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COMPUTATIONAL AND DATA SCIENCES

THE OFFICIAL NEWSLETTER OF IISc BANGALORE, CDS DEPARTMENT

cds.iisc.ac.in

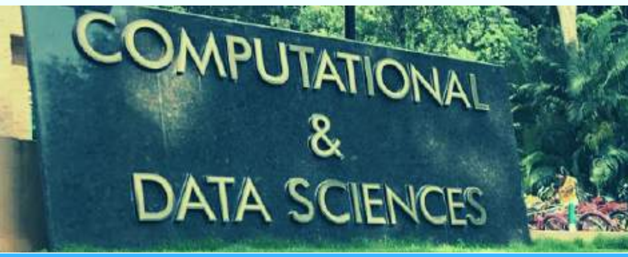
The Department of Computational and Data Science presents the fourth issue of the first volume of the Newsletter series! Through this newsletter, we hope to give you a glimpse into our little world- what we do, where our interests lie and what we hope to achieve. The Department of Computational and Data Sciences (CDS) is an interdisciplinary engineering department covering the broad research areas of computational science and engineering, and scalable computer & data systems.

Our journey began in 1970, when the Computer Centre of the institute was established as a central computing facility. In 1990, it became Supercomputer Education and Research Centre (SERC), providing computing facility to the faculty and students of the Institute. A master's degree programme M.Tech in Computational Science, one of the first of its kind in India, was started by SERC in 1999. Therefore about 16 years later, CDS was formed in December 2015 from the academic wing of SERC.

From the Chair's Desk

It is our pleasure to share the activities of the department through this newsletter. The goal of this publication is to highlight our research activities, achievements of faculty, students and project staff and new initiatives.

The main motive of this news digest is to reach out to the world outside the campus including student , faculty, corporate and any individual who is interested in computational and data sciences. Ultimately, we hope to build a highly connected, a truly inter-disciplinary society and, of course, help us to network.



Faculty Interview

- with Dr. Soumyendu Raha

Q1. Can you tell us about your academic Journey?

I studied Civil Engineering in Jadavpur University in the late 80s, and even obtained a Structural Engineering MTech from IIT Bombay. Then I did freelancing writing small structural engineering codes and computer models for a year or so. In 1994 I was offered the Sommerfeld Fellowship by the graduate school at University of Minnesota. I did my MS in Computer Science and PhD in Scientific Computation. I was in the Computational Mathematics Group which was one of the top 3 Groups of the US at that time. I worked on Constrained Dynamics for my thesis. I liked taking theoretical computer science courses and I was lucky to be taught Combinatorial Optimization by Eugene Shragowitz who was a direct student of Nobel laureate Leonid Vitaliyevich Kantorovich. The University at that time was frequently visited by Engineers from Cray and on sharing my ideas I was invited to work on the Cray X1 multistreaming processor during 1997-1998; that machine became as the worlds fastest machine around 1999. Back in those days there was no multicore design but we put 8 inter communicating vector pipelines on the processor acting similar to 8 cores; these processors were connected in a massively parallel toroidal architecture. This machine was vectorized as well as massively parallel and was of several Teraflops. Back then I also worked on a Tensor Processing Unit which is nothing but a matrix pipeline. For my thesis I worked on the then open problem on how to partition a Constrained Dynamics Problem as a deterministic and indeterminate part. The dynamic model was a high Indexed Differential Algebraic Equations. My advisor was Professor Linda Ruth Petzold, who was one of the top 5 Computational Mathematicians at that time. After My Doctorate I got a job in the Electronic Design Automation group of IBM New York , where I worked on physical design optimization and circuit simulation algorithms for little more than 2 years. Then I joined as Assistant Prof at North Dakota University. Meanwhile, I was in contact with the Indian Institute of Science, and took a faculty position with the SERC-IISc in 2003 and formed the Scientific Computation lab group.

Q2. Can you tell about some of the projects you are working on?

One interesting topic we are working on is numerical study of constrained stochastic differential equations (SDEs) . As a related topic to we are trying to build what is known as diffusion networks and whether such network can be propagated recursively in a Bayesian fashion. We are also interested in spatio-temporal paths of propagation in Reaction-Diffusion Complex Networks.

On the Systems side we are working with CAD lab and are interested in the information complexity and data flow on the chip.

Q3.Can you tell about the project with ISRO ?

The project we worked on was an application of Differential Algebraic Equations(DAE) and the Rough Paths; the idea is to see what projection would a nominal model like the Kepler's laws would need so that these equations will "match" the data from the Ranging stations from the ground. There are anomalies and disturbances in the motion of a satellite in the space, and this projection tries to capture the Noise from the topology of the data for modeling the anomalies. The Data Manifold being the constraint to the nominal equations of motion being the Dynamical system, this becomes a DAE with the projection as the algebraic part. This projection part is essentially a rough path "learned" from the data and is approximated as a Stochastic Differential Equations(SDE) for prediction purposes. Once the learning is sufficient SDE can be used to predict the position of the satellite, which is needed to be uploaded to the satellite for precision positioning purposes.

Q4. You are working on a wide range of projects from Systems Engineering as well as Scientific Computing.How are you able to Manage diverse fields ?

It all lies in having a good foundation in applied mathematics, discrete maths and algorithms. In course of time one gathers more research experience to form a unified mathematical view of things. This opens the door to diverse applications.

Q5. What made you to choose Academia over Industry?

The academic freedom that an institute like IISc provides; that one can choose one's problems and that there is no restriction to climbing out of one's comfort zone and challenge oneself makes academia more attractive for me. Of course, there are trade-offs such as limitations to building a production system.

Q6. How to keep yourself motivated as a Researcher?

It's not the money, awards or administrative positions that keep you motivated; but the reward of solving a challenging problem and that of exploration and innovation that keeps one going. It is like a kaleidoscope whose patterns never repeat.

Q7. What difference you feel as a researcher in US and in INDIA?

As far as I have seen, the US has more resources and a focused problem solving attitude to science and technology research in most places. This leads to concerted effort toward solving difficult problems as well as making innovations and getting insights into existing ones. My Professor in the US would often stress the inter-disciplinary nature of computational and data sciences by comparing the practitioner to a mercenary who would pick up whatever tools needed to solve a useful problem. This points to the fact that one has to learn new things and climb out of comfort zones. In India, we have a lot of talent and these days, I think, we have become quite competitive with respect to the US. It is not just catching up but in many areas we are cutting our own path.

Q8. Do you have any interests other than Academia?

