The Mathematics Consortium

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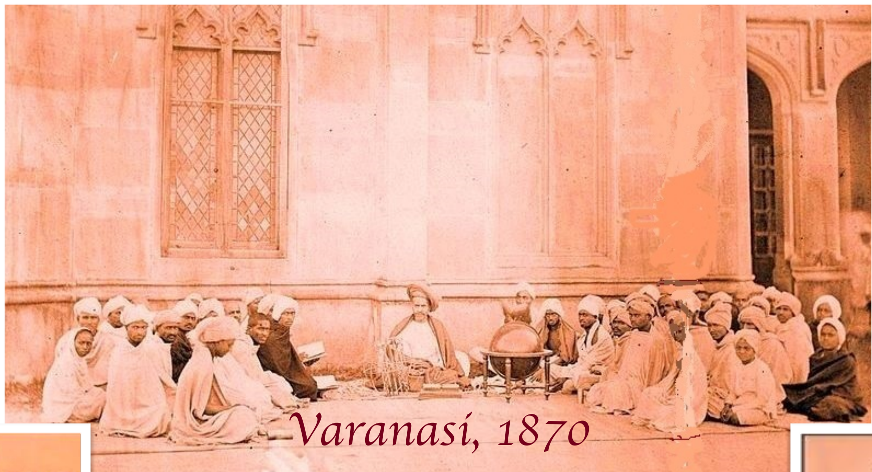
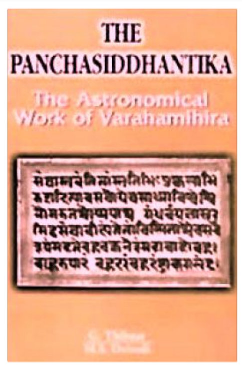
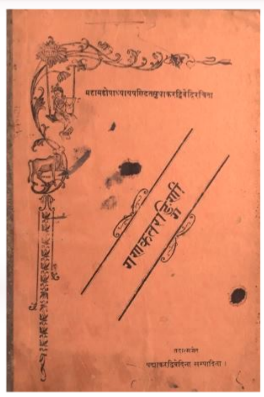
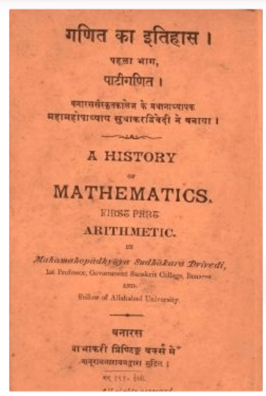
Pt. Bapu Dev Sastri, Teaching with a Globe

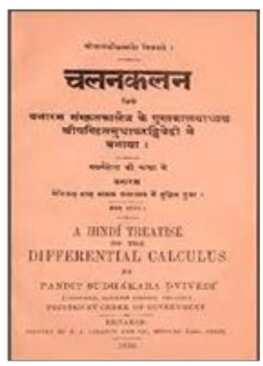


Varanasi, 1870









Some Books Authored By Pt. Sudhakar Dvivedi

Chief Editor: Ravindra S. Kulkarni

Managing Editor: Vijay D. Pathak

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Contents

***About the Cover Page**: In the top row the image is of Pt. Bapu Deva Sastri teaching with a globe, at Queen's College, Varanasi. In the middle row, the first image is the front cover of a book Panchasiddhantika by Varahamihir and the second image is the front cover of a book Chalanakalana- a Hindi treatise on Differential Calculus by Pt. Sudhakar Dvivedi. In the bottom row two images are the front covers of two books Ganakatarangini and Ganit ka Itihas by the same author.*

Typeset and designed by: Praanjala Typesettings, Contact: +91 99603 03874, Email: mr.texdoc@gmail.com.

From the Editors' Desk

India has had an enviable tradition in mathematics, extending two millennia, if not more. However, while there is a huge number of manuscripts witness to the history lying in various repositories, there is nevertheless an acute dearth of material on the original works that are within ready reach of interested scholars and intelligentsia at large. History of mathematics, and Science in general, has not received due attention so far, and lack of adequate authentic literature suitable for it has been one of the major causes that needs to be remedied in this respect. The endeavors towards building up such a knowledge base about the ancient works did get initiated in the 19th century, when various European scholars became interested in the study. Not long after, some Indians joined the effort, and made substantive contributions. In Article 1, Prof. S. G. Dani introduces two of the early scholars, Paṇḍit Bāpu Deva Śastrī and Paṇḍit Sudhākara Dvivedī, and discusses the significance of their contributions towards further development in the area.

The second Article by Prof. Ambat Vijayakumar, is the continuation of the Part I, which appeared in the July, 2022 issue of the TMC Bulletin. The first part shed light on how graph theory got developed into an exciting branch of mathematics. In this part, the Perfect Graphs, which arose from Berge's conjecture are discussed. Some contributions of László Lovász, an Abel laureate 2021, in the theory of perfect graphs, some aspects of 'Ramanujan graphs', and some basics of Random graphs are discussed.

In Article 3, Dr. Lovy Singhal presents an elaborate review of a recently published book (in Hindi) entitled "Aadhunik Bharat Ke Divangat Ganitagya" by Virendra Kumar. This book introduces briefly the lives and works of over 200 renowned Indian mathematicians from the 19^{th} and 20^{th} centuries, who are no more.

In Article 4, Dr. D. V. Shah gives an account of significant developments in the Mathematics world. One of the highlights of this article is an introduction to the winners of the 2022 Field medals and the Shaw prizes, and glimpses of their work. A report on performance of the Indian team at IMO-2022 is also included in this article. It may be worthwhile to spare a thought here for the role played by prizes and recognitions at different levels. There are close to 200 prestigious awards offered internationally for an outstanding contribution to Mathematics. United States alone has announced 86 such awards and India also has contributed 3 awards for the International Mathematics community. These awards are sponsored by Mathematical Societies/Academies in various countries / IMU / individual endowment funds etc. There are specific rules and procedures strictly followed in selecting the awardees. Mathematicians / Scientists in general, work day and night to resolve some long pending unsolved problems in their areas of interest which in the long run benefit the mankind, and not quite aiming to win some award. However, these awards do recognize pains-taking efforts of the awardees and give them a great satisfaction and also encourage young researchers to work with zeal and enthusiasm.

In the Problem Corner, Dr. Udayan Prajapati presents a solution to the problem posed in July 2022 issue and poses a problem on Geometry for our readers. Dr. Ramesh Kasilingam gives a calendar of Academic events, planned during November 2022 to January 2023. Prof. S. A. Katre gives an account of TMC activities and Prof. Sudhir Ghorpade gives update on TMC-Distinguished Lecture Series.

It is a matter of pride for all of us at TMC, that one of the leading editors of TMC Bulletin, Prof. S. G. Dani has been invited to be an Honorary Fellow of TIFR. A brief on highlights of his career as a renowned mathematician are given on the back inner cover of this issue. A few words of appreciation of his contributions to Mathematics and his scholarship form Article 8 by his teacher and a leading mathematician of India, Prof. M. S. Raghunathan.

We are happy to bring out the second issue of Volume 4 in October 2022. We thank all the authors, all the editors, our designers Mrs. Prajkta Holkar and Dr. R. D. Holkar and all those who have directly or indirectly helped us in bringing out this issue on time.

Chief Editor, TMC Bulletin

1. Two pioneering nineteenth century Indian contributors to the history of mathematics

Shrikrishna G. Dani
UM-DAE Centre for Excellence in Basic Sciences
University of Mumbai, Santacruz, Mumbai 400098
Email: shrigodani@cbs.ac.in[1]

Dedicated to the memory of Professor M. L. Dakhani[2]

India has had a rich tradition in mathematics, going at least as far back as the Sulbasutras and the Jaina canonical works from the millennium BCE, and continuing over the centuries through works of many eminent scholars, including Aryabhata (b. 476), Brahmagupta (b. 598), Sridhara (ca. 750), Mahavira (ca. 850), Bhaskaracharya (b. 1114), Thakkura Pheru (ca. 1300), Narayana Pandita (b. 1325), to name a few, and then the Kerala school of Madhava that lasted over two centuries, starting from late 14th century. There is however acute dearth of material on the original works, and achievers of the developments, accessible to scholars in the area.[3] This has in turn resulted also in paucity of authentic expository material reaching the intelligensia in general, and prevalence of many untenable obscurantist beliefs, and mixing up of history and myths.

The endeavours towards building up such a knowledge base about the ancient works can be traced back to the 19^{th} century, when various European scholars became interested in the study of ancient Indian mathematics: the works of George Thibaut (1875) and Albert Das Bürk (1902) on the Sulbasutras, of H. T. Colebrooke (1817), Lancelot Wilkinson (1830s), E. Burgess and G. Whitney (1855), L. Rodet (1879), on the Siddhanta tradition of mathematical astronomy, of Charles Whish (1834) on the Kerala school of Madhava are some of the endeavours which brought a spotlight on the aspect of reconstructing and understanding our past. Various general historical accounts by historians such as Moritz Cantor (1880-1908), David Eugene Smith (1914), Florian Cajori (1919), and others took note and disseminated the findings pertaining the Indian context, thus rejuvenating the pursuit.

Soon some Indians were to join the effort, bringing an Indian face to it. The aim of this article is to introduce two of the early scholars whose endeavours contributed significantly towards further development in the area: Paṇḍit Bāpu Deva Śastrī and Paṇḍit Sudhākara Dvivedī.[4]

Bapu Deva Sastri (1821-1890)

Pandit Bapu Deva Sastri (also known as Nṛsiṃha Deva Sastri) has been the earliest prominent figure in this respect. He was born on 1 November 1821, in Toke, a town on the bank of the Godavari river in the Ahmednagar district of Maharashtra, of parents Pandit Sitarama Shastri and Shrimati Satyabhama. He had his schooling at a traditional Marathi school in Nagpur. There, in particular he learnt his arithmetic and algebra from Bhaskaracharya's books *Līlāvatī* and *Bījagaṇita*, from a Kanyakubja scholar named Dhundiraja Mishra.

A fortuitous development seems to have been instrumental in Bapu Deva Sastri coming to light on a broader scene. Lancelot Wilkinson, who in 1829 was appointed Political Agent by the East India Company to the State of Bhopal, was an enlightened individual keenly interested in

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[1]This is an expanded version of a part of a talk given by the author in the Annual Conference of the Indian Society for History of Mathematics (an online conference organized by Ramjas College, Delhi), on 17 December 2021.

[2]Professor Dakhani was one of my excellant teachers in high school, 60 years ago. He passed away on 18 August 2022.

[3]There are of course various impediments at play in this respect, such as inaccessibility of the original sources, the language, the script (which, contrary to a general perception, is often not Devanagari even when the language is Sanskrit!) etc. which need to be overcome. Overall however, general lack of enlightened interest in meeting the difficulties has been a major factor.

[4]In this article we shall occasionally use the standard diacritical marks to convey the pronounciation precisely, like here, using the standard diacritical marks, but in general do without them, for convenience and to avoid distraction for a general reader, except in the case of the titles of Sanskrit compositions, set in italics.

promoting modern education in India. Also, unlike Macaulay and others who happened to play a major role in setting the tone of British education in India, he was a votary of integrating it with the traditional educational system in India. In particular he believed in teaching contemporary mathematics and astronomy via the Siddhanta astronomy and works of Bhaskaracharya, as a further development on the knowledge on the subject. A school that was set up by the East India Company at Sehore (about 20 miles from Bhopal) where the residency of the Political Agent was situated, provided him an opportunity to implement his ideas of teaching modern astronomy, in Sanskrit, as an extension of the Siddhanta astronomy; see [12].[5] While on a visit to Nagpur in 1838 Wilkinson spotted the talents of the young Bapu Deva and brought him to Sehore for further studies. There Bapu Deva got his major exposure to modern mathematics, and western science in general, from Pandit Sevarama and Wilkinson himself.

Wilkinson is seen to be full of praise for Bapu Deva's ability, and raves about how quickly and well he could absorb Euler's book on Algebra. He avers that Bapu Deva "is more fit to be my gooroo (teacher) than my shishya (student) in all mathematical question." and predicts that "this youth is destined to be the central jewel of the necklace ..." (See [12], page 195).

Pt. Bapu Deva Sastri
(1821-1890)

Wilkinson secured him an appointment as a teacher of Geometry at the Government Sanskrit College (Kashi Sanskrit Pathshala, later Sampoornananda Sanskrit Vishvavidyalaya) in Benares (Varanasi), which he joined in February 1842. He became professor of Mathematics and Astronomy in the same college in 1859, and retired in 1889.[6] Benares was a preeminent center of learning in those days, and he seems to have been a very influencial teacher with a modern approach. His students seem to be spread far and wide in India.[7]

In 1864 he was elected Honorary Member of the Royal Asiatic Society of Great Britain and Ireland; this is interesting especially in the context of the critical assessment of his paper by Spottiwoode, which is discussed later in this article. In 1868 he was conferred the honour Companion of the Order of the Indian Empire (CIE). On the occasion of the Golden Jubilee of the reign of Queen Victoria, in 1887, he (and also Sudhakar Dvivedi) were decorated with the special title Mahamahopadhyaya[8] by the (then British) Government of India; for some more details on these, and numerous other honours and recognitions received by him the interested reader is referred to [1], pages 86 - 87. He passed away in 1890; see[6], page 118, and [1], page 86.

Works of Bapu Deva Sastri

Bapu Deva Sastri is especially known for his translation of Sūrya Siddhānta[9] into English and a revised (edited) version of the English translation of the Golādhyāya of Siddhānta Śiromaṇi[10]

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[5]Wilkinson was also involved in promoting various social reforms about which also the reader will be able to find some details in [12].

[6]It may be noted that he would have been 68 years of age at that time, which may seem surprising. Apparently, however, from some point on it was an extended appointment in recognition of his eminence, with partial emoluments, and he seems to have retired at that time of his own volition, on account of failing health; see [1], page 86-87.

[7]A Nepali colleague had mentioned to me about some scholars from Nepal in ancient Indian works having been students of Bapu Deva Sastri. I have however forgotten the names.

[8]This was abbreviated as "M. M." and used as prefix to the name, like the British titles.

[9]*Sūrya Siddhānta* is an ancient composition with unknown authorship. The known text is from a palm leaf manuscript from the 15^{th} century, and there are also later versions. It was apparently either composed in the 8th century, or revised around then from an earlier version (see [11], page 71) which may go back to the 4^{th} or 5^{th} century; in the latter case it would be older than *Āryabhaṭīya*, composed in 499, which is currently the oldest definitively known composition from the Siddhantic tradition.

[10]It may be noted that though the title mentions "*Siddhānta Śiromaṇi*", only the translation of the Golādhyāya is

prepared by Wilkinson[11], which were published together in [15], in 1861[12]; (Wilkinson died on 13 November 1841, prematurely at the age of 36, soon after the translation was done, and not long after his association with Bapu Deva Sastri; it may be noticed that Bapu Deva took up his appointment at Benares after the demise of Wilkinson.).

