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Reprints

Willis H. Ware

Editor: David Walden

For this inaugural installment of the *Annals* Interviews column, we interviewed Willis Ware,[1] who has been involved in digital computing since the mid-1940s. Ware had a knack for being at the right place at the right time and was involved in several important steps in the spread of digital computing.[2]

***David Walden*: Please speak a bit about your early life.**

Willis Ware: A year or so before I was born in 1920, my father was discharged from the Navy and took a job delivering produce with a horse drawn wagon. My mother of course was a homemaker, a life-time career.

In 1922–1923, my father had a house built in Pleasantville, New Jersey, which is on the mainland and separated from Atlantic City by several miles of wetlands and small creeks. He also took a job with the A&P food market chain. We stayed in Pleasantville until we moved to Ambler, Pennsylvania, in 1930.

When I was 10, I started making balsa wood flyable airplane models using twisted rubber bands for motive power. I also started making primitive radios starting with a crystal set. I read *Popular Mechanics* and various amateur radio publications for ideas and circuits. I snitched loaf pans from my mother's kitchen and used them for chassis. I never built anything larger than two to three tube radios. I also had a complete set of Tom Swift novels that helped me imagine adventures around the world.

I do have a sharp recollection of one event. One day I was riding my tricycle with an older friend who had a two-wheel bicycle. I could not understand why the friend was able to peddle much faster. I noticed that my tricycle did not have a chain, like his bicycle. I concluded that somehow it made the difference—a glimmer of the engineer to be.

***DW*: When did you first become interested in science?**

WW: My interest in science and technology started while I was living at home in Ambler, but it didn't come from my family, whose education had stopped with high school. As I grew, my toys gradually became more complex and realistic. I think that my mother bought my first Erector set as a Christmas gift when I was 10. I then got into the habit of buying the "set of the year" each Christmas with money that I had saved. The sets cost $25 and each one made something special, like a steam locomotive or a zeppelin airship.

When I entered high school, having skipped the fifth grade, I came under the tutelage of George Meyers, the mathematics instructor. He made it a habit of identifying students who he thought had promise. Most days his "picks" stayed after school and drilled on problems—be it algebra, trigonometry, plane geometry, solid geometry. He would also persuade us to apply for scholarships at the University of Pennsylvania, generally in the engineering schools. My year [1937] he had four successes, two of whom chose electrical engineering. If I had to pick one factor that dominated my closure on engineering, it would be Meyers' influence, dedication, and encouragement.

***DW*: Where did you go to college?**

WW: After graduating from high school in 1937, I commuted daily to the Moore School of Electrical Engineering [University of Pennsylvania] as a day student.

***DW*: Had the famous Mauchly-Eckert ENIAC digital computer work started while you were at the University of Pennsylvania Moore School?**

WW: Pres Eckert was a classmate of mine. But if there were any computer events, they were well hidden. As I recall, nothing happened until John Mauchly joined the faculty. He knew about the Army's requirement to generate firing tables for weapons and proposed doing

Background of Willis H. Ware

Born: 31 August 1920, Atlantic City, New Jersey

Education: University of Pennsylvania, BS (electrical engineer), 1941; Massachusetts Institute of Technology, MS (electrical engineer), 1942; and Princeton University, PhD (electrical engineer), 1951.

Professional Experience: Hazeltine Electronics, 1942–1946; Institute for Advanced Study, 1946–1951; North American Aviation, 1951–1952; RAND, 1952–1992.

Honors and Awards: Member of the National Academy of Engineering; Fellow of IEEE, the American Association for Advancement of Science, and the ACM; US Air Force Exceptional Civilian Service Medal 1979; IEEE Centennial Medal, 1984; National Computer System Security Award, 1989; and IEEE Computer Pioneer Award, 1993; IFIP Kristian Beckman Award,1999.

I was able to learn all about the newfangled thing called a computer and be on the forefront of the technology.

it electronically instead of manually with people and desk calculators. But I graduated in June 1941 and Mauchly came later.

