CEE

chemical engineering education

VOLUME 45 • NUMBER 1 • WINTER 2011

Chemical Engineering Division, American Society for Engineering Education

American Institute of Chemical Engineers

Doraiswami (Ramki) Ramkrishna

of Purdue

Feature Articles . . .

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The University of Arizona

ChE educator

Purdue's

Doraiswami (Ramki) Ramkrishna

A Population of One

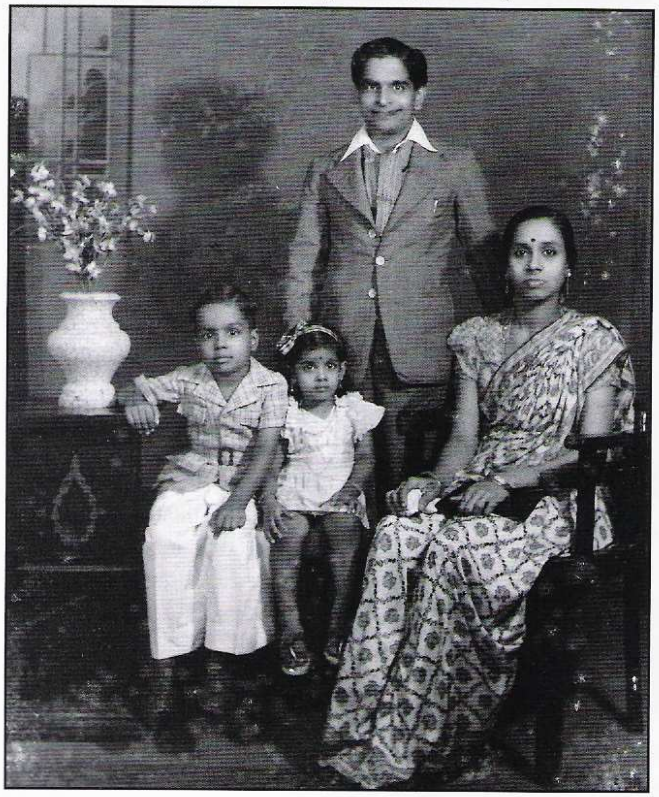
PHIL WANKAT AND ARVIND VARMA
Purdue University

In the sports world if you say Michael or Tiger everyone knows who you mean. In the world of chemical engineering if you say Ramki everyone knows you mean Doraiswami Ramkrishna. Ramki has earned this name recognition by introducing elegant and powerful mathematical techniques, particularly population balances, into chemical engineering. Yet, if you try to apply population balances to Ramki himself, you will fail because Ramki is unique.

Ramki in his office.

EARLY DAYS

Ramki was born in Trichur, India, but grew up in Bombay (now Mumbai) where he had all his elementary and high schooling. During his early school days, his mother was his tutor. She would make sure that he was totally prepared for his exams. One time in fourth grade he returned home after an exam with some of his answer sheets he had neglected to turn in under some blank papers on the clipboard. His mother (now 88) rushed to the school and successfully convinced the teacher of the innocence of what happened! His father, who recently passed away at the age of 100, was a relentless cheerleader throughout his life.



Left, Ramki at age 6 with his parents and sister Leela.

Ramki benefited from excellent (particularly in mathematics) junior college (Ramnarain Ruia) teachers. He graduated from the Department of Chemical Technology at Bombay University in 1960. He dearly recalls Dr. D.K. Sen from Bombay University, who not only taught mathematics but also taught students to love it. If Ramki is a typical example, Dr. Sen was indeed a magician! Young Manmohan Sharma, also from Bombay University, was no less inspiring and set new highs in commitment to teaching. While Ramki can recall some deficiencies in the curriculum, there were many outstanding attributes to the undergraduate program at Bombay University. In addition to mathematics, the organic chemistry and surface and colloid chemistry courses as well as the Unit Operations laboratory were outstanding examples.

Ramki left for the University of Minnesota in September 1960. His admission there occurred through the recommendation of his uncle, Venki, who was a post-doc in the chemistry department at Minnesota.

