IN SEARCH OF ENGINEERING MATHEMATICS

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1. INTRODUCTION

This is the moment for reminiscences. The problem is that I have been here so long that it would take me the whole evening to go back all the way down the memory lane. I am forced, therefore, to be selective, very selective in my story.

Let me start at the beginning. In high school I was fascinated by the book, “Brighter than a Thousand Suns”, written by Robert Jungk. I found it incredible that P.A.M. Dirac predicted the existence of positron by mathematical calculations alone in 1929, and Carl D. Anderson could only discover it by experiment in 1932. From then on my dream was to do research in particle physics. The obvious way to achieve that goal was to start with bachelors study in physics. I decided to take the unusual route of studying applied mathematics first, before specializing in particle physics later. My inspiration then was Professor Satyendra Nath Bose, who also studied applied mathematics first, before switching over to mathematical physics. That was, of course, many years before my time. It is heartening to see his biography appearing in many major international newspapers recently after the announcement of the possible discovery of the Higgs Boson at CERN. Boson, after all, was named after Professor Bose. Incidentally, it took almost fifty years after the prediction of Higgs Boson before it was possibly discovered this July.
I did my bachelors study at Presidency College in Calcutta, which was established in 1817. It was an elite college in the classic English tradition until it was made a full-fledged university recently. Presidency College was one of the two best undergraduate colleges in the whole country, the other one being St Stephens College in Delhi. Professor Bose was, not surprisingly, also a student of Presidency College. My fondest memory of the college, of course, is meeting my life partner who was a student of Statistics there. During my master’s study, at the University of Calcutta, I specialized, as expected, in quantum mechanics. My master’s thesis there was (what else!) on symmetry principles in particle physics. During my study however, one professor encouraged me to do my Ph.D. in the fast developing field of control theory. Another warned me that a career in particle physics follows the zero-one law: one either gets a Nobel Prize or remains unemployed for the rest of his life. Anyway, Arundhati and I got married in the spring of 1969 and we headed for Los Angeles few months later where I joined the Engineering School and Arundhati, a bit later, the Mathematics Department at UCLA.
I could never excuse myself for betraying my adolescent dream. I tried to get some consolation from the fact that I switched from one area of application of mathematics to another: from mathematical physics to engineering mathematics. But what exactly is engineering mathematics? I am in search of that ever since.
2. ILLUSTRATION THROUGH RESEARCH

Right when I started research on my Ph.D. thesis under the supervision of Professor A.V. Balakrishnan after completing my masters in control engineering, the Jet Propulsion Laboratory (JPL) of NASA unexpectedly offered me an unsolicited job. JPL made headline news recently when Curiosity landed on the surface of Mars. At JPL I worked in the orbit determination group and was involved in estimating on-line initial conditions of spacecraft after launch based on observations of the flight path. This is, of course, a smoothing problem whose solution was given few years back by Meditch [12] as a natural extension of the Kalman filter [3].

![Flight radar system](source: Meditch [12]).

The actual implementation of the smoothing algorithm was a different matter though. The late Jerry Bierman in my group at JPL came up right around that time with the seminal idea of square root filtering [7] and we worked on the implementation and error analysis of his scheme for our problem. Square root filtering solves the vexing problem of non-positivity of the error covariance matrix during the updating process. It is based on the Householder transformation used extensively in the numerical linear algebra. This was my first personal experience with what I would characterize as engineering mathematics.

My Ph.D. research project was supported by a grant from NASA, Edwards Air Force Base near Los Angeles. They were studying smooth flights of aircraft (with Tristar engines) under severe wind gust. The project had two parts. The first one concerned estimating parameters of the model of the aircraft in flight. The second one involved
controlling the aircraft for smooth maneuvers under wind gust. The second problem involved somewhat routine application of the LQG theory to the desired problem. The estimation part was trickier as NASA wanted us to investigate it in the original continuous-time formulation. The reason was that the discretized model was giving weird parameter values with real flight data. This was the topic of my research. The American aerospace giant Lockheed already decided to use Tristar engines for their planned L1011 model of aircraft. When my fellow Ph.D. students learnt that I was remotely connected with research on aircraft flights with Tristar engines, they vowed not to fly L1011 ever. I must admit that I thought about their apprehension whenever I flew L1011 later. Interestingly, Lockheed became the major story in the Netherlands as soon as we came here.

