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PROFESSOR TIBOR ŠALÁT (1926–2005)

Pavel Kostyrko — Oto Strauch

The Workshop on the Density Concept to the honor of Professor Šalát was held in Bratislava, Slovakia, May 16–18, 2004. Nobody realized that it would be the last time we would meet Professor Šalát at a common meeting. He died at the age of 79, on May 14, 2005.

Tibor Šalát was born on May 13, 1926 in teacher's family at Vajka over Žitava, in the southern part of Slovakia. He attended the elementary school in Zlaté Moravce and in Šurany. Later he studied at the Faculty of Natural Sciences at the Charles University in Prague, where he graduated in 1950. He was greatly inspired by Czech mathematicians, such as E. Čech, V. Jarník, and M. Kössler to make his career in mathematics. After graduation he spent two years working as a teacher in Nové Zámky. In 1952, he started working for the Comenius University in Bratislava, where in 1962 he was appointed Associate Professor, and in 1977 he became Full Professor and remained working there till his death. In 1952 he obtained a doctor's degree, and in 1958 he defended his candidate thesis dealing with Hausdorff dimension of real sets. In 1974 he defended his doctoral thesis dealing with expansions of real numbers.

Tibor Šalát was one of the most appreciated Slovak mathematicians from scientific, pedagogical and social point of view. He published more than 160 papers and wrote 11 books and monographs and 10 textbooks and lecture notes, some by himself and some jointly with T. Neubrunn, P. Kostyrko, J. Smítal, and others.

Scientific results achieved by Tibor Šalát can be divided into two parts: theory of numbers and theory of real functions. Application of measure and topological methods (probability methods, Lebesgue and Hausdorff measure theory methods, Baire category methods) are common features that can be tracked down through-out his papers dealing mainly with the following areas of the theory of numbers: Cantor's expansions, Lüroth's expansions, continued fractions, summation methods, statistical convergence, uniform distribution mod 1, densities, ratio sets and some parts of the elementary theory of numbers. Papers related to the theory of real functions deal with the following: generalizations of the notions of continuity (quasi-continuity, cliquishness, some-what continuity,

A-continuity, Denjoy property), functions with closed graphs, symmetric properties of real functions, and Darboux property. Some of his results were quoted in monographs [ZB], [V], [Sch], [KN], [G], [DT], and [SP]. Here we would like to present his contribution to some branches of mathematics, while giving a selective description of his work, although an account of his contribution was given in [KS] on the occasion of his 60th birthday.

Some papers written by Tibor Šalát are devoted to the study of sets W of numbers of the form $\sum_{n=1}^{\infty} \varepsilon_n a_n$, where $\sum_{n=1}^{\infty} a_n$ is a given convergent series with positive terms and $\varepsilon_n \in \{1, -1\}$, $n = 1, 2, \dots$. It is known, that the Lebesgue measure μ of this set depends on properties of the series $\sum_{n=1}^{\infty} a_n$. If $a_k > R_k = \sum_{n=1}^{\infty} a_{k+n}$ $(k = 1, 2, \dots)$, then $\mu(W) = \lim_{n\to\infty} 2^{n+1} R_n$. The set W was investigated also by other authors (P. Kesava Menon, A. Turowicz, and others). Tibor Šalát investigated distributions of factors $+1$ and -1 with respect to Lebesgue and Hausdorff measure. He generalized known results of B. Volkmann, V. Knichal, E. Borel, and A. S. Besicovitch concerning dyadic expansions, on the set W. E.g., in [15], it is shown that an analogy of the well known Borel theorem on a distributions of terms in dyadic expansions holds for distribution of factors $+1$ and -1 for a large class of sets W with $\mu(W) = 0$. Obviously, this result is formulated using the notion of Hausdorff dimension. This is an affirmative answer to a problem raised by V. Jarník.

