Disk-based program swapping in 8080-based microcomputers

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Microcomputers, like large-scale computer systems, can benefit from executive routines which can interrupt a running program, save the program and its environment on a disk, and later reload the program and resume execution at the point of interruption. The process is discussed conceptually, and the specific routines for accomplishing the tasks in a North Star DOS environment are presented and documented.

Large-scale computer systems gain a great deal in flexibility and efficiency through the use of executive functions that swap-out low-priority programs or programs that are waiting for I/O in favor of high-priority programs or programs for which the I/O has been completed. When the priority of the swapped-out program comes to the top of the stack again, or when the I/O has been completed, the program is swapped in, and execution resumes where it was interrupted. The process of swapping out, and later, swapping in, involves saving the program and its environment on a storage medium that allows rapid transfer of information, but which is not part of the working memory available to the CPU. The fastest way to accomplish this is to store the program and environment in an external memory, so that swapping in and out can be accomplished at memory read/write speeds. Alternatively, it may be accomplished by utilizing high-speed disk units as the storage medium. Obviously, the executive routines must utilize an algorithm for determining whether the double swap is more efficient than dead time in a particular situation.

Although there are microcomputers for which time-sharing systems have been written, they are based on residence of programs in assigned partitions. A task remains resident in an assigned partition until complete. Under most circumstances, this is a perfectly acceptable way of going about things. Since microcomputers have no peripheral processors, nothing is gained by swapping out a program that is waiting for I/O. In fact, a great deal is lost since the same CPU that must perform the I/O will be required to perform the swap, which results in time lost.

There are, however, circumstances involving priority that do not follow the general rule that swapping is inefficient in microcomputers. Consider a system that is used at times for "batch" data processing, which at

other times may be dedicated to real-time laboratory control and/or data acquisition. There are times when a long batch job might be partially completed before the system must be dedicated to the laboratory control task. In such cases, it is efficient and convenient to utilize the computer time for the batch job as long as possible, interrupt the execution and save the program and its environment, and when the computer again becomes available, reload it and resume execution. Our system software accomplishes just that. Programs may be interrupted and saved on a minidisk, and execution may resume at any time in the future. It is also an invaluable tool during programming, when the program development software often must be overlayed with another subsystem to permit testing the program under development. Using this technique, a single command saves the program development subsystem, and another single command restores it after the program has been tested, eliminating reloading software, program files, and so on.

Since the specific software is not compatible with many systems, the technique will first be discussed in conceptual terms. The software used in our laboratory hardware configuration will be discussed also. The latter should be easily adapted to any 8080-based microcomputer with a floppy-disk or minifloppy-disk system.

Basic requirements are that everything critical to the execution of the program must be saved, and nothing may be altered during the process of saving it. The first requirement may be met on a general basis by the simple technique of saving all memory locations that are normally accessible to the operating system and programs under its control, that is, by saving a complete memory image. The second requirement requires a bit more consideration. The CPU will be used for the swapping operation, so obviously, the swap must either save the contents of all registers or be performed at a point at which the registers contain no useful information. Similarly, the stack must not be disturbed or it will contain the wrong sequence of return addresses upon resuming execution. This can be accomplished by relocating the working stack before any calls are exe-

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cuted. The most formidable problem, however, is how to obtain a "frozen" copy of the same disk operating system (DOS) that will be used to save the program and its environment. Here, we reserve a small section of random-access memory and normally deny the system to access this partition to prevent it from storing data that will be overlaid in the swapping process. A copy of the DOS is then internally swapped into this reserved partition before any disk operations take place. The properly located copy is then used to perform the swap to the disk, which includes the frozen copy of the DOS.

The size of this partition varies from DOS to DOS, and according to how well the DOS is documented. Technically, only those portions of the DOS that will be involved in the actual data transfer need be copied, with the restriction that the segments must have a record size that is a multiple of the disk sector size (transfer to and from the disk actually takes place in sectors, usually 128 or 256 bytes in size). Since documentation of commercially available microcomputer software usually approaches the threshold of criminal negligence, it is often very difficult to determine the routines to be used, and even more difficult to determine if the routines are using scratch-pad memory locations elsewhere. The least frustrating approach is to swap the entire DOS.

