SDS 940 Time-Sharing Computer System

SDS

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FOREWORD

Scientific Data Systems developed the SDS 940 Time-Sharing Computer System to bring to the market new equipment that is compatible with the Berkeley Time-Sharing Software System. The research project that produced this software system was conducted at the University of California, Berkeley. A brief review of the project's history highlights the significance of this pioneering effort.

In June 1963, Project Genie was initiated at Berkeley to study Man-Machine Interaction. Professors Harry Huskey and David Evans served as co-principal investigators. The Office of the Secretary of Defense, Advanced Research Projects Agency (ARPA), provided all necessary funds for the work, which was performed under Contract SD-185.

The technical approach employed required the simultaneous on-line interaction between several investigators and a powerful central digital computer. This factor prompted the decision to develop a low-cost, high-performance, time-sharing computer system.

A critical aspect of the system's performance requirements was the need to provide a very high capability, multi-language structure with extremely fast response time for a limited number of users. Recognizing that the ultimate number of users could grow well beyond initial needs, however, the system designers arranged to handle a larger number of users without severely decreasing responsiveness to any single user.

In early 1964, the decision was made to develop the Berkeley system utilizing the SDS 930 Computer as the central processing unit and incorporating peripheral equipment from several suppliers as design progressed. In September 1964, the SDS 930 was delivered to Berkeley.

By January 1965, the Berkeley research team, led by Melvin Pirtle, had obtained and integrated peripheral equipment and modified the SDS 930 hardware to provide time-sharing features. These features were required by the software architecture established by Pirtle and Dr. Wayne Lichtenberger to implement the Berkeley Time-Sharing Software System. In the meantime, the software package was being developed and, by April 1965, the hardware/software system was on the air and operational.

By mid-1965, various documents describing the Berkeley system's design and implementation had become publicly available and the system had been publicly demonstrated many times.

The system's performance, as evidenced by its documentation and demonstrated capabilities, has already established the Berkeley research work as one of the industry's outstanding time-sharing computer efforts. The low cost at which this performance has been achieved makes the effort even more remarkable.

Recognizing how significantly the Berkeley project advanced the state-of-the-art in time-sharing computation, SDS decided to make the Berkeley Time-Sharing Software System available to the market. This decision led to the development, by SDS, of the SDS 940 Time-Sharing Computer System. The result is a set of SDS-produced equipment that is fully compatible with the Berkeley Time-Sharing Software System. In particular, the time-sharing hardware features of the SDS 940 Computer are based upon documented modifications to the SDS 930 made by the Berkeley group.

Because the central computer of the Berkeley system is a modified SDS 930, which has a fully compatible 930 Operating mode, members of the Berkeley project automatically became members of the SDS Users Group. As a result, the Berkeley Time-Sharing Software System is available, through the SDS Users Group, to other SDS equipment users. In addition, modifications that the Berkeley project members may make to their software for their own use also become available. SDS has assumed responsibility for maintaining interfaces between the Berkeley software and specific SDS hardware that is unique to the SDS 940 system. This arrangement assures the SDS 940 Time-Sharing Computer System user of a fully operational system based on (1) a hardware extension of a field-proven digital computer and (2) a demonstrated, fully operational software system.

SDS 940 Time-Sharing Computer

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SDS 940 CHARACTERISTICS

The SDS 940 is a high-speed, low-cost, general-purpose digital computer that is an extension of the SDS 930. As such, it is fully compatible with all other SDS 900 Series computers. The special features on the SDS 940 that are in addition to those on the 930 include:

- Monitor and User modes of operation with a set of privileged instructions that are reserved to the Monitor mode.
- 930 Operation mode, which makes the SDS 940 operate exactly as an SDS 930.
- A hardware-implemented "memory map" that provides for dynamically relocating, protecting, and executing programs in scattered fragments of memory.
- System Programmed Operators (SYSPOPs), which make Monitor mode service routines available to User mode programs without loss of system control or use of user memory space.
- Nonstop operation protection, which ensures against program hang-ups due to infinite indirect address loops or Execute instruction loops.
- Basic core memory 4096 words, expandable to 65,536 words, all addressable with

  0.7-microsecond access time
  1.75-microsecond cycle time

As an extension of the SDS 930, the SDS 940 retains all of the following characteristics:

- 24-bit word plus parity bit
- Binary arithmetic
- Single address instructions with

  Index Register
  Indirect Addressing
  Programmed Operators

- Memory overlap between Central Processor and I/O with two memory banks
- Memory available in 4, 8, and 16 K banks
- Multiprecision programming facility
- Typical execution times (including memory access and indexing)

Fixed-Point Operations (in microseconds)

Add	3.5
Multiply	7.0

Floating-Point Operations (in microseconds)

	24-Bit Fraction (plus 9-bit Exponent)	39-Bit Fraction (plus 9-bit Exponent)
Add	77	92
Multiply	54	147

- Program interchangeability with other SDS 900 Series Computers
- Parity checking of all memory and input/output operations
- Priority Interrupt System

  SDS I/O Options Interrupts two levels standard, 38 optional

  System Interrupts, 896 optional

- Optional power fail-safe feature permits saving contents of memory and programmable registers in case of power failure.
- Up to four I/O communication channels (with optional interlacing capability), time-multiplexed with computer operation, providing input/output rates of up to one word per 3.5 microseconds
- An optional Direct Memory Access System that allows input/output transfer to occur simultaneously with computer memory access, providing input/output rates of up to one word per 1.75 microseconds
- One to four Direct Access Communication Channels that incorporate the Direct Memory Access System
- Data Multiplex Channel that uses direct memory access connection and accepts/transmits information from external devices, or subchannels, which can operate simultaneously; thus, externally controlled and sequenced equipment can perform input/output

buffering and control operations rather than the computer.

