Hardware and Software

A floppy disk operating system for the 8080 and Z80

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Techniques for the design and implementation of a floppy disk operating system for the 8080A or Z80 microprocessors are described. Implementation details are illustrated through reference to SOS, a prototype Small Operating System which runs with a single IBM-format floppy drive on an 8080. Techniques for floppy disk communication, disk directory design, and system resource management are described and illustrated.

For years, journals such as *Behavior Research Methods & Instrumentation* have presented countless descriptions of the successes achieved by computerized research laboratories using equipment costing tens or hundreds of thousands of dollars. However, as both federal and institutional funds become increasingly difficult to obtain, a growing number of laboratories are forced to consider economic alternatives to total computerization, such as purchasing used equipment or microprocessor-based systems. Those who choose the microprocessor route quickly learn that, although inexpensive hardware is readily available, appropriate software is scarce and difficult to obtain. In a sense, the microprocessor user of today is in a position similar to that of the minicomputer user of a decade ago, in that both find the only practical source of appropriate software is internal. The present paper summarizes techniques central to the design of disk-based system software and illustrates these techniques using SOS, a Small Operating System, for the 8080 or Z80 microprocessor with at least 8K of memory and one floppy disk.

SYSTEM REQUIREMENTS

A disk-based operating system should include as a minimum the following features. (1) A bootstrap loader, often ROM resident, to permit fast loading of the system when the machine is powered up. (2) Disk I/O primitives (e.g., subroutines) that permit reading from and writing to the disk. (3) A disk directory ("table of contents") through which any information stored on the disk can be located. (4) Utility functions for system and data file maintenance such as DIRECTORY (display the "table of contents"), DELETE (to remove an unwanted data file), COPY (to copy an existing data file), RENAME (to alter the name of an existing data file), GET (to load a data file to memory), and SAVE (to create or update information on the disk from information in memory). (5) Utility programs such as a text editor, an assembler, and per-

haps compiler(s) for higher level languages such as BASIC, PASCAL, or FORTRAN.

The list of desirable features can be greatly extended, resulting in the specification of a complex but comprehensive system. However, for a small research laboratory such a system can well represent an unnecessary extravagance. The following discussion will be restricted to the features listed above.

The development of the floppy disk is the single technological achievement which makes possible the creation of a functional but truly inexpensive laboratory computer system. In view of this, the following discussion centers primarily around techniques for organizing and communicating with a floppy disk.

THE FLOPPY DISK AS A SECONDARY STORAGE MEDIUM

A floppy disk is a disk of flexible Mylar 5¼ or 8 in. in diameter which is coated with a magnetic emulsion similar to that on conventional recording tape. Disk drives are available for both sizes which provide either a single read-write head or multiple heads for double-sided recording; data can be written using either a single- or double-density format. Although double-density and double-sided formats are growing rapidly in popularity, the most widely used is the 8-in. disk, single-density and single-sided. This type disk will be used in the following illustrations.

The disk's surface is formatted into a number of concentric "tracks," and each track is divided into a number of "sectors." In order to permit disk transportability from system to system, many manufacturers conform to a standard commonly referred to as the "IBM 3740" format, which provides 26 sectors of 128 bytes for each of 77 tracks. Disks formatted in this way provide 2,002 sectors, or 256,256 bytes of usable storage.

Disk drives are interfaced to the computer via a "controller" which attends to all the details of formatting, error detection, and parallel-serial conversion. Programming, therefore, requires positioning the disk

head to the desired track, locating the desired sector, and transferring one or more sectors of information to or from the disk.

THE DISK DRIVER

The read and write routines (frequently referred to as the disk "driver") are central to the operation of any disk-based operating system. Since all disk I/O operations are mediated by the driver, it should be coded to maximize ease of use and should include facilities for error detection and recovery. Although the disk is accessed by both track number and sector number, the sector/track distinction should be of concern only to the driver, not to the user. A user need only specify a sector relative to the start of the disk or the start of a desired data file. The driver should calculate the correct track and sector within that track.

Dispite the extreme reliability of the floppy disk, errors occasionally occur. The IBM format includes several cyclic redundancy checks (CRCs, similar to a check sum) for each sector transfer. The controller generates a CRC when a sector is written and checks it when that sector is read. If the CRC check reveals an error, a status bit is set by the controller which is accessible to the software. Furthermore, the IBM format includes a sector header that precedes each

sector and contains the correct track and sector address. On each transfer, the controller attempts to verify head position by inspecting this header, and sets an error status bit if the attempt fails.

