into an over-all system partnership with widely varied types of input-output equipment, are now assuming increasing importance. Compared to these problems the purely computing design problems, such as the design of higher-speed multipliers and the like, are far less critical and present fewer unsolved difficulties. This is partly because the principles of arithmetic processing are well defined and partly because the devices for carrying out such processes occupy logically isolated blocks inside a homogeneous system. For the latter reason, the task of coordinating such devices with other parts of the over-all system has usually offered relatively little difficulty. On the other hand, the task of creating a smooth-working system out of a heterogeneous collection of input-output and computing equipment possessing grossly unequal operating properties and performance rates is a critical challenge to the system designer today.

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**SEAC Input-Output System**

*S. GREENWALD*

THE Standards Eastern Automatic Computer (SEAC) is a high-speed computing machine located on the grounds of the National Bureau of Standards at Washington, D. C. It was completed in May 1950 and for most of the time since then has been working on a schedule of 24 hours per day, 7 days per week. The machine is of a serial nature, uses a mercury delay line memory, and may be operated in either the 3- or 4-address mode, at the choice of the operator. The internal circuitry of SEAC is synchronous and works at the rate of 1 megacycle. A word length of 48 binary digits is used, of which there are 45 useful digits including the sign. The remaining three digit times are primarily useful for checking and for allowing sufficient switching time between orders.

Input or output operations on SEAC are accomplished either one word at a time or, more generally, eight words at a time. The reason for using eight words is that a single mercury delay line, of which there are 64 in SEAC, will hold that much information. A block of eight words is known as a group, and any number of groups up to the capacity of the memory may be read in or out by modifying the tape orders appropriately as the operation proceeds.

The input-output equipment had rather modest beginnings and started off with modified Teletype equipment. This included a tape reader and a key board for input operations, and a Teletype printer for output operations. Figure 1 shows part of the input-output equipment and also includes the operator's console.

It soon became evident that there was much to be gained by the use of magnetic-tape and wire-handling devices in speeding up the input and output processes, and thereby putting the various parts of the machine in better balance. For this reason work started on two kinds of equipment:

1. **Magnetic-tape units** devised primarily as an auxiliary memory. These units will hold up to 24,000 words on a 1,200-foot tape, as compared with the high-speed memory which holds only 512 words.
2. **Wire-handling units.** These are commercial units with necessary modifications. They are used primarily as a means of getting a program or data into the machine (input dumper) or obtaining finished data out of the machine (output dumper).

The whole philosophy of the system was to build equipment that would make the machine a more useful tool, not by attempting to build multichannel units with high-performance servos but rather with emphasis on simplicity, low cost, and reliability. Thus, as will be seen later, the tape unit which was eventually designed by the Electronic Computer Laboratory uses no servos and reads and records on a single channel only.

Before going into a description of individual units, it might be well to look at a diagram of the over-all system. The block diagram in Figure 2 shows in a very general way how the various pieces of input-output gear fit in with the computer.

The large box in the center is the computer, containing arithmetic and control circuits, shift register, and control, and other chassis involved in input and output operations. The one beneath represents the memory. The smaller boxes above the computer represent the Teletype unit, the two magnetic wire units, and the four magnetic tape units. The signals to and from this equipment pass through a selector relay chassis. The Teletype has its own separate communication with the machine, partly because of the number of leads involved and partly for historical reasons. Selection of any of the seven units can be made manually or automatically by the manual selector or the automatic selector.

In the computer proper there are the following units: First is the Teletype supervisory control. Among other functions, this chassis causes either the input or output transmitter-distributor (TD) to operate, properly shapes the pulses from the Teletype, counts characters and words, and so forth. The synchronizer changes the asynchronous signals from the Teletype or magnetic equipment to synchronous signals required by the computer. The read chassis is used on input operations. It examines pulses from the input equipment and decides whether a binary one or zero is being received. The record chassis works only on output operations. It produces 12-microsecond pulses on one of two output lines. These ultimately energize a recording head in one of the tape or wire units. The tape and wire control has several functions. It furnishes directional signals which cause tapes to move in forward or reverse directions. It also controls the print rates and the spacing between groups of words on the tape.

The shift register is the speed changer in the machine. Pulses come off the tape at approximately a 6-kc rate; pulses from the Teletype come much more slowly, only 24 pulses per second. The problem is to insert these into a machine which operates at 1 megacycle. Roughly, what happens on input operations is that the shift register is filled up slowly and when the entire word is in place, it is fired endwise into the arithmetic circuits and
memory. Likewise, on output operations the memory feeds information into the shift register at the regular computer rate. It is then fed out at a high audio rate to the tape and wire units or at a much slower rate to the Teletype equipment.

