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Некоторые моменты из жизни Антанаса Лауринчикаса: в поисках Универсальности

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Аннотация

Эта статья посвящена литовскому теоретико-числовику профессору Антанасу Лауринчикасу по случаю его 70-летия. Очерчиваются основные этапы развития его научной карьеры. Хотя А. Лауринчикас начал с вероятностной теории чисел, впоследствии он стал одним из ведущих мировых ученых в области теории дзета-функций, особенно в отношении их универсальности. Приводится краткий обзор его довузовской жизни и описывается развитие его карьеры математика с момента поступления в Вильнюсский университет.

Мы рассмотрим некоторые результаты Антанаса, начиная с ранних, а затем осветим основные результаты.

В конце представлен список научных публикаций А. Лауринчикаса.

Ключевые слова: Антанас Лауринчикас, Вильнюский университет, дзета-функция, предельные теоремы, универсальность, моменты дзета-функции.

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Some Moments in the Life of Antanas Laurinčikas: the Search for Universality

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Abstract

This article is dedicated to Lithuanian number theorist Professor Antanas Laurinčikas on the occasion of his 70th birthday. We sketch the main stages in the development of his scientific career. Although A. Laurinčikas started with probabilistic number theory, later on he became one of the leading world scientists in the theory of zeta-functions, especially concerning their universality. In the review we give a brief account of his pre-university life and the development of his career as a mathematician from the time he entered Vilnius University. We review some results of Antanas starting with early ones and then higlight the main results. At the end a list of scientific publications of A. Laurinčikas is presented.

Keywords: Antanas Laurinčikas, Vilnius University, zeta-functions, limit theorems, universality, moments of zeta-functions.

Bibliography: 25 titles.

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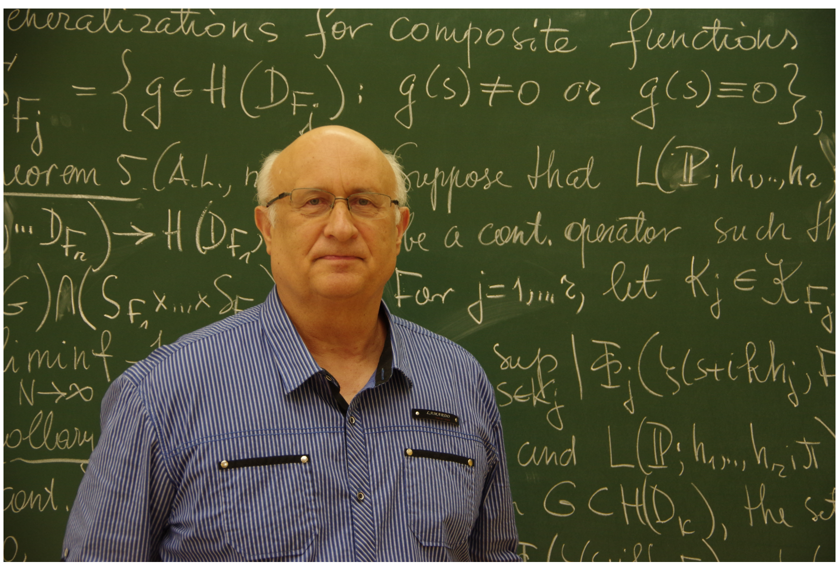
In honor of Professor Antanas Laurinčikas on the occasion of his 70th birthday



1. Short Biography with Some Scientific and Academic Activities

One of the outstanding specialists in the theory zeta functions and the developer of the analytical number theory Antanas Laurinčikas was born in Lithuania on the 17th of February 1948 in the family of Antanina Laurinčikienė and Pranas Laurinčikas. His childhood passed in a small village of Skatikai in Panevėžys district. In 1966, he graduated from Panevėžys Secondary School No. 1, was awarded the Cum Laude diploma and started his studies at the Faculty of Mathematics and Mechanics of Vilnius University.

In 1971, A. Laurinčikas graduated from Vilnius University, awarded with the diploma Cum Laude, and became a postgraduate student under supervision of Professor Kubilius, who was the leading number theorist in Lithuania at that time. In the same year, he started working in the Department of Probability Theory and Number Theory of Vilnius University.



Fig. 1: With parents and sisters Palmyra and Leontina (1948). Fig. 2-3: School year (1961, 1965).

Fig. 4: After lectures of the day are over... (1971).

Antanas Laurinčikas completed his PhD studies in three years and in 1975 defended the thesis (Candidate of Science in Physics and Mathematics) “Value Distribution of Arithmetic Functions” at Minsk University in Belarus. The opponents of his thesis were Professors Vladimir Gennadievich Sprindzuk and Aleksei Georgievich Postnikov.

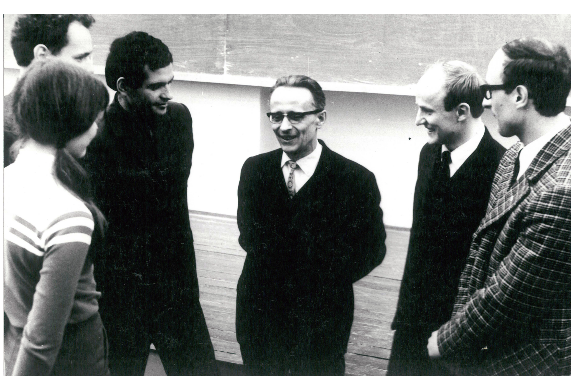



Fig. 5-6: With Professor Jonas Kubilius and colleagues (1975, 1980).

During postgraduate studies, in 1972, he got married. His wife Marytė Kopūstaitė was the last year student at the same Faculty. It is very likely that the interest in mathematics in particular has made the largest impact on occurrence of other common interests and determination to seek them further. In 1976, their family shared a great joy, since the son Laurynas was born at the end of that spring.

Fig. 7: With wife Marytė and son Laurynas (1977).

The enthusiastic and gifted young mathematician has actively pursued his research: he could not limit himself within the borders of his country, and in 1978 he went to the internship at Paris VI University under supervision of Professor Jacques Neveu. This one year long visit determined his scientific career for many years to come: the theory of zeta and L-functions has become his passion, and only from time to time he returned to the classical probabilistic number theory. During this visit, A. Laurinčikas prepared his first paper on the universality of zeta-functions which was presented for publication by the Fields medalist Professor Jean-Pierre Serre. The second internship of A. Laurinčikas took place at V. A. Steklov Mathematical Institute in Moscow in 1986. A famous mathematician Sergei Mikhailovich Voronin who proved his remarkable universality theorem for the Riemann zeta-function was his supervisor during this internship. Both the internship and the acquaintance with Voronin became crucial to Laurinčikas' further carrier.

Investigations of various problems concerning the universality property of zeta-functions became the main field of his intensive research from then and it remains up to now. Nowadays, A. Laurinčikas is one of the leading specialists in this subject worldwide and his remarkable methods are used to prove universality property for various zeta-functions and for some classes or composite zeta-functions.

In 1990, A. Laurinčikas defended his second thesis (Doctor of Science in Physics and Mathematics) "Application of Probabilistic Methods in the Theory of Value Distribution of Dirichlet Series" at Vilnius University. The thesis contains limit theorems for the Riemann zeta-function in the spaces $\mathbb{R}$ and $\mathbb{C}$, limit theorems for Dirichlet L-functions, value-distribution of Dirichlet series with multiplicative coefficients, zero-distribution of certain Dirichlet series, etc. Professors Sergei Mikhailovich Voronin, Aleksandr Vasilyevich Malyshev and Bronius Grigelionis were the opponents of the thesis.