Upon graduation, I left for Boston where I lived in Massachusetts Institute of Technology's graduate house [Ashdown House]. With a Tau Beta Pi Fellowship, I entered MIT's Course VI (electrical engineering) and focused on the Communication Option. The only other choice was the Power Option, and I wanted none of that. The Draft Board allowed me to finish my master's program after WWII erupted in 1941.

When I completed my master's program at MIT in 1942, I accepted an industrial job with Hazeltine's laboratory on Long Island. I worked there all through WWII on classified military equipment and projects.

I married in October 1943 and was, for a time, a resident engineer at a Hazeltine contractor plant in Cincinnati. At war's end, I was back living on Long Island.

_DW_: Was digital technology involved in your work at Hazeltine?

WW: Yes, radar and IFF worked with signals of 10 microseconds or so. Test equipment had to handle such signals [pulses] and circuits as well. Commercial electronics used free running sweeps on oscilloscopes; for pulse work, they needed triggered sweeps and the signal amplifiers needed bandwidths of several megahertz. It was quite a different world from the Moore School labs where the "scopes" were string galvanometers with a mirror arrangement to reflect a light beam onto a film. The phrase "digital technology" was not yet in the lexicon.

_DW_: How did you get to Princeton University?

WW: At the conclusion of the Pacific War in the spring of 1946, I heard about John von Neumann's newly created computer undertaking at the Institute for Advanced Study. I applied and received a job offer, which I promptly accepted, and we lived in Princeton until 1951. It was a good career change because I, having worked on radar and such during WWII, brought important digital technology experience and knowledge to the project.

The job came with the most attractive perk imaginable; I could attend Princeton's graduate school tuition free. As a consequence, I was able to pursue a PhD program while concurrently earning a respectable income to support my family. As a collateral benefit, I was able to learn all about the newfangled thing called a computer and be on the forefront of the technology.

_DW_: Can you talk a bit about the computer project at IAS?

WW: Our mission was to build Johnny von Neumann a machine according to the overall logic that he had documented along with Arthur Burks and Herman Goldstine.[3] Designed to do primarily scientific work, it was parallel, unclocked, 40-bits wide, with no special features for character processing or floating-point arithmetic.

I designed and built special oscilloscopes, a variety of test gear, an experimental output device, and pulse generators. I also shared responsibility for the 1,024 word × 40 bit Williams-Tube memory and the master counter.

_DW_: Did you interact with von Neumann at IAS?

WW: We would chat with von Neumann when he came down to see how things were going, bring him up to date, and so forth—a collegial sort of relation. We would see him maybe a few hours per month.

_DW_: Where you aware of the famous Moore School lectures[4] when you got to IAS in 1946?

WW: I arrived at IAS about July and there was some politicking going on. Von Neumann initially intended to have Eckert run his project, and there was a question of whether people from ENIAC would come to IAS. In fact, Robert Shaw was at IAS for a short while. However, Eckert and Mauchly wanted to start their company and declined interest in IAS, and others from ENIAC didn't want to move to Princeton. I don't know how the connection was made, but Norbert Wiener (cyberneticist at MIT) recommended Julian Bigelow to von Neumann, and he got hired. I don't know how much anybody at IAS knew about the lectures; probably only Herman Goldstine and von Neumann knew about them in detail. If there was any transfer of knowledge from Moore to IAS, it would have probably been via Julian. The IAS bible was the Burks, Goldstein, and von Neumann document.

***DW*: What was your PhD thesis topic?**

WW: I had been assigned the design of the master 10-stage binary counter for the machine. I carved out that work and published it in the *Proceedings of the IRE*.[5]

The period from 1946–1951 was an exciting time. I worked hard at the graduate program, and I found concurrently working a full-time week on the project exciting and fun.

