Making Computers Logical: Edmund Berkeley's promotion of logical machines

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Edmund C. Berkeley, who was one of the founders of Association for Computing Machinery and the author of *Giant Brains*,[1] endeavored to make the knowledge of computing machinery available. Despite the fact that Berkeley did not actually play a pivotal role in either the design or construction of advanced computing machines after the war, he had a singular position in the computer community because he kept trying to "popularize" computing machinery through his activities in ACM[2] and in his own company, Berkeley Enterprises. Berkeley was conscious of his mission lecturing the importance of high speed computing machinery, regardless of whether it was analog or digital or whether it was constructed with relays, vacuum tubes or mechanical counters.

Berkeley's explanation for the structure and principles of each computing machine was quite distinctive, since he had a strong belief that the logical aspect of the computing machines and the parallel between logic and electric circuits should become well-known. Berkeley's literature highly estimated the role of Claude E. Shannon in the switching theory, and it helped to form a discourse that Shannon made in a contribution regarding the design of logical circuits in digital computers in the early computer age. As a matter of fact, in Berkeley's books and articles, Boolean algebra, and Shannon's famous paper in 1938, "a symbolic analysis of relay and switching circuits" were always explained with reference to the theory of computing machinery.

Some historians have argued that the work of Alan Turing, John von Neumann, and Shannon played a role in establishing the idea that computers should be associated with logic.[3] As for Shannon at least however, it cannot be assumed that his work on switching circuits, especially his famous paper in 1938, exerted its influence on the development of computing machines in the 1940s. His 1938 paper focused on the analysis and synthesis of complicated switching circuits used exclusively for telephony and control; few researchers and engineers working with computing machinery except in Bell

[1] Edmund C. Berkeley, *Giant Brains; or, Machines that think*, John Wiley & sons, 1949.
[2] Berkeley's activity in ACM can be found in Atsushi Akera, "Edmund Berkeley and the Origins of ACM", *Communications of the ACM*, Vol.50 No.5, May 2007, pp.30-35., and Jim Adams, "Edmund C. Berkeley: ACM founder", *Communications of the ACM*, Vol.31 No.6, June 1988, pp.781-782.
[3] e. g. Michael Mahoney, "What was the Question? The Origin of the Theory of Computation", *Using History to Teach Computer Science and Related Disciplines*, ed., Atsushi Akera and William Aspray, Computing Research Association, 2004. pp. 225-232.

Telephone Laboratories referred to this paper at the time.[4] It cannot be denied that Berkeley's remark had an effect on forming this kind of commonly accepted view of Shannon's influence on computing machinery and logic.

In this paper, it will be explored how Berkeley reinforced his ideas about the application of binary notation and Boolean algebra in relation to Bell Labs' mathematicians and engineers, such people as George R. Stibitz and Claude Shannon. Then I will focus on Berkeley's popularizing plans of symbolic logic and electrical large-scale computers in his books, articles and toy kits sold by his own firm. Focus will be especially given to the consulting by Shannon on Berkeley's logical toy kits which will then be clarified.

Berkeley and Symbolic logic before the 1940s

When studying mathematics at Harvard University, Berkeley had the chance to recognize the importance of "the methods of rigorous thinking"[5]. Above all, symbolic logic and the Boolean algebra used for precise reasoning fascinated Berkeley and had kept his attention even after graduation.[6] After passing his professional actuarial examinations, Berkeley worked at Mutual Life Insurance as an actuarial clerk for four years and moved to Prudential Insurance in 1934. After getting a position as an assistant mathematician in 1939, he worked not only as an actuary but also computing costs and allowances in policy changes.[7] In 1941 and 1942, Berkeley became familiar with the punch card system in the Methods Department of Prudential, where addition to an IBM machine, special types of punch card machines had been developed and used for statistical processing since the late 19th century.[8]

Berkeley carried out research by himself on the application of symbolic logic in insurance companies. He tried to cope with problems in tabulating conditions of insurance contracts by IBM

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[4] This point will be discussed in a different paper. And also, it is sometimes controversial that to whom the priority of analysis of electric switching circuits using Boolean Algebra should attribute. According to Radomir S. Stankovi´c, Jaakko T. Astola, Mark G. Karpovsky, "Some Historical Remarks on Switching Theory", (http://mark.bu.edu/papers/200.pdf.pdf ,viewed Aug. 31 2010), this topic was explored and published in Russia in 1910, 1934 and 1935. As Paul Cerruzi pointed out in *Reckoners,* (http://ed-thelen.org/comp-hist/Reckoners.html ,viewed Aug 31 2010), analysis of electric switching circuits by binary notation was studied in Japan by Akira Nakshima in the late 1930s (Akihiro Yamada, "History of Research on Switching Theory in Japan", *IEEJ Trans. FM*, Vol.124, No.8, 2004, pp.720-726 (in Japanese). Nakashima' s articles on this topic(only abstract in English) were published in February 1938, and Nakashima stayed Bell Labs from 1939 to 1940. It is hard to imagine that Shannon knew Nakashima's research or his paper before Shannon submitted his master's thesis, because Shannon almost completed his paper by April 1938, according to Stibitz. It would be reasonable to think that the relationship between the relay circuits analysis and binary notation was studied in different places simultaneously.)

