The passing away of Professor Narasimhan is a great loss to mathematics, to the country and, of course, to the numerous people close to him. Narasimhan was a towering figure in contemporary mathematics. He is one of a small number of mathematicians who have made profound, beautiful and lasting contributions in several different (mathematical) fields: algebraic geometry, differential geometry, representation theory, analysis and mathematical physics. In this versatility he has no near rivals from our country. He remained active as a mathematician right...

The recent passing away of M.S. Narasimhan, known to friends as MSN, is a great loss to the mathematical world in general and to India in particular. His interests in mathematics were very broad. He was also generous with his ideas, which explains his proclivity to collaborate with many people, some of whom were top mathematicians and others young students.

I met Professor M. S. Narasimhan just a few times spread over a couple of decades. These were chance encounters. I worked at TIFR for around a decade, after I finished my PhD from Caltech and UCLA in 1995, and came back to India with the goal of working there, and establishing myself as a research mathematician.

I first saw him at a banquet at a summer school I attended in Nice (probably around 1992-1993). I must have seen him a few times during the period I worked in TIFR. On these early occasions I never had a chance to speak to him or interact with him in any meaningful way. I knew him by his fame as a leading mathematician, who had developed a famous school in India based at TIFR, but he was a very distant figure to me.

The next time I remember seeing him was when he was in the audience when I once lectured in Bangalore. This must have been around 2008 or 2009, although it could have been a little earlier. The topic of my lecture was Serre's modularity conjecture, which I had just proved (or was about to complete proving) in work with my French colleague...
is unstable because it has the subbundle $\mathcal{O}(p)$ of positive degree. Mumford also defined $E$ to be semistable if it has a proper subbundle $E'$ of degree $0$ but none of positive degree. If every proper subbundle of $E$ has negative degree, then in Mumford's terminology $E$ is stable.

The Narasimhan-Seshadri theorem, as originally formulated in 1964, says that irreducible unitary flat bundles of rank $n$ on a surface $\Sigma$ are in one-to-one correspondence with stable bundles. The easier direction is to show that for a holomorphic bundle $E$ to have a flat unitary structure, it is necessary for it to be stable. This can be proved by generalizing what one would do in the case $\mathcal{O}(p)/\mathcal{O}(p)\mathcal{O}(q)$. (Again, the approach of Narasimhan and Seshadri would have been somewhat different.) The opposite direction is more difficult: stability is sufficient for the existence of a flat unitary structure. I am not the right one to explain the proof of this.

I have stated the Narasimhan-Seshadri result for bundles of degree $0$ but there was a general statement about bundles of rank $n$ and degree $d$, for any $n$ in gauge language theory, for $d$ not $0$. In the case of a bundle with a single point, it is just a Riemann surface $\Sigma$, the central formulation of their (marginal) result is that for a complex manifold $\Sigma$ of dimension $n$ these (formulation was slightly different). The resulting moduli space is smooth and compact if and only if $\Sigma$ and $d$ are relatively prime, i.e., $(\Sigma,d) = 1$. From a modern point of view $\Sigma$ and $d$ are the ring of algebraic curves. For the following interpretation, $\Sigma$ and $d$ are Dirac currents (breedess and zerozero charge, for instance, and the condition $(\Sigma,d) = 1$ means that $\Sigma$ is a Dirac current configuration with $d$ fluxes, a current cannot separate into two subsystems in a supersymmetric fashion. The Narasimhan-Seshadri theory is a direct consequence of $\Sigma$ and $d$ being relatively prime. The result of this result is that the moduli space of stable bundles is compact. However, if $\Sigma$ and $d$ are relatively prime, then the moduli space of stable bundles is not compact. Hence, Seshadri extended the Narasimhan-Seshadri theorem to an equivalence between complex manifolds of dimension $n$ and degree $d$, for any $n$ and $d$ not relatively prime. For instance, in the most basic case, a Riemann surface $\Sigma$ and a divisor $d \in \mathbb{Z}$, $\Sigma$ can be slightly perturbed to make it irreducible (i.e., it can arise as a limit of irreducible flat bundles). Likewise, opening an equivalence of the Narasimhan-Seshadri theorem, the moduli space of stable bundles is not compact. However, Seshadri extended the Narasimhan-Seshadri theorem to an equivalence between complex manifolds of dimension $n$ and degree $d$, for any $n$ and $d$ not relatively prime. For instance, in the most basic case, a Riemann surface $\Sigma$ and a divisor $d \in \mathbb{Z}$, $\Sigma$ can be slightly perturbed to make it irreducible (i.e., it can arise as a limit of irreducible flat bundles). Likewise, opening an equivalence of the Narasimhan-Seshadri theorem, the moduli space of stable bundles is not compact. However, Seshadri extended the Narasimhan-Seshadri theorem to an equivalence between complex manifolds of dimension $n$ and degree $d$, for any $n$ and $d$ not relatively prime. For instance, in the most basic case, a Riemann surface $\Sigma$ and a divisor $d \in \mathbb{Z}$, $\Sigma$ can be slightly perturbed to make it irreducible (i.e., it can arise as a limit of irreducible flat bundles). Likewise, opening an equivalence of the Narasimhan-Seshadri theorem, the moduli space of stable bundles is not compact. However, Seshadri extended the Narasimhan-Seshadri theorem to an equivalence between complex manifolds of dimension $n$ and degree $d$, for any $n$ and $d$ not relatively prime. For instance, in the most basic case, a Riemann surface $\Sigma$ and a divisor $d \in \mathbb{Z}$, $\Sigma$ can be slightly perturbed to make it irreducible (i.e., it can arise as a limit of irreducible flat bundles).

