

JOHN VINCENT ATANASOFF –
HIS PLACE IN THE HISTORY
OF COMPUTER LOGIC AND TECHNOLOGY

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John Vincent Atanasoff died of a stroke at his home in Frederick, Maryland on 15 June 1995 following a prolonged illness. He was survived by his second wife, three children, and ten grandchildren. Obituaries appeared in *The New York Times* [Baranger 1995], and several newspapers in the Ames, Iowa area where he carried out this work (see [Bruner 1995], [Grause 1995]), as well as in the *History of Logic Newsletter* [Editor 1995] and *Modern Logic* [Editor 1995].

John Vincent Atanasoff was born near Hamilton, New York on 4 October 1903. In the first months of 1937 that he conceived the idea of combining electronics, binary arithmetic, and Boolean algebra to build an electronic digital computer, using binary arithmetic for computation, Boolean switching-relay circuitry for machine logic, and electrical and electronic components for machine hardware.

His father John was born Ivan Atanasov in Bulgaria in 1876 and emigrated to the United States in 1889. In 1900 he received a bachelors degree from Colgate University and worked as an electrical engineer. He died in 1956. In 1900 he married the New Yorker Iva Lucena Purdy, a descendant of revolutionary war general and associate of George Washington, Jeremiah Purdy. Born in 1881, she was an elementary school mathematics teacher, and died in 1983. It was from a recollection of reading one of her eight grade arithmetic textbooks which included a discussion on binary arithmetic that he first conceived the idea of using binary arithmetic for computation in his computer.

Atanasoff became interested in mathematics in 1913, working with his father's sliderule and seeking to understand the mathematical principles

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underlying its use, leading him to study logarithms and trigonometric functions. At this same time, he discovered and studied J. M. Taylor's *College Algebra* (1895), which his father had used at Colgate. Atanasoff graduated from the high school in Mulberry, Florida, in 1920, and received a bachelors degree in electrical engineering from the University of Florida in 1925, a Master of Science degree in mathematics from Iowa State College (now Iowa State University = ISU) in 1926, and a Ph.D. in physics from the University of Wisconsin in 1930 with a thesis on "The Dielectric Constant of Helium" written under the direction of John Van Vleck. While attending the University of Florida, he taught mathematics at Gainesville High School and served as the head of the high school's science department. He was a graduate assistant and instructor in the mathematics department of ISU from 1926 to 1929 and mathematics instructor at the University of Wisconsin in 1929-30. After receiving his Ph.D., he joined the mathematics and physics departments at ISU, serving as assistant professor, 1930-36, associate professor, 1936-42, and Professor *in absentia*, 1942-45. He left ISU in 1942 and served in various research capacities with the U.S. military from 1942 until 1952, when he became an entrepreneur, founding several of his own research and development companies.

It was at ISU that Atanasoff began his search for a calculating machine which would ease the burden and shorten the time that it took to perform tedious computations even on the most sophisticated calculating machines of the day. In particular, he became interested in developing a machine that could easily and quickly handle the computation of approximate solutions for the wave functions with which he had worked in his doctoral thesis on the dielectric constant of helium. Well equipped by his education for the task he was undertaking, Atanasoff began his studies by examining in detail the mechanisms of the calculating machines currently available. He noted that the machinery then current was incapable of handling complex spectral analysis.

During these years, especially beginning around 1934, Atanasoff, with the aid of some of his graduate assistants, also tinkered with the machines then available, and sought ways to link together several machines in order to achieve greater speed in handling more complicated problems. On the basis of this research, Atanasoff's students George L. Gross and C. J. Thorne wrote graduate theses on the use of functionals for the approximate solutions of linear differential equations [Gross 1937; 1939; Thorne 1941], thereby developing a method which made it easier to carry out the required mathematics, while Atanasoff himself in 1936 developed his Laplaciometer, a small analog calculator. It was concluded, on the basis of these studies, that the analog calculators available at the time simply could not solve, efficiently, if at all, large scale systems of linear equations. Atanasoff therefore undertook a study, after 1936, with the assistance of ISU graduate engineering student Clifford Edward Berry (d. 1963), of the possibility of constructing a digital machine. It was on a winter drive across eastern Iowa and into Illinois in early 1937 that Atanasoff conceived of the tripartite idea of combining electronics, binary arithmetic, and Boolean algebra for his machine, using binary arithmetic for computation, Boolean switching-relay circuitry

for machine logic, and electrical and electronic components for the machine hardware.¹ (For an elementary exposition on the application of circuits for binary arithmetic computation, see, e.g. chapter 6 of [Whitesitt 1995].)

By 1939, a model had been constructed, and then, by mid-1940, a full-sized, fully operational prototype of the electronic digital computer, the ABC (Atanasoff-Berry Computer). The ABC could solve a system of 29 equations in 25 unknowns, although only much smaller systems were in fact tested on the ABC (see [Leonard 1996b]). In August 1940, Atanasoff described the ABC in his 36-page manuscript paper “Computing Machine for the Solution of Large Systems of Linear Algebraic Equations” [1940], using the mathematical tools developed by Gross and Thorne. The paper, which was not finally published until 1973 (see [Atanasoff 1973]), gave a full engineering description of the machine, and an account of its logic. A physical description of the hardware is given by S. Augarten [1985, 117]; see also P. E. Ceruzzi [1990, 228–229]. A description of the ABC’s hardware and the mathematics used is given by Mackintosh [1988] and by Burks and Burks [1988, 257–290]. Berry himself gave a description of the design of the electrical data recording and reading mechanism in his [1941] doctoral thesis.

David Burlingmair, an engineer at ISU who is working on the reconstruction of the ABC, explained (as quoted by [Leonard, 1996a] that

Atanasoff wanted to do his calculations by logical action, rather than by enumeration. He used electronic means to hold his data, which he thought was much faster than mechanical. He decided to work in binary, rather than decimal and he wanted to regenerate his memory often so he didn’t lose any information.