Having saved the registers, relocated the stack, and frozen a copy of the DOS, we can proceed to save the environment in a straightforward fashion by transferring the memory contents to the disk, "stepping over" the working DOS, and continuing until all memory has been saved.

Resuming execution is the reverse process. The DOS is used to reload all memory locations from the disk except those utilized by the properly located and working copy of the DOS. The frozen copy of the DOS is swapped back to the original location, the registers and stack pointer are restored as necessary, and a return sequence is initiated by which control passes back to the routine that detected the command to interrupt execution. This routine, in turn, clears all flags and returns to its calling routine, denying that it has detected anything, and the program continues execution, perhaps a week or more later.

Translating the conceptual structure into working code is almost as simple as describing the process. First, it must be decided how the command will be implemented and where it will be detected. The operating system will have a routine that is called, usually between each I/O operation, and often during compute-bound operations, the function of which is to detect an escape character that suspends execution and returns the system to a command mode. This routine is an excellent place to detect a single-special-character command to interrupt execution and save the environment.

In the North Star DOS, this routine detects a CONTROL-C. Its location will vary since it is an I/O routine either written by the user or supplied by an

intermediate vendor for a particular hardware configuration. It can easily be found, however, by examining locations 2017H and 2018H. These locations contain the address of the routine in reverse-byte sequence (e.g., 25 29 means location 2925H). Once the routine is found, it can be disassembled, either with a disassembler or by hand. If it is the last of the I/O routines located in the I/O partition that extends from 2900H to 29FFH, it can simply be extended into unused space. If not, it may be easiest to leave it where it is, place a new routine in lower memory, and change the jump address above to the location of the new routine. Either technique should also work with the CPM DOS, since the routine is located in the BIOS partition.

The command is implemented by deciding first upon the special characters that will command the interrupt and the reload processes. I used a simple stimulus-selection technique and chose CONTROL-I (09H on the keyboard) for the interrupt command and CONTROL-R (12H) to resume execution. The code 09H corresponds to the ASCII code for horizontal tab, and users with software that utilizes this tab function may wish to choose different codes. Whichever codes are chosen, the routine is expanded to look for those codes, as well as the original CONTROL-C, and to call the appropriate routine when detected. It terminates with a normal RET instruction. Be sure that this routine "CALL's" the routine that saves the environment. This operation places a return address in the stack, which is saved. Thus a return from the reloading routine transfers control back to the original routine.

Program 1 contains the instruction sequence for the swapping operations. On entry, the HL register pair is loaded with the origin of the North Star DOS, and the DE register pair is loaded with the origin of the reserved partition in high memory. The first address is a constant for standard North Star systems. The second varies according to the random-access memory available. In most systems, it is probably best to use low memory below the DOS. This allows the system to store source code and data up to the end of existing memory. In our system, however, this area is filled with system routines, and the highest 10 sectors are reserved. Having loaded these addresses, the first routine transfers the DOS to a safe partition, terminating when the incremented H register reaches 2AH, indicating that it points 1 byte past the end of the DOS. Notice that no registers were saved. This is permissible in the North Star DOS since it clears all registers except the program counter and stack pointer before calling the CONTROL-C routine. In other systems, all registers should probably be "PUSH'ed" to the stack.

The next operation is to preserve the contents of the stack pointer, which is stored in the last 2 bytes of the domain of the frozen DOS. It cannot be "PUSH'ed" to the stack, because the user then has to know the location of the stack to find the location of the stack (somewhat like needing one's glasses to find one's glasses).