Seshadri went on to extend the Narasimhan-Seshadri theorem in two directions. The moduli space of automorphisms acting as $\mathbb{C}^*$ on the two summands $E_1 \oplus E_2$. (Or another form of the Narasimhan and Seshadri interpretation, the moduli space of stable bundles, we have to treat $E$ and $E'$ as equivalent.) So Seshadri had to develop an equivalence relation, $\mathcal{E} \equiv \mathcal{E}'$, equivalent to the direct sum. He was able to define a compact moduli space of equivalence classes of semistable (or stable) bundles, basically considering any topological trivialization of $\mathcal{E} \oplus \mathcal{E}'$. On this moduli space he introduced a complex structure, it is necessary for it to be stable. This can be proved by generalizing what one would do in the case $\mathcal{O}(p)/\mathcal{O}(p)\mathcal{O}(q)$. (Again, the approach of Narasimhan and Seshadri would have been somewhat different.) The opposite direction is more difficult: stability is sufficient for the existence of a flat unitary structure. I am not the right one to explain the proof of this.

For example, suppose that $E = \mathcal{O}(p) \oplus \mathcal{O}(q)$, where $p$ is a point in $\Sigma$, a Riemann surface where the sections are holomorphic functions that are allowed to have a simple pole at $p$. Then $E_{p,q}$ is $\mathcal{O}(p) \oplus \mathcal{O}(q)$, but it does not admit any unitary flat connection. This can be proved as follows. $\mathcal{O}(p)$ and therefore $\mathcal{O}(p) \oplus \mathcal{O}(q)$ has a holomorphic section that vanishes at $p$ but not at $q$. It is a unitary connection, and $\mathcal{O}(p) \oplus \mathcal{O}(q)$, then by integration by parts, after picking a Kahler metric on $\Sigma$, one can prove $\int \mathcal{O}(p) \mathcal{O}(q) \mathcal{O}(p) \mathcal{O}(q) = 0$, and hence $\mathcal{O}(p) \mathcal{O}(q) = 0$. Therefore, if $\mathcal{O}(p)$ and not identically zero cannot vanish anywhere. This explanation is in the spirit of gauge theory; it is probably not very close to what Narasimhan and Seshadri would have said in 1964.

Mumford had defined the notion of a stable holomorphic vector bundle over a Riemann surface $\Sigma$. A bundle $E$ is semistable if it is in the set $\mathcal{M}$. If $E$ has a holomorphic subbundle $E'$ of positive degree: $E' \subset E$. This is a subtle invariant of a bundle and incorporate an automorphism of $\Sigma$ that | 3

Fig. 1. A Riemann surface of genus 0 with 5 marked points or punctures

This idea was that the moduli space of flat unitary bundles on a surface with a smooth and compact at just one point in $\Sigma$. But if $\Sigma$ is not smooth, this is somewhat different.) The generalization of the Narasimhan-Seshadri theorem, the moduli space of stable bundles, we have to treat $E$ and $E'$ as equivalent. So Seshadri had to develop an equivalence relation, $\mathcal{E} \equiv \mathcal{E}'$, equivalent to the direct sum. He was able to define a compact moduli space of equivalence classes of semistable (or stable) bundles, basically considering any topological trivialization of $\mathcal{E} \oplus \mathcal{E}'$. On this moduli space he introduced a complex structure, it is necessary for it to be stable. This can be proved by generalizing what one would do in the case $\mathcal{O}(p)/\mathcal{O}(p)\mathcal{O}(q)$. (Again, the approach of Narasimhan and Seshadri would have been somewhat different.) The opposite direction is more difficult: stability is sufficient for the existence of a flat unitary structure. I am not the right one to explain the proof of this.

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If we also consider flat unitary bundles on a surface with a smooth and compact at just one point in $\Sigma$. But if $\Sigma$ is not smooth, this is somewhat different.) The generalization of the Narasimhan-Seshadri theorem, the moduli space of stable bundles, we have to treat $E$ and $E'$ as equivalent. So Seshadri had to develop an equivalence relation, $\mathcal{E} \equiv \mathcal{E}'$, equivalent to the direct sum. He was able to define a compact moduli space of equivalence classes of semistable (or stable) bundles, basically considering any topological trivialization of $\mathcal{E} \oplus \mathcal{E}'$. On this moduli space he introduced a complex structure, it is necessary for it to be stable. This can be proved by generalizing what one would do in the case $\mathcal{O}(p)/\mathcal{O}(p)\mathcal{O}(q)$. (Again, the approach of Narasimhan and Seshadri would have been somewhat different.) The opposite direction is more difficult: stability is sufficient for the existence of a flat unitary structure. I am not the right one to explain the proof of this.

Fig. 1 A Riemann surface of genus 0 with 5 marked points or punctures
Jones's original definition involved the Jones representations of the braid group. A braid is a mathematical concept, a picture like the one sketched in Fig. 3. Points move around in the plane, then return to their starting positions. In this example, I have drawn a braid with 4 strands. Braids form a group because they can be composed by gluing one braid on top of another.

