



Kurepa's early days
and education

Academic career
Administrative
functions and
memberships in
academies

Organization of
scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence
on Yugoslav
mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral
students

Kurepa and other
mathematicians

Kurepa's work in
topology

Kurepa's work in
topology

Kurepa's work in set
theory

Kurepa's work in set
theory

Kurepa's work in set
theory

Kurepa's work in set

ĐURO KUREPA

1907-1993

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Kurepa's early days and education

Djuro Kurepa was born on August 16, 1907 in Majske Poljane near Glina in Srpska Krajina as the fourteenth and last child of Rade and Anđelija Kurepa. He went to elementary and high school in Majske Poljane, Glina and Križevci. Then, he got his diploma in theoretical mathematics and physics at the Faculty of Philosophy of the University of Zagreb in 1931.

Kurepa spent the years 1932–1935 in Paris at the Faculté des Sciences and the Collège de France. There he obtained his doctoral diploma at the Sorbonne in 1935 before a committee whose members were Paul Montel (president), Maurice Fréchet (supervisor), and Arnaud Denjoy.

He was on post-doctoral studies at the University of Warsaw and the University of Paris (1937). After the Second World War he visited Cambridge (Massachusetts), the mathematical departments of the Universities of Chicago, Berkeley and Los Angeles, and the Institute of Advanced Studies in Princeton.

[Kurepa's early days and education](#)

[Academic career
Administrative functions and memberships in academies](#)

[Organization of scientific work](#)

[Awards and honors](#)

[Scientific output](#)

[Lectures](#)

[Kurepa's influence on Yugoslav mathematicians](#)

[Kurepa in Belgrade](#)

[Kurepa in Belgrade](#)

[Kurepa in Belgrade](#)

[Kurepa's doctoral students](#)

[Kurepa and other mathematicians](#)

[Kurepa's work in topology](#)

[Kurepa's work in topology](#)

[Kurepa's work in set theory](#)

[Kurepa's work in set theory](#)

[Kurepa's work in set theory](#)

[Kurepa's work in set](#)



Academic career

Kurepa's early days and education

Academic career

Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

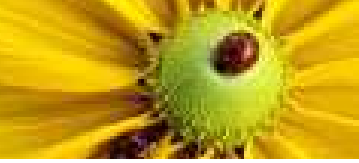
Kurepa's work in set theory

Kurepa's work in set

Kurepa's first employment was at the University of Zagreb in 1931, as an assistant in mathematics. He became an assistant professor at the same institution in 1937, associate professor in 1938, and full professor in 1948.

He stayed in Zagreb until 1965 when he moved to Belgrade where he was invited to be full professor at the Faculty of Science of the University of Belgrade. He stayed there until his retirement in 1977. Meanwhile, he was a visiting professor at Columbia University in New York (Summer School 1959), and Boulder, Colorado, in 1960.

Kurepa died in 1993 in Belgrade in the age of 86.



Administrative functions and memberships in academies

Kurepa's early days and education

Academic career

Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Besides his university teaching, Kurepa organized successfully scientific work, as well, and was very active in administrative matters. Professor Kurepa was the chairman of the Mathematical Department of the Faculty of Philosophy in Zagreb; then since 1970 till 1980 chairman of the Mathematical Seminar of the Institute of Mathematics of SANU (the Serbian Academy of Sciences and Arts).

He was a full member of SANU, the Academy of Science of Bosnia and Herzegovina, and a corresponding member of JAZU (Yugoslav Academy of Sciences and Arts) in Zagreb.



Organization of scientific work

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

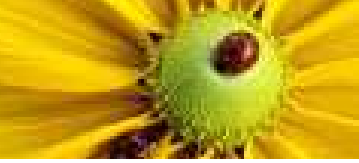
Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Professor Kurepa was the founder and president of the Society of Mathematicians and Physicists of Croatia, and president of the Union of Yugoslav Societies of Mathematicians, Physicists and Astronomers. He was also president of the Yugoslav National Committee for Mathematics, as well as president of the Balkan Mathematical Society.