[5] Edmund C. Berkeley, "Modern Methods of Thinking", June 19, 1930. Box 79, Folder 7, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[6] Edmund C. Berkeley, "Memorandum for John Wiley and Sons from Edmund C. Berkeley", July 22, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. Berkeley's "method of thinking" and the intellectual climate in the 1920s and the 1930s can be found in Bernadette Longo, "Edmund Berkeley, Computers, and Modern Methods of Thinking", *IEEE Annals of the History of Computing*, October-December 2004, pp.4-18.

[7] Edmund C. Berkeley, "Record of Edmund Callis Berkeley", June 4, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[8] Charles Eames, Ray Eames, *A Computer Perspective*, Harvard University Press, 1990, p. 31.

electrical machines by using Boolean algebra.[9] Berkeley confidently believed that the Boolean algebra was "full of potentialities", and he anticipated that it would be easy and suitable for reasoning about clauses and manipulating conditions. Berkeley also thought that the application of Boolean algebra had not been utilized yet and that the useful knowledge of symbolic logic and Boolean algebra was "waiting for a popularizer". [10] Berkeley obviously decided to be that popularizer, and this sense of mission to popularize symbolic logic and Boolean algebra drove him for over 20 years.

Finding Boolean algebra in Computers

Berkeley became interested in large-scale, high-speed, electric computing machines as "mechanical brains", knowing about the Complex Number Calculator completed by Bell Telephone Laboratory in 1939.[11] Berkeley visited Bell Labs in late July 1941 to observe the Complex Number Calculator. Apparently the calculator was "hardly a part of application of symbolic logic", but Berkeley found a parallelism between the Complex Number Calculator and IBM punch card machine used in Prudential, and he learned the detail of Shannon's 1938 paper, that is, the relationship between Boolean algebra and switching circuits.[12] Berkeley realized that, although complex numbers seemed to have nothing to do with insurance company problems, the "branch of mathematics of logic" could be used for solutions to the insurance problems, for example, to organize the punched card system in the company.[13] Berkeley sent a report of the calculator to Stibitz, and Stibitz was impressed by the detailed description by Berkeley.[14]

In September 1941, Berkeley invited Stibitz, Shannon and other Bell Labs engineers to Prudential and discussed for several hours about whether Bell Labs' type of electric relay computers could be applied to the "calculation of insurance company tables and individual policy calculations" or

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[9] Edmund C. Berkeley, "Boolean Algebra Problems", January 25, 1937, Handwritten Memorandum. Box 1, Folder 21, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[10] Edmund C. Berkeley, "Boolean Algebra (The Technique for Manipulating "AND," "OR," "NOT," and Conditions) and Applications to Insurance", *The Record of the American Institute of Actuaries*, Vol. XXVI, Part II, No.54, October, 1937, pp.373-414, and Vol.XXVII, Part I, No. 55, June, 1938, pp.167-176, Reprinted January 1952. Box 68, Folder 1, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[11] Bernadette Longo, "Edmund Berkeley, Computers, and Modern Methods of Thinking", *IEEE Annals of the History of Computing*, October-December 2004, p.9.

[12] At the time, Berkeley had already been in correspondence with Shannon since Alonzo Church introduced Shannon by letter in December 1940, before his visit of Bell Labs.(Alonzo Church, Letter from Church to Berkeley, December. 31, 1940. Box 1, Folder 39, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.) Berkeley and Shannon exchanged ideas in a possibility of application of symbolic logic and the detail of Shannon's 1938 paper by correspondence. Berkeley showed his idea that symbolic logic can be applied for analysis of legal problems on contradiction or redundancy of laws and contracts in the insurance company and requested Shannon to send a reprint of 1938 paper.

[13] Edmund C. Berkeley, "Analysis of the Operation of the Complex Computer, a Machine Developed by the Bell Telephone Laboratories", Application of Symbolic Logic Report No.3, August 3, 1941. Box 2, Folder 18, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. p.5.

