Processes, Coroutines, and Concurrency Chapter 19

When most people speak of multitasking, they usually mean the ability to run several different application programs concurrently on one machine. Given the structure of the original 80x86 chips and MS-DOS' software design, this is very difficult to achieve when running DOS. Look at how long it's taken Microsoft to get Windows to multitask as well as it does.

Given the problems large companies like Microsoft have had trying to get multitasking to work, you might thing that it is a very difficult thing to manage. However, this isn't true. Microsoft has problems trying to make different applications *that are unaware of one another* work harmoniously together. Quite frankly, they have not succeeded in getting existing DOS applications to multitask well. Instead, they've been working on developers to write new programs that work well under Windows.

Multitasking is not trivial, but it is not that difficult when you write an application with multitasking specifically in mind. You can even write programs that multitask under DOS if you only take a few precautions. In this chapter, we will discuss the concept of a DOS *process*, a *coroutine*, and a general *process*.

19.1 DOS Processes

Although MS-DOS is a single tasking operating system, this does not mean there can only be one program at a time in memory. Indeed, the whole purpose of the previous chapter was to describe how to get two or more programs operating in memory at one time. However, even if we ignore TSRs for the time being, you can still load several programs into memory at one time under DOS. The only catch is, DOS only provides the ability for them to run one at a time in a very specific fashion. Unless the processes are *cooperating*, their execution profile follows a very strict pattern.

19.1.1 Child Processes in DOS

When a DOS application is running, it can load and executing some other program using the DOS EXEC function (see "MS-DOS, PC-BIOS, and File I/O" on page 699). Under normal circumstances, when an application (the parent) runs a second program (the child), the child process executes to completion and then returns to the parent. This is very much like a procedure call, except it is a little more difficult to pass parameters between the two.

MS-DOS provides several functions you can use to load and execute program code, terminate processes, and obtain the exit status for a process. The following table lists many of these operations.

Table 67: DOS Character Oriented Functions

Function # (AH)	Input Parameters	Output Parameters	Description
4Bh	al- 0 ds:dx- pointer to program name. es:bx- pointer to LOADEXEC structure.	ax- error code if carry set.	Load and execute program
4Bh	al- 1 ds:dx- pointer to program name. es:bx- pointer to LOAD structure.	ax- error code if carry set.	Load program
4Bh	al- 3 ds:dx- pointer to program name. es:bx- pointer to OVERLAY structure.	ax- error code if carry set.	Load overlay

Table 67: DOS Character Oriented Functions

Function # (AH)	Input Parameters	Output Parameters	Description
4Ch	al- process return code		Terminate execution
4Dh		al- return value ah- termination method.	Get child process return value

19.1.1.1 Load and Execute

The "load and execute" call requires two parameters. The first, in ds:dx, is a pointer to a zero terminated string containing the pathname of the program to execute. This must be a ".COM" or ".EXE" file and the string must contain the program name's extension. The second parameter, in es:bx, is a pointer to a LOADEXEC data structure. This data structure takes the following form:

```
LOADEXEC        struct
EnvPtr          word        ?               ;Pointer to environment area
CmdLinePtr      dword       ?               ;Pointer to command line
FCB1            dword       ?               ;Pointer to default FCB1
FCB2            dword       ?               ;Pointer to default FCB2
LOADEXEC        ends
```

Envptr is the segment address of the DOS *environment* block created for the new application. If this field contains a zero, DOS creates a copy of the current process' environment block for the child process. If the program you are running does not access the environment block, you can save several hundred bytes to a few kilobytes by pointing the environment pointer field to a string of four zeros.

The CmdLinePtr field contains the address of the command line to supply to the program. DOS will copy this command line to offset 80h in the new PSP it creates for the child process. A valid command line consists of a byte containing a character count, a least one space, any character belonging to the command line, and a terminating carriage return character (0Dh). The first byte should contain the length of the ASCII characters in the command line, not including the carriage return. If this byte contains zero, then the second byte of the command line should be the carriage return, not a space. Example:

```
MyCmdLine       byte        12, " file1 file2",cr
```

The FCB1 and FCB2 fields need to point at the two default *file control blocks* for this program. FCBs became obsolete with DOS 2.0, but Microsoft has kept FCBs around for compatibility anyway. For most programs you can point both of these fields at the following string of bytes:

```
DfltFCB         byte        3," ",0,0,0,0,0
```

The load and execute call will fail if there is insufficient memory to load the child process. When you create an ".EXE" file using MASM, it creates an executable file that grabs all available memory, by default. Therefore, there will be *no* memory available for the child process and DOS will always return an error. Therefore, you must readjust the memory allocation for the parent process before attempting to run the child process. The section "Semiresident Programs" on page 1055 describes how to do this.

There are other possible errors as well. For example, DOS might not be able to locate the program name you specify with the zero terminated string. Or, perhaps, there are too many open files and DOS doesn't have a free buffer available for the file I/O. If an error occurs, DOS returns with the carry flag set and an appropriate error code in the ax register. The following example program executes the "COMMAND.COM" program, allowing a user to execute DOS commands from inside your application. When the user types "exit" at the DOS command line, DOS returns control to your program.

```
; RUNDOS.ASM - Demonstrates how to invoke a copy of the COMMAND.COM
;              DOS command line interpreter from your programs.

                include    stdlib.a
```

```
                includelib stdlib.lib

dseg            segment    para public 'data'

; MS-DOS EXEC structure.

ExecStruct      word       0                ;Use parent's Environment blk.
                dword      CmdLine          ;For the cmd ln parms.
                dword      DfltFCB
                dword      DfltFCB

DfltFCB         byte       3," ",0,0,0,0,0
CmdLine         byte       0, 0dh           ;Cmd line for program.
PgmName         dword      filename         ;Points at pgm name.

filename        byte       "c:\command.com",0

dseg            ends

cseg            segment    para public 'code'
                assume     cs:cseg, ds:dseg

Main            proc
                mov        ax, dseg         ;Get ptr to vars segment
                mov        ds, ax

                MemInit                     ;Start the memory mgr.

; Okay, we've built the MS-DOS execute structure and the necessary
; command line, now let's see about running the program.
; The first step is to free up all the memory that this program
; isn't using. That would be everything from zzzzzzseg on.
;
; Note: unlike some previous examples in other chapters, it is okay
; to call Standard Library routines in this program after freeing
; up memory. The difference here is that the Standard Library
; routines are loaded early in memory and we haven't free up the
; storage they are sitting in.

                mov        ah, 62h          ;Get our PSP value
                int        21h
                mov        es, bx
                mov        ax, zzzzzzseg    ;Compute size of
                sub        ax, bx           ; resident run code.
                mov        bx, ax
                mov        ah, 4ah          ;Release unused memory.
                int        21h


; Tell the user what is going on:

                print
                byte       cr,lf
                byte       "RUNDOS- Executing a copy of command.com",cr,lf
                byte       "Type 'EXIT' to return control to RUN.ASM",cr,lf
                byte       0

; Warning! No Standard Library calls after this point. We've just
; released the memory that they're sitting in. So the program load
; we're about to do will wipe out the Standard Library code.

                mov        bx, seg ExecStruct
                mov        es, bx
                mov        bx, offset ExecStruct ;Ptr to program record.
                lds        dx, PgmName
                mov        ax, 4b00h        ;Exec pgm
                int        21h

; In MS-DOS 6.0 the following code isn't required. But in various older
; versions of MS-DOS, the stack is messed up at this point. Just to be
; safe, let's reset the stack pointer to a decent place in memory.
;
; Note that this code preserves the carry flag and the value in the
; AX register so we can test for a DOS error condition when we are done
```

```
; fixing the stack.

                mov         bx, sseg
                mov         ss, ax
                mov         sp, offset EndStk
                mov         bx, seg dseg
                mov         ds, bx

; Test for a DOS error:

                jnc         GoodCommand
                print
                byte        "DOS error #",0
                puti
                print
                byte        " while attempting to run COMMAND.COM",cr,lf
                byte        0
                jmp         Quit

; Print a welcome back message.

GoodCommand:    print
                byte        "Welcome back to RUNDOS. Hope you had fun.",cr,lf
                byte        "Now returning to MS-DOS' version of COMMAND.COM."
                byte        cr,lf,lf,0

; Return control to MS-DOS

Quit:           ExitPgm
Main            endp
cseg            ends

sseg            segment     para stack 'stack'
                dw          128 dup (0)
sseg            ends

zzzzzzseg       segment     para public 'zzzzzzseg'
Heap            db          200h dup (?)
zzzzzzseg       ends
                end         Main
```

19.1.1.2 Load Program

The load and execute function gives the parent process very little control over the child process. Unless the child communicates with the parent process via a trap or interrupt, DOS suspends the parent process until the child terminates. In many cases the parent program may want to load the application code and then execute some additional operations before the child process takes over. Semiresident programs, appearing in the previous chapter, provide a good example. The DOS "load program" function provides this capability; it will load a program from the disk and return control back to the parent process. The parent process can do whatever it feels is appropriate before passing control to the child process.

The load program call requires parameters that are very similar to the load and execute call. Indeed, the only difference is the use of the LOAD structure rather than the LOADEXEC structure, and even these structures are very similar to one another. The LOAD data structure includes two extra fields not present in the LOADEXE structure:

```
LOAD            struct
EnvPtr          word        ?               ;Pointer to environment area.
CmdLinePtr      dword       ?               ;Pointer to command line.
FCB1            dword       ?               ;Pointer to default FCB1.
FCB2            dword       ?               ;Pointer to default FCB2.
SSSP            dword       ?               ;SS:SP value for child process.
CSIP            dword       ?               ;Initial program starting point.
LOAD            ends
```

The LOAD command is useful for many purposes. Of course, this function provides the primary vehicle for creating semiresident programs; however, it is also quite useful for providing extra error recovery,

redirecting application I/O, and loading several executable processes into memory for concurrent execution.

After you load a program using the DOS load command, you can obtain the PSP address for that program by issuing the DOS get PSP address call (see "MS-DOS, PC-BIOS, and File I/O" on page 699). This would allow the parent process to modify any values appearing in the child process' PSP prior to its execution. DOS stores the termination address for a procedure in the PSP. This termination address normally appears in the double word at offset 10h in the PSP. *If you do not change this location, the program will return to the first instruction beyond the int 21h instruction for the load function.* Therefore, before actually transferring control to the user application, you should change this termination address.

19.1.1.3 Loading Overlays

Many programs contain blocks of code that are independent of one other; that is, while routines in one block of code execute, the program will not call routines in the other independent blocks of code. For example, a modern game may contain some initialization code, a "staging area" where the user chooses certain options, an "action area" where the user plays the game, and a "debriefing area" that goes over the player's actions. When running in a 640K MS-DOS machine, all this code may not fit into available memory at the same time. To overcome this memory limitation, most large programs use *overlays.* An overlay is a portion of the program code that shares memory for its code with other code modules. The DOS load overlay function provides support for large programs that need to use overlays.

Like the load and load/execute functions, the load overlay expects a pointer to the code file's pathname in the ds:dx register pair and the address of a data structure in the es:bx register pair. This overlay data structure has the following format:

```
overlay       struct
StartSeg      word       ?
RelocFactor   word       0
overlay       ends
```

The StartSeg field contains the segment address where you want DOS to load the program. The RelocFactor field contains a relocation factor. This value should be zero unless you want the starting offset of the segment to be something other than zero.

19.1.1.4 Terminating a Process

The process termination function is nothing new to you by now, you've used this function over and over again already if you written any assembly language programs and run them under DOS (the Standard Library ExitPgm macro executes this command). In this section we'll look at exactly what the terminate process function call does.

First of all, the terminate process function gives you the ability to pass a single byte *termination code* back to the parent process. Whatever value you pass in al to the terminate call becomes the return, or termination code. The parent process can test this value using the Get Child Process Return Value call (see the next section). You can also test this return value in a DOS batch file using the "if errorlevel" statement.

The terminate process command does the following:

- Flushes file buffers and closes files.
- Restores the termination address (int 22h) from offset 0Ah in the PSP (this is the return address of the process).
- Restores the address of the Break handler (int 23h) from offset 0Eh in the PSP (see "Exception Handling in DOS: The Break Handler" on page 1070)
- Restores the address of the critical error handler (int 24h) from offset 12h in the PSP (see "Exception Handling in DOS: The Critical Error Handler" on page 1071).

- Deallocates any memory held by the process.

Unless you *really* know what you're doing, you should not change the values at offsets 0Ah, 0Eh, or 12h in the PSP. By doing so you could produce an inconsistent system when your program terminates.

19.1.1.5 Obtaining the Child Process Return Code

A parent process can obtain the return code from a child process by making the DOS Get Child Process Return Code function call. This call returns the value in the `al` register at the point of termination plus information that tells you how the child process terminated.

This call (`ah`=4Dh) returns the termination code in the al register. It also returns the cause of termination in the ah register. The `ah` register will contain one of the following values:

Table 68: Termination Cause

Value in AH	Reason for Termination
0	Normal termination (int 21h, ah=4Ch)
1	Terminated by ctrl-C
2	Terminated by critical error
3	TSR termination (int 21h, ah=31h)

The termination code appearing in `al` is valid only for normal and TSR terminations.

Note that you can only call this routine *once* after a child process terminates. MS-DOS returns meaningless values in AX after the first such call. Likewise, if you use this function without running a child process, the results you obtain will be meaningless. DOS does not return if you do this.

19.1.2 Exception Handling in DOS: The Break Handler

Whenever the users presses a ctrl-C or ctrl-Break key MS-DOS may trap such a key sequence and execute an `int 23h` instruction[1]. MS-DOS provides a default break handler routine that terminates the program. However, a well-written program generally replaces the default break handler with one of its own so it can capture ctrl-C or ctrl-break key sequences and shut the program down in an orderly fashion.

When DOS terminates a program due to a break interrupt, it flushes file buffers, closes all open files, releases memory belonging to the application, all the normal stuff it does on program termination. However, it does *not* restore any interrupt vectors (other than interrupt 23h and interrupt 24h). If your code has replaced any interrupt vectors, especially hardware interrupt vectors, then those vectors will still be pointing at your program's interrupt service routines after DOS terminates your program. This will probably crash the system when DOS loads a new program over the top of your code. Therefore, you should write a break handler so your application can shut itself down in an orderly fashion if the user presses ctrl-C or ctrl-break.

The easiest, and perhaps most universal, break handler consists of a single instruction – `iret`. If you point the interrupt 23h vector at an `iret` instruction, MS-DOS will simply ignore any ctrl-C or ctrl-break keys you press. This is very useful for turning off the break handling during critical sections of code that you do not want the user to interrupt.

1. MS-DOS always executes an int 23h instruction if it is processing a function code in the range 1-0Ch. For other DOS functions, MS-DOS only executes int 23h if the Break flag is set

On the other hand, simply turning off ctrl-C and ctrl-break handling throughout your entire program is not satisfactory either. If for some reason the user wants to abort your program, pressing ctrl-break or ctrl-C is what they will probably try to do this. If your program disallows this, the user may resort to something more drastic like ctrl-alt-delete to reset the machine. This will certainly mess up any open files and may cause other problems as well (of course, you don't have to worry about restoring any interrupt vectors!).

To patch in your own break handler is easy – just store the address of your break handler routine into the interrupt vector 23h. You don't even have to save the old value, DOS does this for you automatically (it stores the original vector at offset 0Eh in the PSP). Then, when the users presses a ctrl-C or ctrl-break key, MS-DOS transfers control to your break handler.

Perhaps the best response for a break handler is to set some flag to tell the application and break occurred, and then leave it up to the application to test this flag a reasonable points to determine if it should shut down. Of course, this does require that you test this flag at various points throughout your application, increasing the complexity of your code. Another alternative is to save the original int 23h vector and transfer control to DOS' break handler after you handle important operations yourself. You can also write a specialized break handler to return a DOS termination code that the parent process can read.

Of course, there is no reason you cannot change the interrupt 23h vector at various points throughout your program to handle changing requirements. At various points you can disable the break interrupt entirely, restore interrupt vectors at others, or prompt the user at still other points.

19.1.3 Exception Handling in DOS: The Critical Error Handler

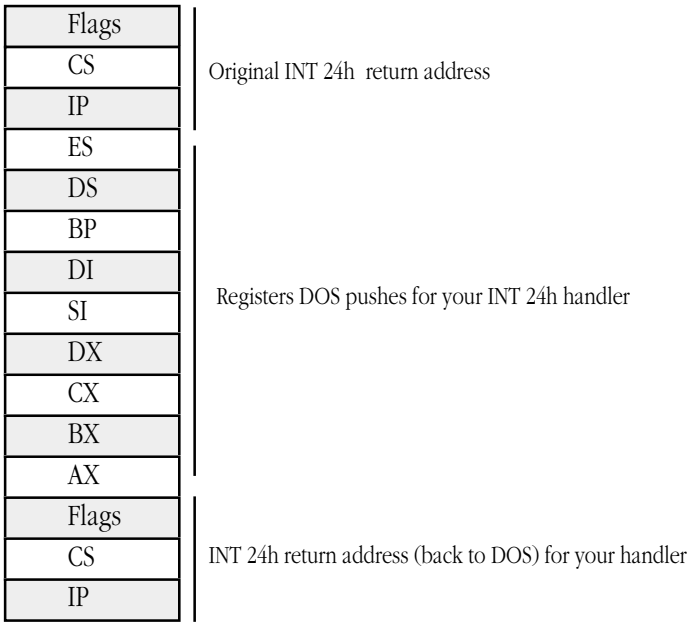
DOS invokes the critical error handler by executing an int 24h instruction whenever some sort of I/O error occurs. The default handler prints the familiar message:

```
I/O Device Specific Error Message
Abort, Retry, Ignore, Fail?
```

If the user presses an "A", this code immediately returns to DOS' COMMAND.COM program; *it doesn't even close any open files.* If the user presses an "R" to retry, MS-DOS will retry the I/O operation, though this usually results in another call to the critical error handler. The "I" option tells MS-DOS to ignore the error and return to the calling program as though nothing had happened. An "F" response instructs MS-DOS to return an error code to the calling program and let it handle the problem.

Of the above options, having the user press "A" is the most dangerous. This causes an immediate return to DOS and your code does not get the chance to clean up anything. For example, if you've patched some interrupt vectors, your program will not get the opportunity to restore them if the user selects the abort option. This may crash the system when MS-DOS loads the next program over the top of your interrupt service routine(s) in memory.

To intercept DOS critical errors, you will need to patch the interrupt 24h vector to point at your own interrupt service routine. Upon entry into your interrupt 24h service routine, the stack will contain the following data:



Stack Contents Upon Entry to a Critical Error Handler

MS-DOS passes important information in several of the registers to your critical error handler. By inspecting these values you can determine the cause of the critical error and the device on which it occurred. The high order bit of the ah register determines if the error occurred on a block structured device (typically a disk or tape) or a character device. The other bits in ah have the following meaning:

Table 69: Device Error Bits in AH

Bit(s)	Description
0	0=Read operation. 1=Write operation.
1-2	Indicates affected disk area. 00- MS-DOS area. 01- File allocation table (FAT). 10- Root directory. 11- Files area.
3	0- Fail response not allowed. 1- Fail response is okay.
4	0- Retry response not allowed. 1- Retry response is okay.
5	0- Ignore response is not allowed. 1- Ignore response is okay.
6	Undefined
7	0- Character device error. 1- Block structured device error.

In addition to the bits in ah, for block structured devices the al register contains the drive number where the error occurred (0=A, 1=B, 2=C, etc.). The value in the al register is undefined for character devices.

The lower half of the di register contains additional information about the block device error (the upper byte of di is undefined, you will need to mask out those bits before attempting to test this data).

Table 70: Block Structured Device Error Codes (in L.O. byte of DI)

Error Code	Description
0	Write protection error.
1	Unknown drive.
2	Drive not ready.
3	Invalid command.
4	Data error (CRC error).
5	Length of request structure is incorrect.
6	Seek error on device.
7	Disk is not formatted for MS-DOS.
8	Sector not found.
9	Printer out of paper.
0Ah	Write error.
0Bh	Read error.
0Ch	General failure.
0Fh	Disk was changed at inappropriate time.

Upon entry to your critical error handler, interrupts are turned off. Because this error occurs as a result of some MS-DOS call, MS-DOS is already entered and you will not be able to make any calls other than functions 1-0Ch and 59h (get extended error information).

Your critical error handler must preserve all registers except al. The handler must return to DOS with an iret instruction and al must contain one of the following codes:

Table 71: Critical Error Handler Return Codes

Code	Meaning
0	Ignore device error.
1	Retry I/O operation again.
2	Terminate process (abort).
3	Fail current system call.

The following code provides a trivial example of a critical error handler. The main program attempts to send a character to the printer. If you do not connect a printer, or turn off the printer before running this program, it will generate the critical error.

```
; Sample INT 24h critical error handler.
;
; This code demonstrates a sample critical error handler.
; It patches into INT 24h and displays an appropriate error
; message and asks the user if they want to retry, abort, ignore,
; or fail (just like DOS).
```

```
                .xlist
                include    stdlib.a
                includelib stdlib.lib
                .list


dseg            segment    para public 'data'

Value           word       0
ErrCode         word       0

dseg            ends

cseg            segment    para public 'code'
                assume     cs:cseg, ds:dseg

; A replacement critical error handler. Note that this routine
; is even worse than DOS', but it demonstrates how to write
; such a routine. Note that we cannot call any Standard Library
; I/O routines in the critical error handler because they do not
; use DOS calls 1-0Ch, which are the only allowable DOS calls at
; this point.


CritErrMsg      byte       cr,lf
                byte       "DOS Critical Error!",cr,lf
                byte       "A)bort, R)etry, I)gnore, F)ail? $"

MyInt24         proc       far
                push       dx
                push       ds
                push       ax

                push       cs
                pop        ds
Int24Lp:        lea        dx, CritErrMsg
                mov        ah, 9             ;DOS print string call.
                int        21h

                mov        ah, 1             ;DOS read character call.
                int        21h
                and        al, 5Fh           ;Convert l.c. -> u.c.

                cmp        al, 'I'           ;Ignore?
                jne        NotIgnore
                pop        ax
                mov        al, 0
                jmp        Quit24

NotIgnore:      cmp        al, 'r'           ;Retry?
                jne        NotRetry
                pop        ax
                mov        al, 1
                jmp        Quit24

NotRetry:       cmp        al, 'A'           ;Abort?
                jne        NotAbort
                pop        ax
                mov        al, 2
                jmp        Quit24

NotAbort:       cmp        al, 'F'
                jne        BadChar
                pop        ax
                mov        al, 3
Quit24:         pop        ds
                pop        dx
                iret

BadChar:        mov        ah, 2
                mov        dl, 7             ;Bell character
                jmp        Int24Lp
MyInt24         endp
```

```
Main            proc
                mov         ax, dseg
                mov         ds, ax
                mov         es, ax
                meminit

                mov         ax, 0
                mov         es, ax
                mov         word ptr es:[24h*4], offset MyInt24
                mov         es:[24h*4 + 2], cs

                mov         ah, 5
                mov         dl, 'a'
                int         21h
                rcl         Value, 1
                and         Value, 1
                mov         ErrCode, ax
                printf
                byte        cr,lf,lf
                byte        "Print char returned with error status %d and "
                byte        "error code %d\n",0
                dword       Value, ErrCode

Quit:           ExitPgm                         ;DOS macro to quit program.
Main            endp

cseg            ends



; Allocate a reasonable amount of space for the stack (8k).
; Note: if you use the pattern matching package you should set up a
;       somewhat larger stack.

sseg            segment     para stack 'stack'
stk             db          1024 dup ("stack ")
sseg            ends


; zzzzzzseg must be the last segment that gets loaded into memory!
; This is where the heap begins.

zzzzzzseg       segment     para public 'zzzzzz'
LastBytes       db          16 dup (?)
zzzzzzseg       ends
                end         Main
```

19.1.4 Exception Handling in DOS: Traps

In addition to the break and critical error exceptions, there are the 80x86 exceptions that can happen during the execution of your programs. Examples include the divide error exception, bounds exception, and illegal opcode exception. A well-written application will always handle all possible exceptions.

