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TAMPERE UNIVERSITY OF TECHNOLOGY
Tampere International Center for Signal Processing

Reprints from the Early Days of Information Sciences

Early Work in Switching Theory and Logic Design in USSR

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ՎԵՐԱՀՐԱՏԱՐԱԿՈՒՄ ՊԱՏՄՈՒԹՅՈՒՆԻՑ

Tampere 2016

Tampere International Center for Signal Processing. TICSP series # 66

Radomir S. Stanković, Jaakko T. Astola, Anatoly A. Shalyto &
Alexander V. Strukov (eds.)

Reprints from the Early Days of Information Sciences

Early Work in Switching Theory and Logic Design in USSR

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Tampere 2016

ISBN 978-952-15-3785-1 (printed)
ISBN 978-952-15-3786-8 (PDF)
ISSN 1456-2774

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2016

Editors' Notice

This publication has been written and edited by
Radomir S. Stanković, Jaakko T. Astola,
Anatoly A. Shalyto, Alexander V. Strukov.

Contents

Abstract vii

1 Introduction 1

2 Early Research in Mathematical Logic in the USSR
- Situation and Circumstances 1

3 Arithmetic Expressions 3
Harvard Laboratory 1951 Report on the Theory of Switching

4 Harvard 1957 Symposium on the Theory of Switching 15

5 School of Gavrilov 29

6 Researchers in Related Areas 35

7 References 40

8 List of Publications of Soviet Union Researchers in 48
First 20 Years of Switching Theory and Logic Design

Reprints from The Early Days of Information Sciences

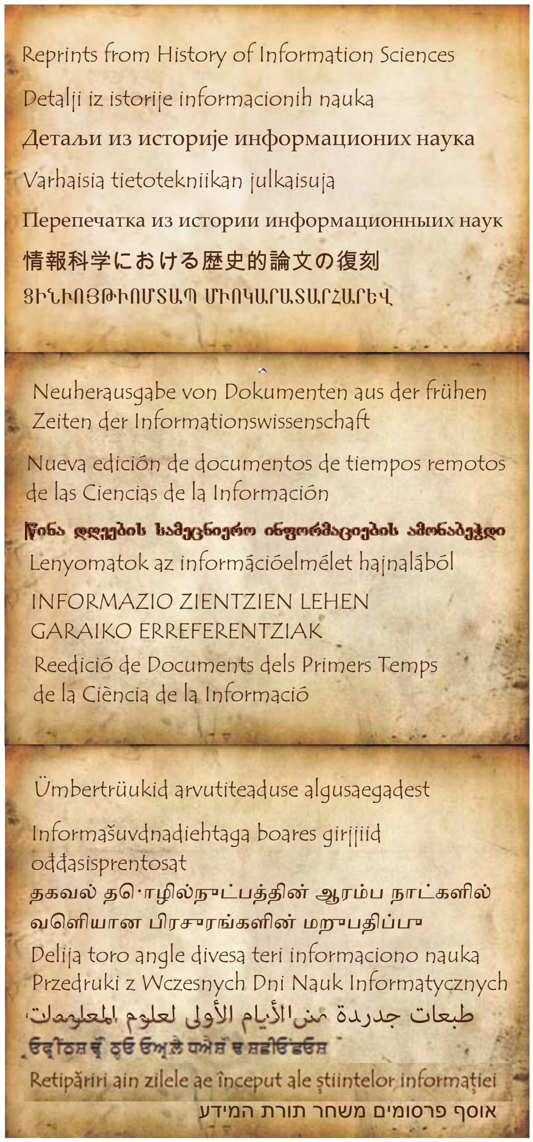
Historical studies about a scientific discipline is a sign of its maturity. When properly understood and carried out, this kind of studies are more than enumeration of facts or giving credit to particular important researchers. They are more of a case of discovering and tracing the ways of thinking that have led to important discoveries. In this respect, it is interesting and also important to recall publications where, for the first time, some important concepts, theories, methods, and algorithms were introduced.

In every branch of science there are some important results published in national or local journals or other publications that have not been widely distributed for different reasons, due to which they often remain unknown to the research community and therefore are rarely referenced. Sometimes the importance of such discoveries is overlooked or underestimated even by the inventors themselves. Such inventions are often re-discovered long after, but their initial sources may remain almost forgotten, and mostly remain sporadically recalled and mentioned within quite limited circles of experts. This is quite often the case with publications in other languages than English, which is currently the most common language in the scientific world.

This series of publications is aimed at reprinting and, when appropriate, also translating some less known or almost forgotten, but important publications, where some concepts, methods or algorithms were discussed for the first time or introduced independently on other related works.

Another aim of the Reprints is to collect and present in the same place publications on a certain particular subject of an important scholar whose scientific work is made significant by contributions to different areas of sciences.

R.S. Stanković, J.T. Astola



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Early Work in Switching Theory and Logic Design in the USSR

Abstract

This publication presents some information about the early work in Switching theory and Logic design in the former Soviet Union and points out certain details of the cooperation with researchers from abo-rad. As an example, we briefly discuss former and recent work in the field of arithmetic expressions and transforms. The second part of the publication consists of a list of publications by Soviet Union researchers in the first 20 years of switching theory and logic design.

1 Introduction

This publication is intended towards presenting the work of researchers in Russia and former Soviet Union in the area of switching theory and logic design in the first 20 years of these fields. In research community, especially in the West, but also in Japan and China, there is a feeling that no proper information on this former work Soviet Union is present. Although certain journals publishing papers on this subject were translated cover to cover, as for example *Avtomatika i Telemekhanika* that is translated as *Automation and Remote Control*, and *Doklady of the Academy of Sciences of USSR*, as well as overviews of this work were sporadically published [19], [23], and some reviews of particular articles appeared in the *Journal of Symbolic Logic*, and elsewhere else, still a complete picture is missing. We would be glad if the present publication can contribute to improve the related knowledge on the benefit of further work in the area.

The presentation is organized as follows. We first briefly review the situation and circumstances under which the work has been done. Then, we present some examples of relationships of leading experts in the area in Soviet Union and abroad. We point out the work in arithmetical expressions for representation of Boolean functions as a particular example illustrating contribution of researchers from this part of the world. A special contribution prepared by A. A. Shalyto is a brief description of the so-called *School of Gavrilov*, an informal by very influential research institution established by Mikhail A. Gavrilov, a World renowned scholar in this area. Finally, we provide an extensive list of publications in the area by the authors from Russia and former Soviet Union including also whenever being informed the data about the review of this work in western literature.

2 Early Research in Mathematical Logic in USSR Situation and Circumstances

Switching theory can be viewed as a scientific discipline that has been developed from symbolic logic due to its algebraization which lead to engineering applications in the area called now Logic design or Digital Logic. In this respect, switching theory is a particular derivative of mathematical logic in general, a derivative that has immense applications leading in the final extent to the modern information technology based world.

Switching theory provides mathematical foundations for the design and optimization of basic and essential elements of digital devices. From the engineering point of view, the switching theory originates in attempts to provide fundamentals for the design of relay and contact networks used in particular in early days of automation control and telephony.

The situation in mathematical logic in imperial Russia and later in Soviet Union can be estimated in the light of philosophical discussions on the foundations, meaning, essence, and purpose of mathematics between supporters of the idealistically and materialistically oriented philosophical approaches.

In the Imperial Russia, materialistic ideas were not widely spread and from that point of view, mathematical logic was not broadly accepted as a scientific discipline. It was a similar situation in the first decades of Soviet Union, since logic including also mathematical logic was considered as an ideologic issue coming from bourgeois philosophy. Therefore, it was neglected of marginalized as a scientific discipline. This situation lasted until the Soviet scholars, among them most notably S. A. Janovskaja, related these areas with dialectic and materialist philosophical approaches, in particular, the Dialectic materialism, as chief directions towards finding answers to global questions in philosophy of science and nature. Pointing out the conformity of mathematical logic to dialectical materialism, was a key point in accepting mathematical logic as a branch of mathematics and a topic for research officially approved and accepted by the state establishment. In this content, to establish a proper place and role of mathematical logic in Soviet Union society and science, in discussions of dialectic and formal logic, the references to the *Mathematical Manuscripts* by Karl Marx, *Materialism and Empiriocriticism* by Vladimir Ilyich Ulyanov Lenin, and *Dialectical and Historical Materialism*, and in particular *Marxism and Problems of Linguistics* both by Joseph Stalin, were greatly used. Further, the practical applications of logical and mathematical logic reasonings were often emphasized [18].

As P. L. Chebychev wrote on the example of cartography, the practice is the best guide for theory and directions where it can be developed since imposes new and different topics for research and to find solutions. This quoting was used as a part of argumentation by S. A. Janovskaja in her attempts to open the roads and provide the place for development of mathematical logic in Soviet Union [18].

For more details on this subject, we refer to [1], [6], [18], [24].

3 Harvard Laboratory 1951 Report on the Theory of Switching - Arithmetic Approach

Discussions about proper underlying mathematical structures for the design of computing devices started already in the late thirties of 20th century, however, the continuous advent in new and emerging technologies keep this question open and challenging.

The fundamentals borrowed from symbolic logic, as Boolean algebra [8], [10], [53], and algebra of logic [9], were suggested by Paul Ehrenfest [11], and further championed by Claude E. Shannon [55]. The same theoretical foundations were developed quite independently by the Japanese scholar Akira Nakashima [43] in a series of lectures at the Japanese Society for Informatics and related publications, and later elaborated by him and his associate Masao Hanzawa [44]. In Soviet Union, theoretical foundations were considered by M. Tsimbalisty [80], and continued by V.I. Shestakov [56], [57], [58] [1], followed by many others, as it can be seen from the enclosed List of Publications. The work of M. Tsimbalisty can be viewed as the first ever published publication in Russian on logic synthesis. For work of Shestakov, we refer to [5], [27].

In 1951, Howard Aiken and his team published a very influential *Report of the Harward Laboratory* [77], recommending the algebraic approach to the description, analysis, and synthesis of arithmetic circuits with concrete applications on the example of related components built in the computer Mark 4 developed at this Lab. The motivation for selecting this approach was expressed as follows (see the reprinted pages)

As regards the mathematical approach to the subject matter of this volume it should be noted that several alternatives exist. The methods of the propositional calculus have been frequently suggested for use in this connection. Again, Boolean algebra was employed by Claude E. Shannon in his discussion of relay circuits. It is believed, however, that the algebraic approach adopted in the present volume provides a particularly convenient vehicle of thought and has the considerable advantage of lying within the province of the average reader's previous mathematical experience. Although this opinion has in part been confirmed by the experience of the Staff of the Computation Laboratory in the design of the Mark IV Calculator, final confirmation must wait until a reasonably large number of persons have had the

[1] It should be remarked that Shestakov worked also in multiple-valued logic [59], [60]. In [?], the term Shestakov-Kleene logic is used together with the therm Kleene-Bočvar logic. It is actually shown that these two calculus and also the 3-valued logic of Lukasiewicz discussed in [51] are all functionally equivalent.

