

The first electronic computer

John Vincent Atanasoff, a theoretical physicist faced with tedious quantum mechanical computations, built an electronic device that featured binary logic, regenerative memory and vector processing in 1939.

Allan R. Mackintosh

Until recently most Europeans interested in computing would have claimed that the first electronic computer was the Colossus, designed and constructed in Bletchley, England, by the mathematician Alan Turing and his colleagues, operational in December 1943 and used to decipher the German Enigma code, with a decisive effect on the course of World War II. Most Americans, on the other hand, would have given the honor to the Electronic Numerical Integrator and Calculator, built by John W. Mauchly and J. Presper Eckert at the Moore School of Electrical Engineering, University of Pennsylvania, and operational in late 1945.

Very few people realize that a functioning electronic computer had in fact been built a number of years earlier, at Iowa State University in Ames. In this article I shall tell the story of that work and its relation to the modern electronic computer. I shall also consider the reasons why this contribution to the computer revolution remained obscure for so long, and I will try to indicate how this episode illustrates and illuminates the nature of the creative process and the relation between research and innovation.

Atanasoff

In the early 1960s I spent six pleasant and fruitful years working in the physics department of Iowa State. On most days I would repair to the coffee room in the basement, where I learned

many useful things, particularly about the rare earth metals. I did not, however, learn that on the outside wall of that room two decades earlier, John Vincent Atanasoff, a professor of physics at Iowa State, and his graduate student Clifford E. Berry had built an electronic digital computer, long before the construction of what I and most other people at that time regarded as the world's first electronic computers. In fact I do not recall once during my years in Ames hearing either of Atanasoff or of his momentous invention.

During the late 1930s and early 1940s many complementary and competing attempts were made to develop electromechanical and electronic computers in the US (by Atanasoff, Henry Howard Aiken, Vannevar Bush, Mauchly and George R. Stibitz), in England (by Turing and his colleagues) and in Germany (by Konrad Zuse and Helmut Schreyer). There are many excellent sources on the history of these efforts, among them a collection of the original papers of these computer pioneers,¹ and Atanasoff himself has chronicled the events surrounding his invention of the electronic computer.²

The events leading to the construction of Mauchly and Eckert's ENIAC were exhaustively examined as a result of a patent dispute between Sperry Rand (who had acquired the ENIAC patent) and Honeywell in the early 1970s. This was settled through a lengthy court case and, after hearing all the available evidence, Judge Earl Larson concluded³ that "between 1937 and 1942, Atanasoff, then a professor of physics and mathematics at Iowa State College, Ames, Iowa, developed and built an automatic electronic digital

computer for solving large systems of linear algebraic equations. . . . Eckert and Mauchly did not themselves invent the automatic electronic digital computer, but instead derived that subject matter from one Dr. John Vincent Atanasoff."

Arthur W. Burks (who was himself involved in the development of ENIAC and subsequent computers) and Alice R. Burks have written a detailed history of the development of ENIAC.⁴ As a result of their extensive study the Burkses conclude unequivocally,⁴ "Thus John Vincent Atanasoff was the inventor of the first electronic computer." I believe that anyone who impartially studied the evidence—as contained, for example, in the records of the Honeywell-Sperry case—would be led to the same conclusion.

Atanasoff's contribution is becoming increasingly recognized in the computer literature—he is acknowledged as the inventor of the computer in several recent books⁵—but physicists are still surprisingly ignorant of the fact that this supremely important machine was invented not by an engineer, nor indeed by an experimental physicist, but by a theorist. Furthermore, his primary motivation was not to construct a device but rather to solve problems in basic research, and his approach was not to develop existing technology but to formulate a radically new set of principles for attaining his goal. At a time when the value of basic research in physics is being questioned in many parts of the world, it is especially pertinent to promote an appreciation of the reasons why so many modern inventions of major importance, including the computer, have been made by

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physicists.

Atanasoff was born in 1903 in New York State, grew up in Florida and took his BS in electrical engineering at the University of Florida in 1925. He received his MS in mathematics from Iowa State in 1926 and his PhD in physics from the University of Wisconsin in 1930. His major professor was John H. Van Vleck and his thesis was entitled "The dielectric constant of helium." This project involved many weeks of laborious computation with a desk calculator (to find numerical solutions to the Schrödinger equation). When Atanasoff returned to Iowa State as a teacher, he continued his interest in computational physics and began to consider ways in which the calculations could be performed more effectively.