[14] George R. Stibitz, Letter from Stibitz to Berkeley, September 24, 1941. Box 1, Folder 47, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

not.[15] Based on Berkeley's idea to introduce a relay calculator into the company, Stibitz and Shannon suggested it would need a function of comparing two numbers and of table making, since the Complex Number Calculator was not designed to carry out sorting or reasoning. The meeting was closed with rather favorable prospects, however a detailed plan was not made because Stibitz was called by NDRC and the circuit construction department was engaged in national defense work. After all, the introduction of Bell Labs' type calculator into Prudential could not be pulled off, although the next meeting was held in March 1945, since Bell Labs was not active in constructing relay calculators and did not decide its attitude on the calculators.[16] Even before the antitrust suit in 1949, Bell Labs had been reluctant to construct calculators, because Bell Labs was not willing to pay for projects which were not associated with telephony.[17] Eventually, in 1947 Prudential introduced UNIVAC, which was an Eckert-Mauchly machine.[18] Berkeley became acquainted with computer scientists through these experiences and deepened his knowledge in computing machinery. Most importantly, the well-constructed Complex Number Calculator and the detail of Shannon's 1938 paper stimulated Berkeley's motivation to popularize symbolic logic and its application.

From December 1942 to July 1946, Berkeley left Prudential temporarily to work for the U.S. Naval Reserve on active duty.[19] Berkeley worked at Harvard Computation Laboratory under Howard Aiken. Berkeley attended to the project of the new type of high-speed relay calculators, called Harvard Mark I and Mark II; Berkeley prepared program tapes for Harvard Mark I and helped the design of Mark II. Soon after he started working at the laboratory in 1945, Berkeley "realized that these mechanical brains would have no difficulty with any symbolism, and could do not only numerical operations but also logical ones to the fullest extent necessary."[20] In other words, Berkeley understood that the high speed electric computers had the hidden possibility to be applied to not only numerical but also logical operation. Through his experience at Harvard Computation Laboratory, his acute interest in symbolic logic and his new interest in high speed calculators were united. Berkeley was then convinced that not only Boolean algebra but also new automatic electric computing machinery should be popularized among the general public and that the detail and functions of the innovation such as Harvard Mark I, II and Bell Labs calculators should be understood by laypeople.

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[15] Edmund C. Berkeley, "Electrical Relay Computing Machine for Insurance Company", Application of Symbolic Logic Report No.6, October 8, 1941, Box 2, George R. Stibitz Papers, Dartmouth College Library.

[16] Edmund C. Berkeley, "Analysis of the Operation of the Complex Computer, a Machine Developed by the Bell Telephone Laboratories", Application of Symbolic Logic Report No.3, August 3, 1941. Box 2, Folder 18, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. p.1.

[17] Claude E. Shannon, Letter from Shannon to Rippenbein, April 11, 1949. Box 1, Folder 3, Papers of Claude Elwood Shannon (MSS 84831), Library of Congress.

[18] John W. Mauchly, Letter from Mauchly to Berkeley, March 28, 1947. Box 3, Folder 61, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[19] Edmund C. Berkeley, "Record of Edmund Callis Berkeley", June 4, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[20] Edmund C. Berkeley, "Memorandum for John Wiley and Sons from Edmund C. Berkeley", July 22, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

After returning to Prudential in 1946, Berkeley worked as a methods analyst and got a position as chief research consultant in April 1947. The experience in U.S. Naval Reserve helped him to arrange application of "modern technology" to company problems, such as the electronic facsimile copying machine, microfilm selector and automatic sequence-controlled calculators.[21] Berkeley left Prudential in 1948 and then established his own business firm, Edmund C. Berkeley and Associates, for his foremost purpose of popularization of symbolic logic and computing machinery.

Berkeley worried that "[o]nly a relatively few scientists, however, understand symbolic logic."[22] Based on his conviction that symbolic logic could be applied to computing machinery and electric circuits best, he wrote several articles in this direction.

For example, in "The Relations of Symbolic Logic and Large-scale Calculating Machines", a paper for a meeting of the Association for Computing Machinery in April 1949,[23] Berkeley stated that the applications of symbolic logic to mechanical brains "have not yet gone very far" but sorting, selecting and tabulating with symbolic logic could be effective applications in insurance companies. Berkeley also pointed out prospectively that in the programming of iterative formulas, such as the formula for square root, symbolic logic would be useful in organizing procedures of calculation and deal with condition branch instructions. In October 1950 in "The Relations between Symbolic Logic and Large-Scale Calculating Machine", Berkeley described the characteristics of symbolic logic in that it "studies mainly nonnumerical relations" and "seeks precise meaning and necessary conclusions". In addition to this, Shannon's "contribution" to computer construction was clearly declared in this paper. Berkeley noted,

> "As a result of work by Claude Shannon, Boolean algebra has proved to be useful in designing and checking electrical circuits using relays or electronic tubes. This application of symbolic logic is important in the design and construction of automatic computers."[24]

Interestingly enough, Berkeley did not have any interest in the famous theoretical work by Alan Turing, which was connected to both the logic and structure of digital computing machinery. [25]