***DW*: You moved to California after your time at IAS. Did you have some image about the importance of computing in aviation and in Southern California that drew you there?**

WW: I knew that I would be finished with my degree by spring 1951, so I went to the IRE annual meeting in New York in March 1951. I registered with North American Aviation and with Hughes Aircraft to test the West Coast job market. I already had in hand an offer from RCA Labs at Princeton. I never heard from Hughes. NAA gave me an offer 25% higher than RCA, which gave me more money and a chance to see other parts of the country.

I moved my wife and our one year-old daughter to California in August 1951. We lived in Whittier for 6 months while I tried to fit into the culture and environment of an aircraft company.

I had no fanciful ideas about computing in aviation; NAA was just a job, and I expected to be a bench engineer on electronic projects. I had no idea what the work would be, much less realize it would be computing in some fashion.

When I arrived on the LA scene in 1951, I couldn't find a computer. All the big aircraft companies had punched-card installations for administrative use. Harold Sarkissian [Computer Research Corporation, CRC] and friends were marketing their Maddida,[6] which had been designed by Floyd Steele at Northrop. There were scattered efforts to do engineering work with punched cards. There were two or three Reeves Analog installations to do simulation studies for aircraft. At Northrop, Bill Woodbury, Rex Rice, and Greg Tobin disobeyed IBM policy and connected two IBM card machines. Truman Wheelock at IBM built an electronic version that they nicknamed the Wooden Wheel. It could do engineering problems and ultimately IBM marketed such a configuration as the IBM Card Programmed Calculator. The aircraft industry influenced computing by being willing, if not anxious, IBM customers. They did not do computer R&D.

UCLA and CalTech had analog machine activities. The technique of designing a machine using Boolean algebra was invented in industry (probably Hughes). The growth of military contracts in all the large aircraft companies created a job market for the Boolean approach. Montgomery Phister perceived the need and made a proposal to UCLA's Extension Service for his course.

I came along a year or so later and noticed there was no broad coverage course, so I made a proposal to the Extension Division. My course had everything—hardware, logical design, programming, system, components—in a one semester, three-hour-per-week offering. I was paid $25 an hour—$75 per night! There were no books, so I worked up a set of lecture notes that became two books published by Wiley in 1963 (volume 1 was fundamentals and programming, and volume 2 was hardware and systems).[7] The first semester was a killer because I had to prepare lecture notes week by week.

The initial semester enrollment was about 25 students. As word spread, the class grew larger, driven by the industrial demand for computer-smart people of all ages. Generally, about half of the class would be older folks from local companies (for instance, Paul Baran, a colleague from RAND). As semesters rolled by, class size grew until I could just squeeze into the largest lecture hall of about 300. By that time, UCLA had appropriate day-faculty and courses, and my classes settled down to around 50 people. I taught the class for about 12 years.

Concurrently, IBM came along with the 701 and the aircraft companies all signed up on a rental basis. Several small companies appeared with magnetic-drum-based machines. CRC even had a machine that combined a digital-differential [nee analog] machine with a multi-register serial arithmetic machine. The two parts were programmable and could work together on a problem. IBM continued its line of 70x machines and R&D installations appeared. Computing on the West Coast had been born.

I was blessed with a stream of fortuitous opportunities that seem to have been orchestrated by some master planner.

***DW*: How did you end up at RAND for the rest of your career?**
WW: RAND was on the lookout for a new big machine to replace the fleet of IBM/CPCs that it used to supplement its punched-card installation. (RAND also had a special-purpose digital machine to produce the famous "Million Random digits" and a Reeves analog machine to do simulations.)

Three people from RAND—John Williams, George Brown, and Bill Gunning—had made a tour of the country to see what advanced machines might become available. IAS was included in their tour. After the tour, RAND decided that the most-promising new machine would be a home-built version of the IAS machine. RAND's plan was to build a copy of the IAS machine, but to make it a professionally engineered machine able to carry a three-shift scientific/engineering workload reliably, in support of the R&D studies of the staff.

