of view, Wittgenstein's philosophy of mathematics seems completely wrong from beginning to end, and superficial at that. The main thrust of Espinoza's argument against Wittgenstein's position is that no anti-realist view of mathematics can explain its applicability to natural sciences.

Espinoza also sees Wittgenstein's philosophy of mathematics as a mere application of the philosophy of his second period (although there is no explicit distinction in this paper between Wittgenstein I and Wittgenstein II) and he concludes that Wittgenstein's conception is untenable: something must be wrong with his whole philosophy of meaning.

Although Wittgenstein's philosophy of mathematics is not the most popular part of his philosophy and, I would say, misconceived from the very beginning, I think that its refutation needs stronger arguments than those offered here. The paper is nevertheless a worthwhile contribution to the complicated topic of the nature of mathematics.

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William Aspray, *John von Neumann and the Origins of Modern Computing*. History of Computing, the MIT Press, 1990. xvii + 376 pp.

Reviewed by

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Interest in applications of mathematics is on the rise these days. As job opportunities in pure mathematics have become increasingly tight, many recent Ph.D.'s, as well as some less recent Ph.D's, look for Wall Street, engineering, business management, and so on, to put their talents to other good uses. Mathematicians oriented towards logic and foundations in oparticular seek and find opportunities in the field of computing. John von Neumann preceded them. William Aspray's description of von Neumann's fundamental contributions to modern computing illustrates this path from the pure towards computers. Von Neumann's many involvements with industry, and with the U.S government and its military, left an extensive paper trail of formal reports and other notes for Aspray to use. Thanks to the generosity of von Neumann's family, Aspray was also allowed access to useful family records. The result is an excellent and entertaining book.

In the first chapter, Aspray presents an overview of Neumann Janos's 'early' life and career, from his birth in a well-to-do Jewish family in Budapest in 1903, to 1942. The 1920s were spent in or near Germany, where Janos mostly worked on set theory and on the foundations of mathematics following Hilbert's program, on Hilbert spaces and related topics, and on the mathematical foundations of quantum mechanics.
Von Neumann abandoned research in foundations in 1931, after Gödel proved the incompleteness theorem. In 1930 Oswald Veblen invited him to Princeton University, but until 1933 he spent half his time in Germany, and the other half in the United States. Then Veblen obtained a more permanent position for John von Neumann at the newly established Institute for Advanced Study (IAS), where he stayed essentially for the rest of his career. Work on operator theory and quantum mechanics continued, and his interests in game theory were renewed. In January of 1943 von Neumann and Oskar Morgenstern delivered the manuscript *Theory of Games and Economic Behavior* to the publisher, just days before von Neumann was called away to England on a war assignment (p. 15). Over there he develops 'an obscene interest in computation' and would be returning home 'a better and impurer man' (p. xv).

William Aspray expresses the situation very well: 'Von Neumann entered the computing scene at a critical, transitional point, when the electronic, digital, stored-program computer was being conceived to replace older and less powerful calculating technology. This transition involved two fundamental tasks: to decide what functional units the computing system should comprise and how these units should be interrelated . . . and to implement the design in electronics so as to achieve a profound increase in calculating speed' (p. xv). Chapter 2 discusses von Neumann's learning phase. The Second World War provided a strong incentive to improve computer power. Von Neumann, a U.S. citizen since 1937, became increasingly involved in government consulting, in particular for the military, and played a limited rôle in the atomic bomb project since September 1943. The implosion detonation design for the plutonium bomb, promoted by von Neumann, required extensive numerical calculations, thereby further increasing his interest in electronic computers. At the time 'computers' were — usually female — employees performing extensive numerical calculations on desk calculators but who, despite their efficiency and hard work, could not keep up with the growing demands. Increasingly more powerful electromechanical accounting machines from IBM were introduced, but each time demand outran supply. Some obvious factors were the mechanical nature of this equipment, and the need for human intervention at many stages of the operations. Von Neumann observed that the machines' abilities for parallel operations made programming significantly more complicated. This taught him to focus on 'single-instruction code where parallel handling of operands was guaranteed not to occur' (p. 30). Von Neumann's extensive travels and contacts informed him about other computing projects, including Howard Aiken's Harvard Mark I and the Bell Telephone relay calculator. By the Summer of 1944, von Neumann's records show his profound understanding of the key concepts of digital computing, including addressing, the rudiments of subroutines, programs-as-data, and conditional branching. The missing component was electronics. It is not certain why von Neumann was not informed about J. Presper Eckert, John W. Mauchly, and the ENIAC project at the University of Pennsylvania's Moore School of Electrical Engineering. Herman Goldstine, a captain in Army Ordnance involved in the ENIAC project as a Ph.D. in mathematics from the University of Chicago, recalls his chance encounter with John von Neumann on the railroad platform in Aberdeen, Maryland (p. 35). The ENIAC was hundreds of times faster than electro-mechanical devices, but its design was essentially complete before von Neumann's visits. However, he was able to make significant contributions to the discussions leading to the design of its successor, the EDVAC. His "First Draft of a Report on the EDVAC", written in the Spring of 1945, is the culmination of these efforts, and includes the description of a stored-program computer using binary numbers for internal use. Intellectual credit is hard to divide among a team that closely cooperates on a design, and possible patent rights added a significant edge to the disputes that followed between Goldstine and von Neumann on one side, and Eckert and Mauchly on the other. By 1947 the ideas of the EDVAC report ended up in the public domain, to von Neumann's satisfaction. Further, he chose to put the ideas of his Electronic Computer Project at the IAS in the public domain too. Eckert and Mauchly were restricted access to the IAS project, for 'they are a commercial group with a commercial patent policy . . . . [W]e cannot work with them directly or indirectly, in the same open manner in which we would work with an academic group which has no such interests. I certainly intend to do my part to keep as much of the field "in the public domain"' (p. 46).

