Raydac Input-Output System

WALTER H. GRAY

RAYDAC, Raytheon's digital automatic computer, is a large-scale electronic machine capable of solving any problem in the field of numerical mathematics. It consists of seven major units, as well as two separate auxiliary units, a problem preparation system, and an output printer.

Although an operator may transfer information to and from the central computer by means of the operator's console, the normal means of communication with the computer is through the external memory section. Since magnetic tape is the storage medium in this external memory, the problem preparation system provides a means of writing information on the magnetic tape and the output printer is used for writing out information from the tape.

Problem Preparation System

The problem preparation system consists of two modified Teletype units with paper-type punching equipment and paper-tape-to-magnetic-tape conversion unit for recording information on magnetic tape for use in the external memory. The process of recording suitably programed information on magnetic tape for insertion into the external memory is accomplished in three steps. First, an operator enters data and order words on a Teletype machine which prepares a perforated paper tape. Then a second operator enters the same data and orders in a second Teletype machine and prepares a second perforated tape. To guard against human error, the first perforated paper tape is read simultaneously with the preparation of the second tape. Should the operator making the second tape strike a key that is not in agreement with the corresponding character on the first paper tape, the Teletype machine will lock. If a conflict should occur, the operator checks the first paper tape with the text, makes the necessary corrections, and proceeds to complete the second paper tape. The information is then taken from the second, error-free, paper tape and recorded on magnetic tape.

Paper Tape Preparation

A modified model 19 Teletype set, shown in Figure 1, is used to prepare the perforated paper tape. Numbers, which may be in either decimal or octal notation, and half-orders in octal notation, are typed out, one at a time. While the operator is typing a number or half-order word, the unit prepares a transfer weighted count which is automatically appended to the word and punched on the tape to be used for checking throughout the machine. The unit prints a copy of...
information which is being typed, and can also print the weighted count of each word, if desired.

Information is punched on paper tape, one frame at a time. Each frame holds an octal or decimal digit, the transfer weight count, and a sign, or a blockmarker. An octal word consists of the sign, 10 octal digits, and their transfer weight count; and occupies 12 frames of paper tape. A decimal word has nine frames: the sign, seven decimal digits, and their transfer weight count. The transfer weight count of either type of word may be any quantity from zero to 15. The remaining code, the blockmarker, denotes the end of one block of information and the start of a new one, and is used in the transfer of information from paper tape to magnetic tape.

The Teletype equipment used in the Raydac input and output equipment has been modified considerably. All electrical and mechanical parts not necessary in performing needed functions were removed to provide space for many added items. The 5-place coding was altered to correspond with the binary-coded decimal notation used in the machine. This required new selector bars and keytops for the perforator keyboards, and new code bars, function bars, and type pallets for the printer units. It may be noted that the numbers 10 through 15 appear on the keys. However, it was necessary to build these codes into the perforator keyboard so that transfer weighted counts could be punched in paper tape, and so that the six keys involving these codes were allowed to remain in the keyboard. A switch is included for sensing the carriage position to ensure that the typing units are in the figures-shift position when handling information for or from the computer. The carriage return function of the printer unit has been altered so that it combines with it line feed, thus often saving one character in operation. The other functions retained are line feeding, spacing, and tabulating, the last being a standard Teletype modification.

The main purpose of the Teletype equipment in the paper-tape preparation units is to produce punched paper tape. The printed copy, which is produced simultaneously, may be used for checking the paper tape against the original programming sheets. The perforator keyboard is then of primary importance. Special selector bars, shown in Figure 2, are used to close the punch switch only when a positive or negative sign, a number from zero to 15, or a blockmarker (apostrophe) is typed. The printer unit carriage must be in the figures-shift position or the punch will not operate. The remainder of the figures-shift and all letters-shift characters can be typed, but will have no effect on tape preparation.

The selector fingers, connected to the keyboard selector bars, in addition to setting up the code combination to be punched, operate a set of five switches, shown in Figure 3, which act as sensing devices for any code combination, to furnish the addends for the transfer weight count adder and to check what is being typed against what appears in the first tape.

Four punch selector fingers are fitted with solenoids, shown in Figure 3, actuated by external circuits to permit the automatic punching of transfer weight counts at the end of every word. A reset solenoid is provided to zero the selector fingers before the weight count is inserted.

