Debugging Tools and Techniques

MS-DOS provides a wide variety of tools to aid in the debugging process. Some are intended specifically for debugging. For example, the DEBUG program is delivered with MS-DOS and provides basic debugging aid; the more sophisticated SYMDEB is supplied with MASM, Microsoft's macro assembler; CodeView, a debugger for high-order languages, is supplied with Microsoft C, Microsoft Pascal, and Microsoft FORTRAN. Others are general MS-DOS services and features that are also useful in the debugging process.

Debugging, like programming, has aspects of both an art and a craft. The craft—the mechanical details of using the tools—is discussed both here and elsewhere in this volume, but the main subject of this article is the *art* of debugging—the choice of the correct tool, the best techniques to use in various situations, the methods of extracting the clues to the problem from a recalcitrant program.

Debugging a program is a form of puzzle solving. As with most intellectual detective work, the following rule applies:

Gather enough information and the solution will be obvious.

The craft of debugging involves gathering the data; the art lies in deciding which data to gather and in noticing when the solution has become obvious.

The methods of gathering data for debugging, listed in order of increasing difficulty and tediousness, fall into four major categories:

- Inspection and observation
- Instrumentation
- Use of software debugging monitors (DEBUG, SYMDEB, and CodeView)
- Use of hardware debugging aids

As mentioned above, part of the art of debugging is knowing which method to use. This is one of the most difficult aspects of debugging—so difficult, in fact, that even programmers with years of experience make mistakes. Many programmers have spent hours single-stepping through a program with DEBUG only to discover that the cause of the problem would have been obvious if they had given the program's output even a cursory check. The only universal rule for choosing the correct debugging method is

Try them all, starting with the simplest.

Inspection and observation

Inspection and observation is the oldest and, usually, the best method of program debugging. It is also the basis for all the other methods. The first step with this method, as with the others, is to gather all the pertinent materials. Program listings, file layouts, report layouts, and program design materials (such as algorithm descriptions and flowcharts) are all extremely valuable in the debugging process.

Desk-checking

Before a programmer can determine what a program is doing wrong, he or she must know the correct operation of the program. There was a time, when computers were rare and expensive resources, that programmers were encouraged not to run their programs until the programs had been thoroughly desk-checked. The desk-checking process involves sitting down with a listing, a hand calculator, and some sample data. The programmer then "plays computer," executing each line of the program manually and writing down on paper the results of each program step. This process is extremely slow and tedious. When the desk-checking is completed, however, the programmer not only has found most of the bugs in the program but also has become intimately familiar with the execution of the program and the values of the program variables at each step.

The advent of inexpensive yet powerful personal computers, combined with the rising cost of programmer time, has made complete desk-checking nearly obsolete. It is now cheaper to run the program and let the computer find the errors. However, the usefulness of the desk-checking technique remains. Many programmers find it helpful to manually execute those sections of a program that they suspect are causing trouble. Even if they don't find errors in the code, the insight they gain into the workings of the code and the values of the variables at each step can be invaluable when applying other debugging techniques.

The inspection-and-observation methodology

The basic technique of the inspection-and-observation method is simple: After gathering all the required materials, run the program and observe. Observe very carefully; events that seem insignificant may be the very clues needed to discover where the program is going astray. As the program executes, note whether each section performs correctly. Does the program clear the screen when it should? Does it ask for input when it should? Does it produce the correct results? Observable events are the debugger's milestones in the execution of the program. If the program clears the screen but writes purple asterisks instead of requesting input, then the problem lies somewhere after the program issues the Clear Screen command but before it writes the input prompt on the screen. At this point, the program listing and design data become important. Inspect the listing and examine the area after the last successful milestone and before the missing milestone. Look for a logic error in the code that could explain the observed data.

If the program produces printed reports, they may also be useful. Watch the screen and listen to the printer. Clues can sometimes be found in the order in which things happen. The light on the disk drive can be another indication of activity. See how disk activity coordinates with screen and printer events. Try to identify each section of the program from these clues. Then use this information to localize the inspection of the listing to isolate the erroneous code.

The values of data given in reports and on the screen can also give clues to what's going wrong. Examining the data and reconstructing the values used to compute it sometimes leads to inferences about data problems. Perhaps a variable was misspelled in the code

or perhaps a data file is in the wrong format or has been corrupted. With this information, the bug can often be isolated. However, a very thorough knowledge of the program and its algorithms is required. *See* Desk-checking above.

MS-DOS provides four commands and filters that are useful in the collection and examination of data for debugging: TYPE, PRINT, FIND, and DEBUG. All these commands display the data in a file in some way. If the data is ASCII (displayable) characters, TYPE and PRINT can be used, with some help from FIND. Binary files can be examined and modified with the DEBUG utility. *See* USER COMMANDS: FIND; PRINT; TYPE; PROGRAMMING UTILITIES: DEBUG.

The TYPE command provides the simplest way to display ASCII data files. This method can be used to examine both input and output files. Checking the input files may uncover some bad (or unexpected) data that causes the program to malfunction; examining the output files will show whether calculations are being performed correctly and may help pinpoint the erroneous calculations if they are not.

The FIND utility is useful in locating specific data in a file. Using FIND is more accurate and definitely less tedious than examining the file manually using the TYPE command. The /N switch causes FIND to also display the relative line number of the matching line—information that is most useful in debugging.

Sometimes the data is too complex to be examined on the screen and printed copy is needed. The PRINT command will produce hard copy of an ASCII file as will the TYPE command if its output is redirected to the printer with the >PRN command-line parameter after the filename.

Not all data files contain pure ASCII data, and displaying such non-ASCII files requires a different approach. The TYPE command can be used, but nonprintable characters will produce garbage on the screen. This technique can still prove useful if the file has a large amount of ASCII data or if the records are regular and the ASCII information always appears at the same location, but no information can be gained about non-ASCII numeric data in such files. Note also that the entire file might not be displayed using TYPE because if TYPE encounters a byte containing 1AH (Control-Z), it assumes it has reached the end of the file and stops.

Clearly, a more useful tool for examining non-ASCII files would be a program that dumps the file in hexadecimal, with an appropriate translation of all displayable characters. Such programs exist in the public domain (through bulletin-board services, for instance) and, in any event, are not difficult to write. MS-DOS does not include a stand-alone file-dumping program among its standard commands and utilities, but the DEBUG program can be used, with minor inconvenience, to display files. This program is discussed in detail later in this article; for now, simply follow these instructions to use DEBUG as a file dumper. To load DEBUG and the program to be debugged, use the form

DEBUG [*drive*:][*path*]*filename.ext*

DEBUG will display a hyphen as a prompt. To see the contents of the file, enter *D* (the DEBUG Display Memory command) and press Enter. DEBUG will display the first 128 (80H) bytes of the file in hexadecimal and will also show any displayable characters.

To see the rest of the file, simply continue entering *D* until the desired area is found. Hard copy of the contents of the display can be made by using the PrtSc key (or Ctrl-PrtSc to print continuously). Note that the offset addresses for the bytes in the file begin at the value in the program's CS:IP registers, which can be viewed by using the Debug R (Display or Modify Registers) command. To obtain the true offsets, subtract CS:IP from the address shown.

The essence of the inspection-and-observation method is careful and thoughtful observation. The computer and the operating system can provide tools to aid in the collection of data, but the most important tool is the programmer's mind. By applying the logical skills they already possess to the observed data, programmers can usually avoid the more complex forms of debugging.

Instrumentation

Debugging by instrumentation is a traditional method that has been popular since programs were holes punched in cards. In general, this method consists of adding something to the program, either internally or externally, to report on the progress of program execution. Programmers call this added mechanism instrumentation because of its resemblance to the measuring instruments used in science and engineering. Instrumentation can be software, hardware, or a combination of both; it can be internal to the program or external to it. Internal instrumentation is always software, but external instrumentation may be either hardware or software.

Internal instrumentation

Internal instrumentation usually consists of display or print statements placed at strategic locations. Other signals to the user can be used if they are available. For instance, the system beeper can be sounded at key locations, perhaps in a coded sequence of beeps; if the device being debugged has lights that can be accessed by the program, these lights can be flashed at important locations in the program. Beeping and flashing do not, however, possess the information content usually required for debugging, so display or print statements are preferred.

The use of display or print statements to display key data and milestones on the screen or printer requires careful planning. First, apply the techniques of inspection and observation described in the previous section to determine the most probable points of failure. Then, if there is some doubt about what path execution is taking through the code, embed messages of the following types after key decision points:

BEGINNING SORT PHASE
ENDING PRINCIPAL CALCULATION
PROCESSING RECORD *XX*

A second way to use display or print statement instrumentation is to embed statements that display the data and interim values used for calculations. This technique can be extremely useful in finding problems related to the data being processed. Consider the QuickBASIC program in Figure 18-1 as an example. The program has no syntax errors and compiles cleanly, but it sometimes produces an incorrect answer.

```
'  EXP.BAS -- COMPUTE EXPONENTIAL WITH INFINITE SERIES
'
' ************************************************************************
' *                                                                      *
' *  EXP                                                                 *
' *                                                                      *
' *  This routine computes EXP(x) using the following infinite series:   *
' *                                                                      *
' *                         x    x^2   x^3   x^4   x^5                   *
' *          EXP(x) = 1 + --- + --- + --- + --- + --- + ...              *
' *                         1!    2!    3!    4!    5!                   *
' *                                                                      *
' *                                                                      *
' *  The program requests a value for x and a value for the convergence  *
' *  criterion, C.  The program will continue evaluating the terms of    *
' *  the series until the difference between two terms is less than C.   *
' *                                                                      *
' *  The result of the calculation and the number of terms required to   *
' *  converge are printed.  The program will repeat until an x of 0 is   *
' *  entered.                                                            *
' *                                                                      *
' ************************************************************************

'
'  Initialize program variables
'
INITIALIZE:
        TERMS = 1
        FACT = 1
        LAST = 1.E35
        DELTA = 1.E34
        EX = 1
'
'  Input user data
'
        INPUT "Enter number:  "; X
        IF X = 0 THEN END
        INPUT "Enter convergence criterion (.0001 for 4 places):  "; C

'
'  Compute exponential until difference of last 2 terms is < C
'
        WHILE ABS(LAST - DELTA) >= C
            LAST = DELTA
            FACT = FACT * TERMS
            DELTA = X^TERMS / FACT
            EX = EX + DELTA
            TERMS = TERMS + 1
        WEND
```

Figure 18-1. A routine to compute exponentials. *(more)*

```
'
'  Display answer and number of terms required to converge
'
        PRINT EX
        PRINT TERMS; "elements required to converge"
        PRINT

        GOTO INITIALIZE
```

Figure 18-1. Continued.

The purpose of the EXP.BAS program is to compute the exponential of a given number to a specified precision using an infinite series. The program computes the value of each term in the infinite series and adds it to a running total. To keep from executing forever, the program checks the difference between the last two elements computed and stops when this difference is less than the convergence criterion entered by the user.

When the program is run for several values, the following results are observed:

```
Enter number:  ? 1
Enter convergence criterion (.0001 for 4 places):  ? .0001
 2.718282
 10 elements required to converge

Enter number:  ? 1.5
Enter convergence criterion (.0001 for 4 places):  ? .0001
 4.481686
 11 elements required to converge

Enter number:  ? 2
Enter convergence criterion (.0001 for 4 places):  ? .0001
 5
 3 elements required to converge

Enter number:  ? 2.5
Enter convergence criterion (.0001 for 4 places):  ? .0001
 12.18249
 15 elements required to converge

Enter number:  ? 3
Enter convergence criterion (.0001 for 4 places):  ? .0001
 13
 4 elements required to converge

Enter number:  ? 0
```

Some of these numbers are incorrect. Table 18-2 shows the computed values and the correct values.

Table 18-2. The Computed Values Generated by EXP.BAS and the Expected Values.

x	Computed	Correct
1.0	2.718282	2.718282
1.5	4.481686	4.481689
2.0	5	7.389056
2.5	12.18249	12.18249
3.0	13	20.08554

Applying the methods from the first section of this article and observing the data quickly reveals a pattern. With the exception of 1, all whole numbers give incorrect results, but all numbers with fractions give results that are correct to the specified convergence criterion. Examination of the listing shows no obvious reason for this. The answer is there, but only an exceptionally intuitive numeric analyst would see it. Because no answer is obvious, the next step is to validate the only information available — that whole numbers produce errors and fractional ones do not. Repeating the first experiment with 2 and a number very close to 2 yields the following results:

```
Enter number:  ? 1.999
Enter convergence criterion (.0001 for 4 places):  ? .0001
 7.38167
 13 elements required to converge

Enter number:  ? 2
Enter convergence criterion (.0001 for 4 places):  ? .0001
 5
 3 elements required to converge

Enter number:  ? 0
```

The outcome is the same — repeating the experiment with a number as near to 2 as the convergence criterion permits (1.9999) produces the same result. The error is indeed caused by the fact that the number is an integer.

Because no intuitive way can be found to solve the mystery by inspection, the programmer must turn to the next method in the hierarchy, instrumentation. The problem has something to do with the calculation of the terms of the series. Therefore, the section of the program that performs this calculation should be instrumented by placing PRINT statements inside the WHILE loop (Figure 18-2) to display all the intermediate values of the calculation.

```
WHILE ABS(LAST - DELTA) >= C
      LAST = DELTA
      FACT = FACT * TERMS
      DELTA = X ^ TERMS / FACT
```

Figure 18-2. Instrumenting the WHILE loop. *(more)*

```
        EX = EX + DELTA
        PRINT "TERMS="; TERMS; "EX="; EX; "FACT="; FACT; "DELTA="; DELTA;
        PRINT "LAST="; LAST
        TERMS = TERMS + 1
    WEND
```

Figure 18-2. Continued.

The print statements used in this WHILE loop are typical of the type used for instrumentation. The program makes no attempt at fancy formatting. The print statements simply identify each value with its variable name, allowing easy correlation of the data and the code in the listing. Repeating the experiment with 1.999 and 2 yields

```
Enter number:  ? 1.999
Enter convergence criterion (.0001 for 4 places):  ? .0001
TERMS= 1 EX= 2.999 FACT= 1 DELTA= 1.999 LAST= 1E+34
TERMS= 2 EX= 4.997001 FACT= 2 DELTA= 1.998 LAST= 1.999
TERMS= 3 EX= 6.328335 FACT= 6 DELTA= 1.331334 LAST= 1.998
TERMS= 4 EX= 6.993669 FACT= 24 DELTA= .6653343 LAST= 1.331334
TERMS= 5 EX= 7.25967 FACT= 120 DELTA= .2660006 LAST= .6653343
TERMS= 6 EX= 7.348292 FACT= 720 DELTA= 8.862254E-02 LAST= .2660006
TERMS= 7 EX= 7.373601 FACT= 5040 DELTA= 2.530806E-02 LAST= 8.862254E-02
TERMS= 8 EX= 7.379924 FACT= 40320 DELTA= 6.323853E-03 LAST= 2.530806E-02
TERMS= 9 EX= 7.381329 FACT= 362880 DELTA= 1.404598E-03 LAST= 6.323853E-03
TERMS= 10 EX= 7.38161 FACT= 3628800 DELTA= 2.807791E-04 LAST= 1.404598E-03
TERMS= 11 EX= 7.381661 FACT= 3.99168E+07 DELTA= 5.102522E-05 LAST= 2.807791E-04
TERMS= 12 EX= 7.38167 FACT= 4.790016E+08 DELTA= 8.499951E-06 LAST= 5.102522E-05
 7.38167
 13 elements required to converge

Enter number:  ? 2
Enter convergence criterion (.0001 for 4 places):  ? .0001
TERMS= 1 EX= 3 FACT= 1 DELTA= 2 LAST= 1E+34
TERMS= 2 EX= 5 FACT= 2 DELTA= 2 LAST= 2
 5
 3 elements required to converge
```

Examination of the instrumentation printout for the two cases shows a drastically different pattern. The fractional number went through 13 iterations following the expected pattern; the whole number, however, quit on the third step. The loop is terminating prematurely. Why? Look at the values calculated for *DELTA* and *LAST* on the last complete step. They are the same, giving a difference of zero. Because this difference will always be less than the convergence criterion, the loop will always terminate early. A moment's reflection shows why. The numerator of the fraction for each term but the first in the infinite series is a power of the number entered; the denominator is a factorial, a product formed by multiplying successive integers. Because $n! = n*(n-1)!$, when an integer is raised to a power equal to itself and divided by the factorial of that integer the result will always be the same as the preceding term. That is what has happened here.

Now that the cause of the problem is found, it must be fixed. How can this problem be prevented? In this case, the problem is caused by a logic error. The programmer misread (or miswrote!) the algorithm and assumed that the criterion for termination was that the difference between the last two terms be less than the specified value. This is incorrect. Actually, the termination criterion should be that the difference between the forming EXP(x) and the last term be less than the criterion. To simplify, the last term itself must be less than the value specified. The correct program listing, including the new WHILE loop, is shown in Figure 18-3.

```
'  EXP.BAS -- COMPUTE EXPONENTIAL WITH INFINITE SERIES
'
' ************************************************************************
' *                                                                      *
' *  EXP                                                                 *
' *                                                                      *
' *  This routine computes EXP(x) using the following infinite series:   *
' *                                                                      *
' *                          x    x^2   x^3   x^4   x^5                  *
' *         EXP(x) = 1 + --- + --- + --- + --- + --- + ...               *
' *                          1!    2!    3!    4!    5!                  *
' *                                                                      *
' *                                                                      *
' *  The program requests a value for x and a value for the convergence  *
' *  criterion, C.  The program will continue evaluating the terms of    *
' *  the series until the amount added with a term is less than C.       *
' *                                                                      *
' *  The result of the calculation and the number of terms required to   *
' *  converge are printed.  The program will repeat until an x of 0 is   *
' *  entered.                                                            *
' *                                                                      *
' ************************************************************************

'
'  Initialize program variables
'
INITIALIZE:
        TERMS = 1
        FACT = 1
        DELTA = 1.E35
        EX = 1
'
'  Input user data
'
        INPUT "Enter number:  "; X
        IF X = 0 THEN END
        INPUT "Enter convergence criterion (.0001 for 4 places):  "; C

'
'  Compute exponential until difference of last 2 terms is < C
'
```

Figure 18-3. Corrected exponential calculation routine. *(more)*

```
        WHILE DELTA > C
            FACT = FACT * TERMS
            DELTA = X^TERMS / FACT
            EX = EX + DELTA
            TERMS = TERMS + 1
        WEND

'
'  Display answer and number of terms required to converge
'
        PRINT EX
        PRINT TERMS; "elements required to converge"
        PRINT

        GOTO INITIALIZE
```

Figure 18-3. Continued.

The program now produces the correct results within the limits of the specified accuracy:

```
Enter number:  ? 1.999
Enter convergence criterion (.0001 for 4 places):  ? .0001
 7.381661
 12 elements required to converge

Enter number:  ? 2
Enter convergence criterion (.0001 for 4 places):  ? .0001
 7.389047
 12 elements required to converge

Enter number:  ? 0
```

This example illustrates how easy it is to use internal instrumentation in high-order languages. Because these languages usually have simple formatted output commands, they require very little work to instrument. When these output commands are not available, however, more work may be required. For instance, if the program being debugged is in assembly language, it is possible that the code required to format and print internal data will be longer than the program being debugged. For this reason, internal instrumentation is rarely used on small and moderate assembly programs. However, large assembly programs and systems often already have print formatting routines built into them; in these cases, internal instrumentation may be as easy as with high-order languages.

External instrumentation

Sometimes it is difficult to use internal instrumentation with a program. If, for instance, the problem is timing related, adding print statements could cloud the problem or, worse yet, make it go away completely. This leaves the programmer in the frustrating position of having the problem only when the cause can't be seen and not having the problem when it can. A solution to this type of problem can sometimes be found by moving the instrumentation outside the program itself. There are two types of external instrumentation: hardware and software.

Hardware instrumentation consists of whatever logic analyzers, oscilloscopes, meters, lights, bells, or gongs are appropriate to the hardware and software under test. Hardware instrumentation is difficult to set up and tedious to use. It is, therefore, usually reserved for those problems directly associated with hardware. Such problems often arise when new software is being run on new hardware and no one is quite sure where the bugs are. Because most programmers reading this book are developing software on tried-and-true personal computer hardware and because most of those programmers are unlikely to have a logic analyzer costing several thousand dollars, we will skip over the use of hardware instrumentation for software debugging. If a logic analyzer must be used, the programmer should remember that the debugging philosophy and techniques discussed in this article can still be applied effectively.

MS-DOS provides a feature that is very useful in building external instrumentation software: the TSR, or terminate-and-stay-resident routine. *See* PROGRAMMING IN THE MS-DOS ENVIRONMENT: CUSTOMIZING MS-DOS: Terminate-and-Stay-Resident Utilities. This feature of the operating system allows the programmer to build a monitoring routine that is, in essence, a part of the operating system and outside the application program. The TSR is loaded as a normal program, but instead of leaving the system when it is done, it remains intact in memory. The operating system provides no way to reexecute the program after it terminates, so most TSRs are interrupt driven.

Because TSRs exist outside the application program, they can be used to build external instrumentation devices. This independence allows them to perform monitoring functions without disturbing the logic flow of the application program. The only areas where interference is likely are those where the TSR and the program must use common resources. These conflicts typically involve timing but can also involve other resources, such as I/O devices, disk files, and MS-DOS resources, including environment space. Some of these problems are addressed in the next example.

The TSR type of external instrumentation software can prove useful in analyzing serial communications. Such an instrumentation program monitors the serial communication line and records all data. To detect protocol or timing problems, the program tags the recorded data so that transmitted data can be differentiated from received data. Hardware devices exist that plug into the serial port and perform both the monitoring and tagging function, but they are expensive and not always handy. Fortunately, this inexpensive piece of software instrumentation will serve in many cases.

Software interrupt calls are made with the INT instruction. Although their service routines must obey similar rules, these interrupts should not be confused with hardware interrupts caused by external hardware events. Software interrupts in MS-DOS are used by an application program to communicate with the operating system and, by extension in IBM systems, with the ROM BIOS. For example, on IBM PCs and compatibles, application programs can use software Interrupt 14H to communicate with the ROM BIOS serial port driver. The ROM BIOS routine, in turn, manages the hardware interrupts from the actual

serial device. Thus, Interrupt 14H does not communicate directly with the hardware. All the programs in this article deal with software interrupts to the ROM BIOS and MS-DOS.

A program to trace the serial data flow must have access to the serial data, so such a program must replace the vector for Interrupt 14H with one that points to itself. The routine can then record all the serial data and pass it along through the serial port. Because the goal is to minimize the effect of this monitoring on the timing of the data, the method used for recording the data should be fast. This requirement rules out writing to a disk file, because unexpected delays can be introduced (and because doing disk I/O from an interrupt service routine under MS-DOS is difficult, if not impossible). Printing the data on paper is clearly too slow, and data displayed on the screen is too ephemeral. Thus, about the only thing that can be done with the data is to write it to RAM. Luckily, memory has become cheap and most personal computers have plenty.

Writing a routine that monitors and records serial data is not enough, however. The data must still flow through the serial port to and from the external serial device. Thus, the monitor program can have only temporary custody of the data and must pass it on to the serial interrupt service routine in the ROM BIOS. This is accomplished by using MS-DOS function calls to extract the address of the serial interrupt handler before the new vector is installed in its place. The process of intercepting interrupts and then passing the data on is known as "daisy-chaining" interrupt handlers. So long as such intercepting programs are careful to maintain the data and conditions upon entrance for subsequent routines (that is, so long as routines are well behaved; *see* PROGRAMMING IN THE MS-DOS ENVIRONMENT: PROGRAMMING FOR MS-DOS), several interrupt handlers can be daisy-chained together with no detriment to processing. (Woe be unto the person who breaks the daisy chain—the results are annoying at best and unpredictable at worst.)

The serial monitoring program, as described so far, correctly collects and stores serial data and then passes it on to the serial port. This may be intellectually satisfying, but it is not of much use in the real world. Some way must be provided to control the program—to start collection, to stop collection, to pause and resume collection. Also, once data is collected, a control function must be provided that returns the number of bytes collected and their starting location, so that the data can be examined.

From all this, it is clear that a serial communications monitoring instrument must

1. Replace the Interrupt 14H vector with one pointing to itself.
2. Save the address of the old interrupt handler.
3. Collect the serial data, tag it as transmitted or received, and store it in RAM.
4. Pass the data on, in a completely transparent manner, to the old interrupt handler.
5. Provide some way to control data collection.

A program that meets all these criteria is shown in Figure 18-4. The COMMSCOP program has three major parts:

Procedure	Purpose
COMMSCOPE	Monitoring and tagging
CONTROL	External control
VECTOR_INIT	Interrupt vector initialization

The *COMMSCOPE* procedure provides the new Interrupt 14H handler that intercepts the serial I/O interrupts. The *CONTROL* procedure provides the external control needed to make the system work. The *VECTOR_INIT* procedure gets the old interrupt handler address, installs *COMMSCOPE* as the new interrupt handler, and installs the interrupt handler for the control interrupt.

```
        TITLE   COMMSCOP -- COMMUNICATIONS TRACE UTILITY
; ************************************************************************
; *                                                                      *
; *  COMMSCOP --                                                         *
; *     THIS PROGRAM MONITORS THE ACTIVITY ON A SPECIFIED COMM PORT      *
; *     AND PLACES A COPY OF ALL COMM ACTIVITY IN A RAM BUFFER.  EACH    *
; *     ENTRY IN THE BUFFER IS TAGGED TO INDICATE WHETHER THE BYTE       *
; *     WAS SENT BY OR RECEIVED BY THE SYSTEM.                           *
; *                                                                      *
; *     COMMSCOP IS INSTALLED BY ENTERING                                *
; *                                                                      *
; *                     COMMSCOP                                         *
; *                                                                      *
; *     THIS WILL INSTALL COMMSCOP AND SET UP A 64K BUFFER TO BE USED    *
; *     FOR DATA LOGGING.  REMEMBER THAT 2 BYTES ARE REQUIRED FOR        *
; *     EACH COMM BYTE, SO THE BUFFER IS ONLY 32K EVENTS LONG, OR ABOUT  *
; *     30 SECONDS OF CONTINUOUS 9600 BAUD DATA.  IN THE REAL WORLD,     *
; *     ASYNC DATA IS RARELY CONTINUOUS, SO THE BUFFER WILL PROBABLY     *
; *.    HOLD MORE THAN 30 SECONDS WORTH OF DATA.                         *
; *                                                                      *
; *     WHEN INSTALLED, COMMSCOP INTERCEPTS ALL INT 14H CALLS.  IF THE   *
; *     PROGRAM HAS BEEN ACTIVATED AND THE INT IS EITHER SEND OR RE-     *
; *     CEIVE DATA, A COPY OF THE DATA BYTE, PROPERLY TAGGED, IS PLACED  *
; *     IN THE BUFFER.  IN ANY CASE, DATA IS PASSED ON TO THE REAL       *
; *     INT 14H HANDLER.                                                 *
; *                                                                      *
; *     COMMSCOP IS INVOKED BY ISSUING AN INT 60H CALL.  THE INT HAS     *
; *     THE FOLLOWING CALLING SEQUENCE:                                  *
; *                                                                      *
; *             AH -- COMMAND                                            *
; *                   0 -- STOP TRACING, PLACE STOP MARK IN BUFFER       *
; *                   1 -- FLUSH BUFFER AND START TRACE                  *
; *                   2 -- RESUME TRACE                                  *
; *                   3 -- RETURN COMM BUFFER ADDRESSES                  *
; *             DX -- COMM PORT (ONLY USED WITH AH = 1 or 2)             *
; *                   0 -- COM1                                          *
; *                   1 -- COM2                                          *
```

Figure 18-4. Communications trace utility. *(more)*

```
; *                                                                    *
; *     THE FOLLOWING DATA IS RETURNED IN RESPONSE TO AH = 3:          *
; *                                                                    *
; *             CX -- BUFFER COUNT IN BYTES                            *
; *             DX -- SEGMENT ADDRESS OF THE START OF THE BUFFER       *
; *             BX -- OFFSET ADDRESS OF THE START OF THE BUFFER        *
; *                                                                    *
; *     THE COMM BUFFER IS FILLED WITH 2-BYTE DATA ENTRIES OF THE      *
; *     FOLLOWING FORM:                                                *
; *                                                                    *
; *             BYTE 0 -- CONTROL                                      *
; *                  BIT 0 -- ON FOR RECEIVED DATA, OFF FOR TRANS.     *
; *                  BIT 7 -- STOP MARK -- INDICATES COLLECTION WAS    *
; *                               INTERRUPTED AND RESUMED.             *
; *             BYTE 1 -- 8-BIT DATA                                   *
; *                                                                    *
; ********************************************************************

CSEG    SEGMENT
        ASSUME  CS:CSEG,DS:CSEG
        ORG     100H                    ;TO MAKE A COMM FILE

INITIALIZE:
        JMP     VECTOR_INIT             ;JUMP TO THE INITIALIZATION
                                        ; ROUTINE WHICH, TO SAVE SPACE,
                                        ; IS IN THE COMM BUFFER

;
;  SYSTEM VARIABLES
;
OLD_COMM_INT    DD      ?               ;ADDRESS OF REAL COMM INT
COUNT           DW      0               ;BUFFER COUNT
COMMSCOPE_INT   EQU     60H             ;COMMSCOPE CONTROL INT
STATUS          DB      0               ;PROCESSING STATUS
                                        ; 0 -- OFF
                                        ; 1 -- ON
PORT            DB      0               ;COMM PORT BEING TRACED
BUFPNTR         DW      VECTOR_INIT     ;NEXT BUFFER LOCATION

        SUBTTL  DATA INTERRUPT HANDLER
PAGE
; ********************************************************************
; *                                                                  *
; *  COMMSCOPE                                                       *
; *     THIS PROCEDURE INTERCEPTS ALL INT 14H CALLS AND LOGS THE DATA*
; *     IF APPROPRIATE.                                              *
; *                                                                  *
; ********************************************************************
COMMSCOPE       PROC    NEAR

        TEST    CS:STATUS,1             ;ARE WE ON?
        JZ      OLD_JUMP                ; NO, SIMPLY JUMP TO OLD HANDLER
```

Figure 18-4. Continued.

(more)

```
        CMP     AH,00H                  ;SKIP SETUP CALLS
        JE      OLD_JUMP                ; .

        CMP     AH,03H                  ;SKIP STATUS REQUESTS
        JAE     OLD_JUMP                ; .

        CMP     AH,02H                  ;IS THIS A READ REQUEST?
        JE      GET_READ                ; YES, GO PROCESS

;
;  DATA WRITE REQUEST -- SAVE IF APPROPRIATE
;
        CMP     DL,CS:PORT              ;IS WRITE FOR PORT BEING TRACED?
        JNE     OLD_JUMP                ; NO, JUST PASS IT THROUGH

        PUSH    DS                      ;SAVE CALLER'S REGISTERS
        PUSH    BX                      ; .
        PUSH    CS                      ;SET UP DS FOR OUR PROGRAM
        POP     DS                      ; .
        MOV     BX,BUFPNTR              ;GET ADDR OF NEXT BUFFER LOC
        MOV     [BX],BYTE PTR 0         ;MARK AS TRANSMITTED BYTE
        MOV     [BX+1],AL               ;SAVE DATA IN BUFFER
        INC     COUNT                   ;INCREMENT BUFFER BYTE COUNT
        INC     COUNT                   ; .
        INC     BX                      ;POINT TO NEXT LOCATION
        INC     BX                      ; .
        MOV     BUFPNTR,BX              ;SAVE NEW POINTER
        JNZ     WRITE_DONE              ;ZERO MEANS BUFFER HAS WRAPPED

        MOV     STATUS,0                ;TURN COLLECTION OFF
WRITE_DONE:
        POP     BX                      ;RESTORE CALLER'S REGISTERS
        POP     DS                      ; .
        JMP     OLD_JUMP                ;PASS REQUEST ON TO BIOS ROUTINE
;
;  PROCESS A READ DATA REQUEST AND WRITE TO BUFFER IF APPROPRIATE
;
GET_READ:
        CMP     DL,CS:PORT              ;IS READ FOR PORT BEING TRACED?
        JNE     OLD_JUMP                ; NO, JUST PASS IT THROUGH

        PUSH    DS                      ;SAVE CALLER'S REGISTERS
        PUSH    BX                      ; .
        PUSH    CS                      ;SET UP DS FOR OUR PROGRAM
        POP     DS                      ; .

        PUSHF                           ;FAKE INT 14H CALL
        CLI                             ; .
        CALL    OLD_COMM_INT            ;PASS REQUEST ON TO BIOS
        TEST    AH,80H                  ;VALID READ?
        JNZ     READ_DONE               ; NO, SKIP BUFFER UPDATE
```

Figure 18-4. Continued. *(more)*

```
        MOV     BX,BUFPNTR              ;GET ADDR OF NEXT BUFFER LOC
        MOV     [BX],BYTE PTR 1         ;MARK AS RECEIVED BYTE
        MOV     [BX+1],AL               ;SAVE DATA IN BUFFER
        INC     COUNT                   ;INCREMENT BUFFER BYTE COUNT
        INC     COUNT                   ; .
        INC     BX                      ;POINT TO NEXT LOCATION
        INC     BX                      ; .
        MOV     BUFPNTR,BX              ;SAVE NEW POINTER
        JNZ     READ_DONE               ;ZERO MEANS BUFFER HAS WRAPPED

        MOV     STATUS,0                ;TURN COLLECTION OFF
READ_DONE:
        POP     BX                      ;RESTORE CALLER'S REGISTERS
        POP     DS                      ; .
        IRET

;
;  JUMP TO COMM BIOS ROUTINE
;
OLD_JUMP:
        JMP     CS:OLD_COMM_INT

COMMSCOPE ENDP

        SUBTTL  CONTROL INTERRUPT HANDLER
PAGE
; ************************************************************************
; *                                                                      *
; *  CONTROL                                                             *
; *     THIS ROUTINE PROCESSES CONTROL REQUESTS.                         *
; *                                                                      *
; ************************************************************************

CONTROL PROC    NEAR
        CMP     AH,00H                  ;STOP REQUEST?
        JNE     CNTL_START              ; NO, CHECK START
        PUSH    DS                      ;SAVE REGISTERS
        PUSH    BX                      ; .
        PUSH    CS                      ;SET DS FOR OUR ROUTINE
        POP     DS
        MOV     STATUS,0                ;TURN PROCESSING OFF
        MOV     BX,BUFPNTR              ;PLACE STOP MARK IN BUFFER
        MOV     [BX],BYTE PTR 80H       ; .
        MOV     [BX+1],BYTE PTR 0FFH    ; .
        INC     BX                      ;INCREMENT BUFFER POINTER
        INC     BX                      ; .
        MOV     BUFPNTR,BX              ; .
        INC     COUNT                   ;INCREMENT COUNT
        INC     COUNT                   ; .
        POP     BX                      ;RESTORE REGISTERS
        POP     DS                      ; .
        JMP     CONTROL_DONE
```

Figure 18-4. Continued.

(more)

```
CNTL_START:
        CMP     AH,01H                  ;START REQUEST?
        JNE     CNTL_RESUME             ; NO, CHECK RESUME
        MOV     CS:PORT,DL              ;SAVE PORT TO TRACE
        MOV     CS:BUFPNTR,OFFSET VECTOR_INIT ;RESET BUFFER TO START
        MOV     CS:COUNT,0              ;ZERO COUNT
        MOV     CS:STATUS,1             ;START LOGGING
        JMP     CONTROL_DONE

CNTL_RESUME:
        CMP     AH,02H                  ;RESUME REQUEST?
        JNE     CNTL_STATUS             ; NO, CHECK STATUS
        CMP     CS:BUFPNTR,0            ;END OF BUFFER CONDITION?
        JE      CONTROL_DONE            ; YES, DO NOTHING
        MOV     CS:PORT,DL              ;SAVE PORT TO TRACE
        MOV     CS:STATUS,1             ;START LOGGING
        JMP     CONTROL_DONE

CNTL_STATUS:
        CMP     AH,03H                  ;RETURN STATUS REQUEST?
        JNE     CONTROL_DONE            ; NO, ERROR -- DO NOTHING
        MOV     CX,CS:COUNT             ;RETURN COUNT
        PUSH    CS                      ;RETURN SEGMENT ADDR OF BUFFER
        POP     DX                      ; .
        MOV     BX,OFFSET VECTOR_INIT   ;RETURN OFFSET ADDR OF BUFFER

CONTROL_DONE:
        IRET

CONTROL ENDP


        SUBTTL      INITIALIZE INTERRUPT VECTORS
PAGE
; ************************************************************************
; *                                                                      *
; *  VECTOR_INIT                                                         *
; *     THIS PROCEDURE INITIALIZES THE INTERRUPT VECTORS AND THEN        *
; *     EXITS VIA THE MS-DOS TERMINATE-AND-STAY-RESIDENT FUNCTION.       *
; *     A BUFFER OF 64K IS RETAINED.  THE FIRST AVAILABLE BYTE           *
; *     IN THE BUFFER IS THE OFFSET OF VECTOR_INIT.                      *
; *                                                                      *
; ************************************************************************

        EVEN                            ;ASSURE BUFFER ON EVEN BOUNDARY
VECTOR_INIT     PROC     NEAR
;
;  GET ADDRESS OF COMM VECTOR (INT 14H)
;
        MOV     AH,35H
```

Figure 18-4. Continued. *(more)*

```
        MOV     AL,14H
        INT     21H
;
;  SAVE OLD COMM INT ADDRESS
;
        MOV     WORD PTR OLD_COMM_INT,BX
        MOV     AX,ES
        MOV     WORD PTR OLD_COMM_INT[2],AX
;
;  SET UP COMM INT TO POINT TO OUR ROUTINE
;
        MOV     DX,OFFSET COMMSCOPE
        MOV     AH,25H
        MOV     AL,14H
        INT     21H
;
;  INSTALL CONTROL ROUTINE INT
;
        MOV     DX,OFFSET CONTROL
        MOV     AH,25H
        MOV     AL,COMMSCOPE_INT
        INT     21H
;
;  SET LENGTH TO 64K, EXIT AND STAY RESIDENT
;
        MOV     AX,3100H          ;TERM AND STAY RES COMMAND
        MOV     DX,1000H          ;64K RESERVED
        INT     21H               ;DONE
VECTOR_INIT ENDP
CSEG    ENDS
        END     INITIALIZE
```

Figure 18-4. Continued.

The first executable statement of the program is a jump to the *VECTOR_INIT* procedure. The vector initialization code is needed only during installation; after initialization of the vectors, the code can be discarded. In this case, the area where this code resides will become the start of the trace buffer; therefore, it makes sense to put the initialization code at the end of the program where it can be overlaid by the trace buffer. The jump at the start of the program is required because the rules for making .COM files require that the entry point be the first instruction of the program.

The vector initialization routine uses Interrupt 21H Function 35H (Get Interrupt Vector) to get the address of the current Interrupt 14H service routine. The segment and offset address (returned in the ES:BX registers) is stored in the doubleword at *OLD_COMM_INT*. Interrupt 21H Function 25H (Set Interrupt Vector) is then used to vector all Interrupt 14H calls to *COMMSCOPE*. Another Function 25H call sets Interrupt 60H to vector to the *CONTROL* routine. This interrupt, which provides the means to control and interrogate the *COMMSCOPE* routine, was chosen because it is unused by MS-DOS and because some IBM technical materials list 60H through 66H as being available for user interrupts. (If, for some reason, Interrupt 60H is not available, simply change the equated symbol *COMMSCOPE_INT* to an available interrupt.)

When the vector initialization process is complete, the routine exits and stays resident by using Interrupt 21H Function 31H (Terminate and Stay Resident). As part of the termination process, the routine requests 1000H paragraphs, or 64 KB, of storage. A little over 500 bytes of this storage area is used for the code; the rest is available for trace data. If the serial port is running at 2400 baud, a solid stream of data will fill this buffer in about two minutes. However, a solid 32 KB block of data is unusual in asynchronous communications and, in reality, the buffer will usually contain many minutes worth of data. Note that the buffer-handling routines in *COMMSCOPE* require that the buffer be aligned on an even byte boundary, so *VECTOR_INIT* is preceded by the EVEN directive.

The interrupt service routine, *COMMSCOPE*, receives all Interrupt 14H calls. First *COMMSCOPE* checks its own status. If it has not been activated, it immediately passes control to the real service routine. If the tracer is active, *COMMSCOPE* examines the Interrupt 14H function in AH. Setup and status requests (AH = 0 and AH = 3) do not affect tracing, so they are passed on directly to the the real service routine. If the Interrupt 14H call is a write-data request (AH = 1), *COMMSCOPE* moves the byte marking the data as transmitted and the data byte itself to the current buffer location and increments both the byte count and the buffer pointer by 2. If the buffer pointer goes to zero, the buffer has wrapped; data collection is turned off and cannot be turned on again without clearing the trace buffer. Because the buffer, which starts at *VECTOR_INIT*, is always on an even byte boundary, there is no danger of the first byte of the data pair forcing a wrap. After the transmitted data is added to the buffer, *COMMSCOPE* passes control to the real service routine.

A read-data request (AH = 2) must be handled a little differently. In this case, the data to be collected is not yet available. In order to get it, *COMMSCOPE* must pass control to the real service routine and then intercept the results on the way back. The code at *GET_READ* fakes an interrupt to the service routine by pushing the flags onto the stack so that the service routine's IRET will pop them off again. *COMMSCOPE* then calls the service routine and, when it returns, retrieves the incoming serial data character from AL. If the incoming data byte is valid (bit 7 of AH is zero), the byte marking the data as received and the data byte itself are placed in the trace buffer, and both the byte count and the buffer pointer are incremented by 2. The buffer-wrap condition is detected and handled in the same manner as with transmitted data. Because the real service routine has already been called, *COMMSCOPE* exits as if it were the service routine by issuing an IRET.

The *CONTROL* procedure provides the mechanism for external control of the trace procedure. The routine is entered whenever an Interrupt 60H is executed. Commands are sent through the AH register and can cause the routine to STOP (AH = 0), START/FLUSH (AH = 1), RESUME (AH = 2), or RETURN STATUS (AH = 3). This routine also sets the communications port to be traced. The required information is provided in DX using the same format as the Interrupt 14H routine. The port information is used only with START and RESUME requests. The RETURN STATUS command returns data in registers: the byte count (CX), the segment address of the buffer (DX), and the offset of the first byte in the buffer (BX).

The COMMSCOP program is assembled using the Microsoft Macro Assembler (MASM), linked using the Microsoft Object Linker (LINK), and then converted to a .COM file using EXE2BIN (*see* PROGRAMMING UTILITIES):

```
C>MASM COMMSCOP;  <Enter>
C>LINK COMMSCOP;  <Enter>
C>EXE2BIN COMMSCOP.EXE COMMSCOP.COM  <Enter>
C>DEL COMMSCOP.EXE  <Enter>
```

The linker will display the message *Warning: no stack segment*; this message can be ignored because the rules for making a .COM file forbid a separate stack segment.

The program is installed by simply typing *COMMSCOP*. Tracing can then be started and stopped using Interrupt 60H. MS-DOS does not allow resident routines to be removed, so COMMSCOP will be in the system until the system is restarted. Also note that, because COMMSCOP is well behaved, nothing disastrous will happen if multiple copies of it are accidentally installed. As each new copy is installed, it chains to the previous copy. When Interrupt 14H is intercepted, the new routine dutifully passes the data on to the previous routine, which repeats the process until the real service routine is reached. The data is added to the trace buffer of each copy, giving multiple, redundant copies of the same data. Because Interrupt 60H is not chained, only the last copy's buffer can be accessed. Thus, the other copies simply waste 64 KB each.

Two techniques can be used to start or stop a trace. The first is to issue Interrupt 60H calls at strategic locations within the program being debugged. With assembly-language programs, this is easy. The appropriate registers are loaded and an INT 60H instruction is executed. Issuing this INT instruction is not much more difficult with higher-order Microsoft languages—both QuickBASIC and C provide a library routine called INT86 that allows registers to be loaded and INT instructions to be executed. (In QuickBASIC, the INT86 library routine is included in the File USERLIB.OBJ; in Microsoft C, it is included in the file DOS.H.) Embedded Interrupt 60H calls can be convenient because they limit tracing to those areas where processing is suspect. Because COMMSCOP marks the buffer each time the trace is stopped and resumed, the separate pieces of a trace are easy to differentiate.

The second technique is to write a simple routine to start or stop the trace outside the program being debugged. The example in Figure 18-5, COMMSCMD, is a Microsoft C program that can perform these functions using the INT86 library function to issue Interrupt 60H calls.

```
/*************************************************************************
*                                                                        *
*  COMMSCMD                                                              *
*                                                                        *
*  This routine controls the COMMSCOP program that has been in-         *
*  stalled as a resident routine.  The operation performed is de-       *
*  termined by the command line.  The COMMSCMD program is invoked       *
*  as follows:                                                           *
*                                                                        *
*                COMMSCMD [[cmd][ port]]                                 *
*                                                                        *
```

Figure 18-5. A serial-trace control routine written in C. *(more)*

```
*  where cmd is the command to be executed                              *
*            STOP   -- stop trace                                       *
*            START  -- flush trace buffer and start trace               *
*            RESUME -- resume a stopped trace                           *
*        port is the COMM port to be traced (1=COM1, 2=COM2, etc.)      *
*                                                                       *
*  If cmd is omitted, STOP is assumed.  If port is omitted, 1 is        *
*  assumed.                                                             *
*                                                                       *
************************************************************************/

#include <stdlib.h>
#include <stdio.h>
#include <dos.h>
#define COMMCMD 0x60

main(argc, argv)
int argc;
char *argv[];
{
    int cmd, port, result;
    static char commands[3] [10] = {"STOPPED", "STARTED", "RESUMED"};
    union REGS inregs, outregs;

    cmd = 0;
    port = 0;

    if (argc > 1)
        {
        if (0 == stricmp(argv[1], "STOP"))
            cmd = 0;
        else if (0 == stricmp(argv[1], "START"))
            cmd = 1;
        else if (0 == stricmp(argv[1], "RESUME"))
            cmd = 2;
        }

    if (argc == 3)
        {
        port = atoi(argv[2]);
        if (port > 0)
            port = port - 1;
        }

    inregs.h.ah = cmd;
    inregs.x.dx = port;
    result = int86(COMMCMD, &inregs, &outregs);


    printf("\nCommunications tracing %s for port COM%1d:\n",
            commands[cmd], port + 1);
}
```

Figure 18-5. Continued.

COMMSCMD is passed arguments in the command line. The first argument is the command to be performed: STOP, START, or RESUME. If no command is specified, STOP is assumed. The second argument is the port number: 1 (for COM1) or 2 (for COM2). If no port number is specified, 1 is assumed.

The COMMSCMD program uses a simple IF filter to determine the function to be performed. The program tests the number of arguments in the command line to see if a port has been specified. If the argument count (*argc*) is 3 (one for the command name, one for the command, and one for the port number), the port number argument is retrieved and converted to an integer. The Interrupt 60H routine expects port numbers to be specified in the same manner as for Interrupt 14H, so the port number is decremented if it is not already zero. The AH register is loaded with the command (*cmd*), the DX register is loaded with the port number (*port*), and the INT86 library function is then used to execute an Interrupt 60H call. When the interrupt returns, COMMSCMD displays a message showing the function and port.