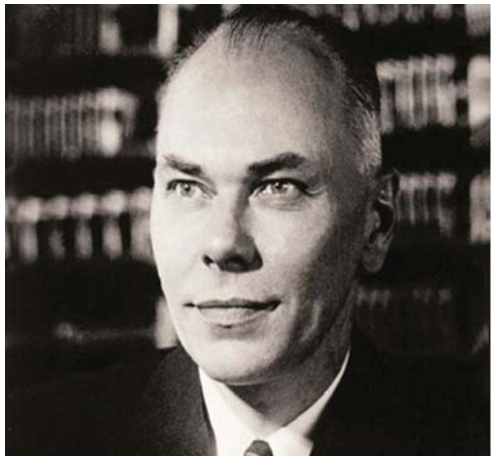

Figure 1: Howard H. Aiken.

opportunity to apply the methods of this volume. Hence, the present writer (Howard H. Aiken) is obliged to record that the general algebraic approach, the switching function, the vacuum-tube operator, and the minimizing chart are his proposals, and that he is responsible for their inclusion herein.

The importance of this publication was immediately recognized by Soviet Union experts and it was translated in Russian and published in 1954 [56] (see the reprinted pages).

These ideas of using the algebraic approach were accepted and further evolved and elaborated by many experts in the world including also authors publishing in Russian.

This work led to the definition of algebraic expressions for representation of Boolean functions and the description of logic circuits. From spectral transforms point of view, this method can be alternatively interpreted as a particular spectral transform, the arithmetic transform, defined in terms of basis functions equivalent to basis functions used in Reed-Muller expressions, but with logic values 0 and 1 viewed as the corresponding integers. Therefore, all the calculations are done over the field of rational numbers. The differences with respect to the work of the group of Aiken is concisely expressed by Prof. Malyugin in a correspondence to R.S. Stanković, as reprinted below. Translated into English, it reads as

---

Prof. V.D.Malyugin
Moscow,
ISP RAS,
Fax 05S 420 20 16

Prof. R. Stankovich,
Finlandiya. Tampere
fax: 358 3 365 3817

Dear Radomir!

I am sending the front pages of the book. This is the work of a laboratory, and because of that there is no an author. Theory - is obviously the work of the head of the laboratory, Prof. Aiken. From the preface, it is clear that the approach proposed by Aiken was used for Mark 4. From the table of contents, it can be seen that the algebraic (arithmetic) forms uses just arithmetic operations $(+-,\cdot)$*, but does not reduce expressions to polynomials, since the brackets are not disclosed. Thank you for the interesting question about Komamiya.*

With respect,
Malyugin

This approach based on arithmetic polynomials and the arithmetic transform was extensively studied and led to important results in representation of switching functions, their circuit realizations in different underlying technologies (sets of available basic gates), and applications in circuit verification and testing, as well as in certain logical network optimization problems, as discussed in a large amount of publications. Since it is quite hard to make a complete review of this broad literature, we will here restrict the reporting to the results in derivation of which the present authors were involved and some references they extensively used. For example, see [2], [12], [13], [14], [15], [16], [17], [20], [21], [22], [29], [30], [31], [32], [33], [34], [35], [36], [42], [61], [79], [82]. For detailed considerations of the subject, we refer to the corresponding chapters in [31], [32], [33], [54], [68], [83], and references therein.

The observation of relationships between the Edge-valued binary decision diagrams (EVBDDs) [26] and arithmetic transform, respectively arithmetic polynomials [63], was the starting point of spectral interpretation of decision diagrams [68]. This interpretation further have led to definition new classes of decision diagrams and methods to determine various versions of arithmetic expressions from them in terms of the so-called extended arithmetic spectrum [37], [52], [64], [67], [70].

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SYNTHESIS OF ELECTRONIC COMPUTING AND CONTROL CIRCUITS

BY

THE STAFF OF THE COMPUTATION LABORATORY

CAMBRIDGE, MASSACHUSETTS

HARVARD UNIVERSITY PRESS

1951

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CONTENTS

Chapter		Page
I	Introduction.	1
II	Vacuum-Tube Operators.	8
III	Switching Functions of Two and Three Variables	15
IV	Switching Functions of *n* Variables	30
V	Minimizing Charts	50
VI	Pyramids and Rectangles	68
VII	Multiple-Output Circuits.	77
VIII	Triggers, Rings, and Digit Counters	93
IX	Time Variables	118
X	Rectifiers	126
XI	Coding Systems	145
XII	Adders and Accumulators	158
XIII	Multipliers	195
Appendix I	Switching Functions of Four Variables	231
	Table I.1.	232
	Table I.2.	233
	Table I.3.	259

PREFACE

During the spring term of the academic year 1947–48, the present writer first offered at Harvard University a course of lectures entitled "Organization of Large-Scale Digital Calculating Machinery." This course included a treatment of general-purpose calculators from the functional and operational point of view and a discussion of individual components such as selection circuits, storage devices, adders, multipliers, etc. The circuits chosen for discussion were all taken from operating computers, and the case method of instruction was largely employed.

At the same time, the Staff of the Computation Laboratory was engaged in the design of computing and control circuits for the Mark III Calculator, making use of experimental results obtained from a research program extending over a ten-year period and the empirical methods of circuit synthesis at that time so widely employed. Thus, both in the laboratory and in the classroom, ample opportunity was offered to observe that the lack of adequate mathematical methods for the investigation of the functional behavior of electronic control circuits represented the largest single obstacle to the rapid development of the subject and to the instruction of students looking forward to an active career in the field.

Harry Rowe Mimno, Professor of Applied Physics, kindly attended the aforementioned course of lectures for two successive years. In addition to giving much valuable advice, Professor Mimno completely concurred with the opinion of the lecturer as to the desirability of undertaking a detailed investigation of the general subject of electronic-control-circuit synthesis. At this time a contract was effected between the United States Air Force and Harvard University which made it possible for the Staff of the Computation Laboratory to embark on a program of research in connection with electronic components for use in computing machinery. This contract, administered by Donald D. Foster for the Air Force, wisely stipulated that development of a general nature, rather than the construction of particular components, was to be the end in view, and thereby made available the opportunity to undertake the investigations leading to the results recorded in the present volume.

Work commenced in April 1948 and led to the sections on control-circuit theory included in the Progress Reports of the Computation Laboratory. For the results included in seven of these, William Burkhart, Theodore Kalin, and the present writer were jointly responsible.

In August 1949 Mr. Burkhart left the Computation Laboratory to join the research staff of the Monroe Calculating Machine Company. Mr. Kalin also left, in December 1949, and became associated with the Air Force Cambridge Research Laboratories. Thereafter the work was concluded with the collaboration of Peter Strong, who, together with the present writer, prepared the pertinent sections of Progress Reports Nos. 8, 13, and 16.

Although those already mentioned were primarily responsible for the production of this volume, many other members of the Staff of the Computation Laboratory have made important contributions. Martha Whitehouse constructed the minimizing charts used so profusely throughout this book, and in addition prepared minimizing charts of seven and eight variables for experimental purposes. J. Orten Gadd, Jr. designed the control tapes employed by the Automatic Sequence-Controlled Calculator in connection with the derivation of the Table of the Switching Functions of Four Variables contained in the Appendix. Frank Gucker and Robert Burns assisted in the construction of the Table of Input Rearrangements also included in the Appendix. Chapter X was greatly influenced by the work of An Wang concerning selenium-rectifier circuits. This chapter also includes mention of the methods of mounting small disk rectifiers developed by Robert E. Wilkins. The work of Benjamin Moore, Marshall Kincaid, Richard Hofheimer, Charles A. Coolidge, Jr., Way Dong Woo, Gerrit Blaauw, Michele Canepa of the Olivetti Company, Ltd., Ivrea, Italy, and others has been used to advantage throughout the book. Particular contri tions have been made to Chapters XII and XIII by Dr. Wang and Mr. Coolidge. previously mentioned, the sections on circuit theory in the Progress Reports represent the chief source of material for the present volume. Several of these reports, however, have undergone revision at the hands of Mr. Strong and the present writer.

As regards the mathematical approach to the subject matter of this volume it should be noted that several alternatives exist. The methods of the propositional calculus have been frequently suggested for use in this connection. Again, Boolean algebra was employed by Claude E. Shannon in his discussion of relay circuits. It is believed, however, that the algebraic approach adopted in the present volume provides a particularly convenient vehicle of thought and has the considerable advantage of lying within the province of the average reader's previous mathematical experience. Although this opinion has in part been confirmed by the experience of the Staff of the Computation Laboratory in the design of the Mark IV Calculator, final confirmation must wait until a reasonably large number of persons have had the opportunity to apply the methods of this volume. Hence, the present writer is obliged to record that the general algebraic approach, the switching function, the vacuum-tube operator, and the minimizing chart are his proposals, and that he is responsible for their inclusion herein.

In addition to the course of lectures at Harvard University, some of the material in the book has been presented in lecture form on other occasions. Mr. Kalin presented a brief summary of Chapters I to IV before the Association for Computing Machinery at Oak Ridge National Laboratory in April 1949. Mr. Burkhart gave a similar lecture before the Institute of Radio Engineers in May 1949 at Cambridge. Lectures have also been given on the subject by the present writer in the course of an European tour during January and February of 1951 at the International Colloquium "Les Machines à Calculer et la Pensée Humaine" at the Institut Blaise Pascal, Paris; at the Kunglig Tekniska Högskola, Stockholm, under the auspices of Matematikmaskinnämnden; the Chalmers Tekniska Högskola, Göteborg; the Eidgenössische Technische Hochschule, Zurich; and at the Institut für Praktische Mathematik, Technische Hochschule, Darmstadt. Professor Leon Brillouin, formerly of Harvard University and now with the International Business Machines Corporation, Professor Douglas Hartree of the University of Cambridge, Professor Charles Manneback of the University of Louvain, Professor Dr. Alwin Walther of the Institut für Praktische Mathematik, Darmstadt, and Dr. John Bowman of the Mellon Institute of Industrial Research have all discussed parts of the manuscript, and by their interest lent especial encouragement to those engaged in the task of compiling this volume.