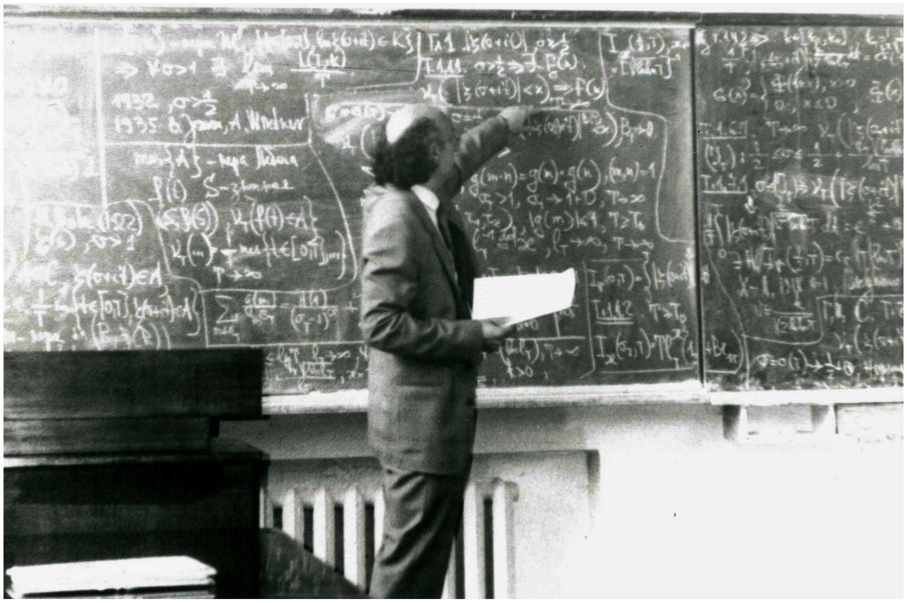


Fig. 8: Defense of the doctoral thesis (1990).

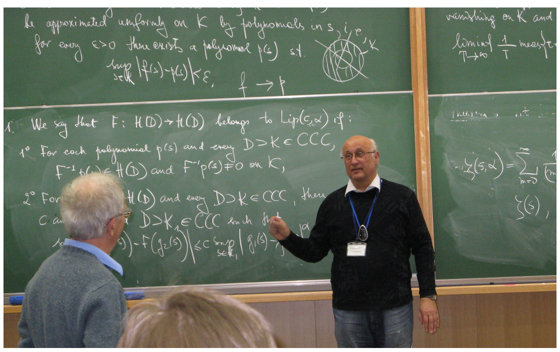
In the same year, the Doctor's Degree in Physics and Mathematics was awarded to him by the Chief Accreditation Commission, and, in 1991, Vilnius University Senate awarded him the title of Professor. Since 1994, Antanas Laurinčikas was an elected member-expert and since 2012 he is a full member of the Lithuanian Academy of Sciences.

Professor ceaselessly continued investigating analytic behaviour of zeta functions given by Dirichlet series. In 1996, he published his first monograph "Limit Theorems for the Riemann Zeta-Function" which became a standard reference in probabilistic number theory in just a decade. In some sense, this important monograph was the first textbook which is mainly devoted to the theory of universality and related topics. According to Mathematical Reviews, this monograph is already quoted 150 times. The second monograph "The Lerch Zeta-Function" was prepared by him jointly with his former PhD student Ramūnas Garunkštis and published in 2002. In general, the number of results that Antanas managed to publish is very impressive: overall, A. Laurinčikas has published almost 400 papers. Most of them by himself, but many in collaboration with some of his 41 coauthors. Most of the papers of Antanas are related to various problems in zeta-function theory. (The list of main publications is given in Section 3). They deal with limit theorems, the phenomenon of universality and its consequences, such as the functional independence and zero distribution. Other papers are related to problems of integral moments on vertical lines, the Lindelof hypothesis, Mellin transforms and other aspects of zeta-functions.

Besides the above mentioned visits, A. Laurinčikas was constantly improving his qualification and sharing his experience while participating in internships or scientific visits at various universities throughout the world, such as Bordeaux I University (1993), J. W. Goethe University in Frankfurt (2001, 2004), I. Newton Institute in Cambridge (2002), Nagoya University (1998, 2007), Research Institute of Mathematical Sciences in Kyoto (2010–2011). The subject-based relationships built during the internships resulted in the implementation of joint international projects (e.g. Limit Theorems of the Riemann Zeta Function and Its Applications; Functions in Number Theory and Their Probabilistic Aspects) and published joint papers written in cooperation with several well-known number theorists Wolfgang Schwarz, Jörn Steuding, Kohji Matsumoto and others.

Fig. 9–10: With co-authors K. Matsumoto (Nagoya, 1998), W. Schwarz and J. Steuding (Frankfurt, 2001).

A. Laurinčikas has periodically delivered his research results at the International (Zurich, 1994; Berlin, 1998; Beijing, 2002) and European (Paris, 1992; Budapest, 1996) Congresses of Mathematicians and various other conferences. In total, he gave talks at more than 100 international conferences.



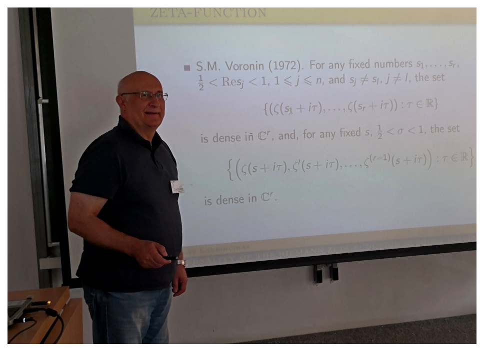


Fig. 11–12: Talks at Conferences (Kyoto, 2010; Będlewo, 2018).

In Lithuania, the results obtained by A. Laurinčikas are highly appreciated and attributed to the scientific works which greatly contributed to the development of science. Twice (which happens

Fig. 13: With President of Lithuanian Academy of Sciences B. Juodka (1999).
Fig. 14: With former PhD student R. Garunkštis (during the award of the Lithuanian Science Prize, 2015).

very rarely) Professor Laurinčikas was awarded the Lithuanian Science Prize. The first was for the cycle of papers "Investigations of Value Distribution of the Riemann Zeta-Function and Other Dirichlet Series (1979–1993)", whereas the second (jointly with his former student R. Garunkštis) was for the cycle "Zeta Functions. Universality, Zeros and Moments (1999–2013)". In particular, during the ceremony of awarding the prize he said the following: "The awarded prizes mean the acknowledgement of the entire community of Lithuanian mathematicians. Successful scientific work requires a specific microclimate, traditions, communication with colleagues. We have all this."

A. Laurinčikas is well known not only in scientific research but also in other academic activities. He is a member (since 2000, a member of the Board) of the Lithuanian Mathematical Society. Since 1992, he is a member of the American Mathematical Society. For many years he has been a member of Vilnius University Council (1991–2001), Šiauliai University Senate (1996–2005), the head of the Department of Probability Theory and Number Theory in Vilnius University (2005–2015). He takes an active part in editorial boards of several journals, like Lithuanian Mathematical Journal, Mathematical Modelling and Analysis, Moscow Journal of Combinatorics and Number Theory, Chebyshevskii Sbornik, Research in Mathematics and Mechanics, is an editor-in-chief of Šiauliai Mathematical Seminar. He is the Reviewer of International Data Bases like Mathematical Reviews, Zentralblatt MATH and the Review Journal (in Russian). A. Laurinčikas is one of the main organizers of the international conferences "Analytic and Probabilistic Methods in Number Theory" arranged in honour of Jonas Kubilius and co-editor of the proceedings of those conferences. He is also a member of the Organizing or Programme Committees of IV, V and VI international conferences "Algebra and Number Theory: Modern Problems an Applications" (Russia), "Voronoï Conferences on Analytic Number Theory and Space Tilings" (Ukraine), V, VI and VII "International Algebraic Conferences in Ukraine". For many years he was in charge of scientific seminars in Number Theory in Vilnius and Šiauliai Universities. Professor is often invited to participate in the doctoral dissertation defences as a member of the Council, opponent and expert both in Lithuania and abroad (Russia, Belarus, Ukraine, Germany, Finland).

