Remembering Philip Rabinowitz

Philip J. Davis and Aviezri S. Fraenkel

The applied mathematician and numerical analyst Philip (Phil, Pinchas, Pinny) Rabinowitz was born in Philadelphia on August 14, 1926, and passed away on July 21, 2006, in Jerusalem. Philip Davis recounts reminiscences from his early scientific career; while Aviezri Fraenkel relates some of his activities at the Weizmann Institute of Science, where he began work in 1955, as well as snapshots from earlier periods.

Philip J. Davis

I had a long and fruitful friendship and collaboration with Phil (Pinny) Rabinowitz that began in the fall of 1952 at the National Bureau of Standards (NBS: now NIST) in Washington, D.C. When I began my employment there in the late summer of 1952, Phil was already there.

Phil (I never called him Pinny) grew up in Philadelphia. He got his Ph.D. degree from the University of Pennsylvania in 1951 under the supervision of Walter Gottschalk with a thesis titled *Normal Coverings and Uniform Spaces*. Of course, this topic in topology was irrelevant to the work of the bureau, and Phil was immediately pulled into numerical analysis, computation, programming, and running mathematical models of importance to members of other portions of the bureau and of the U.S. government.

At that time, the Bureau of Standards had one of the very few electronic digital computers in the world. It came on line in 1950 and was known as the SEAC (Standards Electronic Automatic Computer). Within a very short period of time Phil became an expert programmer on SEAC.

If I remember correctly, some of the features of SEAC were as follows: It had 128 memory cells, and one programmed it in what was called "the four address system". A line of code went typically as follows: take the number in cell 28, combine it with the number in cell 37 according to standard operation S, store the result in cell 6 and go to cell 18 to pick up the next instruction. Computations were in fixed-point arithmetic so that scalings had to be introduced to keep the numbers in bounds. The lines of code were first set out in pencil on standard coding sheets; these were transferred to punch cards or teletype tape, thence to magnetic wire from which they were inserted in SEAC.

In retrospect SEAC would be called a first generation computer. Though many numerical strategies (algorithms) had been worked out for a wide variety of mathematical problems in pre-electronic days, the new computers expanded the algorithmic possibilities tremendously. But it was important to work out by trial and error (and occasionally by theory) which of these strategies were optimal vis-a-vis the limitations of time, storage, money, and the difficulties inherent within the algorithm itself such as complexity, divergence, instability, ill-posedness, etc.

The 1950s were a transitional age computationally speaking. Until about 1955 or so, the electronic computers were still grinding out tables of Special Mathematical Functions and publishing them in bound volumes. Later, this was seen as largely unnecessary; special software would be incorporated into scientific computational packages and would produce values of special functions on call and as needed.

One of Phil's first publications (1954) was a *Table of Coulomb Wave Functions* done jointly with Milton Abramowitz (head of the Bureau of Standards Computation Laboratory) and Carl-Erik Fröberg, a numerical analyst from Lund, Sweden.

Shortly after I arrived in Washington, Phil worked on a project that teamed up Kenneth Cole of the National Institutes of Health and Henry Antosiewicz of NBS. Cole was a biomathematician who studied the Hodgkin-Huxley equations

Philip J. Davis is emeritus professor of applied mathematics at Brown University. His email address is Philip_Davis@Brown.edu.

Aviezri S. Fraenkel is professor of computer science and applied mathematics at the Weizmann Institute of Science. His email address is aviezri.fraenkel@weizmann.ac.il.

of impulse transmission down a nerve fiber. If I remember correctly the H-H model consisted of a system of ordinary nonlinear differential equations. Antosiewicz was an expert in that field. This very successful work was reported as "Automatic Computation of Nerve Excitation" and appeared in the Vol. 3, September 1955 issue of the *Journal of the Society for Industrial and Applied Mathematics* (SIAM).

Some incidental gossip: SIAM was founded around 1952 essentially by Ed Block who was a Ph.D. classmate of mine and who for many years was its managing director. In 1963, Alan Hodgkin and Andrew Huxley won the Nobel Prize in physiology for their work on nerve excitation, and it seems likely to me that the work of Cole, Antosiewicz, and Rabinowitz contributed a bit towards this award. Many years later, around 1988, my wife Hadassah and I met Hodgkin and his American wife socially in Cambridge, England. I told Hodgkin this NBS story, but I do not now remember what his reaction was.