The ABC machine used a Boolean-valued machine language which Atanasoff developed in 1939, taking his inspiration from the binary arithmetic presented, along with several other number-base arithmetics, in a long forgotten elementary school arithmetic textbook which had once belonged to

¹Coincidentally, the German engineer Konrad Zuse (b. 1910) began work on electro-mechanical relay machines in 1934, unwittingly taking Babbage’s analytical engines as his starting point. His aim, like Atanasoff’s, was to build a universal calculating machine which would be capable of alleviating the tedium of solving large systems of linear equations. Like Atanasoff, Zuse decided to use binary rather than decimal arithmetic and he devised, albeit in his own notation, an operating system equivalent to Boolean algebra. [Augarten 1984, 89] asserts that Zuse did not learn of Boole or his work until 1939. Zuse’s early machines used punched tapes. Like Atanasoff, he planned to use vacuum tubes for later machines, but wartime shortages in Germany precluded that option. Zuse began in earnest to build his machines in 1936 and completed the first one in 1938 (see [Evans 1981, 66–69]). There is no clear evidence of any knowledge by Atanasoff of Zuse’s work, or *vice versa*. It would appear, however, that both Atanasoff and Zuse were on an identical course and that only months separated their work and its various stages. On Zuse’s work, see, e.g. [Augarten 1984, 88–89].

his mother. He did not use Boolean algebra directly, asserting that at the time, in 1939, he did not recognize the application of Boolean algebra to his problem. He also described the logic with which computation would take place, using an addition-subtraction mechanism, rather than the simple enumeration used by the analog devices of the day. With regard to the logic, Atanasoff wrote [1984, 240–241] that:

. . . I gained an initial an initial concept of what is called today the “logic circuits.” That is a nonratcheting approach to the interaction between two memory units, or, as I called them in those days, “abaci.” I visualized a black box which would have the following action: suppose the state of abacus 1 and the state of abacus 2 would pass into the box; then the black box would yield the correct results on output terminals.

. . . The black box or computing device was to contain vacuum tubes to carry out these operations. In designing such devices today, we would use an abstract kind of mathematics called Boolean algebra and the so-called truth table. At that time, I had studied this algebra a little, but I did not recognize its application to my undertaking, and I obtained my results by trial, at first, and then by a kind of cognition. I called my logic circuit an add-subtract mechanism. . . .

On the basis of this work, Atanasoff filed an application for a patent on the ABC. (For a personalized account of this history, see [Atanasoff 1984].) The paperwork for the patent application was still in progress when the U.S. entered World War II. Soon thereafter, Atanasoff left ISU to carry out research at the US Naval Ordnance Laboratory in Washington, D.C., and it was left to the administration at ISU to oversee the progress of Atanasoff’s patent application. Apparently, however, in Atanasoff’s absence, the application was never completed, although Atanasoff returned to ISU several times during the course of the war to check on the progress of the application and to prod the responsible legal authorities into action. Arthur Oldenburg, the current chairman of the department of computer science at ISU is reported (by [Frerking 1996] to have said that “[t]hings were in [dis]array and confusion because there was a war at the time” and that the patent on the ABC “got lost and forgotten.” Whether the paperwork was simply lost in the shuffle of the war effort, or the responsible authorities at the college decided that there were other, more pressing, more important concerns, or some combination of these, is not altogether clear. The fact remains that the timing of Atanasoff’s application could not have been more unpropitious. Matters were made even worse by the visit to ISU of John Mauchly (1907 – 1980). The ideas developed by Atanasoff and Berry “such as binary arithmetic and and electronic switching elements, say Martin Campbell-Kelly and William Aspray [1996, 84] “were later rediscovered in connection with electronic computers.”

Mauchly visited Atanasoff and Berry at ISU in June 1941, had seen the ABC, had its construction explained to him by Berry, discussed it in detail with Atanasoff, and had read Atanasoff’s “Computing Machine . . .” paper during his week at ISU; all of this was done with the understanding that Mauchly would not make use of the information which Atanasoff and Berry

were to share with him. In 1943-1946, Mauchly and his colleague John Presper Eckert (1919 – 1995), using the same logical and engineering principles by which Atanasoff and Berry developed for the ABC, built their ENIAC computer. (A technical description of ENIAC is given by [Marcus & Akera 1996]. The original 1946 paper describing ENIAC has recently been reprinted; see [Goldstine & Goldstine 1996].) This situation has recently been summarized by research scientist John Gustafson at the Ames Laboratory, who is quoted (by [Frerking 1996]) as saying that “Mauchly got his ideas from John Atanasoff. Letters revealed that Mauchly visited ISU’s Atanasoff, then acted secretly with the government. There was a paper trail that could be followed and showed it [ENIAC] was based on several machines that Atanasoff invented.” Learning about the development of ENIAC and its workings, Atanasoff believed that Mauchly had appropriated his ideas. The Sperry-Rand company had purchased Mauchly’s patent rights, and a lengthy lawsuit (1971-73) was brought against Sperry by the Honeywell company, on Atanasoff’s behalf, and in which Atanasoff was the star witness. The decision was rendered in favor of Honeywell, and finally, after more than three decades, Atanasoff’s claim as the original inventor of the modern computer was legalized. In life, it may well be that the riches, if not the credit (but in many cases indubitably the credit as well), fall not to those who originate concepts and technological breakthroughs and innovations, but to those who exploit those breakthroughs and innovations. In the light of the apparently close similarities and manifold parallels that seem to be evident between the work of Atanasoff and Zuse and the virtual simultaneity of their work, done independently of one another, one might conclude that the time and coincidence and confluence of technologies and theory made the time propitious for the appearance of the electronic digital computer; that perhaps this work would have been done by someone else even had neither Zuse nor Atanasoff done their work.

Since the time of the law suit, historians of computer science have begun to disentangle the web of confusions and distortions in the record; Oldenburg (quoted by [Frerking 1996]) thus declared that “[t]he history books are just beginning to get the story right. Atanasoff was years ahead of his time.” [Saegrove 1988] is as much a complaint about the short shrift given Atanasoff’s work by books on computing theory and technology published before 1984 as an effort to set the record straight with the assertion that, “[a]lthough the ABC was not as extensive a machine as the ENIAC and the EDVAC, it clearly was an important first step” [Saegrove 1988, 60]. It has only been in the last ten years that popular attention has begun to focus on Atanasoff as the inventor of the computer (see, for example, [ISU 1990], [Mollenhoff 1988] and [Mackintosh 1988]), and especially [Burks & Burks 1988], which examines the theoretical and technological aspects of Atanasoff’s work) to the extent even of becoming an American folk hero on the order of Thomas Edison and Alexander Graham Bell (see, e.g. [Hutchison 1988]). In 1988, Atanasoff was honored by ISU (see [Hutchison 1988], [ISU 1988, 315], and [ISU Math 1988, 1; 1989, 3]), and in 1995, plans were made to construct a replica of the ABC (see [Weiss 1995] and [Leonard 1996a]). Writings in Russian and Bulgarian on Atanasoff and his

work include [Apokin, Belyj & Majstrov 1978; 1978a], and [Apokin & Majstrov 1978], and is included in [Sendov 1972]. Nevertheless, ENIAC and its claims today remain to a large degree the center of attention (see, e.g. [Winegrad 1996]). Campbell-Kelly and Aspray [1996, 86] argue that:

The extent to which Mauchly drew on Atanasoff's ideas remains unknown, and the evidence is massive and conflicting. The ABC was quite modest technology, and it was not fully implemented. At the very least we can infer that Mauchly saw the potential significance of the ABC and this may have led him to propose a similar, electronic solution to the B[allistic] R[esearch] L[aboratory]'s computing problems.

Nevertheless, the question of who invented the first electronic digital computer, or whether ENIAC, the ABC, or some other machine deserves the title of the "first", remains open to question. Herman Goldstein, for example, raises the question. He pointed out [Goldstine 1980, 125] the importance of the role which Atanasoff attached to using Gaussian elimination rather than determinants for solving large systems of equations; this helped to simplify the arithmetic but increased the demands for memory of the machine that Atanasoff envisioned. This point also helps identify several problems with the ABC that led to a question of whether it may properly be called the *first* electronic digital computer. In particular, it had to be reprogrammed for each new task it was assigned and its memory storage capacity was both limited and volatile (see, e.g. [Ceruzzi 1990, 228–230] and [Augarten 1985, 117–118]). More recently, Gustafson described the differences between the ABC and ENIAC as follows (quoted by [Frerking 1996]: 'The ABC used a binary system and was a parallel computer, meaning it could perform more than one function at a time,' whereas the ENIAC 'used a less efficient base-10 system and could do only one function at a time, but it was a larger computer that could be "programmed" by changing wirew and vacuum tubes according to the task.' The question of "priority" is made still more murky when the British Colossus computer is added to the picture: in reply to a statement in the *New York Times* obituary of Eckert on June 7, 1995, B. W. Augenstein, a retired computer scientist who worked for the Rand Corporation, declared [1995] that the Colossus "deserves at least comparable billing [with ENIAC] as the first large-scale electronic computer." There are historians of computer science who will argue, not without justification, that the modern computer is "polygenetic", the result of several branches of mathematics and engineering expertise coming together fruitfully. Certainly electronics played a critical role in the progress of computing, but the ABC was a special machine, even in an important sense a highly specialized machine, one whose basic goal was to solve systems of equations. The concept of the universal machine had a slightly different origin, deriving from the line of work traceable in a line from Babbage to Turing and appearing in the the Mark I. Joel Snow, who is leading the team that is reconstructing the ABC at ISU has gone so far as to assert (as quoted by [Leonard 1996b]), with considerably more hyperbole

than is obviously warranted, that the ABC “is really the first super-computer,” because it “was the only electronic digital computer at time, even though it was designed to solve just one type of problem,” and adding that it admittedly “was still really an experimental machine, but it was loaded with important innovations, many of which show up in today’s modern computers.” One may say perhaps that what Mauchly learned about the ABC was what helped bring all of these “pieces” together and which furnished the last missing bit of engineering knowledge. “Who built the first computer? The answer depends on what you call a computer,” as [Freed 1995, 5] writes — which is, in the final analysis, probably the best we can do in answering the question.

It seems likely that, without the intervention and distractions of America’s entry into the world war, Atanasoff would have received his earned recognition much sooner than he did, in particular as some historians of computer science have detected evidence that Mauchly dissembled in his accounts of his meeting with Atanasoff and Berry, and eventually falsified too his account of the development of ENIAC. It is equally probable that, had Atanasoff’s patent been granted in a timely fashion, the computer would have been available for use several years earlier than it was, and thus could have made some difference in the advance not only of computer science but of mathematical researches related to the American war effort.

Atanasoff’s work can be interpreted from the historical perspective as leading to the culmination of a long history that began with the work of Leibniz and his contemporaries. With regard to practical applications of logic, it is in the line of development from the mechanical calculators of Morland, Pascal and Leibniz, through the analytical and difference engines of Babbage and the logic machines of Stanhope, Jevons, and Marquand, and which was taken up, independently or not, by Turing and Von Neumann. (We have to be careful here: Atanasoff certainly studied, from the engineering side, the technologies of the then-available calculating machines, for example the Bush differential analyzer, as a preparation for his own work in building the ABC.) With regard to theoretical work in logic, the work especially of Boole, Jevons, Charles Peirce, Marquand, and Shannon, and with respect to binary arithmetic the work of Leibniz and Benjamin Peirce, set the stage for the work of Atanasoff. Povarov [1960, 557], in a largely historical appendix to his paper “On Group Invariants of Boolean Functions,” represented the schematic line of descent from Jevons to Shannon, as follows:

Jevons → Clifford → Schröder → Polya → Shannon.

James Mark Baldwin [1901; reprinted THIS ISSUE] describes the technical, and especially the logical aspects, of the devices of Jevons, Venn, and Marquand. Atanasoff himself, however, seems not to have been aware of these lines of historical development in technology, and especially in logic, that prepared the way for his work. His admission that in 1939, he did not recognize the application of Boolean algebra to his problem seems to support this viewpoint.

From one perspective (a perspective adopted by Witold Marciszewski and Roman Murawski; see their [1995]), the history that led to the creation of the ABC might be seen to date to the ancient Greeks, if we understand by this the search for a procedure which can “automatically” solve problems; in this sense, Aristotle’s syllogistic is an “automatic” theorem prover insofar as, given the major and minor premises of a syllogism as input, the syllogistic method, properly carried out, provides the conclusion of the syllogism as output without any special effort beyond knowledge of the rules of syllogistic validity. The square of opposition, the tree of Porphyry, and Raymond Lully’s diagrams can then be interpreted as the ancient and medieval contributions to the graphical aspect of automated theorem proving. In that case, Andrei (or Jan) Khristoforovich Belobodskii’s design of a circular sliderule for articulating Lully’s conception of a mechanical device for calculating syllogisms can then be seen as the seventeenth-century’s contribution to the engineering of a logic machine (see [Anellis 1992, 28]; whether Belobodskii ever did indeed manufacture such a device, however, remains an open historical problem).