Early in 1945 von Neumann made plans to build his 'own' electronic computer and use it for science. Chapter three lists four problems that had to be addressed. First the need for institutional support. This came from the IAS, after Chicago, Harvard, Columbia, and especially Norbert Wiener and MIT, planned to make or made von Neumann attractive offers. Second problem: Funding. Von Neumann's contacts with the atomic bomb project, and particularly with Army Ordnance, paid off in the form of significant funds. Additionally, RCA (storage tube development) and the IAS contributed. In January 1946 von Neumann estimated the total cost of the project at the low amount of $400,000. As is so often the case with big (science) projects, the final bill was much higher; almost twice as high. The expected time to completion would also almost double. Third problem: Personnel. Although no agreement could be reached with Eckert, many other excellent people were attracted to the project, including Goldstine, Julian Bigelow, James Pomerene, and Arthur Burks. Fourth problem: Design and use. The experience with electromechanical designs of the past, the EDVAC report, combined with the technological developments associated with television, radar, and communication, enabled von Neumann's team to understand many requirements concerning an electronic computer. One significant side effect was a new and expanded appreciation for numerical analysis. Another one was the "Preliminary Discussion" report of 1946, the first major account of programming until 1951 (p. 69). The only significant obstacle was housing. The IAS's 1939 building had too little space left by 1946 to house the project, and in the end an expensive 'temporary' building had to be constructed.

In chapter four the construction begins. Until early 1947 a lot of time was spent on furnishing a laboratory, and on the development of test equipment. We read about the successful development of the arithmetical unit, and about the testing of magnetic tape, before the focus changed towards developing a magnetic drum, the forerunner of the magnetic disk.

A main problem, and one of the causes of delay in the construction of the computer, was primary storage. The idea of magnetic core memory was well-known by 1947, but not pursued by the von Neumann team. Instead, RCA promised to develop the Selectron tube, which used electron beams on a metallic unit, and a secondary emission effect mechanism. As no Selectrons had come forth by 1948, the team decided to develop a 'patch' primary memory device in the form of a magnetic drum. Fortunately, by mid 1948, an electrostatic storage tube design, developed by F. C. Williams at Manchester University, became an option, and by early 1950 completed Williams tubes were available. With the development of and steady improvements to the control unit, the computer started to become increasingly available for use by late 1950 and early 1951. The machine was officially dedicated on June 10, 1952, but underwent steady improvements until early 1955. At the time several other computer construction projects were underway too. There were varying degrees of interaction between these. Von Neumann's Electronic Computer Project disseminated its information so well, that many clones of their machine were built worldwide; so well, in fact, that the larger laboratories, like Los Alamos and Argonne, finished theirs at about the same time or even earlier than the IAS. Some clones included significant technical improvements. IBM's 'cloning' culminated in the IBM 701, which went into commercial production during the first half of 1953.