Normally, all keys of a Teletype keyboard operate a universal bar which trips a pawl which, in turn, allows the transmission shaft clutch to close for one revolution of the shaft. In the Raydac units, the universal bar operates a clutch-actuating switch as shown in Figure 4. When a key is depressed, this switch energizes an added clutch solenoid through a step function relay. This change was made so that sufficient time delay could be provided electrically between the pressing of a key and the actuation of the clutch to allow for comparison operations.

The pressing of a key mechanically sets up the selector bars and punch selector fingers. The transmission (or cam) shaft goes through one revolution, thus supplying, by means of contact levers, a serial electrical code to the printer, and causing a printing cycle. During the shaft revolution, a cam closes a switch which operates the punch and transmitter-distributor magnets, provided the punch switch is closed and the printer unit is in the figures-shift position. When the punch magnet is operated, the code set by the selector fingers is punched in paper tape.

Part of the transmitter-distributor function has been changed. The distrib-
utor disk is no longer used as a parallel-to-serial converter but as a source of timing pulses. However, the paper tape reader is used as intended.

Step switches are used to provide sequence control for octal and decimal words, advancing one position for every significant character typed. Thus, for an octal word, a step switch advances 11 positions, and for a decimal word eight positions, arriving at the 12th and 9th positions respectively, which automatically initiate the transfer weight-count-punching cycle.

The first step in weight count insertion is to zero all five punch selector fingers by actuating the reset solenoid. Then the four weight count insertion solenoids are appropriately actuated, setting the punch selector fingers to correspond to the quantity stored in the transfer weight count accumulator, just as though they were set mechanically by the action of pressing a key. After the selector fingers have been set, the clutch solenoid is operated. From this point on, the operation is the same for keyed and automatic cycles.

Four step switches form the transfer weight count adder-accumulator. The addend is derived from the switches operated by the selector fingers for octal operation, the addition is simple. Considering the octal code as three binary digits labelled 1, 2, and 4, all digits labelled 1 are added with weight 1, all 2's added with weight 2, and all 4's with weight 4. For addition, then, the three digits are supplied to three relays which form the addend register, and thence to three step switches of the adder, which are so wired as to represent alternate 1 and 0 steps. If the operation is decimal, however, each frame contains four binary digits, which are separated for each frame of the word into their appropriate weight positions. Since the adder accepts only three digits at a time, two additions are necessary. Timing pulses for digit position switching and adding are supplied by the transmitter-distributor disk.

The first and second paper tapes are prepared on identical units. Both include a paper tape reader, which is part of the transmitter-distributor. The first tape is supplied to the tape reader and indexed. The operator then types the same information again. As each key is depressed, comparison with the corresponding character on the first tape takes place and the printer, punch, and weight count adder are actuated only if the characters agree. It should be noted that the first paper tape is one step ahead of the operator so that each character is read and stored for comparison before the operator punches the corresponding character on the second tape.

The comparison circuit consists of the switches linked to the keyboard punch selector fingers and corresponding relays holding the character read from the first tape. If the positions of any corresponding switches and relays do not agree, a circuit is completed which prevents punch, printer, transmitter-distributor, and weight count adder from operating, and locks the keyboard. The operator must clear the error before proceeding. If the error is made in typing, a button is provided to release the unit but the comparison feature remains effective. If the fault lies on the first tape, the comparison feature must be bypassed for one character by operating another button. Transfer weight counts are also subjected to comparison. In the event that a typing fault lies on the first tape and is corrected in making the second tape, it can be expected that the machine will lock at the point of automatic weight count insertion for that word. Removing the comparison feature allows the proper weight count to be inserted and punched on the second tape.

**Magnetic Tape Preparation**

The second paper tape, which is assumed to be free from error, is then supplied to the paper tape reader of the

Figure 3. Code sense switches and solenoids

Figure 4. Perforator keyboard, side view

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The arrangement of digits for writing tape and for weight count addition is different for octal and decimal words. An additional reading pin, shown in Figure 6, has been installed in the transmitter-distributor reader in the fifth channel to distinguish between the two word types. Only signs and blockmarkers have fifth channel perforations. By virtue of the difference in the number of paper tape frames for octal and decimal words, a reading pin located 12 frames behind the normal reading station indicates that the word about to be read is octal.