The Staff of the Computation Laboratory wishes to express its appreciation of the kind coöperation of the Harvard University Press in making the publication of this and other volumes of the *Annals* possible; in particular Joseph D. Elder, Science Editor of the Press, has rendered valuable editorial assistance.

Jacquelin Sanborn prepared the manuscript for publication with the assistance of Carmela M. Ciampa, who drew the many figures of the book. The photographs of rectifier circuits and the Mark I multiply unit, as well as the films used in making the plates from which the book was printed, were prepared under the direction of Paul Donaldson, photographer of Cruft Laboratory, in part assisted by Robert Burns.

It is a pleasure to acknowledge the support given by contract W19-122-ac-24 between the United States Air Force and Harvard University, without which the present work could not have been undertaken.

Howard H. Aiken

Cambridge, Massachusetts
Janaury 1951

CONTENTS

Chapter		Page
I	Introduction.	1
II	Vacuum-Tube Operators.	8
III	Switching Functions of Two and Three Variables	15
IV	Switching Functions of *n* Variables	30
V	Minimizing Charts	50
VI	Pyramids and Rectangles	68
VII	Multiple-Output Circuits.	77
VIII	Triggers, Rings, and Digit Counters	93
IX	Time Variables	118
X	Rectifiers	126
XI	Coding Systems	145
XII	Adders and Accumulators	158
XIII	Multipliers	195
Appendix I	Switching Functions of Four Variables . .	231
	Table I.1.	232
	Table I.2.	233
	Table I.3.	259

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Проф.Р.Станкович,
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Дорогой Радомир!

Высылаю выходные данные книги.Это труды лаборатории, а потому нет автора.Теория- это повидимому дело рук руководителя лаборатории пр. Айкена.Из предисловия будет понятно, что предлагаемый Айкеном подход использовался для Марк 3,4. Из содержания видно , что алгебраическая(арифметическая) форма использовала только арифметические операции (+,-,.), но не приводилась к полиномам, т.к. скобки не раскрывались.

Спасибо за любопытную информацию о Комамио.

С уважением

Малюгин

СИНТЕЗ ЭЛЕКТРОННЫХ ВЫЧИСЛИТЕЛЬНЫХ И УПРАВЛЯЮЩИХ СХЕМ

Перевод с английского
Е. И. МАМОНОВА, Л. Е. САДОВСКОГО
И Я. А. ХЕТАГУРОВА

Под редакцией
И. И. ШЕСТАКОВА

И Л

ИЗДАТЕЛЬСТВО
ИНОСТРАННОЙ ЛИТЕРАТУРЫ
Москва 1954

Институт автоматики и телемеханики АН СССР
БИБЛИОТЕКА

THE ANNALS OF THE COMPUTATION LABORATORY OF HARVARD UNIVERSITY

Volume XXVII

SYNTHESIS OF ELECTRONIC COMPUTING AND CONTROL CIRCUITS

BY

THE STAFF OF THE COMPUTATION LABORATORY

Cambridge, Massachusetts
1951

ИЗ ПРЕДИСЛОВИЯ ДИРЕКТОРА ВЫЧИСЛИТЕЛЬНОЙ ЛАБОРАТОРИИ ГАРВАРДСКОГО УНИВЕРСИТЕТА

В течение весеннего семестра 1947/48 учебного года автор этого предисловия впервые прочел в Гарвардском университете курс лекций под названием „Проектирование больших цифровых вычислительных машин". Этот курс включал описание вычислительных машин общего назначения с точки зрения управления ими и их работы, а также описание отдельных элементов этих машин, как, например, избирательных цепей, запоминающих устройств, сумматоров, множительных устройств и т. д. Все избранные для изучения схемы были взяты из действующих вычислительных машин.

В это же время сотрудники вычислительной лаборатории были заняты разработкой вычислительных и управляющих схем для машины «Марк-III». При этом использовались экспериментальные результаты, полученные при выполнении программы исследований, рассчитанной на более чем десятилетний период, и эмпирические методы синтеза схем, широко распространенные в то время.

Таким образом, и в лаборатории и в аудитории можно было наблюдать, что отсутствие соответствующих математических методов исследования функций, осуществляемых электронными управляющими схемами, представляет собой главное препятствие для быстрого развития этой области техники и для обучения студентов, стремящихся в ней работать.

Необходимо отметить, что в отношении математического подхода к предмету, рассматриваемому в данной книге, существует несколько возможностей. В этой связи часто предлагались методы исчисления предложений (булева алгебра), которые уже были использованы в теории релейных схем. Однако алгебраический подход, используемый в настоящей книге, представляется особенно удобным и обладающим значительными преимуществами для читателя со средней математической подготовкой. Хотя такое мнение частично подтвердилось опытом сотрудников вычислительной лаборатории при разработке машины «Марк-IV», окончательное подтверждение можно будет получить лишь после того, как достаточное количество людей использует методы, предложенные в этой книге.

Г. Х. Айкен.

Кембридж, Массачузетс
Январь, 1951 г.

4 Harvard 1957 Symposium on Theory of Switching

Anther event interesting to be mentioned when discussing the contributions of Soviet Union researches to Switching theory is the *International Symposium on the Theory of Switching* organized by Howard H. Aiken on April 2-5, 1957, the proceedings of which was published in 1959. As we can read from the preface written by H. Aiken,

The program was planned through the efforts of the present writer, Robert Ashenhurst, Warren Semon of the Staff of the Computation Laboratory, and went through several sessions. After the final printing on March 29, 1957, messages were received from Antonin Svoboda of Czechoslovakia and Michael A. Gavrilov, Gellias N. Povarov, and Vadim N. Roginskij of the Union of Soviet Socialist Republics announcing that they would be unable to attend. Since their papers had already been received they were read by Albert L. Hopkins, Kenneth E. Iverson, Robert Ashenhurst, and Anthony G. Oettinger, respectively. Thanks are due to these members of the Staff of the Computation Laboratory for their willingness to undertake these tasks at the eleventh hour. Thanks are also due Walter Vickery, Nicholas Vitt of the Russian Research Center, and Mark Pivovonsky, Anthony Oettinger, and Peter Calingaert of the Computation Laboratory for their efforts in translating the papers of Misters Gavrilov, Povarov, and Roginskij. On April 5, a letter was received from Alexander Veits of the Union of Soviet Socialist Republics to the effect that he had mailed his paper but will be unable to attend in person. Unfortunately this contribution has apparently been lost in transmission and hence cannot be included in these proceedings.

The complete references of these papers by Soviet Union authors are

Gavrilov, M. A., "A survey of research in the theory of relay networks in the USSR", *Proc. Int. Symp. Theory of Switching*, Harvard University, Cambridge, Mass., Pt. 1, April 1957, 26-53.

Povarov, G. N., "A mathematical theory for the synthesis of contact networks with one input and k outputs", *Proc. Int. Symp. Theory of Switching*, Harvard University, Cambridge, Mass., Pt. 2, April 1957, 74-94.

Roginskij, V N., "A graphical method for the synthesis of multi-terminal contact networks", *Proc. Int. Symp. Theory of Switching*, Harvard University, Cambridge, Mass., Pt. 2, April 1957, 302-315.

In these papers by Gavrilov and Povarov, the reference to the review of

Paul Ehrenfest [11] of the book by Louis Couturat [9] is provided. For this review, see [71].

It is important to notice the closing remarks from the review article of M. A. Gavrilov

A very important task is the automatization of the synthesis of relay networks. In the Soviet Union initial successes have been attained in this field; however, this work requires further development and broadening.

The friendly cooperation of scientists of various countries will undoubtedly permit the solution of the problems set above in a somewhat shortened period of time. The scientists of the Soviet Union are ready to make their further contribution to the development of work in the theory of relay networks.

It is interesting to mention that the Serbian mathematician Djuro Kurepa (George Kurepa in English) from former state Yugoslavia participated at the Symposium and presented the paper "Sets - Logics - Machines", pages 137-146. [2] Recall that several important mathematical concepts were introduced by Professor Kurepa and are called by his name, for example, Kurepa tree, Kurepa topology, Kurepa hypothesis, Kurepa line, Kurepa space, Kurepa family in set theory, Kurepa-Vandermonde matrices, etc. Prof. Kurepa in 1935 described construction of the Aronszajn tree. It is interesting to notice that this important contribution by Aronszajn was newer published in a paper, and the name and championing of the concept are due to Kurepa and his publications

Kurepa, Dj., "Ensembles linéaires et une classe de tableaux ramifiés (tableaux ramifiés de M. Aronszajn)", *Pub. Math. Univ. Belgrade*, 6, 1937, 129160.
Kurepa, Dj., "Ensembles ordonnés et ramifiés", *Pub. Math. Univ. Belgrade*, 4, 1935, 1138.
and also introduced the concept of the left factorial in
Dj. Kurepa, "On the left factorial function !n", *Math. Balkanica*, Vol. 1, 1971, 147153.

For more information about the biographies of Gavrilov, Povarov, and

[2] R.S. Stanković is proud that Prof. Kurepa was a friendly advisor and a supervisor of him, and the president of the defence committees for his MSc. and Ph.D. theses defences.

Figure 2: Vladimir Dmitrievich Malyugin at the bridge over the river Nišava in Niš, Serbia.

Figure 3: Mikhail Aleksandrovich Gavrilov.

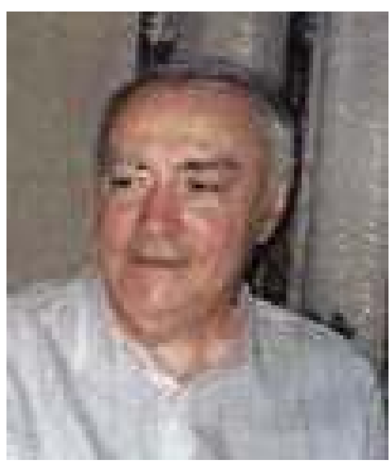

Figure 4: Gellius Nikolaevich Povarov.

Figure 5: Djuro R. Kurepa.

Kurepa, see
Gavrilov
http://www.computer-museum.ru/english/galglory_en/Gavrilov.htm
Povarov
http://www.computer-museum.ru/english/galglory_en/povarov.htm
Kurepa
http://www-history.mcs.st-andrews.ac.uk/Biographies/Kurepa.html

PREFACE

Prior to the advent of large-scale digital computers, switching theory was concerned narily with the theory of relay-contact networks. Since that time the invention of many 7 switches, including rectifiers, transistors, and magnetic cores, and the burgeoning growth ›oth variety and number of applications have considerably broadened its scope. These new ices and applications have stimulated research in the field. As in any new area, the channels ›ommunication among investigators are not well demarcated, and in some cases are non-stent. The present writer felt that a symposium might enable research workers in tching to evaluate the state of the art as regards the problems being studied and the gress being made toward their solution. It was also hoped that the development of needed ımunication channels would be encouraged.