Bapu Deva is seen to have been keenly motivated by the objective to advance the claim that Indian mathematicians anticipated the invention of calculus, as may be seen from his paper [13], published in the Journal of the Asiatic Society of Bengal in 1858. The paper begins with an averment "It appears to be generally believed that the principle of the Differential Calculus was unknown to the ancient Hindu mathematicians. Allow me to correct this impression by the following statement regarding what Bhaskaracharya has written on the subject." and concludes with "Hence it is plain that Bhaskaracharya was fully acquainted with the principle of the Differential Calculus." and adds "The subject, however, was only incidentally and briefly treated of by him; and his followers, not comprehending it fully, have hitherto neglected it entirely." The argument largely relies on an interpretation of the usage of the term tātkālikagati and its correlation with some calculations. The paper attracted the attention of one Mr.Wilson associated with the Royal Asiatic Society of Great Britain and Ireland, who chose to seek an opinion on it from William Spottiswoode, a well-known mathematician of the time who was later President of the Royal Society from 1878 until 1883. Spottiswoode's response was published in an article [17], in 1860, in the Journal of the Society. While he refutes the claim[13] made in the article, about Bhaskaracharya being "fully acquainted with the principle of Differential Calculus", he agrees that the analysis involved "is in the highest degree remarkable"; moreover, he mentions reading the article of Bapu Deva Sastri with great interest, adding "we are much indebted to him for calling our attention to so important an element in the old Indian methods of calculation".

Bapu Deva Sastri played an important role, through his various works and his teaching, in enriching the exposition of Indian mathematics and astronomy in the Siddhanta tradition (see[9]);[14] his blending of the earlier Indian knowledge with the European discourse and following modern notation, proved to be especially fruitful in promoting interest in the topic, in India. He is also known, on the other hand, for exposition of European material including Euclidean geometry *(Rekhāgaṇita)* and Trigonometry *(Trikoṇamiti)*, in Sanskrit which was the medium of instruction and scholarly discourse in India those days.[15] Among his other surviving works it would be worth mentioning a short booklet [14], on the Manmandira Observatory in Varanasi, constructed by Maharaja Jai Singh II of Jaipur in the first half of the 18th century. The book discusses, in

found in the work, together with an Appendix containing a translation of the Jyotpatti - the construction of the canon of sines. Apparently the first modern edition of *Gaṇitādhyāya* came out in 1926; see [5].

[11] It turns out that he had initially translated 19 verses from *Golādhyāya*, pertaining to Bhaskaracharya declaring that the earth is spherical and that it is not supported by any material substance - read Sesha as in the Puranic version - in conformity with modern understanding, which he used to convince the people concerned about his ideas on education; this motivated him to translate the *Golādhyāya*; see [12] - he may eventually have taken up translation of the whole of *Siddhānta Śiromaṇi*, but this was precluded by his untimely death.

[12] This work was reprinted by Philo. Press, Ansterdam (1974), and was reviewed by David Pingree in the Journal for the History of Astronomy, Chalfont St. Giles, Buckinghamshire Vol. 15 lss. 1 (February 1984):47.

[13] There has been a rejoinder to the refutation, in an article of Bibhutibhushan Datta and Avadhesh Narayan Singh, as revised and published by K. S. Shukla in 1984 [3]. It is however far from clear that the arguments correctly and adequately address the concerns raised by Spottiswoode and satisfactorily settle the issue - see [4], pages 355-356; it may be borne in mind here that Datta passed away in 1958, Singh had passed away in 1954, and the article was published about 40 years after the previous work of Datta and Singh, based on their manuscripts which are no longer accessible; as such their own role in the statement made remains uncertain.

[14] Apart from the works mentioned above he is also said to have had his own commentaries on various chapters of Siddhanta Siromani, which do not seem to have survived. Unfortunately his translation of the Surya Siddhanta also seems to have been overshadowed by another translation by Burgess [2], with copious notes, published around the same time.

[15] Titles of as many as 7 published and 13 unpublished books have been listed on [1], page 86.

particular, various yantras (astronomical instruments) in the observatory.[16]

Sudhakara Dvivedi (1855 - 1910)

Close on the heels of Bapudeva Sastri arrived another stalwart who was to have a great impact on the study of history of ancient Indian mathematics: Pandit Sudhakara Dvivedi.

Sudhakara Dvivedi was born in 1855 in the village Khajuri near Benares, of parents Kṛpādatta and Lācī Dvivedī (also referred to as Dubey or Dvivedin). Unfortunately the mother passed away when he was still an infant, and his father was at home only occasionally, as his workplace was away from home. The task of Sudhakara's upbringing thus fell upon some relatives. While they did raise him affectionately, one of the negative fallouts of this circumstance was that his education was delayed. He began his studies only at the age of 8, but thanks to his intelligence and sharp memory he was quick to learn to read and write, and moved on to studying Sanskrit grammar from Pandit Durgadatta (see [1], page 87).[17] His family's outlook was that he should work as a priest (purohit) and astrologer, serving the native and nearby villages. He could equip himself for this soon enough, and got initiated into the activity. He was married at the age of 14.[18]

Following his studies of Sanskrit grammar he moved on to studying mathematics and astronomy, under Pandit Devakrishna, who was a Professor of *Jyotisha* in the Benares Sanskrit College (see [1]). These studies appealed to him a great deal. He also had the benefit of the knowledge and experience of Bapudeva Sastri, who was also teaching in the Benares Sanskrit College. This phase was to have a huge influence on Sudhakara's future course. His keen interest in mathematics led him also to study mathematical topics from European textbooks. This would have naturally affected his engagement with priesthood and his earnings. However, his reputation as a scholar, as well as the popularity that he gained on account of his tutoring many students free of cost, earned him a job. King Lakshmisvara Simha of Darbhanga appointed him as a teacher of Jyotish-shastra in a school in Varanasi. Relieved of the financial stress he applied himself with much vigour to his interest in mathematics and astronomy.

In 1883 he was appointed Chief Librarian of the Government Sanskrit College, Benares. The Library, Sarasvati Bhavan, was very rich in manuscripts, providing him a good opportunity for scholarly pursuits, in terms of ready access to source materials as well as motivation, which indeed he seems to have utilized in full measure. He went on to make enormous contributions in bringing to the fore ancient Indian works, on the one hand, and bringing the European mathematics to the reach of Indian students, on the other.

He was also very successful as a teacher promoting academic scholarship among his pupils. Many of them had soon positioned themselves over a wide region, including Uttar Pradesh, Bihar and Bengal, and some of them, including Baladeva Pathaka, Baladeva Mishra, Genalala Chaudhari, Buddhinatha Jha, Dayanatha Jha, Muralidhara Jha, became quite renowned; (see [8]). One of his students, Sashipala Jha, is known to have translated Book IV of Euclid's *Elements* into Sanskrit. Another student, Gauri Shankara Prasada, donated money to institute a medal in the name of Pandit Dvivedi ([8]).

Commensurate to his eminence he was conferred the title Mahamahopadhyaya in 1887, along with Bapudeva Sastri, and was appointed as a Professor of Mathematics and Astronomy of the Government Sanskrit College, in 1889, upon retirement of the latter, as his successor. He passed away in 1910.[19]

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[16]A translated and edited version of the book with Explanatory notes by Dr. Shakti Dhar Sharma was brought out in 1982, with a foreword by Dr. K. V. Sarma.

[17]Some sources, including [8], mention Pandit Devakrishna in this respect. However, that seems incorrect. Pandit Devakrishna, as noted a few lines down, was a Professor of Jyotisha, and was more likely involved only in his later studies in mathematics and astronomy, as mentioned in [1].

[18]Marriage at a young age was of course common in those days, but in this instance it may also have been influenced by the overall family circumstance.

[19]There are some ambiguities and uncertainties about both his date of birth and his date of passing away. Here I

Sudhakara Dvivedi's works

Pt. Sudhakara Dvivedi
(1855 - 1910)

Pandit Dvivedi has had an impressive oeuvre, especially if one takes into account the relatively short span of his life. He edited numerous important ancient Sanskrit works in mathematics and astronomy, and his endeavours built up a massive edifice of reliable primary sources for studying and writing history of Indian mathematics and astronomy. Many of these works included detailed commentaries with notes and rationales, and became foundational to further discourse on the topic. Professor R. C. Gupta, a renowned historian and an awardee of the coveted Kennet O. May prize in History of Mathematics comments, in [8], that the work shows Pandit Dvivedi's vast knowledge of the history and sources of Indian exact sciences, and adds "Although a century old, much of its material will be found to be still useful."

On the other hand Dvivedi also wrote many books disseminating European mathematics in India, through his books, written in Sanskrit in the initial years, and later in Hindi, following the transition in the medium of instruction and scholarly exchange that was taking place during his time. He was himself a Hindi enthusiast and did a good deal to propagate and establish it in various ways; (see [8], page 390, for more on this).

A comprehensive discussion or even a complete listing of the works would be out of scope (the latter would seem especially pedantic, given the large number of titles involved) for an article such as this one, aiming to give a quick sense of the stature and overall role of the persona involved, in the development of the studies concerned.[20] I shall therefore content myself discussing only some of the major works, together with the conext around them. I am inclined to begin this by recalling his commentary, in Sanskrit, on *Pañcasiddhāntikā* of Varāhamihira.[21] The commentary is included in [19], which was also producced by Thibaut in colloboration with Dvivedi - it would be worthwhile reproducing here the following quote from the Preface to [19] (signed only by Thibaut), throwing light on how much Thibaut valued the collaboration, and the esteem in which he held Pandit Dvivedi.

> As this preface is signed by myself only, I may, I think, here acknowledge — in a somewhat more explicit way than the mere association of names on the title page is capable of doing — the great obligations under which I am to my collaborator Pandit Mahamahopadhyaya Sudhakara Dvivedi. His constant assistance was altogether indispensable to me, and all the more welcome as among the Jyautishas of my acquaintance I know of no other, fully equal to work of this kind and at the same time equally ready to devote himself to a task which in certain aspects is so entirely unremunerative. I may express the hope that the Pandit, who is already so well known for his efforts to spread a knowledge of modern higher Mathematics among his countrymen, will continue to devote a part at least of his learning and talents to the elucidation of the ancient history of science in this country.

The book of Dvivedi and Thibaut [19] also contains a critical review of the work that is

have followed the dates concluded by R. C. Gupta in [8] after some discussion over them, without going into any details about the other dates that have been suggested. A reader interested in the specifics concerned is referred to [8].

[20] For a more detailed account the reader is referred to [8]; see also the brief note on pages 88-90 in [1].

[21] Pañcasiddhāntikā is a treatise of Varāhamihira, dated to be from 575 CE, on mathematical astronomy, consisting primarily of an account of the following five earlier astronomical treatises, the originals of which are now lost: Surya Siddhanta, Romaka Siddhanta, Paulisa Siddhanta, Vasishtha Siddhanta and Paitamaha Siddhanta. For the latest available complete version of it the reader is referred to [16]. The work is a blend of astronomy in the Vedic tradition, from Vedanga Jyotisha, and the Hellenistic astronomy.

presented which has been much cited in literature. The book was reprinted in Lahore in 1930 and Varanasi 1968.

To be sure, Pandit Dvivedi had been working on ancient Indian manuscripts long before the joint work with Thibaut that appeared in 1889. His first venture in this respect is perhaps a commentary named *Pratibhābodhakam*, in Sanskrit, which he composed in 1873, at the age of 18; it is a commentary on *Yantrarāja*[22] which he would edit later, in 1882.

A composition of substantially wider interest, from his early years, is his edition of Bhaskaracharya's *Līlāvatī*, brought out in 1878. The edition included derivations of various rules expounded in the work, which was very beneficial to his readership. It was also published in 1912 in the Benares Sanskrit Series (No. 39)(see [8]). A new edition of the work was brought out by Pandit Muralidhara Thakura in 1938, published by Shriharikrishnanibandhabhavanam, Benares; it is currently available online [18].[23] The other important textbook of those times, *Bījagaṇita* of Bhaskaracharya, was edited by Dvivedi, in 1888, with his notes. An edition of this was brought out by Pandit Muralidhar Jha [10] in 1927, which is also currently available online. Bhaskaracharya's astronomical manual *Karaṇakutūhala* was also edited by Pandit Dvivedi in between, in 1881, with commentary.

Siddhānta-tattva-viveka of Kamalakara, from 1658, is a tail-end work from the Siddhanta tradition. Pandit Dvivedi considered it to be the best among the Siddhanta works (see [8], page 392). He edited it in 1884, with his notes that are considered valuable (published in 1885; see [8]); this has also been revised and published by Mulralidhar Jha and Muralidhara Thakura; it was published in 5 parts, at Benares, during 1924-1935.

Other renowned classic Indian works edited by Pandit Dvivedi include *Vedāṅga Jyotiṣa* of Lagadha (a Vedic era composition from sometime in the millennium BCE, edited in 1906), Sūrya-Siddhānta (the original likely to be from 4^{th} or 5^{th} century, edited in 1906), *Brāhma-sphuṭa-siddhānta* of Brahmagupta (from 628, edited in 1901/02), *Bṛhat-saṃhita* of Varāhmihira (7^{th} century work, edited in 1895 and 1897, in two volumes), *Triśatikā* of Śridhara (from ca. 750, edited in 1899), *Śiṣyadhīvṛddhida-tantra* of Lalla (8^{th} century work, edited in 1886), *Mahāsiddhānta* of Āryabhaṭa II (11^{th} century work, edited in 1910), and *Graha-lāghava* of Gaṇeśa (from 1520, edited in 1904). Many of these are also with commentaries and notes, and many have been followed up in terms of further studies; we omit the details, referring the interested reader to [8] for more information. A breathtaking spread indeed!

As mentioned earlier Pandit Dvivedi was also instrumental in promoting study of European works in India, building on the endeavour initiated by Bapu Deva Sastri, and taking it to higher level. One of his well-known works in this respect is *Dīrghavṛtta-lakṣṇam*, in Sanskrit, composed in 1878 and published in 1881, which is a treatise on the properties of an ellipse. It employs the symbolic mathematical language and notation in the derivations, though not in the statement of the results, for which a more classical verbal style is adopted. Another of his works in Sanskrit, *Bhābhramarekhā-nirūpaṇa* is on the path of the shadow of a gnomon. More influential were his textbooks on higher mathematics, in Hindi. These include one on Differenntial Calculus, *Calana-kalana*, published in 1886, and another on Integral Calculus, *Calarāśi-kalana*, published in 1895. Another book, *Samīkaraṇamīmaṃsa*, dealing with the theory of equations was published in 1897. It may be noted that absence, at that time, of set terminology in Hindi for technical terms for the variety of new notions involved, makes such a venture a stupendous task. In these works the author has cited various western authors, but has also introduced some methods of his own. Apart from the mathematical textbooks covering modern topics, he also contributed a work on European

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[22]Yantraraja is a treatise on astronomy, composed by Mahendra Sūri in 1370.

[23]It may not be out of place to recall here that in his Introduction to the book Pandit Thakura writes "This important work on Indian mensuration was twice edited by Mahamahopadhyaya Pandit Sudhakara Dvivedi. His extraordinary mathematical genius succeded in clearing up many difficult points involved in the work." By way of motivation of his revised edition he notes, however, that it is "far from exhaustive and systematic enough" to suit the students (!), a shortcoming which is sought to be remedied in his edition.

astronomy, *Dyucaracāra*, relating to planetary orbits.

Let me finally come to another of his memorable contributions, consisting of two books dealing with history of mathematics, *Gaṇaka taraṅgiṇī* in Sanskrit, and *Ganit ka Itihas* in Hindi, which are quite unique. It is even remarkable that these projects were conceived over a hundred years back.

Gaṇaka Taraṅginī

Gaṇaka Taraṅginī is an unparalleled book, in Sanskrit, on the lives and works Indian astronomers and mathematicians; it was composed in 1890. It was first featured in serialized form in the monthly journal *Paṇḍit* and was later published in book form in 1892. There have been many posthumous editions of it, including one edited by his son Padmakar Dvivedi (Benares, 1933), and a recent one, [6].

