A Review of ORDVAC Operating Experience

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INTRODUCTION

The ORDVAC is one of three large-scale electronic computers located at the Computing Laboratory of the Ballistic Research Laboratories at Aberdeen Proving Ground, Maryland. It is the newest computer at the laboratory having been delivered in March, 1952. It operates in the binary number system in a parallel asynchronous manner, and it uses an electrostatic memory. Input to the machine is by punched teletype tape or punched IBM cards. Output from the machine is obtained on punched IBM cards, a teletype page printer, or punched teletype tape.

During the period from March 10, 1952 to October 2, 1953, the ORDVAC was available for computation a total of 8,410.18 hours. The total engineering time was 4,189.17 hours, and the remaining 1,104.65 hours was standby time. Standby time includes all the time during which no attempt is made to operate or service the machine. In one week the standby time is 168 hours minus the sum of the total engineering time and the total available time.

The distance between the upper curve and the 168-hour line thus represents standby time, and the number of hours between the curves represents engineering time. During the earlier periods there was a considerable amount of standby time. The lack of sufficiently trained personnel and the lack of programs did not make it desirable to maintain the machine over the weekends. As more programs were completed, however, and the machine load increased, it was soon learned that operating the ORDVAC without interruption reduced the number of troubles encountered on Monday morning and enabled it to be made available for use at an earlier time. At present, the only time that ac power is removed from the computer is for repair of its cooling equipment, or because of a building power failure. Standby time has averaged 13.54 hours per week.

Fig. 2 illustrates the use that has been made of the ORDVAC by a comparison of the various classifications to which machine time is charged.

Machine Performance

The ORDVAC's performance to date is best described by the curves of Fig. 1. The lower curve is a weekly plot of the number of hours the ORDVAC had been available for immediate use. The period described is from March 10, 1952, when the ORDVAC was accepted by the laboratory, until October 1, 1953, a period of 82 weeks. The upper curve of Fig. 1 represents the number of hours each week that the machine had power applied to it.

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problems are not duplicated unless suspected of being in error or, as just stated, unless time permits. Sufficient records have not been kept, but investigation has revealed that approximately 10 hours per week are lost as a result of errors that have occurred. It should not be assumed, however, that the number of errors vary directly with the number of hours lost, because an error may not be detected until several minutes or even hours after it has occurred.

Perhaps one of the best yardsticks for measuring error frequency is the number of errors that occur over a given period while the machine is idle and running the Leap III test. During a three-month period in which the test was run 546.75 hours, the Leap III test failed 141 times due to the memory and 31 times due to the arithmetic unit. The average error-free running time was 3.2 hours. Again this figure is somewhat misleading in that the daily error frequency may vary widely. The time between the errors indicated above varied from a few minutes to a maximum of 24 hours.

**Daily Schedule**

The normal operating schedule includes three periods each day during which the performance of the ORDVAC is checked. The period between 0800 and 1000 hours is set aside for engineering purposes; at this time small changes and improvements may be made, troubles that may have developed during the night shifts are cleared, and, finally, the machine is tested by various self-checking programs. Tests are again made at the conclusion of each working day and at midnight. Upon the successful conclusion of the tests, the ORDVAC is released to the mathematicians who use it during the day. On the night shifts most of the production work is carried out by two technicians per shift who are in charge of the machine. They are not expected to understand the programs that are run, but they follow explicit instructions that are left by the mathematicians. This system has worked quite well. Usually, when a coder arrives at the laboratory in the morning he can expect to find that his program has been completed.

In the course of an average week 30 different problems are placed on the ORDVAC. Each problem may be placed on the machine several times each week. Ballistic computations, such as firing and bombing tables, and trajectories for guided missiles and rockets, form about 40 per cent of the work done by the ORDVAC. Vulnerability computations and data reductions form 25 and 20 per cent respectively. Research problems form 10 per cent and systems tests form 5 per cent of the work.

**Testing the Machine**

Three classes of tests are used to test the units of the ORDVAC. A read-around-ratio test is used for checking the memory; an input-output test is used to test the teletype and card-handling equipment; and the Leap III test already mentioned is used to test the arithmetic and control section and to give a further check on the memory.

Any electrostatic-type memory is subject to a fault which is known as read-around-ratio. In this paper, read-around-ratio refers to the maximum number of times that any one position in the memory may be consulted without causing errors in adjacent positions. A routine is used to scan the entire memory to discover any position or area that may be in an unnecessarily poor condition.