Pedagogical work is the activity that A. Laurinčikas has been closely involved into too. He has supervised several young researchers to their graduation and formed a strong Lithuanian school. In total Antanas was a scientific advisor of 28 PhDs in Mathematics and currently is an advisor of 5 new PhD students. Professor continuously cooperates with his former PhD students, prepares not only papers but also textbooks for students: "Basics of the Theory of Riemann Zeta-Function", "The Lerch Zeta-Function", "Distribution of Prime Numbers", "Introduction to the Theory of Dirichlet Series". We hope that this kind of cooperation will continue in the future.

Fig. 15: With Chairman of Šiauliai University Senate A. Gudavičius and Rector V. Laurutis (Doctor Honoris Causa Inauguration, 2007).
Fig. 16: The Rector of Vilnius University, A. Žukauskas, congratulates on the occassion of the jubilee (2018).

Apart from the Lithuanian Science Prizes, Antanas Laurinčikas has beed honored for various scientific achievements and other academic and pedagogical activities. He was awarded the Medal of Zigmas Žemaitis by the Lithuanian Mathematical Society for his contributions to science, culture and education (2005), he received Vilnius University Rector's award for outstanding scientific achievements (2004, 2009), Vilnius University Rector's acknowledgement (2003, 2006, 2018), Šiauliai University Rector's acknowledgement (2017), Šiauliai University Science Award for a Group of Scientists (leader A. Laurinčikas) for the scientific progress in Šiauliai University (2015). In 2007, Professor Laurinčikas was inaugurated as the Doctor Honoris Causa of Šiauliai University.

To honor Professor A. Laurinčikas, the International Conferences on Number Theory are organised in Lithuania every five years since 2008. Moreover, on the occasion of the 60th jubilee, a book with the bibliographical index of the works by A. Laurinčikas over the period 1972–2008 has been published [6]. It indexes all his research papers, conference presentations and abstracts, preprints, feature articles for public, edited collections of papers and reviewed articles, presented a list of his membership in conference committees as well a list of his works cited by other authors etc.

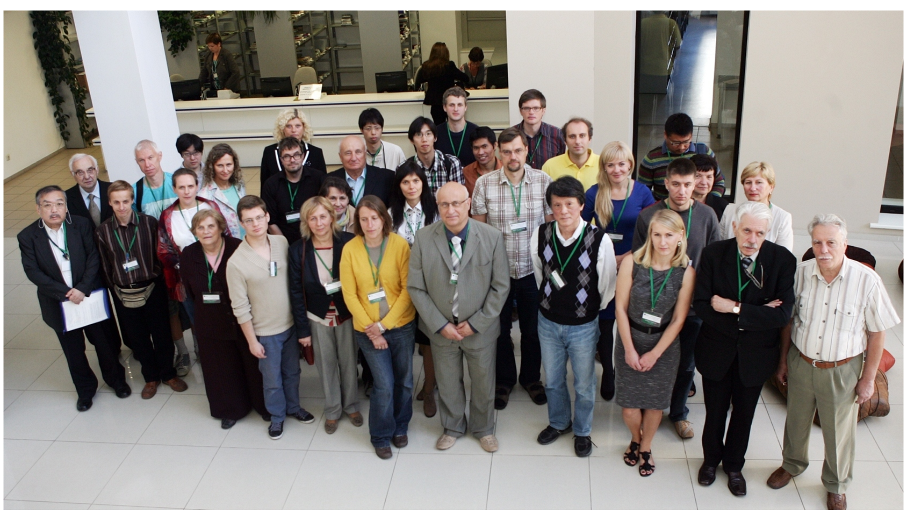


Fig. 17–18: Conferences on Number Theory dedicated to the 60th and 65th birthdays of Antanas.

At the end of this section, we would like to emphasize the most important thing, i.e. Antanas' personal humanity. Everyone who knows him will agree that this Personality is not only a wise and diligent mathematician, but also an example of decency, devotion and tolerance.

2. The Main Problems Considered by A. Laurinčikas

Professor Antanas Laurinčikas has been working on various and quite different topics of number theory for almost fifty years now. It is quite difficult to give a detailed report about every topic. However, ten years ago Professor Jörn Steuding wrote a comprehensive and deep survey on A. Laurinčikas' scientific work *The Mathematical Work of Antanas Laurinčikas – an Interim Report* – [23]. Therefore, in the forthcoming sections we will highlight some of the most representative, significant and possibly important results of his oeuvre. Of course, this choice is very subjective, but we believe that these themes are the most important ones to him too.

2.1. Probabilistic Limit Theorems for Real Multiplicative Arithmetic Functions

The first scientific steps of Antanas Laurinčikas were matching the traditional trajectories of investigation of the Lithuanian school of number theory at that time. They were related mainly with some topics in the theory of arithmetical functions and probabilistic number theory.

A. Laurinčikas prepared his first scientific work jointly with Professor J. Kubilius in the last year of his university studies (1972). Under some additional hypotheses, they obtained a theorem of large deviations for some class $\mathfrak{M}$ of multiplicative functions.

Denote by $N(...)$ the number of $m \in \mathbb{N}$ satisfying the hypotheses written in place of dots.

Theorem 1. *Suppose that $g(m) \in \mathfrak{M}$, $n \to \infty$ and $x = o(\sqrt{\log\log n})$. Then, for the numbers*

$$N\left(m \le n,\, 0 < g(m) < \exp\left\{\lambda \log\log n + x|\lambda|\sqrt{\log\log n}\right\}\right) \quad if \quad x \le 0,$$

$$N\left(m \le n,\, g(m) > \exp\left\{\lambda \log\log n + x|\lambda|\sqrt{\log\log n}\right\}\right) \quad if \quad x \ge 0,$$

the formula

$$n\beta_0 \Phi\left(-|x|\right) \mathrm{e}^{Q_n(x)} \left(1 + \frac{O(|x|+1)}{\sqrt{\log\log n}}\right)$$

is true, while, for the numbers

$$N\left(m \le n,\, -\exp\left\{\lambda \log\log n + x|\lambda|\sqrt{\log\log n}\right\} < g(m) < 0\right) \quad if \quad x \le 0,$$

$$N\left(m \le n,\, g(m) < -\exp\left\{\lambda \log\log n + x|\lambda|\sqrt{\log\log n}\right\}\right) \quad if \quad x \ge 0,$$

the formula

$$n\beta_1 \Phi\left(-|x|\right) \mathrm{e}^{Q_n(x)} \left(1 + \frac{O(|x|+1)}{\sqrt{\log\log n}}\right)$$

is true. Here

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \int\limits_{-\infty}^{x} \mathrm{e}^{-\frac{u^2}{2}} \,\mathrm{d}u,$$

$$\beta_k = \frac{\omega_0 + (-1)^k \omega_1}{2}, \quad \omega_k = \prod_p \sum_{\substack{\alpha=0 \\ g(p^\alpha)\neq 0}}^{\infty} \frac{\mathrm{sgn}^k g(p^\alpha)}{p^\alpha}, \quad k = 0, 1,$$

$$Q_n(x) = \frac{x^2}{2} + \xi - (1+\xi)\log(1+\xi)\log\log n, \quad \xi = \frac{x\,\mathrm{sgn}\lambda}{\sqrt{\log\log n}}.$$

During his postgraduate studies, A. Laurinčikas created the theory of multidimensional characteristic transforms and, using them, obtained the multidimensional asymptotic distribution laws for real multiplicative functions. Also, he developed the theory of characteristic transforms of probability measures on the complex plane and obtained the asymptotic distribution laws for complex-valued multiplicative functions.