The book contains 73 biographical sketches, listed chronologically, starting with Aryabhata (Saka 398 = 476 CE), and includes also Bapu Deva Sastri, his elder colleague, as also Devakrishna, who was mentioned earlier in this article as one of his mentors. The sketches are in about one to two pages in most cases, going upto a few pages in some cases, including Aryabhata, Varahamihira, Bhaskaracharya, Ganesha Daivajna, and Jagannatha Samrat.

The write-up on Bhaskaracharya is the longest. Apart from a description of some of his work, and commentaries on them, the entry includes the inscription found at Patan, near Chalisgaon in Maharashtra (the author mentions Nasik, which is actually somewhat farther, but better known), containing information on the family tree of Bhaskaracharya. The entry on Jagannath Samrat is also almost as long. Jagannatha Samrat (b. 1652) is known for his translation of Euclid's *Elements* into Sanskrit, and discussing about it the present book goes into variety of details of Greek mathematics and mathematicians. Another book by the same author, consisting of a translation of an Arabic astronomical text is also discussed in some detail.

The description in the individual entries proceeds systematically in three parts: The details about birth and family background (as may be available), highlights of works, and finally a short review of the work, including brief comments on the merits and shortcomings, special points about the work etc.

There are however some notable names from history that are missing in the book: Bhaskara-I, Mahavira, Narayana Pandita[24], names from the Kerala school of Madhava. The Kerala school was of course not widely known, especially outside South India, until at least the middle of the 20^{th} century, until the work of C. T. Rajagopal on the topic, though it was initially brought to the attention of the western scholarship in 1830's by Charles Whish. Mahavira also seems to have come into prominence only after the edition of his *Gaṇita Sāra Saṇgraha* by Rangacharya came out in 1912. The absence of Bhaskara I and Narayana Pandita, who are now seen as an integral part of the Siddhanta tradition is, rather puzzling. Interestingly Narayana Pandita is mentioned in his later book *Ganit ka Itihas* (in Hindi), published in 1910, which I will come to next.

Ganit ka Itihas

Another book by the same author, in the spirit of history writing, but with a broader scope, encompassing the wider world, is *Ganit ka itihas — pahala bhag, Patiganit* [7][25]. This is an interesting book (available online), inspired and based on his lectures at the Benaras Government College.[26]

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[24]There are two "Narayana"s mentioned, but they are different, in terms of the descriptions and their periods (born 1571 and 1588 respectively); Narayana Pandita, whose texts are now recognized as the most significant Sanskrit mathematics treatises after those of Bhaskara II, other than the Kerala school (see [11], page 207), flourished in the 14^{th} century.

[25]Though the book is marked as the "first part" no later parts have come to light. It may be noted that he passed away soon after the publicaiton of this book, so the later part was perhaps planned, but remained incomplete at some stage, on account of his passing away.

[26]In the Preface to the book he writes "Banaras Government Sanskrit College ke Jautishacharya pariksha denevale

The book begins with the history of numerals and modes of reckoning in various ancient cultures, apart from Indian ones: from Egypt, Babylonia, Rome, Tibet, the Arabs, Chinese, ... It then goes in to the treatment of arithmetical operations including squares, square-roots, etc., in various cultures. This is followed by topics like series summation (finite), logarithms, with brief description, limiting to whether and how the topic was dealt with by various historical authors, and some key observations; he mentions to have coined a term *laghurikth* for logarithms, which is close in pronunciation to the original English term as well as of significance etymologically, in terms of meaning in Sanskrit; it is noted that *rikth* is the Sanskrit word for wealth inherited (when a father passes away), and *laghu* means small - thus when 10^7 dies (on taking logarithm) we get 7 as "small inheritance" from it (see[7], page 132). Various important results and problems (e.g. Fermat's last theorem and works of Euler, Lagrange, Kummer) are also recalled. The book also contains numerous references to various ancient Indian scriptures in a chatty, though rather patchy, narrative.

In a later part over 40 pages are devoted to a listing of well over 100 mathematical and related personalities, from across the world, with brief biographical details. The names involved are from the historical narrative in the first part; as such the list is neither meant to be exhaustive, nor limited to mathematicians (though involved in the narrative on mathematics, in some way), and the details included are not always commensurate with the historical importance of the person. They are listed alphabetically, according to the initial letter in the name (and not chronologically as in *Gaṇaka Taraṅgiṇī*). The names include Khalifa Abbasiddi Al Mansoor (754) (the first entry), Aristotle, (king) Ashoka, Albert Dürer, Cardan,[27] Jagannath Pandit, Tulasidas (!), Narayana Pandita - yes, he turns up here though was not there in *Gaṇaka Taraṅgiṇī*; it is mentioned that there is a copy of his *Gaṇita Kaumudī* in Cambridge, and that he himself has a copy. It is also mentioned that Narayana had a book on algebra and that a partial copy of the book was there in the Benares Sanskrit College Library.

About Newton he says *"sansar me sabse bade pandit gine jate hain"* (He is considered the greatest scholar (pandit) in the world). On Plato the reader is informed *"Ganit padhane ke liye school banane ke yahi adi purush hain"* (He is the first person to have opened a school devoted to teaching mathematics.)

The book also has an extensive page index at the end, which is a rare feature for an old book.

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vidyarthion ke liye mai har sal ganit ke itihas par kuchh na kuchh vyakhyan deta hun. Pichhale sal vyakhyan dete huye yah ichchha hui ki jaun yah vyakhyan Hindi bhashame likh kar chhapava diya jay to apane deshbhaiyon ka kuchh na kuchh jarur upkar ho."

[27]There is curious story mentioned about Cardan: He was also an astrologer and had predicted to the Pope that he (himself) would die on 21st September 1576, and on that day, though in good health, he committed suicide, thereby conforming the prediction.- Further look up into this indicates however that though Cardan is known to have been an astrologer, this dramatic story, which apparently has been in circulation, does not seem to be supported by reliable evidence.

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TMC Distinguished Lecture Series continues in a renewed format

Sudhir Ghorpade, Department of Mathematics, IIT Bombay, Mumbai
Email: sudhirghorpade@gmail.com

The TMC Distinguished Lecture Series (in short, TMC DLS) began in October 2020. This was during the Covid times, and the typical format of most of the talks in this series was to first release a pre-recorded video of the lecture, solicit questions from registered participants, and then hold a live interaction with the speaker about two weeks after the release of the video lecture. Now that offline activities have resumed in India and elsewhere, the organizers decided to feature lectures held in person at selected Institutes across the country, especially by mathematicians based in India. These lectures are also broadcast live, and at a later date, a video recording of the lecture is released. Accordingly, in the recent past, the TMC DLS featured a colloquium by **Prof. Dipendra Prasad** (Indian Institute of Technology Bombay) entitled *On the tensor product of representations of classical groups*, which was held at IIT Bombay on August 3, 2022, and a colloquium by **Prof. Chandrashekhar Khare** (University of California, Los Angeles, USA) on *Modularity of Galois representations, from Ramanujan to Serre's conjecture and beyond*, which was held at the Tata Institute of Fundamental Research, Mumbai on October 6, 2022.

Since its inception, the TMC DLS has featured colloquiums by some of the best researchers and expositors around the world. These are generally held once a month. The last five issues of the Bulletin contained brief write-ups on the lectures in this series by Professors Yves Benoist (Paris), Bernd Sturmfels (Leipzig/Berkeley), Nalini Anantharaman (Strasbourg), Alex Lubotzky (Jerusalem), Scott Sheffield (MIT), Karen Smith (Michigan), Daniel Wise (Montreal), Mikhail Lyubich (Stoney Brook), Tadeshi Tokieda (Stanford), Siddharth Mishra (Zürich), Noga Alon (TelAviv/Princeton), Mladen Bestvina (Utah), Laura DeMarco (Harvard), Irit Dinur (Weizman), Samit Dasgupta (Duke) and Mahesh Kakade (IISc, Bangalore), Neena Gupta (ISI Kolkata), Melanie Matchett Wood (Harvard), Rekha Thomas (Washington Univ., Seattle), and Amie Wilkinson (Chicago).

The TMC DLS is organized by The (Indian) Mathematics Consortium, and it is co-hosted by IIT Bombay and ICTS-TIFR Bengaluru. More information about the TMC DLS, including the composition of its Scientific Committee as well as Organizing Committee, and the past and forthcoming events is available at:
https://sites.google.com/view/distinguishedlectureseries/

The videos of the talks held thus far are available on the TMC YouTube Channel at: *https://www.youtube.com/channel/UCoarOpo_-9fgzFWDap6dFFw/*

2. Graph Theory 1736-1936 and Beyond - PART 2

Ambat Vijayakumar
Emeritus Professor, Department of Mathematics, Cochin University of Science and Technology
Cochin - 682 022, India. Email: vambat@gmail.com

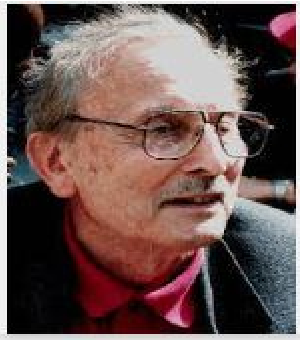
2.1 Introduction

In the earlier part, I had narrated the origin of Graph Theory, paying homage to Leonhard Euler. That article discussed graph coloring and the four color problem, some aspects of spectral graph theory, Fullerene graphs, some chess board problems and concluded with my nostalgic meeting with the legendary mathematician Paul Erdös.

In this part, we shall first discuss the Perfect Graphs, which arose from a conjecture of the celebrated French mathematician Claude Berge (1926-2002); the conjecture was posed when he was visiting the Indian Statistical Institute, Kolkata during 1960s.

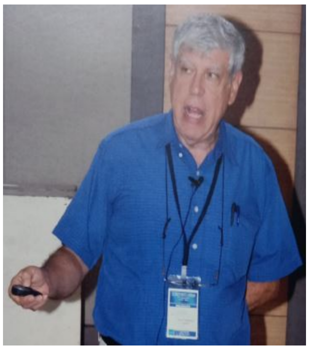
Some contributions of László Lovász - an Abel laureate 2021- in the theory of perfect graphs also and some aspects of 'Ramanujan graphs' will be discussed.

We will also know the exciting information shared by Martin Golumbic of University of Haifa, Israel about the '**Zeroth book of Graph Theory**'[8]. Some basics of Random graphs will also be discussed, which may lead to a discussion on the real world networks - the graph theory in the information age in the concluding part.



Claude Berge

László Lovász - an Abel laureate 2021



Martin Charles Golumbic

Consider the following very interesting,

Berge Mystery Problem:

A Mystery in the Library: Six professors have been to the library on the day that the rare tractate was stolen. Each has entered once, stayed for sometime, and then left. If two were in the library in the same time, then at least one of them saw the other. Detectives questioned the professors and gathered the following testimony: The Facts: • Abe said that he saw Burt and Eddie • Burt said that he saw Abe and Ida • Charlotte claimed to see Desmond and Ida • Desmond said that he saw Abe and Ida • Eddie testified to seeing Burt and Charlotte • Ida said that she saw Charlotte and Eddie.

One of the professors lied, who was he?

This interesting mystery can be solved using the notion of interval graphs, to be discussed later[7].

2.2 Perfect Graphs, Perfect Graph Theorem and Strong Perfect Graph Theorem

The chromatic number of a graph plays a significant role in graph theory. We have seen the importance of four color theorem in Part 1 which concerns chromatic numbers.

The chromatic number of a graph is the minimum number of colors required to color the vertices of a graph such that adjacent vertices receive different colors. It is interesting to note that, the proof that every graph has a chromatic number need to use the Axiom of Choice.

A perfect graph is a graph in which the chromatic number of every induced subgraph equals the order of the largest clique (maximal complete subgraph) of that subgraph (clique number). The simplest example of a graph which is not perfect is C_5, the cycle on 5 vertices, since its chromatic number is three and the clique number is two. The work of Berge is worth mentioning at this point; he is known for two conjectures on perfect graphs which were proved much later.

We shall first give a brief bio sketch of Claude Berge. Berge was born on 5^{th} June 1926 in Paris. In 1957 he was a visiting professor at Princeton University where he worked on one of his first papers on graph theory, published in the Proceedings of the National Academy of Sciences, USA. He published his famous book *Théorie des graphes et ses applications (Graph theory and its Applications)* in 1958 [3], the second book on graph theory ever written. Returning to France from the United States, Berge took up the position as the Director of research at the Centre national de la recherche scientifique (CNRS). Berge won the EURO Gold Medal from the Association of European Operational Research Societies in 1989, and shared with Ronald Graham, the inaugural Euler Medal from the Institute of Combinatorics and its Applications in 1993.

Claude Berge, Øystein Ore, Frank Harary, John Adrian Bondy and U.S.R. Murty could be considered as the pioneering authors in graph theory, and many of us have learned graph theory reading their books.

Berge is particularly remembered for two conjectures on perfect graphs [2] that he made in the early 1960s but were not proved until significantly later:

C1: A graph is perfect if and only if its complement is perfect.

Proved by László Lovász in 1972 and now known as the **(Weak) Perfect Graph Theorem**. Equivalently, in a perfect graph, the size of the maximum independent set (a set of vertices, no two of which are adjacent) equals the minimum number of cliques in a clique cover.

To prove the perfect graph theorem, Lovász used an operation of replacing vertices in a graph by cliques; it was already known to Berge that, if a graph is perfect, the graph formed by this replacement process is also perfect.

C2: A graph is perfect if and only if neither it nor its complement contains an induced cycle of odd length at least five.

Proved by Maria Chudnovsky, Neil Robertson, Paul Seymour, and Robin Thomas[5], published in 2006 and now known as the **Strong Perfect Graph Theorem**. Because this characterization is unaffected by graph complementation, it immediately implies the weak perfect graph theorem.

A **Matching** in a graph, is a collection of edges, no two of which are adjacent (have a common vertex). A **maximum matching** is a matching that contains the largest possible number of edges. Given a matching M, an **alternating path** is a path that begins with an unmatched vertex and whose edges belong alternately to the matching and not to the matching. An **augmenting path** is an alternating path that starts from and ends on unmatched vertices.

Berge's lemma: A matching M is maximum if and only if there is no augmenting path with respect to M.

Perfect graphs are an interesting class of graphs. A graph class becomes interesting when it admits a structural, forbidden or some other beautiful characterizations. Also when it has several other graph classes as examples or when complexity issues are simpler. In the case of perfect graphs, it has both types of characterizations. Further, several well known classes of graphs such as bipartite graphs, chordal graphs, split graphs, line graphs of bipartite graphs,interval graphs, distance hereditary graphs etc. are perfect [9]. All these graph classes are intersection graph models (to be discussed later).

The strong perfect graph conjecture, proposed by Claude Berge in 1960, had a major impact on the development of graph theory over the last 60 years. It has led to the definitions and study of many new classes of graphs for which the strong perfect graph conjecture has been verified. Powerful concepts and methods have been developed to prove the strong perfect graph conjecture for these special cases.

A second motivation for studying perfect graphs besides the strong perfect graph conjecture are their nice algorithmic properties. While the problems of finding the clique number or the chromatic number of a graph are NP-hard in general, they can be solved in polynomial time for perfect graphs.

It is still an open problem to find a combinatorial polynomial time algorithm to color perfect graphs or to compute the clique number of a perfect graph.

Perfectness of graph classes as a MIN-MAX theorem:

A proof that a class of graphs is perfect can be seen as a min-max theorem: the minimum number of colors needed for these graphs equals the maximum size of a clique.

Many important min-max theorems could be found in literature, such as the celebrated max-flow min-cut theorem (1956) due to Ford and Fulkerson, which is in fact a consequence of the celebrated,

Menger's theorem (Karl Menger, 1927): The size of a minimum cut set is equal to the maximum number of vertex disjoint paths between any pair of vertices.