From a more standard (if not necessarily more “rigorous”) position, we might want to begin the mathematical, logical, and technological history with Leibniz and his contemporaries.² Although the search for a *mathesis universalis* predates Leibniz, it was Leibniz who made the first serious and sustained effort to understand logic as the “foundation” of mathematics, who made the first realistic effort to treat logic as a calculus by attempting to algebraicize syllogistics, and who developed a binary arithmetic in the process. Moreover, Leibniz developed a working mechanical calculator, a device of cranks and gears which carried out not only addition and subtraction but also multiplication and division. Leibniz’s calculator was therefore an improvement over that of Pascal, which managed only addition and subtraction. (Pascal’s letter of [1645] regarding his “Machine d’arithmétique” and the royal patent which he received for it appears THIS ISSUE.) Belobodskii then can then more readily be said (if we accept that the claim that he in fact created a device is not apocryphal) to have created the first logic machine, a multilayered circular sliderule similar to (and perhaps influenced by) drawings by Lully and the circular sliderules developed by Oughtred and Delamain, but marked off by Aristotelian categories rather than numbers,

²We obviously cannot, within the confines of this piece, present a detailed history, or even a complete outline, of the history of the development of computational devices and of the mathematics behind their programming (for that, the reader may begin with such works as [Aspray 1990], [Burks & Burks 1988, “Appendix A”, esp. pp. 327–352, and [Gardner 1958]); rather, we give only the most broad sketch of the more salient aspects of this history in order to provide a backdrop to Atanasoff’s work, while taking the opportunity to use the outlines of this history to also note some of the less well known work contributing to these developments, with particular attention to the work of Russian contributors to these developments that is ordinarily virtually unknown outside the former Soviet Union.

which could be used as a mechanical device for carrying out syllogistic deductions, in a kind of three-dimensional Euler diagram.

Beginning our history with Pascal, Belobodskii and Leibniz, we can trace the arithmetic side from Leibniz and Benjamin Peirce. Benjamin Peirce, the father of logician Charles Peirce, developed a system of binary arithmetic [which “follow[s] in the footsteps of Leibnitz” and retains the advantages of Leibnitz’s system but is more economical and perspicuous. The text of the system was sent by Benjamin Peirce to his boss, Carlile P. Patterson, Superintendent of the U.S. Coast Survey on 25 February 1876, and appeared as “Appendix No. 6” of the Coast Survey’s circular [B. Peirce 1876; reprinted THIS ISSUE].

The technological and logical aspects of the history with which we are concerned begins with Leibniz’s work in developing a *calculus ratiocinator* which, in essence — and speaking anachronistically — treats Aristotelian syllogistic as a Boolean-valued algebra. From Morland, Pascal, Belobodskii and Leibniz, we can trace the technological aspects of the engineering through Charles Stanhope, Charles Babbage, William Stanley Jevons, Charles Peirce’s student Allan Marquand, Pavel Dimitrievich Khrushchov (1849 – 1909), and Aleksandr Nikolaevich [in Ukrainian, Oleksandr Mykolaevych] Shchukarev (1864 – 1936), to the conceptual contributions of Alan Turing to the Colossus or of Von Neumann to ENIAC. Burks [1996, 1] describes the conception of Babbage’s “analytical engine” as a “general-purpose computer.”

Tracing the history of logic machines in Russia — far less familiar to most historians than the corresponding work of Western logicians and computer designers, and therefore worth tracing in some detail — helps illuminate the connections between the theoretical and technological aspects

The introduction into Russia of the logical work of Jevons inspired Khrushchov and Shchukarev in their efforts to build a logic machine. Although neither were professional mathematicians — Khrushchov was a chemist, Shchukarev a chemical engineer and physical chemist, both studied logic. Shchukarev, for example, probably first became aware of logic through the publication of a Russian translation by Sleshinskii of Louis Couturat’s *L’Algèbre de la Logique* [Couturat 1909].

F. Kozlovskii of Kiev University helped introduce Boolean logic into Russia; this introduction came in the guise of the Kievan professor’s criticisms of Jevons, in his “Symbolic Analysis of the Forms and Processes of Thought, Structured According to Formal Logic” [Kozlovskii 1882], which appeared a year after a Russian translation by M. A. Antonovich (1835 – 1918) of Jevons’ *The Principles of Science* was published [Jevons 1881]. The Pole Jan Sleszyński [sometimes also given as Śleszyński; in Russian, called Ivan Vladislavovich Sleshinskii; 1854 – 1931], who was teaching logic in Odessa at the time, was led to write on Jevons’s logic machine [Sleshinskii 1893]. The Jevons-type logic machines were built by Shchukarev and Khrushchov; their machines used mechanical processes. In April 1914, Shchukarev demonstrated his logic machine at the Polytechnical Museum in Moscow, and in [Shchukarev 1925], he wrote on the “Mechanization of Thought (The Logic Machine of Jevons)” in which he

dealt with criticisms of his work. A description of Shchukarev's computational cylinder is given in [Povarov 1984]; Shchukarev's own account, written for the museum display of his device, has also recently been reprinted [Shchukarev 1984] as an appendix to [Povarov 1984].

The application of Boolean algebra to the analysis and construction of electrical relay-contact circuitry was suggested in [1910] by Paul Ehrenfest (1880 – 1933) in his review of the Russian edition [1909] of Louis Couturat's *L'Algèbre de la Logique*. Work on the details of this application was begun in 1934–1935 by Viktor Ivanovich Shestakov (b. 1907; mistakenly called “Sestakov” in [Gardner 1958, 1982 edition, 129] and in [Aspray 1990, 117]) and carried out and published in the 1940s (see especially his [1941]). This work was continued by Shestakov and then also taken up by Mikhail Aleksandrovich Gavrilov (1903 – 1979). Meanwhile, Pavel Florenskij (1882 – 1937), in his paper “The Mathematical Applications of Mathematics to Physics”, written some time in the late 1920s or early 1930s (see, e.g., [Shentalinsky 1996, 108]), working independently, in isolation, and probably without knowledge of earlier examples of the device — the earliest being J. H. Hermann's 1814 device — while under arrest by the Soviets, described an electrical integrator such as was used in Bush's differential analyzer as described in 1927.