For a number of years he struggled with the problem of solving linear equations using Gaussian elimination, immersing himself in the computational theories and the available mechanical and electromechanical techniques of the time, and considering various alternative approaches, including electronics, but without making much obvious progress. Then one night in 1937 he made a decisive breakthrough, in a manner best described in his own words⁶:

Well, I remember that the winter of 1937 was a desperate one for me because I had this problem and I had outlined my objectives but nothing was happening, and as the winter deepened, my despair grew and I have told you about the kind of items that were rattling around in my mind and we come to a day in the middle of winter when I went out to the office intending to spend the evening trying to resolve some of these questions and I was in such a mental state that no resolution was possible. I was just unhappy to an extreme degree, and at that time I did something that I had done on such occasions—I don't do it anymore—I went out to my automobile, got in and started driving over the good highways of Iowa at a high rate of speed.

I remember the pavement was clean and dry, and I was forced to give attention to my driving, and as a consequence of that, I was less nervous, and I drove that way for

several hours. Then I sort of became aware of my surroundings. I had, of course, been aware of the road before, but then I became aware of where I was, and I had reached the Mississippi River, starting from Ames, and was crossing the Mississippi River into Illinois at a place where there are three cities, one of which is Rock Island.

I drove into Illinois and turned off the good highway into a little road, and went into a roadhouse there which had bright lights. It was extremely cold and I took off my overcoat. I had a very heavy coat, and hung it up, and sat down and ordered a drink, and as the delivery of the drink was made, I realized that I was no longer so nervous and my thoughts turned again to computing machines.

Now, I don't know why my mind worked then when it had not worked previously, but things seemed to be good and cool and quiet. There were not many people in the tavern, and the waitress didn't bother me particularly with repetitious offers of drinks. I would suspect that I drank two drinks perhaps, and then I realized that thoughts were coming good and I had some positive results.

During this evening in the tavern, I generated within my mind the possibility of the regenerative memory. I called it "jogging" at that time. I'm thinking about the condensers for memory units, and the fact that the condensers would regenerate their own state, so their state would not change with time. If they were in the plus state, for instance, they would stay in the plus state; or, if they were in the negative state, they would stay in the negative state. They would not blink off to zero. Or if you used two positive charges, they would retain their individual identity and would not leak across to each other.

During that same evening, I gained 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. And sometime late in the evening I got in my car and drove home at a slower rate.

The originality and indeed audacity of the approach to computing that Atanasoff conceived in the Illinois roadhouse may be appreciated by comparing it with other devices available at the time. Most computations were performed on electromechanical calculators, able to add, subtract, multiply or divide two numbers at a time; large operations were done on IBM (Hollerith) tabulating machines that used punched cards—the Iowa State statistics department, for example, had such a machine. But these were simple "adding machines"; the most advanced scientific computer at that time was Bush's Differential Analyzer, a mechanical analog computer based on a decimal system. Atanasoff's approach was the diametrical opposite of this, involving instead:

- ▶ A method of computation that was digital (for the sake of precision) and based upon the logical manipulation of binary numbers

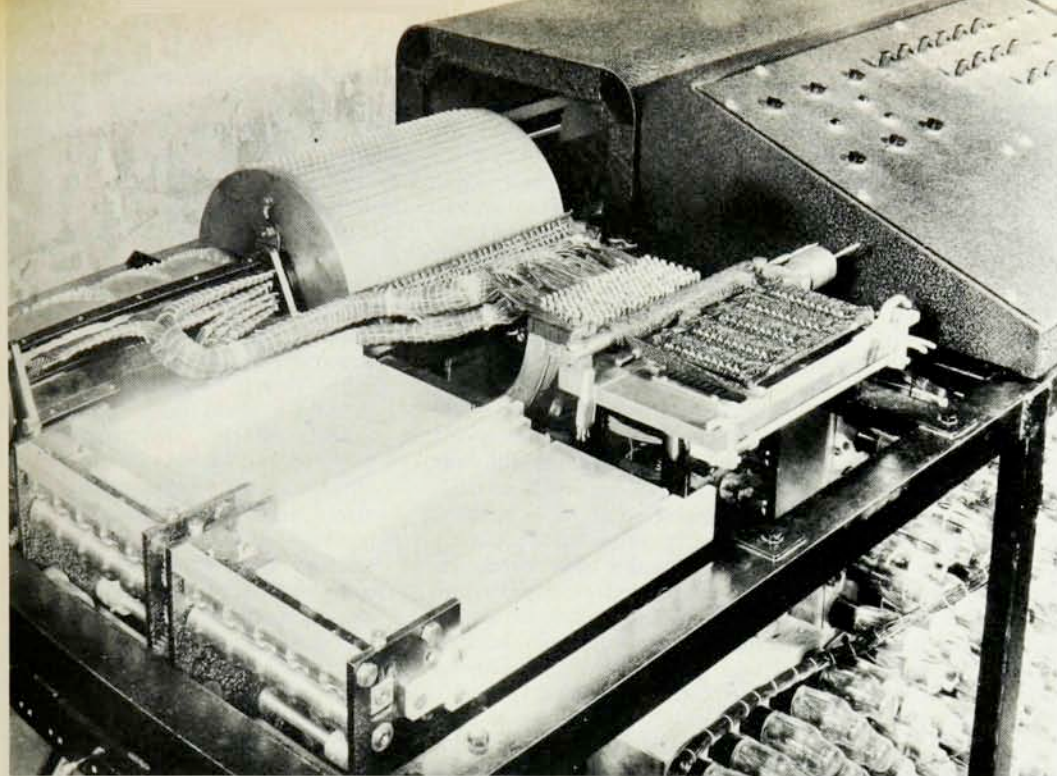
- ▶ A means of computing by electronics (for the sake of speed) for control, logic and arithmetic operations