Yeah I listen a lot of Hindustani and Western classical music. I also used to write short literary pieces; but I am not so active these days. I have Interests in philology and etymology. Of late I have been studying about script evolution particularly that of old historic ones, such as Brahmi etc.

Q9. You are a visiting Researcher to Sobolev University Russia, INSA de Rouen France,Nagoya University Japan. Do you speak any other languages other than English?

"Я немного говорю по русски", yes I do speak some Russian and I learned some German too. I can read Russian language but at a slow pace.

I have an interest in finding Proto-Indo-European roots of words, for example the word weǵ^{h}- meaning to transport from which we have vehicle in English and vaahan in Sanskrit.

Q10. There is a buzzword Machine Learning in Computer Science. What is your opinion on this?

Machine Learning has its limitations. The Machine learning (ML) that you are seeing is 40 years old and within its limitations we are able to get more useful things done thanks to more data and high speed and throughput hardware. I feel that ML is useful when there is no definite mathematical model but there is an intuition on what to look for so that one can tune it to the application at hand with reasonable approximation. Also, Machine learning is not just Deep Networks but there are other areas of ML which are useful, such as topological data analysis and applications of stochastic and functional analyses. Recent works show that Neural Networks are susceptible to even very small adverse perturbations. These limitations are important when creating models.

Q11. What is your advice to young Researchers?

Keep an open mind and if your interested in a problem, identify the gap and don't limit yourself to the tools that you know. There may be tools that can solve the problem more elegantly and efficiently; so go outside your comfort zone and learn and apply these tools to the problem at hand.

Conference Experience

Saurabh Dixit

(PhD candidate @ SCL)

Presented his work at the 9th International Congress on Industrial and Applied Mathematics (ICIAM,2019) held in Valencia, Spain.

Received GARP funding

Held every four years, ICIAM is a leading conference which showcases recent advances in a number of areas of applied mathematics. I presented my work titled Data Assimilation by constraining the nominal dynamics to the observational manifolds, which was jointly done with my advisor Prof. Soumyendu Raha.

The conference featured a number of parallel sessions on a variety of topics including linear algebra, partial differential equations, control theory, optimization etc.

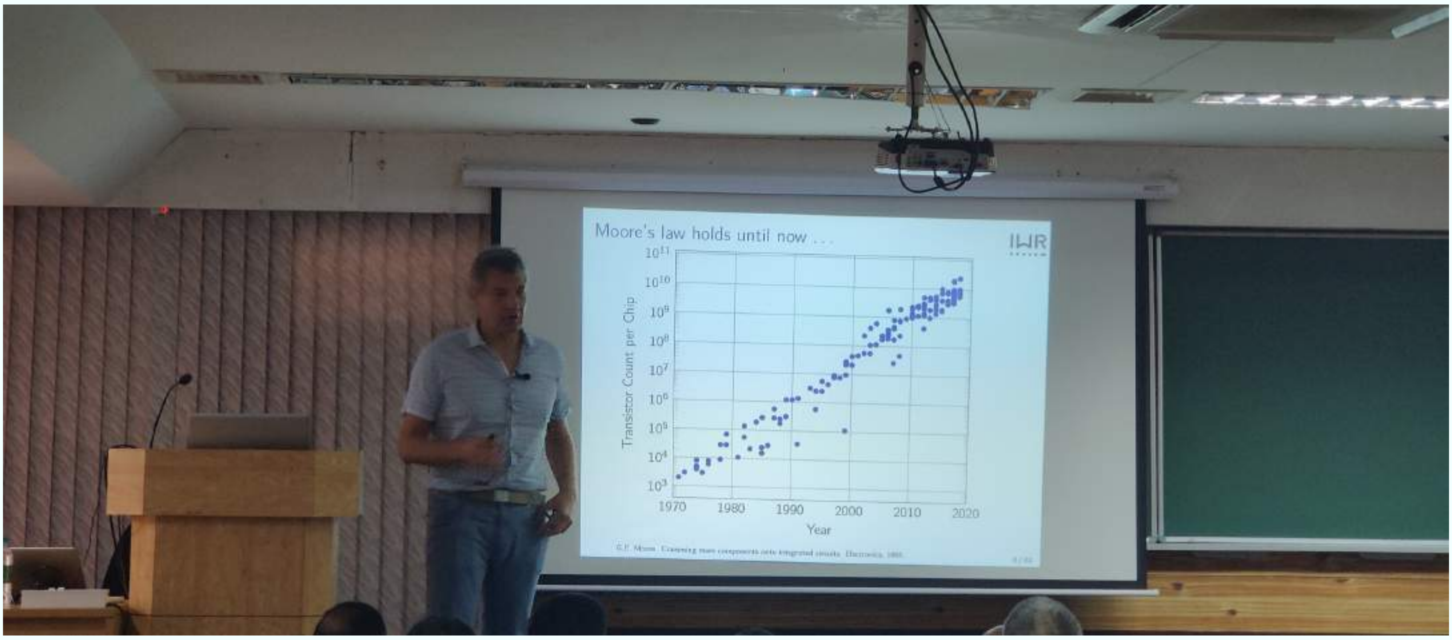
I presented a new approach for prediction of dynamical systems which involves projecting the nominal dynamics onto the observational manifolds. This method was illustrated by implementation on a couple of real-world examples.

There were a number of notable and distinguished researchers present at the conference including Gilbert Strang and Nick Trefethen. Felipe VI, the King of Spain was the chief guest at the opening ceremony. ICIAM prizes were awarded for outstanding contributions in the field of applied mathematics supplemented by the award lectures. A mini symposium on advances on data assimilation organized by Kody Law was of a particular interest to me and was a good exposure to the recent trends in the field. Valencia is a beautiful city divided into an old town with ancient architecture and a modern part consisting of science and art museums. I visited the marvelous L'Oceanogràfic and Museu de les Ciències Príncipe Felipe (the science museum) in a day's tour and was wondered by their gigantic construction and work that went in it. Overall this conference trip was a fruitful and rewarding experience that made me more informed of the advances in my field of work and also the world in general.