Figure 1 illustrates the code in 8080 assembly language for a typical disk driver that includes error recovery procedures. It can be entered at either the READ or WRITE entry points, and expects to find the desired sector address (between 1 and 2,002) in the BC register, the desired number of sectors to be transferred in the DE register, and the memory address in the HL register. Although additional error processing can be included, this driver is entirely adequate for all but the most critical applications.

DISK ORGANIZATION

In the simplest case, disks serviced by a simple operating system need to be divided into three distinct sections: the system loader, the directory, and the user storage area. The term "system loader" refers to a simple routine stored in a known location on a disk (usually Track 0, Sector 1) which on execution loads the monitor (the nucleus of the operating system). If the disk contains only the three sections mentioned, the system loader is required to search the directory for the name of the file containing the system monitor and then load it. For SOS, the system loader is con-

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;      SAMPLE DISK INPUT/OUTPUT DRIVER
;
;
;      EQUATES:
REG0 EQU 0F8H ;COMMAND REG
REG2 EQU 0FAH ;SECTOR REG
REG3 EQU 0FBH ;DATA REG
REG4 EQU 0FCH ;CONTROL REG
RD EQU 088H ;READ COMMAND
WR EQU 0A8H ;WRITE COMMAND
SK EQU 016H ;SEEK COMMAND
;
;      READ ENTRY POINT
READ: CALL SPLIT ;SET SEC. & TRK.
      CALL SEEK ;POSITION HEAD
      RLUP1: SHLD LASTH ;SAVE MEM ADDR
      MOV A,B ;SEC. TO ACC
      OUT REG2 ;XMIT TO CNTRLR
      MVI A,RD ;READ COMMAND
      OUT REG0
      RLUP2: IN REG4 ;WAIT FOR BYTE RDT
      ORA A ;SET FLAGS
      JP RDONE ;JUMP IF DONE.
      IN REG3 ;ELSE GET BYTE
      MOV M,A ;STORE IN RAM
      INX H ;INCR MEM ADDR
      JMP RLUP2 ;LOOP TIL SEC. DONE
      RDONE: CALL SCINC ;INC SEC & DEC CNT
      JMP RLUP1 ;LOOP TIL CNT = 0.
;
;      WRITE ENTRY POINT
WRITE: CALL SPLIT ;SET SEC. & TRK.
      CALL SEEK ;POSITION HEAD
      WLUP1: SHLD LASTH ;SAVE MEM ADDR
      MOV A,B ;SEC. TO ACC
      OUT REG2 ;XMIT TO CNTRLR
      MVI A,WR ;WRITE COMMAND
      OUT REG0
      WLUP2: IN REG4 ;WAIT FOR BYTE RDT
      ORA A ;SET FLAGS
      JP WDONE ;JUMP IF DONE.
      MOV A,M ;ELSE GET BYTE
      OUT REG3 ;WRITE IT TO DISK
      INX H ;INCR MEM ADDR
      JMP WLUP2 ;LOOP TIL SEC. DONE
      WDONE: CALL SCINC ;INC SEC & DEC CNT
      JMP WLUP1 ;LOOP TIL CNT = 0.
;
;      SPLIT - CONV SECT ADDR TO SEC & TRK
SPLIT: PUSH D ;SAVE DE (BLK CNT)
      DCX B ;RANGE 0 - 2001
      LLI D,080DH ;SET D=8 & E=13
      DIVLP: MOV A,B ;IS E .GT. B?
      SUB B ;SUBTRACT E FROM B
      MOSUB ;JUMP, C SET, IF NOT
      MOV B,A ;SUBT DVSR FROM DVND
      MOSUB: CMC ;COMPL 'C' (QUOTIENT)
      MOV A,C ;FETCH QUOTIENT
      RAL ;SHIFT IN 'C' BIT
      MOV C,A ;AND RESTORE.
      MOV A,B ;FETCH DIVISOR
      RAL ;SHIFT IN NEXT BIT
      MOV B,A ;AND RESTORE.
      DCR D ;DEC LOOP COUNT
      JNZ DIVLP ;LOOP FOR CNT OF 8.
      INR B ;SET SECT RANGE 1-26
      POP D ;RESTORE BLK CNT
      RET ;AND RETURN
;
;      SCINC - INC SEC CNT & TEST DONE
SCINC: IN REG0 ;READ STATUS REG
      ANI 0FDH ;MASK ERROR BITS
      JZ NOERR ;JUMP IF ALL OK.
      LHLD LASTH ;ELSE BACK UP HL
      RET ;AND RETRY RD/WR.
      NOERR: DCX D ;DEC SEC COUNT
      MOV A,D ;TEST FOR ZERO
      ORA E ;BOTH BYTES
      JNZ MORE ;JUMP UNLESS DONE
      POP D ;DISCARD 1 RETURN
      RET ;RETURN TO CALLER.
      MORE: INR B ;ON TO NEXT SEC
      MOV A,B ;GET SEC
      CPI 27 ;TRACK DONE?
      RC ;RETURN IF NOT
      MVI B,1 ;ELSE RESET TO 1
      INR C ;AND INCR TRACK
      ;
      ;      SEEK - POSITION DISK HEAD
      MOV A,C ;GET DESIRED TRK
      CPI 78 ;TEST OVERFLOW
      JNC ERROR ;ERROR IF SO
      OUT REG3 ;XMIT TO CNTRLR
      MVI A,SK ;SEEK COMMAND
      OUT REG0 ;START SEEK
      IN REG4 ;WAIT TIL DONE.
      RET ;AND RETURN.

