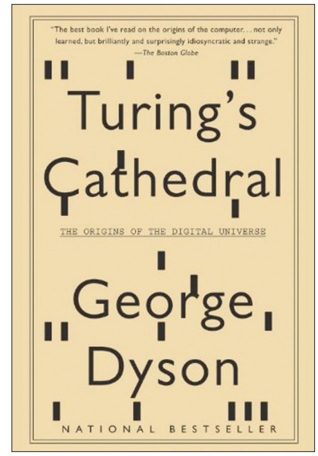
Turing's Cathedral: The Origins of the Digital Universe

Reviewed by Brian E. Blank



Turing's Cathedral: The Origins of the Digital Universe
George Dyson
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In 1936, Alan Turing, sparked by an interest in Hilbert's *Entscheidungsproblem*, introduced the notion of the stored-program Universal Machine. Nine years later, John von Neumann recruited a team of engineers to design and build a concrete realization of Turing's machine at the Institute for Advanced Study in Princeton. Von Neumann's machine, also known as the IAS or Princeton machine and, popularly but incorrectly, as the MANIAC (Mathematical Analyzer, Numerical Integrator, and Computer), was neither the first all-purpose, electronic, digital computer nor the first such machine to employ stored programs. Nevertheless, the IAS machine played an important role in shaping the digital revolution. It was, to borrow a modern phrase, open source. Not only were the design details enthusiastically shared, but teams of engineers from other institutions, national laboratories, and even commercial concerns regularly visited the construction site during the machine's six years of assembly to benefit first-hand from a difficult learning curve. For those unable to call in person, progress reports were disseminated. As a result, the logical architecture of the IAS computer was widely reproduced, and derivative machines were built around the world. By March 1953, the IAS computer and its eight completed offspring[1] held seventy percent of the world's fifty-three kilobytes of high-speed, random-access memory. To George Dyson, historian of technology, the Institute's Electronic Computer Project (ECP) was as close to a point source of the digital universe as any approximation can get. His *Turing's Cathedral* is an account of that enterprise.

If ever there were a book not to be judged by its cover, Dyson's is it. His title is more metaphorical than one might suppose. Turing's seminal 1936 paper, *On computable numbers, with an application to the Entscheidungsproblem*, contained a brilliant thought experiment but no blueprint for a practical implementation of a digital machine. Dyson's subtitle, *The Origins of the Digital Universe*, is out-and-out misleading. Before the IAS machine had its first run, more than a dozen digital computers were fully operational, but the ENIAC (Electronic Numerical Integrator and Computer) is the only one of them that receives more than a passing mention. Underneath the dust jacket, the front cover of *Turing's Cathedral* is devoted to an attractive portrait photograph of the book's namesake, taken in 1951 on the occasion of his election to a Fellowship of the Royal Society. Given the title and cover of Dyson's narrative, a reader might expect Turing to be an essential character for the story inside. Instead, Dyson largely confines his discussion of Turing to the thirteenth of eighteen chapters. In it, we learn that "Engineers avoided Turing's paper because it appeared entirely theoretical." Eleven years after its publication, during the development of von Neumann's machine, Turing *did* help design a practical, physical computer, but in a different style

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[1] *The machines that were based on the IAS computer are often referred to as copies or clones.*

than von Neumann. The question of whether Turing had any influence on von Neumann's contributions to computing has been much debated by historians, but there is no consensus. *Turing's Cathedral* offers no new information to change that.

Fortunately, we know better than to judge a book by its cover, and that must be especially true when the cover has little to do with the book's contents; in this case, those contents have no need of any exaggerated linkage to be of tremendous historical interest. Readers of the *Notices*, in particular, will appreciate Dyson's broad view of his subject. Many of us have visited the IAS and will welcome Dyson's concise, embedded history of its establishment and early years. He also manages to interweave a compact yet useful biography of John von Neumann. Whereas typical readers may find Dyson's life of von Neumann, whose star has waned with the general public,[2] a distraction from the main subject matter of *Turing's Cathedral*, mathematicians, for whom von Neumann remains a legend, will hail its inclusion. It should also be noted that Oswald Veblen, Marston Morse, and Stanislaw Ulam arise frequently in Dyson's treatment, while other mathematicians such as Raoul Bott and Martin Davis make interesting cameo appearances. The eight pages devoted to Kurt Gödel are patently tangential, but they are so absorbing that nobody should object to their presence.

Extensive biographical and institutional backgrounds are not the only unusual elements of Dyson's approach. Departing from the composition style of most historians of computing, who assume that the purpose of building computers is self-evident, Dyson takes a keen interest in the projects that von Neumann intended for the new machine. One paragraph will illustrate both the scope of Dyson's coverage and his knack for synthesis:

> By mid-1953, five distinct sets of problems were running on the MANIAC, characterized by different scales in time: (1) nuclear explosions, over in microseconds; (2) shock and blast waves, ranging from microseconds to minutes; (3) meteorology, ranging from minutes to years; (4) biological evolution, ranging from years to millions of years; and (5) stellar evolution, ranging from millions to billions of years. All this in 5 kilobytes—enough memory for about one-half second of audio, at the rate we now compress music into MP3s.