Giant Brains and logical machines

This enthusiasm of Berkeley was completely reflected in his 1949 book *Giant Brains*. It

[21] Edmund C. Berkeley, "Record of Edmund Callis Berkeley", June 4, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[22] Edmund C. Berkeley, "The Relations between Symbolic Logic and Large-scale Calculating Machines", *Science*, vol. 112, October 6, 1950. p. 395.
[23] Edmund C. Berkeley, "The Relations of Symbolic Logic and Large Scale Calculating Machines", April 19, 1949. Box 1, Folder 31, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[24] Edmund C. Berkeley, "The Relations between Symbolic Logic and Large-scale Calculating Machines", *Science*, vol. 112, October 6, 1950. p. 396.
[25] This might be because Turing's argument is highly abstract and it seemed not to be associated with calculation or reasoning by human in *practical* level. Further research is needed in this point.

described a large variety of calculating machines which worked in 1949, such as the IBM punch card machine, MIT Differential analyzer, Harvard Mark I and II, ENIAC and the Complex Number Calculator, regardless of electric or electronic, analog or digital. The detailed explanation was intended for laypeople; procedure of calculation in each machine, actions of parts of those calculators such as relay and integrator, newly invented memory storage such as magnetic wire, and the delay line and cathode tube were described. Berkeley collected information directly from computer scientists such as Samuel H. Caldwell, Grace Hopper and Stibitz. Berkeley himself knew all about Aiken's Harvard Mark I and II and learned much about ENIAC and differential analyzers at MIT through the meetings of the Eastern ACM around 1947.[26] The contents of this book were well-organized so that over 15,000 copies in total had been sold from the first publication in November 1949 to 1958. Even from 1960 to 1967, over 6,800 copies of the paperback were sold.[27]

This elaborated introductory book was unique in that a whole chapter was assigned to a small machine, the Kalin-Burkhart Logical Truth Calculator, which was not known among scientists, mathematicians or engineers who were involved in computer construction at the time.

According to the review by D. R. Hartree, the Kalin-Burkhart Logical Truth Calculator was probably "the first time to be published" in *Giant Brains*.[28] It was a small machine that was 16 inches tall, 14 inches deep and 30 inches long, and it contained 45 dial switches, 23 snap switches, 85 relays and 6 push buttons.[29] This machine was constructed from March to June 1947, by Theodore A. Kalin and William Burkhart, students of Harvard University at the time, in order to solve problems they had in a symbolic logic class taught by W. V. Quine at Harvard. This machine specialized in logical operation and was not to be used for arithmetic calculation; the machine could deal with four kinds of connectives, AND, OR, IF-THEN and IF AND ONLY IF and could calculate truth values of complicated statements and make a truth table automatically. The logical operators were input by manipulating dial switches and snap switches, and a set of conditions were systematically checked in relatively short time; 128 cases for 7 conditions were processed in 1 and 1/4 minutes, and 256 cases for 8 conditions in 21 and 1/2 minutes.[30] Berkeley noted in *Giant Brains* that the idea of this calculator occurred to Kalin and Burkhart from the reading of Shannon's 1938 paper[31].

Berkeley had taken a seminar in mathematical logic with Quine at Harvard from 1946 to 1947

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[26] In December 1947, a meeting of the Eastern Association for Computing Machinery was held at the Ballistic Research Laboratories, Aberdeen Proving Ground in order to learn about the collection of the laboratories, including ENIAC, Bell relay computer, IBM sequence-controlled relay calculator and a differential analyzer. (Edmund C. Berkeley, "Preliminary Announcement -- Meeting at the Ballistic Research Laboratories, Aberdeen Proving Ground, on December 11-12, 1947", November 7, 1947. Box 8, Folder 57, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.)
[27] R. Hoffman, Letter from R. Hoffman to Berkeley, November 17, 1958. Box 8, Folder 40, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[28] D. R. Hartree, "Book Review: Giant Brains", *British Journal of Applied Physics*, 1950. Box 8, Folder 30, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[29] Edmund C. Berkeley, *Giant Brains; or, Machines that think*, John Wiley & sons, 1949. p.156.
[30] Edmund C. Berkeley, *Giant Brains; or, Machines that think*, John Wiley & sons, 1949. p.166.
[31] Edmund C. Berkeley, *Giant Brains; or, Machines that think*, John Wiley & sons, 1949. p.155.

and got a chance to learn this Kalin-Burkhart Logical Truth Calculator.[32] Berkeley found that this machine could be used for draft making of clauses and contracts in insurance companies, and he regarded the machine as an excellent example of the practical application of symbolic logic and Boolean algebra. Kalin was invited to Prudential in September 1947 to demonstrate the use of this machine to people in the company.[33] Eventually the department of methods at Prudential made a rent contract for the Kalin-Burkhart Logical Truth Calculator for over a year, and experiments for constructing a logical truth calculator for Prudential's laboratory were conducted by Berkeley this methods department.[34] Berkeley even gave a talk about this Kalin-Burkhart Logical Truth Calculator at the meeting of the Association for Symbolic Logic in December 1947.

