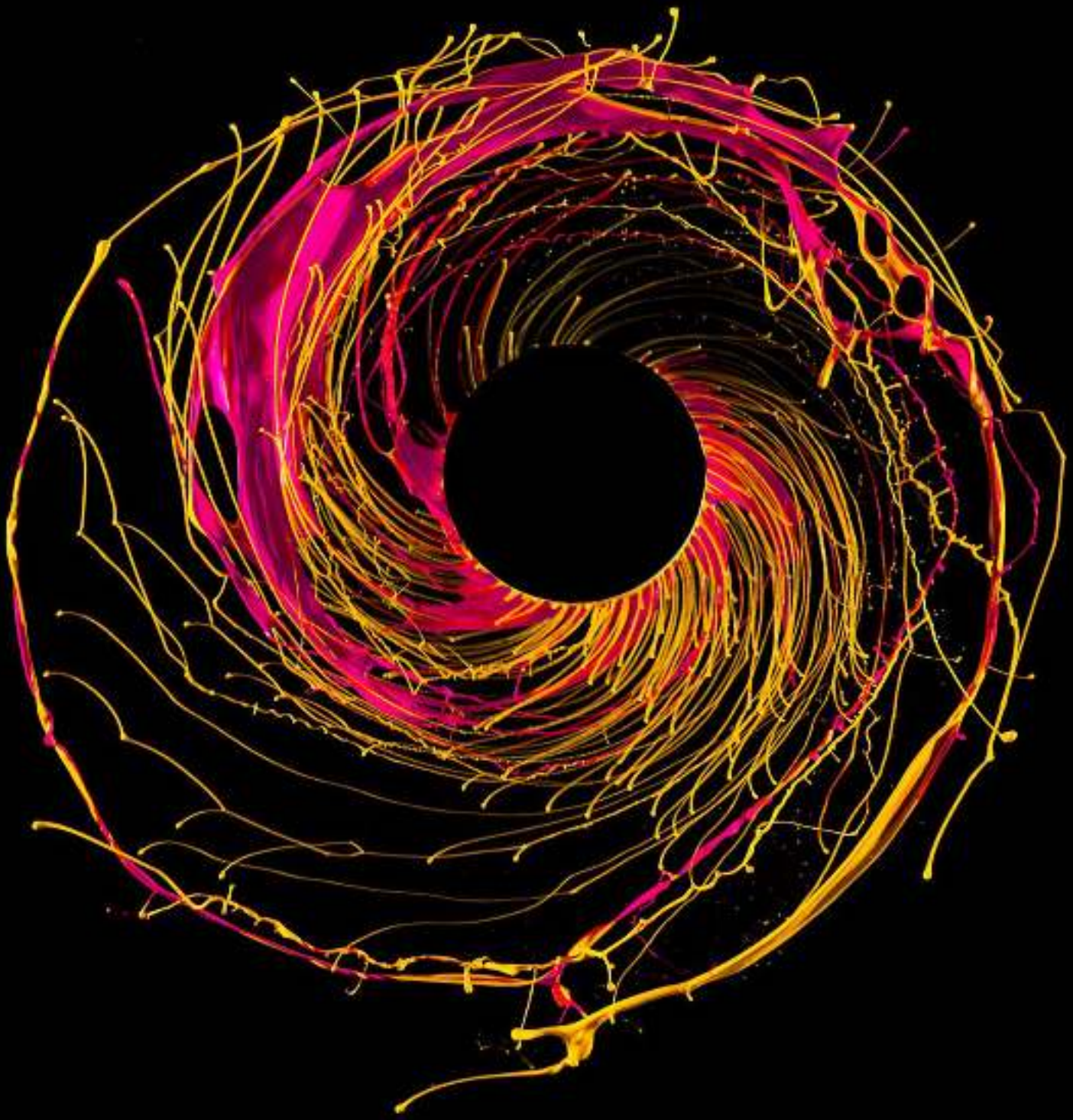
Manual analysis of DTI images for diagnosis of Alzheimer's is time consuming and often does not capture all the information available. So, Ranjan, for his M.S. thesis, developed an automated approach to identify the regions that are most relevant for detecting Alzheimer's.

Implementing machine learning algorithms that extract features prominently linked to the pathology of Alzheimer's as well as removing redundant and unwanted ones, is primarily what Ranjan worked on. Tractography, or the analysis of linking tracts, is a vital part of his work. Continuous white matter pathways are constructed from the DTI images, and the average length of tracts is a by-product of this construction.

"To impart a physical touch, we thought, why not measure them [the number of tracts and their length]? And that was the eureka moment. We nailed down on the best available algorithm for tractography and started out to measure the length and number of tracts in various regions of the brain and compare patterns between DTI images of normal and Alzheimer's subjects' brains," says Ranjan.

This comparison revealed a significant difference. The smaller length of tracts associated with Alzheimer's, he says, may be attributed to loss of neuronal pathways. Qualification of the disorder on the basis of this feature seems a promising technique for diagnosis.

"Our motivation towards working on this particular problem stems from understanding the importance of early diagnosis in this particular disease," says Ranjan. If we learn to predict the disease in its early stages, we might be able to trace its growth and any accompanying structural, biological and functional changes. Imaging technology is at the core of such research efforts, as engineers try and develop methodologies and algorithms to extract information about neurological conditions from images of the brain ■



Developed under the same project as the cover picture, this is another work of art by Fabian Oefner.The setup that has been used to create these images is very simple - Various shades of acrylic paint are dripped onto a metallic rod, which is connected to a drill. When the drill is switched on, the paint starts to move away from the rod, creating these amazing-looking structures. The droplet like shapes at the end of each of these jets illustrate Plateau-Rayleigh jet instability, a phenomenon where a falling stream of fluid tends to break into smaller packets to minimise surface energy

Paper boats and Nuclear reactors

By Raghavi Kodati

Dipin, a fourth year Ph.D. student in the Chemical Engineering department, points out to me something very mundane yet incredible. While chatting over tea, he pours the liquid from one glass to another and points out the way in which the stream of hot tea periodically twitches as it flows down. He explains to me how pressure imbalance within the stream causes this motion of the fluid jet.

Sensing my awe, he goes on, "Do you think there would be any fundamental similarity between inkjet printing and a nuclear reactor accident?" Although seemingly unrelated, the same science, he states, underlies the flows of ink and molten nuclear fuel – the science of fluid jets and their instabilities.

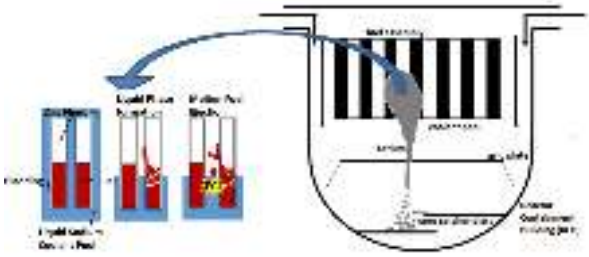
If you have ever wondered why it rains in drops and not as streams of water, you'd have probably stumbled across this concept of jet instability. When the surface of a falling stream of fluid is slightly disturbed by, say, minute air currents, the disturbance can grow and cause the jet to split at the point of disturbance. The split portion of the jet then takes on the spherical shape of drop to minimize the total surface area.

You can also notice this in water-flow from a leaky tap, or when you shake paint off a brush. Known as Plateau-Rayleigh instability, this is exploited in inkjet printers to control the size of the ink drops that finally hit the paper and produce the print.

Although the context is different, a somewhat similar phenomenon is expected to take place in a pool-typed fast breeder nuclear reactor in the event of a nuclear meltdown accident.In particular, a fast breeder reactor like the one being set up at Kalpakkam, Tamil Nadu by the Indira Gandhi Center for Atomic Research (IGCAR). The core of the reactor comprises rods of radioactive fuel, such as uranium or thorium (or their oxides), cladded in stainless steel and surrounded by molten sodium coolant and isotopes – variants of the same element with different number of neutrons – of the fuel element that are non-fissile.

Fissile elements, like the nuclear fuel, are those that can be split by neutrons in a self-sustaining chain-reaction to release enormous amounts of energy. The atoms of the radioactive fuel, upon encountering neutrons, undergo fission to produce smaller non-radioactive atoms, and more neutrons and energy. The surrounding non-fissile isotopes absorb some of these resulting neutrons and transform to fissile isotopes which then act as radioactive fuel. This chain reaction goes on until all the fissionable material inside the reactor is exhausted. In the process, the coolant absorbs the energy released from fission and generates power.

The cooling mechanism is crucial to control the temperatures inside. If this mechanism goes awry, the tremendous amount of energy released can cause steep temperature increase, and the fuel and its steel cladding may melt and flow down through the coolant. This situation is termed a nuclear meltdown or a core disruptive accident (CDA).



A schematic of the Core Disruptive Accident-When the fuel melts, it passes as jets of fluid through the surrounding coolant. Courtesy: Prof.Pushpavanam

One of the containment strategies when this happens is to make the molten fuel solidify as it passes through the coolant. Physical catcher plates are put up beneath the grid-like structure holding the fuel rods. As the fuel melts and passes through the grid, it comes out as fine jets and, ideally, breaks into smaller droplets which solidify when they lose heat to the coolant and settle on the plate. However, if solidification does not happen, and the jet/droplets settle on the plate as a liquid, the fuel material and steel separate, or stratify, and the steel tends to solidify around the fuel. Such an encapsulation is a dangerous state, as it traps the radioactive atoms and emitted neutrons. This can lead to another uncontrolled

reaction and a secondary meltdown. This time, however, being close to the reactor wall, the melt may breach the reactor itself and enter the environment.

To prevent all this happening when there's a CDA, the design of the reactor should incorporate the elements that lead to breakage and solidification of the jets before the molten fuel hits the core catcher plate.

Prof. Pushpavanam of the Chemical Engineering and Prof. Sundararajan of the Mechanical Engineering departments, in collaboration with IGCAR, undertook a study with the aim of identifying whether core disruption in a nuclear reactor with liquid sodium as pool-coolant would lead to stratification on the core catcher plate, or if the jets would just fragment and solidify. By mathematical modeling as well as experimentation, the research team, of which Dipin was a member, proved that pool-coolant reactors always almost result in solidification. Hence, they are inherently safer than, say, light water reactors, for which stratification has been reported.

Compared to the above examples of liquid instability in tap water or rain drops, there's one fundamental difference in which the nuclear reactor accident situation differs. While the other examples are constant temperature phenomena, the temperature of the nuclear jet varies rapidly as it passes through the liquid sodium coolant.

Now, if you were the sort of kid who played with paper boats in rain, you might have tried putting camphor on the water and seen the boat self-propel away from camphor's direction. This happens because wherever camphor dissolves locally, the surface tension of water lowers and the boat is pulled to neighbouring areas with higher surface tension. This liquid movement is called Marangoni effect and arises whenever there is a variation of surface tension on a liquid surface.

The same effect is seen when there is temperature variance on the jet stream. Wherever temperature is lower, the surface tension tends to be higher. As the jet travels through the coolant, the temperature along the surface of the jet stream decreases and the jet is further disturbed by the Marangoni effect produced on the surface. Early breakup of jets was predicted in such a case, and experimentally noticed also. As early breakup means faster solidification, the presence of Marangoni effect favours the safety of this pool type reactor. Another factor causing early breakup was that of increased viscosity due to liquid sodium. The latter is an intuitive result, considering a water jet would break earlier in, say, oil than in air.

Results from commonplace effects like jet instability were extended to analyzing operation hazards of nuclear reactors

Overall, the safety of pool type reactor in the event of a Core Disruptive Accident was favoured not just in theory, but was also substantiated by experiments and numerical simulations. Since experimentation in a nuclear reactor is not feasible, the group chose to work with a simple system substituting glycerol for liquid sodium, aluminium for steel cladding and lead for nuclear fuel. The fundamental equations governing the physics of the process were also established.

Prof. Pushpavanam, the lead researcher in this project, says, that the "theoretical or fundamental research helps one obtain scientific relations than just live with empirical observations. For example, with a theory, you would know the effect of varying the coolant or increasing the size of the nuclear reactor beforehand, and do not have to experiment each time a parameter of the system is changed. This knowledge is crucial as it saves experimentation time and effort. Often, modeling a system mathematically also throws up new insights and gives deeper understanding of the system. Indeed, there's nothing more beautiful than a simple mathematical model explaining the rich physics of a bunch of phenomena! Here too, equations for jet instability were extended admirably to the operation hazards of nuclear reactors"

The results of this project, which is now in its final stages, will aid IGCAR in designing fast breeder reactors, strategized to be set up to utilize the existing nuclear ore reserves of the country and increase energy generation ■

I Tilt and Go

By Vivek Sarda

This project focused on developing an independent mobility device for children with Cerebral Palsy (CP). It's a condition caused by damage to the motor control centres of the brain – the regions which control body movements. Most children who are affected with CP lack independent mobility and are restricted to wheelchairs.

My work under the guidance of Dr. Sujatha Srinivasan at the R2D2 (Rehabilitation Research and Device Development) lab, Department of Mechanical Engineering, IIT Madras, was to design a wheelchair that could be controlled by children affected with CP by using gross movements of their body. We call it the I Tilt and Go, or ITaG, wheelchair.

The extent of mobility in children with CP varies widely: some can only move their head, while others can move only their left hand or right hand. The existing powered wheelchairs are not ideal, because they have to be controlled with a joystick, which requires fine motor skills that these children lack. Hence, a new wheelchair control mechanism had to be designed.

We knew that children with CP have the ability to move their body as a whole and that they can improve their control of this motion over time, with practice. So we decided to use gross body motion as the input to control the wheelchair we were designing. When the user moves forwards or sideways, the wheelchair could be made to move in the corresponding direction.

Coming up with a new design wasn't straightforward. The key features required in the design were that it should be practical, user friendly, affordable and flexible to each child's needs. Initially, we worked on developing an existing mechanism (designed as a part of the B.Tech project of Prashant Poondla), which used a seat that could rotate about two directions (universal joint) based on the motion of the user's body. When the user moved forward/sideways, the seat rotated in the forward/sideways direction. The rotation of the seat was measured by angle sensors and the wheelchair controlled accordingly.