Another part of the transfer circuit is affected by the blockmarker on paper tape. When a blockmarker is read, if 32 words have not been counted since reading of the block began, the unit writes zero words with legitimate weight counts on tape until 32 words are contained in the block. After 32 words have been written, all operation is halted until two successive holes in the magnetic tape have been sensed by the photoelectric reader. The holes denote the end of one block space on the magnetic tape and the beginning of another. The second hole starts the transfer operation again, after a delay sufficient to permit writing to begin well inside the block space. The magnetic tape on the transfer unit moves continually at a very low speed (1.63 inches per minute). Consequently, holes are punched between the coincident printed optical marks to permit sensing with chopped, transmitted light rather than reflected light. The photoelectric cell output can, therefore, be amplified in an a-c circuit, and large hole-to-no-hole signal ratios may be obtained.

The paper tape is positioned in the reader so that the first blockmarker on the tape is read. The sign of the first word of the first block will then be read. The magnetic tape drive is started, but no information transfer takes place until a photohole is sensed, denoting the start of the first block space on magnetic tape. After a delay, the transcription process, which consists of reading paper tape and writing magnetic tape, begins.

A check is performed to ensure that a sign or blockmarker is read at the correct point in the cycle. Failure to read a sign or blockmark at the prescribed point stops the unit, as does reading either one at an incorrect point. A word counter keeps track of the words transferred in each block. If less than 32 words are read from paper tape, zero words are generated. If more than 32 words are placed between blockmarkers on paper tape, an error is indicated.

The Raydac acceptance test routines and problems required the preparation of about 700 blocks of data and program information. The paper tape preparation equipment was operated for a period of about 100 hours, during which time some 20,000 words were typed and their transfer weighted counts generated. One hundred thousand digit-by-digit comparisons were made in the preparation of the second paper tape. The value of punching a second tape was demonstrated by the fact that no error in the transcription from written pages to magnetic tape was noted, even though the same operator prepared both paper tapes, making several errors during the typing of each.

Two sets of magnetic tapes were prepared for the acceptance test, requiring approximately 50 hours of magnetic tape writing. The reliability of operation of the paper-to-magnetic tape converter,

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| * Both positive and negative signs have a 5th-channel perforation. The sign is defined by the first channel.
and its compatibility with the external memory are indicated by the fact that no error was made during the acceptance test in reading information into the external memory.

Experience with the problem preparation system of the Raydac indicates that typing comparison and checking features should be considered in new designs, as should the possibility of preparing magnetic tape directly during the retyping process to save time and tape handling.

**Output Printer System**

The output printer system, shown in Figure 7, prints the contents of the magnetic tape within the external memory units of the Raydac. The primary function of the unit is to print, in a directly readable form, the binary-coded decimal words which are normal problem results. Printing in octal notation is also included to permit checking the contents of a tape prepared by either the external memory or problem preparation system. Since the system is not intended primarily for operation in octal notation, no elaborate format is provided for printing in this mode. The octal word is printed as a sign and 10 digits. Once the number of columns on the page and the number of lines between extra line feeds have been set, no further control of the printing operation is possible. Except for sign printing, where the vane check described later applies, the only check performed is that involving the transfer weight count.

In the decimal modes, however, the programmer has great latitude in the format he may provide. Although the information is read from magnetic tape as a series of 32-word blocks, each word consisting of a sign, 30 binary digits, and the weight count, it is printed in a form almost entirely free from the arrangement of information on the type. Words may be combined into multiprecision or floating-point numbers; decimal points and cut-off may be varied at will. Meaningless zeros at the high end of the word are dropped. Thus, the results on the printed page may be read without need for further interpretation.

One section of the output printer is concerned with reading the information from the tape into a one-word register, and another section with interpreting the information in the register according to the format requirements. The format section acts as the clock of the unit. Information must be available in the register when required.

**Tape Reading Section**

Each block of information on tape contains 32 words of 36 binary digit places each, each word being a square array of 6-by-6 digit places. There are then 192 frames per block, each frame consisting of six information channels and a sync channel. Since it is desired to handle only one word at a time instead of storing an entire block, the tape reading circuits must scan a block 32 times, each time picking out the next word in order, and supplying it to the storage register. Figure 8 is a simplified block diagram of the tape-reading circuits.