DOS does not provide direct support for these exceptions, other than a possible default handler. In particular, DOS does not restore such vectors when the program terminates; this is something the application, break handler, and critical error handler must take care of. For more information on these exceptions, see "Exceptions" on page 1000.

19.1.5 Redirection of I/O for Child Processes

When a child process begins execution, it inherits all open files from the parent process (with the exception of certain files opened with networking file functions). In particular, this includes the default

files opened for the DOS *standard input, standard output, standard error, auxiliary,* and *printer* devices. DOS assigns the file handle values zero through four, respectively, to these devices. If a parent process closes one of these file handles and then reassigns the handle with a Force Duplicate File Handle call.

Note that the DOS EXEC call does not process the I/O redirection operators ("<", and ">", and "|"). If you want to redirect the standard I/O of a child process, you must do this before loading and executing the child process. To redirect one of the five standard I/O devices, you should do the following steps:

1) Duplicate the file handle you want to redirect (e.g., to redirect the standard output, duplicate file handle one).

2) Close the affected file (e.g., file handle one for standard output).

3) Open a file using the standard DOS Create or CreateNew calls.

4) Use the Force Duplicate File Handle call to copy the new file handle to file handle one.

5) Run the child process.

6) On return from the child, close the file.

7) Copy the file handle you duplicated in step one back to the standard output file handle using the Force Duplicate Handle function.

This technique looks like it would be perfect for redirecting printer or serial port I/O. Unfortunately, many programs bypass DOS when sending data to the printer and use the BIOS call or, worse yet, go directly to the hardware. Almost no software bothers with DOS' serial port support – it truly is that bad. However, most programs *do* call DOS to input or output characters on the standard input, output, and error devices. The following code demonstrates how to redirect the output of a child process to a file.

```
; REDIRECT.ASM -Demonstrates how to redirect I/O for a child process.
; This particular program invokes COMMAND.COM to execute
; a DIR command, when is sent to the specified output file.

              include    stdlib.a
              includelib stdlib.lib

dseg          segment    para public 'data'

OrigOutHandle word       ?                ;Holds copy of STDOUT handle.
FileHandle    word       ?                ;File I/O handle.
FileName      byte       "dirctry.txt",0  ;Filename for output data.

; MS-DOS EXEC structure.

ExecStruct    word       0                ;Use parent's Environment blk.
              dword      CmdLine          ;For the cmd ln parms.
              dword      DfltFCB
              dword      DfltFCB

DfltFCB       byte       3," ",0,0,0,0,0
CmdLine       byte       7, " /c DIR", 0dh ;Do a directory command.
PgmName       dword      PgmNameStr       ;Points at pgm name.
PgmNameStr    byte       "c:\command.com",0
dseg          ends

cseg          segment    para public 'code'
              assume     cs:cseg, ds:dseg


Main          proc
              mov        ax, dseg         ;Get ptr to vars segment
              mov        ds, ax
              MemInit                     ;Start the memory mgr.

; Free up some memory for COMMAND.COM:

              mov        ah, 62h          ;Get our PSP value
              int        21h
```

```
                mov     es, bx
                mov     ax, zzzzzzseg   ;Compute size of
                sub     ax, bx          ; resident run code.
                mov     bx, ax
                mov     ah, 4ah         ;Release unused memory.
                int     21h

; Save original output file handle.

                mov     bx, 1           ;Std out is file handle 1.
                mov     ah, 45h         ;Duplicate the file handle.
                int     21h
                mov OrigOutHandle, ax;Save duplicate handle.

; Open the output file:

                mov     ah, 3ch         ;Create file.
                mov     cx, 0           ;Normal attributes.
                lea     dx, FileName
                int     21h
                mov     FileHandle, ax  ;Save opened file handle.

; Force the standard output to send its output to this file.
; Do this by forcing the file's handle onto file handle #1 (stdout).

                mov     ah, 46h         ;Force dup file handle
                mov     cx, 1           ;Existing handle to change.
                mov     bx, FileHandle  ;New file handle to use.
                int     21h

; Print the first line to the file:

                print
                byte    "Redirected directory listing:",cr,lf,0

; Okay, execute the DOS DIR command (that is, execute COMMAND.COM with
; the command line parameter "/c DIR").

                mov     bx, seg ExecStruct
                mov     es, bx
                mov     bx, offset ExecStruct ;Ptr to program record.
                lds     dx, PgmName
                mov     ax, 4b00h       ;Exec pgm
                int     21h

                mov     bx, sseg        ;Reset the stack on return.
                mov     ss, ax
                mov     sp, offset EndStk
                mov     bx, seg dseg
                mov     ds, bx

; Okay, close the output file and switch standard output back to the
; console.

                mov     ah, 3eh         ;Close output file.
                mov     bx, FileHandle
                int     21h

                mov     ah, 46h         ;Force duplicate handle
                mov     cx, 1           ;StdOut
                mov     bx, OrigOutHandle ;Restore previous handle.
                int     21h

; Return control to MS-DOS

Quit:           ExitPgm
Main            endp
cseg            ends

sseg            segment para stack 'stack'
                dw      128 dup (0)
endstk          dw      ?
sseg            ends
```

```
zzzzzzseg       segment     para public 'zzzzzzseg'
Heap            db          200h dup (?)
zzzzzzseg       ends
                end         Main
```

19.2 Shared Memory

The only problem with running different DOS programs as part of a single application is *interprocess communication*. That is, how do all these programs talk to one other? When a typical DOS application runs, DOS loads in all code and data segments; there is no provision, other than reading data from a file or the process termination code, for one process to pass information to another. Although file I/O will work, it is cumbersome and slow. The ideal solution would be for one process to leave a copy of various variables that other processes can share. Your programs can easily do this using *shared memory*.

Most modern multitasking operating systems provide for shared memory – memory that appears in the address space of two or more processes. Furthermore, such shared memory is often *persistent*, meaning it continues to hold values after its creator process terminates. This allows other processes to start later and use the values left behind by the shared variables' creator.

Unfortunately, MS-DOS is not a modern multitasking operating system and it does not support shared memory. However, we can easily write a resident program that provides this capability missing from DOS. The following sections describe how to create two types of shared memory regions – static and dynamic.

19.2.1 Static Shared Memory

A TSR to implement *static shared memory* is trivial. It is a passive TSR that provides three functions – verify presence, remove, and return segment pointer. The transient portion simply allocates a 64K data segment and then terminates. Other processes can obtain the address of the 64K shared memory block by making the "return segment pointer" call. These processes can place all their shared data into the segment belonging to the TSR. When one process quits, the shared segment remains in memory as part of the TSR. When a second process runs and links with the shared segment, the variables from the shared segment are still intact, so the new process can access those values. When all processes are done sharing data, the user can remove the shared memory TSR with the remove function.

As mentioned above, there is almost nothing to the shared memory TSR. The following code implements it:

```
; SHARDMEM.ASM
;
; This TSR sets aside a 64K shared memory region for other processes to use.
;
; Usage:
;
;       SHARDMEM -          Loads resident portion and activates
;                           shared memory capabilities.
;
;       SHARDMEM REMOVE -   Removes shared memory TSR from memory.
;
; This TSR checks to make sure there isn't a copy already active in
; memory. When removing itself from memory, it makes sure there are
; no other interrupts chained into INT 2Fh before doing the remove.
;
;
;
; The following segments must appear in this order and before the
; Standard Library includes.

ResidentSeg     segment     para public 'Resident'
ResidentSeg     ends

SharedMemory    segment     para public 'Shared'
```

```
SharedMemory   ends

EndResident    segment    para public 'EndRes'
EndResident    ends

               .xlist
               .286
               include    stdlib.a
               includelib stdlib.lib
               .list


; Resident segment that holds the TSR code:

ResidentSeg    segment    para public 'Resident'
               assume     cs:ResidentSeg, ds:nothing

; Int 2Fh ID number for this TSR:

MyTSRID        byte       0
               byte       0              ;Padding so we can print it.

; PSP is the psp address for this program.

PSP            word       0

OldInt2F       dword      ?


; MyInt2F-     Provides int 2Fh (multiplex interrupt) support for this
;              TSR. The multiplex interrupt recognizes the following
;              subfunctions (passed in AL):
;
;              00h- Verify presence.     Returns 0FFh in AL and a pointer
;                                        to an ID string in es:di if the
;                                        TSR ID (in AH) matches this
;                                        particular TSR.
;
;              01h- Remove.              Removes the TSR from memory.
;                                        Returns 0 in AL if successful,
;                                        1 in AL if failure.
;
;              10h- Return Seg Adrs.     Returns the segment address of the
;                                        shared segment in ES.

MyInt2F        proc       far
               assume     ds:nothing

               cmp        ah, MyTSRID       ;Match our TSR identifier?
               je         YepItsOurs
               jmp        OldInt2F

; Okay, we know this is our ID, now check for a verify, remove, or
; return segment call.

YepItsOurs:    cmp        al, 0             ;Verify Call
               jne        TryRmv
               mov        al, 0ffh          ;Return success.
               lesi       IDString
               iret                         ;Return back to caller.

IDString       byte       "Static Shared Memory TSR",0

TryRmv:        cmp        al, 1             ;Remove call.
               jne        TryRetSeg

; See if we can remove this TSR:

               push       es
               mov        ax, 0
               mov        es, ax
               cmp        word ptr es:[2Fh*4], offset MyInt2F
               jne        TRDone
               cmp        word ptr es:[2Fh*4 + 2], seg MyInt2F
```

```
                je      CanRemove;Branch if we can.
TRDone:         mov     ax, 1           ;Return failure for now.
                pop     es
                iret

; Okay, they want to remove this guy *and* we can remove it from memory.
; Take care of all that here.

                assume  ds:ResidentSeg

CanRemove:      push    ds
                pusha
                cli                     ;Turn off the interrupts while
                mov     ax, 0           ; we mess with the interrupt
                mov     es, ax          ; vectors.
                mov     ax, cs
                mov     ds, ax

                mov     ax, word ptr OldInt2F
                mov     es:[2Fh*4], ax
                mov     ax, word ptr OldInt2F+2
                mov     es:[2Fh*4 + 2], ax


; Okay, one last thing before we quit- Let's give the memory allocated
; to this TSR back to DOS.

                mov     ds, PSP
                mov     es, ds:[2Ch]    ;Ptr to environment block.
                mov     ah, 49h         ;DOS release memory call.
                int     21h

                mov     ax, ds          ;Release program code space.
                mov     es, ax
                mov     ah, 49h
                int     21h

                popa
                pop     ds
                pop     es
                mov     ax, 0           ;Return Success.
                iret

; See if they want us to return the segment address of our shared segment
; here.

TryRetSeg:      cmp     al, 10h         ;Return Segment Opcode
                jne IllegalOp
                mov     ax, SharedMemory
                mov     es, ax
                mov     ax, 0           ;Return success
                clc
                iret

; They called us with an illegal subfunction value. Try to do as little
; damage as possible.

IllegalOp:      mov     ax, 0           ;Who knows what they were thinking?
                iret
MyInt2F         endp
                assume  ds:nothing
ResidentSeg     ends


; Here's the segment that will actually hold the shared data.

SharedMemory    segment para public 'Shared'
                db      0FFFFh dup (?)
SharedMemory    ends


cseg            segment para public 'code'
                assume  cs:cseg, ds:ResidentSeg
```

```
; SeeIfPresent-         Checks to see if our TSR is already present in memory.
;                       Sets the zero flag if it is, clears the zero flag if
;                       it is not.

SeeIfPresent  proc      near
              push      es
              push      ds
              push      di
              mov       cx, 0ffh          ;Start with ID 0FFh.
IDLoop:       mov       ah, cl
              push      cx
              mov       al, 0             ;Verify presence call.
              int       2Fh
              pop       cx
              cmp       al, 0             ;Present in memory?
              je        TryNext
              strcmpl
              byte      "Static Shared Memory TSR",0
              je        Success

TryNext:      dec       cl                ;Test USER IDs of 80h..FFh
              js        IDLoop
              cmp       cx, 0             ;Clear zero flag.
Success:      pop       di
              pop       ds
              pop       es
              ret
SeeIfPresent  endp



; FindID-     Determines the first (well, last actually) TSR ID available
;             in the multiplex interrupt chain. Returns this value in
;             the CL register.
;
;             Returns the zero flag set if it locates an empty slot.
;             Returns the zero flag clear if failure.

FindID        proc      near
              push      es
              push      ds
              push      di

              mov       cx, 0ffh          ;Start with ID 0FFh.
IDLoop:       mov       ah, cl
              push      cx
              mov       al, 0             ;Verify presence call.
              int       2Fh
              pop       cx
              cmp       al, 0             ;Present in memory?
              je        Success
              dec       cl                ;Test USER IDs of 80h..FFh
              js        IDLoop
              xor       cx, cx
              cmp       cx, 1             ;Clear zero flag
Success:      pop       di
              pop       ds
              pop       es
              ret
FindID        endp



Main          proc
              meminit

              mov       ax, ResidentSeg
              mov       ds, ax

              mov       ah, 62h           ;Get this program's PSP
              int       21h               ; value.
              mov       PSP, bx

; Before we do anything else, we need to check the command line
```

```
; parameters. If there is one, and it is the word "REMOVE", then remove
; the resident copy from memory using the multiplex (2Fh) interrupt.

                argc
                cmp         cx, 1               ;Must have 0 or 1 parms.
                jb          TstPresent
                je          DoRemove
Usage:          print
                byte        "Usage:",cr,lf
                byte        " shardmem",cr,lf
                byte        "or shardmem REMOVE",cr,lf,0
                ExitPgm


; Check for the REMOVE command.

DoRemove:       mov         ax, 1
                argv
                stricmpl
                byte        "REMOVE",0
                jne         Usage

                call        SeeIfPresent
                je          RemoveIt
                print
                byte        "TSR is not present in memory, cannot remove"
                byte        cr,lf,0
                ExitPgm

RemoveIt:       mov         MyTSRID, cl
                printf
                byte        "Removing TSR (ID #%d) from memory...",0
                dword       MyTSRID

                mov         ah, cl
                mov         al, 1               ;Remove cmd, ah contains ID
                int         2Fh
                cmp         al, 1               ;Succeed?
                je          RmvFailure
                print
                byte        "removed.",cr,lf,0
                ExitPgm

RmvFailure:     print
                byte        cr,lf
                byte        "Could not remove TSR from memory.",cr,lf
                byte        "Try removing other TSRs in the reverse order "
                byte        "you installed them.",cr,lf,0
                ExitPgm



; Okay, see if the TSR is already in memory. If so, abort the
; installation process.

TstPresent:     call        SeeIfPresent
                jne         GetTSRID
                print
                byte        "TSR is already present in memory.",cr,lf
                byte        "Aborting installation process",cr,lf,0
                ExitPgm


; Get an ID for our TSR and save it away.

GetTSRID:       call        FindID
                je          GetFileName
                print
                byte        "Too many resident TSRs, cannot install",cr,lf,0
                ExitPgm


; Things look cool so far, so install the interrupts
```

```
GetFileName:    mov         MyTSRID, cl
                print
                byte        "Installing interrupts...",0


; Patch into the INT 2Fh interrupt chain.

                cli                         ;Turn off interrupts!
                mov         ax, 0
                mov         es, ax
                mov         ax, es:[2Fh*4]
                mov         word ptr OldInt2F, ax
                mov         ax, es:[2Fh*4 + 2]
                mov         word ptr OldInt2F+2, ax
                mov         es:[2Fh*4], offset MyInt2F
                mov         es:[2Fh*4+2], seg ResidentSeg
                sti                         ;Okay, ints back on.

; We're hooked up, the only thing that remains is to zero out the shared
; memory segment and then terminate and stay resident.

                printf
                byte        "Installed, TSR ID #%d.",cr,lf,0
                dword       MyTSRID

                mov         ax, SharedMemory  ;Zero out the shared
                mov         es, ax            ; memory segment.
                mov         cx, 32768         ;32K words = 64K bytes.
                xor         ax, ax            ;Store all zeros,
                mov         di, ax            ; starting at offset zero.
        rep     stosw


                mov         dx, EndResident   ;Compute size of program.
                sub         dx, PSP
                mov         ax, 3100h         ;DOS TSR command.
                int         21h
Main            endp
cseg            ends

sseg            segment     para stack 'stack'
stk             db          256 dup (?)
sseg            ends

zzzzzzseg       segment     para public 'zzzzzz'
LastBytes       db          16 dup (?)
zzzzzzseg       ends
                end         Main
```

This program simply carves out a chunk of memory (the 64K in the SharedMemory segment) and returns a pointer to it in `es` whenever a program executes the appropriate `int 2Fh` call (`ah`= TSR ID and `al`=10h). The only catch is how do we declared shared variables in the applications that use shared memory? Well, that's fairly easy if we play a sneaky trick on MASM, the Linker, DOS, and the 80x86.

When DOS loads your program into memory, it generally loads the segments in the same order they first appear in your source files. The UCR Standard Library, for example, takes advantage of this by insisting that you include a segment named `zzzzzzseg` at the end of all your assembly language source files. The UCR Standard Library memory management routines build the heap starting at `zzzzzzseg`, it must be the last segment (containing valid data) because the memory management routines may overwrite anything following `zzzzzzseg`.

For our shared memory segment, we would like to create a segment something like the following:

```
SharedMemory    segment     para public 'Shared'

« define all shared variables here»

SharedMemory    ends
```

Applications that share data would define all shared variables in this shared segment. There are, however, five problems. First, how do we tell the assembler/linker/DOS/80x86 that this is a *shared* segment, rather than having a separate segment for each program? Well, this problem is easy to solve; we don't bother telling MASM, the linker, or DOS anything. The way we make the different applications all share the same segment in memory is to invoke the shared memory TSR in the code above with function code 10h. This returns the address of the TSR's SharedMemory segment in the es register. In our assembly language programs we fool MASM into thinking es points at its local shared memory segment when, in fact, es points at the global segment.

The second problem is minor, but annoying nonetheless. When you create a segment, MASM, the linker, and DOS set aside storage for that segment. If you declare a large number of variables in a shared segment, this can waste memory since the program will actually use the memory space in the global shared segment. One easy way to reclaim the storage that MASM reserves for this segment is to define the shared segment *after* zzzzzzseg in your shared memory applications. By doing so, the Standard Library will absorb any memory reserved for the (dummy) shared memory segment into the heap, since all memory after zzzzzzseg belongs to the heap (when you use the standard meminit call).

The third problem is slightly more difficult to deal with. Since you will not be use the local segment, you cannot initialize any variables in the shared memory segment by placing values in the operand field of byte, word, dword, etc., directives. Doing so will only initialize the local memory in the heap, the system will not copy this data to the global shared segment. Generally, this isn't a problem because processes won't normally initialize shared memory as they load. Instead, there will probably be a single application you run first that initializes the shared memory area for the rest of the processes that using the global shared segment.

The fourth problem is that you cannot initialize any variables with the address of an object in shared memory. For example, if the variable shared_K is in the shared memory segment, you could not use a statement like the following:

```
printf
byte       "Value of shared_K is %d\n",0
dword      shared_K
```

The problem with this code is that MASM initializes the double word after the string above with the address of the shared_K variable *in the local copy of the shared data segment.* This will not print out the copy in the global shared data segment.

The last problem is anything but minor. All programs that use the global shared memory segment *must* define their variables at identical offsets within the shared segment. Given the way MASM assigns offsets to variables within a segment, if you are one byte off in the declaration of *any* of your variables, your program will be accessing its variables at different addresses than other processes sharing the global shared segment. This will scramble memory and produce a disaster. The only reasonable way to declare variables for shared memory programs is to create an include file with all the shared variable declarations for all concerned programs. Then include this single file into all the programs that share the variables. Now you can add, remove, or modify variables without having to worry about maintaining the shared variable declarations in the other files.

The following two sample programs demonstrate the use of shared memory. The first application reads a string from the user and stuffs it into shared memory. The second application reads that string from shared memory and displays it on the screen.