Gunning visited the IAS project frequently to monitor progress and acquire things that he would need to build the RAND copy, so I had ongoing contact with him. I also had a private deal with RAND to supply them with a stream of photos documenting the IAS progress.

After Gunning broke his leg skiing, his superior George Brown realized that "his eggs were all in a basket named 'Gunning.'" If anything serious happened to Bill, or to another staff member who was a private pilot, the machine-building project probably would collapse.

At that point, RAND was worried about the survival of its project, and I, with five years of IAS experience, was 20 miles away on the east side of LA and unhappy with my NAA situation. What could be more obvious? I hopped across town and joined the RAND team. We moved to Santa Monica in May 1952. In Santa Monica my family increased to three children and we lived in two houses, the second of which has been home since 1963.

***DW*: What a fortuitous circumstance.**
WW: From the time I came under the influence of George Meyers to winning a scholarship to Penn to winning a scholarship to MIT to relocation from MIT to Hazeltine to IAS to NAA to RAND, I was blessed with a stream of fortuitous opportunities that seem to have been orchestrated by some master planner. A corollary stream is the Hazeltine experience with early forms of digital technology to many years of growth in real digital experience at RAND. Multiple times, I was at the right place at the right time with the right background. All I had to do was work hard and take advantage of opportunities as they appeared before me.

***DW*: Presumably, you started your career at RAND primarily as an engineering professional.**
WW: Yes, I started as a bench engineer on Johnniac. At first, I participated in the design and construction of parts of the machine and negotiated and monitored external contracts. Remember that I came from IAS with a full load of experience and detailed designs. At RAND, we did not have to do a lot of electronic design for the mainframe. We did do design for the drum and the printer. I would sometimes get "loaned" to USAF projects or to RAND's services component for some task—for example, to design the false floor for the machine room, oversee the air handling cooling system, and design the interface between the 701 and a precision camera display.

***DW*: Please say a bit about the Johnniac.**
WW: It was built with a repertoire of machine-level instructions that were wired in, 20-bits long, and stored two to a 40-bit word. The programmers who worked with it wrote numerous macro-instructions, most of which were single function operations (such as loaders, convert binary-decimal, read or punch a card, and trig functions). None were a complete language in the modern meaning. We were quite proud that the basic repertoire would fit on one side of 8 1/2 × 11" paper. When Cliff Shaw wrote Joss, it was a user-level complete language. Technically, it was an interpreted language. Joss never had an operating system and could never run Fortran, Cobol, and so on.

Johnniac went operational with a 4,096-word core store in 1955. Earlier, with a 256-word Selectron tube memory, it had limited use. We got an early 701, but Johnniac continued to share the corporate work load with it and, later on, with whichever IBM machine we currently had. One job was reserved for the Johnniac—the corporate payroll and checks. By 1965, the economics of running Johnniac and the cost of adding tapes to it led to its decommissioning and retirement to the LA Museum of Science and Industry and later to the Computer History Museum.

Johnniac demonstrated a lot of firsts—a machine that could run hundreds of hours without an error, early program tricks of the trade, a multiuser environment, the first rotating drum printer [126 columns], and for a short while, the largest core memory. Incidentally there were two Joss's: Joss-1 was implemented on Johnniac and used IBM electric typewriters as terminals. As I recall, it serviced 12 users, some of which were on a dial-up basis from US Air Force (USAF) installations. Joss-2 was implemented on a PDP-6 and serviced 32 terminals with automatic line selection. It used IBM Selectric typewriters with a few ancillary buttons.

***DW*: Did von Neumann ever visit Johnniac?**

WW: Von Neumann was a RAND consultant and visited frequently. He demurred at our naming the machine after him, but John D. Williams [Math department head] squelched his objection when he said, "There are hundreds of things in the world named after you, and you can't do anything about it. Accept the honor."

***DW*: When did you begin to move into management?**

WW: As RAND and the Computer Sciences Department grew, it was appropriate to separate the computing services/programming part from the engineering part. I was put in charge of the latter, which made me one of the two associate heads reporting to Paul Armer as head.

