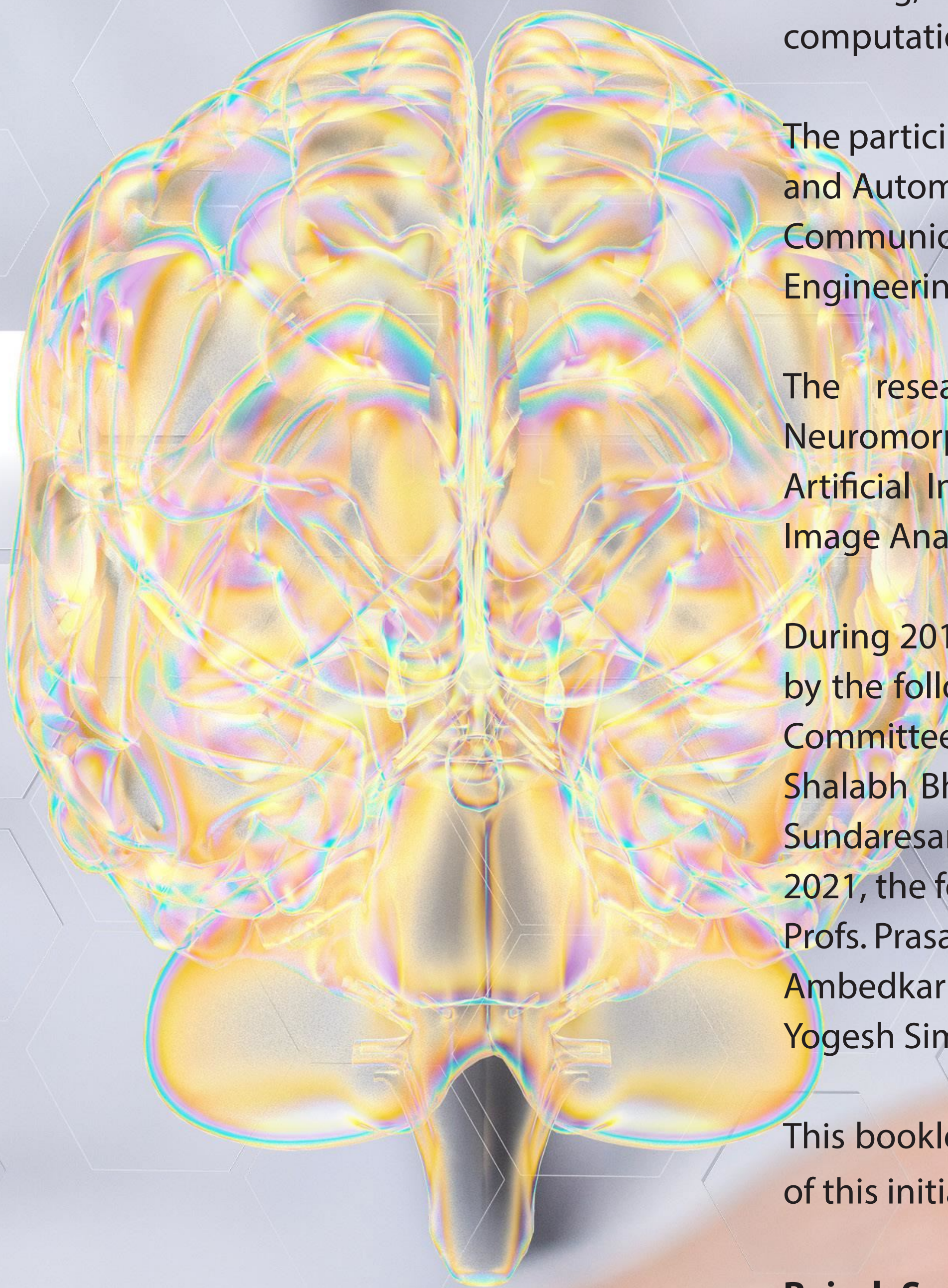
Pratiksha Trust Initiative on

Brain, Computation and Data Science

INDIAN INSTITUTE OF SCIENCE
भारतीय विज्ञान संस्थान

Activities 2022

Contents



Overview

The Brain, Computation and Data Science initiative is the brainchild of Mr. Kris Gopalakrishnan and Mrs. Sudha Gopalakrishnan, founders of the Pratiksha Trust, Bangalore. In June 2015, the Pratiksha Trust set up three Distinguished Chair Professorships at the Indian Institute of Science, Bangalore. The purpose of these Chair Professorships is to bring frontline researchers in the areas of neuromorphic computing, computational neuroscience, machine learning and data science to the IISc campus to help strengthen research and international collaboration in these important emerging areas. The mission of this initiative is to foster intense research collaboration leading to capacity building, ecosystem creation, and high impact research outcomes in brain, computation and data science in IISc and India.

The participating departments and centres of IISc include: Computer Science and Automation, Computational and Data Sciences, Neuroscience, Electrical Communication Engineering, Electrical Engineering, Electronic Systems Engineering, Mathematics, and Molecular Biophysics.

The research areas pursued include: Computational Neuroscience; Neuromorphic Computing and Engineering; Data Science; Machine Learning; Artificial Intelligence; Brain Inspired Algorithms; Neural Signal Processing; Image Analysis; Vision and Visualisation.

During 2016-2021, the activities of this initiative were shaped and anchored by the following members of the Prasanta Kumar Ghosh Scientific Advisory Committee: Profs. P.S. Sastry (Convener); Rishikesh Narayanan (Co-Convener); Shalabh Bhatnagar; K.V.S. Hari; Aditya Murthy; M. Narasimha Murty; Rajesh Sundaresan. Our grateful thanks for their precious time and efforts. From July 2021, the following committee has taken charge:
Profs. Prasanta Kumar Ghosh (Convener); Sridharan Devarajan (Co-Convener); Ambedkar Dukkipati; K.V.S. Hari; Ramesh Hariharan; Supratim Ray; and Yogesh Simmhan.

This booklet provides a bird's eye view of the activities undertaken as a part of this initiative in IISc during 2022.

Rajesh Sundaresan, ECE
Convener, Pratiksha Trust Initiative at IISc

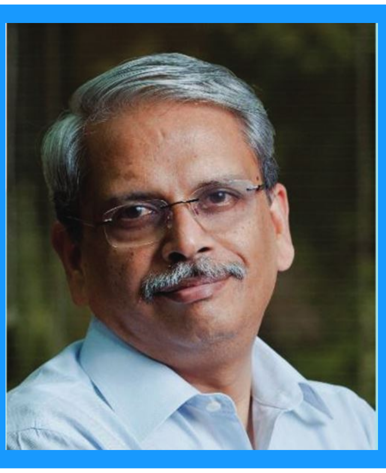
From Director, IISc

"We are immensely grateful to Shri. Kris Gopalakrishnan and Smt. Sudha Gopalakrishnan for choosing the Indian Institute of Science for these generously endowed chair professorships. These chairs intend to invigorate and accelerate extremely important emerging interdisciplinary research areas. I am sure the chair professors will add a new dimension to research collaboration between IISc researchers and star contributors to these areas anywhere in the world."

Govindan Rangarajan
Director, Indian Institute of Science, Bangalore

From Pratiksha Trust Founders

"We hope the launching of these distinguished chair positions will help push the frontiers in brain inspired research. It would be excellent if the collaborations lead to highly creative new computing architectures and algorithms inspired by the functioning of the brain."