- Time-Multiplexed Input/Output Channels operate upon either words or characters. A 6-bit character is the standard character size; 6- and 12-bit characters, or 6-, 12-, and 24-bit characters can be specified as desired. Direct Access Channels operate upon words and characters. These channels accept 6-, 8-, 12-, and 24-bit characters. The number of characters per words is specified by the external device.
- Input/output with Scatter-Read and Gather-Write facility
- Standard input/output

  Time-Multiplexed Communication Channel (without interlace)

  Control Console
- Optional input/output devices

  Automatic typewriter

  Photoelectric paper-tape reader and paper-tape punch, and spooler mounted on cart

  MAGPAK Magnetic Tape System

  Magnetic-tape units (IBM-compatible; binary and BCD)

  Punched-card equipment

  Line printers, graph plotters

  Typewriter with electromechanical paper-tape reader and punch

  Auxiliary disc files

  Communications equipment, teletype consoles, display oscilloscopes

  A/D converters, digital multiplexer equipment, and other special system equipment
- FORTRAN II and symbolic assembler as part of complete software package
- All-silicon semiconductors
- Operating temperature range: 10° to 40°C
- Dimensions: 124 inches x 25-1/2 inches x 65 inches
- Power: 3 kva

INTRODUCTION

The new SDS 940 Computer is the first low-cost system designed specifically for general-purpose simultaneous use by many users. The SDS 940 is unique in that it provides, within a $400,000 computer system, the broad range of programming languages and aids generally found only on multimillion dollar computers. Like multimillion dollar time-sharing systems, the SDS 940 has advanced, sophisticated hardware to deal efficiently with system organization problems that are uniquely characteristic of a time-sharing mode of use.

Developed as an outgrowth of a research program at the University of California, Berkeley, the SDS 940 uses the currently operational Berkeley Time-Sharing Software System and is an extension of the high-performance SDS 930 Computer. Thus, the 940 user is assured of a field-proven, thoroughly operational system with an existing and demonstrable time-sharing software package.

In summary, the SDS 940 permits up to 32 active users to engage simultaneously in on-line program preparation and debugging. Each user views the SDS 940 system as if he has a 16,384-word, 1.75-microsecond-memory-cycle computer at his sole disposal. A single SDS 940 Computer gives the user multiple computer capability at a price of a single computer with few, if any, of the programming or operating restrictions found on other medium-priced time-sharing systems.

System response times are a function of the number of active users. Typical times are:

6 active users	1 second
20 active users	2 seconds
32 active users	3 seconds

DEFINITION OF TIME SHARING

Because time sharing is a generalized term, it assumes different meanings for different people. Attempts at defining the term prove less useful, however, than does listing those aspects that characterize current time-sharing systems. Depending upon the application or the goals of those concerned with a particular system, one or more of the following aspects of time sharing predominates:

- Multiprogramming--Several independent, but perhaps related, programs or routines residing and operating within a single computer system.
- Multiprocessing--Several program processes are executed concurrently within a computer configuration consisting of two or more central processing units.
- Real-Time Processing--Program execution that satisfies a particular operational response time, which can range down to microseconds.
- Remote Processing--User input/output devices are connected by communication facilities to a remotely located computer system.
- Interactive or On-Line Processing--A computer system serves a human user or device through direct communication. For users this often includes conversational interaction.
- Multiple Access--Several on-line communication channels provide access to common computer system.

CHARACTERISTICS OF TIME-SHARING COMPUTER UTILIZATION

Time-sharing operation of a computer system permits allocating use of both space and time on a temporary and dynamically changing basis. Several user programs can reside in core memory at one time while many others reside temporarily in auxiliary disc memory. Computer control is turned over to a resident program for a scheduled time interval or until the program reaches a delay point (such as an I/O operation), whichever occurs first. At this time the user's program can be dumped to disc and subsequently reloaded from disc when his next turn for machine use occurs. Under these conditions, several critical time-sharing operational characteristics become clear:

1. To conserve core space and minimize swap time, user programs should share common routines wherever possible.

2. The interchange of programs between disc and core on a rapidly changing demand basis literally "tears" memory to shreds, leaving space available for program loading in a fragmented, randomly distributed form.

3. Undebugged user programs are almost certain to contain errors, yet must be run without interfering with other user programs or the system Executive program.

TIME-SHARING FUNCTIONAL REQUIREMENTS

These aspects of time sharing impose several hardware requirements not generally found in current computer systems. The hardware for a time-sharing system should enable the user to:

1. Reference program procedures and data independent of their location in physical memory.

2. Dynamically relocate programs in memory.

3. Utilize available fragments of memory without the necessity of repacking distributed resident programs and data.

4. Use common procedures and data by an arbitrary number of programs.

5. Protect system resources, including memory areas of all types and input/output devices, from unauthorized access and use.

6. Protect against interference among independent programs including memory protection, unauthorized interprogram branches, computer halting, or computer hang-ups.

