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# A tribute to Ivan Kiguradze

Irena Rachůnková[1*], Svatoslav Staněk[1], Milan Tvrdý[2], Aleksandre Lomtatidze[3], Ravi P Agarwal[4], Irina Astashova[5], Alexander Domoshnitsky[6], Zuzana Došlá[7], Vyacheslav M Evtukhov[8], Nicolai A Izobov[9], Takasi Kusano[10], Nino Partsvania[11], Mykola Perestyuk[12], Bedřich Půža[13], Miklós Rontó[14] and Nicolai Rozov[5]

Dedicated to Professor Ivan Kiguradze for his merits in mathematical sciences.

*Correspondence:
irena.rachunkova@upol.cz
[1]Department of Mathematics, Faculty of Science, Palacký University, 17. listopadu 12, Olomouc, 77146, Czech Republic
Full list of author information is available at the end of the article

On 12 January 2012, Ivan Kiguradze has celebrated his 75th birthday. A prominent expert in the qualitative theory of differential equations, Professor, Doctor of Science, Academician, he is highly esteemed by his colleagues throughout the world. The ideas and methods due to him are now extensively used. In particular, Kiguradze's lemma, the Kiguradze inequality, Kiguradze classes, and the Kiguradze problem are often encountered in the literature.

Ivan Kiguradze was born in the village of Khidistavi located in the Chokhatauri Municipality in the Guria region of Georgia, where he graduated from the secondary school with a gold medal awarded in 1955.

In 1960, he received his university degree at the Faculty of Mechanics and Mathematics of the Tbilisi State University, where he had been a faculty member then (as an Assistant Professor since 1968 and as a Full Professor since 1973). He entered postgraduate courses at the Chair of Differential and Integral Equations of the Tbilisi State University. In 1963, he obtained a PhD degree, and in 1972 he became Doctor of Science in Physics and Mathematics.

Professor Kiguradze's scientific carrier has always been closely related to the I. Javakhishvili Tbilisi State University and Georgian National Academy of Sciences. Since 1963 till 1989, he had been working at the Tbilisi State University and, since 1973, headed the Department of Ordinary Differential Equations of the Vekua Institute of Applied Mathe-

matics. He was elected a Corresponding Member of the Georgian Academy of Sciences (now Georgian National Academy of Sciences) in 1979 and became Academician in 1993.

In June 1989, Professor Kiguradze was elected the Director of the A. Razmadze Mathematical Institute of the Georgian Academy of Sciences (now A. Razmadze Mathematical Institute of I. Javakhishvili Tbilisi State University), and he held this position till June 2006. Since 2001 he has been holding a post of a head of the Department of Ordinary Differential Equations at that institute. Since 1973 till 2006, he has also been a Professor of the Chair of Differential and Integral Equations at the I. Javakhishvili Tbilisi State University.

Professor Kiguradze has always made many efforts and devoted much energy to pedagogical activities. For more than 40 years he has been teaching general and special courses on ordinary differential equations at the Tbilisi State University, 24 postgraduate students obtained a PhD degree under his supervision. He is actively involved in editorial activities: apart of the membership in the Editorial Boards of several international journals, he is the founder and Editor-in-Chief of *Georgian Mathematical Journal* and *Memoirs on Differential Equations and Mathematical Physics*.

Professor Kiguradze's scientific interests cover a wide range of topics belonging to qualitative theory of ordinary and functional-differential equations. They are mainly related to the following three directions: (1) boundary value problems, (2) asymptotic theory, and (3) oscillation theory. Below we try to give a brief survey of his results.

Kiguradze obtained a number of *a priori* estimates for one-sided differential inequalities subject some boundary value conditions; these estimates form a basis for the construction of a complete theory of initial and boundary value problems for differential equations and systems with nonintegrable singularities with respect to the time variable. In particular, he established sharp criteria providing the solvability and unique solvability of:

- the Cauchy problem [9–11, 79];
- the Cauchy-Nicoletti problem [20, 41];
- the modified Cauchy-Nicoletti problem [42];
- the Vallée-Poussin problem [24, 57, 60, 61];
- the periodic problem [32];
- various two-point problems (together with BL Shekhter) [13, 17, 21, 23, 26–28, 33, 38, 51, 52, 66, 72, 115, 116, 136];
- multipoint and nonlocal problems (together with RP Agarwal, T Kiguradze, A Lomtatidze, and N Partsvania) [54, 66, 119, 141, 142, 146, 147].