First, here is the include file containing the single shared variable declaration used by both applications:

```
; shmvars.asm
;
; This file contains the shared memory variable declarations used by
; all applications that refer to shared memory.

InputLine      byte       128 dup (?)
```

Here is the first application that reads an input string from the user and shoves it into shared memory:

```
; SHMAPP1.ASM
;
; This is a shared memory application that uses the static shared memory
; TSR (SHARDMEM.ASM). This program inputs a string from the user and
; passes that string to SHMAPP2.ASM through the shared memory area.
;
;
                .xlist
                include    stdlib.a
                includelib stdlib.lib
                .list

dseg            segment    para public 'data'
ShmID           byte       0
dseg            ends

cseg            segment    para public 'code'
                assume     cs:cseg, ds:dseg, es:SharedMemory

; SeeIfPresent-Checks to see if the shared memory TSR is present in memory.
;               Sets the zero flag if it is, clears the zero flag if
;               it is not. This routine also returns the TSR ID in CL.

SeeIfPresent    proc       near
                push       es
                push       ds
                push       di
                mov        cx, 0ffh          ;Start with ID 0FFh.
IDLoop:         mov        ah, cl
                push       cx
                mov        al, 0             ;Verify presence call.
                int        2Fh
                pop        cx
                cmp        al, 0             ;Present in memory?
                je         TryNext
                strcmpl
                byte       "Static Shared Memory TSR",0
                je         Success

TryNext:        dec        cl                ;Test USER IDs of 80h..FFh
                js         IDLoop
                cmp        cx, 0             ;Clear zero flag.
Success:        pop        di
                pop        ds
                pop        es
                ret
SeeIfPresent    endp



; The main program for application #1 links with the shared memory
; TSR and then reads a string from the user (storing the string into
; shared memory) and then terminates.

Main            proc
                assume     cs:cseg, ds:dseg, es:SharedMemory
                mov        ax, dseg
                mov        ds, ax
                meminit

                print
                byte       "Shared memory application #1",cr,lf,0

; See if the shared memory TSR is around:

                call       SeeIfPresent
                je         ItsThere
                print
                byte       "Shared Memory TSR (SHARDMEM) is not loaded.",cr,lf
                byte       "This program cannot continue execution.",cr,lf,0
```

```
                ExitPgm

; If the shared memory TSR is present, get the address of the shared segment
; into the ES register:

ItsThere:       mov         ah, cl              ;ID of our TSR.
                mov         al, 10h             ;Get shared segment address.
                int         2Fh

; Get the input line from the user:

                print
                byte        "Enter a string: ",0

                lea         di, InputLine       ;ES already points at proper seg.
                gets

                print
                byte        "Entered `",0
                puts
                print
                byte        "` into shared memory.",cr,lf,0


Quit:           ExitPgm                         ;DOS macro to quit program.
Main            endp

cseg ends

sseg            segment     para stack 'stack'
stk             db          1024 dup ("stack ")
sseg            ends

zzzzzzseg       segment     para public 'zzzzzz'
LastBytes       db          16 dup (?)
zzzzzzseg       ends


; The shared memory segment must appear after "zzzzzzseg".
; Note that this isn't the physical storage for the data in the
; shared segment. It's really just a place holder so we can declare
; variables and generate their offsets appropriately. The UCR Standard
; Library will reuse the memory associated with this segment for the
; heap. To access data in the shared segment, this application calls
; the shared memory TSR to obtain the true segment address of the
; shared memory segment. It can then access variables in the shared
; memory segment (where ever it happens to be) off the ES register.
;
; Note that all the variable declarations go into an include file.
; All applications that refer to the shared memory segment include
; this file in the SharedMemory segment. This ensures that all
; shared segments have the exact same variable layout.

SharedMemory    segment     para public 'Shared'

                include     shmvars.asm

SharedMemory    ends
                end         Main
```

The second application is very similar, here it is

```
; SHMAPP2.ASM
;
; This is a shared memory application that uses the static shared memory
; TSR (SHARDMEM.ASM). This program assumes the user has already run the
; SHMAPP1 program to insert a string into shared memory. This program
; simply prints that string from shared memory.
;
```

```
                .xlist
                include    stdlib.a
                includelib stdlib.lib
                .list

dseg            segment    para public 'data'
ShmID           byte       0
dseg            ends

cseg            segment    para public 'code'
                assume     cs:cseg, ds:dseg, es:SharedMemory

; SeeIfPresent Checks to see if the shared memory TSR is present in memory.
;              Sets the zero flag if it is, clears the zero flag if
;              it is not. This routine also returns the TSR ID in CL.

SeeIfPresent    proc       near
                push       es
                push       ds
                push       di
                mov        cx, 0ffh          ;Start with ID 0FFh.
IDLoop:         mov        ah, cl
                push       cx
                mov        al, 0             ;Verify presence call.
                int        2Fh
                pop        cx
                cmp        al, 0             ;Present in memory?
                je         TryNext
                strcmpl
                byte       "Static Shared Memory TSR",0
                je         Success

TryNext:        dec        cl                ;Test USER IDs of 80h..FFh
                js         IDLoop
                cmp        cx, 0             ;Clear zero flag.
Success:        pop        di
                pop        ds
                pop        es
                ret
SeeIfPresent    endp



; The main program for application #1 links with the shared memory
; TSR and then reads a string from the user (storing the string into
; shared memory) and then terminates.

Main            proc
                assume     cs:cseg, ds:dseg, es:SharedMemory
                mov        ax, dseg
                mov        ds, ax
                meminit

                print
                byte       "Shared memory application #2",cr,lf,0

; See if the shared memory TSR is around:

                call       SeeIfPresent
                je         ItsThere
                print
                byte       "Shared Memory TSR (SHARDMEM) is not loaded.",cr,lf
                byte       "This program cannot continue execution.",cr,lf,0
                ExitPgm

; If the shared memory TSR is present, get the address of the shared segment
; into the ES register:

ItsThere:       mov        ah, cl            ;ID of our TSR.
                mov        al, 10h           ;Get shared segment address.
                int        2Fh

; Print the string input in SHMAPP1:
```

```
                print
                byte        "String from SHMAPP1 is '",0

                lea         di, InputLine     ;ES already points at proper seg.
                puts

                print
                byte        "' from shared memory.",cr,lf,0


Quit:           ExitPgm                       ;DOS macro to quit program.
Main            endp

cseg            ends

sseg            segment     para stack 'stack'
stk             db          1024 dup ("stack ")
sseg            ends

zzzzzzseg       segment     para public 'zzzzzz'
LastBytes       db          16 dup (?)
zzzzzzseg       ends


; The shared memory segment must appear after "zzzzzzseg".
; Note that this isn't the physical storage for the data in the
; shared segment. It's really just a place holder so we can declare
; variables and generate their offsets appropriately. The UCR Standard
; Library will reuse the memory associated with this segment for the
; heap. To access data in the shared segment, this application calls
; the shared memory TSR to obtain the true segment address of the
; shared memory segment. It can then access variables in the shared
; memory segment (where ever it happens to be) off the ES register.
;
; Note that all the variable declarations go into an include file.
; All applications that refer to the shared memory segment include
; this file in the SharedMemory segment. This ensures that all
; shared segments have the exact same variable layout.

SharedMemory    segment     para public 'Shared'

                include     shmvars.asm

SharedMemory    ends
                end         Main
```

19.2.2 Dynamic Shared Memory

Although the static shared memory the previous section describes is very useful, it does suffer from a few limitations. First of all, any program that uses the global shared segment must be aware of the location of every other program that uses the shared segment. This effectively means that the use of the shared segment is limited to a single set of cooperating processes at any one given time. You cannot have two independent sets of programs using the shared memory at the same time. Another limitation with the static system is that you must know the size of all variables when you write your program, you cannot create dynamic data structures whose size varies at run time. It would be nice, for example, to have calls like shmalloc and shmfree that let you dynamically allocate and free memory in a shared region. Fortunately, it is very easy to overcome these limitations by creating a *dynamic shared memory manager.*

A reasonable shared memory manager will have four functions: initialize, shmalloc, shmattach, and shmfree. The initialization call reclaims all shared memory in use. The shmalloc call lets a process allocate a new block of shared memory. Only one process in a group of cooperating processes makes this call. Once shmalloc allocates a block of memory, the other processes use the shmattach call to obtain the address of the shared memory block. The following code implements a dynamic shared memory manager. The code is similar to that appearing in the Standard Library except this code allows a maximum of 64K storage on the heap.

```
; SHMALLOC.ASM
;
; This TSR sets up a dynamic shared memory system.
;
; This TSR checks to make sure there isn't a copy already active in
; memory. When removing itself from memory, it makes sure there are
; no other interrupts chained into INT 2Fh before doing the remove.
;
;
;
; The following segments must appear in this order and before the
; Standard Library includes.

ResidentSeg   segment   para public 'Resident'
ResidentSeg   ends

SharedMemory  segment   para public 'Shared'
SharedMemory  ends

EndResident   segment   para public 'EndRes'
EndResident   ends

              .xlist
              .286
              include   stdlib.a
              includelib stdlib.lib
              .list


; Resident segment that holds the TSR code:

ResidentSeg   segment   para public 'Resident'
              assume    cs:ResidentSeg, ds:nothing


NULL          equ       0


; Data structure for an allocated data region.
;
; Key-  user supplied ID to associate this region with a particular set
;       of processes.
;
; Next- Points at the next allocated block.
; Prev- Points at the previous allocated block.
; Size- Size (in bytes) of allocated block, not including header structure.

Region        struct
key           word      ?
next          word      ?
prev          word      ?
blksize       word      ?
Region        ends

Startmem      equ       Region ptr [0]

AllocatedList word      0             ;Points at chain of alloc'd blocks.
FreeList      word      0             ;Points at chain of free blocks.

; Int 2Fh ID number for this TSR:

MyTSRID       byte      0
              byte      0             ;Padding so we can print it.

; PSP is the psp address for this program.

PSP           word      0

OldInt2F      dword     ?


; MyInt2F-    Provides int 2Fh (multiplex interrupt) support for this
;             TSR. The multiplex interrupt recognizes the following
;             subfunctions (passed in AL):
```

```
;
;               00h- Verify presence.    Returns 0FFh in AL and a pointer
;                                        to an ID string in es:di if the
;                                        TSR ID (in AH) matches this
;                                        particular TSR.
;
;               01h- Remove.             Removes the TSR from memory.
;                                        Returns 0 in AL if successful,
;                                        1 in AL if failure.
;
;               11h- shmalloc            CX contains the size of the block
;                                         to allocate.
;                                        DX contains the key for this block.
;                                        Returns a pointer to block in ES:DI
;                                         and size of allocated block in CX.
;                                        Returns an error code in AX. Zero
;                                         is no error, one is "key already
;                                         exists," two is "insufficient
;                                         memory for request."
;
;               12h- shmfree             DX contains the key for this block.
;                                        This call frees the specified block
;                                         from memory.
;
;               13h- shminit             Initializes the shared memory system
;                                         freeing all blocks currently in
;                                         use.
;
;               14h- shmattach           DX contains the key for a block.
;                                         Search for that block and return
;                                         its address in ES:DI. AX contains
;                                         zero if successful, three if it
;                                         cannot locate a block with the
;                                         specified key.

MyInt2F         proc       far
                assume     ds:nothing

                cmp        ah, MyTSRID;Match our TSR identifier?
                je         YepItsOurs
                jmp        OldInt2F

; Okay, we know this is our ID, now check for a verify, remove, or
; return segment call.

YepItsOurs:     cmp        al, 0             ;Verify Call
                jne        TryRmv
                mov        al, 0ffh;Return success.
                lesi       IDString
                iret                         ;Return back to caller.

IDString byte   "Dynamic Shared Memory TSR",0

TryRmv:         cmp        al, 1             ;Remove call.
                jne        Tryshmalloc

; See if we can remove this TSR:

                push       es
                mov        ax, 0
                mov        es, ax
                cmp        word ptr es:[2Fh*4], offset MyInt2F
                jne        TRDone
                cmp        word ptr es:[2Fh*4 + 2], seg MyInt2F
                je         CanRemove         ;Branch if we can.
TRDone:         mov        ax, 1             ;Return failure for now.
                pop        es
                iret

; Okay, they want to remove this guy *and* we can remove it from memory.
; Take care of all that here.

                assume     ds:ResidentSeg
```

```
CanRemove:      push    ds
                pusha
                cli                     ;Turn off the interrupts while
                mov     ax, 0           ; we mess with the interrupt
                mov     es, ax          ; vectors.
                mov     ax, cs
                mov     ds, ax

                mov     ax, word ptr OldInt2F
                mov     es:[2Fh*4], ax
                mov     ax, word ptr OldInt2F+2
                mov     es:[2Fh*4 + 2], ax


; Okay, one last thing before we quit- Let's give the memory allocated
; to this TSR back to DOS.

                mov     ds, PSP
                mov     es, ds:[2Ch]    ;Ptr to environment block.
                mov     ah, 49h         ;DOS release memory call.
                int     21h

                mov     ax, ds          ;Release program code space.
                mov     es, ax
                mov     ah, 49h
                int     21h

                popa
                pop     ds
                pop     es
                mov     ax, 0           ;Return Success.
                iret



; Stick BadKey here so that it is close to its associated branch (from below).
;
; If come here, we've discovered an allocated block with the
; specified key. Return an error code (AX=1) and the size of that
; allocated block (in CX).

BadKey:         mov     cx, [bx].Region.BlkSize
                mov     ax, 1           ;Already allocated error.
                pop     bx
                pop     ds
                iret


; See if this is a shmalloc call.
; If so, on entry -
; DX contains the key.
; CX contains the number of bytes to allocate.
;
; On exit:
;
; ES:DI points at the allocated block (if successful).
; CX contains the actual size of the allocated block (>=CX on entry).
; AX contains error code, 0 if no error.

Tryshmalloc:    cmp     al, 11h         ;shmalloc function code.
                jne Tryshmfree

; First, search through the allocated list to see if a block with the
; current key number already exists. DX contains the requested key.

                assume  ds:SharedMemory
                assume  bx:ptr Region
                assume  di:ptr Region

                push    ds
                push    bx
                mov     bx, SharedMemory
                mov     ds, bx
```

```
                mov     bx, ResidentSeg:AllocatedList
                test    bx, bx          ;Anything on this list?
                je      SrchFreeList

SearchLoop:     cmp     dx, [bx].Key    ;Key exist already?
                je      BadKey
                mov     bx, [bx].Next   ;Get next region.
                test    bx, bx          ;NULL?, if not, try another
                jne     SearchLoop      ; entry in the list.

; If an allocated block with the specified key does not already exist,
; then try to allocate one from the free memory list.

SrchFreeList:   mov     bx, ResidentSeg:FreeList
                test    bx, bx          ;Empty free list?
                je      OutaMemory

FirstFitLp:     cmp     cx, [bx].BlkSize  ;Is this block big enough?
                jbe     GotBlock
                mov     bx, [bx].Next   ;If not, on to the next one.
                test    bx, bx          ;Anything on this list?
                jne     FirstFitLp

; If we drop down here, we were unable to find a block that was large
; enough to satisfy the request. Return an appropriate error

OutaMemory:     mov     cx, 0           ;Nothing available.
                mov     ax, 2           ;Insufficient memory error.
                pop     bx
                pop     ds
                iret

; If we find a large enough block, we've got to carve the new block
; out of it and return the rest of the storage to the free list. If the
; free block is at least 32 bytes larger than the requested size, we will
; do this. If the free block is less than 32 bytes larger, we will simply
; give this free block to the requesting process. The reason for the
; 32 bytes is simple: We need eight bytes for the new block's header
; (the free block already has one) and it doesn't make sense to fragment
; blocks to sizes below 24 bytes. That would only increase processing time
; when processes free up blocks by requiring more work coalescing blocks.

GotBlock:       mov     ax, [bx].BlkSize  ;Compute difference in size.
                sub     ax, cx
                cmp     ax, 32          ;At least 32 bytes left?
                jbe     GrabWholeBlk    ;If not, take this block.

; Okay, the free block is larger than the requested size by more than 32
; bytes. Carve the new block from the end of the free block (that way
; we do not have to change the free block's pointers, only the size.

                mov     di, bx
                add     di, [bx].BlkSize  ;Scoot to end, minus 8
                sub     di, cx          ;Point at new block.

                sub     [bx].BlkSize, cx  ;Remove alloc'd block and
                sub     [bx].BlkSize, 8   ; room for header.

                mov     [di].BlkSize, cx  ;Save size of block.
                mov     [di].Key, dx    ;Save key.

; Link the new block into the list of allocated blocks.

                mov     bx, ResidentSeg:AllocatedList
                mov     [di].Next, bx
                mov     [di].Prev, NULL   ;NULL previous pointer.
                test    bx, bx          ;See if it was an empty list.
                je      NoPrev
                mov     [bx].Prev, di   ;Set prev ptr for old guy.

NoPrev:         mov     ResidentSeg:AllocatedList, di
RmvDone:        add     di, 8           ;Point at actual data area.
                mov     ax, ds          ;Return ptr in es:di.
                mov     es, ax
```

```
                mov     ax, 0           ;Return success.
                pop     bx
                pop     ds
                iret


; If the current free block is larger than the request, but not by more
; that 32 bytes, just give the whole block to the user.

GrabWholeBlk:   mov     di, bx
                mov     cx, [bx].BlkSize  ;Return actual size.
                cmp     [bx].Prev, NULL   ;First guy in list?
                je      Rmv1st
                cmp     [bx].Next, NULL   ;Last guy in list?
                je      RmvLast

; Okay, this record is sandwiched between two other in the free list.
; Cut it out from among the two.

                mov     ax, [bx].Next     ;Save the ptr to the next
                mov     bx, [bx].Prev     ; item in the prev item's
                mov     [bx].Next, ax     ; next field.

                mov     ax, bx            ;Save the ptr to the prev
                mov     bx, [di].Next     ; item in the next item's
                mov     [bx].Prev, bx     ; prev field.
                jmp     RmvDone



; The block we want to remove is at the beginning of the free list.
; It could also be the only item on the free list!

Rmv1st:         mov     ax, [bx].Next
                mov     FreeList, ax      ;Remove from free list.
                jmp     RmvDone

; If the block we want to remove is at the end of the list, handle that
; down here.

RmvLast:        mov     bx, [bx].Prev
                mov     [bx].Next, NULL
                jmp     RmvDone

                assume  ds:nothing, bx:nothing, di:nothing



; This code handles the SHMFREE function.
; On entry, DX contains the key for the block to free. We need to
; search through the allocated block list and find the block with that
; key. If we do not find such a block, this code returns without doing
; anything. If we find the block, we need to add its memory to the
; free pool. However, we cannot simply insert this block on the front
; of the free list (as we did for the allocated blocks). It might
; turn out that this block we're freeing is adjacent to one or two
; other free blocks. This code has to coalesce such blocks into
; a single free block.

Tryshmfree:     cmp     al, 12h
                jne     Tryshminit


; First, search the allocated block list to see if we can find the
; block to remove. If we don't find it in the list anywhere, just return.

                assume  ds:SharedMemory
                assume  bx:ptr Region
                assume  di:ptr Region

                push    ds
                push    di
                push    bx
```

```
                mov     bx, SharedMemory
                mov     ds, bx
                mov     bx, ResidentSeg:AllocatedList

                test    bx, bx          ;Empty allocated list?
                je      FreeDone
SrchList:       cmp     dx, [bx].Key    ;Search for key in DX.
                je      FoundIt
                mov     bx, [bx].Next
                test    bx, bx          ;At end of list?
                jne     SrchList
FreeDone:       pop     bx
                pop     di              ;Nothing allocated, just
                pop     ds              ; return to caller.
                iret


; Okay, we found the block the user wants to delete. Remove it from
; the allocated list. There are three cases to consider:
; (1) it is at the front of the allocated list, (2) it is at the end of
; the allocated list, and (3) it is in the middle of the allocated list.

FoundIt:        cmp     [bx].Prev, NULL ;1st item in list?
                je      Free1st
                cmp     [bx].Next, NULL ;Last item in list?
                je      FreeLast

; Okay, we're removing an allocated item from the middle of the allocated
; list.

                mov     di, [bx].Next   ;[next].prev := [cur].prev
                mov     ax, [bx].Prev
                mov     [di].Prev, ax
                xchg    ax, di
                mov     [di].Next, ax   ;[prev].next := [cur].next
                jmp     AddFree

; Handle the case where we are removing the first item from the allocation
; list. It is possible that this is the only item on the list (i.e., it
; is the first and last item), but this code handles that case without any
; problems.

Free1st:        mov     ax, [bx].Next
                mov     ResidentSeg:AllocatedList, ax
                jmp     AddFree

; If we're removing the last guy in the chain, simply set the next field
; of the previous node in the list to NULL.

FreeLast:       mov     di, [bx].Prev
                mov     [di].Next, NULL

; Okay, now we've got to put the freed block onto the free block list.
; The free block list is sorted according to address. We have to search
; for the first free block whose address is greater than the block we've
; just freed and insert the new free block before that one. If the two
; blocks are adjacent, then we've got to merge them into a single free
; block. Also, if the block before is adjacent, we must merge it as
; well. This will coalesce all free blocks on the free list so there
; are as few free blocks as possible and those blocks are as large as
; possible.

AddFree:        mov     ax, ResidentSeg:FreeList
                test    ax, ax          ;Empty list?
                jne     SrchPosn

; If the list is empty, stick this guy on as the only entry.

                mov     ResidentSeg:FreeList, bx
                mov     [bx].Next, NULL
                mov     [bx].Prev, NULL
                jmp     FreeDone
```

```
; If the free list is not empty, search for the position of this block
; in the free list:

SrchPosn:     mov       di, ax
              cmp       bx, di
              jb        FoundPosn
              mov       ax, [di].Next
              test      ax, ax            ;At end of list?
              jne       SrchPosn

; If we fall down here, the free block belongs at the end of the list.
; See if we need to merge the new block with the old one.

              mov       ax, di
              add       ax, [di].BlkSize  ;Compute address of 1st byte
              add       ax, 8             ; after this block.
              cmp       ax, bx
              je        MergeLast

; Okay, just add the free block to the end of the list.

              mov       [di].Next, bx
              mov       [bx].Prev, di
              mov       [bx].Next, NULL
              jmp       FreeDone

; Merge the freed block with the block DI points at.

MergeLast:    mov       ax, [di].BlkSize
              add       ax, [bx].BlkSize
              add       ax, 8
              mov       [di].BlkSize, ax
              jmp       FreeDone

; If we found a free block before which we are supposed to insert
; the current free block, drop down here and handle it.

FoundPosn:    mov       ax, bx            ;Compute the address of the
              add       ax, [bx].BlkSize  ; next block in memory.
              add       ax, 8
              cmp       ax, di            ;Equal to this block?
              jne       DontMerge

; The next free block is adjacent to the one we're freeing, so just
; merge the two.

              mov       ax, [di].BlkSize  ;Merge the sizes together.
              add       ax, 8
              add       [bx].BlkSize, ax
              mov       ax, [di].Next     ;Tweak the links.
              mov       [bx].Next, ax
              mov       ax, [di].Prev
              mov       [bx].Prev, ax
              jmp       TryMergeB4

; If the blocks are not adjacent, just link them together here.

DontMerge:    mov       ax, [di].Prev
              mov       [di].Prev, bx
              mov       [bx].Prev, ax
              mov       [bx].Next, di

; Now, see if we can merge the current free block with the previous free blk.

TryMergeB4:   mov       di, [bx].Prev
              mov       ax, di
              add       ax, [di].BlkSize
              add       ax, 8
              cmp       ax, bx
              je        CanMerge
              pop       bx
              pop       di                ;Nothing allocated, just
              pop       ds                ; return to caller.
              iret
```

```
; If we can merge the previous and current free blocks, do that here:

CanMerge:     mov       ax, [bx].Next
              mov       [di].Next, ax
              mov       ax, [bx].BlkSize
              add       ax, 8
              add       [di].BlkSize, ax
              pop       bx
              pop       di
              pop       ds
              iret

              assume    ds:nothing
              assume    bx:nothing
              assume    di:nothing

; Here's where we handle the shared memory initializatin (SHMINIT) function.
; All we got to do is create a single block on the free list (which is all
; available memory), empty out the allocated list, and then zero out all
; shared memory.

Tryshminit:   cmp       al, 13h
              jne       TryShmAttach

; Reset the memory allocation area to contain a single, free, block of
; memory whose size is 0FFF8h (need to reserve eight bytes for the block's
; data structure).

              push      es
              push      di
              push      cx

              mov       ax, SharedMemory  ;Zero out the shared
              mov       es, ax            ; memory segment.
              mov       cx, 32768
              xor       ax, ax
              mov       di, ax
        rep   stosw


; Note: the commented out lines below are unnecessary since the code above
; has already zeroed out the entire shared memory segment.
; Note: we cannot put the first record at offset zero because offset zero
; is the special value for the NULL pointer. We'll use 4 instead.

              mov       di, 4
;             mov       es:[di].Region.Key, 0 ;Key is arbitrary.
;             mov       es:[di].Region.Next, 0 ;No other entries.
;             mov       es:[di].Region.Prev, 0 ; Ditto.
              mov       es:[di].Region.BlkSize, 0FFF8h ;Rest of segment.
              mov       ResidentSeg:FreeList, di

              pop       cx
              pop       di
              pop       es
              mov       ax, 0             ;Return no error.
              iret


; Handle the SHMATTACH function here. On entry, DX contains a key number.
; Search for an allocated block with that key number and return a pointer
; to that block (if found) in ES:DI. Return an error code (AX=3) if we
; cannot find the block.

TryShmAttach: cmp       al, 14h           ;Attach opcode.
              jne       IllegalOp
              mov       ax, SharedMemory
              mov       es, ax

              mov       di, ResidentSeg:AllocatedList
FindOurs:     cmp       dx, es:[di].Region.Key
              je        FoundOurs
              mov       di, es:[di].Region.Next
```

```
                test        di, di
                jne         FoundOurs
                mov         ax, 3               ;Can't find the key.
                iret

FoundOurs:      add         di, 8               ;Point at actual data.
                mov         ax, 0               ;No error.
                iret


; They called us with an illegal subfunction value. Try to do as little
; damage as possible.

IllegalOp:      mov         ax, 0           ;Who knows what they were thinking?
                iret
MyInt2F         endp
                assume      ds:nothing
ResidentSeg     ends


; Here's the segment that will actually hold the shared data.

SharedMemory    segment     para public 'Shared'
                db          0FFFFh dup (?)
SharedMemory    ends




cseg            segment     para public 'code'
                assume      cs:cseg, ds:ResidentSeg

; SeeIfPresent-             Checks to see if our TSR is already present in memory.
;                           Sets the zero flag if it is, clears the zero flag if
;                           it is not.

SeeIfPresent    proc        near
                push        es
                push        ds
                push        di
                mov         cx, 0ffh            ;Start with ID 0FFh.
IDLoop:         mov         ah, cl
                push        cx
                mov         al, 0               ;Verify presence call.
                int         2Fh
                pop         cx
                cmp         al, 0               ;Present in memory?
                je          TryNext
                strcmpl
                byte        "Dynamic Shared Memory TSR",0
                je          Success

TryNext:        dec         cl                  ;Test USER IDs of 80h..FFh
                js          IDLoop
                cmp         cx, 0               ;Clear zero flag.
Success:        pop         di
                pop         ds
                pop         es
                ret
SeeIfPresent    endp



; FindID-       Determines the first (well, last actually) TSR ID available
;               in the multiplex interrupt chain. Returns this value in
;               the CL register.
;
;               Returns the zero flag set if it locates an empty slot.
;               Returns the zero flag clear if failure.

FindID          proc        near
                push        es
```

```
                push    ds
                push    di

                mov     cx, 0ffh        ;Start with ID 0FFh.
IDLoop:         mov     ah, cl
                push    cx
                mov     al, 0           ;Verify presence call.
                int     2Fh
                pop     cx
                cmp     al, 0           ;Present in memory?
                je      Success
                dec     cl              ;Test USER IDs of 80h..FFh
                js      IDLoop
                xor     cx, cx
                cmp     cx, 1           ;Clear zero flag
Success:        pop     di
                pop     ds
                pop     es
                ret
FindID          endp



Main            proc
                meminit

                mov     ax, ResidentSeg
                mov     ds, ax

                mov     ah, 62h         ;Get this program's PSP
                int     21h             ; value.
                mov     PSP, bx

; Before we do anything else, we need to check the command line
; parameters. If there is one, and it is the word "REMOVE", then remove
; the resident copy from memory using the multiplex (2Fh) interrupt.

                argc
                cmp     cx, 1           ;Must have 0 or 1 parms.
                jb      TstPresent
                je      DoRemove
Usage:          print
                byte    "Usage:",cr,lf
                byte    " shmalloc",cr,lf
                byte    "or shmalloc REMOVE",cr,lf,0
                ExitPgm


; Check for the REMOVE command.

DoRemove:       mov     ax, 1
                argv
                stricmpl
                byte    "REMOVE",0
                jne     Usage

                call    SeeIfPresent
                je      RemoveIt
                print
                byte    "TSR is not present in memory, cannot remove"
                byte    cr,lf,0
                ExitPgm

RemoveIt:       mov     MyTSRID, cl
                printf
                byte    "Removing TSR (ID #%d) from memory...",0
                dword   MyTSRID

                mov     ah, cl
                mov     al, 1           ;Remove cmd, ah contains ID
                int     2Fh
                cmp     al, 1           ;Succeed?
                je      RmvFailure
                print
```

```
                byte    "removed.",cr,lf,0
                ExitPgm

RmvFailure:     print
                byte    cr,lf
                byte    "Could not remove TSR from memory.",cr,lf
                byte    "Try removing other TSRs in the reverse order "
                byte    "you installed them.",cr,lf,0
                ExitPgm



; Okay, see if the TSR is already in memory. If so, abort the
; installation process.

TstPresent:     call    SeeIfPresent
                jne     GetTSRID
                print
                byte    "TSR is already present in memory.",cr,lf
                byte    "Aborting installation process",cr,lf,0
                ExitPgm


; Get an ID for our TSR and save it away.

GetTSRID:       call    FindID
                je      GetFileName
                print
                byte    "Too many resident TSRs, cannot install",cr,lf,0
                ExitPgm


; Things look cool so far, so install the interrupts

GetFileName:    mov     MyTSRID, cl
                print
                byte    "Installing interrupts...",0


; Patch into the INT 2Fh interrupt chain.

                cli                     ;Turn off interrupts!
                mov     ax, 0
                mov     es, ax
                mov     ax, es:[2Fh*4]
                mov     word ptr OldInt2F, ax
                mov     ax, es:[2Fh*4 + 2]
                mov     word ptr OldInt2F+2, ax
                mov     es:[2Fh*4], offset MyInt2F
                mov     es:[2Fh*4+2], seg ResidentSeg
                sti                     ;Okay, ints back on.

; We're hooked up, the only thing that remains is to initialize the shared
; memory segment and then terminate and stay resident.

                printf
                byte    "Installed, TSR ID #%d.",cr,lf,0
                dword   MyTSRID

                mov     ah, MyTSRID     ;Initialization call.
                mov     al, 13h
                int     2Fh

                mov     dx, EndResident ;Compute size of program.
                sub     dx, PSP
                mov     ax, 3100h       ;DOS TSR command.
                int     21h
Main            endp
cseg            ends

sseg            segment para stack 'stack'
stk             db      256 dup (?)
sseg            ends
```

```
zzzzzzseg       segment     para public 'zzzzzz'
LastBytes       db          16 dup (?)
zzzzzzseg       ends
                end         Main
```