![Figure 4: A schematic diagram of an aircraft in flight.](image)

The equations of motion looked formidable:

\[
\begin{align*}
\dot{\alpha} &= Z_\alpha \alpha + \dot{\theta} + Z_\delta \delta + Z_{\alpha w_g} \frac{w_g}{\bar{v}} \\
\dot{\theta} &= M_\alpha \alpha + M_\theta \dot{\theta} + M_\delta \delta + M_{\alpha w_g} \frac{w_g}{\bar{v}} \\
N_z &= \frac{\bar{v}}{g} (\dot{\theta} - \dot{\alpha})
\end{align*}
\]

Here \(w_g\) represents the random vertical wind gust velocity, which is assumed to be stationary. Fitting the power spectrum with experimental data, we can write the equations with a five-dimensional state space as:

\[
dX_t = AX_t dt + b \delta_{\text{e.c.t}} dt + f dW_t.
\]

There are four observation variables: the angle of attack, the pitch altitude, the pitch rate and the normal acceleration. The observation vector may be written as:

\[
dY_t = CX_t dt + (4 \bar{v} Z_4) \dot{\nu} dt + G dW_t^\theta.
\]
The discussion that follows is a bit technical. I hope that the audience will bear in mind that we cannot talk about engineering mathematics by only talking about engineering. There has to be some mathematics somewhere. Basically we wanted to estimate parameters of a linear dynamical system where the state evolves as a stochastic differential equation and is only partially observed with an additive noise term. The obvious approach in statistics for parameter estimation is the method of maximum likelihood. This means writing the density of the observation process up to the present time. But the observation data in our problem was a function. We needed, therefore, to write the density (Radon-Nikodym derivative) of the measure generated by the observation process \( p_Y \) with respect to some reference measure. In discrete-time case, as in statistics, the reference measure is the Lebesgue measure. What is the reference measure in function space? The obvious one is, of course, the Wiener measure. But then what is the problem?

Let us now look at our model. If \( G \) is known, one can write the density of \( p_Y \) with respect to \( p_{GW_0} \), so that \( p_{GW_0} \) acts as the reference measure. But suppose that \( G \) is unknown. Then there is no reference measure with respect to which we may write the density of \( p_Y \). This is a consequence of the famous Feldman-Hajek duality of Gaussian measures [14]. How to estimate model parameters when \( G \) is unknown was the subject matter of my thesis. It was a very real engineering problem with an intractable mathematical difficulty. There was no obvious starting point. After months and months of pure agony, I suddenly thought of tweaking the likelihood functional for the case of known \( G \) to come up with some estimation procedure. The question was whether this estimation procedure was any good? One way to check this was to prove consistency of the proposed estimator. But there was no result for proving consistency of parameter estimators for continuous data. I first tried to extend the standard technique used in statistics due to Wald [13] to our case. This turned out to be too difficult for me. I then looked at the weaker result on consistency, originally due to Cramer [9], which had already been extended to the continuous case. Luckily for me, I could prove that my tweaked likelihood functional, indeed, was weakly consistent. Thus my trick somehow worked. It provided a solution to the real engineering problem at hand. But the problem kept bothering me. The real challenge was to prove strong consistency a-la Wald and that eluded me all those years. Finally, Vivek Borkar and I could give a proof of strong consistency for continuous-time models [8], and we could even extend our results to distributed parameter systems as well [4]. This, to me, is a good illustration of engineering mathematics.

In late seventies I got involved in a problem on predicting the salt concentration of the river de Waal at Gorinchem based on the measurements of conductivity (directly related to salt concentration) at Lobith where the river Rhine (de Waal) enters the Netherlands. It was a serious problem at that time because of large discharge of saline water in the Kali mines in France. Of course, it is the French again! The problem became even more urgent with the infamous incident of illegal discharge of pollutants
in Basel by Sandoz, a giant chemical concern at that time. Gorinchem has a big reservoir of water drawn from de Waal to supply drinking water to a large population. A good prediction would alert the authorities on the right moment to stop the river water from entering the reservoir. I even went to Lobith to see how the measurements of conductivity were conducted on the river there.

