

SURVEY PAPER

PROFESSOR RUDOLF GORENFLO
AND HIS CONTRIBUTION
TO FRACTIONAL CALCULUSYury Luchko ¹, Francesco Mainardi ², Sergei Rogosin ³**Abstract***Dedicated to Professor Rudolf Gorenflo
on the occasion of his 80th anniversary*

This paper presents a brief overview of the life story and professional career of Prof. R. Gorenflo - a well-known mathematician, an expert in the field of Differential and Integral Equations, Numerical Mathematics, Fractional Calculus and Applied Analysis, an interesting conversational partner, an experienced colleague, and a real friend. Especially his role in the modern Fractional Calculus and its applications is highlighted.

*MSC 2010: 26A33**Key Words and Phrases: Rudolf Gorenflo, research career, scientific co-operation, fractional calculus***1. Life story**

Rudolf Gorenflo was born on July 31st 1930 in Friedrichstal near Karlsruhe, Germany. He started to be interested in mathematics very early. Being 5 years old and before entering the elementary school he already knew the multiplication table and could apply it. With 10 years Rudolf could perform all operations with the rational numbers and started his own research. He formulated and answered the question regarding the lengths

of the periods of the decimal fractions for the rational numbers like $\frac{1}{7}$ or $\frac{1}{49}$. Mathematics attracted a lot of his attention. Rudolf was one of the best in mathematics at his school and decided to become a school teacher in mathematics and physics. In the very hard post-war years Rudolf entered the Technical University in Karlsruhe. In 1950 he started to learn there mathematics and physics but then decided to become a mathematician. Still he took part in several courses in theoretical physics and engineering sciences - an experience that helped him as a mathematician to always choose a right strategy for solving difficult problems. According to Rudolf Gorenflo, his most exciting experience in mathematics was to learn that a certain type of difference schemes for the heat conduction equation can be interpreted from the random walk viewpoint - of course, this connection reflects also his own "dual nature" as a mathematician and a physicist. In 1956 Rudolf Gorenflo completed his diploma thesis entitled "Meromorphic functions of finite order" (scientific adviser Prof. H. Wittich) and received a diploma in mathematics. In the same year he entered a doctoral course at the Technical University in Karlsruhe. Under supervision of Prof. H. Wittich he worked on applications of complex analysis to the theory of entire functions including the Mittag-Leffler function. His doctoral thesis entitled "On the Wiman-Valiron comparison method for power series and its application in the theory of entire transcendental functions" was successfully defended in 1960. Simultaneously with his research activities Rudolf Gorenflo began to collect his first teaching experiences. In 1957 he started to work as a scientific assistant at the Technical University in Karlsruhe - this was a beginning of a long way to his position as a full professor at the Free University of Berlin many years later. But before becoming completely focusing on teaching and research in mathematics he wanted to see what they are good for and applied for a position in the industry. In 1961-1962 he worked for the Standard Electric Lorenz Company in Stuttgart in the department of informatics. Beginning from 1962 Rudolf Gorenflo dealt mainly with physics combined with mathematical modelling, numerics and computer simulations at the Max-Planck Institute for Plasma Physics in Garching near Munich. His abilities and desire for teaching were approved in 1970 at the Technical University in Aachen with his habilitation in mathematics. In Aachen he has got also the first professorship (1971-1973).

In 1973 Rudolf Gorenflo became a full Professor at the Free University of Berlin, where he is doing research and teaching for already 37 years. He was leader of three FU-sponsored research projects: Modelling and Discretization (1983 - 1988), Regularization (1989 - 1994), Convolutions (1995 - 2003). His valuable contributions, results and achievements both in research, in teaching, as well as in social life at the Free University and

for the international scientific community cannot be overestimated; in the next sections some of them are shortly described.