Next, the registers are loaded with arguments to the DOS routines that transfer memory to the disk. This routine addresses the output to Disk Unit 2. This allows the program to access Unit 1 while a disk is inserted in Unit 2 in preparation for the interrupt. In single-drive systems, it is necessary to insert an I/O loop that waits for a character to be typed on the keyboard before proceeding. This gives the user time to insert a fresh disk in the unit before the interrupt routine begins sequentially accessing the disk with destructive write operations. It is also possible to insert a sequence that queries the disk directory for free space, creates a file of appropriate length in available space, and stores the environment in that file. This entails a lot of overhead, so we use an empty disk and write on the first n sectors. The stack must be relocated before calling the input routine.

The partition-saving routines now follow in sequence. The last routine is specific to the SOL-20 main frame and other main frames that use the standard Processor Technology VDM-1 video display board. When the last save operation is finished, the routine jumps to the system monitor reentry location, from which rebooting operations may be initiated.

A caution: during the saving operations, do not attempt to save the contents of the read-only memory that resides from E800H to EBFFH. This read-only memory is on-board the disk controller board, and certain operations of the disk controller are initiated simply by placing addresses within its domain on the bus address lines. Attempting to transfer the data in these locations results in issuing the disk controller erroneous commands to power up the drive motor, step the track-seek mechanism, lower the head, and so on. Curious computer-jocks who attempt to dump the contents of the read-only memory to unravel the mysteries of the DOS will discover that it creates inexplicable system crashes and initiates erratic behavior in the disk drives.

Turning off power to the drives prevents this and permits copying the read-only memory. During disk operations, however, stay out of its domain.

Having stored the program and its environment, we now turn to the problem of restarting the program. Program 2 illustrates the steps. First, the DOS is booted into memory, and the resume command is issued, whereupon control is transferred to Program 2. Program 2 initiates the read sequences, using the current copy of DOS to load memory. Some users may want to combine the save/load operations into a single set of routines entered with the read or write argument in register B. All other operations are identical and can be performed in the same sequence. After loading memory, the frozen copy of the DOS is transferred to the normal origin. At this point, users with single-drive systems will once again want to insert an input loop to permit placing the correct disk in the disk drive before resuming execution of the program. Be sure that the loop is placed before the stack pointer is restored. The stack pointer is restored, and the accumulator is zeroed out so that it does not accidentally contain a legal character. At this point, if the user "PUSH'ed" the contents of the other register pairs, they will be "POP'ed" in the reverse sequence. A return is then initiated, which transfers control back to the command-detecting routine; it should then return to the calling routine.

These routines should also be easily translated into the appropriate instructions for the Z-80 CPU. Using the LDIR instruction simplifies the memory transfer of DOS.

The routines may be located anywhere in memory. Since all parameters remain in the registers, overlaying the code during the reloading operations has no effect in its execution, since the current instruction resides in the instruction register when the program counter corresponds to the address at which the current byte is being stored.

