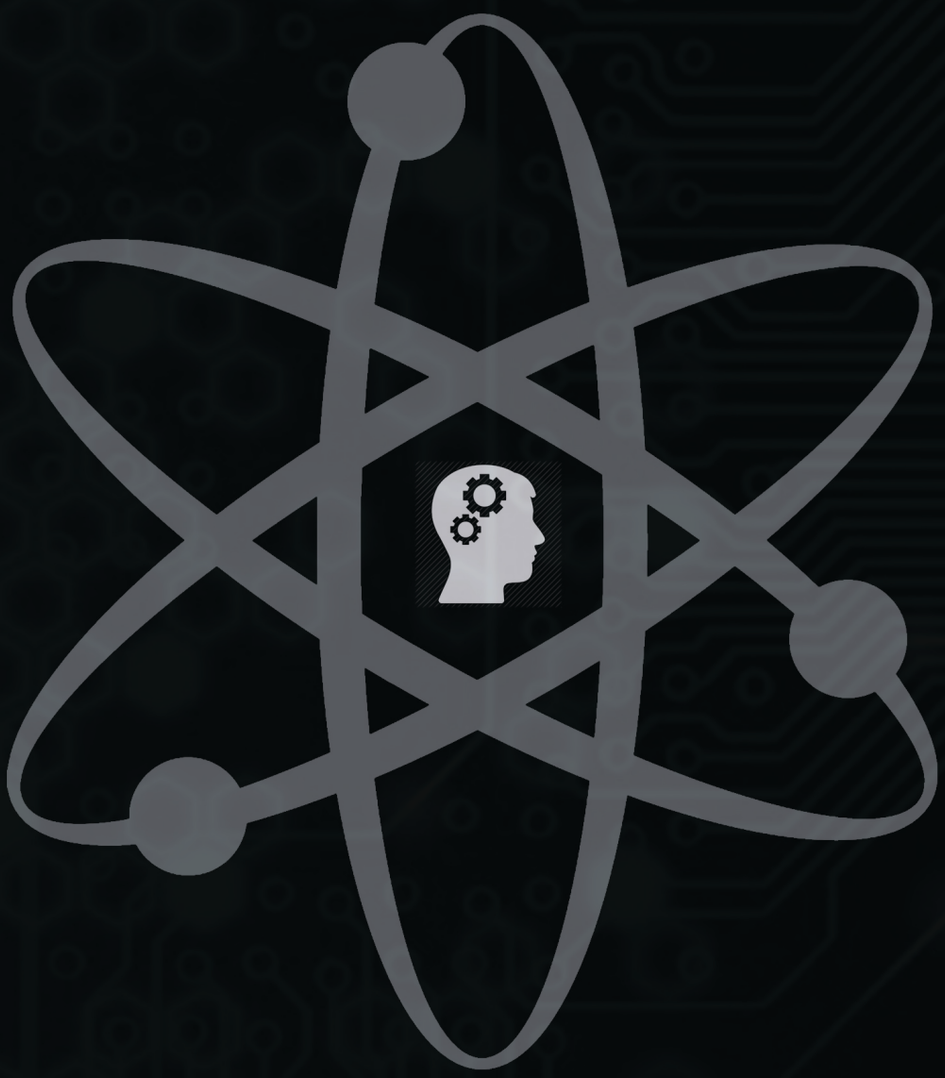
THE FIFTH ESTATE

The Students' Voice of IIT Madras

presents

IMMERSE

IIT Madras Science Magazine



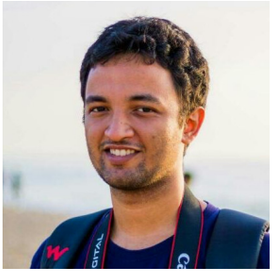
iitmadras

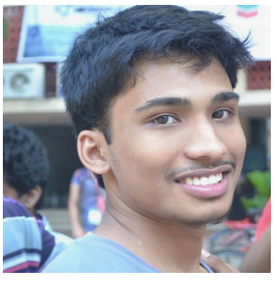
SHAASTRA 2017

THE SPIRIT OF ENGINEERING

CATERPILLAR®

From the Editors


Abhishek Shandilya


Anand Krishnan


G Soorya


Malayaja Chutani

Greetings from Team Immerse!

Immerse is the science communication wing under the aegis of *The Fifth Estate*. Our mandate is to explore and write about research activities that take place in IIT Madras. In doing so, we hope that researchers learn about other fields and students get excited about research. We want Immerse to be a window for prospective students, to peer into the life and work of scientific researchers, and know what to expect.

In this fifth edition of Immerse, we were able to cover a variety of topics. This exhibits only the tip of the vast range of research that takes place within our campus. Immerse is not limited to print edition. More articles will be published on our online platform (t5eiitm.org/immerse).

We take this opportunity to thank the Director and the Dean of Students for their support. We also thank our sponsor *Caterpillar*. And lastly, we thank the professors and research scholars who took out time from their busy schedules to talk to us about their work.

We hope that as you “immerse yourself” in this issue, we are able to excite your imagination, as ours was when we learnt about the various projects that have been covered.

IMMERSE

IIT Madras Magazine on Research in Science and Engineering

From *The Fifth Estate*

From *Shaastra*

Editors

Abhishek Shandilya
Anand Krishnan
G Soorya
Malayaja Chutani

Writers

Akhil Sathuluri
Ananth Sundararaman
Nithin Ramesan
R Mythreyi
Rupesh Kumar
Sriraghav Srinivasan
Vishal Katariya

Sponsorship and PR

Saptarshi Majumdar
Raghul Manosh
Varun Srinivas Sridharan

Design

Radha Krishna Korlam
Abhijit Gupta

This magazine was typeset in LaTeX.

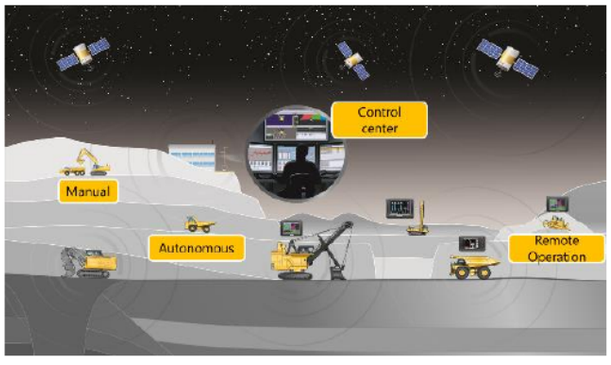
Caterpillar - Leading the Age of Smart Iron

Caterpillar Engineering Design Center - India

We live in an age of Smart. An age of smart phones, smart appliances, smart homes and smart cars, where connected devices are improving lives and revolutionizing work. From job site, to generators, and to machines of all sizes, this is the age where iron flexes its intelligence. This is the age where job sites become their own networks, entire fleets speak the same language and work gets done faster with fewer setbacks. The machinery that enriches lives, powers businesses, and builds communities is given the connectivity to be more efficient, more productive and even safer.

The sophisticated electronics that today's machines host makes available to us a huge set of data. The ability to collect and visualize the data as meaningful information is key to maximizing availability, productivity and safety. In capital intensive industries like construction and mining, the customer needs maximum availability of their equipment and strong predictive analytics makes it possible to diagnose the machine for a problem even before it happens. This technology helps not only to reduce the machine downtime but also saves millions of dollars in machine repair.

While solutions like payload measurement system, grade and compaction controls enable individual machines to perform better, different machines working in harmony determine the productivity of a job site. A fleet management system communicating with the machines, enabling the machines to talk to each other, tracking the machine and material, and scheduling operator shifts can help in maximizing the productivity.



On-Board Cameras with in-cab displays, Radar and/or GPS based Proximity Awareness, RFID based personnel detection, Vision based fatigue detection and fatigue management through wearable technologies are all available today to improve the safety of the personnel on different job sites.

While all these solutions are available either individually or integrated, autonomous mining brings it all together. Right from autonomous drilling, to dozing and hauling, Caterpillar has solutions that enable autonomous mine operations with minimal human intervention. Leading the way, Caterpillar trucks have autonomously hauled more than 200 million tonnes of mineral in one of the mine sites since their deployment in 2012.

CATERPILLAR®

In 91 years of our history, our customers have challenged us to take them further. It is this belief that drives everything we do to make our customers successful. Pushing limits through printing 3D parts, running autonomous mines, bringing renewable power to remote sites, producing wearables that predict a safer future, drone fleets that survey entire site operations, putting augmented reality to work – Caterpillar's footprint in Science and Technology continues to grow. From our very first tractor to enabling NASA build on the red planet, we have spent over ninety years committed to innovation and technology, because the future belongs to those who build it and Caterpillar is Built For It.

CATERPILLAR®

Contents

i		From the Editors
ii		Credits
iii	**Caterpillar**	Leading the Age of Smart Iron
1	**Applied Mechanics**	Learning How We Learn
3	**Biotechnology**	Coffee Under the Microscope
6	**Chemical Engineering**	An Explosion In Data Analysis
11	**Electrical Engineering**	SITARA - A Brighter Grid
15	**Humanities and Social Sciences**	Sacred Moorings
18	**Mathematics**	Computing Outside the Box
21	**Mechanical Engineering**	Designing ISRO Launchpad
24	**Metallurgical and Materials Engineering**	Combating Cancer - Scaling Heights by Scaling Down
27	**Physics**	The science of Whispering Galleries

Learning How We Learn

The pervasiveness of machine learning and big data algorithms is on the rise in today's world. We see it applied everywhere, from predicting where you want to vacation next to which brand of chocolate you're going to buy. These impacts are more superficial, but there are other applications as well, applications that are solving problems that have so far been unsolved by us.

This piece covers a study of motor learning and co-articulation. Motor learning is the change, resulting usually from practice, in the capability for responding to external stimuli. Motor learning involves muscle memory and the recognition of oft-repeated patterns. This project is led by the dynamic Dr. SKM Varadhan of the Applied Mechanics department. Involving the creation of a new alphabet and typing system, as well as custom-made gloves for each participant, this is a truly novel project.

What if somebody told you that learning a particular skill will only need a certain number of days or hours of practice until you became decently competent at it? What if you knew exactly which exercises to practice to learn a skill in the minimum possible time? These are the questions being posed and simultaneously answered by this project. By inventing a new typing task and keyboard system, it is a systematic study of the time-evolution of people's competency at a task that they are attempting for the first time. The trends observed will help greatly the rehabilitation of those with motor neuron disorders, and will also facilitate the engineering of optimal and efficient learning curves, so to speak.