We can modify the two applications from the previous section to try out this code:

```
; SHMAPP3.ASM
;
; This is a shared memory application that uses the dynamic shared memory
; TSR (SHMALLOC.ASM). This program inputs a string from the user and
; passes that string to SHMAPP4.ASM through the shared memory area.
;
;
                .xlist
                include     stdlib.a
                includelib stdlib.lib
                .list

dseg            segment     para public 'data'
ShmID           byte        0
dseg            ends

cseg            segment     para public 'code'
                assume      cs:cseg, ds:dseg, es:SharedMemory

; SeeIfPresent-Checks to see if the shared memory TSR is present in memory.
;               Sets the zero flag if it is, clears the zero flag if
;               it is not. This routine also returns the TSR ID in CL.

SeeIfPresent    proc        near
                push        es
                push        ds
                push        di
                mov         cx, 0ffh            ;Start with ID 0FFh.
IDLoop:         mov         ah, cl
                push        cx
                mov         al, 0               ;Verify presence call.
                int         2Fh
                pop         cx
                cmp         al, 0               ;Present in memory?
                je          TryNext
                strcmpl
                byte        "Dynamic Shared Memory TSR",0
                je          Success

TryNext:        dec         cl                  ;Test USER IDs of 80h..FFh
                js          IDLoop
                cmp         cx, 0               ;Clear zero flag.
Success:        pop         di
                pop         ds
                pop         es
                ret
SeeIfPresent    endp


; The main program for application #1 links with the shared memory
; TSR and then reads a string from the user (storing the string into
; shared memory) and then terminates.

Main            proc
                assume      cs:cseg, ds:dseg, es:SharedMemory
                mov         ax, dseg
                mov         ds, ax
                meminit
```

```
                print
                byte    "Shared memory application #3",cr,lf,0

; See if the shared memory TSR is around:

                call    SeeIfPresent
                je      ItsThere
                print
                byte    "Shared Memory TSR (SHMALLOC) is not loaded.",cr,lf
                byte    "This program cannot continue execution.",cr,lf,0
                ExitPgm


; Get the input line from the user:

ItsThere:       mov     ShmID, cl
                print
                byte    "Enter a string: ",0

                lea     di, InputLine   ;ES already points at proper seg.
                getsm

; The string is in our heap space. Let's move it over to the shared
; memory segment.

                strlen
                inc     cx              ;Add one for zero byte.
                push    es
                push    di

                mov     dx, 1234h       ;Our "key" value.
                mov     ah, ShmID
                mov     al, 11h         ;Shmalloc call.
                int     2Fh

                mov     si, di          ;Save as dest ptr.
                mov     dx, es

                pop     di              ;Retrive source address.
                pop     es
                strcpy                  ;Copy from local to shared.

                print
                byte    "Entered '",0
                puts
                print
                byte    "' into shared memory.",cr,lf,0


Quit:           ExitPgm                 ;DOS macro to quit program.
Main            endp

cseg            ends

sseg            segment para stack 'stack'
stk             db      1024 dup ("stack ")
sseg            ends

zzzzzzseg       segment para public 'zzzzzz'
LastBytes       db      16 dup (?)
zzzzzzseg       ends

                end     Main




; SHMAPP4.ASM
;
; This is a shared memory application that uses the dynamic shared memory
; TSR (SHMALLOC.ASM). This program assumes the user has already run the
; SHMAPP3 program to insert a string into shared memory. This program
```

```
; simply prints that string from shared memory.
;
                .xlist
                include    stdlib.a
                includelib stdlib.lib
                .list

dseg            segment    para public 'data'
ShmID           byte       0
dseg            ends

cseg            segment    para public 'code'
                assume     cs:cseg, ds:dseg, es:SharedMemory

; SeeIfPresent-Checks to see if the shared memory TSR is present in memory.
;               Sets the zero flag if it is, clears the zero flag if
;               it is not. This routine also returns the TSR ID in CL.

SeeIfPresent    proc       near
                push       es
                push       ds
                push       di
                mov        cx, 0ffh          ;Start with ID 0FFh.
IDLoop:         mov        ah, cl
                push       cx
                mov        al, 0             ;Verify presence call.
                int        2Fh
                pop        cx
                cmp        al, 0             ;Present in memory?
                je         TryNext
                strcmpl
                byte       "Dynamic Shared Memory TSR",0
                je         Success

TryNext:        dec        cl                ;Test USER IDs of 80h..FFh
                js         IDLoop
                cmp        cx, 0             ;Clear zero flag.
Success:        pop        di
                pop        ds
                pop        es
                ret
SeeIfPresent    endp



; The main program for application #1 links with the shared memory
; TSR and then reads a string from the user (storing the string into
; shared memory) and then terminates.

Main            proc
                assume     cs:cseg, ds:dseg, es:SharedMemory
                mov        ax, dseg
                mov        ds, ax
                meminit

                print
                byte       "Shared memory application #4",cr,lf,0

; See if the shared memory TSR is around:

                call       SeeIfPresent
                je         ItsThere
                print
                byte       "Shared Memory TSR (SHMALLOC) is not loaded.",cr,lf
                byte       "This program cannot continue execution.",cr,lf,0
                ExitPgm

; If the shared memory TSR is present, get the address of the shared segment
; into the ES register:

ItsThere:       mov        ah, cl            ;ID of our TSR.
                mov        al, 14h           ;Attach call
                mov        dx, 1234h;Our "key" value
                int        2Fh
```

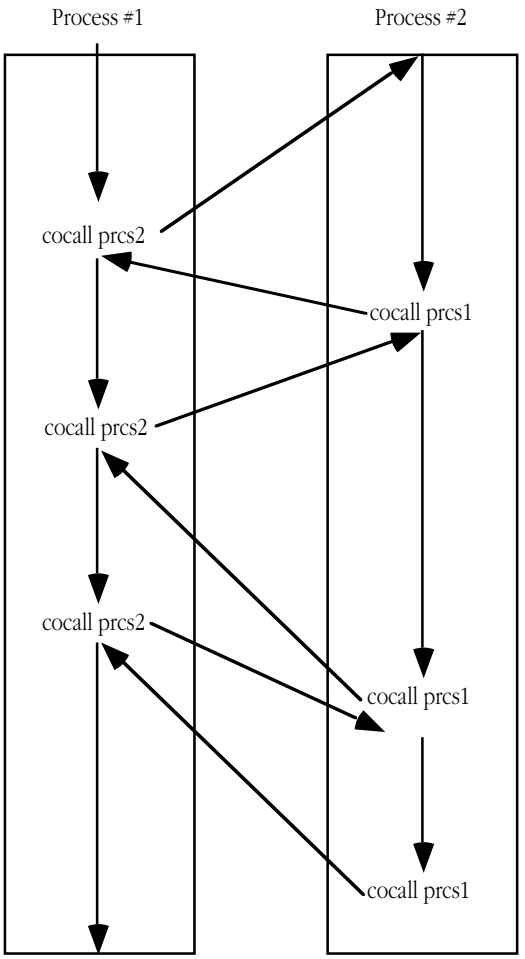
```
; Print the string input in SHMAPP3:

                print
                byte        "String from SHMAPP3 is `",0

                puts

                print
                byte        "' from shared memory.",cr,lf,0


Quit:           ExitPgm                         ;DOS macro to quit program.
Main            endp

cseg ends

sseg            segment     para stack 'stack'
stk             db          1024 dup ("stack ")
sseg            ends

zzzzzzseg       segment     para public 'zzzzzz'
LastBytes       db          16 dup (?)
zzzzzzseg       ends
                end         Main
```

19.3 Coroutines

DOS processes, even when using shared memory, suffer from one primary drawback – each program executes to completion before returning control back to the parent process. While this paradigm is suitable for many applications, it certainly does not suffice for all. A common paradigm is for two programs to swap control of the CPU back and forth while executing. This mechanism, slightly different from the subroutine call and return mechanism, is a *coroutine*.

Before discussing coroutines, it is probably a good idea to provide a solid definition for the term *process*. In a nutshell, a process is a program that is executing. A program can exist on the disk; processes exist in memory and have a program stack (with return addresses, etc.) associated with them. If there are multiple processes in memory at one time, each process must have its own program stack.

A *cocall* operation transfers control between two processes. A cocall is effectively a call and a return instruction all rolled into one operation. From the point of view of the process executing the cocall, the cocall operation is equivalent to a procedure call; from the point of view of the processing being called, the cocall operation is equivalent to a return operation. When the second process cocalls the first, control resumes *not at the beginning of the first process*, but immediately after the cocall operation. If two processes execute a sequence of mutual cocalls, control will transfer between the two processes in the following fashion:



Cocall Sequence Between Two Processes

Cocalls are quite useful for games where the "players" take turns, following different strategies. The first player executes some code to make its first move, then cocalls the second player and allows it to make a move. After the second player makes its move, it cocalls the first process and gives the first player its second move, picking up immediately after its cocall. This transfer of control bounces back and forth until one player wins.

The 80x86 CPUs do not provide a cocall instruction. However, it is easy to implement cocalls with existing instructions. Even so, there is little need for you to supply your own cocall mechanism, the UCR Standard Library provides a cocall package for 8086, 80186, and 80286 processors[2]. This package includes the `pcb` (process control block) data structure and three functions you can call: `coinit`, `cocall`, and `cocalll`.

The `pcb` structure maintains the current state of a process. The `pcb` maintains all the register values and other accounting information for a process. When a process makes a cocall, it stores the return address for the cocall in the `pcb`. Later, when some other process cocalls this process, the cocall operation simply reloads the registers, include `cs:ip`, from the `pcb` and that returns control to the next instruction after the first process' cocall. The `pcb` structure takes the following form:

```
pcb             struct
```

2. The cocall package works fine with the other processors as long as you don't use the 32-bit register set. Later, we will discuss how to extend the Standard Library routines to handle the 32-bit capabilities of the 80386 and late processors.

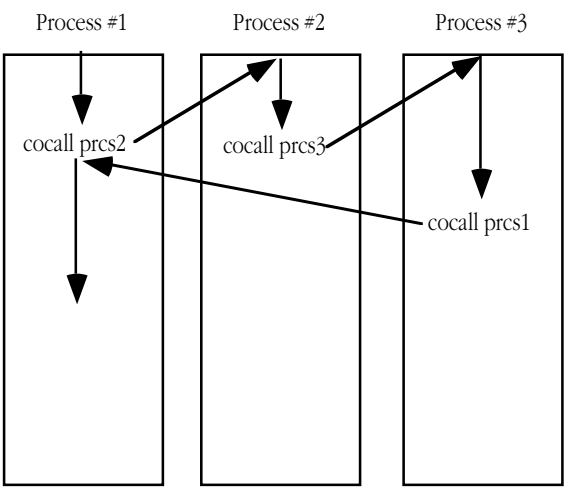
```
NextProc        dword       ?               ;Link to next PCB (for multitasking).
regsp           word        ?
regss           word        ?
regip           word        ?
regcs           word        ?
regax           word        ?
regbx           word        ?
regcx           word        ?
regdx           word        ?
regsi           word        ?
regdi           word        ?
regbp           word        ?
regds           word        ?
reges           word        ?
regflags        word        ?
PrcsID          word        ?
StartingTime    dword       ?               ;Used for multitasking accounting.
StartingDate    dword       ?               ;Used for multitasking accounting.
CPUTime         dword       ?               ;Used for multitasking accounting.
```

Four of these fields (as labelled) exist for preemptive multitasking and have no meaning for coroutines. We will discuss preemptive multitasking in the next section.

There are two important things that should be evident from this structure. First, the main reason the existing Standard Library coroutine support is limited to 16 bit register is because there is only room for the 16 bit versions of each of the registers in the pcb. If you want to support the 80386 and later 32 bit register sets, you would need to modify the pcb structure and the code that saves and restores registers in the pcb.

The second thing that should be evident is that the coroutine code preserves all registers across a cocall. This means you cannot pass information from one process to another in the registers when using a cocall. You will need to pass data between processes in global memory locations. Since coroutines generally exist in the same program, you will not even need to resort to the shared memory techniques. Any variables you declare in your data segment will be visible to all coroutines.

Note, by the way, that a program may contain more than two coroutines. If coroutine one cocalls coroutine two, and coroutine two cocalls coroutine three, and then coroutine three cocalls coroutine one, coroutine one picks up immediately after the cocall it made to coroutine two.



Cocalls Between Three Processes

Since a cocall effectively *returns* to the target coroutine, you might wonder what happens on the *first* cocall to any process. After all, if that process has not executed any code, there is no "return address" where you can resume execution. This is an easy problem to solve, we need only initialize the return address of such a process to the address of the first instruction to execute in that process.

A similar problem exists for the stack. When a program begins execution, the main program (coroutine one) takes control and uses the stack associated with the entire program. Since each process must have its own stack, where do the other coroutines get their stacks?

The easiest way to initialize the stack and initial address for a coroutine is to do this when declaring a pcb for a process. Consider the following pcb variable declaration:

```
ProcessTwo     pcb        {0,           offset EndStack2, seg EndStack2,
                                        offset StartLoc2, seg StartLoc2}
```

This definition initializes the NextProc field with NULL (the Standard Library coroutine functions do not use this field) and initialize the ss:sp and cs:ip fields with the last address of a stack area (EndStack2) and the first instruction of the process (StartLoc2). Now all you need to do is reserve a reasonable amount of stack storage for the process. You can create multiple stacks in the SHELL.ASM sseg as follows:

```
sseg           segment    para stack 'stack'

; Stack for process #2:

stk2           byte       1024 dup (?)
EndStack2      word       ?

; Stack for process #3:

stk3           byte       1024 dup (?)
EndStack3      word       ?

; The primary stack for the main program (process #1) must appear at
; the end of sseg.

stk            byte       1024 dup (?)
sseg           ends
```

There is the question of "how much space should one reserve for each stack?" This, of course, varies with the application. If you have a simple application that doesn't use recursion or allocate any local variables on the stack, you could get by with as little as 256 bytes of stack space for a process. On the other hand, if you have recursive routines or allocate storage on the stack, you will need considerably more space. For simple programs, 1-8K stack storage should be sufficient. Keep in mind that you can allocate a maximum of 64K in the SHELL.ASM sseg. If you need additional stack space, you will need to up the other stacks in a different segment (they do not need to be in sseg, it's just a convenient place for them) or you will need to allocate the stack space differently.

Note that you do not have to allocate the stack space as an array within your program. You can also allocate stack space dynamically using the Standard Library malloc call. The following code demonstrates how to set up an 8K dynamically allocated stack for the pcb variable Process2:

```
mov        cx, 8192
malloc
jc         InsufficientRoom
mov        Process2.ss, es
mov        Process2.sp, di
```

Setting up the coroutines the main program will call is pretty easy. However, there is the issue of setting up the pcb for the main program. You cannot initialize the pcb for the main program the same way you initialize the pcb for the other processes; it is already running and has valid cs:ip and ss:sp values. Were you to initialize the main program's pcb the same way we did for the other processes, the system would simply restart the main program when you make a cocall back to it. To initialize the pcb for the main program, you must use the coinit function. The coinit function expects you to pass it the address of the main program's pcb in the es:di register pair. It initializes some variables internal to the Standard Library so the first cocall operation will save the 80x86 machine state in the pcb you specify by es:di. After the coinit call, you can begin making cocalls to other processes in your program.

To cocall a coroutine, you use the Standard Library cocall function. The cocall function call takes two forms. Without any parameters this function transfers control to the coroutine whose pcb address appears in the es:di register pair. If the address of a pcb appears in the operand field of this instruction, cocall transfers control to the specified coroutine (don't forget, the name of the pcb, *not* the process, must appear in the operand field).