This machine was, as Hartree mentioned, "regarded as a special case of a calculating machine".[35] Berkeley, however, challengingly assigned one chapter to this machine in *Giant Brains* as well as the IBM Punch card machine, MIT differential analyzer, Harvard Mark I and II, ENIAC and the Bell Labs Complex Number Calculator. In the 1940s, before research on programming methods and language emerged, calculating machines were basically for arithmetical calculation but not for logical calculation. In fact, the calculating machines in *Giant Brains*, except for the Kalin-Burkhart Logical Truth Calculator, were not intended to carry out logical reasoning. Berkeley purposely chose the Kalin-Burkhart Logical Truth Calculator for his book because this machine was the first machine that supported Berkeley's acute belief that an important use of computing machinery was reasoning, although obviously the machine was inferior to other computing machines in terms of ability of computing and complexity of mechanisms. In the chapter about the Kalin-Burkhart Logical Truth Calculator in *Giant Brains*, referring to Shannon's 1938 paper, the correspondence between truth values and status of a two position relay was explained. It was probably here that Shannon's 1938 paper was first mentioned in a publication for the general public with reference to computing machines.

Shannon's argument in his 1938 paper was for analysis and synthesis of the complex switching network and was not crucial for practical construction of the calculating machine at the time. In fact, ENIAC and Harvard Mark I carried out their operation in decimal, and the first draft of EDVAC written by John von Neumann did not refer to Shannon's 1938 paper. However, the popularization of symbolic logic in the context of electric and electronic computers in *Giant Brains* made an apparent connection between Shannon's theory and computing machinery, of which people were not conscious. Berkeley noted that a computer is "a machine containing electric circuits which is able to calculate or reason

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[32] Edmund C. Berkeley, "Record of Edmund Callis Berkeley", June 4, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[33] Edmund C. Berkeley, "Kalin-Burkhart Logical Truth Calculator – Demonstration", September 8, 1947. Box 4, Folder 1, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[34] Edmund C. Berkeley, "Kalin-Burkhart Logical Truth Calculator -- Renewal of Rental", March 9, 1948. Box 4, Folder 6, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[35] D.R.Hartree, "Book Review: Giant Brains", British Journal of Applied Physics, 1950. Box 8, Folder 30, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

automatically"[36]. In other words, the two main functions of computing machinery were calculating and reasoning. *Giant Brains* was based on this conception, and it was the result of the combination of Berkeley's enthusiasm to make the importance of computing machines and of symbolic logic appealing.

Making logical robots

After publishing *Giant Brains*, Berkeley's popularization plan expanded to making various robots and manufacturing electric toy kits for education and fun. Berkeley recalled in 1963,

> there are many educational possibilities with small robots, and the planning and understanding of circuits inside these machines (using relays which are just on and off devices) is a most useful and important introduction to logic, symbolic logic, Boolean algebra, and computers.[37]

Berkeley firstly built the robots for rent. In 1950, he constructed a small computer named Simon.[38] Simon "came into existence"[39] when Berkeley gave a talk with Kalin at the meeting of the Association for Symbolic Logic in December 1947. In a sense, Simon was namely a descendant of the Kalin-Burkhart Logical Truth Calculator. The construction of Simon began in 1949 and was finished in April 1950.[40] William A. Porter, who was a skilled engineer involved in the construction of Harvard Mark II, and Robert A Jensen, who was a student at Columbia University, cooperated with the construction of Simon.

The size of Simon was 1 and 1/4 cubic feet, and it had over 130 relays, over 1000 soldering connections[41] and weighed about 39 pounds. This machine was totally intended to be a "simple understandable form" of the computer for educating and entertaining purposes. [42] In the first version, Simon "could handle only numbers 0, 1, 2, 3 and four operations, addition without carry, subtraction, negation without carry, greater than", but after its modification in the next year it could take "in

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[36] Edmund C. Berkeley, *Brainiacs: 201 Small Electric Brain Machines, and How to Make Them*, Berkeley Enterprises, Inc., 1959. p.1.

[37] Edmund C. Berkeley, Letter from Berkeley to Arthur W. Weeks, February 26, 1963. Box 22, Folder 23, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[38] Edmund C. Berkeley, *Brainiacs: 201 Small Electric Brain Machines*, and How to Make Them, Berkeley Enterprises, Inc., 1959. p.2.