7. Minimize overhead costs in the executive routine for the control of the time-sharing environment.

SDS 940 TIME-SHARING HARDWARE FEATURES

The SDS 940 System uniquely meets these functional requirements by providing the following features:

- A hardware-implemented "memory map" that lets users dynamically allocate memory and dynamically relocate and operate programs within scattered fragments of memory. This feature permits programs to reference procedures and data independently of their location in physical memory. It also provides the memory-protection features required by a time-sharing environment.

- Monitor and User modes of operation together with the establishment of and control over a set of privileged instructions that are reserved to the Monitor mode. The privileged instruction set precludes User execution of any instruction that affects peripheral equipment, halts the computer, or changes the mode to the Monitor state without relinquishing control of the computer to a Monitor state program.

- System Programmed Operators (SYSPOPs). SYSPOPs are instruction-structured, generalized calls to the operating system for specific services provided with that system. Their inclusion, together with the memory map, makes it possible to include and efficiently call public routines as common procedures available to all programs.

- Provision of arbitrary interruptibility for long or indefinite sequences of indirect addresses or Execute instructions. This feature assures that no program can hang up the computer through the improper execution of an infinite indirect address chain or infinite Execute instruction sequence.

SDS 940 SPECIFICATIONS

GENERAL

Because the SDS 940 is an extension of the SDS 930 Computer, all SDS 930 specifications apply to the SDS 940, except those specifically noted. Minor exceptions to the 930 specifications do occur when the 940 operates in the Monitor or User mode. To provide complete 930 compatibility and make the full 930 software set available to 940 users, the 940 includes a 930 operating mode. Complete descriptions of the 930 mode are contained in the SDS 930 Computer Reference Manual, SDS publication number 900064C.

The principal ways in which the 940 varies from the 930-- when the 940 operates in the Monitor or User mode-- are presented in this brochure.

The following specific hardware features have been added to the SDS 930 to convert it to a 940 and are invoked only in the Monitor and User modes.

OPERATING MODES

The SDS 940 operates in any of three modes, which are designated as the 930 mode, the Monitor mode, and the User mode.

930 Mode

In the 930 mode, the 940 is completely identical with the SDS 930.

Monitor Mode

In the Monitor mode, the full complement of 930 instructions are at the 940's disposal. Memory addressing is normal, and even the memory extension register can be used if desired. Two changes distinguish this mode from the 930 mode. Monitor mode programs can address memory through the memory map (as described later) thus giving them access to information in user areas utilizing user addresses. To accomplish this, a bit in the instruction word, or in any intermediate indirect address word, invokes the mapping operation for the duration of the instruction. A second, minor change occurs in the location of storage of the overflow indicator at the time of performing subroutine entries. This change applies only to the Monitor mode.

User Mode

In the User mode, the 940 and 930 are completely compatible when the following three changes are made:

1. A set of privileged instructions is defined and forbidden in the User mode. This set consists of all undefined order codes, halt, all input/output orders (including all EOMs except ROV and REO), and all sense orders except for Overflow Test.

2. A new class of operations called system programmed operators (SYSPOPs) is provided. SYSPOPs are an extended form of the standard SDS programmed operators (POPs). The user can still use POPs unique to his application. If he does so, he must reserve space in his portion of memory for the POP transfer vector and for the routines that these POPs invoke. The SYSPOPs, however, permit user access to public routines provided by the operating system. As such they do not occupy any space in the user's memory area. This, in effect, greatly augments the power of the machine that the user has at his disposal without pre-empting any of his allocated memory space.

3. All memory access made in the User mode goes through the memory map.

MEMORY MAP

The memory map provides for dynamic relocation of programs, for fragmentation of memory, and for two modes of memory protection. It is used to convert program addresses (i.e., addresses within the virtual machine in which the user's program assumes that it is operating) to memory addresses (i.e., actual physical core memory locations occupied by the user's program and data). To accomplish this, the memory map operates on the 14-bit 940 address field, which permits user programs to directly address 16,384 words of core memory. The memory map consists of eight 6-bit quantities (designated as R_0, R_1, ... R_7) held in two 24-bit active circuit registers designated as RL1 and RL2. The structure of these registers is as follows:

RL1

R_0	R_1	R_2	R_3
0 5	6 11	12 17	18 23

RL2

R_4	R_5	R_6	R_7
0 5	6 11	12 17	18 23

A program address is converted through the memory map to a memory address in the following manner. The value, i, defined by the three high-order bits of a 14-bit program address, is used to select the proper one of the eight quantities, R_i. The low-order five bits of R_i then have appended to them the 11 low-order bits of the program address to form a 16-bit memory address. This operation does not add ANY time to instruction execution. The mapping process is illustrated by the example shown in Figure 1.

From this description it may be seen that the memory is considered to be divided into 32 pages or blocks, each containing 2048 words. In the mapping mode, memory is accessed under control of a 5-bit page number and an 11-bit address, which specifies a location within the 2048-word page. When mapping is invoked, the upper three bits of a program address constitute the page number. The mapping hardware replaces the user's page number, i, with a physical page number R_i, which may be different from time to time as the program is moved in and out of memory. Because of the spatial relationship of the page number and page address, the user program is not aware of the page structure of the memory. Thus, the mapping hardware permits memory fragmentation by allowing the user's storage to be located in noncontiguous blocks, which appear to the user and to the machine to be contiguous. Because the address field of the 940 contains 14 bits, only 16,384 words or eight pages are directly addressable by any user at any one time. Several techniques are available in the Executive system to allow users to use more than 16,384 words in their programs.