From Dyson's discussion of the Princeton machine's applications to nuclear weapons, we gain insights into the nation's mindset during the tense first decade of the Cold War. Von Neumann's hawkishness is a topic that Dyson does not neglect. As terrifying as the new atomic bombs were, a naive optimism about atoms for peace managed to coexist with the fear. In his chapter on weather prediction, Dyson quotes speculation in the *New York Times* that "Atomic energy might provide a means for diverting, by its explosive power, a hurricane before it could strike a populated place."

Another positive deviation from more technical histories of computing is the degree to which Dyson includes people in his story. He quotes extensively from many existing oral histories, and he secured access to several resources not generally available, including the archives of Julian Himely Bigelow, the first chief engineer of the ECP, and the remarkable writings of Klára von Neumann (née Dán), John von Neumann's second wife. Dyson also performed a timely service conducting many new interviews.[3]

The Institute for Advanced Study

The author, son of physicist Freeman Dyson, has a natural affinity for the Institute for Advanced Study: it is where he grew up. His childhood memories include visits to a barn on the Institute's grounds in which surplus electronic parts from the computer project, long since terminated, were still stored. As one might expect, he proves to be an enthusiastic guide to the IAS. His succinct account hits all the highlights, but, for those with more leisure, there is an alternative. Beatrice Stern's detailed history of the first twenty years of the Institute is now available online [8]. From her first sentence on, Stern's manner of expression offers considerable reading pleasure: "In the autumn of 1928 two elderly residents of South Orange, New Jersey, were quietly searching for a philanthropy worthy to be endowed with their ample fortunes." The benefactors were Louis Bamberger and his sister Carrie Fuld: the source of their wealth had been Bamberger's department store in Newark. Initially they intended the result of their generosity to be a medical college located in or near Newark. They were put in touch with Abraham Flexner, who, through his seat on the Rockefeller Foundation's General Education Board, had already disbursed

[2] *By contrast, Turing's star seems to be burning brightly in the popular press. Time's February 17, 2014, cover story asserts that "The modern computing era began in the 1930s with the work of Alan Turing."*

[3] *Not long after the author started his eight-year writing project, theoretical meteorologist Joseph Smagorinsky advised, "You're within about five years of not having a testifiable witness." Interviewees Smagorinsky, Bigelow, Bott, Benoît Mandelbrot, Atle Selberg, Françoise Ulam, and Nicholas Vonneumann died during the writing of* Turing's Cathedral. *Another interviewee, computer pioneer Willis H. Ware, an ECP engineer who also worked on the construction of the JOHNNIAC at RAND, died in 2013.*

$600,000,000 of excess prosperity. It was Flexner who persuaded the Bamberger siblings that there was a greater need for an institute for advanced study than for another medical college. In May 1930, a certificate of incorporation was signed for the establishment of an institute for advanced study at or in the vicinity of Newark. It was to be, as the Bambergers wrote the trustees, a place where scholars could devote themselves to serious research free from "the diversions inseparable from an institution the major interest of which is the teaching of undergraduates."

Having long been the recipient of requests for educational funds, Flexner had already become familiar with a proposal for a mathematics institute made some years earlier by Oswald Veblen, who, in 1930, was Henry Burchard Fine Professor of Mathematics at Princeton University. With diplomatic persistence, Flexner widened the Bambergers' horizons to include Princeton, arguing that "it might be difficult to get able lecturers to come to Newark." Flexner also had to campaign for an autonomous institute rather than one affiliated with an existing university. Quoting Veblen, he wrote the trustees in September 1931, "It is the multiplicity of its purposes that makes an American University such an unhappy place for a scholar."

In the context of a book about von Neumann's computer, a costly apparatus motivated by the immediacy of threatening geopolitical concerns, Flexner's reasons for proposing that a School of Mathematics be established as the first at the IAS will seem ironic. The indifference of mathematics to practical results, in Flexner's mind, epitomized his vision for the Institute. "Nothing is more likely to defeat itself, nothing is on the whole less productive in the long run than immediacy in the realm of research, reflection, and contemplation." He had a pragmatic argument as well: Mathematics "requires little—a few men, a few students, a few rooms, books, blackboard, chalk, paper, and pencils." The trustees were not easily won over. Dr. Charles Beard, a historian, insisted, "Mathematics can be taught 'safely' in Moscow, Berlin, Rome, and Washington …Chuck mathematics and take economics. Then you begin with the hardest subject." He continued with an appeal to the country's needs: "We have no good schools of higher economics in this land of business schools." A similar theme of urgency was argued by Felix Frankfurter, then a Harvard law professor, but in favor of mathematics: "Needless to say that mathematics is not a subject in which at present many American universities are eminent." Although the Bambergers preferred schools of economics and politics because of their potential for the advancement of social justice, Flexner prevailed. It will be noted that, in the end, the department store magnates paid a considerable sum, but what they bought did not exactly match what they wanted in any particular.