Kris Gopalakrishnan
Founder, Pratiksha Trust, Bangalore

Sudha Gopalakrishnan
Founder, Pratiksha Trust, Bangalore

IISc Team

Scientific Advisory Committee

Prasanta Kumar Ghosh, EE
(Convener, ex-officio)

Sridharan Devarajan, CNS
(Co-Convener, ex-officio)

Vijay Chandru
Stand Life Sciences

Supratim Ray, CNS

Faculty Team (Brain, Computation and Data Science Group)

A.G. Ramakrishnan, EE
Aditya Murthy, CNS
Aditya Sadhanala, CeNSE
Akshay Singh, Physics
Anand Louis, CSA
Animesh Kuley, Physics
Anirban Chakraborty, CDS
Arindam Ghosh, CeNSE
Arjun Jain, CDS
Arkaprava Basu, CSA
Arnab Barik, CNS
Arnab Bhattacharyya, CSA
Arup Polley, ESE
Ashesh Dhawale, CNS
Balaji Jayaprakash, CNS
Banibrata Mukhopadhyay, Physics
Bharadwaj Amrutur, ECE
Chandra Murthy, ECE
Chandra Sekhar Seelamantula, EE
Chetan Thakur, ESE
Chirag Jain, CDS
D. Ambedkar, CSA
Deepak Subramani, CDS
Deepak Kumaran Nair, CNS
Hardik Pandya, ESE
K.V.S. Hari, ECE
Mayank Srivastava, ESE
P.S. Sastry, EE
Partha Talukdar, CDS
Phaneendra Yalavarthy, CDS
Prasanta Kumar Ghosh, EE
R. Venkatesh Babu, CDS
Rajesh Sundaresan, ECE
Rishikesh Narayanan, MBU
S.P. Arun, CNS
Santanu Mahapatra, ESE
Sashikumaar Ganesan, CDS
Shalabh Bhatnagar, CSA
Shayan G. Srinivasa, ESE
Shirish Shevade, CSA

Shishir Nadubettu Yadukumar Kolathaya, RBCCPS

Siddharth Barman, CSA

Siddhartha Gadgil, Mathematics

Soma Biswas, EE

Sridharan Devarajan, CNS

Srikanth Padmala, CNS

Sriram Ganapathy, EE

Sujit K. Sikdar, MBU

Sumantra Sarkar, Physics

Sundeep Prabhakar Chepuri, ECE

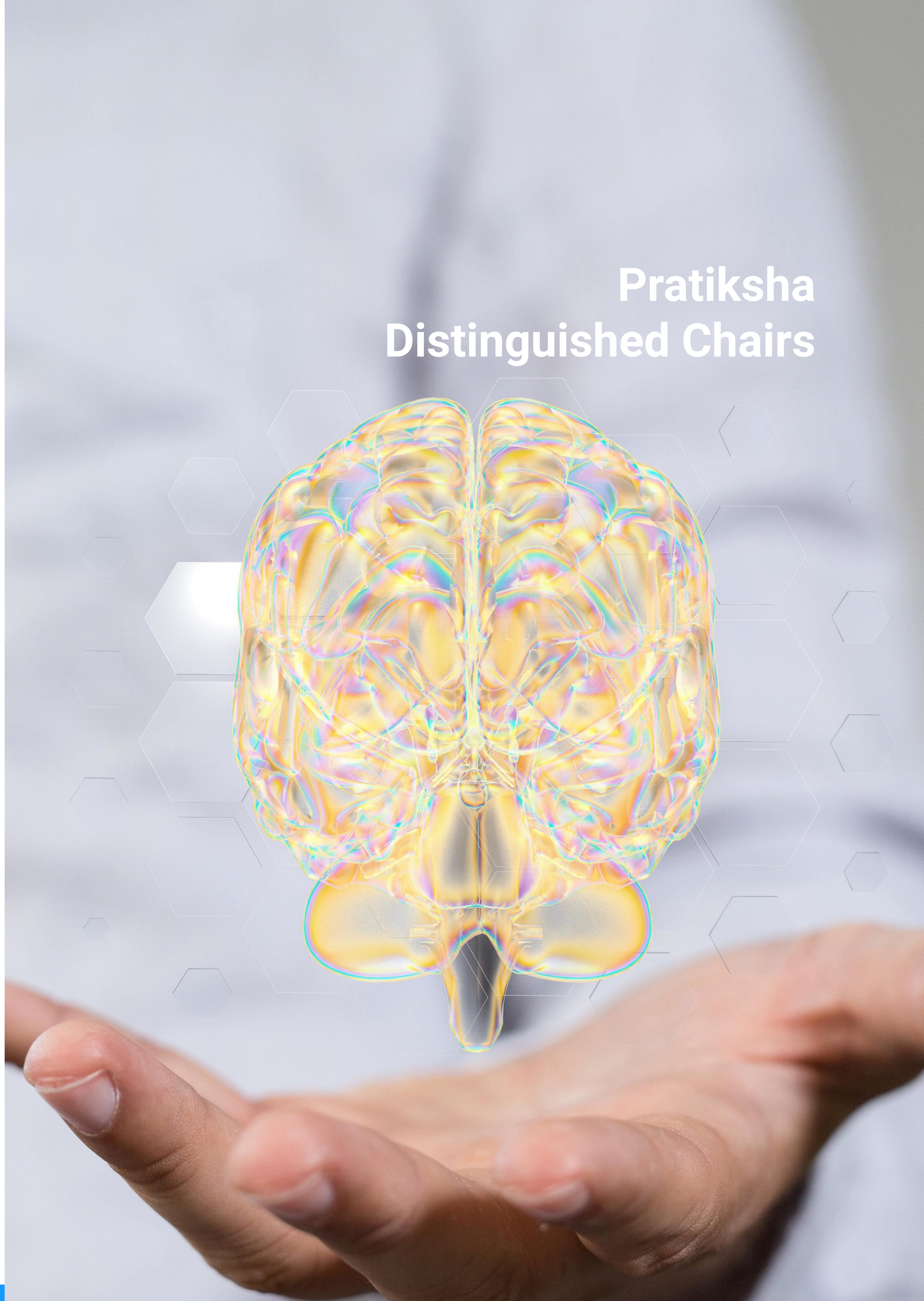
Supratim Ray, CNS

T.V. Prabhakar, ESE

Y. Narahari, CSA

Yogesh Simmhan, CDS

and all other interested faculty members



Pratiksha Distinguished Chairs

Pratiksha Trust Distinguished Chair

Prof. Rajesh P N Rao
CJ and Elizabeth Hwang Professor, Paul G. Allen School of Computer Science and Engineering and Department of Electrical and Computer Engineering, University of Washington (UW), Seattle.

Co-Director, Center for Neurotechnology (CNT)

Adjunct Professor, Bioengineering Department

Faculty member, Neuroscience Graduate Program at UW.

Education

BS- Angelo State University - 1992
MS - University of Rochester - 1994
Ph.D. - University of Rochester - 1998

Expertise

Computational Neuroscience
Brain-Computer Interfacing
Artificial Intelligence

Awards and Distinction

Guggenheim Fellowship
Fulbright Scholar award
NSF CAREER award
ONR Young Investigator Award
Sloan Faculty Fellowship
David and Lucile Packard Fellowship

Offer sent to Prof. Maneesh Sahani for the Smt. Sudha Murty Visiting Chair Professor
Search for the third chair professor is ongoing

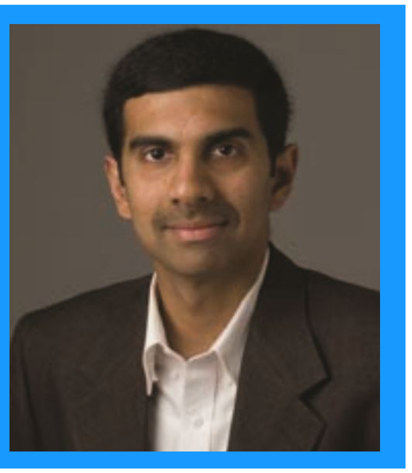
Pratiksha Trust Distinguished Chairs at IIT-Madras