While it may seem like a trivial study, this is actually an investigation of how the central nervous system handles the nontrivial problem of learning a new task. Participants of the (currently ongoing) study will be shown words on a computer screen, and they will be required to type those out in real time using a specially designed, personally tailored glove keyboard (refer the image below). Various locations on the hand correspond to different letters of the alphabet. The glove is made as light and noninvasive as possible, because the unnatural nature of a peripheral on one's hand may impede progress, as well as add an added layer of complexity to the learning.

Tailored Glove for every candidate.

The sensors attached to the glove are numerous and cutting-edge. They are electromagnetic sensors that can measure position with an accuracy of 1.27 microns. To put that in perspective, each hair on your head is between 20 and 200 microns thick. They also measure pitch, yaw and roll, yielding a six-dimensional vector of the sensor position at every instant of measurement. There are a total of 16 sensors on the glove, which translates to a huge amount of data being collected during the typing task.

Motor learning is a change in one's capability to respond and perform certain tasks that comes from practice. Motor learning is ubiquitous. Ever-present in our lives, there are countless examples. Learning to ride a cycle, writing or typing out any language, all these are things that get better with practice. Slowly, we develop muscle memory and attain a proficiency that makes these tasks 'second nature'. A pen or a guitar becomes an extension of our hand.

A key aspect to this proficiency that one attains is explained by the process of coarticulation. Coarticulation refers to the way the brain plaits together different vowels and consonants so that the final vo-

cal output is a smooth whole. Coarticulation as a concept is not limited to speech, but can be extended to other situations too. For example, one coarticulates notes on a guitar, as well as keys while typing on a keyboard. When we know what comes next, we know exactly where to place our hands so as to make movements between discrete steps as fluid as possible.

The large amount of data collected causes a problem in computational power. For every fifteen minutes of typing, the size of data collected is of the order of many tens of megabytes. The study proceeds now with multiple participants, each typing for multiple sessions every day. This results in a massive data set, and anyone who's ever worked on a machine learning problem knows that it's courting disaster to train a model on such a massive data set. This brings us to another aspect of this project, which aims to reduce the size of the data set collected. The sensors on a single hand record 96 different variables at each instant of time, which is huge. It is entirely possible, and almost always true, that some variables are redundant, and can be eliminated from the analysis altogether. This is a problem that has to be attacked from a machine learning perspective. What is interesting is that solving this problem will cause an advance not only in this project, but in other realms of modern computer science.

In scientific projects that are touted to make a big impact in the future, a common feature is the incredible dedication of the project members. While interviewing Dr. Varadhan, the project leader and his masters and doctoral students, the enthusiasm of the project members was overflowing. From the design of the experiments to the precise wooden contraption to capture the electromagnetic data from the sensors, every aspect has been taken care of with the utmost detail.

The applications of this contraption are many. As stated earlier, it will help in the rehabilitation of patients of motor neuron disorders. Finding the most optimal methods to learn new tasks, both ubiquitous and novel, will be greatly beneficial and will save time in a now time- and productivity-obsessed society. A study of the way we learn and coordinate muscles and neurons will add to our knowledge of human neuroscience. There may be windfalls in the way these data sets are handled in the future; in an age of interdisciplinary research, this project elegantly marries neuroscience and machine learning. This is a stepping stone to something more advanced, a marriage of contrasting fields that will only enrich both of them.

Dr. Varadhan S K M is a movement chauvinist. He loves analyzing movements of people. He believes in continuous learning (he still takes online courses). He loves interacting and connecting with students. When he's not working, he loves playing with his daughter. You can know more about his research at https://home.iitm.ac.in/skm/index.html.

Meet the Author

Vishal Katariya is a fourth year B.Tech. student in Engineering Physics. He is interested in quantum physics among other things. He likes reading, writing, music and tennis, which includes a fanatical support of Roger Federer.

Coffee Under the Microscope

Cooperation in nature has long been a topic of study that has fascinated scientists. The interplay between the instincts of an individual organism that prompt it to look out for itself over the well-being of even others of its own species and the possible benefits that can be gained by working together plays out amongst diverse species - in animals, plants, and microscopic organisms.

The extent of cooperation between organisms is largely size-independent. Larger animals often live solitary lives, or travel in herds or packs - examples include herbivores (like deer and antelopes) as well as predators (like lions and hyenas) - but even this cooperation has its limits. The structure of packs is often fluid, with the weaker members being forced out by stronger, more dominant members. Attacks on a herd usually result in stragglers being left for dead. More closely-knit groups do emerge amongst more intelligent species - elephant herds and troops of gorillas and chimpanzees place a much larger emphasis on the survival of all their members, as does human society. As one examines smaller organisms, the various shades of grey usually resolve into black and white - either members of a species cooperate, or they don't.

Dictyostelium Discoideum.

An efficient method of communication within a species is a prerequisite for cooperation. Macroscopic organisms use a combination of chemical methods (for example, via pheromones) and visual cues to communicate. As one delves into the microscopic realms of the living world, though, optical organs are primitive, if they exist at all - making chemicals the only viable method of interaction. Studying how these tiny organisms convey information could provide insights into how our own cells achieve the same, and could also set up useful avenues of approaches into bioengineering.

Professor R. Baskar's group in the Department of Biotechnology at IIT Madras have pushed the envelope of scientific knowledge a little further out during their research in this field, which focused on an organism whose scientific name is Dictyostelium discoideum. Perhaps the most interesting and relevant feature of this organism is that it belongs to a small class of species that form collective bodies known as slime molds.

Generic Slime Mold

Slime molds are an approximately 900-strong group of normally single-celled species that aren't necessarily taxonomically related - instead, their classification into this group is prompted by their ability to aggregate, and form multicellular structures that they then use to reproduce. These unicellular organisms survive on their own in times of abundant sustenance. When food is scarce, though, they form a multicellular body that as a whole, can sense and respond to external stimuli. (Most slime mold species feed on microorganisms that can be found in decomposing plant matter, and can hence

be most commonly found on soil surfaces and forest floors.) The organisms that comprise slime molds are often referred to as "amoeba-like", but they are not actually amoeba. They don't all belong to a well-defined taxonomical kingdom - instead, they're classified for convenience under kingdom Protista (any eukaryote that is neither plant, animal nor fungus).

Historically, however, they were thought to be fungi - a conclusion that was prompted by their method of reproduction. When these multicellular aggregates form, they become a mobile "slug" that can move, albeit very slowly, in search of food. They subsequently form stalks that produce fruiting bodies, which in turn produce spores that are dispersed via the air, finally growing to form unicellular organisms that continue the life cycle. This rather remarkable ability of slime molds to both function initially as autonomous cells, and to later aggregate and cooperate, as mentioned earlier, can only be controlled by changes in the chemical environment of the cell. Prof. Baskar's research focuses on the effects of one chemical on slime molds: caffeine.

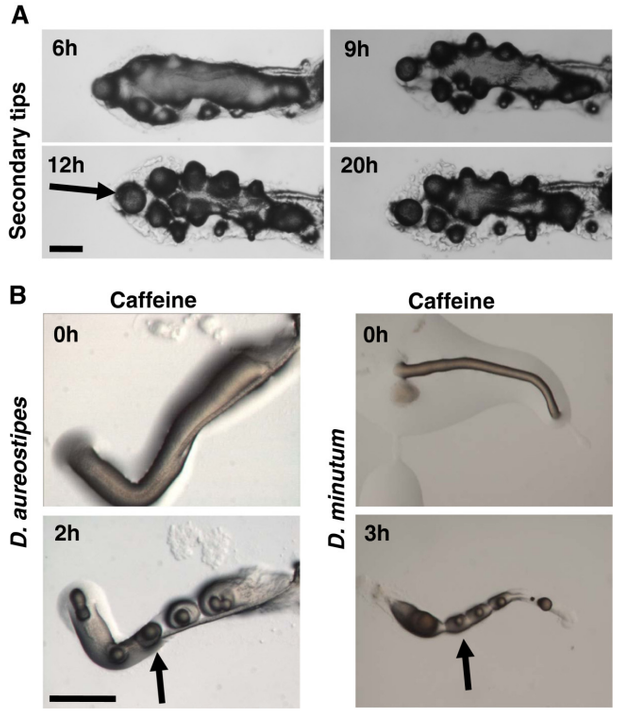


Figure 1: Effect of caffeine on multiple tip formation in different Dictyostelids. **A**) In P. pallidum, secondary tip formation was monitored at 6 h, 9 h, 12 h and 20 h of development. **B**) In D. aureostipes and D. minutum, ectopic tips were observed at 2 h and 3 h, respectively after transferring the slugs in plate containing 5mM caffeine. Arrow indicates multiple tip formation at respective time intervals in different Dictyostelids. Scale bar=200μm. (source: Jaiswal, P., Soldati, T., Thewes, S., Baskar, R; BMC Developemental Biology 2012, 12:26)

Caffeine is best known as a stimulant of the central nervous system in humans - in other words, it keeps us from falling asleep. One of the main methods by which it achieves that is by inhibiting the action of adenosine (by preventing it from bonding with its receptor) - adenosine is the chemical that induces feelings of drowsiness in humans. Existing literature has established that adenosine also plays a major role in the formation and motion of the slime mold aggregate. A natural question to ask, then, is whether caffeine could play a similar inhibitory role in slime molds - and this is precisely the question that Prof. Baskar's work answers.

His group examined the effects of caffeine on two aspects of the slime mold. The first was the sizes of the aggregate formed. Experiments were carried out using a control set of organisms (a control set is a set of test cells to which no modifications have been made - a benchmark, so to speak), and sets to which caffeine or adenosine were added and forced

to aggregate by starving them of a food source. It was observed that the adenosine-treated slime mold formed large aggregates, while the caffeine-treated mold formed small aggregates.The size of a slime mold colony depends on two quantities - the number of cells in the aggregate (and by extensions, the rate of cell division in the colony), and the size of individual cells. Studies revealed that both quantities are significantly lower amongst the caffeine-treated slime mold.

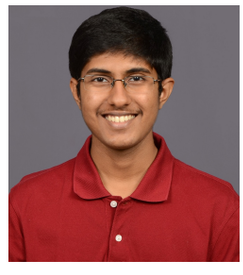
An obvious follow-up question is exactly how these quantities are manipulated by these chemicals. The same adenosine receptors governing drowsiness in humans are unlikely to be present in these organisms. Indeed, a different mechanism was observed - these two reagents manipulated the quantity of glucose present in the cytoplasm of the cell, which directly affects cell growth and division (as the concentration of glucose decreases, so does cell activity).

The second aspect of the slime molds that was considered was the development of the tip of the aforementioned slime mold "slug". The tip is a region of major importance within the aggregate - it acts as a chemical pacemaker, sending periodic waves of a chemical known as cAMP propagating along the length of the slime mold and controlling its movement - an example of a chemical communication method. It's in the best interest of the slime mold to form a single tip, to prevent and signalling conflicts and to ensure uniform motion. This establishment of a single dominant tip is accomplished by high concentrations of adenosine. The addition of caffeine here leads to multiple tip formation, which in turn leads to impaired cell movement.

