RAMAC in Historical Perspective
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Thank you Mr. Chairman, and good evening ladies and gentlemen.

The generous introduction by the Chairman suggests that I have achieved much and possess great talent and vision. Let me immediately disabuse you of that perception.

In my role as Director of Technical Planning for the IBM Research Division in the late 1960s, I wrote a memo asserting that magnetic recording was a “mature technology.” In the memo, I advised researchers, who were interested in advancing information storage technology, to concentrate on solid-state devices having no moving parts.

Dramatic advances in rotating magnetic disk storage systems, during the subsequent decades, suggest that my vision was not entirely perfect. In more recent years, I have wisely concentrated on history – a field in which one attempts to understand the past rather than the future.

In this context, I urge you to trust me as I now assert that the two most important technologies to be invented and developed during the second half of the 20th Century are magnetic disk storage and integrated circuits. Both of these technologies had a truly remarkable quality: namely, the capability for long-term exponential improvements in their cost/performance ratios. Because of this quality, these two technologies have driven advances in science, engineering, and technology. Together, they have defined the shape and scope of the Information Age.

The history of the development of integrated circuits has been widely reported. Much less has been written about the development of magnetic disk storage. Today, I will tell you about that development and about the competitive and innovative environment in which it was achieved. The development began with a multi-year search for machine-readable memories more versatile and faster than punched cards.

So what were these punched cards? How were they used? And what was going on in IBM that caused the RAMAC Project to be started in San Jose?

Punched Card Equipment

Automatic tabulating equipment developed by Herman Hollerith in the late 1800s used stiff paper cards with holes punched in them to represent attributes that could be read by machine, tabulated, and sorted by class. Punched cards thus became the first machine-readable memories for computational purposes. The use of Hollerith’s equipment to tabulate the United States Census of 1890 made Hollerith and his punched cards famous. By 1924 Hollerith’s company had been transformed into IBM by Thomas J. Watson, Sr., who had been hired to manage the company in 1914.

In 1939, as World War II loomed ever closer, the United States government asked IBM (and many other companies) to prepare to manufacture war materiel. In response, IBM expanded many of its manufacturing facilities and purchased a site for a new plant in Poughkeepsie, New York. By 1943, IBM's manufacturing employees had increased from 5,000 to over 12,000 and two-thirds of its manufacturing output consisted of ordnance items.

Munitions produced by IBM were important to the war effort, but the company's punched-card equipment was even more important. It was used in converting the manufacturing facilities of IBM, and many other companies, from peacetime to wartime production. And it was used to handle the logistics of supplying vast military operations, to maintain personnel records for the armed forces, to predict weather conditions over the British Channel, to break enemy codes, to calculate the trajectories of artillery shells, to analyze airframe designs, and to support the development of the atomic bomb.

The German High Command was so concerned about the advantages IBM punched card equipment gave the U.S. Army, that it issued an order to capture an IBM mobile records unit with all of its machines, records, and personnel. But neither the equipment nor its operators were ever captured.

Post-World War II Efforts

The early post-World War II years were hectic times for IBM. Jobs had to be found for employees returning from the armed services as well as for thousands of employees who had been hired for military production. Watson, Sr., was adamant about doing this. Part of his solution was to begin the manufacture of electric typewriters in the Poughkeepsie plant, which had been built to produce machine guns and other munitions.

Maintaining IBM's leadership in punched card equipment was essential. This would require that equipment, little changed during the war, be upgraded as rapidly as possible. The use of electronic circuits for such upgrades had been identified as a high priority by Watson, Sr., during an engineering planning meeting in October 1943 when the war appeared to be coming to an end sooner than it actually did.

A personal priority for Watson, Sr., was to get his two sons into leadership positions in IBM. When his older son, Watson, Jr., returned from the air force and rejoined IBM in January 1946, his father arranged for him to meet with Eckert and Mauchley at the Moore School of the University of Pennsylvania. There he saw the room-sized electronic calculating machine they had built. Known as ENIAC, this Electronic Numerical Integrator and Computer contained 18,000 vacuum tubes. Burned-out tubes were replaced almost daily. Watson, Jr., was sure this machine had no commercial value.