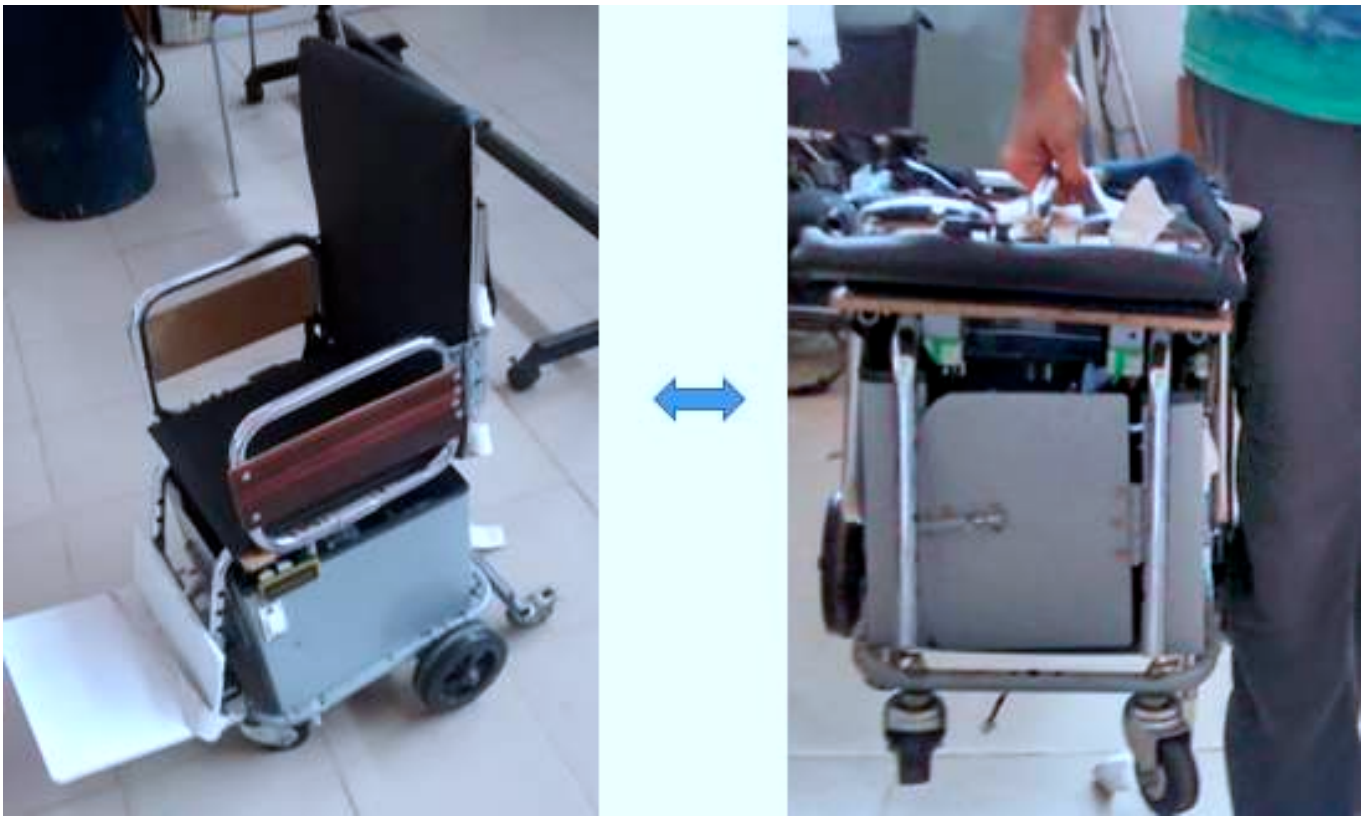
This mechanism was developed and tested with a healthy seven-year-old child. However, the child found it difficult to control the wheelchair because of the moving seat. This difficulty was expected only to be amplified for children with Cerebral Palsy. So, a new mechanism had to be designed which could provide a rigid seat.

One day, while guiding some juniors with their Centre for Innovation (CFI) project, I hit upon a new design. Their project used load cells to find the weight of water cans; moving the water cans on the platform caused changes in the load cell reading. I realized that the same concept could be used to detect gross body movements of the user. The effect caused by the shift of the water can is the same as that of the user moving their body; that is, a shift of the centre of gravity. This effect could be detected by placing a few load cells beneath the seat.

After performing basic calculations, the system seemed feasible. The rest was a matter of investing time and making the idea work in practice. The major challenge here was the scale of the project, which had to be completed in the required amount of time. The wheelchair had to be designed and manufactured, both mechanically and electronically.

Our design uses force sensors placed beneath the seat to detect a shift in the centre of gravity of the user. This method has several advantages which makes it ideal for children with CP. For one, the load cells are inexpensive. These sensors are placed beneath the seat and do not require any additional attachments to the user. The seat itself is virtually rigid and can detect, as input, a wide range of motion, such as that of the head, the trunk or the limbs. In fact, even fine movement, such as that of the head by as little as 30 degrees, can be detected. Moreover, the same system can be used for children weighing from 10 to 30 kgs, and can be calibrated according to the requirements of the child.

We were attempting to build a device which would be a product, so wanted to include the required mechanical features as well. The design, therefore, includes a mechanism for transporting and portability as shown below – where the backrest and armrest fold down, mak-



Mechanism to make the wheelchair compact. Courtesy: Vivek Sarda

ing the wheelchair compact, which can then be lifted by the user much like a briefcase; the arms and the foot rests are also removable.

Safety is a key consideration while designing any assistive device such as a wheelchair. Various safety measures incorporated include an ultrasonic distance sensor placed in front of the wheelchair for collision prevention and a wireless joystick which can be operated by a caregiver to override user instructions. Other electronic features included are data collection through an SD card to track the improvement in the body control of the user through repetitive usage of the wheelchair, and an LCD display providing feedback to the parents or the teacher. It displays the battery level, error messages in case problems arise, and sensor readings to understand the position of the children.

All this design, of course, had to work practically and not remain a model which would work only in the lab. So we field-tested the basic proof-of-concept model at Vidya Sagar, Chennai – an organization that works with children who have CP and other neurological disabilities – for a period of three months with the help of ten children who were severely affected (GMFCS level: 4 and 5) with CP. It was also tested at the Spastics Society of Tamil Nadu (SPASTN) and Blossom Rehab Centre, both in Chennai.

Overall, we were delighted with the positive feedback from all these places. The children enjoyed the independent mobility and also improved their body control in the process. The design seems to provide a good solution for a wheelchair control mechanism for children with CP.

This was my dual degree project, and along the way, it took me to various exhibitions and competitions. I participated in the Inclusive Innovation Resfearch Expo 2013 in Pune and also in the 3rd International Conference on Biomedical Engineering and Assistive Technologies (BEATS) 2014 in Chandigarh, where the project won the best paper award. It won the Jed-i Project Challenge 2014, Bangalore, in the Electrical Division and the Sri Chinmay Deodhar Award 2014 for the Innovative Student Project, IC&SR projects, IIT-M. The design also has a patent pending.

Currently, I am at the R2D2 lab at IIT-M, which aims at developing affordable assistive technology like ITaG, the standing wheelchair, and various other orthotic and prosthetic devices. Although this mechanism was devel-

oped for people with CP, its flexibility makes it adaptable to people with other disabilities such as tetraplegia. We are working on developing a product version of the ITaG for adults and children, which would include an industrial design, apart from the design for manufacturing and assembly. The challenge here is to make the device affordable, as motorized wheelchairs are costly. Also, the device may possibly be beneficial for people with CP throughout the world, as well as for people with high levels of spinal cord injury. On developing the commercial version, we will look for ways to reach out to as many people as possible.

I would like to thank Dr. Sujatha Srinivasan for being an amazing guide. I would also like to thank Dr. Anil Prabhakar and Dr. Namita Jacob for bringing us this project and for helping in various aspects of the process of making this a product. I am grateful to Vidya Sagar, SPASTN and Blossom Rehab Centre for giving us the opportunity to field-test our prototype. I also thank CFI and the Central Workshop here at IIT Madras for providing the manufacturing facility. Finally, I want to thank all the tech junta of CFI and my hostel, Jamuna, for providing various inputs on the project ■


Eve in
Quantum
Land
By Vishakh Hegde
Courtesy: Wikimedia Commons
Modified by: Vishakh Hegde

During World War II, Nazi Germany used the Enigma machine, the then state of the art electro-mechanical encryption device, to encode secret messages in scrambled chunks of alphabets. This enabled Germany to secure a tactical advantage over the Allied Powers. Each Enigma machine had numerous possible electro-mechanical settings and the exact setting was shared between radio operators once every month on code-sheets (printed with soluble ink) before communicating secret messages. Once encrypted, it was next to impossible to decipher the messages transmitted over the public radio channel, unless one had an Enigma machine with information about the exact electro-mechanical settings of the sender's machine. With a key, it was trivial to decrypt the message. However, the Enigma machine had a flaw.

It relied heavily on the prior communication of shared settings, or "keys", as we call them now. Securing the key would allow one to decrypt secret messages for as long as those settings remained unchanged. However, care was taken to communicate the keys privately (and this was hence called the private key distribution protocol) each month, making it difficult to maintain a constant inflow of decrypted German secret messages for the Allied Powers. Marian Rejewski, a Polish mathematician and cryptographer built "bombes", to automate the search for Enigma's electro-mechanical settings. These bombes were greatly improved upon by Alan Turing, working at Bletchley Park and along with Colossus, the world's first programmable electronic digital computer, also designed there, the Allies were able to decode a large fraction of German messages. His work marked the beginning of a new era of information technology.

Today, banks, the e-commerce industry and government military agencies are but a few organizations which rely heavily on cryptography. The RSA cryptosystem, named after it's inventors Ron Rivest, Adi Shamir and Leonard Adleman is a public key system which works on the basic assumption that it is easy to multiply two primes to get a large number, but difficult and time-consuming for current computer systems to obtain prime factors, given a large number. It eliminates the problem of sharing secret keys associated with private-key systems. While it is widely used today, it might become useless a decade or two from now.

Peter Shor, a professor at MIT, showed that it is easy for a quantum computer to break such an encryption using the quantum factoring algorithm he came up with in 1994. Steady progress has been made towards building a practical quantum computer, which experts believe is more than a decade away. Instead of the conventional notion of 'bits', which can either be 0 or 1 at a given point of time, there is a notion of a 'qubit', which can be 0, 1, or any arbitrary superposition of 0 and 1. Such a superposition is possible only in the quantum world where, for example, an electron can have an up-spin, down-spin or any superposition of it. Dubbed "Spooky action at a distance" by Albert Einstein, the phenomenon of entanglement is also unique to the quantum world. Two particles are said to be entangled if knowledge of one of the particles automatically implies knowledge about the other. The phenomena of superposition and entanglement are often exploited to achieve higher computational speeds. Once built, most current cryptosystems like the RSA will be no match for quantum computer's computational power. The consequences can be catastrophic.

"About a year ago, there was this furore over wiretapping by the US on the governments of other countries. There is a fair amount of interest even in India on being able to achieve secure communication and Quantum key distribution (QKD) is one of the Holy Grails for this", says Prof. Anil Prabhakar of the Department of Electrical Engineering at IIT Madras, where he works with Prof. Andrew Thangaraj on using light as a source and optical fibre as a communication channel to achieve quantum key distribution. Says Prof. Anil:

"Demonstrating Quantum Key Distribution in a practical scenario will generate a lot of interest"

The idea is to securely distribute keys between two parties, Alice and Bob, the archetypal placeholder characters in cryptography. The keys are then used to encode messages over classical, that is, our standard, day-to-day channels, communication channels after using one of several encryption techniques like the one-time pad technique to encrypt the message. The quantum channel used to establish the key can potentially be monitored by an eavesdropper, typically known as Eve. QKD relies on the famous "No Cloning Theorem", which states that unknown quantum states cannot be copied. This is unlike the classical scenario where bits can be easily copied and reproduced. Also, in quantum mechanics, we assume that observing (or measuring, in more technical

terms) a quantum system destroys its state. Therefore, any attempt by an eavesdropper to either copy or obtain the key from the channel can be detected easily. Practical implementations of QKD rely on privacy amplification that limit the number of bits of information that Eve can gather, allowing Alice and Bob to use the remaining bits as a secure key. If the channel is severely compromised, Alice and Bob become aware of this and take measures to either secure the channel or stop communication altogether.

BB84, the first quantum key distribution protocol to be proposed, and named after its inventors Charles Bennett and Gilles Brassard, has an Indian connection. It was first presented at a conference in Bangalore in 1984. They also proposed an experimental procedure to demonstrate it. The 0s and 1s can be encoded in photon polarization states which show quantum behavior. There are several layers in the key distribution system. There is a quantum layer and a classical one, where a lot of classical post-processing is carried out. The system becomes insecure if either the classical or the quantum layer gets compromised. "This whole business is therefore trickier than most people think", says Prof. Anil. End-to-end fibres without any amplifiers in their path are a crucial and challenging requirement. Current systems can transmit photons through optical fibres for about 100 km without amplifiers. If there is a need to use an amplifier, it also has to be secured, which is quite a task and a possible drawback of the system right now. However, ongoing research on quantum repeaters can help increase the distances over which Alice and Bob can share a quantum key.

"Where our research at IIT Madras stands today is that we are able to generate keys and transmit them. If somebody, say the defence sector, wants it deployed in India as quickly as possible, we will be able to do it in about six months or a year", he says with a gleam in his eyes. IIT-Madras has also proposed a novel spin wave-optical interaction technique which can encode photons at tens of GHz. However, there are not many commercial sources of magnetic thin films in the world, a key component for this particular scheme of implementation. "A couple of years ago, I identified a source of magnetic thin films and hence started this project. But the comedy of errors is that the source is in Ukraine, which is undergoing a severe political crisis right now", he says, laughing. However, he has enough samples to demonstrate it, and there are ways to grow such thin films in a lab.

There are two major schemes for implementing quantum key distribution. One uses a single photon source and the other, a coherent light source. The single photon source emits light as single photons, and the presence or absence of a photon can act as a 1 or 0, in on-off keying. Coherent sources like lasers which emit lots of photons at a time, and information is often encoded through amplitude or phase modulation.