It's easy to see from the results of Prof. Baskar's research that caffeine and adenosine are a pair of chemicals with antagonistic effects in slime molds, similar to established results for their effects in humans - species that span the spectrum of evolution. The insight provided by these results will improve our understanding of the intricate chemical pathways that allow cells to communicate, potentially advancing pharmacological research, bioengineering methods and evolutionary studies.

Dr. Baskar R is an associate professor in the department of biotechnology. He is an expert in developmental denetics. His research interest lies in pattern formation in cellular slime molds, and mutational landscape during plant development and hybridization. You can know more about his research at https://biotech.iitm.ac.in/Faculty/RB Lab/rb.html

Meet the Author



Nithin Ramesan is a final year undergraduate student of Electrical Engineering. He likes reading, quizzing and writing, and most of all, Calvin and Hobbes.

An Explosion In Data Analysis

What is Data Analysis?

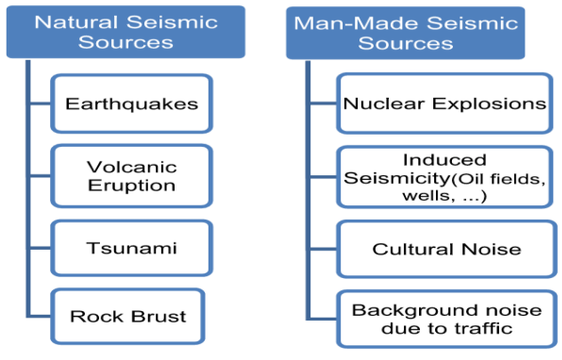
Data analysis is concerned with extracting useful information and drawing meaningful inferences from measurements using a healthy blend of qualitative (e.g. visual) and quantitative (mathematical and statistical) analysis tools. A generic data analysis exercise involves several steps such as inspection, data pre-processing, transformation and modelling or classification; every stage involves inputs from the user, domain knowledge and hypothesis testing. In addition, it is important to take into account the end-use of data analysis, which could be prediction, classification, anomaly detection, etc. since it exerts a significant influence on the course of analysis including the data acquisition mechanism.

During our discussion with Prof Arun K Tangirala of the Department of Chemical Engineering, he smiles, and explains the details of his work on seismic data analysis. He exclaims "it's data analysis, and not data dialysis!" The reason being that data analysis involves extraction of desired information from data, whereas dialysis involves removal of waste from data. When analysis is conducted incorrectly, one may end up with waste or meaningless information. Moreover, it is not just about removing unwanted information but making sense out of what the analyst is left with, which is nothing short of a challenge.

Prof Tangirala is part of the Process Systems Engineering & Data Sciences group, which consists of nearly fifty researchers (faculty, research fellows and scholars). The group is renowned world-wide for its work in process modelling, data analysis, control, monitoring and optimization. The members engage in active and cutting-edge research that is not only theoretically rich, but is also deeply engaged in several high-value interdisciplinary and socially relevant projects through industrial consultancy, sponsorship, and collaborations with leading researchers in the world. On the skill development and training front, several foundational, advanced short-term, and full-semester courses on time-series analysis, system identification, multivariate data analysis, optimization, graph theory, statistical data analysis, and advanced control are offered round the year - a feat that is unique across the globe for a single department.

Understanding Seismic Activity and Analysis

Among the different domains of data, the seismic or under-the-ground data assumes enormous significance for obvious reasons. The ground is continuously at unrest mainly due to waves in ocean, changes in earth's crust, atmospheric variations and human activities.

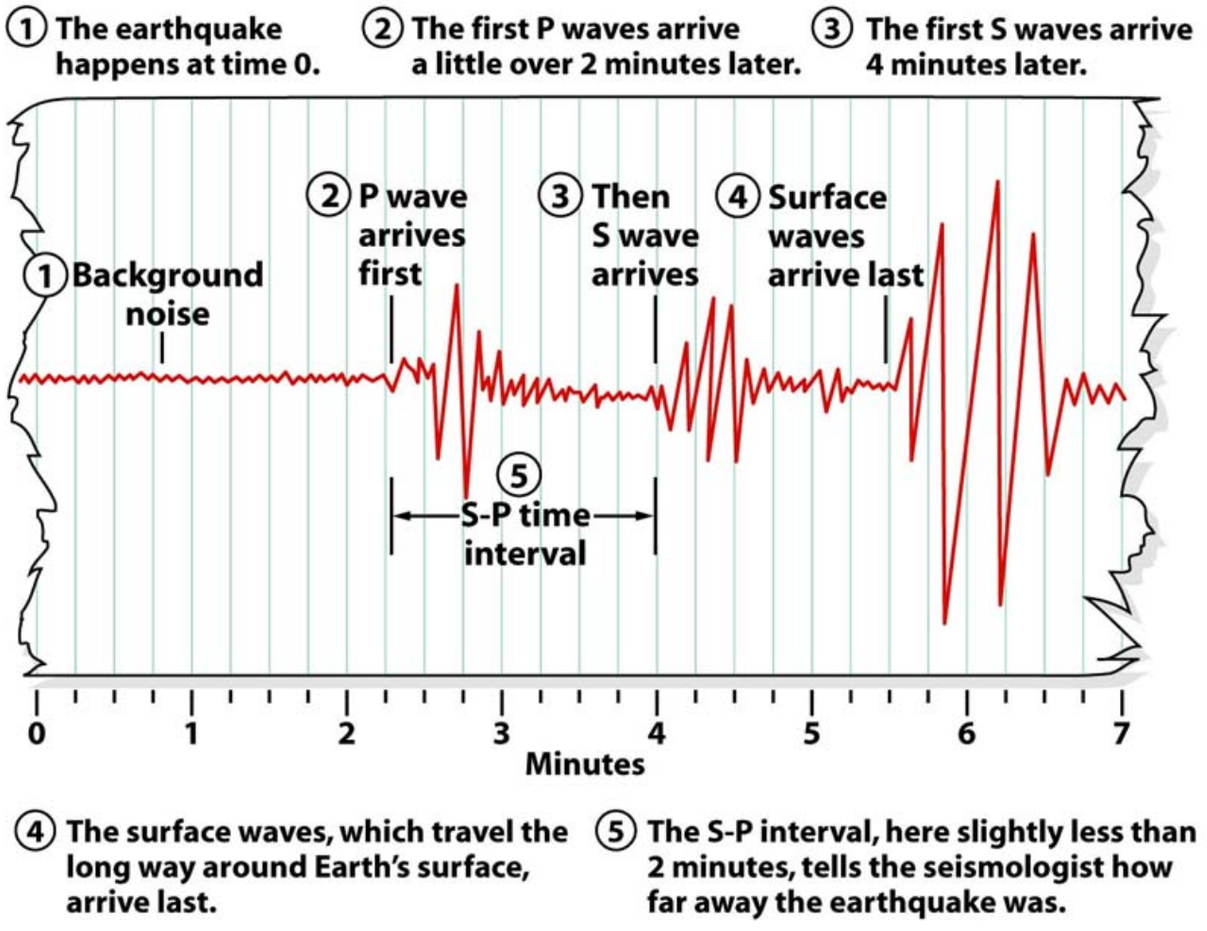


Most predominant natural and man-made sources of seismic activity.

Regardless of the source, all seismic events release energy proportional to their scale. This released energy moves out in all directions as a wave, and is recorded by a *seismometer* or a *seismograph*. Seismograms are recordings of ground vibratory motion obtained from a seismometer. Analysis of these seismograms is vital to our understanding of earth's activity, especially in setting up early warning systems for earthquakes, to determine their source locations, and detect other seismic events such as explosions. Detecting or predicting the damaging part

of an earthquake holds great value in protecting lives and preventing loss of property.

Seismic signals are broadly classified as Body (travel through interior of Earth) and Surface waves (on the surface of Earth). Body waves are comprised of *P waves* (compressional waves, first one to reach the seismometer) and *S waves* (transverse in nature). Body waves cause high frequency vibrations and are less destructive, whereas surface waves, which are comprised of *love* and *Rayleigh waves*, cause low frequency vibrations and are destructive in nature.



Depiction of a typical seismogram recorded at a seismic station.
(source: http://academic.brooklyn.cuny.edu/geology/grocha/plates/platetec19.htm)

Very little time interval exists between the arrival of two different waves. Fortunately, the P wave that arrives first is the least harmful and therefore the detection of its onset is critical to the success of any earthquake warning system. Data is either recorded from a single three component station, which is an array or a network of stations. Data acquired from seismic array or network, as opposed to a single station, enables better signal detection and source location.

The Single three component station measures three spatial components (N-S, E-W, vertical). While it may have large error margins, it is the most cost effective system. It also gives us information about depth and strength of the event.

An array has nearly 9-25 single stations with 10-20 km spacing. It improves the Signal-to-Noise ration (SNR), thereby making it easy to distinguish the signal from background noise. Furthermore, it also facilitates the determination of source azimuth (direction from which signal arrived at the station), local slowness and epicentral distance of the source.

A network of stations, on the other hand, has local, regional or global distribution of more than 50 stations with a common data center. This helps in

more accurate event detection.

Through the analysis of seismic signals from a few or many seismic stations, one can determine the origin time and location of the event and estimate its magnitude (M) - a measure of energy released by seismic sources.

The primary goal of seismic data analysis is to increase the reliability of earthquakes probability estimates. This analysis not only helps in predicting the onset of seismic wave and locating the source of the event, but also in identification of underground nuclear explosions and in imaging Earth's deep interior structures (tomography). It is also used in preparing the seismic risk maps for highly prone regions.

The specific objective of this Board of Nuclear Sciences (BRNS) sponsored project titled "Analysis of Seismic Data for Unsupervised Detection and Classification" is to develop minimal human intervention tools to detect the onset of the P wave so that efficient evacuation and significant reduction in damage caused by the earthquake can be achieved by warning the areas which might get affected by the earthquake. In addition, a classification-based method for distinguishing between earthquakes and explosions will be developed. Finally, the team aims to equip these methods with means of handling missing data due to communication losses using ideas from compressive sensing.

Challenges

A prime challenge in seismic data analysis is that post detection of onset of *P wave* accurately, the lead time (P-S time interval) for issuing warnings is very short, about 2 minutes.

Further, low signal-to-noise ratio (SNR), i.e. large amounts of uncertainty since a typical *P wave* amplitude is usually comparable to that of noise, have to be handled.

A universal time-series model or statistical inference cannot be applied as the seismic signal characteristics vary with the geographical locations, country, local climate etc.