MINNESOTA DAYS

How many Ph.D.s regard their graduate education as a euphoric stretch of inspiration that they would love to live over again? Ramki regards *his* Minnesota days this way! He had as his contemporaries some of the most distinguished colleagues in the chemical engineering profession today: Roger Schmitz, George Gavalas, Morton Denn, Dan Luss, Harmon Ray, Lee Raymond, and Ken Valentas, to name just a few, and he vividly recalls the exciting and lively competition that prevailed. As if the excitement that came from ChE Professors Neal Amundson, Rutherford Aris, Skip Scriven, Arnie Fredrickson, Bill Ranz, and John Dahler were not enough, the mathematics department at Minnesota was his second home with Professors Hans Weinberger, Walt Littman, George Sell, Willard Miller, and James Serrin adding substantially to the quality of students' lives. Ramki fondly remembers the several seminar series of unusual kinds (thanks to Rutherford Aris), and the special group seminar series on "Fun in Hilbert Space," which Ted Davis, Ramki, and Theofanis Theofanous put together.

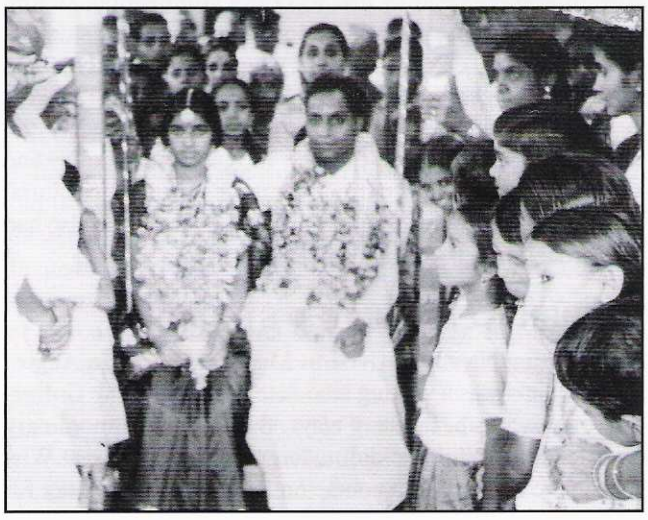
Ramki at graduation with a Ph.D. degree from the University of Minnesota in 1965 with his advisors Arnie Fredrickson (right) and Henry Tsuchiya (left).

Graduate research with Arnie Fredrickson and Henry Tsuchiya was an adventure. Ramki reports "We were friends and spent enormous time discussing a field that we were shaping in new ways." Neal Amundson offered Ramki an instructorship—a position offered only to a privileged few among graduate students—which postponed his plans to return to India and teach. Since Ramki was concerned that his parents would become upset, Henry Tsuchiya wrote a personal letter to Ramki's father to make him understand the opportunity it meant to his son. Becoming an instructor and a part of the undergraduate teaching team was academic training at its best. He savored the faculty lunch discussions at the Campus Club with more appetite than the food. On one occasion, Ramki fondly recalls, Amundson said at the Campus Club, "You know I have been eating at the Campus Club since 1939!" when Ramki responded by saying, "Gee that was about when I was born!" he provoked Neal's snappy reaction, "So who asked you, you idiot!" Subsequently, Ramki served on the faculty at Minnesota as a temporary assistant professor, again at Amundson's request.

Other than choosing parents with good genes, the most important decision a person makes is marrying the right spouse. Ramki made excellent decisions in both cases. In September 1966, Ramki and Geetha were married. It was an unusual "arranged" marriage in that he virtually engineered it himself. She was known to him from childhood, and since marrying has been his constant companion even during his professional involvements, vigorously entertaining professional colleagues with home-cooked food and attending conferences with him around the globe.