In 1932, Oswald Veblen became the first professor to be hired at the IAS. Albert Einstein joined him later that year. In 1933, John von Neumann received the third appointment. Twenty years later, Freeman Dyson observed that the long-term structure of the Institute had already been molded by these first three hires: "The School of Mathematics has a permanent establishment which is divided into three groups, one consisting of pure mathematics, one consisting of theoretical physicists, and one consisting of Professor von Neumann."

Dyson's readers will appreciate the insider's advantages on which he draws, but some shortcomings of his book can be frustrating. He often neglects to reestablish the timeline after his story has hopped forward or backward in time. Preferring to scatter his sources throughout the endnotes, Dyson does not provide a bibliography. And he does not always substantiate asserted facts with references. For example, with no citation, Dyson tells us that Flexner "deferred to Veblen as to candidates, explaining to the trustees that 'mathematicians, like cows in the dark, all look alike.'" When in Flexner's ten years of directing the IAS did he say this? In what way did he *defer* to Veblen? The picture Beatrice Stern paints is that Flexner struggled to resist Veblen's willfulness and clandestine maneuvering, which far exceeded his authority. In its first years, the Institute depended on Princeton University for its library and for offices in Fine Hall. After the acquisition of Veblen, Flexner did not want to be perceived by the Institute's host as a persistent faculty raider. Even as he repeatedly reassured the concerned and less remunerative university that he did not intend to drain the school of its best faculty, Veblen was in the process of luring away von Neumann and James W. Alexander[4] [8, pp. 148–151, 154–157, 162]. In 1934, Erwin Schrödinger turned down an offer of Princeton University's Jones Chair in Mathematical Physics, having been convinced by Veblen, abetted in this case by Weyl and Einstein, that a more lucrative appointment from the Institute would be forthcoming. Flexner, who had been unaware of any such representations, was forced to inform Schrödinger that there were no plans to increase the school's faculty [8, pp. 182–185]. Veblen's talent for getting what he wanted also fell short when he lobbied for more luxurious offices during the construction of the Institute's first building, Fuld Hall. Referring to the faculty's temporary digs in Fine Hall, Flexner retorted, "Weyl is happier in a room smaller than

[4] *Alexander followed by Marston Morse became the fifth and sixth permanent members. Hermann Weyl, who would have been the third but for his vacillation, was the fourth.*

yours, and Johnny is productive in a room smaller than Weyl's."

John von Neumann

John (János) von Neumann was born in 1903. He began his serious mathematical education at the age of thirteen with tutoring from Gabor Szegö, Michael (Mihály) Fekete, and their advisor, Leopold (Lipót) Fejér. To conform to his father's idea of a reasonable profession, he enrolled in the chemical engineering program of the ETH in Zurich, but continued his mathematical studies at the University of Berlin, returning periodically to the University of Budapest (Eötvös Loránd University) to take exams in classes he did not attend. He received a chemical engineering degree from the ETH in 1925 and a doctorate from Budapest in 1926. In the next few years he made fundamental contributions to operator theory, quantum mechanics, and game theory (at the rate of nearly one paper per month), but his mathematical work does not feature in *Turing's Cathedral*. Von Neumann's previous biographer, the late Norman Macrae, had more to say about von Neumann's contributions to mathematics, physics, and economics [7], but readers with a mathematical background are better advised to consult Ulam's retrospective [10], as well as the more specialized articles of Garrett Birkhoff, Halmos, van Hove, Kadison, Murray, and Kuhn and Tucker in the same issue of the *Bulletin*. The Society's volume on von Neumann's legacy is also recommended [4].

Every true genius is unique. In the 1930s, von Neumann's Princeton milieu was populated by Alexander, Bochner, Church, Einstein, Lefschetz, Tucker, Wedderburn, Weyl, Wigner, and Wilks. Regular visitors included Albert, Bernays, Brauer, Dirac, Gödel, Infeld, Montgomery, Pauli, and Ulam. Even in that company, even among the other *Martians*,[5] von Neumann stood out. It is next to impossible to write uninterestingly about such a subject. Even so, Macrae's biography benefited from his interviews with Mariette Kővesi, who, from 1930[6] to 1937, was von Neumann's first wife. Referring to these interviews, Macrae acknowledged, "My talks with her in 1990 set the book alight." Analogously, Dyson profited from gaining access to Klára von Neumann's unpublished autobiography and other writings, which he credits as "the documents that brought this story to life." From the extensive quotes on which Dyson relies, it is evident that Klára was a very fine writer.