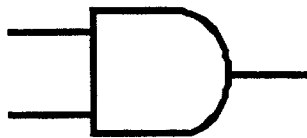
Shestakov's work was contemporaneous with that of the American mathematician Claude Elwood Shannon (b. 1916), in his famed masters thesis at the Massachusetts Institute of Technology of [1938], “A Symbolic Analysis of Relay and Switching Circuits”.³ A paper based upon his thesis was published in [1940]. A second paper was published in [1948]. In the thesis and the papers, Shannon employed ideas similar to those of Charles Peirce to show how to use electrical circuits to carry out arithmetic operations and to show that the calculus used for defining these circuits is equivalent to Boolean algebra. The [1948] paper specifically cites Courant, Huntington, and Whitehead. Writing in 1961, John Eldon Whitesitt explained what Shannon's work meant by saying that “he showed that the basic properties of series and parallel combinations of bistable electrical devices such as relays could be adequately represented by this [i.e. Boolean – I.A.] algebra” (see [Whitesitt 1995, v]). This gives us the now-familiar schemata:⁴

³The published information on the dating of Shannon's thesis and its publication as a journal article seem, unfortunately to be confused; the various histories of computer science tend to disagree among themselves on the relevant dates. Thus, for example, in the “Biographical Sketch” in [American Mathematical Society 1995, 467], we read that Shannon received both his M.S. and Ph.D. in mathematics from MIT in 1940. I follow what appear to be the more-or-less “canonical” dates.

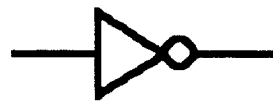
⁴All of the diagrams that follow are based on drawings created by Michael Smith for his freeware HyperCard stack “Digital Logic”, April 17, 1991.



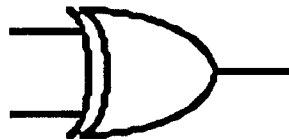
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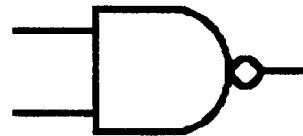
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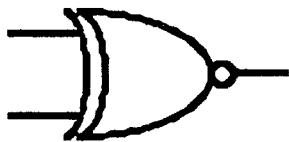
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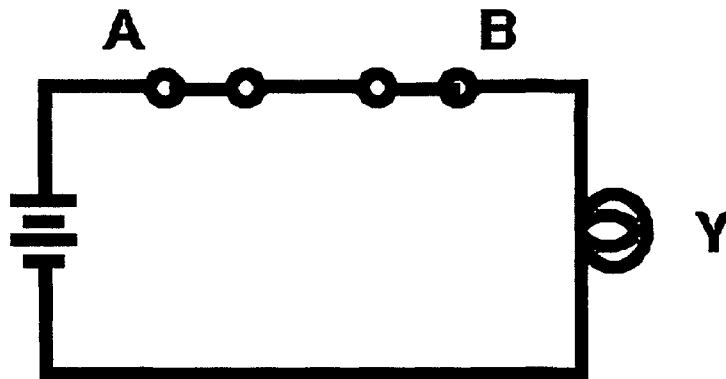
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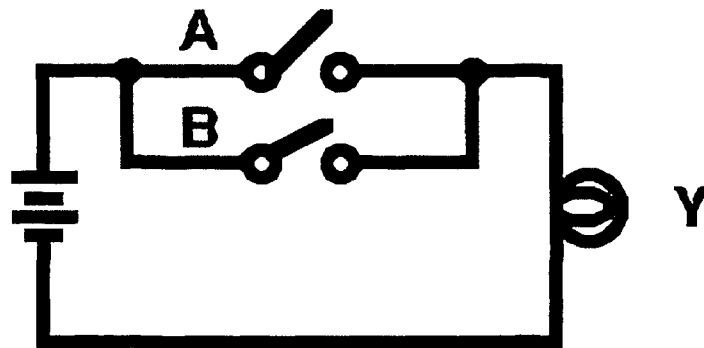
based on and built up from the truth-functional connectives \sim , \wedge , \vee , the relay circuits being based on Boolean algebra, in which truth-values t and f are replaced by Boolean values 0 and 1 respectively and we assign the value 1 to a closed switch so that current can flow and 0 to an open switch through which current cannot flow, then, for example, given inputs A and B

and output Y , we have $A \wedge B = 0$ if and only if $A = 0$ and $B = 0$, that is, if we have



and $A \wedge B = 1$ otherwise.

Similarly, $A \vee B = 1$ if and only if $A = 1$ and $B = 1$, that is, if



This, in practical essence, is one of the ideas that occurred to Atanasoff as he drove through eastern Iowa into Illinois in the beginning of 1937.

It would therefore be interesting, as well as historically enlightening and important, to know whether Atanasoff was aware of Shannon's work by this time or whether Shannon or Shannon's advisor Vannevar Bush were aware of Atanasoff's work, as well as when Shannon began working on the ideas that developed into his thesis and his [1941] paper, especially in view of Atanasoff's assertion that he did not use Boolean algebra directly because in 1939 he did not yet recognize the application of Boolean algebra to his problem.

The application of Boolean algebra to the analysis and construction of electrical relay-contact circuitry was first suggested by Charles Peirce to Marquand in a letter of 30 December 1886 [C. S. Peirce 1886] (discovered in 1970; see [A. W. Burks 1975]), in response in particular to Marquand's [1886] description of his logic machine. In the letter, Peirce says of Marquand's logic machine that he thinks that "it only extends to four simple terms instead of to six as it should" and that it "ought to perform 4 operations, or 3 at least." A. W. Burks [1996, 1] describes Marquand's machine as "an improvement of Jevons's wooden logic machine," and goes on to say [A. W. Burks 1996, 1] that in the letter to Marquand of 1886, Peirce suggested that Marquand "build an electromechanical relay version of that machine." In fact, Peirce then goes on to provide two sketches on the use of electrical circuits with on/off switches, in which, in one case "there is a circuit only if *all* [keys or points where the circuit may be open or closed] are closed" and in the other "there is a circuit if *any one* is closed" and these correspond to "multiplication & addition in Logic." Peirce then goes on to provide two sketches on the use of electrical circuits with on/off switches, in which, in one case "there is a circuit only if *all* [keys or points where the circuit may be open or closed] are closed" and in the other "there is a circuit if *any one* is closed" and these correspond to "multiplication & addition in Logic." Peirce went into more details a year later in his [1887; reprinted THIS ISSUE] paper "Logical Machines". Marquand, [A. W. Burks 1996, 1] tells us, went on to draw the wiring diagrams for his new machine, but *did* not build it, and adds that what he thinks Peirce had in mind [A. W. Burks 1996, 2] was "an electromechanical relay version of Babbage's analytical engine," although such machines were not actually built until the 1940s, contemporaneous with the ENIAC.