Then one day Paul decided he had enough of his management chores, and the two of us switched jobs. All department heads reported to the President Frank Collbohm and VP Richard Goldstine. So I got involved with things at the corporate level as well as department level. Frank had a wonderful attitude toward things in the department. He would say, "If what you are going to do is in the best interests of the Air Force, go do it."

***DW*: You have said elsewhere that you spent one-third of your time at RAND on management, one-third on outside activities, and one-third as an engineering professional.**

WW: That statement is only true after I became department head. I had obligations, self-imposed or outside, in each of the three areas and none of them was a full-time task. So I adopted the three-way division as a convenient arrangement. As Johnniac moved to completion, I had time for professional societies and other panels and committees. I had time for the final third when I moved upward with management obligations. Later some of my engineering third went to getting the System Development Division and later the System Development Corporation (SDC) up and running.

I had a great deal of freedom to manage my work tasking. A lot of the external activities I just did. For the few times that the external thing was an extraordinarily heavy load [such as the Privacy Commission], I would square it away with the front office. A great deal of my outside third was the Air Force Scientific Advisory Board (SAB) and the National Security Agency SAB.

***DW*: How did RAND's and your involvement change as computers and computing became increasingly important to the Air Force?**

WW: RAND had a unique relation with the USAF. As individuals and as an organization, we were the "outside-insider." We worked closely with USAF elements and individuals, generally on a first-name basis. There never was a collection of USAF computer projects. We developed software and gave it to the world and the USAF. As individuals, we served on boards and committees, and we helped the USAF get some of their systems installed and improve their software. We advised on how to effectively and efficiently manage computer technology, meaning systems and their development, people and career paths for them, R&D—the whole computer "schemer. We were informal advisors and consultants.

In one instance, we had learned that SAC [Omaha] was planning a new command and control system, so we visited SAC headquarters. The officer in charge of the project complained that he couldn't communicate with the contract team. It was as though each spoke a different language from a different culture—which in fact was true. We negotiated an arrangement to "entertain" the SAC brass in Santa Monica for a three-day course on "what's a computer all about." It was so successful that the RAND group arranged to repeat the show in Washington for general officers. I don't recall the total number of times we did this, but gradually the short-course was transitioned to USN oversight, and it ultimately became the Department of Defense Computer Institute.

***DW*: What were some of your other "outside" activities?**

WW: In 1985, I was fortunate to be elected to the National Academy of Engineering, and I chaired or was a member of some 30 or so boards or committees under the aegis of the NAE's National Research Council. Many of them were in the interest of the USAF, including the Air Force Studies Board. Between RAND and the NRC, I got to visit many USAF and DoD installations and interact with a variety of military people. Many summers I participated in a summer study held at Woods Hole on Cape Cod.

ARPA asked RAND to have me chair a study to address (what we now call) computer security. The study was briefed to the Defense Science Board and laid the foundation for subsequent USAF and ARPA studies and research projects.[8]

Consequently, I was asked by the Secretary of Commerce to chair a committee to address "personal privacy"—personal information stored in a computer-based system. The work of that Secretary's Special Advisory Committee on Automated Personal Data Systems and its policy recommendations[9] funneled into the Privacy Act of 1974, which created the seven-member Privacy Protection Study Commission to which I was appointed by President Ford (and served as vice chairman). We had a fairly large staff and legal counsel, and we held meetings and public hearings.

We functioned for two years and three months and produced a final report and five individually bound appendices.[10] Thus, I can legitimately claim to have been the driving force for two of the most important policy issues relevant to (what we now call) information systems: information security and personal privacy.

***DW*: You had a great deal of involvement in American Federation of Information Processing Societies (AFIPS) and other professional activities. Can speak to that a bit?**

WW: When the computer field was just emerging, there were three professional societies that claimed ownership. The Institute of Radio Engineers (IRE) and American Institute of Electrical Engineers (AIEE) each had a subgroup to stake out its claim—largely, the hardware aspects. The ACM had no competition for its claim to represent programmers and related skills.