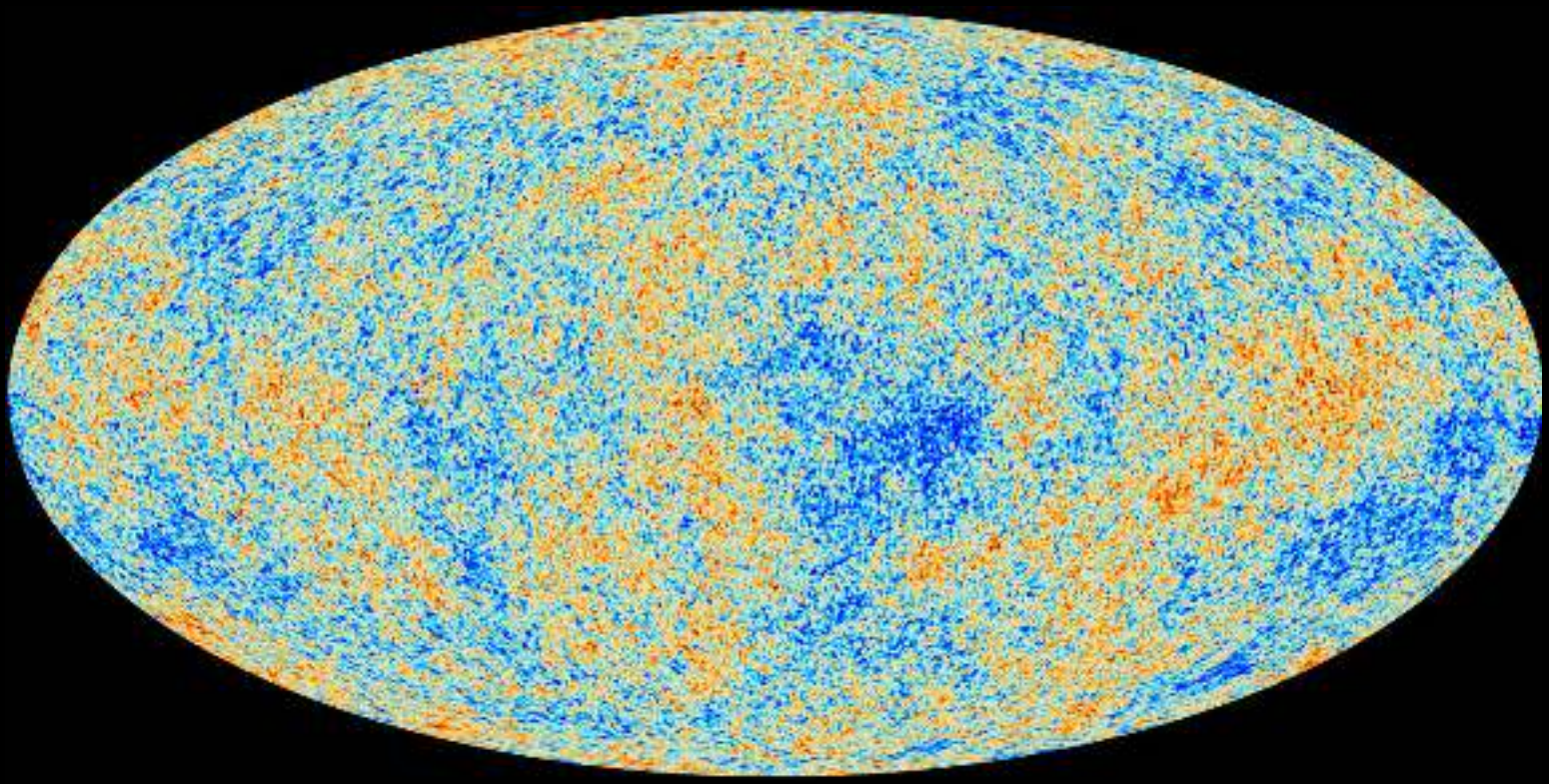
In the phase modulation technique, light from a coherent source is passed through an interferometer. Constructive interference can be labeled as a 1 and destructive interference, a 0. In frequency coded quantum key distribution (FC-QKD), a coherent source is modulated, using an electro-optic crystal, and information is sent on two frequency sidebands. With a similar setup at the receiver we can observe interference over long distances. The spin wave-optical interaction technique is a modification of FC-QKD, where only one sideband is created as opposed to two when an electro-optic modulator is used. Eve can potentially steal information from one of the sidebands generated in the standard frequency-coded technique and the receiver won't always know when Eve steals information. However, with a spin wave-optical interaction, Eve can only tap information from the one existing sideband. Her presence is now easier to detect, thus making the spin wave-optical interaction technique almost twice as secure as the electro-optic frequency-coded technique. Says Prof. Anil:

"IIT Madras was recently approached to lead national efforts on Quantum Key Distribution."

However, productizing a system will require adhering to telecommunication standards, making it compatible with existing optical fibers and adding appropriate features to make it user friendly. There is an opportunity here for an entrepreneur to develop the technology beyond the laboratory, before larger companies will be ready to invest and deploy such systems. Prof. Anil says, "There are a few different flavours of QKD in the world and our systems should compete against them. It has been a great research experience, and we hope to build further on these technologies as we aim for data rates of 400 Gbps to 1 Tbps".

These are the reasons why

But how did we get these in the first place?



Three Degrees above Zero

Courtesy ESA, Planck Collaboration

this exists

By Nithyanand Rao

Courtesy NASA Goddard Space Flight Center

Big Bang had a problem. Our theory of the early universe could not explain how widely-separated regions of it had seemingly influenced each other even though they clearly couldn't have had the time to do so. Either the cosmic speed limit had been broken or it had all begun in a way more improbable than a pencil standing on its tip all by itself.

Then, in 1979, a Stanford postdoc named Alan Guth famously had his "spectacular realization" about just how big the bang must have been. A particle physicist, he found that the standard tools that helped him study worlds far smaller than atoms could also help him to get space in the infant universe to expand by a colossal factor of 10^{28} (one followed by twenty-eight zeroes) in an unimaginably small sliver of time. This meant regions of the universe that are now far apart had a common origin. Inflation, he called it.

But for tiny irregularities in that process , we would not be here. Of the small army of cosmologists worldwide who seek to know what exactly happened, are Dr. L. Sriramkumar of the Physics department of IIT Madras, and his doctoral student V. Sreenath.

Cosmology is not unlike paleontology. Studying the past for clues to understand the present is what paleontologists do. Cosmologists do the same, because the finite speed of light means that they only see celestial objects as they were when the light left them. Like paleontologists, cosmologists can only observe, not experiment. Unlike paleontologists, cosmologists have to be satisfied with observing from millions, sometimes billions, of light years away. (One light year is the distance travelled by light in a year.)

PH

For the most part, this means extracting all possible information from the faint light that reaches us. Depending on the circumstances, light can be thought of as a wave or as a particle. In its wave avatar, light – visible and invisible – from a celestial object reveals lines at particular positions in its spectrum, each one a signature of the element (or the molecule) involved. If the positions of these lines appear shifted towards the blue, more energetic, part of the spectrum compared to a reference source in the laboratory, it means the object is moving towards us. A shift towards the red, less energetic part of the spectrum, means the motion is away from us. Known as the Doppler effect, the extent of this shift is a measure of the object's velocity.

This came in handy when, barely a century ago, astronomers were debating whether the well-known nebulae – diffuse, extended objects – were part of our galaxy, the Milky Way, or if they were galaxies like our own, only very far away. Then, in 1912, the American astronomer Vesto Slipher observed that most nebulae were redshifted – they were receding from us. He had the prescience to note that there might be more to this than the Doppler effect. Following up was Edwin Hubble, whose star rose when he combined the redshifts with the distances to these objects, and came to a startling conclusion, now known as Hubble's law: a nebula twice as far away seemed to be receding twice as fast. That the Milky Way contained everything now became an untenable idea.

In parallel, cosmology emerged as a theoretical science, owing its origin to one man: Albert Einstein. Having already unified space and time into a single entity with the special theory of relativity, Einstein, in 1915, published the general theory of relativity, which revealed the gravitational force to be fundamentally related to the geometry of spacetime.

Physicists like such syntheses. They also make the reasonable demand that a physical law, and its mathematical expression, must be the same for all observers regardless of their positions and velocities.

The all-sky map on the previous page shows the tiny temperature fluctuations, or anisotropies, of the Cosmic Microwave Background (CMB) as observed by the satellite Planck. These correspond to regions of slightly different densities, representing the seeds of all future structure: the stars and galaxies of today.

Broadly speaking, there are three kinds of mathematical objects that help them do this. The simplest, a scalar, is just a number with an associated unit. Temperature is a familiar example. Two people, if they use the same units, will always agree upon the temperature at a given point in space and time regardless of how their respective coordinate systems are related. A vector, meanwhile, is a set of three numbers (for three-dimensional space) which together define a direction in space. Modify the coordinate system, and these three numbers will change, but in such a way that the vector, both magnitude and direction, remains intact. Velocity is an example. The third, and the most general, quantity is a tensor, which can be thought of as a set of three vectors associated with two directions. Thus, in three-dimensional space, a tensor has nine components, which also change in a particular way if you transform the coordinate system.

These three types of quantities can be used to describe not just matter and its associated phenomena, but also entities that are less obviously material. Such as a field, a concept that was introduced as a convenient device to describe how a force propagated, and which later took on a life of its own. One of the concepts at the foundations of modern physics, a field is another way of saying that each point in space can be uniquely associated with a scalar, a vector, or a tensor. Accordingly, we get scalar, vector, or tensor fields.

Each of the four fundamental forces in nature – strong, electromagnetic, weak, and gravitation – has an associated field. A particle that feels any of these forces will have a potential energy by virtue of its interaction with the corresponding field. Moving the particle from one point to another costs the field some energy. If that cost depends only on the positions of the two points and not on the path taken, each point in space can be uniquely assigned a scalar, called potential, which is the amount of energy expended to move the particle to that point from a common reference point. Thus, we get a scalar potential field. The gravitational field in Newtonian gravity is an example.

The general theory of relativity, in contrast, represents the gravitational field mathematically as a tensor field. The source of the gravitational field is the energy-momentum tensor, analogous to mass in Newtonian gravity. It, however, includes energy not only in the form of matter, but also radiation, and momentum. Another tensor called the metric tensor describes the shape of spacetime, which was until then always thought to be flat. Given a particular distribution of matter-energy, a set of equations called Einstein's field equations relates these two tensors and determines the curvature of spacetime. The motion of matter and radiation in this resulting geometry is what manifests itself as the gravitational force. In the words of John Wheeler, who championed Einstein's theory in post-WWII America:

"Spacetime tells matter how to move; matter tells spacetime how to curve."

Now that spacetime was no longer merely an empty stage, it didn't take long for the true nature and scope of the cosmic drama to be realized. Disbelieving his own equations that showed a static universe would be unstable, which was contrary to the prevailing belief, Einstein fudged his equations by introducing an extra term now known as the cosmological constant. This term, a kind of anti-gravity, kept Einstein's model universe from collapsing.

Others were more willing to confront the full implications of general relativity. Among them was the Russian Alexander Friedmann who, in 1922, found his eponymous solutions that described the universe, provided certain simplifying assumptions were made – inevitable given that cosmology, unlike astronomy, is concerned with the universe as a whole.

Cosmologists make the reasonable assumption that the part of the universe we live in isn't special. Any other part of the universe would have a similar distribution of matter-energy and structures, provided we consider sufficiently large scales.

"When we say the universe is homogeneous, we're talking about scales of the order of a hundred megaparsecs," says Sreenath, where a parsec is a unit of distance equal to about 3.26 light years and the prefix mega denotes a million.

A second assumption, called isotropy, is that the universe looks the same in whichever direction you look. These two assumptions, together known as the cosmological principle, are now well-supported by observational evidence.

Friedmann had found the solution that embodied just such a homogeneous and isotropic universe. Independently, a Belgian priest-scientist, Georges Lemaitre, also found the same solution, as did two others. They realized that if the general theory of relativity was correct, the universe had to be either expanding or contracting. Observational evidence supported the former. If you rewind, the galaxies would approach each other, which led Lemaitre to propose that they must all have come from a single initial point, which he dubbed the "primeval atom."

Soon, Hubble published his study of galactic redshifts and their distances, confirming that the universe was indeed expanding, tying together theory and observation in pointing to a universe which had a definite origin.

There was, however, another explanation that seemed possible. What if the universe had no origin and always was just as it is now? The space emptied between galaxies rushing apart could be filled with new matter appearing in just enough quantities to satisfy the cosmological principle. This neatly avoided the questions of how the universe began or what happened before it came into being. This theory, whose main proponent was the British astronomer Fred Hoyle, was called steady state, in appropriate contrast to a big bang (also coined by Hoyle).

An expanding universe naturally means that its energy density – of matter and radiation – is decreasing. But the energy density of radiation decreases faster than that of matter because, apart from the increasing volume, the light redshifts as space expands. A larger wavelength means less-energetic photons, the particle avatar of light.

This, however, is a prediction from general relativity and is distinct from the Doppler effect. Known as the cosmological redshift, this is what Slipher and Hubble had observed.

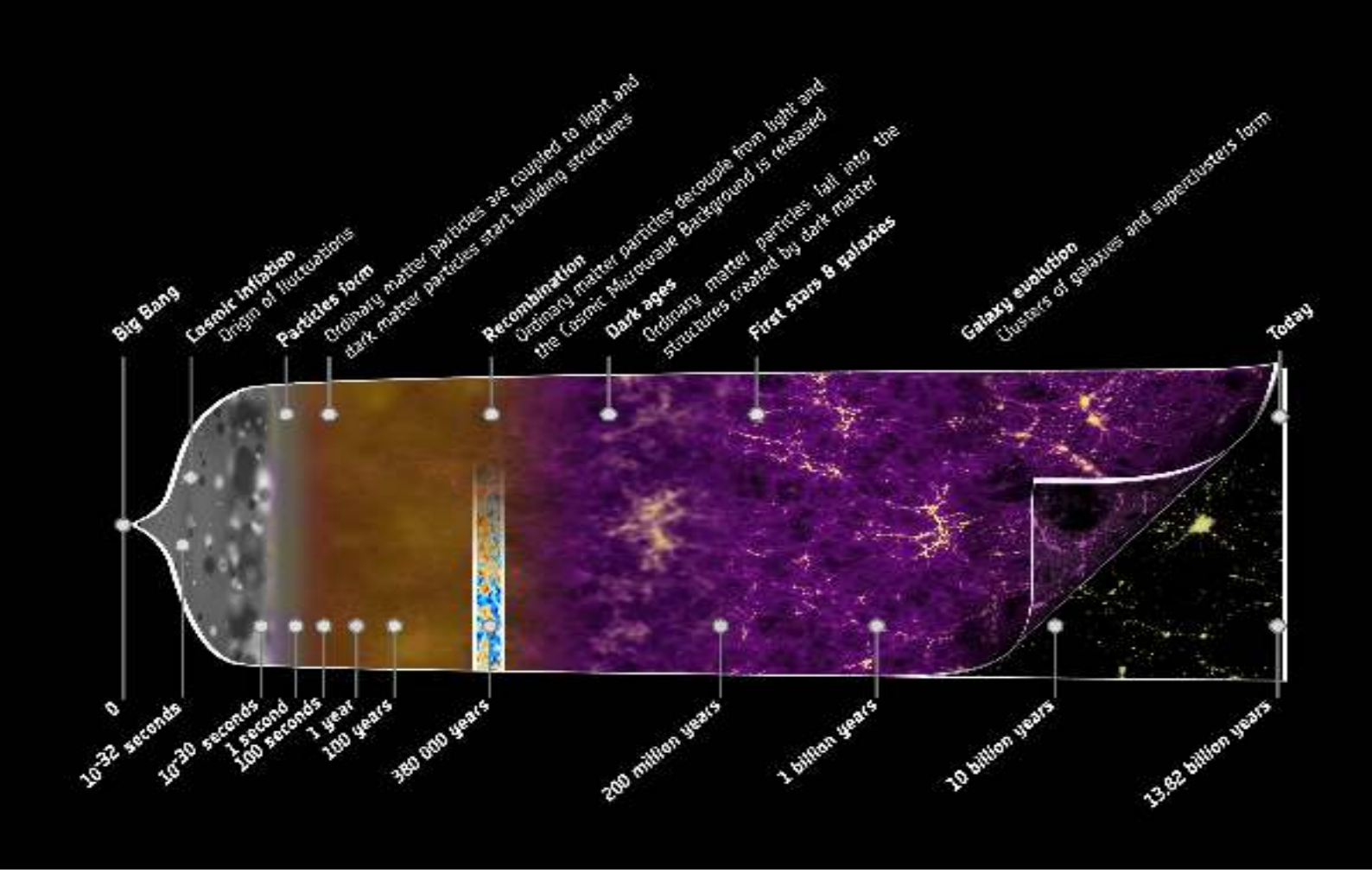
Now, if we run this backwards, the energy density of radiation increases faster than that of matter. Somewhere along the way the two must have been equal – an equality epoch – which cosmologists estimate happened when the universe was a few tens of thousands of years old. At times earlier than this, the universe must have been radiation-dominated and atoms, much less structures, could not have existed. This is because the radiation was energetic enough to break apart any nascent alliance between protons, neutrons and electrons, the three constituents of all atoms.