Program 1

```

0001 *      * * * * *
0002 *      *          <WITCH>          *
0003 *      *      A ROUTINE TO INTERRUPT      *
0004 *      *      EXECUTION OF A PROGRAM      *
0005 *      * * * * *
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0011 *      * L LABORATORY FOR
0012 *      * O NLINE
0013 *      * A CQUISITION OF
0014 *      * D ATA
0015 *      * * * * *

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0016 *
0017 *
0018 * BEGIN BY TRANSFERRING A "FROZEN" COPY
0019 * OF DOS TO RESERVED SYSTEM SCRATCH AREA
0020 *
0021 START LXI H,DOSOR ORIGIN OF DOS
0022 LXI H,RAMSA RAM SCRATCH AREA
0023 TRANS MOV A,M PICK UP A BYTE
0024 STAX D PUT IT IN SCRATCH RAM
0025 INX H BUMP POINTER
0026 INX D BUMP POINTER
0027 MOV A,H HIGH BYTE TO <A>
0028 CPI 2AH =2A MEANS WE'RE DONE
0029 JNZ TRANS OTHERWISE, LOOP
0030 *
0031 * BEFORE ANY STACK OPERATIONS ARE PERFORMED,
0032 * STORE THE CONTENTS OF THE STACK POINTER
0033 *
0034 LXI H,0000H ZERO OUT <HL>
0035 DAD SP ADD <SP>
0036 SHLD RAMSA+9FEH STORE IN END OF SCRATCH AREA
0037 *
0038 * NOW WE CAN USE DOS TO TRANSFER THE CONTENTS
0039 * OF MEMORY TO THE DISK
0040 *
0041 * BEGIN WITH LOW MEMORY DOMAIN
0042 *
0043 MVI A,20H 20H SECTORS
0044 LXI B,0002H 00=WRITE 02=UNIT 2
0045 LXI D,0000H SAVE UP FROM 0000H
0046 LXI H,0000H BEGIN AT SECTOR 0000H
0047 LXI SP,STACK ESTABLISH NEW STACK
0048 CALL DCOM DOS ROUTINE SAVES IT
0049 *
0050 * THEN SAVE THE "FROZEN" DOS
0051 *
0052 MVI A,0AH 0AH SECTORS
0053 LXI B,0002H 00=WRITE 02=UNIT 2
0054 LXI D,RAMSA SAVE FROM SCRATCH AREA
0055 LXI H,0025H BEGIN AT SECTOR 25H
0056 CALL DCOM DOS ROUTINE SAVES IT
0057 *
0058 * NOW SAVE THE HIGH MEMORY DOMAIN
0059 *
0060 MVI A,HSECS NUMBER OF HIGH SECTORS
0061 LXI B,0002H 00=WRITE 02=UNIT 2
0062 LXI D,2A00H SAVE UP FROM 2A00H
0063 LXI H,002AH BEGIN AT SECTOR 002AH
0064 CALL DCOM DOS ROUTINE SAVES IT
0065 *
0066 * FINALLY, SAVE THE MONITOR PARAMETERS
0067 * AND THE MEMORY-MAPPED SCREEN IMAGE
0068 * (FOR SOL-20 VDM)

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```

0069 *
0070      MVI    A,08H          8 SECTORS
0071      LXI    B,0002H       00=WRITE 02=UNIT 2
0072      LXI    D,0C800H      SAVE UP FROM C800H
0073      LXI    H,HSECS+2AH   BEGIN AT NEXT SECTOR
0074      CALL   DCOM          DOS ROUTINE SAVES IT
0075 *
0076 *   FINISHED: JUMP TO SYSTEM MONITOR
0077 *
0078      JMP     SYSTM          MONITOR RE-ENTRY
0079 *
0080 *   SYSTEM EQUATES: VARIABLES ARE ANNOTATED
0081 *
0082 DCOM   EQU    2022H
0083 DOSOR  EQU    2000H
0084 HSECS  EQU    08BH          REMAINING HIGH RAM IN SECTORS
0085 RAMSA  EQU    0B600H       RAM SCRATCH AREA ORIGIN
0086 STACK  EQU    0B5F0H       NEW STACK ABOVE SCRATCH AREA
0087 SYSTM  EQU    0C004H       SYSTEM MONITOR RE-ENTRY ADDRESS
0088      END

```

Program 2

```

0001 *      * * * * *
0002 *      *      <PRINCE>      *
0003 *      *      A ROUTINE TO RESUME      *
0004 *      *      EXECUTION OF A BEWITCHED      *
0005 *      *      PROGRAM      *
0006 *      * * *      * * *
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0011 *      *      *
0012 *      * L ABORATORY FOR      *
0013 *      * O NLINE      *
0014 *      * A CQUISITION OF      *
0015 *      * D ATA      *
0016 *      * * * * *
0017 *
0018 *   FIRST OPERATION IS TO LOAD THE LOWER
0019 *   BLOCK OF MEMORY FROM 0000H TO 2000H
0020 *
0021 START  MVI    A,20H          FIRST 20H SECTORS
0022      LXI    B,0102H       01=READ 02=UNIT 2
0023      LXI    D,0000H       LOAD UP FROM 0000H
0024      LXI    H,0000H       START WITH SECTOR 0000H
0025      CALL   DCOM          DOS ROUTINE LOADS IT