In Washington, my friendship with Phil grew, and Hadassah and I grew to know Phil's family: his wife Terry and his children. One of his sons was born in Washington, and we were invited to the brit. There we met Phil's father and his mother. His father was a major chassidic rabbi in Philadelphia and "held court" there with many followers.

Some years later, on one of my professional trips to Philadelphia, I was able to meet Phil's sister, Margola. I believe she had or was getting a degree in philosophy from the University of Pennsylvania. She showed me around tourist Philadelphia and later we took in a summer theatre production of "Amphitryon 38" (Giradoux/S.N. Behrman) with Kitty Carlyle Hart in one of the roles. In the course of our wandering, Margola told me quite a bit about how it was growing up in a chassidic court in Philadelphia in the late 1940s. I was so amazed and intrigued by what I heard that I told her she ought to do a book of reminiscences. Perhaps she has.

In one of my first jobs at the NBS and as part of an extensive project, I was confronted with the necessity of doing some approximate integrations in the complex plane very accurately. I worked on this with Phil.[1] I thought a good strategy would be to use a very subtle and accurate scheme derived in the early 1800s by the great Carl Friedrich Gauss. Prior to 1954, the Gaussian integration rules were available only up to $n = 16$ points. The values had been calculated on desk calculators—an extremely laborious task—by Lowan, Davids, and Levenson. It was also the case that the Gaussian rules were

Photograph courtesy of the authors.

View of SEAC, circa 1952.

out of favor in the days of paper-and-pencil scientific computation, as the numbers involved were helter-skelter irrational decimals, impossible to remember and difficult to enter on a keyboard without error.

It was my plan to carry the computation beyond $n = 16$. I suggested to Phil that we attempt the Gaussian computation on the SEAC. He was game. I anticipated that it would be desirable to work in double-precision arithmetic to about 30 decimal places, and Phil, who was much more skillful at SEAC coding than I, agreed to write the code that would effectuate the double precision.

But first I had to devise a numerical strategy. The n abscissas of the Gaussian integration rules are the roots of the Legendre polynomials of degree n. The weights corresponding to the abscissas can be obtained from the abscissas by a number of relatively simple formulas. I proposed to get the Legendre polynomials pointwise by means of the known three-term recursion relation. I would get their roots by using Newton's iterative method, starting from good approximate values. These starting values would be provided by a beautiful asymptotic formula that had been worked out in the 1930s by the Hungarian-American mathematician Gabor Szegö.

I didn't know whether this strategy would work. It might fail for three or four different reasons. I was willing to try, and if it worked, good; if it didn't—well, something is always learned by failure. We could give the failure some publicity, and other mathematicians would avoid the pitfalls and might then be able to suggest more successful strategies.

I wrote the code and Phil wrote the double-precision part. I tried to anticipate what scaling would be necessary. I reread my code and checked it for bugs. Phil checked it for bugs. I (or Phil) punched up the code on teletype tape and checked that out. The tape was converted automatically to a wire, and the wire cartridge was inserted in the SEAC. We manually set $n = 20$, crossed our fingers, held our breath, and pushed the button to run the program.

[1] *P. Davis and P. Rabinowitz, "Some SEAC computations of subsonic fluid flows by Bergman's method of integral operators" (1953), in M. Z. v. Krzywoblocki,* Bergman's Linear Integral Operator Method in the Theory of Compressible Fluid Flow*, Springer, Vienna, 1960.*

Photograph courtesy of the authors.

P. J. Davis (left) and P. Rabinowitz (right) laying out an algorithmic strategy. Circa 1955.

The SEAC computed and computed and computed and computed. Our tension mounted. Finally, the computer started to output the Gaussian abscissas and weights. Numbers purporting to be such started to spew out at the teletype printer. The numbers had the right look and smell about them. We punched in $n = 24$ and again pushed the "run" button. Again, success. And ditto for even higher values of n.

The staff of the NBS computing lab declared us "Heroes of the SEAC", a title awarded in those days to programmers whose programs ran on the first try—a rare event—and for some while we had to go around wearing our "medals," which were drawn freehand in crayon on the back of used teletype paper. (The word "hero" was in parody of the practice in the Soviet Union of declaring persons "Heroes of the Soviet Union" for this and that accomplishment.)

