2	University of California, Los Alamos, NM	March 23, 1953
3	Lockheed Aircraft Company, Glendale, CA	April 24, 1953
5	Douglas Aircraft Company, Santa Monica, CA	May 20, 1953
8	U. S. Navy, Inyokern, CA (China Lake)	August 27, 1953
10	North American Aviation, Santa Monica, CA	October 9, 1953
11	Rand Corporation, Santa Monica, CA	October 30, 1953
13	University of California, Los Alamos, NM	December 19 ,1953
14	Douglas Aircraft Company, El Segundo, CA	January 8, 1954
16	University of California, Livermore, CA	April 9, 1954
18	Lockheed Aircraft Company, Glendale, CA	June 30, 1954

In other words, including Lawrence Radiation Lab's acquisitions for Los Alamos, over half the total production went to California purchasers. (Of those, half went to aircraft companies, fulfilling Konrad Zuse's prediction that digital computing would become a necessity for aircraft design.)

It's an impressive list, especially since leasing a 701 was a major commitment for even the largest institution. Anyone who wants to construct the timeline of California's love affair with computing can anchor the origin right here. -- Editors]

ORIGINS AND LEGACY OF THE IBM 701

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THE HISTORICAL SETTING

In January, 1951, Thomas J Watson jr., Executive Vice President of IBM, convened a meeting in his office to discuss a proposal by his assistant, J. W. Birkenstock, for a new computing machine using CRT memory with about 20,000 digits of memory per tube, and with a clock cycle allowing it to multiply two numbers in one millisecond. The proposal suggested that up to 30 machines might be made, beginning with a single prototype, the Defense Calculator, under government contract and nominally a response to computing demands posed by the war in Korea.

At this time there were about twenty electronic stored-program digital computer projects in the world, all but three using binary number representations. Most were patterned after Von Neumann's machine at the Princeton Institute for Advanced Study, with 40 bits per word. The Defense Calculator was planned with a slightly shorter word, 36 bits, and far better input/output facilities than the IAS machine. The difference in word length was corollary to the selection of a 6-bit byte when recording data on magnetic tape, a new storage medium IBM was currently developing.

The Defense Calculator was designed fairly quickly, based on the experience with the IAS machine and with early experimental systems at IBM. Newly developed component packaging methods resulted in a machine remarkably compact for its time. The logic was packaged in 64-pin modules with a row of 8 vacuum tubes on the front of each module; logical operations were performed by germanium diodes in the base of each module. Modules were plugged into a backplane, and the design permitted modules to be swapped while the system was powered up. The resulting CPU occupied a cabinet about the same size as was used 25 years later for the VAX 11/780; a second similar-sized cabinet held 72 cathode ray tubes storing 512 memory bits per tube, for total memory of 1K words.

By April 1952 the prototype Defense Calculator was fully assembled; within two months, the complete system was in use and undergoing debugging. The first production model was shipped in December 1952, to IBM's corporate headquarters at 590 Madison Avenue in New York, and became an instant favorite with sidewalk gawkers. The second machine was delivered to Los Alamos on April 1, 1953, and was working at the site within three days. (In the context of this amazing feat it is worth noting that Los Alamos was operated by the University of California, and that relations between the university and the laboratory were far closer then than in later years.)

Thomas J. Watson sr., preoccupied with his company's almost sacred commitment to electromechanical punched-card technology, still had doubts about the new machine; but they were probably alleviated by the monthly rental of a fully equipped 701, which, at US$17,600, was about ten times the price of a typical family car. His son, on the other hand, noted that customers continued to honor their contracts even while the announced rental fee more than doubled from its original US$8,000. "That was when I felt a real _Eureka!_," he noted decades later in his autobiography. "Clearly we'd tapped a new and powerful source of demand."

On April 7, 1953, the Defense Calculator was publicly unveiled at an event attended by over 150 guests, including John von Neumann, William Shockley, J. Robert Oppenheimer, and a roster of highly placed scientists and executives. At this event, the machine was newly described as the "IBM Electronic Data Processing Machines, known as the 701." A doctored photograph of the prototype Defense Calculator was used in a two page advertisement in National Geographic in 1953, referring to it simply as "The New IBM Electronic Data Processing Machines."