The same function can be performed by the QuickBASIC program in Figure 18-6.

```
' ************************************************************************
' *                                                                      *
' *  COMMSCMD                                                            *
' *                                                                      *
' *  This routine controls the COMMSCOP program that has been in-        *
' *  stalled as a resident routine.  The operation performed is de-      *
' *  termined by the command line.  The COMMSCMD program is invoked      *
' *  as follows:                                                         *
' *                                                                      *
' *             COMMSCMD [[cmd][,port]]                                  *
' *                                                                      *
' *  where cmd is the command to be executed                             *
' *             STOP   -- stop trace                                     *
' *             START  -- flush trace buffer and start trace             *
' *             RESUME -- resume a stopped trace                         *
' *        port is the COMM port to be traced (1=COM1, 2=COM2, etc.)     *
' *                                                                      *
' *  If cmd is omitted, STOP is assumed.  If port is omitted, 1 is       *
' *  assumed.                                                            *
' *                                                                      *
' ************************************************************************

        '
        '  Establish system constants and variables
        '
        DEFINT A-Z

        DIM INREG(7), OUTREG(7)         'Define register arrays
```

Figure 18-6. A QuickBASIC version of COMMSCMD. *(more)*

```
        RAX = 0                         'Establish values for 8086
        RBX = 1                         '  registers
        RCX = 2                         '  .
        RDX = 3                         '  .
        RBP = 4                         '  .
        RSI = 5                         '  .
        RDI = 6                         '  .
        RFL = 7                         '  .

        DIM TEXT$(2)

        TEXT$(0) = "STOPPED"
        TEXT$(1) = "STARTED"
        TEXT$(2) = "RESUMED"

        '
        '  Process command-line tail
        '
        C$ = COMMAND$                   'Get command-line data

        IF LEN(C$) = 0 THEN             'If no command line specified
            CMD = 0                     'Set CMD to STOP
            PORT = 0                    'Set PORT to COM1
            GOTO SENDCMD
        END IF

        COMMA = INSTR(C$, ", ")         'Extract operands
        IF COMMA = 0 THEN
            CMDTXT$ = C$
            PORT = 0
        ELSE
            CMDTXT$ = LEFT$(C$, COMMA - 1)
            PORT = VAL(MID$(C$, COMMA + 1)) - 1
        END IF

        IF PORT < 0 THEN PORT = 0

        IF CMDTXT$ = "STOP" THEN
            CMD = 0
        ELSEIF CMDTXT$ = "START" THEN
            CMD = 1
        ELSEIF CMDTXT$ = "RESUME" THEN
            CMD = 2
        ELSE
            CMD = 0
        END IF

        '
        '  Send command to COMMSCOP routine
        '
SENDCMD:
        INREG(RAX) = 256 * CMD
```

Figure 18-6. Continued.

(more)

```
INREG(RDX) = PORT
CALL INT86(&H60, VARPTR(INREG(0)), VARPTR(OUTREG(0)))
'
'  Notify user that action is complete
'
PRINT : PRINT
PRINT "Communications tracing "; TEXT$(CMD);
IF CMD <> 0 THEN
    PRINT " for port COM"; MID$(STR$(PORT + 1), 2); ":"
ELSE
    PRINT
END IF

END
```

Figure 18-6. Continued.

Both versions of COMMSCMD accept their commands from the command tail; both are invoked with a STOP, START, or RESUME command and a serial port number (1 or 2). If the operands are omitted, STOP and COM1 are assumed.

After data has been collected and safely placed in the trace buffer, it must be read before it can be useful. Interrupt 60H provides a function (AH = 3) that returns the buffer address and the number of bytes in the buffer. The QuickBASIC routine in Figure 18-7 uses this function to get the address of the data and then formats the data on the screen.

```
' ************************************************************************
' *                                                                      *
' *  COMMDUMP                                                            *
' *                                                                      *
' *  This routine dumps the contents of the COMMSCOP trace buffer to     *
' *  the screen in a formatted manner.  Received data is shown in        *
' *  reverse video.  Where possible, the ASCII character for the byte    *
' *  is shown; otherwise a dot is shown.  The value of the byte is       *
' *  displayed in hex below the character.  Points where tracing was     *
' *  stopped are shown by a solid bar.                                   *
' *                                                                      *
' ************************************************************************

'
'  Establish system constants and variables
'
DEFINT A-Z

DIM INREG(7), OUTREG(7)         'Define register arrays

RAX = 0                         'Establish values for 8086
RBX = 1                         ' registers
RCX = 2                         '  .
RDX = 3                         '  .
```

Figure 18-7. Formatted dump routine for serial-trace buffer. *(more)*

```
RBP = 4                                 '  .
RSI = 5                                 '  .
RDI = 6                                 '  .
RFL = 7                                 '  .
                                           /
'
'  Interrogate COMMSCOP to obtain addresses and count of data in
'  trace buffer
'
INREG(RAX) = &H0300                    'Request address data and count
CALL INT86(&H60, VARPTR(INREG(0)), VARPTR(OUTREG(0)))

NUM = OUTREG(RCX)                      'Number of bytes in buffer
BUFSEG = OUTREG(RDX)                   'Buffer segment address
BUFOFF = OUTREG(RBX)                   'Offset of buffer start

IF NUM = 0 THEN END

'
'  Set screen up and display control data
'
CLS
KEY OFF
LOCATE 25, 1
PRINT "NUM ="; NUM;"BUFSEG = "; HEX$(BUFSEG); " BUFOFF = ";
PRINT HEX$(BUFOFF);
LOCATE 4, 1
PRINT STRING$(80,"-")
DEF SEG = BUFSEG

'
'  Set up display control variables
'
DLINE = 1
DCOL = 1
DSHOWN = 0

'
'  Fetch and display each character in buffer
'
FOR I= BUFOFF TO BUFOFF+NUM-2 STEP 2
    STAT = PEEK(I)
    DAT = PEEK(I + 1)

    IF (STAT AND 1) = 0 THEN
        COLOR 7, 0
    ELSE
        COLOR 0, 7
    END IF

    RLINE = (DLINE-1) * 4 + 1
```

Figure 18-7. Continued. *(more)*

```
        IF (STAT AND &H80) = 0 THEN
            LOCATE RLINE, DCOL
            C$ = CHR$(DAT)
            IF DAT < 32 THEN C$ = "."
            PRINT C$;
            H$ = RIGHT$("00" + HEX$(DAT), 2)
            LOCATE RLINE + 1, DCOL
            PRINT LEFT$(H$, 1);
            LOCATE RLINE + 2, DCOL
            PRINT RIGHT$(H$, 1);
        ELSE
            LOCATE RLINE, DCOL
            PRINT CHR$(178);
            LOCATE RLINE + 1, DCOL
            PRINT CHR$(178);
            LOCATE RLINE + 2, DCOL
            PRINT CHR$(178);
        END IF

        DCOL = DCOL + 1
        IF DCOL > 80 THEN
            COLOR 7, 0
            DCOL = 1
            DLINE = DLINE + 1
            SHOWN = SHOWN + 1
            IF SHOWN = 6 THEN
                LOCATE 25, 50
                COLOR 0, 7
                PRINT "ENTER ANY KEY TO CONTINUE:  ";
                WHILE LEN(INKEY$) = 0
                WEND
                COLOR 7, 0
                LOCATE 25, 50
                PRINT SPACE$(29);
                SHOWN = 0
            END IF
            IF DLINE > 6 THEN
                LOCATE 24, 1
                PRINT : PRINT : PRINT : PRINT
                LOCATE 24, 1
                PRINT STRING$(80, "-");
                DLINE = 6
            ELSE
                LOCATE DLINE * 4, 1
                PRINT STRING$(80, "-");
            END IF
        END IF

    NEXT I

    END
```

Figure 18-7. Continued.

COMMDUMP is a simple routine. Like most debugging aids, it lacks needless frills. When it is executed, COMMDUMP displays the data in the trace buffer on the screen in the format shown in Figure 18-8.

```
.012832.132056780001006713205678000100671320567800010067132056780001006713205678
033333303333333333333333333333333333333333333333333333333333333333333333333333
101283231320567800010067132056780001006713205678000100671320567800010067132056 78
--------------------------------------------------------------------------------
000100671320567800010067132056780001006713205678000100 67.#.▌.012832.567813200001
333333333333333333333333333333333333333333333333333333333333333333333333333333
000100671320567800010067132056780001006713205678000100 67338▌101283235678132000 01
--------------------------------------------------------------------------------
006756781320000100675678132000010067567813200001006756781320000100675678132000 01
333333333333333333333333333333333333333333333333333333333333333333333333333333
006756781320000100675678132000010067567813200001006756781320000100675678132000 01
--------------------------------------------------------------------------------
006756781320000100675678132000010067.#.▌.012832.006713205678000100671320567800 01
333333333333333333333333333333333333333333333333333333333333333333333333333333
006756781320000100675678132000010067338▌101283230067132056780001006713205678000 1
--------------------------------------------------------------------------------
006713205678000100671320567800010067132056780001006713205678000100671320567800 01
333333333333333333333333333333333333333333333333333333333333333333333333333333
006713205678000100671320567800010067132056780001006713205678000100671320567800 01
--------------------------------------------------------------------------------
006713205678000 1.#.▌.012832.132056780001006713205678000100671320567800010067132 0
333333333333333333333333333333333333333333333333333333333333333333333333333333
006713205678000 1338▌101283231320567800010067132056780001006713205678000100671320
--------------------------------------------------------------------------------
NUM = 1122 BUFSEG = 1313 BUFOFF = 208          ENTER ANY KEY TO CONTINUE:
```

Figure 18-8. Formatted trace dump routine output.

Note that the data for each byte is presented in two forms. If the byte is greater than 1FH, the ASCII character represented by that number is shown; otherwise, a dot is shown. Directly below each character is the hexadecimal representation of the data. The display shows received data in reverse video and transmitted data in normal video. The mark placed in the buffer when collection is stopped and resumed is represented on the screen as a vertical bar one character wide. The display pauses when the screen is full and waits for a key to be pressed.

Data collected and displayed in this way can be invaluable to the programmer trying to debug a program involving a communications protocol. The example shown above is part of an ordered exchange of sales data for a system using blocked transmissions and ACK/NAK protocol. Like all debugging, finding bugs in such a system requires the collection of large amounts of data. With no data, the causes of problems can be almost impossible to find; with sufficiently large amounts of data, the solutions are obvious.

Several things could be done to the COMMSCOP program to increase its usefulness. For instance, there are six unused bits in the tag accompanying each data byte in the trace buffer. These could be used to record the status of the modem control bits, to place timer ticks in the buffer, or to coordinate the data with some outside event. (Such changes to COMMSCOP would require a more complicated COMMDUMP routine to display them.)

Software debugging monitors

Debugging monitors provide the next level of sophistication in the hierarchy of debugging methods. These monitors are coresident in memory with the application being debugged and provide a controlled testing environment—that is, they allow the programmer to control the execution of the program and to monitor the results. They even allow some problems to be fixed directly and the result reexecuted immediately, without the need to reassemble or recompile.

These monitors are analogous to the TSR serial monitor from the previous section. The debugging monitors, however, do not reside permanently in memory and are controlled interactively from the keyboard during the execution of the program under test. Although this level of control is more flexible than instrumentation, it is also more intrusive into program execution. While the debugging monitor sits and waits for input from the keyboard, the application program is also idle. For programs that must run in real time or must respond to external stimuli, long delays can be fatal. Careful planning and a thorough knowledge of the internal workings of the program are required to debug in such an environment.

Other problems with debugging monitors arise from the nature of the monitors themselves. They are programs, no different from the application program being debugged and are therefore limited to those things that can be done with software. For instance, they can break (stop execution to allow investigation of program status) when a specific instruction address is executed (because this can be done with software), but they cannot break when a data address is referenced (because this would require special hardware). Because these monitors reside in RAM, as do the application program and MS-DOS, they are susceptible to damage from a program running wild. Some trial and error is usually involved in locating the problem causing this kind of damage; breakpoints won't work here because the problem kills the monitor (and usually MS-DOS also).

Microsoft provides three debugging monitors, each with greater capabilities than its predecessor. In order of increasing sophistication, these three monitors are

Monitor	Description
DEBUG	A basic debugging monitor with the ability to load files, modify memory and registers, execute programs, set simple breakpoints, trace execution, modify disk files, and enter assembly-language statements into memory.
SYMDEB	A more advanced debugging monitor incorporating all the features of DEBUG plus more sophisticated data display, support for graphics programs, support for the Intel 80186/80286 microprocessors and the Intel 80287 math coprocessor, improved breakpoints, improved tracing, recognition of symbols from the program being debugged, and limited source-line display.
CodeView	The most sophisticated debugging monitor, incorporating the functionality of SYMDEB (with some differences in the details) plus windows, full source-line support, mouse support, and generally more sophistication on all functions.

Although all these debugging monitors will be discussed here, this section is not intended to be a tutorial on all the commands and options of the monitors—those are presented elsewhere in this volume and in the manuals accompanying the monitors. *See* PROGRAMMING UTILITIES: DEBUG; SYMDEB; CODEVIEW. Rather, this section uses case histories and sample programs to illustrate the techniques for solving various types of common debugging problems. The case histories have been chosen to show a wide range of problems, from simple to extremely complex.

DEBUG

Although DEBUG is the least sophisticated of the software debugging monitors, it is quite useful with moderately complex programs and is an effective tool for learning basic techniques.

Basic techniques

The first sample program is written in assembly language. It is a test program that performs serial input and output and was used to debug COMMSCOP, the serial-trace TSR presented earlier. The routine reads from the keyboard and writes to COM1 by means of Interrupt 14H. It also accepts incoming serial data and displays it on the screen. This process continues until Ctrl-C is pressed on the keyboard. A serial terminal is attached to COM1 to serve as a data source. Figure 18-9 shows the erroneous program.

```
        TITLE TESTCOMM - TEST COMMSCOP ROUTINE
; ************************************************************************
; *                                                                      *
; *  TESTCOMM                                                            *
; *     THIS ROUTINE PROVIDES DATA FOR THE COMMSCOP ROUTINE.  IT READS   *
; *     CHARACTERS FROM THE KEYBOARD AND WRITES THEM TO COM1 USING       *
; *     INT 14H.  DATA IS ALSO READ FROM INT 14H AND DISPLAYED ON THE    *
; *     SCREEN.  THE ROUTINE RETURNS TO MS-DOS WHEN Ctrl-C IS PRESSED    *
; *     ON THE KEYBOARD.                                                 *
; *                                                                      *
; ************************************************************************

SSEG    SEGMENT PARA STACK 'STACK'
        DW      128 DUP(?)
SSEG    ENDS

CSEG    SEGMENT
        ASSUME  CS:CSEG,SS:SSEG
BEGIN   PROC    FAR
        PUSH    DS                      ;SET UP FOR RET TO MS-DOS
        XOR     AX,AX                   ; .
        PUSH    AX                      ; .
```

Figure 18-9. Incorrect serial test routine. *(more)*

```
MAINLOOP:
        MOV     AH,6                    ;USE MS-DOS CALL TO CHECK FOR
        MOV     DL,0FFH                 ; KEYBOARD ACTIVITY
        INT     21                      ; IF NO CHARACTER, JUMP TO
        JZ      TESTCOMM                ; COMM ACTIVITY TEST

        CMP     AL,03                   ;WAS CHARACTER A Ctrl-C?
        JNE     SENDCOMM                ; NO, SEND IT TO SERIAL PORT
        RET                             ; YES, RETURN TO MS-DOS

SENDCOMM:
        MOV     AH,01                   ;USE INT 14H WRITE FUNCTION TO
        MOV     DX,0                    ; SEND DATA TO SERIAL PORT
        INT     14H                     ; .

TESTCOMM:
        MOV     AH,3                    ;GET SERIAL PORT STATUS
        MOV     DX,0                    ; .
        INT     14H                     ; .
        AND     AH,1                    ;ANY DATA WAITING?
        JZ      MAINLOOP                ; NO, GO BACK TO KEYBOARD TEST
        MOV     AH,2                    ;READ SERIAL DATA
        MOV     DX,0                    ; .
        INT     14H                     ; .
        MOV     AH,6                    ;WRITE SERIAL DATA TO SCREEN
        INT     21H                     ; .
        JMP     MAINLOOP                ;CONTINUE
BEGIN   ENDP
CSEG    ENDS
        END     BEGIN
```

Figure 18-9. Continued.

When executed, this program produces a constant stream of zeros from the serial port. Incoming serial data is not echoed on the screen, but the cursor moves as if it were. Further, the Ctrl-C keystroke is not recognized, so the only way to stop the program is to restart the system.

An examination of the listing should reveal the errors that cause these problems, but things do not always happen that way. For the purposes of this case study, assume that the listing was no help. Instrumentation is more difficult for assembly-language programs than for programs written in higher-order languages, so in this case it is advantageous to go directly to a debugging monitor. The monitor for this example is DEBUG.

The first step in using DEBUG is not to invoke the monitor; rather, it is to gather all pertinent listings, link maps, and program design documentation. In this case, the program is so short that a link map will not be needed; all the design documentation that exists is in the program comments.

Now begin DEBUG by typing

```
C>DEBUG TESTCOMM.EXE  <Enter>
```

The filename must be fully qualified; DEBUG makes no assumptions about the extension. Any type of file can be examined with DEBUG, but only files with an extension of .COM, .EXE, or .HEX are actually loaded and made ready for execution. Since TESTCOMM is a .EXE file, DEBUG loads it and prepares it for execution in a manner compatible with the MS-DOS loader. Type the Display or Modify Registers command, R.

```
-R  <Enter>
AX=0000  BX=0000  CX=0131  DX=0000  SP=0100  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=0000   NV UP EI PL NZ NA PO NC
1ACD:0000 1E            PUSH  DS
```

Notice that the SS and CS registers have been loaded to their correct values and that SP points to the bottom of the stack. DS and ES point to an address 100H bytes (10H paragraphs) before the stack segment. (This is because the system sets these registers to point to the program segment prefix [PSP] when a .EXE program is loaded.) Normally, the program code would be responsible for loading the correct value of DS, but this example does not use the data segment, so the program doesn't bother. The register display also shows the instruction at the current value of CS:IP, 1ACD:0000H. The instruction pointer was set to this address because the END statement in the source program specified the procedure *BEGIN* as the entry point and that procedure begins at CS:IP. Note that the instruction displayed below the register information has not yet been executed. This condition is true for all register displays in DEBUG — IP always points to the *next* instruction to be executed, so the instruction at IP has not been executed.

From the symptoms observed during program execution, it is clear that the keyboard data is not reaching the serial port. The failure could be in the keyboard read routine or in the serial port write routine. This code is compact and fairly linear, so the easiest way to find out what is going on is to trace through the first few instructions of the program. Executing five instructions with the Trace Program Execution command, T, will do this.

```
-T5  <Enter>

AX=0000  BX=0000  CX=0131  DX=0000  SP=00FE  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=0001   NV UP EI PL NZ NA PO NC
1ACD:0001 33C0          XOR   AX,AX

AX=0000  BX=0000  CX=0131  DX=0000  SP=00FE  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=0003   NV UP EI PL ZR NA PE NC
1ACD:0003 50            PUSH  AX

AX=0000  BX=0000  CX=0131  DX=0000  SP=00FC  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=0004   NV UP EI PL ZR NA PE NC
1ACD:0004 B406          MOV   AH,06

AX=0600  BX=0000  CX=0131  DX=0000  SP=00FC  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=0006   NV UP EI PL ZR NA PE NC
1ACD:0006 B2FF          MOV   DL,FF

AX=0600  BX=0000  CX=0131  DX=00FF  SP=00FC  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=0008   NV UP EI PL ZR NA PE NC
1ACD:0008 CD15          INT   15
```

The Trace command shows the contents of the registers as each instruction is executed. The register contents are *after* the execution of the instruction listed above the registers and the instruction shown with the registers is the *next* instruction to be executed. The first register display in this example represents the state of affairs after the execution of the PUSH DS instruction, as indicated by SP. The first three instructions set up the stack so that the far return issued at the end of the program will pass control to the PSP for termination. The next two instructions set the registers for a Direct Console I/O MS-DOS call (AH = 060, DL = HFFH for input). After these registers are set up, the program should execute the MS-DOS call INT 21H. However, the next instruction to be executed is INT 15H. This is the reason the keyboard data is not being read. The code requests INT 21, not 21H. This mistake is a common one. The assembler's default radix is decimal, so it converted 21 into 15H. This error can be corrected in memory from within DEBUG and, because the instruction hasn't executed yet, the fix can be tested immediately. To make the correction, use the Assemble Machine Instructions command, A.

```
-A 8  <Enter>
1ACD:0008 int 21  <Enter>
1ACD:000A  <Enter>
```

The *A 8* code instructs DEBUG to begin assembling at CS:0008H. DEBUG prompts with the address and waits for an instruction to be entered. The letter *H* is not needed after the 21 this time because DEBUG assumes all numbers entered with the Assemble command are in hexadecimal form. In general, any valid 8086/8087/8088 assembly-language statement can be entered this way and translated into executable machine code. *See* PROGRAMMING UTILITIES: DEBUG: A. Within its restrictions, the Assemble command is a handy way of making changes. The Enter Data command, E, could also have been used to change the 15H to a 21H, but the Assemble command is safer, especially for complex instructions. After the new instruction has been entered, press Enter again to stop the assembly process.

There is a danger associated with making changes in memory during debugging: The memory copy of the program is temporary; the changes exist only in memory and when DEBUG exits, they are lost. Changes made to .EXE and .HEX files cannot be written back to disk. To avoid forgetting the changes, write them down. When DEBUG exits, edit the source file *immediately*. Changes made to other files can be written back to disk with DEBUG's Write File or Sectors command, W.

To be sure that the change was made correctly, use the Disassemble (Unassemble) Program command, U, to show the instructions starting at CS:0004H.

```
-U 4  <Enter>
1ACD:0004 B406          MOV   AH,06
1ACD:0006 B2FF          MOV   DL,FF
1ACD:0008 CD21          INT   21
1ACD:000A 740C          JZ    0018
1ACD:000C 3C03          CMP   AL,03
1ACD:000E 7501          JNZ   0011
1ACD:0010 CB            RETF
```

```
1ACD:0011 B401          MOV   AH,01
1ACD:0013 BA0000        MOV   DX,0000
1ACD:0016 CD14          INT   14
1ACD:0018 B403          MOV   AH,03
1ACD:001A BA0000        MOV   DX0000
1ACD:001D CD14          INT   14
1ACD:001F 80E401        AND   AH,01
1ACD:0022 74E0          JZ    0004
```

The change has been correctly made. Now, to test the change, start the program to see if characters make it out the serial port. The problem of data from the serial port not making it to the screen remains, however, so instead of simply starting the program, set a breakpoint at the location in the program that handles incoming serial data (CS:0024H). This technique allows the output section of the code to be tested separately. The breakpoint is set using the Go command, G.

```
-G 24  <Enter>

AX=0130  BX=0000  CX=0131  DX=0000  SP=00FC  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=0024   NV UP EI PL NZ NA PO NC
1ACD:0024 B402          MOV   AH,02
-U  <Enter>
1ACD:0024 B402          MOV   AH,02
1ACD:0026 BA0000        MOV   DX,0000
1ACD:0029 CD14          INT   14
1ACD:002B B406          MOV   AH,06
1ACD:002D CD21          INT   21
1ACD:002F EBD3          JMP   0004
1ACD:0031 0000          ADD   [BX+SI],AL
1ACD:0033 0000          ADD   [BX+SI],AL
1ACD:0035 0000          ADD   [BX+SI],AL
1ACD:0037 0000          ADD   [BX+SI],AL
1ACD:0039 0000          ADD   [BX+SI],AL
1ACD:003B 0000          ADD   [BX+SI],AL
1ACD:003D 0000          ADD   [BX+SI],AL
1ACD:003F 0000          ADD   [BX+SI],AL
1ACD:0041 0000          ADD   [BX+SI],AL
1ACD:0043 0000          ADD   [BX+SI],AL
```

As stated earlier, the serial port is attached to a serial terminal. After execution of the program is started with the Go command, all keys typed on the keyboard are displayed correctly on the terminal, thus confirming the fix made to the INT 21H instruction. To test serial input, a key must be pressed on the terminal, causing the breakpoint at CS:0024H to be executed.

The fact that location CS:0024H was reached indicates that Interrupt 14H is detecting the presence of an input character. To test if the character is now making it to the screen, a breakpoint is needed after the write to the screen. The Disassemble command shows the instructions starting at the current IP value. The program ends at CS:002FH; the instructions shown after that are whatever happened to be in memory when the program was loaded. A good place to set the next breakpoint is CS:002FH, just after the Interrupt 21H call.

```
-G 2f  <Enter>

AX=0600  BX=0000  CX=0131  DX=0000  SP=00FC  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=002F   NV UP EI PL NZ NA PO NC
1ACD:002F EBD3          JMP   0004
```

DEBUG shows that the breakpoint was reached and the character did not print (it should have been on the line after *-G 2f*), so something must be wrong with the Interrupt 21H call. A breakpoint just before the MS-DOS call at CS:002DH should reveal the cause of the problem.

```
-G 2d  <Enter>

AX=0662  BX=0000  CX=0131  DX=0000  SP=00FC  BP=0000  SI=0000  DI=0000
DS=1AAD  ES=1AAD  SS=1ABD  CS=1ACD  IP=002D   NV UP EI PL NZ NA PO NC
1ACD:002D CD21          INT   21
```

The key that was entered on the serial terminal (b) is in AL, where it was returned by Interrupt 14H. Unfortunately, it is not in DL, where it is expected by the Direct Console I/O function (06H) of the MS-DOS command. The MS-DOS function was simply printing a null (00H) and then moving the cursor. An instruction (MOV DL,AL) is missing.

Fixing this problem requires the insertion of a line of code, which is usually difficult to do inside DEBUG. The Move (Copy) Data command, M, can be used to move the code located below the point where the insertion is to be made down 2 bytes, but this will probably throw any subsequent addressing off. It is usually easier to exit DEBUG, edit the source file, and then reassemble. In this case, however, because the instruction to be added is near the last instruction, a patch can easily be made by entering only three instructions: the new one and the two it destroys.

```
-A 2d  <Enter>
1ACD:002D mov dl,al  <Enter>
1ACD:002F int 21  <Enter>
1ACD:0031 jmp 4  <Enter>
1ACD:0033  <Enter>
-U 2b  <Enter>
1ACD:002B B406          MOV   AH,06
1ACD:002D 88C2          MOV   DL,AL
1ACD:002F CD21          INT   21
1ACD:0031 EBD1          JMP   0004
1ACD:0033 0000          ADD   [BX+SI],AL
1ACD:0035 0000          ADD   [BX+SI],AL
1ACD:0037 0000          ADD   [BX+SI],AL
1ACD:0039 0000          ADD   [BX+SI],AL
1ACD:003B 0000          ADD   [BX+SI],AL
1ACD:003D 0000          ADD   [BX+SI],AL
1ACD:003F 0000          ADD   [BX+SI],AL
1ACD:0041 0000          ADD   [BX+SI],AL
1ACD:0043 0000          ADD   [BX+SI],AL
1ACD:0045 0000          ADD   [BX+SI],AL
1ACD:0047 0000          ADD   [BX+SI],AL
1ACD:0049 0000          ADD   [BX+SI],AL
```

The new line of code has been inserted and verified with the Disassemble command. The fix is ready to test. The Trace command could be used to single-step through the program to verify execution. A word of warning is in order, however: The DEBUG Trace command should never be used to trace an Interrupt 21H call. Once the trace enters the MS-DOS call, it will wander around for a while and then lock the machine, requiring a restart. Avoid this problem either by setting a breakpoint just beyond the Interrupt 21H call or by using the Proceed Through Loop or Subroutine command, P. The Proceed command operates in a similar manner to the Trace command but does not trace loops, calls, and interrupts.

Because the fix is fairly certain, use the Go command in its simple form with no breakpoints. The program will execute without further intervention from DEBUG.

```
-G  <Enter>
lasdfgh
Program terminated normally
-Q  <Enter>
```

The *lasdfgh* text entered on the serial terminal is displayed correctly. When a Ctrl-C is entered from the keyboard, the program terminates properly and DEBUG displays the message *Program terminated normally.* Now exit DEBUG with the Quit command, Q.

The source code of TESTCOMM should be edited immediately so that it reflects the two changes made temporarily under DEBUG. Figure 18-10 shows the corrected listing.

```
     TITLE TESTCOMM - TEST COMMSCOP ROUTINE
; ********************************************************************
; *                                                                  *
; *  TESTCOMM                                                        *
; *     THIS ROUTINE PROVIDES DATA FOR THE COMMSCOP ROUTINE.  IT READS  *
; *  CHARACTERS FROM THE KEYBOARD AND WRITES THEM TO COM1 USING      *
; *  INT 14H.  DATA IS ALSO READ FROM INT 14H AND DISPLAYED ON THE   *
; *  SCREEN.  THE ROUTINE RETURNS TO MS-DOS WHEN Ctrl-C IS PRESSED   *
; *  ON THE KEYBOARD.                                                *
; *                                                                  *
; ********************************************************************

SSEG    SEGMENT PARA STACK 'STACK'
        DW      128 DUP(?)
SSEG    ENDS

CSEG    SEGMENT
        ASSUME  CS:CSEG,SS:SSEG
BEGIN   PROC    FAR
        PUSH    DS                      ;SET UP FOR RET TO MS-DOS
        XOR     AX,AX                   ; .
        PUSH    AX                      ; .
```

Figure 18-10. Correct serial test routine. *(more)*

```
MAINLOOP:
        MOV     AH,6                    ;USE DOS CALL TO CHECK FOR
        MOV     DL,0FFH                 ; KEYBOARD ACTIVITY
        INT     21H                     ; IF NO CHARACTER, JUMP TO
        JZ      TESTCOMM                ; COMM ACTIVITY TEST

        CMP     AL,03                   ;WAS CHARACTER A Ctrl-C?
        JNE     SENDCOMM                ; NO, SEND IT TO SERIAL PORT
        RET                             ; YES, RETURN TO MS-DOS

SENDCOMM:
        MOV     AH,01                   ;USE INT 14H WRITE FUNCTION TO
        MOV     DX,0                    ; SEND DATA TO SERIAL PORT
        INT     14H                     ; .

TESTCOMM:
        MOV     AH,3                    ;GET SERIAL PORT STATUS
        MOV     DX,0                    ; .
        INT     14H                     ; .
        AND     AH,1                    ;ANY DATA WAITING?
        JZ      MAINLOOP                ; NO, GO BACK TO KEYBOARD TEST
        MOV     AH,2                    ;READ SERIAL DATA
        MOV     DX,0                    ; .
        INT     14H                     ; .
        MOV     AH,6                    ;WRITE SERIAL DATA TO SCREEN
        MOV     DL,AL                   ; .
        INT     21H                     ; .
        JMP     MAINLOOP                ;CONTINUE

BEGIN   ENDP
CSEG    ENDS
        END     BEGIN
```

Figure 18-10. Continued.

DEBUG has a rich set of commands and features. The preceding case study shows the more common ones in their most straightforward aspect. Some of the other commands and some useful techniques are described below. *See* PROGRAMMING UTILITIES: DEBUG.

Establishing initial conditions

When a program is loaded for testing, four areas may require initialization:

- Registers
- Data areas
- Default file-control blocks (FCBs)
- Command tail

These areas may also require changes during testing, especially when the programmer is working around bugs or establishing different test conditions.

Registers. Registers are ordinarily set when the program is loaded. The values in them depend on whether a .EXE, .COM, or .HEX file was loaded. Generally, the segment registers, the IP register, and the SP register are set to appropriate values; with the exception of AX, BX, and CX, the rest of the registers are set to zero. BX and CX contain the length of the loaded file. By MS-DOS convention, when a program is loaded, the contents of AL and AH indicate the validity of the drive specifiers in the first and second DEBUG command-line parameters, respectively. Each register contains zero if the corresponding drive was valid, 01H if the drive was valid and wildcards were used, or 0FFH if the drive was invalid.

To change the value of any register, use an alternate form of the Register command. Enter R followed by the two-letter register name. Only 16-bit registers can be changed, so use the X form of the general-purpose registers:

```
-R AX  <Enter>
```

DEBUG will respond with the current contents of the register and prompt for a new value. Either enter a new hexadecimal value or press Enter to keep the current value:

```
AX 0000
:FFFF  <Enter>
```

In this example, the new value of AX is FFFFH.

When changing registers, exercise caution modifying the segment registers. These registers control the execution of the program and should be changed only after careful and thoughtful consideration.

The Register command can also be used to modify the CPU flags.

Data areas. Initializing or changing data areas is easy, and several methods are provided. The Fill Memory command, F, can be used to initialize areas of RAM. For instance,

```
-F 0 L400 0  <Enter>
```

fills DS:0000H through DS:03FFH with zero. (The absence of a segment override causes the Fill command to use its default segment, DS.) Entering

```
-F CS:100 200 1B "[Hello" 0D  <Enter>
```

fills CS:0100H through CS:0200H with many repetitions of the string 1B 5B 48 65 6C 6C 6F 0D. (Note that an address range was specified, not a length.)

When the wholesale changing of memory is not appropriate, the Enter command can be used to edit a small number of locations. The Enter command has two forms: One enters a list of bytes into the specified memory location; the other prompts with the contents of each location and waits for input. Either form can be used as appropriate.

Default file-control blocks and the command tail. The setting of the default FCBs and of the command tail are related functions. When DEBUG is entered, the first parameter following the command DEBUG is the name of the file to be loaded into memory for debugging. If the next two parameters are filenames, FCBs for these files are formatted at

DS:005CH and DS:006CH in the PSP. *See* PROGRAMMING IN THE MS-DOS ENVIRONMENT: PROGRAMMING FOR MS-DOS: File and Record Management. If either parameter contains a pathname, the corresponding FCB will contain only a valid drive number; the filename field will not be valid. All filenames and switches following the name of the file to be debugged are considered the command tail and are saved in memory starting at DS:0081H. The length of the command tail is in DS:0080H. For example, entering

```
C>DEBUG COMMDUMP.EXE FILE1.DAT FILE2.DAT  <Enter>
```

results in the first FCB (5CH), the second FCB (6CH), and the command tail (81H) being loaded as follows:

```
-D 50  <Enter>
42C9:0050  CD 21 CB 00 00 00 00 00-00 00 00 00 00 46 49 4C   .!...........FIL
42C9:0060  45 31 20 20 20 44 41 54-00 00 00 00 00 46 49 4C   E1   DAT.....FIL
42C9:0070  45 32 20 20 20 44 41 54-00 00 00 00 00 00 00 00   E2   DAT........
42C9:0080  15 20 66 69 6C 65 31 2E-64 61 74 20 66 69 6C 65   . file1.dat file
42C9:0090  32 2E 64 61 74 20 0D 74-20 66 69 6C 65 32 2E 64   2.dat .t file2.d
42C9:00A0  61 74 20 0D 00 00 00 00-00 00 00 00 00 00 00 00   at ............
42C9:00B0  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00   ................
42C9:00C0  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00   ................
```

In this example, location DS:005CH contains an unopened FCB for file FILE1.DAT on the current drive. Location DS:006CH contains an unopened FCB for FILE2.DAT on the current drive. (The second FCB cannot be used where it is and must be moved to another location before the first FCB is opened.) Location DS:0080H contains the length of the command tail, 15H (21) bytes. The next 21 bytes are the command tail prepared by DEBUG; they correspond exactly to what the command tail would be if the program had been loaded by COMMAND.COM instead of by DEBUG.

The default FCBs and the command tail can also be set after the program has been loaded, by using the Name File or Command-Tail Parameters command, N. DEBUG treats the string of characters that follow the Name command as the command tail: If the first two parameters are filenames, they become the first and second FCBs, respectively. The Name command also places the string at DS:0081H, with the length of the string at DS:0080H. Entering the DEBUG command

```
-N FILE1.DAT FILE2.DAT  <Enter>
```

produces the same results as specifying the filenames in the command line. When employed in this manner, the Name command is useful for initializing command-tail data that was not in the command line or for changing the command-tail data to test different aspects of a program. (If files are named in this manner, they are not validated until the Load File or Sectors command, L, is used.) Note that the data following the Name command need not be filenames; it can be any parameters, data, or switches that the application program expects to see.

More on breakpoints

The case study at the beginning of this section used breakpoints in their simplest form: Only a single breakpoint was specified at a time and the execution address was considered to be the current IP. The Go command is also capable of setting multiple breakpoints and of beginning execution at any address in memory. The more general form of the Go command is

G[=*address*] [*address* [*address*...]]

If Go is used with no operands, execution begins at the current value of CS:IP and no breakpoints are set. If the =*address* operand is used, DEBUG sets IP to the address specified and execution then begins at the new CS:IP. The other optional addresses are breakpoints. When execution reaches one of these breakpoints, DEBUG stops and displays the system's registers. As many as 10 breakpoints can be set on one Go command, and they can be in any order.

The breakpoint addresses must be on instruction boundaries because DEBUG replaces the instruction at each breakpoint address with an INT 03H instruction (0CCH). DEBUG saves the replaced instructions internally. When any breakpoint is reached, DEBUG stops execution and restores the instructions at *all* the breakpoints; if no breakpoint is reached, the instructions are not restored and the Load command must be used to reload the original program.

The multiple-breakpoint feature of the Go command allows the tracing of program execution when branches exist in the code. When a program contains, for instance, a conditional jump on the zero flag, a breakpoint can be placed in each of the two possible branches. When the branch is reached, one of the two breakpoints will be encountered shortly thereafter. When DEBUG displays the breakpoint, the programmer knows which branch was taken. Moving through a program with breakpoints at key locations is faster than using the Trace command to execute each and every instruction.

Multiple breakpoints can also be used to home in on a bad piece of code. This technique is particularly useful in those nasty situations when there are no symptoms except that the system locks up and must be restarted. When debugging a problem such as this, set breakpoints at each of the major sections of the program and then note those breakpoints that are executed successfully, continuing until the system locks up. The problem lies somewhere between the last successful breakpoint and the next breakpoint set. Now repeat the processes, setting breakpoints between the last breakpoint and the one that was never reached. By progressively narrowing the gap between breakpoints, the exact offending instruction can be isolated.

Some general comments about the Go command and breakpoints:

- After a program has reached completion and returned to MS-DOS, it must be reloaded with the Load command before it can be executed again. (DEBUG intercepts this return and displays *Program terminated normally.*)
- Because DEBUG replaces program instructions with an INT 03H instruction to form breakpoints, the break address must be on an instruction boundary. If it is not, the INT 03H will be stuck in the middle of an instruction, causing strange and sometimes entertaining results.

- Breakpoints cannot be set in data, because data is not executed.
- The target program's SS:SP registers must point to a valid stack that has at least 6 bytes of stack space available. When the Go command is executed, it pushes the target program's flags and CS and IP registers onto the stack and then transfers control to the program with an IRET instruction. Thus, if the target program's stack is not valid or is too small, the system may crash.
- Finally, and obviously, breakpoints cannot be set in read-only memory (the ROM BIOS, for instance).

Using the Write commands

After a program has been debugged, fixed, and tested with DEBUG, the temptation exists to write the patched program directly back to the disk as a .COM file. This action is sometimes legitimate, but only rarely. The technique will be explained in a moment, but first a sermon:

DON'T DO IT.

One of the greatest sadnesses in a programmer's life comes when, after a program has been running wonderfully, enhancements are made to the source code and the recompiled program suddenly has bugs in it that haven't been seen for months. Always make any debugging patches permanent in the source file immediately.

Unless, of course, the source code is not available. This is the only time saving a patched program is permissible. For example, sometimes commercial programs require patching because the program does not quite fit the hardware it must run on or because bugs have been found in the program. The source of these patches is sometimes word-of-mouth, sometimes a bulletin-board service, and sometimes the program's manufacturer.

Even when legitimate reasons exist to save patched code, precautions should be taken. Be very careful, meticulous, and alert as the patches are applied. Understand each step before undertaking it. Most important of all, always have a backup of the original unpatched program safely on a floppy disk.

Use the Write command to write the program image to disk. A starting address can optionally be specified; otherwise the write starts at CS:0100H. The name of the file will be either the name specified in the last Name command or the name of the program from the DEBUG command line if the Name command has not been used. The number of bytes to be written is in BX and CX, with the most significant half in BX. These registers will have been loaded correctly when the program was loaded, but they should be checked if the program has executed since it was loaded.

The .EXE and .HEX file types cannot be written to disk with the Write command. The command performs no formatting and only writes the binary image of memory to the disk file. Thus, all programs written with Write must be .COM files. The image of a .EXE or .HEX file can still be written as a .COM file provided no segment fixups are required and provided the other rules for a .COM file are followed. *See* PROGRAMMING IN THE MS-DOS ENVIRONMENT: PROGRAMMING FOR MS-DOS: Structure of an Application Program. (A segment fixup is a segment address that must be provided by the loader when the

program is originally loaded. *See* PROGRAMMING IN THE MS-DOS ENVIRONMENT: PROGRAMMING TOOLS: Object Modules.) If a .EXE file containing a segment fixup is written as a .COM file, the new file will execute correctly only when loaded at exactly the same address as the original file, and this is difficult to ensure for programs running under MS-DOS.

If it is necessary to patch a .EXE or .HEX file and the exact addresses relative to the start of the file are known, use the following procedure:

1. Rename (or better yet, copy) the file to an extension other than .EXE or .HEX.
2. Load the program image into memory by placing the new name on DEBUG's command line. Note that the loaded file is an image of the disk file and is not executable.
3. Modify the program image in memory, but *never* try to execute the program. Results would be unpredictable and the program image could be damaged.
4. Write the modified image back to disk using a simple *w*. No other action is needed, because the original load will have set the filename and the correct length in BX and CX.
5. Rename the file to a name with the correct .EXE or .HEX extension. The new name need not be the same as the original, but it should have the same extension.

The same technique can be used to load, modify, and save data files. Simply make sure that the file does not have an extension of .COM, .EXE, or .HEX. The data file will be loaded at address CS:0100H. (DEBUG treats the file much the same as a .COM file.) After patching the data (the Enter command works best), use the Write command to write it back to the disk.

SYMDEB

SYMDEB is an extension of DEBUG; virtually all the DEBUG commands and techniques still work as expected. The major new feature, and the source of the name SYMDEB, is symbolic debugging: SYMDEB can use all public labels in a program for reference, instead of using hexadecimal offset addresses. In addition, SYMDEB allows the use of line numbers for reference in compatible high-order languages; source-line display within SYMDEB is also possible for these languages. Currently, the languages supporting these options are Microsoft FORTRAN versions 3.0 and later, Microsoft Pascal versions 3.0 and later, and Microsoft C versions 2.0 and later. Versions 4.0 and earlier of the Microsoft Macro Assembler (MASM) do not generate the data needed for line-number display and source-line debugging.

In addition to symbolic debugging, SYMDEB has added several other new features and has expanded existing DEBUG features:

- Breakpoints have been made more sophisticated with the addition of "sticky" breakpoints. Unlike the breakpoints set with the Go command, sticky breakpoints remain attached to the program throughout a SYMDEB session until they are explicitly removed. Specific commands are supplied for listing, removing, enabling, and disabling sticky breakpoints.
- DEBUG's Display Memory command, D, has been extended so that data can be displayed in different formats.

- Full redirection is supported.
- A stack trace feature has been added.
- Terminate-and-stay-resident programs are supported.
- A shell escape command has been added to allow the execution of MS-DOS commands and programs without leaving SYMDEB and the debugging session.

These additions allow more sophisticated debugging techniques to be used and, in some cases, also simplify locating problems. To see the advantages of using symbols and sticky breakpoints in debugging, consider a type of program that is one of the most difficult to debug—the TSR.

Debugging TSRs with SYMDEB

Terminate-and-stay-resident routines can be difficult to debug. They exist in two worlds and can have bugs associated with each. At the outset, they are usually simple programs that perform some initialization task and then exit. At this point, they are transformed into another type of beast entirely—resident routines that are more a part of the operating system than of any application program. Each form of the program must be debugged separately, using different techniques.

The TSR routine used for this case study is the same one created previously to serve as external instrumentation to trace serial communications. The program was called COMMSCOP, but to avoid confusion of that working program with the broken one presented here, the name has been changed to BADSCOP. BADSCOP was assembled and linked in the usual manner and then converted to a .COM file using EXE2BIN. When it was installed, it returned normally, but at the first attempt to issue an Interrupt 14H, the system locked up completely. Warm booting was not sufficient to restore it, and a power-on cold boot was required to get the system working again.