Furthermore, he was the founder and for many years the chief editor of the journal *Mathematica Balkanica*, now published in Sofia. Kurepa was also a member of the editorial board of Belgrade's mathematical journals *Publications de l'Institut Mathématique*, *Vesnik* and the German journal *Zeitschrift für mathematische Logik und Grundlagen der Mathematik*.



Awards and honors

Kurepa's early days
and education

Academic career
Administrative
functions and
memberships in
academies

Organization of
scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence
on Yugoslav
mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral
students

Kurepa and other
mathematicians

Kurepa's work in
topology

Kurepa's work in
topology

Kurepa's work in set
theory

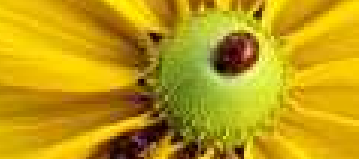
Kurepa's work in set
theory

Kurepa's work in set
theory

Kurepa's work in set

Professor Kurepa earned many awards, honors and distinctions. He received the highest prize of former Yugoslavia, the Award of AVNOJ (1976).

Also, he was a member of the Tesla Memorial Society of the U.S.A. and Canada (1982), the Bernhard Bolzano Charter, and the Gramata Marin Drinov of the Bulgarian Academy of Science (Sofia 1987).



Scientific output

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

The scientific output of Djuro Kurepa was rather large. He published about 200 scientific papers, and more than 700 writings: books, articles, reviews. His papers were published in journals all around the world, and some of them in the most recognized mathematical journals such as:

Mathematische Annalen, Izvestiya Akademii nauk SSSR, Fundamenta Mathematicae, Acta Mathematica, Comptes Rendus de l'Académie des sciences, Bulletin de la Société Mathématique de France, Zeitschrift für mathematische Logik und Grundlagen der Mathematik, Journal of Symbolic Logic, Pacific Journal of Mathematics.

Many of his manuscripts were translated into English, French, Italian, and other languages. Kurepa also wrote about 1000 scientific reviews.



Lectures

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

He delivered lectures at many universities of Europe, America and Asia; for example, at Warsaw, Paris, Moscow, Jerusalem, Istanbul, Cambridge, Boston, Chicago, Berkeley, Princeton and Peking. As Kurepa himself told once:

I lectured at almost each of nineteen universities of (former) Yugoslavia, then in almost every European country, then in Canada, Cuba, Israel and Iraq, and I gave at least ten lectures in each of the following countries: France, Italy, Germany, the Soviet Union and the United States.

He participated at dozens of international mathematical symposia, and many of them were organized by himself (for example, the international conferences in topology in Herceg Novi 1968, Budva-Bečići 1972, Belgrade, 1977.).



Kurepa's influence on Yugoslav mathematicians

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

The influence of Professor Kurepa on the development of mathematics in Yugoslavia was great. As a professor of the University of Zagreb he introduced several mathematical disciplines, mainly concerning the foundations of mathematics and set theory. This is best witnessed by the following words of Kajetan Šeper, a professor of the University of Zagreb:

Professor Kurepa was not only the professional mathematician and teacher, but he was a scientist, philosopher and humanist as well, in the true sense of these words. He was the founder and pioneer in mathematical logic and the foundations of mathematics in Croatia, and modern mathematical theories in Croatia and Yugoslavia. Generally speaking, he was the catalyzer, the initiator and the bearer of mathematical science.

From: *Set theory. Foundations of mathematics*. Symposium dedicated to Djuro Kurepa. Belgrade 1977



Kurepa in Belgrade

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

His arrival to Belgrade in the mid-sixties, and the subsequent influence he had on the mathematical community there, may be described with almost the same words. Professor Kurepa exposed the newest results in diverse mathematical disciplines through many seminars, courses and talks which he delivered at the Faculty of Sciences and the Mathematical Institute.