Jones's original definition of the Jones polynomial of a knot was as follows: We can build a knot by gluing the top and bottom ends of a braid. This is much like what he was doing in the construction. There are many different ways to construct the same knot as the "trace" of a braid. Why would this construction always give the same result?

What is special about the particular representations \( R \) and the coefficients \( \langle \alpha \rangle \) (Ahay recommended these questions for physicists).

A very important step was taken by Tsuchiya and Kanie. They showed that the Jones representations of the braid group are the ones that arise when one decomposes the correlation functions of the two-dimensional \( WZW \) model in conformal blocks, as originally analyzed by V. Knizhnik and A. Zamolodchikov. The background to this statement is as follows. Consider the correlation functions of a primary field in this theory, so it is:

\[
G(z_1, z_2; z'_1, z'_2) = \langle \phi(z_1) \phi(z_2) \rangle_{\text{corr}} = \langle \phi(z_1) \phi(z_2) \rangle_{\text{corr}} - \langle \phi(z_1) \rangle \langle \phi(z_2) \rangle
\]

These functions are neither holomorphic nor antiholomorphic, and so they can be written in the form of a product of a holomorphic and an antiholomorphic function. But Knizhnik and Zamolodchikov showed that:

\[
G(z_1, z_2; z'_1, z'_2) = \sum_{\mu} a_{\mu} \psi_{\mu}(z_1) \bar{\psi}_{\mu}(z_2)
\]

where the functions \( \psi_{\mu}(z) \) and \( \bar{\psi}_{\mu}(z) \) are multivalued holomorphic functions. For example, a Wess-Zumino vector bundle \( \nu \) over the configuration space \( \mathcal{X} \) of \( n \) distinct points \( x_1, \ldots, x_n \) in \( \mathbb{C}^2 \) with a basis given by the \( f_i \). These are automatically flat vector bundles (with the \( f_i \) understood as covariantly constant sections), and their monodromy when the points move around gives representations of the braid group.

When the points are restricted to the complex plane, the correlation functions of the WZW model imply that these representations are unitary, and the observation of Tsuchiya was essentially that, for symmetry group \( G = SU(N) \) and a primary field of dimension \( n \), there are \( n \) distinct representations of the Jones representations.

The holomorphic functions \( f_i \) are called conformal blocks. E. Verlinde had defined operators that act on the space of conformal blocks, and intuitively it seemed that the action of these operators is unitary. The observation of Tsuchiya was essentially that, for symmetry group \( G = SU(N) \) and a primary field of dimension \( n \), there are \( n \) distinct representations of the Jones representations. These are the Jones representations.

Now the question is this: How can we describe these representations and its action on the space of conformal blocks? One possible approach is to use the so-called Verlinde formula, which says that the Jones representation of order \( n \) and \( j \) is

\[
\mathcal{A}_n^j = \mathcal{A}_{n-1}^{j-1} \otimes \mathbb{C} \oplus \mathcal{A}_{n-1}^{j} \otimes \mathbb{C} \oplus \cdots \oplus \mathcal{A}_{n-1}^j \otimes \mathbb{C} \oplus \mathcal{A}_{n-1}^j \otimes \mathbb{C}
\]

where \( \mathcal{A}_n^j \) is a representation of \( G \). These are the \( R \) representations, and \( \langle \alpha \rangle \) defined as:

\[
\langle \alpha \rangle = \mathcal{A}_n^j \otimes \mathcal{A}_n^j \otimes \cdots \otimes \mathcal{A}_n^j \otimes \mathbb{C} \oplus \mathcal{A}_n^j \otimes \mathcal{A}_n^j \otimes \cdots \otimes \mathcal{A}_n^j \otimes \mathbb{C} \oplus \cdots \otimes \mathcal{A}_n^j \otimes \mathbb{C} \oplus \cdots
\]

because the Narasimhan-Seshadri theorem does not apply to flat bundles with non-compact gauge group. The closest analog is Hitchin's theorem about Higgs bundles. After picking a compact structure on \( \Omega \), we can indeed use that theorem, as was shown by Hitchin, to construct a Kahler polarization of the appropriate phase space. But we do not understand what the role of the Higgs bundle is in this context. We have seen that by translating Narasimhan and Seshadri's theorem into the language of geometric quantization, geometric quantization tells us that we should have defined \( \mathcal{A}_n^j \) as an action of \( \mathcal{A}_n^j \) on \( \mathcal{A}_n^j \).

At this point we get "lucky". The answer \( \mathcal{A}_n (\mathcal{M}) \) coincides with a known and in a sense standard — though rather abstract — description of the space of \( WZW \) model conformal blocks on a genus \( \gamma \) surface (I learned this description from N. Seiberg and I was fortunately here at this description was certainly not well-known among physicists at the time. However, this description is now widely used — in a more general form — in research on the geometric Langlands program). This is the basic idea of the Narasimhan-Seshadri theorem, which is:

\[
\mathcal{A}_n^j = \mathcal{A}_n^j \otimes \mathcal{A}_n^j \otimes \cdots \otimes \mathcal{A}_n^j \otimes \mathbb{C} \oplus \mathcal{A}_n^j \otimes \mathcal{A}_n^j \otimes \cdots \otimes \mathcal{A}_n^j \otimes \mathbb{C} \oplus \cdots \otimes \mathcal{A}_n^j \otimes \mathbb{C} \oplus \cdots
\]

Actually, I explained this in the absence of knots. To incorporate knots, we need to use the later refinement of the Narasimhan-Seshadri theorem by Seshadri to include pathologies. Following a deeper analysis of the Jones representations of the braid group, we pick some points \( p_1, \ldots, p_n \) and place knots, in some representations, \( \mathcal{A}_n^j \), \( \mathcal{A}_n^j \), \( \mathcal{A}_n^j \), \( \mathcal{A}_n^j \).