This was the first electronic digital computation of the Gaussian integration rules. In the years since, alternative strategies have been proposed, simplified, and sharpened (by Gautschi, Golub, and others). And though all the theoretical questions that kept us guessing in 1955 have been decided positively, there are many problems as yet unsolved surrounding the Gauss idea.

Phil and I also worked together—in an experimental fashion—on the numerical solution of elliptic partial differential equations using expansions in orthogonal functions, and published a number of papers on that topic.

For Phil and me, our success and our continued interest in approximate integration led to numerous papers and to a book on the topic which, over the years, has been widely used and referenced. Our *Methods of Numerical Integration*, Academic Press, has gone through three editions.

Sometime in the mid-1950s Phil decided to "make aliya" to Israel. An opportunity opened up for him at the Weizmann Instuitute of Science in Rehovot, in connection with the WEIZAC computer (1954) and the GOLEM (1964). He was hired by Chaim Pekeris who headed up the applied math group at the Weizmann Institute. Although we were now separated, our interest in producing a book on numerical integration persisted. We worked together on the book in several places; in Providence, where Phil and his family spent two semesters at Brown in 1965–66, and from February to May 1970 in Rehovot where my wife and two of our children, Ernie and Joey, spent three months. Again, in 1972, I was by myself in Rehovot for about a month, staying in the San Martin Guest House of the Weizmann Institute.

With the publication of the third edition of *Methods of Numerical Integration* in 1975, my interest in the subject slackened, though I believe that Phil published papers in the topic from time to time. He also did a book *A First Course in Numerical Analysis* with Anthony Ralston which has gone through several editions.

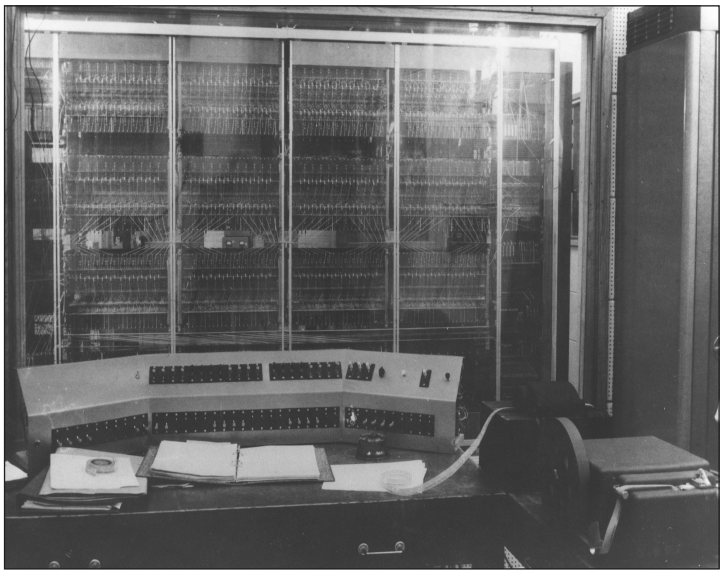
In between and in the years that followed, I would see Phil from time to time at conferences in different parts of the world. In 1969 we were at a conference at the University of Lancaster. The first moon landing occurred during the conference on July 20 and the sessions were suspended while—all agog—we all watched on the TV. The last day of the conference occurred on Tisha b'Av. Phil prepared to leave the conference early and return to London. I asked him why. He replied that sundown occurred earlier in London than in Lancaster and so he would be able to break his fast sooner. An example of his humor.

Aviezri S. Fraenkel[2]

Pinny (I never called him Phil) grew up in Philadelphia in a chassidic-zionist family. Since there was no Jewish day school there at the time, he studied Jewish subjects with a private tutor who came to his house for a few hours on a daily basis. While in high school, and later at the University of Pennsylvania, he attended Talmud lessons given in various synagogues in Philadelphia. He continued these studies until his deathbed.

At the university he studied medicine, but at the end of the first year he did not take a test that took place on Saturday, in order not to desecrate the sanctity of the Sabbath, so he switched to math. He got his first, second, and third degree from the University of Pennsylvania during 1946–1951. There was an important interlude: during 1948–9, Pinny was chosen to go to the new Servomechanism Laboratory at MIT, where he joined the Whirlwind Computer Project numerical analysis group. There he acquired his first experience in writing programs for a digital computer, interacting with

[2] *A shorter version of this part, in Hebrew, appeared recently in a Weizmann Institute publication.*



The front of WEIZAC.