If Americans such as Peirce, Marquand and Shannon were slightly ahead of the others, for example ahead of Ehrenfest and Shestakov, it may be supposed that this was at to a large degree because the former did not have to await translations of the writings of Peirce, Jevons, or Marquand. This explanation naturally supposes that the writings, or at least a substantial portion of the relevant writings, of Peirce, Jevons, and Marquand were available and known to those, like Shannon, who followed them. The modelling of Boolean operations through arithmetical operations at Harvard in the 1950s (*q.v.* [Harvard University 1951]) is quite natural, give the Harvard connection of both Benjamin Peirce and Charles Peirce, as well as Huntington. Huntington, we know, was already quite familiar with the work of Charles Peirce when he wrote "Sets of Independent Postulates for the Algebra of Logic" [Huntington 1904], and as a matter of fact had corresponded with him while working on that paper (see, e.g. [Houser 1991, 21]).⁵ Thus, for example, the loss until 1970 of Charles Peirce's 1886 letter

⁵I have not myself seen any tangible evidence, however, in the Huntington-Peirce correspondence that anything was discussed other than questions relating directly to [Huntington 1904]; thus we cannot assume that Huntington or anyone else at Harvard might have acquired from Charles Peirce, either directly or

to Marquand would not have been a serious handicap to Shannon or anyone at Harvard if such of Marquand's papers as his [1886] or Charles Peirce's [1887] were available. A more meaningful general explanation is that Russian investigators initially had to import the work in algebraic logic of Boole, Jevons, Schröder, Couturat, *et al.*; but that, once done, they very soon caught up to, and then managed to remain coeval with, their colleagues. Moreover, most of the influence was unidirectional, from America and western Europe into Russia, whereas American and western European logicians (with the notable exception of such researchers as Couturat who familiarized himself with the logical work of Poretskii that were published in French), remained largely ignorant of the work of their Russian colleagues, in particular of logical investigations that were published in Russian. In fact, however, Yanovskaya [1948, 41] tells us that Shestakov actually wrote up his results in January 1935, but his paper was not published until 1941, so that Shannon, whose [1939] publication "A Symbolic Analysis of Relay and Switching Circuits" appeared before Shestakov's [1941] "Algebra of Two-terminal Circuits, Constructed Exclusively from Two-terminal Components (Algebra of A-circuits)", thereby received the credit for the results and the claim to priority. (A more detailed and sound explanation or attempt at explanation shall doubtlessly have to await further study.)

The question of how and why Atanasoff was led to use electronic circuits is particularly noteworthy. We know that Peirce's suggestion to Marquand was to use electrical circuitry and batteries. Even if we assume — which we cannot — that Atanasoff knew of the work of Marquand and Peirce, we find here in such knowledge no explanation for Atanasoff's choice. Instead, we are constrained to look elsewhere. Perhaps to Atanasoff's knowledge of the work of his colleagues among the physicists, who in the 1930s were building and using electronic particle counters. One may also ask whether the technology emerging in this period in construction of radios had an influence on Atanasoff's thinking.⁶ [Saegrove 1988, 58] therefore offers the simplest and probably most plausible answer: "Because of [Atanasoff's] strong background in electronics, it was natural for him to opt for the use of electronic components." [Saegrove 1988, 60] notes that economics was also a factor: that the high cost of a magnetic core for the memory medium led to rejection of its use in favor of capacitors.

One of the more recent histories of computational technology in Russian is [Apokin & Majstrov 1990], which includes a most useful bibliography on the subject. Outlines of the history of the technology and mathematics of computer development are given by Gardner [1958], by

indirectly, the notion of modelling Boolean operations through arithmetic operations. The Peirce-Marquand letter, having vanished until 1970, can of course, offer no link in this matter. However, [C. S. Peirce 1887] certainly *could* have been well known to Huntington and others at Harvard.

⁶Electronics also had an especial appeal for other logicians with an interest in the technical, for Jean van Heijenoort, e.g., who taught basic electronics at Harvard during World War II (see, e.g., Feferman 1993, 201]).

Sendov [1972], and by Arthur Burks, who is particularly interested in placing Atanasoff's accomplishments within the historical framework, both as regards the technological aspects of computer hardware [Burks & Burks 1988, 257–290] and the theoretical aspects of the logic of switching theory [Burks & Burks 1988, 293–354]. (A dual review of [Burks & Burks 1988] and [Mollenhoff 1988] is given by Anderson [1988].) Guter and Polunov [1978a; 1978b; 1978c] examine the technical history of computational devices, in particular the machines of Babbage, Augusta Ada Lovelace's role in the origins of programming, and the mathematics that Babbage utilized in designing his calculating engines. The work of Khrushchov and Shchukarev is discussed by Povarov & Petrov [1978]. [Anellis 1982] is a review of the collection by Biryukov and Spirkin [1978] on the history of the role of logic in computer science in which the works of [Guter & Polunov 1978a; 1978b; 1978c] and [Povarov & Petrov 1978] appear. [A. W. Burks 1975] and [Ketner 1984] examine the history of Marquand's logic machines and the influence of Peirce on Marquand's work. Because Biryukov and Spirkin's [1978] collection is not accessible to those who do not read Russian and my review of it [Anellis 1982] is to be found in a journal at which many of *Modern Logic's* readers will not ordinarily look, it may be useful to provide a summary of its salient aspects and of the articles which it contains.⁷ Biryukov [1978] provides a "Foreword" to this anthology in which the work of each contributor to the volume is summarized and set in relation to the organic whole, and which is much more informative than the brief English "Summary" and German "Annotation" appended to the book.