In early 1953, the 701 memory units were upgraded from 512 bits to 1024 bits per CRT, [was this the first implementation of double-density? -- Ed.] and a reference manual was produced.

The entire planned series of eighteen IBM 701's was produced and shipped in only nineteen months -- from December 1952 to June 1954 -- proving that assembly and testing of massive, complex DP machinery held few terrors for this uniquely experienced company. IBM's first venture into commercial electronics at this scale was accomplished with the thoroughness that had become their best-known trademark. After the eighteenth 701 was shipped to Lockheed Aircraft in Burbank, CA, enough spare parts remained on hand to assemble a nineteenth machine, which was delivered to the U. S. Weather Bureau on the last day of February, 1955.

THE IBM 701 INSTRUCTION SET

The IBM 701 had a 36 bit word packed with two 18 bit instructions. Each instruction had a 6 bit opcode, leaving 12 bits for the memory address. Memory was addressed to the half-word, so the architecture allowed up to 2K words, the entire capacity of the upgraded CRT memory subsystem developed in 1953.

The sign bit of each instruction determined whether the instruction was being used to address words or half-words. Negative instructions were word addressed, while positive instructions were half-word addressed. Half words were packed into words in big-endian order, with odd addresses being used to reference the least significant halves.

Numbers were stored in signed magnitude form, and all of the documentation assumed that the values being stored were signed magnitude fractions, with the point immediately to the right of the sign bit and left of all of the magnitude bits.

The machine had an accumulator and a multiplier-quotient register, and new complexity was introduced by two extra magnitude bits at the most significant end of the accumulator. These extra bits allowed sequences such as "load, add, add, add" to be performed before a check for overflow was needed, and allowed such sequences to arrive at correct results even when intermediate values were out of bounds.

The instruction set included 21 programming instructions and 8 input/output instructions. The programming instructions included the expected load, store, add to accumulator, and subtract from accumulator instructions, but also load negated and add or subtract absolute value. As expected, the machine had multiply and divide instructions, but it also had round and multiply and round instructions that incremented the accumulator if the most significant bit of the multiplier-quotient register was one. Finally, there were left and right arithmetic shifts in single and double precision form and a logical and instruction that operated from accumulator to memory.

Control structures were constructed by branch and conditional-branch instructions, but programmers who wanted to code using procedures were forced to write self-modifying code. Conditional branches could branch on zero, branch on positive, or branch on overflow. A special instruction was included to write the address field of a half-word in memory, allowing straightforward self-modification, and there was a halt instruction.

The input/output instructions included instructions for starting unit record read or write operations, for copying one data word to or from a unit record, and for sensing or setting device status or control bits. Special instructions were included to handle backwards reads from tape, to write end-of-file marks on tape, to rewind tape units, and to set the drum address of the next drum transfer, but the central I/O instructions were, to a remarkable extent, equally applicable to all devices.

As noted previously, the sign bit of each instruction was used to determine whether the memory address was a half-word or full-word address, and with a 6 bit opcode field, this would seem to leave room for only 32 instructions. In fact, the 5 control-flow instructions were always used to address half-words, and the 4 shift instructions and I/O instructions did not use the sign bit. As a result, there was plenty of space in the instruction set to extend the machine as later models were introduced.

INPUT/OUTPUT DEVICES

The 701 was developed soon after IBM had constructed an experimental Tape Processing Machine, and the success of that experiment encouraged extensive support for 7-track magnetic tape on the 701. The decision to support 7-track tape, with 6 data tracks and one parity track, led to the selection of a multiple of 6 for the word-length; this tape format, originating with the 701, quickly became an industry standard that was almost universal for the next 15 years.

The 701's tape drives could be supplemented with a fixed-head drum that allowed random access to individual words. Each drum unit had a capacity of 2048 words, and was clearly thought of as swap-space and not as a device for storing files. Other peripherals offered on the IBM 701 were modifications of standard IBM unit-record data processing machines, a card reader, a card punch, and a line printer. These were all "programmable" peripherals, with patch-panels controlling operations on the data encountered. All three devices were limited to 72 characters per line of data printed, punched, or read, with the patch panel controlling the mapping between the

72 columns seen by the computer and the presentation of that data on punch card or listing.