IIT-KANPUR DAYS

Ramki and Geetha returned to India in 1967, where Ramki resumed his academic career as an assistant professor at IIT-Kanpur. This was an extraordinary institution, distinctly apart from others in India because of the academic freedom



Right, the traditional Indian-style wedding of Ramki and Geetha on a swing with garlands in 1966.

it offered young faculty. Consequently, even by international standards, it had probably some of the finest faculty that one could imagine. Ramki recalls his early academic mentors such as his friend and colleague C.V. Seshadri and his department head, M. Gopala Rao, who put together an outstanding chemical engineering faculty. Teaching was held in the highest esteem and recitation lectures were held to the same quality and standards as those at Minnesota. Ramki did some of his early work on linear operators, population balances, and stochastic differential equations at this institute. Colleagues K.S. Gandhi, Arvind Kudchadker, C.N.R. Rao, V.K. Stokes, and Kamalesh Sirkar added substantially to the stimulation. He sentimentally recalls his distinguished friend and colleague Professor Jay Borwanker who taught him stochastic processes privately and collaborated with him on chemical engineering research. Together they published some fundamental papers on the implications of stochastic processes to chemical engineering.

Towards the end of 1973, however, Ramki became unhappy at IIT-Kanpur because of complex political changes that resulted in an extraordinary degree of polarization among the faculty. Many faculty colleagues left and Ramki sought a two-year leave to return to the United States. While at IIT-Kanpur, he had been involved with teaching many distinguished undergraduate students (to mention only a few: Rakesh Agrawal, Santosh Gupta, Rakesh Jain, Anil Kumar, and Amar Shah).

Ramkrishna's very first doctoral student at IIT-K, N.J. Rao, was from electrical engineering and was jointly advised by a colleague from EE and another from mathematics. This research resulted in the development of the first algorithm for solving nonlinear stochastic differential equations and investigated the behavior of chemical reactors subjected to random environmental effects. The work resulted in publications in *SIAM Journal on Control* and in *Chemical Engineering Science*. Dr. Rao subsequently joined the faculty of the Indian Institute of Science in Bangalore, where he eventually rose to become head of the School of Automation. Before leaving IIT-Kanpur, Ramki had guided four other students to their doctoral degrees, three of whom subsequently joined academia. Of these, Rakesh Bajpai, is a Distinguished Professor at Louisiana at Lafayette; P.N. Singh retired as the dean of an Engineering College in Karnataka, India; and Ganesan Narsimhan is currently a professor of Agricultural and Biological Engineering at Purdue University. He also had numerous Master's degree students.

RETURN TO THE UNITED STATES

Ramki and Geetha arrived in Madison, Wisc., in August 1974. Ramki was a visiting associate professor at the University of Wisconsin. In many ways, this was an extraordinary year for him. While he did undergraduate teaching at Wisconsin, he also taught a course on linear operator theory for only two faculty members and two students! The course led to some collaborative research with Ed Lightfoot, and many interesting discussions with Warren Stewart. Ramki recalls with great fondness his friendship with Ed Crosby, with whom his co-teaching was a truly rewarding experience. Crosby's special effort to integrate transport analysis with real life examples has few parallels in the published literature. Another memory that he carries from Wisconsin was the summer lab in which he participated most enthusiastically. Students were given crash projects to design experiments and produce results in a short time!

Ramki returned to Minnesota as a visiting professor in the fall of 1975. At Minnesota, he had the pleasure of teaching the second course of Neal Amundson's triple sequence. He taught linear operator theory to a class that was to produce some truly outstanding academics. With Manfred Morari as his teaching assistant, the class comprised Brian Higgins, Doug Lauffenburger, Gregory and Miretta Stephanopoulos, Ishi Talmon, Kyriakos Zygourakis, and many others.

PURDUE UNIVERSITY DAYS

In the middle of the 1970s, Lowell Koppel as ChE Head embarked on a vigorous and impressive process of building a strong new faculty at Purdue. One key element was hiring senior academics and in August 1976, Ramki joined Purdue University as professor. For Ramki, it was a fresh academic beginning and, unbeknownst to him, the new start of his career at a permanent home.