The proposal was discussed with W. Deming Lewis, director of switching research of Bell ephone Laboratories, Incorporated, as early as 1955. Dr. Lewis concurred as to the desira-ty of holding a meeting, but for some time the matter rested there owing to the press of er commitments and the lack of financial support since it seemed advisable to hold the ıposium on an international scale. Further progress was made in 1956, when Dr. Lewis ised that Bell Telephone Laboratories, Incorporated, would be willing to provide this port in part. Shortly thereafter Mr. J. Paul Roth of International Business Machines poration, Messrs. H. W. Leverenz and J. Wesley Leas of Radio Corporation of America, General Leslie R. Groves of Sperry Rand Corporation pledged the support of their ınizations, thus making it possible to proceed.

The program was planned through the efforts of the present writer, Robert Ashenhurst, Warren Semon of the Staff of the Computation Laboratory, and went through several sions. After the final printing on March 29, 1957, messages were received from Antonin boda of Czechoslovakia and Michael A. Gavrilov, Gellius N. Povarov, and Vadim N. ;inskij of the Union of Soviet Socialist Republics announcing that they would be unable to nd. Since their papers had already been received they were read by Albert L. Hopkins, Kenneth E. Iverson, Robert Ashenhurst, and Anthony G. Oettinger, respectively. nks are due these members of the Staff of the Computation Laboratory for their willingness ndertake these tasks at the eleventh hour. Thanks are also due Walter Vickery, Nicholas Vitt of the Russian Research Center, and Mark Pivovonsky, Anthony Oettinger, and Peter ngaert of the Computation Laboratory for their efforts in translating the papers of srs. Gavrilov, Povarov, and Roginskij. On April 5, a letter was received from Alexander ts of the Union of Soviet Socialist Republics to the effect that he had mailed his paper but ld be unable to attend in person. Unfortunately this contribution has apparently been in transmission and hence cannot be included in these proceedings.

Italy, and others has been used to advantage throughout the book. Particular contri tions have been made to Chapters XII and XIII by Dr. Wang and Mr. Coolidge. previously mentioned, the sections on circuit theory in the Progress Reports represent the chief source of material for the present volume. Several of these reports, however, have undergone revision at the hands of Mr. Strong and the present writer.

As regards the mathematical approach to the subject matter of this volume it should be noted that several alternatives exist. The methods of the propositional calculus have been frequently suggested for use in this connection. Again, Boolean algebra was employed by Claude E. Shannon in his discussion of relay circuits. It is believed, however, that the algebraic approach adopted in the present volume provides a particularly convenient vehicle of thought and has the considerable advantage of lying within the province of the average reader's previous mathematical experience. Although this opinion has in part been confirmed by the experience of the Staff of the Computation Laboratory in the design of the Mark IV Calculator, final confirmation must wait until a reasonably large number of persons have had the opportunity to apply the methods of this volume. Hence, the present writer is obliged to record that the general algebraic approach, the switching function, the vacuum-tube operator, and the minimizing chart are his proposals, and that he is responsible for their inclusion herein.

In addition to the course of lectures at Harvard University, some of the material in the book has been presented in lecture form on other occasions. Mr. Kalin presented a brief summary of Chapters I to IV before the Association for Computing Machinery at Oak Ridge National Laboratory in April 1949. Mr. Burkhart gave a similar lecture before the Institute of Radio Engineers in May 1949 at Cambridge. Lectures have also been given on the subject by the present writer in the course of an European tour during January and February of 1951 at the International Colloquium "Les Machines à Calculer et la Pensée Humaine" at the Institut Blaise Pascal, Paris; at the Kunglig Tekniska Högskola, Stockholm, under the auspices of Matematikmaskinnämnden; the Chalmers Tekniska Högskola, Göteborg; the Eidgenössische Technische Hochschule, Zurich; and at the Institut für Praktische Mathematik, Technische Hochschule, Darmstadt. Professor Leon Brillouin, formerly of Harvard University and now with the International Business Machines Corporation, Professor Douglas Hartree of the University of Cambridge, Professor Charles Manneback of the University of Louvain, Professor Dr. Alwin Walther of the Institut für Praktische Mathematik, Darmstadt, and Dr. John Bowman of the Mellon Institute of Industrial Research have all discussed parts of the manuscript, and by their interest lent especial encouragement to those engaged in the task of compiling this volume.

The Staff of the Computation Laboratory wishes to express its appreciation of the kind coöperation of the Harvard University Press in making the publication of this and other volumes of the *Annals* possible; in particular Joseph D. Elder, Science Editor of the Press, has rendered valuable editorial assistance.

Jacquelin Sanborn prepared the manuscript for publication with the assistance of Carmela M. Ciampa, who drew the many figures of the book. The photographs of rectifier circuits and the Mark I multiply unit, as well as the films used in making the plates from which the book was printed, were prepared under the direction of Paul Donaldson, photographer of Cruft Laboratory, in part assisted by Robert Burns.

It is a pleasure to acknowledge the support given by contract W19-122-ac-24 between the United States Air Force and Harvard University, without which the present work could not have been undertaken.

Howard H. Aiken

Cambridge, Massachusetts
Janaury 1951

PROCEEDINGS OF AN INTERNATIONAL SYMPOSIUM ON THE THEORY OF SWITCHING

2–5 April 1957

PART II

CAMBRIDGE, MASSACHUSETTS
HARVARD UNIVERSITY PRESS
1959

PREFACE

This volume, Part II of the Proceedings of an International Symposium on the Theory of Switching, contains papers delivered during the fourth through the eighth sessions. The complete program and a list of the members of the Symposium can be found in Volume XXIX of the Annals, Part I of the Proceedings.

HOWARD AIKEN

Cambridge, Massachusetts
January 16, 1958

A Survey of Research in the Theory of Relay Networks in the USSR

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Institute of Automatics and Remote Control

Introduction

Contemporary scientific development in the area of automatic, remote-control, and guidance devices is characterized by the emergence of broad general theories. These theories afford deep insight into phenomena related to control through industrial and other processes, and reveal new possibilities and prospects, based on general scientific principles, in this field.

The theory of relay devices is one of these general theories. This theory, which arose comparatively recently out of problems in contact technology, has subsequently been broadened to apply to noncontact devices. It can now be considered as a general theory of pulse-type guidance and control devices, these being typically concerned with the transmission and processing of impulses having two or more fixed states.

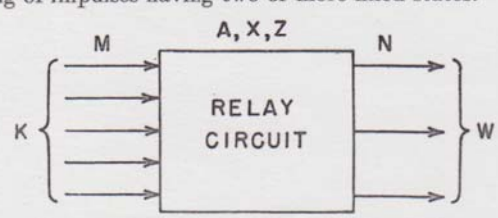

FIG. 1. Schematic diagram of a relay device.

This theory has diverse applications, ranging from the treatment of separate blocks of relay circuits which realize relatively simple particular functions or complex relay circuits which realize complicated functions to the treatment of large-scale relay systems such as are encountered, for example, in the fields of automatic communication and remote control.

Let us consider a general diagram representing the transformation of discrete signals (Fig. 1). We shall let K denote the set of discrete signals that must be processed by the relay device; M the set of channels of communication by which these signals enter the device (the inputs); A the set of elements of the device that receive input signals; Z the set of elements that act to transmit processed signals; X the set of intermediate elements that transmit signals from A to Z and effect their transformation; N the set of channels of communication by which the transformed signals are transmitted to the controlled device (the outputs); and W the set of processed signals.

A Mathematical Theory for the Synthesis of Contact Networks with One Input and k Outputs

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1. Every experienced engineer-designer knows that the synthesis of contact networks constitutes a peculiarly attractive art demanding special logico-combinatory skills and abilities. "Die Ausmittlung von Schaltungen für elektrische Apparate ist eine ebenso anregende Arbeit wie die Lösung einer gewissen Art von Rätseln."[1] As early as the 19th century the possibility of obtaining systematic, regular solutions of network problems was recognized.[2] The application of Boolean algebra predicted by P. Ehrenfest[3] opened up new horizons for the scientific development of methods of network synthesis. Owing to the work of C. E. Shannon,[4,5] V. I. Shestakov,[6,7] M. A. Gavrilov,[8,9] and other research workers of many countries, the synthesis of contact networks is gradually being transformed into a science based on precise calculation.

In this paper is presented a mathematical theory, developed by the author, for the synthesis of contact networks with one input and k outputs. (Other articles[23–25] by the author are devoted to the analysis of networks.) An analogous theory has been constructed by C. E. Shannon[5] for two-terminal contact networks. D. E. Muller[10] recently obtained similar results for combinational electronic networks.

The basic theorems and methods of the theory set forth here by the author were published by him beginning in 1954 in a series of articles[11–22] in Russian and Ukrainian. Following M. A. Gavrilov,[9] the author takes 1 as representing a closed circuit, 0 as representing an open circuit, the Boolean sum as representing a parallel connection of contacts, and the Boolean product as representing a series connection of contacts. Negation is indicated by a bar above a letter ($\bar{x}$). Capital letters $X, Y, Z, \ldots$ represent relays or switches, small letters $x, y, z, \ldots$ represent their make contacts, and small letters with bars $\bar{x}, \bar{y}, \bar{z}, \ldots$ represent their break contacts. A make or a break contact is considered as one contact, a transfer contact as two.

2. A multiterminal contact network is called *directed* if its terminals are uniquely separated into inputs and outputs in accordance with some characteristic. A directed multiterminal network with p inputs and q outputs is called a *multiterminal network of order* (p,q), or a (p,q)*-network*. The operation of renaming inputs as outputs, and outputs as inputs, is called the *transposition* of a directed multiterminal network. Inputs and outputs will be separately indexed by integers $1, 2, \ldots$.

A contact (p,q)-network is called *disjunctive* (in the direction from inputs to outputs) if

Sets—Logics—Machines

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1. *Introduction*

An explicit definition of *set*, *logic*, or *machine* seems elusive. A comparable difficulty occurs in any attempt to define explicitly mathematics, number, matter, beauty, justice, art. Nevertheless, we deal with sets, logics, and machines; and in dealing with them and investigating them, we are at the same time defining them. Our initial impression of them allows us to describe them phenomenologically:

A set is an entity having subsets and certain atomic elements called members, points, units, and so forth.