[39] Edmund C. Berkeley and Robert A. Jensen, "How and Electric Brain Works, Part VI.", *Radio Electronics*, March 1949., in *Constructing Electric Brains*, Reprinted by Edmund C. Berkeley and Associates, 1952. pp. 15-17. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[40] Simon was described in *Giant Brains* published in 1949, but it was not completed at the time.

[41] Edmund C. Berkeley and Robert A. Jensen, "Construction Plan for Simon", second edition, 1952. Box 67, Folder 44, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[42] Edmund C. Berkeley and Robert A. Jensen, "World's Smallest Electric Brain, PartI.", *Radio Electronics*, October 1950., in *Constructing Electric Brains*, Reprinted by Edmund C. Berkeley and Associates, 1952. pp. 1-2. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

numbers up to 255, and perform five mathematical or logical operations"[43] under the control of a punched paper tape or under manual control. Simon became well-known through its appearance in the *Wall Street Journal* on May 22, 1950, and *Radio Electronics* in October 1950.[44] Simon was demonstrated in at least eight cities in the U.S., and about 400 sets were sold. Berkeley, however, was dissatisfied because the price of Simon was too expensive for the market; the cost of materials alone was about $300.

After constructing Squee, a robotic squirrel that could automatically pick up tennis balls, around 1950, Berkeley built the next logical machine called Relay Moe. Relay Moe was an automatic relay machine that was able to play tic-tac-toe with a human opponent, and it was built to study the behavior of an "intelligent machine"[45]. Relay Moe was able to carry out nine arithmetical and logical operations and store one binary digit of information in 20 tracks and had several different strategies, including the one where the human opponent could win.[46] Just like Simon, Relay Moe was reported in *Radio Electronics* in 1956, and it was rented by Berkeley Enterprises, which was a successor of Berkeley Associates, to companies and organizations over eight times. Relay Moe was even exhibited in Stockholm in 1957.[47] Over five complicated robots such as Simon and Relay Moe were designed and constructed by Berkeley Associates and Berkeley Enterprises. Berkeley was still bothered that almost all of the robots were too expensive to reach the general public. Then he found that an electrical toy kit, which was cheap and accessible to young students, was the solution.

Making logical toy kits

Soon after the completion of Simon, Berkeley started to develop an inexpensive switching toy kit.[48] In June 1950, Berkeley planned a "mechanical brain" toy set tentatively named "Simon Half", which would be sold at about $15 and was "not more than $3 to $5 to manufacture".[49] The kit was to contain basic and cheap materials: a wire, battery, battery clamp, panel, bulbs, sockets, nuts, bolts, switching disks and so on. The switching disk was a substitute for the switching relay, which was easy to

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[43] Edmund C. Berkeley and Robert A. Jensen, "Construction Plans for Simon", second edition, March 1952. Box 22, Folder 22, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[44] Edmund C. Berkeley and Robert A. Jensen, "World's Smallest Electric Brain, PartI.", *Radio Electronics*, October 1950., in *Constructing Electric Brains,* Reprinted by Edmund C. Berkeley and Associates, 1952. pp. 1-2. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[45] Edmund C. Berkeley, "An Earning Prospect for Berkeley Enterprises -- A Small Automatic Computer to Do Useful Work", March 25, 1957. Box 21, Folder 60, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[46] Edmund C. Berkeley, "Relay Moe Plays Tick Tack Toe", *Radio Electronics,* December 1956. pp. 50-52.
[47] Edmund C. Berkeley, Letter from Berkeley to Bartram, May 7, 1958. Box 37, Folder 28, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[48] Edmund C. Berkeley, *Brainiacs: 201 Small Electric Brain Machines, and How to Make Them*, Berkeley Enterprises, Inc., 1959. p.2.
[49] Edmund C. Berkeley, "Simon Half: Confidential Memorandum for Associates William A. Porter, Robert A. Jensen, and Andrew Vall from Edmund C. Berkeley", June 17, 1950. Box 37, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

put together and manipulate. The kit was quite simple and contained enough amounts of parts, so that after enjoying an experiment one could easily break up the composed circuit and rearrange the materials for another experiment. This kit was intended be purchased for boys 10 to 14 years of age and for older students around 18 years of age in school. It was thought that there was a big market to sell this kind of toy kit; according to Berkeley, the value of toy kit production in 1947 was,[50]

Mechanical trains	$23,000,000
Other mechanical toys	$16,000,000
Model sets, construction (airplanes, ships and trains, etc.)	$4,900,000

Berkeley believed that this kind of kit must stimulate scientific interest in children and help to deepen their understanding about "mechanical brains". To complete this new type of toy kit, Berkeley asked for consulting from Claude Shannon and his colleague, David Hagelbarger, who were getting to be famous in tinkering and making game playing machines in Bell Labs.