Figure 18-11 is a listing of BADSCOP. The only difference from COMMSCOP, aside from the errors, is the addition of two PUBLIC statements to make all the procedure names and the important data names available to SYMDEB.

```
        TITLE   BADSCOP - BAD VERSION OF COMMUNICATIONS TRACE UTILITY
; ********************************************************************
; *                                                                  *
; *  BADSCOP -                                                       *
; *     THIS PROGRAM MONITORS THE ACTIVITY ON A SPECIFIED COMM PORT  *
; *     AND PLACES A COPY OF ALL COMM ACTIVITY IN A RAM BUFFER.  EACH*
; *     ENTRY IN THE BUFFER IS TAGGED TO INDICATE WHETHER THE BYTE   *
; *     WAS SENT BY OR RECEIVED BY THE SYSTEM.                       *
; *                                                                  *
; *     BADSCOP IS INSTALLED BY ENTERING                             *
; *                                                                  *
; *                     BADSCOP                                      *
; *                                                                  *
```

Figure 18-11. An incorrect version of the serial trace utility. *(more)*

```
; *  THIS WILL INSTALL BADSCOP AND SET UP A 64K BUFFER TO BE USED       *
; *  FOR DATA LOGGING.  REMEMBER THAT 2 BYTES ARE REQUIRED FOR         *
; *  EACH COMM BYTE, SO THE BUFFER IS ONLY 32K EVENTS LONG, OR ABOUT   *
; *  30 SECONDS OF CONTINUOUS 9600 BAUD DATA.  IN THE REAL WORLD,      *
; *  ASYNC DATA IS RARELY CONTINUOUS, SO THE BUFFER WILL PROBABLY      *
; *  HOLD MORE THAN 30 SECONDS WORTH OF DATA.                          *
; *                                                                    *
; *  WHEN INSTALLED, BADSCOP INTERCEPTS ALL INT 14H CALLS.  IF THE     *
; *  PROGRAM HAS BEEN ACTIVATED AND THE INT IS EITHER SEND OR RE-      *
; *  CEIVE DATA, A COPY OF THE DATA BYTE, PROPERLY TAGGED, IS PLACED   *
; *  IN THE BUFFER.  IN ANY CASE, DATA IS PASSED ON TO THE REAL        *
; *  INT 14H HANDLER.                                                  *
; *                                                                    *
; *  BADSCOP IS INVOKED BY ISSUING AN INT 60H CALL.  THE INT HAS       *
; *  THE FOLLOWING CALLING SEQUENCE:                                   *
; *                                                                    *
; *       AH - COMMAND                                                 *
; *            0 - STOP TRACING, PLACE STOP MARK IN BUFFER             *
; *            1 - FLUSH BUFFER AND START TRACE                        *
; *            2 - RESUME TRACE                                        *
; *            3 - RETURN COMM BUFFER ADDRESSES                        *
; *       DX - COMM PORT (ONLY USED WITH AH = 1 or 2)                  *
; *            0 - COM1                                                *
; *            1 - COM2                                                *
; *                                                                    *
; *  THE FOLLOWING DATA IS RETURNED IN RESPONSE TO AH = 3:             *
; *                                                                    *
; *       CX - BUFFER COUNT IN BYTES                                   *
; *       DX - SEGMENT ADDRESS OF THE START OF THE BUFFER              *
; *       BX - OFFSET ADDRESS OF THE START OF THE BUFFER               *
; *                                                                    *
; *  THE COMM BUFFER IS FILLED WITH 2-BYTE DATA ENTRIES OF THE         *
; *  FOLLOWING FORM:                                                   *
; *                                                                    *
; *       BYTE 0 - CONTROL                                             *
; *            BIT 0 - ON FOR RECEIVED DATA, OFF FOR TRANS.            *
; *            BIT 7 - STOP MARK - INDICATES COLLECTION WAS            *
; *                  INTERRUPTED AND RESUMED.                          *
; *       BYTE 1 - 8-BIT DATA                                          *
; *                                                                    *
; ********************************************************************

        PUBLIC  INITIALIZE,CONTROL,VECTOR_INIT,COMMSCOPE
        PUBLIC  OLD_COMM_INT,COUNT,STATUS,PORT,BUFPNTR

CSEG    SEGMENT
        ASSUME  CS:CSEG,DS:CSEG
        ORG     100H                    ;TO MAKE A COM FILE
```

Figure 18-11. Continued. *(more)*

```
INITIALIZE:
        JMP     VECTOR_INIT             ;JUMP TO THE INITIALIZATION
                                        ; ROUTINE WHICH, TO SAVE SPACE,
                                        ; IS IN THE COMM BUFFER

;
;  SYSTEM VARIABLES
;
OLD_COMM_INT    DD      ?               ;ADDRESS OF REAL COMM INT
COUNT           DW      0               ;BUFFER COUNT
COMMSCOPE_INT   EQU     60H             ;COMMSCOPE CONTROL INT
STATUS          DB      0               ;PROCESSING STATUS
                                        ; 0 - OFF
                                        ; 1 - ON
PORT            DB      0               ;COMM PORT BEING TRACED
BUFPNTR         DW      VECTOR_INIT     ;NEXT BUFFER LOCATION

        SUBTTL  DATA INTERRUPT HANDLER
PAGE
; ************************************************************************
; *                                                                      *
; *  COMMSCOPE                                                           *
; *  THIS PROCEDURE INTERCEPTS ALL INT 14H CALLS AND LOGS THE DATA       *
; *  IF APPROPRIATE.                                                     *
; *                                                                      *
; ************************************************************************
COMMSCOPE       PROC    NEAR

        TEST    CS:STATUS,1             ;ARE WE ON?
        JZ      OLD_JUMP                ; NO, SIMPLY JUMP TO OLD HANDLER

        CMP     AH,00H                  ;SKIP SETUP CALLS
        JE      OLD_JUMP                ; .

        CMP     AH,03H                  ;SKIP STATUS REQUESTS
        JAE     OLD_JUMP                ; .

        CMP     AH,02H                  ;IS THIS A READ REQUEST?
        JE      GET_READ                ; YES, GO PROCESS

;
;  DATA WRITE REQUEST - SAVE IF APPROPRIATE
;
        CMP     DL,CS:PORT              ;IS WRITE FOR PORT BEING TRACED?
        JNE     OLD_JUMP                ; NO, JUST PASS IT THROUGH

        PUSH    DS                      ;SAVE CALLER'S REGISTERS
        PUSH    BX                      ; .
        PUSH    CS                      ;SET UP DS FOR OUR PROGRAM
        POP     DS                      ; .
        MOV     BX,BUFPNTR              ;GET ADDRESS OF NEXT BUFFER LOCATION
```

Figure 18-11. Continued. *(more)*

```
        MOV     [BX],BYTE PTR 0         ;MARK AS TRANSMITTED BYTE
        MOV     [BX+1],AL               ;SAVE DATA IN BUFFER
        INC     COUNT                   ;INCREMENT BUFFER BYTE COUNT
        INC     COUNT                   ; .
        INC     BX                      ;POINT TO NEXT LOCATION
        INC     BX                      ; .
        MOV     BUFPNTR,BX              ;SAVE NEW POINTER
        JNZ     WRITE_DONE              ;ZERO INDICATES BUFFER HAS WRAPPED

        MOV     STATUS,0                ;TURN COLLECTION OFF - BUFFER FULL
WRITE_DONE:
        POP     BX                      ;RESTORE CALLER'S REGISTERS
        POP     DS                      ; .
        JMP     OLD_JUMP                ;PASS REQUEST ON TO BIOS ROUTINE
;
;  PROCESS A READ DATA REQUEST AND WRITE TO BUFFER IF APPROPRIATE
;
GET_READ:
        CMP     DL,CS:PORT              ;IS READ FOR PORT BEING TRACED?
        JNE     OLD_JUMP                ; NO, JUST PASS IT THROUGH

        PUSH    DS                      ;SAVE CALLER'S REGISTERS
        PUSH    BX                      ; .
        PUSH    CS                      ;SET UP DS FOR OUR PROGRAM
        POP     DS                      ; .

        PUSHF                           ;FAKE INT 14H CALL
        CLI                             ; .
        CALL    OLD_COMM_INT            ;PASS REQUEST ON TO BIOS
        TEST    AH,80H                  ;VALID READ?
        JNZ     READ_DONE               ; NO, SKIP BUFFER UPDATE

        MOV     BX,BUFPNTR              ;GET ADDRESS OF NEXT BUFFER LOCATION
        MOV     [BX],BYTE PTR 1         ;MARK AS RECEIVED BYTE
        MOV     [BX+1],AL               ;SAVE DATA IN BUFFER
        INC     COUNT                   ;INCREMENT BUFFER BYTE COUNT
        INC     COUNT                   ; .
        INC     BX                      ;POINT TO NEXT LOCATION
        INC     BX                      ; .
        MOV     BUFPNTR,BX              ;SAVE NEW POINTER
        JNZ     READ_DONE               ;ZERO INDICATES BUFFER HAS WRAPPED

        MOV     STATUS,0                ;TURN COLLECTION OFF - BUFFER FULL
READ_DONE:
        POP     BX                      ;RESTORE CALLER'S REGISTERS
        POP     DS                      ; .
        IRET

;
;  JUMP TO COMM BIOS ROUTINE
;
OLD_JUMP:
        JMP     OLD_COMM_INT

COMMSCOPE ENDP
```

Figure 18-11. Continued. *(more)*

```
        SUBTTL  CONTROL INTERRUPT HANDLER
PAGE
; ************************************************************************
; *                                                                      *
; *  CONTROL                                                             *
; *     THIS ROUTINE PROCESSES CONTROL REQUESTS.                         *
; *                                                                      *
; ************************************************************************

CONTROL PROC    NEAR
        CMP     AH,00H                  ;STOP REQUEST?
        JNE     CNTL_START              ; NO, CHECK START
        PUSH    DS                      ;SAVE REGISTERS
        PUSH    BX                      ; .
        PUSH    CS                      ;SET DS FOR OUR ROUTINE
        POP     DS
        MOV     STATUS,0                ;TURN PROCESSING OFF
        MOV     BX,BUFPNTR              ;PLACE STOP MARK IN BUFFER
        MOV     [BX],BYTE PTR 80H       ; .
        MOV     [BX+1],BYTE PTR 0FFH    ; .
        INC     COUNT                   ;INCREMENT COUNT
        INC     COUNT                   ; .
        POP     BX                      ;RESTORE REGISTERS
        POP     DS                      ; .
        JMP     CONTROL_DONE

CNTL_START:
        CMP     AH,01H                  ;START REQUEST?
        JNE     CNTL_RESUME             ; NO, CHECK RESUME
        MOV     CS:PORT,DL              ;SAVE PORT TO TRACE
        MOV     CS:BUFPNTR,OFFSET VECTOR_INIT   ;RESET BUFFER TO START
        MOV     CS:COUNT,0              ;ZERO COUNT
        MOV     CS:STATUS,1             ;START LOGGING
        JMP     CONTROL_DONE

CNTL_RESUME:
        CMP     AH,02H                  ;RESUME REQUEST?
        JNE     CNTL_STATUS             ; NO, CHECK STATUS
        CMP     CS:BUFPNTR,0            ;END OF BUFFER CONDITION?
        JE      CONTROL_DONE            ; YES, DO NOTHING
        MOV     CS:PORT,DL              ;SAVE PORT TO TRACE
        MOV     CS:STATUS,1             ;START LOGGING
        JMP     CONTROL_DONE

CNTL_STATUS:
        CMP     AH,03H                  ;RETURN STATUS REQUEST?
        JNE     CONTROL_DONE            ; NO, ERROR - DO NOTHING
        MOV     CX,CS:COUNT             ;RETURN COUNT
        PUSH    CS                      ;RETURN SEGMENT ADDR OF BUFFER
        POP     DX                      ; .
        MOV     BX,OFFSET VECTOR_INIT   ;RETURN OFFSET ADDR OF BUFFER
```

Figure 18-11. Continued. *(more)*

```
CONTROL_DONE:
        IRET

CONTROL ENDP


        SUBTTL  INITIALIZE INTERRUPT VECTORS
PAGE
; ************************************************************************
; *                                                                      *
; *  VECTOR_INIT                                                         *
; *  THIS PROCEDURE INITIALIZES THE INTERRUPT VECTORS AND THEN           *
; *  EXITS VIA THE MS-DOS TERMINATE-AND-STAY-RESIDENT FUNCTION.          *
; *  A BUFFER OF 64K IS RETAINED.  THE FIRST AVAILABLE BYTE              *
; *  IN THE BUFFER IS THE OFFSET OF VECTOR_INIT.                         *
; *                                                                      *
; ************************************************************************

        EVEN                            ;ASSURE BUFFER ON EVEN BOUNDARY
VECTOR_INIT     PROC    NEAR
;
;  GET ADDRESS OF COMM VECTOR (INT 14H)
;
        MOV     AH,35H
        MOV     AL,14H
        INT     21H
;
;  SAVE OLD COMM INT ADDRESS
;
        MOV     WORD PTR OLD_COMM_INT,BX
        MOV     AX,ES
        MOV     WORD PTR OLD_COMM_INT[2],AX
;
;  SET UP COMM INT TO POINT TO OUR ROUTINE
;
        MOV     DX,OFFSET COMMSCOPE
        MOV     AH,25H
        MOV     AL,14H
        INT     21H
;
;  INSTALL CONTROL ROUTINE INT
;
        MOV     DX,OFFSET CONTROL
        MOV     AH,25H
        MOV     AL,COMMSCOPE_INT
        INT     21H
;
;  SET LENGTH TO 64K, EXIT AND STAY RESIDENT
;
        MOV     AX,3100H                ;TERM AND STAY RES COMMAND
        MOV     DX,1000H                ;64K RESERVED
        INT     21H                     ;DONE
```

Figure 18-11. Continued. *(more)*

```
VECTOR_INIT ENDP

CSEG    ENDS
        END     INITIALIZE
```

Figure 18-11. Continued.

In order to use the symbolic debugging features of SYMDEB, a symbol file must be built in a specific format. The SYMDEB utility MAPSYM performs this function, using the contents of the .MAP file built by LINK. MAPSYM is easy to use because it has only two parameters: the .MAP file and the /L switch (which triggers verbose mode). The symbol table for BADSCOP is built as follows:

```
C>MAPSYM BADSCOP  <Enter>
```

This operation produces a symbol file called BADSCOP.SYM.

Armed with the .SYM file and the usual collection of listing and design notes, the programmer can begin the debugging process using SYMDEB.

The first task is to discover if the BADSCOP TSR is installing correctly. To test this, run the .COM file under SYMDEB by typing

```
C>SYMDEB BADSCOP.SYM BADSCOP.COM  <Enter>
```

Note the order in which operands are passed to SYMDEB — it is not the order that would be expected. All switches (none were used here) must immediately follow the word *SYMDEB*. These switches must be followed in turn by the fully qualified names of any symbol files (in this case, BADSCOP.SYM). Only then is the name of the file to be debugged given. If BADSCOP expected any parameters in the command tail, they would be last. This potential need for command-tail data is the reason the name of the file to be debugged follows the name of the symbol file. SYMDEB knows that the first non-.SYM file it encounters is the file to be loaded; the parameters that follow the filename may be of any form and number.

When SYMDEB begins, it displays

```
Microsoft (R) Symbolic Debug Utility  Version 4.00
Copyright (C) Microsoft Corp 1984, 1985. All rights reserved.

Processor is [80286]
```

The debugger identifies itself and then notes the type of CPU it is running on — in this case, an Intel 80286. The Display or Modify Registers command, R, gives the same display that DEBUG gives, with one exception.

```
-R  <Enter>
AX=0000  BX=0000  CX=0133  DX=0000  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1FD0  SS=1FD0  CS=1FD0  IP=0100   NV UP EI PL NZ NA PO NC
CSEG:INITIALIZE:
1FD0:0100 E90701         JMP  VECTOR_INIT
```

The instruction at CS:IP, JMP, is now preceded by the information that the instruction is at label *INITIALIZE* within segment *CSEG*. An examination of Figure 18-11 shows that this is indeed the case.

To check that all the symbols requested with the PUBLIC statement are present, use the X?* form of the Examine Symbol Map command.

```
-X?*  <Enter>

CSEG: (1FD0)
0100 INITIALIZE   0103 OLD_COMM_INT 0107 COUNT         0109 STATUS
010A PORT         010B BUFPNTR      010D COMMSCOPE     018F CONTROL
020A VECTOR_INIT
```

The display shows that the value of *CSEG* (1FD0H) matches the current value of CS. The offset values shown for the procedure names and data names match the numbers from an assembled listing. Because this is a .COM file, there is only one segment. If there had been other segments — a data segment, for instance — they would have been shown with their values and associated labels and offsets.

The purpose of this test is to determine whether the problems this program is having are caused by an incorrect installation. First, use the Trace Program Execution command, T, to trace through the first few steps.

```
-T7  <Enter>
AX=0000  BX=0000  CX=0133  DX=0000  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1FD0  SS=1FD0  CS=1FD0  IP=020A   NV UP EI PL NZ NA PO NC
CSEG:VECTOR_INIT:
1FD0:020A B435          MOV  AH,35                          ;'5'
AX=3500  BX=0000  CX=0133  DX=0000  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1FD0  SS=1FD0  CS=1FD0  IP=020C   NV UP EI PL NZ NA PO NC
1FD0:020C B014          MOV  AL,14
AX=3514  BX=0000  CX=0133  DX=0000  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1FD0  SS=1FD0  CS=1FD0  IP=020E   NV UP EI PL NZ NA PO NC
1FD0:020E CD21          INT  21  ;Get Interrupt Vector
AX=3514  BX=1375  CX=0133  DX=0000  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0210   NV UP EI PL NZ NA PO NC
1FD0:0210 891E0301      MOV  [OLD_COMM_INT],BX                DS:0103=0000
AX=3514  BX=1375  CX=0133  DX=0000  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0214   NV UP EI PL NZ NA PO NC
1FD0:0214 8CC0          MOV  AX,ES
AX=1567  BX=1375  CX=0133  DX=0000  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0216   NV UP EI PL NZ NA PO NC
1FD0:0216 A30501        MOV  [OLD_COMM_INT+02 (0105)],AX       DS:0105=0000
AX=1567  BX=1375  CX=0133  DX=0000  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0219   NV UP EI PL NZ NA PO NC
1FD0:0219 BA0D01        MOV  DX,010D
```

This part of the program uses Interrupt 21H Function 35H to obtain the current vector for Interrupt 14H. Note that, unlike DEBUG, SYMDEB coasts right through an Interrupt 21H call with no problems. It not only knows enough not to make the call but also displays the type of function call being made, based on the value in AH.

To make sure that the correct vector for the old Interrupt 14H handler has been stored, use the Display Doublewords command, DD, in conjunction with a symbol name.

```
-DD OLD_COMM_INT L1  <Enter>
1FD0:01030  1567:1375
```

This is the correct vector address (1567:1375H). Now trace through the next part of the program, which establishes the new vectors for interrupts.

```
-T8  <Enter>
AX=1567  BX=1375  CX=0133  DX=010D  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=021C   NV UP EI PL NZ NA PO NC
1FD0:021C B425          MOV  AH,25                          ;'%'
AX=2567  BX=1375  CX=0133  DX=010D  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=021E   NV UP EI PL NZ NA PO NC
1FD0:021E B014          MOV  AL,14
AX=2514  BX=1375  CX=0133  DX=010D  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0220   NV UP EI PL NZ NA PO NC
1FD0:0220 CD21          INT  21  ;Set Vector
AX=2514  BX=1375  CX=0133  DX=010D  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0222   NV UP EI PL NZ NA PO NC
1FD0:0222 BA8F01        MOV  DX,018F
AX=2514  BX=1375  CX=0133  DX=018F  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0225   NV UP EI PL NZ NA PO NC
1FD0:0225 B425          MOV  AH,25                          ;'%'
AX=2514  BX=1375  CX=0133  DX=018F  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0227   NV UP EI PL NZ NA PO NC
1FD0:0227 B060          MOV  AL,60                          ;'`'
AX=2560  BX=1375  CX=0133  DX=018F  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=0229   NV UP EI PL NZ NA PO NC
1FD0:0229 CD21          INT  21  ;Set Vector
AX=2560  BX=1375  CX=0133  DX=018F  SP=FFFE  BP=0000  SI=0000  DI=0000
DS=1FD0  ES=1567  SS=1FD0  CS=1FD0  IP=022B   NV UP EI PL NZ NA PO NC
1FD0:022B B80031        MOV  AX,3100
```

Examination of these trace steps shows that all went normally. The new Interrupt 14H vector has been established at *COMMSCOPE*; the vector for the new Interrupt 60H has also been correctly installed. Use the Go command, G, to allow the program to continue to termination and then use the Quit command, Q, to exit SYMDEB.

```
-G  <Enter>

Program terminated and stayed resident (0)
-Q  <Enter>
```

SYMDEB displays the information that the program terminated with a completion code of zero and stayed resident. This is as it should be, and the conclusion is that the installation portion of this TSR is running properly. The problem must be in the real-time execution of the program.

Debugging the resident portion of a TSR is complicated but not especially difficult. A simple program is used to exercise the TSR, and it is this program that is debugged. As this driver program exercises the TSR, the tracing process continues into the resident routine.

Because symbol tables exist for the TSR, symbolic debugging can be used to follow its execution.

The driver program will be TESTCOMM, shown in Figure 18-10. To make the program more easily usable by SYMDEB, one line has been added before the first SEGMENT statement:

```
PUBLIC      BEGIN,MAINLOOP,SENDCOMM,TESTCOMM
```

Using the .MAP file produced by LINK, the MAPSYM routine creates TESTCOMM.SYM. TESTCOMM can now be invoked with two symbol files:

```
C>SYMDEB TESTCOMM.SYM BADSCOP.SYM TESTCOMM.EXE  <Enter>
```

SYMDEB will load both symbol files and then load TESTCOMM.EXE. Because the name of the TESTCOMM.SYM file matches the name of the program being loaded, SYMDEB makes TESTCOMM.SYM the active symbol file.

Use the Register command to show that the test program was properly loaded.

```
-R  <Enter>
AX=0000  BX=0000  CX=0133  DX=0000  SP=0100  BP=0000  SI=0000  DI=0000
DS=38EE  ES=38EE  SS=38FE  CS=390E  IP=0000   NV UP EI PL NZ NA PO NC
CSEG:BEGIN:
390E:0000 1E             PUSH     DS
```

Then use the Examine Symbol Map command to determine whether the symbol files were loaded correctly. The form X* lists all the symbol maps and their segments; the form X?* lists all the symbols for the current symbol map and segment.

```
-X*  <Enter>
[38FE TESTCOMM]
      [390E CSEG]
 0000 BADSCOP
       0000 CSEG
-X?*  <Enter>

CSEG: (390E)
0000 BEGIN    0004 MAINLOOP 0011 SENDCOMM 0018 TESTCOMM
```

The current symbol map and segment are shown in square brackets. The symbol map for BADSCOP is also present but not selected. Note that there are no values associated with BADSCOP in the listing produced by the X?* command, because all the symbols currently available to SYMDEB are shown and only the symbols in TESTCOMM's *CSEG* are available (that is, TESTCOMM.SYM is the only active symbol file).

Recall that the BADSCOP TSR loaded normally but locked the system up at the first attempt to issue an Interrupt 14H. This behavior indicates that the problem is associated with an Interrupt 14H call. TESTCOMM repeatedly makes the system fail, but which of the Interrupt 14H calls within TESTCOMM is causing the trouble is not known. The most straightforward approach would be to put a breakpoint just before each Interrupt 14H instruction. Use the Disassemble (Unassemble) command, U, to find the location of all Interrupt 14H calls.

```
-U MAINLOOP L19  <Enter>
CSEG:MAINLOOP:
390E:0004 B406          MOV  AH,06
390E:0006 B2FF          MOV  DL,FF
390E:0008 CD21          INT  21
390E:000A 740C          JZ   TESTCOMM
390E:000C 3C03          CMP  AL,03
390E:000E 7501          JNZ  SENDCOMM
390E:0010 CB            RETF
CSEG:SENDCOMM:
390E:0011 B401          MOV  AH,01
390E:0013 BA0000        MOV  DX,BADSCOP!CSEG
390E:0016 CD14          INT  14
CSEG:TESTCOMM:
390E:0018 B403          MOV  AH,03
390E:001A BA0000        MOV  DX,BADSCOP!CSEG
390E:001D CD14          INT  14
390E:001F 80E401        AND  AH,01
390E:0022 74E0          JZ   MAINLOOP
390E:0024 B402          MOV  AH,02
390E:0026 BA0000        MOV  DX,BADSCOP!CSEG
390E:0029 CD14          INT  14
390E:002B B406          MOV  AH,06
390E:002D 8AD0          MOV  DL,AL
390E:002F CD21          INT  21
390E:0031 EBD1          JMP  MAINLOOP
```

The Disassemble request starts at *MAINLOOP* and acts on the next 25 (19H) instructions. SYMDEB displays symbol names instead of numbers whenever it can. However, it does get confused from time to time, so a grain of salt might be needed when reading the disassembly. Notice, for instance, the MOV DX,0 instructions at offsets 13H, 1AH, and 26H. SYMDEB has decided that what is being moved is not zero, but BADSCOP!CSEG. (The ! identifies a mapname in the same way a : defines a segment.) In this case, SYMDEB searched its map tables for an address of zero and found one at *CSEG* in BADSCOP. This segment has the address of zero because it has not been initialized.

Ignoring the name confusions, the disassembly clearly shows the three INT 14H instructions at offsets 16H, 1DH, and 29H. Use the Set Breakpoints command, BP, to set a sticky, or permanent, breakpoint at each of these locations. In this way, any Interrupt 14H call issued by TESTCOMM will be intercepted before it executes. Use the List Breakpoints command, BL, to verify the breakpoints.

```
-BP 16  <Enter>
-BP 1D  <Enter>
-BP 29  <Enter>
-BL  <Enter>
0 e 390E:0016 [CSEG:SENDCOMM+05 (0016)]
1 e 390E:001D [CSEG:TESTCOMM+05 (001D)]
2 e 390E:0029 [CSEG:TESTCOMM+11 (0029)]
```

The List Breakpoints command shows that breakpoint 0 is enabled and set to *SENDCOMM+05*, or CS:0016H. Likewise, breakpoint 1 is at CS:001DH and breakpoint 2 is at CS:0029H. It is important to trap on an Interrupt 14H so that the subsequent actions of the Interrupt 14H service routine can be traced. Now allow the program to execute until it encounters a breakpoint.

```
-G  <Enter>
AX=0300  BX=0000  CX=0133  DX=0000  SP=00FC  BP=0000  SI=0000  DI=0000
DS=38EE  ES=38EE  SS=38FE  CS=390E  IP=001D   NV UP EI PL ZR NA PE NC
390E:001D CD14           INT     14                            ;BR1
```

The first Interrupt 14H encountered is the one at the second breakpoint, breakpoint 1, as can be seen from the address at which execution broke. Also, SYMDEB was kind enough to include the comment *;BR1* on the disassembled line, indicating that this is Break Request 1. The instruction at this location is a request for serial port status (AH = 3) and the registers are loaded correctly. Execution can now be passed to the TSR by simply executing the current instruction. (Remember that the instruction displayed at a breakpoint has not yet been executed.)

```
-T  <Enter>
AX=0300  BX=0000  CX=0133  DX=0000  SP=00F6  BP=0000  SI=0000  DI=00Q0
DS=38EE  ES=38EE  SS=38FE  CS=1FD0  IP=010D   NV UP DI PL ZR NA PE NC
1FD0:010D 2EF606090101   TEST       Byte Ptr CS:[0109],01              CS:0109=00
```

The single Trace command has moved execution into the TSR. Note that the Interrupt 14H has changed the value of CS and jumped to location 10DH off the new CS. This location contains the first instruction of the *COMMSCOPE* procedure in the TSR. SYMDEB does not know that a different segment is being executed and must be instructed to use a different map table. Use the Open Symbol Map command, XO, to do this, instructing SYMDEB to set the active map table to BADSCOP!.

```
-XO BADSCOP!  <Enter>
-X?*  <Enter>

CSEG: (0000)
0100 INITIALIZE   0103 OLD_COMM_INT 0107 COUNT         0109 STATUS
010A PORT         010B BUFPNTR      010D COMMSCOPE     018F CONTROL
020A VECTOR_INIT
```

The X?* command shows that the BADSCOP symbols are now the current map. They are not usable, however, because the value of *CSEG*—zero—needs to be changed to the current CS register. To correct this, use the SYMDEB Set Symbol Value command, Z. This command can set any symbol in the current map table to any value; the value can be a number, another symbol, or the contents of a register. In this case, set the value of *CSEG* in BADSCOP! to the current contents of the CS register.

```
-Z CSEG CS  <Enter>
-X*  <Enter>
 38FE TESTCOMM
       390E CSEG
[0000 BADSCOP]
      [1FD0 CSEG]
```

The X* command confirms that BADSCOP! is now the selected symbol map and that the *CSEG* within it has the value 1FD0H. The *CSEG* segment in TESTCOMM is an entirely different entity and still has its correct value, which will be valid when the TSR returns.

With the symbols set, the debugging can begin by tracing the first few instructions. Because *COMMSCOPE* is not currently active, the routine should quickly pass the processing on to the old interrupt handler.

```
-T5  <Enter>
AX=0300  BX=0000  CX=0133  DX=0000  SP=00F6  BP=0000  SI=0000  DI=0000
DS=38EE  ES=38EE  SS=38FE  CS=1FD0  IP=0113   NV UP DI PL ZR NA PE NC
1FD0:0113 7476          JZ  COMMSCOPE+7E (018B)
AX=0300  BX=0000  CX=0133  DX=0000  SP=00F6  BP=0000  SI=0000  DI=0000
DS=38EE  ES=38EE  SS=38FE  CS=1FD0  IP=018B   NV UP DI PL ZR NA PE NC
1FD0:018B FF2E0301      JMP  FAR [0103]                        DS:0103=0000
AX=0300  BX=0000  CX=0133  DX=0000  SP=00F6  BP=0000  SI=0000  DI=0000
DS=38EE  ES=38EE  SS=38FE  CS=0000  IP=0000   NV UP DI PL ZR NA PE NC
0000:0000 381E6715      CMP  [1567],BL                         DS:1567=00
AX=0300  BX=0000  CX=0133  DX=0000  SP=00F6  BP=0000  SI=0000  DI=0000
DS=38EE  ES=38EE  SS=38FE  CS=0000  IP=0004   NV UP DI PL ZR NA PE NC
0000:0004 BC2CE1        MOV  SP,E12C
AX=0300  BX=0000  CX=0133  DX=0000  SP=E12C  BP=0000  SI=0000  DI=0000
DS=38EE  ES=38EE  SS=38FE  CS=0000  IP=0007   NV UP DI PL ZR NA PE NC
0000:0007 2F            DAS
```

STATUS is tested with a mask of 01H at CS:010DH; the test sets the zero flag, indicating that tracing is disabled. The JZ to *COMMSCOPE+7E* (CS:018BH) is taken. At this address is a far jump to the old Interrupt 14H handler at 1567:1375H. The jump is taken and then disaster strikes. Instead of going to the correct address, processing is suddenly at 0000:0000H. Any wild jump is dangerous, but a far jump into low memory is exceptionally so. This explains the system's locking up and requiring a cold boot to recover.

Now that the bug has been caught in the act, it should be a simple matter to determine what went wrong. When the BADSCOP TSR installed itself, it was seen to place the correct offset address at 0103H. Yet whenever the resident portion of the TSR tries to use the value at that address, it finds all zeros. The initialization routine placed the address at the symbol *OLD_COMM_INT* (1FD0:0103H). If that location is examined, the following is found:

```
-DD OLD_COMM_INT L1  <Enter>
1FD0:0103  1567:1375
```

This is the correct address. Why, then, did the programs find zero there? Use the Display Doublewords command to look at the same memory location again, this time using the specific address 0103H rather than a program symbol.

```
-DD 103 L1  <Enter>
38EE:0103  0000:0000
```

The dump of *OLD_COMM_INT* looked at 1FD0:0103H, but the simple dump looked at 38EE:0103H. The explanation is clear when the values of the registers just before the far jump are examined. The CS register contains 1FD0H and the DS register contains 38EEH.

This is the problem—there is a missing CS override on the indirect jump command. When the TSR installed itself, CS and DS were the same because it was a .COM file. When the TSR is entered as the result of an interrupt call, only CS is set; DS remains what it was in the calling program. Without an override, the CPU assumed that the address of the destination of the far call was located at offset 103H from the DS register. This offset, unfortunately, contained zeros, and the program locked up the system.

The problem is now easily corrected. Exit SYMDEB with the Quit command and edit the program source so that the offending line reads

```
OLD_JUMP:
        JMP     CS:OLD_COMM_INT
```

Debugging C programs with SYMDEB

One of SYMDEB's finest features is the ability to debug with source-line data from programs written in Microsoft C, Pascal, and FORTRAN. The actual lines of C or FORTRAN can be included in the debugging display, and the addresses for breakpoints show which line of code the breakpoints are in. Combined with symbolic debugging, these features provide a powerful tool that can significantly reduce debugging time for programs written in a supported language.

The following rather complicated case illustrates SYMDEB at its best. The program BADSCOP from the previous example was not completely debugged. Although the patch to the BADSCOP code at *OLD_JUMP:* did correct the disastrous problem that caused the system to lock up, running the program in a realistic test situation reveals that a subtle problem still remains that might be in either BADSCOP or one of the support programs.

Before we investigate the problem, a quick review of the programs in the COMMSCOP system is in order. At the heart of the system is the Interrupt 14H intercept program COMMSCOP. When executed, this program installs itself as a TSR and intercepts all Interrupt 14H calls. (The incorrect version of the COMMSCOP program is called BADSCOP.) The installed COMMSCOP TSR passes all Interrupt 14H calls on to the real service routine in the ROM BIOS until it is commanded to start tracing. The COMMSCMD routine controls tracing. This control routine can request that COMMSCOP start, stop, or resume tracing for a specific serial port. These commands are facilitated through Interrupt 60H, which is recognized by the COMMSCOP TSR as a command request. When tracing is started, the trace buffer is emptied by zeroing the trace count and setting the buffer pointer to the first buffer location. When tracing is stopped by COMMSCMD's STOP command, a marker is placed in the buffer to indicate the end of a trace segment. Tracing can be resumed with COMMSCMD's RESUME command. Resuming a trace preserves collected data and places new trace data after the marker in the trace buffer. The RESUME command differs from the START command in that the buffer is not emptied.

Now the problem: When the serial data tracing is started with COMMSCMD (*see* Figure 18-5), data is collected normally. When COMMSCMD issues a STOP command and the data is displayed with COMMDUMP (*see* Figure 18-7), the data appears normal. The traced data ends with a stop mark just as it should. However, the RESUME command of

COMMSCMD causes the stop mark to be overwritten with collected data. After this, whenever COMMDUMP displays data an extra byte appears at the end of the data. The problem could be with either BADSCOP or COMMSCMD. SYMDEB has the facilities to debug both the routines at once.

The first step in the debugging process is, as usual, to gather all the listings and design documentation. As a part of this process, the symbol tables needed for SYMDEB must be prepared. The process of preparing a symbol table for BADSCOP has already been explained; however, preparing the SYMDEB input and supporting listings for a C program is slightly more complicated.

First, when the C program is compiled, three switches must be specified. (C switches are case sensitive and must be entered exactly as shown.)

```
C>MSC /Fc /Zd /Od COMMSCMD;  <Enter>
```

The /Zd switch produces an object file containing line-number information that corresponds to the line numbers of the source file. The /Od switch disables optimization that involves complex code rearrangement; localized optimization, peephole optimization, and other simple forms of optimization are still performed. The /Od switch is not required, but code rearrangement can make the resulting object code more difficult to debug.

The /Fc switch invokes a feature of C that is especially important for debugging with SYMDEB: a listing that contains the C source lines and the generated assembler code intermixed. The file is a .COD file; the command line shown above would produce the file COMMSCMD.COD. Figure 18-12 shows the contents of COMMSCMD.COD.

```
;       Static Name Aliases
;
;       $S142_commands  EQU     commands
        TITLE   commscmd
;       NAME    commscmd.C

        .287
_TEXT   SEGMENT  BYTE PUBLIC 'CODE'
_TEXT   ENDS
_DATA   SEGMENT  WORD PUBLIC 'DATA'
_DATA   ENDS
CONST   SEGMENT  WORD PUBLIC 'CONST'
CONST   ENDS
_BSS    SEGMENT  WORD PUBLIC 'BSS'
_BSS    ENDS
DGROUP  GROUP   CONST,  _BSS,   _DATA
        ASSUME  CS: _TEXT, DS: DGROUP, SS: DGROUP, ES: DGROUP
EXTRN   _int86:NEAR
EXTRN   _printf:NEAR
EXTRN   _stricmp:NEAR
EXTRN   _atoi:NEAR
EXTRN   __chkstk:NEAR
_DATA     SEGMENT
```

Figure 18-12. COMMSCMD.COD.

(more)

```
$SG148  DB      'STOP',  00h
$SG151  DB      'START',  00h
$SG154  DB      'RESUME',  00h
$SG157  DB      0ah, 'Communications tracing %s for port COM%1d:',  0ah,  00h
$S142_commands  DB      'STOPPED',  00h
        ORG     $+2
        DB      'STARTED',  00h
        ORG     $+2
        DB      'RESUMED',  00h
        ORG     $+2
_DATA       ENDS
_TEXT       SEGMENT
;¦*** /*************************************************************************
;¦***  *                                                                       *
;¦***  *  COMMSCMD                                                             *
;¦***  *                                                                       *
;¦***  *  This routine controls the COMMSCOP program that has been in-         *
;¦***  *  stalled as a resident routine.  The operation performed is de-       *
;¦***  *  termined by the command line.  The COMMSCMD program is invoked       *
;¦***  *  as follows:                                                          *
;¦***  *                                                                       *
;¦***  *                COMMSCMD [[cmd][ port]]                                *
;¦***  *                                                                       *
;¦***  *  where cmd is the command to be executed                              *
;¦***  *            STOP   -- stop trace                                       *
;¦***  *            START  -- flush trace buffer and start trace               *
;¦***  *            RESUME -- resume a stopped trace                           *
;¦***  *        port is the COMM port to be traced (1=COM1, 2=COM2, etc.)      *
;¦***  *                                                                       *
;¦***  *  If cmd is omitted, STOP is assumed.  If port is omitted, 1 is        *
;¦***  *  assumed.                                                             *
;¦***  *                                                                       *
;¦***  *************************************************************************/
;¦***
;¦*** #include <stdlib.h>
;¦*** #include <stdio.h>
;¦*** #include <dos.h>
;¦*** #define COMMSCMD 0x60
;¦***
;¦*** main(argc, argv)
;¦*** int argc;
; Line 29
        PUBLIC _main
_main   PROC NEAR
        *** 000000      55                      push    bp
        *** 000001      8b ec                   mov     bp,sp
        *** 000003      b8 22 00                mov     ax,34
        *** 000006      e8 00 00                call    __chkstk
        *** 000009      57                      push    di
        *** 00000a      56                      push    si
```

Figure 18-12. Continued. *(more)*

```
;|*** char *argv[];
;|*** {
; Line 31
;       argc = 4
;       argv = 6
;       cmd = -4
;       port = -6
;       result = -2
;       inregs = -34
;       outregs = -20
;|***     int cmd, port, result;
;|***     static char commands[3] [10] = {"STOPPED", "STARTED", "RESUMED"};
;|***     union REGS inregs, outregs;
;|***
;|***     cmd = 0;
; Line 36
        *** 00000b     c7 46 fc 00 00          mov     WORD PTR [bp-4],0    ;cmd
;|***     port = 0;
; Line 37
        *** 000010     c7 46 fa 00 00          mov     WORD PTR [bp-6],0    ;port
;|***
;|***     if (argc > 1)
; Line 39
        *** 000015     83 7e 04 01             cmp     WORD PTR [bp+4],1    ;argc
        *** 000019     7f 03                   jg      $JCC25
        *** 00001b     e9 5d 00                jmp     $I145
                                       $JCC25:
;|***      {
; Line 40
;|***      if (0 == stricmp(argv[1], "STOP"))
; Line 41
        *** 00001e     b8 00 00                mov     ax,OFFSET DGROUP:$SG148
        *** 000021     50                      push    ax
        *** 000022     8b 5e 06                mov     bx,[bp+6]            ;argv
        *** 000025     ff 77 02                push    WORD PTR [bx+2]
        *** 000028     e8 00 00                call    _stricmp
        *** 00002b     83 c4 04                add     sp,4
        *** 00002e     3d 00 00                cmp     ax,0
        *** 000031     74 03                   je      $JCC49
        *** 000033     e9 08 00                jmp     $I147
                                       $JCC49:
;|***             cmd = 0;
; Line 42
        *** 000036      c7 46 fc 00 00          mov     WORD PTR [bp-4],0    ;cmd
;|***         else if (0 == stricmp(argv[1], "START"))
```

Figure 18-12. Continued. *(more)*

```
; Line 43
        *** 00003b      e9 3d 00                jmp     $I149
                                        $I147:
        *** 00003e      b8 05 00                mov     ax,OFFSET DGROUP:$SG151
        *** 000041      50                      push    ax
        *** 000042      8b 5e 06                mov     bx,[bp+6]       ;argv
        *** 000045      ff 77 02                push    WORD PTR [bx+2]
        *** 000048      e8 00 00                call    _stricmp
        *** 00004b      83 c4 04                add     sp,4
        *** 00004e      3d 00 00                cmp     ax,0
        *** 000051      74 03                   je      $JCC81
        *** 000053      e9 08 00                jmp     $I150
                                        $JCC81:
;¦***           cmd = 1;
; Line 44
        *** 000056      c7 46 fc 01 00          mov     WORD PTR [bp-4],1       ;cmd
;¦***        else if (0 == stricmp(argv[1], "RESUME"))
; Line 45
        *** 00005b      e9 1d 00                jmp     $I152
                                        $I150:
        *** 00005e      b8 0b 00                mov     ax,OFFSET DGROUP:$SG154
        *** 000061      50                      push    ax
        *** 000062      8b 5e 06                mov     bx,[bp+6]       ;argv
        *** 000065      ff 77 02                push    WORD PTR [bx+2]
        *** 000068      e8 00 00                call    _stricmp
        *** 00006b      83 c4 04                add     sp,4
        *** 00006e      3d 00 00                cmp     ax,0
        *** 000071      74 03                   je      $JCC113
        *** 000073      e9 05 00                jmp     $I153
                                        $JCC113:
;¦***           cmd = 2;
; Line 46
        *** 000076      c7 46 fc 02 00          mov     WORD PTR [bp-4],2       ;cmd
;¦***        }
; Line 47
                                        $I153:
                                        $I152:
                                        $I149:
;¦***
;¦***    if (argc == 3)
; Line 49
                                        $I145:
        *** 00007b      83 7e 04 03             cmp     WORD PTR [bp+4],3       ;argc
        *** 00007f      74 03                   je      $JCC127
        *** 000081      e9 1b 00                jmp     $I155
                                        $JCC127:
;¦***        {
; Line 50
;¦***        port = atoi(argv[2]);
```

Figure 18-12. Continued.

(more)

```
; Line 51
        *** 000084      8b 5e 06                    mov     bx,[bp+6]               ;argv
        *** 000087      ff 77 04                    push    WORD PTR [bx+4]
        *** 00008a      e8 00 00                    call    _atoi
        *** 00008d      83 c4 02                    add     sp,2
        *** 000090      89 46 fa                    mov     [bp-6],ax               ;port
;¦***          if (port > 0)
; Line 52
        *** 000093      83 7e fa 00                 cmp     WORD PTR [bp-6],0       ;port
        *** 000097      7f 03                       jg      $JCC151
        *** 000099      e9 03 00                    jmp     $I156
                                        $JCC151:
;¦***              port = port-1;
; Line 53
        *** 00009c      ff 4e fa                    dec     WORD PTR [bp-6]         ;port
;¦***          }
; Line 54
                                        $I156:
;¦***
;¦***      inregs.h.ah = cmd;
; Line 56
                                        $I155:
        *** 00009f      8a 46 fc                    mov     al,[bp-4]               ;cmd
        *** 0000a2      88 46 df                    mov     [bp-33],al
;¦***      inregs.x.dx = port;
; Line 57
        *** 0000a5      8b 46 fa                    mov     ax,[bp-6]               ;port
        *** 0000a8      89 46 e4                    mov     [bp-28],ax
;¦***      result = int86(COMMCMD, &inregs, &outregs);
; Line 58
        *** 0000ab      8d 46 ec                    lea     ax,[bp-20]              ;outregs
        *** 0000ae      50                          push    ax
        *** 0000af      8d 46 de                    lea     ax,[bp-34]              ;inregs
        *** 0000b2      50                          push    ax
        *** 0000b3      b8 60 00                    mov     ax,96
        *** 0000b6      50                          push    ax
        *** 0000b7      e8 00 00                    call    _int86
        *** 0000ba      83 c4 06                    add     sp,6
        *** 0000bd      89 46 fe                    mov     [bp-2],ax               ;result
;¦***
;¦***
;¦***      printf("\nCommunications tracing %s for port COM%1d:\n",
;¦***              commands[cmd], port + 1);
; Line 62
        *** 0000c0      8b 46 fa                    mov     ax,[bp-6]               ;port
        *** 0000c3      40                          inc     ax
        *** 0000c4      50                          push    ax
        *** 0000c5      8b 46 fc                    mov     ax,[bp-4]               ;cmd
        *** 0000c8      8b c8                       mov     cx,ax
        *** 0000ca      d1 e0                       shl     ax,1
        *** 0000cc      d1 e0                       shl     ax,1
        *** 0000ce      03 c1                       add     ax,cx
        *** 0000d0      d1 e0                       shl     ax,1
```

Figure 18-12. Continued. *(more)*

```
        *** 0000d2     05 40 00                add     ax,OFFSET DGROUP:$S142_commands
        *** 0000d5     50                      push    ax
        *** 0000d6     b8 12 00                mov     ax,OFFSET DGROUP:$SG157
        *** 0000d9     50                      push    ax
        *** 0000da     e8 00 00                call    _printf
        *** 0000dd     83 c4 06                add     sp,6
;|*** }
; Line 63
                                       $EX138:
        *** 0000e0     5e                      pop     si
        *** 0000e1     5f                      pop     di
        *** 0000e2     8b e5                   mov     sp,bp
        *** 0000e4     5d                      pop     bp
        *** 0000e5     c3                      ret

_main     ENDP
_TEXT     ENDS
END
```

Figure 18-12. Continued.

After the C program is compiled, it must be linked using the /LI switch to indicate that the line number information is to be maintained:

```
C>LINK COMMSCMD /MAP /LI;  <Enter>
```

The /MAP switch is still required to generate a map file of public names for use in building the symbol file, which is created in the usual manner:

```
C>MAPSYM COMMSCMD  <Enter>
```

Everything needed to debug COMMSCMD and BADSCOP is now available. The first test is an attempt to start tracing. To invoke SYMDEB, type

```
C>SYMDEB COMMSCMD.SYM BADSCOP.SYM COMMSCMD.EXE START 1  <Enter>
```

SYMDEB first loads the symbol files for COMMSCMD and BADSCOP and then loads the .EXE file for COMMSCMD. BADSCOP is already in memory, having been loaded by simply running it. (It then stays resident.) The last two entries in the command line load the command tail for COMMSCMD with a start request for COM1. SYMDEB responds with

```
Microsoft (R) Symbolic Debug Utility  Version 4.00
Copyright (C) Microsoft Corp 1984, 1985. All rights reserved.

Processor is [80286]
```

Use the Register and Examine Symbol Map commands to display the initial register values and symbol table information.

```
-R  <Enter>
AX=0000  BX=0000  CX=1928  DX=0000  SP=0800  BP=0000  SI=0000  DI=0000
DS=2CA0  ES=2CA0  SS=2E85  CS=2CB0  IP=010F   NV UP EI PL NZ NA PO NC
_TEXT:__astart:
2CB0:010F B430          MOV  AH,30                      ;'0'
-X*  <Enter>
[2CB0 COMMSCMD]
      [2CB0 _TEXT]
       2E08 DGROUP
 0000 BADSCOP
       0000 CSEG
-X?*  <Enter>
9876 __acrtused    9876 __acrtmsg
_TEXT: (2CB0)
0010 _main         00F6 _atoi
00F9 __chkstk      010F __astart      01AB __cintDIV     01AE __amsg_exit
01B9 _int86        023A _printf       0270 _strcmpi      0270 _stricmp
02C2 __stbuf       0361 __ftbuf       03E7 __catox       043C __nullcheck
0458 __cinit       0507 _exit         051E __exit        054A __ctermsub
0572 __dosret0     057A __dosretax    0586 __maperror    05BA __NMSG_TEXT
05EA __NMSG_WRITE  0613 __output      0E22 __setargv     0F07 __setenvp
0F6D __flsbuf      1098 __fassign     1098 __cropzeros   1098 __positive
1098 __forcdecpt   1098 __cfltcvt     109B _fflush       1103 _isatty
1125 __myalloc     1167 _strlen       1182 _ultoa        118C __fptrap
1192 _flushall     11C3 _free         11C3 __nfree       11D1 _malloc
11D1 __nmalloc     1217 _write        12F1 __cltoasub    12FD __cxtoa
1351 __amalloc     1432 __amexpand    146C __amlink      148E __amallocbrk
14AD _brkctl
DGROUP: (2E08)
0094 STKHQQ        0096 __asizds      0098 __atopsp
009A __abrktb      00EA __abrktbe     00EA __abrkp       00EC __iob
018C __iob2        0204 __lastiob     0212 __aintdiv     0216 __fac
021E _errno        0220 __umaskval    0222 __pspadr      0224 __psp
0226 __osmajor     0226 __dosvermajor 0227 __osminor     0227 __dosverminor
0228 __oserr       0228 __doserrno    022A __osfile      023E ___argc
0240 ___argv       0242 _environ      0244 __child       0246 __csigtab
0278 __cflush      027A __asegds      0286 __aseg1       0288 __asegn
028A __asegr       028C __amblksiz    0292 __fpinit      03A8 _edata
03D0 __bufout      05D0 __bufin       07D0 _end
```

The Register command shows that the first instruction to be executed will be at symbol *__astart* in the _TEXT segment. (Note that C puts a single underscore in front of all public library and routine names; a double underscore indicates routines for C's internal use.) The Examine Symbol Map command reveals that the symbol map COMMSCMD! has two segments, *_TEXT* and *DGROUP*, with *_TEXT* currently selected. The segment in BADSCOP!, *CSEG*, has no value assigned to it because SYMDEB doesn't know where it is; one of the debugging tasks is to determine the location of *CSEG*.