In conclusion, in this article I have described some of the celebrated contributions of Narasimhan and Seshadri and hopefully I have given at least a few hints of the role that their work has played in theoretical physics.
I had come back to India immediately after my thesis in 1973, and joined TIFR as a Visiting Fellow (the entry level postdoctoral position available at some institutions). TIFR changed my career forever. It was a place where my two greatest mathematical interests in the world map of mathematics. It also made one of my early friends, a young person (like myself) trying to do research in pure mathematics in India in the 1990s.

TIFR had established itself in the world of pure mathematics through important theorems proved by mathematicians working there, through the decades from the 1950's onwards, and of these there was none more celebrated than the Narasimhan-Seshadri theorem. It was in an area of algebraic geometry and differential geometry that was far away from my mathematical interests, and this gave me a sense of freedom to think about problems that were not related to the work I was doing in Bombay in times when the world was far less connected than now.

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Mathematicians usually acquire a deep understanding of the theory and try to solve the problems using their expertise on the subject. Narasimhan was of a different mould. Even if he was initially not competent in the given niche, he had the capacity to come to grips with the essentials of a problem and bring to it original way of thinking and solve it. He would fill in the details of the theory later, often holding a seminar on the subject. It was my good fortune to have collaborated with him for decades and, to a certain extent, to have refined this methodology. Our joint papers were published from time to time, between 1956 and 1969. He was my menton, collaborator, and a close friend.

He joined TIFR as a graduate student in 1953 and was deputed to France in 1957. There he came in contact with Takashi Tada, a student of the Fields medalist, Shizuo Iizuka, and in the summer of 1957, facilitated Narasimhan's visit. Kotake and Narasimhan wrote a very interesting paper on the regularity of solutions of linear elliptic equations before coming back to India. In the summer of 1958, Narasimhan and Seshadri settled this question. In these instances, the results came fast and were published soon. At the same time, the TIFR's School of Mathematics did not put undue pressure on its researchers, to publish, which proved to be an advantage. For instance, in my next collaborative result with MSN, the moduli of vector bunches were defined; the problem was to show that these bunches were vector bundles. After we had proved it, we worked on it for nearly a year to get a full understanding of this result in various ways and this enabled further work both by us and others.

MSN had the knack of choosing interesting problems that were within reach – as he would say 'abordable'. As I mentioned above, his ability to absorb the material needed for the problem had been covered by the Differential Geometry seminar. Narasimhan had an abiding interest in Tamil literature, especially contemporary writing. And in conversations with me and with some Tamil writers and their work. He also had a big influence in shaping my political views. Three of us, Narasimhan, Ramanan and myself, went to a particular restaurant for snacks and coffee in the late afternoon and talk about diverse topics (even as mathematicians we did not leave the discussion of figurine unfortunately). Narasimhan was a leftist persuasion, Ramanan in those days was a kind of a liberal. I was almost identical, but when occasionally we differed, I would try to defend my view to him, which was mostly correct and deeply conducted on all occasions, and in faculty meetings, in particular. He would excuse anyone if they failed on that front. He never raised his voice even while he was firm in giving any views on his subjects. During the period he was Dean of the Mathematics faculty he was meticulous in organizing and conducting Faculty meetings. He paid great attention to the wording of his letters to ensure that he said just the right things, but in the right way. He treated the administrative staff courteously, extracting the best out of them.

Narasimhan, along with Seshadri, was one of the promoters of Mathematics at TIFR into an international centre of excellence in mathematics, from the fledgling state it was when he joined it to the internationally renowned institute it is today. The two were about the same age and had been together at college. They continued to be helpful to each other for some 50 years at TIFR, guiding the School of Mathematics that they remained close friends even after they were physically far apart from each other. It would appear that in death too they were close to each other – Seshadri died less than a year ago.

When in 1983 the DAES formed the National Board for Higher Mathematics (NBHM) as an agency for the promotion of higher mathematics in India, Narasimhan was the natural choice to head it. NBHM under his leadership took many initiatives, which went a long way in fulfilling its mandate. He took me as a member of the Board, and later in 1986 made me ex-officio chairman. It was my good fortune to have collaborated with him for the subsequent ten years. Unfortunately, his abilities did not go to waste even while TIFR derailed itself its leadership. In 1992, he accepted an invitation from Alphonso Maroli to head the Mathematics Section at the International Centre for Theoretical Sciences in India. Under his leadership, mathematics at ITCP reached new heights. His advent ensured that initiatives for the promotion of mathematics in the developing world grew rapidly.

He played a big role in setting up programmes of cooperation in mathematics between India and other countries: France, Spain and Brazil. Some of this happened after he retired from IITC and settled in Bengaluru. In Bengaluru, the Centre for Applicable Mathematics was set up at IISc. The International Centre for Theoretical Sciences benefited immensely by his inspiring presence and advice on many matters.