When Klára first spotted von Neumann in Monte Carlo's casino in the late 1920s, he was at the roulette table with a "large piece of paper and a not-too-large mound of chips before him." Von Neumann had a "system", which he delighted in explaining to Klára and her first husband. The system notwithstanding, the mound of chips eventually found its way to its rightful place in the casino's coffers, and Klára paid for the moneyless game theorist's drink. Years later, when von Neumann's first marriage was breaking up in 1937, he reconnected with Klára, who was bored, as she put it, with her second husband, a man eighteen years her senior. John and Klára married in 1938. Klára recorded that von Neumann offered her a divorce when she persisted in her attempts to interest him in skiing, but the marriage endured until his death in 1957. Readers in search of scuttlebutt will do better with [7] and [11] than with Dyson, whose approach to biography leans toward discretion. On the other hand, the standard von Neumann lore—the feats of memory and mental calculation, the testimonials to his superhuman intelligence, the yearly Cadillacs, the reckless driving, the habitual Wall Street banker's attire[7]—are well represented.

Von Neumann's transition into applied and numerical mathematics began in 1937 when he became a consultant to the Ballistics Research Laboratory that the Army Ordnance Department operated at the Aberdeen Proving Ground in Maryland. Veblen had directed the Ballistics group in World War I, and it is believed that he secured von Neumann's involvement when activities in Aberdeen ramped up due to the worsening conditions in Europe. "It was through military science that I was introduced to applied sciences," von Neumann later explained. In 1943, his work for the government took him to England, where he developed "an obscene interest in computational techniques," as he apprised Veblen. It was there that he learned how a National Cash Register accounting machine could be automated to perform some numerical calculations he required. Von Neumann credited that experience with igniting his interest in computing machines. Toward the end of 1943, in Los Alamos, he observed how the equations for the hydrodynamics of implosions could be numerically solved by running punched cards through a sequence of IBM machines. Dyson

[5] *The "Martians" include Erdős, von Kármán, Polyá, Szegő, Szilárd, Teller, and Wigner. The term is credited to Szilárd, who, referring to the lack of sightings of extraterrestrials, is reported to have said, "They are among us, but they call themselves Hungarians."*

[6] *Dyson says 1929, but Macrae dates the wedding to New Year's Day 1930, as does Marina Whitman, von Neumann's daughter from his marriage to Mariette, in her recent memoir,* The Martian's Daughter.

[7] *Dyson includes a tale that may not be so well known in mathematical circles. According to the story, cited in a paper of Paul Samuelson, David Hilbert attended von Neumann's thesis defense. At the end of the presentation, Hilbert had but one question: Who is the candidate's tailor?*

does a good job outlining von Neumann's conversion to an applied mathematician, but the books of historian William Aspray and Herman Goldstine, Assistant ECP Director, chronicle this phase of von Neumann's career even more thoroughly [1], [5].

In April 1943, Goldstine, a University of Michigan mathematician who was fulfilling his military service in Aberdeen at Veblen's behest, brought to his superiors a proposal for the construction of an electronic, general-purpose, digital computer at the University of Pennsylvania's Moore School of Electrical Engineering. No such machine existed at the time, although John Anatasoff at Iowa State had completed a special-purpose precursor the year before. Veblen advised the Army to fund the project despite nearly unanimous skepticism from reviewers that such a venture could succeed. The ENIAC, as the machine was called, was designed by physicist John Mauchly, who was familiar with Anatasoff's computer, and chief engineer J. Presper Eckert. Presumably von Neumann would have learned of the ENIAC from Veblen when it became operational in fall 1945. As it happened, he became aware of the machine in the summer of 1944 thanks to a chance encounter with Goldstine on the Aberdeen railroad platform. Beginning in August 1944, von Neumann regularly visited the Moore School to participate in discussions about the machine and its planned successor, the EDVAC (Electronic Discrete Variable Automatic Computer). In the spring of 1945, Goldstine had von Neumann's notes on the EDVAC project typed up as a document titled "First Draft of a Report on the EDVAC".[8] This report, which contained the first written description of the logical design of a stored-program computer, bore the name of von Neumann alone, thereby leading to the term "von Neumann architecture". Mauchly and Eckert, however, maintained that the report primarily summarized the discussions among members of the entire EDVAC design group. Moreover, they asserted, the design for the implementation of stored-program functionality was in place before von Neumann joined the project. A bitter fight over both intellectual credit and patent rights ensued.

A hint of this controversy occurs on the first page of the preface of *Turing's Cathedral*, where Dyson quotes ECP engineer Willis Ware: "He [von Neumann] was in the right place at the right time with the right connections with the right idea, setting aside the hassle that will probably never be resolved as to whose ideas they really were." In fact, most historians now credit Mauchly and Eckert with the stored-program concept, even if they allow that von Neumann saw further. Dyson analyzes the dispute clearly and with admirable objectivity. Even better, he presents Jan Rajchman's contention that the stored-program concept evolved gradually through a sequence of technological improvements. As evidence of this, Dyson points to the punched paper tape relay computers that George Stibitz and Samuel Williams built at Bell Laboratories. After witnessing a demonstration of their machine, von Neumann reported to Oppenheimer that the "tape carries numerical data, and operational instructions." That was in a letter he wrote on August 1, 1944, a few days before he learned that there was an electronic computer project in the works. At this point, readers of *Turing's Cathedral* may wonder about Turing's place in any of this.