Prof. H.N. Mahabala Chair

Prof. Partha Mitra
Cold Spring Harbor Lab

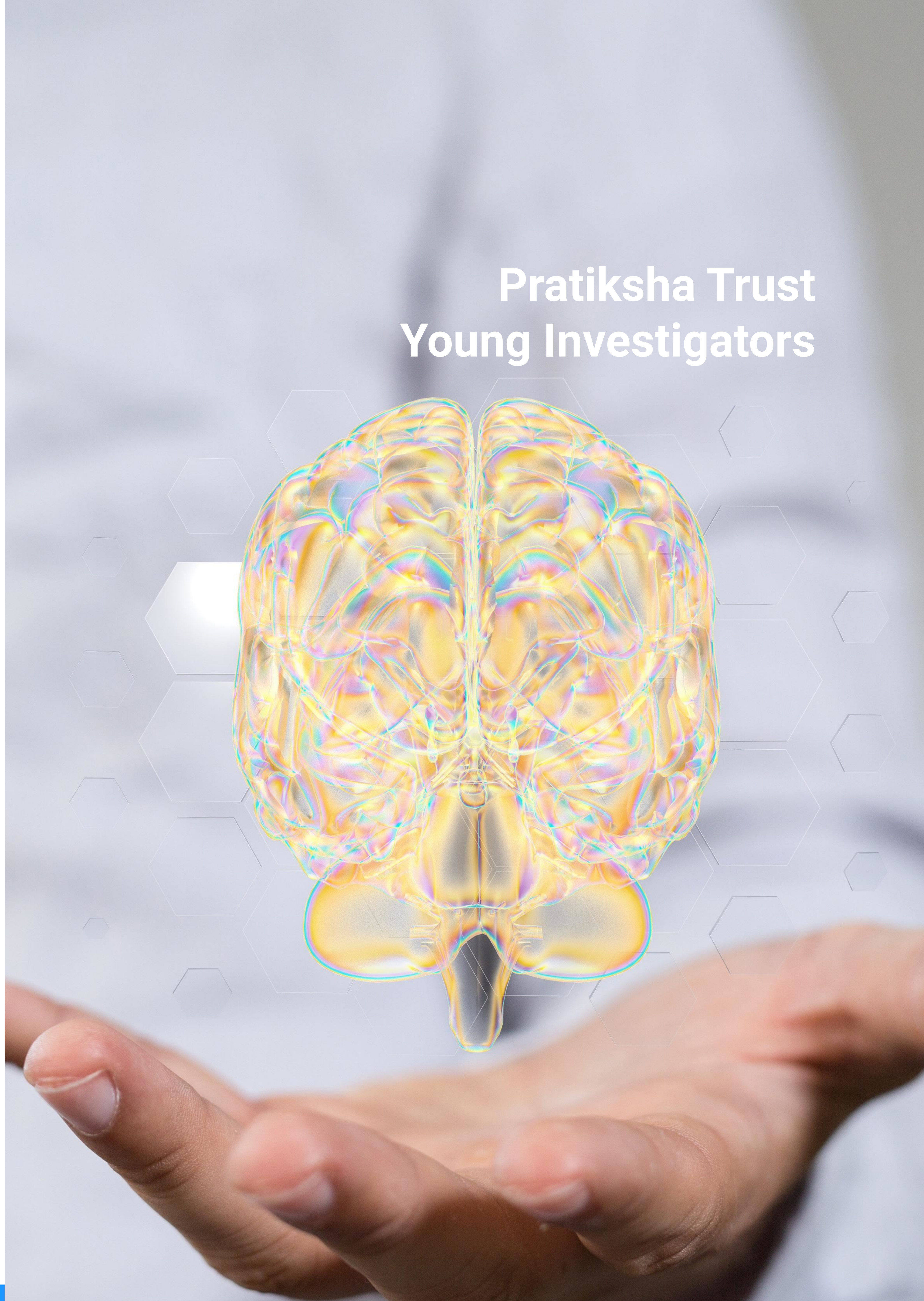
Dr. N.R.Narayana Murthy Chair

Prof. Mriganka Sur
Massachusetts Institute of Technology



Prof. Muthukrishnan Chair

Prof. Anand Raghunathan
Purdue University


Pratiksha Trust
Young Investigators

Pratiksha Trust Young Investigators

These awards have been instituted to recognize and reward the accomplishments of young faculty members or prospective faculty members. The Pratiksha endowment now supports the award of up to five Young Investigator awards at any time. The awardees receive, for two years, a top-up salary of Rs 25000 per month and a research grant of Rs. 3 lakhs per year. Recognition as a Young Investigator will be based on academic achievement at the highest national and international level. Following is the list of Pratiksha Trust YIs

1. Dr. Sriram Ganapathy, Department of Electrical Engineering (2017-19)
2. Dr. Prasanta Kumar Ghosh, Department of Electrical Engineering (2017-19)
3. Dr. Sridharan Devarajan, Centre for Neuroscience (2017-19)
4. Dr. Chetan Singh Thakur, Department of Electronic Systems Engineering (2017-19)
5. Dr. Siddharth Barman, Department of Computer Science and Automation (2018-20)
6. Dr. Anirban Chakraborty, Department of Computational and Data Sciences (2018-20)
7. Dr. Anand Louis, Department of Computer Science and Automation (2019-21)
8. Dr. Sundeep Prabhakar Chepuri, Department of Electrical Communication Engineering (2019-21)
9. Dr. Arkaprava Basu, Department of Computer Science and Automation (2020-22)
10. Dr. Chirag Jain, Department of Computational and Data Sciences (2020-22)
11. Dr. Aditya Sadhanala, Centre for Nanoscience and Engineering (2020-22)
12. Dr. Arindam Khan, Department of Computer Science and Automation (2021-23)
13. Dr. Shishir Kolathaya, Robert Bosch Centre for CyberPhysical Systems and Department of Computer Science and Automation (2021-23)
14. Dr. Utsav Banerjee, DESE (2022-24)
15. Dr. Gugan Thoppe, CSA (2022-24)
16. Dr. Seetosh Goswami, CeNSE (2021-23)

Anand Louis

https://www.csa.iisc.ac.in/~anandl/

Anand Louis is an Assistant Professor in the Department of Computer Science and Automation, IISc since September 2016. He obtained his Ph.D. in "Algorithms, Combinatorics and Optimization" from the Georgia Institute of Technology in 2014. Following this he spent two years as a Postdoctoral Research Associate in the Department of Computer Science in Princeton University before starting his current position in CSA. His research interests lie in algorithms and optimization.

Research Highlight

Humans are increasingly relying on algorithms to make decisions. Depending on the data an algorithm is acting on, the output produced by the algorithm might inadvertently be biased towards some groups in the input. Moreover, algorithms trained using real-world data might inadvertently amplify biases present in the training data. This could have serious social, ethical and legal consequences. Therefore, for various such problems, the algorithms should be designed to ensure that their output is not biased towards any group in the input, while also optimizing the "cost" of the solution produced. We have been studying some such problems in the last few years.

Search and recommendation systems, such as search engines, recruiting tools, online marketplaces, news and social media output ranked lists of items. Our work [1] defined the notion of "underranking" and proved a lower bound on the trade-off achievable for simultaneous underranking and group fairness in ranking. This work also gave an algorithm that takes any given ranking and outputs another ranking with simultaneous underranking and group fairness guarantees comparable to our lower bound.

Our work [2] gave online and offine approximation algorithms for bipartite matching with group fairness constraints; this problem models several important real-world problems such as ad-auctions, scheduling, resource allocation, etc.

Another direction of our research has been in the "beyond worst-case analysis" of algorithms. For many computational problems, the best known algorithms provide a somewhat underwhelming performance guarantee, whereas simple heuristics perform remarkably well in practice. A possible explanation for this phenomenon could be that the instances arising in practice tend to have some inherent structure that makes them "easier" than the worst-case instances. Many attempts have been made by the research community to understand the structural properties of instances arising in practice, and to use them in designing algorithms specifically for such instances, which could perform much better than algorithms for general instances. This includes modelling real-world instances as families of random/semi-random instances, identifying structural properties that real-world instances typically satisfy, etc.

Our work made some important contributions in this direction for the hypergraph independent set problem [3].

[1] "On the problem of underranking in group-fair ranking" Sruthi Gorantla, Amit Deshpande, and Anand Louis. International Conference on Machine Learning (ICML), 2021.

[2] "Matchings with group fairness constraints: Online and offine algorithms" Govind S. Sankar, Anand Louis, Meghana Nasre, and Prajakta Nimbhorkar. International Joint Conference on Artificial Intelligence (IJCAI), 2021.

[3] "Independent sets in semi-random hypergraphs" Yash Khanna, Anand Louis, and Rameesh Paul. Algorithms and Data Structures Symposium (WADS), 2021.

Sundeep Prabhakar Chepuri

https://ece.iisc.ac.in/~spchepuri/

Sundeep Prabhakar Chepuri received his M.Sc. degree (cum laude) in electrical engineering and Ph.D. degree (cum laude) from the Delft University of Technology, The Netherlands, in July 2011 and January 2016, respectively. He was a Postdoctoral researcher at the Delft University of Technology, The Netherlands, a visiting researcher at University of Minnesota, USA, and a visiting lecturer at Aalto University, Finland. He has held positions at Robert Bosch, India, during 2007-2009, and Holst Centre/imec-nl, The Netherlands, during 2010-2011. Currently, he is an Assistant Professor at the Department of ECE at the Indian Institute of Science (IISc) in Bengaluru, India.