Logic is an inference process: A implies B.

A machine is an entity related to its environment by means of input-output devices.

One of the aims of this paper is to present some of the interconnections among sets, logics, and machines, and to demonstrate the fundamental role played by the concept of relation in establishing such connections.

The most common relations are equality $=$, an example of which is identity, and the order relation $<$. Many qualitative notions are described first in terms of order relations (warmer, cheaper, before, greater, more beautiful) and only afterward in terms of an equality relation. In mathematics we are accustomed to expressing ideas chiefly in terms of equality relations. Therefore it is often convenient to reduce a given relation to an equality.

2. *Membership, Inclusion, and Characteristic Function*

The basic relations in set theory are "*to be a member of*" and "*to be a subset of*," denoted by $\in$ and $\subseteq$, respectively. Thus if A, B, C are sets, $A \subseteq B$ means that A is a subset of B, and $B \in C$ means that B is a member of C. All sets under discussion are regarded as subsets of a fixed, arbitrary set M, called the *universal set*.

The *complement* S' of a given set S is the subset of M consisting of all those elements which are not in S; that is, $x \in S'$ if $x \in M$ and not $x \in S$. The set S' is sometimes written $M - S$. The *void set* V is the complement of the universal set M. By convention $V \subseteq S$, for every set S. Thus $A \subseteq B$ means either that $A = V$ or that $x \in A$ implies $x \in B$.

The P-operator establishes a connection between $\in$ and $\subseteq$, where $X \in PM$ means $X \subseteq M$. Thus PM designates the set of all subsets of M. If M is a set of predicates or properties (in particular, the set of all properties relevant to the subject under consideration), then an X such that $X \in PM$ may determine some object or individual that has just those properties included in X.

Procceedings of an International Symposium on the Theory of Switching, Parts I and II. Harvard University Press, Cambridge, Massachusetts, 1959. 305 + 343 pp. $30.00.

This two volume set consists of 39 papers presented at a symposium at Harvard University from April 2–5, 1957. The papers range from ones primarily of mathematical interest through papers concerned with switching theory in contact networks and electronic networks, to papers, mainly of engineering interest, which describe designs for computer circuit elements using various technologies such as magnetic cores, transistors, cryotrons and microwaves.

The volumes, organized as the symposium, are divided into eight sessions. An extensive list of the program and registrants to the symposium precede the first session in Part I. Rather than directly follow this organization, I will attempt to classify these papers into five broad categories and briefly describe some of the subjects.

The first category is survey articles. Indeed, these survey articles on switching research in various countries throughout the world must have been extremely interesting to the symposium attendees. M. A. Gavrilov presents "A Survey of Research in the Theory of Relay Networks in the USSR". He considers three fundamental problems: (1) the synthesis from specified operation conditions to a relay structure to realize these conditions; (2) the analysis of determining the operating conditions of a specified structure; and (3) the problem of transforming structures into equivalent structures having some desired form. His reference to a large number of Russian papers and to a more complete bibliography may also be of interest. J. G. Santesmases summarizes "Switching Research in Spain" with lauditory remarks for the early 1900 Spanish inventor Leonardo Torres-Quevedo, and a description of ferroresonant devices for switching. Finally, A. Walther describes "Switching Research in Germany".

Unfortunately, the long delay between the symposium and the appearance of the proceedings makes these surveys, as well as some of the other articles, extremely outdated in this rapidly expanding field.

The second category, papers concerned with the theory of contact networks, contains eleven papers, thus illustrating the large amount of work that has gone into this area of switching theory. J. P. Roth, in "Algebraic Topological Methods of Synthesis", describes two algebraic methods to obtain a minimum normal form expression for a Boolean function. These methods allow one to include "don't care" conditions in the original specification.

A. Svoboda in "Some Applications of Contact Grids" describes a set of mechanical grids and a graphical representation for a Boolean function which solves the same minimization problem as Roth. The method, as is characteristic of chart methods, becomes unwieldy for functions of more than six or seven variables. He illustrates his method for functions of six variables.

There are several papers which apply graph theory and matrices to combinational contact networks. R. Gould's discussion of "The Application of Graph Theory to the Synthesis of Contact Networks" gives a good survey of pertinent graph theory results. He develops a method for synthesis called the "loop-set synthesis method" which attempts to form a network having only one contact per variable. If such a network is not possible, networks having one additional contact are attempted. This process is iterated until a network is obtained. In "Matrix Methods in the Theory of Switching", W. Semon gives a rather complete discussion of Boolean matrix methods to two-terminal networks. These results can also be found in *"Boolean Matrices and the Design of Combinational Relay Switching Circuits"* by F. E. Hohn and L. R. Schissler *BSTJ* 34(1955) pp. 177–202 and *"The Application of Boolean Matrix Algebra to the Analysis and Synthesis of Relay Contact Networks"* by A. G. Lunts (in Russian), *Doklady Akad. Nauk SSSR* 70(1950) pp. 421–423. F. E. Hohn gives an extension of the matrix techniques to "2N-Terminal Contact Networks" with theorems concerning the cascading of N-input, N-output networks.

Several other papers consider circuits with more than one output. P. Calingaert shows how "Multiple-Output Relay Switching Circuits" can be treated by transforming the problem into a single-output problem. Unfortunately, methods for obtaining minimum contact single-output circuits are still being sought. "A Mathematical Theory for the Synthesis of Contact Networks with One Input and K Outputs" is given by G. N. Povorov, with theorems concerning the structure and complexity of such networks, and a "method of cascades" which cascades K relay trees to a one-input, m-output network to obtain the desired K-output network. Later in the volume, V. N. Roginskij uses this analytic cascade method to produce "A Graphical Method for the Synthesis of Multiterminal Contact Networks". The three other papers in this category are: "Some Relations between the Theory of Contact Networks and Conventional Network Theory" by V. Belevitch, "Some Logical Requirements for the Control of Switching Networks" by B. D. Holbrook, which describes some design considerations for a central office telephone system, and "Some Aspects of Switching Algebra" by R. A. Higonnet and R. A. Grea.

The third category is switching theory with electronic elements. In "The Logic of Fixed and Growing Automata," A. W. Burks presents a rigorous treatment of automata containing logical elements which have discrete input and output values, are synchronous and deterministic. He investigates various equivalence relations for such systems.

D. E. Muller and W. S. Bartky develop a new and interesting approach to asynchronous circuits in "A Theory of Asynchronous Circuits". They rigorously treat the detailed circuit behavior of interconnected logical elements when the relative speeds of the elements are not assumed to be known. D. A. Huffman considers circuits whose terminal behavior is described by a transformation of an ordered sequence of binary inputs into some desired ordered sequence of binary outputs in "An Algebra for Periodically Time-Varying Linear Binary Sequence Transducers".

B. Dunham and J. H. North investigate the possibility of developing logical elements which can be used to produce many functions in "The Use of Multipurpose Logical Devices". Two other papers in this category which are concerned with circuits containing memory are: "The State of Computer Circuits Containing Memory Elements" by A. Van Wijngaarden and "Remarks on the Design of Sequential Circuits" by M. Rubinoff.

The fourth category contains the largest number of papers, but I will not consider each paper separately. These are the papers which consider the design of switching elements using various technologies. So many new developments have occurred in the last three years in these technologies that more recent ideas have been reported which outdate almost all of these papers. The twelve papers, listed in order of appearance, are: "Principles of Transfluxor and Core Circuits" by J. A. Rajchman, "Transistors in Combinational Switching Circuits" by S. H. Caldwell, "Simultaneous-Access Matrix Storage Systems" by R. C. Minnick, "Analysis of Magnetic Amplifier Circuits" by T. H. Bonn, "A New Method of Designing Low-Level, High Speed Semiconductor Logic Circuits" by W. B.

Cagle and W. H. Chen, "Magnetic-Core Logical Circuits" by W. D. Woo, "High-Speed Switching by Rotational Remagnetization" by H. B. Callen, "Magnetic Selectors" by M. Karnaugh, "Circuit Considerations and Logical Design with Direct-Coupled Transistor Logic" by R. A. Kudlich, "Chemical Switches" by B. K. Green, E. Berman, B. Katchen, L. Schleicher, and J. J. Stansbrey, "The Woven Cryotron Memory" by A. E. Slade, and "Microwave Logic" by W. D. Lewis.

The final category contains papers of a more general mathematical nature, although several papers discussed in the second and third categories are also of considerable mathematical interest.

B. Van der Pol gives an "Analytic Treatment of Real Functions Given in Discrete Points Only" in which he presents several interpolation methods which construct a real function of one variable from the data supplied at discrete points. R. L. Ashenhurst introduces "The Decomposition of Switching Functions" which determines whether a Boolean function $f(x_1, x_2, \cdots, x_n)$ can be expressed as $F(y_1, y_2, \cdots, y_s\phi)$ where ϕ is a function $\phi(z_1, z_2, \cdots, z_t)$ and each y_i and z_j are associated with some x_k. A chart method is given to determine what decompositions exist for a given function and applications to synthesis are given. T. Singer considers the same problem in "Some Uses of Truth Tables". In "Logical and Other Kinds of Independence," G. Kjellberg gives a general definition of logical independence. He compares this with the notions of stochastic, linear, and functional independence and dependence. G. Kurepa gives a very general discussion of the connections between operations on sets, algebraic relations, and machines considered as structures having inputs and outputs in a paper entitled "Sets-Logics-Machines". S. Seshu and F. E. Hohn consider "Symmetric Polynomials in Boolean Algebras" presenting theorems on certain linear vector spaces of symmetric polynomials over a Boolean algebra, showing, for example, that the set of symmetric polynomials over a Boolean algebra of 2^p elements is a vector space in $(n + 1)$ dimensions, where n is the number of variables over the ring B. The paper "The Shortest Path Through a Maze" by E. E. Moore presents several algorithms of a combinational nature which can be used to obtain a shortest path, or a least cost path when costs are assigned to edges of the maze. These algorithms have proved useful in various routing problems such as traffic routing for telephones or travel.

These two volumes will undoubtedly prove to be useful references for many years to people interested in switching theory.

Raymond E. Miller
University of Illinois

5 School of Gavrilov

This section is a shortened version of the text written by Anatoly A. Shalyto at the web page discussing the school established by Mikhail A. Gavrilov. A biography of Gavrilov can be found in [45], [50], [84].

What is the Gavrilovsky school?

This is a school on the theory of relay devices and finite automata, that now bears the name a member of the USSR Academy of Sciences Mikhail Aleksandrovich Gavrilov (1903-1979), who for many years worked at the Institute of Control (Institute of Automation and Remote Control), Academy of Sciences of the USSR (Moscow). Mikhail made a decisive contribution to the development of applied theory of automata in our country and also gathering together researchers in the field who have become friends for life.