Despite its unique challenges, analysis of seismic data shares certain commonalities with other domains. For instance, detecting the onset of P wave has close analogies with detection of faults in process industry, with some subtle differences though. In a different and interesting study, strong similarities have been observed between the conditions leading to earthquake and those in a faulty heart through ECG recordings. This is often referred to as the *'human heart-type characterisation in the development of an earthquake'*.

Overview of the Project

The main objective of this work is to develop unsupervised (automated) methods of seismic data analysis so as to minimize user intervention in determining event onsets, source location and classification of earthquakes that eventually reduces reporting time. An additional objective is to develop methods for distinguishing earthquakes from explosions.

Stage 1: Noise Modelling

This stage primarily deals with developing the statistical models for background noise using statistical modelling techniques. Depending on the noise characteristics, a time-series model will be developed. With a statistical/time-series model of the noise in hand, a suitable method for the determination of the onset of earthquakes (P waves) will be devised.

Stage 2: Multi-scale analysis

Once an event is detected accurately, a multi-scale analysis of signals is carried out to separate the events occurring at each scale. This scale separation enhances the characterization of seismic events, which eventually impact the ability of classifier at the next stage.

Stage 3: Classification

Classification of seismic events is nothing but the ability to identify two different events at single station in the presence of large noise levels in order to reduce the reporting time. Thus final stage involves the development of an unsupervised classifier for discriminating two different seismic events at a

single station. Communication losses can severely affect the ability to continually analyze data. In this work, we aim to address these issues by treating the missing mechanism as random and use ideas from the emerging fields of compressive sensing and sparse optimization.

The following figure provides an overview of the approach envisioned for this project. All methods should satisfy the requirements of accuracy and reliability in addition to computation and implementation costs.

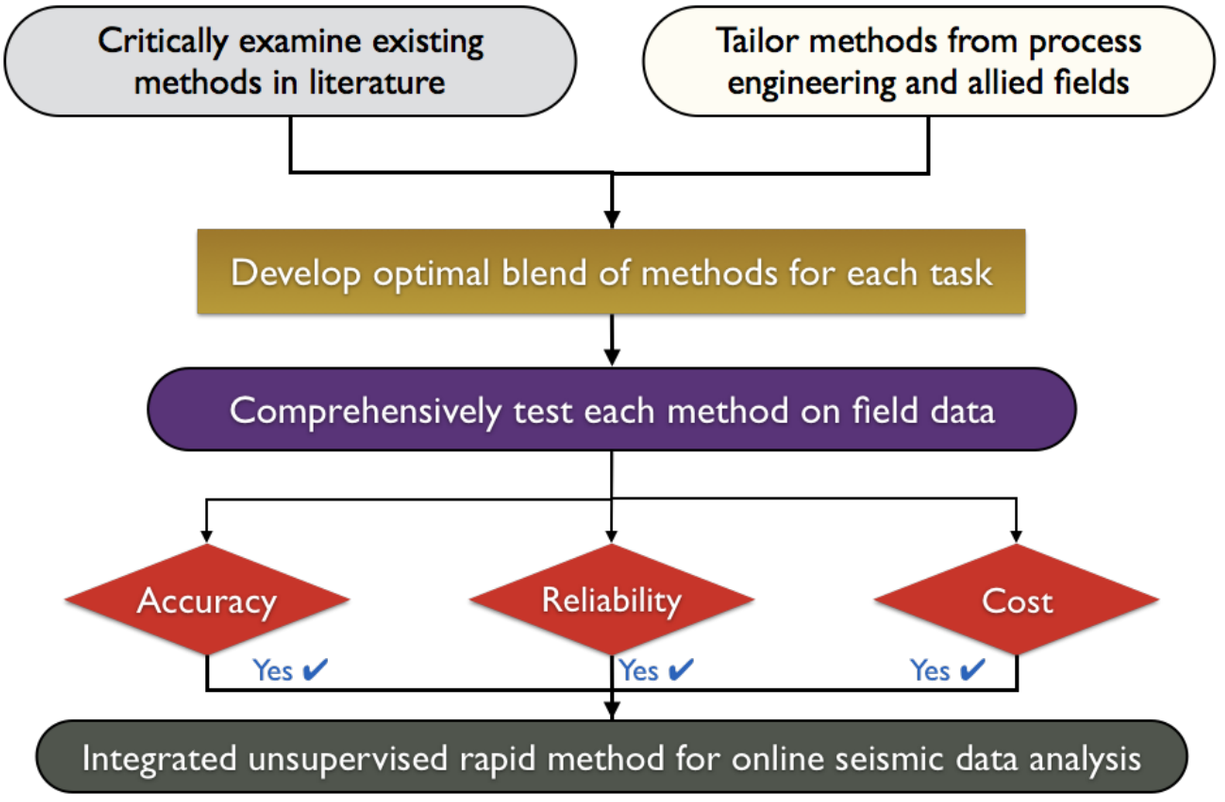


Figure 2: Overview of the method envisioned for this project

Current Status and Future Goals

Understanding the noise model is critical for sound interpretation of the event data. Thus, seismic noise from different stations (worldwide) is being analysed. The present stage of analysis is concerned with rigorous statistical tests for noise characterization (stationarity, linearity, etc.). A systematic procedure that can be universally applied to seismic noise across the globe. Statistical models for seismic noise are being subsequently developed and their variations across the globe are being studied.

Future goals involve validation of noise models, development of methods for detecting onset of P waves and realizing the rest of the project objectives. All models developed shall be validated by the BARC Seismic Division team.

Some background information

The principal collaborator on the Bhabha Atomic Research Center (BARC), Mumbai is Dr. Siddhartha Mukhopadhyay, head of the seismic division team and a leading scientist at BARC. From the IIT-Madras's front, the project is led by Prof. Arun K. Tangirala. Other members of this team include Ms. Kanchan Aggarwal, a project associate and research scholar at IIT-M, who is pursuing her doctoral degree on this project.

Datasets for this work are presently obtained from Incorporated Research Institutions from Seismology (IRIS), [IRIS provides management of, and access to, observed and derived data for the global earth science community which includes ground motion, atmospheric, infrasonic and hydrological

data]. In addition to IRIS, several other sources to download earthquake data are available - SEG, ORFEUS, U.S Geological Survey (USGS), UTAM Seismic data library, etc. Analysis is carried out using a blend of univariate and multivariate stochastic (time-series modelling) and deterministic (e.g. Fourier and wavelet analysis) signal analysis tools in **MATLAB** and **R** software.

Dr. Arun K. Tangirala is a Professor at the Department of Chemical Engineering, IIT Madras since 2004. His research interests span the fields of process control and monitoring, system identification, applied signal processing and fuel cell systems. He has been teaching several full-term and short-term courses on process control, system identification, theory and applications of wavelet transforms, random processes and fuel cell systems.

Meet the Author

Sriraghav Srinivasan is an unapologetic foodie who never misses an opportunity to travel. Raghav would probably be found hunched over the latest Archer book or binge-watching the TV show F.R.I.E.N.D.S. He's an undergraduate Junior at the Biotech Department who's interested in a variety of things from Neuroscience to Financial Markets.

SITARA - A Brighter Grid

On the scorching afternoon of 29th July 2012, circuit breakers on the 400kV Agra-Gwalior-Bina line flung open under the intense load.With 1000 MW power being drawn from this single line whose maximum capacity was near 700MW, the lines were snapped open,instantly breaking the circuit.

The load then burdened the Agra-Bareilly line, which ran in parallel.It also snapped. With each line getting disengaged the power deficit snowballed out of control and toppled every line connected in parallel. Within minutes the entire Northern Region Grid, which innervates half of India collapsed under this cascading catastrophe. 22 states from Assam to Rajasthan and Odisha to Kashmir were plunged into darkness for 2 days. This was the world's largest wide area blackout, with more than 62 crore people's lives rattled for days as the engineers scrimmaged to get the grid back on its feet. The disaster issued a poignant alarm over the dilapidated state of the Indian electric grid as it is today. With common citizens shrugging of the all-too-familiar outages as every day occurrences,only the energy pundits know exactly about the smothering problems that our country's power infrastructure faces.

India is attempting to do something no nation has ever done: build a modern industrialized economy, and bring light and power to its entire population, without dramatically increasing carbon emissions. Simply to keep up with rising demand for electricity,we must add around 15 gigawatts each year over the next 30 years. We get most of our electricity from aging, dirty coal-fired plants. Decrepit transmission grids running on obsolete hand-me-down technology from the West threaten the reliability of the entire energy infrastructure. At least 300 million of India's 1.25 billion people live without electricity. The current Prime Minister's 2014 manifesto has promised to increase India's renewable-energy capacity to 175 gigawatts, including 100 gigawatts of solar, by 2022. In the very near future Indian engineers would have to orchestrate a pandemonium of micro-power generators spread across household rooftops and windy country sides along with Thorium and coal powered generators. SITARA is a step in that direction.

SITARA is an international collaboration to work out the gritty details of the architecture of the grid of the future. The 2-year project named SITARA: Smart Grid to Harness Satellite based Virtual Power Plants for Energy Sustainability, is one of 14 multilateral university partnerships which have been awarded grants by the Global Innovation Initiative in 2015; a joint effort of the UK and US to foster multilateral research collaboration with higher education institutions in Brazil, China, India and Indonesia. SITARA, with a grant of nearly £150,000, is one of eight grants awarded to UK-led partnerships by the British Council and the Department for Business, Innovation and Skills of the Government of UK.

The SITARA consortium includes the University of Bradford, North Carolina State University (US) and Indian Institute of Technology Madras (India). The project consortium will also collaborate with University of Hong Kong, which has a very strong smart grid research infrastructure, to validate some of the developed algorithms.Also the Media Lab Asia and the Centre of Development of Advanced Computing, both affiliated to the Ministry of Communications and Information Technology, Govt. of India would be involved in impact evaluation and dissemination activities.

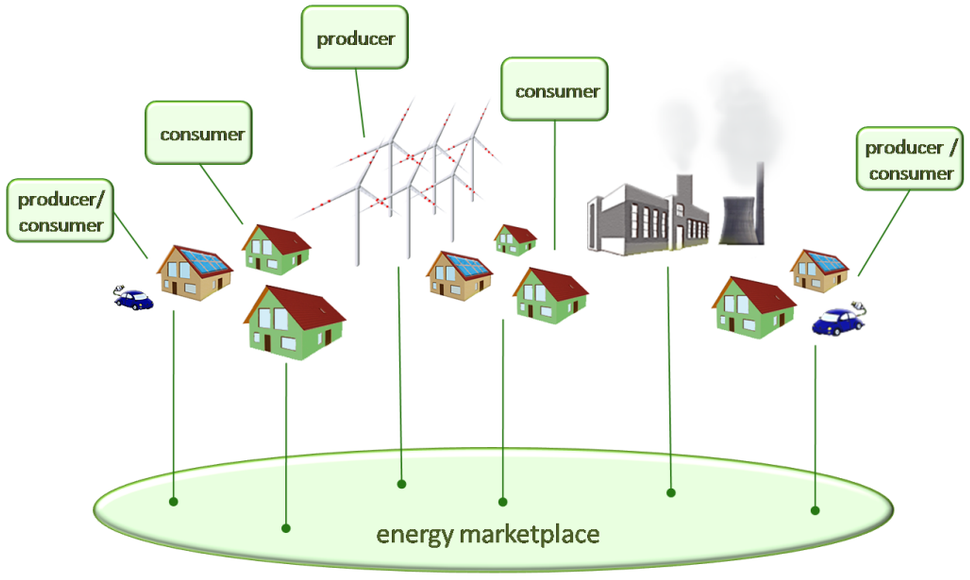


Figure 3: The Distributed Grid of the future

Why do we need a smarter grid?