The universe, however, seemed to be made up of three-quarters hydrogen, nearly one-quarter helium and trace amounts of lithium and beryllium. That the Big Bang hypothesis could account for this naturally was first shown by one of Friedmann's students, George Gamow. He found that the temperature and density of matter in the very early universe would have been high enough for nuclear reactions to produce required quantities of the nuclei of these elements. Fred Hoyle later showed that all the heavier elements including the ones vital for life, such as carbon and oxygen, could be progressively manufactured in the nuclear fusion reactions that power the stars, which appeared much later in the history of the universe.

As space expanded and the temperature dropped, the nuclei formed would pair up with the electrons to form stable atoms. This is the recombination epoch, now dated at about 380,000 years after the Big Bang. Until then, radiation and matter had the same temperature, a condition known as thermal equilibrium. No longer impeded by charged particles, the photons were now free to begin their journey across the vastness of space and the immensity of time, collectively bearing the imprint of their last encounters of that era – a photograph, as it were, of the infant universe.

Lemaitre's primeval atom implied a singularity – infinite energy density and temperature – signalling the breakdown of the known laws of physics. Physicists abhor singularities, a main reason for steady state theory's appeal.

They were far cooler about the other extreme. Anything at a temperature above absolute zero (on the Kelvin scale; about −273 degrees on the Celsius scale) emits electromagnetic radiation. Physicists like to consider an ideal body in thermal equilibrium with its surroundings, which absorbs light of all possible wavelengths. This made the so-called blackbody capable of emitting light of all possible wavelengths too, the intensity distribution of which depends only on the temperature, and is called the blackbody spectrum. Increase or decrease the temperature, and the peak of the distribution – the wavelength at which the intensity of the emitted light is highest – changes. "It's a unique curve which depends only on the temperature and therefore



The history of structure formation in the Universe. Courtesy: European Space Agency

you can determine the temperature of the body," says Dr. Sriramkumar.

A good scientific theory gains currency when, like any good bank account, it gives you back more than what you put in. If there was a Big Bang, then the relic radiation of the recombination epoch should still be around, appearing uniformly from all directions. Feeble because of the cosmological redshift, theorists predicted it would be at a temperature of about 5 K, falling in the microwave region of the spectrum. Crucially, they predicted a blackbody spectrum.

When theories compete, only an experiment can be the referee. Occasionally, this happens by accident. In 1964, radio astronomers trying to detect radio waves bounced off an early satellite prototype found noise – undesired signals – that they couldn't get rid of. With wavelength in the microwave range, this background signal was the same across the sky, night and day, throughout the year. And it didn't come from any specific, known source. It was soon realized that this was the all-pervading radiation Big Bang predicted. And at 3.5 K, it had just about the right temperature.

Cosmologists had found their fossil.

They called it the cosmic microwave background, or CMB. And steady state theory had no satisfactory explanation for it.

There were problems, though. The CMB appeared to have exactly the same temperature wherever they looked. Estimates of the age of the universe, and of its expansion rate now and at earlier times, showed that regions of the sky that are now widely-separated would, soon after the Big Bang, have been pulled apart before they had had time to interact and attain the same temperature. Known as the horizon problem, it seemed to imply that the initial conditions were "fine-tuned" such that the entire universe started out with a uniform temperature. Further, if the CMB was a faithful record of that epoch, it implied that matter distribution in the early universe was also uniform. Why, then, does the universe have stars, galaxies, and us, instead of a diffuse gas of hydrogen?

The universe is still expanding; and in 1998, this expansion was unexpectedly found to be accelerating. This repulsive force is estimated to account for around 68 percent of all the energy in the universe. Dark energy is its name, but little else is known about it.

Opposing this expansion is the gravitational attraction of all the matter-energy in the universe, the density of which determines who wins this cosmic tug of war. Any more dense than it is now, and Einstein's equations showed it should have contracted and collapsed back on itself long ago; any less, and its expansion rate should have kept accelerating, and resulted in a much emptier universe. This represented a second major problem for the Big Bang theory. The energy density of our universe is too close to the critical density required for flatness to be attributed to chance.

Why does the CMB appear to have nearly the same temperature in all directions? Why does the universe have stars, galaxies, and us? And why does it appear to be flat?

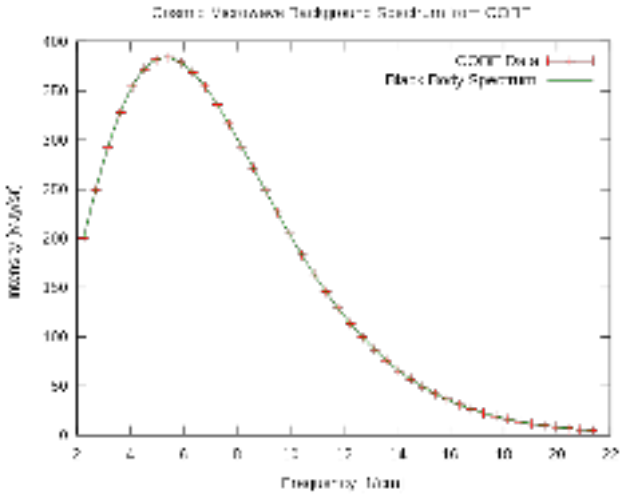
Inflation appeared to solve these problems. If all of the universe we see now is a vastly blown-up version of a region which, before inflation, was small enough to have had time to interact, it means they were in thermal equilibrium to begin with, thereby explaining the uniformity of the CMB from different parts of the sky. And if you start with a very tiny region and blow it up, any initial curvature would get flattened out.

But what mechanism could cause expansion of space?

Alan Guth found that a scalar field with certain properties could cause rapid, accelerated expansion of space in the earliest fractions of a second after the Big Bang. A few others had explored this idea before him, but it was with Guth's paper that the field exploded. What's more, inflation also had a natural mechanism for structure formation in the universe.

Any quantum field, unlike a classical field like that of Newtonian gravity, has uncertainties associated with it as a natural consequence of the laws of quantum mechanics. Thus a scalar field that had exceedingly tiny fluctuations in its otherwise uniform value, would, via inflation, lead to fluctuations in the density distribution of matter in the early universe. These could then act as "seeds" for structure formation, aided by gravitational attraction.

Such inhomogeneities, encoded in the CMB as temperature fluctuations, were found by the NASA satellite Cosmic Background Explorer (COBE) in 1992. Against the average temperature of about 2.73 K, the fluctuations, or anisotropies, were found to be miniscule – about one part in 100,000 – just as predicted by inflation. And it turned out to be the most perfect blackbody spectrum ever observed in nature.



CMB data from COBE (red points) matches the spectrum predicted by the Big Bang theory (solid curve) to an extraordinary degree. Courtesy: NASA

Triumphant though they were, theorists had a lot more work to do. "Inflation is a very simple theory and it works rather well. The challenge is that there is no unique model of inflation. There are many, many models of inflation," says Dr. Sriramkumar.

In the standard inflationary picture, the scalar field, cleverly called the inflaton, can be thought of as having a bowl-shaped potential with a minimum, or vacuum, value at the bottom. If the field starts starts from elsewhere, it will "roll" down to the vacuum value. If the sides of the bowl are not very steep, this process takes time during which the potential energy of the inflaton is the dominant energy density in the universe. Once it reaches the bottom, it will oscillate about the minimum and lose energy by decaying into matter and radiation. When the resulting energy density overpowers the inflaton energy density, the standard Big Bang model takes over.

For a class of inflaton models, called slow-roll, the "friction" that arises naturally because of expansion is

more pronounced, making the field roll down slowly. Different potentials of this class – different-shaped bowls – can be tried out to see which one best accounts for the observed CMB anisotropies that originate from quantum fluctuations, or perturbations, of the inflaton. "If the universe is smooth, that means the density is the same everywhere. If there are tiny perturbations, it means there's something which is fluctuating with position," says Dr. Sriramkumar.

These quantum fluctuations which perturb the placid inflaton can be expressed as the sum of a series of progressively diminishing terms. Adding only the first term of this series to the unperturbed term is a good approximation, called first-order, or linear, perturbation.

The energy-carrying inflaton field, perturbed, passes it on to the energy-momentum tensor; which, invoking Einstein's field equations, perturbs the metric tensor. Now, the metric gives as good as it gets. "When there's fluctuation in the metric, it will be automatically transferred to the matter and radiation in the universe," says Sreenath. Thus, they are "coupled" and have to be studied together.

Each term in the perturbation expansion of the metric tensor is itself the sum of three terms, which, in linear perturbation, are independent and can be studied separately. One, a scalar, contributes most to the CMB anisotropies and is responsible for density fluctuations of the matter-energy distribution – and hence structure formation – in the early universe. While this term originates from quantum fluctuations of the inflaton, another term, a tensor, arises from quantum fluctuations of the space-time metric. The tensor perturbations need no matter-energy source at all and propagate as gravitational waves. Inflation predicts that a vector term is zero; observations agree.

Perturbation of the inflaton field simply refers to how far its value at any point differs from the background value. The simplest assumption is that it is entirely random – equally likely to be more or less than the background value. Mathematically, the perturbation at any point is drawn from a Gaussian distribution (which may not hold for higher-order perturbation.) The most likely value, the peak of the Gaussian distribution, is at zero, and other values occur with decreasing probability the farther they are from zero.

Whether the perturbations at two different points are independent can be studied using what's called the two-point correlation function. For this, cosmologists take its Fourier transform, a standard tool in any physicist's arsenal. Any pattern of fluctuations, no matter how complicated, can be represented as a sum of sinusoidal waves of different wavelengths, called Fourier modes, even though an infinite number of them may be required. The contribution of each mode to the sum – its amplitude – will be, in general, different. A plot of the square of the amplitudes of the Fourier modes against their wave numbers (which can be found from their wavelengths), is called a power spectrum, which offers a window on the nature of the system considered. For example, the power spectrum of a pendulum would be a single spike because it oscillates at one frequency.

The power spectrum of the scalar metric perturbations in the slow-roll scenario turns out to be a nearly-straight, horizontal line. This means that the typical size of the perturbations is almost the same on all scales, making it nearly scale-invariant. Had it been perfectly so, a number called the scalar spectral index would have had the value of exactly one. The near-scale-invariance of slow-roll models makes it about 0.96. The latest observed value comes from data collected by the European space observatory Planck.

"It is found to be 0.96," says Sreenath.

But how do you distinguish between the numerous models which predict this value?

The tensor-to-scalar ratio – the ratio of the tensor power spectrum, found from the tensor perturbations of the metric, to the scalar one – is a second observable. But the signatures of tensor perturbations are difficult to detect in the CMB, and many models predict it's too small to detect.

The correlation functions can be of order higher than two, of which all the odd-ordered ones would be zero if the perturbations were Gaussian. In particular, a non-zero value of the Fourier transform of the three-point correlation function, called the bispectrum, would indicate non-Gaussianity of the perturbations. For the scalar perturbations, this is quantified by f_{NL}, the ratio of the three-point and the two-point scalar correlation functions. Although models which lead to large levels of

non-Gaussianity have been ruled out by the latest data from Planck, something more is required to separate the many models within the slow-roll paradigm which predict the observed f_{NL} value of 10^{-2}, or one part in 100.

Instead of being pure scalar or pure tensor, a three-point correlation function of cross-terms – two scalars and a tensor, or one scalar and two tensors – can be constructed. From their corresponding bispectra, one can define two more non-Gaussianity parameters.

"There have been some attempts in studying tensor three-point functions, but not much work in this direction," says Sreenath. As part of his doctoral thesis, Sreenath developed a numerical method to compute these three-point scalar-tensor cross-correlation functions, as well as the tensor three-point correlation function, of the metric perturbations. Given a particular form of the inflaton potential, its non-Gaussianity parameters can be numerically computed using the code written by Sreenath. Two models – one slow-roll, one not – where analytical results were available, were used to verify the numerical results.

The three-point functions, or their bispectra, involve three different wave numbers. If one of them is much smaller than the other two, it's called a "squeezed limit." In such a case, the scalar three-point correlation function can be expressed completely in terms of the scalar two-point correlation function. Known as the consistency relation, it amounts to saying that, in the squeezed limit, f_{NL} can be expressed in terms of the scalar spectral index alone.

Sreenath, working with Dr. Sriramkumar and one of his former students, showed that the consistency relations are valid not just for the scalar three-point correlation function, but also for the cross-correlation and tensor correlation functions, in the slow-roll scenario.

While the consistency relations hold for any model of the inflaton, the question of its validity for non-slow-roll models had remained relatively unaddressed. Sreenath found that, in the squeezed limit, the consistency relation is valid even for non-slow-roll models. Now, there are models of inflation which involve a second scalar field apart from the inflaton. "If we can verify this relation observationally, we can use it to eliminate two-field models, because it's not valid for two-field models," says Sreenath.

As Sreenath prepares for his doctoral thesis defence, cosmologists worldwide await further data from Planck. But there are a few known anomalies in the CMB that may have to wait for future experiments.

The universe has been bathed in this sea of radiation for almost its entire history, to speak nothing of human history. In this age of renewed hatred and increasingly assertive bigotry, it is good to remind ourselves that we're more than that. H. G. Wells, last of the pre-space-age prophets, said as much: "A day will come, one day in the unending succession of days, when beings, beings who are now latent in our thoughts and hidden in our loins, shall stand upon this earth as one stands upon a footstool, and shall laugh and reach out their hands amidst the stars."