The present memory uses a three-dot system, which has the characteristic of being susceptible to failures of both ones changing to zeros and zeros changing to ones, should the read-around-ratio exceed a safe figure. Two tests are used to determine the read-around-ratio. They are similar except for the method of sensing a failure. The routine is placed in the lower part of the memory from which it automatically proceeds to test the upper half. A number read into the machine from teletype tape determines the number of times each spot is bombarded before the adjacent spots (which had been previously cleared to ones or zeros, depending on the test) are scanned for failures. After half of the memory has been tested, the program is transferred to the tested area from which it proceeds to test the second half. Failures are indicated by a printed word identifying the cathode-ray tube involved and the address that was consulted. Up to a point, failures can usually be eliminated by the proper adjustment of the voltages on the cr tubes.

The input-output units are tested by a simple process of reading identical information into the machine from both teletype tape and cards and immediately punching out the same words. Comparison is made automatically, and discrepancies are printed out on the teletype page printer.

Perhaps the most thorough test is the Leap III test mentioned earlier. It is a revised version of the original Leap frog test written for the ORDVAC while it was still at the University of Illinois; its name is derived from the manner in which it moves itself through the memory. In a period of about fifteen minutes, the routine moves in such a way that each order in it has occupied every memory address. Throughout the leaping process a self-checking system of arithmetic operations using pseudo-random numbers is carried out. If an arithmetic or storage error is detected, a set of twelve numbers are printed to reveal the nature of the error.

Occasionally the routine may fail in such a way that no useful information is obtained from the printed matter if, indeed, anything is printed at all. In this case a special routine is used to search the entire memory for the location of the program and then compare it with a correct copy.

It can be seen that the ORDVAC is used as much as possible to test itself by a highly repetitive use of its

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components. In this way, marginal and intermittent errors may be detected that would otherwise not be found. The usual memory errors are not to difficult to repair; the causes of arithmetic errors are somewhat harder to detect as their effects may propagate. Intermittent failures are especially troublesome if the error frequency is low. In this case an attempt is made to increase the error rate by using special routines which strain the circuits to their limits, by vibrating the circuit components, by varying filament or supply voltages, or by a combination of the above.

ENGINEERING

It was mentioned before that during the nineteen month period under discussion the total amount of engineering work on the ORDVAC amounted to 51.36 hours per week. Broken down into scheduled and unscheduled engineering columns, the time was about evenly divided. They were 25.27 and 26.09 hours per week, respectively. Any engineering which necessarily interrupts the normal operating schedule without advance arrangement is classified as unscheduled engineering. In addition to the time taken each day to test the machine, scheduled engineering includes all the time which is taken for modifications to the machine. The major effort which has been made in the way of modifications to the ORDVAC has been devoted to the input-output system and to the memory.

INPUT-OUTPUT MODIFICATIONS

The ORDVAC was delivered to the Ballistic Research Laboratories having as input a standard speed, five-hole teletype tape reader, and as output, a teletype page printer. Using this equipment, the time necessary to load the entire memory of 1,024 addresses was 38 minutes. The time necessary to print the contents of the entire memory was the same. No change has as yet been made in the page printer. It was realized quickly, however, that a change was necessary in the input in order to speed up the operation of the computer. Within a few weeks after the ORDVAC was placed in operation a control circuit had been designed and built for a modified tape reader which now allows information to be read into the machine at five times the previous rate; that is, the memory can now be filled in 7.5 minutes. This unit has performed exceptionally well, but input and output are still the big bottlenecks to more efficient use of the ORDVAC.

The most important change in input-output has been the addition of card-handling equipment. Before March, 1952, it was realized that card-handling equipment was desirable. The ORDVAC was to be placed in a laboratory with two other large-scale computers, the ENIAC and the EDVAC. The ENIAC already used punched cards, and such a system was being devised for the EDVAC.

There were two possible systems to be considered. The first was an external system in which information punched on cards was to be automatically converted to its binary equivalent by external apparatus. The second was an internal conversion system based on utilizing the ORDVAC itself to accomplish the necessary transformation. The second method was chosen.

The advantage of the internal system lay obviously in the elimination of the necessity for extensive additional equipment; and since established machine operations were utilized, the maximum in reliability was obtained. Another advantage was that less time was required to complete the addition of the equipment to the ORDVAC. The greatest disadvantage of the internal system was that a significant portion of the memory capacity was committed to the conversion program. The space required for both input and output conversions has amounted to 200 words, approximately one-fifth of the memory. Recent improvements of the memory, however, have made it possible to reduce the size of the program.

![Fig. 3—Block diagram of the card input-output system.](From the collection of the Computer History Museum (www.computerhistory.org))

The system is based on double-register gating in which the entire 80-column output can be gated to or from the ORDVAC simultaneously. A block diagram of the system is shown in Fig. 3. An electronic control circuit which is actuated by signals generated in the card punch or card reader allows the contents of the ORDVAC...
registers to be stored in the memory or changed in the interval between punching or reading successive rows on a card.