Chapter five: Computers made possible extensive numerical calculations on such a scale and of such a nature as to require major changes in numerical analysis. Goldstine and von Neumann began a research program in that direction in 1946. One key problem was accumulation of roundoff errors. Applications involved linear algebra problems, partial differential equations, and linear programming. Novel problem solutions were used, like Stan Ulam's Monte Carlo method. This required methods to create (pseudo-) random numbers fast and in large quantities.

'World War II created what [the meteorologist Jule Charney] has called a "near discontinuous change" in meteorological practice' (p.129). This involved vastly increased data collection capabilities. Chapter six addresses the even more extensive advances that were initiated by von Neumann and the electronic computer. With Navy support, a numerical meteorology project was started in 1946. It was hard to find good meteorologists who were willing to come and give the project direction, until Charney joined in 1948. The barotropic model of the atmosphere was improved, and simplified cases tested on the ENIAC, before the IAS computer became available. Better models were developed, and by June of 1953 the Meteorology Group could report '. . . that this phase of the work had ceased to be — for the Project — a matter of major scientific interest' (p. 146). The United States Joint

Numerical Weather Prediction Unit was officially established in July of 1954. Long-term forecast research led by mid-1955 to Norman Phillips' successful model. Von Neumann correctly predicted that short-term and long-term weather forecasting would advance most, but that improvements in mid-range forecasting on the order of a few months would be hardest to accomplish.

Chapter seven presents a long list of applications of the IAS computer to areas besides meteorology. Outside government laboratories like Los Alamos requested user time too. The second largest use, after meteorology, was for astrophysical research of stars, by Martin Schwarzschild and others. A lot of this research included experimenting with (numerical) algorithms. In pure mathematics there were Emil Artin's numerical experiment to support a conjecture of E. E. Kummer in asymptotic number theory (it did not); and in 1952 Ernst Selmer completed his classification of the cubic diophantine equations with the IAS machine. In 1955 the IAS machine was used in developing an Ephemeris for the period 600 BC to 1 BC. Its tables were published in 1962, and used by historians of ancient astronomy. From 1955 onwards, time was spent on developing the rudiments of an operating system, and on adding stored floating point routines. The IAS project officially ended in 1957, but the computer remained in use for another three years.

Chapter eight addresses von Neumann's involvement in the theory of information processing. Early influences include Alan Turing, Claude Shannon, and the Hungarian physicist Rudolf Ortvay. But it was the reading of [McCulloch & Pitts *1943*] that triggered von Neumann's active interest, especially in neural nets and in the character of biological information processing. A 1951 publication of a 1948 paper forms the earliest published account of his theory of automata. His most extensive work in this area involved cellular automata. His last research efforts were in the area of computers and the brain. Von Neumann died, after a year of illness, in February of 1957.

The final chapter nine describes von Neumann's contributions as a scientific consultant and statesman. Von Neumann's wartime service to the Army, the Navy, and the atom bomb project, and his status as a senior scientist, put him in position as one of the prime scientific advisers on computing related matters. Von Neumann had the political wisdom of finding something positive in the other forms of computing — including hand calculation — before recommending electronic computers for all advanced or extensive calculation requirements. The most significant of von Neumann's industrial consulting relations, as far as computing equipment is concerned, was IBM. All through the 1950s, IBM's line of computers was strongly influenced by von Neumann and the IAS computer project. At the height of his consulting career, von Neumann was under contract to over twenty organizations inside and outside government. This included several positions involving US national security, atomic energy, and atomic weapons. The Soviet Union's nuclear buildup made von Neumann into an early leader in the US program to develop intercontinental ballistic missiles. Von Neumann expressed himself as '. . . violently anti-Communist, and . . . violently opposed to Marxism ever since I remember, and quite in particular since I had about a three-months taste of it in Hungary in 1919" (p. 247). But despite their differing personalities and political views, von Neumann testified in defense of Robert Oppenheimer in June of 1954.

William Aspray and the MIT Press enriched our lives with this excellent book. There are relatively few misprints, and the overall organization and layout show high standards. The contents suggest a sincere attempt at objectivity. But even Aspray, with his links to electrical engineering, may be somewhat subjective. On page 176, communication theory is called a rich modern engineering discipline. Communication theory is just as much a mathematical discipline! But there is historical justification for Aspray's view. From the point of view of the mathematics community, communication theory and theoretical computer science have this in common, that if mathematicians underappreciate a field for too long, then it will be called something other than mathematics and it will be studied and taught elsewhere.

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