The topics of his lectures included: the construction of Cohen forcing, some questions concerning independence results in cardinal and ordinal arithmetic, ordered sets and general topology. But he was attracted to other mathematical topics, too. He gave valuable contributions to analysis, algebra, number theory, and even to those mathematical disciplines which were just appearing, as computer science, for example.

The universality of his spirit is portrayed by the list of university courses he taught: Algebra, Analysis and Topology and Set Theory.



Kurepa in Belgrade

Kurepa's early days
and education

Academic career
Administrative
functions and
memberships in
academies

Organization of
scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence
on Yugoslav
mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral
students

Kurepa and other
mathematicians

Kurepa's work in
topology

Kurepa's work in
topology

Kurepa's work in set
theory

Kurepa's work in set
theory

Kurepa's work in set
theory

Kurepa's work in set

By publishing his doctoral dissertation in extenso in *Publications Mathématiques de l'Université de Belgrade*, 4 (1935), 1-138, Kurepa made a first contact with the Belgrade mathematical community. In the beginning of the fifties these contacts became deeper and more frequent. So, from a text

Povodom 35 godina knjige „Teorija skupova” profesora Djure Kurepe (On the occasion of 35 years of the book "Set theory" of Djuro Kurepa), *Istorijski spisi iz matematike i mehanike, Istorija matematičkih i mehaničkih nauka*, knj. 2, Matematički institut, Beograd, 1989.

of Professor Zlatko Mamuzić we learn that Kurepa was invited already in 1952 to visit the University of Belgrade.



Kurepa in Belgrade

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

On this occasion he gave talks on the theory of matrices, and held a seminar with topics in set theory, topology and algebra. In the same text we find the names of attendants of the seminar: Professor Mamuzić himself, Časlav Stanojević (who later became Professor of the University of Rolla, Missouri), Simon Ćetković (later Professor of the Faculty of Electric Engineering in Belgrade), Mirko Stojaković (Professor of Algebra of the University of Novi Sad) and others.

By attending these seminars, many mathematicians gained ideas for their mathematical papers, while graduate students obtained themes for their master and doctoral theses. Many of these themes were formulated or initiated by Kurepa.



Kurepa's doctoral students

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

These works include virtually all doctoral theses of the older generation of topologists, and many algebraists from all over Yugoslavia:

Svetozar Kurepa, Zlatko Mamuzić, Sibe Mardešić, Pavle Papić, Viktor Sedmak, and a few years later, Ljubomir Ćirić, Rade Dacić, Milosav Marjanović, Veselin Perić, Milan Popadić, Ernest Stipanić and Mirko Stojaković. Professor Kurepa was supervisor (altogether 42 times) or a member of examination boards for doctoral dissertations for many other mathematicians: Miroslav Ašić, Nataša Božović, Dušan Ćirić, Aleksandar Ivić, Milena Jelić, Gojko Kalajdžić, Ljubiša Kočinac, Žarko Mijajlović, Nada Miličić, Mila Mršević, Marica Prešić, Zoran Šami, Stevo Todorčević, Ratko Tošić, and others.

Many of these mathematicians continued and developed further Kurepa's work, notably Stevo Todorčević.



Kurepa and other mathematicians

Kurepa's early days and education

Academic career

Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Professor Kurepa had contacts with many mathematicians of the highest rank from all around the world. Thanks to him some of them visited Belgrade:

A. Tarski, P. Alexandroff, M. Krasner, N.A. Shanin, K. Devlin and others. Professor Kurepa especially was proud of his encounter with Nikola Tesla, the great Serbian scientist and engineer, with whom Kurepa was fascinated.

He also met Kurt Gödel and Albert Einstein.



Kurepa's work in topology

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

In topology Kurepa was interested in some generalizations (non-numerical) of distance functions. In this context there is a notion of Kurepa's pseudo-metric spaces. As it was already mentioned, in the middle of thirties Kurepa was a doctoral student in Paris, and at that time he was influenced by the French mathematical school, particularly by the work of M. Fréchet.

