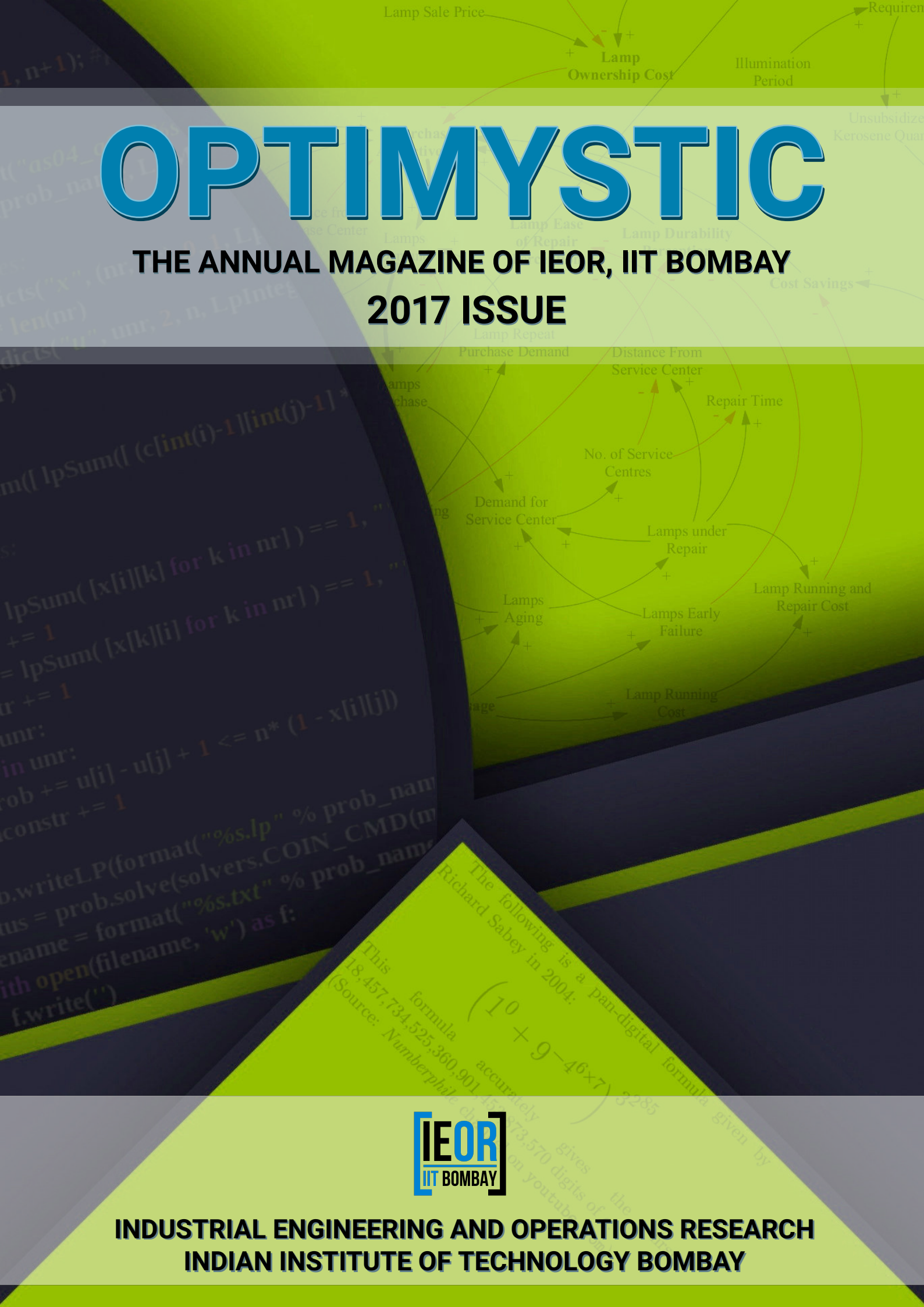

OPTIMYSTIC

THE ANNUAL MAGAZINE OF IEOR, IIT BOMBAY

2017 ISSUE

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INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH
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From the Magazine Team

Dear readers,

Welcome to the comeback edition of our departmental magazine. The resurrection of Jesus is the central tenet of Christian theology. As the Nicene Creed says: “On the third day he rose again in accordance with the Scriptures”. Likewise, after the first edition in 2014, our departmental magazine gets resurrected here in the third year and it gives us immense joy and satisfaction to finally re-introduce “OPTIMYSTIC”.

In this edition, we try to bind together each and every aspect of our IEOR family and we hope it inspires every IEORian to actively contribute in the development of our department academically and also in extra-curricular activities. It represents the creative side of our students to a fair degree—something that we think we all need to reconnect with, amidst the busy schedule of semester exams, surprise quizzes and all those assignments that make you want to bang your head on the wall.

We thank all of you who stood by us patiently and contributed in the development of our magazine when there were days when the only thing we had to offer was our own confusion. Also we are lucky to have talented students in our department because of whom we have shown consistent performances in sports and cult activities over years.

Hope you appreciate our efforts. Happy reading!!!

Mohsin Dalvi
Ashlin Ghosh
Raja Chauhan

From the H.O.D.'s Desk

I congratulate the students of IEOR who have taken the initiative and have contributed to this edition of the department magazine. While the area that IEOR deals with is a vibrant one and keeps reinventing itself in fruitful ways over the years, it is necessary for us from time to time, to articulate our thoughts and to re-discover that the field is and what its relevance is. In some way, this magazine contributes to fulfilling this need.

While OR has always drawn upon rigorous mathematics and statistics in its development, it is only in the last ten years or so that IEOR at IIT Bombay has got students with these backgrounds as part of its family. This year marks the significant career move of one of our alumni, Vikas Vikram Singh, who was the first person with a Mathematics background to graduate from IEOR with a Ph.D. Vikas has taken up a faculty position in the Mathematics Department at IIT Delhi. Subsequently, Anusuya Ghosh has graduated as also our first M.Sc.-PhD graduate, Manu Gupta. We expect these and other alumni to make their mark, not only in the mathematics of OR, but also in industry research, consulting and other areas.

IEOR has been in the news through an activity involving Prof Jayendran Venkateswaran and many of his students and associates (in the Energy Sciences and Engineering and other groups at IIT Bombay). This is to do with the Solar Urja Lamp (SoUL) initiative, which has now been scaled up to a national level activity. It has received prestigious acclaim, most recently one of their projects won the Prime Minister's award for Innovation (Excellence in Public Administration) during the National Civil Services Day 2017, one of only 2 awards chosen among more than 800 entries nationally. Professionally, the activity has touched upon project management, supply chain design and management, system dynamics and diffusion of technology, inventory management, manufacturing facility design, operations management and data analytics in many areas. It has been a great interdisciplinary learning experience for many of us and we are not done yet! We look forward to further achievements of this group.

During the end semester time, here are some of reflections on examinations. We may be seeing the last phase of the good old three-hour pen and paper examination, the way things are becoming digital. A paper and pen exam (especially a closed book one) that keeps a student occupied for three hours with his or her thoughts, some of which are finally written down on a blank answer book, is a work of art. For the student, it is the ultimate spiritual experience in that field, perhaps never again replicated. Take Integer Programming. Even a future top-notch researcher in Integer Programming may never again spend a full three hours, undisturbed by anything else, immersed in the topic. At the end of this time, irrespective of the outcome (especially grades), the student knows very well what he or she knows in that field. It is a form of self realization for which adults in later life spend a lot of effort on and often pay money to others who create the atmosphere and opportunity where this self-realization can happen. And here we provide it for free!

Dr. Narayan Rangaraj
Professor, IEOR

Contents

What is IEOR all about?

Utility as an asset becomes associated with an invention whenever an agglomeration of interrelated decisions during the process of transformation of an input to output are implemented, managed, analyzed and evaluated, leading to a sequence of correlated tasks that ultimately results in a branch acting as a bridge between invention and its optimal result by incorporating scientific results in the process, that may prove to be a threshold for other related processes to be studied and improved upon.

Conveyor belt as an evidence of past is one such example that gave a concrete vision to the invention of the first ever mass-produced car by Henry Ford. Since then, many miles were added to the journey of industrial development and now in 21st century we are able to discover a milestone in form of industrial engineering which is still being explored and developed as a field, sharing common ideas with management sciences, systems engineering, manufacturing engineering, operations research, behavioral studies and so on. Various concepts that are bought under the broad framework of Industrial Engineering include operations analysis, services and infrastructure systems, supply chain management, quality control and so on.

While the benefits of Taylor's scientific principles were being reaped by industrial firms, World War II showed the emergence and need for operational research that used advanced analytical expertise to make better decisions. While solution determination of any complex process used to be a sole priority in past, the emergence of Operations Research (OR) prioritized the need for approaching towards optimal solutions. With mathematics as a base and sharing strong ties with computer sciences and statistics, every single situation demanding a solution can be modeled as an OR problem. Simplex method, developed by George Dantzig as the soul of OR, is being developed and applied to many fields like game theory, network analysis, logistics, project management and so on.