The best way to learn how to use coroutines is via example. The following program is an interesting piece of code that generates mazes on the PC's display. The maze generation algorithm has one major constraint – there must be no more than one correct solution to the maze (it is possible for there to be no solution). The main program creates a set of background processes called "demons" (actually, daemon is the correct term, but demon sounds more appropriate here). Each demon begins carving out a portion of the maze subject to the main constraint. Each demon gets to dig one cell from the maze and then it passes control to another demon. As it turns out, demons can "dig themselves into a corner" and die (demons live only to dig). When this happens, the demon removes itself from the list of active demons. When all demons die off, the maze is (in theory) complete. Since the demons die off fairly regularly, there must be some mechanism to create new demons. Therefore, this program randomly spawns new demons who start digging their own tunnels perpendicular to their parents. This helps ensure that there is a sufficient supply of demons to dig out the entire maze; the demons all die off only when there are no, or few, cells remaining to dig in the maze.

```
; AMAZE.ASM
;
; A maze generation/solution program.
;
; This program generates an 80x25 maze and directly draws the maze on the
; video display. It demonstrates the use of coroutines within a program.

                .xlist
                include    stdlib.a
                includelib stdlib.lib
                .list

byp             textequ    <byte ptr>

dseg            segment    para public 'data'

; Constants:
;
; Define the "ToScreen" symbol (to any value) if the maze is 80x25 and you
; want to display it on the video screen.

ToScreen        equ        0


; Maximum X and Y coordinates for the maze (matching the display).

MaxXCoord       equ        80
MaxYCoord       equ        25

; Useful X,Y constants:

WordsPerRow     =          MaxXCoord+2
BytesPerRow     =          WordsPerRow*2

StartX          equ        1                ;Starting X coordinate for maze
StartY          equ        3                ;Starting Y coordinate for maze
EndX            equ        MaxXCoord        ;Ending X coordinate for maze
EndY            equ        MaxYCoord-1      ;Ending Y coordinate for maze

EndLoc          =          ( (EndY-1)*MaxXCoord + EndX-1)*2
StartLoc        =          ( (StartY-1)*MaxXCoord + StartX-1)*2

; Special 16-bit PC character codes for the screen for symbols drawn during
; maze generation. See the chapter on the video display for details.

                ifdef      mono             ;Mono display adapter.

WallChar        equ        7dbh             ;Solid block character
```

```
NoWallChar      equ         720h            ;space
VisitChar       equ         72eh            ;Period
PathChar        equ         72ah            ;Asterisk

                else                        ;Color display adapter.

WallChar        equ         1dbh            ;Solid block character
NoWallChar      equ         0edbh           ;space
VisitChar       equ         0bdbh           ;Period
PathChar        equ         4e2ah           ;Asterisk

                endif



; The following are the constants that may appear in the Maze array:

Wall            =           0
NoWall          =           1
Visited         =           2

; The following are the directions the demons can go in the maze

North           =           0
South           =           1
East            =           2
West            =           3


; Some important variables:


; The Maze array must contain an extra row and column around the
; outside edges for our algorithm to work properly.

Maze            word        (MaxYCoord+2) dup ((MaxXCoord+2) dup (Wall))

; The follow macro computes an index into the above array assuming
; a demon's X and Y coordinates are in the dl and dh registers, respectively.
; Returns index in the AX register

MazeAdrs        macro
                mov         al, dh
                mov         ah, WordsPerRow ;Index into array is computed
                mul         ah              ; by (Y*words/row + X)*2.
                add         al, dl
                adc         ah, 0
                shl         ax, 1           ;Convert to byte index
                endm

; The following macro computes an index into the screen array, using the
; same assumptions as above. Note that the screen matrix is 80x25 whereas
; the maze matrix is 82x27; The X/Y coordinates in DL/DH are 1..80 and
; 1..25 rather than 0..79 and 0..24 (like we need). This macro adjusts
; for that.

ScrnAdrs        macro
                mov         al, dh
                dec         al
                mov         ah, MaxXCoord
                mul         ah
                add         al, dl
                adc         ah, 0
                dec         ax
                shl         ax, 1
                endm



; PCB for the main program. The last live demon will call this guy when
; it dies.

MainPCB         pcb         {}
```

```
; List of up to 32 demons.

MaxDemons       =           32                  ;Must be a power of two.
ModDemons       =           MaxDemons-1         ;Mask for MOD computation.

DemonList       pcb         MaxDemons dup ({})

DemonIndex      byte        0                   ;Index into demon list.
DemonCnt        byte        0                   ;Number of demons in list.


; Random number generator seed (we'll use our random number generator
; rather than the standard library's because we want to be able to specify
; an initial seed value).

Seed            word        0

dseg            ends



; The following is the segment address of the video display, change this
; from 0B800h to 0B000h if you have a monochrome display rather than a
; color display.

ScreenSeg       segment     at 0b800h
Screen          equ         this word           ;Don't generate in date here!
ScreenSeg       ends


cseg            segment     para public 'code'
                assume      cs:cseg, ds:dseg

; Totally bogus random number generator, but we don't need a really
; great one for this program. This code uses its own random number
; generator rather than the one in the Standard Library so we can
; allow the user to use a fixed seed to produce the same maze (with
; the same seed) or different mazes (by choosing different seeds).

RandNum         proc        near
                push        cx
                mov         cl, byte ptr Seed
                and         cl, 7
                add         cl, 4
                mov         ax, Seed
                xor         ax, 55aah
                rol         ax, cl
                xor         ax, Seed
                inc         ax
                mov         Seed, ax
                pop         cx
                ret
RandNum         endp

; Init-  Handles all the initialization chores for the main program.
;        In particular, it initializes the coroutine package, gets a
;        random number seed from the user, and initializes the video display.

Init            proc        near
                print
                byte        "Enter a small integer for a random number seed:",0
                getsm
                atoi
                free
                mov         Seed, ax

; Fill the interior of the maze with wall characters, fill the outside
; two rows and columns with nowall values. This will prevent the demons
; from wandering outside the maze.


; Fill the first row with Visited values.
```

```
                cld
                mov     cx, WordsPerRow
                lesi    Maze
                mov     ax, Visited
        rep     stosw

; Fill the last row with NoWall values.

                mov     cx, WordsPerRow
                lea     di, Maze+(MaxYCoord+1)*BytesPerRow
        rep     stosw

; Write a NoWall value to the starting position:

                mov     Maze+(StartY*WordsPerRow+StartX)*2, NoWall


; Write NoWall values along the two vertical edges of the maze.

                lesi    Maze
                mov     cx, MaxYCoord+1
EdgesLoop:      mov     es:[di], ax                     ;Plug the left edge.
                mov     es:[di+BytesPerRow-2], ax       ;Plug the right edge.
                add     di, BytesPerRow
                loop    EdgesLoop


                ifdef   ToScreen

; Okay, fill the screen with WallChar values:

                lesi    Screen
                mov     ax, WallChar
                mov     cx, 2000
        rep     stosw

; Write appropriate characters to the starting and ending locations:

                mov     word ptr es:Screen+EndLoc, PathChar
                mov     word ptr es:Screen+StartLoc, NoWallChar

                endif                       ;ToScreen


; Zero out the DemonList:

                mov     cx, (size pcb)*MaxDemons
                lea     di, DemonList
                mov     ax, dseg
                mov     es, ax
                xor     ax, ax
        rep     stosb

                ret
Init            endp



; CanStart- This function checks around the current position
; to see if the maze generator can start digging a new tunnel
; in a direction perpendicular to the current tunnel. You can
; only start a new tunnel if there are wall characters for at
; least two positions in the desired direction:
;
;                         ##
;                        *##
;                         ##
;
; If "*" is current position and "#" represent wall characters
; and the current direction is north or south, then it is okay
; for the maze generator to start a new path in the east dir-
; ection. Assuming "." represents a tunnel, you cannot start
; a new tunnel in the east direction if any of the following
; patterns occur:
```

```
;
;         .#    #.             ##         ##                ##     ##
;        *##   *##            *.#        *#.               *##    *##
;         ##    ##             ##         ##                .#     #.
;
; CanStart returns true (carry set) if we can start a new tunnel off the
; path being dug by the current demon.
;
; On entry,    dl is demon's X-Coordinate
;              dh is demon's Y-Coordinate
;              cl is demon's direction

CanStart      proc       near
              push       ax
              push       bx

              MazeAdrs                  ;Compute index to demon(x,y) in maze.
              mov        bx, ax

; CL contains the current direction, 0=north, 1=south, 2=east, 3=west.
; Note that we can test bit #1 for north/south (0) or east/west (1).

              test       cl, 10b        ;See if north/south or east/west
              jz         NorthSouth

; If the demon is going in an east or west direction, we can start a new
; tunnel if there are six wall blocks just above or below the current demon.
; Note: We are checking if all values in these six blocks are Wall values.
; This code depends on the fact that Wall characters are zero and the sum
; of these six blocks will be zero if a move is possible.

              mov        al, byp Maze[bx+BytesPerRow*2] ;Maze[x, y+2]
              add        al, byp Maze[bx+BytesPerRow*2+2] ;Maze[x+1,y+2]
              add        al, byp Maze[bx+BytesPerRow*2-2] ;Maze[x-1,y+2]
              je         ReturnTrue

              mov        al, byp Maze[bx-BytesPerRow*2] ;Maze[x, y-2]
              add        al, byp Maze[bx-BytesPerRow*2+2] ;Maze[x+1,y-2]
              add        al, byp Maze[bx-BytesPerRow*2-2] ;Maze[x-1,y-2]
              je         ReturnTrue

ReturnFalse:  clc                        ;Clear carry = false.
              pop        bx
              pop        ax
              ret

; If the demon is going in a north or south direction, we can start a
; new tunnel if there are six wall blocks just to the left or right
; of the current demon.

NorthSouth:   mov        al, byp Maze[bx+4];Maze[x+2,y]
              add        al, byp Maze[bx+BytesPerRow+4];Maze[x+2,y+1]
              add        al, byp Maze[bx-BytesPerRow+4];Maze[x+2,y-1]
              je         ReturnTrue

              mov        al, byp Maze[bx-4];Maze[x-2,y]
              add        al, byp Maze[bx+BytesPerRow-4];Maze[x-2,y+1]
              add        al, byp Maze[bx-BytesPerRow-4];Maze[x-2,y-1]
              jne        ReturnFalse

ReturnTrue:   stc                        ;Set carry = true.
              pop        bx
              pop        ax
              ret
CanStart      endp



; CanMove-     Tests to see if the current demon (dir=cl, x=dl, y=dh) can
;              move in the specified direction. Movement is possible if
;              the demon will not come within one square of another tunnel.
;              This function returns true (carry set) if a move is possible.
;              On entry, CH contains the direction this code should test.
```

```
CanMove         proc
                push        ax
                push        bx

                MazeAdrs                        ;Put @Maze[x,y] into ax.
                mov         bx, ax

                cmp         ch, South
                jb          IsNorth
                je          IsSouth
                cmp         ch, East
                je          IsEast

; If the demon is moving west, check the blocks in the rectangle formed
; by Maze[x-2,y-1] to Maze[x-1,y+1] to make sure they are all wall values.

                mov         al, byp Maze[bx-BytesPerRow-4];Maze[x-2, y-1]
                add         al, byp Maze[bx-BytesPerRow-2];Maze[x-1, y-1]
                add         al, byp Maze[bx-4];Maze[x-2, y]
                add         al, byp Maze[bx-2];Maze[x-1, y]
                add         al, byp Maze[bx+BytesPerRow-4];Maze[x-2, y+1]
                add         al, byp Maze[bx+BytesPerRow-2];Maze[x-1, y+1]
                je          ReturnTrue
ReturnFalse:    clc
                pop         bx
                pop         ax
                ret


; If the demon is going east, check the blocks in the rectangle formed
; by Maze[x+1,y-1] to Maze[x+2,y+1] to make sure they are all wall values.

IsEast:         mov         al, byp Maze[bx-BytesPerRow+4];Maze[x+2, y-1]
                add         al, byp Maze[bx-BytesPerRow+2];Maze[x+1, y-1]
                add         al, byp Maze[bx+4];Maze[x+2, y]
                add         al, byp Maze[bx+2];Maze[x+1, y]
                add         al, byp Maze[bx+BytesPerRow+4];Maze[x+2, y+1]
                add         al, byp Maze[bx+BytesPerRow+2];Maze[x+1, y+1]
                jne         ReturnFalse
ReturnTrue:     stc
                pop         bx
                pop         ax
                ret


; If the demon is going north, check the blocks in the rectangle formed
; by Maze[x-1,y-2] to Maze[x+1,y-1] to make sure they are all wall values.

IsNorth:        mov         al, byp Maze[bx-BytesPerRow-2];Maze[x-1, y-1]
                add         al, byp Maze[bx-BytesPerRow*2-2];Maze[x-1, y-2]
                add         al, byp Maze[bx-BytesPerRow];Maze[x, y-1]
                add         al, byp Maze[bx-BytesPerRow*2];Maze[x, y-2]
                add         al, byp Maze[bx-BytesPerRow+2];Maze[x+1, y-1]
                add         al, byp Maze[bx-BytesPerRow*2+2];Maze[x+1, y-2]
                jne         ReturnFalse
                stc
                pop         bx
                pop         ax
                ret


; If the demon is going south, check the blocks in the rectangle formed
; by Maze[x-1,y+2] to Maze[x+1,y+1] to make sure they are all wall values.

IsSouth:        mov         al, byp Maze[bx+BytesPerRow-2];Maze[x-1, y+1]
                add         al, byp Maze[bx+BytesPerRow*2-2];Maze[x-1, y+2]
                add         al, byp Maze[bx+BytesPerRow];Maze[x, y+1]
                add         al, byp Maze[bx+BytesPerRow*2];Maze[x, y+2]
                add         al, byp Maze[bx+BytesPerRow+2];Maze[x+1, y+1]
                add         al, byp Maze[bx+BytesPerRow*2+2];Maze[x+1, y+2]
                jne         ReturnFalse
                stc
```

```
                pop     bx
                pop     ax
                ret

CanMove         endp



; SetDir- Changes the current direction. The maze digging algorithm has
; decided to change the direction of the tunnel begin dug by one
; of the demons. This code checks to see if we CAN change the direction,
; and picks a new direction if possible.
;
; If the demon is going north or south, a direction change causes the demon
; to go east or west. Likewise, if the demon is going east or west, a
; direction change forces it to go north or south. If the demon cannot
; change directions (because it cannot move in the new direction for one
; reason or another), SetDir returns without doing anything. If a direction
; change is possible, then SetDir selects a new direction. If there is only
; one possible new direction, the demon is sent off in that direction.
; If the demon could move off in one of two different directions, SetDir
; "flips a coin" to choose one of the two new directions.
;
; This function returns the new direction in al.

SetDir          proc    near

                test    cl, 10b         ;See if north/south
                je      IsNS            ; or east/west direction.

; We're going east or west. If we can move EITHER north or south from
; this point, randomly choose one of the directions. If we can only
; move one way or the other, choose that direction. If we can't go either
; way, return without changing the direction.

                mov     ch, North       ;See if we can move north
                call    CanMove
                jnc     NotNorth
                mov     ch, South       ;See if we can move south
                call    CanMove
                jnc     DoNorth
                call    RandNum         ;Get a random direction
                and     ax, 1           ;Make it north or south.
                ret

DoNorth:        mov     ax, North
                ret

NotNorth:       mov     ch, South
                call    CanMove
                jnc     TryReverse
DoSouth:        mov     ax, South
                ret



; If the demon is moving north or south, choose a new direction of east
; or west, if possible.

IsNS:           mov     ch, East        ;See if we can move East
                call    CanMove
                jnc     NotEast
                mov     ch, West        ;See if we can move West
                call    CanMove
                jnc     DoEast
                call    RandNum         ;Get a random direction
                and     ax, 1b          ;Make it East or West
                or      al, 10b
                ret

DoEast:         mov     ax, East
                ret
```

```
DoWest:         mov         ax, West
                ret

NotEast:        mov         ch, West
                call        CanMove
                jc          DoWest

; Gee, we can't switch to a perpendicular direction, see if we can
; turn around.

TryReverse:     mov         ch, cl
                xor         ch, 1
                call        CanMove
                jc          ReverseDir

; If we can't turn around (likely), then keep going in the same direction.

                mov         ah, 0
                mov         al, cl              ;Stay in same direction.
                ret

; Otherwise reverse direction down here.

ReverseDir:     mov         ah, 0
                mov         al, cl
                xor         al, 1
                ret
SetDir          endp



; Stuck-        This function checks to see if a demon is stuck and cannot
;               move in any direction. It returns true if the demon is
;               stuck and needs to be killed.

Stuck           proc        near
                mov         ch, North
                call        CanMove
                jc          NotStuck
                mov         ch, South
                call        CanMove
                jc          NotStuck
                mov         ch, East
                call        CanMove
                jc          NotStuck
                mov         ch, West
                call        CanMove
NotStuck:       ret
Stuck           endp



; NextDemon-    Searches through the demon list to find the next available
;               active demon. Return a pointer to this guy in es:di.

NextDemon       proc        near
                push        ax

NDLoop:         inc         DemonIndex          ;Move on to next demon,
                and         DemonIndex, ModDemons ; MOD MaxDemons.
                mov         al, size pcb        ;Compute index into
                mul         DemonIndex          ; DemonList.
                mov         di, ax              ;See if the demon at this
                add         di, offset DemonList ; offset is active.
                cmp         byp [di].pcb.NextProc, 0
                je          NDLoop

                mov         ax, ds
                mov         es, ax
                pop         ax
                ret
NextDemon       endp
```

```
; Dig-          This is the demon process.
;               It moves the demon one position (if possible) in its current
;               direction. After moving one position forward, there is
;               a 25% chance that this guy will change its direction; there
;               is a 25% chance this demon will spawn a child process to
;               dig off in a perpendicular direction.

Dig             proc        near

; See if the current demon is stuck. If the demon is stuck, then we've
; go to remove it from the demon list. If it is not stuck, then have it
; continue digging. If it is stuck and this is the last active demon,
; then return control to the main program.

                call        Stuck
                jc          NotStuck

; Okay, kill the current demon.
; Note: this will never kill the last demon because we have the timer
; process running. The timer process is the one that always stops
; the program.

                dec         DemonCnt

; Since the count is not zero, there must be more demons in the demon
; list. Free the stack space associated with the current demon and
; then search out the next active demon and have at it.

MoreDemons:     mov         al, size pcb
                mul         DemonIndex
                mov         bx, ax

; Free the stack space associated with this process. Note this code is
; naughty. It assumes the stack is allocated with the Standard Library
; malloc routine that always produces a base address of 8.

                mov         es, DemonList[bx].regss
                mov         di, 8                           ;Cheating!
                free

; Mark the demon entry for this guy as unused.

                mov         byp DemonList[bx].NextProc, 0   ;Mark as unused.


; Okay, locate the next active demon in the list.

FndNxtDmn:      call        NextDemon
                cocall                      ;Never returns




; If the demon is not stuck, then continue digging away.

NotStuck:       mov         ch, cl
                call        CanMove
                jnc         DontMove

; If we can move, then adjust the demon's coordinates appropriately:

                cmp         cl, South
                jb          MoveNorth
                je          MoveSouth
                cmp         cl, East
                jne         MoveWest

; Moving East:

                inc         dl
                jmp         MoveDone

MoveWest:       dec         dl
```

```
                jmp         MoveDone

MoveNorth:      dec         dh
                jmp         MoveDone

MoveSouth:inc   dh

; Okay, store a NoWall value at this entry in the maze and output a NoWall
; character to the screen (if writing data to the screen).

MoveDone:       MazeAdrs
                mov         bx, ax
                mov         Maze[bx], NoWall

                ifdef       ToScreen
                ScrnAdrs
                mov         bx, ax
                push        es
                mov         ax, ScreenSeg
                mov         es, ax
                mov         word ptr es:[bx], NoWallChar
                pop         es
                endif

; Before leaving, see if this demon shouldn't change direction.

DontMove:       call        RandNum
                and         al, 11b             ;25% chance result is zero.
                jne         NoChangeDir
                call        SetDir
                mov         cl, al

NoChangeDir:


; Also, see if this demon should spawn a child process

                call        RandNum
                and         al, 11b             ;Give it a 25% chance.
                jne         NoSpawn

; Okay, see if it's possible to spawn a new process at this point:

                call        CanStart
                jnc         NoSpawn

; See if we've already got MaxDemons active:

                cmp         DemonCnt, MaxDemons
                jae         NoSpawn

                inc         DemonCnt            ;Add another demon.


; Okay, create a new demon and add him to the list.

                push        dx                  ;Save cur demon info.
                push        cx

; Locate a free slot for this demon

                lea         si, DemonList- size pcb
FindSlot:       add         si, size pcb
                cmp         byp [si].pcb.NextProc, 0
                jne         FindSlot


; Allocate some stack space for the new demon.

                mov         cx, 256             ;256 byte stack.
                malloc

; Set up the stack pointer for this guy:
```

```
                add     di, 248         ;Point stack at end.
                mov     [si].pcb.regss, es
                mov     [si].pcb.regsp, di

; Set up the execution address for this guy:

                mov     [si].pcb.regcs, cs
                mov     [si].pcb.regip, offset Dig

; Initial coordinates and direction for this guy:

                mov     [si].pcb.regdx, dx

; Select a direction for this guy.

                pop     cx              ;Retrieve direction.
                push    cx

                call    SetDir
                mov     ah, 0
                mov     [si].pcb.regcx, ax

; Set up other misc junk:

                mov     [si].pcb.regds, seg dseg
                sti
                pushf
                pop     [si].pcb.regflags
                mov     byp [si].pcb.NextProc, 1        ;Mark active.


; Restore current process' parameters

                pop     cx              ;Restore current demon.
                pop     dx

NoSpawn:

; Okay, with all of the above done, it's time to pass control on to a new
; digger. The following cocall passes control to the next digger in the
; DemonList.

GetNextDmn:     call    NextDemon

; Okay, we've got a pointer to the next demon in the list (might be the
; same demon if there's only one), pass control to that demon.

                cocall
                jmp     Dig
Dig             endp


; TimerDemon-   This demon introduces a delay between
;               each cycle in the demon list. This slows down the
;               maze generation so you can see the maze being built
;               (which makes the program more interesting to watch).

TimerDemon      proc    near
                push    es
                push    ax

                mov     ax, 40h         ;BIOS variable area
                mov     es, ax
                mov     ax, es:[6Ch]    ;BIOS timer location
Wait4Change:    cmp     ax, es:[6Ch]    ;BIOS changes this every
                je      Wait4Change     ; 1/18th second.

                cmp     DemonCnt, 1
                je      QuitProgram
                pop     es
                pop     ax
                call    NextDemon
                cocall
                jmp     TimerDemon
```

```
QuitProgram:  cocall    MainPCB          ;Quit the program
TimerDemon    endp



; What good is a maze generator program if it cannot solve the mazes it
; creates? SolveMaze finds the solution (if any) for this maze. It marks
; the solution path and the paths it tried, but failed on.
;
; function solvemaze(x,y:integer):boolean

sm_X          textequ   <[bp+6]>
sm_Y          textequ   <[bp+4]>

SolveMaze     proc      near
              push      bp
              mov       bp, sp

; See if we've just solved the maze:

              cmp       byte ptr sm_X, EndX
              jne       NotSolved
              cmp       byte ptr sm_Y, EndY
              jne       NotSolved
              mov       ax, 1            ;Return true.
              pop       bp
              ret       4

; See if moving to this spot was an illegal move. There will be
; a NoWall value at this cell in the maze if the move is legal.

NotSolved:    mov       dl, sm_X
              mov       dh, sm_Y
              MazeAdrs
              mov       bx, ax
              cmp       Maze[bx], NoWall
              je        MoveOK
              mov       ax, 0            ;Return failure
              pop       bp
              ret       4

; Well, it is possible to move to this point, so place an appropriate
; value on the screen and keep searching for the solution.

MoveOK:       mov       Maze[bx], Visited

              ifdef     ToScreen
              push      es               ;Write a "VisitChar"
              ScrnAdrs                   ; character to the
              mov       bx, ax           ; screen at this X,Y
              mov       ax, ScreenSeg    ; position.
              mov       es, ax
              mov       word ptr es:[bx], VisitChar
              pop       es
              endif

; Recusively call SolveMaze until we get a solution. Just call SolveMaze
; for the four possible directions (up, down, left, right) we could go.
; Since we've left "Visited" values in the Maze, we will not accidentally
; search back through the path we've already travelled. Furthermore, if
; we cannot go in one of the four directions, SolveMaze will catch this
; immediately upon entry (see the code at the start of this routine).

              mov       ax, sm_X         ;Try the path at location
              dec       ax               ; (X-1, Y)
              push      ax
              push      sm_Y
              call      SolveMaze
              test      ax, ax           ;Solution?
              jne       Solved

              push      sm_X             ;Try the path at location
```

```
                mov     ax, sm_Y        ; (X, Y-1)
                dec     ax
                push    ax
                call    SolveMaze
                test    ax, ax          ;Solution?
                jne     Solved

                mov     ax, sm_X        ;Try the path at location
                inc     ax              ; (X+1, Y)
                push    ax
                push    sm_Y
                call    SolveMaze
                test    ax, ax          ;Solution?
                jne     Solved

                push    sm_X            ;Try the path at location
                mov     ax, sm_Y        ; (X, Y+1)
                inc     ax
                push    ax
                call    SolveMaze
                test    ax, ax          ;Solution?
                jne     Solved
                pop     bp
                ret     4

Solved:
                ifdef   ToScreen        ;Draw return path.
                push    es
                mov     dl, sm_X
                mov     dh, sm_Y
                ScrnAdrs
                mov     bx, ax
                mov     ax, ScreenSeg
                mov     es, ax
                mov     word ptr es:[bx], PathChar
                pop     es
                mov     ax, 1           ;Return true
                endif

                pop     bp
                ret     4
SolveMaze       endp


; Here's the main program that drives the whole thing:

Main            proc
                mov     ax, dseg
                mov     ds, ax
                mov     es, ax
                meminit


                call    Init            ;Initialize maze stuff.
                lesi    MainPCB         ;Initialize coroutine
                coinit                  ; package.

; Create the first demon.
; Set up the stack pointer for this guy:

                mov     cx, 256
                malloc
                add     di, 248
                mov     DemonList.regsp, di
                mov     DemonList.regss, es

; Set up the execution address for this guy:

                mov     DemonList.regcs, cs
                mov     DemonList.regip, offset Dig

; Initial coordinates and direction for this guy:
```

```
                mov     cx, East          ;Start off going east.
                mov     dh, StartY
                mov     dl, StartX
                mov     DemonList.regcx, cx
                mov     DemonList.regdx, dx

; Set up other misc junk:

                mov     DemonList.regds, seg dseg
                sti
                pushf
                pop     DemonList.regflags
                mov     byp DemonList.NextProc, 1       ;Demon is "active".
                inc     DemonCnt
                mov     DemonIndex, 0



; Set up the Timer demon:

                mov     DemonList.regsp+(size pcb), offset EndTimerStk
                mov     DemonList.regss+(size pcb), ss

; Set up the execution address for this guy:

                mov     DemonList.regcs+(size pcb), cs
                mov     DemonList.regip+(size pcb), offset TimerDemon

; Set up other misc junk:

                mov     DemonList.regds+(size pcb), seg dseg
                sti
                pushf
                pop     DemonList.regflags+(size pcb)
                mov     byp DemonList.NextProc+(size pcb), 1
                inc     DemonCnt

; Start the ball rolling.

                mov     ax, ds
                mov     es, ax
                lea     di, DemonList
                cocall

; Wait for the user to press a key before solving the maze:

                getc

                mov     ax, StartX
                push    ax
                mov     ax, StartY
                push    ax
                call    SolveMaze

; Wait for another keystroke before quitting:

                getc

                mov     ax, 3             ;Clear screen and reset video mode.
                int     10h

Quit:           ExitPgm                   ;DOS macro to quit program.
Main            endp

cseg            ends

sseg            segment   para stack 'stack'

; Stack for the timer demon we create (we'll allocate the other
; stacks dynamically).

TimerStk        byte      256 dup (?)
EndTimerStk     word      ?
```

```
; Main program's stack:

stk             byte        512 dup (?)
sseg            ends

zzzzzzseg       segment     para public 'zzzzzz'
LastBytes       db          16 dup (?)
zzzzzzseg       ends
                end         Main
```