Gavrilovsky school - can be viewed as a unique phenomenon that has no analogues in the modern world of science. In no field of science, in any country in the world there is no a school that would have existed for more than forty years with meetings of the School have been held in different cities of the USSR.

From School M. A. Gavrilova evolved a number of other schools: for diagnosis, for modular structures, design automation.

During this time, the school was attended by hundreds of people, some of whom I will mention below. I cannot enumerate all of them, since I joined the school in 1971, and did not attend it very often, but, apparently, I was the last to enter the school of MAGu (Mikhail Aleksandrovich Gavrilov) and, unfortunately, it seems that I can be the last one to finish it, because "some there are no, and those are far away." Especially as the journal "Automation and Remote Control", based in the Institute of Control, ceases to be a bulwark of this research direction, as no longer accept articles on logic synthesis, assuming now that this area is not scientific anymore, but rather technological. Although, as the S. V. Yablonsky used to say, "If science is not speculative, it does not become obsolete".

The theory of relay devices began to develop in the world with the pioneering work of the Japanese scholar Akira Nakashima (1935). In 1938, Claude. E. Shannon (1916-2001) published a similar work "Symbolic Analysis of Relay and Switching Circuits", which had a huge impact on the development of this field of science in the world. Victor I. Shestakov (1907-1987) in 1941 published a paper "Some mathematical methods of designing and simplifying bipolar circuits Class A", that was prepared in the manuscript form in 1935-1938 at the Physics Department of Moscow State University of M. V. Lomonosov.

But, before Shestakov in our country (in Kazan) worked I. Zhegalkin (thirty years ahead of Americans Reed and Muller), whose work in 1924 in Russian, I saw in 1995 in the United States at a conference on situational control (proposed by D. A. Pospelov) in the hands of a military expert from Pentagon engaged in NP-hard problems. Unexpectedly, he found me on the Internet and renewed interest in research in the field of Zhegalkin polynomials. By the way, note that the first task for which it has been proven NP-complete, is the problem of "Satisfiability of Boolean formulas", and all the other tasks of this class can be reduced to it.

And long before Zhegalkin, in Kazan worked Platon S. Poretsky, the author of the seminal works on mathematical logic presented and published already in 1884. The possibility of application of algebra of logic in the design of relay circuits have been pointed out by Charles Pierce in 1885 [3] and in Russia by Paul Ehrenfest a physicist the St. Petersburg (1910). The list of forerunners in the design of relay circuits should include our compatriots A. Kutty and M. Timbalistij (1928), see the list of publications bellow.

After work of V. I. Shestakov in this field of science, in the Soviet Union came the era of M. A. Gavrilov, which could (if there would not be the fight with cybernetics, the Iron Curtain, and other charms typical for us) change the area on the world level, especially since C. E. Shannon departed very soon from the work in this area.

M. A. Gavrilov (MAG) began his scientific work with practical investigations on the remote control system (telemechanics), in which the relay based devices were built heuristically. He came to the conclusion that this class of devices can be synthesized using formalized methods, about which he wrote one of the first in the world books: Gavrilov, M.A., *Theory of Relay-contact Circuits*, Moscow, Publishing House of the USSR Academy of Sciences, 1950. The first book on the subject was published in 1947 by the Austrian scientist O. Plehl under the title "Schalter und Apparatebau".

However, the way of Gavrilov in this direction was not strewn with roses. Gavrilov had to wait for the defense of his doctoral thesis on the subject until in 1946. The defense was possible just thanks to the efforts of the philosopher S. A. Janowskaya, who was able to convince the authorities that the usage of Boolean algebra in the synthesis of logical circuits is not

[3], Peirce (1885), "On the Algebra of Logic -A Contribution to the Philosophy of Notation", *American Journal of Mathematics*, 7, two parts, first part published 1885, 180202.

an idealism, and especially it is not contrary to Marxism-Leninism, etc. Thanks are due also to Aksel Ivanovich Berg. Further, he was elected in the Academy of Sciences relatively late (1963). Interestingly, it was written an artistic book about MAG and his associates (which is rarely happen to scientists, especially not during their lives). Yuri Weber published a book entitled "When the Answer Comes", if I remember correctly by "Detgiz"! This book was later reprinted by the publishing house "Belles-lettres" in the series "Road to the Unknown."

Everything started after the book of M. A. Gavrilov that was published in 1950!!!

G. N. Povarov (with whom I corresponded in 2007) has published over then papers in 50-ies, even before defending his candidate of doctor of sciences dissertation (doctor, unfortunately, for some reason did not become, but in spite of that he become a very renowned scientist) with a dozen articles in the "Reports of the Academy of Sciences". Recall what was the level of publication at that time in the majority of former dissertations, in particular for the candidate of the doctor of science, and especially in computer science.

P. P. Parkhomenko received a gold medal for the machine to minimize relay circuits at the World Exhibition in Brussels in 1956.

I said above that I am not writing a history, but just a "reflection", so let enumerate some of the schools, that I remember or know which originated as descendants of the Schol of Gavrilov. "Students" are split into classes with respect to the principal researcher or on a territorial basis.

Students of M. A. Gavrilov - O. P. Kuznetsov, V. D. Kazakov, Yu. L. Tomfeljd, B. L. Timofeyev, V. M. Ostianu, V. F. Ljakhovich, V. V. Devjatakov, E. I. Pupirev, A. A. Ambartsumyan, A. I. Potekhin, S. A. Stepanenko, L. G. Bivol, A. N. Malevich, E. N. Zapoljskih, A. B. Chichkovsky, B. I. Lipatnikov, S. A. Iskra, L.A . Ivchenkov, L. A. Sholomov, A. Y. Makarevskii, L. B. Shipilina, A. V. Markov, L. A. Vol'vovskii, A. K. Grigoryan , B. Sh. Okudzhava, B. A. Lagovier, I. E. Voeckler, M. J. Zolotarevskaya, E. Galaktionova, E. A. Grebenyuk, S. B. Kotlyar, et al.

Students of V. M. Glushkov, who developed a methodology for synthesis of digital automata and solved the generalized fifth Hilbert problem (Institute of Cybernetics, Kyiv) -Yu. V. Kapitonova, A. A. Letichevsky, G. E. Tsetlin, A. A. Stogniy, Z. L. Rabinovich, Z. L. Ivaskiv, V. N. Koval, A. N. Chebotarev, L. V. Matsevity, V. P. Derkach, E. L. Denisenko, N. S. Chaika, V. G. Alekseenko, T. Mishchenko, S. S. Gorokhovsky, V. G. Bodnarchuk,

E. I. Komuhaev, V. V. Litvinov, et al.

Students of I. V. Prangishvili (Institute of Automation and Control, Moscow) - V. V. Ignatuschenko, V. D. Malyugin, E. V. Babicheva, N. A. Abramova, M. A. Uskach, V. M. Vishnevsky, I. L. Medvedev, G. G. Stetsyura, A. Veitz, V. G. Chachanidze, G. G. Asatiani, T. D. Abuladze, I.P. Egorov, I. A. Stepanovskaya, I. V. Speranskaya, G. M. Popova, O. G. Smorodinova, A. A. Chudin, E. G. Prokhorov, V. K. Bykhovsky, D. V. Pevcov, V. V. Sokolov, M. A. Zuenkov, etc.

Students of V. G. Lazarev (Institute for Information Transmission Problems, Moscow) - E. I. Piilj, V. F. Dyachenko, G. G. Savvin, V. A. Garmash, O. F. Naumchuk (Sergeeva) , G. V. Kreynin, V. M. Isyanov, E. B. Ershova, V. A. Ershov, T. L. Maystrova, O. Ivanova, E. N. Turuta, V. M. Chentsov, A. V. Butrimenko, V. G. Chernyaev, A. G. Saveliev, I. D. Seiful, V. N. Doniants, A. I. Firsov, F. I. Pepinov, E. A. Kondratieva, E. P. Soprunenko, N. Ya. Parshenkov, A. V. Soloviev, G. V. Bogdanova, N. Zoreva , etc.

Students of V. I. Varshavski (Leningrad) - Ya. Rosenblum, B. L. Avsievich, I. M. Bogolyubov, I. P. Vorontsova, V. A. Peschanskii, V. B. Marakhovskii, N. A. Starodubtsev, B. S. Tsirlin, A. V. Kondratyev , M. A. Kishenevsky, A. R. Taubin, A. G. Astanovsky, R. L. Finkelstein, A. V. Yakovlev.

Students of A. D. Zakrevskij (Tomsk State University, Institute of Engineering Cybernetics, Minsk) - A. E. Yankovskaya, Yu. V. Pottosin, A. Yu. Matrosov, V. G. Novoselov, V. F. Roth ko, H. R. Toropov, G. P. Agibalov, N. V. Yevtushenko, L. D. Cheremisinova, P. N. Bibilo, B. N. Schneider, V. K. Vasilenok, et al.

Students of E. A. Yakubaitis (Institute of Automation and Computer Science, Riga) - G. F. Fritsnovich, A. Gobzemis, V. P. Chapenko, V. G. Gorobetc, A. F. Petrenko, A. L. Gurtovtsev, A. Ya. Kalnberzin, E. Ya. Greenberg, I. G. Ilzinya, I. G. Lembersky, E. E. Lange, Ya. Ya. Kalnins, A. Yu. Tolmachev, et al.

Students of D. A. Pospelov - V. N. Zakharov, V. E. Hazatsky, V. N. Vagin, et al.

Students of A. V. Kalyaeva (Taganrog Radio Engineering Institute) - A.

N. Melikhov, V. M. Kureichik, L. S. Bernstein, G. I. Ivanov, N. G. Topolsky, V. F. Guzik, O. N. Pyavchenko, V. V. Lisyak, V. I. Kodachigov, O. B. Makarevich, N. I. Vitiska, N. I. Denisenko, V. A. Kalashnikov, et al.

Students of P. P. Parkhomenko (Institute of Automation and Remote Control, Moscow) - V. R. Gorovoj, V. V. Karibskii, E. S. Sogomonyan, G. P. Aksenova, V. F. Khalchev, M. F. Karavai, et al.
Diagnostics related to the theory of automata, was a topic of research of I.V. Kogan, and D.M. Grobman.

Students of V.P. Tchistov (Institute of Mathematics, Sverdlovsk) - V. P. Bityutskii, N. V. Zakurdaev, N. V. Kovalin, I. A. Kononenko, I. O. Sitnikov, M. A. Gogina, etc.