2. Scientific interests and results

During his research career Prof. R. Gorenflo dealt with and obtained valuable results in several areas of Mathematics. Especially his contributions to the Fractional Calculus can be evaluated to be innovative, valuable, and important for the further development of this research area. In the book entitled “Abel Integral Equations: Analysis and Applications” written jointly by him and Sergio Vessella, published by Springer-Verlag, Berlin, in 1991 in the series Lecture Notes in Mathematics the authors in fact pushed forward a modern approach to the Fractional Calculus, i.e. not just deducing some theoretical results, but applying them to model systems, processes and phenomena of the real world. These ideas were the driving force for his research and academic career. To understand them, let us have a short look at the origins of his scientific activities.

In his student years Rudolf Gorenflo was mainly interested in the theory of functions of one complex variable, in particular in value distribution theory and growth properties. Both his diploma thesis and his doctoral thesis were devoted to this theoretical topic.

But already during his time at the Standard Electric Lorenz Company in Stuttgart he had to learn how to apply mathematics to industrial problems. His main duties there were to design and to perform computer simulations, mainly of waiting lines in communication networks. Rudolf Gorenflo had to study Monte-Carlo simulation method and queueing theory and to apply them. At this time, he entered the world of randomness, which is one of the beloved areas of his research interests up to now.

At the Max Planck Institute for Plasma-Physics in Garching near Munich (1962 - 1970) Rudolf Gorenflo could use his knowledge of complex analysis and of electronic computing machines to investigate several practical problems. There he dealt with plane problems of magneto-hydrostatics and magneto-hydrodynamics, the Monte Carlo simulations of particle flights in a rarefied gas, the theory and application of difference schemes to ordinary and partial differential equations (e.g. for large scale computation of toroidal magnetic fields and systems of diffusion, convection, and reaction), and with evaluations of spectroscopic measurements (in the rotationally symmetric case via Abel integral equations of the first kind). The latter activity aroused his interest in ill-posed problems.

Moreover, at the Max Planck Institute for Plasma-Physics Rudolf Gorenflo was responsible for consulting and assisting physicists and engineers in the mathematical and numerical treatment of their problems. This was

the time, he perfected his ability to communicate with applied scientists, to speak with them and to understand their requirements - a quality that many of the colleagues dealing with the applications of Fractional Calculus are thankful to him for. A special experience was his collaboration with a group from the neighbouring Max Planck Institute for Extraterrestrial Physics in the development of instruments for measuring the flux of neutrons in the solar wind.

During his time at the University in Aachen (1970 - 1973) and then at the University in Berlin (since 1973) Prof. R. Gorenflo's primary aim was to share his understanding of the applied mathematics with his students and colleagues. His main research interests were divided between integral equations and the neighboring subject of inverse and ill-posed problems, difference schemes for parabolic differential equations, and different topics in Fractional Calculus. By dealing with any of these topics, his interest was motivated by real applications, by the desire to understand the nature of certain physical processes and to describe them mathematically.

Within his research in the field of integral equations, Prof. R. Gorenflo considered them from different viewpoints, firstly, as a tool for modeling processes with a "memory", second, as a deep mathematical theory, and third, as an application of the developed numerical methods to the investigation of the qualitative behavior of their solutions. Exactly this combination of the different viewpoints led to a series of deep results presented in his book with Sergio Vessella about Abel Integral Equations and in his book with D.D. Ang, V.K. Le, and D.D. Trong "Moment Theory and Some Inverse Problems in Potential Theory and Heat Conduction", Lecture Notes in Mathematics 1792 (2002), Springer-Verlag, Heidelberg. Prof. R. Gorenflo also contributed (in collaboration with co-authors) to the theory of the inverse problems in heat conduction, asymptotic properties of singular values, nonlinear inverse problems, problems of recovery of a function from its moments.

Within his research in the theory of difference schemes for parabolic differential equations Prof. R. Gorenflo always tried to use his physical intuition. In particular, his main intention was to develop and investigate difference scheme that imitate essential properties of the diffusion processes that were modelled, namely properties of conservation of mass or energy, preservation of non-negativity, properties of growth and decay. He also tried to see his research objects from different viewpoints that he learned during his academic and industrial career. In this way, the difference schemes he developed allow a double interpretation, namely as that of a process of discrete redistribution of an extensive quantity on the grid-points, and as that of a random walk discrete in space and time, of a particle wandering

according to a diffusion process described by the parabolic equation at hand.