The memory map registers are loaded by an EOM, POT sequence. An EOM 21000 clears the RL1 register, and the following POT instruction loads it with a new 24-bit setting. Similarly, an EOM 20400 clears the RL2 register, and the following POT instruction loads it with a new 24-bit setting. These operations require a total of eight memory cycles or 14 microseconds.

The memory map also provides two modes of memory protection. Only the lower five of the six bits in the R_i quantity are used for actual page numbers. Memory addresses obtained by mapping are therefore 16 bits long, permitting up to 65,536 words of core memory in the system. The sixth bit of the quantity R_i designates a read-only block. The facility to have read-only storage enables users to share subsystems directly without interference and without the necessity of calling the monitor constantly to change the R_i quantities. Any Write re-

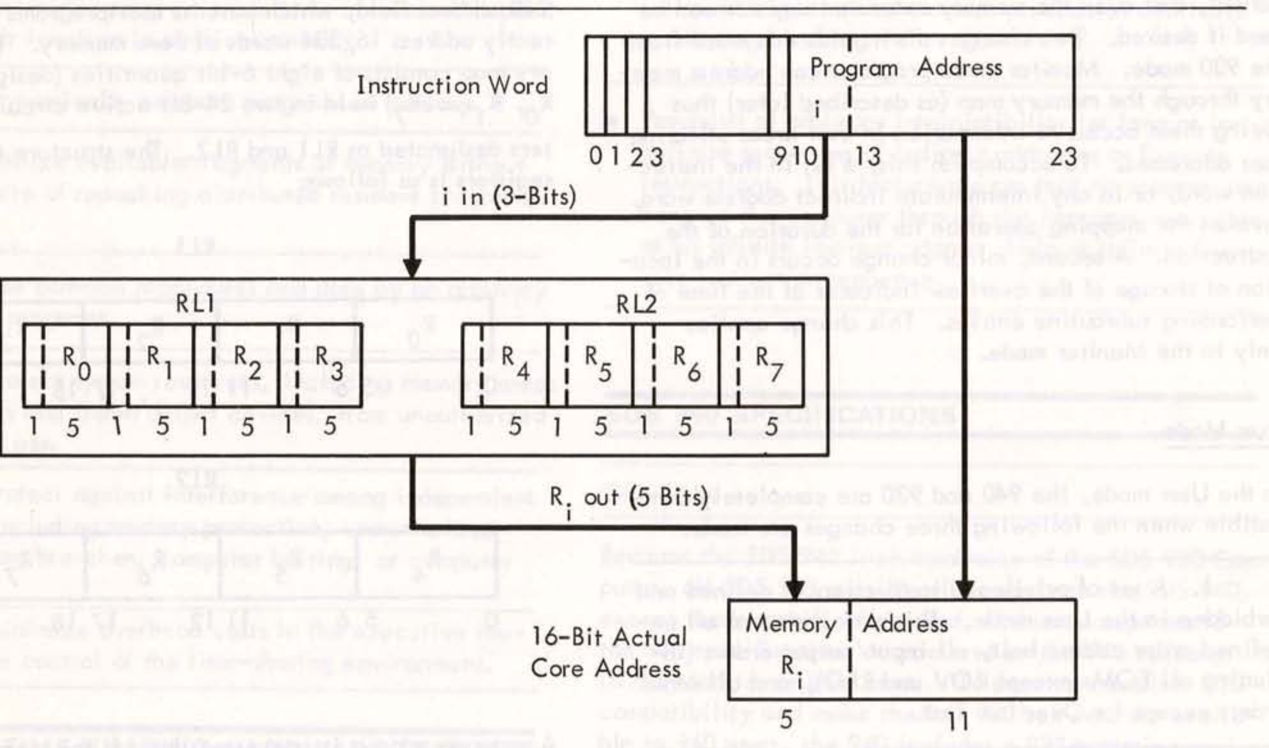


Figure 1. SDS 940 Mapping Process

quest that involves a reference to an R_i quantity with a sixth bit of one and nonzero value in its low-order five bits results in the conversion of the instruction to a NOP and a trap to cell 0043_8.

Absolute memory protection (i.e., protection against any reference) is accomplished by using $R_i = 100000$ to mean that no memory is assigned to the page i. Any reference to an R_i quantity with this value results in conversion of the instruction to a NOP and a trap to cell 0041_8.

Figure 2 shows a 6144-word memory allotment distributed in 2048-word blocks at 24000, 64000, and 14000. The block at 14000 is read-only. It may be seen that reference to any program address greater than 13777 points to one of the quantities R_3 through R_7, causing an out-of-bounds trap. Note that the user can transfer control, for example, to his locations 10000 through 13777, but an attempt to store information there causes the trap to occur.