C places initialization and preamble code at the front of its object modules. This code can be skipped during debugging, so this example begins at the label *_main*. Examination of the code at this label using the Disassemble command reveals the following:

```
-U _main  <Enter>
commscmd.C
29:  int argc;
_TEXT:_main:
2CB0:0010 55            PUSH    BP
2CB0:0011 8BEC          MOV     BP,SP
2CB0:0013 B82200        MOV     AX,0022
2CB0:0016 E8E000        CALL    __chkstk
2CB0:0019 57            PUSH    DI
```

This disassembly shows the way source-line information is displayed. These instructions are generated by line 29 of COMMSCMD.C. When the disassembly is compared with the listing in Figure 18-12, the same instructions are seen. However, their addresses are different. The addresses in the disassembly are relative to the start of the segment *_TEXT*, but the addresses in the listing are relative to the start of *_main*. SYMDEB allows address references to be made relative to a symbol, so breakpoints can be set as displacements from *_main* and the addresses shown in the listing can be used.

Because the location of the problem being debugged is not known, breakpoints must be placed strategically throughout COMMSCMD to trace the execution of the program. Use the Set Breakpoints command to set the breakpoints.

```
-BP _main+1e  <Enter>
-BP _main+36  <Enter>
-BP _main+56  <Enter>
-BP _main+76  <Enter>
-BP _main+7b  <Enter>
-BP _main+9c  <Enter>
-BP _main+b7  <Enter>
-BP _main+e5  <Enter>
-BL  <Enter>
0 e 2CB0:002E [_TEXT:_main+1E (002E)] commscmd.C:41
1 e 2CB0:0046 [_TEXT:_main+36 (0046)] commscmd.C:42
2 e 2CB0:0066 [_TEXT:_main+56 (0066)] commscmd.C:44
3 e 2CB0:0086 [_TEXT:_main+76 (0086)] commscmd.C:46
4 e 2CB0:008B [_TEXT:_main+7B (008B)] commscmd.C:49
5 e 2CB0:00AC [_TEXT:_main+9C (00AC)] commscmd.C:53
6 e 2CB0:00C7 [_TEXT:_main+B7 (00C7)] commscmd.C:58
7 e 2CB0:00F5 [_TEXT:_main+E5 (00F5)] commscmd.C:63
```

The List Breakpoints command shows the breakpoint addresses in three ways: first the absolute segment:offset address, then the displacement from the label *_main*, and finally the line number in COMMSCMD.C.

The first part of the COMMSCMD program decodes the arguments and sets the appropriate values for *cmd* and *port*. If there are no arguments, this decoding is skipped; if there are arguments, the decoding begins at line 41, so the first breakpoint is set there. If the criterion of line 41 is met (the first argument is STOP), then line 42 is executed. The second breakpoint is set there. Reaching the second breakpoint means that a STOP command was properly decoded. If the command was not STOP, execution continues at line 43. If this

test is passed, line 44 is executed. This is the location of the third breakpoint. If the test at line 44 fails but the one at line 45 is passed, then the breakpoint at line 46 is executed. Whether or not one of the tests passes, execution ends up at line 49. At this point, the program tests for the presence of a second operand. If there is a second operand, execution traps at line 53, where the program decrements the port number to put it in the proper form for the Interrupt 60H handler. Execution will then always stop in line 58, just before the call to *_int86*. (*_int86* is a library routine that loads registers and executes INT instructions.)

When the program is run with *START1* in the command tail, it gives the following results:

```
-G  <Enter>
AX=0022  BX=0F82  CX=0019  DX=0098  SP=0F7E  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=002E   NV UP EI PL NZ NA PO NC
41:               if (0 == stricmp(argv[1],"STOP"))
2CB0:002E B83600          MOV        AX,0036                    ;BR0
-G  <Enter>
AX=0000  BX=415A  CX=0000  DX=0098  SP=0F7E  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=0066   NV UP EI PL ZR NA PE NC
44:                       cmd = 1;
2CB0:0066 C746FC0100      MOV        Word Ptr [BP-04],0001      ;BR2 SS:0FA0=0000
-G  <Enter>
AX=0000  BX=415A  CX=0000  DX=0098  SP=0F7E  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=008B   NV UP EI PL ZR NA PE NC
49:            if (argc == 3)
2CB0:008B 837E0403        CMP        Word Ptr [BP+04],+03       ;BR4 SS:0FA8=0003
-G  <Enter>
AX=0001  BX=00D0  CX=0000  DX=0000  SP=0F7E  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00AC   NV UP EI PL NZ NA PO NC
5              port = port-1;
2CB0:00AC FF4EFA          DEC        Word Ptr [BP-06]           ;BR5 SS:0F9E=0001
-G  <Enter>
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F78  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00C7   NV UP EI PL ZR NA PE NC
2CB0:00C7 E8EF00          CALL       _int86                     ;BR6
```

The first break occurs at line 41, indicating that one or more arguments were present in the command line. The next break is at line 44, where the program sets the *cmd* code for Interrupt 60H to 1, the correct value for a start request. The next break occurs at line 49, where the program checks the number of arguments. If this number is 3, then there is a second argument in the command line. (Remember that, in C, the first argument is the name of the routine, so an argument count of 3 actually means that there are 2 arguments present.) The number of arguments is at BP+04, or SS:0FA8H, and it is indeed 3. Therefore, the next break is at line 53. The program decrements the current value of *port*, leaving a value of 0, which is what Interrupt 60H expects to see for COM1.

Continuing execution causes a break just before the call to *_int86*. To validate that the Interrupt 60H call is being made correctly, set a breakpoint just before the INT 60H instruction is issued. Unfortunately, no listing of *_int86* is available, so no alternative

exists but to trace the execution of the routine until the INT instruction is issued. The details of the processing are of no interest to this debugging session, so they can be ignored until an INT 60H is seen. (The trace offers a great deal of information about how C interfaces with subroutines. Studying the trace would be educational but is beyond the scope of this example.)

```
-T 5  <Enter>
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F76  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01B9   NV UP EI PL ZR NA PE NC
_TEXT:_int86:
2CB0:01B9 55              PUSH     BP
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F74  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01BA   NV UP EI PL ZR NA PE NC
2CB0:01BA 8BEC            MOV      BP,SP
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F74  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01BC   NV UP EI PL ZR NA PE NC
2CB0:01BC 56              PUSH     SI
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F72  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01BD   NV UP EI PL ZR NA PE NC
2CB0:01BD 57              PUSH     DI
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F70  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01BE   NV UP EI PL ZR NA PE NC
2CB0:01BE 83EC0A          SUB      SP,+0A
-T 5  <Enter>
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01C1   NV UP EI PL NZ AC PE NC
2CB0:01C1 C646F6CD        MOV      Byte Ptr [BP-0A],CD                SS:0F6A=BE
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01C5   NV UP EI PL NZ AC PE NC
2CB0:01C5 8B4604          MOV      AX,[BP+04]                         SS:0F78=0060
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01C8   NV UP EI PL NZ AC PE NC
2CB0:01C8 8846F7          MOV      [BP-09],AL                         SS:0F6B=01
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01CB   NV UP EI PL NZ AC PE NC
2CB0:01CB 3C25            CMP      AL,25                              ;'%'
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01CD   NV UP EI PL NZ AC PO NC
2CB0:01CD 740A            JZ       _int86+20 (01D9)
-T 5  <Enter>
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01CF   NV UP EI PL NZ AC PO NC
2CB0:01CF 3C26            CMP      AL,26                              ;'&'
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01D1   NV UP EI PL NZ AC PE NC
2CB0:01D1 7406            JZ       _int86+20 (01D9)
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01D3   NV UP EI PL NZ AC PE NC
2CB0:01D3 C646F8CB        MOV      Byte Ptr [BP-08],CB                SS:0F6C=B0
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01D7   NV UP EI PL NZ AC PE NC
```

(more)

```
2CB0:01D7 EB0C          JMP     _int86+2C (01E5)
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01E5   NV UP EI PL NZ AC PE NC
2CB0:01E5 8C56F4        MOV     [BP-0C],SS                    SS:0F68=0F74
-T 5  <Enter>
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01E8   NV UP EI PL NZ AC PE NC
2CB0:01E8 8D46F6        LEA     AX,[BP-0A]                    SS:0F6A=60CD
AX=0F6A  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01EB   NV UP EI PL NZ AC PE NC
2CB0:01EB 8946F2        MOV     [BP-0E],AX                    SS:0F66=0060
AX=0F6A  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01EE   NV UP EI PL NZ AC PE NC
2CB0:01EE 8B7E06        MOV     DI,[BP+06]                    SS:0F7A=0F82
AX=0F6A  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=0F82
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01F1   NV UP EI PL NZ AC PE NC
2CB0:01F1 8B05          MOV     AX,[DI]                       DS:0F82=0100
AX=0100  BX=00D0  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=0F82
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01F3   NV UP EI PL NZ AC PE NC
2CB0:01F3 8B5D02        MOV     BX,[DI+02]                    DS:0F84=0000
-T 5  <Enter>
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=0F82
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01F6   NV UP EI PL NZ AC PE NC
2CB0:01F6 8B4D04        MOV     CX,[DI+04]                    DS:0F86=0000
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=0F82
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01F9   NV UP EI PL NZ AC PE NC
2CB0:01F9 8B5506        MOV     DX,[DI+06]                    DS:0F88=0000
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0089  DI=0F82
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01FC   NV UP EI PL NZ AC PE NC
2CB0:01FC 8B7508        MOV     SI,[DI+08]                    DS:0F8A=0000
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0000  DI=0F82
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=01FF   NV UP EI PL NZ AC PE NC
2CB0:01FF 8B7D0A        MOV     DI,[DI+0A]                    DS:0F8C=0000
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F66  BP=0F74  SI=0000  DI=0000
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=0202   NV UP EI PL NZ AC PE NC
2CB0:0202 55            PUSH    BP
-T 5  <Enter>
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F64  BP=0F74  SI=0000  DI=0000
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=0203   NV UP EI PL NZ AC PE NC
2CB0:0203 83ED0E        SUB     BP,+0E
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F64  BP=0F66  SI=0000  DI=0000
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=0206   NV UP EI PL NZ AC PE NC
2CB0:0206 FF5E00        CALL    FAR [BP+00]                   SS:0F66=0F6A
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F60  BP=0F66  SI=0000  DI=0000
DS=2E08  ES=2E08  SS=2E08  CS=2E08  IP=0F6A   NV UP EI PL NZ AC PE NC
2E08:0F6A CD60          INT     60
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=0000
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0190   NV UP DI PL NZ AC PE NC
1313:0190 80FC00        CMP     AH,00
AX=0100  BX=0000  CX=0000  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=0000
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0193   NV UP DI PL NZ NA PO NC
1313:0193 7521          JNZ     01B6
```

When the Interrupt 60H call is encountered at offset 0F6AH, the values passed to it can be checked. AH contains 1 and DX contains 0—the correct values for START COM1.

In order to use the symbols for BADSCOP, use the Open Symbol Map command, XO, to switch to the correct symbol map. Then, because the value of *CSEG* is not defined in the map, use the Set Symbol Value command to set *CSEG* to the current value of CS. (CS was changed to the correct value for BADSCOP when the program executed the INT 60H instruction.)

```
-XO BADSCOP!  <Enter>
-Z CSEG CS    <Enter>
-X?*          <Enter>

CSEG: (1313)
0100 INITIALIZE   0103 OLD_COMM_INT 0107 COUNT        0109 STATUS
010A PORT         010B BUFPNTR      010D COMSCOPE     0190 CONTROL
020A VECTOR_INIT
```

Because the BADSCOP symbols now have meaning, a great deal of trouble can be avoided by setting a breakpoint at *CONTROL*, the entry point for Interrupt 60H, so that it will no longer be necessary to trace the *_int86* routine to find the INT 60H command. Execution will automatically stop when the Interrupt 60H handler is entered.

```
-BP CONTROL  <Enter>
-BL  <Enter>
0 e 2CB0:002E [COMMSCMD!_TEXT:_main+1E (002E)] commscmd.C:41
1 e 2CB0:0046 [COMMSCMD!_TEXT:_main+36 (0046)] commscmd.C:42
2 e 2CB0:0066 [COMMSCMD!_TEXT:_main+56 (0066)] commscmd.C:44
3 e 2CB0:0086 [COMMSCMD!_TEXT:_main+76 (0086)] commscmd.C:46
4 e 2CB0:008B [COMMSCMD!_TEXT:_main+7B (008B)] commscmd.C:49
5 e 2CB0:00AC [COMMSCMD!_TEXT:_main+9C (00AC)] commscmd.C:53
6 e 2CB0:00C7 [COMMSCMD!_TEXT:_main+B7 (00C7)] commscmd.C:58
7 e 2CB0:00F5 [COMMSCMD!_TEXT:_main+E5 (00F5)] commscmd.C:63
8 e 1313:0190 [CSEGS:CONTROL]
```

With the housekeeping tasks done, the business of debugging BADSCOP can begin. The first thing *CONTROL* does is check for a stop request. If no stop request is present, the routine jumps to the check for a start request. (The first test and jump were already complete when the trace ended above.) The test for a start request is passed. *CONTROL* places the port number in a local variable, resets the buffer pointer and the buffer count, and turns tracing status on. With all this complete, *CONTROL* returns.

```
-T 5  <Enter>
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01B6   NV UP DI PL NZ NA PO NC
1313:01B6 80FC01          CMP     AH,01
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01B9   NV UP DI PL ZR NA PE NC
1313:01B9 751C            JNZ     CONTROL+47 (01D7)
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01BB   NV UP DI PL ZR NA PE NC
1313:01BB 2E88160A01      MOV     CS:[PORT],DL                    CS:010A=00
```

(more)

```
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01C0   NV UP DI PL ZR NA PE NC
1313:01C0 2EC7060B010202 MOV     Word Ptr CS:[BUFPNTR],VECTOR_INIT (0209) CS:010B=0202
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01C7   NV UP DI PL ZR NA PE NC
1313:01C7 2EC70607010000 MOV     Word Ptr CS:[COUNT],0000          CS:0107=0002
-T 5  <Enter>
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01CE   NV UP DI PL ZR NA PE NC
1313:01CE 2EC606090101   MOV     Byte Ptr CS:[STATUS],01           CS:0109=01
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01D4   NV UP DI PL ZR NA PE NC
1313:01D4 EB2B           JMP     CONTROL+71 (0201)
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0201   NV UP DI PL ZR NA PE NC
1313:0201 CF             IRET
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F60  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=2E08  IP=0F6C   NV UP EI PL NZ AC PE NC
2E08:0F6C CB             RETF
AX=01BB  BX=E81E  CX=3F48  DX=0000  SP=0F64  BP=0F66  SI=1CE7  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=0209   NV UP EI PL NZ AC PE NC
2CB0:0209 5D             POP     BP
```

As can be seen from the trace, *CONTROL* performed correctly, so execution of the routine can continue.

```
-G  <Enter>
Communications tracing STARTED for port COM1:
AX=002F  BX=0001  CX=0C13  DX=0000  SP=0FA6  BP=0000  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00F5   NV UP EI PL NZ NA PE NC
2CB0:00F5 C3             RET                                ;BR7
```

COMMSCMD has written the message to the user and trapped at the breakpoint set at the end of *_main*. The Examine Symbol Map command now shows that SYMDEB has automatically switched to the symbol map for COMMSCMD.

```
-X*  <Enter>
[2CB0 COMMSCMD]
      [2CB0 _TEXT]
       2E08 DGROUP
 0000 BADSCOP
       1313 CSEG
```

No problems have been encountered with the START command; now the same process of checking COMMSCMD and BADSCOP must be repeated for the STOP command. (Even if problems had been found with the START command, it would be imprudent not to test the other commands — they could have errors, too.) SYMDEB could be exited and restarted with new commands, but this would mean the loss of the painfully created set of breakpoints. Instead, a new copy of COMMSCMD is loaded without leaving SYMDEB. One problem with this, however, is that when SYMDEB loads an .EXE file, it adds the value of the initial CS register to the addresses of the segments in the symbol map whose name

matches the .EXE file. This is fine the first time the program loads, but the second time, all the values are doubled and therefore incorrect. To avoid this error, the addresses must be adjusted before the load. Use the Set Symbol Value command to subtract CS from each segment name in COMMSCMD!. The Examine Symbol Map command shows the new values.

```
-Z _TEXT _TEXT-CS  <Enter>
-Z DGROUP DGROUP-CS  <Enter>
-X*  <Enter>
[2CB0 COMMSCMD]
      [0000 _TEXT]
       0158 DGROUP
 0000 BADSCOP
       1313 CSEG
```

The Name File or Command-Tail Parameters command, N, and the Load File or Sectors command, L, can now be used to load a new copy of COMMSCMD.EXE.

```
-N COMMSCMD.EXE  <Enter>
-L  <Enter>
-X*  <Enter>
[2CB0 COMMSCMD]
      [2CB0 _TEXT]
       2E08 DGROUP
 0000 BADSCOP
       1313 CSEG
```

Notice that the segment values inside COMMSCMD! are the same as they were when the program was first loaded. Use the Name command again, this time to set the command tail to contain a STOP command for COM1. The breakpoint table from the first execution is still set, so the program can now be traced in the same way.

```
-N STOP 1  <Enter>
-G  <Enter>
AX=0022  BX=0F84  CX=0019  DX=0098  SP=0F80  BP=0FA6  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=002E   NV UP EI PL NZ NA PO NC
41:             if (0 == stricmp(argv[1],"STOP"))
2CB0:002E B83600          MOV     AX,0036                       ;BR0
-G  <Enter>
AX=0000  BX=415A  CX=0000  DX=0098  SP=0F80  BP=0FA6  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=0046   NV UP EI PL ZR NA PE NC
42:                 cmd = 0;
2CB0:0046 C746FC0000      MOV     Word Ptr [BP-04],0000         ;BR1 SS:0FA2=0000
-G  <Enter>
AX=0000  BX=415A  CX=0000  DX=0098  SP=0F80  BP=0FA6  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=008B   NV UP EI PL ZR NA PE NC
49:         if (argc == 3)
2CB0:008B 837E0403        CMP     Word Ptr [BP+04],+03          ;BR4 SS:0FAA=0003
-G  <Enter>
AX=0001  BX=00D0  CX=0000  DX=0000  SP=0F80  BP=0FA6  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00AC   NV UP EI PL NZ NA PO NC
53:                 port = port-1;
```

(more)

```
2CB0:00AC FF4EFA          DEC     Word Ptr [BP-06]              ;BR5 SS:0FA0=0001
-G  <Enter>
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F7A  BP=0FA6  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00C7   NV UP EI PL ZR NA PE NC
2CB0:00C7 E8EF00          CALL    _int86                        ;BR6
```

COMMSCMD detected that this is a stop request for COM1 and set the arguments for *_int86* correctly. Because a breakpoint is now set at *CONTROL*, tracing until the Interrupt 60H call is found is not necessary. Simply executing the program will cause it to stop at *CONTROL*.

```
-G  <Enter>
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F5C  BP=0F68  SI=7400  DI=E903
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0190   NV UP DI PL NZ AC PO NC
CSEG:CONTROL:
1313:0190 80FC00          CMP     AH,00                         ;BR8
```

The registers are set correctly for a stop request on COM1 (AH = 0, DX = 0). The routine can now be traced to check for correct operation. First, however, a quick look at the symbol maps shows that SYMDEB has automatically switched to BADSCOP's symbols.

```
-X*  <Enter>
 2CB0 COMMSCMD
       2CB0 _TEXT
       2E08 DGROUP
[0000 BADSCOP]
      [1313 CSEG]
-T 5  <Enter>
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F5C  BP=0F68  SI=7400  DI=E903
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0193   NV UP DI PL ZR NA PE NC
1313:0193 7521            JNZ     CONTROL+26 (01B6)
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F5C  BP=0F68  SI=7400  DI=E903
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0195   NV UP DI PL ZR NA PE NC
1313:0195 1E              PUSH    DS
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F5A  BP=0F68  SI=7400  DI=E903
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0196   NV UP DI PL ZR NA PE NC
1313:0196 53              PUSH    BX
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F58  BP=0F68  SI=7400  DI=E903
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0197   NV UP DI PL ZR NA PE NC
1313:0197 0E              PUSH    CS
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F56  BP=0F68  SI=7400  DI=E903
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0198   NV UP DI PL ZR NA PE NC
1313:0198 1F              POP     DS
-T 5  <Enter>
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F58  BP=0F68  SI=7400  DI=E903
DS=1313  ES=2E08  SS=2E08  CS=1313  IP=0199   NV UP DI PL ZR NA PE NC
1313:0199 C606090100      MOV     Byte Ptr [STATUS],00          DS:0109=01
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F58  BP=0F68  SI=7400  DI=E903
DS=1313  ES=2E08  SS=2E08  CS=1313  IP=019E   NV UP DI PL ZR NA PE NC
1313:019E 8B1E0B01        MOV     BX,[BUFPNTR]                  DS:010B=0202
AX=001E  BX=0202  CX=0000  DX=0000  SP=0F58  BP=0F68  SI=7400  DI=E903
DS=1313  ES=2E08  SS=2E08  CS=1313  IP=01A2   NV UP DI PL ZR NA PE NC
```

(more)

```
1313:01A2 C60780          MOV     Byte Ptr [BX],80                  DS:0202=80
AX=001E  BX=0202  CX=0000  DX=0000  SP=0F58  BP=0F68  SI=7400  DI=E903
DS=1313  ES=2E08  SS=2E08  CS=1313  IP=01A5   NV UP DI PL ZR NA PE NC
1313:01A5 C64701FF        MOV     Byte Ptr [BX+01],FF               DS:0203=FF
AX=001E  BX=0202  CX=0000  DX=0000  SP=0F58  BP=0F68  SI=7400  DI=E903
DS=1313  ES=2E08  SS=2E08  CS=1313  IP=01A9   NV UP DI PL ZR NA PE NC
1313:01A9 FF060701        INC     Word Ptr [COUNT]                  DS:0107=0000
-T 5  <Enter>
AX=001E  BX=0202  CX=0000  DX=0000  SP=0F58  BP=0F68  SI=7400  DI=E903
DS=1313  ES=2E08  SS=2E08  CS=1313  IP=01AD   NV UP DI PL NZ NA PO NC
1313:01AD FF060701        INC     Word Ptr [COUNT]                  DS:0107=0001
AX=001E  BX=0202  CX=0000  DX=0000  SP=0F58  BP=0F68  SI=7400  DI=E903
DS=1313  ES=2E08  SS=2E08  CS=1313  IP=01B1   NV UP DI PL NZ NA PO NC
1313:01B1 5B              POP     BX
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F5A  BP=0F68  SI=7400  DI=E903
DS=1313  ES=2E08  SS=2E08  CS=1313  IP=01B2   NV UP DI PL NZ NA PO NC
1313:01B2 1F              POP     DS
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F5C  BP=0F68  SI=7400  DI=E903
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01B3   NV UP DI PL NZ NA PO NC
1313:01B3 EB4C            JMP     CONTROL+71 (0201)
AX=001E  BX=3F48  CX=0000  DX=0000  SP=0F5C  BP=0F68  SI=7400  DI=E903
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0201   NV UP DI PL NZ NA PO NC
1313:0201 CF              IRET
```

CONTROL correctly detected that this was a stop request. It then saved the user's registers and established a DS equal to CS. (Remember that BADSCOP is a .COM file and CS = DS = SS.) Having done this, the routine moves a zero to *STATUS*, which turns the trace off. It then moves 80H FFH to the buffer to indicate the end of a trace session, increments *COUNT* to allow for the new entry, and restores the user's registers. What it does *not* do is increment the buffer pointer to allow for the stop marker. This behavior is entirely consistent with the observed phenomena: When a trace is stopped and resumed, the stop marker is missing and the count is one too high. The fix is to add

```
INC     BX          ;INCREMENT BUFFER POINTER
INC     BX          ; .
MOV     BUFPNTR,BX  ; .
```

to the *CONTROL* procedure before the registers are restored. (Insert these lines later with your favorite editor.)

Even though the bug has been found, the rest of the routine should be checked for other possible bugs.

```
-G  <Enter>
Communications tracing STOPPED for port COM1:
AX=002F  BX=0001  CX=0C13  DX=0000  SP=0FA8  BP=0000  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00F5   NV UP EI PL NZ AC PO NC
2CB0:00F5 C3              RET                                   ;BR7
```

Loading a new copy of COMMSCMD, setting the command tail to *RESUME 1*, and monitoring program execution yields the following:

```
-N COMMSCMD.EXE  <Enter>
-Z _TEXT _TEXT-CS  <Enter>
-Z DGROUP DGROUP-CS  <Enter>
-X*  <Enter>
[2CB0 COMMSCMD]
      [0000 _TEXT]
       0158 DGROUP
 0000 BADSCOP
       1313 CSEG
-L  <Enter>
-X*  <Enter>
[2CB0 COMMSCMD]
      [2CB0 _TEXT]
       2E08 DGROUP
 0000 BADSCOP
       1313 CSEG
-N RESUME 1  <Enter>
-G  <Enter>
AX=0022  BX=0F82  CX=0019  DX=0098  SP=0F7E  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=002E   NV UP EI PL NZ NA PO NC
41:             if (0 == stricmp(argv[1],"STOP"))
2CB0:002E B83600         MOV     AX,0036                        ;BR0
-G  <Enter>
AX=0000  BX=415A  CX=0000  DX=0098  SP=0F7E  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=0086   NV UP EI PL ZR NA PE NC
46:                 cmd = 2;
2CB0:0086 C746FC0200     MOV     Word Ptr [BP-04],0002          ;BR3 SS:0FA0=0000
-G  <Enter>
AX=0000  BX=415A  CX=0000  DX=0098  SP=0F7E  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=008B   NV UP EI PL ZR NA PE NC
49:         if (argc == 3)
2CB0:008B 837E0403       CMP     Word Ptr [BP+04],+03           ;BR4 SS:0FA8=0003
-G  <Enter>
AX=0001  BX=00D0  CX=0000  DX=0000  SP=0F7E  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00AC   NV UP EI PL NZ NA PO NC
53:                 port = port-1;
2CB0:00AC FF4EFA         DEC     Word Ptr [BP-06]               ;BR5 SS:0F9E=0001
-G  <Enter>
AX=0060  BX=00D0  CX=0000  DX=0000  SP=0F78  BP=0FA4  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00C7   NV UP EI PL ZR NA PE NC
2CB0:00C7 E8EF00         CALL     _int86                         ;BR6
-G  <Enter>
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0190   NV UP DI PL NZ AC PE NC
CSEG:CONTROL:
1313:0190 80FC00         CMP     AH,00                          ;BR8
-T 5  <Enter>
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0193   NV UP DI PL NZ NA PO NC
1313:0193 7521           JNZ     CONTROL+26 (01B6)
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01B6   NV UP DI PL NZ NA PO NC
1313:01B6 80FC01         CMP     AH,01
```

(more)

```
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01B9   NV UP DI PL NZ NA PO NC
1313:01B9 751C          JNZ     CONTROL+47 (01D7)
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01D7   NV UP DI PL NZ NA PO NC
1313:01D7 80FC02        CMP     AH,02
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01DA   NV UP DI PL ZR NA PE NC
1313:01DA 7516          JNZ     CONTROL+62 (01F2)
-T 5  <Enter>
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01DC   NV UP DI PL ZR NA PE NC
1313:01DC 2E833E0B0100   CMP     Word Ptr CS:[BUFPNTR],+00          CS:010B=0202
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01E2   NV UP DI PL NZ NA PO NC
1313:01E2 741D          JZ      CONTROL+71 (0201)
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01E4   NV UP DI PL NZ NA PO NC
1313:01E4 2E88160A01     MOV     CS:[PORT],DL                       CS:010A=00
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01E9   NV UP DI PL NZ NA PO NC
1313:01E9 2EC606090101   MOV     Byte Ptr CS:[STATUS],01            CS:0109=00
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=01EF   NV UP DI PL NZ NA PO NC
1313:01EF EB10          JMP     CONTROL+71 (0201)
-T 5  <Enter>
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F5A  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=1313  IP=0201   NV UP DI PL NZ NA PO NC
1313:0201 CF            IRET
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F60  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=2E08  IP=0F6C   NV UP EI PL NZ AC PE NC
2E08:0F6C CB            RETF
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F64  BP=0F66  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=0209   NV UP EI PL NZ AC PE NC
2CB0:0209 5D            POP     BP
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F66  BP=0F74  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=020A   NV UP EI PL NZ AC PE NC
2CB0:020A 57            PUSH    DI
AX=0265  BX=001E  CX=3F48  DX=0000  SP=0F64  BP=0F74  SI=0000  DI=7400
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=020B   NV UP EI PL NZ AC PE NC
2CB0:020B 8B7E08        MOV     DI,[BP+08]                         SS:0F7C=0F90
-G  <Enter>
Communications tracing RESUMED for port COM1:
AX=002F  BX=0001  CX=0C13  DX=0000  SP=0FA6  BP=0000  SI=0089  DI=1065
DS=2E08  ES=2E08  SS=2E08  CS=2CB0  IP=00F5   NV UP EI PL NZ NA PE NC
2CB0:00F5 C3            RET                                    ;BR7
-Q  <Enter>
```

The processing of a resume request is correct. Thus, the problem with stop processing in BADSCOP was the only problem. The corrected BADSCOP, which is actually COMMSCOP, is shown in Figure 18-4.

CodeView

CodeView is the most sophisticated debugging monitor produced by Microsoft. It combines the philosophy and many of the commands of its predecessors, DEBUG and SYMDEB, with true source-code debugging. The availability of source lines and symbols allows CodeView to rival the convenience of program development and debugging previously available only in interpreters such as Microsoft GW-BASIC. However, this high level of interaction with the source program is also the root of its problems for advanced debugging.

In order to provide the debugger with the tools to debug at the source-line level and to interrogate program variables, CodeView is required to have a detailed knowledge of how high-order languages work and of their internal conventions. This is not a problem for languages like C, Pascal, and FORTRAN, versions of which are produced by the same company that created CodeView. The object code generated by these compilers obeys a stringent set of rules and conventions. Assembly-language programs, however, tend to follow their own rules and traditions, making them quite different from C programs, with their own separate debugging needs.

C, Pascal, and FORTRAN programmers will find CodeView a dream to use. Assembly-language programmers using versions of MASM earlier than 5.0 will find CodeView cumbersome and will have to weigh its advantages over its disadvantages. All users will, however, appreciate the good design and programming that have gone into CodeView. It is pleasing to know that someone understands the programmer's debugging needs and is trying to ease the burden.

CodeView has added several welcome functions to the debugger's repertoire, but one of these new features towers above the rest — watchpoints. The debugger can watch the values of program variables or expressions and set breakpoints on them, making it possible to stop execution if an expression evaluates to zero or if a location changes. Previous debugging monitors have been limited to tracing and breaking on instructions. This new facet of debugging changes, somewhat, the approach to resolving a bug.

In the previous discussion of debugging techniques, an orderly application of techniques from inspection and observation through instrumentation to debugging monitors was recommended. This sequence is still recommended with CodeView, but now the instrumentation features have been integrated into the debugging monitor.

A simple example

The following example shows how CodeView uses the instrumentation approach to isolate a problem and then uses the debugging monitor functions to solve it. The example is also an introduction to CodeView commands and techniques. The commands are, for the most part, similar to those used by SYMDEB. Those commands that differ greatly are indicated. This example, like all the examples and demonstrations in this article, is not intended to be a complete tutorial — CodeView commands are summarized elsewhere in this book and explained in detail in the manual accompanying the product. *See* PROGRAMMING UTILITIES: CODEVIEW. The example simply shows some of the more common CodeView commands and demonstrates debugging techniques using them.

UPPERCAS.C (Figure 18-13) is a simple program whose sole function is to convert a canned string to uppercase. When executed, the program prints a few of the characters from the string and some that aren't in the string. Inspecting the listing doesn't reveal the cause of the problem. (Some readers with experience writing C programs will see the cause of the problem, because it is quite common; pretend, for now, that the listing is of no help and enjoy the wonders of CodeView.)

```
/*************************************************************************
 *                                                                       *
 * UPPERCAS.C                                                            *
 *    This routine converts a fixed string to uppercase and prints it.   *
 *                                                                       *
 *************************************************************************/

#include <ctype.h>
#include <string.h>
#include <stdio.h>

main(argc,argv)

int argc;
char *argv[];

{
char    *cp,c;

        cp = "a string\n";

        /*  Convert *cp to uppercase and write to standard output  */

        while (*cp != '\0')
                {
                c = toupper(*cp++);
                putchar(c);
                }

}
```

Figure 18-13. An erroneous C program to convert a string to uppercase.

Like SYMDEB, CodeView requires some special preparation to produce a suitable executable file. CodeView, however, makes the job much simpler. Using the Microsoft C Compiler, compile the program with

```
C>MSC /Zi UPPERCAS;  <Enter>
```

(Remember that C is case sensitive when interpreting switches, so the /Zi switch should be entered exactly as shown.) The /Zi switch instructs the compiler to generate the symbol tables and line-number information needed by CodeView. Other options appropriate to the program can also be included, but /Zi is required.

To form an executable file, use the Microsoft Object Linker (LINK) as follows:

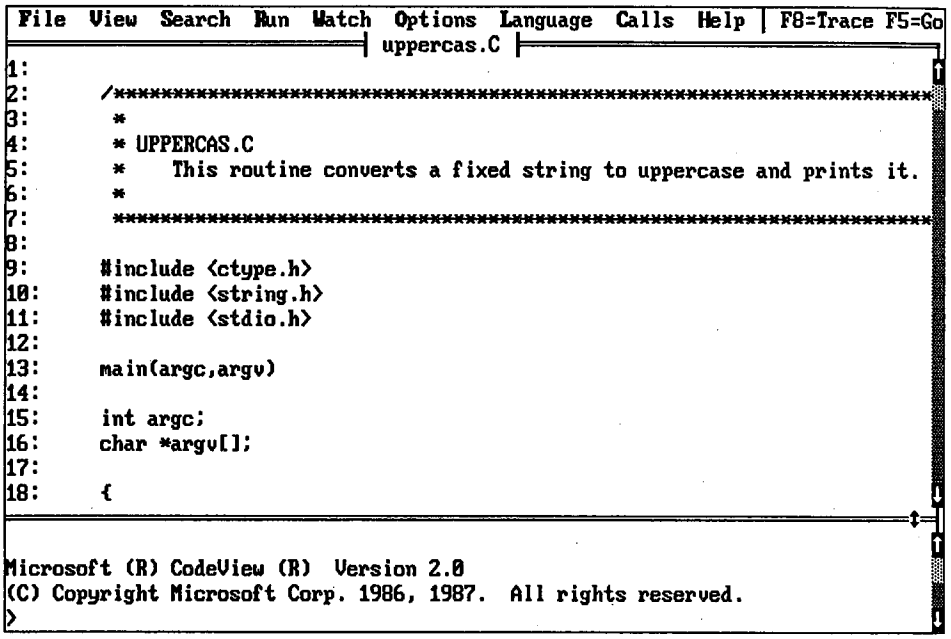
```
C>LINK /CO UPPERCAS;  <Enter>
```

This command line instructs LINK to build an executable file with the information needed for CodeView. Other options can be used as needed or desired. The output of LINK, UPPERCAS.EXE, will be larger than a .EXE file built without /CO (about 2600 bytes larger in this case), but the program will run correctly when executed without CodeView.

Starting CodeView is straightforward. Simply type

```
C>CV UPPERCAS  <Enter>
```

CodeView loads UPPERCAS.EXE. It locates UPPERCAS.C, the source file, and loads that too. It then presents a full-screen display similar to this:



This display has two windows open: the display window, which shows the program being debugged, and the the dialog window, which currently contains only the copyright notice and a prompt (>) for input. The F6 function key moves the cursor back and forth between the two windows.

CodeView can be instructed from either window to go to a specific line (that is, to execute until a specific line is reached). If the cursor is in the display window, use the arrow keys to select a line and press the F7 key. Execution will proceed until the selected line (or the end of the program) is reached. To start execution without specifying a stop line, press F5.

The same functions can be performed from the dialog window using typed commands, which may seem more familiar. Enter the Go Execute Program command, G, optionally followed by an address. Execution will continue until the specified address is reached

or until stopped by something else, such as the end of the program. In this sense, the CodeView Go command is the same as that of DEBUG and SYMDEB. Unlike those routines, however, CodeView's Go command does not allow an equals operator (=).

The address for the Go command can be specified in several ways. Because the display window is currently showing only source lines, it is appropriate to set the stop location in terms of line numbers. The syntax of a line-number specification is the same as in SYMDEB — simply enter the line number preceded by a period:

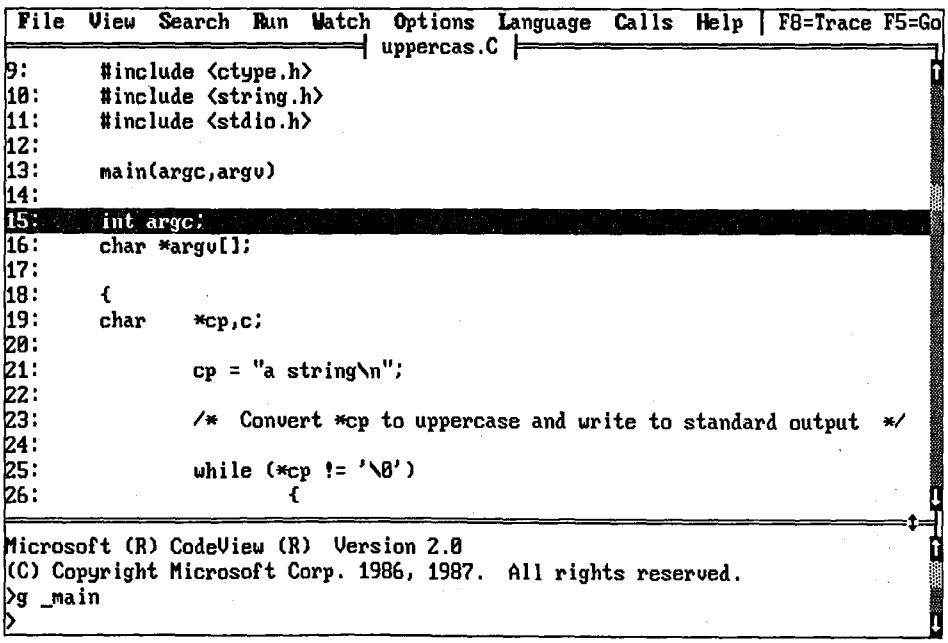
```
>G .27  <Enter>
```

Note that the line number is specified in decimal. This seemingly innocent statement uncovers one of the problem areas in CodeView, especially for assembly-language programmers. The default radix for CodeView is decimal. This convention works well for things associated with the C program, such as line numbers, but is very inconvenient for addresses and other similar items, which are usually in hexadecimal. Hexadecimal numbers must be specified using the cumbersome C notation. Thus, the number FF3EH would be entered as 0xff3e. The radix can be changed using the Change Current Radix command, N (different from the DEBUG and SYMDEB N command). (The problems associated with hexadecimal numbers in early versions of CodeView are no longer present in versions 2.0 and later.)

The radix problem can be avoided, for the moment, by using labels. Issue

```
>G _main  <Enter>
```

to cause CodeView to execute until the main routine is reached. CodeView then shows



The display shows line 15 in reverse video, indicating that CodeView has stopped there. This is the first line of the *main()* module, but it is not executable. Press the F10 key, which has the same effect as entering the Step Through Program command, P, in the dialog window, to cause line 19 to be executed. The reverse video line is then 21, which is the next line to be executed.

To see the changes to *cp*, **cp*, and *c*, establish a watch on these three variables. To use the Watch Word command, WW, for the word *cp*, type

```
>WW cp  <Enter>
```

When entered from the dialog window, this command opens the watch window at the top of the screen and displays the current value of *cp*. To display the expression at **cp*, use the Watch Expression command, W?, as follows:

```
>W? cp,s  <Enter>
```

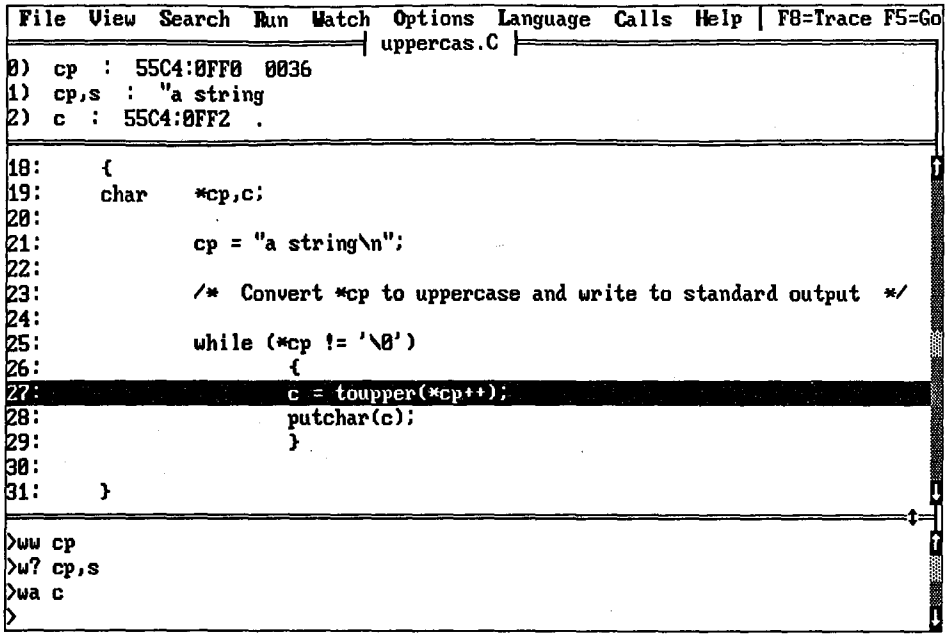
This expression will display the null-delimited string at **cp*. Finally, to see the ASCII character value of *c*, use the Watch ASCII command, WA:

```
>WA c  <Enter>
```

The results of these watch commands are shown in the following screen:

```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              uppercas.C
0)  cp  :  55C4:0FF0  5527
1)  cp,s  :  ""
2)  c  :  55C4:0FF2  .

9:      #include <ctype.h>
10:     #include <string.h>
11:     #include <stdio.h>
12:
13:     main(argc,argv)
14:
15:     int argc;
16:     char *argv[];
17:
18:     {
19:     char    *cp,c;
20:
21:             cp = "a string\n";
22:

>ww cp
>w? cp,s
>wa c
>
```

The values displayed in the watch window are not yet defined because line 21, which initialized *cp*, has not been executed. Press F8 to rectify this. Press it again to bring the execution of the program into the main loop.



The pointer *cp* now contains the correct address. The Display Memory command, D, could be used to display the contents of DS:0036H, just as in DEBUG and SYMDEB. (This step is not necessary, however, because there is a formatted display of memory in the watch window at 1). The variable *c* has not yet been initialized.

Press the F8 key to execute line 27. A curious and unexpected thing happens, as shown in the next screen:

```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              uppercas.C
0)  cp  :  55C4:0FF0  0038
1)  cp,s  :  "string
2)  c  :  55C4:0FF2

18:     {
19:     char    *cp,c;
20:
21:             cp = "a string\n";
22:
23:             /*  Convert *cp to uppercase and write to standard output  */
24:
25:             while (*cp != '\0')
26:                     {
27:                     c = toupper(*cp++);
28:                     putchar(c);
29:                     }
30:
31:     }

>ww cp
>w? cp,s
>wa c
>
```

Notice that the value of *cp* has changed from 0036H to 0038H. The line of code, however, indicates that the pointer should have been incremented by only one (**cp++*). The second character of the string, a blank, has been loaded into *c*. This could explain the apparent random selection of characters being displayed (actually every other character) and the garbage characters displayed (the zero at the end of the string might be skipped, causing the routine to continue converting until a zero is encountered somewhere in memory).

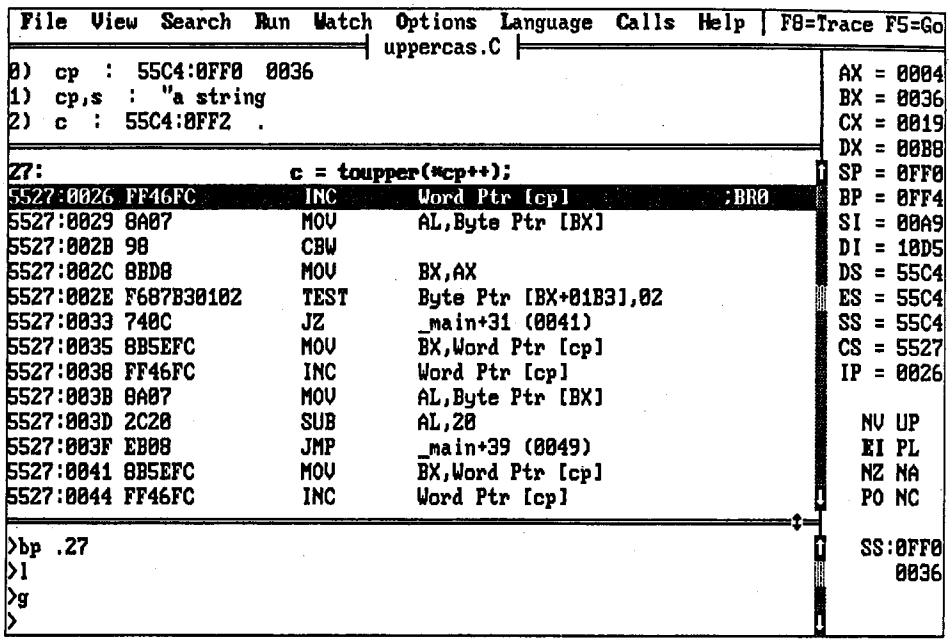
Source-line debugging does not reveal enough about what is happening in this case. To look more closely at the mechanism of the program, the program must be restarted. Before doing this, set a breakpoint at line 27:

```
>BP .27  <Enter>
```

Then restart (actually, reload) the program with the Reload Program command, L. Note that watch commands and breakpoints are preserved when a program is restarted. Executing the restarted program with G yields

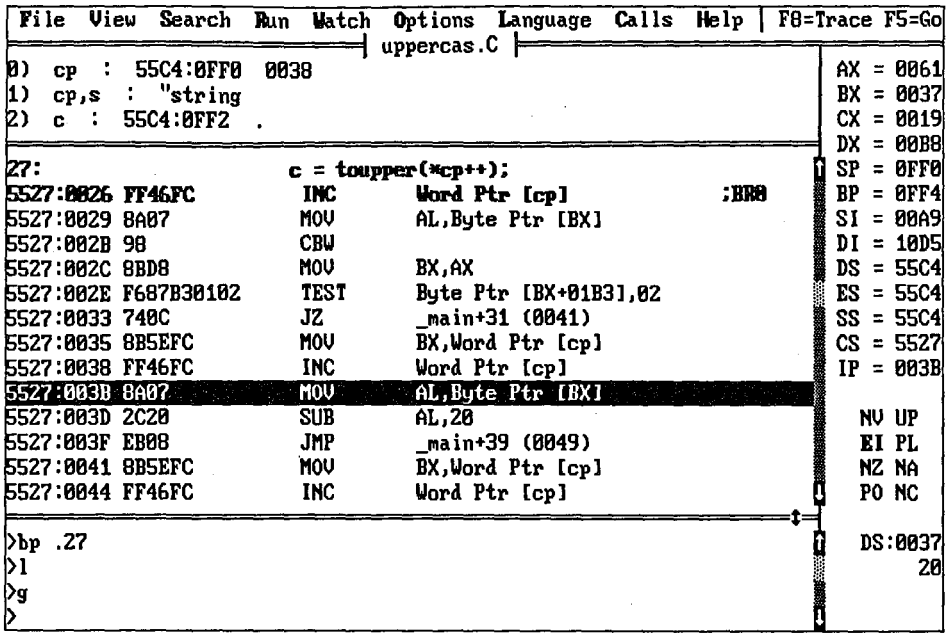
```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              uppercas.C
0)  cp  :  55C4:0FF0  0036
1)  cp,s  :  "a string
2)  c  :  55C4:0FF2  .

18:     {
19:     char    *cp,c;
20:
21:             cp = "a string\n";
22:
23:             /*  Convert *cp to uppercase and write to standard output  */
24:
25:             while (*cp != '\0')
26:                     {
27:                     c = toupper(*cp++);
28:                     putchar(c);
29:                     }
30:
31:     }

>bp .27
>l
>g
>
```

The display shows line 27 in reverse video, indicating that it is the next line to be executed. The pointer *cp* has the correct value, as shown in the watch window. Now Press the F2 key to turn on the register display and press F3 to show the assembly code.