Let P be a probability measure on $(\mathbb{C}, \mathcal{B}(\mathbb{C}))$. The characteristic transform $\varphi(t,k)$ of P is defined by the formula

$$\varphi(t,k) = \int\limits_{\mathbb{C}\setminus\{0\}} |z|^{it} \mathrm{e}^{ik \arg z} \mathrm{d}P, \quad t \in \mathbb{R}, \quad k \in \mathbb{Z}.$$

In 1975, he proved several continuity theorems for probability measures on $(\mathbb{C}, \mathcal{B}(\mathbb{C}))$ in terms of characteristic transforms and applied this to prove limit theorems for the complex-valued function

$$\left(A'_n g(m)\right)^{\frac{1}{B'_n}} \mathrm{e}^{i \frac{f(m) - A''_n}{B''_n}},$$

where $g(m)$ and $f(m)$ are real multiplicative and additive arithmetic functions, respectively, and A', A'' and $B'_n > 0$, $B''_n > 0$ are certain normalising constants. The distribution laws obtained generalized those of the famous paper of H. Delange [5]. Also, A. Laurinčikas under influence of Professor I. Kátai, considered multiplicative functions defined on the set of values of polynomials. For them he obtained asymptotic distribution laws with estimates of the rate of convergence.

Since 1980, A. Laurinčikas focuses on the theory of zeta-functions, but from time to time he returns to classical probabilistic number theory.

2.2. Moment Problem

For the zeta-function $Z(s)$ with critical line $\sigma = \sigma_c$, the moment problem consists of finding the asymptotics or estimates for

$$I_k(\sigma, T; Z) = \int\limits_0^T |Z(\sigma + it)|^{2k} \, \mathrm{d}t, \quad \sigma \geq \sigma_c, \quad k \geq 0,$$

as $T \to \infty$. In various problems the results of such kind replace the individual values of zeta-functions. For example, the Lindelöf conjecture states that

$$\zeta\left(\frac{1}{2} + it\right) \ll_\epsilon t^\epsilon, \quad t \geq t_0 > 0,$$

with every $\epsilon > 0$ is equivalent to the estimate

$$I_k\left(\frac{1}{2}, T; \zeta\right) \ll_{\epsilon,k} T^{1+\epsilon}, \quad k \in \mathbb{N}.$$

Also, there is a conjecture [24] asserting that

$$I_k\left(\frac{1}{2}, T; \zeta\right) \sim c(k) T (\log T)^{k^2}$$

as $T \to \infty$. However, the progress in this problem is very slow. For example, G. H. Hardy and J. E. Littlewood (1918) proved that $c(1) = 1$, A. E. Ingham (1926) evaluated $c(2) = \frac{1}{2\pi^2}$ and A. Laurinčikas (1996) showed that $c\left(u(\sqrt{2 \log\log T})^{-1}\right) = 1$, $u > 0$.

Let $\sigma_T = \frac{1}{2} + \frac{1}{l_T}$ with $l_T > 0$, $l_T \nearrow \infty$,

$$\kappa_T = \begin{cases} \left(2^{-1}\log l_T\right)^{-\frac{1}{2}} & \text{if} \quad l_T \le \log T, \\ \left(2^{-1}\log\log T\right)^{-\frac{1}{2}} & \text{if} \quad l_T \ge \log T, \end{cases}$$

and $L_T = \min(l_T, \log T)$. Similarly to the case $\sigma = \frac{1}{2}$, there is a conjecture asserting that

$$I_k\left(\sigma_T, T; \zeta\right) \sim a(k) L_T^{k^2}$$

as $T \to \infty$. J. B. Conrey and A. Ghosh proved the following [4]: under assumption of the Riemann hypothesis, one has

$$I_k\left(\frac{1}{2}, T; \zeta\right) \ge (c_k + o(1)) T (\log T)^{k^2}.$$

A. Laurinčikas (1995) generalized it and proved the estimate

$$I_k\left(\sigma_T, T; \zeta\right) \ge a_k T L_T^{k^2}$$

with some explicit a_k. Also, various unconditional and conditional estimates were obtained for $I_k\left(\sigma_T, T; \zeta\right)$ with fractional k.

Let

$$E(\sigma, T) = I_1(\sigma, T; \zeta) - \zeta(2\sigma) T - (2\pi)^{2\sigma - 1}(2 - 2\sigma)^{-1}\zeta(2 - 2\sigma) T^{2 - 2\sigma}.$$

The Atkinson type formula estimates and the mean square estimates were obtained for $\frac{1}{2} < \sigma < 1$, by K. Matsumoto and T. Meurman [19], and by A. Ivič and K. Matsumoto [11]. A. Laurinčikas (1992, 1993) considered their versions for $\sigma = \sigma_T$ and uniformly with respect to σ.

Jointly with his students A. Laurinčikas investigated moments of various other zeta-functions and obtained some asymptotical formulas. In 2001, jointly with D. Šiaučiūnas he proved an asymptotical formula for $I_1(\sigma, T; \zeta(s; \mathfrak{a}))$, $1/2 \le \sigma < 1$, where $\zeta(s; \mathfrak{a})$ is classical periodic zeta-function. D. Klusch [15] obtained asymptotical formula for $I_1(\sigma, T; L(\lambda, \alpha, s))$, $1/2 \le \sigma \le 1$, where $L(\lambda, \alpha, s)$ is the Lerch zeta-function. A. Laurinčikas jointly with R. Garunkštis and J. Steuding (2003) proved an approximate functional equation for $L(\lambda, \alpha, s)$ and estimated the error term in Klusch's formulae. Some results were obtained for the functions

$$\zeta_\lambda(s) = \sum_{m=1}^{\infty} \frac{\mathrm{e}^{2\pi i \lambda m}}{m^s}, \quad \sigma > 1.$$

In this case, with D. Šiaučiūnas he obtained (2007, 2009) the asymptotics for $I_2(\sigma, T; \zeta_\lambda)$ with irrational and rational λ. Also, jointly with J. Karaliūnaitė (2007) he proved an average version of the Atkinson type formula for $\zeta_\lambda(s)$ on the critical line.