Input/output was complicated particularly by the utterly bizarre data formats of cards and print records. For example, cards were read row by row, so that two 36 bit words of input contained one row of data from the punched card, while the character code used on the card used each column to hold one 12 bit character. This comes very close to the philosophy espoused in Jackson W. Granholm's "How to Design a Kludge" (Datamation, Feb. 1962, page 30), and many programmers were forced to spend hours writing code to translate between character data formats.

Another problem with input-output was that all data transfers were done under program control, which -- assuming moderately high performance of tapes and drums -- placed stringent timing constraints on I/O code. On later systems, the life of programmers was greatly simplified by the introduction of direct memory access I/O devices.

THE DESCENDANTS OF THE 701

The IBM 701 and 702, introduced within weeks of each other, defined two parallel lines of development for electronic computing, with the 701 intended for scientific and military customers, while the 702 was aimed at the business market. (The 702 was a decimal digit serial computer descended from the experimental Tape Processing Machine; it was developed in parallel with the 701, using similar technology, but it was not related to the 701 at the instruction set level.) Watson jr. understood that the 701 was, to use today's term, a "power user's machine," and provided energetic support for the quick development of a more capable successor.

At the end of 1953, while the earliest 701s were still being delivered, Gene Amdahl -- later well known as the co-designer of the IBM System/360 and the founder of Amdahl Corporation -- was put in charge of developing a follow-on to the 701. On May 7, 1954, this was unveiled as the IBM Type 704 Electronic Data Processing Machine. The 704, almost three times as fast as the 701, was the first commercially available computer to incorporate floating-point arithmetic, and the first IBM computer to have index registers. The 704 systems control program (SCP), which monitored the progress of calculation and offered program control for input/output, can be considered IBM's first operating system.

Perhaps the primary innovation of the new model was ferrite core fast memory, which was announced in October 1954, even before the first 704 was delivered. The first core memory unit for the 704 was installable in sizes up to 4,096 words; within two years, 32K words of core could be installed. This technology contributed much of the 704's speed and offered greatly improved reliability. However, the expansion of 704 main memory to over 2K words posed a problem that programmers have faced with annoying frequency on later machines, that of addressing a large main memory with a small direct address field.

SHARE

In August 1955, IBM gave a seminar in Los Angeles, as a briefing for potential 704 customers. Several executives who attended that seminar met again almost immediately, on August 22, to establish a group for mutual support and pooling of information on the 704, called SHARE. The rapid growth of SHARE -- possibly the first, certainly a very early, computer users' group -- was particularly important to the success of the IBM 704. By the end of 1980, SHARE had grown to represent over 1,500 computer installations, of which the majority did scientific work.

LANGUAGES

The speed and power of the 704, its register architecture, and the SCP's ability to perform low-level grunt work, encouraged the development of larger applications which incorporated subroutine programming. Code reusability became an issue, and conformity to agreed coding guidelines became crucial to this. Even at the inaugural meeting, members of SHARE agreed on the need for a uniform assembly language format for the 704; eventually, an assembler written by Roy Nutt of United Aircraft emerged as the standard.

Higher-level languages also received attention. As early as late 1953, John Backus began to argue for the development of a compiler for the 704 specifically, and in 1956 a group under his direction completed this project, by then known as FORTRAN. Optimized for numeric calculation, this language offered unprecedented computational power and guaranteed the future of the 704 for years to come. The 72 column limit originally imposed by the 701/704 card-reader continues to puzzle FORTRAN programmers to this day.

BEYOND THE 704

IBM eventually sold 123 Model 704's, a gratifying improvement over sales of the 701 and a total that absolutely mandated aggressive development. The 704 was followed by the Model 709, the last vacuum tube machine in this series, and by the experimental transistorized machine known internally as the

709TX. Borrowing heavily from the advances of Project STRETCH while remaining fully compatible with the 709, the impressive TX was re-designated 7090 when the first example was sold to Sylvania in October 1958. The 7094 and 7094 II, announced in the early 1960s, were faster still.