Photograph reproduced with permission of the Weizmann Institute of Science.

people such as Alan Perlis (numerical solutions of integral equations), J. W. Carr (2-register method for floating point computations), Charles Adams (programming languages), Alex Orden and Edgar Reich (solution of linear equations). In Boston he also met Terry, whom he married shortly after getting his Ph.D. in 1951. During 1951–55 he worked at the Computation Laboratory, National Bureau of Standards, Washington, DC.

In 1954, the first digital computer in Israel was constructed under the leadership of Jerry Estrin, who was a member of the team that had just finished constructing John von Neumann's first "stored program" computer at the Institute for Advanced Study, Princeton. Jerry later went to the Engineering Department at the University of California, Los Angeles. The initiator of WEIZAC's construction was the late Chaim L. Pekeris, head of the Applied Mathematics Department at the Weizmann Institute. The WEIZAC project was recently recognized by the Institute for Electrical and Electronics Engineers as a Milestone in the History of Computing. The unveiling of the plaque took place at the Institute on December 5, 2006. On that occasion the team members who constructed the machine received the WEIZAC Medal. Pinny and some others got it posthumously.

Major operation times of WEIZAC were, addition: 50 microsecs; multiplication: 750 microsecs on the average; division: 850 microsecs. It had one of the first ferrite core memories with 4,096 words; memory access time: 10 microsecs. A unique feature of the machine was its word length: 40 bits. Input/output was via punched paper tape.

Pekeris invited Pinny to head the software development, which Pinny began in 1955, after relocating in Israel. Pinny wrote the first utility programs and built up the scientific software library, in the form of subroutines, which constituted the basic infrastructure for numerical solutions of mathematical problems. In addition he gave programming courses at various levels to many people who later became the leading programmers in Israel. In addition to Institute scientists, key personnel from government, defense, and industry participated. Pinny was the pioneer who triggered the large potential of software and high-tech industries in Israel.

Pinny taught numerical analysis at the Hebrew University, Jerusalem, and Tel Aviv and Bar Ilan Universities, in addition to the Weizmann Institute, and helped various colleges to establish computer science programs. In 1968 he received the annual prize of the Israeli Information Processing Society, the Israeli parallel of the U.S.-based Association for Computing Machinery. He traveled extensively, collaborating with mathematicians all over the continents. A conference "Numerical Integration", the core of his scientific interests, was dedicated to his sixtieth birthday. The meeting took place in Halifax, Nova Scotia, in August, 1986.

He helped the defense establishment in writing their first programs. During the tense days preceding the 6-day war, he wrote new programs and backup programs at the Institute, as fallback protection in case the defense department's main computer should become incapacitated.

Among his students were applied mathematician Nira Dyn of Tel Aviv University and computer scientist Mira Balaban of Ben Gurion University. In 1991 Nira organized an international conference on numerical analysis at Tel Aviv University, to mark Pinny's retirement. Mira is interested in artificial intelligence, especially computer music. She wrote her Ph.D. thesis on this topic, under the joint supervision of Pinny and Eli Shamir of Hebrew University. This enabled Pinny to fuse his loves for science and art.

Pinny was a passionate connoisseur of the fine arts, especially paintings, and a frequent visitor at modern art galleries. A large collection of modern paintings decorated every free inch of the walls of his home. He had a sharp eye for recognizing young talents, whose creations he purchased before they became famous, thus encouraging budding talents. As a token of thanks, some of them, such as Menashe Kadishman, dedicated some of their creations to him. He loved music ardently, especially that of Jean Sibelius.

He also encouraged and guided young mathematical talents. David Harel began concentrating on topology for his M.Sc. degree at Tel Aviv University. After one year he decided to leave his studies and become a programmer. Pinny advised

THE AMERICAN UNIVERSITY IN CAIRO

The Department of Mathematics and Actuarial Science anticipates two faculty vacancies.

The successful candidate will teach all levels of undergraduate mathematics courses, as well as participate in research. The second position is open only for candidates with expertise to teach in the Actuarial Science Major.

Position # MATH-1/2-08

- PhD is required

One-, two- or three-year appointment, subject to mutual agreement will begin September 2008. Renewal of an appointment depends upon institutional needs and/or the appointee's performance.