Barely a generation later, we have now reached out beyond the stars to almost the beginning of time, seeking answers to questions that were once thought to belong exclusively to the realm of metaphysics and theology. There are few things that bear greater testimony to human ingenuity and the power of the scientific method than the fact that all this began with poetry written in the language of Nature by the hand of its most accomplished master, combined with nothing more than careful observation and analysis of the most ancient light in the universe, just three degrees above zero ■

Equality in Difference

BY LIZA TOM & SHILPA MENON

What is it that brings and holds communities together? What compels human beings to associate with only some of their fellow beings, while excluding some others – even to the point of ignoring their existence? Can we think of new ways of identifying with others that are less exclusive? At its root, Anjana Raghavan's thesis, 'Towards a Corporeal Cosmopolitanism: Articulating the Body in Contemporary Notions of Cosmopolitan Belonging', seeks to address these questions.

In the world we are familiar with, societies are defined by laws, citizenship, rights, codes, conventions and norms. But in communities that are on the margins of our society, we see alternative ways of forging a collective identity through shared experiences: Grief. Trauma. Joy. Sensuality.

Why does society accept groups that are defined by strict, 'given' maxims and marginalise those that are defined by shared emotions and experiences? The answer lies in ways of thinking that date back to the beginnings of Western philosophy. Reason and objectivity on the one hand, and emotion and subjectivity on the other, have conventionally been associated with two irreconcilable realms: the mind and the body. Plato believed that 'true' reality was comprised entirely of ideas, and that material reality was a mere imitation of the Ideal. By positing 'I think, therefore I am', Descartes constructed the entire notion of human existence around the rational mind, capable of logical thinking. The body, according to him, belonged to the mechanical, material world – a wholly different realm. The mind had dominance over the body: the ideal man became one who could quell his base bodily desires using the power of his mind. It is a misconception to associate this construction of polarities with a particular civilization – the 'Western' one – it is, rather, a way of thinking that is pervasive and common to all patriarchal thinking.

Over time, the concepts of mind, strength, reason and masculinity became tied to one another, creating a complex. In contrast, a woman – femininity – came to be defined in terms of her body, deemed emotional, irrational and weak. By the same token, the European colonisers saw colonised peoples as 'inferior' races, irrational and effeminate, with their bodies – their dark, exposed skin, their wanton desires and their 'barbarity' – defining their identities. As 'superior' races which were endowed with rational minds, it was their duty to 'teach' the indigenous people to be civilized and indeed, more human. 'Mind' and 'body' thus became stand-ins for complexes of concepts that reinforced one another.

These biases found place in our written codes and constitutions and took the form of enforceable rules. Legal and cultural institutions like government, family and marriage became the gatekeepers that ensured their perpetuation across the ages, even as traditional understandings of the mind and body were challenged by emerging disciplines like psychoanalysis.The body – with the irrational, the emotional, the personal – remained 'invisible' or 'elided' in all these spheres; it was simply not acknowledged.

We ignored – and continue to ignore – the fact that there are no two watertight categories of 'mind' and 'body'. Where can one draw the line?

This elision – rendering invisible – of a certain set of factors in all mainstream, formal structures is a point regularly emphasised in radical feminist and postcolonial theories.The body, indeed, is the site of many such 'elisions', and both disciplines saw theorizing upon the body as an important means of challenging the systems they aimed to change. Radical feminism is a school of feminism that focuses on patriarchy – a system of power that privileges males as a norm – as a crucial source of female oppression. Unlike liberal feminism, which sought equal rights and opportunities for women within the existing social structures, radical feminists believed that inequality was a trait of the structures themselves, and that true liberation can only come when these structures were changed or overthrown. Postcolonial literature and theory refers to an entire body of work which emerged as a reaction to colonialism. It consists of works by scholars and writers from former (and current) European and American colonies which questioned the truth value of colonial knowledge – the systematic construction of the superiority of the cultural institutions, moral values and and knowledge systems of the West, coupled with a denigration of the East as being inferior, intellectually and morally. As Anjana says, "Subaltern, queer and feminist scholarship, by and large, encourages an acceptance of strangeness; they tell us to engage with the irreducible difference, to critique from inside and outside."

The chasm between these realms of mind and body is such that many may find the notion ridiculous: how can the emotional and deeply personal aspects of one's experience find a place in laws? Aren't laws ideally objective and universal? What we overlook is that such ideals have been constructed and reinforced within society, and are not 'given' to us from 'elsewhere'. That which has been made by us, then, can be questioned, changed. Laws can be made to incorporate 'irrational' or 'bodily' aspects. However, this requires us to dismantle our categories of binaries and prejudices. It requires us to question the

basis of absolute distinction between the 'objective' and 'subjective', and the idea that emotions are somehow harmful to our decision-making processes.

Cosmopolitanism is characterised by its emphasis on inclusivity and dialogue, and corporealism focuses on bringing to the fore important aspects of humanity that we have ignored so far. Historically, both schools have been at loggerheads. Somewhere, they must meet.

Cosmopolitanism refers to a school of thought that traditionally belonged to the world of the mind – the idea that one can, at once, belong to the confines of a particular community and be a citizen of the world – a 'man of the world'. In Greek, 'kosmos' means 'world' and 'polis' means 'city'. Cosmopolitanism, then, celebrates a common humanity. Such a feat would be possible by virtue of the capacity of the human mind to be logical and to make sacrifices for the sake of shared, universal goals; to enter into social contracts. Current notions of liberalism, secularism, democracy and human rights all draw from this broad idea. Although a very broad school of thought with great diversity in itself, Anjana focusses on the more contemporary versions of cosmopolitanism, characterised by equality and dignity, legal regulation, consent, hospitality, inclusive decision-making, etc.

With feminist and postcolonial movements gaining influence, both theoretically – in academia – and politically, people began to raise the question: 'Who can be a citizen of the world?' Although it seemed as if cosmopolitanism is open to all, an examination of the historical conditions in which the ideals of universal citizenship – liberty, equality and fraternity being among them – emerged in Europe revealed that this was not so. Only a propertied, white, oppressive, non-pagan male who subscribed to certain ideals would be 'worthy' of this tag. Colonised, 'savage' peoples and women were tacitly excluded – they were irrational and sensual beings who were simply not 'human' enough. Critical theorists – such as radical feminists and Marxists – soon began to question such biased assumptions behind the very structures of human knowledge as we know them, so as to cause a real change in the way society functions. They aimed at getting mainstream thought – academic and popular – to acknowledge its flaws and making it more inclusive, where the silence surrounding these 'sub-humans' could be questioned. They established that human experience fell between the poles of male–female, civilized–savage, good–evil.

Corporealism is an idea within this framework. It seeks to challenge mainstream ways of looking at the world and constructing knowledge, by bringing in the question of the 'corporeal' – the body – or aspects relating to it. For example, gender is not a given, naturally determined category like biological sex or an abstract ideal of 'manliness' and 'womanliness', but a difference in the ways people use their bodies to 'enact' the idea of being a man or woman in order to conform to social expectations. There is nothing dictating the sort of gender-specific activities and behaviour that a man or a woman engage in but historically and culturally-defined norms. The notion of 'ideal' Man and Woman is thus challenged by theorising on the body – on how so much of how we use and think of our body is determined not by natural drives, but by social norms.

Anjana Raghavan, as a teenager, sought answers in sociology and feminist theory. It helped her to stop thinking destructively about the sexual violence inflicted upon most women and girls of her age. It helped her to understand; to see the bigger picture of structural oppression. She quotes literary theorist Walter Mignolo when asked about what drove her research: "This work is the result of conversations". This outlook carried her through her roles as academician, teacher and counsellor in Queer Women's Cells. But soon, she began to notice that a lot of the experiences that characterised being a woman, a person of alternate sexuality, a victim of sexual violence or a subaltern (less privileged in relation to another) in general simply could not be brought into the classroom where theories of social order – relating to human rights or governance, for example – were being discussed. In contrast, she saw a critical gap between theory creation and the process of healing from sexual violence in some of the spaces that she worked in. There wasn't any space to negotiate this lack of validity of emotion, violence and the experience of violence and suffering; of 'affect'. Why do we need to create such a space in today's world? Grief and mourning are sim-


The Koovagam Festival, where transgender women from all over India ritually become first the rejoicing brides, and then the mourning widows, of the mythological Aravan. Courtesy: Siri Bulusu via Flickr CC-BY-NC 2.0

ilar to violence in terms of affect, but they transcend the violence that causes them. They create different kinds of community bonds and relationships which often help to deal with violence and trauma. Anjana says that "an articulation of any kind of global understanding of ethics or ways of living requires a constant engagement with vulnerability, especially in a world that is so deeply wounded by subjugation, colonialisms and genocides."

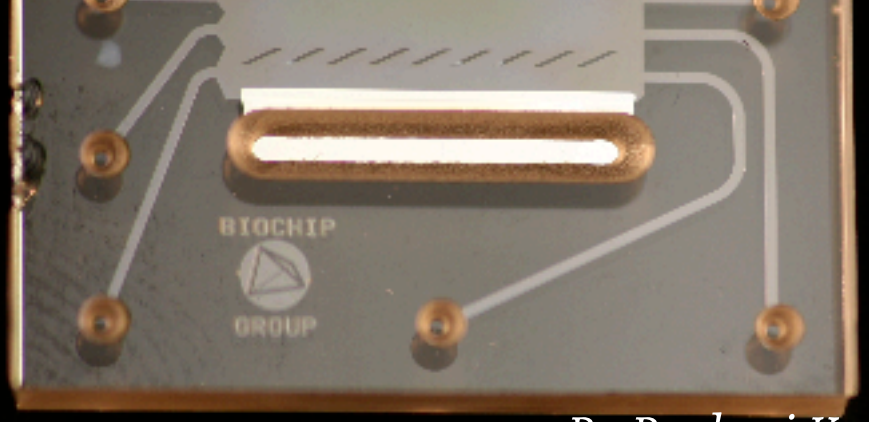
What Anjana attempts is a practical and theoretical dialogue between, on the one hand, this mainstream theory on community-formation, citizenship and belonging, and on the other, subaltern perspectives on the body as an important site of social bonds and experience. Through her work, she wants to address the elision of the body and emotion in theory. Why 'elision'? The word 'exclusion' implies intention, that somehow the body was very deliberately set aside in theory because it was an inferior site of knowledge. There is the element of intentionality that affords recognition even through negation – that is, to say 'X is not true/acceptable' is still to articulate 'X'; to bring it into the realm of discourse. Elision is more insidious. It implies an "exclusion by glossing over". The body is never missed. "You don't even know that it's not there", says Anjana.

There is a need to qualify her own position with respect to her work; her justification for using the two theoretical positions – cosmopolitanism and corporealism – that she does. Anjana says that cosmopolitanism – a shared humanity, a system based on commonalities – is something we still yearn for (hence she says, the constant emphasis on things like 'unity in diversity'). She recognizes that it was a dangerous choice to pick a theory which was so populist and so utopian, and which, moreover, has been widely criticised for its Eurocentric, one-size-fits-all approach. But she felt that inclusion of awareness of race, gender and the body mustn't be limited to just radical theories (theories that seek to overthrow oppressive structures). Anjana speaks of a 'double consciousness' of her subaltern position – because she is an Indian and a woman – and also her privileges, as a member of the English-speaking middle-class. One locates one's identity in several, often conflicting ways. Hence the use of cosmopolitanism, a theory which can accommodate a variety of human experiences, unlike subaltern theories, which tend to exclude those from outside their group, precluding dialogue beyond a point.

Her aim goes beyond a critique of this failure on the part of epistemological frameworks – frameworks of valid knowledge – to incorporate crucial human ways of knowing. It attempts to translate this into practice. As an example, Anjana cites the recent regulation of fairness cream advertisements by the Advertising Standards Council of India (ASCI). It is a beginning; the positive result of the public questioning its

own hidden biases. Constitutionalism – a product of cosmopolitan thinking – can provide a safe, regulated space where marginalised communities can verbalise oppression and demand structural change. Although change has to come from many other quarters, given the structure of legal democracy that many of us inhabit, constitutional activism becomes a major pivot-point. The experiences of the Aravanis and other transgender communities at the Koovagam Festival, the women of the Indo-Caribbean diaspora who connect to a shared heritage through 'cooking groups', and other marginalised peoples can be articulated in the same framework as law and policy.The aim of such a corporeal cosmopolitanism, then, will be "to further explore and indeed, fight for, a critical feminist dialogue within cosmopolitanism" to create "a light that is also made of the darkness, a grand cosmopolitanism that is made out of littleness and a conversation that will always be open to silences."

SEPARATE. SORT. REPEAT.



By Raghavi Kodati

Sitting in front of the humungous two storey turbomachinery workshop in the Fluid Mechanics laboratory of the Applied Mechanics department, is a relatively tiny and ultra-clean Microfluidics lab that works with objects that are a millionth of the size of those turbomachines. Headed by Prof. Ashis Kumar Sen of the Mechanical Engineering department, it houses interdisciplinary graduate and undergraduate students working to understand the principles of fluid flow in microchannels – channels only as thick as a hair strand – and to develop commercial technologies that exploit these principles.

At such small dimensions, the flow is predictably smooth and displays interesting phenomena that may not be observed at larger scales . One such device under development at this lab is a portable diagnostic microfluidic chip that'll help detect cancer from a sample of blood. With an estimated 7 lakh deaths last year, cancer ranks high on the list of diseases prevalent in India. If the device is successful, it could go a long way towards improving early diagnosis of the disease, helping prevent deaths.

Containing a network of microchannels, the size of such a device would be a few inches and it would be small and cheap enough for point of care application – that is, diagnosis at the patient's location doing away with bulky hospital equipment and reducing the waiting time. Commercial point of care devices that measure insulin content already exist for diabetic patients and a flurry of research is on to develop microfluidic devices that can do the same for other illnesses, this project being one of them.

Sajeesh Parayil is a third year Ph.D student with Prof. Ashis and takes time out to explain what they are trying to accomplish in their work. Building microchannels is often the toughest and most laborious part, says Sajeesh. Using photolithography, the required design of microchannels is patterned onto a silicon wafer by a machine called mask aligner, available at the micro-electromechanical systems (MEMS) lab in the Electrical Engineering department. Later, this blueprint is used to mould the microchannels with polymeric material and they are then adhered to a glass base to make a chip. This process has to be standardized for various sizes and it is this trial and error process that is often challenging.

The identification of circulating tumour cells (CTCs) in blood is a possible means of detecting cancer. CTCs are cancerous cells shed into the bloodstream from existing tumours. These travel through the bloodstream and cause metastasis; that is, they spread cancer to distant parts of the body. These cells are also larger and more deformable than a normal healthy cell. This fact that cancerous cells have increased deformability is exploited in developing this microfluidic device that separates CTCs from other cells in the blood.

Cancerous cells are highly deformable. This fact can be exploited to identify them when blood flows in microchannels

A micropump accomplishes the initial task of infusing blood into the chip. Kumar, who is working on the design of the micropump, explains how varied the approaches can be. Underlying all of them, however, is the same concept: a pump drives a fluid from an area of low pressure to one of high pressure. By controlling the pressure across the two ends of the pump, one can control the amount and direction of flow. A multitude of sensors can be used to detect and control pressures, contributing to the variety in design.