Obviously, not excluding the fact that '*OR is the perfect way of obtaining satisfactory answers to the problems to which otherwise worse answers would be given*', many critical problems of industrial engineering are also solved using OR techniques. Starting from websites like Facebook and LinkedIn using OR to create a database of connections of their users, to the analysis of manufacturing processes of indigenous companies, one can find ample use of OR in every field of industrial engineering.

With rapid advances in technology and engineering, Industrial Engineering and Operations research can be moulded and studied in different forms. Hence, a promising career in fields of IE and OR is quite evident in near future. Industrial Engineering provides us with the flexibility to work in distinct fields as industrial engineers discover ways to make operations better.

Considering the bright future prospects of IE and O.R. in mind, the department of Industrial Engineering and Operations Research (IEOR) was set up in IIT Bombay by Prof. P. G. Awate and Prof. A. Subash Babu.Sice its founding, the department has been growing by leaps and bounds and is gradually competing to become one of the best institutions in the field of IE and OR, not only in India, but also worldwide.

Faculty Members at IEOR

Prof. Prakash G. Awate

Academic background:

- B.Tech. (Mechanical Engg.), IIT Bombay (1968)
- M.S. (Operations Research), Cornell University
- Ph.D. (Operations Research), Cornell University

Research Interests: Applications of techniques of OR and AI methods in problems areas related to production-inventory systems, scheduling and distribution in application areas such as supply chains and railways.

Courses Taught: Industrial Scheduling; Inventory Control and Management Systems.

Prof. Narayan Rangaraj

Academic background:

- B.Tech. (Mechanical Engg.), IIT Bombay (1986)
- Ph.D. (Mathematical Sciences), Johns Hopkins University (1990)

Research Interests: Railway Operations Management, Optimisation, Logistics and Supply Chain Management, Pricing and Revenue Management.

Courses Taught: Operations Analysis; Service and Infrastructure Systems; Engineering Statistics; Pricing and Revenue Management; IEOR for Health Care; Quantitative Methods in SCM.

Prof. Nandyala Hemachandra

Academic background:

- B. Tech. (Electrical and Electronics Engg.), College of Engineering, Kakinada
- M. Tech. (Control Systems Engg., EE), IIT Kharagpur
- Ph. D. (Dept. of Computer Science and Automation), IISc Bangalore

Research Interests: Operations Research methodologies like Markov decision models, Queueing models, Game theory, etc. Application areas include Communication networks, Supply chains, Financial Engineering, Logistics and Power systems.

Courses Taught: Optimization Techniques; Decision analysis and game theory; Markov decision processes; Selected applications of stochastic models; Networks, Games and Algorithms.

Prof. K. S. Mallikarjuna Rao

Academic background:

- M.Sc. (Mathematics), Andhra University, Vishakhapatnam
- Ph.D., Dept. of Mathematics, IISc Bangalore

Research Interests: Deterministic and Stochastic control, Game Theory, Viscosity Solutions, Markov Decision Processes, Mathematical Finance.

Courses Taught: Probability Models; Operations Analysis; Decision Analysis and Game Theory; Markov Decision. Processes.

Prof. Jayendran Venkateswaran

Academic background:
- M.Sc.(Tech.), Engg. Technology, BITS, Pilani (2000)
- M.S., Industrial Engg., The University of Arizona, Tucson (2002)
- Ph.D., Systems and Industrial Engg. (with minor in Biomedical Engg.), The University of Arizona, Tucson (2005)

Research Interests: Modelling, simulation and analysis of complex systems (viz. supply chains).

Courses Taught: Operations Analysis; Service and Infrastructure Systems; Discrete Event System Simulation; System Dynamics Modelling and Analysis; Quantitative Models for SCM.

Prof. Vishnu Narayanan

Academic background:
- B.Tech. (Mechanical Engg.), IIT Bombay
- M.Tech. (Mechanical Engg.), IIT Bombay
- Ph.D., (Industrial Engg. and OR), University of California, Berkeley

Research Interests: Mathematical Programming especially Integer Programming, Convex Optimization, Polyhedral Theory.

Courses Taught: Optimization Models; Optimization Techniques; Linear Systems; Integer Programming.

Prof. Veeraruna Kavitha

Academic background:
- B.E., Electronics Engg., UVCE, Bangalore University (1994)
- M.Sc.(Engg.), IISc Bangalore (2002)
- Doctorate, ECE Dept., IISc Bangalore (2007)

Research Interests: Stochastic processes, Queuing Theory, Polling systems, Optimal control, Game theory, Stochastic approximation, Wireless communications.

Courses Taught: Introduction to Stochastic Models; Advanced Stochastic Processes for OR.

Prof. Ashutosh Mahajan

Academic background:
- B.Tech. (Hons.), Production and Industrial Engg., IIT Delhi, India (1999–2003)
- Ph.D., Industrial and Systems Engg. (ISE), Lehigh University, (2003–2009)

Research Interests: Mixed-Integer Linear and Nonlinear Optimization, Algorithms, Software and Applications of Optimization.

Courses Taught: Optimization Models; Modelling and Computation Lab; IEOR for Health Care; Integer Programming–Theory and Computations.

Prof. Manjesh Kumar Hanawal

Academic background:
- B.E., Dept. of ECE, MANIT Bhopal, India (2000–2004)
- M.S. (Engg.), Dept. of ECE, IISc Bangalore, India (2007–2009)
- Ph.D., Team MAESTRO, INRIA and University of Avignon, France (2009–2013)

Research Interests: Communication Networks, Machine Learning, Network Economics.

Courses Taught: Online Machine Learning; Selected Application of Stochastic Models.

Prof. A. Subash Babu

Academic background:
- B.E. (Hons.) (OR and Computers), College of Engineering, Guindy (1971)
- SQC & OR, Indian Statistical Institute (1974)
- Post-Graduation, Industrial Engg., College of Engineering, Guindy (1975)
- Ph.D., Operations Management, IIT Delhi (1980)

Research Interests: Reconfigurable Manufacturing Systems, Agile Manufacturing Systems, Enterprise and Knowledge management systems, Advanced MRP and Scheduling Systems, Service Engineering.

Courses Taught: Quality Control and Reliability; Quantitative Methods in Project Management

A Brief Insight into Ph.D Research Areas

"I am working with Prof. Jayendran V. and Prof. Narayan Rangaraj on the modelling of problems related to pallet/container industry, which includes testing and analyzing of pooling and integration concepts between product supply chains and pallet/container supply chains. We are interested to study the sustainability and green aspects of the pallet industry. My other interests lie in applying metaheuristics for complex and hard problems, and simulation modelling and analysis of the supply chains."

Ratnaji Vanga

"Global Optimization is one of the most difficult problems to solve in general. Motivated by my supervisor Prof. Ashutosh Mahajan, I started exploring this area and now am currently working on Mixed-Integer Bilinear Programming. My work focuses on different relaxation techniques for non-convex Mixed-Integer sets and mainly concerns with finding facet defining inequalities for Mixed-Integer Bilinear Covering Set. This type of set appears in many real life problems such as the celebrated Cutting Stock problem, Pre-Pack problem etc."

Hamidur Rahman

"I have been working with Prof. Jayendran V. on medicine supply chain management during an infectious disease outbreak. Our work primarily focuses on exploring the effect of drug supply chain on the epidemic dynamics and developing policies for better supply chain management. This problem is akin to the supply chain management of new products. My broader research interests include, but not limited to, simulation, optimization, mathematical modeling, and statistical data analysis."

Siddhartha Paul

"I am working with Prof. Jayendran V. and Prof. Tom V. Mathew on solving the traffic congestion problem for non-lane following traffic. One way of reducing congestion is by using appropriate green times in signalized junctions such that the delay perceived by each vehicle is reduced and throughput (number of vehicles crossing the junction per cycle) increases. We have used simulation and optimization based approaches to determine the optimal green times for each phase in a junction. We have also developed an approach for real-time adaptive signal coordination in arterial road network. My research interests are analytics and optimization. I love to do mathematical modelling and coding."

Alok Patel

"I am working with Prof. Veeraruna Kavitha in the realm of polling models. Polling models have wide range of application in computer communication networks, production systems and traffic and transportation systems. Multiple queues are served by single server in polling models. My current research focuses on different interesting problems such as 'Serve on the move polling

models', 'Bus bunching' and 'Achievable region of polling systems' which have the above mentioned applications. Our work mainly focuses on stability and performance of the system."