Narasimhan received numerous awards and honours; I mention a few: Fellowship of the Royal Society; the World Academy of Sciences; prize for Mathematics, the King Faisal Prize for Mathematics and the Padma Bhushan of the Government of India.

Despite his stature and achievements, he always remained accessible, especially to anyone who wanted to discuss mathematics with him. He was always good company and had interesting things to say on a wide variety of subjects. As a liberal, he was in recent years much distressed at our country's failure to hold mathematics. However, his magnetic personality, and perhaps shield him from greater despondency. The way he kept abreast of most recent developments in mathematics, was truly amazing.

I have dwelt at some length on my personal interactions with Narasimhan in the expectation that it will throw some light on aspects of his personality. The internet has ample information on his public persona, in particular about his great achievements as a mathematician.

His passing away is a major personal loss – he was a close friend and mentor.

M S. Raghunathan was a student of S. R. Narasimhan and retired as Professor from the School of Mathematics at Tata Institute of Fundamental Research. Currently he is Adjunct Professor of Mathematics at Chennai Mathematical Institute.
Those who saw in my father a rather patrician aloofness may be surprised to learn of his humble beginnings in a tiny village in Tamil Nadu, where there was not even a school. He, therefore, had to drive a bullock cart every day to the school in the nearby town. An early childhood spent sharing the traditional shaped head andتان (head) (of the South Indian brahman, and wearing diamond studs in his ears. However, after his father passed away when my father was twelve, years of financial hardship followed. Chilappaa (his father's pet name for my father – it means 'cherished one') found his way home much later with a bag of books circulating library had just opened there. He spent the time he was sent to the town with money to return home – to find, occasionally, that the bullock would have been unmoored, and run all the way back home.

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Recently, after he passed away, a group of people were trying to find a single word to capture the essence of my father's personality. My friend Rajpal Gehabur chose 'gentleman'. George Thompson chose 'remarkable'. After some thought, I chose 'mathematician'. For there were too many other aspects to his personality, his overwhelming love and passion for mathematics defined him, and mathematics brought him great joy. My abiding memory of my father is of him lying in bed, one leg crossed over the other, his nose buried in a yellow Springer Verlag volume, or scribbling equations on a notepad. One little-known idiosyncrasy of his was that he believed that mathematics could be solved with black bic ballpoint pens. Though he was proud of his Mont Blanc fountain pen, he succumbed from bic anxiety: the fear that he would run out of bic pens, as a result of which his mathematical creativity would dry up. I would therefore return from trips to Europe with dozens of these cheap ballpoint pens in my luggage. I now find that his desk drawers are filled with packs of bic pens, the sight of which seems particularly poignant and evocative to me, and brings tears to my eyes. When he was focusing on mathematics, the rest of the world receded: once, when he was about seven, my mother came to me with a funny look on his face, and said, “I just went and told Appa that I thought I had broken my brush, he was working and didn’t reply.” \"Don’t worry, Mohan, I’ll buy you another one!\"

I was born prematurely and was very tiny, and my father used to call me epikalos (because, of course, e – O). One of my earliest memories of my father is related to mathematics. I must have been about four years old, I was in his office at TIFR, and, standing on a chair, was writing numbers on his blackboard. He wrote, "0, 1, 2, 3," and then turned and asked him, "Apna, what number comes before zero? He got tremendously excited by this question, explained to me about negative numbers, and kept boasting about my precocity to everyone. \"I know it,\" he told me; my father, many years later, \"that she would one day become a mathematician. \"There was then a small pause, before he continued, a little sadly, \"Or, maybe... a physicist.\"

I did indeed go on to become a physicist, and my father tried very hard to understand what I was working on, reading through the introductory solid state physics books by Kittel (which he didn't like because of its lack of rigour) and Ashcroft and Mermin (which he approved of). Once, when he was in hospital with six broken ribs, he was in great pain, and to distract him, I asked for help with some mathematics, I was stuck on. I tried to explain to him the problem - I was attempting to solve, and failed completely! We seemed to speak totally different languages. I would say something like, \"The atoms sit on a trigonal lattice,\" to which he would respond, \"That sentence makes no sense!\" Both of us found this very frustrating, but that night, as he lay in bed sleepless with pain, he suddenly grasped the question I was working on, and the next morning I had a nearly written solution waiting for me! However, he refused to be a co-author on the paper, explaining that he had a policy of only accepting authorship on a paper if he understood every word of it, and that he couldn't understand most of what I had written!

Indeed, his grasp of physics (as of many practical things) had astonishing lucacure. After he complained that he could not finish a bottle of wine in one sitting, I bought him a vacuum wine saver. He assumed that he knew how to use it, and was very happy with it. It was only several years later that he actually used it in front of me. He employed it correctly to pump out the air from the bottle, but then removed it, left the bottle open to the air, and then reinstered the cork. My jaw dropped, I heard, \"What are you DOING?\" Annoyed, he replied, \"I pumped out the air!\" I asked, \"Then you left the bottle open! What then was the point in pumping out the air beforehand? Have you found that \"nature abhors a vacuum?\" I was visiting me in Cambridge UK, and as we were chatting, he exclaimed that he had always been fascinated by the Rosetta Stone, both because of its interest in Ancient Egypt and because the mathematician Andre Weil invoked it when drawing analogies between number theory, function fields and Riemann surfaces. I was visiting me in Cambridge UK, and as we were chatting, he exclaimed that he had always been fascinated by the Rosetta Stone, both because of its interest in Ancient Egypt and because the mathematician Andre Weil invoked it when drawing analogies between number theory, function fields and Riemann surfaces.
T. R. RAMADAS

Narasimhan always insisted – he differed from the viewpoint of von Neumann – that mathematics has its rich internal logic, and that capable people find natural questions with good taste and a feel for structure, its landscape could be illuminated without recourse to physical intuition.