In the 1950s, Shannon became well-known not only as the founder of the information theory but as a game machine builder. Shannon enjoyed tinkering with Hagelbarger in Bell Labs, and the machines were sometimes opened to the public. A chess-playing machine and maze-solving machine made by Shannon appeared in articles and magazines such as *Life.*[51] Shannon even wrote technical reports with Hagelbarger about their machines, ones like the mind-reading machine and Nim playing machine.[52] Though tinkering was a favorite hobby for Shannon, his machine had some implications related to telephony or switching theory anyway, since Bell Labs did not actively approve works that had nothing to do with telephone technology.

One of the works was the relay kit for college students, devised for Bell Labs by Shannon and Hagelbarger in 1954. In the technical report "A Relay Laboratory Outfit for Colleges, Jan 10 1954",[53] they proposed an idea to provide the relay kits to college laboratory courses for Bell Labs' "long-range policy", that is, to cultivate future switching engineers. Using this kit, constructed with relays used in the real telephone switching system, students could easily learn the circuit design by connecting a wire into the main plug board. The kit was suggested also as a commercial opportunity for Western Electric,

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[50] Edmund C. Berkeley, "Simon Half: Confidential Memorandum for Associates William A. Porter, Robert A. Jensen, and Andrew Vall from Edmund C. Berkeley", June 17, 1950. Box 37, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[51] Mai Sugimoto, Claude Shannon's Maze Solving Machine: Transition of its interpretation in Bell Labs, *PHS Studies*, Vol.4, 2010 (in Japanese). pp.1-19.

[52] The collection of Shannon's robots is now preserved in the MIT museum. The papers on these robots can be found in *Claude Elwood Shannon Collected Papers*.

[53] Claude E. Shannon and D.W. Hagelbarger, "A Relay Laboratory Outfit for Colleges", Jun 10, 1954, *Claude Elwood Shannon Collected Papers*, ed., N.J.A. Sloane and Aaron D. Wyner, IEEE Press 1993. pp.715-726.

which was a manufacturer of the relays.[54] The kit could implement the Perpetual Calendar, Morse coder, decoder and game playing circuits such as Nim and Tower of Hanoi. Knowing Shannon and Hagelbarger were familiar with making robots and kits, Berkeley asked them for consulting.

Discussion between Shannon, Hagelbarger and Berkeley began in December 1954, although the agreement in consulting was set for early 1955.[55] Comments by Shannon and Hagelbarger covered a wide range about the kit. They even discussed with Berkeley marketing, experiments to be suggested for customers, materials of the kit and its cost.[56] But mainly the consulting was focused on the design of experiments which could be performed with the kit. They proposed a lot of experiments such as an Adder, Multiplier, Morse encoder and decoder, Combination lock, Burglar alarm, Nim machine and Tic-tac-toe machine. Most of them were included in their paper entitled "Relay Laboratory Outfit" in 1954 or in another paper "The 3-Relay Kit", which was written by Shannon and Hagelbarger.[57] Some of their suggestions were related to their past works. For example, the Secret coder and decoder, which were eventually adopted, were obviously from Shannon's previous work on cryptography in the 1940s.[58] Consequently, in the completed toy kit, which was named "Geniac", over ten experiments out of 33 were formed directly from their consulting.

Furthermore, Shannon and Hagelbarger understood Berkeley's enthusiasm on Boolean algebra and binary notation quite well. Hagelbarger noted in his handwritten memorandum in February 1955,

> Solution of Experiments on Binary Arithmetic and computer coding
> "This is the way the 'Giant Brains' calculates" etc etc [sic]
> you should be able to write this introduction so that it has glamour appeal to the brighter kids. It will also generate a future market for more advanced kits.[59]

Berkeley also learned of their plan for the rather advanced kit, "Three Relay kit" and promised to help them move forward with their plan, if they decided to do so.[60]

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[54] Edmund C. Berkeley, Memorandum about meeting with Claude Shannon, December 3, 1954. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[55] Edmund C. Berkeley, Letter from Berkeley to Shannon and Hagelbarger, June 25, 1955. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[56] Edmund C. Berkeley, Memorandum about meeting with Claude Shannon, December 3, 1954. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis, Edmund C. Berkeley, Memorandum about meeting with Claude Shannon, December 31, 1954. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[57] Claude E. Shannon, "The 3-Relay Kit", n.d., Box 11, Folder 17, Papers of Claude Elwood Shannon (MSS 84831), Library of Congress.
[58] Claude E. Shannon, "Communication Theory of Secrecy Systems", October 1949, *Claude Elwood Shannon Collected Papers*, ed., N.J.A. Sloane and Aaron D. Wyner, IEEE Press 1993. pp.84-143.
[59] David Hagelbarger, Memorandum for Berkeley, February 14, 1955. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[60] Edmund C. Berkeley, Letter from Berkeley to Shannon and Hagelbarger, June 25, 1955. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