M. Venkateswara Rao K.

"I am pursuing my research in Game theory under Prof. K. S. Mallikarjuna Rao. Specifically, I have much interests in Colonel Blotto game which is basically a resource-allocation game. My current work also includes finding winning strategies for Board games"

Ravi Kant Rai

"I work with classification problems (formal versions like classifying emails as spam or ham) which forms a major part of machine learning. The solution techniques lie at the intersection of statistics, optimization and computer science. I work with Prof. N. Hemachandra. More specifically, we are attempting to develop and study new criterion (loss functions) that can measure the performance of the decision makers (classifiers) obtained by solving the classification problems. Apart from this, we are also interested in giving a game theory perspective to classification problems."

Sandhya Tripathi

"I am currently working on Simulation-based Optimisation with input data uncertainty under the guidance of Prof. Jayendran V. My research mainly focuses on deriving an algorithmic procedure for determining the best solution for simulation-based optimisation with input data uncertainty. Other areas of interests are hybrid metaheuristics, railway scheduling and integer programming."

Sathishkumar L.

"My work is focussed on exploiting parallelism in global optimization of mixed-integer nonlinear programs (MINLPs), a very general and difficult-to-solve class of optimization problems. My research interests include non-convex optimization, convexity detection, mixed-integer linear programming and many more interesting areas. I implement my algorithms in MINOTAUR, a 'cute' and open-source MINLP solver primarily written by Prof. Ashutosh Mahajan."

Prashant Palkar

"I am working on solving convex mixed-integer nonlinear optimization problems by reformulating them and exploiting specific structures to get better bounds. I also work on MINOTAUR, an open-source framework for mixed-integer nonlinear problems. My other research interests include mixed-integer linear optimization, non-linear optimization, simulation-based optimization etc."

Meenarli Sharma

"I am working with professor Veeraruna Kavitha. We are working on the topic "Systemic Risk In Financial Network". Systemic risk is collapse of network if a component or a group of component fails as a whole. We built a sparse network model and are now analyzing the stability of the financial network and also trying phase transitions related results."

Indrajit Saha

"The chemical shipping industry is a billion dollar industry. One of the most important problems in the field of maritime transportation industry is routing and scheduling of chemical tankers (parcel tankers). Owing to the complexity of route network and different trade restrictions this problem in the real world becomes an extremely difficult problem to solve. As a result, we are studying the routing and scheduling of parcel tankers in order to come up with better OR models and novel solution approaches for the effective and profitable working of the maritime transportation networks."

Anurag Ladage

"I am working with Prof. Jayendran V. on system dynamics modeling of supply chains and other operational issues faced during diffusion of a new product in rural areas. Due to rural areas being geographically expansive, lead times become long and uncertain, which may introduce oscillations in inventory levels and affect diffusion rate. We are also interested in policy analysis and exploring the long-term dynamics between product diffusion process and the community."

Mohsin Dalvi

Research Conferences and Seminars

Louis-Martin Rousseau, full professor at Polytechnique Montréal, University of Montréal, and a Canada Research Chair in Healthcare Analytics and Logistics, delivered a seminar entitled "Packing issues and optimization models in Supply Chains" on 5th April 2016.

Prof. Manjesh K. Hanawal presented his work titled "Jamming Attack on In-band Full Duplex Communications: Detection and Countermesaures" at INFOCOM 2016 held in San Francisco from 10th to 15th April 2016.

Research scholar Umakanta Pattanayak presented his work "Local Polyhedrality of Integer Hulls of Strictly Convex Sets" at the Mixed-Integer Programming Workshop (poster) held on Miami from 23rd to 26th May, and at the SIAM Discrete Mathematics Conference (contributed talk) held in Atlanta from 6th to 10th June 2016.

IEOR Faculty members gave talks at the Game Theory & Optimization Conference held on 9th and 10th June at IIT Madras. Prof. Vishnu Narayanan gave a talk on "Local Polyhedrality of some Integer Hulls", Prof. N. Hemachandra talked on " Some Aspects of Excess-Based Solution Concepts for Cooperative Games" and Prof. K. S. Mallikarjuna Rao talked on "PDE Approach to Nonexpansive Ergodic Control".

Profs. K.S. Mallikarjuna Rao and Vishnu Narayanan gave a 10 lecture course on optimization at IISc Bangalore as part of the IFCAM Summer School on Large-Scale Optimization, also organized as part of the National Mathematics Initiative (NMI), held from 28th June to 7th July 2016.

Manu Kumar Gupta defended his doctoral thesis entitled "*Dynamic Priority Scheduling in Multi-class Queues: Pricing, Achievable Regions and Applications*" on 4th July 2016. The research was carried out under the supervision of Prof. Jayendran and Prof. N. Hemachandra. This was the was the first doctoral defense by a M.Sc-Ph.D dual degree student of IEOR.

Dr. Suchismita Tarafdar, Assistant Professor in the Department of Economics at the School of Humanities and Social Sciences, Shiv Nadar University, delivered a seminar entitled "Generalized Envelope Theorems: Applications to Dynamic Programming" on 12th July 2016.

Prof. Jayendran attended the 34th International Conference of the System Dynamics Society organized at TU Delft, Netherlands from 17th to 21st July 2016. He also participated in the System Dynamics summer school held at TU Delft from 13th to

15th July 2016. He also presented a paper entitled “Inventory Management in Response to an Unfolding Epidemic”, and a poster entitled “Modeling New Product Diffusion under Uncertainty”. Both were joint work with his doctoral student Siddhartha Paul.

IEOR students participated in “SPJIMR–POMS India Chapter Conference on Big Data Analytics for Optimizing Supply Chains” held at SPJIMR, Mumbai on 29th and 30th July 2016.
Research scholar Siddhartha Paul presented a paper on “Studying Bullwhip Effect in Supply Chain: A System Dynamics Approach” co-authored with Prof Debabrata Das (IIM Kashipur). Research scholar Meenarli Sharma presented a paper on “Automatic Reformulation of Convex Mixed-Integer Non-Linear Program” co-authored with Prof A. Mahajan. M.Tech students Salman Memon and Vinay Rai presented a paper on “Triangulation Studies and Data Analysis to Understand Causes of Product Failure” co-authored with Prof. Jayendran.

IEOR students and faculty participated in OR2016 – Annual International Conference of the German Operations Research Society at Helmut Schmdit University, Hamburg, Germany during 30th August to 2nd September 2016.
Tilak Raj Singh, a research scholar, presented a paper on “Optimization models for vehicle planning in the pre-production phase”.
Shripad Salsingikar, a research scholar, presented a paper on “Freight train routing and scheduling in a large railway network” co-authored with Prof N. Rangaraj.
Prof Narayan Rangaraj also attended the conference with above mentioned students.

Dr. Swaprava Nath, post-doctoral fellow at the Computer Science Department, Carnegie Mellon University, delivered a seminar on economics and computation on 22th September 2016.

Dr. Sven Leyffer, senior computational mathematician and part of the Laboratory for Advanced Numerical Simulations (LANS) in the Mathematics and Computer Science Division at Argonne National Laboratory, and Senior Fellow of the Computation Institute, The University of Chicago, delivered a seminar entitled “Mixed-Integer PDE-Constrained Optimization” on 26th September 2016.

IEOR had visitors from Mercedes Benz Research and Development India - MBRDI Bengaluru, which is part of Daimler Mercedes Benz worldwide, on 6 October, 2016.
Mr Satheeskaran Navaratnam (Vice President, IT and Engineering Services at MBRDI) and Mr Tilak Raj Singh (Senior Data Scientist at MBRDI - and also a research scholar at IEOR) presented a talk on "IT @ MBRDI : Data - the new Oil", and had discussions with students and faculty.

Research scholar Arko Chatterjee gave a talk entitled “Coordinating to Anti-Coordinate on Networks” on 19th October 2016.

Dr. P. Balamurugan, post-doctoral researcher in SIERRA Project Team, INRIA-Ecole Normale Superieure, delivered a seminar entitled “Efficient Algorithms for a class of Saddle-Point Optimization Problems” on 25th October 2016.

Dr. K. P. Naveen, DST-INSPIRE faculty with the Department of Electrical Engineering, Indian Institute of Technology Madras, delivered a seminar entitled “Coverage Properties of One-Dimensional Infrastructure-Based Wireless Networks” on 8th November 2016.

Anusuya Ghosh defended her Ph.D. thesis titled “*Semidefinite representation of convex sets*” on 16th November 2016. The research work was carried out under Prof. Vishnu Narayanan.

Gaurav Nanda, Ph.D. candidate in the School of Industrial Engineering at Purdue University, delivered a seminar entitled “Improving the Accuracy and Efficiency of Injury Coding using Machine Learning, Expert Knowledge, and Linguistics” on 25th November 2016.

Prof. Jayendran attended the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) organized at Bali, Indonesia from 4th to 6th December 2016. He presented the following two papers:

- "Empirical Studies of New Product Diffusion Under Uncertainty", a joint work with research scholar Siddhartha Paul, M.Tech student R. Vidyadhar, Prof. Chetan S. Solanki (ESE) and Prof. N.C. Narayanan (CTARA).
- "Simulation and Optimization Based Approach for Job Shop Scheduling Problems", a joint work with Pooja Kulkarni (M.Tech batch of 2016).