The existing Standard Library coroutine package is not suitable for programs that use the 80386 and later 32 bit register sets. As mentioned earlier, the problem lies in the fact that the Standard Library only preserves the 16-bit registers when switching between processes. However, it is a relatively trivial extension to modify the Standard Library so that it saves 32 bit registers. To do so, just change the definition of the pcb (to make room for the 32 bit registers) and the sl_cocall routine:

```
                .386
                option      segment:use16

dseg            segment     para public 'data'

wp              equ         <word ptr>

; 32-bit PCB. Note we only keep the L.O. 16 bits of SP since we are
; operating in real mode.

pcb32           struc
regsp           word        ?
regss           word        ?
regip           word        ?
regcs           word        ?

regeax          dword       ?
regebx          dword       ?
regecx          dword       ?
regedx          dword       ?
regesi          dword       ?
regedi          dword       ?
regebp          dword       ?

regds           word        ?
reges           word        ?
regflags        dword       ?
pcb32           ends


DefaultPCB      pcb32       <>
DefaultCortn    pcb32       <>

CurCoroutine    dword       DefaultCortn  ;Points at the currently executing
                                          ; coroutine.
dseg            ends


cseg            segment     para public 'slcode'

;===============================================================================
;
; 32-Bit Coroutine support.
;
; COINIT32- ES:DI contains the address of the current (default) process' PCB.

CoInit32        proc        far
                assume      ds:dseg
                push        ax
```

```
                push    ds
                mov     ax, dseg
                mov     ds, ax
                mov     wp dseg:CurCoroutine, di
                mov     wp dseg:CurCoroutine+2, es
                pop     ds
                pop     ax
                ret
CoInit32        endp


; COCALL32- transfers control to a coroutine. ES:DI contains the address
; of the PCB. This routine transfers control to that coroutine and then
; returns a pointer to the caller's PCB in ES:DI.

cocall32        proc    far
                assume  ds:dseg
                pushfd
                push    ds
                push    es              ;Save these for later
                push    edi
                push    eax
                mov     ax, dseg
                mov     ds, ax
                cli                     ;Critical region ahead.


; Save the current process' state:

                les     di, dseg:CurCoroutine
                pop     es:[di].pcb32.regeax
                mov     es:[di].pcb32.regebx, ebx
                mov     es:[di].pcb32.regecx, ecx
                mov     es:[di].pcb32.regedx, edx
                mov     es:[di].pcb32.regesi, esi
                pop     es:[di].pcb32.regedi
                mov     es:[di].pcb32.regebp, ebp

                pop     es:[di].pcb32.reges
                pop     es:[di].pcb32.regds
                pop     es:[di].pcb32.regflags
                pop     es:[di].pcb32.regip
                pop     es:[di].pcb32.regcs
                mov     es:[di].pcb32.regsp, sp
                mov     es:[di].pcb32.regss, ss

                mov     bx, es          ;Save so we can return in
                mov     ecx, edi      ; ES:DI later.
                mov     edx, es:[di].pcb32.regedi
                mov     es, es:[di].pcb32.reges
                mov     di, dx          ;Point es:di at new PCB

                mov     wp dseg:CurCoroutine, di
                mov     wp dseg:CurCoroutine+2, es

                mov     es:[di].pcb32.regedi, ecx ;The ES:DI return values.
                mov     es:[di].pcb32.reges, bx

; Okay, switch to the new process:

                mov     ss, es:[di].pcb32.regss
                mov     sp, es:[di].pcb32.regsp
                mov     eax, es:[di].pcb32.regeax
                mov     ebx, es:[di].pcb32.regebx
                mov     ecx, es:[di].pcb32.regecx
                mov     edx, es:[di].pcb32.regedx
                mov     esi, es:[di].pcb32.regesi
                mov     ebp, es:[di].pcb32.regebp
                mov     ds, es:[di].pcb32.regds

                push    es:[di].pcb32.regflags
                push    es:[di].pcb32.regcs
                push    es:[di].pcb32.regip
                push    es:[di].pcb32.regedi
```

```
                mov     es, es:[di].pcb32.reges
                pop     edi
                iret
cocall32        endp


; CoCall32l works just like cocall above, except the address of the pcb
; follows the call in the code stream rather than being passed in ES:DI.
; Note: this code does *not* return the caller's PCB address in ES:DI.
;

cocall32l       proc    far
                assume  ds:dseg
                push    ebp
                mov     bp, sp
                pushfd
                push    ds
                push    es
                push    edi
                push    eax
                mov     ax, dseg
                mov     ds, ax
                cli                     ;Critical region ahead.

; Save the current process' state:

                les     di, dseg:CurCoroutine
                pop     es:[di].pcb32.regeax
                mov     es:[di].pcb32.regebx, ebx
                mov     es:[di].pcb32.regecx, ecx
                mov     es:[di].pcb32.regedx, edx
                mov     es:[di].pcb32.regesi, esi
                pop     es:[di].pcb32.regedi
                pop     es:[di].pcb32.reges
                pop     es:[di].pcb32.regds
                pop     es:[di].pcb32.regflags
                pop     es:[di].pcb32.regebp
                pop     es:[di].pcb32.regip
                pop     es:[di].pcb32.regcs
                mov     es:[di].pcb32.regsp, sp
                mov     es:[di].pcb32.regss, ss

                mov     dx, es:[di].pcb32.regip ;Get return address (ptr to
                mov     cx, es:[di].pcb32.regcs ; PCB address.
                add     es:[di].pcb32.regip, 4  ;Skip ptr on return.
                mov     es, cx                  ;Get the ptr to the new pcb
                mov     di, dx                  ; address, then fetch the
                les     di, es:[di]             ; pcb val.
                mov     wp dseg:CurCoroutine, di
                mov     wp dseg:CurCoroutine+2, es

; Okay, switch to the new process:

                mov     ss, es:[di].pcb32.regss
                mov     sp, es:[di].pcb32.regsp
                mov     eax, es:[di].pcb32.regeax
                mov     ebx, es:[di].pcb32.regebx
                mov     ecx, es:[di].pcb32.regecx
                mov     edx, es:[di].pcb32.regedx
                mov     esi, es:[di].pcb32.regesi
                mov     ebp, es:[di].pcb32.regebp
                mov     ds, es:[di].pcb32.regds

                push    es:[di].pcb32.regflags
                push    es:[di].pcb32.regcs
                push    es:[di].pcb32.regip
                push    es:[di].pcb32.regedi
                mov     es, es:[di].pcb32.reges
                pop     edi
                iret


cocall32l       endp
cseg            ends
```

19.4 Multitasking

Coroutines provide a reasonable mechanism for switching between processes that must take turns. For example, the maze generation program in the previous section would generate poor mazes if the daemon processes didn't take turns removing one cell at a time from the maze. However, the coroutine paradigm isn't always suitable; not all processes need to take turns. For example, suppose you are writing an action game where the user plays against the computer. In addition, the computer player operates independently of the user in real time. This could be, for example, a space war game or a flight simulator game (where you are dog fighting other pilots). Ideally, we would like to have *two* computers. One to handle the user interaction and one for the computer player. Both systems would communicate their moves to one another during the game. If the (human) player simply sits and watches the screen, the computer player would win since it is active and the human player is not. Of course, it would considerably limit the marketability of your game were it to require two computers to play. However, you can use *multitasking* to simulate two separate computer systems on a single CPU.

The basic idea behind multitasking is that one process runs for a period of time (the *time quantum* or *time slice*) and then a timer interrupts the process. The timer ISR saves the state of the process and then switches control to another process. That process runs for its time slice and then the timer interrupt switches to another process. In this manner, each process gets some amount of computer time. Note that multitasking is very easy to implement if you have a coroutine package. All you need to do is write a timer ISR that cocalls the various processes, one per timer interrupt A timer interrupt that switches between processes is a *dispatcher*.

One decision you will need to make when designing a dispatcher is a policy for the process selection algorithm. A simple policy is to place all processes in a queue and then rotate among them. This is known as the *round-robin policy*. Since this is the policy the UCR Standard Library process package uses, we will adopt it as well. However, there are other process selection criteria, generally involving the priority of a process, available as well. See a good text on operating systems for details.

The choice of the time quantum can have a big impact on performance. Generally, you would like the time quantum to be small. The time sharing (switching between processes based on the clock) will be much smoother if you use small time quanta. For example, suppose you choose five second time quanta and you were running four processes concurrently. Each process would get five seconds; it would run very fast during those five seconds. However, at the end of its time slice it would have to wait for the other three process' turns, 15 seconds, before it ran again. The users of such programs would get very frustrated with them, users like programs whose performance is relatively consistent from one moment to the next.

If we make the time slice one millisecond, instead of five seconds, each process would run for one millisecond and then switch to the next processes. This means that each processes gets one millisecond out of five. This is too small a time quantum for the user to notice the pause between processes.

Since smaller time quanta seem to be better, you might wonder "why not make them as small as possible?" For example, the PC supports a one millisecond timer interrupt. Why not use that to switch between processes? The problem is that there is a fair amount of overhead required to switch from one processes to another. The smaller you make the time quantum, the larger will be the overhead of using time slicing. Therefore, you want to pick a time quantum that is a good balance between smooth process switching and too much overhead. As it turns out, the $^1/_{18}$th second clock is probably fine for most multitasking requirements.

19.4.1 Lightweight and HeavyWeight Processes

There are two major types of processes in the world of multitasking: *lightweight processes*, also known as *threads*, and *heavyweight processes*. These two types of processes differ mainly in the details of memory management. A heavyweight process swaps memory management tables and moves lots of data

around. Threads only swap the stack and CPU registers. Threads have much less overhead cost than heavyweight processes.

We will not consider heavyweight processes in this text. Heavyweight processes appear in protected mode operating systems like UNIX, Linux, OS/2, or Windows NT. Since there is rarely any memory management (at the hardware level) going on under DOS, the issue of changing memory management tables around is moot. Switching from one heavyweight application to another generally corresponds to switching from one application to another.

Using lightweight processes (threads) is perfectly reasonable under DOS. Threads (short for "execution thread" or "thread of execution") correspond to two or more concurrent execution paths within the same program. For example, we could think of each of the demons in the maze generation program as being a separate thread of execution.

Although threads have different stacks and machine states, they share code and data memory. There is no need to use a "shared memory TSR" to provide global shared memory (see "Shared Memory" on page 1078). Instead, maintaining *local* variables is the difficult task. You must either allocate local variables on the process' stack (which is separate for each process) or you've got to make sure that no other process uses the variables you declare in the data segment specifically for one thread.

We could easily write our own threads package, but we don't have to; the UCR Standard Library provides this capability in the *processes package*. To see how to incorporate threads into your programs, keep reading…

19.4.2 The UCR Standard Library Processes Package

The UCR Standard Library provides six routines to let you manage threads. These routines include `prcsinit`, `prcsquit`, `fork`, `die`, `kill`, and `yield`. These functions let you initialize and shut down the threads system, start new processes, terminate processes, and voluntarily pass the CPU off to another process.

The `prcsinit` and `prcsquit` functions let you initialize and shutdown the system. The `prcsinit` call prepares the threads package. You must call this routine before executing any of the other five process routines. The `prcsquit` function shuts down the threads system in preparation for program termination. `Prcsinit` patches into the timer interrupt (interrupt 8). `Prcsquit` restores the interrupt 8 vector. It is very important that you call `prcsquit` before your program returns to DOS. Failure to do so will leave the int 8 vector pointing off into memory which may cause the system to crash when DOS loads the next program. Your program must patch the break and critical error exception vectors to ensure that you call `prcsquit` in the event of abnormal program termination. Failure to do so may crash the system if the user terminates the program with ctrl-break or an abort on an I/O error. `Prcsinit` and `prcsquit` do not require any parameters, nor do they return any values.

The `fork` call spawns a new process. On entry, `es:di` must point at a pcb for the new process. The `regss` and `regsp` fields of the `pcb` must contain the address of the *top* of the stack area for this new process. The `fork` call fills in the other fields of the `pcb` (including cs:ip)/

For each call you make to `fork`, the `fork` routine returns *twice*, once for each thread of execution. The parent process *typically* returns first, but this is not certain; the child process is usually the second return from the `fork` call. To differentiate the two calls, `fork` returns two process identifiers (PIDs) in the `ax` and `bx` registers. For the parent process, `fork` returns with `ax` containing zero and `bx` containing the PID of the child process. For the child process, `fork` returns with `ax` containing the child's PID and `bx` containing zero. Note that both threads return and continuing executing the same code after the call to `fork`. If you want the child and parent processes to take separate paths, you would execute code like the following:

```
        lesi    NewPCB          ;Assume regss/regsp are initialized.
        fork
        test    ax, ax          ;Parent PID is zero at this point.
        je      ParentProcess       ;Go elsewhere if parent process.

; Child process continues execution here
```

The parent process should save the child's PID. You can use the PID to terminate a process at some later time.

It is important to repeat that you must initialize the `regss` and `regsp` fields in the `pcb` before calling `fork`. You must allocate storage for a stack (dynamically or statically) and point `ss:sp` at the last word of this stack area. Once you call `fork`, the process package uses whatever value that happens to be in the `regss` and `regsp` fields. If you have not initialized these values, they will probably contain zero and when the process starts it will wipe out the data at address 0:FFFE. This may crash the system at one point or another.

The `die` call kills the current process. If there are multiple processes running, this call transfers control to some other processes waiting to run. If the current process is the only process on the system's *run queue*, then this call will crash the system.

The `kill` call lets one process terminate another. Typically, a parent process will use this call to terminate a child process. To kill a process, simply load the `ax` register with the PID of the process you want to terminate and then call `kill`. If a process supplies its own PID to the `kill` function, the process terminates itself (that is, this is equivalent to a `die` call). If there is only one process in the run queue and that process kills itself, the system will crash.

The last multitasking management routine in the process package is the `yield` call. `Yield` voluntarily gives up the CPU. This is a direct call to the dispatcher, that will switch to another task in the run queue. Control returns after the `yield` call when the next time slice is given to this process. If the current process is the only one in the queue, `yield` immediately returns. You would normally use the `yield` call to free up the CPU between long I/O operations (like waiting for a keypress). This would allow other tasks to get maximum use of the CPU while your process is just spinning in a loop waiting for some I/O operation to complete.

The Standard Library multitasking routines only work with the 16 bit register set of the 80x86 family. Like the coroutine package, you will need to modify the pcb and the dispatcher code if you want to support the 32 bit register set of the 80386 and later processors. This task is relatively simple and the code is quite similar to that appearing in the section on coroutines; so there is no need to present the solution here.

19.4.3 Problems with Multitasking

When threads share code and data certain problems can develop. First of all, reentrancy becomes a problem. You cannot call a non-reentrant routine (like DOS) from two separate threads if there is ever the possibility that the non-reentrant code could be interrupted and control transferred to a second thread that reenters the same routine. Reentrancy is not the only problem, however. It is quite possible to design two routines that access shared variables and those routines misbehave depending on where the interrupts occur in the code sequence. We will explore these problems in the section on synchronization (see "Synchronization" on page 1129), just be aware, for now, that these problems exist.

Note that simply turning off the interrupts (with `cli`) may not solve the reentrancy problem. Consider the following code:

```
        cli                     ;Prevent reentrancy.
        mov     ah, 3Eh         ;DOS close call.
        mov     bx, Handle
        int     21h
        sti                     ;Turn interrupts back on.
```

This code will not prevent DOS from being reentered because DOS (and BIOS) turn the interrupts back on! There is a solution to this problem, but it's not by using `cli` and `sti`.

19.4.4 A Sample Program with Threads

The following program provides a simple demonstration of the Standard Library processes package. This short program creates two threads – the main program and a timer process. On each timer tick the background (timer) process kicks in and increments a memory variable. It then yields the CPU back to the main program. On the next timer tick control returns to the background process and this cycle repeats. The main program reads a string from the user while the background process is counting off timer ticks. When the user finishes the line by pressing the enter key, the main program kills the background process and then prints the amount of time necessary to enter the line of text.

Of course, this isn't the most efficient way to time how long it takes someone to enter a line of text, but it does provide an example of the multitasking features of the Standard Library. This short program segment demonstrates all the process routines except `die`. Note that it also demonstrates the fact that you must supply int 23h and int 24h handlers when using the process package.

```
; MULTI.ASM
; Simple program to demonstrate the use of multitasking.


                .xlist
                include    stdlib.a
                includelib stdlib.lib
                .list


dseg            segment    para public 'data'

ChildPID        word       0             ;Child's PID so we can kill it.
BackGndCnt      word       0             ;Counts off clock ticks in backgnd.

; PCB for our background process. Note we initialize ss:sp here.

BkgndPCB        pcb        {0,offset EndStk2, seg EndStk2}

; Data buffer to hold an input string.

InputLine       byte       128 dup (0)

dseg            ends

cseg            segment    para public 'code'
                assume     cs:cseg, ds:dseg

; A replacement critical error handler. This routine calls prcsquit
; if the user decides to abort the program.


CritErrMsg      byte       cr,lf
                byte       "DOS Critical Error!",cr,lf
                byte       "A)bort, R)etry, I)gnore, F)ail? $"

MyInt24         proc       far
                push       dx
                push       ds
                push       ax

                push       cs
                pop        ds
Int24Lp:        lea        dx, CritErrMsg
                mov        ah, 9             ;DOS print string call.
                int        21h

                mov        ah, 1             ;DOS read character call.
                int        21h
```

```
                and     al, 5Fh         ;Convert l.c. -> u.c.

                cmp     al, 'I'         ;Ignore?
                jne     NotIgnore
                pop     ax
                mov     al, 0
                jmp     Quit24

NotIgnore:      cmp     al, 'r'         ;Retry?
                jne     NotRetry
                pop     ax
                mov     al, 1
                jmp     Quit24

NotRetry:       cmp     al, 'A'         ;Abort?
                jne     NotAbort
                prcsquit                ;If quitting, fix INT 8.
                pop     ax
                mov     al, 2
                jmp     Quit24

NotAbort:       cmp     al, 'F'
                jne     BadChar
                pop     ax
                mov     al, 3
Quit24:         pop     ds
                pop     dx
                iret

BadChar:        mov     ah, 2
                mov     dl, 7           ;Bell character
                jmp     Int24Lp
MyInt24         endp


; We will simply disable INT 23h (the break exception).

MyInt23         proc    far
                iret
MyInt23         endp


; Okay, this is a pretty weak background process, but it does demonstrate
; how to use the Standard Library calls.

BackGround      proc
                sti
                mov     ax, dseg
                mov     ds, ax
                inc     BackGndCnt      ;Bump call Counter by one.
                yield                   ;Give CPU back to foregnd.
                jmp     BackGround
BackGround      endp


Main            proc
                mov     ax, dseg
                mov     ds, ax
                mov     es, ax
                meminit


; Initialize the INT 23h and INT 24h exception handler vectors.

                mov     ax, 0
                mov     es, ax
                mov     word ptr es:[24h*4], offset MyInt24
                mov     es:[24h*4 + 2], cs
                mov     word ptr es:[23h*4], offset MyInt23
                mov     es:[23h*4 + 2], cs

                prcsinit                ;Start multitasking system.
```

```
                lesi    BkgndPCB        ;Fire up a new process
                fork
                test    ax, ax          ;Parent's return?
                je      ParentPrcs
                jmp     BackGround      ;Go do backgroun stuff.

ParentPrcs:     mov     ChildPID, bx    ;Save child process ID.

                print
                byte    "I am timing you while you enter a string. So type"
                byte    cr,lf
                byte    "quickly: ",0

                lesi    InputLine
                gets

                mov     ax, ChildPID    ;Stop the child from running.
                kill

                printf
                byte    "While entering '%s' you took %d clock ticks"
                byte    cr,lf,0
                dword   InputLine, BackGndCnt

                prcsquit

Quit:           ExitPgm                 ;DOS macro to quit program.
Main            endp

cseg            ends

sseg            segment stack 'stack'

; Here is the stack for the background process we start

stk2            byte    256 dup (?)
EndStk2         word    ?

;Here's the stack for the main program/foreground process.

stk             byte    1024 dup (?)
sseg            ends

zzzzzzseg       segment public 'zzzzzz'
LastBytes       db      16 dup (?)
zzzzzzseg       ends
                end     Main
```

19.5 Synchronization

Many problems occur in cooperative concurrently executing processes due to *synchronization* (or the lack thereof). For example, one process can *produce* data that other processes *consume*. However, it might take much longer for the producer to create than data than it takes for the consumer to use it. Some mechanism must be in place to ensure that the consumer does not attempt to use the data before the producer creates it. Likewise, we need to ensure that the consumer uses the data created by the producer before the producer creates more data.

The *producer-consumer problem* is one of several very famous *synchronization* problems from operating systems theory. In the producer-consumer problem there are one or more processes that produce data and write this data to a shared buffer. Likewise, there are one or more consumers that read data from this buffer. There are two synchronization issues we must deal with – the first is to ensure that the producers do not produce more data than the buffer can hold (conversely, we must prevent the consumers from removing data from an empty buffer); the second is to ensure the integrity of the buffer data structure by allowing access to only one process at a time.