Other papers written by Tibor Šalát deal with the metric theory of expansion of real numbers. Especially, with continuous fractions, Cantor and Lüroth expansions of real numbers. Foundations of the metric theory of Cantor expansions were formulated by A. Rényi and P. Erdös. Their results are improved, using topological and Hausdorff measure methods in papers [16], [28]. Let $\{q_k\}_{k=1}^{\infty}$ be a sequence of integers with $q_k \geqslant 2$ for $k = 1, 2, \dots$. Any real number $0 < x < 1$ leads to the Cantor series $x = \sum_{k=1}^{\infty} \frac{\varepsilon_k(x)}{q_1 q_2 \cdots q_k}$. Assuming $\sum_{k=1}^{\infty} \frac{q_k}{(q_1 q_2 \cdots q_k)^{\varepsilon}} < \infty$ for every $\varepsilon > 0$, Tibor Šalát, in [16], has given the following explicit formula

$$\dim M_{(a_k)} = \liminf_{n\to\infty} \frac{\log \prod_{k=1}^{n} \min(a_k, q_k)}{\log \prod_{k=1}^{n} q_k}$$

for Hausdorff dimension of the set $M_{(a_k)}$ of all $x \in (0,1)$ satisfying $\varepsilon_k(x) < a_k$, $k = 1, 2, \dots$, for given positive integers a_k. This result was extended by H. Wegmann [W]. In paper [21] he formulated certain "metric valuations" of efficiency criteria for irrationality of sums of Cantor's series, which are due to A. Oppenheim (cf. [34]) are given.

Problems concerning the metric theory of continuous fractions and Cantor expansions are investigated in [33], [36], [38], [42]. In [38], he studied a transformation $T(\{x_k\}_{k=1}^{\infty}) = \sum_{k=1}^{\infty} \frac{[x_k q_k]}{q_1 q_2 \dots q_k}$ and proved that if $\lim_{n\to\infty} \frac{1}{n} \sum_{k=1}^{n} \frac{1}{q_k} = 0$, then the set $T(\{x_k\}_{k=1}^{\infty})$, where $\{x_k\}_{k=1}^{\infty}$ belongs to the family of all uniformly distributed sequences, is a set of full measure in $[0,1]$. The paper [G2] written by J. Galambos is strongly related to this result.

Foundations of the metric theory of Lüroth's series were established by L. Holzer. A detailed investigation of Lüroth expansions is done in [40] by using probabilistic methods and Lebesgue and Hausdorff measure theory. This paper completes the basic paper of L. Holzer published in 1928. Almost all basic results presented in the papers devoted to Cantor and Lüroth series, are quoted in the monograph [G]. A recent quotation of the paper [40] is in [B–K].

In papers [43] and [52], ratio sets of sets of natural numbers are introduced and investigated. For a set $A \subset \mathbb{N}$, where $\mathbb{N}$ is the set of all natural numbers, $R(A)$ denotes the set of all numbers of the form a/b, where $a, b \in A$. The set A is said to be a ratio base for the set $\mathbb{Q}^+$ of all positive rational numbers if $R(A) = \mathbb{Q}^+$, and A is called rationally dense (in the interval $(0,\infty)$) if $R(A)$ is dense in $(0,\infty)$. In [43], it is shown that if the upper asymptotic density of A is 1, then A is rationally dense. In the above mentioned papers, Tibor Šalát used the following method of dyadic numbers of sets $A \subset \mathbb{N}$, which was introduced by German mathematicians (cf. H. H. Ostmann [O; pp. 17, 189–201]): For $A = \{a_1 < a_2 < \dots\} \subset \mathbb{N}$, put $\rho(A) = \sum_{k=1}^{\infty} 2^{-a_k}$. Then ρ is a one-to-one map of the family $\mathcal{U}$ of all infinite subsets A of $\mathbb{N}$ to $(0,1]$. If $\mathcal{S} \subset \mathcal{U}$, then $\rho(\mathcal{S}) = \{\rho(A) \colon A \in \mathcal{S}\} \subset (0,1]$, and "greatness" of $\rho(\mathcal{S})$ has an influence on "greatness" of the family $\mathcal{S}$. Tibor Šalát proved, e.g., for the family $\mathcal{S}$ of all ratio bases of $\mathbb{Q}^+$, that the set $\rho(\mathcal{S})$ has full measure and is residual in $(0,1]$ (cf. [43], [52]). The method of dyadic numbers $\rho(A)$ of sets $A \subset \mathbb{N}$ is used in [60], [66], [68] for an investigation of some additive problems in the theory of numbers.