Prof. Jayendran also chaired the sessions 'Systems Modeling and Simulation 1' and 'Supply Chain Management 4'.

Srijita Ghosh, research scholar at New York University, delivered a seminar entitled "Selective Attention and Costly Learning" on 12th December 2016.

Prof. Jayendran was invited to the IIIE International Conference on Best Practices in Supply Chain Management organized at Thiruvananthapuram, India, on 22nd and 23rd December 2016. He gave a talk on "Supply Chain challenges in sustaining technology interventions in rural India". He was also one of the panelists for a panel discussion on "Evolutionary trends in Supply Chain Management". He also chaired a session on "Rural Supply Chain and Reverse Supply Chain".

Tilak Raj Singh defended his Ph.D. thesis titled "*Configuration planning in mass customization: Optimization based models*" on 9th January 2017. The research work was carried out under Prof. Narayan Rangaraj and Dr. Reinhold Klass. The external examiner was Prof. Anshuman Tripathy of IIM Bangalore.

Dr. M. Tanveer, Ramanujam Fellow in the Discipline of Mathematics at IIT Indore, delivered a seminar entitled "An efficient knn-based weighted twin support vector regression" on 21st January 2017.

Dr. Charitha Cherugondi, Visiting Assistant professor in the Discipline of Mathematics at IIT Indore, delivered a seminar entitled "Regularization Strategies for Monotone Variational Inequalities" on 27th January 2017.

Positively Puzzled

Some puzzles to beguile you...

1. On a man's tombstone, it is said that one sixth of his life was spent in childhood and one twelfth as a teenager. One seventh of his life passed between the time he became an adult and the time he married; five years later, his son was born. Alas, the son died four years before he did. He lived to be twice as old as his son did. How old did the man live to be?
2. What is wrong with the following mathematical proof?

$$\begin{aligned} a &= 9.999\cdots \\ 10a &= 99.999\cdots \\ 10a - a &= 90 \\ 9a &= 90 \\ a &= 10 \\ 9.999\cdots &= 10 \end{aligned}$$

3. A medieval scientist used a smart way to measure time for an experiment lasting 15 minutes. He used two hourglasses, one measuring 7 minutes and the other 11 minutes. How did he measure the 15 minutes?
4. The scientist later found a 4 minute hourglass in his cabinet. This time his experiment was 9 minutes long. How did he measure the 9 minutes using hourglasses which measure 4 minutes and 7 minutes?
5. A toy store ordered 7 small bags and 18 large bags of identical marbles. When the marbles arrived, it was discovered that the bags had broken during shipping, and all 233 of the marbles were rolling around loose in the box. How was the store manager able to determine how many marbles were supposed to go in each small bag and in each large bag?

IEOR Moves Into A New Building

The interdisciplinary academic unit of Industrial Engineering and Operations Research, after its founding, was entirely housed within the Mechanical Engineering building. The department grew with time and additional rooms were acquired in the old Computer Science Engineering building and the Transit Building. When the Biosciences and Bioegineering department moved into a new enlarged building, the Institute authorities decided to renovate the old BSBE building and allot it to IEOR.

2016 was a landmark year in the history of IEOR as the entire department finally moved into its own premises. The department building was formally inaugurated on 19th August, 2016. The inauguration ceremony was graced by the presence of the Institute Director, present and former Deputy directors, Dean (Infrastructure Planning and Support), and his team.

The ceremony began by the lighting of lamps. It was a very momentous occasion when Dean IPS Prof. B. V. S. Vishwanadham presented the department keys to Prof. N. Hemachandra, Convenor of IEOR. All the faculty members talked about their journeys, experiences and their stay in the IEOR family, and motivated the students to excel in their research work. This was very heart-warming for every student as everyone would now be sharing one roof.

Students and faculty members shifted into the new building by September. Prof. Ashutosh Mahajan along with research scholars Arun Verma and Prashant Palkar took special efforts in installing and setting up network communication lines. The office staff oversaw all pending works and followed up in resolving all teething issues that come with relocating into new premises.

Organisational Activities by Students

IEOR Students Association (IEORSA). the student body of IEOR, is lead by the IEOR Council led by a General Secretary and Joint Secretaries (Academics, Cultural, Sports, Human Resources, and Library and Publications). The council organizes workshops and functions for the IEOR family all year round.

LaTeX Workshop

It has been a practice within the IEOR family that senior students would hold hands of the juniors and 'pull' them up from a layman level. In line with this philosophy, IEORSA, for a number of years, has been organizing a workshop for teaching the basics of LaTeX. This year too, for the benefit of incoming students, IEORSA arranged a workshop for LaTeX beginners which was conducted by research scholar Hamidur Rahman on 24th and 25th September 2016.

Bridge Courses

Beginning post-graduate studies in a highly demanding interdisciplinary program at one of the most reputed institutes comes with its own share of learning curves. In order to bring students' the basics of IEOR courses up to scratch, IEORSA devised bridge courses on optimization and probability.

Research scholar Hamidur Rahman conducted evening lectures and explained basic optimization theory concepts to 1st year M.Tech students. In addition, 2nd year M.Tech student R. Vidyadhar conducted a workshhop on introductory Python programming.

Farewell to Graduating Students

A farewell function was organised by the IEORSA for the 2016 passing-out batch of M.Tech and PhD students on 23 June 2016. IEOR faculty members joined in to spend some time with them. Vinay Rai, general secretary of IEORSA, was the presenter for the evening.

The graduating students introduced themselves briefly, shared their experiences in IEOR and on campus, and shared their future plans. They were then presented with gifts by the faculty members. The faculty members shared their thoughts and blessed the outgoing batch with their advice.A vote of thanks was given by the presenter and was followed by a group photograph and dinner.

Orientation for Incoming Students

An orientation session for newly-admitted students was conducted by IEORSA. M.Tech and PhD students had their orientation on 15th July 2016 and MSc-PhD dual degree students had theirs on 16th July 2016.

The new entrants and present students briefly introduced themselves. Prof A. Mahajan gave an overview of the IEOR interdisciplinary programme. Prof V. Kavitha, faculty advisor for M.Tech students, and Prof V. Narayanan, faculty advisor for PhD students, talked about course and other academic requirements. All faculty members then introduced themselves and spoke briefly about courses they would being covering.

This was followed by an informal interaction

between the new students and the IEORSA and ISCP (Institute Students Companion Programme) teams. Then the senior students explained the semester registration process and provided assistance for the same.

Freshers' Welcome

IEORSA organised a freshers' welcome get-together for July entrants on 29th August 2016. IEOR faculty members graced the occasion, and conveyed their wishes to the newcomers for their stay in the campus.

The usual activity of students introducing themselves was tweaked a bit. Students were arranged in pairs, asked to share their details with each other, and introduce their partners to the crowd. This was followed by a game of pictionary and other fun games. Overall, this was a fruitful exercse in building camaraderie among IEOR students.

Teacher's Day Function

IEOR students organised a function on 5th September on the occasion of Teacher's day. Students took the opportunity to share experiences, express gratitude towards faculty members, and seek their blessings.

Dussehra Pooja

IEOR office staff and students organized Dussehra pooja on 10th October 2016. The families of faculty members and staff also participated in the pooja. This was the first festive event held in the new IEOR building.

IEOR Day Celebrations

IEOR Day was organized on 18th March 2017 with the objective to bring together industry experts, faculty, students and alumni to discuss developments and share ideas in this field. Talks and panel discussions were organised to facilitate this exchange. The theme for this year was 'Analytics'

Prof. N. Hemachandra (Professor and Convenor, IEOR), Prof. Narayan Rangaraj (Professor, IEOR), Prof. P. V. Balaji (Dean–R&D), Dr. Siddhartha Sengupta (Key-note speaker) and Dr. Ashwani Kumar (Key-note speaker) inaugurated the event by lighting the lamp, followed by inaugural address from Prof. N. Hemachandra.

After the inauguration ceremony, Dr. Siddhartha Sengupta delivered first key-note talk of the day on "Advanced Analytics: A non-linear Information and Communication Technology Services innovation". Dr, Sengupta had joined Tata Consultancy Services Ltd in 1982, and after his retirement in 2011, still continues the association with TCS. Later, Dr. Ashwani Kumar took the stage to deliver second key-note talk of the event. Dr. Ashwani Kumar is General Manager at Centre for Railway Information Systems (CRIS) where he heads Analytics, Ticketing and Web Application groups. Theme of his key-note talk was "A Practical Perspective on Big Data and Analytics: Hype vs Hands-on". During the tea-break after second key-note talk, Dr. Siddhartha Sengupta and Dr Ashwani Kumar interacted with other participants of the event.