![Image of measurement station at Lobith](image)

**Figure 5: The measurement station at Lobith**

The model used for this purpose was a simple diffusion-transport one, thus a simple parabolic partial differential equation. The problem arose because there were no natural boundary conditions for the problem. The measurements at Lobith were, of course, noisy and it was not clear how one would handle partial differential equations with noisy boundary conditions. Standard modeling of measurement uses additive white noise affecting the signal. The paths of white noise are derivatives of Wiener process paths; in fact, they are generalized functions and there was no theory to study parabolic equations with such wild boundary conditions. We decided to forget the mathematical complications and just discretized our model, thereby transforming the boundary conditions into inputs to the states. Now we had the usual discrete-time stochastic dynamical system of which we knew everything! So we calculated likelihood and estimated the diffusion and transport coefficients [5]. The prediction results are shown
As usual, the problem kept bothering me. I wondered whether we could study the original problem with boundary conditions disturbed by white noise. Ten years later I took a new look at the problem with Shin-Ichi Aihara. We argued that the real boundary conditions are admissible; the only problem was that they were unknown. We, therefore, converted the whole problem into an optimal control problem for distributed parameter systems. With this formulation we could use the theory developed by Lions [11] to solve our problem. The only difficulty was that the necessary conditions of optimality led to such complicated partial differential equations that we had no idea what to do with them in practice [1].

In a way we solved the problem but the whole thing kept nagging us. Finally in 2010 we came up with an entirely new idea. We solved the problem by studying a transformed state for which we could prove the existence and uniqueness of solution. Once this was established, we could convert back to the original state [2]. As a matter of fact, we are presenting this result in the forthcoming CDC conference in Maui, Hawaii. It took me literally thirty years to have finally a crack at the problem. This gave me a real taste of engineering mathematics.
Coming back to the likelihood functional again, there is a problem between modeling and real data processing. The likelihood functional involves Itô integrals with respect to the observation process $Y$. But any real data is a band-limited version of $Y$, due to limitations of all measuring instruments. The question is: how close is the likelihood functional evaluated with real data to the ideal one? In fact, they differ a lot and we need to adjust this difference by introducing an Itô correction term. But this needs to be calculated on a case-by-case basis and is highly unsatisfactory.

![Figure 7: Real Observation data; $dY_t = s_t \, dt + dW_t$ and $y_t = s_t + n_t$ (band limited versions)](image)

There is a more fundamental reason behind this difference. All formulas on stochastic system theory based on the Wiener process model hold almost surely, as they must from the basic axioms of probability theory. Since Wiener paths are almost surely nowhere differentiable, this means that the formulas do not hold for paths that are differentiable at least somewhere. Now it is not possible for the integrated version of the band-limited observation (real data) to be nowhere differentiable. If you see any observation in practice, you know what I mean. Thus paths corresponding to real data belong to a set of measure zero and have no relevance for the theoretical formulas. One way to circumvent this difficulty is to force the sample paths of the observation process to be $L_2$ functions to correspond to real data. But then white noise (or its integrated version) cannot be formulated in a probability space with a countably additive probability measure. One could still develop an acceptable theory using a
finitely additive probability space instead. Balakrishnan [6] developed this theory and the amazing feature was that all correction terms in nonlinear filtering and likelihood functional appeared naturally in this formulation. Losing countable additivity is no small matter, however. Martingales, the most powerful tool of probability theory, cannot be used anymore. Ravi Mazumdar, Shin-Ichi Aihara and I worked for years on many facets of this problem, but were unable to get rid of this fundamental drawback. Our most satisfying result was to derive the MAP estimator for nonlinear filtering. But it remained an isolated theory outside the mainstream and we finally abandoned our research with heavy hearts.

My longest scientific association was with Henk Blom and his co-workers at the NLR. It started with his research that led to his Ph.D. in 1990. Henk’s thesis got wide acclaim among data fusion experts all over the world. It was also the first attempt to formulate a hybrid stochastic dynamical system in continuous time, by which he meant a system with jumps in the state and the parameters occurring simultaneously. It was a bold effort, but had some technical complications. After Henk submitted his thesis a committee member came to me with pages and pages of questions regarding his formulation and mathematical statements. I felt like an arbiter between a pure mathematician and an electrical engineer. When the professor finally agreed to my explanations, I felt vindicated in my undefined profession of engineering mathematics. For many years thereafter, Henk and I had close contact through master thesis projects of a steady stream of our students in his group at NLR, a good number of whom were hired by NLR after their graduation. Our cooperation became intense again at the start of this century when we worked in the same working group on “Accident Risk Assessment” of a large EU project with the acronym HYBRIDGE, followed by a more implementation oriented project with the fancy name iFLY. Our efforts were concentrated on calculating extremely small collision probabilities of aircraft in flight using Monte Carlo simulation. We had to go back to Henk’s thesis and get deeper into the existence question of the model of a truly stochastic hybrid dynamical system. Henk, Mrinal Ghosh (Indian Institute of Science), Jaroslav Krystul and I worked on various aspects of this problem. Regarding Monte Carlo simulation, we wanted to explore a method that could only be applied to processes that are strongly Markov. It took us years to finally come up with a flawless proof that our stochastic hybrid model is indeed strongly Markov. Our most comprehensive paper will finally appear hopefully before the end of this year [10]. The implementation of the Monte Carlo method is, of course, far more interesting in practice.