The papers in the collection by Biryukov and Spirkin [1978] are devoted to the study of the development of logical and algebraic calculi and to their use for formalization of languages suitable for use in algorithmic structures for computing machinery. Some attention is also paid to the development of calculating machines themselves, from the primitive abacus to the primitive engines of Pascal, Leibniz, and Babbage, and the modern electronic digital processors of the mid-twentieth century era of Turing, Von Neumann and Birkhoff, with attention paid (by Povarov & Petrov [1978]) to Russian contributions of the immediate pre- and post-revolutionary generations (*ca.* 1880–1925). The great concentration of interest of all contributors to the volume, however, lies with the work of the mathematicians whose work in mathematizing logic made possible the modern calculating machines. Here, the central focus of attention is on the work of Ernst Schröder particularly in the algebraization of logic.

In the first selection, "The Interdependent Characteristics of Calculating Machines with Their Development", L. I. Majstrov [1978] sees the primary function of the calculating engine as interaction with its mathematical or cybernetic environment through a more or less formalized language (algebraic logic as it grew more sophisticated; simple numeric computation at the outset). That means that such machines can contribute to the development of

⁷What follows is essentially a corrected and slightly revised version of [Anellis 1982].

increasingly sophisticated machines. This function is traced from the basic abacus or pre-mechanical apparatus to the mechanical calculating engines of Pascal, Leibniz, among others, to the electromechanical machines of and Babbage, among others in the nineteenth and early twentieth centuries, and concluding with the electronic computers of the mid-twentieth century, such as ENIAC, the MARK I and II, and EDVAC produced by I.B.M. and other firms.

Guter and Polunov [1978a], as we noted, focus their attention in “Towards a History of Difference Engines” on the period in which Babbage was the foremost contributor to the development of calculating devices (1830 – 1930) and discuss the construction of such devices. In “Augusta Ada Lovelace and the Origins of Programming” [1978b], they relate the work of Lady Lovelace to the mathematical constructions of Boole and De Morgan; the influence of Byronic philosophy on the technical contributions of Babbage; and discuss the development of analytic methods whereby algorithms may be presented for calculating engines and utilized for programming of these engines, relating these developments to work in arithmetic, algebraic, and trigonometric functions. We are also given a preview into the use of switching theory as a development of Boolean algebra. In “The Mathematical Work of Charles Babbage” [1978c], the discussion reverts, as the title suggests, from the mechanical inventions of Babbage to his work as a mathematician, with some attention to his work in trigonometry, but especially to his work in analysis, functional calculus, theory of equations, and number theory, as well as questions in game theory. Babbage’s work is shown to have especial interest for a study of cybernetics inasmuch as Babbage himself had worked on the construction of calculating engines utilizing much of his own mathematical contributions.

Povarov and Petrov’s paper on “Russian Logic Machines” is the least mathematical of all of the contributions to this volume. It is a purely historical account of the earliest work of Russians, from *ca.* 1880–1925) to, in the words of Biryukov [1978, 7], “artificially enhance human reason” [*“iskusstvennykh ‘usilitelej’ chelovecheskogo razuma”*]. Khrushchov and Shchukarev were by no means the only figures involved in the efforts in Russia to modify and improve Jevons’ logic machine, but they are the central figures in the history which Povarov and Petrov recount, and it was said of Khrushchov’s machine that it was a prime exemplar of a logical apparatus, a fine specimen of a calculating engine. We may note that Veligzhanin and Povarov’s [1971] paper “Towards a History of the Construction of Logic Machines in Russia” deals with the work of Khrushchov and Shchukarev.

In the next paper, we are returned to the “mainstream” of developments by Biryukov himself and his coauthor A. Yu. Turovtseva in their paper “The Logico-gnoseological Views of Ernst Schröder” [Biryukov & Turovtseva 1978]. The work of Schröder has a three-fold importance, playing a role not merely in the algebraic development of logic but thereby in the development of machine methods of calculation, and also in the process of the

development of mathematical logic as we know it today.⁸ For the authors of this article, the larger aspect of Schröder's work within the context of the history of mathematical logic and its philosophical aspects are most important. Briefly setting forth the impact of Schröder's work and its relevance, the authors discuss specifically the work of Schröder, speaking for example of his work on the algebra of sets, with their focus concentrated naturally on his *magnum opus*, the *Vorlesungen über die Algebra der Logik*. Next, their attention is turned to Schröder's philosophical views. We gather from Biryukov and Turovtseva that his interest, not unlike that of Frege, centered on the meaning and characterization of *meaning*. We are given the algebra of classes, which serves as a mathematical language, the syntactic elements of the calculus being signs (*znakom*) which designate "things-in-themselves" (*veshchej v sebe*), usually physical entities. Sections on the objectivity of logic and modality, semiotics (the theory of signs), the problem of the realization of the logical program of Leibniz, and a concluding section on Schröder's "algebraico-logical" calculus follow. This extensive discussion of the work of Schröder is followed by another paper on Schröder. Schröder's work is seen to have had an important influence on A. I. Mal'cev's work, as

⁸There is, for example, a quantification theory in Schröder's algebraic logic, a point which did not come through clearly in my [1995], probably because the focus of my attention there was centered primarily on Peirce. The false dichotomy of the so-called "algebraic" and "quantification-theoretic" in logic needs to be abandoned, as I said in "Peirce Rustled . . ." and which was one of the main points in my paper co-authored with Nathan Houser, "Nineteenth century roots of algebraic logic and universal algebra" (in H. Andréka, J. D. Monk & I. Néméti, editors, *Algebraic Logic (Proceedings of the Conference in Budapest, 1988)*, Colloq. Math. Soc. J. Bolyai vol. 54 (Amsterdam/New York, North-Holland, 1991), 1–36).

While the distinction between these traditions is artificial and the result of bad history, the terminology of "algebraic" and "quantification-theoretic" is misleading *at best*. That is why in "Peirce Rustled . . ." I also provided several other alternatives to "quantification-theoretic", such as "function-theoretic" and "logistic"—none of which are really themselves either particularly enlightening or entirely without problem — in discussing the history of this false "duality". I don't know the origin of the terminology of "algebraic" vs. "quantification-theoretic"; perhaps it is folkloric. It is indubitably based on the — false but common — belief that the Boole-Peirce-Schröder logic was devoid of a full quantification theory if not of quantifiers.