After tea-break, next event was first Panel Discussion of the day. This panel included personnel from academia as well as industry. Discussion was moderated by Prof. Jayendran Venkateswaran (Associate Professor, IEOR). Panel members included Dr. Dinesh Garg (Associate Professor in Department of Computer Science and Engineering at IIT Gandhinagar), Dr. T S Chandrashekar (Principal Data Scientist at Enterprise Data Analytics & Business Intelligence division at Target Corporation), Mr. Vinod Mathur, (Strategic Consultant at JDA Softwares), Prof. Narayan Rangaraj (Professor, IEOR) and Mr. Abhijit Joshi (Associate Director at Ideas Revenue Solutions). Topic of the discussion was "The Impact of Operations Research and Analytics on Industry". This panel discussion went for more than an hour and lot of participation was observed from audience, which included their view on topic as well as some thought provoking questions. First panel discussion was concluded with the announcement of lunch break.

IEOR students took the opportunity of lunch break to showcase their research work via poster presentations. After lunch break, few alumni and faculty members took stage and gave brief talks on various topics of Operations Research. Dr. Tilak Raj Singh (Senior Data Scientist, Mercedes Benz Research and Development India) was first speaker of this series. Dr. Tilak has completed his M.Tech. and Ph.D from IEOR, IIT Bombay. He delivered a talk on "Applications of data analytics in automotive industry". Dr. Rahul Patil (Assistant Professor of Operations Management at the S.J.M. School of Management, IIT Bombay) was next to deliver his talk. With his talk, he threw some light on "Application of Operations Research in Industrial Scheduling". Mr. Prashant Jani who is a knowledge expert with McKinsey & Company and leads Global Supply Chain

Centre of Competence talked about “Operations Analytics at McKinsey & Company”. To conclude this series of talks, Prof. N. Hemachandra (Convenor, IEOR) delivered a talk on “Business Cycles in some service systems”.

Second panel discussion of the day began after the series of talks. This panel discussion was on topic “Current research and development activities in analytics in Indian industry”, and panel of this discussion was made of various individuals from industries. Mr. Arun Kumar (Research Scientist at Conduent Labs India), Mr. Vaibhav Srivastava (Practice Expert in Operations Advanced Analytics, McKinsey & Company), Mr. Raj Sharma (Director, Analytics and FP&A, at JDA Software) and Mr. Jai Mrug (Founder and CEO of M76 analytics) were part of the panel and Prof. Ashutosh Mahajan (Assistant Professor, IEOR) moderated this discussion.

Prof. Vishnu Narayanan (Assistant Professor, IEOR) took the stage after conclusion of second panel discussion. This was the time to thank two of most senior faculty members of IEOR, Prof. A. S. Babu and Prof P. G. Awate. These faculty members were formally felicitated for their invaluable contribution towards the development of IEOR programme at IIT Bombay. Current students, alumni and faculty members of IEOR used this opportunity to personally express their gratitude towards the professors. Prof. A. S. Babu and Prof. P. G. Awate also shared their journey and expressed their happiness in being a part of IEOR.

IEOR and McKinsey Knowledge Centre had organized an online analytics contest for students all over India. This contest had an interesting OR Analytics problem called “Big Buck Challenge”. More than 1600 students registered for this competition. Problem statement and solutions were discussed before announcing the names of the final three winners.

Prof. Manjesh Hanawal (Assistant Professor, IEOR) then took stage and concluded IEOR Day by delivering the vote of thanks to all student volunteers and faculty members for making the event possible.

Later in the evening, everyone gathered on the terrace of the IEOR building for dinner and informal interaction. This was a wonderful occasion to take few pictures. After dinner, IEOR Day came to an end with a big group photograph.

Clusters... Right one or Wrong one?

Each person in this world is emotionally, behaviorally, intellectually so unique that for each and every one, a new biological nomenclature should be given. Still, we always cluster everyone in the categories of ethnicity, race, religion, caste, region, language, gender and what else. Just because we cluster people in a category doesn't mean that each cluster has a uniform characteristics. No, not at all. People are different. Their thinking, reflexes, and approaches are all different. It is very much possible that a person from Pakistan might get more connected to someone in Madhya Pradesh, or an Islamist might have more similarity with someone who follows Buddhism. But we still tie everyone into one or more clusters because of social norms. A person who disobeys a rule or law may be easily pardoned in our society, but if someone crosses a social norm, then they would be forever condemned.

Our national leaders who fought for freedom of our country were initially scattered throughout the country. They were not connected to each other. But once they met at their first INC meeting, they then realized how people from different backgrounds had similar thoughts. Our Indian leaders got support from all over the world, especially from the scholars, writers, activists of the same land which colonized us. Many leaders from different countries fought for us in our nation.

Who are these leaders? Are they extraordinary, because of their background? No, they are special because of their qualities which are not defined by any of these: religion, caste, race, region, language, gender, etc. There is only one similarity, most of them are educated. Yes, modern education was needed for our national leaders at that time to free themselves from the prevailing social norms and evils. These educated Indians felt that they are born with the responsibility to create a Free India. And they succeeded, in the sense that they removed foreign hegemony and imperialism. However, they have not completely freed our India from social evils. Along with social evils, there was proliferation of administrative evils such as corruption, red-tapism, procrastination and many such things. Whose responsibilities are those now? Who is going to continue the work of our national leaders?

Just because I am saying all these things, doesn't mean that I am perfect and I obey all rules. I have jumped many signal lights, I drove a bike without a license, and I have bribed the train ticket collector. I paid a bribe of ₹100 instead of a fine of ₹230, and I felt proud to have saved ₹130. But I didn't save ₹130 by being smart, rather I saved it by corrupting the system. I corrupted the system which was created by our national leaders. I corrupted the system for which blood and sweat was drained and shed. Then I realized that what I had done was not a smart move, but was a crime. So I took it upon myself to not to bend rules again.

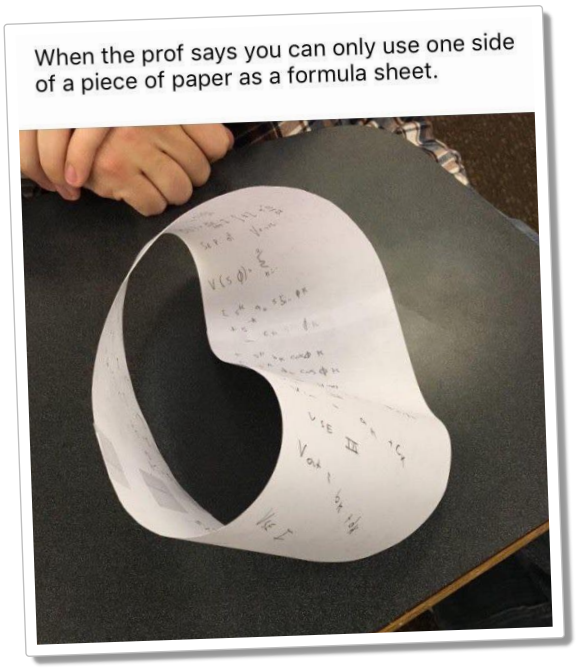
I got an opportunity to redeem myself. When I was journeying by train, I entered a Sleeper coach with an unreserved ticket, and I was not the only one there. Half of the passengers in that coach was of same category as myself. I momentarily belonged to the cluster of people who were traveling in a Sleeper coach without a proper ticket on that train and on that day. Truth be told, clinging to a cluster makes us feel safe. It makes us think that we are not alone. But is it

the right thing to do to cling to any cluster? I very well know that the cluster I was belonging at that moment was not a good one, so I was ready to free myself from that cluster. It so happened that the train had halted at a station, and the coach was so full that even Almighty God would have found it difficult to enter it. So how would the TTE manage? The TTE was trying to enter the coach where it was slightly free, and not into the one in which I belonged. When he crossed before our cluster, I grabbed my moment. I called him and paid the required fine. The happiest emotion was not just getting the feeling that I am not corrupt at that moment, but seeing other persons from your cluster change. Yes, 2-3 people also paid the fine. Thus, I became the leader of a new cluster: people who were traveling in the Sleeper coach without a proper ticket on that train and on that day, and had paid the required fine.

So it always matters to which cluster we belong. We should belong to a cluster where we not only reject any harm on others, but also proudly obey the laws which were framed by our national leaders. As descendants of our national leaders, it is our responsibility to prevent corruption of the system and to be humane and respectful to everyone through an unbiased eye, an eye which should be blind to religion, caste, race, region, language, gender, etc. Along with that, we are also duty bound to conserve the resources of the world. Turning off unnecessary taps and switches alone can extend the lifetime of our future generations. If there is a problem in a switch or a tap, let us visit: `https://gymkhana.iitb.ac.in/cms_new/` and book a complaint, which is the least that we can do for IITB and India.