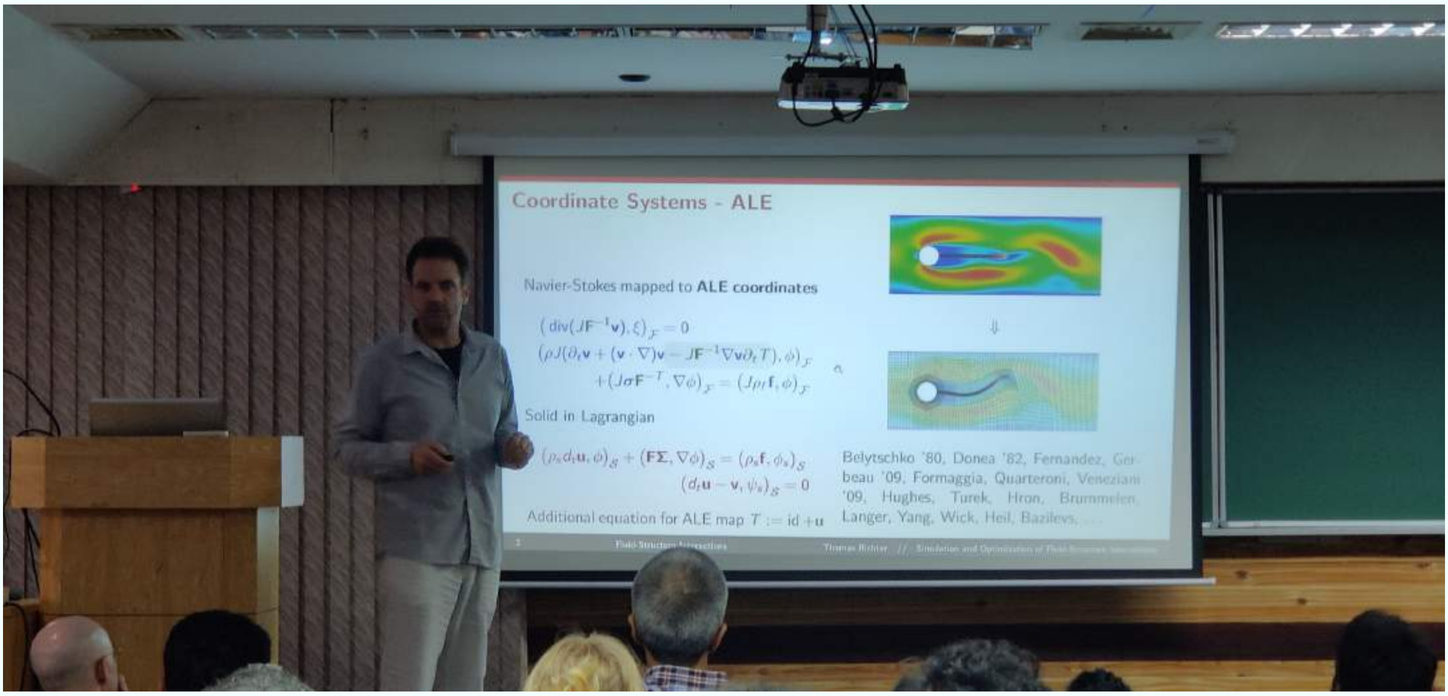
Indo-German Conference on Computational Mathematics

The Indo German Conference on Computational Mathematics (IGCM 2019) was held at the Department of Computational and Data Sciences between December 2 to December 4, 2019. The objective of the conference was to provide an interdisciplinary platform to present and discuss the most recent innovations, trends, and challenges in the frontier areas of computational mathematics. The conference brought knowledge on recent advances in numerical analysis of partial differential equations (PDEs) & stochastic PDEs, efficient and robust numerical schemes for solving complex problems, optimal control and inverse problems, scalable parallel algorithms, hybrid MPIOpenMP algorithms with GPU computing. The organizing institutes were Indian Institute of Science, University of Hohenheim, Mahindra Ecole Centrale College of Engineering and Indo German Science and Technology Centre. Delegates from Germany, India, etc gave special talks regarding the novel trends and best practices in the field. The conference hosted paper presentations and poster presentations where ideas of researchers from all over the world were presented. Three of the best works presented were awarded best poster award. Below are some pictures from the conference.

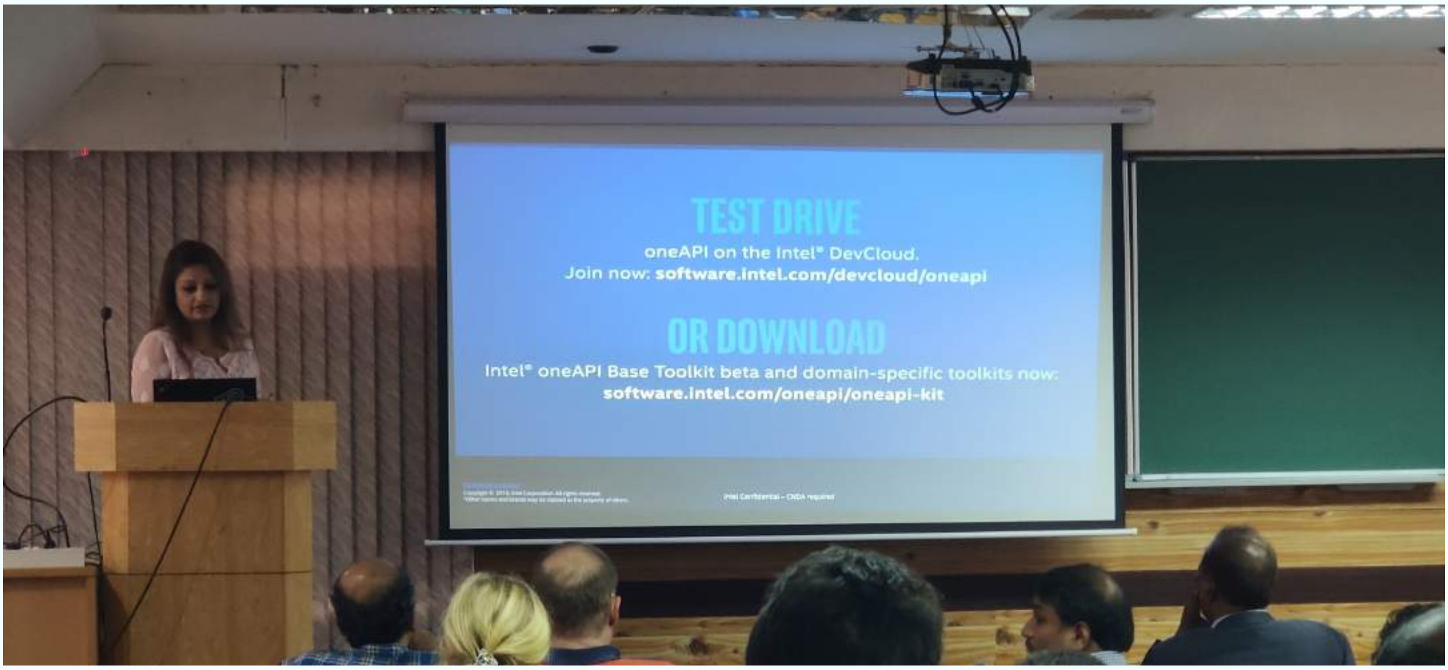
Dr. Sashikumaar Ganesan at the Inaugural of IGCM 2019