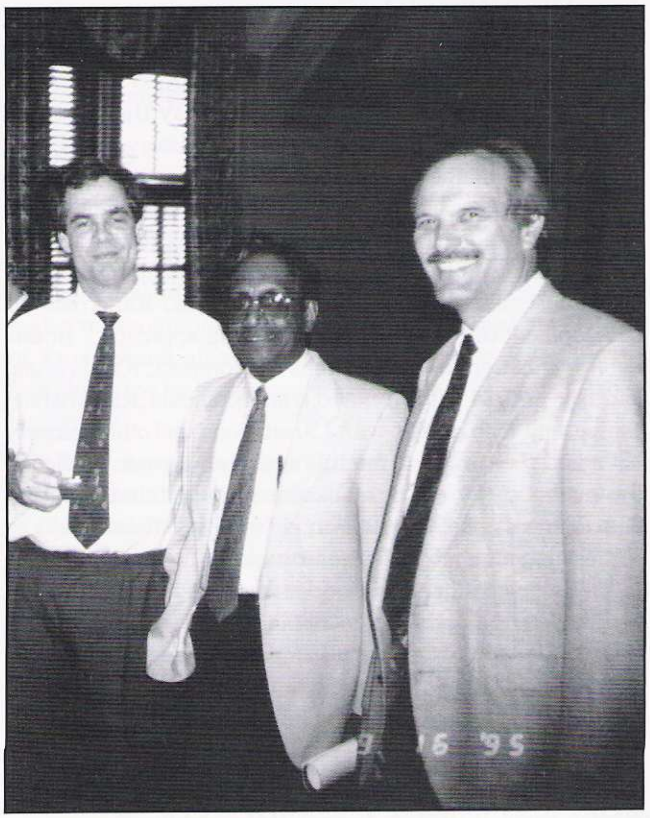
Although he started with an undergraduate transport course, he soon became almost exclusively involved with graduate teaching at Purdue. In addition to linear operator theory, he taught Transport Phenomena I and II, Chemical Reaction Engineering, and a course on Probabilistic Methods in Chemical Engineering. While developing extensive notes teaching

Ramki pictured with his colleagues Henry Lim and George Tsao in 1987 at a departmental celebration of their awards. Ramki won the Alpha Chi Sigma, Henry the Food Pharmaceutical and Bioengineering Award, and George the Marvin Johnson Award.

linear operators at IIT-Kanpur, Ramki had discussed the topic with Neal Amundson during one of his short visits to Minnesota. They published numerous papers on application of linear operators to solve problems in transport and chemical reaction engineering that became very popular. The stability of a permanent home at Purdue, Amundson's continued encouragement to Ramki, and the continued opportunity to teach graduate students led to their book, *Linear Operator Methods in Chemical Engineering,* published by Prentice Hall in 1985.

Ramki attributes his long and continuing association with Purdue to the quality of many of his colleagues. With Jim Caruthers, Nicholas Peppas, and Nick Delgass his early days were especially exciting. The opportunity to collaborate with George Tsao, hired by Purdue at about the same time, helped Ramki to return to research in the biological area on which he had gotten his Ph.D. at Minnesota. With an outstanding group of students, he developed the cybernetic approach to modeling biological systems. Another exceptional group worked in the area of applied mathematics and chemical reaction engineering.

Ramki's influence on the junior faculty at Purdue has been profound in both research and teaching. Jim Caruthers and Nicholas Peppas in the seventies, Frank Doyle in the nineties, and John Morgan (since 2000) are outstanding examples of his mentees. When he was an assistant professor, Caruthers



Jim Caruthers, Ramki, and Nick Delgass, in 1995.

religiously attended courses taught by Ramki. Ramki was the official mentor of Frank Doyle and John Morgan. He has had publications with all of the foregoing mentees. In teaching, he was involved in shaping undergraduate courses in transport phenomena. As an example, the then newly instituted heat and mass transfer course was team taught by Ramki and Linda Wang, with the first seven weeks handled by Ramki to set the course contents.

Over the years, many of Ramkrishna's students have sought their future in academia. This influence has been not only at Purdue but on an international scale through research collaborations in India, Belgium, Germany, and China. Ramki's first Ph.D. student at Purdue, E. Terry Papoutsakis, is currently a Distinguished Professor of Chemical Engineering at the University of Delaware, while the second, Kendree Sampson, went to Eastman Kodak for five years before joining Ohio University where he is currently associate dean. Three others in the early eighties joined academia: Prasad Dhurjati to the U. Delaware, Dhinakar Kompala to the U. Colorado-Boulder, and Satish Parulekar to Illinois Institute of Technology. In the nineties Pedro Arce, now head at Tennessee Technological University, and A. Narang, now Associate Professor, I.I.T. Delhi, became professors. This trend continues in the current decade: Jeff Varner (Associate Professor at Cornell), Tanmay Lele (Assistant Professor at U. Florida), and Jamey Young (Assistant Professor at Vanderbilt).