Dr. Chepuri was a recipient of the Best Student Paper Award at the IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) in 2015. He is currently an Associate Editor of the EURASIP Journal on Advances in Signal Processing, and an elected member of the EURASIP Technical Area Committee (TAC) on Signal Processing for Multisensor Systems.

Research Highlight

Many science applications deal with data having an underlying graph structure, e.g., social networks, transportation networks, brain networks, sensor networks, protein-protein interactions, and meshed surfaces in computer graphics, to list a few. For such applications, more recently, deep learning for graph-structured data, formalized as deep graph learning is receiving steady research attention.

I will discuss two such specific research themes described as work packages (WP) that I have been pursuing with the Pratiskha Trust fellowship.

WP.1: Deep Learning for graph-structured data

Graph neural networks (GNNs) have become very popular for processing and analyzing graph-structured data in the last few years. GNN architectures learn low-dimensional graph-level or node-level embeddings useful for several downstream machine learning tasks by using message passing as their basic building block that aggregates information from neighborhoods. We propose GNN architectures that precompute the node features from different neighborhood depths using a bank of neighborhood aggregation graph operators simultaneously. We refer to such GNN architectures with parallel aggregation as PA-GNNs. Due to the precomputations, PA-GNNs have a natural advantage of reduced training and inference time. We also provide theoretical conditions under which a generic PA-GNN model is provably as powerful as the popular Weisfeiler-Lehman (WL) graph isomorphism test in discriminating non-isomorphic graphs. These results have been submitted for a journal publication and is currently under review:

- Doshi, S. and Chepuri, S.P., 2021. Graph Neural Networks with Parallel Neighborhood Aggregations for Graph Classification. arXiv preprint arXiv:2111.11482.

WP.2: Graph topology inference from data

Having a good quality graph is central to any graph-based signal processing or machine learning task. Depending on the nature of the application, most of the data analytics with graph-structured data assume that the graph is given. In some cases, graphs are not readily available, but based on the available training data a graph that best explains the data can be constructed.

In this work package, we focus on learning sparse graphs with a core-periphery structure. A core-periphery structure in graphs refers to the presence of densely connected groups of core vertices and sparsely connected periphery vertices. Core vertices are those vertices that have cohesive connections among them. Peripheral vertices, on the other hand, are not well connected to each other but are relatively well connected to core vertices. We propose several generative models for data associated with core-periphery structured networks to model the dependence of node attributes on core scores of the nodes of a graph through a latent graph structure. Using the proposed model, we jointly infer a sparse graph and nodal core scores that induce dense (sparse) connections in core (respectively, peripheral) parts of the network.

The results from the work package are published or under peer-review as:

- Gurugubelli, S. and Chepuri, S.P., 2021. Learning Sparse Graphs with a Core-periphery Structure. arXiv preprint arXiv:2110.04022. (ICASSP 2022)
- Gurugubelli, S. and Chepuri, S.P., 2022. Learning Core-Periphery Structures in Graphs from Node Attributes (in prep. for journal submission)

Gugan Chandrashekhar Mallika Thoppe

My research spans two broad areas: applied probability and stochastic optimization. In 2022, I worked on several projects under these two topics as listed below. Some of these projects led to publications in the year 2023 (please see the publications details in the 2023 report). Other projects are either close to completion or we are writing papers based on the outcomes.

https://sites.google.com/site/guganctb/

Research Highlight

Applied Probability

- Connections between minimal spanning acycles and shadows in random complexes
  Status: Published in 2023 in the Discrete Analysis journal
- Volatility of Betti Numbers in Dynamic Linial-Meshulam Complexes
  Status: Ongoing work

Reinforcement Learning

- Q-learning with -greedy exploration and function approximation
  Status: An initial version was presented as part of the Invited session in 15th Indian Control Conference, 2022. An extended journal version is currently under preparation.
- Momentum in Stochastic Approximation
  Status: Published in the 39th Conference on Uncertainty in Artificial Intelligence, 2023.
- Distribution Stochastic Approximation with Momentum
  Status: An initial version will be presented as part of the invited session in the 16th Indian Control Conference, 2023. An extended journal version is currently under preparation.

Expenditure Report: No part of ₹6 lakh contingency was spent in 2022 since I was visiting Prof. Michel Benaim in Switzerland from Oct. to Dec. 2022.

Sreetosh

http://www.cense.iisc.ac.in/sreetosh-goswami

Artificial Intelligence (AI) has traversed numerous cycles of hype, alternating between awe at the capabilities of our computing machines and disillusionment when confronted with the intricate nature of natural cognitive processes. While recent achievements, such as algorithms surpassing human champions in complex games, may suggest the dawn of the AI era, a closer look reveals that the underlying machines demand impractical resources such as kilowatts of power and extensive, costly algorithm preparation and training. For functions like intelligence, cognition, and decision-making, today's most advanced computing systems pale in comparison to the brain in terms of both energy efficiency and space utilization. Our limitation stems from the use of conventional passive circuit elements attempting to emulate the highly non-linear dynamics of a brain operating on the edge of chaos. Our research aims to revamp computing at a fundamental level introducing a new generation of molecular circuit elements to capture intricate, reconfigurable, dynamic logic operations within nano-scale material properties. Our interest spans a broad-spectrum spanning device physics all the way towards development of chips and implementing them for executing AI workloads.
The two primary highlights of our work done during 2022 were as follows:

Research Highlight

By manoeuvring the supramolecular dynamics in a molecular memristor, we demonstrated that all possible functional variations of a neuromorphic circuit element could be captured in a single device. From diode, all the way to non-volatile and volatile, unipolar and bipolar memories with digital and analog transitions were realized by tweaking the operating conditions of just one device. This facilitated unprecedented design space for realizing plasticity and reconfigurability which is a holy grail in neuromorphic computing.

Ref: Rath, S. P., Thompson, D., Goswami, S., & Goswami, S. (2023). Many-Body Molecular Interactions in a Memristor. Advanced Materials, 35(37), 2204551.

We developed the largest to-date functional crossbars incorporating molecular materials and realized a 32-bit adder that outperformed a state-of-the-art commercial adder unit. Their in-memory platform exhibited a 47× higher energy efficiency, 93× faster operation, and 9% of the footprint, leading to a 4390 times improved energy-delay product compared to the most energy-efficient CMOS-based multicore adder available today.

Ref: Rath, S. P., Yi, S. I., Deepak, Venkatesan, T., Bhat, N., Goswami, S., R. Stanley Williams, & Goswami, S. (2023). Energy and Space Efficient Parallel Adder Using Molecular Memristors. Advanced Materials, 35(37), 2206128.

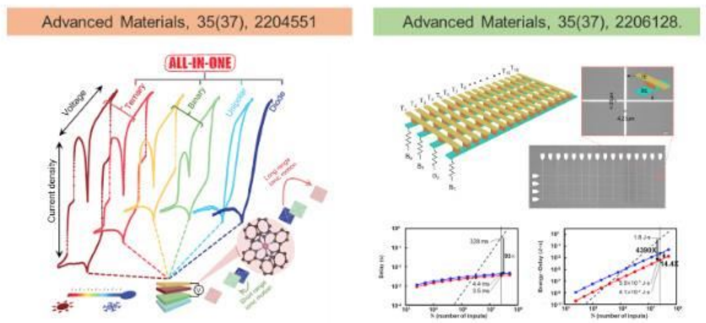


Figure: The summary of the research progress made in 2022

Arkaprava Basu

https://www.csa.iisc.ac.in
/~arkapravab/

Arkaprava Basu joined the Indian Institute of Science (IISc), Bangalore in February 2016 as an Assistant Professor in the Department of Computer Science and Automation. His research focuses on building more efficient computing systems through better coordination between the hardware and the software.