Kiguradze together with RP Agarwal developed a new method for investigation of boundary value problems for differential equations with strong singularities with respect to the time variable, on the basis of which he obtained unimprovable conditions for the solvability of the Dirichlet and focal boundary value problems for higher-order strongly singular linear, quasi-half linear, and nonlinear differential equations [120, 125, 145].

For nonlinear differential equations with singularities with respect to phase variables, Kiguradze established optimal sufficient conditions for the solvability of the Cauchy problem [148], nonlocal problems [149, 150] and periodic type problems [151].

Kiguradze established inequalities of the Kolmogorov-Gorni type for monotone functions, on the basis of which sharp conditions for the solvability of the Kneser problem for nonlinear differential equations were found and asymptotic estimates for Kneser solutions were proved [16, 19, 22, 47]. Together with I Rachůnková he obtained complete results on the solvability of the Kneser problem for two-dimensional differential systems [48]. More-

over, he obtained necessary and sufficient conditions for the existence of Kneser solutions blowing-up and vanishing at infinity for higher-order nonlinear differential equations with singularities with respect to the time and phase variables, as well as global two-sided estimates for such solutions [105, 107].

On the basis of the technique of *a priori* estimates and generalization of the notion of lower and upper Nagumo functions for differential systems, Kiguradze and his students completely studied a wide class of problems with nonlinear and nonlocal boundary conditions [30, 31, 37, 39, 43, 44, 55, 56, 58, 65, 67, 118, 126, 140, 144]. In particular, he proved the solvability of these problems for nonlinear differential equations and systems with right-hand sides rapidly increasing with respect to the phase variable, introduced the notion of a strong isolated solution of a nonlinear problem, proved the stability of such a solution under small perturbations of the differential system. Together with T Kiguradze he also obtained unimprovable sufficient conditions for solvability and unique solvability of nonlocal boundary value problems for higher-order nonlinear partial differential equations of hyperbolic type [130].

Kiguradze proved the general theorem on the solvability of a nonlinear operator equation in the Banach space (so-called principle of *a priori* boundedness), on the basis of which he established abstract analogs of the well-known Conti-Opial type theorems in the theory of differential equations [132].

A fundamental contribution was made by Kiguradze to the theory of boundary value problems on an infinite interval. In particular:

- for nonautonomous differential systems, he found unimprovable conditions which guarantee, respectively, the existence, uniqueness and stability of periodic, bounded and vanishing at infinity solutions [45, 63, 65, 80, 117, 121, 137, 138];
- for second-order nonlinear nonautonomous differential equations, he proved theorems on the existence of at least one periodic solution [18, 40] and an infinite set of periodic solutions [135], and together with S Staněk he established sufficient conditions for the existence of extremal solutions of a periodic problem [110];
- together with T Kusano, A Lomtatidze and S Baslandze he established unimprovable sufficient conditions for the existence and uniqueness of periodic solutions of higher-order nonlinear nonautonomous differential equations [59, 99, 102, 106, 108, 124, 131, 139].

Attempts to find criteria for the existence of so-called proper solutions of strongly nonlinear differential equations led Kiguradze to boundary value problems on a semiaxis with integral conditions, whose theory was developed in [51, 64, 75].

Some of the above-mentioned results, dealing with boundary value problems, were summarized in the monographs [40, 81, 82] and the surveys [65, 66], well known to specialists and often used by them.

Kiguradze has studied in detail boundary value problems for functional-differential equations, as well. In particular, together with B Půža he proved:

- criteria for the Fredholm property and well-posedness of boundary value problems with functional conditions for both regular [84, 114] and singular [109, 115] linear differential and functional-differential systems;
- description of a class of linear boundary value problems for which the entries of Green's matrix are sign-constant [81, 82, 104, 114];

- efficient and sharp conditions ensuring the unique solvability of multipoint and periodic type problems for regular linear differential systems and equations [81–84, 86, 117, 124] and two-point boundary value problems for singular differential systems [83, 115];
- optimal, in a sense, conditions for the Fredholm property and unique solvability of two-point boundary value problems for higher-order linear differential equations with strong singularities, as well as conditions for the stability of the solutions under small perturbations of the right-hand side of the equation [119, 125].