The reading cycle is initiated by the format circuit, which emits a read-next-word pulse, starting the tape drive in the forward direction. The next stimulus is the photoelectric reading of the coincident optical marks, which indicate the beginning of the block and open the reading circuit of the sync channel. The sync pulses are supplied to a 6-counter, which in turn feeds a 33-counter. At the start of a block, both counters are set so that the first sync pulse provides an output from the 33-counter, which opens the read-in circuits of the six information channels. The 6-counter also operates a matrix which switches the information channels to appropriate stages of the one-word register as the count advances. When six sync pulses have been read, the entire word is stored. The seventh sync pulse produces a 6-counter output which shuts off the information channel read-in circuits and advances the count in the 33-counter. At the end of the block, 192 sync pulses have been read and the 33-counter contains a count of 32. Coincident optical marks, denoting the end of the block, shut off the sync channel reader, stop the tape drive and, after a delay, reverse the tape drive. First the end-of-block optical marks are sensed, then the beginning-of-block marks stop the tape drive and prepare the circuits for the next pass over the block.

The reading heads are now poised at the head of the block, the register is reset, and a second read-next-word pulse arrives, initiating the next scan. Now, however, the 33-counter must receive two inputs from the 6-counter before the information channel read-in circuits are opened and the second word of the block will be read into storage.

The subsequent scannings are similar. The 33-counter processes once for each pass, so that the third word is stored on the third pass, and so forth, until all 32 words of the block have been read. After
Figure 8. Tape reading circuits simplified, block diagram

Figure 9. Output printer typing unit

32 forward scans of a block, the tape drive reversal is inhibited so that scanning will proceed to the next block and the circuit is in the same state as it was at the beginning of the first block.

The static register contains 35 binary digit positions, since the first digit position of a word is always blank. These may be grouped as the sign, 10 octal digits, and weight count; or as the sign, 7-decimal digits, weight count, and two binary digits for format instructions.

**Format Control Section**

The format controls of the printer consist of five parts. Each part governs one phase of the format for one column of printed results. When a number is printed, a control circuit steps ahead to the next group of controls to derive the format instructions for the next column. Up to 10 columns may be printed on a page and the format of each column is separately controlled.

The first set of controls has four positions which control the mode of printing. A decimal word may be printed with its sign, as a single precision number or the first part of a multiprecision number. Or a decimal word may be printed without sign, as a later part of a multiprecision number or as an absolute value. No more than two decimal digits of a word may be printed as a decimal exponent with its sign, and appear located between parentheses. An octal word may also be printed with its sign. If the control calls for a sign, a negative number is printed with a minus sign and a space is used instead of a plus sign for positive numbers.

The second set of controls specifies the position or absence of the decimal point in the corresponding column, effective only for the sign and no-sign modes of printing. The eight possible positions of the decimal point, with respect to the 7-decimal digits of the word, plus the absence of the decimal point, are the nine positions of this control. When the decimal point is printed, all zeros occurring before the first significant digit which lies to the left of the decimal point are dropped. If the first significant digit occurs to the right of the decimal point, all zeros to the right of the decimal point are printed and a zero is printed immediately to the left of the decimal point. The sign is placed immediately before the first digit printed. The decimal points of all numbers printed in the same column appear in a vertical line regardless of the number of insignificant zeros dropped from each number.

To accomplish the dropping of insignificant zeros, notice is taken of any decimal digit which might be zero. It is then possible to determine how many digits to drop and how many spaces to move before printing the sign. A relay matrix, controlled by the word stored in the register, accomplishes this by controlling the manner in which code relays are operated by the sequence circuit.

The third set of controls determines the point in the word beyond which digits are cut off. The setting may be made to cut off anywhere from after the first digit to after the seventh. Cut-off is effective only for the sign and no-sign modes of printing.

The fourth set of controls specifies the carriage action of the printer following the printing of each column. Each control may be set to space, tabulate, carriage return, or take no action at all, as in the case of printing multiprecision words. Just as a carriage return ends the printing on a line, since the line feed function is combined with carriage return, so the setting of a switch to carriage return marks the last group of switches which controls the printing operation. Thus, if the format is set so that carriage return follows the printing of the third word on a line, only the first three groups of format controls affect the format.