Enabling two way communication between the energy producer and consumer is the essence of the whole smart grid idea. This would currently allow for efficient usage of our limited energy resources.But the smart grid paradigm is more than teaching the old grid new tricks.It will become the enabling technology for large scale distributed grids to even exist in the future.

Power quality in distributed grids is a major concern.In a network where power influx can capriciously vary at a slightly strong gust or a cloudy dark sky, maintaining your wall socket at 220V 50Hz is going to be quite a challenge. Unlike a coal fired power plant where we can just yank up the flames at the peak demand, we need smarter solutions for a grid which depends mostly on renewables. Among other concerns, surges or transients are also a major one. These are brief overvoltage spikes or disturbances on a power waveform that can degrade or destroy electronic equipments. Transients can reach amplitudes of tens of thousands of volts even though they only last for microseconds.

Also in the future when anybody on the grid can supply electricity back to the it,new problems would arise.Like a serious issue,which is known as "islanding" in EE parlance.It's a condition in which distributed generators like solar panels or wind turbines continue to generate power and feed the grid, even though the electrical power from the utility is turned off.Utility workers who may think that there is no power when the utility power is shut down, but the grid may still be powered by to the distributed generators. In addition to solving several such problems a smart grids enables dynamic pricing of power even within a single day. This can greatly ease the loading on the grid.When the peak hours are charged more than the lean ones who wouldn't schedule using their heavy appliances away from the peak hour?

The Virtual Power Plant

At the core of SITARA's approach at this multidimensional problem, is the concept of a Virtual Power Plant. The aggregation of hundreds of homes with solar power and their battery storage will provide the utility with a cost-effective and innovative "virtual power plant".So instead of installing a new centralized power plant, these hundreds of micro-generators can be dynamically orchestrated to behave as a single effective power plant. This can supplement the traditional energy delivery model thus improving the grid resiliency, reliability and sustainability.

VPPs are supported by cloud-based software, monitoring and automation equipment and an optimisation engine. VPPs are able to extract flexibility out of small scale generators and customers, allow-

ing them to respond to varying amounts of renewable supply on the system whilst compensating them for doing so.

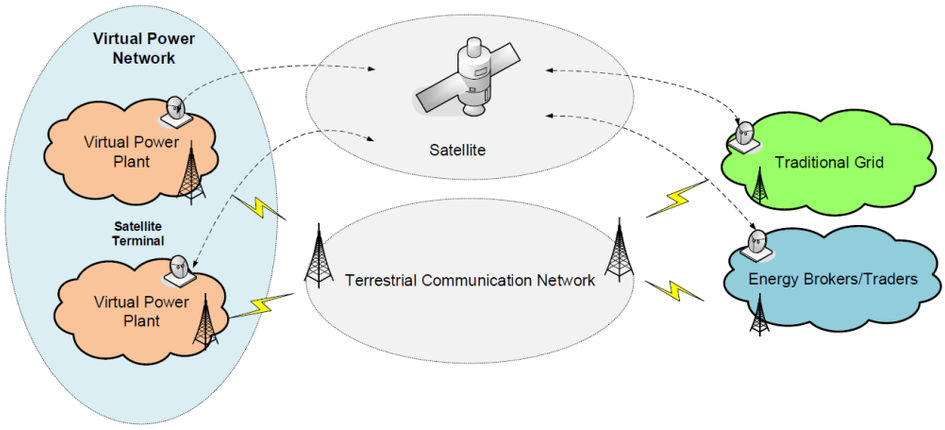


Figure 4: Schematic for Virtual Power Plant

IITM and SITARA

SITARA is split in 5 work packages each focusing on ways to address separate aspects of the project. IITM is responsible for the 2nd Work package which focuses on developing predictive models for consumer behaviour. Prof-Swarup and his team have analyzed data sets in Virtual power plants consisting of renewable energy and storage to predict electrical behavior and cost behavior. The group have identified key variables which significantly factor in when considering the load behaviour and have developed a robust prediction algorithm based on artificial neural networks.

Artificial neural networks roughly mimics the brain while it tries to ascertain the mathematical relationship between the final observed variable and the parameters.Parameters included where

- **Calendar variables**: Like the day of the week, whether it is a weekday or holiday and hour of the day which influence energy forecasting significantly.
- **Weather variables**: Climatic conditions considered include temperature, humidity, wind chill index, illumination,rainfall, precipitation, cloud cover and some special events like typhoon or sleet occurrences.
- **Holiday effects**: Local events, including holidays and festivities, also affect the energy demand.

These events may lead to either an increase or decrease in demand.Influences of these events are usually local.Random events and disturbances such as abnormal consumption behavior, idiosyncratic and social habits of the individuals account for the randomness in the final data. This energy forecasting model was used to predict the consumption pattern in Sydney of the year 2010. The past hourly load pattern and temperatures data of Sydney was obtained for the years 2006-2009. This was used to “train” the neural network,that is to rigorously calculate the relationship between the energy load and different parameters.

The model was able to forecast reliably onto the test set and thus could be used as the prediction engine in SITARA. Based on this analysis Prof. Swarup and his team have also proposed dynamic pricing schemes., ie pricing based on which cluster the consumer falls into, is it the heavy usage end or the nominal usage end and which part of the day is are they in.

Much integration of various work modules needs to be done.In the larger scheme of SITARA IITM’s contributions stand as an integral component. But many knobs and gears need to be turned before SITARA can truly mark an impact on the current grid

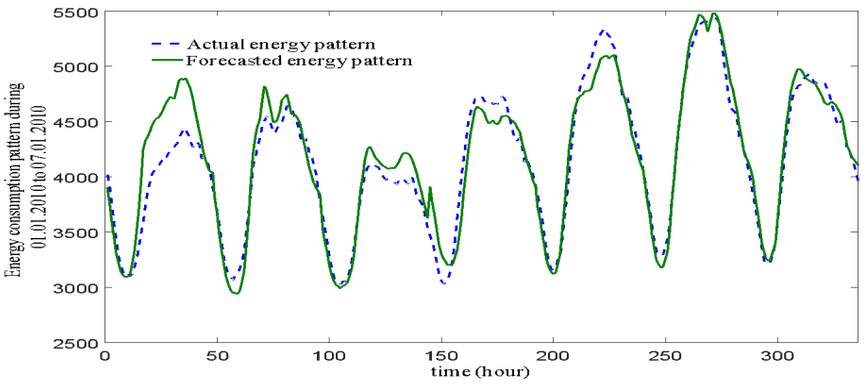


Figure 5: Comparison of Prediction to Actual

scenario.In part SITARA also aims to train Indian electrical engineers in aspects of the smart grid technology.Student exchange programs between collaborating universities have seen productive exchange of ideas and skills cross international borders. The project has a major part of work coming ahead and we hope we come one step closer to a better smarter grid when it finds completion.

Prof. K. Shanti Swarup received his M.Tech degree in Power Systems and Control Engineering from REC (NIT) Warangal. He obtained his PhD in Electrical Engineering from IISc Bangalore in the field of Power Systems and Artificial Intelligence. He has worked in Advanced R&D, Mitsubhishi Electric Corporation, Japan as consultant and software developer for intelligent power management systems. He has wide industrial and academic experience in India and abroad.His primary research interests at IIT-M are in the areas of Power System Modelling,Operation and Control and Distributed Artificial Intelligence.

Meet the Author

G Soorya is a third year chemical engineering student. He is an avid reader of popular science and is passionately curious about ”networks,links and connections”. He is particularly interested in Systems Biology,Circuit-design and research-spun off entrepreneurship.

Sacred Moorings

Figure 6: South Canara

The number of city-dwellers in the world is continually growing, especially in developing countries. It is believed that the urban population in Asia will double between 2000 and 2030. Urban research has not only put emphasis on megalopolises ie., privileged environments for production and concentration of national wealth, innovation and talent, but also on critical societal and environmental problems. The SUBURBIN project was started with the call for a deeper understanding,an attempt to draw the line between rural and urban, between administrative status and functional reality.

Nestled between the Western Ghats in the East and the Arabian Sea to the West, South Canara's trade based economy is intensively connected through the state and associated to wider connections: northward to Goa and en route to Bombay, east to Bangalore via the Western Ghats, and south heading to Kerala. While the Konkan Railway is a significant connector, its disconnection in the south is claimed by some to be the result of the political lobbying of the powerful bus companies. It is here that Dr. Solly Benjamin carried out his research work exploring coastal Karnataka's territories as multiple epistemologies. His research puts forward a threepronged argument beginning with socially and institutionally embedded complex configurations in South Canara to form relational spaces. Secondly, he looked at land, as both a site and a realm embodying history,attached to forms of property control and transfer,with cultural meanings built into its geography. Thirdly, he analyses the fishing economy of

Maple as a trans-national space — a reminder of this region's trading history with East Africa and South-East Asia, and China.

The 'Aliya-santana' form of inheritance passes landed property to the maternal nephew instead of one's progeny – and is seen to be critical in maintaining their parcels intact to avoid 'fragmentation'. As a long standing social practice, this was recognized as law by the court system as far back as 1843 in British India.The first rule guide in English was published in 1864 by the German Press Mission in Mangalore.An important issue here is that property is seen to be female, while honor (a practice of its management as a title located in the Bhoota) is male centered. Within this, the Bhoota, forms a 'title' to that 'sta-ana'. In Bunt houses it is common to find a room dedicated for the bhoota.

However, the tenancy legislation in 1972 with amendments in 1978 sought to abolish mulagani and chalagani tenancy systems and establish mulagenidars (tenants) at the cost of the mulgars (landlords). By 1982-83, these had extensive impact and destabilized the bunt chieftains' access to agricultural surpluses. Their large plots were alienated into smaller parcels giving their control and surpluses to the Billavas who formed their militia and Poojaris castes. Many middle class Bunts and other non-Brahmin groups found their way to Bombay seeking employment in the Bollywood film industry or in the small restaurant business ,'Udupi Hotels',working under South Canara Brahmin owners. Many others, the Shetty of the Bunt middle castes joined the underworld involved in smuggling.