So much for the over-all view. Now, each of these units may be examined in somewhat greater detail.

**Tape Units**

In examining one of the tape units, it will be noticed, in Figure 3, that there are two capstans: the one on the right causes forward motion, that on the left, reverse motion. In either case a small jam roller forces the tape against the capstan. The speed of tape motion is 5 feet per second. The tape is allowed to fall into either of two plate-glass compartments by merely folding over itself. There are no reels in the system. The tape is oxide-coated plastic and is also coated with a very thin layer of aluminum on the reverse side. The aluminum coating is very important in preventing electrostatic troubles, whereby the tape tends to stick to itself and to the glass. There are three heads (left to right), erase, read, and record. These are standard commercially available single-channel tape heads. Several switches can be noticed in the illustration. These control the motor speed, printing, and erasing, and permit the tape to be moved under manual or computer control.

Access to the circuitry is from the back. Each tape unit has a similar chassis which communicates with the computer through two cables, one for d-c and filament power, a second mainly for signals. A typical chassis is shown in Figure 4.

There are actually four circuits on each chassis located in the tape unit:

1. **Writing circuits.** A positive 12-microsecond signal on one of the two lines from the computer is amplified, and energizes one side of a center-tapped write head for a one and the other side for a zero. In this way the tape is magnetized in opposite directions and gives the characteristic bipolarity signals when read back. The rate at which signals are impressed on the tape is determined by a multivibrator in the computer and is presently set somewhat higher than 6 kc.

2. **Reading circuits.** Also on this chassis is a preamplifier to pick up the weak signals from the read head and through a 2-stage amplifier to bring them up to a standard 2-volt level.

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*Greenwald—SEAC Input-Output System*
3. **Erase circuits.** The erase signal is brought from the selector relay chassis at about a 10-volt level, is amplified and transformer-coupled to the erase head at a level of about 200–250 volts. A 100-kc sine wave is used for erasing.

4. **Solenoid circuits.** The chassis also contains amplifiers to operate the solenoids, which in turn cause the tape to move in either direction. Pickup time is of the order of 5 milliseconds and most of this time is spent in energizing the solenoids.

It should be pointed out that the tape movement and reading and recording are under the automatic control of the machine. However, erasing is a manual operation independent of the machine. Before a tape is used, it is completely erased. This can be done ahead of time if desired, so no computer time is lost. For example, it is possible to use three of the tape units with the computer while erasing the fourth unit. There had been some thought at one time of causing the erase circuits to be activated automatically along with the print circuits but the extra complication was not thought worth while for these applications.

**Input-Output Dumpers**

Figure 5 shows the “input and output dumpers.” It is a modified version of a commercially available dictating unit that uses magnetic wire. The changes made include mechanical modifications to speed up the wire to 8 feet per second. The head was changed to permit higher fidelity signals to be obtained. The electronic circuitry was completely replaced by circuits similar to those used in the tape units, with one exception. The input dumper can be used for reading only, and the output dumper can be used for recording only. Two switches have been provided on each unit. These permit the wire to be manipulated into position for a given program.

This kind of unit has turned out to be tremendously convenient. Each mathematician using the machine generally has several of the snap-in cartridges which fit into the main unit. These he keeps with him for use whenever he has computer time. Various programs are marked off as shown. Dozens of different programs, problems, or sets of data can be stored on a single cartridge. Also, test routines are recorded to be used by the engineers during testing or maintenance periods. The method of initially recording these programs on the cartridge will be described later, in the paper on auxiliary equipment. By using the wire unit, it is possible to load the acoustic memory completely in 12 seconds, including switch manipulation.

**Teletype Unit**

Figure 6 shows the Teletype equipment that is now in use. It consists of a modified Teletype tape reader, keyboard,
bars are set up in the Teletype printer, after which the appropriate key is struck. Teletype is mainly used now for manual input and output operations. For example, suppose we wish to troubleshoot a particular routine. By means of the Teletype we can ask that the contents of a particular memory cell be printed out. If it is incorrect, a correct word can be inserted via the keyboard.

The Teletype equipment seems to be most useful in three ways: for troubleshooting the machine, for troubleshooting new programs, and for those programs where there is a great deal of computation but very little output data. However, because of their speed, magnetic tape and wire are used for practically all programs.