Mapping is always performed in the User mode. Mapping for individual instructions can also be invoked in the

RL 1			
00101	001101	100011	100000

RL 2			
100000	100000	100000	100000

00000	0	2048-Word Block
00001	1	2048-Word Block
00010	2	2048-Word Block
00011	3	mapped location of program addresses 10000 - 13777
00100	4	2048-Word Block
00101	5	mapped location of program addresses 00000 - 03777
00110	6	2048-Word Block
00111	7	2048-Word Block
01000	8	2048-Word Block
01001	9	2048-Word Block
01010	10	2048-Word Block
01011	11	2048-Word Block
01100	12	2048-Word Block
01101	13	mapped location of program addresses 04000 - 07777
01110	14	2048-Word Block
01111	15	2048-Word Block
10000	16	2048-Word Block

Figure 2. Example of a 6144-Word Memory Allocation and Its Mapping

Monitor mode. When accessing memory in the Monitor mode to obtain the effective address of an instruction, any word encountered with bit 0 set causes the mapping operation to apply immediately and for the duration of the instruction. Thus, in the Monitor mode, an instruction with bit 0 set causes its address field to be taken through the map, while an instruction with a chain of indirect addresses invokes mapping the first time bit 0 occurs in an indirect address. In the latter case, subsequent indirect references also use the map until the instruction is completed.

SYSTEM PROGRAMMED OPERATORS (SYSPOPS)

Input/output instructions are among the privileged instructions not allowed in the User mode. The operating system must do all I/O for the user; and he must, therefore, be able to call the system for such services. Also, the system Executive program includes many complex services, some of which are of great potential value to a user. Such services should be provided by system calls. The System Programmed Operators (SYSPOPs) permit such calls to be accomplished.

SYSPOPs are an extension of a normal SDS 930 feature--the Programmed Operator (POP). Setting a bit in the instruction word invokes POPs. They function as a special kind of subroutine call. In the execution of a POP, the op code bits are not decoded in the usual way. Instead, they are taken to be the relative address in a transfer vector beginning at 00100_8 to which control is transferred. At the same time, the contents of the program counter and the status of the overflow indicator are stored together with an indirect address bit in location 00000. Single arguments or the location of a list of arguments can thus be transmitted to the body of the POP indirectly through the link in 00000. The address field of a POP is not used in getting to the POP routine. Thus it, too, is available for transmitting address information to the POP routine. The format of a POP is the same as that of a normal machine instruction; hence the POP provides a convenient way of simulating nonexistent machine instructions.

The SDS 940 not only has the POP feature but also provides its SYSPOP extension. A SYSPOP is a POP instruction that contains a one in bit 0. If a SYSPOP is encountered in the User mode, the 940 immediately reverts to the Monitor mode before executing the POP operation. The user thus has the facility to jump to public service programs through the standard system transfer vector, which is outside his allocated memory space. This feature puts an additional 64 "machine instructions" at the user's disposal--instructions which require none of his memory allocation or other attention. The return link from a SYSPOP-entered routine automatically forces the system to the mode that existed upon execution of the SYSPOP so that SYSPOP routines can be used by programs in either the Monitor or User mode with no loss of system control. In essence, the POPs of the Monitor mode are the SYSPOPS of the User mode.

MODE-CHANGING CAPABILITY

The 930 mode is invoked whenever the computer is in Idle and the start button on the console is depressed. Transition to the 930 mode can be effected only in this manner. The transition from the 930 to Monitor mode is made by executing an EOM 22000. The transition from Monitor to User mode is made by executing any jump to an address in which mapping is invoked. The user can cause a transition from User to Monitor mode only by executing a SYSPOP, which returns control to the Executive system. An interruption or a trap that occurs when in a User mode also causes the machine to revert to the Monitor mode. There is no means for transferring directly between 930 mode and User mode.

To provide closure, the previous mode of the machine is stored as a single bit in bit 0 of the subroutine link of both interrupt and SYSPOP routines. Since bit 0 is also the bit that invokes mapping, when the return instruction is executed, the mode automatically reverts to the mode under which the computer was operating at the time of the interrupt or the execution of the SYSPOP. If arguments are accessed indirectly through the link, mapping is or is not applied, depending on the mode storage bit. Hence, SYSPOP routines, which operate in the Monitor mode, will correctly address memory through the link independent of the mode of the calling program.

It may thus be seen that interrupt routines are independent of the mode of the machine at the time of the interrupt and that the system routines explicitly called by the various programs do not require software interpretation of:

- The mode of the call program (Monitor or User),
- The location of the call,
- The location of the arguments (Map or no Map), and
- The specific action requested.

It should be noted that interrupt routines take no more time and, in fact, are no different from similar routines in a non-time-sharing system. Further, the overhead associated with calls to the system (SYSPOPs) is only four memory cycles or 7 microseconds.

HARDWARE HANG-UP PREVENTION

To continue to provide extremely rapid response to interrupts and to insure that user programs cannot inadvertently tie the computer up in an indefinitely long uninterruptible state, interrupt requests take precedence over indirect address calculations and Execute instructions. If either operation is in progress when an interrupt request occurs, the operation is converted to a NOP; and the interrupt request acknowledged. The link to the interrupt routine contains the address of the aborted instruction. Upon return from the interrupt routine, the aborted instruction begins anew. This feature insures the system against indefinite hang-up due to infinite address or Execute loops in a user's program. This feature is operative in the Monitor and User modes, and is inoperative in the 930 mode.

BERKELEY TIME-SHARING COMMUNICATIONS SYSTEM

The Teletype communications system provided with the 940 system permits the transfer of 11-unit, 10-character-per-second Teletype information between any SDS 900 Series computer and Model 35 Teletype Keyboard/Printers. Communications systems are based on the use of two basic building blocks: the CTE-10 Asynchronous Communications Controller and the CTE-11 Full-Duplex Line Group.