Last, but not the least, is the recent and continuing collaboration we have with Thales. The initiative came from my former student Yvo Boers and his colleague Hans Driessen, an electrical engineer from Delft. It started with master thesis projects a decade ago and we have not looked back ever since. Cooperation started in earnest when Thales fully financed a Ph.D. project, with no strings attached, for in-depth studies on some issues arising out of their research on particle filtering. Particle filtering, also known as
“sequential Monte Carlo technique” is a relatively recent method to filter signals from noise in highly nonlinear models. Soon after the start of this project, NWO awarded Yvo a Casimir grant that enabled him for 4 years to spend 12 hours per week to do fundamental research with us on particle filtering. This was an ideal industry-university collaboration. It led to many publications, and to joint participation in a large EU Marie Curie project, called MCIMPULSE. With Xsens being a partner in the project as well, the region of Twente has a disproportionate share in the whole endeavor. Currently we are working together on many facets of tracking and detection with multiple targets, sensor management and various speeding up techniques in data fusion.

Figure 8: Situation where assignment of labels to tracks is ambiguous.
3. THE DUTCH EXPERIENCE

Now what exactly is engineering mathematics? A thoughtful scientist friend of mine once characterized applied mathematics as “theorems in search of applications”. In my mind engineering mathematics is “engineering problems in search of theorems for their solutions”. Now applied physics ceased to be a separate discipline in the United States long ago. Applied mathematics kept its precarious existence until the space war. When Sputnik was launched in 1957, there was panic in the United States and huge funding went to the universities to catch up. Engineering faculties there welcomed mathematicians willing to work in their fields with open arms. Quite sophisticated mathematicians joined faculties of electrical, mechanical, aerospace and industrial engineering departments. The ensuing research activities by these mathematicians and some of their traditional engineering colleagues best fit my definition of engineering mathematics. When I came to the Netherlands, I realized that no such interaction between mathematicians and engineers occurred here on a large scale. On the other hand, research in these borderline areas started here as well, but mostly in the applied mathematics departments of the THs (technological universities). Thus from an electrical engineer I became an applied mathematician again. This gave me a perfect opportunity to develop further my ideas on engineering mathematics by actively participating in the educational programs of my leerstoel (chair) and my department.

During my tenure as dean, we started a masters program for foreign students. The legal status of our action was debatable. Getting financing for the students was a distant dream. There was huge resistance from the faculty council. The prime movers, Brenny van Groesen and I, worked hard to make it a reality despite all odds. Now was my chance and we christened our masters program “engineering mathematics”. It was gratifying to watch many of our ideas incorporated later in the masters programs of applied mathematics in all three of our technological universities. Within few years of our effort foreign students have become a permanent fixture of Dutch universities. The reason behind this sudden openness, as is usual here, was purely commercial. With declining university enrollment and the tendency of Dutch students to increasingly prefer “softer” studies, this was essential for economic viability of our universities.

When I first came to the THT (University of Twente at present), I had no idea about the functions of different scientific personnel in the Dutch university system. I heard the German words Lehrstuhl and Herr Professor more as jokes about the archaic university structure in Germany. I had no interest to learn about the structure in the Netherlands. I was planning to move back to North America after one year, and was only interested in writing papers. But there was another visitor like me in the department, on leave from the Bell Laboratories, who wanted to stay here for personal reasons. He took great pains to understand the system and explained it to me to stress the point that it was just as archaic as in Germany. At the same time, some of my leftist Dutch colleagues tried to impress on me about the recent “democratization” of the Dutch universities.
I was horrified to imagine the situation before “democratization”. I had a taste of the system the first week I came to work here. During the usual morning coffee break, I asked at the canteen for tea. The lady there told that I could not get tea in the morning because Professor Kwakernaak was on vacation. I was dumbfounded when someone explained that Kwakernaak was the only leerstoelhouder (chair professor) who took tea in the morning, and the policy of the canteen was to prepare tea in the morning only when he was present in the campus.