Dr. Peter Bastian's talk on Efficient Implementations of High Order Discontinuous Galerkin Methods



Dr. Thomas Richter's talk on Efficient Newton-Multigrid framework for Monolothic Fluid-Structure Interaction



Ms. Akanksha Bilani's talk about HPC and AI in Intel at IGCM 2019

Professor's Counsel

- with Dr. Murugesan Venkatapathi

Q1. In the modern world, due to rapid changes in technology, the skills having relevance today may not be useful tomorrow. How to prepare oneself for future uncertainties and for life-long learning??

I think we might have to grudgingly accept that periodic training and 'certified' education in specialized emerging areas may be inevitable for economic reasons. One has to note that the average lifetime of a company on the Fortune 500 list is only 15 years now. But there is a need for an everyday curiosity-driven learning in the background, that (a) makes us aware of the broad contours of the technological landscape beyond our own expertise and (b) is focused on the more fundamental/basic ideas. This helps us to be well prepared quick learners, and tide over rapid fluctuations in the field of technologies and skills. I would also say that in such fickle environments, one should never get too consumed by a temporary success or failure and we have to work on the long-term average.

Q2. According to you, what is the definition of research, and how to cultivate a mindset for research?

I would compare research to the effort by a group of people stuck deep inside unfamiliar woods. While being in a group does give comfort, the likelihood of finding a way out increases if everyone tries their own way, and may be compare notes at the end of the day. This basically requires people to be adventurous (curious), courageous, and diligent in mapping out conclusions from sparse observations. To put it in context, both too much and too little of a literature survey on the topic, could hurt the chances of a discovery by future research, for example. I think the challenge in professional science today is to benefit from public (or private) funding and the collective research, but wander away from the mainstream thought. I think we have an acute need for amateur scientists who can also manage the garb of a professional.

Q3. In academia, there is pressure to 'publish or perish'. The result is that many research papers are not active contributors to science or are of low utility. What is the remedy? Or how to maintain a balance between professional aspirations and publishing ethics?

I think publications are required to the extent that it ensures accountability to the public funding we get, and serves as a validated record of our observations. Since more than a decade now, it has significantly diverged from this original purpose. The number of publications have been used as an approximation for the individual's scientific contributions. More recently it has been used as default tie breakers for hiring, as the supply significantly out-numbers the demand in the workforce. But I remind my students that all this is true only when the significance and results of a work may not be very apparent. Once we produce research that is shown to be significant from an application or a scientific point of view, the number of papers fully recedes into the background. I should also emphasize that the typical bulk metrics we come up with, are all based on a 'correlation' and not a verified 'causation'. In the past, we did find that there is a reasonable correlation of the number of publications to the contributions of a researcher. Once a correlation is used as a metric, it should take us only a decade or two to bias it, get this correlation to zero, and make it unusable. I think that the next generation would be wasting their times if they worried much about this metric, because a very different new metric is due soon and I cant say what that is. In fact, all parameters used in ranking of institutions are too based on such decaying correlations, but on a longer time scale. These correlations of certain metrics with the actual discoveries and inventions (of the faculty, students and alumni) are picked up from the universities that were on the top of their game from 50s through 90s of the last century. No wonder these rankings fluctuate violently every year beyond the rank 50 or so, as such significant outcomes at these other universities had little correlation with the used parameters.

Q4. After a long time since Independence, we still haven't produced enough Nobel Laureates, technological entrepreneurs. What are your views behind our lag?

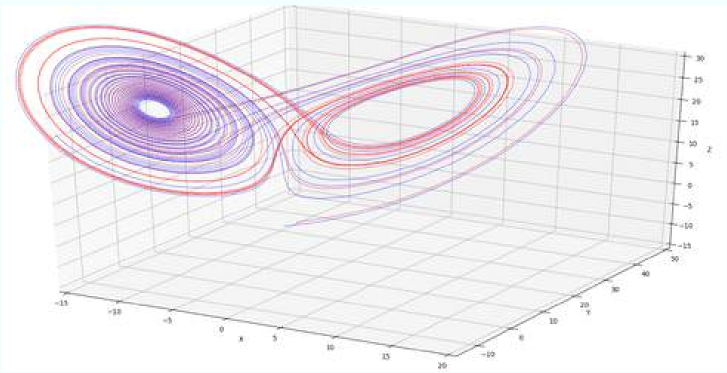
I think the contribution of Indians to modern Science has been notable and we did punch way above our weight, if seen from an economic point of view. Yes, the big discoveries or singular contributions from individuals working here may not have been in proportion to the population. I may not be competent enough to fully understand the other causes, apart from the known lower financial investments in Science here. I observed that being a small minority in the global scientific workforce, we had to follow the mainstream in the west just to be recognized as professionals. This conservatism might have precluded major discoveries which require us to take independent long-term bets. This could change soon, and I think our research is becoming increasingly self-directed.

Q5. Many research students are feeling stressed now a days. What are your suggestions to cope with the stress and maintain a good mental health?

As I mentioned before, it helps to look back and look forward without being consumed by the immediate success or failure. From a practical point of view, we have to maintain a good balance between investing in the ‘certified’ education and the real long-term growth in our ideas and capabilities. For example, I would restrict myself to manageable coursework in meeting the requirements of the degree, and not be too ambitious. I would rather audit other classes and learn consistently on my own, if my interests demand it. I do come across good students who have managed their formal requirements badly, and on the other hand students with great GPAs who cant handle even the simplest questions of an interview. Also, being regular at a hobby or sport quickly resets our minds and bodies, and can teach us important lessons that our professional lives might be too slow to teach. On the personal front, our consistent goals over a long-term are good health and mental well-being, and our efforts in all other spheres of life should align with these. I remind myself that the short-supply of opportunities has always been large in human society, irrespective of the economic and demographic variables. In terms of our basic needs, I think we in the modern world are quite lucky compared to our ancestors. I think being thankful for what we have got, working hard, and keeping things as simple as possible across the board, are some useful tools to achieve the best we can.