The CTE-10 provides the cabinet, power supply, patch panel, and other support equipment, plus the control elements, for up to four CTE-11 units. Each CTE-11 unit provides complete and simultaneous send-receive capability for four full-duplex, asynchronous Teletype lines.

When operating with a full complement of four CTE-11 units, each CTE-10 provides full-duplex capability for 16 Teletype lines. All lines can be simultaneously engaged in two-way transmission on a completely asynchronous basis.

Multiple sets of such configurations can be tied together to form a communications system of any size. The interface of the communications system thus generated operates through the parallel I/O connector (POT/PIN) of the computer and uses two interrupt locations.

Recognition of the presence of a new call (ring recognition) or of a user disconnect (disconnect detection) is optionally provided at the expense of two additional interrupts. Computer-controlled dial-out capability is optionally available on an RPQ basis.

This form of communications control is required by the Berkeley Time-Sharing Software System, which is designed to examine each character from each Teletype before the next character arrives. The Teletype keyboards are decoupled from their printing mechanisms, with the computer providing independent control over the printers. Thus, a character is transmitted from a user keyboard to the computer where it is examined. The computer then returns one or more characters to the user's printer. Except when traffic is extremely heavy, the user is unaware of the turn-around delay of the character through the computer. The asynchronous nature of the transmission system assures this characteristic of system performance.

The hardware buffering used in the full-duplex mode for the Teletype I/O operations imposes duty-cycle limitations that tend to restrict the number of simultaneously active users to 32. This restriction actually exists only under a worst-case situation in which all 32 lines are simultaneously inputting and outputting at their maximum rates. The number of lines that can be connected to the system is practically unlimited; and the number of actual active users can be considerably greater than 32, based on the probabilistic distribution of simultaneous I/O demands. I/O processing time for 32 users utilizes less than 5 percent of the computer's main-frame time.

BERKELEY TIME-SHARING SOFTWARE SYSTEM

The Berkeley Time-Sharing Software System is a well-designed, integrated set of software that uses the latest concepts of interactive multiprogramming. A generalized system, it permits user operations in languages ranging from a machine-oriented assembly language through a FORTRAN Compiler to a sophisticated List Processor. The operating system is geared to maximize both responsive service to the user and operating efficiency. In particular, maximum use is made of reentrant processes and common routines. The software elements currently available are reviewed in the following paragraphs.

TIME-SHARING MONITOR

The Monitor functions provide all I/O service to user programs; selective communications service for interactive message processing (selective "end-of-message" control characters); error processing and recovery, multiprocessing "forks"; multilevel, nested, intervention ("break") capability; memory allocation and control; interstation communication; and scheduling of user program operations.

TIME-SHARING EXECUTIVE

The Time-Sharing Executive function processes all user requests (Executive Commands) and allows users to call for, operate, and modify object programs using all available system services. The Executive provides complete bookkeeping facilities for file storage in and retrieval from secondary memory. It also includes facilities for collecting accounting data. The Executive can deal with both "experts" and "novices" in terms of the kind of interactive communications desired.

SYSTEM PROGRAMMED OPERATORS (SYSPOPS)

An important facility in the Berkeley system is the ability for user programs to directly access a set of "public" subroutines. These are not replicated for each user but are used in common. Such subroutines rapidly and conveniently perform many of the basic chores that all interactive and production programs must perform. Thus, SYSPOPs enable users to create new application programs rather easily, given such a service framework. These system-supplied functions include:

- Teletype input and output functions
- I/O word and block output functions
- Character string manipulation functions
- Floating-point arithmetic
- System service calls of various types

SYMBOLIC MACRO-ASSEMBLER

The Symbolic Macro-Assembler is a two-pass assembler with subprogram, literal, and powerful macro facilities. It is similar to the standard SDS Meta-Symbol assembler. Its output is accepted for use by the debugging program DDT, providing all the Symbol tables for effective program checkout in terms of source languages.

DDT

DDT, a versatile sophisticated on-line debugging package, permits the user to examine, search, change, and insert break-point and step-trace instructions in his program at the symbolic level. It permits the use of literals in the same manner as the assembler. It can load both absolute and relocatable assembler-produced files. Its command language is geared to rapid interactive operation by the on-line user.

QED

QED is a generalized text editor that allows the on-line user to create and modify symbolic text for any purpose. This includes inserting, deleting, and changing lines of text; a line-edit feature; a powerful symbolic search feature; automatic tabs the user can set; and ten string buffers. The user can automatically save a set of editing commands for "canned" execution later (cliches).

LISP

LISP is an extremely powerful symbol-manipulating language that uses recursive, list-processing techniques. It is particularly valuable for nonnumeric applications and logical analysis. The Berkeley system is interpretive and has the added capability of employing M-expressions, which are closer to the user's problem language than the normal input form.

SNOBOL

SNOBOL is a programming language that provides complete facilities for the manipulation of strings of characters. SNOBOL is particularly applicable to programs associated with text editing, information retrieval, linguistics, compiling, and symbolic manipulation of algebraic expressions.

FORTRAN II

The standard SDS 900 Series FORTRAN II has been adapted to operate under the Berkeley system. Essentially a production processor, it can accept symbolic source-language input created on-line by QED. Thus an on-line compile-execute-edit-compile cycle can be achieved in the system.