An analysis of transport and connectivity, following this, traces their evolution since the early nineteen thirties to emphasizes ethnic and families lobby to engage with higher public authorities on issues of regulation and infrastructure. Here, Dr. Benjamin cites the example of the CPC bus company,which under its patriarch VS Kamath, spurred the Canara Springs as a large service workshop led by the Kudva family in 1922.This was part of its maintenance division.Incredibly, due to the shortage in the supply of imported leaf springs, they started to fabricated these out of imported 'spring steel' in a spring manufacturing unit at Maroli, Mangalore in 1949. By the 1960s, the patriarch V S Kudva (1899-1967) started a steel-smelting factory inaugurated by the Prime Minister, Lal Bahadur Shastri. It was the first time that an Indian entrepreneur dealt with the shortage of spurred metal using innovative processing.VS Kudva is also credited in establishing few more companies: In 1938, he established Canara Sales Corporation Ltd, in 1941 Canara Motor and General Engineering Company, and in 1947 he started Canara Tyre and Rubber Works Limited. The transport economy saga demonstrates the role of particular families. His actions were territorialized in South Canara and integrated wider linkages into drivers economic logics co-constituted in complex ways.

Today, Malpe is one of the largest harbors dedicated to fishing with more than 2,000 boats (some larger ones costing more than INR. 50 crores each) that has lot of allied activities such as cold storage, freezing plants for ice manufacture, refrigerated trucks, mechanical repair, and an extensive production of various types of fishing nets. This expansion of the fishing trade is also due to the 50 years old extensive form of associations and federation that started as marketing bodies of dry fish. Later, during the 1980s, it went onto organize, lobby, and politicize issues to claim funds, subsidies and attention at various political levels. In the grand sweeps of history, the local configurations, specific to the South Canara and open to the world, seems almost natural – shaped by 'locational' advantages. It is often easily forgotten that constructed spaces is supported by historical resources, by inherited properties and long-distances linkages. The 1976 Census of Karnataka takes note of the 'Chinna Bhootas' in Basrur near Kundapura. The Regional Resource Centre, an important library and archive on South Canara's history and culture, includes several historical texts that underlie Malpe transoceanic routes.

Since the 2nd century AD, notably toward the west, Greece and Rome. Sea routes we're existing even before during the 11-13th Century AD, as attested by traces of trade between the ancient port of Basarur (Basrur near Kundapura) and the ancient Greece but also with China and other locations in

South-East Asia. In more recent times, South Canara's connections with the Gulf and beyond, to Europe and North America, as well Australia and Singapore, have played a key role in opening up such new transnational opportunities in varied aspects, notably around fishing and cashew nut processing. These logics can be relatively autonomous, at times contesting in relationships. It reveals South Canara as a site constituted of guardian spirits and spirit possession, and deeply imbibed in real estate practices.

Dr. Solomon J. Benjamin is an associate Professor, Dept. of Humanities and Social Sciences. He obtained a PhD in Urban Studies and Planning from MIT and has been a fellow at the University of Gottingen, research associate at the French Institute Pondicherry (FIP), and a professor at the Manipal School of Architecture and Planning (MSAP) before taking up his current position. He is on the editorial board of Antipode (a journal of critical studies)

Meet the Author

Ananth Sundararaman is a final year undergraduate student in the Department of Civil Engineering. He loves to travel, quiz and play football. He loves to watch Liverpool play and his biggest fear like Asterix, is the sky falling on his head.

Computing Outside the Box

Computability

"What do you think you can compute?" Dr Kalpana Mahalingam and Prof R Rama , of the Department of Mathematics, ask me at the outset of our meeting to discuss their recent project. They explain that computability is the ability to solve a problem in an effective manner. And in their line of work, they develop some mathematical models and formalise the idea of computability.

When a layman thinks of computation, his first worry is whether the problem can be solved in a practical amount of time, with the methods used. But the more basic question is whether the problem can be solved or not. This solvability depends on how intractable the problem is, or the magnitude of parameters or constraints that the problem depends on. As a basic example, consider adding two numbers. We expect to receive the answer immediately. Now, if we increase the number of numbers we wish to add, the time required increases. And as the number of parameters are increased, we may arrive at a point, such that we cannot expect anything from the computer anymore.

This happens because of the manner in which a computer looks for solutions. Given a problem, suppose the possible set of solutions consist of, say, a million possibilities, from which only one or two are the correct solutions, the computer has to sift through all the possibilities in a sequential manner. What makes matters worse is that it is not known whether a solution exists or not, in the first place.

The professors tell me that in theory, one can say which problem can and cannot be tackled by a computer in a practical amount of time, and their classification has been done. If we know which class our problem falls into, then we know whether it can be computable or not by a computer.

New Methods of Computation

But what happens if it is known that a problem cannot be solved by a computer? Are there other ways to solve the problem? Can we incorporate other ideas to solve these problems efficiently? What if we solve such problems outside the computer?

Scientists turned to biological systems in search for computing machines.

In 1987, Tom Head came up with a theoretical model in which the splicing operation of DNA molecules could be used to simulate computing models. Another scientist, Leonard Adleman, carried out a biochemical experiment using DNA strands, to solve a 7-node instance of the traveling salesman problem. In the traveling salesman problem there are a given number of cities, of which some are connected by routes. The traveling salesman starts his journey from one city, and has to go through all cities exactly once, and finally come back to the original city. Whether such a path exists, given a certain map with certain connections is not known. This is because we do not have a complete characterisation of this problem. This means that this question cannot be answered based on certain properties of the map of cities. The only way to tackle such a problem is by brute force checking, that is by checking through all the possibilities. A computer does this in a sequential manner, which is computationally expensive.

Adleman's experiment is important, because it showed that biological systems can be used to solve hard computational problems. So far, mathematical tools had been used to understand biology, but this instance showed transfer of techniques from biology to mathematics. And this is truly exciting, as could be seen in the enthusiastic manner in which both the professors smiled back at me.

In Adleman's experiment, the key to arriving at an answer is that the "biological computation" happens in a parallel manner. The roadblock that was being faced when using a traditional computer was its sequential problem solving technique, which is not faced here.

Figure 7: The Molecular Computing Group

The Project

This kind of parallel computation technique is the motivation behind Dr Kalpana and Prof Rama's project "Mathematical aspects of computability models based on different data structures". As part of this project, they are studying some aspect of membrane computing and combinatorics of words.

As part of the project, the professors and their team looks at data structures (for example strings, arrays), and how they behave under the action of given control structure. A control structure is an instruction to be applied to a data structure. Controls dictate whether a data structure can be computed or not. And having different controls gives different levels of computability.

This project is funded by the Department of Science and Technology.

Molecular Computing

Membrane computing is a type of molecular computing. In this model, the computation components have a hierarchically arranged structure. These components are allowed to communicate with each other with certain restrictions. Here, the data structures under consideration are 2-dimensional arrays. The instructions given to the array data structure can ask the arrays to expand or contract in one direction or both directions.

This computational technique is being used to study how different pictures (with certain properties e.g. hollow triangles) can be generated, and how a robot can move on a grid (given certain sets of instructions).

A challenge in looking at parallel computation techniques is dependability: if computation is taking place in a parallel manner, how does one know whether the parallel instances of the computation will halt? This depends on the control structures being used, and is under further study.

Combinatorics of Words

A word or a string is another form of data structure. It is a concatenation of a given set of symbols. In this part of the project, the aim is to understand the structure of words. This is done by mapping words to matrices, called Parikh matrices. The elements of these matrices depend on the structure of the words. The question that they are studying is how to characterise words by looking at their corresponding matrices. This is a reconstruction problem, which is computationally difficult.

Combinatorics of words is an important com-

putability aspect that needs attention and needs to be developed. This technique can be used for bioinformatics, and to decode languages.

The Team

The Molecular Computing Group is comprised of Prof R Rama, Dr Kalpana Mahalingam, Dr Manasi Kulkarni, Dr W I Sureshkumar, Prithwineel Paul, Sivasankar M, and Harshita Rathore.

Dr. Kalpana Mahalingam is an assistant professor in the department of Mathematics. She has 14 years of experience in teaching and about the same in research. Her research interest lies in DNA computing, theory of codes, formal language theory and combinatorics of words. You can know more about her research at https://home.iitm.ac.in/kmahalingam/

Prof. Rama R is a professor in the Department of Mathematics. During her 25 years of experience in research and teaching she has worked in topics like in DNA computing, Membrane Computing and Contextual Grammars, Cryptography and Picture Generation. You can know more about her research at http://mat.iitm.ac.in/home/ramar/public_html/index.html

Meet the Author

Malayaja Chutani is a second year PhD student in the Physics department. She is interested in complex systems, and currently is on a mission to become proficient in Python.

Designing ISRO Launchpad

"There are some who question the relevance of space activities in a developing nation. To us, there is no ambiguity of purpose. We do not have the fantasy of competing with the economically advanced nations in the exploration of the moon or the planets or manned space-flight. But we are convinced that if we are to play a meaningful role nationally, and in the community of nations, we must be second to none in the application of advanced technologies to the real problems of man and society." - **Dr. Vikram Sarabhai**

Religion is one of the last places where one can expect scientific and rational thought to be encouraged, much less space exploration. But remarkably, this is where the story of India's space story started – in a church in Kerala. The clamour of scepticism and disapproval of India's Mars Mission focused on how wasteful expenditure on space was for a developing country like India. But what most critics fail to see is the indispensable role played by ISRO in the India story through the development of communication facilities. Satellite television now covers 100% of the Indian landmass and ISRO has also setup 1.75 lakh satellite communication terminals, which support services such as village telephony, data and broadband connectivity, and Automated Teller Machines for banks. The projects also aim to establish smart schools and classrooms along with telemedicine networks across India.

Many of ISRO's missions and launches have relied on support from other countries such as Russia and self-reliance lies high on the organisation's list. The development and testing of India's indigenous Cryogenic engine has been an ongoing pursuit at ISRO for the past 20 years and one which aims to be culminated in 2016 with the launch of the GSLV Mark III. The absence of India's own cryogenic engine has seen a reliance on other agencies for launch of heavy satellites. The success of GSLV Mark III is also critical for India's ambitious manned missions and the recent success of the testing of the cryogenic engine signals a major breakthrough in advancing India's space reach.

With more than 50 space missions planned for the next five years, ISRO is working to set up a high-tech third launch pad very soon at its space centre in Sriharikota.

Accordingly, the new launch complex will provide complete support for vehicle assembly, fuelling, checkout and launch operations. Apart from these, it will have facilities for launching sounding rockets meant for studying the earth's atmosphere.