This system has proved quite reliable and is preferred to tape by the mathematicians. The usual practice is first to prepare a program on tape and immediately transcribe it to cards with a special routine that automatically reads from the tape and punches, in binary form, twenty-four words per card. Cards are used thereafter.

Several forms of input may be used. One form, just mentioned, in which 24 words per card are used, allows the memory to be filled in about 30 seconds. Another form of input, used for decimal data input and for which the 200-word input-output conversion routine is required, allows only eight decimal words to be punched on a card. Each card may be read into the ORDVAC in 1,033 milliseconds; this is equal to a rate of about 60 cards per minute. Data cards of this type may be used on either the ORDVAC or the ENIAC and may be handled with the usual card-handling equipment. By a third input method, 12 words are read from a card and stored in the machine by a repetition of an "order pair."

**Memory**

The electrostatic memory has always been the ORDVAC's weakest unit. Prior to June, 1953, the memory operated rather consistently at a read-around-ratio of 10 to 16. A restriction of 10 placed on the coders resulted in slower routines or routines that occupied a larger portion of the memory. In addition to read-around-ratio difficulties, there existed the problem of obtaining cr tubes whose screens were free of impurities. Type 3KP1 cr tubes were used for storage. Approximately 25 per cent of those tested were acceptable; most of the rejections were due to impurities which could cause improper storage. Until May, 1953, approximately 60 cr tubes were removed from the machine for various reasons: About two-thirds of the total number were removed because of the impurities in their screens; five were removed without proper cause; and the remaining tubes were removed because voltage adjustments could no longer hold the read-around-ratio of those tubes above 10. No cr tubes have burned out under normal operating conditions, although five were burned out when subjected to abnormal conditions.

In May, 1953, it was learned that the University of Illinois was obtaining improved read-around by using a three-dot system. In this system, as used in the ORDVAC, two dots represent a one, and three dots represent a zero. The first and third dots occur at the same location.

The change over from a two-dot system was made about June 1, 1953. Considerable difficulty was encountered with the sensing pulse; and, in order to strengthen it sufficiently so that its excursion would not vary with the number of zeros sensed, it was necessary to incorporate a pulse transformer into the circuit. The new system caused the read-around-ratio to be increased by a factor of three so that it then varied between 32 and 48.

In the hope of further improving the reliability of the electrostatic memory, a number of type C73376B cr tubes, which are under development by RCA, were obtained and installed in the ORDVAC. At this writing they have been in the ORDVAC 1,500 hours and seem to be operating satisfactorily. The read-around-ratio is at present guaranteed to be 80 and is usually 100; the flaw problem no longer exists since these tubes are virtually flaw free. Although the reliability of the memory has been increased, the improvement is not very noticeable in Fig. 1. Unfortunately, a series of arithmetic errors, which were for the most part due to a group of bad solder connections, temporarily counteracted the improved memory performance.

The greatest difficulty experienced with the new tubes was due to their centering characteristics. Upon installation a large number of tubes had to be immediately removed, because corners of the 1024 spot raster projected beyond the useful surface of the screen. Ten tubes were removed for this reason. The ORDVAC, like most machines using electrostatic memories, operates its cr tubes in a parallel manner; thus a positioning of the raster which is beneficial to one tube might render the other tubes completely useless.

A test was made on the centering of 40 type C73376B cr tubes and, for comparison purposes, on 40 type 3KP1 tubes chosen at random. The results indicated that the experimental tubes were somewhat inferior in this respect.

In the design of an electrostatic memory, careful consideration should be given to the problem of centering the raster in the cr tubes if the maximum benefit is to be obtained from the unit. It is believed that in a three-inch tube the undeflected beam should be positioned by some method internal or external to the tube to within 2.5 mm of the center of the tube face.

Three tubes have since been removed from the ORDVAC because of the deterioration of the quality of the signals presented to the regeneration amplifier. The signals degenerated to the point that adjustments of the tube voltages would no longer make the signals reliable.

**Preventative Maintenance**

In September, 1952, a tube-removal program was initiated as a part of a preventative maintenance program. Since almost all of the troubles encountered were the result of shorted or low emission tubes, it was believed that such a program would be helpful in eliminating a potential source of trouble. Blocks of tubes were removed at two-week intervals, and were replaced by new ones. The location and the number of tubes involved were dependent upon the area in which troubles had been occurring most frequently. The number usually varied from 50 to 100. At present the ORDVAC has operated about 18,000 hours, and virtually all of its 3,000 tubes have been replaced at least once. The effect of the
block-tube change was felt almost immediately, and the procedure is believed to be an important factor in the gradual increase of available time noted in Fig. 1.