The preference that Professor Ramkrishna's students have shown for academia comes more from merely interacting with him than through explicit persuasion. It also does not imply that those that went to work in industry did not succeed. Shiv Baloo's performance at Amoco was so spectacular that he was specially chosen to negotiate with EPA in behalf of Amoco (this was reported not by the former student but by an Amoco officer who asked for more graduates like Shiv). Atul Narang who also went to Amoco performed very well there until his eventual decision to enter academia. Harold Wright rose quickly through the ranks at Conoco to be a senior manager. Ted Pirog has similarly performed outstandingly at ExxonMobil. Ramachandran Muralidhar turned down an academic offer from the Indian Institute of Science to join ExxonMobil to work with Fred Krambeck who reported back to Ramki that "Murali was a genius."

In the hope that India would grant a dual citizenship (which did not occur), Ramki waited until 1994 to become a U.S. citizen. This led to an unusual situation when Gary Tatterson invited him to present a talk at Savannah River Company unaware that Ramki was not a U.S. citizen. When he arrived at the company, the strict security requirements forbid him from entering the facility so that his audience had to be summoned to a cafeteria outside the facility to listen to the talk! Ramki's desire to be involved in India found expression in his association with the Indian Institute of Science - Bangalore, which he visited for 15 consecutive years (1982-1997) and

collaborated with Professors K.S. Gandhi and R. Kumar. During this period he participated actively in the doctoral dissertations of P. Das, S. Manjunath, S.K. Gupta, and R. Bandyopadhyaya, among which two are currently active in academia. Since then, Ramkrishna has had a continuing collaboration with Professors Joshi and Yadav of the Institute of Chemical Technology - Mumbai (his own alma mater, now renamed, and the top-ranked ChE program in India), with trips often funded by NSF International Programs. This interaction enabled his vigorous participation in the doctoral theses of students Amol Kulkarni, Manish Bhole, P.R. Sowbna, and Chinmay Rane. From Belgium, he had Ingmar Nopens and Jo Maartens as visiting scholars to interact with his research group. From Germany, C. Borchert, A. Franz, and Ansgar Bohmann visited Ramkrishna's group for several months. In the United States, interactions with Professor Wei-Shou Hu's research group at the University of Minnesota have led to Hu's students Sarika Mehra and Anushree Chatterjee visiting Purdue. Two of Ramki's long-term postdoctoral students, Sanjeev Kumar Gupta and Jayanta Chakraborty, now teach at IISc Bangalore and IIT Kharagpur, respectively. All of the foregoing interactions have led to several publications in the chemical engineering literature.

RESEARCH

Professor Ramkrishna has a long and distinguished record of original and outstanding contributions through publications, conference presentations, and books, which have had enormous impact on many areas of chemical engineering. His contributions have been mainly on the development of novel mathematical frameworks to solve basic chemical engineering problems displaying deterministic and stochastic behaviors. The novelty is displayed in the use of analysis to (i) establish fresh formulations yielding efficient solutions, (ii) establish new experimental protocols for verification and extraction of phenomenology, and (iii) found an entirely new framework for the modeling of biological systems. He is widely regarded as a world leader in the application of mathematics to chemical engineering. Ramki fondly recalls research collaboration with Neal Amundson and his long association with Rutherford Aris, his idol in mathematics and a major source of inspiration. More recently his contributions have focused on new developments in population balance modeling of particulate systems, cybernetic modeling of biological systems, and, most recently, on modeling of chemotherapy with special emphasis on acute lymphoblastic leukemia. His book *Population Balances. Theory and Applications to Particulate Systems* (Academic Press, 2000) has had worldwide acclaim with 394 citations, and continues to amass more.