Some papers of Tibor Šalát are devoted to the study of properties of asymptotic density of sets $A \subset \mathbb{N}$ and to applications of this notion in other areas of mathematics. E.g., the statistical convergence of sequences, which was introduced by H. Fast and I. J. Schoenberg using the notion of asymptotic density is investigated in [71]. Here a distribution of statistically convergent sequences in spaces of sequences is described. In [120] (with A. Schinzel) and [122], Tibor Šalát gave three interesting examples of number-theoretic sequences statistically convergent to zero.

In papers [83], [86] (with R. Tijdeman), and [111] (with M. Paštéka), some new properties of the asymptotic density and measure density are studied. In [77] (with F. Schweiger), from the above point of view, a connection between sets $A \subset \mathbb{N}$ and their g-adic expansions are investigated. (If $A = \{a_k\}_{k=1}^{\infty}$ is an increasing sequence of positive integers, then the real number $\alpha(A) = 0, c_1, c_2, \dots$ arises in such a way that after the symbol 0 the expressions of the numbers $a_1, a_2, \dots$ in g-adic scale are successively written.) If $\mathcal{S}$ denotes the family of all $A \subset \mathbb{N}$ for which $\alpha(A)$ is simply normal, then $\rho(\mathcal{S})$ is a set of the first category in $(0,1]$ of the type $G_{\delta\sigma\delta}$ and its Lebesgue measure is 1.

H. Steinhaus observed that the set of all prime numbers has the following property (S): For every $x \in (0,\infty)$ there exists a sequence $\{q_n\}_{n=1}^{\infty}$ of primes such that $q_n/n \to x$. In paper [89] (with W. Narkiewicz), the family of all sets $A \subset \mathbb{N}$ with the property (S) is investigated in details and compared with the family of all sets $A \subset \mathbb{N}$ rationally dense in $(0,\infty)$. It is shown, e.g., that every set with the property (S) is rationally dense.

The notion of uniform distribution $\bmod 1$ is studied in papers [69], [97], [98], [102], [106], [107]. In [102] (with Š. Porubský and O. Strauch) a new type of functions, so called uniform distribution preserving functions, is introduced. Here, the function $f\colon [0,1] \to [0,1]$ is uniform distribution preserving if for any uniformly distributed sequence x_n, $n = 1,2,\dots$ in $[0,1]$ the sequence $f(x_n)$ is also uniformly distributed. Paper [102] was a motivation for some other papers. For instance, a generalization of this notion on compact spaces can be found in the paper of R. F. Tichy and R. Winkler [TW]. For current results concerning these maps, see [SP, p. 2–45, 2.5.1]

In papers dealing with the theory of real functions mostly topological methods and measure theory methods are used. These papers can be divided into several areas.

In the first collection of papers, various classes of functions are investigated ([25], [26], [47], [60], [64], [70]).

Another collection of papers deals with some generalizations of the notion of continuity ([53], [63], [67], [75], [79], [81], [82]). In [53] (with J. S. Lipiński), the set of points of quasicontinuity of real function is characterized: A set E is the set of all quasicontinuity points of a function $f\colon \mathbb{R}^n \to \mathbb{R}$ if and only if $(\operatorname{Int} E^c) - E$ is a set of the first Baire category.

Other papers are devoted to the study of properties of some important functions. E.g., a generalized Banach indicatrix in [55] and [58] is introduced and investigated. Papers [80] and [90] are devoted to the study of the exponent of convergence $\lambda(A)$, which was introduced by G. Pólya and G. Szegö for every unbounded nondecreasing sequence $A = \{a_k\}_{k=1}^{\infty}$ of positive numbers in the following way: $\lambda(A) = \inf\left\{\sigma > 0 : \sum\limits_{k=1}^{\infty} a_k^{-\sigma} < +\infty\right\}$. Let S^+ be the metric space of all sequences of the above mentioned type endowed with the Fréchet metric. The exponent of convergence is a function $\lambda\colon S^+ \to [0,+\infty)$. It is shown that λ is a function of Baire class two, everywhere discontinuous, without the Darboux property.