Chaos Theory

The notion of chaos was first introduced by Poincaré at the end of 19th century as a consequence to the three body problem. The problem of finding the general solution to the motion of more than two orbiting bodies in the solar system has haunted even Mathematicians like Newton. Oscar II, king of Sweden, announced a prize for anyone who could find the solution to this problem. The prize was given to Poincaré even though he didn't completely solve the problem but led to the theory of chaos.



The theory of chaos became more popular in 1963 when Edward Norton Lorenz from M.I.T was able to obtain a deterministic Non-periodic system from a series of equations which came to be known as the Lorenz equations. His discovery was an accident which happened on a winter day in 1961. The simulations which Lorenz did was on a machine, a Royal McBee was a thicket of wiring and vacuum tubes. The machine occupied a significant portion of his office and made an annoying noise, everyday the machine would print out weather estimates at various times.

On this day he decided to take a shortcut instead of running the whole simulation he started midway through. He started with values from the earlier printout, he then went to the hallway to get away from the noise and drink a cup of coffee. When he came back he saw something unexpected, the new run should have exactly duplicated the old but the values which were printed deviated from the pattern of the last run and after one month it showed no resemblance. He initially thought that the vacuum tubes have failed but later realized that there was no malfunction but the computer's memory has six decimal places like 0.506127 but only three appeared on the printout, so the value he gave was rounded off was a shorter rounded off values, this small deviation in the initial condition grew with time. Such systems where states are determined by deterministic laws but are highly susceptible to initial conditions are called chaotic systems. The branch of study of such systems is called chaos theory. Some examples of chaotic systems include water wheel, the first chaotic system discovered by Edward Lorenz, double pendulum etc. In the Matlab command window if you type 'lorenz' you can see the Lorenz attractor. For getting the plots as above you can see Ref[4].

References:

1.Lorenz, E.N., 1963. Deterministic nonperiodic flow. Journal of the atmospheric sciences, 20(2), pp.130-141.

2.Chaos: Making a New Science By James Gleick

3.wikipedia

4.https://github.com/abhishekajay/Lorenz63

Flora and Fauna of IISc

First, the campus of IISc spans over 420 acres of terrain in the middle of the garden city Bangalore. Though the garden city had slowly turned into a concrete jungle due to its rapidly expanding population, IISc takes immense effort in preserving the century old ecosystem inside the campus. The campus is so densely covered by trees such that it lowers the mean temperature of the campus by at least 2 degree celsius compared with the mean city temperature. One should seriously try visiting the campus during early morning because early morning walks inside the campus is just a pure bliss, where one could see tiny specks of sunlight fight its way through the dense branches of the high grown trees giving the place a heavenly vibe. With all the trees in campus, the lawn of the main building is probably the only place where you would be able to look up and see the clear sky without any hinderance. However, just by walking closer to the lane one could suddenly see the bright sky getting eclipsed by a huge flock of doves murmurating above your heads. It does not take much time for some one to realize that all the roads in the campus are also named after trees. The campus also get colored up due to the budding flowers of various colors that blooms during different time of the year like bright yellow and pink flowers (March-May) bright scarlet red flower (August-October). Many of the trees in the campus are exotic i.e. coming originally from other countries. Amidst this wide variety of trees, one could assume that the only common thing that they see around is the common lawn grass found carpeting the terrain. Well then look closely, there are about 45 different species of grass grow within the campus. While enjoying these flora, one should also keep in mind to not to go deep inside because the campus is known to host at least 10 different species of snakes, both venomous and non venomous. However if you get to see one (which every IIScian would have experienced it at least once in their IISc Lifetime..!) , don't panic..! it is very rare for someone to encounter a venomous snake in the places where the academic buildings are located. We people at IISc are blessed in someway to wake up every morning to the melodious chirping sounds and not to the traffic noises on road like every other metropolitan citizen. Yes, IISc hosts about more than 140 different species of birds. So if you are a bird watcher, its time for you to zoom in further with your binoculars because you never know what you might stumble onto. Well sky is not the only region inside IISc to zoom onto. If you could zoom further into the grass carpeted terrain, you could witness more than 72 different species ants found inside the campus (who would have guessed these..!). You could see all those species of ants preserved in the insect museum at Center for Ecological Sciences. Further all detailed information about the various species of flora and fauna can be obtained from this URL "http://ces.iisc.ac.in/new/?q=flora-and-fauna-of-iisc".
Image Credits: CES - IISc and Incredible Karnataka.






Meet our Research Assistants

Ratnakar Gadi

(Project Associate
QUEST Lab)

Q1. Can you share the background with us?

Hello, I am Ratnakar Gadi, a project associate in the QUEST (Quantification of Uncertainty in Engineering, Science and Technology) lab since May, 2019. Here, I am working on a project which deals with providing ocean state forecasts using finite volume code(MSEAS developed at MIT) and data assimilation. I have completed my bachelor's of engineering degree in Naval Architecture and Marine Engineering from Andhra University College of Engineering, and master's in Ship Hydromechanics at TU Delft. My research interests include ship hydrodynamics and hydroelasticity, ocean modelling and numerical solutions to partial differential equations. As a research assistant at TU Delft, I worked on Radar signal post-processing and hydro-elasticity. The former dealt with filling missing data in the radar images of surface waves, whereas, the latter was associated in developing a beam model of ship and arriving at the thickness parameter to ensure that the stiffness of the model and ship matched. This model helped us in investigating why particular ships were prone to container losses during their journey. My master thesis dealt with providing an efficient methodology of hydrodynamic loads computation in nonlinear 2D flows,which culminated in a publication in the thirty-third International Workshop on Water Waves and Floating bodies and a Runners-up award for TUCK fellowship in April 2018. In my free time, I like to box, watching science documentaries and read biographies of scientists.

Q2. You were a professional boxer and a cricket player. How has sports helped you in your endeavours?

Sports has always helped me in keeping a check on my stress levels. It made me more calm and peaceful; and, at the same time, made me feel more energetic and confident. I learned how to maintain composure in the tense moments; and how to handle failures. I have learned that like in competitive sport, sometimes in our life, we may not succeed as per our expectations even after giving our best, in these moments, instead of over criticizing ourselves, we need to find our shortcomings and try to never repeat our mistakes.I would like to suggest that everyone should indulge in one form of sports.

Q3. Since you also have international exposure in research, can you also write about some of the learning as per your experience?

