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.

Fig. 1—ORDVAC weekly performance chart.

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.

Within the period under discussion at present, an average of 37.17 hours per week was spent on code checking, 38.29 hours per week spent in production, and 23.03 hours per week classified as idle time. The title "idle time" is not intended to indicate that the machine is not in use during that time. The machine is made to run continually a test called Leap III, but it is available for other use at any time. Should the Leap III routine fail, the following time is immediately classified as unscheduled engineering until the cause of the error has been corrected, and the routine has successfully operated for fifteen minutes.

Recently, after all scheduled problems have been run, the remaining time has been used for problem duplication in an attempt to discover any errors that may have occurred during a regular production run. Normally

Fig. 2—Machine-time classification chart for an average week.

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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 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 CRT 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
components. In this way, marginal and intermittent errors may be detected that would otherwise not be found. The usual memory errors are not 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.

It is interesting to note the manner in which the University of Illinois has in the past used the ORDVAC remotely. The University would send to the Ballistic Research Laboratories a program through regular teletype channels which would be placed in the ORDVAC after insuring that the program had been received correctly. Answers were obtained on tape and returned to the University by mail or by the teletype channels. Thus the ORDVAC is available to any laboratory in the country having the necessary coding staff.

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.

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 pre­
fined to tape by the mathematicians. The usual prac­
tice is first to prepare a program on tape and immedi­
ately 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 re­
quired, allows only eight decimal words to be punched
on a card. Each card may be read into the ORD­
VAC’s weakest unit. Prior to June, 1953, the memory
operated satisfactorily. The read-around-ratio is at
least 80 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 re­
moved 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 memory performance.
In this system, used in the ORD­
VAC, two dots represent a one, and three dots represent
a zero. The first and third dots occur at the same loca­
tion.

The change over from a two-dot system was made
about June 1, 1953. Considerable difficulty was en­
countered 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 ob­
tained 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 improved, 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 im­
proved memory performance.

The greatest difficulty experienced with the new tubes
was due to their centering characteristics. Upon instal­
lation a large number of tubes had to be immediately re­
moved, 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 ma­
chines 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 re­
spect.

In the design of an electrostatic memory, careful con­
sideration 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 ORD­
VAC because of the deterioration of the quality of the sig­
als 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 ini­
tiated as a part of a preventative maintenance pro­
gram. Since almost all of the troubles encountered were
the result of shorted or low emission tubes, it was be­
lieved that such a program would be helpful in eliminat­
ing 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 in­
olved 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 op­
erated about 18,000 hours, and virtually all of its 3,000
tubes have been replaced at least once. The effect of the

\[ \text{J. M. Wier, "Recent Improvement of ILLIAC Memory," Univ. of Illinois Graduate College, Digital Computer Laboratory, Internal Report no. 45; March 25, 1953.} \]
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 manyadder 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 or 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 reoccurrence 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.

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**Discussion**

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

**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.

**B. B. Paine** (Massachusetts Institute of Technology): Could you elaborate on the tube acceptance test program? Is preburning 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 tele-type transmission from the University of Illinois? How many? How detected? How corrected?