It characterizes the connectivity of a graph. Dilworth's theorem [6] is named after Robert Dilworth (1914 - 1993), an American mathematician.

Theorem (Dilworth,1950): The minimum number of chains in a partition of a partially ordered set into chains equals the maximum size of an antichain.

Equivalently, the complements of comparability graphs are perfect.

A comparability graph (also known as transitively orientable graph, partially orderable graph, containment graph, divisor graph) is a graph that connects pairs of elements that are comparable to each other in a partial order. Equivalently, a comparability graph is a graph that has a **transitive orientation**.

Mirsky's theorem, named after **Leonid Mirsky** (1918 - 1983), a Russian-British mathematician states:

Theorem (Mirsky, 1971): In any finite partially ordered set the size of the longest chain equals the smallest number of antichains into which the set may be partitioned.

Equivalently, comparability graphs are perfect. Note that this theorem is the dual of Dilworth's Theorem.

The perfect graph theorem can be used to deduce Dilworth's theorem from Mirsky's theorem and vice versa [7]. Mirsky's Theorem is related to the Gallai-Hasse-Roy-Vitaver theorem relating longest paths and colorings in graphs, and to the Erdös-Szekeres theorem on monotonic subsequences. Such inter-relationships make the study of mathematics quite exciting.

2.3 Intersection Graph Models

An intersection graph [14], is a graph that represents the pattern of intersections of a family of sets. Any graph can be represented as an intersection graph, but some very interesting and useful classes of graphs can be defined by the types of sets that are used to form an intersection representation of them. As an example, if the sets are intervals, we have the notion of interval graphs.

Formally, an intersection graph G is an undirected graph formed from a family of sets $S_i, i = 0, 1, 2, \cdots$ by creating one vertex v_i for each set S_i, and connecting two vertices v_i and v_j by an edge whenever the corresponding two sets have a nonempty intersection, that is, $E(G) = \{\{v_i, v_j\} \mid i \neq j, S_i \cap S_j \neq \emptyset\}$.

An **interval graph** is defined as the intersection graph of intervals on the real line, one of the interesting notions linking graphs and ordered sets. The graph C_4, the cycle on four vertices is a simple example of a graph which is not an interval graph. The **line graph** of a graph G is defined as the intersection graph of the edges of G. The graph $K_{1,3}$ (Claw) is not a line graph. We have a well-known forbidden subgraph characterisation of line graphs due to L. W. Beineke [1]. A **clique graph** is the intersection graph of maximal cliques of another graph. There are many other intersection graph models such as chordal graphs, circular arc graphs etc., most of which admit a forbidden subgraph characterisation and finds applications in social sciences, computational geometry, biological modelling etc.. [17]. All these graph operators are important in the study of 'graph dynamics'[15] also.

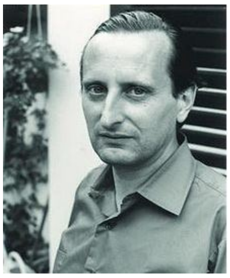
2.4 Topological Combinatorics

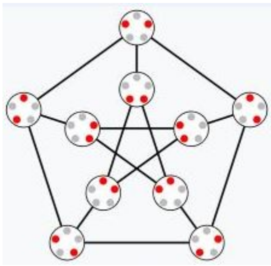
1978, methods from algebraic topology were used to solve a problem in combinatorics when László Lovász [10] proved the Kneser Conjecture, thus beginning the new field of topological combinatorics. Lovász's exciting proof used the Borsuk-Ulam theorem and this theorem retains a prominent role in this field.

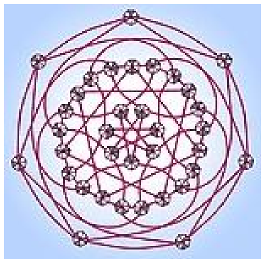
Borsuk-Ulam theorem: Every continuous function from an n-sphere into Euclidean n-space maps some pair of antipodal points to the same point.

Two points on a sphere are called antipodal if they are in exactly opposite directions from the sphere's center. This theorem has many equivalent versions and analogues and has been used in the study of 'fair division problems' in Game theory.

The **Kneser graph** $K(n,k)$ is the graph whose vertices correspond to the k-element subsets of a set of n elements, and where two vertices are adjacent if and only if the two corresponding sets are disjoint. Kneser graphs are named after Martin Kneser (1928-2004), a German mathematician, who first studied them in 1956.


Martin Kneser


Kneser graph: $K(5,2)$


Kneser graph: $K(7,3)$

The Kenser graph $K(n,k)$ has $\binom{n}{k}$ vertices. Each vertex has exactly $\binom{n-k}{k}$ neighbors.

When $k=2$, the Kneser graph is a strongly regular graph (discussed extensively in Part1), with parameters $\left(\binom{n}{2},\binom{n-2}{2},\binom{n-4}{2},\binom{n-3}{2}\right)$. However, it is not strongly regular when $k>2$, as different pairs of nonadjacent vertices have different numbers of common neighbors depending on the size of the intersection of the corresponding pairs of sets.

The Kneser graph $K(n,1)$ is the complete graph on n vertices, $K(n,2)$ is the complement of the line graph of the complete graph on n vertices and $K(2n-1,n-1)$ is the odd graph O_n; in particular $O_3 = K(5,2)$ is the Petersen graph.

Kneser Conjecture (1956): The chromatic number of the Kneser graph $K(n,k)$ for $n \geq 2k$ is exactly $n-2k+2$.

As Kneser conjectured, as a case, the Petersen graph has chromatic number 3. This conjecture was proved in several ways. László Lovász proved this in 1978 using topological methods, giving rise to the field of topological combinatorics.

Another interesting class of graphs closely related to Kneser Graphs are the Johnson Graphs.

The **Johnson graph** $J(n,k)$ is the graph whose vertices are the k-element subsets of an n-element set, two vertices being adjacent when they meet in a $(k-1)$-element set. The Johnson graph $J(n,2)$ is the complement of the Kneser graph $K(n,2)$.

At many places in this article, we see the exciting contributions of the Hungarian mathematician László Lovász(1948-). He served as a Professor at Eötöos Lornd University, Budapest and is best known for his work in combinatorics for which he was awarded the 2021 Abel Prize jointly with Avi Wigderson. He was the President of the International Mathematical Union from 2007 to 2010 and the President of the Hungarian Academy of Sciences from 2014 to 2020. Recipient of several other coveted recognitions such as the Kyoto Prize in Basic Sciences (2010), John von Neumann

Theory Prize (2006), Gödel Prize (2001), Knuth Prize (1999),Wolf Prize (1999), Fulkerson Prize (1982, 2012), Pólya Prize (SIAM) (1979), he is widely acclaimed as a gentleman academician.

He was a Plenary speaker in the 'International Conference on Recent Trends Graphs and Combinatorics (ICRTGC)', organised by us in Cochin during August 2010 as a Satellite Conference of the International Congress of Mathematicians held in Hyderabad. His exciting way of lecturing, and depth of knowledge has attracted many young researchers. In honour of Lovász as an Abel Laureate, our department organised a webinar in 2021, in which Lovász, Abhishek Methuku (currently at the University of Birmingham) and myself delivered lectures.

In collaboration with Erdös in the 1970s, Lovász developed complementary methods to Erdös's existing probabilistic graph theory techniques. This included the Lovász local lemma, which has become a standard technique for proving the existence of rare graphs. He also played a dominant role to formulate, in 1972, the Erdös-Faber-Lovász conjecture, recently proved by Abhishek Methuku, Dong Yeap Kang, Tom Kelly, Daniela Kühn and Deryk Osthus, all from the University of Birmingham, in 2021. He is also one of the eponymous authors of the LLL - Lenstra-Lenstra-Lovász lattice reduction algorithm.

Lovász lecturing in ICRTGC-2010 at Cochin. Sitting from Left to right: Ambat Vijayakumar, Patrice Ossona de Mendez, Janos Pach, Douglas Rall.

2.5 Random Graphs

A Random graph can be described by a probability distribution, or by a random process which generates them. Tools from both graph theory and probability theory are used in the theory of random graphs. Most widely discussed is the **Erdös-Rényi random graph model** (1959) where, all graphs on a fixed vertex set with a fixed number of edges are equally likely. An extensive study of random graphs is in Béla Bollobás [4].

2.6 Some Other Recent 'Graph Excitements'

(a) **Ramanujan graphs**

Ramanujan graphs are quite exciting for various reasons, as explained in Ram Murty[16]. We denote by $\lambda(G)$, the maximum of the absolute values of all the non-trivial eigenvalues of the adjacency matrix of a graph G. It is easy to see that, for a k-regular graph, $\lambda(G) \leq k$. A Ramanujan graph is a k-regular simple graph satisfying $\lambda(G) \leq 2\sqrt{k-1}$. The complete graphs, complete bipartite graphs and the Petersen graph are the simplest examples. Paley graphs are an infinite family of Ramanujan graphs. The Shrikhande graph (see part 1) is not a Ramanujan graph, though strongly regular.

Ramanujan graphs were first named in Alexander Lubotzky [11] in 1988. In his paper, Lubotzky constructed families of Ramanujan graphs using the Ramanujan conjecture, Ramanujan graphs have become an object of great interest. These graphs have a wide variety of applications in error-correction codes, network reliability, and cryptography. Constructing infinite families of k-regular Ramanujan graphs for every fixed k is an interesting challenge. Margulis [13] and independently Lubotzky, Phillips and Sarnak [11] gave the first explicit constructions of infinite families of Ramanujan graphs. These had degrees $p+1$, for primes p, $p \equiv 1(mod\ 4)$.

Adam Marcus, Daniel Spielman and Nikhil Srivastava [12] proved that there exist bipartite Ramanujan graphs of every degree and every number of vertices. The proof uses an operation called 2-lifts and the method of interlacing polynomials. The proof techniques are quite ingenious. They won the prestigious Polya prize (SIAM) in 2014 and the Michael and Sheila Held Prize (2021) for their solution to **Kadison-Singer problem**.

The Ramanujan graphs are expander graphs - finite, highly connected sparse (adjacency matrix has more zeros than ones) graphs. They play an important role in computer science for network constructions, error correcting codes, algorithms etc..

Open Problem: There exists infinitely many non-bipartite k-regular Ramanujan graphs for $k \geq 3$.

(b) **The Zeroth Book of Graph Theory**

In Part 1 of this article, we saw the significance of the year 1936, the year in which the first book on graph theory was published by Dénes König. But M. C. Golumbic, from University of Haifa, Israel and a friend of Cochin, has a startling information about, "**The Zeroth Book of Graph Theory: An Annotated Translation of Les Réseaux (ou Graphes)**" (Springer, 2021). The fact that twelve editions of it were published in 2021 reveals the importance of the book. Marking 96 years since its first appearance, this book provides an annotated translation of Sainte-Laguë's (1882-1950), the seminal monograph Les réseaux (ou graphes), drawing attention to its fundamental principles and ideas.

Sainte-Laguë's 1926 monograph appeared only in French, but in the 1990s H. Gropp, the author of the book "From Sainte-Lagué to Claude Berge - French graph theory in the twentieth century" had published a number of English papers describing several aspects of the book. In the 10 years following the appearance of "Les réseaux (ou graphes)", the development of graph theory continued, culminating in the publication of the first full book on the theory of finite and infinite graphs in 1936 by Dénes Kónig. This remained the only well-known text until Claude Berge's 1958 book on the theory and applications of graphs.

2.7 Conclusion

We find, these days, especially after the emergence of the information era, a wonderful growth of graph theory. What is surprising, and welcome, is the use of graph theoretic tools in proving results in seemingly unrelated and relatively new areas of research. As we shall see in the concluding part (Part 3), graph theory enters brain network research. The remarks by the veteran researcher M. Ram Murty of Queen's University, Canada also, in his recent talks, that 'Graph theory will be one of many disciplines needed to understand the brain', will hopefully take us to a long way.

Acknowledgment: The author thanks the unknown referee for suggesting some changes, which improved the article and Dr. K. Pravas, Government Maharajas College, Ernakulam, for helping in the typesetting.

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3. BOOK REVIEW
Aadhunik Bharat Ke Divangat Ganitagya, by Virendra Kumar (in Hindi, Namaskar Books, New Delhi 2022)

Lovy Singhal,
Email: lovysinghal@gmail.com

In 600 pages or so, E. T. Bell's *Men of Mathematics* told us stories of about forty mathematicians beginning with Eudoxus of Cnidus [2]. This bunch of forty was then understood to be representative of the tribe. The present book under review sets itself a much more modest goal and yet proves to be a *tour de force*.

Our journey begins at stratospheric heights with Radhanath Sikdar (of the 'Great Trigonometric Survey' fame) who was born in the first quarter of the nineteenth century and culminates with Sudipta Dutta who was born in the last quarter of the twentieth. The choice of the beginning has been justified as it being around the time that Indian academics started communicating in English and adopted western conventions in their work.

Along the way, we are introduced to algebraists (Ramchundra, I. S. Luthar, Daya-Nand Verma, Amit Roy, Vinay Deodhar), algebraic geometers (S. S. Abhyankar, M. S. Narasimhan, C. S. Seshadri, C. P. Ramanujam, A. Ramanathan), analysts (C. T. Rajagopal, Pesi Masani, U. N. Singh, Wazir Hasan Abdi, J. R. Choksi, Raghavan Narasimhan, V. N. Singh, Ranjan Roy, S. R. Sinha, Sudipta Dutta etc.), astronomers (Swathi Thirunal Rama Varma, G. V. Juggarow, A. Venkat Narasingh Rao, C. Ragoonathachary, Samanta Chandra Sekhar, R. S. Kushwaha, Shambhu Dayal Sinvhal etc.), combinatorialists (R. C. Bose, S. S. Shrikhande, B. D. Acharya), computer scientists (Samarendra Kumar Mitra, Rajeev Motwani), experts on differential equations (Shyam Lal Yadava), geometers (Sir Ashutosh Mukherjee, Syamadas Mukhopadhyay, Ratan Shanker Mishra, V. K. Patodi, Subhashis Nag), historians of mathematics (Bapudeva Sastri and his notable successor Sudhakara Dvivedi, K. S. Shukla, T. A. Sarasvati Amma, K. V. Sarma), logicians (George Padmadan), mathematical physicists (Meghnad Saha, S. K. Trehan, Anadi Sankar Gupta, Roddam Narasimha), number-theorists (Srinivasa Ramanujan, S. S. Pillai, Hansraj Gupta, T. Vijayaraghavan, S. Minakshisundaram, P. Kesava Menon, C. S. Venkataraman, K. G. Ramanathan, K. S. Chandrasekharan, M. V. Subbarao, K. Ramachandra, V. C. Dumir etc.), optimizers (Chanchal Singh), probabilists (Alladi Ramakrishnan, Ashok Maitra), relativity theorists (S. Chandrasekhar, P. C. Vaidya, A. K. Raychaudhuri) and statisticians (P. C. Mahalanobis, Anil Kumar Bhattacharyya, M. C. Chakrabarti, Purnendu Kumar Bose, M. N. Ghosh, Anil Kumar Gayen, V. S. Huzurbazar, Hari Kinkar Nandi, G. K. Kanji, Geetha Ramachandran etc.). All of this is not to namedrop but to highlight the breadth of the coverage at offer in terms of research areas. The author has an unmistakable resolve about not discriminating between different tributaries of the riverine system. Regrettably, that has also meant several practitioners of astrology, Vedic mathematics and other such hocus-pocus creeping in.