The display highlights line 27, indicating that a breakpoint exists at this line. The line of code at CS:0026H is in reverse video, indicating that it is the next line to be executed.

The previous instruction has loaded BX with *[cp]*. The first thing the code for line 27 does is increment the word at memory location *[cp]*. The initial value of *cp* is in BX, so the **cp++* request can now be executed. Use the F8 key to single-step through the lines of code. Notice that when only source lines are on the screen, F8 steps one source line at a time, but when assembly code is shown, F8 steps one assembly line at a time. Single-stepping through the code, note how the registers and watch window change. Everything appears normal until CS:0038H is executed.



Notice that the value of *cp* in the watch window has incremented again. The line of C code has two increments hidden in it, not the expected single increment. Why is this?

To find the answer, examine the *toupper()* macro. The following definition, extracted from CTYPE.H, explains what is happening:

```
#define _UPPER          0x1       /* uppercase letter */
#define _LOWER          0x2       /* lowercase letter */
#define isupper(c)       ( (_ctype+1)[c] & _UPPER )
#define islower(c)       ( (_ctype+1)[c] & _LOWER )

#define _tolower(c)      ( (c)-'A'+'a' )
#define _toupper(c)      ( (c)-'a'+'A' )

#define toupper(c)       ( (islower(c)) ? _toupper(c) : (c) )
#define tolower(c)       ( (isupper(c)) ? _tolower(c) : (c) )
```

The argument to *toupper()*, *c*, is used twice, once in the macro that checks for lowercase, *islower()*, and once in *_toupper()*. The argument is replaced in this case with **cp++*, which has the famous C unexpected side effects. Because the unary post-increment is the handiest way to perform the function desired in the program, fixing the problem by changing the code in the main loop is undesirable. Another solution to the problem is to use the function version of *toupper()*. Because *toupper()* is defined as a function in STDIO.H, simply deleting *#include <ctype.h>* would solve the problem. Unfortunately, this would also deprive the program of the other useful definitions in CTYPE.H. (Admittedly, the features are not currently used by the program, but little programs sometimes grow into mighty systems.) So to keep CTYPE.H but still remove the macro definition of

toupper(), use the #undef command. (Because *tolower()* has the same problem, it should also be undefined.) The corrected listing is shown in Figure 18-14.

```
/*************************************************************************
 *                                                                       *
 * UPPERCAS.C                                                            *
 *    This routine converts a fixed string to uppercase and prints it.   *
 *                                                                       *
 *************************************************************************/

#include <ctype.h>
#undef toupper
#undef tolower
#include <string.h>
#include <stdio.h>

main(argc,argv)

int argc;
char *argv[];

{
char    *cp,c;

        cp = "a string\n";

        /*  Convert *cp to uppercase and write to standard output  */

        while (*cp != '\0')
                {
                c = toupper(*cp++);
                putchar(c);
                }

}
```

Figure 18-14. The corrected version of UPPERCAS.C.

An example using screen output

A problem with DEBUG is that it writes to the same screen as the program does. Both SYMDEB and CodeView, however, allow the debugger to switch back and forth between the screen containing the program's output and the screen containing the debugger's output. This feature is a special option with SYMDEB and is sometimes clumsy to use, but with CodeView, keeping a separate program output screen is automatic and switching back and forth involves simply pressing a function key (F4).

The following example program is intended to display an ASCII lookup table with all the displayable characters available on an IBM PC. The expected output is shown in Figure 18-15.

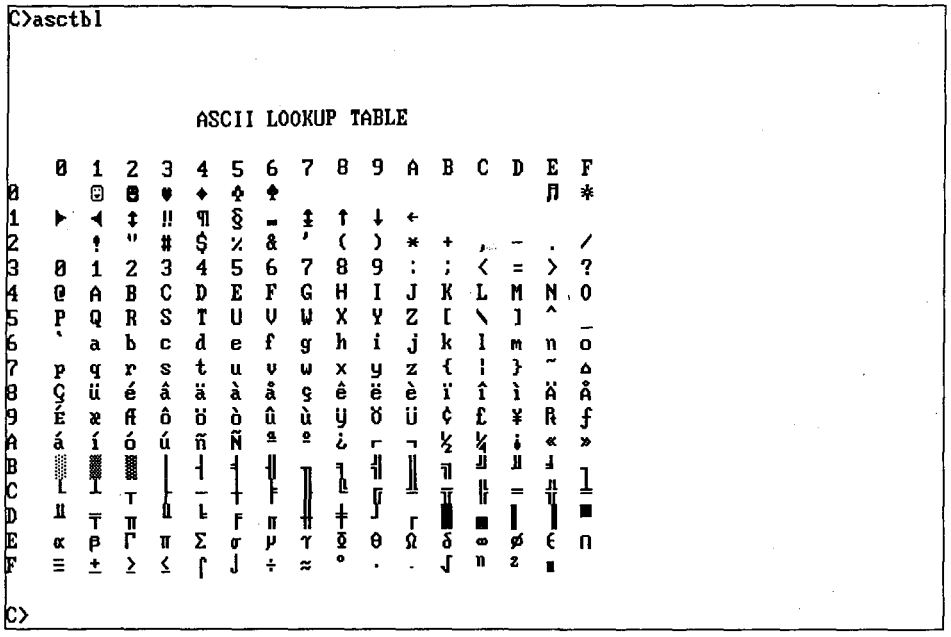


Figure 18-15. The output expected from ASCTBL.C.

The program that should produce this display, ASCTBL.C, is shown in Figure 18-16.

```
/*************************************************************************
 *                                                                       *
 *  ASCTBL.C                                                             *
 *   This program generates an ASCII lookup table for all displayable    *
 *   ASCII and extended IBM PC codes, leaving blanks for nondisplayable  *
 *   codes.                                                              *
 *                                                                       *
 *************************************************************************/

#include <ctype.h>
#include <stdio.h>

main()
{
int i, j, k;
        /* Print table title. */
        printf("\n\n\n                ASCII LOOKUP TABLE\n\n");

        /* Print column headers. */
        printf("    ");
        for (i = 0; i < 16; i++)
                printf("%X  ", i);
        fputchar("\n");
```

Figure 18-16. An erroneous program to display ASCII characters. *(more)*

```
        /* Print each line of the table. */
        for (i = 0, k = 0; i < 16; i++)
                {
                /* Print first hex digit of symbols on this line. */
                printf("%X   ", i);
                /* Print each of the 16 symbols for this line. */
                for (j = 0; j < 16; j++)
                        {
                        /* Filter nonprintable characters. */
                        if ((k >= 7 && k <= 13) || (k >= 28 && k <= 31))
                                printf("   ");
                        else
                                printf("%c  ", k);
                        k++;
                        }
                fputchar("\n");
                }
}
```

Figure 18-16. Continued.

The problem to be debugged in this example is evident when the program in Figure 18-16 is compiled, linked, and executed. Here is the resulting display:

```
C>asctbl


                ASCII LOOKUP TABLE

   0 1 2 3 4 5 6 7 8 9 A B C D E F h0     ☺ ☻ ♥ ♦ ♣ ♠
                  ‼ * y1  ▶ ◀ ↕ !! ¶ § ▬ ↨ ↑ ↓ →           y2
  ! " # $ % & ' ( ) * + , - . / y3  0 1 2 3 4 5 6 7 8
9 : ; < = > ? y4  @ A B C D E F G H I J K L M N O y5  P
 Q R S T U V W X Y Z [ \ ] ^ _ y6  ` a b c d e f g h i
 j k l m n o y7  p q r s t u v w x y z { | } ~ ⌂ y8  Ç
ü é â ä à å ç ê ë è ï î ì Ä Å y9  É æ Æ ô ö ò û ù ÿ Ö
Ü ¢ £ ¥ ₧ ƒ yA  á í ó ú ñ Ñ ª º ¿ ⌐ ¬ ½ ¼ ¡ « » yB  ░
▓ ▓ │ ┤ ╡ ╢ ╖ ╕ ╣ ║ ╗ ╝ ╜ ╛ ┐ yC  └ ┴ ┬ ├ ─ ┼ ╞ ╟ ╚ ╔
╩ ╦ ╠ ═ ╬ ╧ yD  ╨ ╤ ╥ ╙ ╘ ╒ ╓ ╫ ╪ ┘ ┌ ▓ ▓ ▌ ▐ ▀ yE  α ß
Γ π Σ σ µ τ Φ Θ Ω δ ∞ ø ε ∩ yF  ≡ ± ≥ ≤ ⌠ ⌡ ÷ ≈ ° ∙ ·
√ ⁿ ² ■   y
C>
```

Something is clearly wrong. The output is jumbled and no pattern is immediately obvious. To locate the problem, first prepare a .EXE file and start CodeView as follows:

```
C>MSC /Zi ASCTBL;  <Enter>
C>LINK /CO ASCTBL;  <Enter>
C>CV ASCTBL  <Enter>
```

CodeView starts and displays the following screen:

```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              asctbl.C
1:
2:      /*************************************************************************
3:       *
4:       *  ASCTBL.C
5:       *   This program generates an ASCII lookup table for all displayable
6:       *   ASCII and extended IBMPC codes, leaving blanks for nondisplayable
7:       *   codes.
8:       *
9:       *************************************************************************
10:
11:     #include <ctype.h>
12:     #include <stdio.h>
13:
14:     main()
15:     {
16:     int i, j, k;
17:             /* Print table title. */
18:             printf("\n\n\n                    ASCII LOOKUP TABLE\n\n");


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(C) Copyright Microsoft Corp. 1986, 1987.  All rights reserved.
>
```

The start of the source program is shown in the display window and the dialog window contains an input prompt. Press the F10 key three times to bring execution to line 21. (Remember that the line indicated in reverse video has not yet been executed.)

```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              asctbl.C
9:      ************************************************************************
10:
11:     #include <ctype.h>
12:     #include <stdio.h>
13:
14:     main()
15:     {
16:     int i, j, k;
17:             /* Print table title. */
18:             printf("\n\n\n                ASCII LOOKUP TABLE\n\n");
19:
20:             /* Print column headers. */
21:             printf("    ");
22:             for (i = 0; i < 16; i++)
23:                     printf("%X  ", i);
24:             fputchar("\n");
25:
26:             /* Print each line of the table. */

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>
```

The display heading has been printed at line 18. Press the F4 key to display what the program has written on the screen.

```
C>cv asctbl


                ASCII LOOKUP TABLE
```

Note: Any information on the screen when you started CodeView will remain on the virtual output screen until program execution clears it or forces it to scroll off.

The table heading has been properly written to the screen. Press the F4 key again to return to the CodeView display. Continue executing the program with the F10 key to bring the program to line 24.

```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              asctbl.C
9:      ************************************************************************
10:
11:     #include <ctype.h>
12:     #include <stdio.h>
13:
14:     main()
15:     {
16:     int i, j, k;
17:             /* Print table title. */
18:             printf("\n\n\n                ASCII LOOKUP TABLE\n\n");
19:
20:             /* Print column headers. */
21:             printf("    ");
22:             for (i = 0; i < 16; i++)
23:                     printf("%X  ", i);
24:             fputchar("\n");
25:
26:             /* Print each line of the table. */

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(C) Copyright Microsoft Corp. 1986, 1987.  All rights reserved.
>
```

At this point in program execution, the column headings have been written on the screen. Press the F4 key again to see the results.

```
C>cv asctbl


              ASCII LOOKUP TABLE

   0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
```

The output of the program is still correct, so allow execution to continue by pressing F4 to return to the CodeView screen and then pressing the F10 key. This will execute the call to the *fputchar()* function to write a newline character.

```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              asctbl.C
21:             printf("    ");
22:             for (i = 0; i < 16; i++)
23:                     printf("%X  ", i);
24:             fputchar("\n");
25:
26:             /* Print each line of the table. */
27:             for ( i = 0, k = 0; i < 16; i++)
28:                     {
29:                     /* Print first hex digit of symbols on this line. */
30:                     printf("%X   ", i);
31:                     /* Print each of the 16 symbols for this line. */
32:                     for (j = 0; j < 16; j++)
33:                             {
34:                             /* Filter non-printable characters. */
35:                             if ((k >= 7 && k <= 13) || (k >= 28 && k <= 31)
36:                                     printf("   ");
37:                             else
38:                                     printf("%c  ", k);

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>
```

Examination of the output screen shows that the display is now incorrect.

```
C>cv asctbl

              ASCII LOOKUP TABLE

  0 1 2 3 4 5 6 7 8 9 A B C D E F h
```

A lowercase *h* has been written to the screen instead of a newline character. Further execution demonstrates that newline characters written with *fputchar()* are not working. A closer inspection of the *fputchar()* function is needed.

To see what is happening, use the Reload Program command to restart execution at the top of the program. Change the cursor window with the F6 key, use the arrow keys to place the cursor on line 24, and press F7. This brings execution back to line 24, where *fputchar()* is called. Press the F3 key to place the display in assembly mode and the F2 key to show the CPU registers and flags. The first assembly instruction of the *fputchar()* function call is about to be executed.

```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              asctbl.C
24:             fputchar("\n");                                  AX = 0003
5527:004E B86800        MOV     AX,0068                          BX = 0001
5527:0051 50            PUSH    AX                               CX = 0001
5527:0052 E83F01        CALL    _fputchar (0194)                 DX = 03C0
5527:0055 83C402        ADD     SP,+02                           SP = 0F90
27:             for ( i = 0, k = 0; i < 16; i++)                 BP = 0F96
5527:0058 C746FE0000    MOV     Word Ptr [i],0000                SI = 00A9
5527:005D C746FA0000    MOV     Word Ptr [k],0000                DI = 1075
5527:0062 837EFE10      CMP     Word Ptr [i],+10                 DS = 566D
5527:0066 7D68          JGE     _main+c0 (00D0)                  ES = 566D
5527:0068 EB05          JMP     _main+5f (006F)                  SS = 566D
5527:006A FF46FE        INC     Word Ptr [i]                     CS = 5527
5527:006D EBF3          JMP     _main+52 (0062)                  IP = 004E
30:                     printf("%X  ", i);
5527:006F FF76FE        PUSH    Word Ptr [i]                       NV UP
5527:0072 B86A00        MOV     AX,006A                            EI PL
5527:0075 50            PUSH    AX                                 ZR NA
5527:0076 E84801        CALL    _printf (01C1)                     PE NC

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>l
>
```
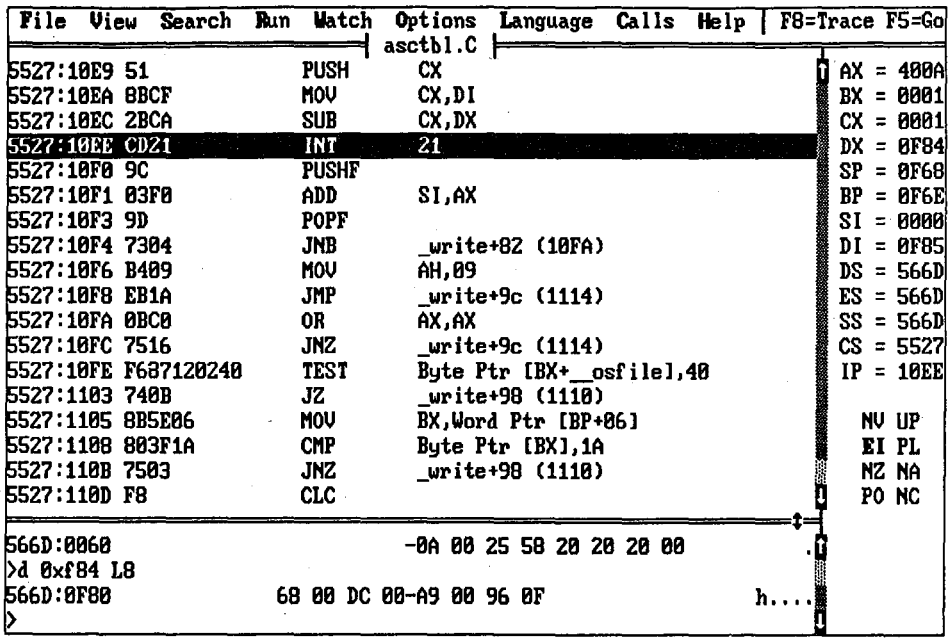

Notice that the parameter being passed to the function by means of the stack is 0068H. Use the Display Memory command to display DS:0068H. (Note the hexadecimal notation.)

```
File  View  Search  Run  Watch  Options  Language  Calls  Help | F8=Trace F5=Go
                              asctbl.C
24:             fputchar("\n");                                  AX = 0003
5527:004E B86800        MOV     AX,0068                          BX = 0001
5527:0051 50            PUSH    AX                               CX = 0001
5527:0052 E83F01        CALL    _fputchar (0194)                 DX = 03C0
5527:0055 83C402        ADD     SP,+02                           SP = 0F90
27:             for ( i = 0, k = 0; i < 16; i++)                 BP = 0F96
5527:0058 C746FE0000    MOV     Word Ptr [i],0000                SI = 00A9
5527:005D C746FA0000    MOV     Word Ptr [k],0000                DI = 1075
5527:0062 837EFE10      CMP     Word Ptr [i],+10                 DS = 566D
5527:0066 7D68          JGE     _main+c0 (00D0)                  ES = 566D
5527:0068 EB05          JMP     _main+5f (006F)                  SS = 566D
5527:006A FF46FE        INC     Word Ptr [i]                     CS = 5527
5527:006D EBF3          JMP     _main+52 (0062)                  IP = 004E
30:                     printf("%X  ", i);
5527:006F FF76FE        PUSH    Word Ptr [i]                       NV UP
5527:0072 B86A00        MOV     AX,006A                            EI PL
5527:0075 50            PUSH    AX                                 ZR NA
5527:0076 E84801        CALL    _printf (01C1)                     PE NC

>l
>d 0x68 L8
566D:0060                       -0A 00 25 58 20 20 20 00          .
>
```

The contents of memory at this address consist of a null-delimited string containing a newline character. The representation of \n is correct. To see how the string is handled, use the trace key, F8, to single-step through *fputchar()* and subordinate functions. These functions are complicated; nearly 100 steps are required to reach the MS-DOS Interrupt 21H call that actually writes the screen.



The AH register's contents, 40H, indicate that the Interrupt 21H call is a request for a write to a device. The BX register has the handle of the device, 1, which is the special file handle for standard output (*stdout*). For this program as it was invoked, standard output is the screen. The CX register indicates that 1 byte is to be written; DS:DX points to the data to be written. The contents of memory at DS:0F84H finally reveal the cause of the problem: This memory location contains the *address* of the data to be written, not the data. The *fputchar()* function was called with the wrong level of indirection.

Examination of the listing shows that all the newline requests were made with

```
fputchar("\n");
```

Strings specified with double quotes are replaced in C functions with the address of the string, but the function expected the actual character and not its address. The problem can be corrected by replacing the *fputchar()* calls with

```
fputchar('\n');
```

The newline character will now be passed directly to the function.

This kind of problem can be avoided. C provides the ability to check the type of each parameter passed to a function against the expected type. If the following definition is included at the top of the C program, incorrect types will generate error messages:

```
#define LINT_ARGS
```

The corrected listing is shown in Figure 18-17. This new program produces the correct output.

```
/*************************************************************************
 *                                                                       *
 *  ASCTBL.C                                                             *
 *   This program generates an ASCII lookup table for all displayable    *
 *   ASCII and extended IBM PC codes, leaving blanks for nondisplayable  *
 *   codes.                                                              *
 *                                                                       *
 *************************************************************************/

#define LINT_ARGS
#include <ctype.h>
#include <stdio.h>

main()
{
int i, j, k;
        /* Print table title. */
        printf("\n\n\n                ASCII LOOKUP TABLE\n\n");

        /* Print column headers. */
        printf("    ");
        for (i = 0; i < 16; i++)
                printf("%X  ", i);
        fputchar('\n');

        /* Print each line of the table. */
        for (i = 0, k = 0; i < 16; i++)
                {
                /* Print first hex digit of symbols on this line. */
                printf("%X   ", i);
                /* Print each of the 16 symbols for this line. */
                for (j = 0; j < 16; j++)
                        {
                        /* Filter nonprintable characters. */
                        if ((k >= 7 && k <= 13) || (k >= 28 && k <= 31))
                                printf("   ");
                        else
                                printf("%c  ", k);
                        k++;
                        }
                fputchar('\n');
                }
}
```

Figure 18-17. The correct ASCII table generation program.

CodeView is a good choice for debugging C, Pascal, BASIC, and FORTRAN programs. The fact that versions of MASM earlier than 5.0 do not generate data for CodeView makes CodeView a poorer choice for these assembly-language programs. These disadvantages must be weighed against the ability to set watchpoints and to trap nonmaskable interrupts (NMIs). CodeView is also not as well suited as SYMDEB for debugging programs that interact with TSRs and device drivers, because CodeView does not provide any mechanism for including symbol tables for routines not linked together.

Hardware debugging aids

Hardware debuggers are a combination of hardware and software designed to be installed in a PC system. The software provides features much like those available with SYMDEB and CodeView. The advantages of hardware debuggers over purely software debuggers can be summarized in three points:

- Crash protection
- Manual execution break
- Hardware breakpoints

A hardware debugger can provide program crash protection because of its independence from the PC software. If the program being debugged goes wild and destroys the operating system of the PC, the hardware debugger is protected by virtue of being a separate hardware system and is capable of recovering enough control to allow the user to find out what happened.

All hardware debuggers offer a means of breaking into the program under test from some external source — usually a push button in the hands of the programmer. The mechanism used to get the attention of the PC's CPU is the nonmaskable interrupt (NMI). This interrupt provides a more reliable means of interrupting program execution than the Break key because its operation is independent of the state of interrupts and other conditions.

Hardware debuggers usually have access to the address and data lines on the PC bus, allowing them to set *hardware* breakpoints. Thus, these debuggers can be set to break when specific addresses are referenced. They execute the breakpoint code from a debugging monitor, which generally runs from their own memory. This memory is usually protected from the regular operating system and the application program.

Although hardware debuggers can be used to instrument a program, they should not be confused with the external hardware instrumentation discussed earlier in this article. The logic analyzers and in-circuit emulators mentioned there are general-purpose test instruments; the hardware debuggers are highly specific devices intended to do only one thing on one type of hardware — provide debugging monitor functions at a hardware level to IBM PC-type machines. It is this specialization that makes hardware debuggers so much easier to use for programmers trying to get a piece of code running.

Because this volume deals only with MS-DOS and associated Microsoft software, a detailed discussion of hardware debuggers and debugging would not be appropriate. Instead, a few popular hardware products that work with MS-DOS utilities are mentioned and a general discussion of debugging with hardware is presented.

Several manufacturers make hardware products that can be used for debugging. These products vary in the features offered and in their suitability for various kinds of debugging. Three of these products that can be used with SYMDEB are

- IBM Professional Debug Utility
- PC Probe and AT Probe from Atron Corporation
- Periscope from The Periscope Company, Inc.

These boards can be used with SYMDEB by specifying the /N switch when the program is started. When used in this way, however, the hardware provides little more than a source of NMIs to interrupt program execution; otherwise, SYMDEB runs as usual. This restriction may not be acceptable to a programmer who wants to use the sophisticated debugging software that accompanies these products and makes use of their hardware features. For this reason, these boards are rarely used with SYMDEB.

The general techniques of debugging with hardware aids will already be familiar to the reader—they are the same techniques discussed at length earlier in this article. The techniques of inspection and observation should still be applied; instrumentation is facilitated by hardware; a debugging monitor accompanies all hardware debuggers and the same techniques discussed for DEBUG, SYMDEB, and CodeView apply. No new techniques are needed to use these devices. The changes in the details of the techniques come with the added features available with the hardware debuggers. (Remember that all these features are not universally available on all hardware debuggers.)

The manual interrupt feature of hardware debuggers is useful in a system crash. Every programmer, especially assembly-language programmers, has had the situation where the program runs wild, destroys the operating system, and locks up the system. The techniques described in previous sections of this article show that about the only way to solve these problems without hardware help is to set breakpoints at strategic locations in the program and see how many are passed before the system locks up. The breakpoints are placed at finer and finer increments until the instruction causing the crash is located.

This long and ugly procedure can sometimes be shortened with a hardware debugger. When the system crashes, the programmer can push the manual interrupt button, suspend program execution, and give control to the debugger card. At this point, the programmer can use the debugging monitor software supplied with the card to sniff around memory looking for something suspicious. Clues can sometimes be found by examining the program's stack and data areas—provided, of course, that they are still in memory and haven't been destroyed, along with the operating system, by the rampaging program. This approach is not always an immediate solution to the problem, however; often, the start-and-set-breakpoints process has to be repeated even with a hardware debugger. The hardware will, however, possibly shed some light on the causes of the problem and shorten the procedure.

Another feature offered by many of the debugging boards is the ability to set breakpoints on events other than the execution of a line of code. Often, these boards will allow the programmer to break on a reference to a specific memory location, to a range of memory

locations, or to an I/O port. This feature allows a watch to be set on data, analogous to the watchpoint feature of CodeView. This technique is almost always useful, as it is with CodeView, but there is one class of problems where it is *essential* to reaching a solution.

Consider the case of a program that seems to be running well. Every so often, however, an ampersand appears in the middle of a payroll amount, or occasionally the program makes an erroneous branch and executes the wrong path. Suppose that, after painstaking investigation, the programmer discovers that these problems are being caused by a change in a specific location in memory sometime during the execution of the program. In debugging, the discovery of the cause of a problem usually leads almost instantly to a fix. Not so in this case. That byte of memory could be changed by an error in the program, by a glitch in the operating system or in a device driver, or by cosmic rays from outer space. Discovering the culprit in a case like this is almost impossible without the help of hardware breakpoints. Setting a breakpoint on the affected memory location and running the program will solve the problem. As soon as the memory location is changed, the breakpoint will be executed and the state of the system registers will point a clear finger at the instruction that caused the problem.

Hardware debuggers can provide significant aid to the serious programmer. They are especially helpful in debugging operating systems and operating-system services such as device drivers. They are also helpful in complicated situations where many programs may be running at the same time. The consensus among programmers who have hardware debuggers is that they are well worth the money.

Summary

Although Microsoft and others have provided an impressive array of technology to aid in program debugging, the most important tool a programmer has is his or her native wit and talent. As the examples in this article have illustrated, the technology makes the task easier, but never easy. In all cases, however, it is the programmer who debugs the program and solves the problems.

Technology will never be able to replace the person for solving the problem of a bug-ridden program. (This is an area where artificial intelligence will undoubtedly fail.) Therefore, it is the skills discussed in the first part of this article — debugging by inspection and observation — that deserve the greatest attention and practice. All the other techniques and technologies, with their ever-increasing sophistication, are only extensions of these basic techniques. A programmer who can debug effectively at the lowest level of technology will always be ready to use whatever advanced technology is available.

Therefore, as a final word, remember the rule that opened this article:

Gather enough information and the solution will be obvious.

All the rest of this article was merely a discussion of ways to gather the information.

Steve Bostwick

Article 19
Object Modules

Object modules are used primarily by programmers. The end user of an MS-DOS application need never be concerned with object code, object modules, and object libraries because application programs are almost always distributed as .EXE or .COM files that can be executed with a simple startup command.

An application programmer writing in a high-level language can use object modules and object libraries without knowing either the format of object code or the details of what the utilities that process object modules, such as the Microsoft Library Manager (LIB) and the Microsoft Object Linker (LINK), are actually doing. Most application programmers simply regard the contents of an object module as a "black box" and trust their compilers and object module utility programs to do the right thing.

A programmer using assembly language or an assembly-language debugger such as DEBUG or SYMDEB, however, might want to know more about the content and function of object modules. The use of assembly language gives the programmer more control over the actual contents of object modules, so knowing how the modules are constructed and examining their contents can sometimes help with program debugging.

Finally, a programmer writing a compiler, an assembler, or a language translator must know the details of object module format and processing. To take advantage of LIB and LINK, a language translator must construct object modules that conform to the format and usage conventions specified by Microsoft.

Note: This article assumes some background knowledge of the process by which source code is converted into an executable file in the MS-DOS environment. *See* PROGRAMMING IN THE MS-DOS ENVIRONMENT: PROGRAMMING FOR MS-DOS: Structure of an Application Program; PROGRAMMING TOOLS: The Microsoft Object Linker; PROGRAMMING UTILITIES.

The Use of Object Modules

Although some MS-DOS language translators generate executable 8086-family machine code directly from source code, most produce object code instead. Typically, a translator processes each file of source code individually and leaves the resulting object module in a separate file bearing a .OBJ extension. The source-code files themselves remain unchanged. After all of a program's source-code modules have been translated, the resulting object modules can be linked into a single executable program. Because object modules frequently represent only a portion of a complete program, each source-code module usually contains instructions that indicate how its corresponding object code is to be combined with the object code in other object modules when they are linked.

The object code contained in each object module consists of a binary image of the program plus program structure information. This object code is not directly executable. The binary image corresponds to the executable code that will ultimately be loaded into memory for execution; it contains both machine code and program data. The program structure information includes descriptions of logical groupings defined in the source code (such as named subroutines or segments) and symbolic references to addresses in other object modules.

The program structure information is used by a linkage editor, or linker, such as Microsoft LINK to edit the binary image of the program contained in the object module. The linker combines the binary images from one or more object modules into a complete executable program.

The linker's output is a .EXE file—a file containing executable machine code that can be loaded into RAM and executed (Figure 19-1). The linker leaves intact all of the object modules it processes.

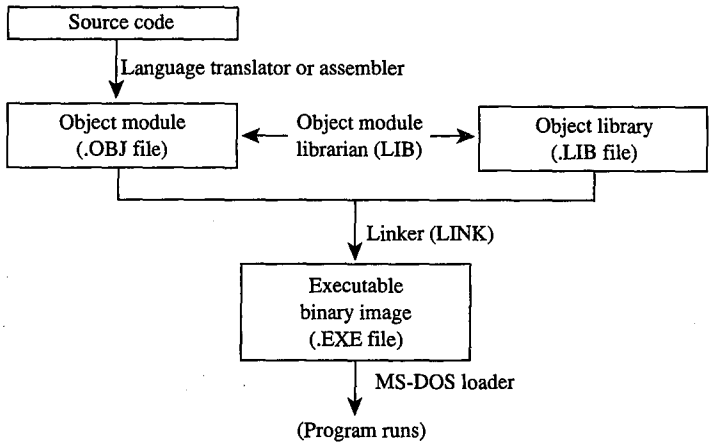


Figure 19-1. Generation of an executable (.EXE) file.

Object code thus serves as an intermediate form for compiled programs. This form offers two major advantages:

- Modular intermediate code. The use of object modules eliminates the overhead of repeated compilation of an entire program whenever changes are made to parts of its source code. Instead, only those object modules affected by source-code revisions need be recompiled.
- Shareable format. Object module format is well defined, so object modules can be linked even if they were produced by different translators. Many high-level-language compilers take advantage of this commonality of object-code format to support "interlanguage" linkage.

Contents of an object module

Object modules contain five basic types of information. Some of this information exists explicitly in the source code (and is subsequently passed on to the object module), but much is inferred by the program translator from the structure of the source code and the way memory is accessed by the 8086.

Binary Image. As described earlier, the binary image comprises executable code (such as opcodes and addresses) and program data. When object modules are linked, the linker builds an executable program from the binary image in each object module it processes. The binary image in each object module is always associated with program structure information that tells the linker how to combine it with related binary images in other object modules.

External References. Because an object module generally represents only a small portion of a larger program that will be constructed from several object modules, it usually contains symbols that allow it to be linked to the other modules. Such references to corresponding symbols in other object modules are resolved when the modules are linked.

For example, consider the following short C program:

```
main()
{
        puts("Hello, world\n");
}
```

This program calls the C function *puts()* to display a character string, but *puts()* is not defined in the source code. Rather, the name *puts* is a reference to a function that is external to the program's *main()* routine. When the C compiler generates an object module for this program, it will identify *puts* as an external reference. Later, the linker will resolve the external reference by linking the object module containing the *puts()* routine with the module containing the *main()* routine.

Address References. When a program is built from a group of object modules, the actual values of many addresses cannot be computed until the linker combines the binary image of executable code and the program data from each of the program's constituent object modules. Object modules contain information that tells the linker how to resolve the values of such addresses, either symbolically (as in the case of external references) or relatively, in terms of some other address (such as the beginning of a block of executable code or program data).

Debugging Information. An object module can also contain information that relates addresses in the executable program to the corresponding source code. After the linker performs its address fixups, it can use the object module's debugging information to relate a line of source code in a program module to the executable code that corresponds to it.

Miscellaneous Information. Finally, an object module can contain comments, lists of symbols defined in or referenced by the module, module identification information, and

information for use by an object library manager or a linker (for example, the names of object libraries to be searched by default).

Object module terminology

When the linker generates an executable program, it organizes the structural components of the program according to the information contained in the object modules. The layout of the executable program can be conceptually described as a run-time memory map after it has been loaded into memory.

The basic structure of every executable program for the 8086 family of microprocessors must conform to the segmented architecture of the microprocessor. Thus, the run-time memory map of an executable program is partitioned into segments, each of which can be addressed by using one of the microprocessor's segment registers. This segmented structure of 8086-based programs is the basis for most of the following terminology.

Frames. The memory address space of the 8086 is conceptually divided into a sequence of paragraph-aligned, overlapping 64 KB regions called frames. Frame 0 in the 8086's address space is the 64 KB of memory starting at physical address 00000H (0000:0000 in segment:offset notation), frame 1 is the 64 KB of memory starting at 00010H (0001:0000), and so on. A frame number thus denotes the beginning of any paragraph-aligned 64 KB of memory. For example, the location of a 64 KB buffer that starts at address B800:0000 can be specified as frame 0B800H.

Logical Segments. The run-time memory map for every 8086 program is partitioned into one or more logical segments, which are groupings of logically related portions of the program. Typically, an MS-DOS program includes at least one code segment (that contains all of the program's executable code), one or more data segments (that contain program data), and one stack segment.

When a program is loaded into RAM to be executed, each logical segment in the program can be addressed with a frame number—that is, a physical 8086 segment address. Before the MS-DOS loader transfers control to a program in memory, it initializes the CS and SS registers with the segment addresses of the program's executable code and stack segments. If an MS-DOS program has a separate logical segment for program data, the program itself usually stores this segment's address in the DS register.

Relocatable Segments. In MS-DOS programs, most logical segments are relocatable. The loader determines the physical addresses of a program's relocatable segments when it places the program into memory to be executed. However, this address determination poses a problem for the MS-DOS loader, because a program may contain references to the address of a relocatable segment even though the address value is not determined until the program is loaded. The problem is solved by indicating where such references occur within the program's object modules. The linker then extracts this information from the object modules and uses it to build a list of such address references into a segment relocation table in the header of executable files. After the loader copies a program into memory for execution, it uses the segment relocation table to update, or fix up, the segment address references within the program.

Consider the following example, in which a program loads the starting addresses of two data segments into the DS and ES segment registers:

```
mov     ax,seg _DATA
mov     ds,ax               ; make _DATA segment addressable through DS
mov     ax,seg FAR_DATA
mov     es,ax               ; make FAR_DATA segment addressable through ES
```

The actual addresses of the _DATA and FAR_DATA segments are unknown when the source code is assembled and the corresponding object module is constructed. The assembler indicates this by including segment fixup information, instead of actual segment addresses, in the program's object module. When the object module is linked, the linker builds this segment fixup information into the segment relocation table in the header of the program's .EXE file. Then, when the .EXE file is loaded, the MS-DOS loader uses the information in the .EXE file's header to patch the actual address values into the program.

Absolute Segments. Sometimes a program needs to address a predetermined segment of memory. In this case, the program's source code must declare an absolute segment so that a reference to the corresponding frame number can be built into the program's object module.

For example, a program might need to address a video display buffer located at a specific physical address. The following assembler directive declares the name of the segment and its frame number:

```
VideoBufferSeg    SEGMENT at 0B800h
```

Segment Alignment. When a program is loaded, the physical address of each logical segment is constrained by the segment's alignment. A segment can be page aligned (aligned on a 256-byte boundary), paragraph aligned (aligned on a 16-byte paragraph boundary), word aligned (aligned on an even-byte boundary), or byte aligned (not aligned on any particular boundary). A specification of each segment's alignment is part of every object module's program structure information.

High-level-language translators generally align segments according to the type of data they contain. For example, executable code segments are usually byte aligned; program data segments are usually word aligned. With an assembler, segment alignment can be specified with the SEGMENT directive and the assembler will build this information into the program's object module.

Concatenated Segments. The linker can concatenate logical segments from different object modules when it builds the executable program. For example, several object modules may each contain part of a program's executable code. When the linker processes these object modules, it can concatenate the executable code from the different object modules into one range of contiguous addresses.

The order in which the linker concatenates logical segments in the executable program is determined by the order in which the linker processes its input files and by the program

structure information in the object modules. With a high-level-language translator, the translator infers which segments can be concatenated from the structure of the source code and builds appropriate segment concatenation information into the object modules it generates. With an assembler, the segment class type can be used to indicate which segments can be concatenated.

Groups of Segments. Segments with different names may also be grouped together by the linker so that they can all be addressed within the same 64 KB frame, even though they are not concatenated. For example, it might be desirable to group program data segments and a stack segment within the same 64 KB frame so that program data items and data on the stack can be addressed with the same 8086 segment register.

In high-level languages, it is up to the translator to incorporate appropriate segment grouping information into the object modules it generates. With an assembler, groups of segments can be declared with the GROUP directive.

Fixups. Sometimes a compiler or an assembler encounters addresses whose values cannot be determined from the source code. The addresses of external symbols are an obvious example. The addresses of relocatable segments and of labels within those segments are another example.

A fixup is a language translator's way of passing the buck about such addresses to the linker. Typically, a translator builds a zero value in the binary image at locations where it cannot store an actual address. Accompanying each such location is fixup information, which allows the linker to determine the correct address. The linker then completes the fixup by calculating the correct address value and adding it to the value in the corresponding location in the binary image. The only fixups the linker cannot fully resolve are those that refer to the segment address of a relocatable segment. Such addresses are not known until the program is actually loaded, so the linker, in turn, passes the responsibility to the MS-DOS loader by creating a segment relocation table in the header of the executable file.

To process fixups properly, the linker needs three pieces of information: the LOCATION of the value in the object module, the nature of the TARGET (the address whose value is not yet known), and the FRAME in which the address calculations are to take place. Object modules contain the LOCATION, TARGET, and FRAME information the linker uses to calculate the appropriate address for any given fixup.

Consider the "program" in Figure 19-2. The statement:

```
start:  call    far ptr FarProc
```

contains a reference to an address in the logical segment *FarSeg2*. Because the assembler does not know the address of *FarSeg2*, it places fixup information about the address into the object module. The LOCATION to be fixed up is 1 byte past the label *start* (the 4-byte pointer following the *call* opcode 9AH). The TARGET is the address referenced in the *call* instruction—that is, the label *FarProc* in the segment *FarSeg2*. The FRAME to which

the fixup relates is designated by the group *FarGroup* and is inferred from the statement

```
ASSUME  cs:FarGroup
```

in the *FarSeg2* segment.

```
                                        title   fixups


                                FarGroup GROUP  FarSeg1,FarSeg2

0000                            CodeSeg SEGMENT byte public 'CODE'
                                        ASSUME  cs:CodeSeg

0000  9A 0000 ---- R            start:  call    far ptr FarProc

0005                            CodeSeg ENDS


0000                            FarSeg1 SEGMENT byte public     ;part of FarGroup

0000                            FarSeg1 ENDS


0000                            FarSeg2 SEGMENT byte public
                                        ASSUME  cs:FarGroup

0000                            FarProc PROC    far
0000  CB                                ret                     ;a FAR return
                                FarProc ENDP

0001                            FarSeg2 ENDS

                                        END
```

Figure 19-2. A sample "program" containing statements from which the assembler derives fixup information.

There are several different ways for a language translator to identify a fixup. For example, the LOCATION might be a single byte, a 16-bit offset, or a 32-bit pointer, as in Figure 19-2. The TARGET might be a label whose offset is relative either to the base (beginning) of a particular segment or to the LOCATION itself. The FRAME might be a relocatable segment, an absolute segment, or a group of segments.

Taken together, all the information in an object module that concerns the alignment and grouping of segments can be regarded as a specification of a program's run-time memory map. In effect, the object module specifies what goes where in memory when a program is loaded. The linker can then take the program structure information in the object modules and generate a file containing an executable program with the corresponding structure.

The Structure of an Object Module

Although object modules contain the information that ultimately determines the structure of an executable program, they bear little structural resemblance to the resulting executable program. Each object module is made up of a sequence of variable-length object records. Different types of object records contain different types of program information.

Each object record begins with a 1-byte field that identifies its type. This is followed by a 2-byte field containing the length (in bytes) of the remainder of the record. Next comes the actual structural or program information, represented in one or more fields of varied lengths. Finally, each record ends with a 1-byte checksum.

The sequence in which object records appear in an object module is important. Because the records vary in length, each object module must be constructed linearly, from start to end. More important, however, is the fact that some types of object records contain references to preceding object records. Because the linker processes object records sequentially, the position of each object record within an object module depends primarily on the type of information each record contains.

Types of object records

Microsoft LINK currently recognizes 14 types of object records, each of which carries a specific type of information within the object module. Each type of object record is assigned an identifying six-letter abbreviation, but these abbreviations are used only in documentation, not within an object module itself. As already mentioned, the first byte of each object record contains a value that indicates its type. In a hexadecimal dump of the contents of an object module, these identifying bytes identify the start of each object record.

Table 19-1 lists the types of object records supported by LINK. The value of each record's identifying byte (in hexadecimal) is included, along with the six-letter abbreviation and a brief functional description. The functions of the 14 types of object records fall into six general categories:

- Binary data (executable code and program data) is contained in the LEDATA and LIDATA records.
- Address binding and relocation information is contained in FIXUPP records.
- The structure of the run-time memory map is indicated by SEGDEF, GRPDEF, COMDEF, and TYPDEF records.
- Symbol names are declared in LNAMES, EXTDEF, and PUBDEF records.
- Debugging information is in the LINNUM record.
- Finally, the structure of the object module itself is determined by the THEADR, COMENT, and MODEND records.

Table 19-1. Types of 8086 Object Records Supported by Microsoft LINK.

ID byte	Abbreviation	Description
80H	THEADR	Translator Header Record
88H	COMENT	Comment Record
8AH	MODEND	Module End Record
8CH	EXTDEF	External Names Definition Record
8EH	TYPDEF	Type Definition Record
90H	PUBDEF	Public Names Definition Record
94H	LINNUM	Line Number Record
96H	LNAMES	List of Names Record
98H	SEGDEF	Segment Definition Record
9AH	GRPDEF	Group Definition Record
9CH	FIXUPP	Fixup Record
0A0H	LEDATA	Logical Enumerated Data Record
0A2H	LIDATA	Logical Iterated Data Record
0B0H	COMDEF	Communal Names Definition Record

Object record order

The sequence in which the types of object records appear in an object module is fairly flexible in some respects. Several record types are optional, and if the type of information they carry is unnecessary, they are omitted from an object module. In addition, most object record types can occur more than once in the same object module. And, because object records are variable in length, it is often possible to choose, as a matter of convenience, between combining information into one large record or breaking it down into several smaller records of the same type.

As stated previously, an important constraint on the order in which object records appear is the need for some types of object records to refer to information contained in other records. Because the linker processes the records sequentially, object records containing such information must precede the records that refer to it. For example, two types of object records, SEGDEF and GRPDEF, refer to the names contained in an LNAMES record. Thus, an LNAMES record must appear before any SEGDEF or GRPDEF records that refer to it so that the names in the LNAMES record are known to the linker by the time it processes the SEGDEF or GRPDEF records.

A typical object module

Figure 19-3 contains the source code for HELLO.ASM, an assembly-language program that displays a short message. Figure 19-4 is a hexadecimal dump of HELLO.OBJ, the object module generated by assembling HELLO.ASM with the Microsoft Macro Assembler. Figure 19-5 isolates the object records within the object module.

```
        NAME    HELLO

_TEXT   SEGMENT byte public 'CODE'

        ASSUME  cs:_TEXT,ds:_DATA

start:                                  ;program entry point
        mov     ax,seg msg
        mov     ds,ax
        mov     dx,offset msg           ;DS:DX -> msg
        mov     ah,09h
        int     21h                     ;perform int 21H function 09H
                                        ;(Output character string)
        mov     ax,4C00h
        int     21h                     ;perform int 21H function 4CH
                                        ;(Terminate with return code)
_TEXT   ENDS


_DATA   SEGMENT word public 'DATA'

msg     DB      'Hello, world',0Dh,0Ah,'$'

_DATA   ENDS


_STACK  SEGMENT stack 'STACK'

        DW      80h dup(?)              ;stack depth = 128 words

_STACK  ENDS

        END     start
```

Figure 19-3. The source code for HELLO.ASM.

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  80 07 00 05 48 45 4C 4C 4F 00 96 25 00 00 04 43  ....HELLO..%...C
0010  4F 44 45 04 44 41 54 41 05 53 54 41 43 4B 05 5F  ODE.DATA.STACK._
0020  44 41 54 41 06 5F 53 54 41 43 4B 05 5F 54 45 58  DATA._STACK._TEX
0030  54 8B 98 07 00 28 11 00 07 02 01 1E 98 07 00 48  T....(.........H
0040  0F 00 05 03 01 01 98 07 00 74 00 01 06 04 01 E1  .........t......
0050  A0 15 00 01 00 00 B8 00 00 8E D8 BA 00 00 B4 09  ................
0060  CD 21 B8 00 4C CD 21 D5 9C 0B 00 C8 01 04 02 02  .!..L.!.........
0070  C4 06 04 02 02 B6 A0 13 00 02 00 00 48 65 6C 6C  ............Hell
0080  6F 2C 20 77 6F 72 6C 64 0D 0A 24 A8 8A 07 00 C1  o, world..$.....
0090  00 01 01 00 00 AC                                ......
```

Figure 19-4. A hexadecimal dump of HELLO.OBJ.