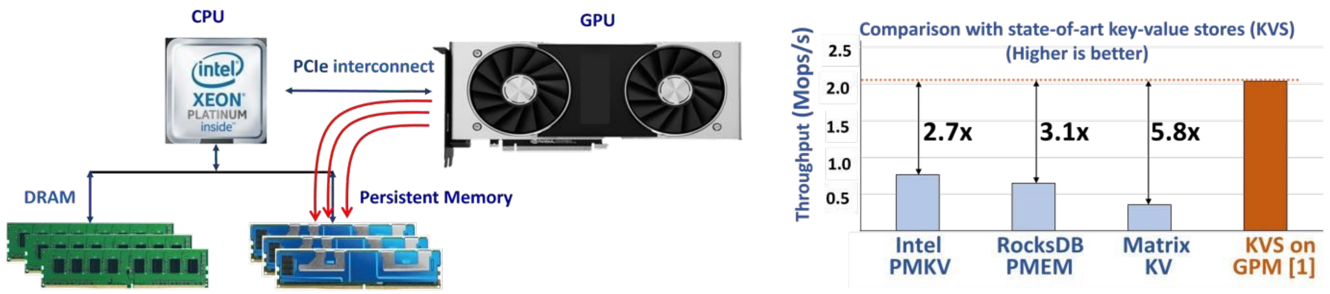
Arkaprava received the Intel Rising Star Faculty Award for 2021; he is one of the only 10 recipients of this award from universities across the globe and the only one from India. Arkaprava is also a recipient of the Google India Research Award 2022, Dr APJ Abdul Kalam young researcher HPC award 2021, besides the Pratiksha Trust Young Investigator Award.

Research Highlight

Harnessing the knowledge embedded in the massive amounts of data that the world produces everyday needs commensurately massive compute capability. Graphics Processing Units or GPUs that were originally designed for video gamers, are today the backbone for data-centric computing, including the deep learning. GPU's ability to process large amounts of data in parallel makes it an ideal choice.

However, GPUs are hamstrung by limited amount of on-board memory and the lack of direct access to high-capacity storage. A GPU's compute capability can go waste waiting for data to arrive. In an orthogonal trend, emerging persistent memory (PM) technology has recently become commercially available under the aegis of Intel Optane DC memory. PMs have significantly higher capacity than convention memory technologies, e.g., DRAM, and are also persistent like storage devices, e.g., SSD. Till now, however, only the CPUs have been able to leverage persistent memory to blur the long-held distinction between memory and storage.

In our recent work [1], we built the first known system that enables programs executing on GPUs to directly access data residing on the PM without the intervention of the CPU. Benefits of this system, which we name GPM (GPU with Persistent Memory), are manifold. GPM allows programs to leverage both the compute parallelism of GPU and the persistence and capacity of the PM. Important applications, such as persistent key-value stores that forms the backbone of many of today's internet services speed up by multiple times while executing on GPM (Figure below). Further, GPU-accelerated databases, checkpointing of partially trained weight in long-running DNN training, accelerate by 5-15X! We believe GPM has the potential become a key platform for large-scale data processing in the future.



GPU with Persistent Memory: GPM

[1] "Leveraging Persistent Memory from a GPU", Shweta Pandey, Aditya K. Kamath, Arkaprava Basu.
In 27th International Conference on Architectural Support for Programming Languages and Operating Systems (ASPLOS) 2022.

Chirag Jain

http://cds.iisc.ac.in/faculty/
chirag

Chirag Jain is an assistant professor in the Department of Computational and Data Sciences at the Indian Institute of Science. He directs ATCG lab which develops efficient computational algorithms for data-intensive problems in biology. In response to challenging computational problems, the lab develops solutions that are provably-good, scalable in practice, and useful for life scientists to draw new insights from high-throughput data. Prior to his appointment at IISc, he worked as a post-doctoral fellow with Adam Phillippy at the National Institutes of Health. In 2019, he received Ph.D. at Georgia Tech, where he was advised by Srinivas Aluru. He did his bachelors in computer science at Indian Institute of Technology Delhi. He's a recipient of the Georgia Tech College of Computing Dissertation Award.

Research Highlight

Background: An accurate genome reconstruction from a set of DNA sequencing fragments (or reads) is necessary to get a complete view of the target genome. Genome sequences of several species, including humans, comprise challenging repetitive substrings. Despite four decades of research, genome assembly remains one of computational biology's fundamental algorithmic problems. The recent breakthroughs in DNA sequencing technologies allow sequencing long (> 10 kbp) reads of a target genome with > 99% accuracy. This technology, commonly referred to as long-read sequencing, promises to enable automated reconstruction of complete genomes for the first time. In 2022, Nature chose long-read sequencing as their 'Method of the Year'. Thanks to the quick development of long-read assembly algorithms by the community, we are beginning to see de novo assembly of reference-quality human genomes with a clear separation of sequences of paternal and maternal origin. These advances will have a tremendous impact on healthcare and agriculture. But despite the significant advances, there are unresolved algorithmic challenges that must be addressed before long-read assembly can be established as the gold standard of clinical and basic research analysis.

Progress and Impact: In our recent published work, we mathematically formulated the coverage-preserving property of a graph. Informally, we called a graph as coverage-preserving if it guarantees that the target genome can be spelled as a walk in the graph, given sufficient sequencing depth. We demonstrated that this property is violated by the commonly used string graph formulation, both in theory and practice. Removal of contained reads occasionally introduces breaks in the graph by removing all reads that cover one or more genome intervals. Further continuing this work, my lab has mathematically derived an expression to calculate the probability of the occurrence of breaks in a string graph (assuming reads are sampled uniformly and independently from a genome). Calculating the probability is challenging due to an extremely large sample size (all possible exponential number of read sequencing outputs in an experiment). We overcame this challenge by efficiently partitioning the sample space and utilizing ordinary generating functions. The obtained probability estimates have led to novel insights into how the choice of sequencing technology and sequencing depth influences the chances of introducing unfavourable breaks in the graph. Next, we developed novel heuristics and an open-source assembly implementation to overcome the problem of contained reads. Using experiments with real human sequencing datasets, we demonstrated an improvement in the assembly contiguity by a factor of two compared to the state-of-the-art solutions. The manuscript describing these methods and results is currently under review.

Publications:

- Chirag Jain*. "Coverage-preserving sparsification of overlap graphs for long-read assembly" Bioinformatics 2023. https://doi.org/10.1093/bioinformatics/btad124
- Sudhanva Shyam Kamath, Mehak Bindra, Debnath Pal, and Chirag Jain*. "Telomere-to-telomere assembly by preserving contained reads" (submitted) Preprint: https://doi.org/10.1101/2023.11.07.565066

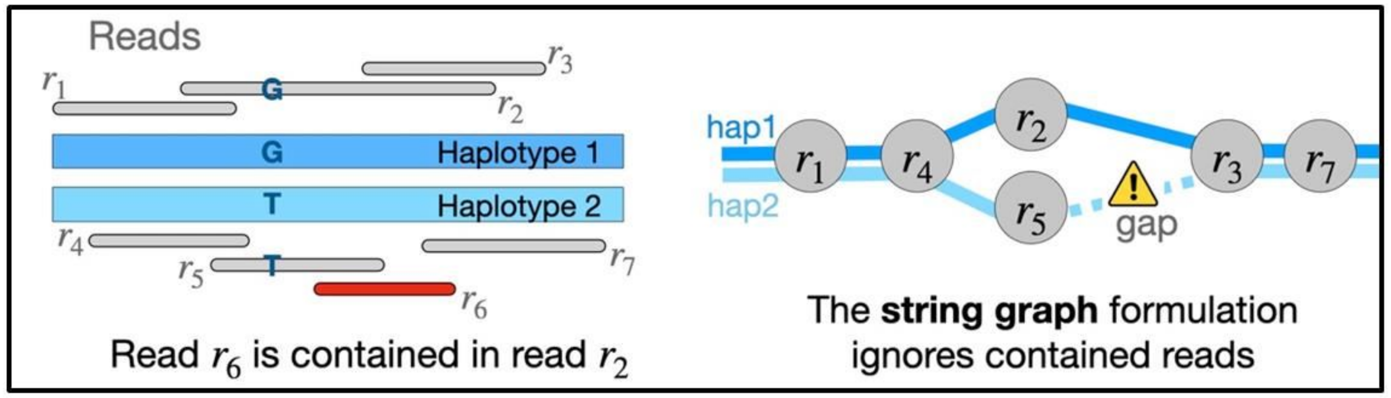
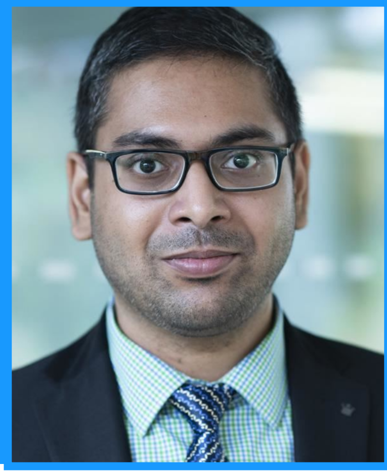


Figure 1. An example of an assembly error caused by removal of contained read r6 . It breaks the connectivity between reads r5 and r3, which was necessary to spell the second haplotype.