Issues of diversity have been adequately handled. When reading Bell's selection, we are introduced to only one female mathematician - Sofya Kovalevskaya, but there are many more to be found here. If their number pales in comparison to males, it is merely hinting at the constraints faced by Indian women in their professional lives. There is considerable geographic diversity too. The traditional dominance of Bengal and Madras Presidencies in Indian academia is palpable but there are fair number of entries from other states. This is both due to the author's efforts at compiling an exhaustive database as well as the universal appeal of the subject. For those regions which may be missing out, he cannot be faulted and the blame lies elsewhere. Curiously enough, Nepal-born Gopal Prasad Pandey who is credited to be the first to write math textbooks in Nepali language has been appropriated for inclusion here. This reviewer found a sizeable number of individuals who might have owned their Muslim heritage (for example, Sir Ziauddin Ahmad, M. R. Siddiqui, Wazir Hasan Abdi, S. Izhar Husain, Abul Hasan Siddiqi and others). There were at least two Parsees. One other person was born in a mixed marriage. We have a royal who was (nominally) given away to a Muslim mendicant by his superstitious parents. Caste, which is omnipresent in Indian society, has been featured in the book mostly in laudatory terms. While Brahmin, Jamindari and royal lineages are often mentioned positively, a rather well-known incident of casteism faced by Meghnad Saha has been overlooked [1]. An aspiring undergraduate will, however, find hope in the fact that almost as many mathematicians delineated in the book had no family background in academics as the ones who did.

The reader will meet kings and seers, victims of schizophrenia and judges of Constitutional Courts, fellows of the Royal Society and followers of Gandhian philosophy, institution builders and winners of Shanti Swarup Bhatnagar Prize in Mathematical Sciences. A word of caution is pertinent over here. Fanboys, be they as eminent as Jagadguru Shankaracharya Swami Bharatikrishna Tirtha or Sir Shah Muhammad Sulaiman, cannot legitimately be tagged as mathematicians. The sin is compounded when mistaken attempts at challenging well-established scientific theories are hailed instead of being called out. It may leave a young person confused as to why have Indian scholars been disputing fundamental concepts from her higher secondary textbook, without possessing any credible evidence to support their claims. Similarly, the author fails to point out that certain Padma awards were bestowed purely for extraneous reasons and have nothing to do with the academic achievements of the persons concerned. This general reluctance to separate the wheat from the chaff is at least partially responsible for the post-truth world we are stuck in.

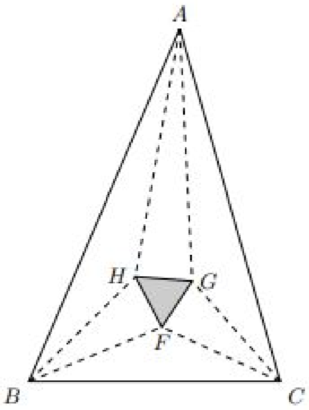
Somewhat unsurprisingly, one of the longest sketches is on the phenomenon that was Srinivasa Ramanujan. The importance of accessible and affordable textbooks (specifically, Carr's *A synopsis of elementary results in pure mathematics* [3] in his case) becomes amply clear as soon as we start to read his life's story. It is difficult to not wonder that times must surely have been simpler when personal letters from people sitting in far-away lands would be sufficient for the almighty University of Madras to sanction a grant of 75 rupees per month in Ramanujan's support. His benign mentor G. H. Hardy would even go to the extent of enjoining colleagues Littlewood, Gilbert Walker and E. H. Neville to ensure that the orthodox Brahmin boy from Kumbakonam did indeed cross the seas to be at Cambridge [6]. It is, therefore, unfathomable that the author considered it wise to make a snide remark at the Englishman's expense opining thus: "There was so much work in this [= Ramanujan's second] notebook that if Hardy had edited it, his whole life might have been consumed." Whether this claim might have been true or not is irrelevant; celebrating one genius need not entail belittling another. Those who are eager to know more about the man may be referred to Kanigel's excellent account [7].

There are enough anecdotes in the book which gain new importance in the light of more contemporary events. Mahalanobis was bestowed with fellowship of the Pakistan Statistical Association in 1952 while being on the Planning Commission of the Indian Republic. This would have been a scoop for our present mainstream television media. A schoolgoing Saha's lack of means being confused for an act of defiance by the then ruling dispensation would be laughable if it were not so off-putting. In today's times, the Bengali Professor might have been decried as a member of the *tukde-tukde* gang. We also come across the poignant tale of a student who was compelled by circumstances to perform the last rites of his doctoral advisor. Many other figures who appear were also witnesses to the partition of the Indian subcontinent and its associated horrors. One is astounded to learn that most mathematicians of that era continued to publish and teach regularly throughout the troubled period. That often required them to ply their trade from one department to another and/or switch research topics. Both domestic and international mobility would continue to remain a theme for successive generations of their intellectual descendants.

Interspersed among the biographical sketches lies the story of the development of various departments and institutions found in the country. For example, the Indian Mathematical Society was born out of an *Analytic Club* which had been initiated by V. Ramaswami Aiyar and two of his friends. We come to know how Mahalanobis rallied his colleagues, old and young, to set up Indian Statistical Institute at Calcutta in 1932. When a newly established 'Ramanujan Institute of Mathematics' needed a Director, the number-theorist T. Vijayaraghavan was summoned from Dhaka and when a postgraduate Department of Statistics had to be set up at the University of Bombay, a Bengali gentleman named M. C. Chakrabarti was invited to head the same. In the fifties, two southerners K. Chandrasekharan and K. G. Ramanathan built the School of Mathematics at the Tata Institute of Fundamental Research from scratch, but not without considerable patronage from higher powers. A fellow-traveller in the School of Physical Sciences there, Alladi Ramakrishnan would go on to establish the Institute of Mathematical Sciences at Madras. Some of their painstaking efforts, successes, trials and tribulations are well documented in the book. We also see statistics departments appearing on many other university campuses as well as various regional and/or specialized mathematical societies being formed. The sheer number of statisticians who are on the list serve to showcase India's powerhouse status in this branch. In fact, K. C. Sreedharan Pillai helped in founding the Statistical Center of the University of the Philippines in his role as a United Nations personnel. Implicit remains the warning of how even the best of the institutions can crumble under the weight of constant bureaucratic stress, financial crunch and political interference.

Returning to the Indian Mathematical Society for a moment, several of its early office-bearers have been chosen for inclusion. One such M. T. Naraniengar gave an elementary proof of a beautiful theorem in planar geometry which this reviewer cannot resist the temptation to restate:

Theorem. *(Morley's trisector theorem). Let ABC be any triangle in the plane. Also, let its angle trisectors be named AG, AH, BH, BF, CF and CG in an anticlockwise fashion. The three points of intersection F, G and H of pairs of these adjacent trisectors form an equilateral triangle.*



It was first discovered by Frank Morley in 1899. Before Naraniengar, all the available proofs involved concepts from college-level mathematics at the minimum [9]. Another Indian M. Satyanarayana provided a trigonometric argument in support of the statement. This theorem has continued to fascinate generations of scholars, with the Fields medallist Alain Connes providing an algebraic proof around a century later [4]. Interestingly, Morley was the President of the American Mathematical Society from 1919 to 1920 while Naraniengar headed the Indian Mathematical Society in the early 1930's for two consecutive terms.

Beyond academic matters, the author helps to dispel the oft-repeated myth that Indian mathematicians constitute a pack of impractical no-gooders. From time to time, we find them emerging on the national scene to assist Governments with economic planning, benchmarking Indian Standards, computing ballistic trajectories so as to be able to manufacture arms indigenously, contributing to agricultural policy making, dedicating personal libraries to the society, ensuring Quality Control in Indian industries, gracing the boards of Public Service Commissions, helping the military with intelligence gathering, laying the foundations of India's booming IT sector, providing their inputs in the development of the space programme, running welfare homes for the underprivileged and securing foreign technical aid for the country. That does not quite paint a picture of people living in their ivory towers. However, none of above-mentioned responsibilities are considered prime for broadcasting on primetime television and some of it has to be necessarily carried out in a quiet fashion. This would sadly imply that the myth is more than likely to subsist.

A special mention must be made of some of the acts of rebellion against the Establishment. Let us start from the start: Sikdar had no hesitation in paying a princely sum of 200 rupees as fine in the year 1843. His crime was standing up for the rights of his colleagues at the Survey Department. As has been already hinted, Meghnad Saha was kicked out of Dhaka Collegiate School for participating in the Swadeshi Movement. When André Weil was unceremoniously dismissed from Aligarh Muslim University, the number-theorist T. Vijayaraghavan thought it better to move to Dhaka University rather than accepting a promotion which was offered to him unasked for that would have meant stabbing his close colleague in the back. Anil Kumar Bhattacharyya resigned from his leadership position at Presidency College, Calcutta protesting against some activities of the Department of Education, Government of West Bengal. The relativist P. C. Vaidya resigned from his teaching position at a local Rajkot college due to differences with the then-reigning royal family. He was happy to sustain himself via private math tuitions while training the youth for pursuing freedom struggle in a non-violent manner. As we continue to turn the pages, this readiness to speak truth to power slowly tends to zero.

Each article begins on a fresh page which helps the reader to begin afresh as well. Typographical errors and oversights are expected and understandable in any work of this size. We shall confine ourselves to a few glaring ones: Subhodhchandra has been wrongly named as Mahalanobis' father in place of Probodh Chandra [8, 3]. K. G. Ramanathan served as an Editor of *Acta Arithmetica* and not *Acta Mathematica* [7]. The geometer Syamadas Mukhopadhyaya (and not the academician politician Syama Prasad Mukherjee) used to mentor R. C. Bose during his time as a research associate. In fact, Bose never wrote a doctoral thesis till he needed to travel to the United States as a visiting faculty. He was awarded a D. Litt. by the University of Calcutta in 1947, and not in 1928 as has been told in the book.

It is disappointing to note that no attention whatsoever has been paid towards copyrights or to give due credits when borrowing people's images. Some of these must certainly be in public domain with the lapse of time and others can be claimed as fair-use but an acknowledgement is the bare minimum requirement. The author has done a commendable job in providing translations for a lot of mathematical jargon but too many English phrases have managed to escape his scrutiny. Most pieces read like hagiographies with no attempt visible at engaging critically with the object of enquiry. On several occasions, achievements have been listed in a haphazard manner and fact(oid)s have been repeated within the scope of one biography itself. Many paragraphs have been directly translated from English Wikipedia and some have been copied verbatim. The book may nevertheless prove to be a useful source in those pockets of the subcontinent where English remains a distant dream and internet connectivity is sparse. It must also be made an optional reading for trainee officers at LBSNAA, Mussoorie for that may sensitize a prospective Joint Secretary about the futility of frugality when it comes to funding mathematics. The rôle of various scholarships and Chair Professorships in nurturing and furthering young mathematical careers can hardly be overstated. For the next edition, it is humbly recommended that a mini English-Hindi dictionary of scientific terms be appended at the end.

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4. What is happening in the Mathematical world?

Devbhadra V. Shah
Department of Mathematics, VNSGU, Surat; Email: drdvshah@yahoo.com

4.1 HYPERGRAPHS REVEAL A SOLUTION TO A 50-YEAR-OLD PROBLEM

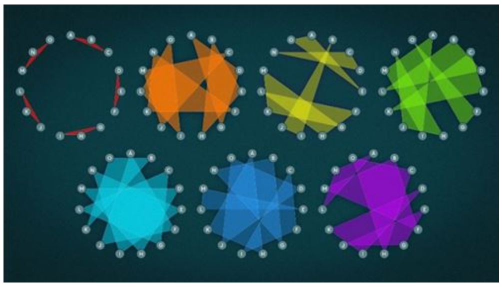

Figure - 1

In 1850, mathematician Thomas Penyngton Kirkman proposed his "schoolgirl problem": "Fifteen young ladies in a school walk out three abreast for seven days in succession: It is required to arrange them daily, so that no two shall walk twice abreast."

Kirkman's problem essentially asks whether there are 7 arrangements (See Figure-1)of these triangles that connect all the schoolgirls to one another, but with the added restriction that no two triangles in these 7 arrangements share an edge. Edge-sharing would imply that two schoolgirls have to walk together more than once. To a modern mathematician, this kind of problem is realized as a hyper graph (super imposing all 7 arrangements) - a set of nodes collected in groups of three or more. The 15 schoolgirls are nodes, and each group of "three abreast" can be thought of as a triangle, with three lines, or edges, connecting three nodes.

This problem and others like it have captivated mathematicians for the nearly two centuries since Kirkman posed his question. In 1973, the legendary mathematician Paul Erdős posed a similar problem. He asked whether it is possible to build a hypergraph connecting the triangles, with two seemingly incompatible properties. First, every pair of nodes must be connected by exactly one triangle, as with the schoolgirls. This property makes the graph dense with triangles. The second requirement forces the triangles to be spread out in a very precise way. Specifically, it requires that for any small group of triangles, there are at least three more nodes than all the nodes that are the vertices of the triangles in a group.

Now, with an intricate 50-page proof, four mathematicians have shown that it is always possible to build such a hypergraph as long as you have enough nodes. The work was done by the team consisting of *Mehtaab Sawhney* and *Ashwin Sah*, graduate students at the Massachusetts Institute of Technology; *Michael Simkin*, a postdoctoral fellow at the Center of Mathematical Sciences and Applications at Harvard University; and *Matthew Kwan*, a mathematician at the Institute of Science and Technology, Austria.

The amount of technicality that they went through just to get this was amazing. The research team built a system that satisfied Erdös' requirements by starting with a random process for choosing triangles and engineering it with extreme care to suit their needs. Their strategy was to carefully build the hypergraph out of individual triangles.

The authors are optimistic that their technique can be extended beyond this one problem. They have already applied their strategy to a problem about Latin squares. Beyond that, there are several questions that may eventually yield to the absorption methods involved here. There are so many problems in combinatorics, especially in design theory, where random processes are a really powerful tool. One such problem, the Ryser-Brualdi-Stein conjecture, is also about Latin squares and has awaited a solution since the 1960s. Though absorption may need further development before it can fell that problem, it has come a long way since its inception.

Source: *https://www.wired.com/story/hypergraphs-reveal-a-solution-to-a-50-year-old-problem/*

4.2 A POST-QUANTUM CIPHER WAS BROKEN BY A 2013 PROCESSOR IN AN HOUR

Recently, the NIST, the US standards-setting body, announced the first four algorithms for post-quantum cryptography. Such algorithms promise to solve one of the biggest problems created by the advent of quantum computers due to their ability to break public key cryptography used today, for communications on the Internet. Four further algorithms are under consideration for standardization to have greater variety and, therefore, a better overall security level. One of these, SIKE, was unexpectedly broken and therefore cannot become a standard. Not without some irony, the cipher was broken by a traditional computer of limited power.

An important aspect to keep in mind is that this attack does not affect in any way the already standardized ciphers: they are, in fact, based on completely different mathematical techniques and without any relationship with that used for SIKE. The ciphers already approved, therefore, remain safe, at least until proven otherwise.

Public key cryptography involves the use of mathematical techniques that allow you to use two keys, one public and one private, to encrypt a data. Using the public key, only those in possession of the private key will be able to read the data. On the other hand, the sender can also send the digital signature made using own private key, which can be verified by the receiver using the senders public key. This way authenticity of the sender is verified. The important thing is that when using public-key cryptography, it is not necessary for two parties to have already shared "traditional" cryptographic key in advance: It is thanks to this feature that public-key cryptography has become essential for communications on the Internet.