```
       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F

THEADR
0000  80 07 00 05 48 45 4C 4C 4F 00                    ....HELLO.

LNAMES
0000                                  96 25 00 00 04 43           .%...C
0010  4F 44 45 04 44 41 54 41 05 53 54 41 43 4B 05 5F  ODE.DATA.STACK._
0020  44 41 54 41 06 5F 53 54 41 43 4B 05 5F 54 45 58  DATA._STACK._TEX
0030  54 8B                                          T.

SEGDEF
0030        98 07 00 28 11 00 07 02 01 1E                ...(......

SEGDEF
0030                                        98 07 00 48             ...H
0040  0F 00 05 03 01 01                                ......

SEGDEF
0040                    98 07 00 74 00 01 06 04 01 E1       ...t......

LEDATA
0050  A0 15 00 01 00 00 B8 00 00 8E D8 BA 00 00 B4 09  ................
0060  CD 21 B8 00 4C CD 21 D5                          .!..L.!.

FIXUPP
0060                           9C 0B 00 C8 01 04 02 02         ........
0070  C4 06 04 02 02 B6                                ......

LEDATA
0070                    A0 13 00 02 00 00 48 65 6C 6C       ......Hell
0080  6F 2C 20 77 6F 72 6C 64 0D 0A 24 A8             o, world..$.

MODEND
0080                                        8A 07 00 C1             ....
0090  00 01 01 00 00 AC                                ......
```

Figure 19-5. The object records in HELLO.OBJ.

As shown most clearly in Figure 19-5, each of the object records begins with the single byte value identifying the record's type. The second and third bytes of each record contain a single 16-bit value, stored with its low-order byte first, that represents the length (in bytes) of the remainder of the object record.

The first record, THEADR, identifies the object module and the last record, MODEND, terminates the object module. The second record, LNAMES, contains a list of segment names and segment class names that LINK will use to lay out the run-time memory map. The three succeeding SEGDEF records describe the three corresponding segments defined in the source code.

The order in which the object records appear reflects both the structure of the source code and the record order constraints already mentioned. The LNAMES record appears before the three SEGDEF records because each SEGDEF record contains a reference to a name in the LNAMES record.

The binary data representing each of the two segments in the source code is contained in the two LEDATA records. The first LEDATA record represents the *_TEXT* segment; the second specifies the data in the *_DATA* segment. The FIXUPP record following the first LEDATA record contains information about the address references in the *_TEXT* segment. Again, the order in which the records appear is important: the FIXUPP record refers to the LEDATA record preceding it.

References between object records

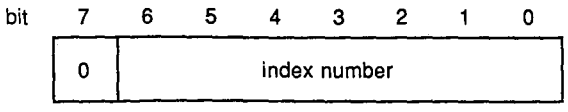
Object records can refer to information in other records either indirectly, by means of implicit references, or directly, by means of indexed references to names or other records.

Implicit References. Some types of object records implicitly reference another record in the same object module. The most important example of such implicit referencing is in the FIXUPP record, which always contains fixup information for the preceding LEDATA or LIDATA record in the object module. Whenever an LEDATA or LIDATA record contains a value that needs to be fixed up, the next record in the object module is always a FIXUPP record containing the actual fixup information.

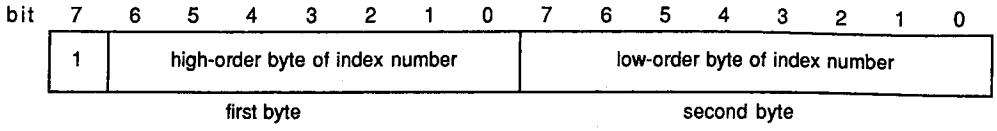
Indexed References to Names. An object record that refers to a symbolic name, such as the name of a segment or an external routine, uses an index into a list of names contained in a previous object record. (The LNAMES record in Figure 19-5 is an example.) The first name in such a list has the index number 1, the second name has index number 2, the third has index number 3, and so on. Altogether, a list of as many as 32,767 (7FFFH) names can be incorporated into an object module—generally adequate for even the most verbose programmer. (LINK does, however, impose its own version-specific limits.)

Indexed References to Object Records. An object record can also refer to a previous object record by using the same type of index. In this case, the index number refers to one of a list of object records of a particular type. For example, a FIXUPP record might refer to a segment by referencing one of several preceding SEGDEF records in the object module. In that case, a value of 1 would indicate the first SEGDEF record in the object module, a value of 2 would indicate the second, and so on.

The *index-number* field in an object record can be either 1 or 2 bytes long. If the number is in the range 0–7FH, the high-order bit (bit 7) is 0 and the low-order 7 bits contain the index number, so the field is only 1 byte long:



If the index number is in the range 80–7FFFH, the field is 2 bytes long. The high-order bit of the first byte in the field is set to 1, and the high-order byte of the index number (which must be in the range 0–7FH) fits in the remaining 7 bits. The low-order byte of the index number is specified in the second byte of the field:



The same format is used whether an index refers to a list of names or to a previous object record.

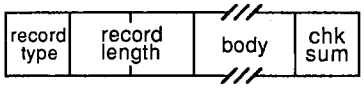
Microsoft 8086 Object Record Formats

Just as the design of the Intel 8086 microprocessor reflects the design of its 8-bit predecessors, 8086 object record formats are reminiscent of the 8-bit software tradition. In 8-bit systems, disk space and RAM were often at a premium. To minimize the space consumed by object records, information is packed into bit fields within bytes and variable-length fields are frequently used.

Microsoft LINK recognizes a major subset of Intel's original 8086 object module specification (Intel Technical Specification 121748-001). Intel also proposed a six-letter name for each type of object record and symbolic names for fields. These names are documented in the following descriptions, which appear in the order shown earlier in Table 19-1.

The Intel record types that are not recognized by LINK provide information about an executable program that MS-DOS obtains in other ways. (For example, information about run-time overlays is supplied in LINK's command line rather than being encoded in object records.) Because they are ignored by LINK, they are not included here.

All 8086 object records conform to the following format:



The *record type* field is a 1-byte field containing the hexadecimal number that identifies the type of object record (*see* Table 19-1).

The *record length* is a 2-byte field that gives the length of the remainder of the object record in bytes (excluding the bytes in the *record type* and *record length* fields). The record length is stored with the low-order byte first.

The *body* field of the record varies in size and content, depending on the record type.

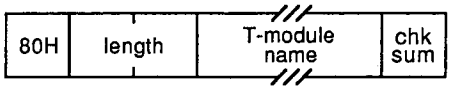
The *checksum* is a 1-byte field that contains the negative sum (modulo 256) of all other bytes in the record. In other words, the checksum byte is calculated so that the low-order byte of the sum of all the bytes in the record, including the checksum byte, equals zero.

Note: As shown in the preceding example, the boxes used to depict the fields vary in size. The square boxes used for *record type* and *chksum* indicate a single byte, the rectangular box used for *record length* indicates 2 bytes, and the diagonal lines used for *body* indicate a variable-length field.

80H THEADR Translator Header Record

The THEADR record contains the name of the object module. This name identifies an object module within an object library or in messages produced by the linker.

Record format



T-module name

The *T-module name* field is a variable-length field that contains the name of the object module. The first byte of the field contains the number of subsequent bytes that contain the name itself. The name can be uppercase or lowercase and can be any string of characters.

The *T-module name* is used by LIB and LINK within error messages. Language translators frequently derive the *T-module name* from the name of the file that contains a program's source code. Assembly-language programmers can specify the *T-module name* explicitly with the assembler NAME directive.

Location in object module

As its name implies, the THEADR record must be the first record in every object module generated by a language translator.

Example

The following THEADR record was generated by the Microsoft C Compiler:

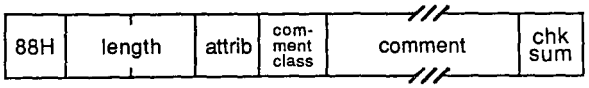
```
       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  80 09 00 07 68 65 6C 6C 6F 2E 63 CB              ....hello.c.
```

- Byte 00H contains 80H, indicating a THEADR record.
- Bytes 01–02H contain 0009H, the length of the remainder of the record.
- Bytes 03–0AH contain the *T-module name*. Byte 03H contains 07H, the length of the name, and bytes 04H through 0AH contain the name itself (*hello.c*). (In object modules generated by the Microsoft C Compiler, the THEADR record indicates the filename that contained the C source code for the module.)
- Byte 0BH contains the checksum, 0CBH.

88H COMENT Comment Record

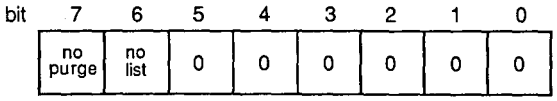
The COMENT record contains a character string that may represent a plain text comment, a symbol meaningful to a program such as LIB or LINK, or even binary-encoded identification data. An object module can contain any number of COMENT records.

Record format



Attrib

Attrib is a 1-byte field in which only the first 2 bits are meaningful:



- If bit 7 (*no purge*) is set to 1, utility programs that manipulate object modules should not delete the comment record from the object module. Bit 7 can thus protect an important comment, such as a copyright message, from deletion.
- If bit 6 (*no list*) is set to 1, utility programs that can list the contents of object modules are directed not to list the comment. Bit 6 can thus hide a comment.
- Bits 5 through 0 are unused and should be set to 0.

Microsoft LIB ignores the *attrib* field.

Comment class

Comment class is a 1-byte field whose value provides information about the type of comment. The original Intel specification provided for the following possible *comment class* values:

Value	Use
00H	Language-translator comment (the name of the translator that generated the object module).
01H	Copyright comment.
02–9BH	Reserved for Intel proprietary software.

Microsoft language translators can generate several other classes of COMENT record that communicate specific information about the object module to LINK:

Value	Use
81H	Obsolete; replaced by *comment class* 9FH.
9CH	MS-DOS version number. Some language translators create a COMENT record with a 2-byte binary value in the *comment* field indicating the MS-DOS version under which the module was created. This record is ignored by LINK.
9DH	Memory model. The *comment* field contains a string that indicates the memory model used by the language translator. The string contains one of the lowercase letters s, c, m, l, and h to designate small, compact, medium, large, and huge memory models. Microsoft language translators generate COMENT records with this *comment class* only for compatibility with the XENIX version of LINK. The MS-DOS version of LINK ignores these COMENT records.
9EH	Sets Microsoft LINK's DOSSEG switch.
9FH	Default library search name. LINK interprets the contents of the *comment* field as the name of a library to be searched in order to resolve external references within the object module. The default library search can be overridden with LINK's NODEFAULTLIBRARYSEARCH switch.
0A1H	Indicates that Microsoft extensions to the Intel object record specification are used in the object module. For example, when COMDEF records are used within an object module, a COMENT record with *comment class* 0A1H must appear in the object module at some point before the first COMDEF record. LINK ignores the *comment* string in COMENT records with this *comment class.*
0C0H–0FFH	Reserved for user-defined comment classes.

Comment

The *comment* field is a variable-length string of bytes that represent the comment. The length of the string is inferred from the length of the object record.

Location in object module

A COMENT record can appear almost anywhere in an object module. Only two restrictions apply:

- A COMENT record cannot be placed between a FIXUPP record and the LEDATA or LIDATA record to which it refers.
- A COMENT record cannot be the first or last record in an object module. (The first record must always be a THEADR record and the last must always be MODEND.)

Examples

The following three examples are typical COMENT records taken from an object module generated by the Microsoft C Compiler.

This first example is a language-translator comment:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  88 07 00 00 00 4D 53 20 43 6E                  .....MS Cn
```

- Byte 00H contains 88H, indicating that this is a COMENT record.
- Bytes 01–02H contain 0007H, the length of the remainder of the record.
- Byte 03H (the *attrib* field) contains 00H. Bit 7 (*no purge*) is set to 0, indicating that this COMENT record may be purged from the object module by a utility program that manipulates object modules. Bit 6 (*no list*) is set to 0, indicating that this comment need not be excluded from any listing of the module's contents. The remaining bits are all 0.
- Byte 04H (the *comment class* field) contains 00H, indicating that this COMENT record contains the name of the language translator that generated the object module.
- Bytes 05H through 08H contain the name of the language translator, MS C.
- Byte 09H contains the checksum, 6EH.

The second example contains the name of an object library to be searched by default when LINK processes the object module containing this COMENT record:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  88 09 00 00 9F 53 4C 49 42 46 50 10            .....SLIBFP.
```

- Byte 04H (the *comment class* field) contains 9FH, indicating that this record contains the name of a library for LINK to use to resolve external references.
- Bytes 05–0AH contain the library name, SLIBFP. In this example, the name refers to the Microsoft C Compiler's floating-point function library, SLIBFP.LIB.

The last example indicates that the object module contains Microsoft-defined extensions to the Intel object module specification:

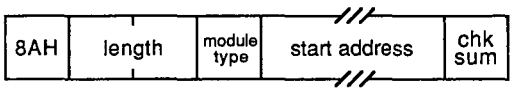
```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  88 06 00 00 A1 01 43 56 37                     .....CV7
```

- Byte 04H indicates the *comment class*, 0A1H.
- Bytes 05–07H, which contain the *comment* string, are ignored by LINK.

8AH MODEND Module End Record

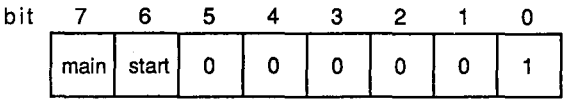
The MODEND record denotes the end of an object module. It also indicates whether the object module contains the main routine in a program, and it can, optionally, contain a reference to a program's entry point.

Record format



Module type

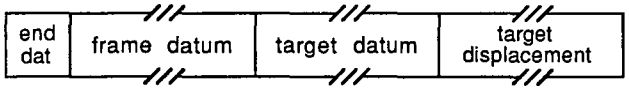
The *module type* field is an 8-bit (1-byte) field:



- Bit 7 (*main*) is set to 1 if the module is a main program module.
- Bit 6 (*start*) is set to 1 if the MODEND record contains an entry point (*start address*).
- Bit 0 is set to 1 if the *start address* field contains a relocatable address reference that LINK must fix up. If bit 6 is set to 1, bit 0 must also be set to 1. (The Intel specification allows bit 0 to be set to 0, to indicate that *start address* is an absolute physical address, but this capability is not supported by LINK.)

Start address

The *start address* field appears in the MODEND record only when bit 6 is set to 1:



The format and interpretation of the *start address* field corresponds to the *fixup* field of the FIXUPP record. The *end dat* field corresponds to the *fix dat* field in the FIXUPP record. Bit 2 of the *end dat* field, which corresponds to the *P* bit in a *fix dat* field, must be zero.

Location in object module

A MODEND record can appear only as the last record in an object module.

Example

Consider the *MODEND* record of the HELLO.ASM example:

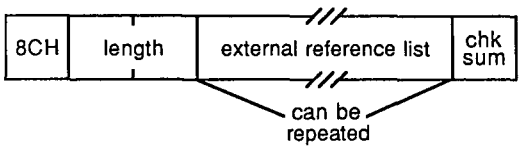
```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  8A 07 00 C1 00 01 01 00 00 AC                  ..........
```

- Byte 00H contains 8AH, indicating a MODEND record.
- Bytes 01–02H contain 0007H, the length of the remainder of the record.
- Byte 03H contains 0C1H (11000001B). Bit 7 is set to 1, indicating that this module is the main module of the program. Bit 6 is set to 1, indicating that a *start address* field is present. Bit 0 is set to 1, indicating that the address referenced in the *start address* field must be fixed up by LINK.
- Byte 04H (*end dat* in the *start address* field) contains 00H. As in a FIXUPP record, bit 7 indicates that the frame for this fixup is specified explicitly, and bits 6 through 4 indicate that a SEGDEF index specifies the frame. Bit 3 indicates that the target reference is also specified explicitly, and bits 2 through 0 indicate that a SEGDEF index also specifies the target. *See also* FIXUPP 9CH Fixup Record below.
- Byte 05H (*frame datum* in the *start address* field) contains 01H. This is a reference to the first SEGDEF record in the module, which in this example corresponds to the *_TEXT* segment. This reference tells LINK that the start address lies in the *_TEXT* segment of the module.
- Byte 06H (*target datum* in the *start address* field) contains 01H. This too is a reference to the first SEGDEF record in the object module, which corresponds to the *_TEXT* segment. LINK uses the following *target displacement* field to determine where in the *_TEXT* segment the address lies.
- Bytes 07–08H (*target displacement* in the *start address* field) contain 0000H. This is the offset (in bytes) of the *start address*.
- Byte 09H contains the checksum, 0ACH.

8CH EXTDEF External Names Definition Record

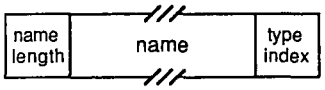
The EXTDEF record contains a list of symbolic external references — that is, references to symbols defined in other object modules. The linker resolves external references by matching the symbols declared in EXTDEF records with symbols declared in PUBDEF records.

Record format



External reference list

The *external reference list* is a variable-length field containing a list of names and name types, each formatted as follows:



- The *name length* is a 1-byte field containing the length of the *name* field that follows it. (LINK restricts *name length* to a value between 01H and 7FH.)
- The *type index* is a 1-byte reference to the TYPDEF record in the object module that describes the type of symbol the name represents. A *type index* value of zero indicates that no TYPDEF record is associated with the symbol. A nonzero value indicates which TYPDEF record is associated with the external name. Microsoft LINK recognizes TYPDEF records only for the purpose of declaring communal variables. *See* 8EH TYPDEF Type Definition Record below.

LINK imposes a limit of 1023 external names.

Location in object module

Any EXTDEF records in an object module must appear before the FIXUPP records that reference them. Also, if an EXTDEF record contains a nonzero *type index*, the indexed TYPDEF record must precede the EXTDEF record.

Example

Consider this EXTDEF record generated by the Microsoft C Compiler:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  8C 25 00 0A 5F 5F 61 63 72 74 75 73 65 64 00 05  .%.._acrtused..
0010  5F 6D 61 69 6E 00 05 5F 70 75 74 73 00 08 5F 5F  _main.._puts.._
0020  63 68 6B 73 74 6B 00 A5                          chkstk..
```

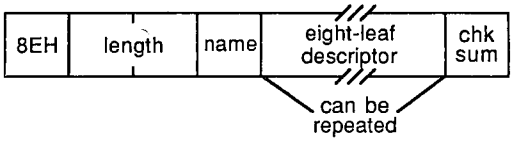
- Byte 00H contains 8CH, indicating that this is an EXTDEF record.
- Bytes 01–02H contain 0025H, the length of the remainder of the record.
- Bytes 03–26H contain a list of external references. The first reference starts in byte 03H, which contains 0AH, the length of the name *__acrtused*. The name itself follows in bytes 04–0DH. Byte 0EH contains 00H, which indicates that the symbol's type is not defined by any TYPDEF record in this object module. Bytes 0F–26H contain similar references to the external symbols *_main*, *_puts*, and *__chkstk*.
- Byte 27H contains the checksum, 0A5H.

8EH TYPDEF Type Definition Record

The TYPDEF record contains details about the type of data represented by a name declared in a PUBDEF or an EXTDEF record. This information may be used by the linker to validate references to names, or it may be used by a debugger to display data according to type.

Starting with Microsoft LINK version 3.50, the COMDEF record should be used for declaration of communal variables. For compatibility, however, later versions of LINK recognize TYPDEF records as well as COMDEF records.

Record format



Although the original Intel specification allowed for many different type specifications, such as scalar, pointer, and mixed data structure, LINK uses TYPDEF records to declare only communal variables. Communal variables represent globally shared memory areas—for example, FORTRAN common blocks or uninitialized public variables in C.

The size of a communal variable is declared explicitly in the TYPDEF record. If a communal variable has different sizes in different object modules, LINK uses the largest declared size when it generates an executable module.

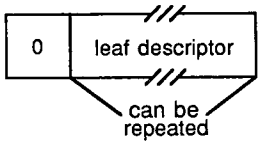
Name

The *name* field of a TYPDEF record is a 1-byte field that is always null; that is, it contains a single zero byte.

Eight-leaf descriptor

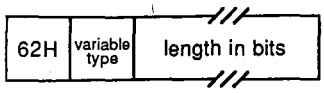
The *eight-leaf descriptor* field, in the original Intel specification, was a variable-length field that contained as many as eight "leaves" that could be used to describe mixed data structures.

Microsoft uses a stripped-down version of the *eight-leaf descriptor*, because the field's only function is to describe communal variables:



- The first field in the *eight-leaf descriptor* is a 1-byte field that contains a zero byte.
- The *leaf descriptor* field is a variable-length field that is itself divided into four fields ("leaves") that describe the size and type of a variable. The two possible variable types are NEAR and FAR.

  If the field describes a NEAR variable (one that can be referenced as an offset within a default data segment), the format is

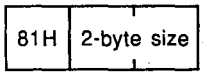


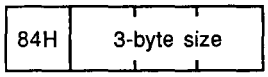
  - The 1-byte field containing 62H signifies a NEAR variable.
  - The *variable type* field is a 1-byte field that specifies the variable type:

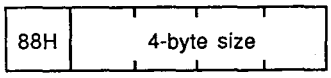
77H	Array
79H	Structure
7BH	Scalar

    This field is ignored by LINK.
  - The *length in bits* field is a variable-length field that indicates the size of the communal variable. Its format depends on the size it represents. If the size is less than 128 (80H) bits, *length in bits* is a 1-byte field containing the actual size of the field:

    If the size is 128 bits or greater, it cannot be represented in a single byte value, so the *length in bits* field is formatted with an extra initial byte that indicates whether the size is represented as a 2-, 3-, or 4-byte value:







If the *leaf descriptor* field describes a FAR variable (one that must be referenced with an explicit segment and offset), the format is

- The 1-byte field containing 61H signifies a FAR variable.
- The 1-byte *variable type* for a FAR communal variable is restricted to 77H (array). (As with the NEAR *variable type* field, LINK ignores this field.)
- The *number of elements* is a variable-length field that contains the number of elements in the array. It has the same format as the *length in bits* field in the *leaf descriptor* for a NEAR variable.
- The *element type index* is an index field that references a previous TYPDEF record. A value of 1 indicates the first TYPDEF record in the object module, a value of 2 indicates the second TYPDEF record, and so on. The TYPDEF record referenced must describe a NEAR variable. This way, the data type and size of the elements in the array can be determined.

Location in object module

Any TYPDEF records in an object module must precede the EXTDEF or PUBDEF records that reference them.

Examples

The following three examples of TYPDEF records were generated by the Microsoft C Compiler version 3.0. (Later versions use COMDEF records.)

The first sample TYPDEF record corresponds to the public declaration

```
int    foo;            /* 16-bit integer */
```

The TYPEDEF record is

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  8E 06 00 00 00 62 7B 10 7F                     .....b{..
```

- Byte 00H contains 8EH, indicating that this is a TYPDEF record.
- Bytes 01–02H contain 0006H, the length of the remainder of the record.
- Byte 03H (the *name* field) contains 00H, a null name.
- Bytes 04–07H represent the *eight-leaf descriptor* field. The first byte of this field (byte 04H) contains 00H. The remaining bytes (bytes 05–07H) represent the *leaf descriptor* field:
  - Byte 05H contains 62H, indicating this TYPDEF record describes a NEAR variable.
  - Byte 06H (the *variable type* field) contains 7BH, which describes this variable as a scalar.
  - Byte 07H (the *length in bits* field) contains 10H, the size of the variable in bits.

- Byte 08H contains the checksum, 7FH.

The next example demonstrates how the variable size contained in the *length in bits* field of the *leaf descriptor* is formatted:

```
char    foo2[32768];            /* 32 KB array */

       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  8E 09 00 00 00 62 7B 84 00 00 04 04              .....b{.....
```

- The *length in bits* field (bytes 07–0AH) starts with a byte containing 84H, which indicates that the actual size of the variable is represented as a 3-byte value (the following 3 bytes). Bytes 08–0AH contain the value 040000H, the size of the 32 KB array in bits.

This third C statement, because it declares a FAR variable, causes two TYPDEF records to be generated:

```
char    far     foo3[10][2][20];        /* 400-element FAR array */
```

The two TYPDEF records are

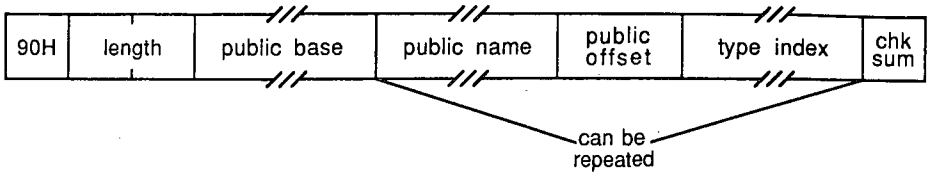
```
       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  8E 06 00 00 00 62 7B 08 87 8E 09 00 00 00 61 77  .....b{.......aw
0010  81 90 01 01 7E                                    ....~
```

- Bytes 00–08H contain the first TYPDEF record, which defines the data type of the elements of the array (NEAR, scalar, 8 bits in size).
- Bytes 09–14H contain the second TYPDEF record. The *leaf descriptor* field of this record declares that the variable is FAR (byte 0EH contains 61H) and an array (byte 0FH, the *variable type*, contains 77H).
  - Because this TYPDEF record describes a FAR variable, bytes 10–12H represent a *number of elements* field. The first byte of the field is 81H, indicating a 2-byte value, so the next 2 bytes (bytes 11–12H) contain the number of elements in the array, 0190H (400D).
- Byte 13H (the *element type index*) contains 01H, which is a reference to the first TYPDEF record in the object module — in this example, the one in bytes 00–08H.

90H PUBDEF Public Names Definition Record

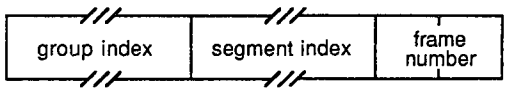
The PUBDEF record contains a list of public names. When object modules are linked, the linker uses these names to resolve external references in other object modules.

Record format



Public base

Each name in the PUBDEF record refers to a location (a 16-bit offset) in a particular segment or group. The *public base*, a variable-length field that specifies the segment or group, is formatted as follows:



- *Group index* is an index field that references a previous GRPDEF record in the object module. If the *group index* value is 0, no group is associated with this PUBDEF record.
- *Segment index* is also an index field. It associates a particular segment with this PUBDEF record by referencing a previous SEGDEF record. A value of 1 indicates the first SEGDEF record in the object module, a value of 2 indicates the second, and so on. If the *segment index* value is 0, the *group index* must also be 0—in this case, the *frame number* appears in the *public base* field.
- The 2-byte *frame number* appears in the *public base* field only when the *group index* and *segment index* are both 0. In other words, the *frame number* specifies the start of an absolute segment. If present, the value in the *frame number* field indicates the number of the frame containing the public name.

Public name

Public name is a variable-length field containing a public name. The first byte specifies the length of the name; the remainder is the name itself. (The Intel specification allows names of 1 to 255 bytes. Microsoft LINK restricts the maximum length of a public name to 127 bytes.)

Public offset

Public offset is a 2-byte field containing the offset of the location referred to by the *public name*. This offset is assumed to lie within the segment, group, or frame specified in the *public base* field.

Type index

Type index is an index field that references a previous TYPDEF record in the object module. A value of 1 indicates the first TYPDEF record in the module, a value of 2 indicates the second, and so on. The *type index* value can be 0 if no data type is associated with the public name.

The *public name*, *public offset*, and *type index* fields can be repeated within a single PUBDEF record. Thus, one PUBDEF record can declare a list of public names.

Location in object module

Any PUBDEF records in an object module must appear after the GRPDEF and SEGDEF records to which they refer. Because PUBDEF records are not themselves referenced by any other type of object record, they are generally placed near the end of an object module.

Examples

The following two examples show PUBDEF records created by the Microsoft Macro Assembler.

The first example is the record for the statement

```
PUBLIC  GAMMA
```

The PUBDEF record is

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  90 0C 00 00 01 05 47 41 4D 4D 41 02 00 00 F9     ......GAMMA....
```

- Byte 00H contains 90H, indicating a PUBDEF record.
- Bytes 01–02H contain 000CH, the length of the remainder of the record.
- Bytes 03–04H represent the *public base* field. Byte 03H (the *group index*) contains 0, indicating that no group is associated with the name in this PUBDEF record. Byte 04H (the *segment index*) contains 1, a reference to the first SEGDEF record in the object module. This is the segment to which the name in this PUBDEF record refers.
- Bytes 05–0AH represent the *public name* field. Byte 05H contains 05H (the length of the name), and bytes 06–0AH contain the name itself, *GAMMA*.
- Bytes 0B–0CH contain 0002H, the *public offset*. The name *GAMMA* thus refers to the location that is offset 2 bytes from the beginning of the segment referenced by the *public base*.
- Byte 0DH is the *type index*. The value of the *type index* is 0, indicating that no data type is associated with the name *GAMMA*.
- Byte 0EH contains the checksum, 0F9H.

The next example is the PUBDEF record for the following absolute symbol declaration:

```
        PUBLIC    ALPHA
ALPHA   EQU       1234h
```

The PUBDEF record is

```
       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000   90 0E 00 00 00 00 00 05 41 4C 50 48 41 34 12 00  ......ALPHA4....
0010   B1
```

- Bytes 03–06H (the *public base* field) contain a *group index* of 0 (byte 03H) and a *segment index* of 0 (byte 04H). Since both the *group index* and *segment index* are 0, a *frame number* also appears in the *public base* field. In this instance, the *frame number* (bytes 05–06H) also happens to be 0.
- Bytes 07–0CH (the *public name* field) contain the name *ALPHA*, preceded by its length.
- Bytes 0D–0EH (the *public offset* field) contain 1234H. This is the value associated with the symbol *ALPHA* in the assembler EQU directive. If *ALPHA* is declared in another object module with the declaration

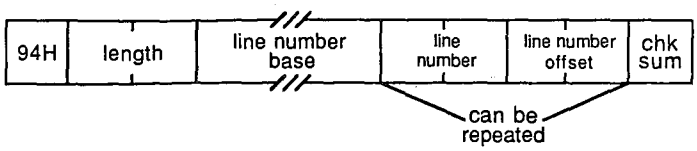
  ```
      EXTRN     ALPHA:ABS
  ```

  any references to *ALPHA* in that object module are fixed up as absolute references to offset 1234H in frame 0. In other words, *ALPHA* would have the value 1234H.
- Byte 0FH (the *type index*) contains 0.

94H LINNUM Line Number Record

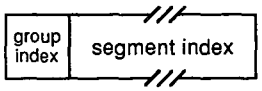
The LINNUM record relates line numbers in source code to addresses in object code.

Record format



Line number base

The *line number base* describes the segment to which the line number refers. Although the complete Intel specification allows the line number base to refer to a group or to an absolute segment as well as to a relocatable segment, Microsoft restricts references in this field to relocatable segments. The format of the *line number base* field is



- The *group index* field always contains a single zero byte.
- The *segment index* is an index field that references a previous SEGDEF record. A value of 1 indicates the first SEGDEF record in the object module, a value of 2 indicates the second, and so on.

Line number

Line number is a 2-byte field containing a line number between 0 and 32,767 (0–7FFFH).

Line number offset

The *line number offset* is a 2-byte field that specifies the offset of the executable code (in the segment specified in the *line number base* field) to which the line number in the *line number* field refers.

The *line number* and *line number offset* fields can be repeated, so a single LINNUM record can specify multiple line numbers in the same segment.

Location in object module

Any LINNUM records in an object module must appear after the SEGDEF records to which they refer. Because LINNUM records are not themselves referenced by any other type of object record, they are generally placed near the end of an object module.

Example

The following LINNUM record was generated by the Microsoft C Compiler:

```
       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000   94 0F 00 00 01 02 00 00 00 03 00 08 00 04 00 0F  ................
0010   00 3C                                           ..
```

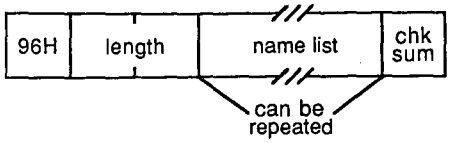
- Byte 00H contains 94H, indicating that this is a LINNUM record.
- Bytes 01–02H contain 000FH, the length of the remainder of the record.
- Bytes 03–04H represent the *line number base* field. Byte 03H (the *group index* field) contains 00H, as it must. Byte 04H (the *segment index* field) contains 01H, indicating that the line numbers in this LINNUM record refer to code in the segment defined in the first SEGDEF record in this object module.
- Bytes 05–06H (a *line number* field) contain 0002H, and bytes 07–08H (a *line number offset* field) contain 0000H. Together, they indicate that source-code line number 0002 corresponds to offset 0000H in the segment indicated in the *line number base* field.

  Similarly, the two pairs of *line number* and *line number offset* fields in bytes 09–10H specify that line number 0003 corresponds to offset 0008H and that line number 0004 corresponds to offset 000FH.
- Byte 11H contains the checksum, 3CH.

96H LNAMES List of Names Record

The LNAMES record is a list of names that can be referenced by subsequent SEGDEF and GRPDEF records in the object module.

Record format



Name list

Name list is a variable-length field that contains the list of names. Each name is preceded by 1 byte that defines its length, which can be a value between 0 and 255 (0–0FFH).

The names in the list are indexed implicitly in the order they appear: The first name in the list has an index of 1, the second name has an index of 2, and so forth. References to the names contained in *name list* by subsequent object records, such as SEGDEF, are accomplished by using this index number. LINK imposes a limit of 255 logical names per object module.

Location in object module

Any LNAMES records in an object module must appear before the GRPDEF or SEGDEF records that refer to them. Because it does not refer to any other type of object records, an LNAMES record usually appears near the start of an object module.

Example

The following LNAMES record contains the segment and class names specified in all three of the assembler statements:

```
_TEXT    SEGMENT byte public 'CODE'
_DATA    SEGMENT word public 'DATA'
_STACK   SEGMENT para public 'STACK'
```

The LNAMES record is

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  96 25 00 00 04 43 4F 44 45 04 44 41 54 41 05 53  .%...CODE.DATA.S
0010  54 41 43 4B 05 5F 44 41 54 41 06 5F 53 54 41 43  TACK._DATA._STAC
0020  4B 05 5F 54 45 58 54 8B                          K._TEXT.
```

- Byte 00H contains 96H, indicating that this is an LNAMES record.
- Bytes 01–02H contain 0025H, the length of the remainder of the record.

- Byte 03H contains 00H, a zero-length name.
- Byte 04H contains 04H, the length of the class name CODE, which is found in bytes 05–08H. Bytes 09–26H contain the class names DATA and STACK and the segment names *_DATA*, *_STACK*, and *_TEXT*, each preceded by 1 byte giving its length.
- Byte 27H contains the checksum, 8BH.

98H SEGDEF Segment Definition Record

The SEGDEF record describes a logical segment in an object module. It defines the segment's name, length, and alignment, and the way the segment can be combined with other logical segments. LINK imposes a limit of 255 SEGDEF records per object module.

Object records that follow a SEGDEF record can refer to it to identify a particular segment.

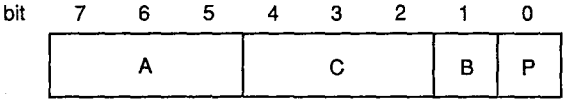
Record format

Segment attributes

Segment attributes is a variable-length field:

The ACBP byte

The contents and size of the *segment attributes* field depend on the first byte of the field, the ACBP byte:



The bit fields in the ACBP byte describe the following characteristics of the segment:

A **A**lignment in the run-time memory map
C **C**ombination with other segments
B **B**ig (a segment of exactly 64 KB)
P **P**age-resident (not used in MS-DOS)

The A field. Bits 7–5 of the ACBP byte, the *A* field, describe the logical segment's alignment:

A = 0 (000B) Absolute (located at a specified frame address)
A = 1 (001B) Relocatable, byte aligned
A = 2 (010B) Relocatable, word aligned
A = 3 (011B) Relocatable, paragraph aligned
A = 4 (100B) Relocatable, page aligned

The original Intel specification includes two additional segment-alignment values not supported in MS-DOS.

The following examples of Microsoft assembler SEGMENT directives show the resulting values for the *A* field in the corresponding SEGDEF object record:

```
aseg    SEGMENT at 400h                 ; A = 0
bseg    SEGMENT byte public 'CODE'      ; A = 1
cseg    SEGMENT para stack 'STACK'      ; A = 3
```

The C field. Bits 4–2 of the ACBP byte, the *C* field, describe how the linker can combine the segment with other segments. Under MS-DOS, segments with the same name and class can be combined in two ways. They can be concatenated to form one logical segment, or they can be overlapped. In the latter case, they have either the same starting address or the same end address and they describe a common area of memory.

The value in the *C* field corresponds to one of these two methods of combining segments. Meaningful values, however, also depend on whether the segment is absolute (A = 0) or relocatable (A = 1, 2, 3, or 4). If A = 0, then *C* must also be 0, because absolute segments cannot be combined. Values for the *C* field are

C = 0 (000B)	Cannot be combined; used for segments whose combine type is not explicitly specified (private segments).
C = 1 (001B)	Not used by Microsoft.
C = 2 (010B)	Can be concatenated with another segment of the same name; used for segments with the *public* combine type.
C = 3 (011B)	Undefined.
C = 4 (100B)	As defined by Microsoft, same as C = 2.
C = 5 (101B)	Can be concatenated with another segment with the same name; used for segments with the *stack* combine type.
C = 6 (110B)	Can be overlapped with another segment with the same name; used for segments with the *common* combine type.
C = 7 (111B)	As defined by Microsoft, same as C = 2.

The following examples of assembler SEGMENT directives show the resulting values for the *C* field in the corresponding SEGDEF object record:

```
aseg    SEGMENT at 400H             ; C = 0
bseg    SEGMENT public 'DATA'       ; C = 2
cseg    SEGMENT stack 'STACK'       ; C = 5
dseg    SEGMENT common 'COMMON'     ; C = 6
```

See PROGRAMMING IN THE MS-DOS ENVIRONMENT: PROGRAMMING TOOLS: The Microsoft Object Linker.

The B and P fields. Bit 1 of the ACBP byte, the *B* field, is set to 1 (and the *segment length* field is set to 0) only if the segment is exactly 64 KB long.

Bit 0 of the ACBP byte, the *P* field, is unused in MS-DOS. Its value should always be 0.

Frame number and offset

The *frame number* and *offset* fields of the *segment attributes* field are present only if the segment is an absolute segment (A = 0 in the ACBP byte). Taken together, the *frame number* and *offset* indicate the starting address of the segment.

- *Frame number* is a 2-byte field that contains the frame number of the start of the segment.
- *Offset* is a 1-byte field that contains an offset between 00H and 0FH within the specified frame. LINK ignores the *offset* field.

Segment length

Segment length is a 2-byte field that specifies the length of the segment in bytes. The length can be from 00H to FFFFH. If a segment is exactly 64 KB (10000H) in size, *segment length* should be 0 and the *B* field in the ACBP byte should be 1.

Segment name index, class name index, and overlay name index

Each of the *segment name index*, *class name index*, and *overlay name index* fields contains an index into the list of names defined in previous LNAMES records in the object module. An index value of 1 indicates the first name in the LNAMES record, a value of 2 the second, and so on.

- The *segment name index* identifies the segment with a unique name. The name may have been assigned by the programmer, or it may have been generated by a compiler.
- The *class name index* identifies the segment with a class name (such as CODE, FAR_DATA, and STACK). The linker places segments with the same class name into a contiguous area of memory in the run-time memory map.
- The *overlay name index* identifies the segment with a run-time overlay. Starting with version 2.40, however, LINK ignores the *overlay name index*. In versions 2.40 and later, command-line parameters to LINK, rather than information contained in object modules, determine the creation of run-time overlays.

Location in object module

SEGDEF records must follow the LNAMES record to which they refer. In addition, SEGDEF records must precede any PUBDEF, LINNUM, GRPDEF, FIXUPP, LEDATA, or LIDATA records that refer to them.

Examples

In this first example, the segment is byte aligned:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  98 07 00 28 11 00 07 02 01 1E                  ...(......
```

- Byte 00H contains 98H, indicating that this is a SEGDEF record.
- Bytes 01–02H contain 0007H, the length of the remainder of the record.

- Byte 03H contains 28H (00101000B), the ACBP byte. Bits 7–5 (the *A* field) contain 1 (001B), indicating that this segment is relocatable and byte aligned. Bits 4–2 (the *C* field) contain 2 (010B), which represents a *public* combine type. (When this object module is linked, this segment will be concatenated with all other segments with the same name.) Bit 1 (the *B* field) is 0, indicating that this segment is smaller than 64 KB. Bit 0 (the *P* field) is ignored and should be zero, as it is here.
- Bytes 04–05H contain 0011H, the size of the segment in bytes.
- Bytes 06–08H index the list of names defined in the module's LNAMES record. Byte 06H (*the segment name index*) contains 07H, so the name of this segment is the seventh name in the LNAMES record. Byte 07H (the *class name index*) contains 02H, so the segment's class name is the second name in the LNAMES record. Byte 08H (the *overlay name index*) contains 1, a reference to the first name in the LNAMES record. (This name is usually null, as MS-DOS ignores it anyway.)
- Byte 09H contains the checksum, 1EH.

The second SEGDEF record declares a word-aligned segment. It differs only slightly from the first.

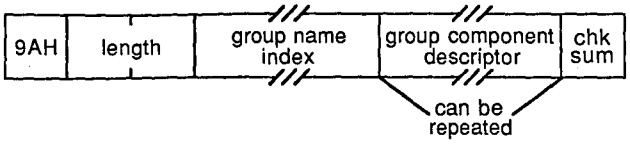
```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  98 07 00 48 0F 00 05 03 01 01                  ...H......
```

- Bits 7–5 (the *A* field) of byte 03H (the ACBP byte) contain 2 (010B), indicating that this segment is relocatable and word aligned.
- Bytes 04–05H contain the size of the segment, 000FH.
- Byte 06H (the *segment name index*) contains 05H, which refers to the fifth name in the previous LNAMES record.
- Byte 07H (the *class name index*) contains 03H, a reference to the third name in the LNAMES record.

9AH GRPDEF Group Definition Record

The GRPDEF record defines a group of segments, all of which lie within the same 64 KB frame in the run-time memory map. LINK imposes a limit of 21 GRPDEF records per object module.

Record format

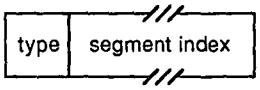


Group name index

Group name index is an index field whose value refers to a name in the *name list* field of a previous LNAMES record.

Group component descriptor

The *group component descriptor* consists of two fields:



- *Type* is a 1-byte field whose value is always 0FFH, indicating that the following field contains a *segment index* value. The original Intel specification defines four other types of *group component descriptor* with the values 0FEH, 0FDH, 0FBH, and 0FAH. LINK ignores these other *type* values, however, and assumes that the *group component descriptor* contains a *segment index* value.
- The *segment index* field contains an index number that refers to a previous SEGDEF record. A value of 1 indicates the first SEGDEF record in the object module, a value of 2 indicates the second, and so on.

The *group component descriptor* field is usually repeated within the GRPDEF record, so all segments constituting the group can be included in one GRPDEF record.

Location in object module

GRPDEF records must follow the LNAMES and SEGDEF records to which they refer. They must also precede any PUBDEF, LINNUM, FIXUPP, LEDATA, or LIDATA records that refer to them.

Example

The following example of a GRPDEF record corresponds to the assembler directive:

```
tgroup  GROUP seg1,seg2,seg3
```

The GRPDEF record is

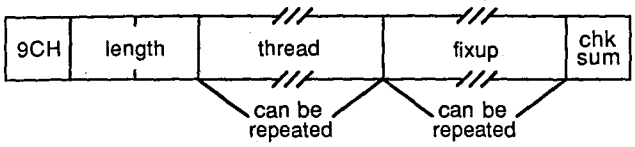
```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9A 08 00 06 FF 01 FF 02 FF 03 55                ..........U
```

- Byte 00H contains 9AH, indicating that this is a GRPDEF record.
- Bytes 01–02H contain 0008H, the length of the remainder of the record.
- Byte 03H contains 06H, the *group name index*. In this instance, the index number refers to the sixth name in the previous LNAMES record in the object module. That name is the name of the group of segments defined in the remainder of the record.
- Bytes 04–05H contain the first of three *group component descriptor* fields. Byte 04H contains the required 0FFH, indicating that the subsequent field is a *segment index*. Byte 05H contains 01H, a *segment index* that refers to the first SEGDEF record in the object module. This SEGDEF record declared the first of three segments in the group.
- Bytes 06–07H represent the second *group component descriptor*, this one referring to the second SEGDEF record in the object module.
- Similarly, bytes 08–09H are a *group component descriptor* field that references the third SEGDEF record.
- Byte 0AH contains the checksum, 55H.

9CH FIXUPP Fixup Record

The FIXUPP record contains information that allows the linker to resolve (fix up) addresses whose values cannot be determined by the language translator. FIXUPP records describe the LOCATION of each address value to be fixed up, the TARGET address to which the fixup refers, and the FRAME relative to which the address computation is performed.

Record format



Thread and fixup fields

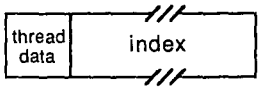
A FIXUPP record can contain zero or more *thread* fields and zero or more *fixup* fields. Each *fixup* field describes the method to be used by the linker to compute the TARGET address to be placed at a particular location in the executable image, relative to a particular FRAME. The information that determines the LOCATION, TARGET, and FRAME can be specified explicitly in the *fixup* field. It can also be specified within the *fixup* field by a reference to a previous *thread* field.

A *thread* field describes only the method to be used by the linker to refer to a particular TARGET or FRAME. Because the same *thread* field can be referenced in several subsequent *fixup* fields, a FIXUPP record that uses *thread* fields may be smaller than one in which *thread* fields are not used.

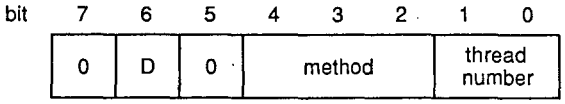
Thread and *fixup* fields are distinguished from one another by the high-order bit of the first byte in the field. If the high-order bit is 0, the field is a *thread* field. If the high-order bit is 1, the field is a *fixup* field.

The thread field

A *thread* field contains information that can be referenced in subsequent *thread* or *fixup* fields in the same or subsequent FIXUPP records. It has the following format:



The *thread data* field is a single byte comprising five subfields:



- Bit 7 of the *thread data* byte is 0, indicating the start of a *thread* field.
- The *D* field (bit 6) indicates whether the *thread* field specifies a FRAME or a TARGET. The *D* bit is set to 1 to indicate a FRAME or to 0 to indicate a TARGET.
- Bit 5 of the *thread data* byte is not used. It should always be set to 0.
- Bits 4 through 2 represent the *method* field. If *D* = 1, the *method* field contains 0, 1, 2, 4, or 5. Each of these numbers corresponds to one method of specifying a FRAME (*see* Table 19-2). If *D* = 0, the *method* field contains 0, 1, 2, 4, 5, or 6, each of which corresponds to one of the methods of specifying a TARGET (*see* Table 19-3).