A few weeks later, his father showed him the company's top-secret electronic project. It was a fully operational product prototype with electronic arithmetic circuits, based on ones designed and tested in the IBM Endicott Laboratory in 1941 and '42. The young

Watson was impressed. He urged that this machine be announced and marketed as "the world's first commercial electronic calculator" – even if only a few could be sold.

Tom Watson also accepted his father's offer that he be responsible for the company's entry into electronics. Enticing his son into accepting this assignment was one of the most important sales the master salesman ever made.

The product prototype was announced later that year as the IBM 603 Electronic Multiplier. It contained approximately 300 vacuum tubes. Two years later, it was replaced by the faster and more versatile IBM 604 Electronic Calculating Punch with over 1,400 vacuum tubes. The IBM 604 provided computational capability unmatched by any other product of its time.

Beginning in 1949, the IBM 604 was also offered in combination with other equipment to create what was unofficially known as the "poor man's ENIAC." Officially, it was called the Card Programmed Electronic Calculator, or simply CPC. By the mid-1950s, over 5,000 IBM 604s and 70 CPC's were in use by customers.

Competition

IBM's market leadership in electronic computation and data processing was jolted in 1951 when the U.S. Census Bureau accepted the first UNIVAC. It was designed by Eckert and Mauchly, who had previously designed the ENIAC. UNIVAC was the first commercial, von Neumann-type, stored-program computer to be placed into production. It was far more powerful than the IBM 604 or CPC.

Its arithmetic and logic functions were implemented with electronic vacuum-tube circuits. The high-speed main memory was implemented with an acoustic mercury delay-line. And magnetic tape was used to store information that that might otherwise have been stored on punched cards.

The possibility that IBM's punched-card equipment could be replaced by electronic computers, equipped with magnetic-tape storage devices, was a sobering thought. Watson, Jr., was particularly concerned.

His concern was heightened by the fact that IBM's primary competitor in punched card equipment, Remington Rand, had purchased the Eckert-Mauchly Computer Corporation in 1950 and Engineering Research Associates (ERA) in 1951. These two startup companies were technologically strong. ERA, for example, had been established to work on secret military engineering projects, and it had become the leader in developing magnetic drum storage devices.

The young Watson became more fearful than ever that he might fail in the job his father had given him. He made use of any evidence that the company was lagging in the marketplace to demand greater efforts from his engineers.

Developments leading to the introduction of IBM's von Neumann-type, stored-program computers were now given even greater emphasis. Among the new technologies being developed were cathode-ray-tube memories, rotating magnetic drum memories, and high-performance magnetic tape storage units.

Watson, Jr., had already argued forcefully and successfully to convince his father to authorize a four-fold increase in the number of employees in research and development from fewer than 1,000 in 1950 to more than 4,000 five years later. Still the company's research and development capabilities were strained to the limit. And a serious recruiting problem had been revealed. There was a shortage of qualified engineers, especially in electronics. Many engineers, especially those on the West Coast, were reluctant to relocate to Poughkeepsie or Endicott, New York.

Establishing the San Jose Laboratory

Out of these concerns a plan evolved to establish a new laboratory in San Jose, California. There the company had operated a card-manufacturing plant since the early 1940s. Reynold B. Johnson was chosen to establish and manage the laboratory.

Johnson had been hired by Watson, Sr., in 1934 to develop the first automatic test scoring machine. This machine introduced the concept of electrically sensing pencil marks made on paper. It was announced in 1937 as the IBM International Test Scoring machine, and was the forerunner of many other products. Following this success, Johnson demonstrated his innovative and leadership capabilities many times.

Named manager of the IBM San Jose Laboratory in January 1952, Johnson soon signed a five-year lease for a small building at 99 Notre Dame Avenue. Advertisements for scientists and engineers yielded so many top-quality responses that Johnson concluded he needed someone with strong electronics background to help in assessing applicants.

To fill this role, he chose Louis D. Stevens, who had worked three years in the IBM Poughkeepsie Laboratory on a variety of projects. These included magnetic tape and drum storage devices and input-output systems for large computers. Stevens accepted the position of Johnson's technical assistant and began reviewing job applications. The number of employees in the new San Jose Laboratory was increased to 30 by early summer and to 60 by the end of the year.