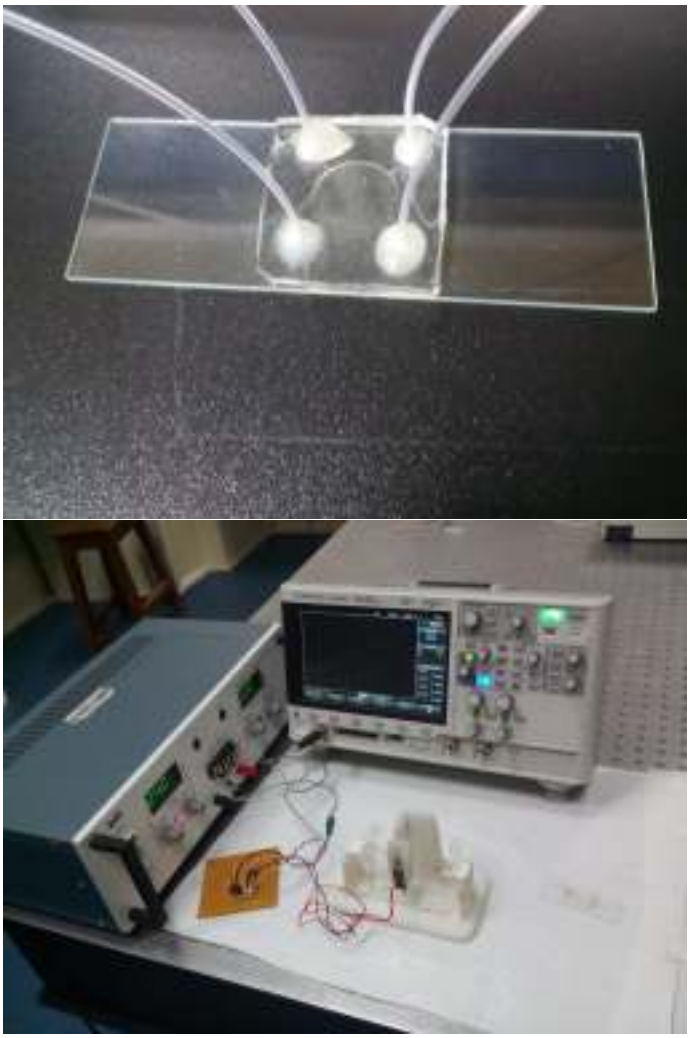
ME

After the blood is taken in through the micropump, it is diluted to very low concentrations in a solvent called PBS, and passed through a separator to collect cells from the blood plasma. This separator is a rather simple T-shape or Y-shape junction that works based on a phenomenon called the Zweifach Fung effect.

Sneha Maria, another Ph.D scholar in the lab, helps me visualize this law. "Imagine a ball suspended in water travelling down a pipe to a junction where it branches into two channels with different flow rates. Which path would it choose? Intuitive as it may seem, it enters the channel with higher flow rate. Somehow, the ball seems to know it's path before it even arrives at the junction." This same observation was initially made by Zweifach and Fung in blood flow in capillaries. When blood flowing through a capillary encounters a bifurcation, it was noticed that the blood cells almost always preferred one branch over the other, while the plasma flowed in both the channels.

Sneha continues to explain this phenomenon, "Difference in flow rates in the two branches at the bifurcation point plays a crucial role. Higher flow rate in a channel implies lesser pressure and lesser resistance to flow. This lower resistance to flow drives the ball to enter the channel with higher flow rate."

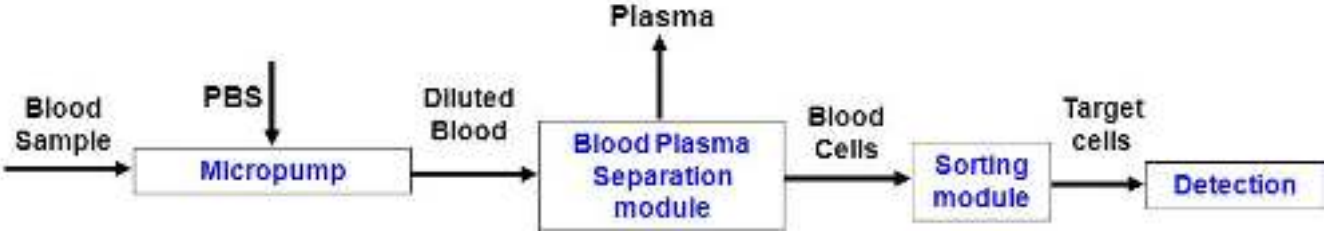
Sneha is working on applying this phenomenon to design a separation module in the microfluidic device, that can separate blood cells from it's substrate liquid. When blood flows through this module, fitted with multiple Y or T junctions, the plasma separates from the cells, giving a concentrated cell stream. While the separated cells proceed further, the separated plasma can be collected and used for other diagnostic purposes, such as a glucose test.



Experimenting with microfluidic chips, Courtesy: N.Kumar

Next is the sorting step, where the CTC's are classified from the normal cells. Students in Prof. Ashis' lab are working on devising different sorting techniques. One of the main ideas, however, is to exploit the increased deformability of CTCs.

When a microchannel is fitted with side branches of different sizes, cells enter different channels falling in the path of their streamlines. The streamlines, which are imaginary lines indicating direction of flow, get aligned



Layout of the proposed Lab-on-chip device

to different side branches based on the size and shape of the cell. This principle is called hydrodynamic filtration in scientific parlance.

When deformability of a cell is higher, its shape and size strongly change with flow conditions. For the device, this means that cancerous cells can be 'filtered' from the normal cells under controlled flow conditions using hydrodynamic filtration. The sorted cancerous cell can later be detected by any biological or chemical sensor.

Among the other sorting techniques being developed in this lab, there is one based on dielectrophoresis - a phenomena seen in the presence of electric field and one based on filtration through porous membranes - still based on difference in size and stiffness of cancer cells. There's additional work on characterizing blood cell flow through flexible microchannels. This would help us understand the actual flow conditions through blood capillaries.

Although the device appears simple conceptually, it's no secret that, in scientific research, the devil lies in the experimental details. Experiments are often hard, expensive and time consuming. Manufacturing microchannels and dealing with the variety of biological cells are just two of the challenges involved in this project. The team is currently using cancer cells and yeast cells available from the Biotechnology department to refine the design, which would enable them to move on to advanced experimentation. Once the first hurdle of a working prototype is crossed, the team envisions putting everything – materials, manufacturing and design – together in a cost-efficient, scalable manner, and build a portable cancer detection device that can be used in health resource-poor settings in India and elsewhere.

Notwithstanding the above challenges, optimism is high among this group of researchers. Recently, a research team at Columbia University manufactured a microfluidic chip that was used to detect HIV, based on a series of chemical reactions taking place in those channels. When deployed in Rwanda, the device showed nearly 100 percent detection rate with only 4-5 percent false positives, comparable to the standard lab- and microscopy-based procedure. The results are heartening and are sparking activity in developing microfluidic devices everywhere, including this project at IIT Madras ■

Chess, checkers and backgammon are all games in common parlance. For mathematicians, however, the definition of a game is not quite so limited. For example, they would define two male deer fighting over a female as a game too. On closer inspection of these games between male animals, it is observed that whatever strategy each of the males use, they are fighting to convey their point and not necessarily to injure the other. In military terms, this is known as a limited war, in which the belligerents participating in the war do not expend all of the available resources at their disposal.

The questions now immediately arise: Do such limited-war strategies evolve only to ensure the species' survival, or do the squabbling individuals find this to be the best strategy for themselves as well? What happens if some individuals have another, better idea for conflict resolution? Will the ones who hold on to the old strategy jump ship if they come across many better strategies?

It was about ten years ago that Professor A.J. Shaiju of the Mathematics Department, then a postdoctoral researcher in France, first read about this problem. Many years passed, but the problem stayed with him and he returned to it after joining IIT Madras in 2009. He published a paper entitled *Evolutionary Stability Against Multiple Mutations*, detailing his work on the problem in 2012; his first paper in this field known as evolutionary game theory (EGT).

Game theory is the mathematical study of decision-making games or situations which involve rational agents. The book *Theory of Games and Economic Behaviour*, published in 1944 by the mathematician John von Neumann and the economist Oskar Morgenstern, is regarded as the foundational book on game theory. Perhaps the best known game theorist is John Nash, upon whom the book and the movie, *A Beautiful Mind* were based. He made seminal contributions to game theory with his work on non-cooperative games (where participants make decisions independently) and introduced the idea of what is now known as the "Nash equilibrium". The application of game theory to evolutionary biology was pioneered by John Maynard Smith, an aeronautical engineer who switched to the study of genetics early in his career, and G. R. Price. Their 1973 *Nature* paper, *The Logic of Animal Conflict*, led to the birth of EGT.

The paper examines the nature of conflict between two individuals of the same species, typically between two males over mates, territory and other resources. One observation which received a lot of attention at the time was the limited war phenomenon seen in these conflicts – the conflicts involved "inefficient weapons or ritualized tactics," as Smith and Price described it, rather than "battles to the death." One of the explanations for this observation that was accepted in those days was that in the absence of such toned-down, conventional methods, many individuals would be injured, threatening the survival of the species.

Smith and Price weren't satisfied with this explanation: it assumed the operation of group selection, where natural selection acts at the level of the group instead of at the more conventional level of the individual, which they saw as applicable only in special circumstances. They also felt that group selection by itself was not sufficient to account for the complex behavioural and anatomical adaptations seen in many species. For a phenomenon this common, they felt that following the limited war tactics had to result in gains at an individual level. In other words, it had to be sensible for any individual to adopt the limited war strategy considering only its own interests, without paying heed to the greater good of the species.

Thinking of these tactics in terms of a conflict between two individuals, or pairwise games, they sought to extend ideas from game theory. The question they sought to answer was: which strategy – limited war or all-out/total war – would be favoured under individual selection? The strategy would have to be stable under natural selection, or evolutionarily stable. Here, a stable strategy is one which an individual will adopt, or retain if already adopted, because it gives the individual a better payoff, on average, against all its opponents.

Strategies may be pure, where the individual employs the same strategy, for example, limited war, in every conflict/game; or mixed, in which case the individual employs different strategies for different conflicts, choosing a particular strategy with some probability. For example, choosing a limited war strategy for half the conflicts and an all-out war strategy for the other half is a mixed strategy, which is thus nothing but a combination of more than one pure strategy. Mathematically, if p stands for the limited war strategy and q for the all-out war strategy, then the above example of a mixed strategy could be represented as $0.5\,p + 0.5\,q$. A payoff matrix is always defined in terms of two individuals playing pure strategies against each other, with

the rows representing one player and the columns the opponent. For instance, in a game with two strategies p and q, the payoff matrix could be as follows:

	p	q
p	-1	2
q	3	0

The Payoff (x, y), of playing one mixed strategy (x) against another (y) can be easily obtained as

$$\text{Payoff}(ap + bq, cp + dq) = ac\,\text{Payoff}(p,p) + ad\,\text{Payoff}(p,q) + bc\,\text{Payoff}(q,p) + bd\,\text{Payoff}(q,q).$$

Payoffs are generally calculated by averaging over a large number of contests and over all the other members of the population.

What is a stable strategy?

For a strategy p to be stable, it must be robust to mutant strategies appearing in small proportions. In other words,

$$\text{Payoff}(p, \epsilon \cdot r + (1-\epsilon)\,p) > \text{Payoff}(r, \epsilon \cdot r + (1-\epsilon)\,p).$$

Here, ϵ corresponds to the proportion of the population which suddenly employs the mutant strategy r. Thus, on an average, every other individual is employing the mixed strategy $(\epsilon \cdot r + (1-\epsilon) \cdot p)$, since a fraction ϵ of the population is using the mutant strategy r and a fraction $(1-\epsilon)$ is still using the old strategy p. If the above condition does not hold, it would be more beneficial to use the mutant strategy r rather than the original strategy p, in which case the equilibrium state (in which everyone was using p) would not be stable as individuals would start switching to the more beneficial strategy.

Box 1. Stable Strategies

Smith and Price defined an evolutionarily stable strategy (ESS) as "a strategy that, if most of the members of the population adopt it, there is no mutant strategy that gives higher reproductive fitness." The concept of an ESS would go on to become one of the most important concepts in evolutionary game theory.

To understand evolutionary stability, consider a strategy p, which can be pure or mixed. If p is stable, then, in an equilibrium, all individuals would have adopted this strategy. Now, suppose a new pure strategy, called a mutant strategy r, is introduced in the population and a small number of individuals adopt it, disturbing the equilibrium. If the payoff for an individual adopting this new pure strategy – or some mixed strategy which can be created in combination with this pure strategy – when pitted against another individual using strategy p, is higher than the payoff in the case where it too adopts the strategy p, then individuals using the strategy p will start switching to other strategies to increase their payoff. Hence, the population will no longer remain in the state where p was the prevalent strategy. In such a situation, due to the introduction of the mutant strategy, p does not remain a stable strategy.

One must note here that as far as evolutionary stable strategies are concerned, we are looking at the average behaviour of individuals in a population. Hence, one does not differentiate between the case where half the individuals of a population adopt strategy S_1 and half of them adopt S_2 from the case where all of them adopt a mixed strategy with S_1 and S_2 in equal proportions. A population state at an instant of time is a set of numbers, which are the fractions of the population associated with each pure strategy. Since we are looking only at average behaviour, a population state defines a strategy.

To demonstrate that individual selection is a possible explanation for the limited war behaviour, they used the following game theoretic model, and ran computer simulations based on it . A pairwise game was modelled as a sequence where each contestant could make one of three moves – C (conventional tactics) which are unlikely to cause serious injury, D (dangerous tactics) which are likely to cause the opponent serious damage if employed, or R (retreat). If a contestant makes the move D, then the opponent may get seriously injured, with some fixed probability. A seriously injured opponent has to retreat. So, a game ends either when one of the contestants voluntarily retreats, or when one is injured after a successful dangerous tactic by the opponent. At the end of a game, there was a payoff to both the contestants, based on whether they won or lost, and the injuries they sustained. Box 2 gives an example of a game that uses this model.

Based on 2000 such random contests, Smith and Price estimated the payoff matrix by averaging over the payoffs in each of these contests. They showed that the

As an example, consider that each individual is programmed with one of five strategies: Hawk, where the individual always attempts to play the move D and is thus a total war strategy, and four other limited war strategies, named Mouse, Bully, Retaliator and Prober-Retaliator.

1. Mouse: Never plays move D. Retreats at once from the game, if the opponent chooses D. Otherwise, it plays C till a certain preassigned number of moves are completed.
2. Bully: Plays D if making the first move. Plays C in response to D and D in response to C. Retreats if opponent plays D a second time.
3. Retaliator: Plays D if making the first move. Plays C in response to C, and retreats by playing R after a certain number of moves. If the opponent plays D, retaliates by playing D.
4. Prober-Retaliator: When making the first move, or the move after an opponent has played C, a Prober-Retaliator plays C with high probability and D with low probability. Reverts to playing C if opponent retaliates, but continues playing D if the opponent continues to play C.