WHAT WAS ACCOMPLISHED?

The 70x family accomplished more for IBM than could, probably, ever have been foreseen when the original specification was laid down. It defined a computer architecture that endured for thirteen years, and might have lasted much longer. It gave notice that IBM, long the dominant vendor in tab card equipment, intended to be as formidable a competitor in the lucrative new world of computer-driven data processing. It proved that IBM's polished sales force could sell computers as effectively as they had sold less sophisticated products -- a transition managed less well by many of IBM's competitors. Finally and conclusively, it dethroned Remington Rand as the primary American builder of computers.

The 7094 II marked the end of the line for the 701 architecture. Lack of market was not an issue; demand for these computers and for compatibles could have continued for many years. Rather, the SPREAD report of December 1961 changed the underlying direction of IBM's marketing policy for computers.

Until 1964, IBM built two parallel lines of computers for users in different categories. Construction for science, higher education and the military was exemplified by the 701, 704, 709, 7090/94, and 1620, while machines meant for business and industry included the 702, 705, 7070, and the 1401 and its successors. Naturally, potential customers didn't line up into the two long neat rows that IBM would have preferred, and many users ran "business" applications on "scientific" computers or _vice versa_.

IBM never argued with success unless it envisioned greater success. The SPREAD report warned that, although this two-pronged approach had resulted in tremendous market share for IBM, it entailed wasteful division and duplication of effort internally. The company's array of niche machines should be replaced by a line founded on a single basic architecture, with enough gradation in power, capacity, and peripheral capability to fill the needs of any prospective customer for an IBM computer. This idea, and five billion dollars, resulted in the innovative and immensely superior System/360.

Without a doubt, the 360 series justified its titanic investment -- the largest in any single American industrial project to that time -- and went on to become the "greater success" that Tom

Watson and Vin Learson had predicted. But for many computer users and historians, a 701, 704 or 709x remains the machine that quintessentially defines "big iron."

REFERENCES

Most of this material comes from _IBM's Early Computers_, Bashe, Johnson, Palmer and Pugh, MIT Press, 1986. This book gives an excellent overview of IBM's role in the early part of the computer era, and it gives moderate technical detail. Incidental reference has also been made to Cortada's _Historical Dictionary of Data Processing_, Greenwood Press, 1987, and to Tom Watson's autobiography, _Father, Son & Co._, Bantam, 1990; the quotation above is from page 243 of that edition. [The introductory table is abridged from "Customer Experiences" by Cuthbert Hurd, _Annals of the History of Computing_, Volume 5, Number 2, page 175, (c) April 1983 IEEE, and reprinted by permission. -- Ed.]

I have also used my 1953 copy of IBM's "Principles of Operation" document for the IBM 701. This agrees in most places with the technical appendix in Bashe, Johnson et al, but gives far more detail on instruction timing and I/O data formats. It begins with an introduction to programming that is remarkably timeless; the machine may be obsolete, but the fundamental material a programmer must know in order to program in machine language has not changed!

LAND OF THE SILENT GIANTS:
A Day at Livermore

On October 27, 1993, we -- Tom Ellis, Tim Swan and KC -- met at CHAC's garage and rolled up our sleeves for the drive. In El Cerrito it was a bright, warm fall morning; the heat in Livermore, thirty miles further from the coast and bordering the Valley's stony desert, might be punishing by comparison. National _and_ local security had dictated that the Lawrence Livermore National Laboratory be plunked down in a sparsely populated bowl of scrubland framed by far hills, cut by service roads as straight and black as electrical tape. It's not the moon but it could easily be, say, New Mexico or Nevada.

Very Federal white-on-blue signs direct the persevering visitor to "Computer Museum, Pod F," a small, detached frame building that the museum shares with a dosimetry lab. While the museum is part of LLNL, the _building_ it's in belongs to the Livermore School District, making the installation's status more precarious than it otherwise would be.