- ▶ The preliminary concept of a computing machine, with an architecture in which the computational function and the regenerative binary memory are separated.

These three are among the fundamental principles on which modern electronic computing is based.

The prototype

Although Atanasoff was convinced that he had found the right principles for electronic computation, translating these principles into practice would obviously require a prodigious effort. In this effort he received vital assistance, as he always emphasizes, from the late Clifford E. Berry, who worked with him as a graduate student from 1939 to 1942. It is clear that they were both obsessed by electronic computing during this time. Atanasoff recalls how busy they were with other matters,



The Atanasoff-Berry computer in 1942. One of the memory drums with its condensers can be seen in the middle of the photo; the logic circuits are at the bottom right. In the foreground are a base-2 card reader and punch; its occasional failure prevented the machine from functioning perfectly. This is the last photograph taken of ABC; the machine was later cannibalized for parts.

but notes that² "I do not remember a single instance in which either of us did not have time for the computer; our hearts were really in this adventure."

The first step was to construct a small prototype to test the essential elements of Atanasoff's conception, the electronic logic circuits—which had to be designed from scratch since nothing similar had been built before—and the regenerative binary memory. With remarkable speed they constructed the prototype sketched in the upper figure on page 29, which first operated successfully in October 1939. It contained two memories, each comprising 25 condensers, mounted on the two sides of the Bakelite disk shown at the top left of the figure, and each capable of holding a 25-digit binary number, equivalent to an 8-digit decimal number. In analogy with the keyboard and counter registers of a desk calculator, Atanasoff and Berry called them the "keyboard abacus" and the "counter abacus." Binary numbers were initially placed in the abaci by charging those condensers that corresponded to a binary 1 and leaving uncharged those corresponding to 0. Pressing a switch caused a single rotation of the disk, during which the electronic logic unit, which was connected by scanning brushes to the outer ends of the condensers, added the number in the

keyboard abacus to that in the counter abacus. At the same time the number in the keyboard abacus was refreshed by the regenerating circuit, to ensure that the memory was not lost by charge leakage—this was Atanasoff's "memory jogging."

The prototype, which worked reliably and accurately from the beginning, was not of course a very impressive computer. It could only add or subtract 8-digit numbers, and using paper and pencil was undoubtedly much quicker for the purpose. Nonetheless the device bears the same relation to electronic computing as, for example, the Wright brothers' airplane bears to aeronautics. "Once our prototype had proved successful, we both knew that we could build a machine that could do almost anything in the way of computing," Atanasoff wrote later.² Allowing for a certain degree of hyperbole, this was true enough. By demonstrating the viability of the principles, the prototype opened up the path that led directly to the modern computer.

The Atanasoff-Berry computer

Atanasoff's goal of removing the drudgery from physical computation, while expanding its power manyfold, was now within sight. In 1940 he wrote a detailed description⁷ of his computer

design in connection with grant applications (he received \$5330 from the officials of the Research Corporation, who deserve unstinted praise for their prescience). The proposal indicated the type of problem he had in mind:

It is the main purpose of this paper to present a description and exposition of a computing machine which has been designed principally for the solution of large systems of linear algebraic equations. . . .