I always have this thought that nobody has the right to call something orsomeone right or wrong, because someone's right might be someone else's wrong. But as we live in a society, our actions surely affect others. In that case we are bound to follow the above things by assuming it is right thing to do. Because in none of the above cases, are we harming anyone, even by mistake. However, it will not be easy to do all the above. It would be a rather hard path for everyone, because we have generated lots of prejudices and stereotypes till this point of time. Naturally, it is not going to be a cake walk for everyone to give up those prejudices and stereotypes in a day. But if we can bring change to our society just by changing ourselves, then it is definitely worth trying!!!

R. Vidhyadhar
M.Tech, 2nd year



The Final Attempt

Once a mountaineer went for his dream tracking to Roughest Weather Mountain. He went all prepared and after setting his camp he started his upward journey. He could reach to the top in a very quick time, but on the return journey, the weather deteriorated drastically. High speed wind with the heavy snow fall was making it impossible for him to descend. He was unable to see even his feet due to frost around. He just wanted to reach his base camp at the earliest in order to save his life. He continued his efforts for quite a long and found it to be in vain as his speed was very slow. He decided to stop in way and wait at the same place so as to save his energy till weather gets better. After 4 hours when finally the clouds gave way to sun, he was DEAD. He had succumbed to hypothermia.

It's tragic, right? Very tragic!!!!

The worst part is He died just 5 meters above his base camp where all necessary aid was there to save his life. He died just before his final attempt.

Moral: Open to Interpretation...

Shashank Mishra
M.Tech, 2nd year

Invigorate Your Dreams

"You have to dream before your dreams can come true", aptly said by the 'People's President', Dr. APJ Abdul Kalam. Dreams serve as our goals, as long as we believe in them and constantly follow them. Life without dreams is like the night sky without stars; no sparkle, no shine, no vigour and all darkness everywhere. The essence of life is in doing and enjoying things that makes you happy. If we let go of our dreams, then life serves no purpose. The dream to be 'healthier', comes along with the commitment to lead life in the so called 'healthier' way. It further paves the way to actions. First, set the goal that finally helps in achieving the dream and then perform to attain the goals. Initially the gap between the goal and the dream would be enormously large. As we set higher and higher goals, this gap diminishes. Of course, as the intensity of goals increases, the efforts needed to achieve these goals would also increase. But the ultimate dream of attaining success would truly be a motivation to put in more and more efforts at each stage of the goal achievement process.

All of us are unique and capable enough to do meaningful things in life. But being 'unique' makes the difference. Dreams enlighten the so called 'uniqueness' of an individual. We need dreams to cope up with the stresses we have in our everyday lives. But, if we give up, we end up nowhere. The path of fulfilling dream is not always smooth. Setting the right goals and choosing the right way of achieving the goals is equally important.

Here comes the need of invigorating our dreams. Dreams pave the way to success. No matter how we need to succeed in life, our dreams can always get us there. It being cracking a job interview, or starting own business or learning something challenging, dreams will help us succeed in all ways. Just believe and follow them. They would definitely lead to a state of positivity.

The dream of one's life is not essentially the pictures he sees in his sleep. The dreams in our sleep would no longer be a part of us, once we are awake from the sleep. But the dreams of life comes true only when we are awaken. So the right dream can lead one to the most peaceful state of mind. The satisfaction of achieving such a dream is again the motivator to dream and dream.

Sreenath S.
M.Tech, 1st year

Pan-Digital Formula

A pan-digital formula is one that is built by using all digits. The following formula was given by Richard Sabey in 2004:

$$\left(1^0 + 9^{-4^{6\times 7}}\right)^{3^{2^{85}}}$$

This formula accurately gives the first 18, 457, 734, 525, 360, 901, 453, 873, 570 digits of e, or *Euler's number*.

PROOF: Let $x = 3^{2^{85}}$.
$\therefore x = 3^{2\times 2^{84}} = 9^{2^{2\times 42}} = 9^{4^{6\times 7}}$
$\therefore$ formula has the form $\left(1 + x^{-1}\right)^x$
Standard formula: $\lim_{x\to\infty} \left(1 + x^{-1}\right)^x = e$

Source: *Numberphile* channel on youtube.com

A love that never dies

There was that crowded place
She crawled around looking for her favorite face
Suddenly she smiled and took a pause
There her mother was.

From alphabets to numbers
And shapes to colours
Her mother taught her all those days
Standing by her in every phase.

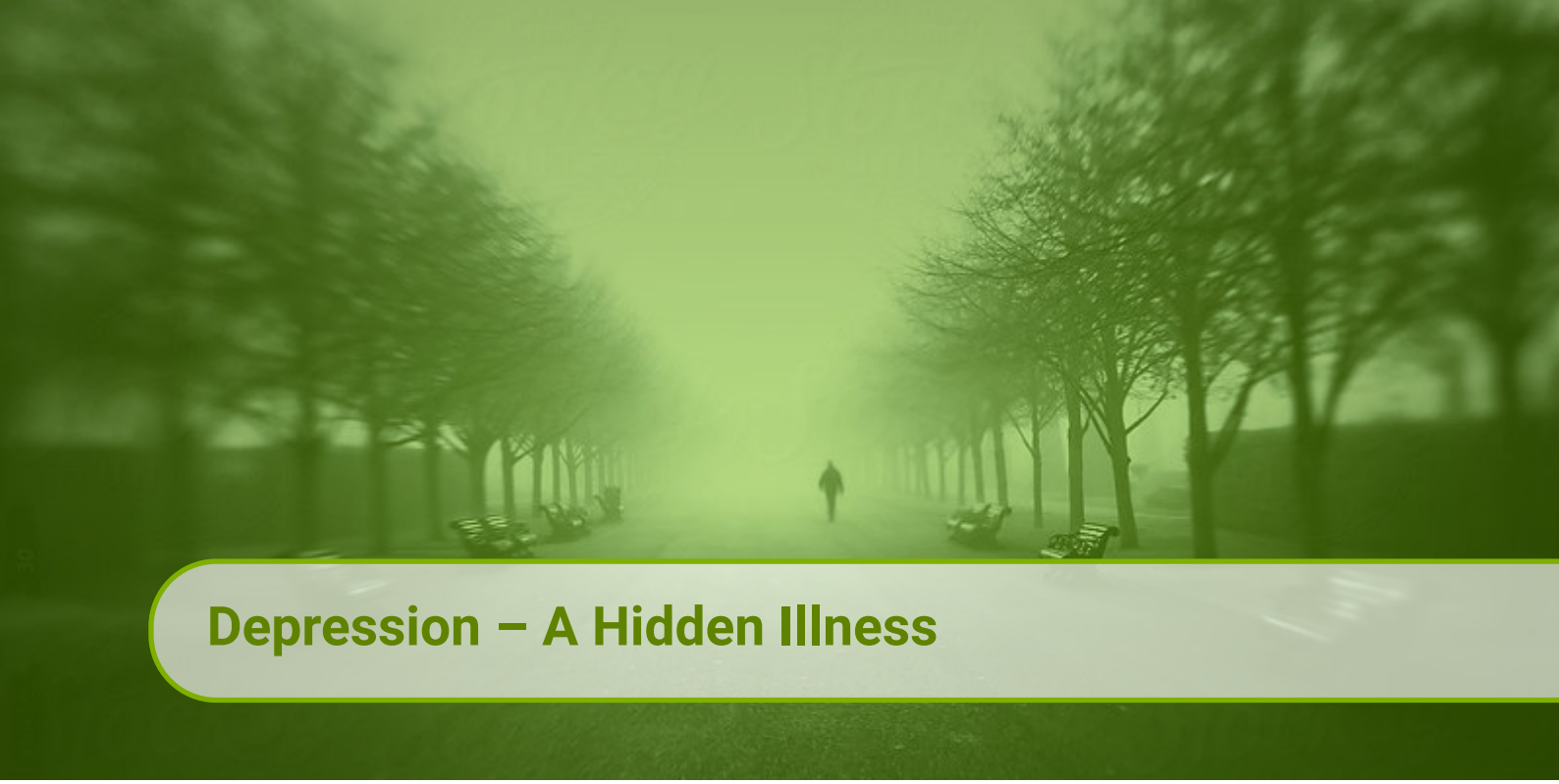
School was over and it was time to move on
Away from her mother she was now gone
Her mother had taught her to be strong
But how could she live without her for so long.

There were those days when life got a little messed
Moments when she needed some rest
A call from her mother seemed to make everything clear
'Life is hard but there is no need to fear'.

And hence two decades went by
And now she was some twenty
Happy she was still when told by others
That her face resembles her mother's.

All of a sudden there was a sigh
When she realised that in another city miles away
Her mother was too growing old
And she couldn't even put the time on a hold.