Since only a carriage return can follow printing in the 10th column, no carriage control is included in the 10th group of switches. In its place, an extra line feed control provides for an additional line feed after every 1 to 9 lines of printing, or for no extra line feeds, depending on the setting.
One way in which the word itself affects the format has been mentioned in the matter of zero drop-off preceding the first significant digit. The format is affected by the word in two other ways.

Each group of four binary digits, specifying a decimal digit in the binary-coded decimal notation, can legitimately represent zero to 9. Any configuration from 10 to 15 will not be printed, but will cause the printer to space.

The two binary digits available for format instructions at the register are used as follows. If both are zero, the word is printed according to the controls set for it. If either or both are not zero, the word is not printed at all, but the carriage may be instructed to tabulate, carriage-return, or take no action, in which case the format remains in the same column. If the format is in the last column of a line and tabulation is ordered, a carriage return is substituted. By the use of these codes in the word, the programmer may provide for the skipping of words and manipulation of the carriage when the strict columnar format provided by switches is not sufficient for the problem.

**Printer**

A Teletype model-13 printer is used with the output printer system. Since Teletype printers are designed primarily for ruggedness and reliability, speed of operation is not high. Used as input devices, machine speed is not a serious handicap, since the input rate is dictated by the proficiency of the operator. However, in output printing, the printer mechanism is a definite limitation. When used in connection with the Raydac, the effective speed is still further reduced, since a vane check operation has been incorporated in the operating cycle.

Several modifications have been made to the Teletype machines, in addition to the coding change. Switches have been stacked between the five code vanes of the printer to indicate the code combination set up as shown in Figure 9. Switches have also been added to the carriage and tabulator to sense when the carriage is at the left and when tabulation is completed. These switches are necessary since the time consumed by the carriage to complete its action depends upon its position along the line when carriage return is ordered, and upon the distance tabulated. A switch has also been added to sound an alarm if the printer should be in the letters-shift position. The keyboard is furnished with the printer so that the unit may be used to record pertinent data on the result sheets.

The printer operates from a serial code, while the output of the format circuits is a parallel code. The disk of a transmitter-distributor is used for parallel-to-serial conversion and the paper tape reader of the unit is not used. The codes supplied by the format circuit are for printing digits zero to 9, minus sign, decimal point, and parentheses; and for ordering the space, tabulate, carriage-return, and line-feed functions.

A check is performed for each character to ensure that the printer vanes set up the proper code. Although performance of this check slows down slightly the effective printing speed, since the vanes must all be set up before the check is performed, it ensures conclusively that the information appearing on the printed page agrees with the information residing in the register. A transfer weight count check is performed on each word by comparing the weight count on the tape with the weight count generated by a parallel adder connected to the register holding the word. Assurance that the printed information is correct is therefore given, since the failure of either the weight count check on the register contents or the vane check stops the printing process.

All acceptance test magnetic tapes were proofread at least twice by the output printer to show that the information on the tapes was correct, using octal printing. The printing time for this operation was about 35 hours.

It should be noted here that the printing time of a word varies with the form and content of the word printed. The maximum time, excluding time for completion of carriage action following the printing of a word, is 2.8 seconds, required for an octal word or for a decimal word printed with sign, decimal point at the left and no digits cut off. A word printed as a decimal exponent requires 1.8 seconds of printing time and a coded word to order no carriage action requires 0.6 second of printer time for processing.

The output printer system of the Raydac has handled over 20,000 blocks of magnetic tape, representing more than 400 hours of system operation. Experience indicates that the designer of new output printing systems should consider checking both the information read from tape and the information printed. These checks provide excellent diagnostic indications during the test period and provide comforting assurance during operation that correct information is being printed.

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Operating Experience with Raydac

FRANKLIN R. DEAN

THE RAYDAC acceptance tests were run from June 4 to July 19, 1952, in five sessions of 3 days each. The tests were divided into three phases. Phase 1 consisted of programmed test routines which caused each unit of the computer to go through its various combinations of operations. This included tests of the terminal equipment, central control, and internal memory; the arithmetic unit; and the external memory. Phase 1 also included an exhaustive test of all checking and error-detecting circuits. Phase 2 was a single mass data-handling problem calling for large volumes of input and output data with relatively little actual computation. Phase 3 consisted of the solution of a full-length physical problem to which a reliable numerical solution was already available.