Having worked directly for Watson, Sr., for many years, Johnson was familiar with his methods. The older Watson personally hired and managed the company's senior technical people, who were known as inventors. He told the inventors what product improvements were needed and then assigned one or more of them the task of inventing the desired improvements.

Plans for future products were secret, and so were the assignments given to inventors. Because more than one inventor might be assigned the same task, inventors seldom discussed their work with each other. And their subordinates were admonished to be equally secretive.

Johnson also knew that Ralph L. Palmer had established a much more open environment in the IBM Poughkeepsie Laboratory. In 1950, Palmer had been given responsibility for all developments in transistors and other solid-state devices. He believed the only way for IBM engineers to get ahead of the fast moving external competition was to share information and ideas with each other.

In the San Jose Laboratory, Johnson chose to take this concept one step further. He told the engineers that they should be familiar with every project in the Laboratory. Then he said the number one priority of each engineer was to help other engineers in the laboratory. The second priority was to work on one's own assignment. This policy has been given credit by many engineers for the laboratory's rapid technical progress.

A primary task for many weeks was to identify good research projects. Many projects were identified. Some were dropped, and some were carried forward. But it took only one project to make the entire activity worthwhile. That project produced the world's first magnetic disk storage product and provided the primary mission of the San Jose Laboratory for many years.

Initiating the RAMAC Project

The project that created RAMAC was formally begun in September 1952 under Arthur J. Critchlow. His initial assignment was to study the manner in which information was organized, formatted, stored, and processed using punched-card equipment – and then to seek a better solution. He learned that punched card equipment performed customer tasks best when processing could be done in batches on sequentially sorted information. Serious problems arose when more nearly random access was needed.

Inventory control was a particularly important application of the more nearly random type. Typically, each order required that several cards be located manually, removed from the stack of cards, and replaced by updated cards. To facilitate this clerical activity, drawers of cards were set out on work tables so that several persons could access cards from the same file. This arrangement was called a "tub file." Replacing this inelegant, tedious, and error-prone process soon became the project's objective.

One of Critchow's first proposals was a conveyer belt that would bring punched cards to the clerks instead of having clerks walk around looking for punched cards. Numerous types of storage devices were also considered. These included magnetic tapes, tape loops, strips, drums, and disks.

Magnetic tape was unacceptable for random access applications because of the long time required to reel the tape from one location to another. Magnetic drums provided rapid access to stored information, but because information was stored only on the outside surface of a rotating cylinder, volumetric efficiency was low and costs would be high. Among these and less well known structures, theoretical analyses generally predicted that magnetic disks would be superior because of anticipated good access times and volumetric efficiency.

In April 1953, Johnson attended an IBM sales convention in Los Angeles. There he met with key sales representatives and corporate executives who convinced him of the urgent need for new products. A motivating factor was a request for bid sent to thirty companies by the U.S. Air Force. It was seeking a device to handle inventory accounting and control at all airbases. Transactions had to be processed as they arrived. IBM product planners asserted that this type of requirement was not unique to the Air Force. A highly respected IBM product planner further asserted that even simple accounting tasks would benefit from handling each business transaction as it occurred.

Johnson made his decision. Upon returning to San Jose, he announced that the planning phase was over. The Laboratory was committed to developing a storage device with rotating disks and movable heads.

With the benefit of hindsight, it is not surprising that magnetic disk storage was the solution. The design of the IBM 350 Disk Storage Unit used on RAMAC seems quite obvious. What could be more simple or obvious than spinning a number of disks continuously on a vertical spindle, with a read-write head that could be moved up or down parallel to the spindle and then thrust between selected disks to read or write the desired information?

This design is obvious today, but it was not obvious then. Consider, for example, a magnetic disk storage device devised almost two years earlier by Jacob Rabinow, a researcher at the National Bureau of Standards. Known as the "notched-disk memory," it stored digital information on magnetically coated disks with pie-shaped notches cut out of them.

The disks were mounted on an axel that had been bent around into the shape of a ring. The notches in the disks were normally aligned toward the center of the ring. A read-write head, mounted on an arm that pivoted about an axis at the center of the ring, could be rotated through the notches of the disks to any desired disk. Information was then written on, or read from, the selected disk by rotating the disk one full turn. Disks not selected for the read-write operation remained stationary.