First, I would like to emphasize the importance of proper planning in research. This involves pinning down one's objectives and the way of its execution, as clearly as possible. If we do not set our objectives clearly, we tend to lose motivation for research work. Hence, it is advisable for students to plan their work before they start it. Though, it may appear that planning consumes significant time, it will provide a mental clarity regarding the project scope as well as it's execution.

Second, if planning is hard, sticking to your plan is even harder. But, I would suggest students to stick to their plan and not give up, although they might be lagging behind. Third, A proper and thorough interpretation of results is very important part of research work. According to my master's thesis guide, one thing many researchers tend to overlook is proper verification and validation of your research work. The researcher should know both the strengths and shortcomings of his research work. And fourth is the presentation of one's work to the outside world. Good technical writing is an important skill which can be gained by constant practise. And even if is not for outside audiences, the process of writing down one's thoughts/work will result in further clarity.

Shirish Potu

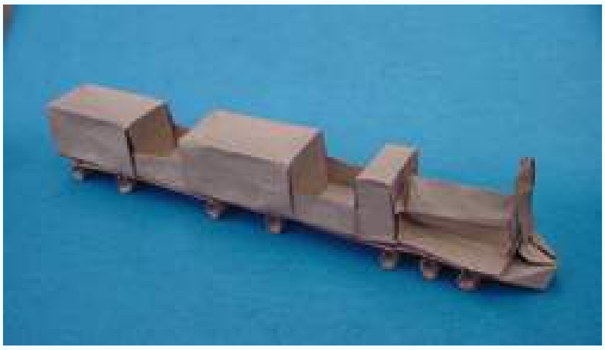
(Data Science
Researcher at Shell
Technology Center,
Bengaluru)

I was a Junior Research Fellow in Professor Soumyendu Raha's Scientific Computation Lab from March 2018 to June 2019. I wasn't a student here. When I look back on the reasons why my time in IISc has had such a profound influence on me, it is less because of academic learning and more about the truly admirable people of CDS that I've had the fortune to meet, interact with and befriend. Abhay showed me that you can be the smartest person in the room and still be amongst the most cheerfully humble. From Abhishek I learnt that before you become a Bayesian with your own set of heavy priors, it is important to be a fresh sponge that is ready to soak up everything on offer. Dinesh showed that even in a campus that thrives on pressure, you can meet all the deadlines that need to be met and still have time for friendship and fun in equal measure. From yet another Dinesh I learnt that you can hold the highest degree in the room and also be kind, gentle, big brotherly and friendly all in one. From Saurabh I learnt the value of patience and perseverance, qualities that lie at the core of success in research and clichéd as it may be, in life. From Sumit I understood the curiosity that drives a truly passionate researcher and learnt the beautiful art of stitching seemingly disparate concepts into wholesome emergence. From Vikram I learnt that despite all the lemons life throws at you, you should never ever give up on that continuous pursuit of meaning, learning and happiness. Vishal showed me the joy of making active dialogue as opposed to insecure silence, and that learning gets so much deeper when you inculcate the former. From Anand, my mentor, teacher, friend and big brother, apart from all that he taught me in subject matter, I learnt just about every quality that is mentioned above. He takes the cake.The most important lesson though, I learnt from my P.I., Prof. Raha. He showed that regardless of the number in your age, it is in remaining a curious student for life that we can hope to joyously decode the intricate complexities of our seemingly mathematical Universe. And so you see, IISc makes a student out of just about anybody. To this institute and to the Department of Computational and Data Sciences to whom all of us belonged, I say with all my heart –Thank you for the lessons, and thank you for the wonderful memories.

Computational Origami

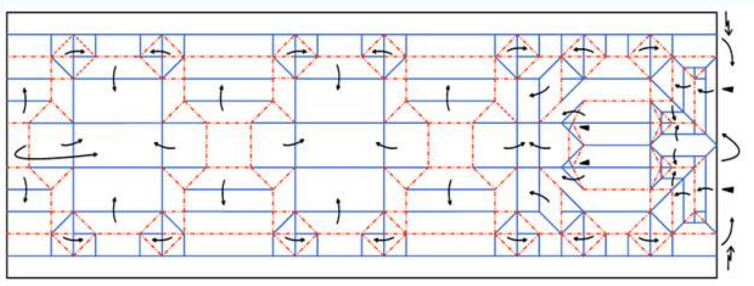
Imagine materials that have the ability to change physical properties, say geometry, in a programmable fashion be it based on user input or autonomous response to the environment. Say, flat sheets of interlocking panels that could be configured to any 3D shape on command. This is the pipe dream that is "programmable matter" A world where you can program the physical properties of an object as easily as you program the software. That, of course, doesn't exist yet. But its building blocks are taking shape through research on efficient algorithms for characterizing foldability, and finding efficient folding processes, or in proving that such algorithms are impossible.

While we are far from having materials that can fold autonomously into desired shapes, humans have been practising the art of paper folding, origami, for centuries. Perfecting a fold is a tedious process. Finding the optimal length, angle and ordering between creases to get the desired geometry is anything but straight forward.



This is an origami train created by Emmanuel Mooser, a swiss physicist. This silly little train called the Mooser's train is a fold that has inspired and challenged folders for 5 decades. Take a look at the fold patterns for the same to appreciate how hard going from a desired 3D shape to the fold pattern is.

Origami (paper folding) has lead to an intriguing collection of problems to study mathematically and computationally. Origami mathematics is a recent branch of mathematics (whose major study started circa 1980) that studies the properties of origami, such as what patterns you might get when you unfold a flat origami. Going from design to crease pattern is hard. The interesting question is "Can we design an efficient (polynomial) algorithm, a geometric folding algorithm, that given a 3D shape generates the fold pattern if it exists?" Computational origami is a new branch of computer science that explores efficient algorithms for solving paper-folding problems.This field essentially began with Robert Lang's work on algorithmic origami design, starting around 1993. Since then, the field of computational origami has grown significantly.



Erik Demaine has been working at this unique intersection of art, geometry and algorithms. Since joining the faculty of MIT, as a professor of computer science in 2001, aged 20, he has been working on geometric folding algorithms. More formally, he works on the broader context of folding and unfolding k-dimensional objects in n-dimensional space, $k \leq n$.

In 1999, in a milestone paper in computational origami, Erik had described an algorithm that could determine how to fold a piece of paper into any conceivable 3-D shape. However, the algorithm gave sub-optimal folding patterns. The resulting structures tended to have lots of seams rendering them less sturdy. Continuing on this, Demaine and Tomohiro Tachi, University of Tokyo, presented a universal algorithm for folding origami shapes that guarantees a minimum number of seams at the Symposium on Computational Geometry in July 2017.