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Figure 1. A sample floppy disk I/O driver. The driver is entered with the desired disk sector in the BC register, the total sector count in the DE register, and the starting memory address in the HL register.

siderably shortened by reserving a fourth distinct section of the disk for the monitor. The entire first track (26 sectors), minus the one sector assigned to the system loader, is reserved for this purpose. SOS reserves the next three tracks (78 sectors) for the directory and uses the remainder of the disk for file storage. On power-up, a ROM-resident bootstrap loads the system loader, which in turn loads the monitor and transfers control to it.

The disk directory is used as an index, or table of contents, through which files on the disk are located. A minimum disk system must retain at least the file name and the starting location (a sector address) in each directory entry. More complex systems also retain creation dates, last-access dates, file version numbers, file types, and additional relevant statistics for each file. In SOS, each directory entry contains the file name, its starting sector address, its size in blocks, its memory origin address, and (if the file is an executable program) its entry address. Files are named with a one- to six-letter file name and a two-letter file type (such as TX for text or DT for data).

For any disk system, it is essential that directory manipulation routines prohibit the accidental duplication of a file name and provide a means of managing disk space which becomes fragmented as old files are deleted and new ones are created. Among the most elegant methods for avoiding fragmentation is the technique of dynamically allocating disk sectors as needed, keeping track of their use with "bit maps" or linked lists. A second method involves creating a "dummy" directory entry for each sector or collection of sectors that has been freed by virtue of a file deletion. The third and simplest technique (used by SOS) is to periodically execute a "packing" routine that systematically collects all fragmented space and arranges it contiguously at the end of the disk. Packing need be performed only when required storage approaches the capacity of a disk pack.

SOS avoids both file name duplication and unnecessary fragmentation by performing two passes over the directory whenever a new file name is added. On the first pass, the entire existing directory is searched; if an old copy of the file name is located, it is deleted. On the second pass, the first area of the disk large enough to house the new file is used for its storage.

The system designer is cautioned to avoid attempting to save time by maintaining a portion of a disk directory or sector mapping information in RAM. Floppy controllers typically provide no mechanism for notifying a program if a disk is changed. Hence, it is possible to swap disks and create a situation where directory or sector mapping information for the wrong disk is in RAM, potentially leading to destruction of all information on the disk. Some commercially available operating systems have actually made this mistake.

UTILITY FUNCTIONS

Any disk operating system includes a collection of utility functions that perform necessary directory and file maintenance. Utilities fall into two general classes, those executed by keyboard command and those executed by call from a running program.

Keyboard-executable utilities presuppose the existence of a keyboard monitor that accepts and parses commands entered at the keyboard and directs them to the appropriate utility routines. For example, SOS accepts commands consisting of a directive followed by an optional list of arguments. The parser performs the following steps, in order. (1) The directive name is saved. (2) A pointer to the argument list is stored in a location accessible to any program. (3) A short table of utilities included in the monitor (GET, SAVE, and PATCH) is searched; if the directive is found, the appropriate utility is executed. (4) If the directive is not found in the monitor, the disk directory is searched for an executable program of that name; if found, it is loaded and executed. On execution, such programs can access the optional argument list by using the pointer saved in Step 2.

This technique has the advantage of providing extensibility. Any time a user requires an additional directive, he need only program the service routine for that directive and store it on the disk, and it effectively becomes a new SOS command. In operation, the distinction between monitor-resident and disk-resident utilities is transparent to the user. The SOS system includes a collection of frequently used disk-resident utilities coded in this manner (for directory listing, file deletion, file copying, file renaming, and disk packing).

The second class of utility functions are those accessible from within an executing program. As a bare minimum, a small operating system should provide facilities for program manipulation of disk files. In addition, a small system might include facilities for frequently used operations such as programmed timed delays, real-time clock support (for reaction time measurement), ASCII-decimal conversion, and any other operation that is unique to a particular application. SOS provides a carefully protected facility for program manipulation of disk files through three subroutine calls. The subroutine OPEN associates a file name with a "logical unit number" (an integer between 1 and 15). The subroutines READ and WRITE are used to transfer one or more sectors from/to the file associated with a particular logical unit number. The technique of associating a file name with a number and performing disk I/O with respect to the number is used frequently on larger systems. Among its many advantages, it permits the coding of a program without explicit knowledge of those files on which it will operate when executed.