Saumya Suri
M.Sc-Ph.D, 1st year



Depression – A Hidden Illness

When we get a cut on our hand, it bleeds and we know whether to put a bandage or visit a doctor, because we can see the cut and feel the pain. But, nostalgic feeling persisting in your body, mood swings, restlessness, loss of enjoyment in things that were once pleasurable, fatigue, anxiety, feeling of loneliness, feeling helpless... What are all these feelings exactly? What do they signify? Why does a person feel this way? Does this remain just for a while or last forever? Well, all these thoughts and feelings are blindfold indications that you are not well, and there is no physical injury inflicted. You cannot determine whether there is any need to even ponder on this situation or not.

So, when one feels this way, how do we usually react to it? We often try to neglect it assuming that I am feeling this way because of so-and-so reason. It imbalances our emotional health which is reflected by the change in our behavior. The thing now is—do we want to live our whole life going through such a phase in life or such a persistent feeling taking control over our well-being? Well if you think NO, then there is real need to understand WHY, HOW, WHEN, WHERE of these situations and an answer to these questions.

Well friends, every other person you meet is feeling the same that you are going through and there is no need to hide such a feeling. Emotional imbalance is often related to person's inability to do things on their weakness. In student life, what I observed is FEAR, GUILT, PAST, CAPABILITY and RELATIONSHIPS are the most common reason why we get into something which is fancily called DEPRESSION. Each person wants to be heard, but now questions arise: With whom shall I share? Will people mock at me? What will they think of me? Shall I consult a psychologist? Ohhhh, please, I am not mad; it's just I am feeling down because of x reason. And endless questions and fears start engulfing your mind. But one should at least once visit a psychologist to understand a cause or at least to open up your heart to someone who can understand you. He would initially council you, try to help you get on track, and give you some motivational advice so that you feel good and get energized. But if it still persists, then there is a real need to exactly understand the problem.

The various emotions we experience are the result of chemical reactions taking place inside your body. The hormones released inside our body may either make us feel good or make us feel bad. Stimulating the production of feel-good hormones can help easy your agony till you are able to deal with the problem at hand. Your body exists in two states—fight-or-flight (or sympathetic state) and digest (or parasympathetic state). Due to everyday stress, you are in a fight-or-flight state. It is the neurotransmitter that helps control the brains reward and pleasure centers. It keeps you mentally alert. A hormone named DOPAMINE is induced for this.

There is another hormone, a happy hormone named SEROTONIN that regulates your body's sleep cycle and temperature. It controls your appetite and lowers sensitivity to pain. It is this hormone that makes you feel satisfied or we can say, it is a mood-enhancing hormone. Serotonin is produced through Vitamin D (it synthesizes hormones which influence neurotransmitter production), carbohydrate rich foods, black pepper (it contains piperine that

inhibits depression-inducing hormones), and massage and exercise.

The feel-positive hormone ENDORPHINS reduce anxiety and act as a sedative. Endorphins are produced through exercising and sweating, and acupuncture. Another hormone, OXYTOCIN, also called love hormone, increases bonding, social behavior and closeness between parents, children and couples. In women, it is produced during childbirth. It reduces stress responses and motivates you to seek support. It is produced through spending time with loved ones, and through physical intimacy.

Now with this clarity in mind, I hope I have succeeded in throwing light on the need of consultation during this phase. There is hormonal imbalance and so I suggest a need to consult a psychologist for further assistance if these feelings persist for long. Dear reader, please try to understand what your friend, family member, or any person for that matter is going through and that your love, compassion, support can be life transforming change for that person. The help you have to provide is free of cost and the best gift you can provide to humanity. There are lot of people suffering with depression and since they didn't get any help or there was no one to understand and help them have eventually ended up their lives. They were not weak, they were ill and needed your help.

Parents play a very important role in this. So, sudden behavioural changes as a symptom of depression should be noticed. Parents should ask his friends, enquire in college to know whether he has some problem that you are not aware of. Start being friendlier to him, gain his confidence that you will not mock at him for whatsoever reason and forgive him and help him in this stage.

There are 332 million people in the world affected by depression, and 56 million of them are living just in India. This is the saddest truth of our country. It is mostly the younger generation that is being affected by this, and they feel so helpless that ending their lives feels simpler for them than living. But we should never forget what our parents do for us, and seeing us succeed is the only joy they cherish. We children should respect their sacrifices and efforts that they make for us, and should not let it all go waste just by ending our lives. There are many people who would come forward to help you, guide you, only if you ask for it.

Harshal Yeole
M.Tech, 2nd year
&
Aditi Tirpude
(M.Tech, NIT Surathkal)

Positively Puzzled (Solutions)

Solution 1:

Let x = age of man at time of death

$\therefore x = x/6 + x/12 + x/7 + 5 + x/2 + 4$

$\Rightarrow x = 75x/84 + 9 \Rightarrow x = 84$ years

Alternate Solution 1:

The man lived 1/12 of his life as a teenager. There are seven teen years. $\therefore 7 \times 12 = 84$.

Solution 2:

$9.99999\cdots$ is an infinite geometric sum:

$\therefore 9\left(\frac{1}{10}\right)^0 + 9\left(\frac{1}{10}\right)^1 + 9\left(\frac{1}{10}\right)^2 + \cdots$

$= \frac{9}{1 - \frac{1}{10}} = 10$

$\therefore$ there is nothing wrong with the proof.

Alternate Solution 2:

$$a = 9.9999\cdots = 3 \times 3.3333\cdots$$
$$= 3 \times (10/3) = 10$$

$\therefore$ there is nothing wrong with the proof.

Solution 3:

- At time 0, start hourglasses A (7 mins.) and B (11 mins.).
- After 7th min., A runs out. Turn A around.
- After 11th min., B runs out, and A completes 4 mins. Turn A around.
- After 15th min., A runs out. Stop.

Solution 4:

- At time 0, start hourglasses A (4 mins.) and B (7 mins.).
- After 4th min., A runs out. Turn A around.
- After 7th min., B runs out, and A completes 3 mins. Turn B around.
- After 8th min., A runs out, and B completes 1 min. Turn B around.
- After 9th min., B runs out. Stop.

Solution 5:

Let x and y be no. of marbles in small and large bags. $\Rightarrow 7x + 18y = 233,\ x, y \in \mathbb{Z}, x < y$

We can't solve one equation with two unknowns. But we will try to tighten the bounds on x and y.

Assume $y = x$. Then,

$7y + 18y = 233 \Rightarrow y = 9.32$

If $y \leq 9.32$, then $y < x$, which is not allowed.

$\therefore y = 9.32$ is lower bound. $\because y \in \mathbb{Z}, y \geq 10$.

Assume $x = 1$. Then,

$7 + 18y = 233 \Rightarrow y = 12.555$

When $x > 1$, y reduces. $\therefore y = 12.555$ is upper bound. $\because y \in \mathbb{Z}, y \leq 12$.

$\therefore\ y \in \{10, 11, 12\}$. Substituting each into equation, we get x as 7.57, 5 and 2.42 respectively.

$\because x \in \mathbb{Z}$, solution is $x = 5, y = 11$.

Reproducible Research with Python and LaTeX

Research is often presented in formats like slideshows, journal articles, books, or even websites. However, these documents are not the research, but only a means to announce a project's findings. *Reproducible research* refers to the idea that the ultimate product of research is the paper along with the computational code, data, etc. used to produce the results, so as to enable reproducibility of results and create new work based on the research. *Reproducibility*, one of the main principles of the scientific method, is the ability of an entire experiment or study to be duplicated, either by the same researcher or by someone else working independently. Let us first see Python and LaTeX in brief before looking at a motivation for reproducible research.

Python Programming

Python is an open-source language created by Guido van Rossum and was first released in 1991. The Python interpreter and the extensive function libraries are freely available and follow a community-based development model. The language is named after the BBC show "Monty Python's Flying Circus". The present versions are 2.7 and 3.6 (the versions are not fully mutually compatible).

Python is an interpreted language, which saves considerable time during program development because no compilation and linking is necessary. It has a clean elegant syntax and indentation structure which makes it easy to learn and use for beginners. Programs written in Python are much shorter than equivalent C, C++ or Java programs.

Being a very-high-level object-oriented language, it has high-level data types built in such as flexible arrays and dictionaries. It is therefore a powerful programming language and is applicable to a much larger problem domain. Today, extensive specific libraries written in Python are available for numerical computation, statistics, machine learning, control systems, big data analytics, simulation, application development, file operations, web development, financial applications, and graphing and visualization.

LaTeX Typesetting

TeX (pronounced *tek*) is an open-source typesetting system for creating text files. It was created by the renowned computer scientist Donald Knuth in the early 1980s out of frustration that the typesetting method for printing the second edition of Volume 2 of his well-known monograph *The Art of Computer Programming* had become obsolete. In the early 1980s, Leslie Lamport created LaTeX on top of TeX in the early 1980s to provide a higher level language to work.