Within a period of eight months, 850 tubes were replaced in blocks; out of these tubes, 394 would not pass the inspection given all tubes that are used in the ORDVAC. The tubes used in the computer are, for the most part, types 6J6, 2C51, and 5687. Upon inspection it was found that about 50 per cent of the 6J6 type were bad. The most frequent cause of failure in this type tube was "shorted" elements. "Shorted" is meant to include those tubes whose elements were joined by a high-resistance path so that a leakage current was detected upon inspection. About 30 per cent of the 2C51 type tubes were found to be bad. Again, the most frequent cause of failure was "shorted" elements. The greatest percentage of bad tubes was found among the 5687 type. About 75 per cent of these would not pass inspection. The majority of the rejections in this case was due to low emission and cathode-to-heater leakage. It is interesting to note that the ORDVAC had been operating rather satisfactorily with such poor tubes in use.

The major cause of trouble in the ORDVAC has been tube failures. The conservative design, in which a safety factor of two was used in the rating of components, has made other failures practically nonexistent. Occasionally, however, bad solder connections do appear, as noted before, and they usually appear in groups. Recently, the cause for a great many adder failures was eliminated by the discovery of a wiring error which caused 200 volts to be applied between the heater and cathode of 50 tubes. Such wiring errors are difficult to eliminate except through continued use of the machine.

Perhaps one of the greatest potential sources of trouble in a machine is dust or dirt. In almost any installation some dirt is certain to enter the cooling system regardless of the elaborateness of the filtering system. Simply exposing the components for necessary maintenance will allow a great deal of dust to enter the system. A computer using an electrostatic memory is especially susceptible to dust, unless it is elaborately protected, because the high-voltage wiring forms a fine precipitator. This has been one of the great sources of trouble in the ORDVAC—not great in the sense of occurrence, but great in the sense of damage that may be done.

During the summer of 1952, sufficient dust had collected on the wiring so that the 2,000 volts arced to ground in a number of places. The damage included several clamping tubes that were exploded, at least six-memory chassis that had to be replaced, and five cr tubes that were burned out. The arcing was eliminated by floating the high-voltage system and supplying it with a high impedance variable high voltage. In a darkened room, the arcs were both audible and visible, and they were eliminated by cleaning and separation of the wiring where possible. The manner in which the ORDVAC is constructed makes proper cleaning almost impossible, but a little care has thus far prevented a recurrence of the trouble.

CONCLUSION

Recent improvements to the electrostatic memory have removed certain restrictions on coders and have led to shorter and faster programs. A preventative maintenance program consisting chiefly of periodic tests and a systematic exchange of tubes, along with the improvements to the ORDVAC, have resulted in an average of 103.10 hours out of a possible 154.46 hours each week over a period of 19 months being made available for computation. It is expected that even a higher number of available hours will be obtained in the future when procedures are perfected and operators gain more experience.

Discussion

Harvey Rosenberg (Burroughs Adding Maching Corporation): How many control relays are used? What was their reliability?

Mr. Williams: In addition to the few relays used to control the power to the ORDVAC there are six telephone-type relays and one stepping relay which are used in conjunction with the teletype output system. No trouble has been experienced with the power control relays; the stepping relay has required minor adjustment only three times in two years; and it has been necessary to replace two of the telephone-type relays because of broken contact arms.

B. B. Paine (Massachusetts Institute of Technology): Could you elaborate on the tube acceptance test program? Is pre-burning used?

Mr. Williams: Before all tubes are placed in the ORDVAC they are given four tests. The first is a very simple short test in which the tube is tapped manually while a neon is watched. No attempt is made to actually measure the resistance between elements. The second test is an emission test. The third test is a cut-off test. If I remember correctly, in this test about 20 volts bias is placed on the tubes and no more than about 50 microamperes plate current is allowed to flow. The fourth test is a filament-to-cathode leakage test in which no more than 50 ma current at 150 volts is allowed. Tubes are not pre-burned at present, and few tube failures can be credited to this fact.

E. L. Harder (Westinghouse Electric Corp.): Were errors detected in the teletype transmission from the University of Illinois? How many? How detected? How corrected? How was transmission of errors verified?

Mr. Williams: In answer to these questions I will go into more detail on the manner in which the tapes were handled. The University of Illinois initiated contact by transmitting their program directly to the Signal Corps office at Aberdeen Proving Ground, preceding the program with instructions to the ORDVAC operator. Immediately upon receipt of the tape, it was transmitted back to the University of Illinois where it was compared with the original copy. If an error was detected upon comparison, the procedure was repeated until a correct transmission was verified. In a one month period during the summer of 1952 transmitting time averaged about forty-five minutes a day. There were several human errors made in this period, but there were only two mechanical errors.