Utsav Banerjee



http://cds.iisc.ac.in/faculty/chirag

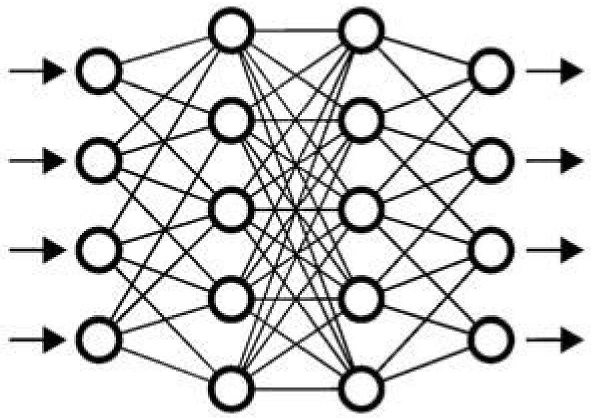
Utsav Banerjee is an Assistant Professor in the Department of Electronic Systems Engineering at the Indian Institute of Science. He received his B.Tech. degree in electronics and electrical communication engineering from the Indian Institute of Technology Kharagpur in 2013, and his S.M. and Ph.D. degrees in electrical engineering and computer science from the Massachusetts Institute of Technology in 2017 and 2021 respectively.
He currently leads the Secure Intelligent and Efficient Systems (SINESys) Lab at IISc. His research interests include cryptography, hardware security, digital circuits, embedded systems and VLSI chip design. He received the President of India Gold Medal from IIT Kharagpur in 2013, the Irwin and Joan Jacobs Presidential Fellowship from MIT in 2015, the Qualcomm Innovation Fellowship in 2016, the Pratiksha Trust Young Investigator Award from IISc in 2022 and the ABB HvG Research Award in 2022.

Research Highlight

Cybersecurity is a major concern with the tremendous growth of the Internet and the proliferation of Internet-connected electronic devices. The growth of cloud and edge computing has motivated the emergence of computing as a service where machine learning, image processing, data mining, database management and other computations are outsourced to cloud servers and edge devices. Although the communications are encrypted, the data needs to be decrypted before computation leading to concerns about data confidentiality and computation integrity. To address concerns about data privacy, there is significant interest in the field of privacy-preserving computation. Computation on encrypted data can be theoretically achieved using various sophisticated cryptographic tools, e.g., homomorphic encryption and functional encryption. However, they are several orders of magnitude slower than their unencrypted counterparts due to computational complexity and memory overheads. This motivates the need for new architectures and efficient hardware accelerators to enable practical secure and privacy-preserving machine learning. Utsav and his group are working to integrate hardware acceleration into the privacy-preserving compute framework to bridge the gap between security and efficiency. This involves the unification of various cryptographic algorithms for the efficient realization of privacy-preserving computation with application-specific optimizations, followed by efficient algorithm-architecture co-design for high-performance large-scale secure machine learning computation using custom hardware.

Along with the privacy of outsourced computation, it is also important to ensure the security of machine learning implementations on embedded processors. It is becoming increasingly popular for edge devices to use neural network hardware accelerators or software implementations of such algorithms for energy-efficient decision making. This requires local storage of the associated machine learning models, which are not only intellectual properties of the service providers but also contain sensitive information about the private training data. These stored models are vulnerable to side-channel attacks and adversarial fault attacks. Utsav and his group are also working on the design of side-channel-resistant and fault-resilient software implementations and hardware architectures for neural networks as well as other machine learning and signal processing algorithms.

There have been significant advances in the theory and implementation of machine learning algorithms, but its security aspects are only recently gaining attention. This research will lead to new implementation-level advances in the field of secure privacy-preserving machine learning as well as robust embedded machine learning implementations, both enabled by efficient hardware architectures and co-design with software.



Aditya Sadhanala

Aditya Sadhanala is currently an Assistant Professor at the Centre for Nano Science and Engineering (CeNSE) at the Indian Institute of Science, Bengaluru since October 2019. He obtained his B.E. in Electronics from University of Mumbai, India in 2009, MSc in Nanoelectronics from University of Manchester, UK in 2010, followed by his Ph.D. degree in Physics (2015) from the University of Cambridge, UK. During his PhD he worked on investigating the photophysical properties of hybrid perovskites using photothermal deflection spectroscopy.

Aditya also holds several awards and recognitions, few notable ones being – 2021 International Science Council, 2020 MRS Nelson "Buck" Robinson Science and Technology Award for Renewable Energy, British Indian Award in the Science & Technology and Royal Society endorsed Exceptional Promise candidate. He also holds a distinction of being a highly cited researcher in the interdisciplinary field last four consecutive years 2019 - 2023 – Web of Science, Clarivate.

http://www.cense.iisc.ac.in/aditya-sadhanala

Research Highlight

Aditya's research currently focusses on nanostructured thin-film optoelectronics, ultra-sensitive spectroscopic techniques and to innovate pathways for low-cost decentralized manufacturing of emerging optoelectronics. These can be broadly classified under the following three themes:

1) Novel nano-structured/engineered thin-film semiconductors and photonics: To use novel & efficient nano-structured sustainable thin-film semiconductors and optoelectronic devices with feature sizes of functional elements down to 20nm that fall within the exciton diffusion or capture radius for most thin-film semiconductors.

2) Next-generation organic & 2D-perovskite hybrid sensing, memory and computation technologies: In-situ infiltration-based hybridisation of organic & 2D-perovskite semiconductors to enable hybrid bio-compatible sensors and neuromorphic computing applications. We have developed a low-cost atomic layer deposition (ALD) tool for such semiconductor hybridisation. Devices like - novel nanoparticles organic memory field-effect transistor (NOMFET) and nanoparticles hybrid memory field-effect transistor (NHFET) are being fabricated by using this low-cost, highly controlled and large area compatible infiltration synthesis methods. NOMFET & NHFET are devices that mimic biological synapses that can be triggered both by electrical and optical means. Much of this research work has been supported by the Pratiksha Young Investigator Chair position.

3) New methodologies for ultra-high sensitivity semiconductor spectroscopy: To develop the world's first photothermal deflection spectroscopy 2.0 (PDS 2.0) facility for ultra-high sensitivity of sub- and intra-band carrier studies at ambient, variable temperature & pressure conditions. This tool would act as a rapid screening tool for new semiconductors at both academic and industry level. Also, as a novel diagnostics tool for rapid and sensitive detection of bacteria and viruses (including COVID-19).

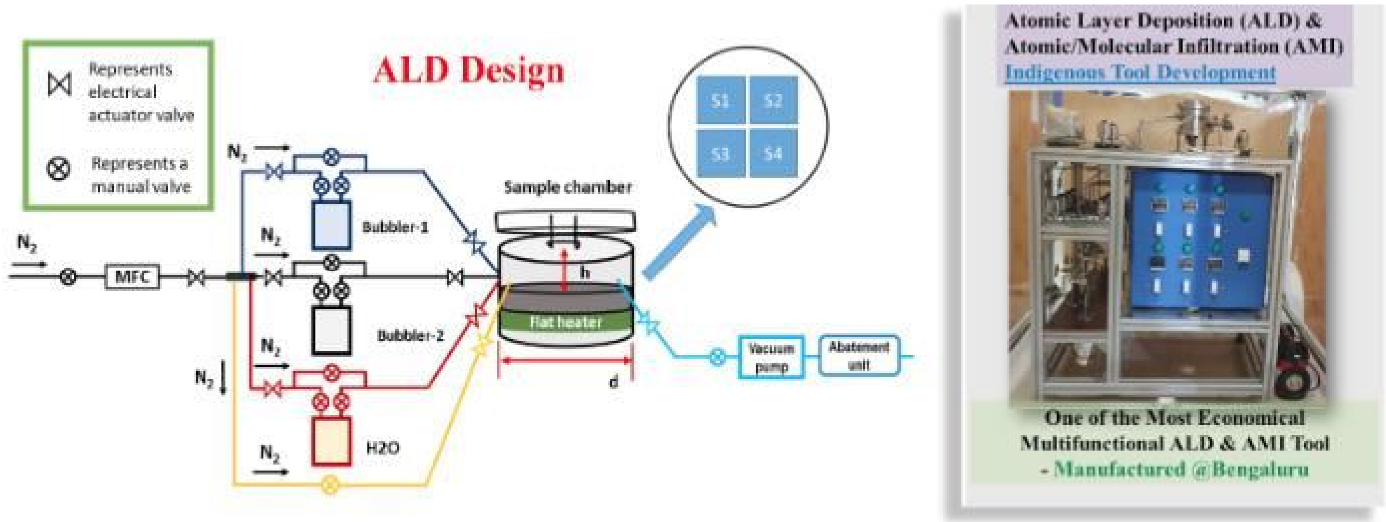


Figure 1: Schematic and photo of the homemade ALD tool – used for semiconductor hybridisation.