While studying integral equations of Abel type and some neighboring problems, Prof. R. Gorenflo started to be interested in the theory of special functions that is helpful for the solution of integral equation in closed form and in the Fractional Calculus and allows a very natural formulation and solution of Abel type integral equation. He furthermore continued to work on ill-posed problems, inversion of fractional integration being a specific example.

These interests were also stimulated by research visits to Prof. R. Ruttman at the University of Massachusetts in Dartmouth (USA) in 1992 and 1994, to Prof. B. Rubin in Jerusalem 1993 and 1995, and to Prof. M. Yamamoto in Tokyo 1995. Then by his participation in an international workshop on Fractals and Fractional Differentiation organized by A. Le Méhauté and A. Oustaloup in Bordeaux (France) in summer of 1994. In Bordeaux he made acquaintance with Prof. F. Mainardi finding in him a collaborator, a co-author, and a friend for many years. As a matter of fact they started joint research with the initial value problems for the basic differential equations of fractional order (fractional relaxation and oscillation). This collaboration was then re-inforced during the work on a joint and two individual lecture notes for a Course organized by A. Carpinteri and F. Mainardi at the International Centre for Mechanical Sciences, Udine, Italy in September 1996 to explore the possible connections between Fractals and Fractional Calculus in Continuum Mechanics.

Beginning from this time, the main research activities and achievements of Prof. R. Gorenflo are devoted to Fractional Calculus. First he began working on ordinary fractional differential equations and related special functions, and later extended his interests to many other actual research topics of Fractional Calculus, its applications and generalizations. Among other things, he investigated special functions of FC like the Mittag-Leffler and the Wright functions both from the analytical and numerical viewpoints, developed numerical methods for the integral and differential equations of the fractional order, constructed operational calculi for FC operators, considered the initial- and boundary-value problems for fractional differential equations. In all cases he was interested not just in the underlying mathematics but in the applications of the results, too. In particular, in his works and in the works of his co-authors some important models for the adequate description of anomalous physical processes like slow and fast relaxation, oscillation, and diffusion in terms of fractional differential equations were investigated. Nowadays we can already speak about a wide collection of FC models in physics, engineering, medicine, and other sciences

even including finance. Without any doubts, several pioneering works in this area were done by Prof. R. Gorenflo and his co-authors.

During the last years, in collaboration with Prof. F. Mainardi and his students and other colleagues, Prof. R. Gorenflo started to investigate the partial fractional equations (fractional in time or in space or in both time and space) that are suitable for modeling non-classical diffusion processes. In the framework of this collaboration, various types of random walk models were devised and analyzed. Prof. R. Gorenflo himself considers this activity to be a fascinating generalization of his earlier investigations of difference schemes conserving mass or non-negativity (or energy) in classical diffusion processes. He often said to Mainardi that he had discovered in Paris a new random walk model after a glass of good red wine produced in Bordeaux!

In the framework of the recent 4th IFAC Workshop on Fractional Differentiation and Its Applications (FDA'10) Prof. R. Gorenflo was honored by the international FC community for his valuable contributions to this field. The special session "Fractional Calculus: Basic Theory and Neighbouring Fields" of the FDA'10 was completely dedicated to Prof. R. Gorenflo on the occasion of his 80th anniversary. Moreover, he received an FDA'10 award in the category "Professional Life Achievements" that was designed to recognize and appreciate excellence in Fractional Calculus.