Utility. In the treatment of many mathematical problems one requires the solution of systems of linear simultaneous algebraic equations. The occurrence of such systems is especially frequent in the applied fields of statistics, physics and technology. The following list indicates the range of problems in which the solution of systems of linear algebraic equations constitutes an essential part of the mathematical difficulty:

1. Multiple correlation.
2. Curve fitting.
3. Method of least squares.
4. Vibration problems including the vibrational Raman effect.
5. Electrical circuit analysis.
6. Analysis of elastic structures.
7. Approximate solution of many problems of elasticity.
8. Approximate solution of prob-

lems of quantum mechanics.

9. Perturbation theories of mechanics, astronomy and the quantum theory.

The computer he devised was designed to solve sets of linear equations with up to 29 unknowns by Gaussian elimination; its salient features are shown in the lower sketch on the facing page. The principle of the calculation is straightforward. The keyboard and counter abaci are now drums, rather than disks, and each can contain 30 numbers, each of which is specified by its sign and 50 binary digits. The 30 constants from two of the equations are placed in the abaci. A given constant is then eliminated from the counter abacus CA by subtracting a multiple of all constants in the keyboard abacus KA from the corresponding ones in CA. Repeating this procedure 28 times with different pairs of equations eliminates one of the unknowns and reduces the problem to 28 linear equations and unknowns. Successive application of this elimination method reduces the problem to one equation with one unknown, and working backwards up the hierarchy of equations gives the complete solution.

The Atanasoff-Berry computer was constructed between 1939 and 1942. ABC used the principles that had been demonstrated in the prototype in a rational and elegant manner. The coefficients of two of the equations were punched in decimal form on IBM cards, read in on a specially designed reader, converted to base 2 by a conversion drum and stored on the abaci. A designated coefficient on CA was reduced to zero by a variant of Atanasoff's nonrestoring method of division. The coefficients on the keyboard abacus were subtracted from those on the counter until the designated coefficient changed sign, after which the binary digits on KA were shifted one step to the right (corresponding to division by 2). The coefficients on KA were then added to CA until another sign change occurred. Repeating this process of alternate adding and subtracting, with a shift between each step, reduced the designated coefficient to zero. One addition or subtraction was performed by the logic circuits for all coefficients (a vector operation in modern parlance) for each rotation of the drums; rotations occurred once per second. Additional circuits refreshed the digits in each KA and shifted them when the sign changed. When one coefficient had been eliminated, the others (the eliminant) were punched in binary form on a card, which was stored until needed in a later step.

The input-output device for the binary cards—also designed by Atanasoff—

used electrical recording and reading: At the output, thyatron circuits produced carbonized spots on the card; the spots were detected for reading by their lower resistivity. Punching or reading a card took one second. This system had worked well in preliminary tests, but when it was incorporated into ABC it produced an error about once in every 10^4 – 10^5 punching and reading operations. This meant that the machine could not handle large systems of equations satisfactorily, although it could readily solve small systems.

Atanasoff and Berry were still trying to solve this problem when the war forced them to abandon work on their computer. Berry went to work in a draft-deferred position in California (Atanasoff was unable to persuade the local draft board that electronic computing could have any relevance for the war effort), and Atanasoff himself joined the US Naval Ordnance Laboratory. The last photograph of ABC, taken on 18 May 1942, is shown on page 27. The computer was neither used nor further perfected thereafter, and it ultimately suffered the fate of most aging equipment, being cannibalized and finally dismantled.

It is customary to describe ABC as an uncompleted machine. It is perhaps more accurate to characterize it as a functioning but fallible computer. The electronic computing part, designed essentially to calculate eliminants between pairs of equations with up to 29 unknowns, was a brilliant success. Even with the faults in the binary card system, such an eliminant could usually be obtained accurately. By checking and recalculating, it was possible to solve sets of simultaneous equations. This was a simple process for small sets and became more tedious and difficult as their size increased, but in any case ABC, even in its flawed form, represented a major advance in computational power over the means previously available for solving linear equations.

Considering the remarkable speed with which this project was carried out, it is reasonable to assume that the problem with the binary card system would have been solved within a few months, either by eliminating its occasional faults or by replacing it. IBM input-output systems that would have been perfectly satisfactory for the purpose (and that were later used on ENIAC) had existed for decades,⁴ and by demonstrating the power of his computer in practice, Atanasoff could surely have obtained financial support to purchase what he needed. Thus, if his efforts had not been terminated by the war, ABC would very likely have been fully operational by 1943. The history of electronic computing would then

have been very different, but the results would ultimately have been the same, because Atanasoff's ideas were communicated to Mauchly, who, with Eckert, exploited and developed them in a further superb accomplishment of electronic computing, the construction of ENIAC.