Less satisfactory is Dyson's review of von Neumann's relationship with IBM. In the book's first intimation of a financial arrangement, Dyson mentions that von Neumann, having become an IBM consultant, drove to their laboratory in Poughkeepsie twice a month. The period of time in which these consultations took place is not provided. Twenty-five pages later, we are told that "von Neumann entered into a series of lucrative personal consulting contracts with IBM," but again there is no indication of the effective dates (or the level of lucre). Dyson does quote one sentence from a May 1, 1945, draft of a retainer agreement: it stipulates that "Von Neumann agrees to assign to IBM, with the exception of the inventions specified below, the entire rights to any and all improvements and inventions made by him." Dyson, however, does not catalog the excluded inventions listed in the contract. With the wording of his next sentence in the book, "As Eckert later complained, 'he [von Neumann] sold all our ideas through the back door to IBM,"' Dyson seems to acquiesce to the claims of the ENIAC group. After these incomplete disclosures on pages 55 and 80, Dyson abandons the thread until page 139, when he quotes chief engineer Bigelow's assertion that von Neumann started consulting with IBM in mid-1947; it would seem from the context, when the ECP engineers were required to accept a new contract that would allow them no patent rights. If there is any use to Bigelow's implication that von Neumann and IBM were profiting from his engineering team's concessions, it is to show the extent to which von Neumann kept his chief engineer out of the loop. The new contract was

[8]*The ENIAC was not initially a stored-program computer, but, in 1948, it was retrofitted to operate that way. A reboot of the Pygmalion story involving the von Neumanns arose during that endeavor. John, acting as Henry Higgins, wanted to determine if someone without mathematical training could succeed as a coder. He did not look far for his Eliza Doolittle: he selected Klára, a "mathematical moron" (as she called herself) with no formal education beyond high school, as his guinea pig for the experiment. Not only did Klára code impressively for the ENIAC in its original configuration, but she is also credited with a significant contribution toward the successful retrofit* [9].

necessitated by the assignment of patent rights to the United States government. After inserting this red herring, Dyson puts aside von Neumann's collaboration with IBM until page 267, where we are told of an ECP engineer who asserted, "IBM people kept coming almost weekly to look at the machine's development," and Bigelow, who characterized the IBM 701 computer, Big Blue's gateway to commercial computer domination, as "a carbon copy of our machine." And that is where the thread ends. Brickbats to Dyson not only for his disjointed narration, but also for raising pertinent ethical concerns without elucidating any of them. Nowadays, when many university professors must fill out annual financial disclosure and conflict of interest forms, more is expected from an author.[9]

The IAS Computer

Von Neumann had many scientific interests that would benefit from the availability of a high-speed computer, but one was paramount, and those who knew him knew it. Ted Taylor, a physicist who worked at Los Alamos during the ECP years, ignored the astrophysics, biology, and meteorology to get to the point of von Neumann's project: "The objective of the von Neumann computer was pretty specifically to be able to do the coupled hydrodynamics and radiation flow necessary for H-bombs." Françoise Ulam, perhaps overstating the impact of the IAS machine, expressed the same idea from a different perspective: "It is an irony of fate that much of the high-tech world we live in today, the conquest of space, the extraordinary advances in biology and medicine, were spurred on by one man's monomania and the need to develop electronic computers to calculate whether an H-bomb could be built or not."

At the beginning of the Cold War, there was strong opposition to the building of a hydrogen bomb (or "Super"), but the argument was that if the United States did not build it first, then the Soviet Union would. There was strong opposition to von Neumann building an electronic computer at the Institute, but the argument was that, if he did not build it there, then he would leave and build it elsewhere—Harvard, MIT, the University of Chicago, and IBM were courting von Neumann and his machine. Among the members of the School of Mathematics, the strongest opposition to the ECP was voiced by Albert Einstein, who, knowing von Neumann's motives and inclinations, feared the project "will further ideas of 'preventive' wars."

Referring to the perception that von Neumann favored a preemptive strike against Soviet Russia, Macrae wrote, "I cannot find anything in his papers that suggests that he advocated that, although a lot of honest people thought that he did." With access to documents that were not at Macrae's disposal, Dyson is able to quote a letter in which von Neumann related to Klára a conversation between Oppenheimer and Veblen. Von Neumann wrote, "He [Oppenheimer] disagreed with my views about a 'quick' [preventive] war, but that I might well be right." That letter was private, but von Neumann did not conceal his views. According to Klára, "Johnny quite openly advocated preventive war before the Russians became too strong." Von Neumann's daughter [11, p. 11] and Freeman Dyson [3, p. 160] say the same. Furthermore, in the 1950s you could hardly go public more effectively than by speaking on the record to a *Life* reporter; that is what von Neumann did, and this is how he was quoted: "If you say, why not bomb them tomorrow, I say, why not today? If you say at five o'clock, I say why not at one o'clock?"[10]