3. Scientific collaborations

The important role of Prof. R. Gorenflo in Fractional Calculus is not restricted to his own contributions to this field. He always paid a lot of attention to the work with young scientists, supported them and shared with them his ideas, hints, and suggestions. Ten of his students defended their PhD thesis: Matthias Blumenfeld (at Free University of Berlin, 1983) Dinh Nho Hao (from Vietnam, at Free University of Berlin, 1991), Christine Kutsche (at Free University of Berlin, 1994), Katrin Bühring (at Free University of Berlin, 1995, supervised jointly with Prof. S. Prößdorf), Holger Stephan (at Free University of Berlin, 1995, supervised jointly with Prof. H. Gajewski), Evelyn Buckwar (at Free University of Berlin, 1996), Gabriela Witte (at Free University of Berlin, 1997), Talaat El Danaf (from Egypt, at El-Menoufia University, Egypt, 1998), Alain Nkamnang (from Cameroon, at Free University of Berlin, 1999), Entsar Ahmed Abdalla Abdel-Rehim (from Egypt, at Free University of Berlin, 2004). During periodical visits to the University of Bologna (Italy) he had the opportunity to be co-supervisor for master theses in Physics of three students of Prof. Mainardi: Gianni Pagnini (2000), Alessandro Vivoli (2002) and Claudia Manzoni (2002).

Prof. R. Gorenflo was and is ready to communicate with young scientists both in person, say during the conferences or workshops, or via electronic communication media helping them in finding suitable literature, interesting research topics, or with ideas how to solve this or that problem. Even nowadays, as a Professor emeritus, he has been a supervisor of two diploma theses in Mathematics (concerning topics of FC) at the Free University of Berlin written by Honorata Inga Zadworna and Christian I. Schulz.

During his time in Aachen and in Berlin he has given courses and held seminars in several fields, e.g. Numerical Mathematics, Introduction to Computer Science, Basic Analysis, Ill-posed Problems, Integral Equations, Integral Transforms, Functional Analysis. He was furthermore engaged in courses for non-mathematicians: e.g. Differential Geometry for students of geodesy, Mathematics for physicists, Mathematics for biologists and mineralogists, Statistics for biologists.

Of course, Prof. R. Gorenflo helped and assisted not only his students and young scientists but his colleagues, too. There is one of his phrases known, namely, “to work together”. At the Department of Mathematics and Informatics of the Free University of Berlin, there were always scientists invited by him. They were supported by the FU Berlin, DAAD Program, the Alexander von Humboldt Foundation, DFG and other special funds. All of these guests were working jointly with Prof. R. Gorenflo. They came from different places around the world from Japan and Vietnam in the far East, to Canada in the West, and to Egypt and Cameroon in the South.

Prof. R. Gorenflo had special relations with colleagues from the former Soviet Union (Azerbaijan, Belarus, Russia, Uzbekistan). He invited them to visit his university, supported them both from the scientific and administrative viewpoints, and helped with ideas and hints in their research work. Many of them including two authors of this article were introduced by Prof. R. Gorenflo into the beautiful world of Fractional Calculus and its applications and are very thankful to him for this. At the Department of Mathematics and Informatics of the Free University there even was a joke that Prof. R. Gorenflo is “the most Russian German” at the Free University.

One other aspect of his contribution to mathematics in general and to FC in particular is his participation in a huge number of conferences all over the world and in his talks given there. He likes traveling, entering new mathematical subjects, and discovering new countries and cultures. At the important conference on Fractional Calculus in Tokyo, organized by Prof. K. Nishimoto, he met many of the leading people of FC and special functions. Many times he visited Hanoi and Ho Chi Minh City for joint

research on inverse and ill-posed problems. It should be especially noted that due to his joint work with many people Prof. R. Gorenflo acquired many friends who are grateful to him for his activities, constant interest to all new matters, optimism and deep knowledge in many areas of life and science.

His friends wish him to be healthy, to keep for a long time all his nice features and love to Fractional Calculus. Many happy returns!

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List of selected publications

This list should provide the reader with an impression about the wide range of the scientific interests of Prof. R. Gorenflo. A fairly complete list of his publications can be found at the Web-site

<http://www.fracalmo.org/gorenflo/index.htm>

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