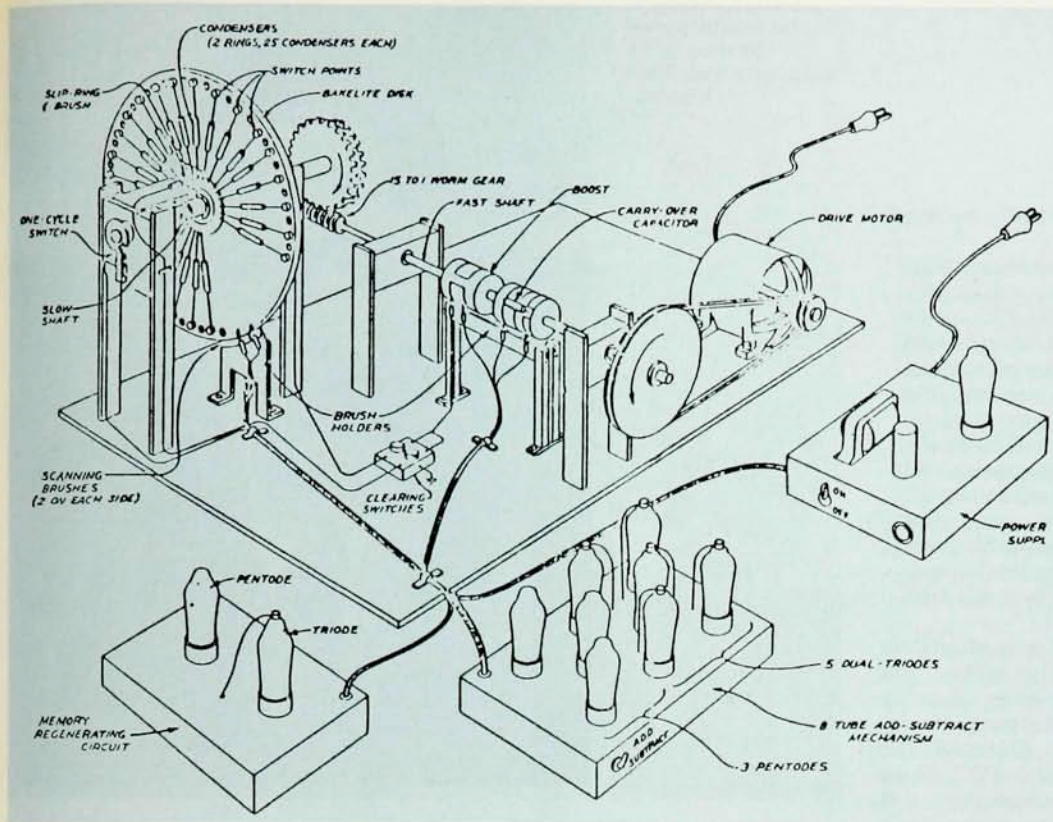
The influence of ABC

In their history of ENIAC, the Burkses summarize Atanasoff's achievement⁴:

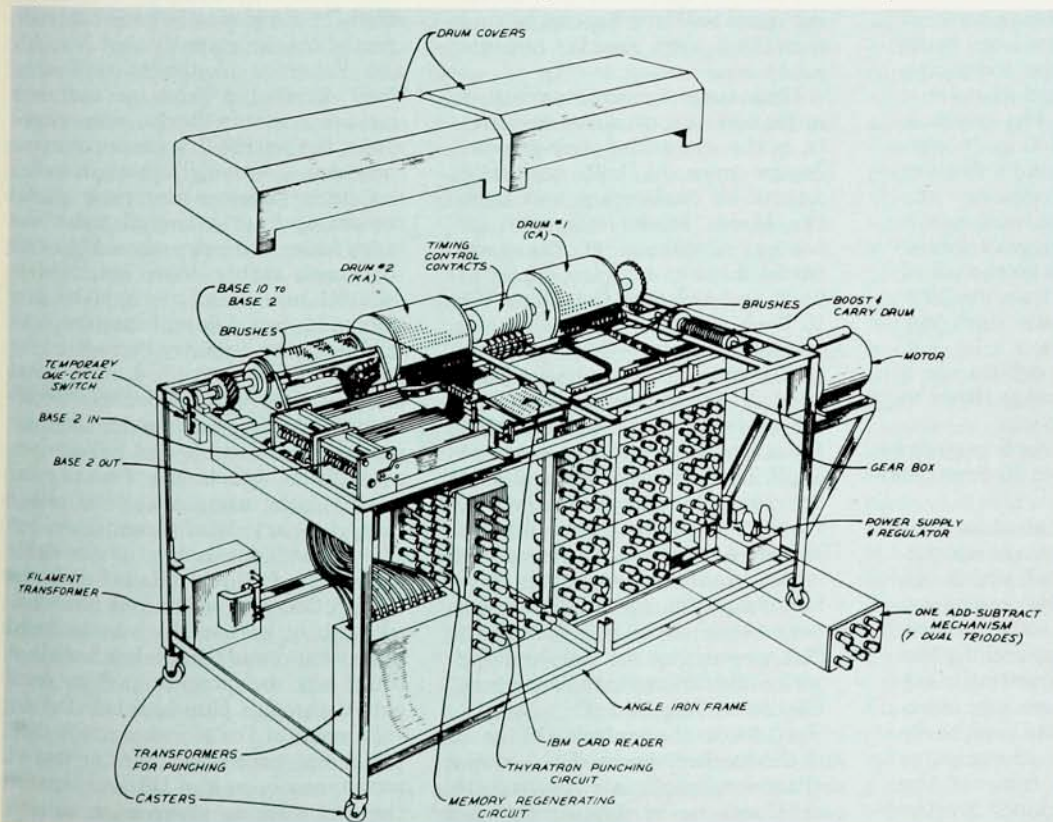
So, clearly, Atanasoff had achieved a great deal in his pioneering efforts. He invented a novel form of serial store suitable for electronic computation. He also conceived, developed and proved the fundamental principles of electronic switching for digital computation, principles encompassing arithmetic operations, control, base conversion, the transfer and restoration of data, and synchronization. He designed a well-balanced electronic computing machine utilizing this store and these principles and having a centralized architecture of store, arithmetic unit, control circuits and input-output with base conversion. His was the first special-purpose electronic computer ever invented: Indeed, it was the first electronic computer of any degree of generality ever invented. Finally, even though his machine was relatively slow, processing pulses at the rate of 60 per second as compared to the ENIAC's 100 000, and the ENIAC differed in other important respects, Atanasoff's principles for electronic computation played a crucial role in the circuitry of the ENIAC and all its successors.

John V. Atanasoff even contributed the original idea that resulted in the ENIAC, the idea that the machine he had developed could "be converted into an integrator," or differential analyzer.

Mauchly and Atanasoff first met at the end of 1940, after a lecture in which Mauchly had presented results obtained with his analog electrical harmonic analyzer. Their common interest in computers led to Atanasoff's inviting Mauchly to visit Ames and to a friendly correspondence throughout 1941. In the spring Samuel Caldwell, who was working on the design of the new MIT Differential Analyzer, visited Atanasoff and told him about the use of electronics in the new analog machine. Atanasoff, who "knew that we could build a machine that could do almost anything in the way of computing," immediately realized that his own electronic digital computer could be converted into an integrator to solve differ-



Prototype and computer. The sketch above shows the prototype computer completed in October 1939. During a single rotation of the memory disk the logic circuits added the numbers stored in condensers on one side of the disk to those stored on the other and a regenerating circuit refreshed the memory. The sketch below shows the computer built in 1939-42. The machine could simultaneously add or subtract 30 coefficients during one rotation.



Atanasoff in 1938, at the time he started working on his computer at Iowa State University.



ential equations. On 31 May he wrote to Mauchly:

The figures on the electronic differential integrator seem absolutely startling. During Dr. Caldwell's last visit here, I suddenly obtained an idea as to how the computing machine which we are building can be converted into an integrator. Its action would be analogous to numerical integration and not like that of the Bush Integrator which is, of course, an analog machine, but it would be very rapid and the steps in the numerical integration could be made arbitrarily small.

It was this idea that was ultimately realized in ENIAC. The matter was discussed extensively when Mauchly visited Ames for the better part of a week in June 1941. Atanasoff and Berry also demonstrated ABC, which was then nearing completion, and Mauchly was allowed to work with it and to read and make notes on Atanasoff's article. Mauchly was very enthusiastic about the computer, and on 28 June he wrote to a colleague:

Immediately after commencement here, I went out to Iowa State University to see the computing device which a friend of mine is constructing there. His machine, now nearing completion, is electronic in operation and will solve within a very few minutes any system of linear equations involving no more than thirty variables. It can be adapted to do the job of the Bush differential analyzer more rapidly than the Bush machine does, and it costs a lot less. My own computing devices use a different principle, more likely to fit small computing jobs.