On page 7 Dyson tells us that the IAS computer "was christened MANIAC," a name he uses throughout *Turing's Cathedral*. The name originated at the Moore School not as an acronym but as an epithet for ENIAC when it did not work right. There is no doubt that the name MANIAC was commonly used at Princeton for the IAS machine—it appears in the writings of Klára, Marina von Neumann Whitman, and Freeman Dyson—and found its way from there into the popular press. Continuing to refer to the IAS computer as the MANIAC, however, can only bring confusion,[11] because MANIAC was the *official*

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[9] *For clarification of Dyson's muddled account, see* [1, pp. 241–245]. *A few details here will avoid presumptions of impropriety. The draft agreement of May 1945 was never finalized. When von Neumann received the green light for the ECP, he abandoned his IBM plans. In any event, he had obtained permission from both the IAS and the government to consult with IBM. The first of his consulting contracts with IBM dates to late 1951.*

[10] *Interview with Clay Blair Jr., reported in "Passing of a Great Mind",* Life, *volume 42, Number 8, February 25, 1957. At the time of this writing, the Wikipedia article on Dr. Strangelove, Stanley Kubrick's fictional, bomb-loving character, states that Strangelove was a composite of RAND strategist Herman Kahn, rocket scientist Wernher von Braun, physicist Edward Teller, and von Neumann. The first two men are, without doubt, correctly included, and Teller's inclusion is plausible. Von Neumann is apparently included because of the mistaken belief of the article's authors that he "proposed the strategy of mutual assured destruction." The purpose of preventive war, of course, was to prevent mutual assured destruction. See footnote 11.*

[11] *For instance, the Wikipedia article on Mutual Assured Destruction, at the time of this writing, claims that "The strategy of Mutually Assured Destruction and the acronym MAD are due to John von Neumann (1903–1957), who had a taste for humorous acronyms, another example being his MANIAC computer." Witness the error propagation. The term "assured destruction" was common in American military circles in the 1960s and made public by Secretary of Defense Robert McNamara. The addition of mutual and the acronym MAD are believed to have been introduced by Don-*

name of the Los Alamos "clone". Nicholas Metropolis, who led the group that built the MANIAC at Los Alamos, proposed the name not as the acronym Dyson mentioned, but "in an attempt to put an end to all such baptismal practices" [9]. With only nineteen pages remaining in his book, Dyson finally lets on that usage of the name MANIAC for the IAS machine might not be right.

On November 12, 1945, television pioneer Vladimir Zworykin hosted the first ECP meeting in his office at RCA's research laboratory in Princeton. His RCA colleague, Jan Rajchman, who was then developing a 4096-bit electrostatic storage tube, was also present. At the meeting, the ECP group decided to use Rajchman's tube, the Selectron, for the IAS computer's memory. Development of the Selectron, however, fell behind schedule. By the time the first operational unit became available in the autumn of 1948, ECP engineers had opted to use the Williams Tube, a type of externally altered cathode ray tube that Frederic Williams and Tom Kilburn had just developed as a binary storage device.[12] The switch to the Williams tube permitted the use of inexpensive, off-the-shelf 5CP1A oscilloscope tubes. The workhorse of the IAS computer was another readily available tube, the 6J6, which RCA had developed for mobile WWII equipment. Of the 3,474 tubes in the IAS machine, 1,979 were 6J6s. ECP engineers discovered that, in addition to the well-known problems of vacuum tube degradation and failure, the tubes, even when new, differed greatly from their specified electrical characteristics. The challenge was to build a reliable machine from thousands of unreliable components.[13] One part of the solution was to disregard the published specifications and redesign the computer based on the characteristics of the weakest tube found in a sample of 1000. James Pomerene, who replaced Bigelow as chief engineer in 1951, once pulled some tubes that were in service in the computer and had them tested. As he recalled, "You never saw a crummier bunch of tubes in your life!"

Readers who crave the details of the obsolete components on which the IAS computer was based will not be disappointed with Dyson's reporting. He attributes much of the credit for coaxing collectively acceptable behavior from individually problematic parts to Jack Rosenberg, an electrical engineer who was overlooked in [1] and [5]. Because most readers of *Turing's Cathedral* will not be acquainted with many members of the ECP staff, Dyson includes a six-page who's who of his story's "principal characters".[14] It is a very useful feature, but it is also a source of frustration. The first entry is for Katalin (Lili) Alcsuti, a cousin of von Neumann. Principal character? There is no index entry for her. Admittedly she does appear as an eleven-year-old in two photographs and as a newlywed in another. Atle Selberg is also listed as a principal character, but he had no ECP role other than being husband to Hedvig, who collaborated with astrophysicist Martin Schwarzschild and was lead ECP coder. Verena Huber-Dyson, the author's mother, is also found among the principal characters even though her only part in the book is to praise Bigelow's good looks and purposefulness. (The index gives her maiden name as Haefeli. That was actually her married name from her first marriage. The name of Dyson's half sister, Katarina, is spelled Katharina in the text.)