Still my leftist Dutch colleagues remained ecstatic about the “democratization” and were very proud that this phenomenon even made it to the Anglo-Saxon media. From their explanation I understood that the critical point was the designation of the university council as co-administrator of the university. The council had the right to approve the budget and its consent was mandatory in a host of key issues. This gave the university council veto power in important decisions and the scientific staff an opportunity to make a political career. Real change at the level of leerstoel was, however, minimal. The career path of a scientific staff remained as uncertain as ever. After I decided to stay here, my friends in the United States often asked me how on earth I could work in this hierarchical system in the Continent. My answer was always the same: Huibert Kwakernaak. Huib was never a rebel. He followed all official procedures meticulously. But I was convinced that he never believed in the archaic university system prevalent here. Gradually I started negotiating for the leerstoel (chair) in all organs based on my own judgment, without even consulting him first. I tried, of course, to keep him informed about all developments, but the freedom and trust he bestowed on me helped me immensely to keep my career frustration in check until I finally had leerstoel of my own.

My fascination with politics kept me intrigued about “democratization” of Dutch universities. I wanted to get direct experience of this democratization process without spoiling my research. So I ran and won a seat in the faculty council. This was perfect. It was far less time consuming than in the university council and helped in developing better understanding with my departmental colleagues. The issues were of direct interest to me and the discussions were fruitful. The “democratization” at that level was real and indirectly broke the leerstoel barrier. Then in 1987 I got my own leerstoel. Now I did not have to bother about research anymore. This was the time to taste real “democratization” and I ran as lijsttrekker (leading the list) in the university council election for a left leaning party, called KPS at that time. Of course, professors are supposed to be lijstduwers (pushing the list) and my decision must have puzzled many well-meaning people in the campus. My crazy decision also generated curiosity and goodwill among the scientific staff and I received huge number of votes in the election. Unfortunately, university council membership was far less exciting than I thought. In the preparatory meeting two weeks prior to the monthly council meeting, we were given ready-made proposals with no real possibility of bringing meaningful changes. The strategy of the administration was to make very minor changes to cater to our egos.
without giving any ground on the fundamentals. Deadlines made it even more difficult
to get into serious discussions. I decided not to run for the council again. I really
admire those who continue their valiant efforts in the university council despite these
frustrations. Ironically, when the party of my leftist colleagues came to power after
many years, their education minister did away with “democratization” by dramatically
curtailing powers of the university council.

The history of our university is inextricably connected with the history of the availability
of coffee. When I first joined the THT in 1974, we were served coffee punctually
between 09:00 and 09:15, and then again between 14:00 and 14:15, every working
day by coffee girls who came with freshly prepared coffee in wheeled trays. This
was the late stage of the wirtschaftswunder in Europe. In those laidback days of
Joop den Uyl, this was the only way to ensure punctuality of the staff. Of course,
we had ritualistic coffee breaks in the canteen from 10:00 to 10:30, and then again
between 15:00 and 15:30, as well. Canteens had only round tables then, with one
table occupied exclusively by one leerstoelhouder and his staff during coffee breaks.
The Dutch coalition government finally fell, what else, over hypotheekaftrek (mortgage
deduction). In came more business friendly government of Dries van Agt. A committee
was formed to suggest cost cutting measures for universities by abolishing even some
departments, if necessary. Our administration got alarmed that, may be, our whole
university would be abolished. We are suffering from this angst ever since. In panic,
the authorities abolished coffee girls making rounds throughout the buildings with their
wheeled trays. We had to go to the canteen, as soon as we came to the university,
as well as when we returned there after lunch at home, to get our coffee. Coffee girls
became mysteriously canteen ladies. Without the relaxing effect of coffee being served
in our rooms, we had no option but to work a bit harder. Then came the no-nonsense
government of Ruud Lubbers. It was decided to judge our research every five years.
Coffee started being served through machines, where canteen ladies poured freshly
prepared coffees. Without any diversion of coffee girls or canteen ladies, our research
output increased to satisfy the demand from The Hague. Then Soviet Union collapsed
and it was the triumph of unfettered capitalism. The “new labor” had to be invented
by professional socialists to ever get back to power. The strategy paid off and Wim
Kok became our Prime Minister. The new idea of onderzoekschool (research school)
was born. There was a scramble for everyone to get into at least one, and for safely
possibly many, research schools. Volumes of repetitive proposals were written and the
work pressure became so high that very little time was left for going to the canteen for
the daily requirements of coffee. Research groups started preparing their own coffees,
with each member tipping in for the costs. It was supposed to be illegal, but pressure
of work made everyone look the other way. It was also the period of professional
managers taking over the helms of public institutions, like universities and hospitals.
Wim Kok, after all, graduated from Nijenrode. One enduring difference I noticed
whenever I visited a company for my work was the free availability of coffee from
automatic machines there. This must have helped in the productivity of the employees.
Sure enough, within few years of the introduction of the new management philosophy, free automatic coffee machines were placed all over our campus. During the last decade, I totally lost interest in Dutch politics, for obvious reasons. I do not complain though, as I got my free coffee.