Let us proceed to enumeration of other "students" in different research centers all over USSR.

Moscow - M. L. Tsetlin, D. Kharkevich, G. S. Pospelov, R. R. Varshamov, V. N. Roginskii, A. A. Arkhangeljskaya, V. I. Neiman, A. A. Talj, M. A. Aizerman, L. I. Rozenoer, L. A. Gusev, I. M. Smirnov, E. A. Trahtengerts, A. N. Yurasov, E. K. Voishvillo, Y. I. Meckler, V. V. Vorzheva, V. P. Didenko, V. I. Ivanov, A. D. Talantsev, N. P. Vasiliev, Y. L. Shagalovich, V. A. Gorbatov, V. L. Stefanyuk, S. M. Domanickii, V. I. Maksimov, S. A. Yuditskii, A. A. Tagaevskaya, T. K. Efremov, T. K. Berends, I. D. Zaslavsky, J. A. Schroeder, V. M. Ozernoi, N. P. Red'kin, M. G. Millerova, N. N. Ivanov, V. V. Rudnev, G. I. Mikhailov, A. M. Kukinov, M. I. Shamrov, Yu. A. Popov, P.E. Bochkov, Yu.V. Golunkov, E.I. Gurvich, E.A. Gurvitz, E.G. Dulepov, V.M. Karasik, V.L. Beljawskii, A.D. Kazakov, et al.

Leningrad - M. G. Karpovsky, S. I. Baranov, O. F. Nemolochnov, G. R. Firdman, B. G. Pittel, V. V. Sapozhnikov, Vl. V. Sapozhnikov, Ya.G. Karpov, V.L. Artyuhov, G.A. Kopeiikin, A.A. Shalyto, V.N. Kondratiev, G.A. Kuharev, E. S. Moskalev, V. L. Perchuk , V. S. Dudkin, L. Yu. Lapkin, A. N. Berlin, S. D. Aljtschulj, G. I. Gilman, G. I. Rog, E. D. Ioheljson, G. S. Avsarkisyan, I. Levin, etc.

Kiev - E. N. Vavilov, G. P. Tailor, B. P. Egorov, D. B. Shishkov, V. I. Kartashov, S. P. Kartasheva, I. V. Safonov, and others.

Novosibirsk - O. L. Bandman, E. V. Evreinov, G. Kosarev, Y. I. Fet, L. I. Makarov, S. V. Makarov, V. P. Markova, S. V. Piskunov, S. M. Achasova, P. A. Anishev, A. I. Mishin, B. A. Sedristy, Yu. V. Merekin, S. N. Sergeev, Yu. N. Korneev, A. A. Koifman, V. A. Skorobogatov, V. G. Horoshevsky, I. V. Ilovajskij, A. I. Khrushchev, V. I. Potapov, S. G. Sedukhin, et al.

Minsk - A. Sh. Bloch, V. I. Lades, A. I. Pavlovsky, V. A. Kazuschik, K. V. Ponomarenko, G. V. Neverov, A. V. Gorelik, A. A. Utkin, V. A. Sklyarov, V. N. Sinev, V. P. Shmerko, S. N. Yanushkevich, E. N. Zaitseva, and others.

Yaroslavl - Yu. A. Mamatov

Novocherkassk - M. S. Melnikov

Penza - V. I. Levin

Ryazan - A. P. Koryachko

Riga - I. E. Strazdin, A. N. Sklyarevich, V. L. Bielawski

Vladivostok - V. P. May, G. R. Greiner, R. S. Goldman, V. P. Chipulis, L. I. Tokmakova

Donetsk, Saratov - A. M. Bogomolov, D. V. Speransky, A. S. Barashko, I. S. Grunskii, V. A. Kozlovsky, A. A. Barkalov, V. A. Tverdohlebov, et al.

Kishinev - V. Z. Krištal, M.S. Bulat

Tallinn - R. Ubar, B. G. Tamm, E. H. Tyugu, H. I. Tanya, A. E. Keevalik

Uzhgorod - N. N. Aizenberg

Sevastopol - E. A. Butakov, V. I. Ostrovsky

Frunze - V. V. Obrazovc, Yu. N. Arsentiev, V. M. Kopylenko, T. G. Bazarbaeva, Z. I. Vostrova,

Tbilisi - V. V. Chavchanidze, A. H. Giorgadze, G. A. Ananiashvili, G. S. Tsiramua

Baku - R. H. Faradzhev, Askerov Charles, I. V. Hamidov

Kaunas - Abraytis L. B., Atstopas F. F., Zhintelis G. V., et al.

Tashkent - D. A. Abdulaev, D. Yunusov

Kharkiv - V. A. Popov, I. T. Skibenko, I. G. Moklyak, A. V. Sychev, V. A. Mishchenko, V. D. Kozyuminsky, A. N. Semashko, et al.

Tiraspol - V. S. Vykhovanets

6 Researchers in Related Areas

Note that many other scientists worked in the field of applied theory of automata. They are not mentioned above since do not participate in the work of the School of Gavrilov. At that time, actively worked S.A. Mayorov, G. I. Novikov, V. I. Skorubsky, V. B. Smolov, D. V. Puzankov, E. P. Balashov, G. A. Petrov, B. V. Barashenkov, M. B. Ignatyev, V. A. Torgashev, L. Y. Kravtsov, B. P. Kuznetsov, and many others.

In research on theory of probabilistic automata involved were R. G. Bukharaev, V. G. Sragovich, G. N. Tsertsvadze, A. Lorenz, Yu. A. Flerov, M. K. Chirkov, V. V. Novorusskii, et al.

Besides research in applied theory of automata, in the USSR there was a school of mathematicians studied the theory of automata, which worked mainly at the Institute of Applied Mathematics, USSR Academy of Sciences (Moscow) and the Moscow State University and has had a significant impact on the applied theory of automata and professionals working in this field.

The leader of this school O.B. Lupanov is still active. The summary of his PhD thesis occupies a little more than a page, instead being just a recording sheet, as usually happens.

At the defense, Lupanov presented a proof of the asymptotic estimate of complexity of the minimal network realizing an arbitrary Boolean function, which reduced the similar estimate of C. E. Shannon to a half. The author of this reminiscences, had the honor to talk with O. Lupanov, and this conversation he will remembered for a lifetime. Although without a preliminary agreement, the conversation started in 22.15 hours, and ended well after midnight. The conversation was at the Hills of Lenin in the winter and on the cold weather, and it was necessary to return to home after the talk. In spite of all these inconvenient circumstance, and although being among most renowned authors in discrete mathematics, and seeing me for the first time [4], Lupanov listened to me carefully and with no hurry.

Another interesting issue. At an occasion, I talked about the anniversary of Lupanov with my supervisor V. L. Artyukhov, who wrongly supposed that Oleg Borisovich is in age of eighty, instead of just fifty, because Lupanov was already so widely known for many years.

Students of this school also included S. V. Yablonsky, Yu. I. Zhuravlev, I. A. Chegis, G. Potapov, Yu. L. Vasilyev, A. D. Korshunov, R. V. Freivald, V. V. Martyniuk, G. A. Shestopal, Yu. T. Medvedev, V. I. Lowenstein, G. P. Gavrilov, and V. B. Kudryavtsev, S. V. Aleshin, A. S. Podkolzin, N. A. Karpova , V. M. Khrapchenko, V. A. Buevich, A. A. Karatsuba, M. I. Kratko, V. N. Redko, A. V. Kuznetsov, A. A. Sapozhenko, B. A. Subbotovskaya, etc.

In addition, in Moscow at that time worked such well-known scientists in the field of discrete mathematics and artificial intelligence as A. S. Adian, V. A. Uspensky, M. A. Kronrod, G. M. Adelson-Velskii, and E. M. Landis. The concept of AVL-trees and Evgenii Landis trees are studied all over the world in courses related to the theory of algorithms. V. L. Arlazarov, A. Uskov, L. G. Khachiyan, proposed a polynomial algorithm for linear programming. Then, there were working B. C. Zaripov, and many others.

In Novosibirsk, in the automata theory and discrete mathematics worked B. A. Trakhtenbrot, N. E. Kobrin, Yu. L. Ershov, A. V. Gladki, V. A. Kuzmin, V. V. Glagolev, M. I. Kratko , R. E. Krichevskii, V. A. Evstigneev, et al.

In this area in Riga worked Y. M. Barzdin, in Kazan - R. G. Nigmatullin. In Leningrad studies in mathematical logic performed N. A. Shanin, Yu. V. Matiyasevich, who solved the tenth Hilbert problem, S. Yu. Maslov, A. O. Slisenko, G. S. Tseitin, and in theory of automata - E. I. Nechiporuk [5], and A.G. Luntz.

Research on automata theory in the USSR have been carried out in parallel with the development of practical and theoretical programming. In establishing of it involved were renowned scholars, such as A. A. Abramov, A. L. Brudno, Yu. I. Yuanov, A. P. Ershov, V. P. Ivannikov (chief editor

[4] I should confess, that Lupanov had in his bookshelf my book that I sent him a bit earlier.

[5] See, Stanković, R. S., Astola, J. T., (eds.), *Reprints from the Early Days of Information Sciences, On the Contributions of E. I. Nechiporuk to Switching Theory*, TICSP # 36, 2007, ISBN 978-952-15-1788-4

of the journal "Programming"), M. R. Shura-Bura, R. I. Podlovchenko, O. S. Kulagina, S. S. Lavrov, I. B. Zadihailo, E. Z. Lyubimskii, L. A. Lyusternik, S. S. Kamynin, L. A. Kaluzhnin, V. V. Martynyuk, N. P. Trifonov, E. A. Zhogolev, V. F. Turchin, V. I. Shestakov, V. S. Shtarkman, E. L. Yushchenko, V. S. Koroljuk , V. N. Agafonov, I. V. Pottosin, V. N. Kasyuanov, V. A. Nepomnyashchii, V. E. Kotov, V. K. Sabelfeld, A. S. Narinyani, V. A. Valkovskii, etc.

Work on the theory of automata and programming was used indirectly and directly in the design of national computer technology, some examples of which (for example, the machine M-10 and BESM-6) are not inferior, and in many respects, superior to their foreign counterparts. It is primarily true for classified devices, as otherwise the Soviet Union could not provide a defense parity. Among the founders of domestic computer technology should be noted such outstanding designers as S. A. Lebedev, J. S. Brooke, B. I. Rameev (who become a Doctor of Technical Sciences without higher education), N. I. Bessonov, Y. Y. Bazilevskii, N. Y. Matyuhin, N. P. Brusentsov, L. N. Korolev, M. A. Kartcev, N. G. Bruevich, B. N. Malinovsky, B. V. Bunkin, V. S. Burtsev, V. A. Melnikov, B. A. Babayan, et al.