This seems really weird, doesn't it? Nevertheless, it represented the best idea of a serious inventor. And Rabinow deserves credit. For his design helped stimulate IBM engineers to create a better design.

Developing RAMAC

The better design had a 20-inch high, vertical spindle on which were mounted 50 continuously rotating aluminum disks, each 24 inches in diameter and coated with a magnetic paint. A spacing of 3 tenths of an inch between disks was sufficient to allow a magnetic read-write head to be positioned to any one of the 100 tracks on both sides of each disk. Each track could hold 500 alphanumeric characters, so the storage capacity of the entire unit was 5 million characters. The maximum time required to position a read-write head on the desired track and sector of the desired disk was 8 tenths of a seconds.

Many technical problems were identified and overcome before this design was achieved. Magnetic recording surfaces and compatible read-write heads were designed, sprayed-on magnetic-oxide coatings were replaced with smoother spun-on coatings; mechanisms for raising and lowering the read-write heads to the desired disk and then thrusting the heads into the desired track were built; and electronic circuits capable of driving the read-write heads and sensing the output signals were created.

The most serious problem was maintaining the desired spacing between the read-write head and a rotating disk. Ultimately, an air-bearing using forced air was selected. Remarkably, a head-to-disk spacing of one thousandth of an inch could be maintained even though the rotating disk itself might wobble as much as 60 times that amount.

Among the many systems design problems, the problem of record addressing was particularly challenging. It consisted of finding a way to place records on disks automatically in a space-efficient manner, combined with an addressing scheme that would permit them to be found, quickly and automatically. Fortunately for the San Jose engineers, one of Watson, Sr.'s prolific inventors, Hans Peter Luhn, had already devised a solution, which came to be known as "randomizing and chaining."

In November 1953, Reynolds promoted Stevens to manager of the RAMAC project. Engineering leadership under Stevens continued to be provided by William A. Goddard and John W. Haanstra, while Albert S. Hoagland continued to provide expertise in magnetic recording. The first successful reading and writing of information on rotating magnetic disks was demonstrated three months later. The first of five engineering prototypes was fully operable in January 1955.

Because of the growing, company-wide recognition of the significance of the RAMAC project, Johnson was authorized to build 14 prototype systems for use inside IBM, and by selected customers. The purpose was to obtain early information on customer usage and product reliability. The first delivery to a customer occurred in June 1956.

Announcement, Competition, and Product Delivery

In September 1956, Watson, Jr., formally announced the IBM 305 RAMAC system. It consisted of a 305 processing unit, a 350 disk storage unit, a card punch, a printer, a console, and a power supply. The monthly rental was $3,200, of which $650 was for the disk storage unit. The name, RAMAC, had been chosen as an acronym for Random Access Method of Accounting and Control, which conveyed the idea that all related accounting ledgers could be updated every time a transaction card was read.

For Watson, Jr., 1956 was a momentous year. In addition to announcing the world's first computer with magnetic disk storage, he had settled the antitrust suit begun in 1952 by the U.S. Justice Department; the first computer in the massive SAGE air-defense system was installed; the world's first all solid-state computing machine (the IBM 608) was being readied for production; in May, he had replaced his father as IBM's chief executive officer; and one month later, the older Watson (who had managed IBM for 42 years) died of a heart attack.

The most significant competition to RAMAC was provided by IBM's arch rival Remington Rand. Its Univac File Computer was equipped with up to ten magnetic drums of the type pioneered by its ERA subsidiary. Because drum storage used one read-write head per track, the Univac File Computer offered substantially better performance than RAMAC, but at a higher price. Announced almost two years before RAMAC, this competitive offering put great pressure on the engineers in San Jose. Tom Watson had cited this announcement as further proof that IBM was behind in the marketplace.

However, the volumetric storage efficiency of drums was inferior to disks. Even when equipped with its maximum of ten drums, the Univac File computer offered only one-third the storage capacity of RAMAC. The cost-performance superiority of disks over drums would become increasingly evident during the ensuing years. Drum storage would become obsolete in little over a decade.

Remington Rand's use of its well-proven drum technology in the File Computer may have been a good, short-term business decision. But its failure to make a major early investment in magnetic disk technology was perhaps its most serious technological mistake in its many-year competition with IBM.