Box 2. Game theory model to simulate limited war behaviour

Hawk strategy was not an ESS, since the payoff for using the Retaliator and Prober-Retaliator strategies against Hawk was greater than that of using Hawk itself. This proved that individual selection, which refers here to the fact that each individual plays every contest with the same strategy, could explain the predominance of the limited war strategy.

The realm of application of this result was limited, however, by the fact that it only considered a single mutation in a population. It is conceivable that a population may be subject to various mutations and it is here that Prof. Shaiju steps into the picture. He first came across the problem of the stability of an ESS when multiple mutant strategies emerge in a population in a book by the mathematician Waloddi Weibull on evolutionary game theory. A remark in the book claimed that "an ESS may not be stable against multiple mutations," and proved it with an example (See Box 3). His postdoctoral advisor, however, merely said this was an interesting problem and left it at that. Prof. Shaiju then moved on to another postdoctorate, for a further three years, in a different area.

It was only after he joined IIT Madras as an assistant professor in 2009 that he began working on this problem, in collaboration with Prof. Mallikarjuna Rao of the Department of Industrial Engineering and Operations Research, IIT Bombay and Dr. Rao's Ph.D student A. S. Ghatak.

"One example in real life that we have had in mind for this problem is as follows," says Prof. Shaiju. "Consider a virus attacking a population in a particular region. Suppose another virus attacks before the effect of the first virus has died down. Now, the stability of the population in this situation can only be looked at by considering its stability against multiple mutations.we worked on this problem for about two years. The first paper was published in 2012. It took us time to get to the results we obtained."

Generalizing the notion of stability against a single mutation to stability against multiple mutations, Prof. Shaiju arrived at an important result, a theorem which proves that an ESS stable against multiple mutations is necessarily a "pure" strategy. To understand what pure and mixed strategies mean in this case, consider the payoff matrix again. It defines the payoff by playing one pure strategy (such as "Hawk" or "Mouse") against another. Individuals can also adopt strategies which are a weighted combination of these two strategies, the mixed strategies defined earlier. In general, a mixed strategy could possibly be an ESS against a single mutation. However, the theorem Prof. Shaiju came up with proves that a mixed strategy cannot be an ESS against multiple mutations.

Consider a game with two pure strategies, having the payoff matrix

	u	v
u	-1	0
v	0	-1

The strategy $p = (0.5, 0.5)$, which is a mixed strategy of half u and half v, is an ESS for the above game, according to the traditional definition. In other words, it is stable to the introduction of a single mutant strategy in small proportions.

Now, consider the case where we have two mutant strategies, $r_1 = (0.25, 0.75)$ and $r_2 = (0.75, 0.25)$ introduced in the proportions $\epsilon_1 = 0.25$ and $\epsilon_2 = 0.25$. With a bit of calculation we can see that the payoffs of p and r_1 against the average strategy of the population would be:

$P(p, 0.5\,p + 0.25\,r_1 + 0.25\,r_2) = 0.5\,P(p,p) + 0.25\,P(p,r_1) + 0.25\,P(p,r_2)$
$P(r_1, 0.5\,p + 0.25\,r_1 + 0.25\,r_2) = 0.5\,P(r_1,p) + 0.25\,P(r_1,r_1) + 0.25\,P(r_1,r_2)$

Now,
$P(p,p) = P(0.5\,u + 0.5\,v, 0.5\,u + 0.5\,v) = 0.25(-1) + 0.25(-1) = -0.5$
$P(p,r1) = P(0.5\,u + 0.5\,v, 0.25\,u + 0.75\,v) = -1(0.5 \times 0.25 + 0.5 \times 0.75) = -0.5$
$P(p,r2) = P(0.5\,u + 0.5\,v, 0.75\,u + 0.25\,v) = -1(0.5 \times 0.75 + 0.5 \times 0.25) = -0.5$
$P(r1,p) = P(0.25\,u + 0.75\,v, 0.5\,u + 0.5\,v) = -1(0.25 \times 0.5 + 0.75 \times 0.5) = -0.5$
$P(r1,r1) = P(0.25\,u + 0.75\,v, 0.25\,u + 0.75\,v) = -1(0.25 \times 0.25 + 0.75 \times 0.75) = -0.625$
$P(r1,r2) = P(0.25\,u + 0.75\,v, 0.75\,u + 0.25\,v) = -1(0.25 \times 0.75 + 0.75 \times 0.25) = -0.375$

We can see that the payoffs for both p and r_1, against the average strategy of the population, are equal. In fact, they are equal for any value of $\epsilon_1 = \epsilon_2 < 0.5$. This means that playing r_1 is as favourable as playing p, and the population will shift away from the equilibrium state where everyone was playing p, with some individuals shifting to r_1. In this case, we can see that p, though an ESS, is not robust to multiple mutations when they appear in equal small proportions.

Box 3. Illustrating the instability of an Evolutionary Stable Strategy against multiple mutations

"Initially, we did not know that an ESS with multiple mutations would have to be pure. Then, as we were working we were trying to get an example of a mixed strategy which would be an ESS robust against multiple mutations. But when we did not find one, we began to wonder if it may not be possible to have such a strategy, and whether we could prove this."

Games, such as the classic Hawk-Dove one, do not have any ESS which is pure. The above theorem means that such games do not have any strategy which is stable to multiple mutations. This result could have implications in evolutionary biology, though Prof. Shaiju and his co-authors leave this as an open question in the paper's conclusion.

Another important result the paper proved was that a strategy is evolutionarily stable against two mutations if and only if it is stable against more than two mutations. This result is quite significant since it reduces the problem of proving an ESS to be stable against multiple mutations to one of proving that it is stable against two mutations. "For this result, we got many good opinions and appreciation, because although the problem was there in people's minds, no one had really attacked that problem mathematically before", Prof. Shaiju tells us.

A second paper, a continuation of the same line of work, was published in the journal International Game Theory Review (IGTR) in 2013. The paper proves the powerful result that if in a game with exactly two pure strategies, a pure strategy is an ESS, then that pure strategy is also an ESS which is stable to multiple mutations.

After the publication of these two papers, Prof. Shaiju has continued to work in the domain of evolutionary game theory, with his current Ph.D. student, Dharini. The problem they are working on is slightly different from the earlier one in that it allows for a continuum of strategies rather than a finite set. The population state in this sense becomes a measure (like a function, similar to probability density function), rather than a probability vector of finite dimension. The problem that they try to investigate is whether there can exist a population state to which the population converges in such a case. Although it has been studied since $1989-90$, prior work on this problem has been limited, not due to lack of interest, but due to its technical difficulty.

An important goal of their current research is to relate the notions of being evolutionarily stable and being dynamically stable. A population state is dynamically stable if it does not change with time. In other words, even a small perturbation in the population state, which changes it to some point in its neighborhood, will converge (return back) to the original population state. Though all evolutionarily stable states are dynamically stable, the converse is not guaranteed to hold except in some special cases. The relation between these two concepts is not very well understood in the case where we have a continuum of strategies. Understanding this better is a focus of Prof. Shaiju's current research.

When asked about his motivation to pursue mathematics as his field of study, Dr. Shaiju remarks, "There is actually nothing in particular that motivated me. Since my childhood, it came naturally to me. If a teacher would ask me to solve a problem on the board, I could comfortably do so. Additionally, I had good teachers in my Master's, [and then as] Ph.D [and] postdoc supervisors. They were kind enough to help out and were quite nice people. They were enthusiastic about their own way of doing things, maybe different from the way I do things. For instance, one person worked in Control Theory, one in Game Theory and some others in other areas. All of them , however, were enthusiastic about their own work. So,we also felt enthusiastic about our own work. We did not try to imitate them. But their motivation helped me along . But as far as my motivation is concerned, I don't think I have constructed it. It was there, and I got the required support from my teachers and guides."

The **HAWK-DOVE** game is a classic example often studied in game theory, with a good natural analogy for the strategies used. An agent which adopts the "Hawk" strategy always attacks, whereas an agent which adopts the "Dove" strategy always tries to flee. This is in fact just a simplified version of the more complicated game used by Smith and Price in their paper. Note that the terms "Hawk" and "Dove" have nothing to do with the birds per se. Let V be the reward for winning, while C is the cost of fighting. Now, when two hawks meet, they will always fight and win or lose with equal probability $1/2$. Hence, the average payoff for a hawk playing against another hawk is $(V-C)/2$. A hawk playing against a dove always wins, hence the payoff is V. A dove playing against a hawk does not win anything, hence the payoff is 0. A dove playing against a dove may win or lose the reward with equal probability, hence the payoff is $V/2$.

	Hawk	*Dove*
Hawk	$(V-C)/2$	V
Dove	0	$V/2$

If $V > C$, it means that it is always preferable to fight and win the reward. In this case, the "Hawk" strategy ends up being a pure ESS, since

Payoff (Hawk, Hawk) > Payoff (Dove, Hawk); and Payoff (Hawk, Dove) > Payoff (Dove, Dove)

However, in the case where $V < C$, the ESS is not a pure strategy, since it is preferable to play like a hawk in some turn and play like a dove in other turns (rather than using the same strategy every turn). So, in this case the ESS is the mixed strategy where a V/C fraction of the population utilizes the hawk strategy and the remaining population uses the dove strategy.

Tapping into WAVE ENERGY

By Gautham Krishnan

That the world needs to transition to renewable sources of energy is clear. Of these, solar and wind power are the leading contenders, receiving most of the investment in the renewable energy sector. Much less talked about, is ocean energy. Prof. Sannasiraj and Prof. Sundar of the Department of Ocean Engineering, IIT Madras along with research scholar John Ashlin are making efforts to rectify that. Of the alternative sources of energy, only hydroelectric and nuclear power, apart from solar and wind, have matured enough to become commercialized. Many other sources of energy, such as biomass, ocean and geothermal, are still in their formative stages.

Ocean energy refers to a wide variety of energy sources which involve the ocean. As technology has advanced, harnessing energy from tidal variation, marine currents, salinity gradient, offshore wind, ocean thermal energy and wave energy, has become viable. Of these, wave energy stands out as a promising resource for clean energy production for a simple reason – it's available almost everywhere.

What makes wave energy different from the others? Just below the ocean surface, the spatial concentration of wave power is about five times larger than the corresponding wind power 20 metres above the sea surface, and 20 to 30 times that of solar power. This means that nations with considerably long coastlines, such as India, can favourably exploit this resource.The bountiful kinetic energy that the ocean waves carry can be successfully converted to electricity via turbines.Depending on their principles of working and their offshore location, a number of devices – such as attenuators, oscillating water columns, overtopping wave energy converters, and floating point type absorbers – have been, and are being, developed to extract energy from the waves.

Based on how they work, wave energy devices fall into two main groups: active devices, where the interface element moves in the direction of the wave action and produces mechanical work; and passive devices, where the device remains stationary and the water movement relative to the structure is what does the work. For example, the attenuator, an active device, is a long, semi-submerged floating structure aligned parallel to the wave direction and anchored to the seafloor. Existing forms of this technology are composed of multiple sections that rotate relative to one another in a pitch-and-heave motion. The differing heights of the waves create an up-and-down motion of the section, which flexes the hinges, and this is turned into electricity via hydraulic pumps.

On the other hand, the oscillating wave surge converter, a passive device, consists of a paddle arm pivoted on a fixed submerged structure which oscillates with the waves. A hydraulic pump is then used to convert this motion to electrical energy.The research group here at IIT Madras focuses on oscillating water columns (OWC), which can be considered the closest to maturity among passive devices.

An OWC consists of a land-backed chamber in which the front wall has an opening to let waves pass into it whilst the rear wall extends down to the seabed. The wave action makes the water level in the chamber oscillate, and this causes the air in the chamber to flow in and out through a turbine, resulting in the generation of electrical energy. Since the OWC is a fixed, passive device close to the shore, its setting up and maintenance is relatively simple, compared to other moving or submerged wave energy converters. By contrast, if an attenuator was found to be damaged, it would have to be hauled from wherever it was deployed in the ocean to the nearest shore and then serviced.

Another advantage of OWCs is that they can be mounted on existing shore structures like breakwaters, which are those structures constructed on coasts to reduce the intensity of wave action in inshore waters and thereby reduce coastal erosion or provide safe harbourage. One of the aims of the present project is to incorporate the OWCs into such breakwaters so as to save money and resources. "Instead of seawall and groynes, we should deploy oscillating water column devices parallel to the coastline as it will act as a sea wall and a power generator," said Prof. Raj.

This team is also researching how the efficiency of power generated, that is, the fraction of the total power received from the waves which is converted to electricity, depends on various factors involved. Important among the methods to enhance the efficiency of the OWC are increasing the turbine efficiency and finding out the best physical structure that can obtain maximum response from the waves. In other words, figuring out the best hydrodynamic model.

For studying the effect of physical structure, an oscillating column chamber with four different bottom profiles - flat, linear slope and circular arc profiles were considered and tested in the Ocean Engineering department's wave basin. A wave basin is a laboratory setup used to study the behaviour of surface waves, useful for testing models of ships, offshore structures, and breakwaters. It has an actuator (wave generator) at one end and a wave absorbing surface at the other.

The models were installed in the wave basin and were tested for energy conversion efficiency, height of water level oscillation and pressure inside the chamber. The chamber with circular arc bottom profile was found out to be favourable with respect to the latter two aspects. Because it has a smooth entrance in form of an arc, the incoming water loses less energy at this chamber entrance, leaving more energy for conversion inside the chamber. This demonstrates an advantage of providing a circular arc profile at the flow entrance of the chamber. However, this is yet to be tallied with results obtained from mathematical models of the OWC breakwater system, which are theoretical models wherein the factors and variations obtained from the above experiments will be predicted, verified and analysed mathematically.

But technical difficulties apart, there are immense commercial challenges in setting up an OWC. The capital costs are very high leading to power costs as high as Rs. 100 per unit of electricity generated. Prof. Raj, however, sounds positive about it. Despite the high capital cost, the lifetime levelized cost of ocean energy turns out to be comparable to that of offshore wind energy. Once the technology is made scalable and large projects are commissioned, the cost could even be brought down to 20 percent of its current value. A four kilometre stretch of the north Chennai coast can generate nearly 20 MW of wave energy through OWC devices and this can be extended to both the Indian eastern seaboard as well as the West coast.

Further experiments are underway aiming to further increase the OWC efficiency. Prof. Raj has presented these new developments at the 11th International Conference on Hydro-science & Engineering in Hamburg, Germany. This research has also been recognized and funded by the Norwegian Research Council.

If India and other developing countries are to travel along the road towards sustainable development, reliable and cheap sources of power are the first necessity. With their efforts to make the ocean a more accessible source of energy, this research group at IIT-M is helping us get closer to that goal ■

TI(Y)RELESS

By Bhargavi Suryanarayanan

In 2013, road accidents claimed the lives of 1,37,423 people in India, according to the National Crime Records Bureau. For every thousand vehicles, there were 443 accidents injuring 470 people.