Along these lines, Kurepa took a new approach to the notion of space. He defined the notion of pseudo-distancial space (espaces pseudo-distanciés) generalizing the Fréchet's class (D). In this approach, values of distance function range over a totally ordered set, instead of the set of positive reals, and the triangle condition on distance function is replaced by an interesting relation in ordered sets.



Kurepa's work in topology

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

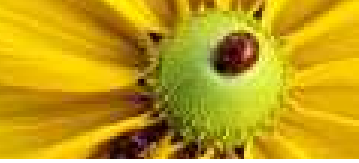
Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Later Frechet arrived at the same notion, and since then this class of abstract spaces are known as "Kurepa-Fréchet spaces". A lot of results on this classes of spaces are obtained by Z. Mamuzić, P. Papić, A. Appert, J. Colmez, V.G. Boltjanski and others.

It is interesting that Kurepa wrote last time about these spaces in 19925. Someone probably would recognize in this class of spaces the notion of Zadeh's fuzzy sets. Anyway, there is the phrase sets of fuzzy structure" 6 in his book Set theory from 1951.



Kurepa's work in set theory

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Trees, partially ordered sets in which every lower cone is a well-ordered set, may be considered as a natural generalization of ordinal numbers. They are a special type of ramified sets which Kurepa introduced in his doctoral thesis "Ensembles ordonnés et ramifiés". By widespread opinion, for example

K. Kunen, *Set Theory*, North-Holland, Amsterdam, 1983, p. 69,

this capital work is a first systematic study on set-theoretical trees. In his thesis, and later in his papers

Ensembles lineaires et une classe de tableaux ramifiés and

A propos d'une generalisation de la notion d'ensamles bien ordonnés



Kurepa's work in set theory

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa introduced fundamental notions of the theory of infinite trees:

Aronszajn tree an infinite tree of the cardinality and height \aleph_1 in which every chain and every level is at most countable,

Suslin tree, an Aronszajn tree in which every antichain is countable, and

Kurepa tree, a tree of the cardinality and height \aleph_1 which has at least \aleph_2 branches of the height \aleph_1 .



Kurepa's work in set theory

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Thus, Kurepa found in Suslin and Kurepa trees two extremal notions, the first one without long chains (i.e. of the length \aleph_1), while the Kurepa tree has a lot of them, at least \aleph_2 . Kurepa proved many interesting properties concerning these structure. Probably the best known is the following equivalence with the Suslin hypothesis

SH \Leftrightarrow There is no Suslin tree.

Here, SH denotes notable Suslin hypothesis that there is no Suslin line, i.e. a linearly ordered set L of the countable cellularity (i.e. every set of pairwise disjoint intervals of L is at most countable), but which does not have a countable dense subset.



Kurepa's work in set theory

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Lebesgue in 1905 identified implicitly analytic functions with Baire functions. In his proof he used an argument which was "simple and short", but it was wrong. The mistaken step in the proof was hidden in the proof of a lemma which he considered trivial, namely that a projection of a Borel set is also a Borel set.

Ten years later, Suslin, a young and talented Luzin's student found the mistake. Suslin introduced the notion of analytic set, as a projections of Borel sets, and he proved that there are analytic sets that are not Borel sets. So emerged descriptive set theory, one of the deepest parts of set theory. However, Suslin died soon (in 1919), and the formulation of Suslin hypothesis appear after his death in his paper in *Fundamenta Mathematicae*, a year later.

This hypothesis will play the central role in the development of the theory of infinite trees, and in this progress Kurepa's work was of the principal importance.



Kurepa's work in set theory

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Kurepa was trying since 1935 to solve SH. He did not succeed in this, simply it was not possible in this time. Tools of the classical set theory that Cantor founded, and Zermelo, Fraenkel, Hausdorff, Tarski and others developed, were not adequate.

However, Kurepa was the first who understood the importance of trees in set theory. Some set-theorists discovered later again properties of these partially ordered sets. For example, Miller in 1943, and Sierpinski in 1948 independently discovered the mentioned equivalence which Kurepa found already in 1935.