The basic constraints in folding a piece of paper are that the paper is folded continuously (no ripping), while preserving distances along its surface (no stretching), and not causing the paper to self-intersect (no crossing).

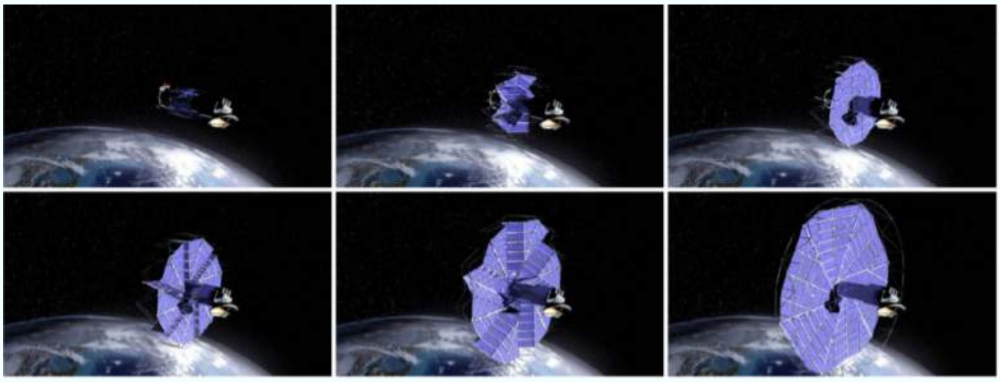
The algorithm generates optimal (guaranteed minimal seams) crease patterns for producing any polyhedron. First, it maps the faces of the target polyhedron onto a flat surface. The faces which are adjacent in 3D are, in general, far apart on the flat surface being folded. The idea then is to fold away the space separating the faces to form the polyhedron. Developing a method to generate the crease patterns to fold away the extra space involved a number of different insights, but a central one was that they could be approximated as a Voronoi diagram.

"It completes what I would characterize as a quest that began some 20-plus years ago: a computational method for efficiently folding any specified shape from a sheet of paper. Along the way, there have been several nice demonstrations of pieces of the puzzle: an algorithm to fold any shape, but not very efficiently; an algorithm to efficiently fold particular families of tree-like shapes, but not surfaces; an algorithm to fold trees and surfaces, but not every shape. This one covers it all! The algorithm is surprisingly complex, but that arises because it is comprehensive. It truly covers every possibility. And it is not just an abstract proof; it is readily computationally implementable."

-Robert Lang, one of the pioneers of computational origami

Origami in Space

A group at NASA's Jet Propulsion Lab is using origami techniques to optimize the packing and deployment of solar panels and other large objects shipped to space. Origami techniques are being used to find an optimal way to ship the large, fragile solar arrays into space. In the paper "The Solar Umbrella: a Low-Cost Demonstration of Scalable Space Based Solar Power", researchers at NASA's Jet Propulsion Laboratory (JPL) explore the feasibility and cost of building and deploying a solar power farm in space. Shown in the image below is a depiction of the folded solar umbrella as it is unfolded to its full flat width after being launched into orbit.



Transmitting Antenna Deployment via Thickness Accommodating Origami-Based Flasher Model. Taken from the paper "The Solar Umbrella: a Low-Cost Demonstration of Scalable Space Based Solar Power".

The Miura Fold

Japanese astrophysicist Koryo Miura invented the miura fold for deployable solar arrays for space applications. With the Miura fold, you can take a large piece of paper and fold it into a small space and — most importantly — fold and unfold it in one movement each. For space-bound solar panels, this means that only one motor would need to be used for deployment. In the solar umbrella shown above, a variation of the Miura fold was used to create the design, allowing the 25-meter diameter solar array to be stowed in a space just 2.8 meters by 4 meters. Japan's 1996 Space Flyer Unit deployed the 2D Array from a Miura folded configuration in space.

There is a wide range of folding and unfolding problems, some going back several centuries and still unsolved, like unfolding convex polyhedra, while others are more recent like protein folding. In the last few years, there has been tremendous progress on many of the fundamental problems in folding and unfolding, yet some of the most important questions still remain open. The future of computational origami looks promising and exciting.

References

- Origami Anything http://news.mit.edu/2017/algorithm-origami-patterns-any-3-D-structure-0622
- Erik Demaine's Folding and Unfolding Page: http://erikdemaine.org/folding/
- Solving a Space Problem with Origami Principles : https://www.comsol.com/blogs/solving-space-problem-origami-principles/

Further reading

Between the Fold (56 mins watch)
"Depicts a cast of fine artists and eccentric scientists (from MIT and NASA) who have devoted their lives to the unlikely medium of modern origami."

Fractals are cool! But where are they applied?

A fractal is defined as a geometric shape that is recursively composed of similar patterns at different scales. If you happen to zoom into a section of the fractal, you would get the same pattern over and over again in a repeating fashion. The term fractal was coined by Benoit Mandelbrot. It is derived from the Latin word fractus, which means broken or fractured. Fractals are abundant in natural phenomena and artistic work.

Mathematical analysis of fractals started when Leibniz considered the idea of recursive self similarity. However, the first graphical example of a fractal came in 1872 when Karl Weirstrass came up with a function which is continuous everywhere but differentiable nowhere.

Fractals define patterns and shapes which cannot be described using Euclidean geometry and their inherent recursive nature makes them more appropriate for an algorithmic description. Some of the famous examples of fractals are the Cantor set, the Koch curve, the Sierpinski triangle, the Mandelbrot set, and the Lorenz model.

The characteristics which make fractals interesting are:

- Its structure is defined by fine and small scale substructures.
- Its shape cannot be defined by Euclidean geometry.
- It is recursive and shows iteration to some degree. They appear similar at all levels of magnification.

Fractals are found abundantly in nature. Shapes of clouds, patterns on ferns and leaves of trees, lightning and snowflakes are a few examples. The Barnsley fern and the Lightning fractals are shown here:

Applications of fractals include:

- **Computer science:** Fractals are employed in image compression and they give better performance than standard compression techniques such as JPEG. One issue with the standard formats is that the image gets pixelated upon zooming. However this is not the case with fractals owing to their recursive structure. In Fact the image gets better upon zooming.

- **Fluid mechanics:** The study of turbulence in flows is very adapted to fractals. Turbulent flows are chaotic in nature which makes them suitable to be simulated using fractals. Simulations of flames, porous media and other turbulent effects employ fractals.