A LaTeX file consists of content in simple text form and includes mark-up tags for formatting, referencing and document structuring. Since a LaTeX file is a text file, it can be opened using any text editor. For instance, in order to render the mathematical equation

$$\Gamma(\alpha) = \int_0^\infty e^{-x}\, x^\alpha \, dx$$

we type the following in a LaTeX document:

```
$ \displaystyle \Gamma \left(\alpha\right)
= \int_0^\infty e^{-x} \, x^\alpha \ dx $
```

Clearly, the interface in LaTeX resembles a programming language IDE (integrated development environment), and this seems intimidating. However, the output document (which is usually a `.pdf` file) has uniform formatting, beautiful mathematical equations, polished tables, and consistent output across all computer systems. Therefore, LaTeX is widely used for publication of books and scientific communication. Also, websites such as Wikipedia use TeX to render mathematical equations.

Reproducible Research

In research, to prevent what is called as "garbage in, garbage out", we prefer that data not be manually copied into analysis tools. Therefore, programming tools are used for linking with data files and extracting data. The same tools carry out analyses and generate results. However, these analyses results remain delinked with publication tools during dissemination of results, i.e., incorporating the results into the report requires manual copying, which (obviously) is an error-prone process. What reproducible research essentially aims to do is create this linkage.

Suppose we want to include, in a report, the value of compounded returns for a given principal, compounding rate and compounding time. We compute the returns using a calculator, spreadsheet or computer program, and copy the results into the report. Now, if the compounding rate changes, the revised results would be copied into the report, possibly at multiple locations, again, which can introduce errors. This provides the motivation for incorporating some form of automation into the report-writing process. We will see how Python can be integrated into LaTeX for accomplishing this goal.

Pweave

Pweave is a scientific report generator and a literate programming tool for Python. It is inspired by Sweave, an excellent reproducible research tool for R programmers. Pweave was created by Matti Pastell in 2010, and the present version is 0.25, which is compatible with Python 2.7 and 3.4+. Pweave can be installed from source code or by using `pip`.

Pweave runs Python code present in the source document (having `.texw` extension), captures results from data analysis, and includes results and plots in the output document (which can be a LaTeX, HTML or markdown file). The input document contains text and code separated by special mark-ups. The code fragments may be in the form of code chunks or inline code. *Weaving* a Pweave source file produces a document that contains text and weaved code together with its evaluated output. Following steps are involved in embedding Python into LaTeX using Pweave:

1. Embed Python code using Pweave mark-ups alongwith text to create a `.texw` file.
2. Create `.tex` file by running `Pweave`:
   ```
   pweave -f tex yourfile.texw
   ```
   For other output formats, replace `tex` by appropriate keyword.
3. Create a `.pdf` fle by running `pdflatex`:
   ```
   pdflatex yourfile.tex
   ```

A **code chunk** starts with line marked as `<< >>=` and ends with line marked as `@`. The code between the start and end markers is executed and the output is captured to the `.tex` document. The following code defines a function to calculate compound interest :

```
<<>>=
def amtcompound(P, r, t):
    return round( P * ( (1+r) ** t ) , 2 )
@
```

When the `.texw` file is compiled using Pweave, the above Python code between the mark-ups get added to the `.tex` file inside a `verbatim` environment. In order to hide the code in the `.tex` file, add `echo=False` option in the starting mark-up, as is seen in the following code chunk.

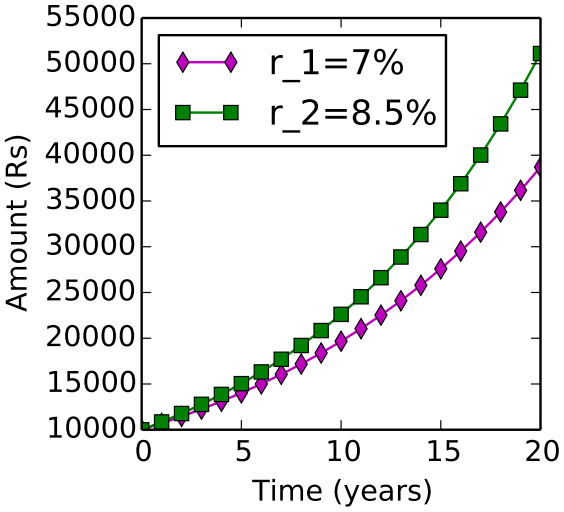
```
<<echo=False>>=
import numpy as np
t = np.arange(0, 20+1, dtype=np.float)
p, r1, r2 = 10000, 7./100, 8.5/100
p_ar = np.full(np.shape(t),p)
vfunc = np.vectorize(amtcompound)
ap1, ap2 = vfunc(p, r1, t), vfunc(p, r2, t)
@
```

For displaying plots, Python uses the `matplotlib` library. In following code chunk, option `Fig=True` is used in starting mark-up in order to generate plots. The generated plot is saved as a `.pdf` file in the 'figures' folder which lies in the same location as the Pweave file. This plot gets added to the `.pdf` file when the generated `.tex` file is compiled.

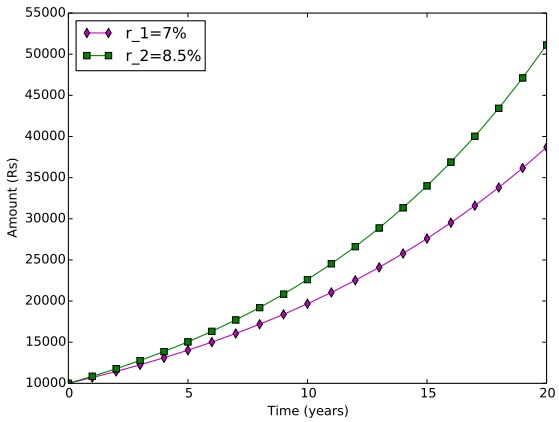
```
<<fig=True, width='25em', echo=False>>=
import matplotlib.pyplot as plt
plt.figure(figsize=(3,3))
plt.plot(t, ap1, 'md-', label="r_1=7%")
plt.plot(t, ap2, 'gs-', label="r_2=8.5%")
plt.xlabel('Time (years)')
plt.ylabel('Amount (Rs)')
plt.legend(loc=2)
plt.savefig("myplot.pdf", dpi=300,
    bbox_inches="tight")
@
```

The generated plot is saved as a `.pdf` file in the 'figures' folder which lies in the same location as the Pweave file. This plot gets added to the `.pdf` file when the generated `.tex` file is compiled.

However, the above chunk also contains code for explicitly saving the plot as a `.pdf` file. This file `mypdf.pdf` gets saved in the same location as the Pweave file. The following figures show that there is a huge difference in the plots produced by the code chunk. The `plt.figure(figsize=(3,3))` code should have produced a plot with proportionally large text sizes. Clearly, it is the `savefig` Python command faithfully produced the intended plot.



Plo saved due to `savefig` Python command.



Plot saved due to `fig=True` option in code chunk

So, in order to use `myplot.pdf` instead of the above one in the document, set the `fig` option to `False`, and add the `\includegraphics` LaTeX command to add the plot in the document.

```
\begin{figure}[h!]
\centering \includegraphics
   [width=0.5\textwidth]{myplot.pdf}
\caption{Returns for first 20 years}
\end{figure}
```

Now, suppose we change the value in variable `t` from 20 to 25 in the second code chunk. Instead of manually changing the figure caption above, we can use **inline evaluation** of Python code for auto-updating of the caption. The mark-ups `<\%= \%>` and `<\% \%>` are used for inline code evaluation with and without display of results respectively. So, we modify the caption line to

```
\caption{Returns for <%=int(t[-1])%> years}
```

Now, using inline evaluation, we can refer to results of analyses without any manual copying. Consider the following example of inline evaluation:

```
After <% t2=25; print(t2)%> years at
<%= r1*100 %>\% annual compounding rate,
the annualised return rate is <%=
(amtcompound(1,r1,t2) - 1) * 100/t2 %>\%.
```

That, after compiling, would give the following in the output `.tex` file:

```
After 25 years at
7.0\% annual compounding rate,
the annualised return rate is 17.72\%.
```

which, in the final `.pdf` file would read as:

After 25 years at 7.0% annual compounding rate, the annualised return rate is 17.72%.

By simply changing variable values above, the new results would get incorporated in the document without manual copying.

Final Thoughts

There are other approaches apart from Pweave for incorporating Python code into LaTeX. These include using LaTeX packages like `python` and `pythontex`. However, these suffer from the following limitation: Suppose it is required to submit LaTeX files while publishing research findings. The Pweave approach would generate a `.tex` file containing no trace of Python code, and would be as good as a manually created document. On the other hand, if `python` or `pythontex` packages are used, then compiling the `.tex` file would require the presence of a proper Python installation with the publisher.

Using Pweave code chunks and inline code evaluation, we can link data files, Python code (and even import our own Python script files) and LaTeX, and incorporate automation into a scientific report. All these files together achieve the aim of reproducible research.

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