An official seeking anonymity said the new launch pad would be designed for launching Geosynchronous Satellite Launch Vehicle Mark III (GSLV Mk-III), carrying heavier satellites, as well as reusable launch vehicle, India's own version of a space shuttle.

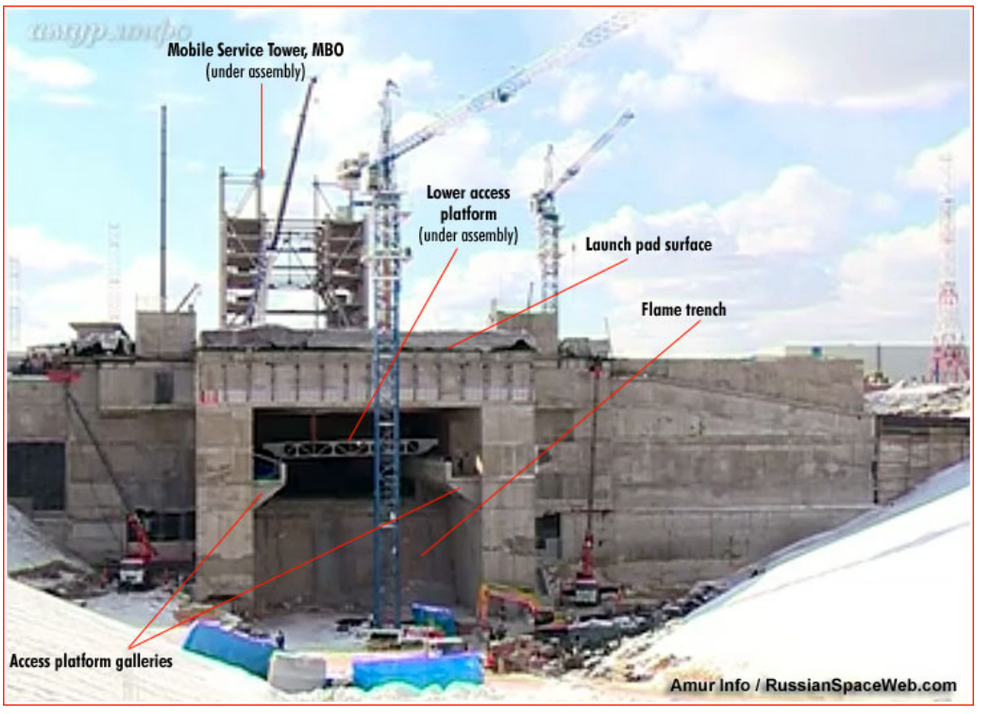
With the design of the new launch pad underway, Dr. Sundarajan T, a professor at the Thermodynamics and Combustion laboratory, and his lab are working on the simulations of defector duct to suit the requirements. The lab had previously worked on the simulations for the High Altitude Testing (HAT) facility in Mahendragiri where the new cryogenic engine testing had taken place. After a series of endurance tests and the latest successful HAT test, the engine is now ready.

A jet exhaust deflector is a structure that redirects the high energy exhaust from a jet engine to prevent damage and injury. The structure must be strong enough to withstand heat and high speed air streams as well as dust and debris carried by the turbulent air.

Speaking about the design of the jet deflector duct, he talks about all the design constraints involved in the process. A launch pad generally contains a fixed or mobile service structure, which provides one or more access platforms to inspect and maintain the vehicle, and an umbilical structure which provides the vehicle with propellants, cryogenic fluids, electrical power, communications, and telemetry prior to launch.We need to make sure that the plume from the jet doesn't hit the umbilical tower. The jet deflector duct has to be designed in such a way that all the gases from the plumes are discharged into the atmosphere without getting trapped, which otherwise would lead to explosions.

The speeds with which these gases are expelled are very high, around 2000-3000 metres per second. At such high speeds the plume coming out produces shock waves. Ducts are designed suitably directing the fumes and reducing its impact. Intense noise and vibrations are one of the leading factors contributing to structural damage. One way to reduce impact is to spray huge amount of water which absorbs energy, thereby containing the noise. The method is called the Sound Suppression Water System. The water is not only used to cool the structures from the intense exhaust, but also to dampen the sound vibrations coming from the main engines and solid rocket boosters. Any simulations for the design also takes into account the effect of moisture which is sprayed in. Computational Fluid Dynamics (CFD) simulations enable the team to model the entire process while varying parameters to see its effect. CFD is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by constraints.

There are a lot of design variations possible. The new launch pad is being made to withstand heavier payloads. The jet deflector is also be designed to be multi-purpose so as to handle different kinds of engines, which also use different compositions of fuel. If all the constraints are satisfied then we move onto the testing phase. At ISRO nothing is taken for granted directly from the simulations. The first phase of testing is called the cold testing, where high pressure air or nitrogen is distributed in through the 1/10th or 1/20th scale of the model. These are also simulated using CFD and then compared against the experimental results. Once this test is successful we move onto the hot test where instead of nitrogen we take kerosene and burn it to produce hot gases. Generally cold tests can be done multiple times be-



cause there is an abundance of nitrogen for the cold tests, but hot tests are done only one or two times because it may lead to damage of the rocket over multiple use and depletes a lot of resources. While the testing phase is underway, feedback from the tests are weighed into consideration and redesigned over many iterations.

A dream which began in a quaint church in Kerala now stands at the precipice of establishing India's dominion over the world through its venture into space. IITM has a long proud standing tradition of working closely with ISRO, evident from the numerous successful projects undertaken. Owing to this the institute has the ISRO – IITM Space Technology CELL sponsored by ISRO. The opportunity to work in space technology is now just a small leap away, thanks to IIT Madras. After all it's just rocket science.

Prof. Sundararajan T is an alumnus of our very own IIT Madras Mechanical engineering department. He received his M.Tech degree in Mechanical Engg. & Applied Mechanics from Univ. of Pennsylvania. Where he subsequently obtained his Ph.D in Heat transfer. His lab works on a number of industrial sponsored projects from both domestic and abroad. He primarily works on Heat Transfer, Spray Combustion, Reacting Jets, CFD.

Meet the Author

Rupesh Kumar is a third year mechanical engineering student. He is a science enthusiast in general and is into a variety of technological domains. He particularly likes material design, machine mechanics and modelling. Science writing is new for him and he is up for the challenge. He is a huge sci-fi fan and may the force be with him.

Combating Cancer - Scaling Heights by Scaling Down

Suppose we are playing a combat game and we see an army attacking ours, wouldn't it be convenient if we could somehow sneak in some of our soldiers into the enemy camp and start fighting them from within? If the opponent army is actually a mass of cells multiplying without control, eating up important nutrients that we will otherwise use for our survival, it'll be called cancer. So by having soldiers who could fight this army from within, we'd have an advantage. This is exactly what Dr. Arivazhagan, a Post Doctoral Fellow of the Department of Metallurgical and Materials Engineering, is trying to achieve.

As we enter the Research Scholars Room at the Metal Forming Lab located beside the new Campus Cafe canteen, he greets us with an enthusiastic smile and there is an aura of confidence around him that portrays his proficiency in this field. His research involves making what are called nano-particles and infusing them with drugs to treat cancer. Cancer cells are targeted using these nano-particles so that the drug is delivered efficiently.

To understand more about the research, we must first understand what nano-particles really are. The word "nano" hints that it deals with particles at the nano-scale. The one foot scale we are better familiar with has divisions that go up to one millimetre, which is one thousandth of a metre. One thousandth of a millimetre is a micron. We're now on the scale of a human hair, which is about 40 to 50 microns wide. One thousandth of a micron is a nanometre. This is the nano-scale. It's difficult even to imagine such a small scale because we don't see particles of such a scale with our eyes. Large molecules and molecular clusters which make up many things around us belong to this scale.

Things get very interesting when we go to such small scales because by tweaking materials at this fundamental level, we get highly targeted and specific properties. Nano-materials have applications in many fields stretching from physics to biology and beyond. Medicinal applications exemplify the usefulness of nano-materials best because the biomechanisms that drive all living beings run on such scales. The applications of bio-nanomaterials are thereby vast.

Richard Feynman once said, "There's plenty of room at the bottom" while speaking about nanomaterials. The future looks pretty bright down here.

According to a report released by the International Agency for Research in Cancer which comes under the World Health Organisation, there were 14 million new cases of cancer in the year 2012, and the number is increasing. "There are about fifty types of cancer and lung cancer has the highest number of cases", says Dr. Arivazhagan, "Hence, I am working on finding a cure for it."

Common ways to treat cancer involve radiation, chemotherapy (extremely potent chemical drugs) and surgical removal of the tumour. Often two or more of these techniques are used at once. But there are other, more specific ways to treat cancer that can target only the cancer cells. In chemotherapy, the drug enters the bloodstream and affects all the cells that divide very quickly. Since cancer cells also exhibit this trait, they get destroyed. But there could be healthy cells that can be affected by the drugs. The cells in the hair roots and bone marrow for example divide more rapidly than many cancer cells. That is why this treatment leads to severe side effects, hair loss being the most benign of them. In targeted therapy, some properties of the cancer cells that are unique to them are used as criteria to select them for treatment. Hence, by employing nano-

particles, we can have another medium of drug delivery which doesn't rely on the bloodstream entirely. It is possible to both coat and infuse nano-particles of the right size with drugs and deliver them to targeted cells. They should be small enough to not clog capillaries, but big enough to get imbibed into the cell. These particles are called nano-carriers and they have dimensions of about 50-100 nanometres. Due to its efficiency in drug delivery and fewer side effects, research on such drug delivery systems is very important for the future of cancer treatment.

In Dr. Arivazhagan's research, the nano-particles are made of Boron Nitride (BN), a ceramic. BN has attracted considerable attention as a nano-material because of its structural similarity to the more famous carbon nanomaterials. On one hand, BN is similar to diamond in its hardness and is used for sample cutting, but on the other hand, experiments suggest that it is a bio-compatible material. Dr. Arivazhagan explains the counter-intuitive properties. "It's a carrier", he says, "We need large surface areas for carriers and that doesn't depend upon a material's hardness". Depending on whether the drug is hydrophilic (water loving) or hydrophobic (water hating), we must design the nano-carriers by tuning the material at the nano-scale. We can make nanowires, nanotubes, and other 3D structures. In this research, spherical particles are being produced.