Arindam Khan

Dr. Arindam Khan is an Assistant Professor in the Department of Computer Science and Automation at the Indian Institute of Science. He did his PhD in Algorithms, Combinatorics, and Optimization (ACO) from Georgia Institute of Technology, Atlanta, USA. Before that, he obtained B. Tech and M. Tech (Dual Degree) from the Department of Computer Science and Engineering, Indian Institute of Technology, Kharagpur. Arindam is a recipient of the Best Paper Award in MFCS 2020, Google India Research Award 2021, and Priti Shankar Teaching Award 2022.

He is broadly interested in the design and analysis of algorithms and theoretical computer science. His current research interests include Approximation Algorithms, Online Algorithms, Computational Geometry, Theoretical ML, and Fairness.

https://www.csa.iisc.ac.in/~-arindamkhan/

Research Highlight

Optimization problems are ubiquitous in this modern era of science and technology. However, many optimization problems can be hard due to computational challenges (intractability) and/or the lack of knowledge about the input (uncertainty). Arindam's recent research has focused on finding efficient approximate solutions for such hard optimization problems. In their recent breakthrough result [1] in computational geometry, Arindam and his co-authors, made progress on Maximum Independent Set of Rectangles (MISR) -- a fundamental problem in computational geometry, approximation algorithms, and combinatorial optimization. In this problem, given a set of (possibly overlapping) rectangles on a plane, one needs to find the maximum number of non-overlapping set of rectangles. MISR finds numerous applications in practice, e.g., in map labeling, data mining, and resource allocation. This recent work develops new mathematical techniques and extends the present techniques to their limits.

Arindam's another recent joint work resolved a two-decade-old conjecture on online bin packing under the i.i.d. model [2]. In online bin packing, a classical problem in online algorithms and combinatorial optimization, items arrive one by one and their sizes are revealed upon their arrival and they must be packed immediately and irrevocably in bins of unit size. The goal is to pack all items into the minimum number of bins. In the i.i.d. model, item sizes are sampled independently and identically from an unknown probability distribution. The paper [2] provided a near-optimal efficient algorithm for online bin packing under i.i.d. model, settling a long-standing open problem.

Arindam has also been studying foundational problems at the intersection of machine learning and algorithms for big data. Recent research [3] by his group studies the Stochastic Multi-armed Bandit problem under bounded arm-memory. Modern data science deals with massive data sets that may arrive rapidly and may not be fully stored. Streaming and dynamic algorithms deal with this large data stream by working in a few passes over the data and use limited memory. Multi-armed bandit is a classical exploration-exploitation framework in online learning. Their NeurIPS'21 paper [3] gave near-optimal guarantees for streaming algorithms for best-arm identification and regret minimization for multi-armed bandits. This has many applications in clinical trial design, news recommendation, dynamic pricing, ad allocation, etc.

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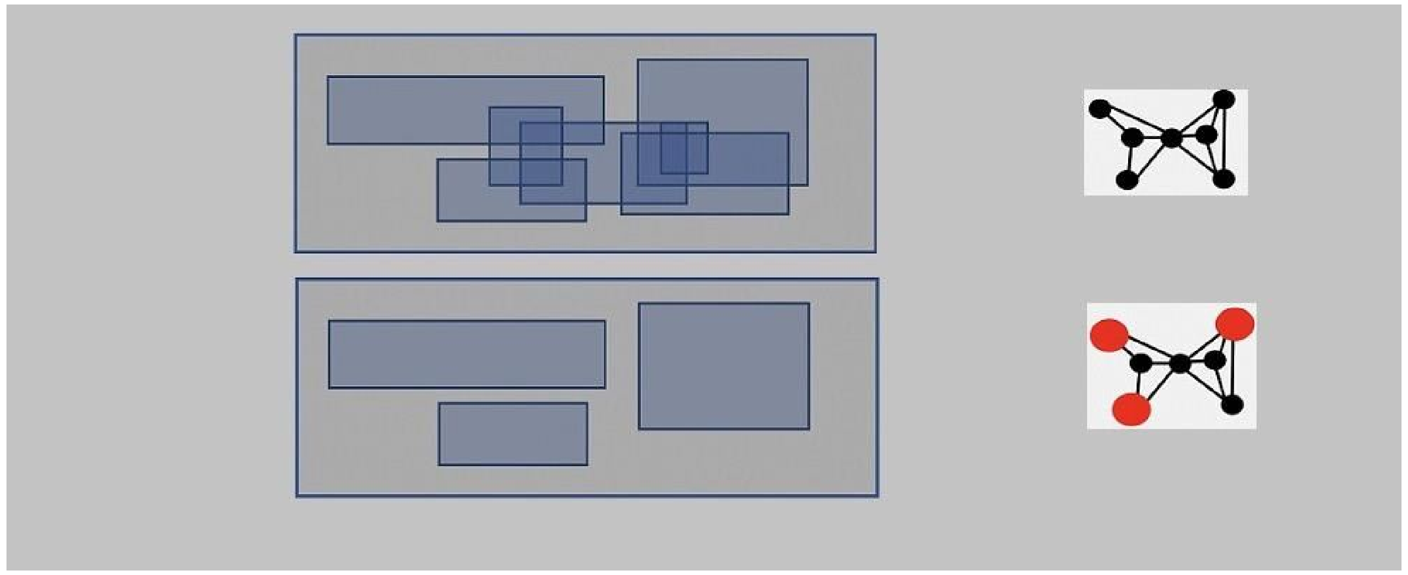