Among his many outstanding qualities was a remarkably disciplined curiosity. This was reflected in the breadth and depth of his work, which ranged over the analysis of differential and integral operators, representation theory, geometry, mathematical physics, and large parts of algebraic geometry. His scholarship in Mathematics was vast and penetrating. His mathematical rigor, his facility never worked on number theory per se (and confessed to a lack of intuition for analytic number theory) he was fascinated by the interplay between representation theory, and arithmetic. After the appearance of Wiles’ proof, he invested significant effort understanding Langlands program, and of many us benefitted by his aphoristic summaries.

Coming of age mathematically at TIFR, at a time when the influence of Dirac (via Badhwa and Weyl) [via K. Chandrasekharan] was certainly present, it was natural (I imagine) that Narasimhan engaged with the mathematics of physics. This had an impact on his mathematics, though analysis and geometry remained his major preoccupations.

Let me list somewhat carefully the points of contact between my work and Narasimhan’s. Many of these were not at all equally consequential, of course. But their very number points to his wide-ranging intellectual engagement, and of course, friendship!

1) Given a partial differential equation invariant under a group (of "symmetries"), one gets for free an action on its space of solutions. If the equation is invariant in space, the space of solution is a vector space and one gets a representation. The discovery by Dirac of his equation, and consequences for physics and mathematics, is well-known. Harish-Chandra’s interest in representation theory was kindled by the ensuing interest in "invariant wave equations".

It was Narasimhan’s fantastic idea, flawlessly executed by his students, Harish-Chandra, that a version of the Dirac equation formulated on an appropriate homogeneous space, would give a "realization" of certain discrete series representations, a cornerstone of Harish-Chandra’s theory.

2) Narasimhan had an abiding interest in the masterful synthesis (due to Hörmander and others) of PDEs and geometric structures, and he was very aware of the uses of symmetric space, wave-front sets, the Hamilton-Jacobi equation, Maslov indices, etc. By then he had met him in 1972-73; I think that he also understood the ideas of geometric quantisation, and was aware of their limited success.

3) Among Narasimhan’s close friends was PP. Divakaran, with whom he carried on a dialogue that spanned decades, a dialogue that covered mathematics, physics, politics, culture, and much else. Narasimhan’s interest in physics has been described – in the TIFR memorial speech – as a "correct" analytical setting for the Dirac equation, and the geometric realization of the field of a magnetic monopole. In this connection I had many very useful discussions with Narasimhan. It was a pleasure to discuss with him, and he always seemed to be very interested in my work. I was constantly wanting to connect with my mathematician colleagues at TIFR and once they asked me to give a mini course in Quantum Mechanics... I do not think I was very successful. Narasimhan later told me that the physicist must be correct. Seeing my stunned expression, he laughed and said that the physicists had a different intuition, many times they knew the physicist must be correct. They would release me from proof writing, and they would be very keenly interested in what I was doing and what were the recent interesting results in string theory. Many times he wanted to know the details and would ask me to come to his office and explain it on the blackboard. And there were many times he would give some suggestions, or some ideas that helped me to solve some of the problems those days.

I remember one occasion very vividly. During one of the conversations, he cut up there was some result that a mathematician and a theoretical physicist had independently obtained that contradicted each other. His own inclination was that the mathematical result was correct. "Surely Narasimhan said, the physicist must be correct. Seeing my stunned expression, he laughed and said that the physicists had a different intuition, many times they knew what it is now.

During the years he was at ICTP in Trieste I always made it a point to meet him during my yearly visits and enjoy his hospitality during many dinners with good Italian wine. The focus of our discussions was about how to do better in Indian science.

In August 2007 after the ICTS was formally approved I invited him to be on the International Advisory Board which he served from March 2013. During the 5 years we spent at ICTS in the "core institute" an ICTS was then called, I greatly benefitted from his advice. More than his words I felt supported by his presence. He was always there and was always very positive about ICTS and its trajectory. After he moved to the campus in Shivalkote he visited us on several occasions.

His last visit to ICTS was in February of 2009 during the program on "Moduli of Bundles and Related Structures" and the inaugural `Madhava Lectures' by P. P. Divakaran. At that time, ICTS organized a discussion session on the early days of mathematics at TIFR in which Narasimhan, Seshadri, Raghunathan, Divakaran and Celine Simpson participated along with some of us from ICTS. It was an amazing session of historical value that is reproduced in an issue of ICTS Notes. Here Narasimhan spoke at length about the early years that established the school of mathematics at TIFR and the mathematical excellence that was achieved there.

In his passing away in India and the world at large have lost a great mathematician and an inspiring mentor and builder of mathematical institutions.