In SOS, file communication is mediated by a table referred to as a "file control block." The FCB is modified by the OPEN routine and utilized by the READ and WRITE routines. In both cases, the logical unit number is used to index the FCB. When OPEN is executed, it performs a directory search to locate the appropriate file. If so specified (by appropriate arguments to OPEN), a new empty file is created. In either case, the file's starting and ending sector addresses are inserted into the correct FCB entry for use by the READ and WRITE routines. FCB entry 0 is always open to the entire disk (for use by the system utility routines), thus leaving 15 logical unit numbers for use by user programs. Figure 2 illustrates the code used by the central disk driver to process all file references through the FCB. On entry, it assumes that the logical unit number is in the left 4 bits of the BC register, and the desired sector relative to the start of the file is in the remaining 12 bits. This routine is integrated into the SOS disk driver illustrated in Figure 1, beginning at the label SPLIT.

The complete SOS system includes three additional utilities: a text editor, an assembler, and a BASIC interpreter. These utilities have been coded to utilize the disk structure described above and to provide the tools necessary for most applications. All three utilities have been carefully optimized to use as little RAM as possible (the editor and assembler are each small enough to execute from a single 1k-byte ROM). A detailed description of these three utilities is beyond the scope of this paper.

SUMMARY

We have attempted to summarize design considerations and implementation techniques for a small general-purpose disk operating system. The techniques have

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FILE CONTROL BLOCK PROCESSING
SPLIT: DCX   B      ;RESET RANGR 0-2001
        PUSH  H      ;SAVE MEMORY ADDR
        PUSH  D      ;SAVE SECTOR COUNT
        MOV   A,B     ;GET FILE NUMBER
        PUSH  PSW     ;AND SAVE IT
        ANI   7       ;MASK OUT FILE NUMBER
        MOV   B,A     ;BC NOW EQUALS RELATIVE SEC NUM
        POP   PSW     ;FILE NUMBER BACK TO ACC
        ANI   0F0H    ;LEFT NIBBLE IS FILE NUMBER
        RAR   R        ;ACC NOW EQUALS FILE NUM TIMES 8
        LXI   H,FCB   ;POINT HL TO FILE CONTROL BLOCK START
        ADD   L        ;ADD FILE NUMBER TIMES 8 (SINCE EACH
        MOV   L,A     ;FCB ENTRY IS 8 BYTES LONG)
        JNC   NOCY     ;SKIP UNLESS CARRY
        INR   H        ;PROPAGATE CARRY
        MOV   E,M     ;GET FILE STARTING SEC AD FROM FCB TO DE
        INX   H
        MOV   D,M
        INX   H
        XCHG          ;MOVE TO HL
        DAD   B        ;ADD RELATIVE SEC AD TO STARTING AD
        MOV   B,H
        MOV   C,L      ;AND RESTORE IN BC.
        XCHG          ;FCB ENTRY START PLUS 2 BACK TO HL
        MOV   E,M     ;GET 2'S COMPLEMENT ENDING ADDR TO DE
        INX   H
        MOV   D,M
        INX   H
        MOV   M,C     ;SAVE ADDR FOR THIS READ OR WRITE IN F.C.B.
        INX   H
        MOV   M,B
        POP   H        ;BLOCK COUNT BACK TO HL
        PUSH  H        ;LEAVE ON STACK
        DAD   B        ;HL NOW EQUALS LAST SEC TO BE READ OR WRITTEN
        DAD   D        ;SUBTRACT ENDING ADDRESS
        POP   D        ;RESET DE TO SEC COUNT
        POP   H        ;RESTORE MEMORY ADDRESS TO HL
        JNC   DIVD8    ;JUMP UNLESS READ-PAST-EOF ERROR
        POP   D        ;DISCARD 1 RETURN FROM STACK
        RET           ;AND RETURN WITH CY SET TO INDICATE ERROR.

DIVD8:

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Figure 2. File control block processing. This routine, which is an optional component of the disk driver, processes a file number in the left 4 bits of the BC register. It expects to find the file control block beginning at symbolic location FCB.

been explored by implementing SOS, a small operating system for an 8080 or Z80 with at least 8K of RAM and a single IBM-format floppy disk. Copies of the system have been evaluated on both 8080 and Z80 processors using the Tarbell disk controller, and, from all reports, it has served as an entirely adequate developmental vehicle despite its extreme simplicity.

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