Consider what can happen in a simple producer-consumer problem. Suppose the producer and consumer processes share a single data buffer structure organized as follows:

```
buffer          struct
Count           word        0
InPtr           word        0
OutPtr          word        0
Data            byte        MaxBufSize dup (?)
buffer          ends
```

The Count field specifies the number of data bytes currently in the buffer. InPtr points at the next available location to place data in the buffer. OutPtr is the address of the next byte to remove from the buffer. Data is the actual buffer array. Adding and removing data is very easy. The following code segments *almost* handle this job:

```
; Producer-   This procedure adds the value in al to the buffer.
;             Assume that the buffer variable MyBuffer is in the data segment.

Producer        proc        near
                pushf
                sti                             ;Must have interrupts on!
                push        bx

; The following loop waits until there is room in the buffer to insert
; another byte.

WaitForRoom:    cmp         MyBuffer.Count, MaxBufSize
                jae         WaitForRoom

; Okay, insert the byte into the buffer.

                mov         bx, MyBuffer.InPtr
                mov         MyBuffer.Data[bx], al
                inc         MyBuffer.Count      ;We just added a byte to the buffer.
                inc         MyBuffer.InPtr      ;Move on to next item in buffer.

; If we are at the physical end of the buffer, wrap around to the beginning.

                cmp         MyBuffer.InPtr, MaxBufSize
                jb          NoWrap
                mov         MyBuffer.InPtr, 0
NoWrap:
                pop         bx
                popf
                ret
Producer        endp


; Consumer-   This procedure waits for data (if necessary) and returns the
;             next available byte from the buffer.

Consumer        proc        near
                pushf                           ;Must have interrupts on!
                sti
                push        bx
WaitForData:    cmp         Count, 0            ;Is the buffer empty?
                je          WaitForData         ;If so, wait for data to arrive.

; Okay, fetch an input character

                mov         bx, MyBuffer.OutPtr
                mov         al, MyBuffer.Data[bx]
                dec         MyBuffer.Count
                inc         MyBuffer.OutPtr
                cmp         MyBuffer.OutPtr, MaxBufSize
                jb          NoWrap
                mov         MyBuffer.OutPtr, 0
NoWrap:
                pop         bx
                popf
                ret
Consumer        endp
```

The only problem with this code is that it won't always work if there are multiple producer or consumer processes. In fact, it is easy to come up with a version of this code that won't work for a single set of producer and consumer processes (although the code above will work fine, in that special case). The problem is that these procedures access global variables and, therefore, are not reentrant. In particular, the problem lies with the way these two procedures manipulate the buffer control variables. Consider, for a moment, the following statements from the Consumer procedure:

```
                dec         MyBuffer.Count

          « Suppose an interrupt occurs here »

                inc         MyBuffer.OutPtr
                cmp         MyBuffer.OutPtr, MaxBufSize
                jb          NoWrap
                mov         MyBuffer.OutPtr, 0
NoWrap:
```

If an interrupt occurs at the specified point above and control transfers to another consumer process that reenters this code, the second consumer would malfunction. The problem is that the first consumer has fetched data from the buffer but has yet to update the output pointer. The second consumer comes along and removes *the same byte as the first consumer.* The second consumer then properly updates the output pointer to point at the next available location in the circular buffer. When control eventually returns to the first consumer process, it finishes the operation by incrementing the output pointer. *This causes the system to skip over the next byte which no process has read.* The end result is that two consumer processes fetch the same byte and then skip a byte in the buffer.

This problem is easily solved by recognizing the fact that the code that manipulates the buffer data is a critical region. By restricting execution in the critical region to one process at a time, we can solve this problem. In the simple example above, we can easily prevent reentrancy by turning the interrupts off while in the critical region. For the consumer procedure, the code would look like this:

```
; Consumer-   This procedure waits for data (if necessary) and returns the
;             next available byte from the buffer.

Consumer      proc        near
              pushf                           ;Must have interrupts on!
              sti
              push        bx
WaitForData:  cmp         Count, 0            ;Is the buffer empty?
              je          WaitForData         ;If so, wait for data to arrive.

; The following is a critical region, so turn the interrupts off.

              cli

; Okay, fetch an input character

              mov         bx, MyBuffer.OutPtr
              mov         al, MyBuffer.Data[bx]
              dec         MyBuffer.Count
              inc         MyBuffer.OutPtr
              cmp         MyBuffer.OutPtr, MaxBufSize
              jb          NoWrap
              mov         MyBuffer.OutPtr, 0
NoWrap:
              pop         bx
              popf                            ;Restore interrupt flag.
              ret
Consumer      endp
```

Note that we cannot turn the interrupts off during the execution of the whole procedure. Interrupts must be on while this procedure is waiting for data, otherwise the producer process will never be able to put data in the buffer for the consumer.

Simply turning the interrupts off does not always work. Some critical regions may take a considerable amount of time (seconds, minutes, or even hours) and you cannot leave the interrupts off for that amount

of time[3]. Another problem is that the critical region may call a procedure that turns the interrupts back on and you have no control over this. A good example is a procedure that calls MS-DOS. Since MS-DOS is not reentrant, MS-DOS is, by definition, a critical section; we can only allow one process at a time inside MS-DOS. However, MS-DOS reenables the interrupts, so we cannot simply turn off the interrupts before calling an MS-DOS function an expect this to prevent reentrancy.

Turning off the interrupts doesn't even work for the consumer/producer procedures given earlier. Note that interrupts *must* be on while the consumer is waiting for data to arrive in the buffer (conversely, the producers must have interrupts on while waiting for room in the buffer). It is quite possible for the code to detect the presence of data and just before the execution of the `cli` instruction, an interrupt transfers control to a second consumer process. While it is not possible for both processes to update the buffer variables concurrently, it is possible for the second consumer process to remove the *only* data value from the input buffer and then switch back to the first consumer that removes a phantom value from the buffer (and causes the `Count` variable to go negative).

One poorly thought out solution is to use a flag to control access to a critical region. A process, before entering the critical region, tests the flag to see if any other process is currently in the critical region; if not, the process sets the flag to "in use" and then enters the critical region. Upon leaving the critical region, the process sets the flag to "not in use." If a process wants to enter a critical region and the flag's value is "in use", the process must wait until the process currently in the critical section finishes and writes the "not in use" value to the flag.

The only problem with this solution is that it is nothing more than a special case of the producer/consumer problem. The instructions that update the in-use flag form their own critical section that you must protect. As a general solution, the in-use flag idea fails.

19.5.1 Atomic Operations, Test & Set, and Busy-Waiting

The problem with the in-use flag idea is that it takes several instructions to test and set the flag. A typical piece of code that tests such a flag would read its value and determine if the critical section is in use. If not, it would then write the "in-use" value to the flag to let other processes know that it is in the critical section. The problem is that an interrupt could occur after the code tests the flag but before it sets the flag to "in use." Then some other process can come along, test the flag and find that it is not in use, and enter the critical region. The system could interrupt that second process while it is still in the critical region and transfer control back to the first. Since the first process has already determined that the critical region is not in use, it sets the flag to "in use" and enters the critical region. Now we have two processes in the critical region and the system is in violation of the *mutual exclusion requirement* (only one process in a critical region at a time).

The problem with this approach is that testing and setting the in-use flag is not an uninterruptable (*atomic*) operation. If it were, then there would be no problem. Of course, it is easy to make a sequence of instructions non-interruptible by putting a `cli` instruction before them. Therefore, we can test and set a flag in an atomic operation as follows (assume in-use is zero, not in-use is one):

```
            pushf
TestLoop:   cli                         ;Turn ints off while testing and
            cmp       Flag, 0           ; setting flag.
            je        IsInUse           ;Already in use?
            mov       Flag, 0           ;If not, make it so.
IsInUse:    sti                         ;Allow ints (if in-use already).
            je        TestLoop          ;Wait until not in use.
            popf

; When we get down here, the flag was "not in-use" and we've just set it
; to "in-us." We now have exclusive access to the critical section.
```

3. In general, you should not leave the interrupts off for more than about 30 milliseconds when using the 1/18th second clock for multitasking. A general rule of thumb is that interrupts should not be off for much more than abou;50% of the time quantum.

Another solution is to use a so-called "test and set" instruction – one that both tests a specific condition and sets the flag to a desired value. In our case, we need an instruction that both tests a flag to see if it is not in-use and sets it to in-use at the same time (if the flag was already in-use, it will remain in use afterward). Although the 80x86 does not support a specific test and set instruction, it does provide several others that can achieve the same effect. These instructions include xchg, shl, shr, sar, rcl, rcr, rol, ror, btc/btr/bts (available only on the 80386 and later processors), and cmpxchg (available only on the 80486 and later processors). In a limited sense, you can also use the addition and subtraction instructions (add, sub, adc, sbb, inc, and dec) as well.

The exchange instruction provides the most generic form for the test and set operation. If you have a flag (0=in use, 1=not in use) you can test and set this flag without messing with the interrupts using the following code:

```
InUseLoop:      mov         al, 0               ;0=In Use
                xchg        al, Flag
                cmp         al, 0
                je          InUseLoop
```

The xchg instruction atomically swaps the value in al with the value in the flag variable. Although the xchg instruction doesn't actually test the value, it does place the original flag value in a location (al) that is safe from modification by another process. If the flag originally contained zero (in-use), this exchange sequence swaps a zero for the existing zero and the loop repeats. If the flag originally contained a one (not in-use) then this code swaps a zero (in-use) for the one and falls out of the in use loop.

The shift and rotate instructions also act as test and set instructions, assuming you use the proper values for the in-use flag. With in-use equal to zero and not in-use equal to one, the following code demonstrates how to use the shr instruction for the test and set operation:

```
InUseLoop:      shr         Flag, 1             ;In-use bit to carry, 0->Flag.
                jnc         InUseLoop           ;Repeat if already in use.
```

This code shifts the in-use bit (bit number zero) into the carry flag and clears the in-use flag. At the same time, it zeros the Flag variable, assuming Flag always contains zero or one. The code for the atomic test and set sequences using the other shift and rotates is very similar and appears in the exercises.

Starting with the 80386, Intel provided a set of instructions explicitly intended for test and set operations: btc (bit test and complement), bts (bit test and set), and btr (bit test and reset). These instructions copy a specific bit from the destination operand into the carry flag and then complement, set, or reset (clear) that bit. The following code demonstrates how to use the btr instruction to manipulate our in-use flag:

```
InUseLoop:      btr         Flag, 0             ;In-use flag is in bit zero.
                jnc         InUseLoop
```

The btr instruction is a little more flexible than the shr instruction because you don't have to guarantee that all the other bits in the Flag variable are zero; it tests and clears bit zero without affect any other bits in the Flag variable.

The 80486 (and later) cmpxchg instruction provides a very generic synchronization primitive. A "compare and swap" instruction turns out to be the only atomic instruction you need to implement almost *any* synchronization primitive. However, its generic structure means that it is a little too complex for simple test and set operations. You will get an opportunity to design a test and set sequence using cmpxchg in the exercises. For more details on cmpxchg, see "The CMPXCHG, and CMPXCHG8B Instructions" on page 263.

Returning to the producer/consumer problem, we can easily solve the critical region problem that exists in these routines using the test and set instruction sequence presented above. The following code does this for the Producer procedure, you would modify the Consumer procedure in a similar fashion.

```
; Producer-     This procedure adds the value in al to the buffer.
;               Assume that the buffer variable MyBuffer is in the data segment.

Producer        proc        near
```

```
                pushf
                sti                             ;Must have interrupts on!

; Okay, we are about to enter a critical region (this whole procedure),
; so test the in-use flag to see if this critical region is already in use.

InUseLoop:      shr         Flag, 1
                jnc         InUseLoop

                push        bx

; The following loop waits until there is room in the buffer to insert
; another byte.

WaitForRoom:    cmp         MyBuffer.Count, MaxBufSize
                jae         WaitForRoom

; Okay, insert the byte into the buffer.

                mov         bx, MyBuffer.InPtr
                mov         MyBuffer.Data[bx], al
                inc         MyBuffer.Count      ;We just added a byte to the buffer.
                inc         MyBuffer.InPtr      ;Move on to next item in buffer.

; If we are at the physical end of the buffer, wrap around to the beginning.

                cmp         MyBuffer.InPtr, MaxBufSize
                jb          NoWrap
                mov         MyBuffer.InPtr, 0
NoWrap:
                mov         Flag, 1             ;Set flag to not in use.
                pop         bx
                popf
                ret
Producer        endp
```

One minor problem with the test and set approach to protecting a critical region is that it uses a *busy-waiting* loop. While the critical region is not available, the process spins in a loop waiting for its turn at the critical region. If the process that is currently in the critical region remains there for a considerable length of time (say, seconds, minutes, or hours), the process(es) waiting to enter the critical region continue to waste CPU time waiting for the flag. This, in turn, wastes CPU time that could be put to better use getting the process in the critical region through it so another process can enter.

Another problem that might exist is that it is possible for one process to enter the critical region, locking other processes out, leave the critical region, do some processing, and then reenter the critical region all during the same time slice. If it turns out that the process is always in the critical region when the timer interrupt occurs, none of the other processes waiting to enter the critical region will ever do so. This is a problem known as *starvation* – processes waiting to enter the critical region never do so because some other process always beats them into it.

One solution to these two problems is to use a synchronization object known as a semaphore. Semaphores provide an efficient and general purpose mechanism for protecting critical regions. To find out about semaphores, keep reading...

19.5.2 Semaphores

A semaphore is an object with two basic methods: wait and signal (or release). To use a semaphore, you create a semaphore variable (an instance) for a particular critical region or other *resource* you want to protect. When a process wants to use a given resource, it *waits* on the semaphore. If no other process is currently using the resource, then the wait call sets the semaphore to in-use and immediately returns to the process. At that time, the process has exclusive access to the resource. If some other process is already using the resource (e.g., is in the critical region), then the semaphore *blocks* the current process by moving it off the run queue and onto the semaphore queue. When the process that currently holds the

resource *releases* it, the release operation removes the first waiting process from the semaphore queue and places it back in the run queue. At the next available time slice, that new process returns from its wait call and can enter its critical region.

Semaphores solve the two important problems with the busy-waiting loop described in the previous section. First, when a process waits and the semaphore blocks the process, that process is no longer on the run queue, so it consumes no more CPU time until the point that a release operation places it back onto the run queue. So unlike busy-waiting, the semaphore mechanism does not waste (as much) CPU time on processes that are waiting for some resource.

Semaphores can also solve the starvation problem. The wait operation, when blocking a process, can place it at the end of a FIFO semaphore queue. The release operation can fetch a new process from the front of the FIFO queue to place back on to the run queue. This policy ensures that each process entering the semaphore queue gets equal priority access to the resource[4].

Implementing semaphores is an easy task. A semaphore generally consists of an integer variable and a queue. The system initializes the integer variable with the number of processes than may share the resource at one time (this value is usually one for critical regions and other resources requiring exclusive access). The wait operation decrements this variable. If the result is greater than or equal to zero, the wait function simply returns to the caller; if the result is less than zero, the wait function saves the machine state, moves the process' `pcb` from the run queue to the semaphore's queue, and then switches the CPU to a different process (i.e., a `yield` call).

The release function is almost the converse. It increments the integer value. If the result is not one, the release function moves a `pcb` from the front of the semaphore queue to the run queue. If the integer value becomes one, there are no more processes on the semaphore queue, so the release function simply returns to the caller. Note that the release function does *not* activate the process it removes from the semaphore process queue. It simply places that process in the run queue. Control always returns to the process that made the release call (unless, of course, a timer interrupt occurs while executing the release function).

Of course, any time you manipulate the system's run queue you are in a critical region. Therefore, we seem to have a minor problem here – the whole purpose of a semaphore is to protect a critical region, yet the semaphore itself has a critical region we need to protect. This seems to involve circular reasoning. However, this problem is easily solved. Remember, the main reasons we do not turn off interrupts to protect a critical region is because that critical region may take a long time to execute or it may call other routines that turn the interrupts back on. The critical section in a semaphore is very short and does not call any other routines. Therefore, briefly turning off the interrupts while in the semaphore's critical region is perfectly reasonable.

If you are not allowed to turn off interrupts, you can always use a test and set instruction in a loop to protect a critical region. Although this introduces a busy-waiting loop, it turns out that you will never wait more than two time slices before exiting the busy-waiting loop, so you do not waste much CPU time waiting to enter the semaphore's critical region.

Although semaphores solve the two major problems with the busy waiting loop, it is very easy to get into trouble when using semaphores. For example, if a process waits on a semaphore and the semaphore grants exclusive access to the associate resource, then that process never releases the semaphore, any processes waiting on that semaphore will be suspended indefinitely. Likewise, any process that waits on the same semaphore twice without a release in-between will suspend itself, and any other processes that wait on that semaphore, indefinitely. Any process that does not release a resource it no longer needs violates the concept of a semaphore and is a logic error in the program. There are also some problems that may develop if a process waits on multiple semaphores before releasing any. We will return to that problem in the section on *deadlocks* (see "Deadlock" on page 1146).

4. This FIFO policy is but one example of a release policy. You could have some other policy based on a priority scheme. However, the FIFO policy does not promote starvation.

Although we could write our own semaphore package (and there is good reason to), the Standard Library process package provides its own wait and release calls along with a definition for a semaphore variable. The next section describes those calls.

19.5.3 The UCR Standard Library Semaphore Support

The UCR Standard Library process package provides two functions to manipulate semaphore variables: WaitSemaph and RlsSemaph. These functions wait and signal a semaphore, respectively. These routines mesh with the process management facilities, making it easy to implement synchronization using semaphores in your programs.

The process package provides the following definition for a semaphore data type:

```
semaphore      struct
SemaCnt        word       1
smaphrLst      dword      ?
endsmaphrLst   dword      ?
semaphore      ends
```

The SemaCnt field determines how many more processes can share a resource (if positive), or how many processes are currently waiting for the resource (if negative). By default, this field is initialized to the value one. This allows one process at a time to use the resource protected by the semaphore. Each time a process waits on a semaphore, it decrements this field. If the decremented result is positive or zero, the wait operation immediately returns. If the decremented result is negative, then the wait operation moves the current process' pcb from the run queue to the semaphore queue defined by the smaphrLst and endsmaphrLst fields in the structure above.

Most of the time you will use the default value of one for the SemaCnt field. There are some occasions, though, when you might want to allow more than one process access to some resource. For example, suppose you've developed a multiplayer game that communicates between different machines using the serial communications port or a network adapter card. You might have an area in the game which has room for only two players at a time. For example, players could be racing to a particular "transporter" room in an alien space ship, but there is room for only two players in the transporter room at a time. By initializing the semaphore variable to two, rather than one, the wait operation would allow two players to continue at one time rather than just one. When the third player attempts to enter the transporter room, the WaitSemaph function would block the player from entering the room until one of the other players left (perhaps by "transporting out" of the room).

To use the WaitSemaph or RlsSemaph function is very easy; just load the es:di register pair with the address of desired semaphore variable and issue the appropriate function call. RlsSemaph always returns immediately (assuming a timer interrupt doesn't occur while in RlsSemaph), the WaitSemaph call returns when the semaphore will allow access to the resource it protects. Examples of these two calls appear in the next section.

Like the Standard Library coroutine and process packages, the semaphore package only preserves the 16 bit register set of the 80x86 CPU. If you want to use the 32 bit register set of the 80386 and later processors, you will need to modify the source code for the WaitSemaph and RlsSemaph functions. The code you need to change is almost identical to the code in the coroutine and process packages, so this is nearly a trivial change. Do keep in mind, though, that you will need to change this code if you use any 32 bit facilities of the 80386 and later processors.

19.5.4 Using Semaphores to Protect Critical Regions

You can use semaphores to provide mutually exclusive access to any resource. For example, if several processes want to use the printer, you can create a semaphore that allows access to the printer by only one process at a time (a good example of a process that will be in the "critical region" for several minutes

at a time). However the most common task for a semaphore is to protect a critical region from reentry. Three common examples of code you need to protect from reentry include DOS calls, BIOS calls, and various Standard Library calls. Semaphores are ideal for controlling access to these functions.

To protect DOS from reentry by several different processes, you need only create a DOSsmaph variable and issue appropriate WaitSemaph and RlsSemaph calls around the call to DOS. The following sample code demonstrates how to do this.

```
; MULTIDOS.ASM
;
; This program demonstrates how to use semaphores to protect DOS calls.

                .xlist
                include    stdlib.a
                includelib stdlib.lib
                .list


dseg            segment    para public 'data'

DOSsmaph        semaphore  {}

; Macros to wait and release the DOS semaphore:

DOSWait         macro
                push       es
                push       di
                lesi       DOSsmaph
                WaitSemaph
                pop        di
                pop        es
                endm

DOSRls          macro
                push       es
                push       di
                lesi       DOSsmaph
                RlsSemaph
                pop        di
                pop        es
                endm


; PCB for our background process:

BkgndPCB        pcb        {0,offset EndStk2, seg EndStk2}

; Data the foreground and background processes print:

StrPtrs1        dword      str1_a, str1_b, str1_c, str1_d, str1_e, str1_f
                dword      str1_g, str1_h, str1_i, str1_j, str1_k, str1_l
                dword      0

str1_a          byte       "Foreground: string 'a'",cr,lf,0
str1_b          byte       "Foreground: string 'b'",cr,lf,0
str1_c          byte       "Foreground: string 'c'",cr,lf,0
str1_d          byte       "Foreground: string 'd'",cr,lf,0
str1_e          byte       "Foreground: string 'e'",cr,lf,0
str1_f          byte       "Foreground: string 'f'",cr,lf,0
str1_g          byte       "Foreground: string 'g'",cr,lf,0
str1_h          byte       "Foreground: string 'h'",cr,lf,0
str1_i          byte       "Foreground: string 'i'",cr,lf,0
str1_j          byte       "Foreground: string 'j'",cr,lf,0
str1_k          byte       "Foreground: string 'k'",cr,lf,0
str1_l          byte       "Foreground: string 'l'",cr,lf,0

StrPtrs2        dword      str2_a, str2_b, str2_c, str2_d, str2_e, str2_f
                dword      str2_g, str2_h, str2_i
                dword      0

str2_a          byte       "Background: string 'a'",cr,lf,0
str2_b          byte       "Background: string 'b'",cr,lf,0
```

```
str2_c          byte        "Background: string 'c'",cr,lf,0
str2_d          byte        "Background: string 'd'",cr,lf,0
str2_e          byte        "Background: string 'e'",cr,lf,0
str2_f          byte        "Background: string 'f'",cr,lf,0
str2_g          byte        "Background: string 'g'",cr,lf,0
str2_h          byte        "Background: string 'h'",cr,lf,0
str2_i          byte        "Background: string 'i'",cr,lf,0

dseg            ends

cseg            segment     para public 'code'
                assume      cs:cseg, ds:dseg

; A replacement critical error handler. This routine calls prcsquit
; if the user decides to abort the program.


CritErrMsg      byte        cr,lf
                byte        "DOS Critical Error!",cr,lf
                byte        "A)bort, R)etry, I)gnore, F)ail? $"

MyInt24         proc        far
                push        dx
                push        ds
                push        ax

                push        cs
                pop         ds
Int24Lp:        lea         dx, CritErrMsg
                mov         ah, 9               ;DOS print string call.
                int         21h

                mov         ah, 1               ;DOS read character call.
                int         21h
                and         al, 5Fh             ;Convert l.c. -> u.c.

                cmp         al, 'I'             ;Ignore?
                jne         NotIgnore
                pop         ax
                mov         al, 0
                jmp         Quit24

NotIgnore:      cmp         al, 'r'             ;Retry?
                jne         NotRetry
                pop         ax
                mov         al, 1
                jmp         Quit24

NotRetry:       cmp         al, 'A'             ;Abort?
                jne         NotAbort
                prcsquit                        ;If quitting, fix INT 8.
                pop         ax
                mov         al, 2
                jmp         Quit24

NotAbort:       cmp         al, 'F'
                jne         BadChar
                pop         ax
                mov         al, 3
Quit24:         pop         ds
                pop         dx
                iret

BadChar:        mov         ah, 2
                mov         dl, 7               ;Bell character
                jmp         Int24Lp
MyInt24         endp


; We will simply disable INT 23h (the break exception).

MyInt23         proc        far
                iret
MyInt23         endp
```

```
; This background process calls DOS to print several strings to the
; screen. In the meantime, the foreground process is also printing
; strings to the screen. To prevent reentry, or at least a jumble of
; characters on the screen, this code uses semaphores to protect the
; DOS calls. Therefore, each process will print one complete line
; then release the semaphore. If the other process is waiting it will
; print its line.

BackGround    proc
              mov       ax, dseg
              mov       ds, ax
              lea       bx, StrPtrs2      ;Array of str ptrs.
PrintLoop:    cmp       word ptr [bx+2], 0 ;At end of pointers?
              je        BkGndDone
              les       di, [bx]          ;Get string to print.
              DOSWait
              puts                        ;Calls DOS to print string.
              DOSRls
              add       bx, 4             ;Point at next str ptr.
              jmp       PrintLoop

BkGndDone:    die                         ;Terminate this process
BackGround    endp


Main          proc
              mov       ax, dseg
              mov       ds, ax
              mov       es, ax
              meminit


; Initialize the INT 23h and INT 24h exception handler vectors.

              mov       ax, 0
              mov       es, ax
              mov       word ptr es:[24h*4], offset MyInt24
              mov       es:[24h*4 + 2], cs
              mov       word ptr es:[23h*4], offset MyInt23
              mov       es:[23h*4 + 2], cs

              prcsinit                    ;Start multitasking system.

              lesi      BkgndPCB          ;Fire up a new process
              fork
              test      ax, ax            ;Parent's return?
              je        ParentPrcs
              jmp       BackGround        ;Go do background stuff.

; The parent process will print a bunch of strings at the same time
; the background process is doing this. We'll use the DOS semaphore
; to protect the call to DOS that PUTS makes.

ParentPrcs:   DOSWait                     ;Force the other process
              mov       cx, 0             ; to wind up waiting in
DlyLp0:       loop      DlyLp0            ; the semaphore queue by
DlyLp1:       loop      DlyLp1            ; delay for at least one
DlyLp2:       loop      DlyLp2            ; clock tick.
              DOSRls

              lea       bx, StrPtrs1      ;Array of str ptrs.
PrintLoop:    cmp       word ptr [bx+2],0 ;At end of pointers?
              je        ForeGndDone
              les       di, [bx]          ;Get string to print.
              DOSWait
              puts                        ;Calls DOS to print string.
              DOSRls
              add       bx, 4             ;Point at next str ptr.
              jmp       PrintLoop

ForeGndDone:  prcsquit
```

```
Quit:           ExitPgm                         ;DOS macro to quit program.
Main            endp

cseg            ends

sseg            segment    para stack 'stack'

; Here is the stack for the background process we start

stk2            byte       1024 dup (?)
EndStk2         word       ?

;Here's the stack for the main program/foreground process.

stk             byte       1024 dup (?)
sseg            ends

zzzzzzseg       segment    para public 'zzzzzz'
LastBytes       db         16 dup (?)
zzzzzzseg       ends
                end        Main
```

This program doesn't directly call DOS, but it calls the Standard Library puts routine that does. In general, you could use a single semaphore to protect all BIOS, DOS, and Standard Library calls. However, this is not particularly efficient. For example, the Standard Library pattern matching routines make no DOS calls; therefore, waiting on the DOS semaphore to do a pattern match while some other process is making a DOS call unnecessarily delays the pattern match. There is nothing wrong with having one process do a pattern match while another is making a DOS call. Unfortunately, some Standard Library routines *do* make DOS calls (puts is a good example), so you must use the DOS semaphore around such calls.