The completed kit Geniac, which means "Genius Almost-Automatic Computer", was apparently named after famous large-scale electrical computers. Geniac consisted of a wire, panel, six switching tables that could rotate to switch contacts, ten flash lamps and so on, which could be easily put together and taken apart for the 33 possible experiments. A booklet which explained how to assemble the materials for each experiment was attached to the kit.[61] In addition to this, a reprint of Shannon's 1938 paper, "A symbolic analysis of relay and switching circuits" was enclosed in the kit box as an advanced teaching material. Berkeley Enterprises reprinted the paper in 1952 for the first time, and they continued to reprint it until at least 1959.

Unfortunately, Berkeley got involved in a troubling situation. The manufacturer of the Geniac kit went bankrupt, and then formed his own firm to sell another "Geniac" kit without Berkeley's permission.[62] After that, Berkeley cooked up other kits, Tyniac and Brainiac.

Tyniac, "Tiny Almost—Automatic Computer" was put on the market in December 1955, soon after the trouble with Geniac's manufacturer. Tyniac was developed as a "smaller, simpler and better kit"[63] than Geniac, and it contained four switching discs and four flashlights for 13 experiments. In the Tyniac manual, the last chapter was devoted to experiments to study Boolean algebra in switching circuits. It was emphasized in the manual that Boolean algebra was "a new kind of algebra", which was "one of the best approaches" for the design of switching circuits;[64] it is also noted that Claude Shannon discovered that Boolean algebra could be applied to switching circuits.[65] Although it was "not the only one" to design switching circuits, Boolean algebra "is a useful and powerful tool" so that people would "doubtless find out and learn more and more interesting and important applications of Boolean algebra as people become more and more accustomed to regarding AND, OR, and NOT as operators for calculating with, much like the operators PLUS, MINUS, TIMES, and DIVIDED BY", Berkeley noted.[66]

Brainiac, "BRAIN-Imitating Almost-Automatic Computer" was sold in 1957, after Berkeley and Berkeley Enterprises decided to modify Geniac, which had been emphasized as a fun-game device, into a training device.[67] Brainiac was developed as a comprehensive kit, incorporating Geniac and Tyniac. The Brainiac kit had over 450 parts, including six switching discs and ten flashlights. Each switching disc

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[61] *Geniacs Manual,* 1955. Box 37, Folder 45, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[62] Edmund C. Berkeley, Memorandum for J. B. Felshin, June 8, 1958. Box 38, Folder 41, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[63] *Tyniacs Manual*, 1956. Box 37, Folder 60, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. p.5.
[64] *Tyniacs Manual,* 1956. Box 37, Folder 60, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. p.6.
[65] *Tyniacs Manual*, 1956. Box 37, Folder 60, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. p.42.
[66] T*yniacs Manual*, 1956. Box 37, Folder 60, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. p.46.
[67] L. Hewitt, "Letter from Lee Hewitt to Berkeley, Geniac Manual Revision", June 30, 1957. Box 38, Folder 15, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

had 65 holes to fasten a bridging conductor. In addition to the 33 experiments of Geniac and the 13 of Tyniac, 155 new experiments were suggested for Brainiac by 1959 in the attached, thick manual. Brainiac, of course, aimed at the popularization of Boolean algebra; even "A Simple Kalin-Burkhart Logical Truth Calculator" could be constructed using the Brainiac kit. Berkeley stated in a personal note that "each one teaches something new and useful about electrical computing and reasoning circuits" and "[o]ne section of the manual includes a careful introduction to Boolean Algebra". This Brainiac kit was sold for a rather reasonable price, about $20. In 1958, Brainiac was selected as a "Device of Enrichment Topics" in a pamphlet on "Teaching Aids" for mathematics teachers, published by the Teaching Aids Subcommittee of the Secondary School Curriculum Committee.[68] Berkeley's purpose for educating and lecturing was accomplished at least partly by this Brainiac kit.

Berkeley's apparently bizarre kit business was lined with his sense of mission in popularization symbolic logic and computing machinery, and being supported by the experts of switching theory, Shannon and Hagelbarger, it was accepted to an extent in hobbyist culture. It is not easy to clarify how logic was used in computer science; however, at least in the case of Berkeley, he always tried to implement logical operations mechanically, until he started to work on LISP. After Brainiac, Berkeley shifted the core of his activity to writing books, although Brainiac had been sold at least until the late 1960s. His *Giant Brains* also had been sold during the 1960s, and it helped to distribute his idea on computer machinery and logic.

[68] Letter from the National Council of Teachers of Mathematics, December 12, 1958. Box 38, Folder 59, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.