  In the case of a TARGET address, only bits 3 and 2 of the *method* field are used. When *D* = 0, the high-order bit of the value in the *method* field is derived from the *P* bit in the *fix dat* field of any subsequent *fixup* field that refers to this *thread* field. Thus, if *D* = 0, bit 4 of the *method* field is also 0, and the only meaningful values for the *method* field are 0, 1, and 2.
- The *thread number* field (bits 1 and 0) contains a number between 0 and 3. This number is used in subsequent *fixup* or *thread* fields to refer to this particular *thread* field.

  The *thread number* is implicitly associated with the *D* field by the linker, so as many as eight different *thread* fields (four FRAMEs and four TARGETs) can be referenced at any time. A *thread number* can be reused in an object module and, if it is, always refers to the *thread* field in which it last appeared.

Table 19-2. FRAME Fixup Methods.

Method	Description
0	The FRAME is specified by a segment index.
1	The FRAME is specified by a group index.
2	The FRAME is indicated by an external index. LINK determines the FRAME from the external name's corresponding PUBDEF record in another object module, which specifies either a logical segment or a group.
3	The FRAME is identified by an explicit frame number. (Not supported by LINK.)
4	The FRAME is determined by the segment in which the LOCATION is defined. In this case, the largest possible frame number is used.
5	The FRAME is determined by the TARGET's segment, group, or external index.

Table 19-3. TARGET Fixup Methods.

Method	Description
0	The TARGET is specified by a segment index and a displacement. The displacement is given in the *target displacement* field of the FIXUPP record.
1	The TARGET is specified by a group index and a *target displacement.*
2	The TARGET is specified by an external index and a *target displacement.* LINK adds the displacement to the address it determines from the external name's corresponding PUBDEF record in another object module.
3	The TARGET is identified by an explicit frame number. (Not supported by LINK.)
4*	The TARGET is specified by a segment index only.
5*	The TARGET is specified by a group index only.
6*	The TARGET is specified by an external index. The TARGET is the address associated with the external name.
7*	The TARGET is identified by an explicit frame number. (Not supported by LINK.)

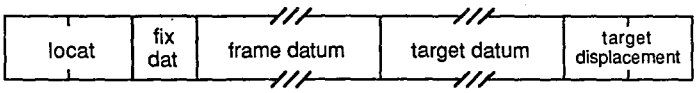
*TARGET methods 4–7 are analogous to the preceding four, except that methods 4–7 do not use an explicit displacement to identify the TARGET. Instead, a displacement of 0 is assumed.

The *index* field either contains an index value that refers to a previous SEGDEF, GRPDEF, or EXTDEF record, or it contains an explicit frame number. The interpretation of the index value depends on the value of the *method* field of the *thread data* field:

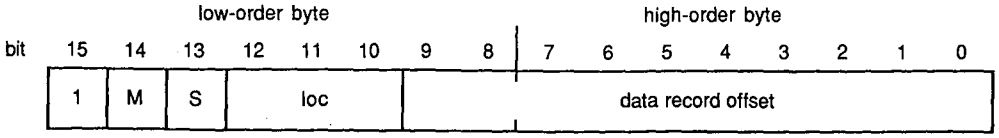
method = 0	Segment index (reference to a previous SEGDEF record)
method = 1	Group index (reference to a previous GRPDEF record)
method = 2	External index (reference to a previous EXTDEF record)
method = 3	Frame number (not supported by LINK; ignored)

The fixup field

The *fixup* field provides the information needed by the linker to resolve a reference to a relocatable or external address. The *fixup* field has the following format:



The 2-byte *locat* field has an unusual format. Contrary to the usual byte order in Intel data structures, the most significant bits of the *locat* field are found in the low-order, rather than the high-order, byte:

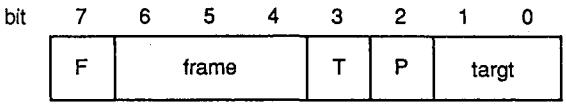


- Bit 15 (the high-order bit of the *locat* field) contains 1, indicating that this is a *fixup* field.
- Bit 14 (the *M* bit) is 1 if the fixup is segment relative and 0 if the fixup is self-relative.
- Bit 13 (the *S* bit) is currently unused and should always be set to 0.
- Bits 12 through 10 represent the *loc* field. This field contains a number between 0 and 5 that indicates the type of LOCATION to be fixed up:

loc = 0	Low-order byte
loc = 1	Offset
loc = 2	Segment
loc = 3	Pointer (segment:offset)
loc = 4	High-order byte (not recognized by LINK)
loc = 5	Loader-resolved offset (treated as *loc* = 1 by the linker)

- Bits 9 through 0 (the *data record offset*) indicate the position of the LOCATION to be fixed up in the LEDATA or LIDATA record immediately preceding the FIXUPP record. This offset indicates either a byte in the *data* field of an LEDATA record or a data byte in the *content* field of an *iterated data block* in an LIDATA record.

The *fix dat* field is a single byte comprising five fields:



- Bit 7 (the *F* bit) is set to 1 if the FRAME for this fixup is specified by a reference to a previous *thread* field. The *F* bit is 0 if the FRAME method is explicitly defined in this *fixup* field.
- The interpretation of the *frame* field in bits 6 through 4 depends on the value of the *F* bit. If *F* = 1, the *frame* field contains a number between 0 and 3 that indicates the *thread* field containing the FRAME method. If *F* = 0, the *frame* field contains 0, 1, 2, 4, or 5, corresponding to one of the methods of specifying a FRAME listed in Table 19-2.
- Bit 3 (the *T* bit) is set to 1 if the TARGET for the fixup is specified by a reference to a previous *thread* field. If the *T* bit is 0, the TARGET is explicitly defined in this *fixup* field.
- Bit 2 (the *P* bit) and bits 1 and 0 (the *targt* field) can be considered a 3-bit field analogous to the *frame* field.
- If the *T* bit indicates that the TARGET is specified by a previous *thread* reference (*T* = 1), the *targt* field contains a number between 0 and 3 that refers to a previous *thread* field containing the TARGET method. In this case, the *P* bit, combined with the 2 low-order bits of the *method* field in the *thread* field, determines the TARGET method.

If the *T* bit is 0, indicating that the target is explicitly defined, the *P* and *targt* fields together contain 0, 1, 2, 4, 5, or 6. This number corresponds to one of the TARGET fixup methods listed in Table 19-3. (In this case, the *P* bit can be regarded as the high-order bit of the method number.)

Frame datum is an index field that refers to a previous SEGDEF, GRPDEF, or EXTDEF record, depending on the FRAME method.

Similarly, the *target datum* field contains a segment index, a group index, or an external index, depending on the TARGET method.

The *target displacement* field, a 2-byte field, is present only if the *P* bit in the *fixdat* field is set to 0, in which case the *target displacement* field contains the 16-bit offset used in methods 0, 1, and 2 of specifying a TARGET.

Location in object module

FIXUPP records must appear after the SEGDEF, GRPDEF, or EXTDEF records to which they refer. In addition, if a FIXUPP record contains any *fixup* fields, it must immediately follow the LEDATA or LIDATA record to which the fixups refer.

Examples

Although crucial to the proper linking of object modules, FIXUPP records are terse: Almost every bit is meaningful. For these reasons, the following three examples of FIXUPP records are particularly detailed.

A good way to understand how a FIXUPP record is put together is to compare it to the corresponding source code. The Microsoft Macro Assembler is helpful in this regard, because it marks in its source listing address references it cannot resolve. The "program" in Figure 19-6 is designed to show how some of the most frequently encountered fixups are encoded in FIXUPP records.

```
                                TITLE   fixupps
                        _TEXT   SEGMENT byte public 'CODE'
                                ASSUME  cs:_TEXT
                                EXTRN   NearLabel:near
                                EXTRN   FarLabel:far

0000                            NearProc        PROC    near

0000  E9 0000 E                        jmp     NearLabel       ;relocatable word offset
0003  EB 00 E                          jmp     short NearLabel ;relocatable byte offset
0005  EA 0000 ---- R                    jmp     far ptr FarProc ;far jump to a known seg
000A  EA 0000 ---- E                    jmp     FarLabel     ;far jump to an unknown seg

000F  BB 0015 R                         mov     bx,offset LocalLabel ;relocatable offset
0012  B8 ---- R                         mov     ax,seg LocalLabel    ;relocatable seg
```

Figure 19-6. A sample "program" showing how some common fixups are encoded in FIXUPP records. (more)

```
0015  C3                    LocalLabel:     ret

                            NearProc        ENDP

0016                        _TEXT   ENDS


0000                        FAR_TEXT        SEGMENT byte public 'FAR_CODE'
                                    ASSUME  cs:FAR_TEXT

0000                        FarProc PROC    far

0000  CB                            ret

                            FarProc ENDP

0001                        FAR_TEXT        ENDS

                                    END
```

Figure 19-6. Continued.

The assembler generates one LEDATA record for this program:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0010  A0 1A 00 01 00 00 E9 00 00 EB 00 EA 00 00 00 00  ................
0020  EA 00 00 00 00 BB 00 00 B8 00 00 C3 67           ............g
```

Bytes 06–2BH (the *data* field) of this LEDATA record contain 8086 opcodes for each of the instruction mnemonics in the source code. The gaps (zero values) in the *data* field correspond to address values that the assembler cannot resolve. The linker will fix up the address values in the gaps by computing the correct values and adding them to the zero values in the gaps. The FIXUPP record that tells the linker how to do this immediately follows the LEDATA record in the object module:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 21 00 84 01 06 01 02 80 04 06 01 02 CC 06 04  .!..............
0010  02 02 CC 0B 06 01 01 C4 10 00 01 01 15 00 C8 13  ................
0020  04 01 01 A3                                      ....
```

- Byte 00H contains 9CH, indicating this is a FIXUPP record.
- Bytes 01–02H contain 0021H, the length of the remainder of the record.
- Bytes 03–07H represent the first of the six *fixup* fields in this record:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 21 00 84 01 06 01 02 80 04 06 01 02 CC 06 04  .!..............
0010  02 02 CC 0B 06 01 01 C4 10 00 01 01 15 00 C8 13  ................
0020  04 01 01 A3                                      ....
```

The information in this *fixup* field will allow the linker to resolve the address reference in the statement

```
jmp     NearLabel
```

- Bytes 03–04H (the *locat* field) contain 8401H (1000010000000001B). (Recall that this field does not conform to the usual Intel byte order.) Bit 15 is 1, signifying that this is a *fixup* field, not a *thread* field. Bit 14 (the *M* bit) is 0, so this fixup is self-relative. Bit 13 is unused and should be set to 0, as it is here. Bits 12–10 (the *loc* field) contain 1 (001B), so the LOCATION to be fixed up is a 16-bit offset. Bits 9–0 (the *data record offset*) contain 1 (0000000001B), which informs the linker that the LOCATION to be fixed up is at offset 1 in the *data* field of the LEDATA record immediately preceding this FIXUPP record—in other words, the 2 bytes immediately following the first opcode 0E9H.
- Byte 05H (the *fix dat* field) contains 06H (00000110B). Bit 7 (the *F* bit) is 0, meaning the FRAME for this fixup is explicitly specified in this *fixup* field. Bits 6–4 (the *frame* field) contain 0 (000B), indicating that FRAME method 0 specifies the FRAME. Bit 3 (the *T* bit) is 0, so the TARGET for this fixup is also explicitly specified. Bits 2–0 (the *P* bit) and the *targt* field contain 6 (110B), so TARGET method 6 specifies the TARGET.
- Byte 06H is a *frame datum* field, because the FRAME is explicitly specified (the *F* bit of the *fix dat* field = 0). And, because method 0 is specified, the *frame datum* is an index field that refers to a previous SEGDEF record. In this example, the *frame datum* field contains 1, which indicates the first SEGDEF record in the object module: the _TEXT segment.
- Similarly, byte 07H is a *target datum*, because the TARGET is also explicitly specified (the *T* bit of the *fix dat* field = 0). The *fix dat* field also indicates that TARGET method 6 is used, so the *target datum* is an index field that refers to the *external reference list* in a previous EXTDEF record. The value of this index is 2, so the TARGET is the second external reference declared in the EXTDEF record: *NearLabel* in this object module.

- Bytes 08–0CH represent the second *fixup* field:

```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 21 00 84 01 06 01 02 80 04 06 01 02 CC 06 04  .!..............
0010  02 02 CC 0B 06 01 01 C4 10 00 01 01 15 00 C8 13  ................
0020  04 01 01 A3                                      ....
```

This *fixup* field corresponds to the statement

```
jmp     short NearLabel
```

The only difference between this statement and the first is that the jump uses an 8-bit, rather than a 16-bit, offset. Thus, the *loc* field (bits 12–10 of byte 08H) contains 0 (000B) to indicate that the LOCATION to be fixed up is a low-order byte.

- Bytes 0D–11H represent the third *fixup* field in this FIXUPP record:

```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 21 00 84 01 06 01 02 80 04 06 01 02 CC 06 04  .!..............
0010  02 02 CC 0B 06 01 01 C4 10 00 01 01 15 00 C8 13  ................
0020  04 01 01 A3                                      ....
```

This *fixup* field corresponds to the statement

```
jmp     far ptr FarProc
```

In this case, both the TARGET's frame (the segment *FAR_TEXT*) and offset (the label *FarProc*) are known to the assembler. Both the segment address and the label offset are relocatable, however, so in the FIXUPP record the assembler passes the responsibility for resolving the addresses to the linker.

- Bytes 0D–0EH (the *locat* field) indicate that the field is a *fixup* field (bit 15 = 1) and that the fixup is segment relative (bit 14—the *M* bit = 1). The *loc* field (bits 12–10) contains 3 (011B), so the LOCATION being fixed up is a 32-bit (FAR) pointer (segment and offset). The *data record offset* (bits 9–0) is 6 (0000000110B); the LOCATION is the 4 bytes following the first far jump opcode (EAH) in the preceding LEDATA record.
- In byte 0FH (the *fix dat* field), the *F* bit and the *frame* field are 0, indicating that method 0 (a segment index) is used to specify the FRAME. The *T* bit is 0 (meaning the *target* is explicitly defined in the *fixup* field); therefore, the *P* bit and *targt* fields together indicate method 4 (a segment index) to specify the TARGET.
- Because the FRAME is specified with a segment index, byte 10H (the *frame datum* field) is a reference to the second SEGDEF record in the object module, which in this example declared the *FAR_TEXT* segment. Similarly, byte 11H (the *target datum* field) references the *FAR_TEXT* segment. In this case, the FRAME is the same as the TARGET segment; had *FAR_TEXT* been one of a group of segments, the FRAME could have referred to the group instead.

- The fourth assembler statement is different from the third because it references a segment not known to the assembler:

```
jmp     FarLabel
```

Bytes 12–16H contain the corresponding *fixup* field:

```
          0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
  0000  9C 21 00 84 01 06 01 02 80 04 06 01 02 CC 06 04  .!..............
  0010  02 02 CC 0B 06 01 01 C4 10 00 01 01 15 00 C8 13  ................
  0020  04 01 01 A3                                      ....
```

The significant difference between this and the preceding *fixup* field is that the *P* bit and *targt* field of the *fix dat* byte (byte 14H) specify TARGET method 6. In this *fixup* field, the *target datum* (byte 16H) refers to the first EXTDEF record in the object module, which declares *FarLabel* as an external reference.

- The fifth *fixup* field (bytes 17–1DH) is

```
          0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
  0000  9C 21 00 84 01 06 01 02 80 04 06 01 02 CC 06 04  .!..............
  0010  02 02 CC 0B 06 01 01 C4 10 00 01 01 15 00 C8 13  ................
  0020  04 01 01 A3                                      ....
```

This *fixup* field contains information that enables the linker to calculate the value of the relocatable offset *LocalLabel*:

```
mov     bx,offset LocalLabel
```

- Bytes 17–18H (the *locat* field) contain C410H (1100010000010000B). Bit 15 is 1, denoting a *fixup* field. The *M* bit (bit 14) is 1, indicating that this fixup is segment relative. The *loc* field (bits 12–10) contains 1 (001B), so the LOCATION is a 16-bit offset. The *data record offset* (bits 9–0) is 10H (0000010000B), a reference to the 2 bytes in the LEDATA record following the opcode 0BBH.
- Byte 19H (the *fix dat* byte) contains 00H. The *F* bit, *frame* field, *T* bit, *P* bit, and *targt* field are all 0, so FRAME method 0 and TARGET method 0 are explicitly specified in this *fixup* field.
- Because FRAME method 0 is used, byte 1AH (the *frame datum* field) is an index field. It contains 01H, a reference to the first SEGDEF record in the object module, which declares the segment *_TEXT*.

  Similarly, byte 1BH (the *target datum* field) references the *_TEXT* segment.
- Because TARGET method 0 is specified, an offset, in addition to a segment, is required to define the TARGET. This offset appears in the *target displacement* field in bytes 1C–1DH. The value of this offset is 0015H, corresponding to the offset of the TARGET (*LocalLabel*) in its segment (*_TEXT*).

- The sixth and final *fixup* field in this FIXUPP record (bytes 1E–22H) is

```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 21 00 84 01 06 01 02 80 04 06 01 02 CC 06 04  .!..............
0010  02 02 CC 0B 06 01 01 C4 10 00 01 01 15 00 C8 13  ................
0020  04 01 01 A3                                      ....
```

This corresponds to the segment of the relocatable address *LocalLabel*:

```
mov     ax,seg LocalLabel
```

- Bytes 1E–1FH (the *locat* field) contain C813H (1100100000010011B). Bit 15 is 1, so this is a *fixup* field. The *M* bit (bit 14) is 1, so the fixup is segment relative. The *loc* field (bits 12–10) contains 2 (010B), so the LOCATION is a 16-bit segment value. The *data record offset* (bits 9–0) indicates the 2 bytes in the LEDATA record following the opcode 0B8H.
- Byte 20H (the *fix dat* byte) contains 04H, so FRAME method 0 and TARGET method 4 are explicitly specified in this *fixup* field.
- Byte 21H (the *frame datum* field) contains 01H. Because FRAME method 0 is specified, the *frame datum* is an index value that refers to the first SEGDEF record in the object module (corresponding to the *_TEXT* segment).
- Byte 22H (the *target datum* field) contains 01H. Because TARGET method 4 is specified, the *target datum* also references the *_TEXT* segment.

- Finally, byte 23H contains this FIXUPP record's checksum, 0A3H.

The next two FIXUPP records show how *thread* fields are used. The first of the two contains six *thread* fields that can be referenced by both *thread* and *fixup* fields in subsequent FIXUPP records in the same object module:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 0D 00 00 03 01 02 02 01 03 04 40 01 45 01 C0  ...........@.....
```

Bytes 03–04H, 05–06H, 07–08H, 09–0AH, 0B–0CH, and 0D–0EH represent the six *thread* fields in this FIXUPP record. The high-order bit of the first byte of each of these fields is 0, indicating that they are, indeed, *thread* fields and not *fixup* fields.

- Byte 03H, which contains 00H, is the *thread data* byte of the first *thread* field. Bit 7 of this byte is 0, indicating this is a *thread* field. Bit 6 (the *D* bit) is 0, so this field specifies a TARGET. Bit 5 is 0, as it must always be. Bits 4 through 2 (the *method* field) contain 0 (000B), which specifies TARGET method 0. Finally, bits 1 and 0 contain 0 (00B), the *thread number* that identifies this *thread* field.

  Byte 04H represents a segment *index* field, because method 0 of specifying a TARGET references a segment. The value of the index, 3, is a reference to the third SEGDEF record defined in the object module.
- Bytes 05–06H, 07–08H, and 09–0AH contain similar *thread* fields. In each, the *method* field specifies TARGET method 0. The three *thread* fields also have *thread numbers* of 1, 2, and 3. Because TARGET method 0 is specified for each *thread* field, bytes 06H, 08H, and 0AH represent segment *index* fields, which reference the second, first, and fourth SEGDEF records, respectively.
- Byte 0BH (the *thread data* byte of the fifth *thread* field in this FIXUPP record) contains 40H (01000000B). The *D* bit (bit 6) is 1, so this *thread* field specifies a FRAME. The *method* field (bits 4 through 2) contains 0 (000B), which specifies FRAME method 0. Byte 0CH (which contains 01H) is therefore interpreted as a segment *index* reference to the first SEGDEF record in the object module.
- Byte 0DH is the *thread data* byte of the sixth *thread* field. It contains 45H (01000101B). Bit 6 is 1, which indicates that this *thread* specifies a FRAME. The *method* field (bits 4 through 2) contains 1 (001B), which specifies FRAME method 1. Byte 0EH (which contains 01H) is therefore interpreted as a group *index* to the first preceding GRPDEF record.

  The *thread number* fields of the fifth and sixth *thread* fields contain 0 and 1, respectively, but these *thread numbers* do not conflict with the ones used in the first and second *thread* fields, because the latter represent TARGET references, not FRAME references.

The next FIXUPP example appears after the preceding record, in the same object module. This FIXUPP record contains a *fixup* field in bytes 03–05H that refers to a *thread* in the previous FIXUPP record:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 04 00 C4 09 9D F6                        .......
```

- Bytes 03–04H represent the 16-bit *locat* field, which contains C409H (1100010000001001B). Bit 15 of the *locat* field is 1, indicating a *fixup* field. The *M* bit (bit 14) is 1, so this fixup is relative to a particular segment, which is specified later in the *fixup* field. Bit 13 is 0, as it should be. Bits 12–10 (the *loc* field) contain 1 (001B), so the LOCATION to be fixed up is a 16-bit offset. Bits 9–0 (the *data record offset* field) contain 9 (0000001001B), so the LOCATION to be fixed up is represented at an offset of 9 bytes into the data field of the preceding LEDATA or LIDATA record.

- Byte 05H (the *fix dat* byte) contains 9DH (10011101B). The *F* bit (bit 7) is 1, so this *fixup* field references a *thread* field that, in turn, defines the method of specifying the FRAME for the fixup. Bits 6–4 (the *frame* field) contain 1 (001B), the number of the *thread* that contains the FRAME method. This *thread* contains a *method* number of 1, which references the first GRPDEF record in the object module, thus specifying the FRAME.

  The *T* bit (bit 3 in the *fix dat* byte) is 1, so the TARGET method is also defined in a preceding *thread* field. The *targt* field (bits 1 and 0 in the *fix dat* byte) contains 1 (01B), so the TARGET *thread* field whose *thread number* is 1 specifies the TARGET. The *P* bit (bit 3 in the *fix dat* byte) contains 1, which is combined with the low-order bits of the *method* field in the *thread* field that describes the target to obtain TARGET method number 4 (100B). The TARGET *thread* references the second SEGDEF record to specify the TARGET.

The last FIXUPP example illustrates that the linker performs a fixup by adding the calculated address value to the value in the LOCATION being fixed up. This function of the linker can be exploited to use fixups to modify opcodes or program data, as well as to resolve address references.

Consider how the following assembler instruction might be fixed up:

```
lea  bx,alpha+10h   ; alpha is an external symbol
```

Typically, this instruction is translated into an LEDATA record with zero in the LOCATION (bytes 08–09H) to be fixed up:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  A0 08 00 01 00 00 8D 1E 00 00 AC                ...........
```

The corresponding FIXUPP record contains a *target displacement* of 10H bytes (bytes 08–09H):

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 08 00 C4 02 02 01 01 10 00 82                ...........
```

This FIXUPP record specifies TARGET method 2, which is indicated by the *targt* field (bits 2–0) of the *fixdat* field (byte 05H). In this case, the linker adds the *target displacement* to the address it has determined for the TARGET (*alpha*) and then completes the fixup by adding this calculated address value to the zero value in the LOCATION.

The same result can be achieved by storing the displacement (10H) directly in the LOCATION in the LEDATA record:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  A0 08 00 01 00 00 8D 1E 10 00 9C                ...........
```

Then, the *target displacement* can be omitted from the FIXUPP record:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  9C 06 00 C4 02 06 01 01 90                      .........
```

This FIXUPP record specifies TARGET method 6, which does not use a *target displacement.* The linker performs this fixup by adding the address of *alpha* to the value in the LOCATION, so the result is identical to the preceding one.

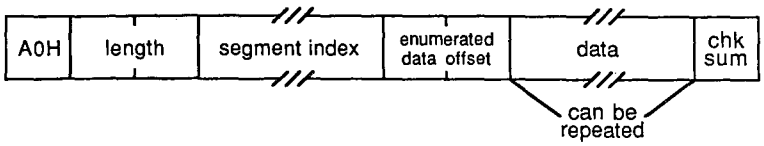
The difference between the two techniques is that in the latter the linker does not perform error checking when it adds the calculated fixup value to the value in the LOCATION. If this second technique is used, the linker will not flag arithmetic overflow or underflow errors when it adds the displacement to the TARGET address. The first technique, then, traps all errors; the second can be used when overflow or underflow is irrelevant and an error message would be undesirable.

0A0H LEDATA Logical Enumerated Data Record

The LEDATA record contains contiguous binary data — executable code or program data — that is eventually copied into the program's executable binary image.

The binary data in an LEDATA record can be modified by the linker if the record is followed by a FIXUPP record.

Record format



Segment index

The *segment index* is a variable-length index field. The index number in this field refers to a previous SEGDEF record in the object module. A value of 1 indicates the first SEGDEF record, a value of 2 the second, and so on. That SEGDEF record, in turn, indicates the segment into which the data in this LEDATA record is to be placed.

Enumerated data offset

The *enumerated data offset* is a 2-byte offset into the segment referenced by the *segment index*, relative to the base of the segment. Taken together, the *segment index* and the *enumerated data offset* fields indicate the location where the enumerated data will be placed in the run-time memory map.

Data

The *data* field contains the actual data, which can be either executable 8086 instructions or program data. The maximum size of the *data* field is 1024 bytes.

Location in object module

Any LEDATA records in an object module must be preceded by the SEGDEF records to which they refer. Also, if an LEDATA record requires a fixup, a FIXUPP record must immediately follow the LEDATA record.

Example

The following LEDATA record contains a simple text string:

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  A0 13 00 02 00 00 48 65 6C 6C 6F 2C 20 77 6F 72   ......Hello, wor
0010  6C 64 0D 0A 24 A8                                 ld..$.
```

- Byte 00H contains 0A0H, which identifies this as an LEDATA record.
- Bytes 01–02H contain 0013H, the length of the remainder of the record.

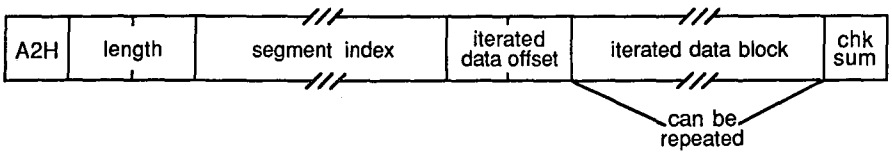
- Byte 03H (the *segment index* field) contains 02H, a reference to the second SEGDEF record in the object module.
- Bytes 04–05H (the *enumerated data offset* field) contain 0000H. This is the offset, from the base of the segment indicated by the *segment index* field, at which the data in the *data* field will be placed when the program is linked. Of course, this offset is subject to relocation by the linker because the segment declared in the specified SEGDEF record may be relocatable and may be combined with other segments declared in other object modules.
- Bytes 06–14H (the *data* field) contain the actual data.
- Byte 15H contains the checksum, 0A8H.

0A2H LIDATA Logical Iterated Data Record

Like the LEDATA record, the LIDATA record contains binary data — executable code or program data. The data in an LIDATA record, however, is specified as a repeating pattern (iterated), rather than by explicit enumeration.

The data in an LIDATA record may be modified by the linker if the LIDATA record is followed by a FIXUPP record.

Record format



Segment index

The *segment index* is a variable-length index field. The index number in this field refers to a previous SEGDEF record in the object module. A value of 1 indicates the first SEGDEF record, 2 indicates the second, and so on. That SEGDEF record, in turn, indicates the segment into which the data in this LIDATA record is to be placed when the program is executed.

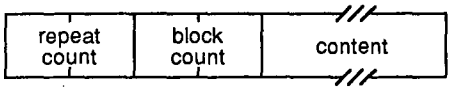
Iterated data offset

The *iterated data offset* is a 2-byte offset into the segment referenced by the *segment index*, relative to the base of the segment. Taken together, the *segment index* and the *iterated data offset* fields indicate the location where the iterated data will be placed in the run-time memory map.

Iterated data block

The *iterated data block* is a variable-length field containing the actual data — executable code and program data. *Iterated data blocks* can be nested, so one *iterated data block* can contain one or more other *iterated data blocks*. Microsoft LINK restricts the maximum size of an *iterated data block* to 512 bytes.

The format of the *iterated data block* is



- *Repeat count* is a 2-byte field indicating the number of times the *content* field is to be repeated.
- *Block count* is a 2-byte field indicating the number of *iterated data blocks* in the *content* field. If the *block count* is 0, the *content* field contains data only.

- *Content* is a variable-length field that can contain either nested *iterated data blocks* (if the *block count* is nonzero) or data (if the *block count* is 0). If the *content* field contains data, the field contains a 1-byte count of the number of data bytes in the field, followed by the actual data.

Location in object module

Any LIDATA records in an object module must be preceded by the SEGDEF records to which they refer. Also, if an LIDATA record requires a fixup, a FIXUPP record must immediately follow the LIDATA record.

Example

This sample LIDATA record corresponds to the following assembler statement, which declares a 10-element array containing the strings *ALPHA* and *BETA*:

```
db      10 dup('ALPHA','BETA')
```

The LIDATA record is

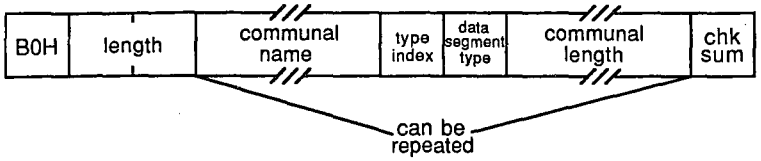
```
       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  A2 1B 00 01 00 00 0A 00 02 00 01 00 00 00 05 41  ...............A
0010  4C 50 48 41 01 00 00 00 04 42 45 54 41 A9        LPHA.....BETA.
```

- Byte 00H contains 0A2H, identifying this as an LIDATA record.
- Bytes 01–02H contain 1BH, the length of the remainder of the record.
- Byte 03H (the *segment index*) contains 01H, a reference to the first SEGDEF record in this object module, indicating that the data declared in this LIDATA record is to be placed into the segment described by the first SEGDEF record.
- Bytes 04–05H (the *iterated data offset*) contain 0000H, so the data in this LIDATA record is to be located at offset 0000H in the segment designated by the *segment index*.
- Bytes 06–1CH represent an *iterated data block*:
  - Bytes 06–07H contain the *repeat count*, 000AH, which indicates that the *content* field of this *iterated data block* is to be repeated 10 times.
  - Bytes 08–09H (the *block count* for this *iterated data block*) contain 0002H, which indicates that the *content* field of this *iterated data block* (bytes 0A–1CH) contains two nested *iterated data block* fields (bytes 0A–13H and bytes 14–1CH).
  - Bytes 0A–0BH contain 0001H, the *repeat count* for the first nested *iterated data block*. Bytes 0C–0DH contain 0000H, indicating that the *content* field of this nested *iterated data block* contains data, rather than more nested *iterated data blocks*. The *content* field (bytes 0E–13H) contains the data: Byte 0EH contains 05H, the number of subsequent data bytes, and bytes 0F–13H contain the actual data (the string *ALPHA*).
  - Bytes 14–1CH represent the second nested *iterated data block*, which has a format similar to that of the block in bytes 0A–13H. This second nested *iterated data block* represents the 4-byte string *BETA*.
- Byte 1DH is the checksum, 0A9H.

0B0H COMDEF Communal Names Definition Record

The COMDEF record is a Microsoft extension to the basic set of 8086 object record types defined by Intel that declares a list of one or more communal variables. The COMDEF record is recognized by versions 3.50 and later of LINK. Microsoft encourages the use of the COMDEF record for declaration of communal variables.

Record format



Communal name

The *communal name* field is a variable-length field that contains the name of a communal variable. The first byte of this field indicates the length of the name contained in the remainder of the field.

Type index

The *type index* field is an index field that references a previous TYPDEF record in the object module. A value of 1 indicates the first TYPDEF record in the module, a value of 2 indicates the second, and so on. The *type index* value can be 0 if no data type is associated with the public name.

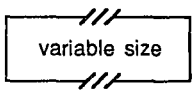
Data segment type

The *data segment type* field is a single byte that indicates whether the communal variable is FAR or NEAR. There are only two possible values for *data segment type*:

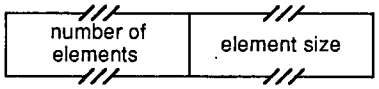
61H	FAR variable
62H	NEAR variable

Communal length

The *communal length* is a variable-length field that indicates the amount of memory to be allocated for the communal variable. The contents of this field depend on the value in the *data segment type* field. If the *data segment type* is NEAR (62H), the *communal length* field contains the size (in bytes) of the communal variable:



If the *data segment type* is FAR (61H), the *communal length* field is formatted as follows:

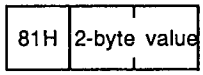


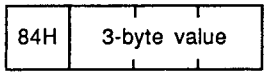
A FAR communal variable is viewed as an array of elements of a specified size. Thus, the *number of elements* field is a variable-length field representing the number of elements in the array, and the *element size* field is a variable-length field that indicates the size (in bytes) of each element. The amount of memory required for a FAR communal variable is thus the product of the *number of elements* and the *element size.*

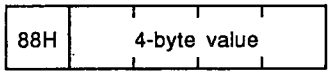
The format of the *variable size*, *number of elements*, and *element size* fields depends upon the magnitude of the values they contain:

- If the value is less than 128 (80H), the field is formatted as a 1-byte field containing the actual value:

- If the value is 128 (80H) or greater, the field is formatted with an extra initial byte that indicates whether the value is represented in the subsequent 2, 3, or 4 bytes:







Groups of *communal name*, *type index*, *data segment type*, and *communal length* fields can be repeated so that more than one communal variable can be declared in the same COMDEF record.

Location in object module

Any object module that contains COMDEF records must also contain one COMENT record with the *comment class* 0A1H, indicating that Microsoft extensions to the Intel object record specification are included in the object module. This COMENT record must appear before any COMDEF records in the object module.

Example

The following COMDEF record was generated by the Microsoft C Compiler version 4.0 for these public variable declarations:

```
int     foo;                    /* 2-byte integer */
char    foo2[32768];            /* 32768-byte array */
char    far foo3[10][2][20];    /* 400-byte array */
```

The COMDEF record is

```
      0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0000  B0 20 00 04 5F 66 6F 6F 00 62 02 05 5F 66 6F 6F   . ..._foo.b..._foo
0010  32 00 62 81 00 80 05 5F 66 6F 6F 33 00 61 81 90   2.b...._foo3.a..
0020  01 01 99                                         ...
```

- Byte 00H contains 0B0H, indicating that this is a COMDEF record.
- Bytes 01–02H contain 0020H, the length of the remainder of the record.
- Bytes 03–0AH, 0B–15H, and 16–21H represent three declarations for the communal variables *foo*, *foo2*, and *foo3*. The C compiler prepends an underscore to each of the names declared in the source code, so the symbols represented in this COMDEF record are *_foo*, *_foo2*, and *_foo3*.
  - Byte 03H contains 04H, the length of the first *communal name* in this record. Bytes 04–07H contain the name itself (*_foo*). Byte 08H (the *type index* field) contains 00H, as required. Byte 09H (the *data segment type* field) contains 62H, indicating this is a NEAR variable. Byte 0AH (the *communal length* field) contains 02H, the size of the variable in bytes.
  - Byte 0BH contains 05H, the length of the second *communal name*. Bytes 0C–10H contain the name, *_foo2*. Byte 11H is the *type index* field, which again contains 00H as required. Byte 12H (the *data segment type* field) contains 62H, indicating that *_foo2* is a NEAR variable.

    Bytes 13–15H (the *communal length* field) contain the size in bytes of the variable. The first byte of the *communal length* field (byte 13H) is 81H, indicating that the size is represented in the subsequent 2 bytes of data — bytes 14–15H, which contain the value 8000H.
  - Bytes 16–1BH represent the *communal name* field for *_foo3*, the third communal variable declared in this record. Byte 1CH (the *type index* field) again contains 00H as required. Byte 1DH (the *data segment type* field) contains 61H, indicating this is a FAR variable. This means the *communal length* field is formatted as a *number of elements* field (bytes 1E–20H, which contain the value 0190H) and an *element size* field (byte 21H, which contains 01H). The total size of this communal variable is thus 190H times 1, or 400 bytes.
- Byte 22H contains the checksum, 99H.

Richard Wilton

Article 20
The Microsoft Object Linker

MS-DOS object modules can be processed in two ways: They can be grouped together in object libraries, or they can be linked into executable files. All Microsoft language translators are distributed with two utility programs that process object modules: The Microsoft Library Manager (LIB) creates and modifies object libraries; the Microsoft Object Linker (LINK) processes the individual object records within object modules to create executable files.

The following discussion focuses on LINK because of its crucial role in creating an executable file. Before delving into the complexities of LINK, however, it is worthwhile reviewing how object modules are managed.

Object Files, Object Libraries, and LIB

Compilers and assemblers translate source-code modules into object modules (Figure 20-1). *See* PROGRAMMING IN THE MS-DOS ENVIRONMENT: PROGRAMMING TOOLS: Object Modules. An object module consists of a sequence of object records that describe the form and content of part of an executable program. An MS-DOS object module always starts with a THEADR record; subsequent object records in the module follow the sequence discussed in the Object Modules article.

Object modules can be stored in either of two types of MS-DOS files: object files and object libraries. By convention, object files have the filename extension .OBJ and object libraries have the extension .LIB. Although both object files and object libraries contain one or

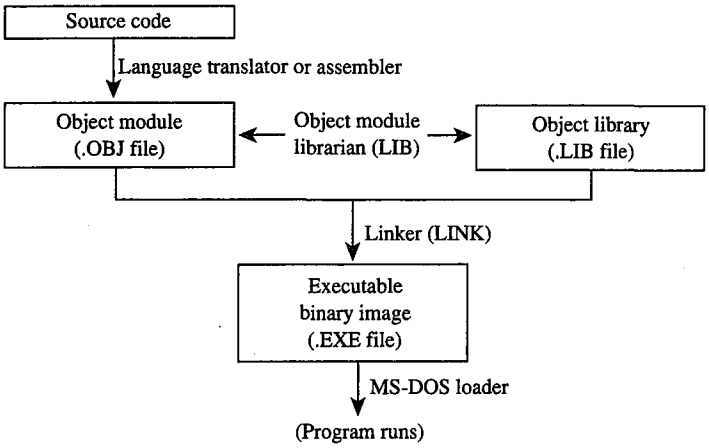


Figure 20-1. Object modules, object libraries, LIB, and LINK.

more object modules, the files and the libraries have different internal organization. Furthermore, LINK processes object files and libraries differently.

The structures of object files and libraries are compared in Figure 20-2. An object file is a simple concatenation of object modules in any arbitrary order. (Microsoft discourages the use of object files that contain more than one object module; Microsoft language translators never generate more than one object module in an object file.) In contrast, a library contains a hashed dictionary of all the public symbols declared in each of the object modules, in addition to the object modules themselves. Each symbol in the dictionary is associated with a reference to the object module in which the symbol was declared.

LINK processes object files differently than it does libraries. When LINK builds an executable file, it incorporates all the object modules in all the object files it processes. In contrast, when LINK processes libraries, it uses the hashed symbol dictionary in each library to extract object modules selectively — it uses an object module from a library only when the object module contains a symbol that is referenced within some other object module. This distinction between object files and libraries is important in understanding what LINK does.

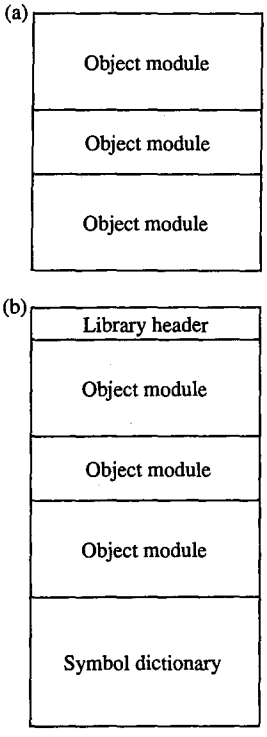


Figure 20-2. Structures of an object file and an object library. (a) An object file contains one or more object modules. (Microsoft discourages using more than one object module per object file.) (b) An object library contains one or more object modules plus a hashed symbol dictionary indicating the object modules in which each public symbol is defined.

What LINK Does

The function of LINK is to translate object modules into an executable program. LINK's input consists of one or more object files (.OBJ files) and, optionally, one or more libraries (.LIB files). LINK's output is an executable file (.EXE file) containing binary data that can be loaded directly from the file into memory and executed. LINK can also generate a symbolic address map listing (.MAP file)—a text file that describes the organization of the .EXE file and the correspondence of symbols declared in the object modules to addresses in the executable file.

Building an executable file

LINK builds two types of information into a .EXE file. First, it extracts executable code and data from the LEDATA and LIDATA records in object modules, arranges them in a specified order according to its rules for segment combination and relocation, and copies the result into the .EXE file. Second, LINK builds a header for the .EXE file. The header describes the size of the executable program and also contains a table of load-time segment relocations and initial values for certain CPU registers. *See* Pass 2 below.

Relocation and linking

In building an executable image from object modules, LINK performs two essential tasks: relocation and linking. As it combines and rearranges the executable code and data it extracts from the object modules it processes, LINK frequently adjusts, or relocates, address references to account for the rearrangements (Figure 20-3). LINK links object modules by resolving address references among them. It does this by matching the symbols declared in EXTDEF and PUBDEF object records (Figure 20-4). LINK uses FIXUPP records to determine exactly how to compute both address relocations and linked address references.

Object Module Order

LINK processes input files from three sources: object files and libraries specified explicitly by the user (in the command line, in response to LINK's prompts, or in a response file) and object libraries named in object module COMENT records.

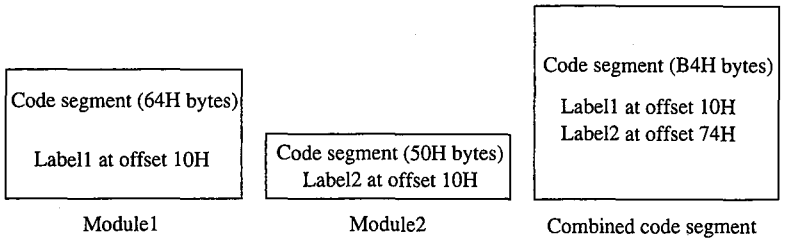


Figure 20-3. A simple relocation. Both object modules contain code that LINK combines into one logical segment. In this example, LINK appends the 50H bytes of code in Module2 *to the 64H bytes of code in* Module1. *LINK relocates all references to addresses in the code segment so that they apply to the combined segment.*

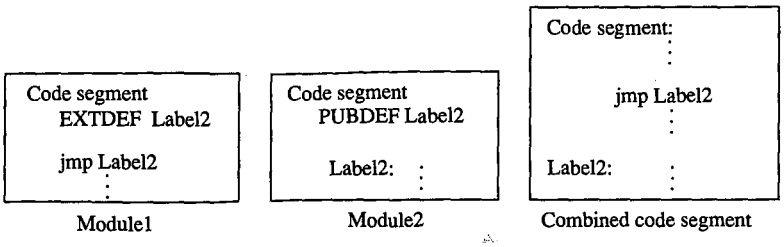


Figure 20-4. Resolving an external reference. LINK resolves the external reference in Module1 *(declared in an EXTDEF record) with the address of* Label2 *in* Module2 *(declared in a PUBDEF record).*

LINK always uses all the object modules in the object files it processes. In contrast, it extracts individual object modules from libraries—only those object modules needed to resolve references to public symbols are used. This difference is implicit in the order in which LINK reads its input files:

1. Object files specified in the command line or in response to the *Object Modules* prompt
2. Libraries specified in the command line or in response to the *Libraries* prompt
3. Libraries specified in COMENT records

The order in which LINK processes object modules influences the resulting executable file in three ways. First, the order in which segments appear in LINK's input files is reflected in the segment structure of the executable file. Second, the order in which LINK resolves external references to public symbols depends on the order in which it finds the public symbols in its input files. Finally, LINK derives the default name of the executable file from the name of the first input object file.

Segment order in the executable file

In general, LINK builds named segments into the executable file in the order in which it first encounters the SEGDEF records that declare the segments. (The /DOSSEG switch also affects segment order. *See* Using the /DOSSEG Switch below.) This means that the order in which segments appear in the executable file can be controlled by linking object modules in a specific order. In assembly-language programs, it is best to declare all the segments used in the program in the first object module to be linked so that the segment order in the executable file is under complete control.

Order in which references are resolved

LINK resolves external references in the order in which it encounters the corresponding public declarations. This fact is important because it determines the order in which LINK extracts object modules from libraries. When a public symbol required to resolve an external reference is declared more than once among the object modules in the input libraries, LINK uses the first object module that contains the public symbol. This means that the actual executable code or data associated with a particular external reference can be varied by changing the order in which LINK processes its input libraries.

For example, imagine that a C programmer has written two versions of a function named *myfunc()* that is called by the program MYPROG.C. One version of *myfunc()* is for debugging; its object module is found in MYFUNC.OBJ. The other is a production version whose object module resides in MYLIB.LIB. Under normal circumstances, the programmer links the production version of *myfunc()* by using MYLIB.LIB (Figure 20-5). To use the debugging version of *myfunc()*, the programmer explicitly includes its object module (MYFUNC.OBJ) when LINK is executed. This causes LINK to build the debugging version of *myfunc()* into the executable file because it encounters the debugging version in MYFUNC.OBJ before it finds the other version in MYLIB.LIB.

To exploit the order in which LINK resolves external references, it is important to know LINK's library search strategy: Each individual library is searched repeatedly (from first library to last, in the sequence in which they are input to LINK) until no further external references can be resolved.