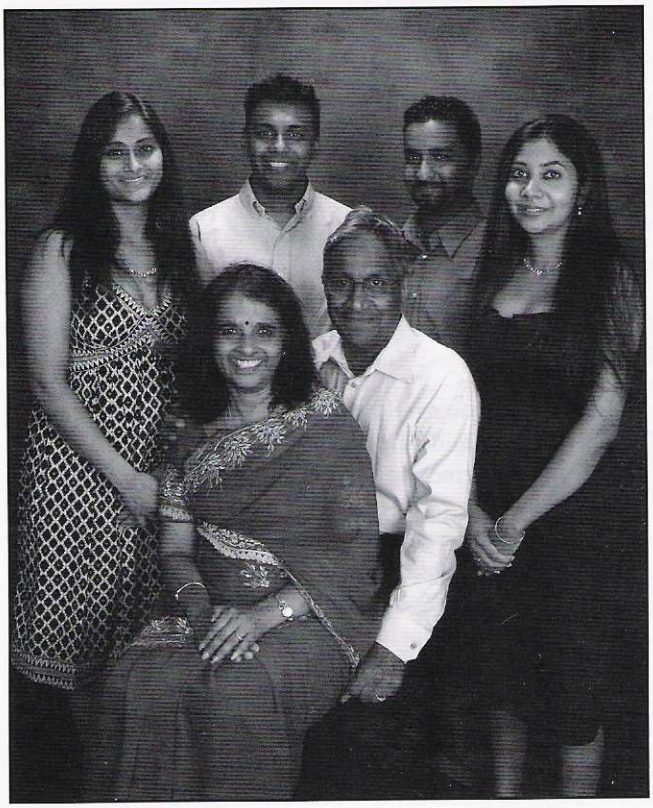
In 2003 the *AIChE Journal* invited Professors Ramkrishna and Amundson to write a review of *Mathematics in Chemical Engineering* over the last 50 years. This article, published in 2004, was subsequently listed as one of the most downloaded articles of the journal for that year.

Ramki at his 60th birthday celebration in 1999 with felicitator Rutherford Aris.

In 2009, a special issue of *Chemical Engineering Science* was dedicated to Professor Ramkrishna for his leadership in the area of population balances. The guest editors wrote ". . . we would like to take the opportunity to dedicate this issue to Professor Doraiswami Ramkrishna. Eight years after the publication of his milestone book, he has reached another milestone as he celebrated his 70th birthday in 2008. His efforts during the last four decades, be it almost half a century, have been crucial for the development of the Population Balance Model framework and have greatly influenced the current state of knowledge."

The development of the so-called cybernetic framework by Ramki and his research group is regarded as a major contribution to biochemical engineering. Jay Bailey stated, "This is a personal commentary on the history and future prospects of mathematical modeling and analysis in biochemical engineering. Major transitions in these fields were driven by the appearance of the Aiba, Humphrey, and Millis text, Fredrickson's guidance on conceptualizing mathematical representations of cell populations, and Ramkrishna's development of the cybernetic modeling approach." In this regard, although the publications of Kompala, Ramkrishna, and Tsao in 1984 with 90 citations and Kompala, Ramkrishna, Jansen, and Tsao in 1986 with 130 citations, and others already have had their impact, the full and even greater impact of this methodology will be realized in the near future as recent developments on cybernetic modeling have found ways to address large metabolic systems to describe their dynamics in ways that no other framework is equipped to do. Their applications to the development of biofuels by the fermentation route, a problem of enormous importance today, is already under way in Ramki's group. Ramki is currently writing a monograph on this topic, to be published by the Cambridge University Press.

In collaboration with Purdue Professors Hannemann (ChE/BME), Rundell (BME), Leary (BME) and the Indianapolis Riley Children's Hospital, Ramki has recently launched an



Ramki and Geetha with their sons and daughters (-in-law).

active new project for using his modeling talents to design patient-specific therapeutic strategies for the treatment of Acute Lymphoblastic Leukemia.