A lot of attention has been paid to zeta function

$$\zeta(s, F) = \sum_{m=1}^{\infty} \frac{c(m)}{m^s}, \quad \sigma > \frac{\kappa + 1}{2},$$

where F is a normalized Hecke eigen cusp form of weight κ with respect to the full modular group with coefficients $c(m)$, $m \in \mathbb{N}$, of the Fourier series expansion at ∞. A. Laurinčikas jointly with R. Ivanauskaitė (2005), under an analogue of Riemann hypothesis for $\zeta(s, F)$, obtained the following asymptotical formula

$$I_{2u\kappa_T}(\sigma_T, T; \zeta(s, F)) = T \mathrm{e}^{\frac{\kappa^2}{2}} (1 + \mathrm{o}(1)), \quad T \to \infty,$$

uniformly in $u > 0$ in every bounded interval, where

$$\sigma_T = \frac{\kappa}{2} + \frac{\phi_T\sqrt{\log\log T}}{\log T},$$

$\phi_T > 0$, $\phi_T \to \infty$ and $\log\phi_T = \mathrm{o}(\log\log T)$. Moreover, jointly with J. Steuding (2007) he proved that, for $k = \frac{1}{n}$,

$$I_{2k}\left(\frac{\kappa}{2}, T; \zeta(s, F)\right) \gg T(\log T)^{k^2},$$

and, under an analogue of the Riemann hypothesis,

$$I_{2k}\left(\frac{\kappa}{2}, T; \zeta(s, F)\right) \ll T(\log T)^{k^2}.$$

Many authors investigated moments of Dirichlet L-functions $L(s,\chi)$, where χ is a Dirichlet character modulo q. A. Laurinčikas jointly with A. Kačėnas and S. Zamarys (2005) obtained the estimates, for $k = \frac{1}{n}$, $n \in \mathbb{N}$,

$$c_1(q)T(\log T)^{k^2} \ll I_k\left(\frac{1}{2}, T; L(s,\chi)\right) \le c_2(q)T(\log T)^{k^2},$$

where $c_1(q) \le c_2(q)$ are positive constants.

2.3. Limit Theorems

An idea of application of probabilistic methods in the theory of zeta-functions belongs to H. Bohr. This idea was realized in joint work with B. Jessen [2]. They proved that, for $\sigma > 1$, the limit

$$\lim_{T\to\infty} \frac{J\{t \in [0,T] : \log\zeta(\sigma + it) \in R\}}{T}$$

exists, where $J\{A\}$ denotes the Jordan measure of a measurable set $A \in \mathbb{R}$, and R is a rectangle on $\mathbb{C}$ with edges parallel to the axis. Two years later, they extended the above result to the region $\sigma > \frac{1}{2}$. In their proof Bohr and Jessen created and used the theory of sums of convex curves. The rate of convergence in Bohr-Jessen's theorems was estimated by K. Matsumoto in [16] and [17], and jointly with G. Harman in [9]. A generalization of Bohr-Jessen's results for more general zeta-functions was given by K. Matsumoto for zeta-functions of cusp forms, Dedekind zeta-functions, zeta-functions of algebraic number fields, zeta-functions given by polynomial Euler product (1989, 1990, 1991, 1992).

New versions of Bohr-Jessen's theorems were given by B. Jessen and A. Wintner [13]. More precisely, they developed a method of infinite convolutions of probability measures. Later V. Borchsenius and B. Jessen [3] gave a method of almost periodic functions.

In the fifth decade of 20th century, the theory of the weak convergence of probability measures was created and developed by A. N. Kolmogorov, P. Erdös, M. Kac, J. L. Doob, M. Donsker, Yu. V. Prokhorov, L. LeCam, V. S. Varadarajan.

Let $\mathcal{B}(X)$ denote the Borel σ-field of the metric (or topological) space X, and P and P_n, $n \in \mathbb{N}$, be probability measure on $(X, \mathcal{B}(X))$. We recall that P_n, as $n \to \infty$, converges weakly to P if, for every real continuous bounded function f on X,

$$\lim_{n\to\infty} \int_X f\mathrm{d}P_n \to \int_X f\mathrm{d}P.$$

It turned out to be convenient to state Bohr-Jessen's type results in the form of limit theorems on the weak convergence of probability measures.

At that time, A. Laurinčikas had already a good knowledge in probability theory because his advisor Professor J. Kubilius was not only a number theorist but also a probabilist, and the advisor in Paris VI Professor J. Neveu was an expert in probability theory too. Thus, Antanas started to use the classical probabilistic theory and application of probabilistic methods in the theory of zeta-functions. As we have mentioned above, this was realized in the thesis of doctor of sciences, and some years later, in his monograph devoted to limit theorems not only for the Riemann zeta-function but also for Dirichlet L-functions and more general Dirichlet series.

For example, the Bohr-Jessen theorem can be stated in the following form.

THEOREM 2. *Suppose that $\sigma > \frac{1}{2}$ is fixed. Then, on $(\mathbb{C}, \mathcal{B}(\mathbb{C}))$, there exists a probability measure P_σ such that*

$$\frac{1}{T}\text{meas}\left\{t \in [0,T] : \zeta(\sigma+it) \in A\right\}, \quad A \in \mathcal{B}(\mathbb{C}),$$

converges weakly to P_σ as $T \to \infty$.

The behaviour of $\zeta(s)$ on the critical line $\sigma = \frac{1}{2}$ is more complicated, since in this case a certain normalization is needed. Probably in 1945, A. Selberg (unpublished) obtained the following limit theorem in this case: for any measurable set $A \subset \mathbb{C}$ having a positive Jordan content,

$$\frac{1}{T}\text{meas}\left\{t \in [0,T] : \frac{\log\zeta(\frac{1}{2}+it)}{\sqrt{\log\log t}} \in A\right\} = \frac{1}{\pi}\int\limits_A \mathrm{e}^{-x^2-y^2}\mathrm{d}x\mathrm{d}y.$$

This was generalized in the monograph of D. Joyner [14], for more general zeta-functions.

A. Laurinčikas considered $\zeta\left(\frac{1}{2}+it\right)$ itself but not the logarithm $\log\zeta(\frac{1}{2}+it)$. Let

$$G(x) = \begin{cases} \Phi(\log x) & \text{if} \quad x > 0, \\ 0 & \text{if} \quad x \le 0, \end{cases} \qquad \Phi(x) = \frac{1}{\sqrt{2\pi}}\int\limits_{-\infty}^{x} \mathrm{e}^{-\frac{u^2}{2}}\mathrm{d}u.$$

With this notation, in 1996, A. Laurinčikas proved the following:

THEOREM 3. *Let $l_T \le \log T$ and $\sigma_T = \frac{1}{2} + \frac{1}{l_T}$. Then the distribution function*

$$\frac{1}{T}\text{meas}\left\{t \in [0,T] : |\zeta(\sigma_T+it)|^{\frac{1}{\sqrt{2^{-1}\log l_T}}} < x\right\}$$

converges pointwise to $G(x)$ as $T \to \infty$.

Let $\phi_T \nearrow \infty$ and $\phi_T = o(\log\log T)$ as $T \to \infty$. Then, for $\sigma \in \left[\frac{1}{2}, \frac{1}{2} + \frac{\phi_T\sqrt{\log\log T}}{\log T}\right]$, the distribution function

$$\frac{1}{T}\text{meas}\left\{t \in [0,T] : |\zeta(\sigma+it)|^{\frac{1}{\sqrt{2^{-1}\log\log T}}} < x\right\}$$

converges pointwise to $G(x)$ as $T \to \infty$.

Similar results also hold in the complex plane. For example, the probability measure

$$\frac{1}{T}\text{meas}\left\{t \in [0,T] : \left(\zeta\left(\frac{1}{2}+it\right)\right)^{\frac{1}{\sqrt{2^{-1}\log\log T}}} \in A\right\}, \quad A \in \mathcal{B}(\mathbb{C}),$$

converges weakly to the lognormal probability measure on $(\mathbb{C}, \mathcal{B}(\mathbb{C}))$ as $T \to \infty$. Some results near the critical line $\sigma = \frac{\kappa}{2}$ were obtained by A. Laurinčikas jointly with his student R. Ivanauskaitė

(2005) for zeta-functions of normalized Hecke eigen cusp forms of weight κ for the full modular group.