```

```

0026 *
0027 * THEN THE DOS, NORMALLY LOCATED FROM
0028 * 2000H TO 29FFH, IS LOADED IN A RESERVED
0029 * SYSTEM SCRATCH AREA
0030 *
0031 *      MVI    A,0AH          0AH SECTORS THIS TIME
0032 *      LXI    B,0102H       01=READ 02=UNIT 2
0033 *      LXI    D,RAMSA       LOAD INTO RAM SCRATCH AREA
0034 *      LXI    H,0020H       START WITH SECTOR 0020H
0035 *      CALL   DCOM          DOS ROUTINE LOADS IT
0036 *
0037 * NEXT, THE REMAINING RAM IS LOADED FROM
0038 * 2A00 TO THE END OF AVAILABLE MEMORY
0039 *
0040 *      MVI    A,HSECS       HIGH MEMORY IN SECTORS
0041 *      LXI    B,0102H       01=READ 02=UNIT 2
0042 *      LXI    D,2A00H       LOAD UP FROM 2A00H
0043 *      LXI    H,002FH       START WITH SECTOR 2FH
0044 *      CALL   DCOM          DOS ROUTINE LOADS IT
0045 *
0046 * FINALLY, THE MONITOR PARAMETERS AND
0047 * THE MEMORY-MAPPED SCREEN IMAGE ARE
0048 * LOADED FROM C800H TO CFFFH
0049 *
0050 *      MVI    A,08H          8 SECTORS
0051 *      LXI    B,0102H       01=READ 02=UNIT 2
0052 *      LXI    D,C800H       LOAD UP FROM C800H
0053 *      LXI    H,HSECS+2AH   SECTOR TO BEGIN AT
0054 *      CALL   DCOM          DOS ROUTINE LOADS IT
0055 *
0056 * NOW THAT EVERYTHING IS IN MEMORY, WE
0057 * CAN TRANSFER THE 'FROZEN' DOS TO ITS
0058 * CORRECT ORIGIN
0059 *
0060 *      LXI    H,RAMSA       BEGINNING OF SCRATCH AREA
0061 *      LXI    H,DOSOR       ORIGIN OF DOS
0062 * TRANS  MOV    A,M         PICK UP A BYTE
0063 *      STAX   D             PUT IT DOWN WHERE IT BELONGS
0064 *      INX    H             BUMP POINTER
0065 *      INX    D             BUMP POINTER
0066 *      MOV    A,D           MOVE HIGH BYTE TO <A>
0067 *      CPI    2AH           =2A MEANS WE'RE DONE
0068 *      JNZ    TRANS        IF NOT, LOOP
0069 *
0070 * RESTORE THE STACK POINTER
0071 *
0072 *      LHLD   STAKP         GET STORED STACK POINTER
0073 *      SPHL                     PUT IT IN <SP>
0074 *
0075 * NOW WE SET THE FLAGS TO INDICATE THAT
0076 * NO INTERRUPT CHARACTER WAS DETECTED

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```
0077 *  
0078      MVI    A,00H      ZERO OUT <A>  
0079      CPI    0FFH      COMPARE IT TO FFH  
0080 *  
0081 *  AND RETURN (MUCH LATER) TO THE CALLING ROUTINE  
0082 *  
0083      RET              RETURN TO I/O ROUTINE  
0084 *  
0085 *  SYSTEM EQUATES:  VARIABLES ARE ANNOTATED  
0086 *  
0087 DOSOR  EQU    2000H  
0088 ICOM   EQU    2022H  
0089 HSECS  EQU    8BH      REMAINING HIGH RAM IN SECTORS  
0090 RAMSA  EQU    0B600H    RAM SCRATCH AREA ORIGIN  
0091 STAKP  EQU    29FEH
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