The calculations necessary for the use of public key cryptography are, however, often demanding and for this reason protocols for the exchange of symmetric keys are often used. In this way, a high level of safety is achieved, coupled with superior performance. This process is called "encapsulation".

SIKE, an abbreviation that stands for *Supersingular Isogeny*[1] *Key Encapsulation* (encapsulation of keys through supersingular isogenies), a proposed algorithm for standardization designed to replace the current ones, vulnerable to attacks by quantum computers.

Recently, some researchers from the University of Leuven, in the Netherlands, published a preliminary study in which they claim to have succeeded in breaking the new algorithm with a traditional computer in less than an hour. To be specific, the researchers used a single core from an Intel Xeon E5-2630v2 processor, launched in 2013. The researchers will now receive $50,000, up for grabs from NIST.

SIKE uses isogenies: simplifying a lot, these are mathematical transformations to carry out transformations from curve A to curve B. The attack found by the researchers is based on the fact that these transformations are not performed directly, but through intermediate steps: By determining the intermediate curves it is possible to trace the key used for the encryption and, in fact, break the algorithm.

The attack is valid for the published algorithm, which involves the use of a step to generate the key. In theory, it is possible that using a two-step algorithm is not susceptible to the same attack and is therefore safe. However, for the moment SIKE to be considered out of the game, at least in the current incarnation.

It is important to note that this result may appear negative, but it is actually exactly the reason why cryptographic algorithms are subjected to stages of public criticism. If we did not proceed in this way, the risk would be that weak algorithms were standardized, perhaps even implemented in hardware, only to later discover that there was an attack capable of breaking them. Therefore, it is necessary, once again, to underline how active and open collaboration leads to the best results. Thanks to open and public processes it is possible to involve people with different experiences and knowledge, so as to arrive at the best possible results.

Source: *https://sparkchronicles.com/a-post-quantum-cipher-was-broken-by-a-2013-processor-in-an-hour/*

1. In algebraic geometry, an isogeny is a morphism of algebraic groups (also known as group varieties) that is surjective and has a finite kernel.

4.3 KERR BLACK HOLES ARE PROVED TO BE STABLE

In 1963, the mathematician Roy Kerr found a solution to Einstein's equations that precisely described the space-time outside what we now call a rotating black hole. In the nearly six decades since his achievement, researchers have tried to show that these so-called *Kerr black holes* are stable. What that means is that if someone starts with something that looks like a Kerr black hole and give it a little bump - by throwing some gravitational waves at it, for instance - what you expect, far into the future, is that everything will settle down, and it will once again look exactly like a Kerr solution. The opposite situation - a mathematical instability - would have posed a deep challenge to theoretical physicists and would have suggested the need to modify, at some fundamental level, Einstein's theory of gravitation.

In a 912-page paper posted online, *Szeftel* (Left), *Elena Giorgi* (Middle) of Columbia University and *Sergiu Klainerman* (Right) of Princeton University have proved that slowly rotating Kerr black holes are indeed stable. The work is the product of a multiyear effort. The entire proof - consisting of the new work, an 800-page paper by Klainerman and Szeftel from 2021, plus three background papers that established various mathematical tools - totals roughly 2,100 pages in all. The new result does indeed constitute a milestone in the mathematical development of general relativity. The proof is the first major breakthrough in this area of general relativity since the early 1990s.

One reason the question of stability has remained open for so long is that most explicit solutions to Einstein's equations, such as the one found by Kerr, are stationary. These formulas apply to black holes that are just sitting there and never change; those are not the black holes we see in nature. To assess stability, researchers need to subject black holes to minor disturbances and then see what happens to the solutions that describe these objects as time moves forward.

For example, imagine sound waves hitting a wineglass. Almost always, the waves shake the glass a little bit, and then the system settles down. But if someone sings loudly enough and at a pitch that exactly matches the glass's resonant frequency, the glass could shatter. Giorgi, Klainerman and Szeftel wondered whether a similar resonance-type phenomenon could happen when a black hole is struck by gravitational waves.

They considered several possible outcomes. A gravitational wave might, for instance, cross the event horizon of a Kerr black hole and enter the interior. The black hole's mass and rotation could be slightly altered, but the object would still be a black hole characterized by Kerr's equations. Or the gravitational waves could swirl around the black hole before dissipating in the same way that most sound waves dissipate after encountering a wineglass. Or they could combine to create havoc. The gravitational waves might congregate outside a black hole's event horizon and concentrate their energy to such an extent that a separate singularity would form. The space-time outside the black hole would then be so severely distorted that the Kerr solution would no longer prevail. This would be a dramatic sign of instability.

The three mathematicians relied on a strategy that had been previously employed in related work. Klainerman emphasized that he and his colleagues have built on the work of others. He considers the latest paper a collective achievement, and he would like the new contribution to be viewed as "a triumph for the whole field."

So far, stability has only been proved for slowly rotating black holes. It has not yet been demonstrated that rapidly rotating black holes are also stable. In addition, the researchers did not determine precisely how small the ratio of angular momentum to mass has to be in order to ensure stability.

Going beyond this problem is a much bigger one called the final state conjecture, which basically holds that if we wait long enough, the universe will evolve into a finite number of Kerr black holes moving away from each other. The final state conjecture depends on Kerr stability and on other sub-conjectures that are extremely challenging in themselves. To some, that statement might

sound pessimistic. Yet it also illustrates an essential truth about Kerr black holes: They are destined to command the attention of mathematicians for years, if not decades, to come.
Source: *https://www.quantamagazine.org/black-holes-finally-proven-mathematically-stable-20220804/?mc_cid=4e59d2834c&mc_eid=df6d259cb7*

4.4 INDIA WINS 6 MEDALS, RANKS 24^{TH} AT IMO 2022

The International Mathematical Olympiad (IMO) 2022 was conducted in Oslo, Norway during Jul 9-16, 2022. The Indian team won one gold and five bronze medals. Bengaluru-based *Pranjal Srivastava* scored a hattrick with his third consecutive gold medal at IMOs and is the first Indian to have won three gold medals at IMO. A total of 104 countries participated in IMO this year. India secured 24^{th} rank at the event.

First IMO was held in 1959 and 63^{rd} IMO was held in 2022. India started participating in 1989 and participated in all IMOs so far except in 61^{st} IMO in 2020.

The Indian team for IMO 2022 was led by *Niranjan Balachandran*, IITB (Leader), *Shanta Laishram*, ISI Delhi (Deputy Leader), *Sutanay Bhattacharya* (Observer A) and *Spandan Ghosh* (Observer B) from IISc., Bengaluru.

Details of the Indian team and the result are as follows:

Year	Contestant [♀♂][←]	P1	P2	P3	P4	P5	P6	Total	Rank		Award
									Abs.	Rel.	
2022	Arjun Gupta	7	3	2	7	7	2	28	146	75.34%	Bronze medal
2022	Adhitya Mangudy Venkata Ganesh	7	7	0	7	7	0	28	146	75.34%	Bronze medal
2022	Kaustav Mishra	3	7	0	7	7	0	24	247	58.16%	Bronze medal
2022	Atul Shatavart Nadig	7	7	2	1	7	0	24	247	58.16%	Bronze medal
2022	Vedant Saini	7	7	0	7	5	1	27	187	68.37%	Bronze medal
2022	Pranjal Srivastava	7	7	2	7	7	4	34	38	93.71%	Gold medal

Table 1: Indian Team - Individual Results

Year	Team size			P1	P2	P3	P4	P5	P6	Total	Rank		Awards			
	All	M	F								Abs.	Rel.	G	S	B	HM
2022	6	6	0	38	38	6	36	40	7	165	24	77.67%	1	0	5	0

Table 2: Team Results - India

Figure: 2

Source: *https://www.republicworld.com/education/news/imo-2022-india-wins-6-medals-ranks- 24 th -at-international-mathematical-olympiad-articleshow.html*

4.5 Awards

4.5.1 Fields Medal awarded to four eminent mathematicians

Four mathematicians were awarded the Fields Medal on 5 July, 2022 in Helsinki, including the Ukrainian *Maryna Viazovska*, (first from left) the second woman to receive the prestigious award since its creation in 1936. The other three winners (from left to right) of this distinction are the British *James Maynard*, from the University of Oxford, the American-South Korean *June Huh*, from Princeton and French mathematician *Hugo Duminil-Copin* from the University of Geneva.

The Fields Medal, considered the equivalent of a "Nobel in mathematics", is awarded every four years in recognition of outstanding mathematical achievements and the promise of future accomplishments. The award, which includes a gold medal accompanied by a check for over $11,500, rewards "exceptional findings" by mathematician under 40 years of age. The winners are normally announced at the International Congress of Mathematicians. This year the congress was originally scheduled to take place in Saint Petersburg, Russia but was moved to Helsinki due to the Russian incursion into Ukraine.

Maryna Viazovska

Out of a total of about 60 recipients of this award, so far there has been only one woman, Maryam Mirzakhani, to have received this highest honor in 2014 (she died of cancer in 2017). Now, the sphere-packing number theorist 37-year-old Ukrainian Maryna Viazovska, holder of the Chair for Number Theory at the Swiss Federal Institute of Technology Lausanne, has become the second woman to win a Fields Medal in the award's 86-year history. She was awarded the prize for solving a centuries-old version of a geometric problem, in which she demonstrated the densest packing of identical spheres in eight dimensions.

The so called "sphere packing problem" dates back to the 16^{th} century, when the question of how cannonballs should be stacked to get the densest possible solution was raised. This problem has preoccupied mathematicians for more than four centuries. In 1611, Johannes Kepler proposed the hypothesis that the densest type sphere packing is the pyramid-shaped one stacked on top of the other - but had to leave this hypothesis unproven. This hypothesis was finally proven in 1998 (for which a computer had to be used). The volume is then a little more than 74 percent filled with spheres - more is not possible.

Now the mathematicians wondered whether this statement could also be proven for higher dimensions. Viazovska took it to another dimension - the 8^{th} and 24^{th}, to be precise - solving it in a way that drew widespread praise from top mathematicians. Formulating the problem, in the same way, complicates matters because each dimension is different, and the optimal solution depends very much on the dimension. She focused on 8 and 24 dimensions because these are special dimensions, and the solutions are particularly elegant. The way spheres are packed in these special dimensions is remarkably symmetrical.

Viazovska was born on Dec. 2, 1984, in Kyiv, Ukraine. Because she developed a passion for mathematics at a young age, her path to the subject was relatively easy. After earning her Bachelor's degree at the National Taras Shevchenko University in Kyiv, Viazovska went to Germany to earn a Master's degree at the Technical University of Kaiserslautern (2007) before moving to the University of Bonn, where she completed her doctorate on modular forms in 2013. During her postdoctoral research at the Berlin Mathematical School and the Humboldt University of Berlin, Viazovska tackled the sphere packing problem in 8 and 24 dimensions. In December 2016, she accepted an offer from EPFL to become an Assistant Professor with tenure-track status. Just one year later, at the age of 33, she was promoted to Full Professor.

James Maynard

35-year-old James Maynard, Professor at Oxford University, received the medal for his spectacular contributions to the analytic theory of numbers, which have enabled important advances in the understanding of the structure of the prime numbers and in the Diophantine approach.

According to the award citation. “His work is highly ingenious, often leading to surprising breakthroughs on important problems that seemed to be inaccessible by current techniques.” On his way to winning a Fields Medal, James Maynard has cut a path through simple-sounding questions about prime numbers that have stumped mathematicians for centuries.

Even though everyone else in Maynard’s family was oriented toward the humanities, he always found himself on the path that offered the most mathematics. While in the Graduate School at Oxford, his extraordinary mathematical strength became apparent.

One of the best things that can happen to a mathematician happened to James Maynard in 2013. Fresh out of graduate school, he solved one of the discipline’s oldest and most central problems, about the spacing of prime numbers. It was an achievement that ordinarily would have garnered him fame. There was just one difficulty: Another mathematician had proved the most headline-grabbing part of Maynard’s result a few months earlier, using a completely different method. Number theorists, however, instantly recognized Maynard as someone to watch. In the years that followed, Maynard more than justified those early hopes, knocking down one fundamental problem after another.

Lately, that work has taken the form of a three–paper series about how prime numbers are distributed on the number line. Apart from the numbers 2 and 5, all primes end in 1, 3, 7 or 9, so you could imagine labeling four buckets with those digits and then dropping each prime into its associated bucket as you walk down the number line. Mathematicians have long known that the buckets will all eventually end up with roughly the same number of primes, and this is true not just in base 10 but in any base. What mathematicians don’t know, however, is how quickly the buckets start evening out, a question with implications for many other core questions about prime spacing. For many bases, Maynard has now shown that the buckets even out faster than a famous speed barrier on which mathematicians were previously stuck. The papers are really impressive technical achievements.

Maynard in January 2020 received the Frank Nelson Cole Prize in Number Theory at the Joint Mathematics Meetings in Denver. While this prize is officially awarded for a single notable paper, in Maynard’s case the prize committee could not resist citing three papers, all of which appeared in top mathematics journals.After Maynard proved his theorem about small gaps between primes, number theorists hastened to apply his insights to other problems.

June Huh

39-year-old June Huh, a Professor at Princeton University in the United States, received the award for transforming the field of geometric combinatorics using methods from Hodge’s theory, tropical geometry and singularity theory. His profound insights connecting combinatorics and geometry have led to this highest honor. Huh is the first mathematician of Korean descent to win the medal.

Huh was awarded the prize for applying the ideas of Hodge theory to combinatorics and his proof of the Dowling–Wilson conjecture for geometric lattices, among other reasons. Using methods of Hodge theory, tropical geometry, and singularity theory, June Huh, with his collaborators, has transformed the field of geometric combinatorics.

Using purely combinatorial techniques in his groundbreaking work, Huh applied the ideas of Hodge theory to combinatorics, which deals with the study of countable discrete structures, to solve problems that mathematicians had struggled to solve for almost 40 years. A simplified way of looking at Huh's work is to imagine having a sequence of numbers containing some kind of hidden pattern. For example, in the sequence 2, 4, 8, 16, the pattern is that each consecutive number is multiplied by 2. To find the hidden pattern, Huh sees the numbers in this sequence instead as dimensions of some space.

Huh's contributions also involve proving Read's conjecture, about the unimodality of the coefficients of chromatic polynomials in the context of graph theory. Building upon this proof, Huh also proved the Rota Conjecture, which focuses on a more abstract class of structures called matriods. Huh's other contributions include proofs of the Dowling-Wilson and Mason conjectures. Among most of his works, especially the groundbreaking connections he has established between algebraic geometry and combinatorics, Huh has profoundly linked seemingly unrelated areas of mathematics.

Despite having won the most prestigious award in mathematics, Huh's relationship with the subject has not always been a good one. He had no interest at a young age, in being a mathematician and later even dropped out of high school to become a poet. Huh in 2002, majored in physics and astronomy. His outlook on mathematics changed after an encounter with Heisuke Hironaka, a recipient of the Fields Medal in 1970. After receiving his Ph.D. in 2014, Huh joined the Institute for Advanced Study (IAS) in Princeton, where he was an Oswald Veblen Fellow until 2017, and a visiting professor from 2017 to 2020.

Hugo Duminil-Copin

36-year-old Hugo Duminil-Copin, a specialist in Probability theory, Professor at the University of Geneva (UNIGE), and also a Permanent Professor at the Institut des Hautes Études Scientifiques (Paris), was awarded the Fields for the exceptional quality of his work in statistical physics. He was awarded for having solved long-standing problems in the probabilistic theory of phase transitions, which has opened several new lines of research.