Denouements

By the mid-1950s, von Neumann had become disenchanted with Princeton. Moreover, his appointment to the Atomic Energy Commission in 1954 precipitated a falling-out with Veblen. For many years, Klára had been hoping to relocate to the West Coast. In March 1956, von Neumann accepted a professor-at-large-position with the University of California. One month later, however,

ald G. Brennan at the time of the SALT negotiations later in the 1960s. The reviewer is not familiar with any acronym due to von Neumann, but he did have a taste for puns, of which Los Ulamos (for Stanislaw and Françoise) might be mentioned.

[12] *Williams and Kilburn also built a stored-program computer, the Manchester Small-Scale Experimental Machine (known as the SSEM or Baby), to test the feasibility of their tube storage. On June 21, 1948, Kilburn wrote a 17-instruction program that, by starting with $2^{18} - 1$, decrementing by 1, and running for 52 minutes, found 2^{17} to be the largest proper divisor of 2^{18}. It is this program that has a claim to being the first stored program implemented on an electronic computer.*

[13] *Younger readers, who are not accustomed to purchasing replacement television parts in their neighborhood convenience stores, may not fully appreciate the magnitude of this challenge. In the days before solid state components attained their dominant role in consumer electronics, the reviewer worked in a corner tobacco store that stocked radio and television tubes. As an aid to customers, an RCA tube-testing machine was available to the do-it-yourselfer who owned a television set that was on the fritz. Business was moderately brisk.*

[14] *A complete list of the documented ECP staff and affiliated researchers is available from the IAS website:* `http://library.ias.edu/files/pdfs/ecpstaff.pdf`. *It includes the reviewer's colleague, A. Edward Nussbaum (1925–2009), ECP coder in 1952 and 1953. In the mid-1990s, the reviewer showed Nussbaum, whose relationship with computers had become distant after four decades, some impressive capabilities of computer algebra systems. That prompted Nussbaum to reminisce about the final shakedown tests of the IAS machine in which the computer raced von Neumann to complete some computations. The reviewer regrets that he did not foresee his current task and consequently did not record the details.*

he was admitted to Walter Reed Hospital, where he spent the better part of a year before he died from metastasizing cancer. Ulam described his friend's mental deterioration as heartbreaking. Dyson's readers will concur.

The Institute never wanted von Neumann's computer, and, once he was gone, the Institute acted quickly to be rid of it. On July 1, 1957, ownership of and responsibility for the machine was transferred to Princeton University. However, right from the start, the University had trouble getting the machine to work. Bigelow was called in and restored the computer to service. In June 1958, Schwarzschild informed Hedvig Selberg, "Your code has run the last couple of weeks wonderfully." Nevertheless, within the month, Princeton announced the retirement of the machine, explaining that it was "essentially developmental and not very carefully engineered." At midnight on July 15, 1958, Bigelow disconnected the power.

Julian Bigelow visited von Neumann every weekend during his final hospitalization and read science journals to him until communication became fruitless. He received many offers of employment after the ECP was closed down, but he declined them. Because he had become a permanent member, the IAS could not terminate his employment, but the institution could and did freeze his salary. To Dyson, Bigelow was the link between theory and the real world. The ECP required members who conceived things and members who built things. Bigelow did both. Atle Selberg remembered him as a "thinker". Martin Davis described him as a man who was most effective with a soldering iron. Bigelow has rarely received his due, but Dyson's appreciative portrayal remedies previous oversights.

In 1958 Klára married Carl Eckart, a distinguished geophysicist at the Scripps Institution of Oceanography. Describing her four marriages, Dyson writes, "The first had been for romance, the second for money, the third for brains, and the fourth for California." On the last page of her unfinished autobiography, Klára wrote, "La Jolla is a wonderful place and I feel that I do not have to travel anymore because I am there already." Not long afterwards, in November 1963, she died, aged 52. Her body, clothed in a black dress, was found washed up on Windansea Beach, La Jolla. Von Neumann's last Cadillac was parked nearby.

Features and Errors

Dyson's penchant for passing along intriguing tidbits is generally laudable, but sometimes he repeats information without questioning it. For example, Dyson, referring to the IAS computer, tells us on page 7, "The new machine was …put to its first test, during the summer of 1951, with a thermonuclear calculation that ran for sixty days nonstop." This assertion is based on the recollection of Bigelow decades later. (Dyson quotes Bigelow's testimony on page 216.) Historians are usually cautious about such memories. Is "nonstop" really credible? Aspray reports that there were a few machine errors during the run [1, p. 85], as would be expected from a computer that would not be officially operational until June 10, 1952. Are we to believe that the computer became *less* reliable in the year during which such glitches were eliminated? According to Aspray, "Unscheduled maintenance decreased to the point that the machine was available 80 percent of the time between July 1952 and June 1953" [1, p. 86].