Figure 8: Dr. Arivazhagan with his Chemical Vapur Deposition (CVD) apparatus

The nano-particles are synthesised by a technique known as Chemical Vapour Deposition (CVD for short). We observe as he takes us around the lab, explaining the working of the CVD machine. From the name Chemical Vapour Deposition, it's understood that the required product is deposited from a vapour state. The product is formed from a reaction between a compound that easily evaporates and can produce the product by reacting with other gases. In the case of BN nano-particles, the volatile compound taken is Boron Trioxide and it's made to react with Ammonia. White BN nano-particles are deposited after the reaction. Liquid Ammonia and Boron Trioxide are first made into a mist using sound waves with frequency exceeding the human audible limit, in a machine called ultrasonic nebuliser. The mist is made to react at a temperature of around 1100 degrees inside a vacuum. "It takes about two and a half hours to reach that temperature and then the deposition takes place for thirty to forty minutes", Dr. Arivazhagan says enthusiastically. After leaving sufficient time for the sample to get deposited, the vacuum is turned off and the sample is collected. The size is controlled by changing the conditions

of the reaction. "We need a lot of sample to perform the analysis because there is an amount of trial and error involved in the analysis stages" he comments. The collection of the sample is being carried out presently, the next step is analysing the properties of the obtained nano-particles in a series of steps called characterisation.

Once the BN nano-particles are found to be ready, experiments will be conducted with curcumin as the cancer therapy drug. Curcumin, a component of turmeric, is a natural cancer treatment drug often used for lung cancer therapy. The experiments involve analysis of four sets of sample lung cancer cells — one set without any added drug or delivery system, one set of cells treated with curcumin alone, one set with cells treated with BN nanoparticles not infused with curcumin, and one set of cells treated with BN nano-particles infused with curcumin. From the results of these analyses, which includes the measurement of cytotoxicity or the ability to kill cancer cells, it'll be known if such a drug delivery system is viable or not. "I chose curcumin because it's cheap", Dr.Arivazhagan observes, "Since it's difficult to manufacture nano-particles, it's important that the other components are less expensive so the treatment can be made affordable."

Nanomaterials is a truly interdisciplinary field with a combination of Physics, Chemistry, Biology, Materials and Engineering involved and the future looks promising as the conventional boundaries are dissolving in the field. As far as biological applications go, this is the right moment for a revolution and we are part of one now. "If the results are good, we can even patent it", Dr.Arivazhagan remarks with a smile. Success of this research will mean there's a possible and accessible treatment available for lung cancer in the future, and that is his dream. We hope that his dream comes true.

Prof. S S Bhattacharya is a professor in the Department of Metallurgical and Materials Engineering. He did his undergraduate and doctoral studies in the same department. His research interests are Nanocrystalline Materials, Superplasticity of Materials (Analytical and Experimental), Superplastic Forming, Metal Forming, High Temperature Deformation Behaviour of Materials, and Advanced Materials Testing. You can know more about his research at https://mme.iitm.ac.in/ssb/

Meet the Author

R Mythreyi is a second year undergraduate student of the Department of Metallurgical and Materials Engineering. Having got a glimpse of the world of materials science,she plans to pursue research in the field. Her compelling love for books and music tends to make her reading list and playlists surpass the borders of conventional genres. She also has a keen interest in exploring ways to optimise the use of technology. Oftentimes, she finds solace in writing.

The Science of Whispering Galleries

One of the more curious and architecturally significant feature of the St. Paul's cathedral in London is the whispering gallery in the central dome. This phenomenon was first discovered by Lord Rayleigh in 1878 at the St. Paul's Cathedral in London. He observed that when present at one end of the circular dome, a person standing at the diametrically opposite point over 30m away could hear words spoken in mild tones. Later, this phenomenon was explained by the theory of resonance based on wave interference. The theory utilises the ability of sound waves to interfere with each other to result in higher or lower pitches. Sound waves emanating from the source travel along the curvature of the enclosure and return to the initial point only to interfere with the tail of the wave. This results in the formation of locations of high pitch due to constructive interference and low pitch from destructive interference and hence, every position along the curved wall has a specific pitch associated to it.

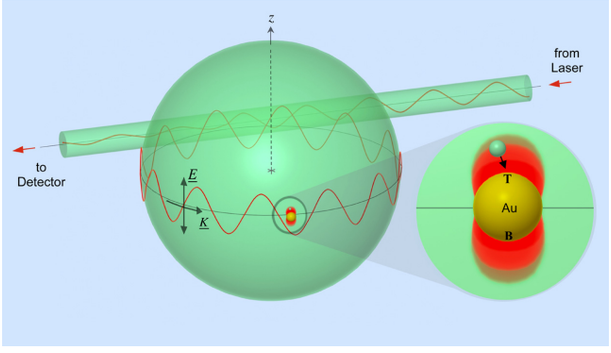


Figure 9: Plasmonic Enhancement of Whispering Gallery Modes

This is why a person standing on one end of the room can hear whispers uttered at the other end as the sound loses intensity slowly (linear) when compared to the fast drop in intensity in open space (quadratic). This set up of high pitches are known as "Whispering Gallery Modes" (WGM) and have been discovered and applied in solid cylinders and spheres as a method of non-destructive testing to evaluate properties of materials. They have also been found to exist in various cosmological systems such as the vibrations of the Earth after big earthquakes and in the pulsations of rapidly rotating stars.

However, in recent years, it has been found that light also exhibits similar properties due to its wave nature similar to that of sound. In the case when monochromatic light is passed parallel to a glass microsphere, grazing the sphere, it undergoes the same phenomenon observed above with sound where the point of grazing acts as a point source and the light waves interfere to produce similar formations of high and low pitches or WGMs. However, the loss of energy over time in the case of light is a very small fraction compared to that of sound and hence, the WGM setup can last for a longer amount of time as shown by the Quality factor for light which is around 10^{10} compared to 10^4 found in acoustics which translates to a million times more time required for the waves to decay.

This theory has been put to use in designing micro resonators that bounce laser light along a circular glass ring also known as "waveguides". These microresonators are mainly used to manufacture WGM biosensors which help in the detection and analysis of biological nanoparticles (less than the size of a single virus). The particle is attached to the ring in which WGMs are setup, which in turn disturbs the

light wave and produces a change in the resonant frequency. This disturbance can be picked up using a detector and the data can be used to calculate the size of the particle. The design goal of these biosensors were detection capabilities of sizes less than a single virion.

Figure 10: St. Paul's Cathedral Whispering Gallery

This phenomena observed with light has been put to use in designing micro resonators that bounce laser light along a circular glass ring. However, various other shapes such as spheres and cylinders can also be used and all these structures are commonly known as "waveguides". These microresonators are mainly used to manufacture WGM biosensors which help in the detection and analysis of biological particles of sizes larger than that of a single virion such as Influenza A. The biosensors have a tapered optical fiber along the surface which drives the resonance. The optical fiber also helps detect the change in light frequency as the change draws more power from the fiber, resulting in a dip in intensity which can be used to calculate the change. This ability to detect frequency change is important as the resonant frequency of the biosensor changes when a biomolecule is introduced on the surface of the microresonator due to Raman Scattering of the light which can be detected using the optical fiber and used for analysis of the biomolecules properties.

However, sizes less than that of a virion could not be calculated by the standard microresonator as the fluctuations in frequency produced by smaller particles were found to be less than the error produced by thermal fluctuations in the resonator and fluctuations in laser frequency. But owing to the needs to detect particles of smaller sizes such as proteins for bio engineering, the design goal of these biosensors were detection capabilities of sizes less than a single virion.

Hence, it was needed that the shift produced by these particles be enhanced to the detectable range. This was achieved by the use of surface plasmon particles introduced on the surface of the sphere. Surface Plasmon particles undergo resonance when the electrons of the particles have a natural frequency equal to that of the incident light on them. This results in the oscillating electrons to produce electromagnetic fields of their own which in turn enhances the effect produced on resonant frequency by the biomolecules. This enhancement can be used to bring the change in frequency to detectable ranges and by compensating for the enhancement, we will be able to calculate the sizes of the smaller particles.

This is where the research of Prof. Bisht comes into play. He found that doping the microsphere with a dye around the sphere results in a large enhancement of the Raman scattering signal which is used to analyze the biomolecule. Raman scattering is a phenomenon where a molecule scatters photons of lower frequency than that of a photon which is incident upon it. This occurs when light of a certain frequency hits the particle and excites it into a higher energy level and another photon of lesser frequency

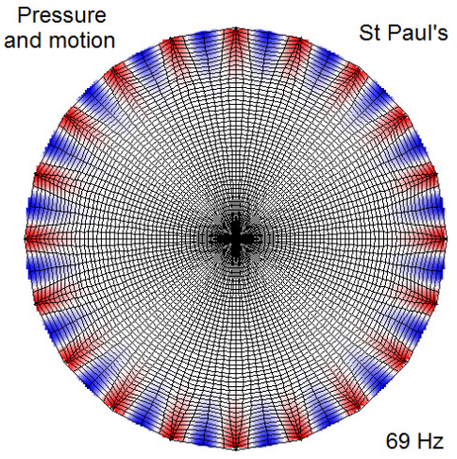


Figure 11: Visualization of Whispering Gallery Mode (WGM)

is released when the particle goes to a lower energy state. However, the Raman scattering signal is very weak. It has been enhanced through many mechanisms like "Resonance Raman scattering" which occurs when the optical energy at a mode matches that of the resonance frequency of the material being observed and "Surface Enhancement" as explained above.

Prof. Bisht and his team have also found that by carefully selecting the parameters, it is possible to enhance the Raman signal by nearly two orders of magnitude and also deduced that the enhancements depend on factors such as pump wavelength and the refractive index of the microsphere. "With the Raman scanner, a hand-held device weighing less than 250g, it is now possible to scan a surface non-intrusively and in real time to detect super microscopic traces of a wide variety of molecules from pathogens and drugs to explosive chemicals," says Prof. Bisht.

Prof. Prem B Bisht received his PhD degree in the field of physics titled Time-domain spectrosocopy of the excited state from the Kumaun University in Naini Tal, India. He has more than 18 years of teaching experience in the Undergraduate and Post-graduate level at IITM. He is also a visiting researcher in many universities abroad. His research interests include the ultrafast dynamics of the excited state and the generation and characterisation of the femtosecond pulse.

Meet the Author

Anand Krishnan is a third year undergraduate student of the Department of Chemical Engineering. He loves endurance spo He led the water polo team of IIT Madras in the recent Inter-IIT Sports Meet and also won the Best Swimmer Award.

Thanks for Reading

Readers of Immerse include faculty members and students at other IITs, IISERs and NITs, where we will send copies, just like we do every time. Apart from the online audience, of course.

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

If you found this issue exciting and would like to contribute next time, be it as an editor, writer, photographer or graphic designer, please get in touch with us at the same email address. We will let you know how you can contribute.

In any case, if you have anything to say, be it praise or criticism, we welcome your views. Let us know by email or comments on our website.

t5eiitm.org/immerse

THE FIFTH ESTATE

The Students' Voice of IIT Madras

t5eiitm.org/immerse

Immerse 2017, Issue 5

iitmadras

SHAASTRA 2017

THE SPIRIT OF ENGINEERING

CATERPILLAR®