AWARDS

Ramki received AIChE's Alpha Chi Sigma Award in 1987 for his seminal contributions in mathematics to chemical engineering. Mumbai University awarded him the UDCT Diamond Award in 1994 among 18 others in a one-time cumulative recognition event. In 2006, he received the "Jewel" of Ruia Award, along with an outstanding surgeon, as the first alumni to be so recognized by Ruia College of Bombay University.

In 2009, he received the Platinum Award among other distinguished alumni of Mumbai University from the Institute of Chemical Technology. In 1998, the AIChE granted him the Wilhelm Award for Chemical Reaction Engineering, for his outstanding contributions to chemical and biochemical reaction engineering. In 2004, he won the Thomas Baron Award for his contributions and investigations of particulate systems from the Particle Technology Forum of AIChE.

He won the Senior Humboldt Award in 2001 to visit the Max Planck Institute in Magdeburg, Germany. In 2004, Ramki received the Honorary Doctor of Science from the University of Minnesota. He was then only the sixth chemical engineer to be so honored by the University of Minnesota in the previous 50 years. His innovative contributions led to his election to the National Academy of Engineering in 2009, with a citation that reads: "For creation of new model concepts and solutions that improved the engineering of biological and particulate processes."

In addition to becoming the H.C. Peffer Distinguished Professor in 1994 (named after the founding Head of the School), Ramki has won his share of awards from Purdue. Nicholas Peppas organized a surprise get-together in the School in 2001 to celebrate Ramki's 25th year at Purdue. In 2005, Ramki received the Purdue Research Excellence Award from the College of Engineering and in 2010 he received the College Mentoring Excellence Award for his mentoring of graduate students and junior faculty.

FAMILY

Geetha accompanies Ramki to every professional meeting he attends. They are proud of their two sons, Sriram (a computer scientist), living in Portland, Ore., and Arvind (a design engineer), living in Novi, Mich. They are equally proud of their daughters-in-law Banu (married to Sriram and a practicing dentist) and Usha (married to Arvind, with a Master's degree in biomedical engineering). Arvind commented, "Dad was a lot of fun when I was a kid. However, he was extremely competitive. Particularly in video games! He wasn't the type that would say "oh . . . I'll let him win a game or two." It was more like "I'm going to crush him!" I remember when we first bought our Nintendo; Dad would always challenge me to a game of Nintendo Golf. I had beaten him so many times until finally he achieved a -18 and edged a win over my -16!"

Ramki's family has been a constant source of strength. His three siblings have spoiled him with their adulation, while his parents and uncle have been a constant source of encouragement. Ramki's first grandson, Rohan, was born in March 2008. When Rohan was born, Ramki finished teaching his class at Purdue and drove to the hospital in Southfield, Mich., to visit Rohan. The weather had turned nasty and by the time he arrived in Michigan, it was pitch dark and foggy with virtually zero visibility. He had gone astray and found himself in Ypsilanti with no available sense of direction (this happens frequently!). After what seemed like a long time, he found the City Hall with lights inside and people apparently in a meeting. He let himself in, announcing that he was hopelessly lost. A young lady among them said, "Why, aren't you Professor Ramkrishna from Purdue? I am Christie and got my Ph.D. at Purdue some years ago with Professor Peppas!" Ramki excitedly responded by saying, "Of course I remember you, Christie, you were in my transport course!" What followed was a hug, fond recall of some memories, and very clear directions for the right path to the hospital!

Because his brothers and sister are so much a part of his life, they are known to most of Ramki's colleagues and friends. They have even attended many AIChE meetings to

be with him. His younger brother Jaichandra writes, "Ramki has been the life and breath of our family and has given the immediate and extended families great memories, many of which we continue to reminisce. One of my early boyhood memories about my brother, then a high school kid himself, is his uncanny ability to narrate stories to children and humor them. He would do it in such gripping details, often with make-believe characters, to keep the interest flowing of even the wayward among us! Kids often clung to him for more and Ramki would oblige and occasionally twisted the lines to scare the more mischievous ones into behaving!"

Communication between Ramki and his father was unique since his early college-student days and it was always in English, which was very much the medium for serious communication at home. Ramki would discuss his academic courses, the faculty, and his classmates with great excitement each day to a very receptive, encouraging, and proud father. This continued throughout his academic career to the point that most of his family knew almost every colleague and his past students in the chemical engineering field by their names and accomplishments!