- **Telecommunications:** Fractal shaped antennas greatly reduce the size and load of antennas for a given frequency of use.

- **Surface physics:** Fractals are used to describe the roughness of surfaces. A rough surface is characterized by a combination of two different fractals.
- **Medicine:** Biosensor interactions can be studied by using fractals.

Fractals are also used in architectures as illustrated below. This is a pattern taken from the ceiling of a mosque.

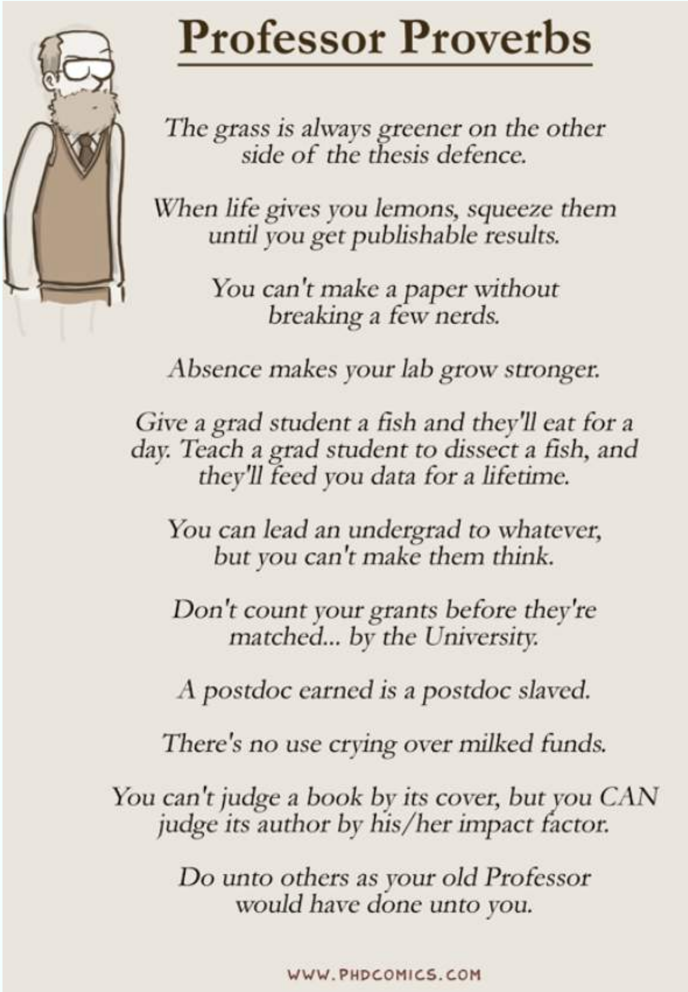
You can understand more on fractals and their applications from the videos whose links are given below:

- ***https://www.youtube.com/watch?v=XwWyTts06tU***
- ***https://www.youtube.com/watch?v=xLgaoorsi9U***
- ***https://www.youtube.com/watch?v=qhbuKbxJsk8***
- ***https://www.youtube.com/watch?v=WCC_w9P1SfA***

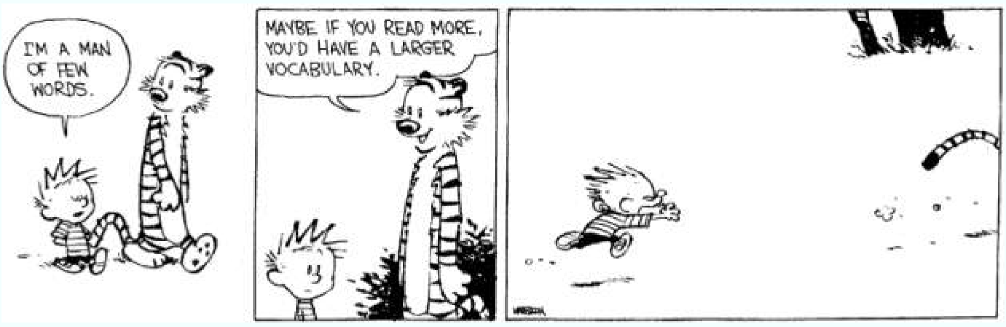
Comically Correct

Life of an(y) Project

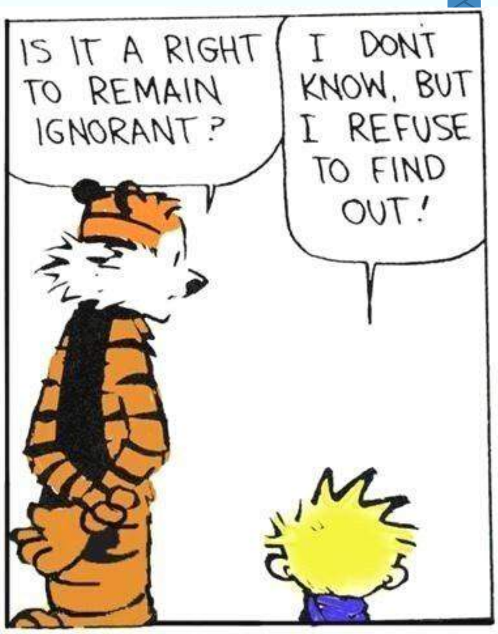
What does the cool prof say?!



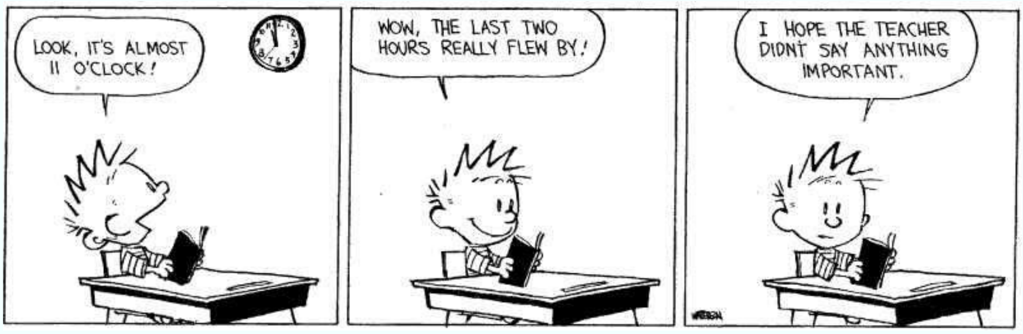
Word Power Made Easy



You have the right to remain ignorant 🙅



When you are not a morning person!



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