Some results of Tibor Šalát deal with the structural properties of some functional spaces from the Baire category point of view. E.g., in [91] (with P. Kostyrko), there is shown: Let $b\Delta$ (bA) be the metric space of all bounded derivatives (approximately continuous functions) on the interval $[0,1]$ furnished with the metric of uniform convergence. Then the set of all functions in $b\Delta$ (bA), the set of discontinuity points of which has full measure, is a residual G_δ-set in $b\Delta$ (bA). In papers [114], [115], [119] (with J. Tóth and L. Zsilinszky), the structure of the space of metrics on a given set is studied.

In the last period from 1996 to 2005, Tibor Šalát published more than 30 papers, some of them jointly with co-authors J. T. Tóth, M. Mačaj, J. Tomanová, V. Baláž, J. Červeňanský, O. Strauch, J. Bukor, J. Borsík, J. Činčura, M. Paštéka, P. Kostyrko, and others. These papers are results of his two regular scientific seminars which took place on Comenius University in Bratislava: The Number Theory Seminar and the Seminar on The Theory of Real Functions. His papers can be divided into the following main parts: The theory of densities and related convergence ([134], [137], [138], [139], [140], [142], [143], [145], [147], [148], [151], [152]); functions preserving some types of convergence ([124], [126], [136], [146]); uniform distribution theory (topological properties, porosity) ([130], [149]); and ratio sets ([127], [128]).

In [138] he introduced (with co-authors P. Kostyrko a W. Wilczyński) a new notion called I-convergence, where I is a non-empty ideal of subset of the set $\mathbb{N}$ of positive integers. Here $x_n \to x$ with respect to the ideal I if for every $\varepsilon > 0$ we have $\{n \in \mathbb{N}\colon |x_n - x| \geqslant \varepsilon\} \in I$. This notion directly extends the notion of statistical convergence. Further properties of I-convergence can be found in [143] and [152].

In [140] (with J. Tomanová), for the arithmetic function $f(n) = \prod_{d|n} d$, is proved that the sequence $(\log\log f(n))/(\log\log n)$ statistically converges to $1+\log 2$ but does not I-converge to this number if I is the ideal of all $A \subset \mathbb{N}$ for which $\sum_{a\in A} \frac{1}{a} < \infty$.

In [139] (co-authors P. Kostyrko, M. Mačaj and O. Strauch) it is proved that the set of all statistical limit points of a given real sequence x_n, $n = 1,2,\dots$, is characterized as an F_σ-set and coincides with the set of all discontinuity points of distribution functions of x_n. Here (cf. J. A. Fridy [F]) a real number x is said to be a statistical limit point of x_n if there exists a subsequence x_{k_n} such that $x_{k_n} \to x$ and the set of indices k_n has a positive upper asymptotic density.

Tibor Šalát was the editor in chief in *Acta Mathematica Universitatis Comenianae* for many years. Furthermore, he was member of the editorial board of *Mathematica Slovaca* and *Tatra Mountains Mathematical Publications*.

A great part of Tibor Šalát professional career is connected with his pedagogical activities. He was a born teacher, partly owing to his mastery of the language, but, most of all, he was an excellent teacher because of his extreme clarity of mind and his profound intellectual honesty. During more than forty years he gave almost all courses in mathematical analysis and wrote more than 10 textbooks and lecture notes for students. For many years Tibor Šalát was leading scientific seminars on the theory of real functions and on the theory of numbers. Further, he was involved in the Ph.D. research of many students and served as the supervisor for a many of them. A list of his Ph.D. students is attached.

Professor Tibor Šalát is recognized as one of the most important personalities in the area of science in Slovakia, where he was active for many years. His organizing activities included the head of the Slovak Mathematical Society. During his scientific and pedagogical work, Tibor Šalát received many appreciations and awards. Note some of them: In 1980 he was awarded the Gold Medal of the Comenius University, in 1986 the Gold Honourable Plaquette of Jur Hronec of Slovak Academy of Sciences for his merits in mathematical sciences, and in 1996 he was awarded the Jur Hronec Prize of *Matica slovenská*.

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V. List of Ph.D. students of Tibor Šalát

J. Smítal (1972)
P. Kostyrko (1972)
A. Neubrunnová (1974)
V. László (1979)
O. Strauch (1980)
J. Doboš (1986)
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M. Paštéka (1992)