Also, limit theorems in various spaces were obtained by A. Laurinčikas for Matsumoto zeta-functions (class of zeta-functions defined by polynomial Euler product), Hurwitz zeta-functions, Lerch zeta-functions, periodic Hurwitz zeta-functions, periodic zeta-functions, Esterman zeta-functions, zeta-functions of cusp forms, zeta-functions of newforms, Dirichlet L-functions, zeta-functions of finite Abelian groups, zeta-functions of elliptic curves, general Dirichlet series, some classes or sublasses of zeta-functions (e.g. for zeta-functions from a sublass of the Selberg class) and for various composite functions of zeta-functions. A. Laurinčikas began to consider weighted limit theorems for zeta-functions too. For example, he proved weighted limit theorems for general Dirichlet series, for twists with Dirichlet character of zeta-functions of cusp forms, for zeta-functions of elliptic curves, etc. A lot of mentioned results are given jointly with his former PhD students R. Kačinskaitė, J. Ignatavičiūtė, R. Šleževičienė, I. Belovas, J. Genys, V. Balinskaitė, A. Javtokas, A. Kolupayeva and others.

In principle, in such problems one can investigate continuous and discrete cases. In the continuous case, the weak convergence of the measure

$$\frac{1}{T}\text{meas}\left\{t \in [0,T] : Z(s+i\tau) \in A\right\}, \quad A \in \mathcal{B}(X),$$

as $T \to \infty$, can be investigated, where the shifts τ can take arbitrary real values. While, in discrete case, the shift τ takes values from certain discrete set, and the weak convergence of the measure

$$\frac{1}{N+1}\#\left\{0 \le m \le N : Z(s+imh) \in A\right\}, \quad A \in \mathcal{B}(X),$$

as $N \to \infty$, $h > 0$ is a fixed number, is analyzed. Here, X can be $\mathbb{R}$, $\mathbb{C}$, the space of analytic functions $H(G)$ or meromorphic functions $M(G)$, where G is a region in $\mathbb{C}$.

Limit theorems in the space $H(G)$ are important themselves and have applications in the theory of universality. Theorems of such a kind were proposed by B. Bagchi in his PhD thesis [1]. A. Laurinčikas developed and simplified Bagchi's method and applied it for many other classes of zeta-functions. J. Steuding extended [22] this theory for L-functions from the Selberg class.

2.4. Universality

Universality of zeta-functions is the main field of investigations of A. Laurinčikas. Most of his results are described in detail in a very extensive survey on the universality for zeta and L-functions [18] prepared by Professor Kohji Matsumoto.

In 1975, S. M. Voronin discovered the universality of the Riemann zeta-function [25]. Let $0 < r < \frac{1}{4}$. Voronin proved that, for any continuous non-vanishing function $f(s)$ in the disc $|s| \le r$ which is analytic in the open disc $|s| < r$, and every $\varepsilon > 0$, there exists a real number $\tau = \tau(\varepsilon)$ such that

$$\max_{|s|\le r}\left|\zeta\left(s+\frac{3}{4}+i\tau\right) - f(s)\right| < \varepsilon.$$

This interesting result has been noticed and further developed by many mathematicians.

S. M. Gonek [8] in his PhD thesis developed Voronin's method and obtained the joint universality (hybrid) for Dirichlet L-functions. He also proved universality of Hurwitz zeta-functions with rational parameter. As we have already mentioned above, in 1979, A. Laurinčikas obtained the universality for a class of Dirichlet series with multiplicative coefficients. In fact, he likes very much a probabilistic approach in the proof of universality that is based on limit theorems in the space $H(D)$, where D is the right-hand side of the critical strip. A. Reich, B. Bagchi and A. Laurinčikas improved Voronin's theorem to the following more general statement.

Let $\mathcal{K}$ be a class of compact subsets of $D = \{s \in \mathbb{C} : \frac{1}{2} < \sigma < 1\}$ with connected complements, and let $H_0(K)$, $K \in \mathcal{K}$, be the class of continuous non-vanishing functions on K which are analytic in the interior of K. Then, the following is true:

Theorem 4. *Let $K \in \mathcal{K}$ and $f(s) \in H_0(K)$. Then, for every $\epsilon > 0$,*

$$\liminf_{T\to\infty} \frac{1}{T} \text{meas} \left\{ \tau \in [0, T] : \sup_{s \in K} |\zeta(s + i\tau) - f(s)| < \epsilon \right\} > 0.$$

Universality of other zeta and L-functions, including the functions approximating all analytic not necessary non-vanishing functions defined on the strip D, has been considered by A. Laurinčikas too. For example, universality for the Lerch zeta-function (1997, 2000, 2010), for the Matsumoto zeta-function (1998), for zeta-functions of cusp forms (with K. Matsumoto, 2001), for zeta-functions attached to finite Abelian groups (2001), for zeta-functions with multiplicative coefficients (with R. Šleževičienė, 2002), for Estermann zeta-functions (with R. Garunkštis, R. Šleževičienė and J. Steuding, 2002), for general Dirichlet series (with W. Schwarz and J. Steuding, 2003), for zeta-functions of elliptic curves (with V. Garbaliauskienė, 2005), for zeta-functions of new forms (with K. Matsumoto and J. Steuding, 2003, 2005), for periodic Hurwitz zeta-functions (with A. Javtokas, 2006; R. Macaitienė, 2009), for periodic zeta-functions (with D. Šiaučiūnas, 2007, 2010), for some functions related to zeta-functions of certain cusp forms (with K. Matsumoto and J. Steuding, 2013; with D. Šiaučiūnas, 2018), for the Hurwitz zeta-function (with E. Buivydas, R. Macaitienė and J. Rašytė, 2012, 2014), for the functions from the Selberg class (with R. Macaitienė, 2017), etc.

Moreover, A. Laurinčikas gave a generalization of Theorem 4 to composite functions, e.g. $F(\zeta(s))$, $F(\zeta(s, \alpha))$, where $F : H(D) \to H(D)$ is a certain operator (2011, 2012; with K. Janulis, D. Jurgaitis and R. Macaitienė, 2016), and an interesting hybrid universality of certain composite functions involving Dirichlet L-functions (with K. Matsumoto and J. Steuding, 2013). From general theorems, one can derive the universality of elementary functions, for example, of $\sin \zeta(s)$, $\sinh \zeta(s)$, $e^{\zeta(s)}$, $\zeta^k(s)$.

For zeta-functions the joint universality is also known. In this case, a collection of analytic functions is approximated simultaneously by shifts of zeta-functions. The first results in this direction were obtained independently by S. M. Voronin (1975), S. M. Gonek (1979) and B. Bagchi (1981) for Dirichlet L-functions $L(s, \chi)$. The last version of such a universality was given by A. Laurinčikas in 2011.

Theorem 5. *Let $\chi_1, ..., \chi_r$ be pairwise non-equivalent Dirichlet characters. For $j = 1, ..., r$, let $K_j \in \mathcal{K}$ and $f_j(s) \in H_0(K_j)$. Then, for every ϵ, one has*

$$\liminf_{T\to\infty} \frac{1}{T} \text{meas} \left\{ \tau \in [0, T] : \sup_{1 \le j \le r} \sup_{s \in K_j} |L(s + i\tau, \lambda_j) - f_j(s)| < \epsilon \right\} > 0.$$

Note that zeta-functions having a joint universality property must be independent in a certain sense. Therefore, for the joint universality of zeta functions some additional hypotheses are needed. In the case of Dirichlet L-functions, the independence is ensured by non-equivalence of characters. Therefore, the joint universality for zeta-functions is a more complicated problem than that of ordinary universality.