I have lost a friend and someone whom I looked up to.

Spenta R. Wadia is Founding Director, Emeritus Distinguished Professor and Infosys Homi Bhabha Chair Professor at ICTS-TIFR, Bengaluru.

Spenta R. Wadia

NARASIMHAN AND ICTS

Spenta R. Wadia

KUMAR S. NARAIN

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Mathematics was always played in its role in the growth of a cultural identity, a treasure trove of information about the essence of a uniquely Indian tradition. Its cultural context, it is essential to remember that language does not play a role except in the making of a uniquely Indian tradition. Its cultural context, it is essential to remember that language does not play a role except in the making of an identity of cultural distinction. The history of the mathematical infinity of India is a fascinating one, ironical, it never even got a proper capital, the value of cultural distinction and the attainment of a distinct identity.
The Indus to Dilmunia: the first great southern migration

When the highly evolved urban phase of the Indus civilization collapsed around 1900–1800 BC, what happened to the people who built all those magnificent cities? No one believes any longer that they were massacred by invading Aryans. The archaeological evidence is that the peak of the Indus culture was a result of climatic/ecological disruptions, was followed closely by the appearance of a small-town population of petty settlements, devoid of any of the signatures of the high urban culture. A reasonable hypothesis is that part of the population stayed around in the vicinity of their homes, to be absorbed gradually in the culture of the Vedic Sanskrit speakers who succeeded them, while others, more in the role of body and mind, moved away leaving only the resources that had sustained them in their prosperity. Civilisations do not die totally and abruptly leaving only inanimate ruins behind; they either get overtaken by new arrivals or move off in search of greener pastures.

Unlike the Vedic Aryas, the Indus people had written language but we only know that they loved mathematics, probably more than we do, not however, that they knew how to express it. What was that language and is it possible to find fossilised bits of it in later Indian languages, preferably in those which are still alive today? We need to establish a direct line connecting us to our remotest ancestors which we will also have in hand in the openings of a systematic approach to an eventual decipherment of the Indus script itself.

Almost all of the dozens of attempts that have been made to read the Indus script have failed but one, more than the others at first sight, refuses to die. Its central thesis is that the Indus language was the original Dravidian tongue, the ancestor of Old Tamil. As far as I know, the hypothesis was first advanced by Father Henry St. Xavier’s College in Bombay – when its only supporter was a factor a language currently spoken in a part of Baluchistan, Bral, has close Dravidian roots – and taken up by several other scholars, not always with the necessary rigour. There is, however, one person who has brought exciting new credibility to the conjecture and that is Iravatham Mahadevan, in a series of identifications of a sample of Indus signs and even short phrases with expressions in Dravidian languages. The reasoning is intrinsic, too intricate for me to try and explain, but persuasively logical.

For a language, even one with a rudimentary writing form of writing like that of the Dravidians, there must have been a empire in the migration of its speakers and they must have left other, material traces of their displacement. The last few decades have seen several discoveries in Tamil Nadu and Kenia of inscriptions on rock and pottery of groups of characters having an affinity with Indus signs. Each of the inscriptions appear to be written from right to left (like the Indus writing which is one of the few things we know about it). But merely looking at signs may be less than absolutely convincing; together, they merge into a cohesive picture of what can happen to cultural identities when people in the sea or in deserts, shift places, unknown, to uncertain destinations along uncharted roads. Mahadevan has several examples of Indus-Draavidian equivalents but the icing on the cake has to be his extension of linguistic concordances to include Vedic Sanskrit as well. The reasoning is again subtle and opaque, but the result is that, even when experts refuse to accept that the Vedic grid has been properly interpreted, such a scenario remains plausible. The image below (courtesy: Arvind Paranjape) shows a typical Indus sign (left to right) and Vedic word (right to left). The Vedic word is taken to mean “to go on” or “to go forth.” The Indus sign may stand for the verb “to go on” or “to begin.”

R. gveda

Āryabhat

Fig. 1 & 2: The Dravidian roots of the Vedic?

Aryabhata and the great eastern migration

This is in fact one of the greatest mathematicians of all time. yogurt. He knew from his own calculations, the average solar day, that was known to the Vedic Aryans, the fact that the sun is not exactly a power of 1, 2, 3, 4, 5, 6, or 10, more exactly 365 1/4 days, but not less (as to the Vedic 10 though there are also some weights in decimal order). The consensus view is that it was 8: 2: 1: 1: 1 in 4: 5: 6: 7: 8: 9: 10: 10. The image below (courtesy: Arvind Paranjape) is of a sculptural portrait of him as imagined at the 5th century was out, some of them had names like Buddhagupta and Tathagatagupta. The scale and opulence of the monuments (as well as the distances the artists travelled) is extraordinary high quality, from Mathura in the north, to Sarnath and farther east, to Ajanta and Kanheri and several places south of the Vindhyas. The iconographic and stylistic unity we see in Gandharan and in late Gupta and early post-Gupta art from virtually every region on the periphery of the empire is, given the distances involved, nothing short of startling. I restrict myself here to one theme out of many of the bountiful standing Buddha in abroad or saru county.