CONVERSATIONAL ALGEBRAIC LANGUAGE (CAL)

The Berkeley system contains a conversational algebraic language that resembles the Joss language developed by the RAND Corporation. This interpretive language is primarily aimed at small numerical problems in a highly interactive environment. It is an incremental compiler.

HELP

The HELP package provides on-line question-answering service for use by the time-sharing Executive and the previously described subsystems. HELP affords users convenient access to a direct self-teaching facility, which accepts questions on system or subsystem usage in natural language and answers appropriately.

SYSTEM OPERATION

The time-sharing Monitor accepts new users on-line if adequate storage is available. Scheduling is generally on a round-robin basis except that a program that has been held up for I/O operation completion is given top priority upon that completion. Alternative or additional priority features can readily be incorporated in the system. User programs can only access 16,384 words of core memory directly; but, by means of the FORK request, programs can initiate concurrent processing on additional 16,384-word elements. The initiating program can, at all times, monitor and control any of the lower level "forks."

Those service processors that are re-enterable are used in common for all users of those services. Thus, no replication in core or secondary storage is required; and swapping is minimized. This also applies to "public" subroutines accessed via SYSPOPs.

Input messages are processed according to a character ECHO table indicated by the using program. This defines those control characters that are to be recognized as an end-of-message. The system will only work with full-duplex communication lines, which makes possible much of the system sophistication. A production-type operation; e.g., a compilation, is activated as with any interactive process and is scheduled in a nonbatched manner. Thus, the "operator's" console is a Teletype--the same as that of any other interactive user.

PLANNED SOFTWARE EXTENSIONS

The following programs are being planned for ultimate inclusion in the Berkeley system and will be made available to SDS 940 users as they are completed.

DYNAMIC REAL-TIME OPERATIONS

Though critical real-time processes can be permanently embedded within the present Monitor system, a facility is being planned to provide for dynamically activating such processes and temporarily dedicating system resources to them.

ALGOL

The standard SDS ALGOL (8192-word version) will be interfaced to the Berkeley system in the same manner as FORTRAN II.

SYSTEM MAINTENANCE

A facility to update the Berkeley system on magnetic tape is planned for implementation so that users can modify and extend their initial system.