Duminil-Copin is a probability expert with a passion for physics; his work focuses on the mathematical branch of statistical physics. He studies phase transitions - sudden changes in the properties of matter, such as the transition of water from the gaseous to the liquid state - using Probability theory. In particular, he uses Probability theory to analyze mathematical models that describe three distinct phenomena: material porosity (via percolation theory), ferromagnetism (via the Ising model) and polymers (via the study of self-avoiding walks).

The first seeks to understand the mechanisms at work in porous materials such as pumice or coffee: what path does water take when it passes through such a material, for example? The second attempts to determine the behaviour of magnets, and in particular the progressive loss of their magnetism, when they are subjected to high temperatures. The third seeks to determine the positioning of polymers when they are immersed in a solvent.

By using new connections between these classical models, and by developing a theory of 'dependent percolation', Duminil-Copin has obtained transformative results that have improved our understanding of critical phenomena in statistical physics. This is purely fundamental research with no direct application. Nevertheless, modelling phase transitions mathematically is very important: it allows us to better understand the behaviour of matter. It gives us solid foundations that can be used for applied research with a view to industrial developments that are as yet impossible to foresee.

Hugo Duminil-Copin was born on 26 August 1985 in Châtenay-Malabry (France) and grew up near Paris. In 2005, he began his studies at the École Normale Supérieure in Paris. He then obtained his teaching qualifications and a Master's degree in Probability and Statistics from the

Université Paris-Saclay (formerly Université Paris-Sud). Duminil-Copin joined UNIGE in 2008. In 2011, he completed his doctoral thesis, which was supervised by Professor Stanislav Smirnov, a Fields Medal winner of 2010.

UNIGE appointed Duminil-Copin Professor in 2013 and Full Professor in 2014, when he was just 29 years old. He also joined the Institut des Hautes Études Scientifiques á Bures-Sur-Yvette (Paris) in 2016. He has received numerous awards, including the European Mathematical Society Prize and the Breakthrough Foundation's New Horizons in Mathematics Award.

Sources:

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6. *https://www.dailyprincetonian.com/article/2022/07/princeton-university-professor-june- huh -2022-fields-medal-first-korean-recipient-math-mathematics*

4.5.2 Israeli math researchers share $1.2 million Shaw Prize in Mathematical Sciences

Prof. Noga Alon (Left) of Tel Aviv University and Princeton University and Prof. Ehud Hrushovski (Right), a Merton Professor of Mathematical Logic, University of Oxford, UK have become the second and third Israelis ever to win the international Shaw Prize in Mathematical Sciences.

Prof. Alon is one of the world's leading researchers in mathematics and computer science, and Prof. Ehud Hrushovskiis renowned mathematical logician. The Shaw Prize was awarded to these two Israelis "for their remarkable contributions to discrete mathematics and model theory with interaction notably with algebraic geometry, topology and computer sciences." The prestigious Shaw Prize has been compared to the Nobel Prize, which does not include a mathematics category.

The Shaw Prize was founded in 2002 by the Hong Kong media tycoon Run Run Shaw, who decided to award it annually to "individuals, regardless of race, nationality, gender and religious belief, who have recently achieved significant breakthroughs in academic and scientific research or applications and whose work has resulted in a positive and profound impact on mankind," in three categories - mathematics, astronomy, and life sciences and medicine. The prize in each category is $1.2 million.

The Shaw Prize was awarded to Prof. Alon for the entirety of his groundbreaking work, which has included laying the foundations for streaming algorithms used in Big Data analysis and the development of algebraic and probabilistic methods to deal with problems in combinatorics, graph theory and additive number theory. "He introduced new methods and achieved fundamental results which entirely shaped the field," the judges wrote.

Prof. Hrushovski is well known for several fundamental contributions to Model theory with applications to algebraic-arithmetic geometry and number theory, in particular in the branch that has become known as Geometric Model theory. His Ph.D. thesis revolutionized Stable Model theory (a part of Model theory arising from the Stability theory introduced by Saharon Shelah). Shortly afterwards he found counter examples to the Trichotomy Conjecture of Boris Zilber and his method of proof has become well known as Hrushovski construction and found many other applications since. One of his most famous results is his proof of the geometric Mordell-Lang conjecture in all characteristics, using model theory in 1996. This deep proof was a landmark in logic and geometry. He has had many other famous and notable results in Model theory and its applications to geometry, algebra, and combinatorics.

Noga Alon, born in 1956, is Professor Emeritus of Mathematics and Computer Science at Tel Aviv University and Professor of Mathematics at Princeton University. He joined Tel Aviv University in 1985, where he served as head of the School of Mathematical Sciences and was entrusted with the Chair of Combinatorics and Computer Science at TAU's Blavatnik School of Computer Science. In the past, he has won the Israel Prize, the EMET Prize and the Gödel Prize. He also serves on the editorial boards of more than a dozen international technical journals and has given invited lectures at many conferences, including plenary addresses in the 1996 European Congress of Mathematics and in the 2002 International Congress of Mathematicians.

Born in 1959, Hrushovski currently is Merton Professor of Mathematical Logic, University of Oxford, UK. He was also Professor of Mathematics at the Hebrew University of Jerusalem. He previously taught at Princeton, MIT and the Hebrew University. He was an invited speaker at the 1990 International Congress of Mathematicians and a plenary speaker at the 1998 ICM. He is a recipient of the Erdős Prize of the Israel Mathematical Union in 1994, the Rothschild Prize in 1998, the Karp Prize of the Association for Symbolic Logic in 1993 (jointly with Alex Wilkie) and again in 1998, In 2019 he was awarded the Heinz Hopf Prize. He was elected a Fellow of the Royal Society in 2020.

Sources:

1. *https://www.jpost.com/israel-news/article-709389*
2. *https://en.wikipedia.org/wiki/Ehud_Hrushovski*

4.5.3 Computer scientist Prof. Mark Braverman wins the 2022 IMU Abacus Medal

38-year-old *Mark Braverman* of Princeton University has been awarded the IMU Abacus Medal by the International Mathematical Union, widely considered the highest honor a computer scientist can receive. The award was previously known as the Nevanlinna Prize, but it was renamed after historians pointed out that the Finnish researcher after whom it was named was a Nazi sympathizer. The Abacus Medal is awarded once every four years, and the winner must be under 40.

The IMU's award citation noted that Braverman's contributions to information complexity have led to a deeper understanding of different measures of information cost when two parties communicate with each other. His work has paved the way for new coding strategies that are less vulnerable to transmission errors and novel approaches to compressing data during transmission and manipulations.

For more than a decade, Braverman has been developing a new transformative theory of interactive communication, expanding and enriching the pioneering work that Claude Shannon began eight decades ago. Braverman's growing framework allows researchers to translate abstract concepts like "information" and "knowledge" into precise mathematical terms. As a result, they can recast hard problems as more precise statements. This program has led to new insights into the limitations of computation and speaks directly to the way people interact online.

The citations for other awards he received, including a Presburger Award from the European Association for Theoretical Computer Science and a Waterman Award from the National Science Foundation, often point out the far-reaching application of his work to other fields.

Source: *https://www.quantamagazine.org/mark-braverman-wins-the-imu-abacus-medal-20220705/*

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5. Problem Corner

Udayan Prajapati
Head, Mathematics Department, St. Xavier's College, Ahmedabad
Email: udayan.prajapati@gmail.com

In the July 2022 issue of TMC Bulletin, we posed a problem from Number theory for our readers. We have received three solutions to that problem, one by Shrestha Suraiya, a student from Bhaskaracharya Pratishthana, Pune, Prof. J. N. Salunke from Latur and Prof. M. R. Modak from Pune.

We also pose a problem on Geometry, for our readers. Readers are invited to email their solutions to Udayan Prajapati (udayan64@yahoo.com), Coordinator, Problem Corner, on or before 15^{th} December, 2022. Most innovative solution will be published in the subsequent issue of the bulletin.

Problem from Previous Issue:

Solve for integers x and $y, x^2(y+1)+y^2(x+1)=0$.

Solution by Prof. Modak: Write the equation as $x^2(y+1)=-y^2(x+1) \cdots\cdots (1)$

Clearly, $x=0$ if and only if $y=0$ and $x=-1$ if and only if $y=-1$

Hence $(x,y)=(0,0),(-1,-1)$ are solutions of (1).

We show that these are the only solutions.

Suppose (x,y) is an integral solution of (1) and $x \neq 0, -1$. Hence, x and $(x+1)$ are co-prime.

So by (1), $x^2|y^2(x+1)$ and hence $x^2|y^2$.

Similarly, since $x \neq 0, -1$ implies that $y \neq 0, -1$, (1), shows that $y^2|x^2$.

Hence, as $x^2, y^2 > 0, x^2 = y^2$ or $x = \pm y$. So by (1), $x+y+2=0$.

If $x=y$ then $2x+2=0$ or $x=-1$ which contradicts our assumption.

If $x=-y$ then $2=0$ which is false.

Hence, $(x,y)=(0,0),(-1,-1)$ are the only solutions of (1).

Alternate Solution (by Shrestha Suraiya and Prof. Salunke):

As shown in the earlier solution, $(x,y)=(0,0),(-1,-1)$ are solutions of (1).

We show that these are the only solutions by an alternate method.

Suppose (x,y) is an integral solution of (1) and $x \neq 0, -1$.

Writing Equation (1) as a quadratic equation in y, we get $(x+1)y^2+x^2y+x^2=0$.

A necessary condition for this equation to have an integral root, is its discriminant

$D = x^4 - 4x^2(x+1) = z^2$, for some integer z.

So, x divides z.

Assuming that $z = xw$ for some integer w, we get $x^2-4x-4=w^2$.

That is, $(x-2)^2 - w^2 = 8$.

It can be easily verified that this is possible only if $(x-2)^2=9$ and $w^2=1$.

Hence $x=-1$ or $x=5$. If we put $x=5$ in (1) then y is not an integer.

This contradicts our assumption.

Hence $(x,y)=(0,0),(-1,-1)$ are the only solutions of (1).

Problem for this issue

Let $ABCD$ be a quadrilateral. Let the diagonals AC and BD meet at P. Let O_1 and O_2 be the circumcenters of triangles APD and BPC. Let M, N and O be the midpoints of AC, BD and O_1, O_2. Then show that $OM = ON$.

□□□

6. TMC Activities

S. A. Katre,
Lokmanya Tilak Chair, S. P. Pune University, Pune, Email: sakatre@gmail.com

A NASI-TMC TRIMESTER PROGRAMME

(This is a continuation of the report in the July 2022 issue)

The Mathematics Consortium had initiated a NASI-TMC Trimester programme of 1 year duration on Triangle Groups, Belyi Uniformization and Modularity organised by **Bhaskaracharya Pratishthana**, Pune during 1 Sept. 2021 - 31^{st} Aug. 2022. For a report on the First Trimester (Sept-Dec. 2021) and the Second Trimester (Jan.-April 2022) pl. see July 2022 issue of the Bulletin. The 3^{rd} Trimester started from 1^{st} May 2022 and was over by 31^{st} August 2022.
In the Third Trimester there were talks on:

Orbifold Curves: Geometry and Arithmetic, *Modularity of Calabi-Yau Varieties*, Calabi conjecture(s) and examples, Hodge theory of Compact Kähler Manifolds, Counting Points on Calabi-Yau Varieties over Finite Fields, Hypergeometric Motives, Hypergeometric Functions in One and Several Variables, Dualities in String Theory, Supercongruences for Rigid Hypergeometric Calabi-Yau threefolds, Whipple Formula for hypergeometric values, Monodromy of Picard-Fuchs differential equations for Calabi-Yau threefolds, K_1 of a K_3 surface, Hecke Traces via Hypergeometric Character Sums, Dualities in String Theory, Hypergeometric Groups and Their Arithmeticity, Hypergeometric Supercongruence Conjectures of Long, Cohomology and p-adic Congruences, Calabi-Yau Differential Operators, Calabi-Yau Manifolds, Modularity and Arithmetic Geometry, Calabi-Yau threefolds coming from a hypergeometric family of K_3 surfaces, Mirror symmetry and Calabi-Yau families over the thrice-punctured sphere, Mirroring towers: Fibration and degeneration in Calabi-Yau geometry, The arithmetic of families of Calabi-Yau manifolds: black holes and modularity, QM Abelian Varieties, Hypergeometric Character Sums and Modular Forms, Modular Forms and Calabi-Yau Varieties.
In total 66 mathematicians gave 95 talks in the year-long series, which includes 24 Indians speakers (18 India based and six from abroad), 21 Europeans, 13 American, 5 Canadian, 2 East Asian and 1 South American speaker.

Speakers for the whole 1-year programme:

Indian Speakers: Ravi S. Kulkarni, *BP Pune*; T. N. Venkataramana, *TIFR Mumbai*; B. Sury, *ISI Bangalore*; Kapil Paranjape, *IISER Mohali*; Jaya N. Iyer, *IMSc Chennai*; Kingshook Biswas, *ISI Kolkata*; Sudarshan Gurjar, *IIT Bombay*; Shaunak Deo, *IISc, Bangalore*; Subhojoy Gupta, *IISc Bangalore*; Sudhanshu Shekhar, *IIT Kanpur*; Vamsi Pritham Pingali, *IISc Bangalore*; Sandip Singh, *IIT Bombay*; Shiroman Prakash, *Dayalbagh Edu. Insti. Agra*; Guhan Venkat, *Ashoka University, Delhi*; Ramesh Sreekantan, *ISI Bangalore*; Rakesh Pawar, *IISER Pune*; Mihir Sheth, *IISc Bangalore*; Chaitanya Ambi, *CMI Chennai*; A. Raghuram, *Fordham University, New York*; Anand Deopurkar, *Australian National Univ., Canberra*; Barinder Banwait, *Heidelberg, Germany*; Anwesh Ray, *Univ. of British Columbia, Vancouver*; Anirudh Gurjale, *Univ. of Rochester*; Neelima Borade, *Princeton Univ.*

From East Asia:

Ser Peow Tan, *National Univ. of Singapore*; Yifan Yang, *National Taiwan Univ.*

European Speakers:

Frits Beukers, *Utrecht Univ.*; Frederic Campana, *Univ. of Lorraine, France*; Philip Candelas, *Univ. of Oxford, Oxford*; Xenia de la Ossa, *Univ. of Oxford, Oxford*; Fernando Rodriguez Villegas, *ICTP Trieste, Italy*; Albrecht Klemm, *Univ. of Bonn*; Pilar Bayer, *Univ. of Barcelona*; Alexander Mednykh, *Sobolev Insti. of Math.*; Novosibirsk, Leila Schneps, *CNRS, Paris*; Hartmut Monien, *Bonn Univ.*; John Parker, *Durham Univ.*; Loic Merel, *Univ. of Paris*; Masha Vlasenko, *IM-PAN,* *Warsaw*; Samir Siksek, *Univ. of Warwick*; Angelos Koutsianas, *Aristotle Univ. of Thessaloniki, Greece*; Nicolas Billerey, *Université Clermont Auvergne, France*; Nuno Freitas, *Instituto de Ciencias Matematicas (ICMAT), Madrid*; Gianluca Faraco, *MPI, Bonn*; Bram Petri, *Univ. of Paris, 6 Sorbonne*; Claire Burrin, *ETH Zurich*; Philippe Michaud-Jacobs, *Univ. of Warwick*.

American Speakers:

Wen-Ching Winnie Li, *Pennsylvania State Univ.*; Jerome Hoffman, *Louisiana State Univ.*; Pete L. Clark, *Univ. of Georgia*; Ling Long, *Louisiana State Univ.*; John Voight, *Dartmouth College, Hanover*; Ursula Whitcher, *Math. Reviews, AMS*; Sam Schiavone, *MIT (Massachusetts Insti. of Tech.)*; Will Chen, *IAS, Princeton*; Levent Alpoge, *Harvard Univ.*; Andrew Harder, *Lehigh Univ.*; Fang Ting Tu, *Louisiana State Univ, USA*; Michael Allen, *Oregon State Univ.*; Juanita Duque Rosero, *Dartmouth College, Hanover*.