Teletype operates at six characters per second, giving about 24 binary digits. Since a word in SEAC is 48 bits, this takes 2 seconds per word. To fill the memory from Teletype therefore takes 1,024 seconds or about 17 minutes.

On the other hand, the wire works at about 3.2 kc. So each word of 48 bits takes about 1/64 of a second. If we add the time taken by 512 words, plus the time for gaps between groups of eight words, plus starting time, we come out with a figure of 12 to 13 seconds to fill the memory completely. This is at least a factor of 85 over Teletype.

Selector Relay Unit and Selection System

The unit which provides the communication between the magnetic units and the computer is the selector relay chassis. This chassis contains a bank of ten relays. Each one is 8-pole and of the plug-in variety. One or more may be energized when a particular input-output operation is called for.

The cabinet shown in Figure 7 not only houses the relays but other equipment as well. One is the master oscillator which provides the low-level erase signals to all tape units. The other is the amplifier which receives signals from the pre-amplifiers in the wire and tape units. This chassis amplifies the 2-volt signals and amplifies and shapes them, so that at the output terminals a standard 3-micro-second 18-volt signal is obtained. These are the signals that are then sent to the computer for interpretation. In this cabinet is located a 4-inch speaker on which one can listen in on the tape and wire signals. This turns out to be very useful in monitoring programs.

The only other unit remaining to be described outside the computer is the manual selector panel. As shown in Figure 8, it contains a bank of ten main switches. Each switch is designated by a given hexadecimal code such as 03, 05, 06, 09, and so on. Each switch has 11 positions, one Off position, and ten for ten possible input-output units, of which seven are now used.

Perhaps at this point it would be well to explain the selection system. An order in SEAC may be described by 11 hexadecimal digits plus a sign. In a tape order, the second and third most significant digits in the code determine the input or output unit to be used.

Figure 9 contains an example of a typical tape input order in SEAC. Each code number, such as 03, 05, and so on, is generally related to a specific piece of equipment. However this is not always the case, as will be shown. Thus, 03 in general, means Teletype will be used; 05 means input dumper; 06, output dumper, and so on. Let us take a typical problem. Here the coder might designate input from wire, put most of his output data on tape unit number 1, and print out occasional words on Teletype to indicate punch, and printer. A hexadecimal or base-16 code is used. This employs the numbers 0 through 9 and the letters A through F. Five-hole paper tape is used to provide not only for the numbers but for sign, space, and carriage return. Essentially, what happens on input is as follows: One line of the Teletype tape is above the metal sensing fingers in the tape reader. These fingers move upward in one operation and set up the four binary digits in parallel. Because of the organization of the input-output system this information must be sent to the computer bit by bit in serial fashion. This is the function of the TD, on which a rotating brush examines four small segments previously energized by the fingers. This information is transmitted to the Teletype supervisory control where the signals are shaped before being sent to the rest of the computer.

When printing out information, another TD is set in motion. This output TD merely sets the rate at which the computer information will be printed. Signals from the computer are sent through the supervisory control and during the revolution of the TD, the code...
Typical tape order

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SWITCH CODE

Figure 9 (left). Selector code

Figure 11 (above). Block diagram of the shift register

the present stage of the problem. He would then set up the switches in the normal ways, 03 to Teletype, 05 to input dumper, and 09 to tape unit number 1. However, suppose that at the time the problem was to be run on the computer, trouble was encountered with the first tape unit. All the coder has to do is set code 09 to tape unit number 2 by means of the 09 switch on the selector panel. Now all references for 09 go to tape unit number 2. In other words a given code number can mean any unit as designated by the switch on the control panel. The flexibility of the system means that units do not have to be continually plugged in and out when trouble is encountered. Furthermore, the operator can use the unit that is most appropriate for the present state of a given program. Coded selection can always be overridden by the direct selector switch, if desired.

The code system is based on the energizing of at least two out of five input lines. Thus, of the two hexadecimal characters only five binary digits are used. This particular method appeared to give the advantage of economy of equipment, where no more than ten input-output units were expected to be used.

This system also makes it possible to record on two or more units at once, providing they are compatible. Thus all four tape units could record simultaneously the same information if necessary.

Shift Register

It might be interesting to describe the means of going from relatively slow input equipment to the high-speed portion of the machine. This is the function of the shift register, which in this case acts as a speed changer.