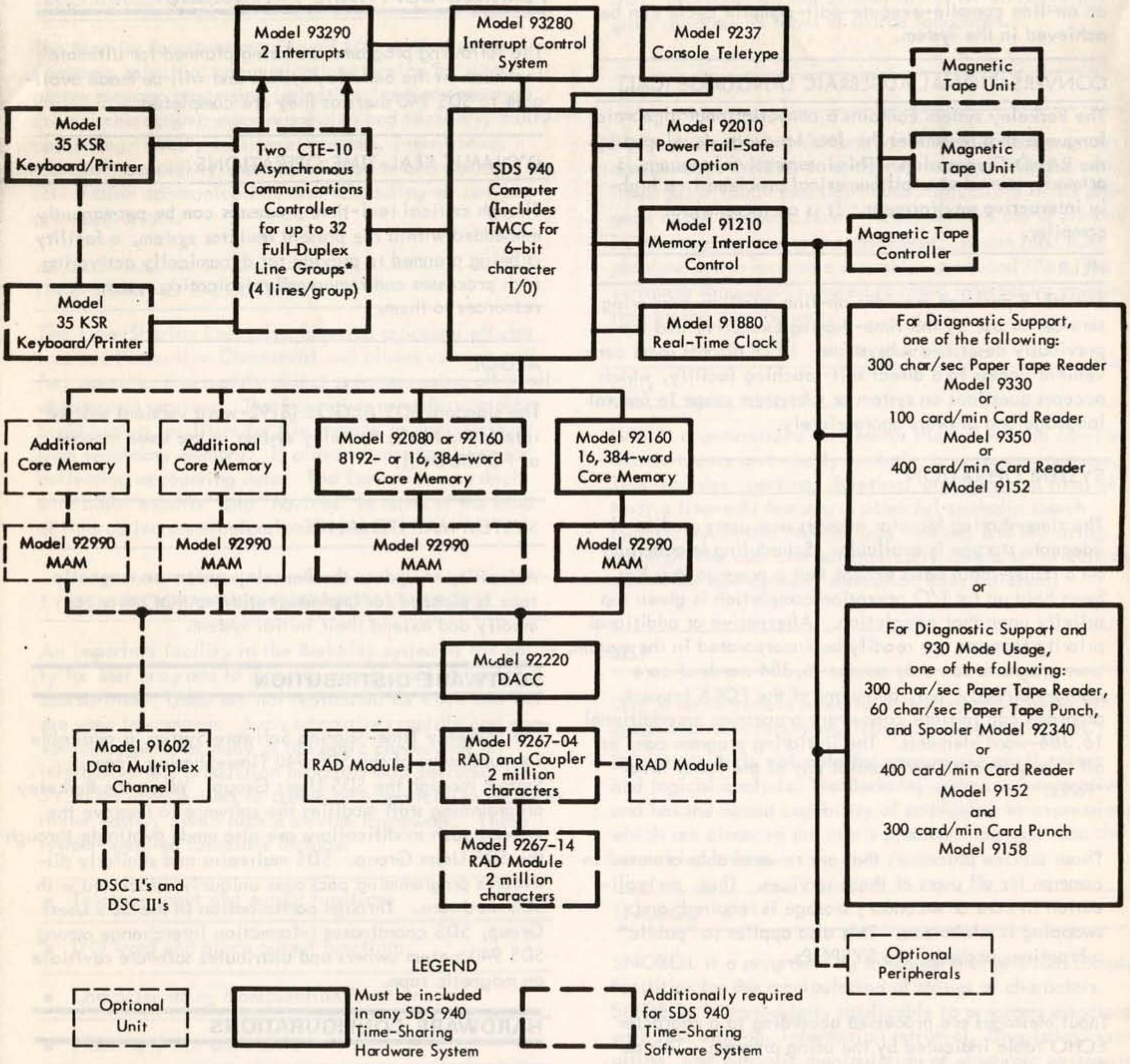
SOFTWARE DISTRIBUTION

The Berkeley Time-Sharing Software System is available for purchasers of the SDS 940 Time-Sharing Computer System through the SDS Users Group. When the Berkeley programming staff modifies the software to improve the system, such modifications are also made available through the SDS Users Group. SDS maintains and similarly distributes programming packages uniquely associated with SDS hardware. Through participation in the SDS Users Group, SDS coordinates information interchange among SDS 940 system owners and distributes software revisions on magnetic tape.

HARDWARE CONFIGURATIONS

REQUIREMENTS FOR BERKELEY SYSTEM

The SDS 940 system, Figure 3, can be supplied in a wide range of configurations to meet the requirements of a broad spectrum of applications. The minimum hardware configuration required by the Berkeley Time-Sharing Software System contains the following equipment:



* Provided by eight CTE-11 Full-Duplex Line Groups

Figure 3. Block Diagram, SDS 940 Time-Sharing Computer System

- SDS 940 Computer, including a built-in Time-Multiplexed Communications Channel (TMCC) without interlace
- One SDS Model 92160 16,384-Word Core Memory Module
- One additional SDS Model 92080 or 92160 8192- or 16,384-Word Core Memory Module
- One SDS Model 92990 Multiple Access to Memory Unit for each memory module
- One SDS Model 92220 Direct-Access Communication Channel (DACC)
- One SDS Model 9267-04 Rapid-Access Disc (RAD) Storage Unit and Coupler with 2,097,152 characters of storage. (A single RAD is minimal and does not supply sufficient storage for extensive user files. Two or more units are strongly recommended for multi-user efficiency. A total of three additional SDS Model 9267-14 RAD Storage Modules can be attached to the Model 9267-04.)
- One SDS Model 91210 Memory Interlace Control Unit
- One SDS Model 92481 Control for 1-8 Tape Transports: 75 ips, 200 character/inch, 15kc
- Two SDS Model 92461 Tape Transports: 75 ips, 200 character/inch
- One SDS Model 93280 Interrupt Control System
- Two SDS Model 93290 Levels of Priority Interrupt
- One SDS Model 91880 Real-Time Clock
- One (or more) SDS Model CTE-10 Asynchronous Communications Controller for up to four full-duplex line groups
- One (or more) SDS Model CTE-11 Full-Duplex Line Groups each providing four full-duplex asynchronous Teletype lines, one line per user station
- One Teletype Model KSR 35 Keyboard/Printer arranged for split operation for each user station. (Printer should be independent of keyboard and operated on a full-duplex circuit. Proper provision must be made for tying into the computer's communication system, either locally, or remotely through private lines or the switched network.)

DIAGNOSTICS AND 930 MODE SUPPORT

Besides the equipment already described, which is directly required for the Berkeley Time-Sharing Software System, an SDS 940 installation requires some form of paper tape or card input for diagnostic purposes. If the SDS 940 user intends to operate the 940 as a 930, using standard SDS stoftware, the system must be supplied with paper tape or card input/output capability at a performance level suitable for its efficient use in this mode. Under these conditions, the appropriate one of the following additional equipment sets are strongly recommended.

- For Diagnostic Support

  1. One SDS Model 9330 Photoelectric Paper Tape Reader: 300 character/second, with electronics for rack mounting, or

  2. One SDS Model 9350 Card Reader and Coupler: 100 card/minute, or

  3. One Model 9152 Card Reader and Coupler: 400 card/minute.

- For Diagnostic Support and 930 Mode Usage

  1. One SDS Model 92340 Photoelectric Paper Tape Reader: 300 character/second; paper tape punch, 60 character/second; and spooler mounted in cart, or

  2. One SDS Model 9152 Card Reader and Coupler: 400 card/minute, and

  3. One SDS Model 9158 Card Punch and Coupler: 300 card/minute.

OPTIONS FOR PERFORMANCE INCREASE

The SDS 940 Time-Sharing Computer System permits expansion in several directions. Additional memory modules, bringing the total amount of core storage up to a maximum of 65,536 words, can be provided. As previously noted, system performance is greatly improved through use of a second RAD unit. Further expansion to a total of four RAD units can readily be incorporated by including additional SDS Model 9267-14 Modules. Expansions in RAD storage beyond this capacity require additional Model 9267-04 and 9267-14 units.

The peripheral equipment facility of the central computer installation can be greatly expanded by including an appropriate complement of standard SDS peripherals including line printers, card punches, paper tape devices, and display equipment. The power fail-safe option can be added to further assure system integrity.

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