Shishir Kolathaya

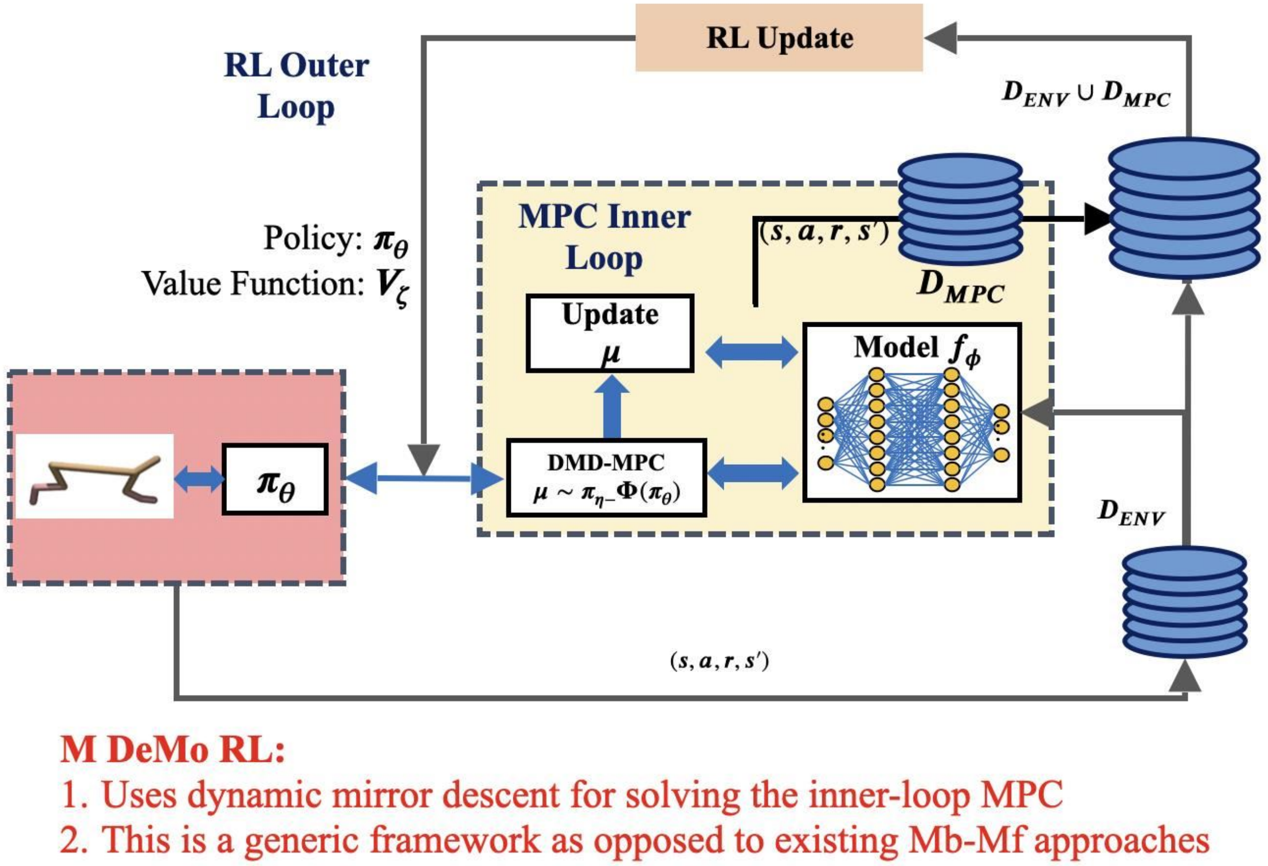
http://www.shishirny.com/

Shishir is an Assistant Professor of the Robert Bosch Centre for Cyber Physical Systems (RBCCPS) and the Department of Computer Science and Automation (CSA) in IISc Bangalore. He received his Ph.D. degree in Mechanical Engineering (2016) from the Georgia Institute of Technology, M.S. degree in Electrical Engineering (2012) from Texas A&M University, and B.Tech. degree in Electrical Engineering (2008) from the National Institute of Technology Karnataka, Surathkal. He started his career in the field of robotics, especially in the domain of legged robots. His primary focus as a PhD student was on stability and control of walking robots. Shishir has now diversified to other fields like safety-critical control, and machine learning for all kinds of robotic platforms.

Research Highlight

Model-Free Reinforcement Learning (Mf-RL) algorithms are widely applied to solve tasks like dexterous manipulation and agile locomotion as they eliminate the need to model the complex dynamics of the system. However, these techniques are data hungry and require millions of interactions with the environment. Furthermore, these characteristics highly limit successful training on hardware as undergoing such high number of transitions in hardware environments is infeasible. Thus, to overcome this hurdle, various works have settled for a two-loop model based approach, typically referred to as Model-based Reinforcement Learning (Mb-RL). Such strategies take the benefit of the explored dynamics of the system by learning the dynamics model, and then determining an optimal policy in this model. Hence this "inner-loop" optimization allows for a better choice of actions before interacting with the original environment.

The process of planning with the learnt model is mainly motivated by the Model Predictive Control (MPC), which is a well-known strategy used in classical real-time control. Given the model and the cost formulation, a typical MPC structure can be formulated in the form of a finite horizon trajectory optimization problem. By exploiting this approach of using approximated dynamics, methods like Cross-Entropy Method (CEM) and Model Predictive Path Integral (MPPI) have been used to achieve high reward gains. Improvements were shown in the training time; however, these results are preliminary and yet to be completely formalized. With this viewpoint, we propose a generic framework that integrates a model-based optimization scheme with model free off-policy learning. Motivated by the success of online learning algorithms in RC buggy models, we combine them with off-policy Mf learning, thereby leading to a two-loop Mb-Mf approach. We implement dynamic mirror descent (DMD) algorithms on a model-estimate of the system, and then the outer loop Mf-RL is used on the real system. The main advantage with this setting is that the inner loop is computationally light; the number of iterations can be large without effecting the overall performance. Since this is a hierarchical approach, the inner loop policy helps improve the outer loop policy, by effectively utilizing the control choices made on the approximate dynamics. This approach, in fact, provides a more generic framework for some of the Mb-Mf approaches.



This work was accepted as a conference paper at the International Conference on Robotics and Automation (ICRA), 2022.

Interdisciplinary PhD program in Brain and Artificial Intelligence

The interactions among the faculty members involved in the Brain, Computation and Data group formed under Pratiksha Trust initiatives, led to the proposal for an inter-disciplinary PhD program in Brain and Artificial Intelligence to give a thrust to research in this important area. This interdisciplinary PhD program is aimed at promoting research at the intersection of neuroscience and artificial intelligence, by providing wholesome training that spans both fields and blurs their distinctions. Its focus would be on computational approaches to understanding brain function and their synergistic interactions with artificial intelligence paradigms.

This unique program commenced its operations from the academic year 2020-21. Students with MSc or equivalent degree in any branch of Sciences or BE/BTech or equivalent degree in any discipline or 4-year Bachelor of Science degree (and who have qualified in national eligibility tests as needed) are eligible to apply to this program. The students are interviewed to assess both their background as well as aptitude for inter-disciplinary research. Each selected student will be working with two advisers belonging to two different departments, reflecting the inter-disciplinary flavor of the program. The following committee of faculty members are currently handling the academic administration of this program: Ambedkar Dukkipati, CSA; S.P. Arun, CNS; Chetan Singh Thakur, ESE; Rajiv Soundararajan, ECE; Rishikesh Narayanan, MBU; P.S. Sastry, EE; Siddhartha Gadgil, MA; R. Venkatesh Babu, CDS.

Areas of Research:
Brain Inspired Artificial Intelligence
Machine Learning
Signal Processing
Theoretical and Computational Neuroscience
Cellular, Systems and Cognitive Neuroscience
Sensory Systems: Vision, Speech
High-Level Cognitive Processes: Learning, Attention, Decision Making
Brain machine Interfaces
Neuromorphic Computation, Neuromorphic Hardware

List of students
Sveekruth Pai
Mainak Biswas
Satyapreet Singh Yadav
Kashmiri Manishrao Lande

DCC members:
Ambedkar Dukkipati
Chetan Singh Thakur
Rajiv Soundararajan
Rishikesh Narayanan
SP Arun
Subbayya Sastry Pidaparthy
Supritam Ray
Venkatesh Babu Radhakrishnan

BAI Convener: Venkatesh Babu
DCC Chair: Supratim Ray

The program started with an initial intake of 5 students per year and it is proposed to gradually increase the intake over a period of 5 years. It is expected that in the steady-state there will be 30 to 40 Ph.D. students on roll at any point of time. This unique program is expected to provide a significant boost to this important interdisciplinary area.

Activities Planned for 2023

Moonshot project

A moonshot project on the theme of Brain Co-Processors is being planned with the active involvement of multiple faculty, spanning several departments, at IISc.

Visits by Distinguished Chair Professors

Visits by chair professors are being planned for
Prof. Rajesh Rao
Prof. Maneesh Sahani

Workshop on Brain, Computation, and Learning, IISc Bangalore

Following the past versions of this workshop, the next one is being planned.

Organization of brainstorming workshops

Discussion on and around moonshot project problem to synergize different teams in this mission

Recruitment of Post-doctoral fellows

To accelerate the research activities related to moonshot project

Providing travel support to students

To encourage students to present their work at different conferences and workshops related to Brain, Computation and Data Science.

Recruitment of more students in the BAI PhD Program

This will gradually enable the activity in the BCD area through more focused problems through PhD students.

Exchange of graduate student visitors between IISc and other universities

Student exchange is aimed at benefiting from international collaborations

Research Publications

2022

Liza K and Ray S (2022) Local interactions between steady-state visually evoked potentials at nearby flickering frequencies. Journal of Neuroscience. Accepted.

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Arjun B. S., V S N Sitaramgupta V, Aswin S, Shilpa Rao and Hardik J. Pandya, "A System-based Approach for the Evaluation of Electromechanical Properties of Brain Tumors." 44th IEEE EMBC International Engineering in Medicine and Biology Conference, Glasgow, Scotland, July 11-15, 2022.

2021

Murty DVPS, Manikandan K, Kumar WS, Ramesh RG, Purokayastha S, Nagendra B, Abhishek ML, Balakrishnan A, Javali M, Rao NP and Ray S (2021). Stimulus-induced Gamma rhythms are weaker in human elderly with Mild Cognitive Impairment and Alzheimer's Disease. eLife. 10:e61666 DOI: 10.7554/eLife.61666.

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