Together with S Gelashvili he found sufficient conditions for the unique solvability of multipoint boundary value problems for systems of functional-differential equations, and constructed stable finite-difference schemes for the numerical solution of such problems [78].

Having improved the technique of *a priori* estimates for solutions of one-sided differential inequalities with nonlinear boundary conditions, Prof. Kiguradze together with R Hakl, N Partsvania, B Půža, Z Sokhadze, and IP Stavroulakis developed a new method for the investigation of nonlinear boundary value problems, which was then efficiently used to obtain the following results:

- general theorems on the solvability of nonlinear boundary value problems for systems of regular [88, 92] and singular [109, 113] functional-differential equations (the principle of *a priori* boundedness and the Conti-Opial type theorems);
- optimal conditions for the local and global solvability and the unique solvability of the weighted Cauchy problem [77, 87, 89, 90] for systems of nonlinear evolution singular functional-differential equations; in the cases where there is no uniqueness, the structure of the solution set of the problem is analyzed [95];
- Kamke type theorems on the existence of minimal and maximal solutions of a multipoint and periodic boundary value problems for regular nonlinear differential systems [91, 104], as well as solvability and well-posedness criteria [91–93, 98, 103, 123, 133];
- sufficient conditions for the solvability of the Kneser and two-point boundary value problems for higher-order nonlinear functional-differential equations and for two-dimensional nonlinear functional-differential systems with advanced arguments [69, 101, 111];
- criteria for the solvability and unique solvability of the Vallée-Poussin and Dirichlet problems for singular functional-differential equations [85, 109, 122];
- an analog of the Fredholm theorem for the so-called semilinear boundary value problems, which implies, in particular, sharp integral solvability conditions of a two-point boundary value problem for semilinear second-order singular differential equations [109].

From the 1960s to the beginning of the 1990s Kiguradze and his students (T Chanturia, G Kvinikadze, D Izjumova) studied the asymptotic behavior of solutions of nonautonomous ordinary differential equations including equations with power nonlinearities of the Emden-Fowler type.

Kiguradze constructed a transformation that reduces a second-order Emden-Fowler equation to an equation with almost constant coefficients and developed a technique for the study of the latter. This method allowed him to derive asymptotic formulas for an ar-

bitrary proper solution of the general Emden-Fowler equation both in the oscillation and nonoscillation cases [3, 6, 12].

For second- and higher-order strongly nonlinear differential equations, Kiguradze proved the existence of singular solutions of the first and the second kind and proper solutions of various types (bounded, vanishing at infinity, slowly increasing, rapidly increasing, *etc.*) and established asymptotic estimates for such solutions [4, 7, 15, 49–51, 68]. For linear equations, he established asymptotic representations of solutions [5, 68] and solved the Bernatskii problem on the dimension of the space of solutions vanishing at infinity [53].

For the Emden-Fowler type two-dimensional differential system, Kiguradze together with M Cecchi, Z Došlá, and M Marini obtained optimal conditions guaranteeing the existence of positive solutions of two-point boundary value problems. On the basis of this result they proved the theorem on the existence of blow-up solutions of the above-mentioned system and obtained asymptotic estimates of these solutions [129].

Kiguradze's studies played a distinguished role in the development of the theory of oscillations of differential and functional-differential equations. He developed in some sense final criteria for the oscillation of solutions to linear differential equations and differential equations of the Emden-Fowler type [1, 2, 4, 14, 34]. For nonlinear equations of higher order, Kiguradze suggested the construction of a first-order equation the absence of whose proper solutions results in oscillation property of the original equation. The sufficient criteria of the oscillation property thus obtained are necessary for a wide class on nonlinear differential equations [1, 4, 8, 25, 35, 36, 46, 62, 68, 70].