QUIRKS

Ramki takes full advantage of the license given to professors to be slightly eccentric. Nick Delgass relates an incident where Ramki stopped him in the hallway and showed him an article that had just appeared in the *AIChE Journal*. The problem solved happened to be one of three Ramki had assigned to his class for homework that week.

Ramki has an obsession for chalk and chalkboards. He loves to lecture from the chalkboard. By the end of the lecture every inch of the board is covered with complex equations and derivations written in beautiful, neat handwriting. Typically, Ramki teaches without referring to any notes or book, without pausing once or making a small mistake. He will only look at his notes as a last resort when he senses something is not right. When he realizes the mistake and goes back over the entire board revising each equation, the class moans loudly because they have to go back through their notes and edit each equation. Since ink is much more difficult to edit than chalk, everyone's notes are a mess. Ramki has a chalkboard in his office at home that covers almost an entire wall. He often uses it to work out ideas or to practice his lectures. After every lecture, Ramki absentmindedly puts the piece of chalk that he had been using into his pocket. He has a desk drawer that is overflowing with little used pieces of chalk.

Ramki is also an excellent and competitive carom (an Indian game that is a combination of pool and checkers) player. Unfortunately, the competitiveness, but not the excellence, extends to his driving. He is forgetful and does not always notice small details such as stop signs. Ramki is also a tremendous fan of cricket, which is quirky in the United States.

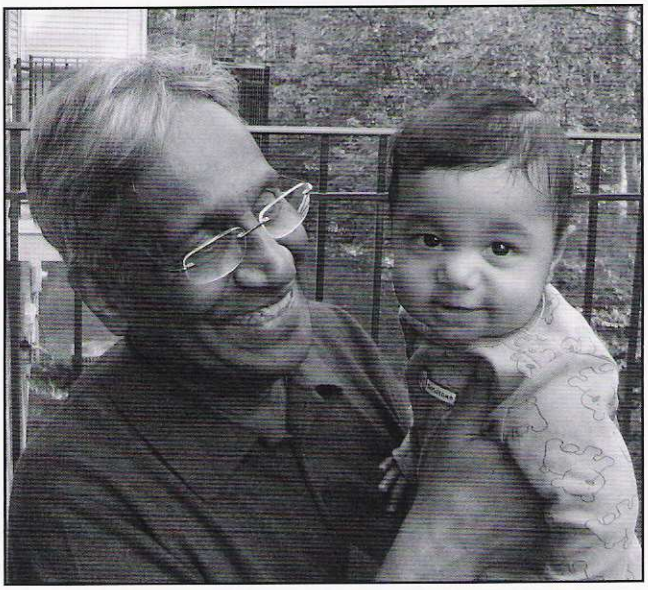
Our hero *is* forgetful. He once told a forgetful student "By the time you are my age, you won't even remember your name." Another story: a student was at oral exam, frantically waiting for all the committee members to show up. Everybody else did show up on time, and then Professor Peppas told the student: "You might want to check with Ramki, as I tried to reach him a few minutes ago and he was not in his office." So the student went to Ramki's office and found him immersed in a journal article. When told that he was late for the oral exam he retorted: "You should have reminded me!"

SUMMARY

Ramki has pioneered novel mathematical techniques to solve complex and important problems in chemical and biochemical engineering. His contributions have resulted in original research articles of lasting value and influential books. He has impeccably high standards, which are a model for his colleagues and students. He has served as mentor par excellence to numerous graduate students and junior faculty, who are now prominent in our profession. He provides selfless service to the School, having served as chair of many important committees (Graduate, Awards, and Global Programs to name a few) and associate head for three years during 2004-06. He is a loving husband, father, and grandfather, who takes pride in the accomplishments of his family and takes time to attend important events of his extended family. With all these characteristics, kind personality, and a great sense of humor, Ramki is indeed a population of one!

ACKNOWLEDGMENT

The assistance of Mrs. Cristina Farmus was invaluable in preparing this paper. ❐



Population growth: Ramki with Rohan, his first grandchild.