The Mauchly-Atanasoff correspondence continued, and on 30 September Mauchly wrote:

A number of different ideas have come to me recently anent computing circuits—some of which are more or less hybrids, combining your methods with other things, and some of which are nothing like your machine. The question in my mind is this: Is there any objection, from your point of view, to my building some sort of computer which incorporates some of the features of your machine? For the time being, of course, I shall be

lucky to find time and material to do more than merely make exploratory tests of some of my different ideas, with the hope of getting something very speedy, not too costly etc.

Ultimately a second question might come up, of course, and that is, in the event that your present design were to hold the field against all challengers, and I got the Moore School interested in having something of the sort, would the way be open for us to build an "Atanasoff Calculator" (à la Bush analyzer) here?

Atanasoff replied:

Our attorney has emphasized the need of being careful about the dissemination of information about our device until a patent application is filed. This should not require too long, and, of course, I have no qualms about having informed you about our device, but it does require that we refrain from making public any details for the time being. It is, as a matter of fact, preventing me from making an invited address to the American Statistical Association.

In fact, due to the confusion of the war and the ineffectiveness of the lawyers and university officials involved, this patent was never applied for, even though Atanasoff's report was later

declared to be more than adequate for a patent application.²

The war, which brought Atanasoff's efforts in computing to an abrupt halt, created the opportunity that Mauchly and Eckert exploited so brilliantly. They directed a team of engineers (including Arthur Burks) who created ENIAC, the world's first general purpose computer. Although they inherited the basic ideas of electronic digital computing from Atanasoff, ENIAC was much faster and larger than ABC, with thousands rather than hundreds of vacuum tubes, and it could be programmed for different problems by modifying the circuitry through a plug board.⁴ It also contained many novel features that were of decisive importance for further progress in electronic computing. Mauchly and Eckert deviated from Atanasoff's fundamental principles by using a decimal rather than a binary calculational base, but this turned out not to be a viable approach. On the other hand, the British Colossus, which was constructed slightly earlier than ENIAC, used binary logic, and though less flexible, it could also be programmed to some extent through plug boards.⁸ The development of the stored-program computer also proceeded more or less simultaneously in the US and Britain; the first working program on an electronic stored-program computer was



John Vincent Atanasoff at 80 years of age. The occasion was a celebration at Iowa State University in 1983.

run on 21 June 1948 at Manchester University. Soon thereafter commercial stored-program computers became available—the Ferranti Mark I in Britain, and UNIVAC from Mauchly and Eckert's company—and the computer revolution was truly launched.

In recent years, interest in special purpose computers, analogous to ABC, has revived, especially in connection with the solution of scientific problems. The astonishing similarity between ABC and a modern vector processor for solving linear equations has been analyzed in detail in a recent article⁹; the basic principles are the same, but the speed differs by roughly a factor of 10^8 !

The long path to recognition

In 1947 Mauchly and Eckert applied for a patent, based on their work on ENIAC, that covered essentially all aspects of electronic computing. The patent was issued in 1964 and Sperry Rand, who in the meantime had acquired it, began to collect royalties. Honeywell declined to pay, and Sperry therefore sued. Honeywell's lawyers learned of Atanasoff's work—indirectly, through a book by R.K. Richards¹⁰—and consulted Atanasoff in 1967. He observed that some parts of the ENIAC patent were derived from his own work on ABC, and was consequently called as a witness in the court case in 1971–72. The trial was a gargantuan

affair, lasting 135 working days, involving 77 witnesses and filling over 20 000 pages of transcript. In his decision, Judge Larson declared the ENIAC patent invalid because, among other reasons, the subject matter was derived from Atanasoff. Despite the enormous economic interests involved, Sperry did not appeal the decision.

In his judgment, Larson summarized Atanasoff's achievement³:

In December 1939, Atanasoff completed and reduced to practice his basic conception in the form of an operating breadboard model of a computing machine.

This breadboard model machine, constructed with the assistance of a graduate student, Clifford Berry, permitted the various components of the machine to be tested under actual operating conditions. The breadboard model established the soundness of the basic principles of design, and Atanasoff and Berry began the construction of a prototype or pilot model, capable of solving with a high degree of accuracy a system of as many as 29 simultaneous equations having 29 unknowns. By August 1940, in connection with efforts at further funding, Atanasoff prepared a comprehensive manuscript which fully described the principles of his machine, including detailed design

features. By the time the manuscript was prepared in August 1940, construction of the machine, destined to be termed in this litigation the Atanasoff-Berry computer or "ABC," was already far advanced. The description contained in the manuscript was adequate to enable one of ordinary skill in electronics at that time to make and use an ABC computer.