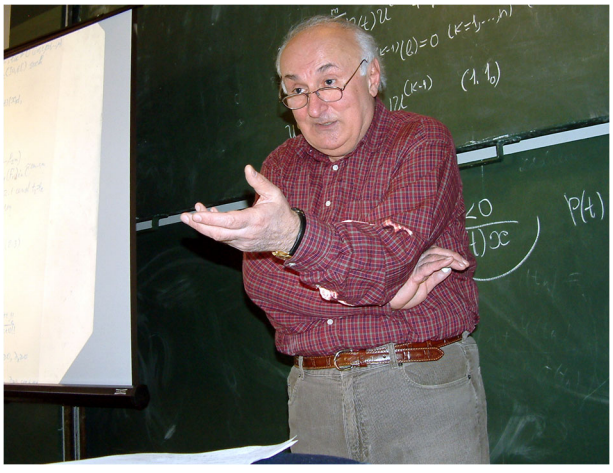
We must especially point out Kiguradze's theorems related to the existence of proper oscillatory solutions of essentially nonlinear differential equations [51, 68]. These are the results that bring the theory of oscillations into a complete form.

The most of the results by Kiguradze and his disciples on the asymptotic and oscillation of solutions of nonautonomous differential equations were summarized in his monograph [68] written jointly with T Chanturia and translated into English [71].

Deep and complete results are obtained by Kiguradze in the qualitative theory of functional-differential equations as well. In particular:

- together with Z Došlá he established criteria for boundedness, stability and vanishing at infinity of solutions of second-order linear advanced differential equations [96, 100];
- together with D Chichua he proved the theorem on the existence of proper oscillatory solutions for higher-order essentially nonlinear functional-differential equations [76];
- together with N Partsvania and IP Stavroulakis he found necessary and sufficient conditions for the oscillation of solutions of nonlinear advanced functional-differential equations [94, 97, 112];
- together with N Partsvania he proved the Esclangon-Landau type theorem on *a priori* estimates of bounded solutions of systems of higher-order nonlinear functional-differential equations [127];
- together with Z Sokhadze he established *a priori* estimates of solutions of systems of functional-differential inequalities appearing in the theory of boundary value problems, as well as in the stability theory. On the basis of these estimates, they obtained new sufficient conditions for the boundedness, uniform stability, and uniform asymptotic stability of solutions of nonlinear delay differential systems [128].

On behalf of many his friends and colleagues all over the world, let us wish Professor Ivan Kiguradze good health, a long life, and new inspiration and creative success.





**Competing interests**
The authors declare that they have no competing interests.

**Authors' contributions**
All authors read and approved the final manuscript.

**Author details**
[1]Department of Mathematics, Faculty of Science, Palacký University, 17. listopadu 12, Olomouc, 77146, Czech Republic. [2]Institute of Mathematics, Academy of Sciences of the Czech Republic, Žitná 25, Praha, 11567, Czech Republic. [3]Institute of Mathematics, Academy of Sciences of the Czech Republic, Branch in Brno, Žižkova 22, Brno, 61262, Czech Republic. [4]Department of Mathematics, Texas A&M University-Kingsville, 700 University Blvd., Kingsville, TX 78363-8202, USA. [5]Faculty of Mechanics and Mathematics, Lomonosov Moscow State University, Moscow, Russia. [6]Department of Mathematics and Computer Sciences, Ariel University, Ariel, 44837, Israel. [7]Department of Mathematics and Statistics, Faculty of Sciences, Masaryk University, Kotlářská 2, Brno, 61137, Czech Republic. [8]The Institute of Mathematics, Economics and Mechanics, Odessa I.I. Mechnikov National University, Dvoryanska 2, Odessa, 65082, Ukraine. [9]State Scientific Institution, The Institute of Mathematics, 11 Surganov Street, Minsk, 220072, Belarus. [10]Department of Mathematics, Faculty of Science, Hiroshima University, Higashi-Hiroshima, 739-8526, Japan. [11]Andrea Razmadze Mathematical Institute, I. Javakhishvili Tbilisi State University, 6, Tamarashvili Str., Tbilisi, 0177, Georgia. [12]Faculty of Mechanics and Mathematics, Taras Shevchenko National University of Kiev, Academician Glushkov Prospectus, Kyiv, 03127, Ukraine. [13]Institute of Informatics, Faculty of Business and Management, Technical University in Brno, Kolejní 2906/4, Brno, 61200, Czech Republic. [14]Department of Analysis, Faculty of Mechanical Engineering and Information Science, University of Miskolc, Miskolc-Egyetemváros, Miskolc, 3515, Hungary.

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