A. Laurinčikas considered the question of joint universality in detail. He has obtained various results for the Lerch zeta-functions (with K. Matsumoto, 2006), Hurwitz zeta-functions (2008, 2013) and periodic Hurwitz zeta-functions (with A. Javtokas, 2008; with S. Skerstonaitė, 2009; with J. Rašytė, 2012, 2014), periodic zeta-functions (2006, 2007; with R. Macaitienė, 2009; 2016), twists of automorphic L-functions (with K. Matsumoto, 2004), zeta-functions with periodic coefficients (2010), Dirichlet L-functions (with A. Dubickas, 2015), Lerch zeta-functions (with A. Mincevič, 2018), etc.

Furthermore, A. Laurinčikas investigated a so-called mixed joint universality initiated by H. Mishou (2007) who obtained the joint universality for the Riemann zeta and Hurwitz zeta-functions [20]. In a wide sense, the mixed joint universality is understood as a joint universality for zeta or L-functions having and not having Euler product. So, a lot of interesting results on mixed joint universality for some zeta and L-functions have been obtained by A. Laurinčikas too. For example, for periodic zeta-function with multiplicative coefficients and periodic Hurwitz zeta-functions (2010; with R. Kačinskaitė, 2011), for zeta functions of normalized Hecke cusp forms and Hurwitz zeta-functions (with D. Šiaučiūnas, 2012), for the Riemann and Lerch zeta-functions (with R. Macaitienė, 2013), for Dirichlet L-functions and Lerch zeta-functions (with R. Macaitienė, 2014), for the Riemann and Hurwitz zeta-functions (with E. Buivydas, 2015), for Dirichlet L-functions and Hurwitz zeta-functions (with K. Janulis, 2013; with J. Karaliūnaitė and V. Garbaliauskienė, 2017), for the Riemann and periodic Hurwitz zeta-functions (with R. Macaitienė, 2018).

J.-L. Mauclaire and A. Laurinčikas introduced independently a modified version of universality for zeta-functions when the positivity of a lower density of the set of approximating shifts is replaced by that of the density. For example, in the case of the Riemann zeta-function, he obtained with L. Meška (2014) that if $K \in \mathcal{K}$ and $f(s) \in H_0(K)$, then the limit

$$\lim_{T\to\infty} \frac{1}{T} \text{meas} \left\{ \tau \in [0,T] : \sup_{s\in K} |\zeta(s+i\tau) - f(s)| < \varepsilon \right\} > 0$$

exists for all but at most countably many $\varepsilon > 0$. The latter result was extended to other zeta-functions as well.

We recall that a sequence $\{x_k : k \in \mathbb{N}\} \subset \mathbb{R}$ is called uniformly distributed modulo 1 if, for every interval $[a,b) \subset [0,1)$,

$$\lim_{n\to\infty} \frac{1}{n} \sum_{k=1}^{n} \chi_{[a,b)}(\{x_k\}) = b - a,$$

where $\chi_{[a,b)}$ is the indicator function of $[a,b)$, and $\{x_k\}$ denotes the fractional part of x_k. A. Dubickas and A. Laurinčikas (2016) proposed an application of sequences that are uniformly distributed modulo 1 to discrete universality. This idea was successfully implemented in some later papers by Antanas and his students.

A. Laurinčikas with his former students R. Garunkštis and R. Macaitienė (2017, 2018) began to use imaginary parts γ_k of non-trivial zeros of the Riemann zeta-function in discrete shifts $Z(s+i\gamma_k h)$, $h > 0$, of zeta-functions Z approximating analytic functions. Moreover, jointly with D. Šiaučiūnas and A. Vaiginytė (2018) he extended universality theorems for shifts $Z(s + i\varphi(\tau))$ with a certain differentiable function $\varphi(\tau)$.

Universality of zeta-functions contains one very important problem – all universality theorems are not effective in the sense that, although the set of shifts $Z(s + i\tau)$ approximating a given analytic function is infinite, we do not know any concrete value τ with approximating property. For applications, it suffices to know an interval for τ. However, this seems to be a very complicated problem too.

A. Laurinčikas observed (1997) that the universality effectivization problem for the Riemann zeta-function can be reduced to the estimate of rate of convergence in a limit theorem in the space of analytic functions. Let f be a function which we want to approximate, and

$$A(\epsilon, f) = \{g \in H(D) : \rho(f,g) < \epsilon\}.$$

Suppose that $A(\epsilon, f)$ is a continuity set of the limit measure P_ζ in a limit theorem for $\zeta(s)$, i.e.,

$$\frac{1}{T} \text{meas} \{\tau \in [0,T] : \zeta(s+i\tau) \in A(\epsilon, f)\} = P_\zeta(A(\epsilon, f)) + R_T(\epsilon, f),$$

where

$$\lim_{T\to\infty} R_T(\epsilon, f) = 0.$$

Now let $T > 0$ be such that

$$|R_T(\epsilon, f)| < P_\zeta\left(A(\epsilon, f)\right).$$

Then, there exists $\tau \in [0, T]$ such that, for a given $K \in \mathcal{K}$,

$$\sup_{s\in K} |\zeta(s + i\tau) - f(s)| < \epsilon.$$

Unfortunately, the estimate for the error term $R_T(\epsilon, f)$ in the limit theorem above seems to be a difficult problem.

An important result in the effectivization problem has been obtained by R. Garunkštis [7]. Suppose that the function $f(s)$ is analytic in the disc $|s| \leq 0.05$ with $\max\limits_{|s|\leq 0.05} |f(s)| \leq 1$. Then R. Garunkštis proved that, for every $\epsilon > 0$, there exists $\tau \in \mathbb{R}$,

$$0 \leq \tau \leq \exp\{\exp\{10\epsilon^{-13}\}\},$$

such that

$$\max_{|s|\leq 0.00001} \left|\log\zeta\left(s + \frac{3}{4} + i\tau\right) - f(s)\right| < \epsilon.$$

Moreover,

$$\liminf_{T\to\infty} \frac{1}{T}\text{meas}\left\{\tau \in [0, T] : \max_{|s|\leq 0.00001} \left|\log\zeta\left(s + \frac{3}{4} + i\tau\right) - f(s)\right| < \epsilon\right\} \geq \exp\{-\epsilon^{-13}\}.$$

The most important results are given by A. Laurinčikas jointly with R. Garunkštis, K. Matsumoto, J. Steuding and R. Steuding (2010). They solved the effectivization problem for discs. Let, for $\underline{b} = (b_0, b_1, ..., b_{n-1}) \in \mathbb{C}^n$,

$$\| \underline{b} \| = \sum_{0\leq k<n} |b_k| \quad \text{and} \quad A(n, \underline{b}, \epsilon) = |\log|b_0|| + \left(\frac{\| \underline{b} \|}{\epsilon}\right)^{n^2}.$$

Moreover, let

$$M(\tau) = \max_{|s-s_0|=r} |\zeta(s + i\tau)|.$$

THEOREM 6. *Let $\sigma_0 \in \left(\frac{1}{2}, 1\right)$, $s_0 = \sigma_0 + it$, $K = \{s \in \mathbb{C} : |s - s_0| \leq r\}$ and $f : K \to \mathbb{C}$ be a continuous function, $f(s_0) \neq 0$, analytic in $|s - s_0| < r$. Then, for any $\epsilon \in (0, |f(s_0)|)$, there exist real numbers $\tau \in [T, 2T]$ and $\delta = \delta(\epsilon, f, \tau) > 0$ defined by*

$$M(\tau)\frac{\delta^n}{1-\delta} = \frac{\epsilon}{3}\left(2 - \mathrm{e}^{\delta r}\right)$$

such that

$$\max_{|s-s_0|\leq\delta r} |\zeta(s + i\tau) - f(s)| < \epsilon.$$

Here $T = T(f, \epsilon, \sigma_0) > r$ satisfies

$$T \geq C(n, \sigma_0)\exp\left\{\exp\left\{\delta A\left(n, \underline{f}, \frac{\epsilon}{3}\right)^{\frac{8}{1-\sigma_0}+\frac{8}{\sigma_0-\frac{1}{2}}}\right\}\right\}$$

with a positive effectively computable constant $C(n, \sigma_0)$, δ is effectively computable, and

$$\underline{f} = \left(f(s_0), f'(s_0), ..., f^{(n-1)}(s_0)\right).$$

Some interesting results, including universality of zeta-functions from the Selberg class, can be found in the monograph [22].