Larson signed his decision on 19 October 1973. The following day the "Saturday Night Massacre" of the Watergate affair took place—President Nixon fired the special prosecutor and the Assistant Attorney General, and the Attorney General resigned; the OPEC oil embargo was also imposed that weekend. The result of the trial was therefore not widely noticed. Indeed recognition has only really been accorded to Atanasoff during this decade, largely due to the expert, scholarly and thorough investigations and writings of the Burkses.

What are the reasons for the extraordinary delay of over 40 years before the significance of Atanasoff's achievement was appreciated?

► First, as we have seen, the war terminated Atanasoff's effort on ABC when he was just on the verge of triumphant success. The confusion of the early war years was also largely responsible for Iowa State's failure to file for the patent that would have established his priority.

► Second, there was no organization or person whose interest lay in elucidating this priority. It is surprising that Mauchly, who was received in so friendly and open a manner in Ames, and who was initially so enthusiastic about ABC, was unable in later life to acknowledge having learned anything of significance from Atanasoff.

► Third, Atanasoff himself made no particular efforts to explore the significance of his contribution or to publicize it. He has the character of the true inventor, being fully engrossed with the problem of the moment, and his efforts and interests in other fields, including distinguished service during the war, the founding and running of his own company, and the creation of many different inventions, left him for many years with little time to contemplate his earlier accomplishments in computing.

► Finally, though Iowa State is an



Clifford E. Berry, a graduate student in electrical engineering in 1939, became Atanasoff's student and his collaborator in the construction of the first computer.

excellent university, with, for example, one of the first and best materials science centers in the world, it is not particularly close to the major centers of academic influence. I believe that if Atanasoff had carried out his work at Berkeley or Harvard, or indeed Cambridge or Copenhagen, he would have been recognized as the inventor of the electronic computer long ago.

Fortunately his achievement has now become widely recognized in the literature, and Atanasoff has received honorary degrees and various prizes—including most recently the Holley Medal, the highest honor bestowed by the American Society of Mechanical Engineers, "for pioneering research, invention and construction of the first electronic digital computer, providing the basic concepts of the use of electric and electronic means, the use of binary numbers, the use of direct logic for calculation without enumeration and the use of a regenerative memory, all used in modern computers."

Creativity and innovation

The fascinating story of Atanasoff's achievement provokes a number of reflections about research and innovation. The sagacity of those who should have been concerned with promoting these activities frequently left much to be desired. Atanasoff found it difficult to obtain recognition of the importance of his work, or backing for it from funding agencies—with the honorable exception of the Research Corporation. Iowa State deserves credit for supporting his project at its inception, but the

officials concerned clearly had no concept of its significance, and their obtuseness cost the university dearly when they failed to apply for a patent. Atanasoff also attempted to interest IBM in his ideas, but could not convince them of the potentialities of electronic computation. After the war, he worked on computing again for a while at the Naval Ordnance Laboratory, where he and John Von Neumann had mutually enlightening discussions, but the project was canceled and he was moved to what his superiors considered more important tasks.

The way in which Atanasoff conceived the basic principles for his computer is a classic example of the creative process, which is familiar to most research scientists. He started with the long and frequently frustrating process of immersing himself in all aspects of the problem, without making much obvious progress. But when he had absorbed all this information, and his mind had time to work on it, largely unconsciously, the perfect solution became apparent to him while he was engaged in a completely different activity. To the uninitiated, his 200-mile drive through the dry state of Iowa might seem just a particularly inefficient way of obtaining a drink, but Atanasoff knew perfectly well what he was doing. He had appreciated that the mind needs variety and relaxation to perform its creative mysteries.

Atanasoff devised a design for an electronic digital computer that was so perfect that it is difficult, even with the benefit of hindsight, to see how it could

be improved upon with the resources that were available to him. Not only did he describe this design (in an article that is a major milestone in the history of computing), but he and Berry converted it into a practical and operating machine with their own hands. Some might regard this as eccentric behavior for a theoretical physicist, but when asked about the origins of his inventive skills, Atanasoff replied: "I couldn't have had a better training. Theoretical physics is a uniquely effective discipline." Indeed any problem in basic research that strains a student's personal resources of imagination and ingenuity to the utmost is an effective preparation for a career as an innovator. It is not a coincidence that so many major advances in technology have been made by research scientists. The ultimate springs of innovation have always been located in the scientific enterprise, and the frontiers of science and technology are inextricably intertwined.

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