In his zeal to share diverting material, Dyson often tosses in facts that raise obvious questions that are left unanswered. For instance, within the space of four pages, Dyson acquaints his readers with three facts about British physicist Klaus Fuchs: 1) On May 28, 1946, Fuchs and von Neumann jointly filed for a patent on the design of an H-bomb;[15] 2) Fuchs was a Soviet agent; 3) Fuchs confessed to espionage on January 27, 1950. Nothing more is said about any of this. Readers who are immoderately inquisitive will surely want to know, What was the outcome of the patent application?

Dyson, like Aspray, Goldstine, and Macrae before him, lists the BESM in Moscow as a clone of the IAS machine. If true, what irony! Von Neumann built the IAS machine to effect the means for destroying Moscow. In doing so, was he also responsible for the construction of a machine in Moscow that could effect the means for destroying Washington, thereby giving rise to MAD after all? Given that the Soviet Union gained access to highly classified H-bomb materials, there can be little doubt that the procurement of widely circulated design plans for the IAS machine, if needed, would have been trivial. But, by itself, that does not mean that the BESM was a clone. Soviet historians and some Western scholars have disputed the contention that it was [2], [6].

There are rather too many errors for comfort in *Turing's Cathedral*, but they tend to be inconsequential. Willis Ware is said to have joined RAND, "where the JOHNNIAC had just been built." Actually, Ware was hired by RAND in May 1952 to help build the JOHNNIAC. Although different RAND engineers state different dates for when the JOHNNIAC "went on the air," an idiom that originated in an era when computers relied on radio tubes, the earliest date given is the first half of 1953. In a similar error, Richard Feynman is said

[15] *Although nuclear technology was new, there was a precedent. Szilárd had previously patented the A-bomb.*

to have been a graduate student when he was at Los Alamos. In fact, Feynman's Ph.D. was awarded in 1942, but construction at Los Alamos did not finish until November 30, 1943. Dyson refers to two different British kings as "Her Majesty". One wonders if these references are due to error or to a feud between the author and His Majesty's Foreign Office.

Summary

It is difficult to avoid the conclusion that *Turing's Cathedral* is an idiosyncratic, undisciplined, crazy quilt of a book. The reviewer had no preconceived notions about the sort of book that might be authored by a man who once lived for three years in a treehouse 95 feet above the ground, but the eccentricities of *Turing's Cathedral* do not seem inconsistent with what might be imagined. And yet, for all its flaws, shortcomings, and waywardness, it is a book that amply rewards its readers. By all rights, it should have been rendered redundant by the engrossing biography of Macrae and the expert histories of Aspray and Goldstine that preceded it. But it is not. In large part, that is because Dyson is not so much a biographer or historian as he is a storyteller. It is a labor at which he excels. Over the ages, the best stories have been about extraordinary people performing exceptional deeds. That is just the sort of story that Dyson tells. Once upon a time, bards spun tales of wizards and warriors. In Dyson's hands, computer wizards and cold warriors make splendid substitutes.

References

[1] William Aspray, *John von Neumann and the Origins of Modern Computing*, The MIT Press, 1990.

[2] G. D. Crowe and S. E. Goodman, S. A. Lebedev and the birth of Soviet computing, *IEEE Annals of the History of Computing* **16** (1994), 4–24.

[3] Freeman Dyson, A walk through Johnny von Neumann's garden, *Notices of the AMS* **60** (2013), 154–161.

[4] James Glimm, John Impagliazzo, Isadore Singer (eds.), *The Legacy of John von Neumann*, Proceedings of Symposia in Pure Mathematics, v. **50**, American Mathematical Society, 1990.

[5] Herman H. Goldstine, *The Computer from Pascal to von Neumann*, Princeton University Press, 1972.

[6] Vera B. Karpova and Leonid E. Karpov, *History of the Creation of BESM: The First Computer of S. A. Lebedev Institute of Precise Mechanics and Computer Engineering*, Perspectives on Soviet and Russian Computing IFIP Advances in Information and Communication Technology Volume 357, 2011, 6–19.

[7] Norman Macrae, *John von Neumann: The Scientific Genius who Pioneered the Modern Computer, Game Theory, Nuclear Deterrence, and Much More,* Pantheon Books, 1992. Reprinted by the American Mathematical Society, 1999.

[8] Beatrice M. Stern, *A History of the Institute for Advanced Study 1930-1950*, typewritten manuscript, May 31, 1964, `http://library.ias.edu/files/stern_pt2.pdf` and `http://library.ias.edu/files/stern_pt1.pdf`.

[9] N. Metropolis and J. Worlton, A Trilogy on Errors in the History of Computing, *IEEE Annals of the History of Computing* **2** (1980), 49–59.

[10] S. Ulam, John von Neumann, 1903-1957, *Bull. Amer. Math. Soc.* **64** (1958), 1–49, `http://www.ams.org/journals/bull/1958-64-03/`.

[11] Marina von Neumann Whitman, *The Martian's Daughter: A Memoir*, University of Michigan Press, 2012.