Canadian Speakers:

Noriko Yui, *Queen's Univ. in Kingston*, Ontario; Imin Chen, *Simon Fraser Univ., Canada*; Charles Doran, *Univ. of Alberta, Canada*; Patrick Allen, *McGill Univ., Canada*; Vesselin Dimitrov, *Univ. of Toronto*.

South American:

Hossein Movasati, *IMPA (Instituto de Matematica Pura e Aplicada), Rio de Janeiro*.

Chairs for the talks: (other than speakersand members of OC).

S. G. Dani, *CEBS Mumbai*; Sujatha Ramdorai, *UBC Vancouver*; Dipendra Prasad, *IIT Bombay*; Nitin Nitsure, *TIFR Mumbai*; A J Parmeshwaran, *TIFR Mumbai*; Minhyong Kim, *CAMS Edinburgh*; Ravi Raghunathan, *IIT Bombay*; Anima Nagar, *IIT Delhi*; Mainak Poddar, *IISER Pune*; Shripad Garge, *IIT Bombay*; Anuradha Garge, *Univ of Mumbai*; Ajit Kumar, *ICT Mumbai*; Somnath Jha, *IIT Kanpur*; Akhilesh P, *KSOM Kerala*; Siddhi Pathak, *CMI Chennai*; Swarnendu Dutta, *ISI Kolkata*; Narasimha Kumar, *IIT Hyderabad*; Diganta Borah, *IISER Pune*; Rupam Barman, *IIT Guwahati*; Soumya Sankar, *Ohio State*; Amita Malik, *MPI Bonn*; Manami Ray, *Fordham Univ.*.

Advisory Board: Henri Darmon, *McGill Univ., Montreal*; Ravi Kulkarni, *BP Pune and CUNY, New York*; Sujatha Ramdorai, *Univ. British Columbia, Vancouver*; Dinesh Thakur, *Univ. Rochester, Rochester and BP, Pune*; John Voight, *Dartmouth College, Hanover*.

Organizing Committee: Krishnendu Gongopadhyay, *IISER Mohali, Chandigarh*; S. A. Katre (Convener), *SPPU and BP, Pune*; Supriya Pisolkar, *IISER Pune*; Devendra Tiwari (Coordinator) *BP Pune*.

For First Trimester: Jitendra Bajpayi, *MPI, Bonn* and Chandrasheel Bhagwat, *IISER, Pune*.

The Mathematics Consortium thanks all the above mathematicians and also to the following for their interest and support: Armand Brumer, *Fordham Univ.*; C S Rajan, *TIFR/Ashoka Univ.*; Kirti Joshi, *Arizona Univ.*; Eknath Ghate, *TIFR Mumbai*; Rajesh Gopakumar, *ICTS Bangalore*; HenriCohen, *Univ. Bordeaux*; J K Verma, *IIT Bombay*; Mahan Mj, *TIFR Mumbai*; Kalyan Chakraborty, *KSOM Kerala*; C S Dalawat, *HRI*; Amit Hogadi, *IISER Pune*; Riddhi Shah, *JNU*; Amala Bhave, *JNU*; Hemant Bhate, *SPPU*; Eduard Looijenga, *Utrecht Univ.*.

Special thanks are due to Dr Devendra Tiwari who coordinated the whole programme.

It is proposed to publish Proceedings of the Trimester Programme in 3 parts with Dinesh Thakur, U. Rochester and BP Pune, as Editor-in-Chief, Devendra Tiwari BP Pune as Associate Editor.
For more information, and YouTube Video and slides see:
https://sites.google.com/view/bms2021/home?authuser=0 or www.bprim.org

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7. International Calendar of Mathematics Events

Ramesh Kasilingam
Department of Mathematics, IITM, Chennai;
Email: rameshk@iitm.ac.in

November 2022:

- November 2-4, 2022, Group actions and surgery on manifolds, Clifford Lectures in memory of Slawomir Kwasik, Tulane University, New Orleans.
  sse.tulane.edu/math/clifford-lectures
- November 14-16, 2022, Interactions and Applications of Homotopical Algebra and Geometry, University of Luxembourg.
  https://math.uni.lu/SuperWork/homotopicalconference.html
- November 16-18, 2022, Statistics and Mathematical Modelling in Combination, La Trobe University City Campus, Melbourne, Australia.
  www.mathematics.org.au/sys/public/home.php?conf_id=57
- November 25-27, 2022, International Conference on History of Mathematics, Center for IKS, IIT Madras and ISHM, at Chennai, India.
  https://indianshm.org/index.php/conferences/400-ishm-conf-nov-2022.
- November 28, 2022 - December 2, 2022, Tensor Categories in Sydney, University of Sydney.
  www.maths.usyd.edu.au/u/kevinc/TensorCat.html

December 2022:

- December 2-3, 2022, International Conference on Mathematics and Its Applications (Icma 2022), Faculty of Science and Technology, Fez, Morocco.
  sites.google.com/view/icma2022
- December 5-16, 2022, Program on ERGODIC THEORY AND DYNAMICAL SYSTEMS (HYBRID), ICTS, TIFR, Bengaluru. *https://www.icts.res.in/program/etds2022.*
  The fundamental contributions of S. G. Dani, who turns 75 this year, will be celebrated during the program.
- December 8-10, 2022, 6th International Conference on Recent Advances in Mathematical Sciences and its Applications (RAMSA - 2022), Jaypee Institute of Information Technology, A-10, A - Block, Industrial Area, Sector - 62, Noida, Uttar Pradesh, India - 201309.
  www.jiit.ac.in/jiit/ramsa/
- December 16-18, 2022, International Conference on Cryptology & Network Security with Machine Learning (ICCNSML 2022), Sachendi, India.
  https://www.psit.ac.in/events/ICCNSML
- December 27-30, 2022, The 88th Annual Conf. of the Indian Math. Soc., The Birla Institute of Technology, Mesra-835 215, Ranchi, Jharkhand, India.
  https://88annualimsconf.bitmesra.ac.in/.

January 2023:

- January 22-25, 2023, Symposium on Discrete Algorithms (SODA23), Florence, Italy.
- January 10-12, 2023, International Conference on Graphs, Networks and Combinatorics (ICGNC 2023), Ramanujan College, University of Delhi, Delhi, India.
- January 9-13, 2023, 18th Summer School in Discrete Mathematics, ISCV, Valparaíso, Chile.
- January 20-27, 2023, Winter school on "Singularities and low dimensional topology", part of the semester on Singularities and low dimensional topology, Erdös Center Budapest, Hungary.

□□□

8. A few words about Shrikrishna G. Dani

M. S. Raghunathan
UM-DAE Centre for Excellence in Basic Sciences
Vidyanagari, Santacruz, Mumbai 400098
Email: madabusisr@gmail.com

Shrikrishna Gopalrao Dani is one of India's finest mathematicians. "Homogeneous Dynamics" is an area of mathematics that has over the last 60 years acquired considerable importance in mathematics as a whole. Work in this area has enabled the solution of some longstanding problems in number theory - the Oppenheim Conjecture, to cite one example. Dani is among the pioneers responsible for this development.

Dani's doctoral thesis (inspired by some work of Ya. G. Sinai) was already a highly significant contribution to homogenous Dynamics. The thesis followed by some further work showed that a semi-simple element in a semi-simple Lie group G which generates a non relatively compact subgroup of G acting on G/Γ, Γ an irreducible lattice, is a Bernoulli shift; Dani also determined the entropy of this automorphism. I may add here that Dani embarked on this area of Homogenous Dynamics on his own. The Tata Institute of Fundamental Research where he was a student had no real experts in the area, an indication of his independence. I was his thesis guide, but I learnt some Homogeneous Dynamics from him rather than the other way round. Dani has indeed done me proud as a student.

Later Dani went on to look at the action of unipotent subgroups of G. He proved the first interesting results about horocycle actions on G/Γ. His work led me to make a conjecture about orbits of unipotent groups. I had mentioned this to Dani who put it down as "Raghunathan's Conjecture" and stated a closely related conjecture of his own which in fact was an insight that was to help prove the former.

Dani then moved on to the study of 1-parameter unipotent groups and obtained many beautiful results with very interesting applications to diophantine questions in number theory. Some of this work is in collaboration with G A Margulis.

I will stop with this brief account of Dani's mathematical work. Dani has other results with which I am not adequately familiar.

Starting with early nineteen nineties, Dani got interested in the History of Mathematics. He is today recognized as one of the leading experts in the area, especially Indian Mathematics. I note here that he rendered some public service by writing an article on "Vedic Mathematics" debunking exaggerated claims for it.

Dani has taken considerable interest in the promotion of mathematics in the country. He has been a member of several committees engaged in promoting mathematics. He was a member of the National Board for Higher mathematics from 1996 to 2015 serving as Chairman during 2006-2011. He has also served on Editorial Boards of mathematics and history of mathematics journals.

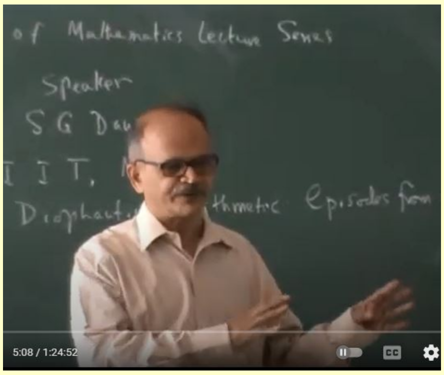
I will end this brief write-up about Dani with a short biographical note.

Dani - incidentally, any one outside his immediate family seems to address him or refer to him as Dani and the first name Shrikrishna is seldom used - was born in Belgaum and grew up going to school there and in another nearby (smaller) town Hukkeri. His father was in the Police Service which meant some transfers. He went to Junior College in Belgaum and moved to Mumbai (then Bombay) for undergraduate studies at the Institute of Science. He majored in Physics (with Mathematics as subsidiary). His decision to pursue science was partly the result of his obtaining National Scince Talent Scholarship and partly in rebellion of sorts against the then clamour for Engineering (his father was keen on his pursuing Engineering).

After graduating with a Physics degree Dani decided to pursue mathematics at the Masters level. This was partly due to the influence of a senior student, Mangesh Rege. He joined the Tata Institute of Fundamental Research (TIFR) in 1969. He met Jyotsna Ghate, a fellow student there and they were married soon after. Jyotsna is a good mathematician. She showed considerable promise as a student and I cannot help speculating that she was keener on helping Dani achieve big things than promoting her own career in mathematics.

□□□

Professor S. G. Dani invited to be an Honorary Fellow of TIFR



The Council of Management of the Tata Institute of Fundamental Research (TIFR) invited Prof. Shrikrishna G. Dani to be an Honorary Fellow of TIFR on May 18, 2022. It is needless to say that Honorary Fellows of TIFR are eminent personalities recognized for their distinguished contributions in science, public life, and their association with TIFR. With this Honor, Prof. Dani joins the list of 17 earlier elite Fellows which includes Professors G. A. Margulis, D. Mumford, C. N. R. Rao, S. R. S. Varadhan, M. S. Raghunathan, Ashok Sen, Mr. Ratan N. Tata etc.

Prof. Dani had a long and fruitful career at the TIFR, Mumbai, from August 1969 until June 2012 when he retired as Distinguished Professor (Served as Dean, Mathematics Faculty, 1994-1997). Subsequently he was affiliated with the Indian Institute of Technology (IIT) Bombay for five years, and since July 2017 has been with the UM-DAE Centre for Excellence in Basic Sciences, Mumbai, and is currently the Chair of the School of Mathematical Sciences of the Centre.

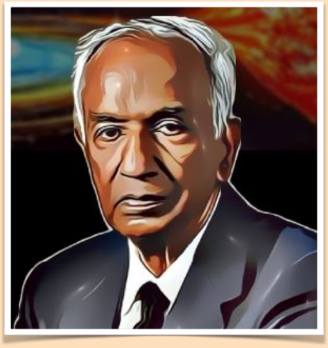
His select international long-term appointments (on deputation from TIFR) include: Institute for Advanced Study, Princeton, USA (1976-77 and 1983-84, as Visiting Member); Yale University, New Haven, Connecticut, USA (1977-78, as Gibbs Instructor); University of Gottingen, Germany (1990-91); Mathematical Sciences Research Institute, Berkeley, USA (1991-92). Over the last two decades he has been a frequent visitor to University of Rennes 1 and University of Aix-Marseille, in France, for research collaboration.

He has made extensive research contributions in many areas of mathematics, including Ergodic theory, Dynamics, Number theory, and Measures on groups, and has also written many articles on history of mathematics in India, of ancient as well as recent times.

The awards received by him include the Mathematical Sciences Prize of TWAS (the World Academy of Sciences), the Shanti Swarup Bhatnagar Prize, and the Srinivasa Ramanujan Medal of the Indian National Science Academy. He is a Fellow of TWAS and all the three national academies of science in India: INSA (Delhi), IASc (Bengaluru) and NASc (Allahabad).

He was a Member of the National Board of Higher Mathematics from 1996 to 2015, and its Chairman during 2006-2011. He was also President of the Commission for Development and Exchange, of the International Mathematical Union, during 2007-10, President of the Indian Mathematical Society during 2014-15, President of the Indian Society for History of Mathematics (ISHM) during 2008-19, and was a member of the Executive Committee of the International Commission for History of Mathematics (ICHM), during 2015-18. He was the first President of the Mathematics Teachers' Association, India, during 2018-21.

He has been on the Editorial Boards of several international journals. He was the Editor of the Proceedings of the Indian Academy of Sciences (Mathematical Sciences) during 1987-2000 and is currently the Editor of *Ganita Bharati*, the Bulletin of the Indian Society for History of Mathematics. He is also one of the editors of the Bulletin of The Mathematics Consortium.



Subrahmanyan Chandrasekhar (19 Oct. 1910 - 21 Aug. 1995)

An American astrophysicist of Indian origin, and mathematician. His mathematical treatment of stellar evolution yielded many theoretical models of massive stars and black holes. Was awarded the 1983 Noble Prize for Physics jointly with William A. Fowler. Introduced the notion of 'dynamic friction', Chandrasekhar limit - The maximum mass limit of a white dwarf.

George Bernard Dantzig (08 Nov. 1914 - 13 May 2005)

An American mathematician, Computer Scientist, and Statistician. Made contribution to industrial engineering, operations research, computer science, economics and Statistics. Known for the simplex algorithm for solving a LPP. Contributed to decomposition theory, sensitivity analysis, large-scale optimization, nonlinear programming, & programming under uncertainty.

George Pólya (13 Dec. 1887 - 07 Sep. 1985)

A Hungarian mathematician, Physicist, and Statistical. Made fundamental contributions to Combinatorics, Number Theory, Numerical Analysis and Probability theory. Known for Pólya-Szegó inequality, Pólya conjecture, Pólya enumeration theorem. Wrote 5 books: How to Solve it, Mathematics, Plausible Reasoning, and 2 books with Szegó on: Problems and Theorems in Analysis.

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43/16 Gunadhar Banglow, Erandawane, Pune 411004, India.
Email: tmathconsort@gmail.com   Website: themathconsortium.in

Contact Persons

Prof. Vijay Pathak   Prof. S. A. Katre
vdpmsu@gmail.com (9426324267)   sakatre@gmail.com (9890001215)

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