2.5. Consequences and Applications of the Universality Phenomenon

Universality property has a lot of important applications. For example, it is used for the investigation of functional independence of zeta-functions, for zero-distribution and for solving some questions in algebraic number theory. In this subsection, we will discuss some topics investigated by A. Laurinčikas.

Functional independence. In 1887, O. Hölder proved an algebraic-differential independence for the Euler gamma-function $\Gamma(s)$ [10]. More precisely, there is no polynomial $p \not\equiv 0$ for which

$$p\left(s, \Gamma(s), \Gamma'(s), ..., \Gamma^r(s)\right) \equiv 0.$$

In 1960, during the second International Congress of Mathematicians, D. Hilbert observed in the statement of his 18th problem that Hölder's result implies the algebraic-differential independence of the Riemann zeta-function $\zeta(s)$, and conjectured that the function

$$\zeta(s, x) = \sum_{m=1}^{\infty} \frac{x^m}{m^s}$$

also has the same property. This was proved by A. Ostrowski [21]. Further progress in this field was given by S. M. Voronin who proved the functional independence of the function $\zeta(s)$: the function $\zeta(s)$ does not satisfy any differential equation of the form

$$\sum_{k=0}^{m} s^k F_k\left(y(s), y'(s), ..., y^{(n-1)}(s)\right) = 0,$$

where $F_0, ..., F_m$ are continuous functions not all of which $\equiv 0$.

It turned out that the universality implies the functional independence of zeta-functions. Using this, A. Laurinčikas obtained the functional independence for various collections of Lerch zeta-functions (with K. Matsumoto, 2000), collections of twists of authomorphic L-functions (with K. Matsumoto, 2004), universal shifts of zeta-functions (with J. Kaczorowski and J. Steuding, 2006), periodic Hurwitz zeta-functions (2008), zeta-functions of elliptic curves (with V. Garbaliauskienė, 2011), zeta-functions of cusp forms (with K. Matsumoto and J. Steuding, 2013) and other functions.

Zero-distribution. A. Laurinčikas (jointly with R. Garunkštis) created the theory of zero-distribution for the Lerch zeta-function. They described zero-free regions, introduced the definition of trivial zeros, proved an asymptotic formula for the total number of zeros. Also, they obtained some estimates for the number of zeros in various regions. For example, jointly with R. Garunkštis, R. Šleževičienė and J. Steuding, he obtained estimates for the number of zeros of the Estermann zeta-function (2002), with D. Šiaučiūnas for the Hurwitz zeta-function (2012) and for periodic zeta-functions (2013).

Moreover, using the universality theorems, A. Laurinčikas obtained the estimates for the number of zeros of linear combinations of Matsumoto zeta-functions (1998), linear combinations of twisted authomorphic L-functions (with K. Matsumoto, 2004), derivatives of zeta-functions of cusp forms (2005), composite functions $F(\zeta(s))$ (2013), etc.

2.6. Mellin Transforms of the Riemann Zeta-function

In 1995, Y. Motohashi observed that the modified Mellin transforms

$$\mathcal{Z}_k\left(s, \frac{1}{2}\right) = \int_1^{\infty} \left|\zeta\left(\frac{1}{2} + ix\right)\right|^{2k} x^{-s} \mathrm{d}x$$

can be applied to the investigation of the moments

$$\int_0^T \left|\zeta\left(\frac{1}{2}+it\right)\right|^{2k} \mathrm{d}t.$$

For this, one needs to investigate the properties of $\mathcal{Z}_k(s, \frac{1}{2})$. This was done by A. Laurinčikas together with A. Ivič and M. Jutila [12].

Let $\frac{1}{2} < \rho < 1$ be a fixed number. A. Laurinčikas (2008–2011) investigated the Mellin transform $\mathcal{Z}_1(s, \rho)$, obtained a meromorphic continuation for it and gave some mean value estimates.

3. List of Scientific Works

The present section will display the list of scientific works published by A. Laurinčikas. It is quite possible that we have accidentally left out a few publications. Nevertheless, we hope that this long list is quite complete. It not only repeatedly reveals the extent of the mathematical problems dealt with by Antanas, but also proves his devotion to mathematics and immeasurable diligence.

The list does not include the abstracts of conference communications.

3.1. Articles

1. Kubilius, J., Laurinčikas, A. 1972, "On large deviations of multiplicative functions“, *Liet. Mat. Rink.*, vol. 12 (2), pp. 77–85 (in Russian).

2. Laurinčikas, A. 1974, “The distribution of the values of arithmetic functions defined on a polynomial set“, *Liet. Mat. Rink.*, vol. 14 (1), pp. 85–97 (in Russian) ≡ 1975, *Lith. Math. J.*, vol. 14, pp. 62–71.

3. Laurinčikas, A. 1975, “Multidimensional distribution of values of multiplicative functions“, *Liet. Mat. Rink.*, vol. 15 (2), pp. 13–24 (in Russian) ≡ *Lith. Math. J.*, vol. 15 (2), pp. 207–216.

4. Laurinčikas, A. 1975, “Distribution of values of complex functions“, *Liet. Mat. Rink.*, vol. 15 (2), pp. 25–39 (in Russian) ≡ *Lith. Math. J.*, vol. 15 (2), pp. 217–227.

5. Laurinčikas, A. 1975, “On value-distribution of complex arithmetic functions“, *Liet. Mat. Rink.*, vol. 15 (2), pp. 136–137 (in Russian).

6. Laurinčikas, A. 1976, “Large deviations of arithmetic functions“, *Liet. Mat. Rink.*, vol. 16 (1), pp. 159–171 (in Russian).

7. Laurinčikas, A. 1976, “The limiting distribution of the values of multiplicative functions“, *Liet. Mat. Rink.*, vol. 16 (2), pp. 121–131 (in Russian) ≡ *Lith. Math. J.*, vol. 16 (2), pp. 229–235.

8. Laurinčikas, A. 1976, “On joint value-distribution of additive and multiplicative functions“, *Liet. Mat. Rink.*, vol. 16 (2), pp. 190–192 (in Russian).

9. Laurinčikas, A. 1977, “ Value-distribution of additive function $f(p+1)$“, *Liet. Mat. Rink.*, vol. 17 (3), pp. 114–116 (in Russian).

10. Laurinčikas, A. 1977, “Distribution of multiplicative functions“, *Liet. Mat. Rink.*, vol. 17 (4), pp. 139–148 (in Russian) ≡ *Lith. Math. J.*, vol. 17 (4), pp. 531–538.

11. Laurinčikas, A. 1978, “Vertical distribution of the Dirichlet series with multiplicative coefficients“, *Liet. Mat. Rink.*, vol. 18 (2), pp. 152–153 (in Russian).

12. Laurinčikas, A. 1979, “Distribution des valeurs de certaines séries de Dirichlet“, *C.R. Acad. Sc. Paris, série A*, vol. 289 (2), pp. 43–45.

13. Laurinčikas, A. 1979, “Sur les séries de Dirichlet et les polynômes trigonométriques“, *Séminaire de Théorie des Nombres*, 1978–1979, Exp. 24, CNRS, Talence, p. 13.

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