Fig. 4 is a particularly lovely example from late (4th-5th C.) Gandhara. Fig. 5–7, equally if not more graceful, are less in the neighbourhood of Gandhara in the north-west, and in late Gupta and early post-Gupta art from the north, with the longest side about 28cm (allowing for erosion, etc.). Some months back I was at Pattanam, the recently excavated site near Kochi of a port trading with Mediterranean and west Asian empire (possibly the failed Muziris). Among the mariners we find vases of all kinds, fired bricks (of indigenous fabrication) of the same dimensions. And, embossed on a polished or clay, a little eye-looking whose first appearance is also in the Indus civilisation.

From the diversity of the ratio, it is a reasonable guess that the Indus people counted using a standardized (a number system), because of the need to count (6 to 28). There are too many possible variants of 1, 2, 3, 4, 5, 6, in the world that today is less than 10, than as it was an afterthought (and, intriguingly, in Sanskrit, the number is 2 and 9 in current usage, respectively).

There are, however, questions about chronology which are as yet unanswered. The archaeological evidence from Tamil Nadu-Kerala (Dilmunca to the Mediterranean people) is not older than about the 3rd C. BC and that includes the site of Kharadi near Madur, very recently unearthed and very Harappan in its use of fired bricks and cardinally aligned walls. Perhaps future work will help fill in the gap in time. (Note added: the continuing excavations at Kharadi have now unearthed artefacts datable to ca 600 BC.) Or perhaps, more interestingly, the traveller took their time over the long journey, groups of them putting down roots along places at the way. Let us only note that there is first millennium BC archaeological sites with a strong Indus Valley signature on the natural routes from Sind-Gujarat to Dilmunica, for example Daimabad, east of Pune.

I have spent some time over the theologies of the Indus-Dravidian connection because there are compelling narratives about what the Indus Civilisation could have been, though they are, in terms of evidence, nowhere near as persuasive as the others at first sight, refuses to die. The episodes of my title are thus not new (as I guess some readers may think), but may be less than absolutely convincing; together, they merge into a cohesive picture of what can happen to cultural identities when people in the sea or in deserts, shift places, unknown, to uncertain destinations along uncharted roads. Mahadevan has several examples of Indus-Draavidian equivalents but the icing on the cake has to be his extension of linguistic concordances to include Vedic Sanskrit as well. The reasoning is again subtle and opaque, but the result is that, even when experts refuse to accept that the Vedic grid has been properly interpreted, such a scenario remains plausible. The image below (courtesy: Arvind Paranjape) shows a typical Indus sign (left to right) and Vedic word (right to left). The Vedic word is taken to mean “to go on” or “to go forth.” The Indus sign may stand for the verb “to go on” or “to begin.”

Aryabhata was the greatest mathematician and astronomer that India produced; he was in fact one of the greatest mathematicians of all time. Anyway, one knew from his own calculated value of the mathematical constant π, that was 3.14159 and was correct to five decimal places. Then, he added the knowledge of the ancient Sumerians who used the number 3 1/7 (3.11429) for calculations with the right answer, that is, the diameter of the circle. In this way, he established the formula for the circle circumference (2πr), the area (πr²), and the volume (4/3πr³) of a sphere. The first approximation of the mathematical constant pi (π) was 22/7. In the 5th century, it was known to the Chinese and Indians that the value of pi was between 3.14 and 3.15. This was a significant advancement in mathematics and science. However, the exact value of pi was not known until the 18th century, when mathematicians used infinite series to calculate it to a high degree of precision.

The problem is that, from a very early time (Parini oranges), there have been references to two Aryabhatta, one more in the neighbourhood of Gandhara, the other in the river Narava and Godavari in northern Maharashtra. The quest for Aryabhata’s roots quickly turns into a

There are very many other representations in these (and many Mahayana sites which have close affiliations to Gandhara, especially popular in Ajanta and Kanheri in the Buddhist in his transcontinental Amritabha form, the supreme lord of the cosmos in its infinite multiplicity, accomplished by Buddhagupta also defined. Let us all again that the region of Gandhara was where the final apotheosis of the Buddha occurred.

The only sensible explanation I know of for this sudden spurt of explicitly Gandharvan Mahayana arts when it was not even established, one of the sites of the Buddhist influence, Kanheri, Ajanta! For instance, the Mahayana sites which have close affiliations to Gandhara, especially popular in Ajanta and Kanheri in the Buddhist in his transcontinental Amritabha form, the supreme lord of the cosmos in its infinite multiplicity, accomplished by Buddhagupta also defined. Let us all again that the region of Gandhara was where the final apotheosis of the Buddha occurred.

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Towards the last quarter of the 5th century monastic establishments ceased to be jewelled on the axis of the world, the four conventional yugas, the Brahmin title bhat. t. a. It is in these chaotic times that Aryabhata the compassionate Bodhisattva for having led the wanderer safely across perilous lands to a new haven. The sedentary monks of Gandhara would have had no use for this particular wanderer, he is the travelling Bodhisattva.

It is in these chaotic times that Aryabhata the mathematician or astronomer (whom von Gehlen) are two temples in a complex of nine, from the time of Ashoka, more north–south than the westward, and one of the first rector was Vasabandhu, a celebrated spiritual philosopher from Kanheri. In the midst of all the turmoil, the great migration thus also initiated a renewal: north India's intellectual and aesthetic life shifted its centre of gravity decisively across its borders, to thrive afresh over six or seven centuries until that came to an end at the hands of Muhammad Ghor.

The Samkritisamhit of Kerala: Madhava

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