In any case, while Peirce's work has received renewed attention since the 1989 sesquicentennial celebration of his birth, study of Schröder's work has not received as much attention as it deserves, and we may suspect that Schröder's *Vorlesungen* has been perceived by some — myself included, I must admit — and may still be perceived by many others, as little more than a systematization of the work of Peirce. The sad fact is that little is known about what Schröder did to expand and develop the field and what his original contributions, beyond systematizing Peirce's work, may have been. It is therefore to be hoped that those who are in a position to develop the history of Schröder's contributions to logic will do so. There is clearly much historical work yet to be done.

seen from the selection of papers in his *Algebraicheskie sistemy* (*Algebraic Systems*). This point is taken up again in another context in the next paper.

S. G. Ibragimov, a leading Soviet specialist on Schröder, in his [1978] paper “On the Logico-algebraic Work of Ernst Schröder, Anticipating Theory of Quasigroups”, gives an exposition of Schröder’s work on group theory, and particularly as it relates to the history of quasigroups, which are groupoids in which the equations $xa = b$ and $ay = b$ each have a unique solution for every couple of elements a, b . A *loop* of a quasigroup E is a quasigroup with a neutral or identity element e , such that $ea = ae = a$. If E is a copy of its elements, then the matrix table for E is an effective decision procedure for solving equations in E . Ibragimov sees the origins of the work on theory of algorithms of Church, Kleene, Kolmogorov, Markov, and Mal’cev as following from the algebraic foundations initially set forth by Schröder in the *Vorlesungen* and “Über Algorithmen und Kalkülen” (the latter published in Russian translation in 1888). In these and other works, including the *Vorlesungen*, Schröder worked out within his absolute algebra the tabular algorithms for a number of quasigroups, and examined their geometric representations as well. Schröder himself helped develop quasigroup theory in such works as his *Lehrbuch der Arithmetik und Algebra* (1873), *Über die formalen Elemente der absoluten Algebra* (1874), and “Über Algorithmen und Kalkülen” and helped formulate the connection between algebraic structures and arithmetic algorithms ([Peckhaus 1994] and [Thiel 1994] explore some aspects of this work of Schröder from another perspective.) The algebraic structures of logical systems, especially as presented by Schröder — in the Boole-Schröder algebra — therefore provide the syntactical apparatus for the construction of algorithms for the programming of modern calculating machines, and this is how they serve as the preparatory basis of the work of Church, Turing, Kolmogorov, Mal’cev, Markov, and Kleene in the theory of algorithms. (We may note that in the 1970s, e.g., Soviet mathematicians were very active in studying the recursive characteristics of groups and that these studies appeared in *Sibirskij Matematicheskij Zhurnal* and *Algebra i Logika* throughout the period.)

In the final paper in this collection, “On the Dynamics of the Interactions of Various Aspects of Infinity”, N. N. Nutsunidze [1978] briefly traced the history of the concepts of the infinite, from the philosophical concepts of the ancients (e.g. Zeno) and the early moderns on the borderlines between mathematics and philosophy (e.g. Bolzano) to the mathematical concepts of transfinite arithmetic as developed by Dirichlet and Dedekind, Weierstraß and Cantor, Kronecker’s anti-infinitistic response to Cantor’s transfinite set theory to the effect that “God made the integers; all the rest is the work of man”, and including the twentieth-century work of Fraenkel and Bar-Hillel, for who the infinite is considered set-theoretically, and Kolmogorov, Weyl and Brouwer from the stances of constructivism. Nutsunidze explores the history of infinity because the set-theoretic approach to transfinite numbers has permitted us to understand the infinite arithmetically, and a search was thus undertaken to determine whether functions on transfinite

numbers are effectively computable. If these functions are decidable, then we can construct algorithms which will permit computers to generate values for large cardinal arguments of these arithmetic functions. That takes the history to the mid-1970s and the work, from the standpoint of Markov's algorithmic variety of constructivism, of N. A. Shanin and members of the Leningrad school on mechanical theorem proving. (From the Leningrad school, we have, for example, G. E. Mints' 1972 results on the finite analysis of transfinite proofs. I would also add that work in the mid-1970s of recursion theorists such as Belyakin — e.g. in his work on iterated Kleene computability and superjump, to name only one among very many — likewise carries one more aspect of this history to the next stage).

With rare exceptions, the papers in this collection do not touch upon developments, either mathematical or computer-scientific, much beyond the first third of this century, that is, to almost the precise moment in history when Atanasoff was beginning his search for a mechanical computational device. And so we are brought back to view the scene as Atanasoff and his contemporaries knew it as they began their own work.

Did Atanasoff know about any of the historical background that prepared the way for his own work? There is nothing in his accounts to suggest that he was aware of any part of the history that we have recounted, and his already-mentioned declaration that in 1939 he did not recognize the application of Boolean algebra to his problem adds credence to the suspicion that he was not only unaware of, but most probably also unconcerned with, the history of programming logic and the history of logic machine construction except as he found the latter in its present state.

Of course a scientist need not — however reluctant and chagrined a historian of that science may be at having to admit it — be conscious of the history of his field in order to contribute to it, but need only keep abreast of the work of his contemporary colleagues in order to utilize and expand on their work. Atanasoff's contributions to the development of computers and his application of the Boolean logic of relay-switching circuits amply illustrates this fact. An appreciation for this history, one would like to think, would have facilitated Atanasoff's work, and perhaps have contributed to both a greater and an earlier recognition of Atanasoff's work. Nor does lack of knowledge of the history of a field of research necessarily detract from the accomplishments and innovations that creative scientists bestow upon the world. Within the context of the "working" mathematician, this means neither more or less than risking, in the pressure to live within an environment where "a theorem a day means promotion and pay", duplication of results that have already been published, or worse, of reproducing results that have already been rejected. Research — the search of the literature — is the way most mathematicians avoid these two pitfalls. The historian of mathematics may deem a search of only *contemporary* or *current* literature to be insufficient: but this is what makes the historian a historian when he or she is not being a "working" mathematician and the "working" mathematician a research mathematician when he or she is not studying the history of mathematics. The same can doubtlessly be said about engineers when they go about designing and building their ABC's without examining the entire history of mechanical theorem proving and the history of the technology of

computational machinery. As historians, we are perhaps better able to appreciate the accomplishments of Atanasoff than he and his contemporaries could have.

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