In theory, we could use separate semaphores to protect DOS, different BIOS calls, and different Standard Library calls. However, keeping track of all those semaphores within a program is a big task. Furthermore, ensuring that a call to DOS does not also invoke an unprotected BIOS routine is a difficult task. So most programmers use a single semaphore to protect all Standard Library, DOS, and BIOS calls.

19.5.5 Using Semaphores for Barrier Synchronization

Although the primary use of a semaphores is to provide exclusive access to some resource, there are other synchronization uses for semaphores as well. In this section we'll look at the use of the Standard Library's semaphores objects to create a *barrier*.

A barrier is a point in a program where a process stops and waits for other processes to synchronize (reach their respective barriers). In many respects, a barrier is the dual to a semaphore. A semaphore prevents more than *n* processes from gaining access to some resource. A barrier does not grant access until at least *n* processes are requesting access.

Given the different nature of these two synchronization methods, you might think that it would be difficult to use the WaitSemaph and RlsSemaph routines to implement barriers. However, it turns out to be quite simple. Suppose we were to initialize the semaphore's SemaCnt field to zero rather than one. When the first process waits on this semaphore, the system will immediately block that process. Likewise, each additional process that waits on this semaphore will block and wait on the semaphore queue. This would normally be a disaster since there is no active process that will signal the semaphore so it will activate the blocked processes. However, if we modify the wait call so that it checks the SemaCnt field before actually doing the wait, the n^{th} process can skip the wait call and reactivate the other processes. Consider the following macro:

```
barrier         macro       Wait4Cnt
                local       AllHere, AllDone
                cmp         es:[di].semaphore.SemaCnt, -(Wait4Cnt-1)
                jle         AllHere
                WaitSemaph
                cmp         es:[di].semaphore.SemaCnt, 0
                je          AllDone
AllHere:        RlsSemaph
AllDone:
                endm
```

This macro expects a single parameter that should be the number of processes (including the current process) that need to be at a barrier before any of the processes can proceed. The SemaCnt field is a negative number whose absolute value determines how many processes are currently waiting on the semaphore. If a barrier requires four processes, no process can proceed until the fourth process hits the barrier; at that time the SemaCnt field will contain minus three. The macro above computes what the value of SemaCnt should be if all processes are at the barrier. If SemaCnt matches this value, it signals the semaphore that begins a chain of operations with each blocked process releasing the next. When SemaCnt hits zero, the last blocked process does not release the semaphore since there are no other processes waiting on the queue.

It is very important to remember to initialize the SemaCnt field to zero before using semaphores for barrier synchronization in this manner. If you do not initialize SemaCnt to zero, the WaitSemaph call will probably not block any of the processes.

The following sample program provides a simple example of barrier synchronization using the Standard Library's semaphore package:

```
; BARRIER.ASM
;
; This sample program demonstrates how to use the Standard Library's
; semaphore objects to synchronize several processes at a barrier.
; This program is similar to the MULTIDOS.ASM program insofar as the
; background processes all print a set of strings. However, rather than
; using an inelegant delay loop to synchronize the foreground and background
; processes, this code uses barrier synchronization to achieve this.

                .xlist
                include    stdlib.a
                includelib stdlib.lib
                .list


dseg            segment    para public 'data'

BarrierSemaph   semaphore  {0}              ;Must init SemaCnt to zero.
DOSsmaph        semaphore  {}

; Macros to wait and release the DOS semaphore:

DOSWait         macro
                push       es
                push       di
                lesi       DOSsmaph
                WaitSemaph
                pop        di
                pop        es
                endm

DOSRls          macro
                push       es
                push       di
                lesi       DOSsmaph
                RlsSemaph
                pop        di
                pop        es
                endm


; Macro to synchronize on a barrier:
```

```
Barrier         macro       Wait4Cnt
                local       AllHere, AllDone
                cmp         es:[di].semaphore.SemaCnt, -(Wait4Cnt-1)
                jle         AllHere
                WaitSemaph
                cmp         es:[di].semaphore.SemaCnt, 0
                jge         AllDone
AllHere:        RlsSemaph
AllDone:
                endm



; PCBs for our background processes:

BkgndPCB2       pcb         {0,offset EndStk2, seg EndStk2}
BkgndPCB3       pcb         {0,offset EndStk3, seg EndStk3}

; Data the foreground and background processes print:

StrPtrs1        dword       str1_a, str1_b, str1_c, str1_d, str1_e, str1_f
                dword       str1_g, str1_h, str1_i, str1_j, str1_k, str1_l
                dword       0

str1_a          byte        "Foreground: string 'a'",cr,lf,0
str1_b          byte        "Foreground: string 'b'",cr,lf,0
str1_c          byte        "Foreground: string 'c'",cr,lf,0
str1_d          byte        "Foreground: string 'd'",cr,lf,0
str1_e          byte        "Foreground: string 'e'",cr,lf,0
str1_f          byte        "Foreground: string 'f'",cr,lf,0
str1_g          byte        "Foreground: string 'g'",cr,lf,0
str1_h          byte        "Foreground: string 'h'",cr,lf,0
str1_i          byte        "Foreground: string 'i'",cr,lf,0
str1_j          byte        "Foreground: string 'j'",cr,lf,0
str1_k          byte        "Foreground: string 'k'",cr,lf,0
str1_l          byte        "Foreground: string 'l'",cr,lf,0

StrPtrs2        dword       str2_a, str2_b, str2_c, str2_d, str2_e, str2_f
                dword       str2_g, str2_h, str2_i
                dword       0

str2_a          byte        "Background 1: string 'a'",cr,lf,0
str2_b          byte        "Background 1: string 'b'",cr,lf,0
str2_c          byte        "Background 1: string 'c'",cr,lf,0
str2_d          byte        "Background 1: string 'd'",cr,lf,0
str2_e          byte        "Background 1: string 'e'",cr,lf,0
str2_f          byte        "Background 1: string 'f'",cr,lf,0
str2_g          byte        "Background 1: string 'g'",cr,lf,0
str2_h          byte        "Background 1: string 'h'",cr,lf,0
str2_i          byte        "Background 1: string 'i'",cr,lf,0

StrPtrs3        dword       str3_a, str3_b, str3_c, str3_d, str3_e, str3_f
                dword       str3_g, str3_h, str3_i
                dword       0

str3_a          byte        "Background 2: string 'j'",cr,lf,0
str3_b          byte        "Background 2: string 'k'",cr,lf,0
str3_c          byte        "Background 2: string 'l'",cr,lf,0
str3_d          byte        "Background 2: string 'm'",cr,lf,0
str3_e          byte        "Background 2: string 'n'",cr,lf,0
str3_f          byte        "Background 2: string 'o'",cr,lf,0
str3_g          byte        "Background 2: string 'p'",cr,lf,0
str3_h          byte        "Background 2: string 'q'",cr,lf,0
str3_i          byte        "Background 2: string 'r'",cr,lf,0

dseg            ends

cseg            segment     para public 'code'
                assume      cs:cseg, ds:dseg

; A replacement critical error handler. This routine calls prcsquit
; if the user decides to abort the program.
```

```
CritErrMsg      byte        cr,lf
                byte        "DOS Critical Error!",cr,lf
                byte        "A)bort, R)etry, I)gnore, F)ail? $"

MyInt24         proc        far
                push        dx
                push        ds
                push        ax

                push        cs
                pop         ds
Int24Lp:        lea         dx, CritErrMsg
                mov         ah, 9               ;DOS print string call.
                int         21h

                mov         ah, 1               ;DOS read character call.
                int         21h
                and         al, 5Fh             ;Convert l.c. -> u.c.

                cmp         al, 'I'             ;Ignore?
                jne         NotIgnore
                pop         ax
                mov         al, 0
                jmp         Quit24

NotIgnore:      cmp         al, 'r'             ;Retry?
                jne         NotRetry
                pop         ax
                mov         al, 1
                jmp         Quit24

NotRetry:       cmp         al, 'A'             ;Abort?
                jne         NotAbort
                prcsquit                        ;If quitting, fix INT 8.
                pop         ax
                mov         al, 2
                jmp         Quit24

NotAbort:       cmp         al, 'F'
                jne         BadChar
                pop         ax
                mov         al, 3
Quit24:         pop         ds
                pop         dx
                iret

BadChar:        mov         ah, 2
                mov         dl, 7               ;Bell character
                jmp         Int24Lp
MyInt24         endp


; We will simply disable INT 23h (the break exception).

MyInt23         proc        far
                iret
MyInt23         endp


; This background processes call DOS to print several strings to the
; screen. In the meantime, the foreground process is also printing
; strings to the screen. To prevent reentry, or at least a jumble of
; characters on the screen, this code uses semaphores to protect the
; DOS calls. Therefore, each process will print one complete line
; then release the semaphore. If the other process is waiting it will
; print its line.

BackGround1     proc
                mov         ax, dseg
                mov         ds, ax
```

```
; Wait for everyone else to get ready:

                lesi    BarrierSemaph
                barrier 3

; Okay, start printing the strings:

                lea     bx, StrPtrs2    ;Array of str ptrs.
PrintLoop:      cmp     word ptr [bx+2],0 ;At end of pointers?
                je      BkGndDone
                les     di, [bx]        ;Get string to print.
                DOSWait
                puts                    ;Calls DOS to print string.
                DOSRls
                add     bx, 4           ;Point at next str ptr.
                jmp     PrintLoop

BkGndDone:      die
BackGround1     endp


BackGround2     proc
                mov     ax, dseg
                mov     ds, ax

                lesi    BarrierSemaph
                barrier 3

                lea     bx, StrPtrs3    ;Array of str ptrs.
PrintLoop:      cmp     word ptr [bx+2],0 ;At end of pointers?
                je      BkGndDone
                les     di, [bx]        ;Get string to print.
                DOSWait
                puts                    ;Calls DOS to print string.
                DOSRls
                add     bx, 4           ;Point at next str ptr.
                jmp     PrintLoop

BkGndDone:      die
BackGround2     endp



Main            proc
                mov     ax, dseg
                mov     ds, ax
                mov     es, ax
                meminit


; Initialize the INT 23h and INT 24h exception handler vectors.

                mov     ax, 0
                mov     es, ax
                mov     word ptr es:[24h*4], offset MyInt24
                mov     es:[24h*4 + 2], cs
                mov     word ptr es:[23h*4], offset MyInt23
                mov     es:[23h*4 + 2], cs

                prcsinit                ;Start multitasking system.

; Start the first background process:

                lesi    BkgndPCB2       ;Fire up a new process
                fork
                test    ax, ax          ;Parent's return?
                je      StartBG2
                jmp     BackGround1     ;Go do backgroun stuff.

; Start the second background process:

StartBG2:       lesi    BkgndPCB3       ;Fire up a new process
                fork
```

```
                test        ax, ax              ;Parent's return?
                je          ParentPrcs
                jmp         BackGround2         ;Go do backgroun stuff.

; The parent process will print a bunch of strings at the same time
; the background process is doing this. We'll use the DOS semaphore
; to protect the call to DOS that PUTS makes.

ParentPrcs:     lesi        BarrierSemaph
                barrier     3

                lea         bx, StrPtrs1        ;Array of str ptrs.
PrintLoop:      cmp         word ptr [bx+2],0 ;At end of pointers?
                je          ForeGndDone
                les         di, [bx]            ;Get string to print.
                DOSWait
                puts                            ;Calls DOS to print string.
                DOSRls
                add         bx, 4               ;Point at next str ptr.
                jmp         PrintLoop

ForeGndDone:    prcsquit

Quit:           ExitPgm                         ;DOS macro to quit program.
Main            endp

cseg            ends

sseg            segment     para stack 'stack'

; Here are the stacks for the background processes we start

stk2            byte        1024 dup (?)
EndStk2         word        ?

stk3            byte        1024 dup (?)
EndStk3         word        ?

;Here's the stack for the main program/foreground process.

stk             byte        1024 dup (?)
sseg            ends

zzzzzzseg       segment     para public 'zzzzzz'
LastBytes       db          16 dup (?)
zzzzzzseg       ends
                end         Main
```

Sample Output:

```
Background 1: string 'a'
Background 1: string 'b'
Background 1: string 'c'
Background 1: string 'd'
Background 1: string 'e'
Background 1: string 'f'
Foreground: string 'a'
Background 1: string 'g'
Background 2: string 'j'
Foreground: string 'b'
Background 1: string 'h'
Background 2: string 'k'
Foreground: string 'c'
Background 1: string 'i'
Background 2: string 'l'
Foreground: string 'd'
Background 2: string 'm'
Foreground: string 'e'
Background 2: string 'n'
Foreground: string 'f'
Background 2: string 'o'
Foreground: string 'g'
```

```
Background 2: string 'p'
Foreground: string 'h'
Background 2: string 'q'
Foreground: string 'i'
Background 2: string 'r'
Foreground: string 'j'
Foreground: string 'k'
Foreground: string 'l'
```

Note how background process number one ran for one clock period before the other processes waited on the DOS semaphore. After this initial burst, the processes all took turns calling DOS.

19.6 Deadlock

Although semaphores can solve any synchronization problems, don't get the impression that semaphores don't introduce problems of their own. As you've already seen, the improper use of semaphores can result in the indefinite suspension of processes waiting on the semaphore queue. However, even if you correctly wait and signal individual semaphores, it is quite possible for correct operations on *combinations* of semaphores to produce this same effect. Indefinite suspension of a process because of semaphore problems is a serious issue. This degenerate situation is known as *deadlock* or *deadly embrace*.

Deadlock occurs when one process holds one resource and is waiting for another while a second process is holding that other resource and waiting for the first. To see how deadlock can occur, consider the following code:

```
; Process one:

              lesi       Semaph1
              WaitSemaph

        « Assume interrupt occurs here »

              lesi       Semaph2
              WaitSemaph
               .
               .
               .

; Process two:

              lesi       Semaph2
              WaitSemaph
              lesi       Semaph1
              WaitSemaph
               .
               .
               .
```

Process one grabs the semaphore associated with Semaph1. Then a timer interrupt comes along which causes a *context switch* to process two. Process two grabs the semaphore associated with Semaph2 and then tries to get Semaph1. However, process one is already holding Semaph1, so process two blocks and waits for process one to release this semaphore. This returns control (eventually) to process one. Process one then tries to graph Semaph2. Unfortunately, process two is already holding Semaph2, so process one blocks waiting for Semaph2. Now both processes are blocked waiting for the other. Since neither process can run, neither process can release the semaphore the other needs. Both processes are deadlocked.

One easy way to prevent deadlock from occurring is to never allow a process to hold more than one semaphore at a time. Unfortunately, this is not a practical solution; many processes may need to have exclusive access to several resources at one time. However, we can devise another solution by observing the pattern that resulted in deadlock in the previous example. Deadlock came about because the two processes grabbed different semaphores and then tried to grab the semaphore that the other was holding. In

other words, they grabbed the two semaphores in a different order (process one grabbed Semaph1 first and Semaph2 second, process two grabbed Semaph2 first and Semaph1 second). It turns out that two process will never deadlock if they wait on common semaphores *in the same order*. We could modify the previous example to eliminate the possibility of deadlock thusly:

```
; Process one:

                lesi       Semaph1
                WaitSemaph
                lesi       Semaph2
                WaitSemaph
                  .
                  .
                  .

; Process two:

                lesi       Semaph1
                WaitSemaph
                lesi       Semaph2
                WaitSemaph
                  .
                  .
                  .
```

Now it doesn't matter where the interrupt occurs above, deadlock cannot occur. If the interrupt occurs between the two WaitSemaph calls in process one (as before), when process two attempts to wait on Semaph1, it will block and process one will continue with Semaph2 available.

An easy way to keep out of trouble with deadlock is to number *all* your semaphore variables and make sure that all processes acquire (wait on) semaphores from the smallest numbered semaphore to the highest. This ensures that all processes acquire the semaphores in the same order, and that ensures that deadlock cannot occurs.

Note that this policy of acquiring semaphores only applies to semaphores that a process holds concurrently. If a process needs semaphore six for a while, and then it needs semaphore two after it has released semaphore six, there is no problem acquiring semaphore two after releasing semaphore six. However, if at any point the process needs to hold *both* semaphores, it must acquire semaphore two first.

Processes may release the semaphores in any order. The order that a process releases semaphores does not affect whether deadlock can occur. Of course, processes should always release a semaphore as soon as the process is done with the resource guarded by that semaphore; there may be other processes waiting on that semaphore.

While the above scheme works and is easy to implement, it is by no means the only way to handle deadlock, nor is it always the most efficient. However, it is simple to implement and it always works. For more information on deadlocks, see a good operating systems text.

19.7 Summary

Despite the fact that DOS is not reentrant and doesn't directly support multitasking, that doesn't mean your applications can't multitask; it's just difficult to get different applications to run independently of one another under DOS.

Although DOS doesn't switch among different programs in memory, DOS certainly allows you to load multiple programs into memory at one time. The only catch is that only one such program actually executes. DOS provides several calls to load and execute ".EXE" and ".COM" files from the disk. These processes effectively behave like subroutine calls, with control returning to the program invoking such a program only after that "child" program terminates. For more details, see

- "DOS Processes" on page 1065
- "Child Processes in DOS" on page 1065

- "Load and Execute" on page 1066
- "Load Program" on page 1068
- "Loading Overlays" on page 1069
- "Terminating a Process" on page 1069
- "Obtaining the Child Process Return Code" on page 1070

Certain errors can occur during the execution of a DOS process that transfer control to exception handlers. Besides the 80x86 exceptions, DOS' *break handler* and *critical error handler* are the primary examples. Any program that patches the interrupt vectors should provide its own exception handlers for these conditions so it can restore interrupts on a ctrl-C or I/O error exception. Furthermore, well-written program always provide replacement exception handlers for these two conditions that provide better support that the default DOS handlers. For more information on DOS exceptions, see

- "Exception Handling in DOS: The Break Handler" on page 1070
- "Exception Handling in DOS: The Critical Error Handler" on page 1071
- "Exception Handling in DOS: Traps" on page 1075

When a parent process invokes a child process with the LOAD or LOADEXEC calls, the child process inherits all open files from the parent process. In particular, the child process inherits the *standard input, standard output, standard error, auxiliary I/O,* and *printer* devices. The parent process can easily redirect I/O to/from these devices before passing control to a child process. This, in effect, *redirects* the I/O during the execution of the child process. For more details, see

- "Redirection of I/O for Child Processes" on page 1075

When two DOS programs want to communicate with each other, they typically read and write data to a file. However, creating, opening, reading, and writing files is a lot of work, especially just to share a few variable values. A better alternative is to use *shared memory.* Unfortunately, DOS does not provide support to allow two programs to share a common block of memory. However, it is very easy to write a TSR that manages shared memory for various programs. For details and the complete code to two shared memory managers, see:

- "Shared Memory" on page 1078
- "Static Shared Memory" on page 1078
- "Dynamic Shared Memory" on page 1088

A coroutine call is the basic mechanism for switching control between two processes. A "cocall" operation is the equivalent of a subroutine call and return all rolled into one operation. A cocall transfers control to some other process. When some other process returns control to a coroutine (via cocall), control resumes with the first instruction after the cocall code. The UCR Standard Library provides complete coroutine support so you can easily put coroutines into your assembly language programs. For all the details on coroutines, plus a neat maze generator program that uses coroutines, see

- "Coroutines" on page 1103

Although you can use coroutines to simulate multitasking ("cooperative multitasking"), the major problem with coroutines is that each application must decide when to switch to another process via a cocall. Although this eliminates certain reentrancy and synchronization problems, deciding when and where to make such calls increases the work necessary to write multitasking applications. A better approach is to use *preemptive multitasking* where the timer interrupt performs the context switches. Reentrancy and synchronization problems develop in such a system, but with care those problems are easily overcome. For the details on true preemptive multitasking, and to see how the UCR Standard Library supports multitasking, see

- "Multitasking" on page 1124
- "Lightweight and HeavyWeight Processes" on page 1124
- "The UCR Standard Library Processes Package" on page 1125
- "Problems with Multitasking" on page 1126
- "A Sample Program with Threads" on page 1127

Preemptive multitasking opens up a Pandora's box. Although multitasking makes certain programs easier to implement, the problems of process synchronization and reentrancy rears its ugly head in a multitasking system. Many processes require some sort of synchronized access to global variables. Further, most processes will need to call DOS, BIOS, or some other routine (e.g., the Standard Library) that is not reentrant. Somehow we need to control access to such code so that multiple processes do not adversely affect one another. Synchronization is achievable using several different techniques. In some simple cases we can simply turn off the interrupts, eliminating the reentrancy problems. In other cases we can use test and set or semaphores to protect a *critical region*. For more details on these synchronization operations, see

- "Synchronization" on page 1129
- "Atomic Operations, Test & Set, and Busy-Waiting" on page 1132
- "Semaphores" on page 1134
- "The UCR Standard Library Semaphore Support" on page 1136
- "Using Semaphores to Protect Critical Regions" on page 1136
- "Using Semaphores for Barrier Synchronization" on page 1140

The use of synchronization objects, like semaphores, can introduce new problems into a system. *Deadlock* is a perfect example. Deadlock occurs when one process is holding some resource and wants another and a second process is hold the desired resource and wants the resource held by the first process[5]. You can easily avoid deadlock by controlling the order that the various processes acquire groups of semaphores. For all the details, see

- "Deadlock" on page 1146

5. Or any chain of processes where everyone in the chain is holding something that another process in the chain wants.