As can be seen from Figure 10, the shift register and its control comprise two racks of equipment. Its size and complexity are due to its many functions. Only three of these functions will be mentioned:
1. Inversion of words.
2. Acting as intermediary between the input-output equipment and the serial acoustic memory.
3. Acting as a register for an experimental Williams memory that uses the parallel mode.

The need for inverting numbers or words is brought about as follows. The normal method of writing numbers on paper or putting numbers into the machine via keyboard is to put them in with the most significant digit written first. Thus in writing 38945 we first write the three, then the eight, and so on. However, the machine uses the number with the least significant figure first, for obvious reasons, in addition, subtraction, and so on.

Figure 11 shows in very simplified form, the method by which the shift register does its work. There are 48 flip-flops arranged to form a closed loop. Note that the shift register only shifts in one direction, to the right.

An input operation starts with the clearing of the shift register and the injection of a so-called marker pulse in stage 47. Its function is to indicate when an operation is completed. After the marker is inserted, the first pulse from the tape or Teletype is entered in position 46. Soon after this, the loop is shifted by a train of 47 pulses. At the end of this time the marker has advanced one stage to the left, that is, stage 48, and the first digit is in stage 47. The second digit is now placed in stage 46, and this same type of shift takes place again.

This is done 47 times until the marker ends up in stage 46, the most significant digit in stage 45, the next most significant digit in stage 44, and the least significant digit in stage 1. The fact that the marker is detected by the timing pulse at this time indicates that the word is now in position. The control changes, so that the loop is broken at A and B, and the next shift train affects only the first 45 stages. This time a 43-pulse train is generated which shifts the word along the bus where it is routed to the memory.

This is the manner in which words are put into the acoustic memory. Getting words out of memory is somewhat similar and proceeds as follows. The marker is again set up in stage 47, and the number is brought into the shift register via stage 45. By shifting 45 times, the word is gotten into position with the least significant digit in stage 1. At a signal from the tape unit that it is ready for information, the digit in 45 is transferred to the tape unit and about 2 microseconds later a shift of 47 steps takes place. This puts the contents of stage 44 in position 45, and that of stage 45 in position 46. At the next signal the pulse in 46 is eradicated and that in 45 read out. When the marker finally gets into position 46, the shift register signals the computer that the operation is over and we are ready to proceed with the next operation.

This completes the general description of the SEAC input-output system with the exception of two units, the read chassis and the synchronizer chassis. However, circuits performing similar functions are described in the paper on auxiliary equipment.

Input-Output Devices Used With SEAC

JAMES L. PIKE

The input-output devices that are used with SEAC can be classified rather generally as either low-speed or high-speed equipment. In the low-speed class, the use of Teletype equipment for the basic keyboard and printer, useful in troubleshooting and program checks, was suggested because of its reliability and its availability.

The principle followed in adapting Teletype to our computer was to avoid any modification to the basic mechanism that would affect its reliability. The code bars were reground and filled in where necessary, to alter the code. Most of the function bars were removed and the few remaining were modified with respect to the code they recognize. A Teletype transmitter-distributor (TD) is used to provide the timing signals to the computer for output printing at the standard Teletype rate.

Work is now in progress on adapting Flexowriter apparatus to the basic input-output functions of a computer. Its operating rate is slightly higher, about 10 characters per second as compared with six for Teletype. The Flexowriter has several advantages in that it may be adapted to perform functions not readily possible with Teletype apparatus. It offers such additional features as upper and lower case letters, 6- or 7-unit code, color change, and tabulating.

The basic difference in the two types of equipment is that Teletype operates sequentially and Flexowriter operates in parallel. The Teletype apparatus is well suited to serial input-output since it includes distributing and collecting apparatus. The Flexowriter, since it is not designed to be operated over long lines, handles the units in each code character simultaneously on separate lines. In many types of computer circuitry, of course, this is a preferable arrangement.

The standard Flexowriter system comprises a punched-paper tape reader and a punch built into an electric typewriter as one complete unit. The Teletype machine in use with SEAC for some two and one-half years has proved quite reliable, and it remains to be seen whether Flexowriter equipment will provide similar reliability.

High-Speed Input-Output

As soon as SEAC was put into routine operation, it became evident that a faster system for getting information into and out of the computer would be highly desirable. On many problems the time spent reading punched-paper tape input or printing output on the Teletype printer was more than 95 per cent of the computer time on the problem. This very inefficient use of the computer was remedied by the addition of input-output dumper units. These are magnetic wire recording devices adapted from the mechanism of an office dictating machine, as pictured in Figure 1. This equipment was chosen.