An annual national convention had gotten started, and by agreement, the three societies formed a standing committee of 12 (the National Joint Computer Committee, NJCC) whose only function was to organize and run the conferences. At first they were named the EJCC and WJCC; later, they were SJCC and FJCC computer conferences.[11] Isaac Auerbach had spawned the International Federation of Information Processing (IFIP) and it led to pressure for the US to join. There was also pressure from other societies to become a part of the conferences. All this culminated in recasting the NJCC to become the AFIPS, which would take over the biannual conferences and become the US connection to IFIP.

I had progressed through the IRE side. In successive years, I went through the offices of the IRE Professional Group on Electronic Computers at the West Coast level and then nationally. Thus, I had been one of the four IRE members of NJCC, and with its dissolution, I was elected AFIPS' first president. (In the background, the IRE and AIEE had merged to become IEEE.) After two terms, my tours of duty with the field's professional societies were done.

AFIPS accepted several other societies as members. Eventually intersociety politics and squabbles caused a lot of dissension. The ACM and the IEEE Computer Society each had grown large and wished to have their own national meetings. The need for a multi-society had vanished and so AFIPS was dismantled. It was a passing segment in the evolution of the IT field.

***DW*: Paul Baran, who died recently, worked in Keith Uncapher's group in the RAND department of which you were deputy directory as he did some of the earliest work relating to what we now call packet switching. To what extent were you aware of Baran's work?**

WW: I was fully aware of the work Baran was doing. I'd occasionally sit in when he was entertaining a high mucky muck from AT&T or someone from the communications industry. I'd also drop into his office to chat with him and ask if he needed anything. I did not envision packet digital communication taking over the world, but I think Paul did, as possibly did Keith. Certainly, all three of us were closely coupled to the USAF requirement for a survivable communications system.

DW: You prominently acknowledge Baran in you memoir.[12]

WW: Paul's entrepreneurial successes enabled him to generously support other organizations and people. Over the years, he had generously supported the RAND Alumni Association. When there was some question about whether RAND would support the publication of my history manuscript, he arranged to contribute funds for that purpose without my knowledge. Paul had a soft spot in his heart for RAND; he believed its organizational structure and its people quality were what the country needed to deal with its intractable problems.

DW: Thank you very much, Willis, for participating in this interview. You are one of the wisest and most genial people I have met in my decades in the world of computing.

References and Notes

1. This interview was conducted by email between 2 April and 1 June 2010 and then edited down to this published version.
2. Willis has previously sat for two scholarly interviews and has written a memoir: N. Stern, "An Interview with Willis H. Ware," Charles Babbage Inst., Univ. of Minnesota, CBU accession number OH37, 19 Jan. 1981; http://special.lib.umn.edu/cbi/oh/display.phtml?sub=964; J.R. Yost, "An Interview with Willis Ware," CBI, Univ. of Minnesota, CBU accession number OH356, 11 Aug. 2003; W.H. Ware, *RAND and the Information Evolution: A History in Essays and Vignettes,* RAND, 2008, www.rand.org/pubs/corporate_pubs/CP537.html.
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7. W.H. Ware, *Digital Computer Technology and Design,* vols. I and II, John Wiley & Sons, 1963.
8. *Security Controls for Computer Systems,* tech. report R-609-PR, RAND, Defense Science Board Task Force on Computer Security, 1972. R-609-1-PR was reissued Oct. 1979. This widely circulated report was informally known as "the Ware report."
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10. Privacy Protection Study Commission, *Personal Privacy in an Information Society,* tech. report, 1977.
11. EJCC, WJCC, SJCC, and FJCC stand for East, West, Spring, and Fall Joint Computer Conferences.
12. Ware, *RAND and the Information Evolution.*