Using infinite trees, Kurepa found examples of topological spaces with important and unusual properties. One example of this kind is connected with Suslin line. Namely, Kurepa proved in *La condition de Suslin et une propriété caractéristique des nombres réels*, C.R. Acad. Sci. Paris 231, (1950), 1113-1114, that the topological square of the Suslin continuum \mathbf{K} has uncountable cellularity, while \mathbf{K} itself has the countable cellularity.



Kurepa's work in set theory

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Kurepa was not able to prove the existence or nonexistence of Suslin tree, neither of Kurepa tree. The postulate that there is a Kurepa tree was named Kurepa hypothesis, shortly KH. The complete solution of the problem of the existence of these trees was solved in the beginning of seventies, when the new method, Cohen's forcing, became a standard and prime tool in set theory. So Solovay, Tennenbaum and Jensen proved that SH is independent from $ZFC + CH$ (Zermelo-Fraenkel set theory plus Continuum Hypothesis), while K. Devlin proved in 1978 that every theory

$$ZFC \pm CH \pm SH \pm KH$$

is consistent. This fact shows that the nature of the postulates SH and KH differs from the others axioms of ZFC. Hence, it is clear why these structures play so important role in various constructions in set theory, general topology, model theory and infinite combinatorics.



Kurepa's work in number theory

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

Kurepa had a distinguished ability to sense a good problem and a fine construction, especially if they are connected to ordered sets. We cannot mention all examples of this kind, but one problem from number theory deserves a special attention, as it was considered by several Yugoslav mathematicians and mathematicians from abroad.

Kurepa formulated during a mathematical gathering in Ohrid in 1971 the following problem. First he defined an arithmetical function $!n$ by

$$!n = 0! + 1! + \dots + (n-1)!$$

Then the formulation of $!n$ -hypothesis is stated as follows:

The greatest common divisor of $!n$ and $n!$ is 2.



Kurepa's work in number theory

Kurepa's early days and education

Academic career

Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

Kurepa's influence on Yugoslav mathematicians

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

Kurepa's work in topology

Kurepa's work in topology

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set theory

Kurepa's work in set

This hypothesis has a lot of interesting equivalences, and it was considered by L. Carlitz, Wagstaff, W. Keller, Slavić, Šami, Žižović, Stanković, Gogić, Ivić, Mijajlović, and others.

This hypothesis is stated in R. Guy's book *Unsolved problems in number theory*, Springer-Verlag, 1981, as problem B44.

The hypothesis was tested by computers for $n < 1000000$ (Mijajlović, Gogić in 1991). Kurepa announced the solution (he rang me up one early morning in the spring 1992 to tell me this), but he never published the solution. R. Guy in a letter to me in 1991 mentioned that R. Bond from Great Britain might solved the left factorial hypothesis, but this proof never appeared.

The $!n$ -hypothesis was finally proved by Daniel Barsky and Bénéline Benzaghoul in the paper *Nombres de Bell et somme de factorielles*, *Journal de Théorie des Nombres de Bordeaux* 16 (2004), 117.



Conclusion

Kurepa's early days and education

Academic career
Administrative functions and memberships in academies

Organization of scientific work

Awards and honors

Scientific output

Lectures

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Kurepa in Belgrade

Kurepa in Belgrade

Kurepa's doctoral students

Kurepa and other mathematicians

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Kurepa was attracted by many areas of mathematics, besides set theory, general topology, foundations, and number theory. His work includes also topics in algebra (theory of matrices), numerical mathematics, computer science and fixed-point theory. It is not possible to discuss here his full mathematical achievements. Let us mention that several papers on this matter are already published.

There is also some further discussion in introductory texts of the book *Selected Works of Đuro Kurepa* (eds.: S. Todorčević, Z. Mamuzić, A. Ivić and Ž. Mijajlović). Math. Instit., Belgrade, 2005. In short we may say:

Đuro Kurepa has great merits for the development of the foundations of set theory and mathematics in general.