![Image of The Statesman newspaper](image)

*Figure 9: My article “The Path Less Beaten” as it appeared in The Statesman.*

What next? In the Dutch weather fishing is not an attractive proposition for an Indian. Being unable to transform myself into “new labor” I could not free myself from the prejudice of associating golf with social status. So, after thinking long and hard, I have decided to try my luck in writing opinion page articles in a major Indian English language newspaper, The Statesman. It was founded in 1875 and is one of the oldest newspapers in the country. One of my themes is the relevance of the ideas of Wilhelm von Humboldt in Indian education today. It was indeed painful for me to watch my own university steadily abandoning von Humboldt’s ideas during the last decade. Now that teaching and research have been completely decoupled here, I realized that time was ripe for my retirement. I have to still continue working part time this academic year to help my final year master students to graduate. I also have three Ph.D. students under my supervision. Thereafter, I can concentrate on my new adventure of writing opinion page perspectives on Indian education and related topics.
4. WORD OF THANKS

Now I have reached the end of my speech. It is time to give word of thanks. My long and varied activities at the university would not have been possible without the help of numerous people, too many to be mentioned individually. This does not diminish my indebtedness to each and every one of them. Special mention must be made of my colleagues in our system theory group. The composition of the group changed over the course of years, but the camaraderie remained always the same.

I have pleasant memories of interaction with my colleagues in the “Dutch Network on Systems and Control”, later subsumed in the onderzoekschool DISC. I should also mention my colleagues of the department of applied mathematics. During my long association with the departmental administration, first via faculty council, then as dean and finally as department chairman, I always got unstinted support from my colleagues. My fondest memory is of the small group I worked closely with during my deanship. I am also grateful for my reception in the Finance and Accounting department where I had a joint appointment for many years. I appreciate my association with the College van Bestuur (Governing Board), fellow members of the university council, fellow deans, fellow MT (Management Team) members of EWI (Faculty of Electrical Engineering, Mathematics and Computer Science) and many others. There is one person I have to mention here by name. He is my former student and colleague, Michel Vellekoop. It is a great privilege for any university to have Michel in its faculty. I am most fortunate to have known him closely.

I am deeply grateful to my colleagues in industry who supervised many of my students during their master’s thesis projects. My special thanks are for those who gave me research contracts in various phases of my academic career. In particular, I would like to thank Ralph van Put and Nico van Hijligenberg who supported me from the very beginning in realizing my dream of setting-up a Master in Financial Engineering program in the Netherlands.

Finally it is time for some personal words. My parents and father-in-law are no more. It was beyond my wildest dream that my mother-in-law, a remarkable lady who just turned ninety, would be able to attend my lecture today. My daughter Alyssa kept me young all these years. Through her I learnt everything about ABBA and Madonna, about Tom Cruise and Nicole Kidman, about the latest pop chart until she left for California after her Atheneum. Later I learnt from her about acting schools Lee Strasberg and The Stellar Adler, investment banks Goldman Sachs and Morgan Stanley, about the Yuppies and post feminism and what it takes to be a true New Yorker. I am grateful to my son-in-law, Alvaro, for his willingness to always help me understand the intricacies of the bond market, and to my grandchildren, Carolina and Alvarito, for letting me realize a hitherto unknown source of enjoyment.
Now I come back to my fixed point after selective sojourn down my memory lane. Arundhati has been my sole support from the day I left India. It is needless to mention her unconditional encouragement in all my efforts. I only want to show my gratitude to this building:

![Figure 12: The Baker Hall of Presidency College.](image)

It is on the second floor of this building where I first met Arundhati during our common physics lectures. It is on the third floor of this building, in the numerical analysis laboratory of her statistics department, where she agreed to share her destiny with me for her whole life.

To paraphrase Gabriel Garcia Marquez, whose voice is permanently silenced by cruel fate, I would like to stop by saying: This is the tale I wanted to tell today.

Thank you all for your patience.
ACKNOWLEDGEMENT

I am grateful to my dear friend Shin-Ichi Aihara for his indispensable help in preparing this booklet and the accompany presentation.
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