Delivery of production models of RAMAC began in June 1957. One year later, the system was enhanced to permit attachment of two storage units rather than just one. Over one thousand IBM 305s were built before production ended in 1961.

Post-RAMAC Activities

After putting Stevens in charge of the entire RAMAC Project back in 1953, Reynold Johnson devoted more of his time to what he liked best – working on new ideas. In fact, during all the time RAMAC was being developed, Johnson maintained advanced technology activities in a variety of areas. Most important was the work on aerodynamic sliders, which flew read-write heads at a fixed height above a rotating disk without using forced air.

Late in 1957, this activity was placed under Stevens, with Alan F. Shugart as engineering manager. Shugart's task was to expedite development of a slider-based, Advanced Disk File (ADF) for use on large computers. Intended users for the ADF included the SABRE reservation system being developed for American Airlines and the Stretch supercomputer, scheduled for delivery to the Los Alamos Scientific Laboratory.

To achieve an early product delivery schedule, many promising – but unproven – concepts were dropped. These included voice-coil actuators (which were successfully introduced in the mid-1060s with track-following servo systems) and perpendicular magnetic recording (which has yet to fulfill its promise of providing higher density than conventional longitudinal magnetic recording).

In June 1961 the company's first disk-storage product with slider technology was announced as the IBM 1301 Disk Storage. The 1301 could be ordered with one 25-disk module or with two modules, one mounted above the other on the rotating vertical spindle. Each module was served by a comb-like access mechanism that moved 24 arms in concert. Each arm had two recording heads, one to serve the surface above the arm and one the surface below. Once the comb had been positioned, the active head was selected by electronic switching.

With one head for each disk surface, the performance of the unit was substantially better than RAMAC and similar to that of the Univac File Computer – but at a much lower cost. It was the first clear evidence in the market that magnetic drums would not long survive the onslaught of magnetic disk storage devices.

Of considerable significance historically is that the IBM 1301 achieved a bit storage density of 26,000 bits per square inch. This was 13 times greater density than on RAMAC. Two years later, a follow-on product (the IBM 1302 Disk Storage) provided an additional four-fold increase in storage density.

Also of significance is the 1962 announcement of the IBM 1311 Disk Storage Drive, which featured the first removable disk packs. Each removable pack contained six 14-inch diameter disks and weighed only 10 pounds. Its storage capacity was 2 million characters, or approximately that of 25,000 IBM punched cards.

Work toward this product had been initiated in 1958 by Jack Harker, who had previously led research work on aerodynamic sliders. The low cost and convenience of removable disk packs accelerated the transition from punched-card systems to computer systems.

Conclusion

Thus it is that only six years after RAMAC was announced, the San Jose development team had created significantly improved disk storage products that began the exponential rate of improvement that has characterized disk storage for 50 years.

Disk storage devices today have dramatically better access times, data rates, and storage densities than RAMAC. In particular, storage densities available in products are up to 80 billion bits per square inch. This is 40 million times the storage density in RAMAC.

Not only are unimaginably vast amounts of information storage now available in large computers and internet servers, but many tiny hand-held devices now contain one-inch diameter rotating disks with almost 1,000 times the storage capacity of the original RAMAC.

Advances in integrated circuits have been equally remarkable. For example, in the forty years since the first computer with integrated-circuit memory chips was announced in 1966, the bits per chip have increased from 16 on a 55 mil chip to as much as 1 billion on a 520 mil chip. This is a 0.7 million-fold increase in bits per square inch or a 62 million-fold increase in bits per chip.

The number of bits per square inch has doubled once every two years on average for both of these technologies. The rapid improvement of these two technologies has not just upgraded existing devices and applications – rather, it has significantly altered the way we do business, obtain information, have fun, and interact with each other.

Because of the exponential rate of improvement in both of these technologies, my lap-top computer is approximately one thousand times more powerful and one thousand times less expensive than the IBM System/360 computers announced in 1964. Every time you and I log onto the Internet and search for information or make a purchase, we are using information storage and processing capabilities that were beyond realistic prediction less than two decades ago. There can be no doubt that magnetic disk storage and integrated circuits have defined, and redefined, the shape and scope of the Information Age.

I am pleased to be here to commemorate the creation of one of the two greatest technologies to be invented and developed during the second half of the 20th Century. And I am honored to share this event with some of the people who made it happen.

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