Automata Theory, Programming, and Computer Science have developed in the framework of a single direction, called by N. Wiener "Cybernetics" (now viewed as the "Informatics" or "Computer Science"), which was also characterized by consideration of wildlife management. This area was studied by N. V. Timofeev-Resovskii, I. I. Shmal'gauzen, A. R. Luria, V. S. Gurfinkel, and many others.

The role of A. I. Berg, M. G. Gaase-Rapoport, A. A. Dorodnicyn, V. A. Kotelnikov, B. V. Gnedenko, N. P. Buslenko, R. L. Dobrushin, M. M. Bongard, I. A. Poletaeva, A. I. Kitov, N. A. Krinitsky in the development of cybernetics in the USSR cannot be overestimated.

Many of these experts mentioned above are renowned scientists at the world level, but in addition to them, the development of cybernetics in our country was supported and contributed by such giants of science as L.V. Kantorovich, M.V. Keldysh, M.A. Lavrent'ev, S. L. Sobolev, P. S. Novikov, A. A. Markov (Jr.), I. M. Gelfand, A. I. Maltsev, A. A. Lyapunov.

A few words of Alexei A. Lyapunov (1911-1973), a pupil of N. N. Luzin, who made a great contribution to the development of theoretical programming in the world.

Alexei Andreyevich read for students of the Moscow State University, the Department of Computational Mathematics, in the 1952-53 academic year a short course entitled "Principles of programming" consisting of just eight lectures. From this course, later developed courses on symbolic programming languages, compilers (called earlier as programming programs) and the theory of program schemes. Alexei began his course when programmers were rare, there were not many of them, and all that was related to electronic computers was classified. A direct acquaintance of Alexei A. with the first domestic computer machine, created under the leadership of S. A. Lebedev in Feofaniya that is near Kiev, was considerably useful in solving fundamental problems of future programming (see, Podlovchenko).

By the way, a small world, one of the book publishers asked a professor of Moscow State University, Rimma Ivanovna Podlovchenko, to give feedback on the outline of a book "Theory of Automatic Programming", written by me in collaboration with N. I. Tukkel.

Turning to the review of the achievements of Lyapunov, we note first of all his work on the theory of programming. Already in the early days of programming, we have been aware of the difficulties in creating large programs without drawing the appropriate flowchart in terms of fairly large operations. In 1953, Alexei proposed a method for preliminary description of programs in terms of operator schemes, which was focused on a clear allocation of the main operators and to build a kind of algebra transformation programs. This method, due to the usage of algebraic expressions, was much more convenient than the previously applied method of flowcharts. It has become the primary means of automatization of programming and is the basis of the ideas of the Soviet school of programming. These ideas were further explored and improved by the Soviet (Yu. I. Yanov, A. P. Ershov) and foreign scientists. In this way "it was achieved a better understanding of how to deal with flow graphs of programs in an equivalent manner and to evaluate the resulting programs in view of their logical flow graphs" (B. Trakhtenbrot).

IEEE (The Institute of Electrical and Electronic Engineers) as the international community exists for over 100 years. In 1946, it was established a structural unit - the Computer Society, which brings together hundreds of thousands of professionals working in the field of computer science and industry: computer science, programming, production of computer equipment, and computer business. The most prestigious award of the society - the medal "Computer Pioneer" - was established in 1981. Its purpose is to recognize and present to the world community the outstanding individuals whose efforts created and developed computer technology, provided that their main contribution was made at least 15 years ago. Among the 55 winners of this prestigious award, there are such classics of computer science, as John Atanasov - for creating one of the first electronic computers, Nicolaus Wirth - for the development of language "Pascal", George McCarthy and

Marvin Minsky - for the work in the field of artificial intelligence, E. Kodd - for inventing the relational data model and others.

In this list (considerably because of the Iron Curtain) there were not Soviet scientists. In 1996, at the fiftieth anniversary of its establishment, the Computer Society make a great effort to restore historical justice, and awarded by medals "Computer Pioneer" V. M. Glushkov, S. A. Lebedev, and A. A. Lyapunov - for achievements in establishing foundations of Computer Engineering and Programming" (G. V. Karatkevich).

In addition, note that the formulation of automata theory and the theory of programming happened in the pre-Internet era place, which virtually eliminates results obtained in these areas from the sphere of interests of Russian youth, for which the Internet is almost the only source of knowledge. Although this trend still does not swept the whole world, for example, the Cambridge University Library subscribes to 55,000 magazines (!) that are probably read ("Izvestia", of 19.04.2002).

An extended form of this article was published at Internet on 03.07.2002
Amended and supplemented on 10.08.2007

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7 List of Publications of Soviet Union Researchers in First 20 Years of Switching Theory and Logic Design

In this section, we present a list of publications by researchers in former Soviet Union until 1958. The list is compiled from different sources including [23], [38], [39], [40], [41], [46], [47], [48], [49], [62], [75], as well as reviews appearing in the *Journal of Symbolic Logic*, and personal communication with experts in the field as Vladimir D. Malyugin, Vladimir N. Shmerko, and others. We are well aware that, in spite of our best efforts, it is probably incomplete, and we apologize for any missing reference, this is unintentionally done, and we would be grateful for any updating, correcting, and improving the list.

1881

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1884 Porecskij, P.S., On the Method for Solving Logical Equations and on the Inverse Methods for Mathematical Logic, *Sobranie protokolov zasedanii z. mat.*, Kazan, Russia, Vol. 2, 1884, 161- 330, (In Russain).

1913

2. Parentsev, N.N. "Neskolko slov po povodu knigi L. Kutura "Filosofskii principy matematiki" (A few words apropos of L. Couturat's book, "Filosofskie principy matmatiki") (cf. 10021). Izvestia Fiziko-Matematiceskago Obscestva pri Imperatorskom Kazanskom Universitete (Bulletin de la Société Physico-Mathématique de Kasan), Ser. 2, Vol. 19, No. 1, 1913, 15-23.

1927

3. Zhegalkin, I. I., "The technique of calculation of statements in symbolic logic", *Matem. Sbornik*, Vol. 34, 1927, 9-28.

1928

4. Tsimbalisty, M., "On the question of simplification in the construction of relay circuits", *Trudy Leningrad Eksper. Elektrotekh. Labor*, No. 8, 1928, 19, (In Russian).

5. Zhegalkin, I.I., "Aritmetization of symbolic logic", *Math. Sb.*, Vol. 35, 1928, 311-377, (In Russian).

1938

6. Shestakov, V. I., "Some Mathematical Methods for the Construction and Simplification of Two-Terminal Electrical Networks of Class *A*", PhD Dissertation, defended on September 28, 1938, at The Lomonosov State University, Moscow, Russia, 1938.

1941

7. Shestakov, V. I., "Algebra of two terminal networks constructed exclusively of two terminal elements (Algebra of A-networks)", *Zhur. Tekh. Fiz.*, Vol. 11, No. 6, 1941, 532-549, *Avtomat. i Telemekh.*, No. 2, 1941, 15, (In Russian), *J. Simbolic Logic*, Vol. 21, 1941, 399, (Review).

8. Shestakov, V. I., "Algébra dvuhpolusnyh shém, postro' ennyh isklzititél'no iz dvuhpoldsnikov (Algébra A-shém)" (An algebra of two-terminal circuits constructed exclusively of two-terminal components (Algebra of A-circuits)), *Avtomatika i telemkhanika*, 1941, 15-24. [6]

1943

9. Gavrilov, M. A., "The synthesis and analysis of relay-contact networks", *Avtomat. i Telemekh.*, Vol. 4, 1943.

1944

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10. Shestakov, V. I., "On a certain symbolic computation, applicable in the theory of electrical relay circuits", *Uchenye zapiski MGU, Matematika*, Vol. 73, kn. 5, 1944, 45-48, (In Russian).

1945

11. Gavrilov, M. A., "Methods for the synthesis of relay-contact networks", *Elektrichestvo*, No. 2, 1945, 54-59, (Rev.) J. Symbolic Logic, Vol. 23, p. 367.

12. Gavrilov, M. A., "Relay contact networks with rectifying elements", *Izv. AN SSSR*, No. 3, 1945, 153-164. (In Russian.)

13. Gavrilov, M. A., "Determination of the number of contacts in relay decoding networks and their distribution between the relays", *Izv. AN SSSR*, No. 12, 1945, 1109-1127. (In Russian), Rev: Math. Rev., Vol. 8, p. 190.

1946

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1947

16. Aranovich, B. I., *Matrix Methods for the Analysis and Synthesis of Relay-contract Networks*, Leningradski Elektrotekhnicheskii Institut, 1947.

17. Bryleev, A M., "Theorems of inversions and the synthesis of relay contact networks", *Tekh. Zheleznykh Dorog*, No. 1, 1947, 12-15, (In Russian).

18. Gavrilov, M. A, "On a certain general method of transformation of relay contact network", *Avtomat. i Telemekh.*, Vol. 8, No. 2, 1947, 89-107, (In Russian.)

19. Gavrilov, M. A, "Structural classification of relay contact networks", *Avtomat. i Telemekh.*, Vol. 8, No. 4, 1947, 297-307, (In Russian.)

20. Gavrilov, M. A., "Analysis of relay contact networks", *Elektrichestvo*, No. 4, 1947, 5-13, (In Russian.)

21. Sadovskij, L. L., "Algebraization of a problem in theory of control by computing automata", *Usp. Mat. Nauk*, No. 2, 1947, 6.

22. Volotskij, A, "Elements of the theory of relay contact networks", *Vestnik svjazi*, Elektrosviaz, No. 7, 1947, 16-18, (In Russian).

1948

23. Bryleev, A. M., "Theoretical methods for synthesizing relay contact networks of class N", *Tekh. Zheleznykh Dorog*, No. 8, 1948, 23-24, (In Russian).

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28. Shatsev, N. Z., "Elements of the theory of relay contact networks", *Trudy Voennotransportnoj Akad.*, No. 13, 1948, 129-133, (In Russian).

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From 1957, abstract of 17 publications were presented in *Automation Express*.

From 1950, 15 publications were translated into English from *Avtomatika i Telemekhanika* as the version of this journal *Automation and Remote Control* and from *Dokl. AN SSSR*.

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P.O. Box 527
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ISBN 978-952-15-3785-1 (printed)
ISBN 978-952-15-3786-8 (PDF)
ISSN 1456-2774