Salary and rank are according to scale based on qualifications and professional experience. For expatriates, benefits include housing, annual round-trip air travel for appointee and qualifying dependents, plus schooling for the equivalent of up to two children at Cairo American College. In view of AUC's protocol agreement with the Egyptian government, which requires specific proportions of Egyptian, U.S., and third-country citizen faculty, at this time preference will be given to qualified applicants who are U.S. citizens.

For complete details and application information:

http://aucegypt.interviewexchange.com

An independent, non-profit, apolitical, non-sectarian and equal-opportunity institution.

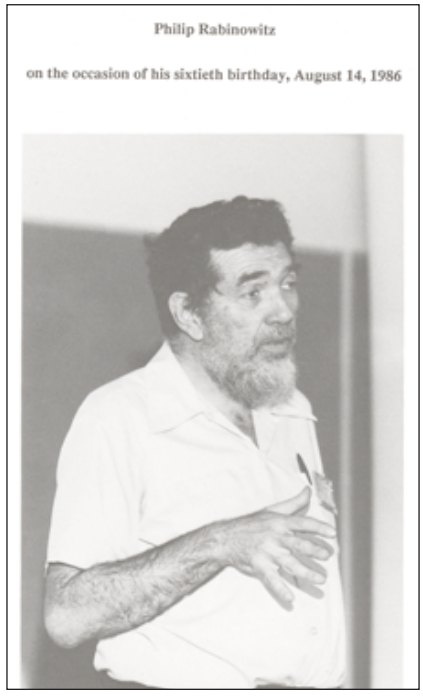


Image courtesy of the authors.

The cover page of the proceedings, "Numerical Integration", NATO Series, *Math and Physical Sciences*, Vol. 203, 1987.

him to meet Amir Pnueli. As a result, David wrote his M.Sc. degree in computer science under Amir. Both later got the Israel Prize in computer science. Amir is also a Turing Prize laureate.

In June 1956 Shaula and I got married. Weeks before, Pinny secretly began hoarding the colored "holes" of the punched paper tape. When we paraded to the podium where the marriage ceremony took place, Pinny tossed the confetti on our heads.

During the hot and humid summers of Rehovot, home of the Weizmann Institute, Pinny usually went abroad working with colleagues. During later years, when he reduced his travel, he purchased a house in Efrat, near Jerusalem, where his daughter lives, and the climate is cooler and drier. There he and Terry spent the summers. During winter they lived in Rehovot. Over the years, those winters became shorter and the summers got longer. During the last winter of his illness he also stayed in Efrat.

Pinny's personality reflected a harmonious fusion of Judaic values, love for the land of Israel, science, and the fine arts. May his memory be blessed.

City University of Hong Kong is one of eight higher education institutions directly funded by the Government of the Hong Kong Special Administrative Region through the University Grants Committee (Hong Kong). It aims to become one of the leading universities in the Asia-Pacific region through excellence in professional education and applied research. In two studies, City University of Hong Kong ranks among the top 200 universities in the world, and among the top ten universities in the Greater China region. The mission of the University is to nurture and develop the talents of students and to create applicable knowledge in order to support social and economic advancement. The student population is approximately 26,000 enrolled in over 170 programmes at the associate degree, undergraduate and postgraduate levels. The medium of instruction is English.

The University invites applications for the following posts. Candidates with applied research achievements will receive very positive consideration. Relevant experience in business and industry will be a definite asset.

Associate Professor/Assistant Professor ***[Ref. A/505/49]***
Department of Mathematics

Duties : Teach undergraduate and postgraduate courses, supervise research students, conduct research in areas of Applied Mathematics, and perform any other duties as assigned.

Requirements : A PhD in Mathematics/Applied Mathematics/Statistics with an excellent research record.

Salary and Conditions of Service
Salary offered will be highly competitive and commensurate with qualifications and experience. Appointment will be on a fixed-term gratuity-bearing contract. Fringe benefits include annual leave, medical and dental schemes, and housing benefits where applicable.

Application and Information
Further information about the posts and the University is available at http://www.cityu.edu.hk, or from the Human Resources Office, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong [Fax : (852) 2788 1154 or (852) 2788 9334/email: hrojob@cityu.edu.hk]. Please send an application letter enclosing a current curriculum vitae to the Human Resources Office by **15 January 2008**. Please quote the reference of the post applied for in the application and on the envelope.

The University reserves the right to consider late applications and nominations, and to fill or not to fill the positions.