The time between six and eleven p.m. accounted for 16.8% of accidents and that between midnight and three a.m. was only slightly less dangerous. Although how many of these accidents were caused by sleep deprivation or fatigue is not known, these factors are believed to be a major cause, especially at night. Studies reveal that drivers experience micro-sleep – periods of low awareness and fatigue – while driving, which could be the cause of several accidents.

Studies reveal that drivers experience periods of low awareness and fatigue while driving, which could be the cause of several accidents

The Rehabilitation Bioengineering Group in the Department of Engineering Design, IIT Madras, is working on developing devices to detect fatigue in drivers and alert them. The question of how to detect this tiredness while a person is driving is vexing. Attaching wires to the driver's body is obviously impractical. Vehicle parameters such as the rotation of the steering wheel or the speed of the vehicle may conceivably be used to detect fatigue. Video imaging can also track eye movements, blink rates, and facial expressions, and these could be used to infer fatigue.

However, the problem with these methods is that they are sensitive to external factors, like the ambient light, the vibration of the car, and so on. Besides, these methods only detect fatigue after it has occurred; they cannot predict when it will occur. What is needed is a reliable and accurate way to detect fatigue without disturbing the driver or being intrusive; one that can anticipate the onset of fatigue.

To isolate the physiological and psychological causes of fatigue, driving simulators can be used. Prof. Venkatesh Balasubramanian and the team of staff and students at Rehabilitation Bioengineering Group have worked on developing a system that uses multimodal signals to identify driver fatigue. Some of the signals used are an electroencephalogram (EEG) to measure brain activity and surface electromyography (EMG) to measure muscle activity, gripping forces, etc. These systems and various algorithms developed have been tested extensively on different driving simulators. Using this methodology, they were able to pinpoint which muscles were most affected by fatigue while driving and also how factors such as posture and seat pressure had a role to play.

One of these experiments using EMG compared the performance of professional race-car drivers and computer gamers while driving. They found that the latter group, who sit for hours in front of a screen playing simulated driving games, are more prone to lower back pain than professional race-car drivers. The professional racers keep fit and exercise regularly, reducing the probability of serious muscle fatigue or pain. It was found that just fifteen minutes of driving can indicate early changes that can help predict driver fatigue and other physiological discomforts such as pain. The main muscles focused on this particular study were medial deltoid (shoulder muscle), splenius capitis (a muscle at the back of the neck), and the trapezius type II fibers (major muscle at the back of the body).

Another study, also conducted at IIT-M, found a significant increase in alpha and theta waves in participants during simulated driving, along with a significant decrease in beta waves. Alpha waves predominate in the brain when we perform activities that don't require much thinking. Beta waves are just the opposite - predominating when we think. Theta waves increase in frequency during light sleep; they're there when you're half-awake and just drifting off to sleep. It was observed that alpha waves increased and beta wave decreased after one hour of simulated driving.

Using the results of all these studies, researchers at RBG are developing a device that uses sensors embedded in the car seat to pick up symptoms of fatigue and

A glimpse of the simulated driving experiment on computer gamers, Courtesy: Prof.Venkatesh Balasubramanian

alert the driver through alerting systems installed on the vehicle. The sensors eliminate the need for wires or any other invasive measurement of muscle activity, used here as a proxy for brainwaves. These sensors have been developed by the researchers working on the project in IIT Madras, and nothing like it has been done till now, says Rahul Bharadwaj, a Ph.D. student working on this project. A patent for this technology has been filed and is pending. This technology has extensive commercial application and can help avoid many accidents.

Driver fatigue and behaviour has also been estimated using seat pressure sensors. This study also showed that driving for an hour results in pressure being exerted on the muscles of the thighs and buttocks. This results in oxygen deficiency in these muscles, leading to discomfort and fatigue.

In related studies, muscle fatigue in people riding motorcycles have also been studied at RBG. Bikers have much higher rates of fatigue, and are involved in the highest number of accidents in India, compared to those who use other forms of transport. Therefore, developing mechanisms for detecting and combating fatigue in motorcyclists is crucial to help prevent accidents, and Prof. Balasubramanian undertook a study to determine the factors involved.

The research focused on "seat discomfort"; that is, the long-term effect on the human body of sitting on a motorcycle seat. The researchers examined muscle activity, seat interface pressure, heart rate and blood pressure to determine the causes of fatigue. They found that some muscle groups like the erector spinae (at the back) and latissimus dorsi medial (the muscle group that helps rotate the arms) showed increased fatigue. The study also found that the peak impact and pressure during riding was on the ischium region (the bone at the

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lower-rear part of the pelvis).

This study found that to minimize injury, the rider should distribute weight evenly and apply less pressure on the thigh area. The motorcycle rider starts out riding with an erect posture, then leans forward, thereby shifting pressure from the spine to the thighs. Also, while riding, the static seated posture causes obstruction of blood supply and hence oxygen deficiency. Ideally, the entire butt should have equal pressure to minimize fatigue, and the motorcyclist should ride with an erect posture. The study also recommends that motorcycles be designed to the needs of each individual to reduce discomfort. While that may not be feasible, motorcycle companies need to take into account the findings of studies like this to modify their designs and make them more comfortable for riders.

The team also conducted studies to assess the impact of cycling on the body. These found that the forward bend that cyclists adopt while cycling might contribute to lower back pain. Those who already have this problem tend to be more prone to fatigue and pain due to cycling – whether it's aerobic or on the road.

Aerobic bicycles have hard seats that cause greater fatigue in the lower back. Also, the position of their handlebars means that users need to stretch out their arms more to grip them, causing fatigue in the arms and aggravating the fatigue in the lower back.

Another study was conducted to evaluate the best bicycle design to reduce fatigue. Three types of cycles – the rigid frame, the sports, and the suspension – were used in this study. The back, shoulder and arm muscles of the participants were analysed using an EMG.

The rigid frame bicycle is your average one used by most people. It has a fixed rear, a rigid frame, and no suspension. The suspension bike has linkages between the rear and the front for a progressive spring rate. The sports bicycle has a drop handlebar, narrow tyres, and no suspension.

The suspension bicycle was found to be the best ride on rough terrain. When the cycle encounters a bump, the spring compresses, reducing the impact of the bump on the rider. Thus there is less energy cost to the rider and greater comfort while riding. The fatigue caused by riding on a suspension bicycle is lower than that of the other two types. In rigid frame bicycles especially, the shoulder and arm muscles showed greater signs of fatigue owing to the prolonged stretching of the arm to grip the handlebars.

The researchers found that the sports cycles led to the highest incidence of fatigue among the three types of bicycles. It also affords the least manoeuvrability. Commenting on this surprising result – after all, one would expect that sports cycles to be the most comfortable to ride – Rahul says that sports companies design the cycles for speed and agility rather than comfort. Now, it is up to the cycle companies to incorporate the results of these studies ■

Games of Great ENTROPY

By Aahlad Manas

Richard Feynman, in 1959, delivered a lecture titled "There's Plenty of Room at the Bottom", which inspired the field of nanotechnology decades later. Speaking about nano-sized surgical robots, perfectly controlled chemical syntheses and super-dense computer circuitry, Feynman laid the philosophical and conceptual foundations of how the ability to manipulate matter at an atomic scale could change the world.

The Advanced Materials Research group at IIT Madras, headed by Prof. B. S. Murty, is striving to realize that vision. Every material hitherto used by mankind can, and will eventually, benefit from the fruits of nanotechnology. Painting an Asimovian picture of nanotechnology as the way towards the next epoch of scientific advancement, Prof. Murty envisages a future with self-cleaning surfaces, energy-harvesting buildings and cancer-treating nanomites.

While Prof. Murty works on varied materials like glasses, composites and alloys, the focus right now is a very recent development in materials science, namely high entropy alloys, or HEAs. The concept as such was introduced independently in the 1980s, first by Prof. Brian Cantor (University of Bradford), and then by Prof. S. Ranganathan (Indian Institute of Science) and Prof. J.W. Yeh (National Tsing Hua University).

Conventional alloys are made of one metal in large proportion and a few other elements in small quantities. HEAs, by contrast, contain five to thirteen elements, exclusively metals, in equal proportions. This results in structures that are simple, unordered lattices, as opposed to the highly-ordered metallic structures. Such a structure gives rise to a physical phenomenon called the sluggish diffusion effect. This effect applies to the constituent metal atoms and restricts their movement by diffusion to such an extent that the alloys become extremely stable even at high temperatures. This is attributed largely to what can be thought of as a measure of randomness, called configurational entropy. The unordered structures increase the configurational entropy, which in turn decreases a quantity called the Gibbs energy. The lower the energy, the more inherently stable the alloy becomes. The objective is to make solid solutions – solids with the molecular or atomic structure of a solution, a mixture of liquids – out of this material.

As a recipient of the Shanti Swarup Bhatnagar Award, Prof. Murty's research has been of great importance, with a long of list over three hundred journal papers and fourteen patents establishing his authority over the field of materials science. In the textbook he has co-authored with Prof. Yeh, he writes that the field is still in its infancy. Despite this, scientists' vision for materials research has been changed by the introduction of HEAs. They hold the possibility of exciting discoveries, leading to a new materials revolution which could find applications everywhere. Says Prof. Murty:

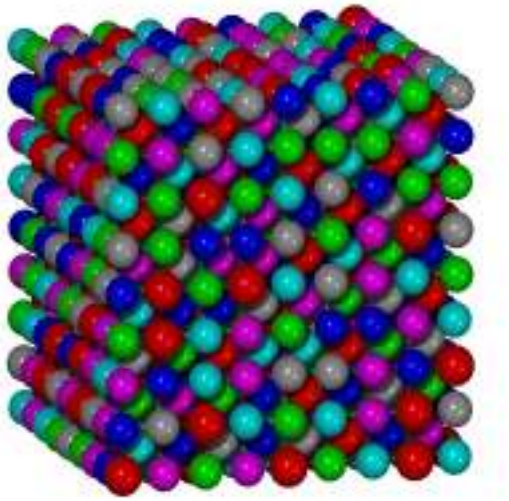
"The solution to every problem cannot be the same"

HEAs, though, have the potential to solve many of them. Their various properties find applications in fields including, but not limited to, medicine, nuclear energy, and fabrication of microelectronic chips and superconductors.

There are a few verified combinations that have found immediate applications and hold the promise of further improvement. An HEA made out of calcium (Ca), magnesium (Mg), zinc (Zn), strontium (Sr) and ytterbium (Yb) slowly releases calcium, and hence enhances bone regeneration when implanted in the bone. This is used in the treatment of osteoporosis, a degenerative bone disease characterized by low bone mass and density.

As HEA coatings easily form an amorphous structure with very low roughness, they can be used for non-stick coatings. They also find application in, for instance, a diffusion-barrier. Diffusion barriers are typically thin layers of metal, usually only a few microme-

tres thick, placed between two other metals. They protect both the metals from corrupting each other. In modern applications such barrier metals are used in integrated circuits to chemically isolate semiconductors from soft metal interconnects, while also maintaining electrical connectivity between them. Typically a layer of barrier metal must surround every copper interconnection in modern copper-based chips, to prevent diffusion of copper into surrounding materials. One such HEA, AlCoCrCuFeNiTi, made of aluminium, cobalt, chromium, copper, iron, nickel and titanium, makes for a good non-stick coating that is used as a mould in which solar cells are set.



BCC structure of AlCoCrCuFeNiTi. Courtesy: MDPI AG (Basel, Switzerland)

Another useful HEA is CuInGaSe, made of copper, indium, gallium and selenium. It has been tested for use as the back electrode of a thin-film solar cell, because of its thermally stable amorphous structure, superior diffusion-barrier property, and higher reflectivity and conductivity as compared to the typical back electrode made of molybdenum. The energy conversion efficiency has been found to have effectively increased by 9%.

High-temperature operations and environments like smithing, welding, engines and turbines are among the most prominent applications of materials science, specifically alloys. Super alloys have been the industry standard for these in recent years due to their anomalous high-temperature behaviour. Unlike standard metals and alloys, superalloys' strength and durability increases with temperature. However, HEAs have shown themselves to be even better, in both strength and durability, at high temperatures. Most heat-resistant superalloys today fall short of the high-temperature stability characteristics of HEAs.

The alloy $Co_{1.5}CrFeNi_{1.5}Ti_{0.5}$ (cobalt, chromium, iron, nickel and titanium) has a structure which makes it harder than stainless steel. On a measure of hardness called the Vickers Pyramid Number, or HV, this HEA stands at 378 HV. A peak hardness of 513 HV can be obtained by a process called aging, performed at 800 degrees Celsius. For comparison, stainless steel has a maximum hardness of 180 HV. This HEA can be used in severe conditions such as the components of underground electrical pumps used in oil well systems. Due to its high-temperature strength and oxidation resistance, this alloy has been used for components such as connecting rods and holders for high-temperature tensile, or maximum stress, testing machines at up to 1000 degrees Celsius. At this temperature, its hardness is still quite high, around 250 HV and this is higher than that of most commercial superalloys.

To be able to design and fabricate better materials, Prof. Murty aims to understand, at a fundamental level, the physics behind interactions at the atomic scale and the stability of molecules. The better our understanding, the easier it will be to design and fabricate new nanomaterials with better qualities. In particular, the more we understand the physics underlying HEAs, greater will be the ease and accuracy with which we will be able to predict their properties. Many qualities of HEAs, and alloys in general, such as strength, resistivity etc. improve as the material structure shrinks down to the nano-scale. When this happens, presently available techniques to analyze and understand the interactions, though robust, are no longer powerful enough to capture quantum effects. The techniques required to manipulate and fabricate the materials also become more challenging and those available now are often ineffective.

Prof. Murty, armed with some of the best equipment available, intends to tackle the problems of material science for the next generation. He says his research is closely related to his motivation to be a teacher which has been driven him since his B.Tech years and in his own words, "Salary is my by-product." With the advent of HEAs, he hopes to see a new era for materials science soon ■

Thanks for Reading

Other readers of this *Immerse* will include faculty members and students at the other IITs, the IISERs and the NITs, where we'll be sending copies, just like we did last time. Apart the online audience, of course.

But that'll be it from three out of the four of us who are editors – we'll be leaving at the end of this semester. While *Immerse* will remain in capable hands, we need your help.

If you're a student at IIT Madras and would like your research project to be featured, we'd be delighted to hear from you. Email us at `t5e.iitm@gmail.com`.

If you are excited by reading this issue and would like to contribute next time, be it as a writer, a photographer, a graphic artist, or a designer, please get in touch with us at the same email address. We'll tell you how you can contribute.

In any case, if you have something to say, be it praise or criticism, we welcome your views. Let us know by filling this feedback form `goo.gl/ogEwdY`, also accessible from this QR code

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