Phase 1

Terminal Equipment Tests

The terminal equipment tests involved the operation of the problem preparation unit, the output printer, the control console, and the directly connected printer.

Problem Preparation Unit. This test routine consisted of orders and data which were punched on paper tape and transferred onto magnetic tape by the conversion unit. To determine whether the preparation unit performed correctly, the magnetic tape was then put on the output printer, and the information printed out. Agreement between the printed listings and the original manuscripts was to be considered a demonstration of satisfactory operation. The original manuscript consisted of 32 orders and 160 numbers.

Three attempts were required before this test was passed. The first attempt failed because the speed of the transmitter-distributor governing the preparation of the first paper tape was set at an incorrect speed, through an oversight of maintenance personnel. This caused transfer weight count check errors to occur while preparing the second punched paper tape. The second attempt failed as a result of malpositioning of the magnetic tape on the paper to magnetic tape converter unit. The third attempt passed successfully without error.

It was also demonstrated that all combinations of errors occurring in the problem preparation unit were detected by the transfer-weight-count-error detection system.

Output Printer. This routine was designed to test the output printer and its several modes of operation, using a variety of formats and numbers. Specific instructions for the setting of the output printer controls were given on a master tabulation sheet which showed the form and contents of the printed results. Agreement between these results and the tabulation sheet was to be considered satisfactory performance for this test. Various formats were tested by separately adjusting the controls of the 10 printed page columns. This routine was completed without error on the first attempt.

Control Console. This routine was devised for the express purpose of testing the external memory of the computer in its several modes of operation. The four external memory orders; hunt-prepare-to-read, hunt-prepare-to-write, read, and write, were used in a variety of combinations. Program checks were inserted to verify the correctness of the machine's operations. Hunting, reading, and writing were performed on the magnetic tapes of all four external memories. The test was self-cycling, requiring no operator intervention at any point. To pass, the computer was to operate continuously without error for a period of 5 minutes. This test was passed successfully on the first attempt, running without error for 1 hour and 23 minutes. It stopped as a result of a transfer weight count error of one of the operands transferred to the arithmetic unit. During this test, approximately 7,000 36-bit words were written on and 6,300 36-bit words read from the magnetic tape. After the completion of this test, it was also demonstrated that all operational and transfer weight count error-detecting circuits in the central control performed properly.

Central Control and Internal Memory

This test consisted of 15 separately coded routines which tested the variables that effect the processing of an order by the central control. These variables are the type of address (regular addresses of the internal memory, special addresses of static registers and void addresses) and the time of selection of these addresses. Orders consisting of all combinations and permutations of the different types of addresses were programmed. The time of selection was varied by deliberately placing the operands in certain relative word positions. In the course of the routines all internal memory positions were read from and written into at least once. The program of these routines was such that, upon completion of the last routine, the first routine was inserted again. One cycle of the routine took approximately 36 seconds. To pass this test, the computer was to operate continuously for at least 5 minutes without error. The test was completed successfully on the first attempt, running for 26 minutes and 45 seconds. The machine stopped at this time as a result of an arithmetic unit error that was detected by the arithmetic weight count check. It was also demonstrated that all operational and transfer weight count error-detecting circuits in the central control performed properly.

External Memory

This routine was devised for the express purpose of testing the external memory of the computer in its several modes of operation. The four external memory orders; hunt-prepare-to-read, hunt-prepare-to-write, read, and write, were used in a variety of combinations. Program checks were inserted to verify the correctness of the machine's operations. Hunting, reading, and writing were performed on the magnetic tapes of all four external memories. The test was self-cycling, requiring no operator intervention at any point. To pass, the computer was to operate continuously without error for a period of 5 minutes. This test was passed successfully on the first attempt, running without error for 1 hour and 23 minutes. It stopped as a result of a transfer weight count error of one of the operands transferred to the arithmetic unit. During this test, approximately 7,000 36-bit words were written on and 6,300 36-bit words read from the magnetic tape. After the completion of this test, it was also demonstrated that all operational and transfer weight count error-detecting devices operated satisfactorily.

Arithmetic Unit

The variables in the arithmetic unit test routine were the 26 operations and

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