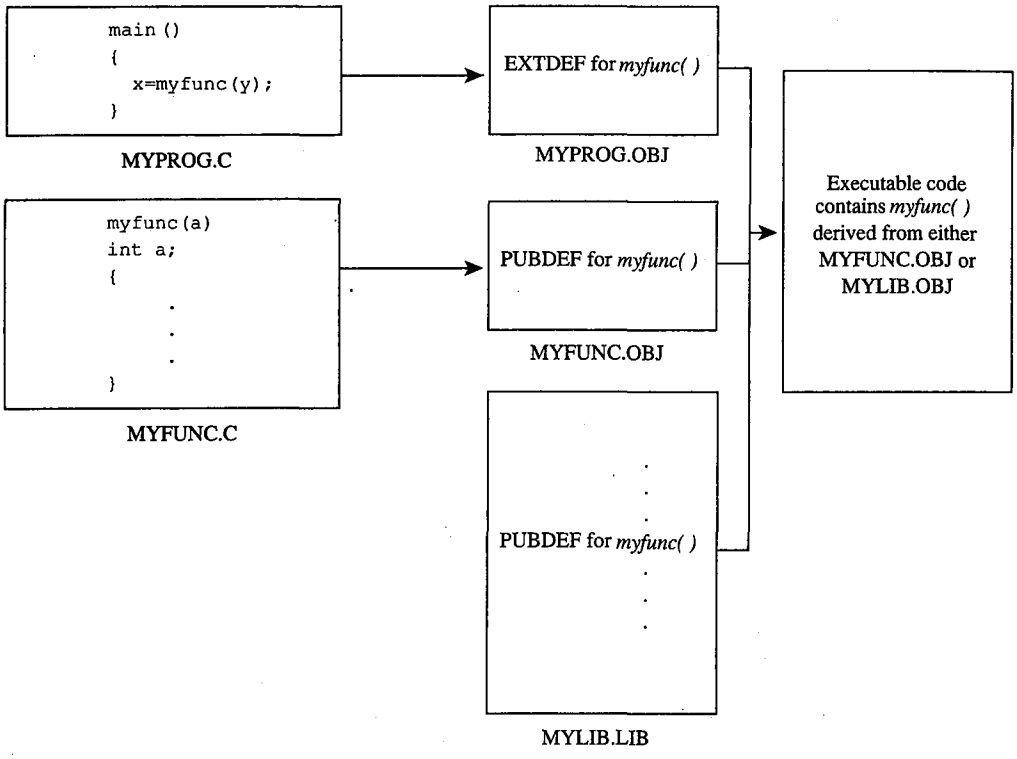


Figure 20-5. Ordered object module processing by LINK. (a) With the command LINK MYPROG,,,MYLIB, *the production version of* myfunc() *in MYLIB.LIB is used. (b) With the command* LINK MYPROG+ MYFUNC,,,MYLIB, *the debugging version of* myfunc() *in MYFUNC.OBJ is used.*

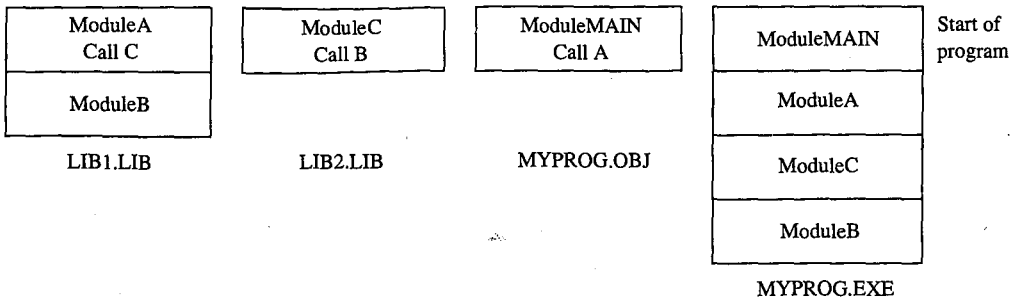


Figure 20-6. Library search order. Modules are incorporated into the executable file as LINK extracts them from the libraries to resolve external references.

The example in Figure 20-6 demonstrates this search strategy. Library LIB1.LIB contains object modules *A* and *B*, library LIB2.LIB contains object module *C*, and the object file MYPROG.OBJ contains the object module *MAIN*; modules *MAIN*, *A*, and *C* each contain an external reference to a symbol declared in another module. When this program is linked with

```
C>LINK MYPROG,,,LIB1+LIB2  <Enter>
```

LINK starts by incorporating the object module *MAIN* into the executable program. It then searches the input libraries until it resolves all the external references:

1. Process MYPROG.OBJ, find unresolved external reference to *A*.
2. Search LIB1.LIB, extract *A*, find unresolved external reference to *C*.
3. Search LIB1.LIB again; reference to *C* remains unresolved.
4. Search LIB2.LIB, extract *C*, find unresolved external reference to *B*.
5. Search LIB2.LIB again; reference to *B* remains unresolved.
6. Search LIB1.LIB again, extract *B*.
7. No more unresolved external references, so end library search.

The order in which the modules appear in the executable file thus reflects the order in which LINK resolves the external references; this, in turn, depends on which modules were contained in the libraries and on the order in which the libraries are input to LINK.

Name of the executable file

If no filename is specified in the command line or in response to the *Run File* prompt, LINK derives the name of the executable file from the name of the first object file it processes. For example, if the object files PROG1.OBJ and PROG2.OBJ are linked with the command

```
C>LINK PROG1+PROG2;  <Enter>
```

the resulting executable file, PROG1.EXE, takes its name from the first object file processed by LINK.

Segment Order and Segment Combinations

LINK builds segments into the executable file by applying the following sequence of rules:

1. Segments appear in the executable file in the order in which their SEGDEF declarations first appear in the input object modules.
2. Segments in different object modules are combined if they have the same name and class and a *public*, *memory*, *stack*, or *common* combine type. All address references within the combined segments are relocated relative to the start of the combined segment.
   - Segments with the same name and either the *public* or the *memory* combine type are combined in the order in which they are processed by LINK. The size of the resulting segment equals the total size of the combined segments.
   - Segments with the same name and the *stack* combine type are overlapped so that the data in each of the overlapped segments ends at the same address. The size of the resulting segment equals the total size of the combined segments. The resulting segment is always paragraph aligned.
   - Segments with the same name and the *common* combine type are overlapped so that the data in each of the overlapped segments starts at the same address. The size of the resulting segment equals the size of the largest of the overlapped segments.
3. Segments with the same class name are concatenated.
4. If the /DOSSEG switch is used, the segments are rearranged in conjunction with DGROUP. *See* Using the /DOSSEG Switch below.

These rules allow the programmer to control the organization of segments in the executable file by ordering SEGMENT declarations in an assembly-language source module, which produces the same order of SEGDEF records in the corresponding object module, and by placing this object module first in the order in which LINK processes its input files.

A typical MS-DOS program is constructed by declaring all executable code and data segments with the *public* combine type, thus enabling the programmer to compile the program's source code from separate source-code modules into separate object modules. When these object modules are linked, LINK combines the segments from the object modules according to the above rules to create logically unified code and data segments in the executable file.

Segment classes

LINK concatenates segments with the same class name after it combines segments with the same segment name and class. For example, Figure 20-7 shows the following compiling and linking:

```
C>MASM MYPROG1;  <Enter>
C>MASM MYPROG2;  <Enter>
C>LINK MYPROG1+MYPROG2;  <Enter>
```

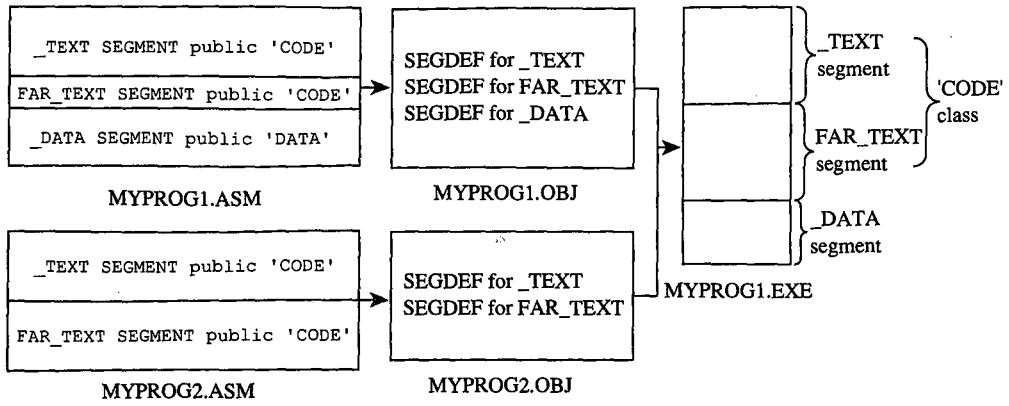


Figure 20-7. Segment order and concatenation by LINK. The start of each file, corresponding to the lowest address, is at the top.

After MYPROG1.ASM and MYPROG2.ASM have been compiled, LINK builds the *_TEXT* and *FAR_TEXT* segments by combining segments with the same name from the different object modules. Then, *_TEXT* and *FAR_TEXT* are concatenated because they have the same class name ('CODE'). *_TEXT* appears before *FAR_TEXT* in the executable file because LINK encounters the SEGDEF record for *_TEXT* before it finds the SEGDEF record for *FAR_TEXT*.

Segment alignment

LINK aligns the starting address of each segment it processes according to the alignment specified in each SEGDEF record. It adjusts the alignment of each segment it encounters regardless of how that segment is combined with other segments of the same name or class. (The one exception is *stack* segments, which always start on a paragraph boundary.)

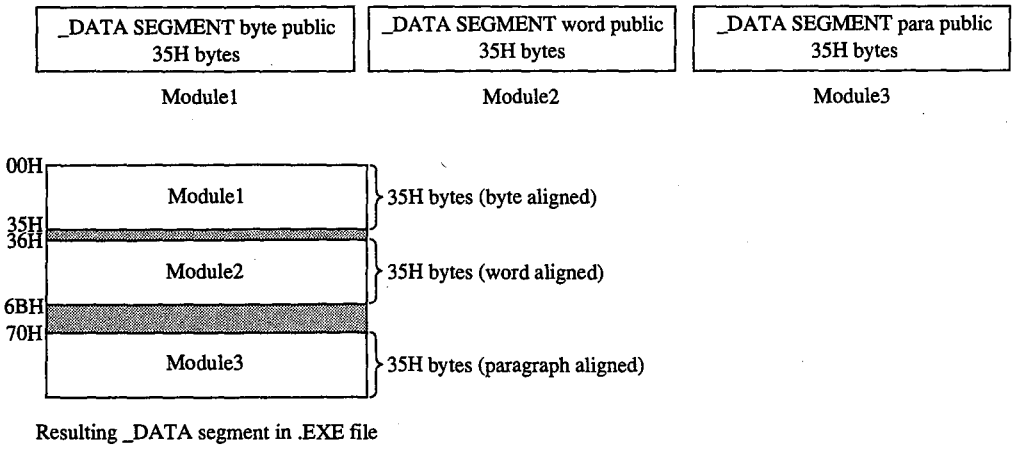


Figure 20-8. Alignment of combined segments. LINK enforces segment alignment by padding combined segments with uninitialized data bytes.

Segment alignment is particularly important when public segments with the same name and class are combined from different object modules. Note what happens in Figure 20-8, where the three concatenated *_DATA* segments have different alignments. To enforce the word alignment and paragraph alignment of the *_DATA* segments in *Module2* and *Module3*, LINK inserts one or more bytes of padding between the segments.

Segment groups

A segment group establishes a logical segment address to which all offsets in a group of segments can refer. That is, all addresses in all segments in the group can be expressed as offsets relative to the segment value associated with the group (Figure 20-9). Declaring segments in a group does not affect their positions in the executable file; the segments in a group may or may not be contiguous and can appear in any order as long as all address references to the group fall within 64 KB of each other.

```
DataGroup       GROUP     DataSeg1,DataSeg2
CodeSeg         SEGMENT   byte public 'CODE'
                ASSUME    cs:CodeSeg

                mov       ax,offset DataSeg2:TestData
                mov       ax,offset DataGroup:TestData

CodeSeg         ENDS

DataSeg1        SEGMENT   para public 'DATA'
                DB        100h dup(?)
DataSeg1        ENDS

DataSeg2        SEGMENT   para public 'DATA'
TestData        DB        ?
DataSeg2        ENDS
                END
```

Figure 20-9. Example of group addressing. The first MOV loads the value 00H into AX (the offset of TestData *relative to* DataSeg2*); the second MOV loads the value 100H into AX (the offset of* TestData *relative to the group* DataGroup*).*

LINK reserves one group name, DGROUP, for use by Microsoft language translators. DGROUP is used to group compiler-generated data segments and a default stack segment. *See* DGROUP below.

LINK Internals

Many programmers use LINK as a "black box" program that transforms object modules into executable files. Nevertheless, it is helpful to observe how LINK processes object records to accomplish this task.

LINK is a two-pass linker; that is, it reads all its input object modules twice. On Pass 1, LINK builds an address map of the segments and symbols in the object modules. On Pass 2, it extracts the executable code and program data from the object modules and builds a memory image—an exact replica—of the executable file.

The reason LINK builds an image of the executable file in memory, instead of simply copying code and data from object modules into the executable file, is that it organizes the executable file by segments and not by the order in which it processes object modules. The most efficient way to concatenate, combine, and relocate the code and data is to build a map of the executable file in memory during Pass 1 and then fill in the map with code and data during Pass 2.

In versions 3.52 and later, whenever the /I (/INFORMATION) switch is specified in the command line, LINK displays status messages at the start of each pass and as it processes each object module. If the /M (/MAP) switch is used in addition to the /I switch, LINK also displays the total length of each segment declared in the object modules. This information is helpful in determining how the structure of an executable file corresponds to the contents of the object modules processed by LINK.

Pass 1

During Pass 1, LINK processes the LNAMES, SEGDEF, GRPDEF, COMDEF, EXTDEF, and PUBDEF records in each input object module and uses the information in these object records to construct a symbol table and an address map of segments and segment groups.

Symbol table

As each object module is processed, LINK uses the symbol table to resolve external references (declared in EXTDEF and COMDEF records) to public symbols. If LINK processes all the object files without resolving all the external references in the symbol table, it searches the input libraries for public symbols that match the unresolved external references. LINK continues to search each library until all the external references in the symbol table are resolved.

Segments and groups

LINK processes each SEGDEF record according to the segment name, class name, and attributes specified in the record. LINK constructs a table of named segments and updates it as it concatenates or combines segments. This allows LINK to associate each public symbol in the symbol table with an offset into the segment in which the symbol is declared.

LINK also generates default segments into which it places communal variables declared in COMDEF records. Near communal variables are placed in one paragraph-aligned public segment named c_common, with class name BSS (block storage space) and group

DGROUP. Far communal variables are placed in a paragraph-aligned segment named FAR_BSS, with class name FAR_BSS. The combine type of each far communal variable's FAR_BSS segment is private (that is, not *public*, *memory*, *common*, or *stack*). As many FAR_BSS segments as necessary are generated.

After all the object files have been read and all the external references in the symbol table have been resolved, LINK has a complete map of the addresses of all segments and symbols in the program. If a .MAP file has been requested, LINK creates the file and writes the address map to it. Then LINK initiates Pass 2.

Pass 2

In Pass 2, LINK extracts executable code and program data from the LEDATA and LIDATA records in the object modules. It builds the code and data into a memory image of the executable file. During Pass 2, LINK also carries out all the address relocations and fixups related to segment relocation, segment grouping, and resolution of external references, as well as any other address fixups specified explicitly in object module FIXUPP records.

If it determines during Pass 2 that not enough RAM is available to contain the entire image, LINK creates a temporary file in the current directory on the default disk drive. (LINK versions 3.60 and later use the environment variable TMP to find the directory for the temporary scratch file.) LINK then uses this file in addition to all the available RAM to construct the image of the executable file. (In versions of MS-DOS earlier than 3.0, the temporary file is named VM.TMP; in versions 3.0 and later, LINK uses Interrupt 21H Function 5AH to create the file.)

LINK reads each of the input object modules in the same order as it did in Pass 1. This time it copies the information from each object module's LEDATA and LIDATA records into the memory image of each segment in the proper sequence. This is when LINK expands the iterated data in each LIDATA record it processes.

LINK processes each LEDATA and LIDATA record along with the corresponding FIXUPP record, if one exists. LINK processes the FIXUPP record, performs the address calculations required for relocation, segment grouping, and resolving external references, and then stores binary data from the LEDATA or LIDATA record, including the results of the address calculations, in the proper segment in the memory image. The only exception to this process occurs when a FIXUPP record refers to a segment address. In this case, LINK adds the address of the fixup to a table of segment fixups; this table is used later to generate the segment relocation table in the .EXE header.

When all the data has been extracted from the object modules and all the fixups have been carried out, the memory image is complete. LINK now has all the information it needs to build the .EXE header (Table 20-1). At this point, therefore, LINK creates the executable file and writes the header and all segments into it.

Table 20-1. How LINK Builds a .EXE File Header.

Offset	Contents	Comments
00H	'MZ'	.EXE file signature
02H	Length of executable image MOD 512	Total size of all segments plus .EXE file header
04H	Length of executable image in 512-byte pages, including last partial page (if any)	
06H	Number of run-time segment relocations	Number of segment fixups
08H	Size of the .EXE header in 16-byte paragraphs	Size of segment relocation table
0AH	MINALLOC: Minimum amount of RAM to be allocated above end of the loaded program (in 16-byte paragraphs)	Size of uninitialized data and/or stack segments at end of program (0 if /HI switch is used)
0CH	MAXALLOC: Maximum amount of RAM to be allocated above end of the loaded program (in 16-byte paragraphs)	0 if /HI switch is used; value specified with /CP switch; FFFFH if /CP and /HI switches are not used
0EH	Stack segment (initial value for SS register); relocated by MS-DOS when program is loaded	Address of stack segment relative to start of executable image
10H	Stack pointer (initial value for register SP)	Size of stack segment in bytes
12H	Checksum	One's complement of sum of all words in file, excluding checksum itself
14H	Entry point offset (initial value for register IP)	MODEND object record that specifies program start address
16H	Entry point segment (initial value for register CS); relocated by MS-DOS when program is loaded	
18H	Offset of start of segment relocation table relative to start of .EXE header	
1AH	Overlay number	0 for resident segments; >0 for overlay segments
1CH	Reserved	

Using LINK to Organize Memory

By using LINK to rearrange and combine segments, a programmer can generate an executable file in which segment order and addressing serve specific purposes. As the following examples demonstrate, careful use of LINK leads to more efficient use of memory and simpler, more efficient programs.

Segment order for a TSR

In a terminate-and-stay-resident (TSR) program, LINK must be used carefully to generate segments in the executable file in the proper order. A typical TSR program consists of a resident portion, in which the TSR application is implemented, and a transient portion, which executes only once to initialize the resident portion. *See* PROGRAMMING IN THE MS-DOS ENVIRONMENT: CUSTOMIZING MS-DOS: Terminate-and-Stay-Resident Utilities.

Because the transient portion of the TSR program is executed only once, the memory it occupies should be freed after the resident portion has been initialized. To allow the MS-DOS Terminate and Stay Resident function (Interrupt 21H Function 31H) to free this memory when it leaves the resident portion of the TSR program in memory, the TSR program must have its resident portion at lower addresses than its transient portion.

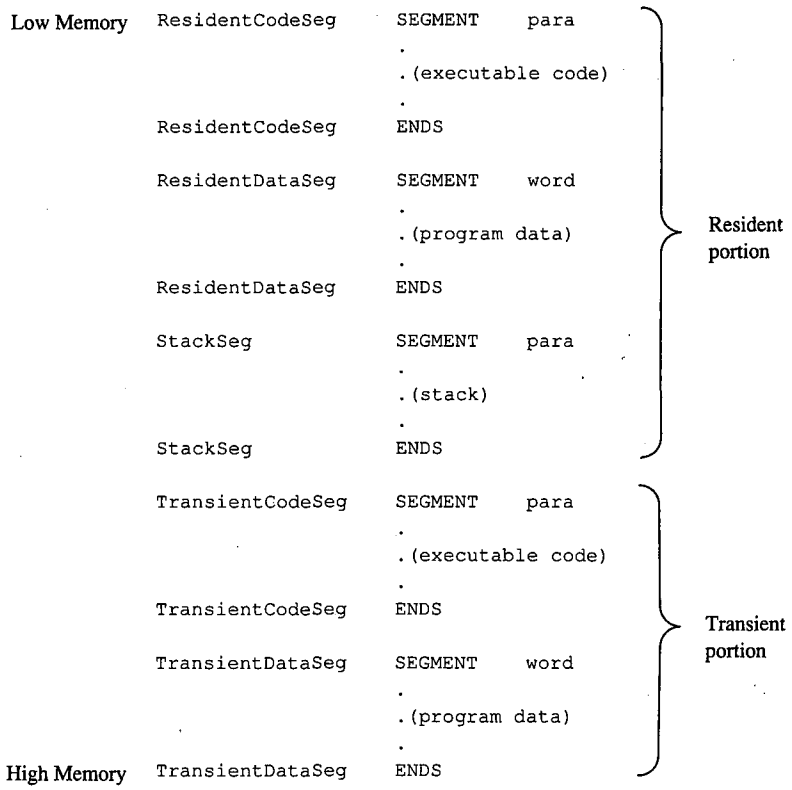


Figure 20-10. Segment order for a terminate-and-stay-resident program.

In Figure 20-10, the segments containing the resident code and data are declared before the segments that represent the transient portion of the program. Because LINK preserves this segment order, the executable program has the desired structure, with resident code and data at lower addresses than transient code and data. Moreover, the number of paragraphs in the resident portion of the program, which must be computed before Interrupt 21H Function 31H is called, is easy to derive from the segment structure: This value is the difference between the segment address of the program segment prefix, which immediately precedes the first segment in the resident portion, and the address of the first segment in the transient portion of the program.

Groups for unified segment addressing

In some programs it is desirable to maintain executable code and data in separate logical segments but to address both code and data with the same segment register. For example, in a hardware interrupt handler, using the CS register to address program data is generally simpler than using DS or ES.

In the routine in Figure 20-11, code and data are maintained in separate segments for program clarity, yet both can be addressed using the CS register because both code and data segments are included in the same group. (The SNAP.ASM listing in the Terminate-and-Stay-Resident Utilities article is another example of this use of a group to unify segment addressing.)

```
ISRgroup        GROUP     CodeSeg,DataSeg
CodeSeg         SEGMENT   byte public 'CODE'
                ASSUME    cs:ISRgroup
                mov       ax,offset ISRgroup:CodeLabel
CodeLabel:      mov       bx,ISRgroup:DataLabel
CodeSeg         ENDS

DataSeg         SEGMENT   para public 'DATA'
DataLabel       DW        ?
DataSeg         ENDS
                END
```

Figure 20-11. Code and data included in the same group. In this example, addresses within both CodeSeg *and* DataSeg *are referenced relative to the CS register by grouping the segments (using the assembler GROUP directive) and addressing the group through CS (using the assembler ASSUME directive).*

Uninitialized data segments

A segment that contains only uninitialized data can be processed by LINK in two ways, depending on the position of the segment in the program. If the segment is not at the end of the program, LINK generates a block of bytes initialized to zero to represent the segment in the executable file. If the segment appears at the end of the program, however, LINK does not generate a block of zeroed bytes. Instead, it increases the minimum run-time memory allocation by increasing MINALLOC (specified at offset 0AH in the .EXE header) by the amount of memory required for the segment.

Therefore, if it is necessary to reserve a large amount of uninitialized memory in a segment, the size of the .EXE file can be decreased by building the segment at the end of a program (Figure 20-12). This is why, for example, Microsoft high-level-language translators always build BSS and STACK segments at the end of compiled programs. (The loader does not fill these segments with zeros; a program must still initialize them with appropriate values.)

```
(a)             CodeSeg     SEGMENT     byte public 'CODE'
                            ASSUME      cs:CodeSeg,ds:DataSeg
                            ret
                CodeSeg     ENDS

                DataSeg     SEGMENT     word public 'DATA'
                BigBuffer   DB          10000 dup(?)
                DataSeg     ENDS
                            END

(b)             DataSeg     SEGMENT     word public 'DATA'
                BigBuffer   DB          10000 dup(?)
                DataSeg     ENDS

                CodeSeg     SEGMENT     byte public 'CODE'
                            ASSUME      cs:CodeSeg,ds:DataSeg
                            ret
                CodeSeg     ENDS
                            END
```

Figure 20-12. LINK processing of uninitialized data segments. (a) When DataSeg, *which contains only uninitialized data, is placed at the end of this program, the size of the .EXE file is only 513 bytes. (b) When* DataSeg *is not placed at the end of the program, the size of the .EXE file is 10513 bytes.*

Overlays

If a program contains two or more subroutines that are mutually independent—that is, subroutines that do not transfer control to each other—LINK can be instructed to build each subroutine into a separately loaded portion of the executable file. (This instruction is indicated in the command line when LINK is executed by enclosing each overlay subroutine or group of subroutines in parentheses.) Each of the subroutines can then be overlaid as it is needed in the same area of memory (Figure 20-13). The amount of memory required to run a program that uses overlays is, therefore, less than the amount required to run the same program without overlays.

A program that uses overlays must include the Microsoft run-time overlay manager. The overlay manager is responsible for copying overlay code from the executable file into memory whenever the program attempts to transfer control to code in an overlay. A program that uses overlays runs slower than a program that does not use them, because it takes longer to extract overlays separately from the .EXE file than it does to read the entire .EXE file into memory at once.

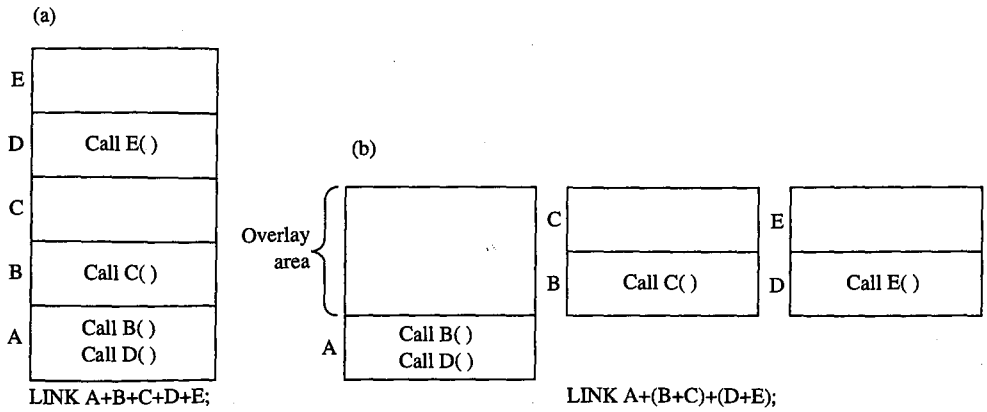


Figure 20-13. Memory use in a program linked (a) without overlays and (b) with overlays. In (b), either modules (B+C) or modules (D+E) can be loaded into the overlay area at run time.

The default object libraries that accompany Microsoft high-level-language compilers contain object modules that support the Microsoft run-time overlay manager. The following description of LINK's relationship to the run-time overlay manager applies to versions 3.00 through 3.60 of LINK; implementation details may vary in future versions.

Overlay format in a .EXE file

An executable file that contains overlays has a .EXE header preceding each overlay (Figure 20-14). The overlays are numbered in sequence, starting at 0; the overlay number is stored in the word at offset 1AH in each overlay's .EXE header. When the contents of the .EXE file are loaded into memory for execution, only the resident, nonoverlaid part of the program is copied into memory. The overlays must be read into memory from the .EXE file by the run-time overlay manager.

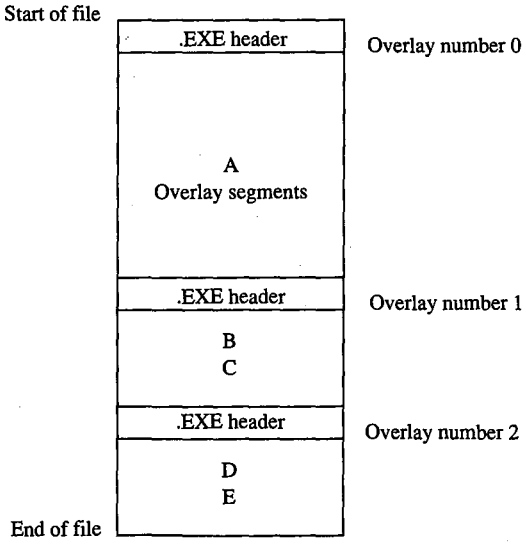


Figure 20-14. .EXE file structure produced by LINK A + (B+C) + (D+E).

Segments for overlays

When LINK produces an executable file that contains overlays, it adds three segments to those defined in the object modules: OVERLAY_AREA, OVERLAY_END, and OVERLAY_DATA. LINK assigns the segment class name 'CODE' to OVERLAY_AREA and OVERLAY_END and includes OVERLAY_DATA in the default group DGROUP.

OVERLAY_AREA is a reserved segment into which the run-time overlay manager is expected to load each overlay as it is needed. Therefore, LINK sets the size of OVERLAY_AREA to fit the largest overlay in the program. The OVERLAY_END segment is declared immediately after OVERLAY_AREA, so a program can determine the size of the OVERLAY_AREA segment by subtracting its segment address from that of OVERLAY_END. The OVERLAY_DATA segment is initialized by LINK with information about the executable file, the number of overlays, and other data useful to the run-time overlay manager.

LINK requires the executable code used in overlays to be contained in segments whose class names end in *CODE* and whose segment names differ from those of the segments used in the resident (nonoverlaid) portion of the program. In assembly language, this is accomplished by using the SEGMENT directive; in high-level languages, the technique of ensuring unique segment names depends on the compiler. In Microsoft C, for example, the /A switch in the command line selects the memory model and thus the segment naming defaults used by the compiler; in medium, large, and huge memory models, the compiler generates a unique segment name for each C function in the source code. In Microsoft FORTRAN, on the other hand, the compiler always generates a uniquely named segment for each SUBROUTINE and FUNCTION in the source code, so no special programming is required.

LINK substitutes all far CALL instructions from root to overlay or from overlay to overlay with a software interrupt followed by an overlay number and an offset into the overlay segment (Figure 20-15). The interrupt number can be specified with LINK's /OVERLAYINTERRUPT switch; if the switch is omitted, LINK uses Interrupt 3FH by default. By replacing calls to overlay code with a software interrupt, LINK provides a mechanism for the run-time overlay manager to take control, load a specified overlay into memory, and transfer control to a specified offset within the overlay.

```
(a)         EXTRN     OverlayEntryPoint:far
            call      OverlayEntryPoint    ; far CALL

(b)         int       IntNo                ; interrupt number
                                           ;  specified with /OVERLAYINTERRUPT
                                           ;  switch (default 3FH)
            DB        OverlayNumber        ; overlay number
            DW        OverlayEntry         ; offset of overlay entry point
                                           ;  (the address to which
                                           ;  the overlay manager transfers
                                           ;  control)
```

Figure 20-15. Executable code modification by LINK for accessing overlays. (a) Code as written. (b) Code as modified by LINK.

Run-time processing of overlays

The resident (nonoverlaid) portion of a program that uses overlays initializes the overlay interrupt vector specified by LINK with the address of the run-time overlay manager. (The OVERLAY_DATA segment contains the interrupt number.) The overlay manager then takes control wherever LINK has substituted a software interrupt for a far call in the executable code.

Each time the overlay manager executes, its first task is to determine which overlay is being called. It does this by using the return address left on the stack by the INT instruction that invoked the overlay manager; this address points to the overlay number stored in the byte after the interrupt instruction that just executed. The overlay manager then determines whether the destination overlay is already resident and loads it only if necessary. Next, the overlay manager opens the .EXE file, using the filename in the OVERLAY_DATA segment. It locates the start of the specified overlay in the file by examining the length (offset 02H and offset 04H) and overlay number (offset 1AH) in each overlay's .EXE header.

The overlay manager can then read the overlay from the .EXE file into the OVERLAY_AREA segment. It uses the overlay's segment relocation table to fix up any segment references in the overlay. The overlay manager transfers control to the overlay with a far call to the OVERLAY_AREA segment, using the offset stored by LINK 1 byte after the interrupt instruction (*see* Figure 20-15).

Interrupt 21H Function 4BH

LINK's protocol for implementing overlays is not recognized by Interrupt 21H Function 4BH (Load and Execute Program). This MS-DOS function, when called with AL = 03H, loads an overlay from a .EXE file into a specified location in memory. *See* SYSTEM CALLS: INTERRUPT 21H: Function 4BH. However, Function 4BH does not use an overlay number, so it cannot find overlays in a .EXE file formatted by LINK with multiple .EXE headers.

DGROUP

LINK always includes DGROUP in its internal table of segment groups. In object modules generated by Microsoft high-level-language translators, DGROUP contains both the default data segment and the stack segment. LINK's /DOSSEG and /DSALLOCATE switches both affect the way LINK treats DGROUP. Changing the way LINK manages DGROUP ultimately affects segment order and addressing in the executable file.

Using the /DOSSEG switch

The /DOSSEG switch causes LINK to arrange segments in the default order used by Microsoft high-level-language translators:

1. All segments with a class name ending in *CODE*. These segments contain executable code.
2. All other segments outside DGROUP. These segments typically contain far data items.

3. DGROUP segments. These are a program's near data and stack segments. The order in which segments appear in DGROUP is
   - Any segments of class BEGDATA. (This class name is reserved for Microsoft use.)
   - Any segments not of class BEGDATA, BSS, or STACK.
   - Segments of class BSS.
   - Segments of class STACK.

This segment order is necessary if programs compiled by Microsoft translators are to run properly. The /DOSSEG switch can be used whenever an object module produced by an assembler is linked ahead of object modules generated by a Microsoft compiler, to ensure that segments in the executable file are ordered as in the preceding list regardless of the order of segments in the assembled object module.

When the /DOSSEG switch is in effect, LINK always places DGROUP at the end of the executable program, with all uninitalized data segments at the end of the group. As discussed above, this placement helps to minimize the size of the executable file. The /DOSSEG switch also causes LINK to restructure the executable program to support certain conventions used by Microsoft language translators:

- Compiler-generated segments with the class name BEGDATA are placed at the beginning of DGROUP.
- The public symbols _edata and _end are generated to point to the beginning of the BSS and STACK segments.
- Sixteen bytes of zero are inserted in front of the _TEXT segment.

Microsoft compilers that rely on /DOSSEG conventions generate a special COMENT object record that sets the /DOSSEG switch when the record is processed by LINK.

Using the /HIGH and /DSALLOCATE switches

When a program has been linked without using LINK's /HIGH switch, MS-DOS loads program code and data segments from the .EXE file at the lowest address in the first available block of RAM large enough to contain the program (Figure 20-16). The value in the .EXE header at offset 0CH specifies the maximum amount of extra RAM MS-DOS must allocate to the program above what is loaded from the .EXE file. Above that, all unused RAM is managed by MS-DOS. With this memory allocation strategy, a program can use Interrupt 21H Functions 48H (Allocate Memory Block) and 4AH (Resize Memory Block) to increase or decrease the amount of RAM allocated to it.

When a program is linked with LINK's /HIGH switch, LINK zeros the words it stores in the .EXE header at offset 0AH and 0CH. Setting the words at 0AH and 0CH to zero indicates that the program is to be loaded into RAM at the highest address possible (Figure 20-16). With this memory layout, however, a program can no longer change its memory allocation dynamically because all available RAM is allocated to the program when it is loaded and the uninitialized RAM between the program segment prefix and the program itself cannot be freed.

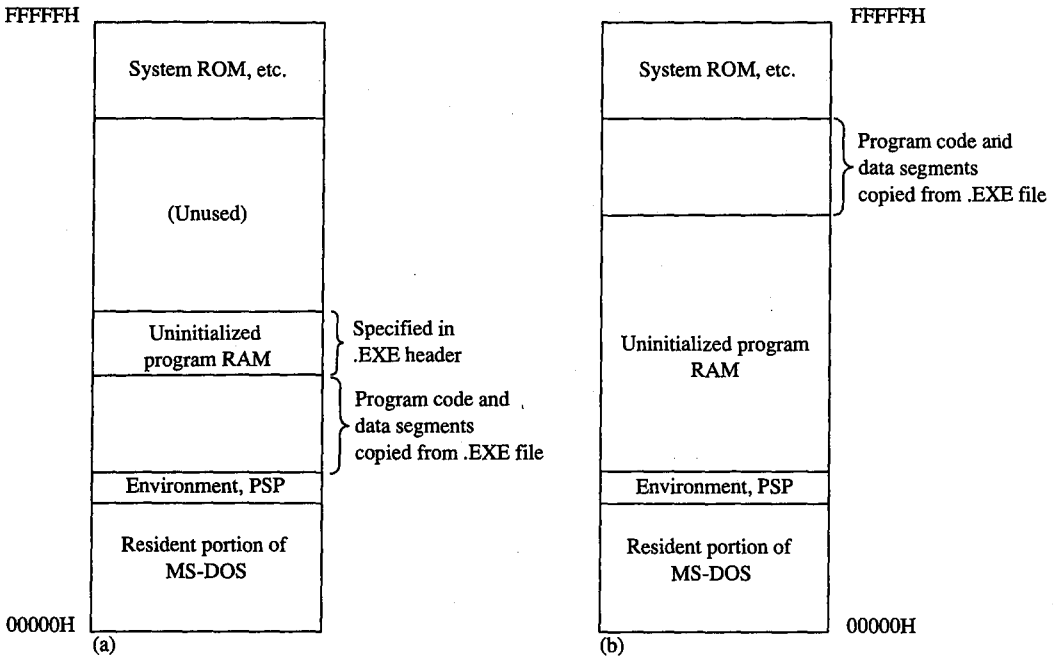


Figure 20-16. Effect of the /HIGH switch on run-time memory use. (a) The program is linked without *the /HIGH switch. (b) The program is linked* with *the /HIGH switch.*

The only reason to load a program with this type of memory allocation is to allow a program data structure to be dynamically extended toward lower memory addresses. For example, both stacks and heaps can be implemented in this way. If a program's stack segment is the first segment in its memory map, the stack can grow downward without colliding with other program data.

To facilitate addressing in such a segment, LINK provides the /DSALLOCATE switch. When a program is linked using this switch, all addresses within DGROUP are relocated in such a way that the last byte in the group has offset FFFFH. For example, if the program in Figure 20-17 is linked without the /DSALLOCATE and /HIGH switches, the value of offset *DGROUP:DataItem* would be 00H; if these switches are used, the linker adjusts the segment value of DGROUP downward so that the offset of *DataItem* within DGROUP becomes FFF0H.

Early versions of Microsoft Pascal (before version 3.30) and Microsoft FORTRAN (before version 3.30) generated object code that had to be linked with the /DSALLOCATE switch. For this reason, LINK sets the /DSALLOCATE switch by default if it processes an object module containing a COMENT record generated by one of these compilers. (Such a COMENT record contains the string *MS PASCAL* or *FORTRAN 77. See* PROGRAMMING IN THE MS-DOS ENVIRONMENT: PROGRAMMING TOOLS: Object Modules.) Apart from this special requirement of certain language translators, however, the use of /DSALLOCATE and /HIGH should probably be avoided because of the limitations they place on run-time memory allocation.

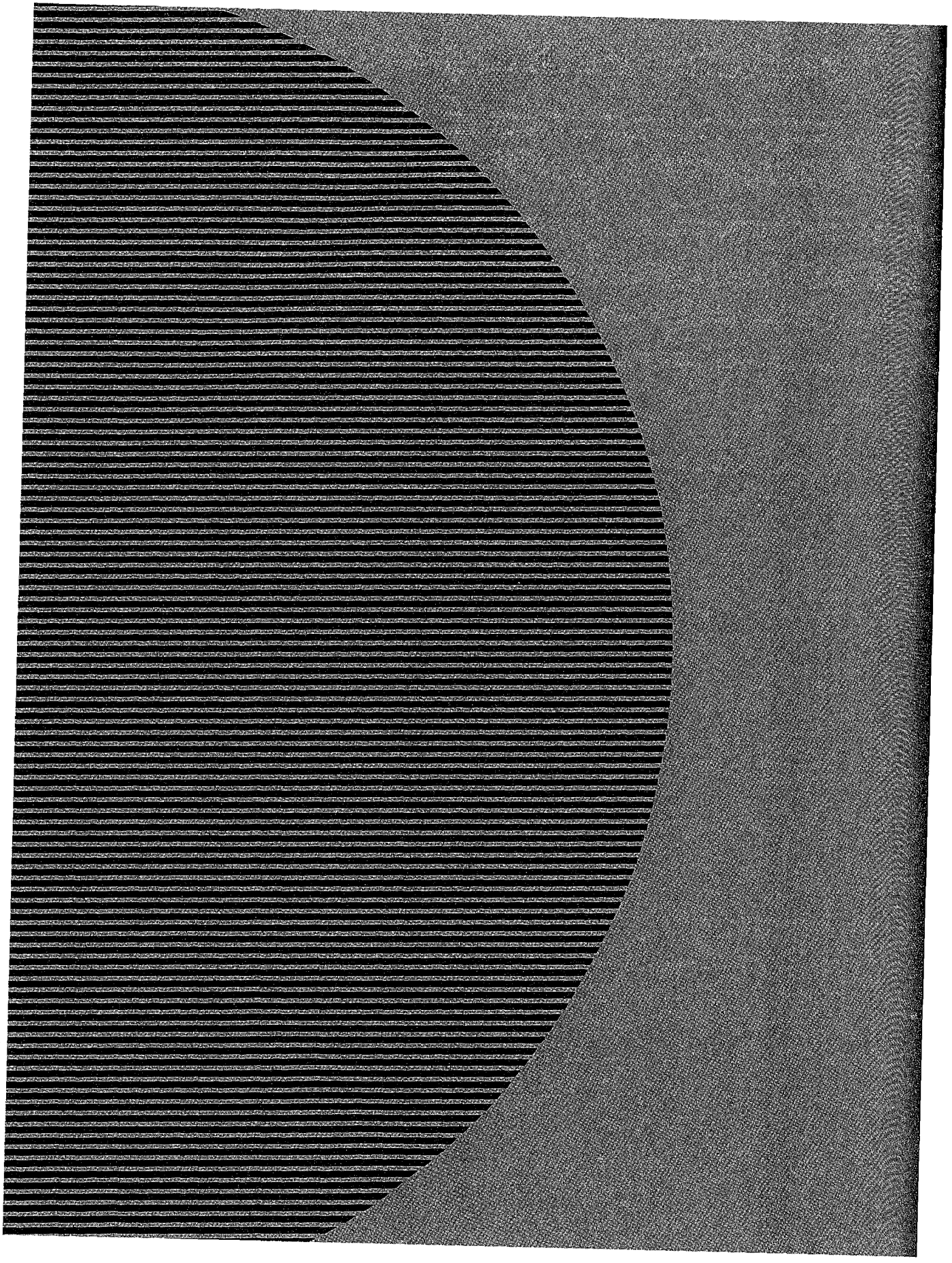
```
DGROUP          GROUP     _DATA
_DATA           SEGMENT   word public 'DATA'
DataItem        DB        10h dup (?)
_DATA           ENDS

_TEXT           SEGMENT   byte public 'CODE'
                ASSUME    cs:_TEXT,ds:DGROUP
                mov       bx,offset DGROUP:DataItem
_TEXT           ENDS
                END
```

Figure 20-17. The value of offset DGROUP:DataItem *in this program is FFF0H if the program is linked with the /DSALLOCATE switch or 00H if the program is linked without using the switch.*

Summary

LINK's characteristic support for segment ordering, for run-time memory management, and for dynamic overlays has an impact in many different situations. Programmers who write their own language translators must bear in mind the special conventions followed by LINK in support of Microsoft language translators. Application programmers must be familiar with LINK's capabilities when they use assembly language or link assembly-language programs with object modules generated by Microsoft compilers. LINK is a powerful program development tool and understanding its special capabilities can lead to more efficient programs.

Richard Wilton



Section III
User Commands

Introduction

This section of *The MS-DOS Encyclopedia* describes the standard internal and external MS-DOS commands available to the user who is running MS-DOS (versions 1.0 through 3.2). System configuration options, special batch-file directives, the line editor (EDLIN), and the installable device drivers normally included with MS-DOS are also covered.

Entries are arranged alphabetically by the name of the command or driver. The configuration, batch-file, and line-editor directives appear alphabetically under the headings CONFIG.SYS, BATCH, and EDLIN, respectively. Each entry includes

- Command name
- Version dependencies and network information
- Command purpose
- Prototype command and summary of options
- Detailed description of command
- One or more examples of command use
- Return codes (where applicable)
- Informational and error messages

The experienced user can find information with a quick glance at the first part of a command entry; a less experienced user can refer to the detailed explanation and examples in a more leisurely fashion. The next two pages contain an example of a typical entry from the User Commands section, with explanations of each component. This example is followed by listings of the commands by functional group.

The following terms are used for command-line variables in the sample syntax:

drive	a letter in the range A–Z, followed by a colon, indicating a logical disk drive.
path	a specific location in a disk's hierarchical directory structure; can include the special directory names . and ..; elements are separated by backslash characters (\).
pathname	a file specification that can include a path and/or drive and/or filename extension.
filename	the name of a file, generally with its extension; cannot include a drive or path.

Note: PC-DOS, though not an official product name, is used in this section to indicate IBM's version of the disk operating system originally provided by Microsoft. Commands sometimes have slightly different options or appear for the first time in different versions of MS-DOS and PC-DOS. When a command appears only in the IBM versions, the abbreviation IBM appears in the heading area. Significant differences between MS-DOS and PC-DOS versions of a command are indicated in the *Syntax* and *Description* portions of the entry.

HEADING
The command name as the user would enter it or as it would be used in a batch or system-configuration file.

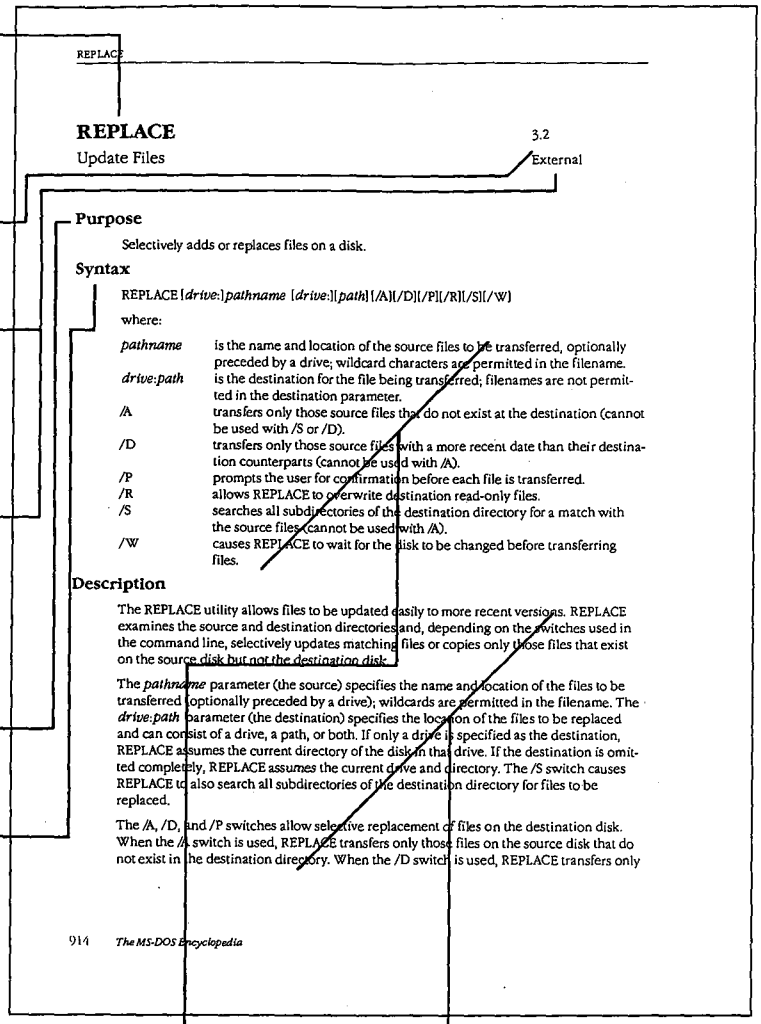
ICON-1
MS-DOS version dependency.

ICON-2
Whether the command is internal (built into COMMAND.COM) or external (loaded from a disk file when needed).

ICON-3
The abbreviation IBM if the command is present only in PC-DOS and the warning *No Net* if the command cannot be used across a network.

PURPOSE
An abstract of command purpose and usage.

SYNTAX
A prototype command line, with variable names in italic and optional parameters in square brackets. The various elements of the command line should be entered in the order shown. Any punctuation must be used exactly as shown; in commands that use commas as separators, the comma usually must be included as a placeholder even if the parameter is omitted. Except where noted, commands, parameters, and switches can be entered in either uppercase or lowercase. With MS-DOS versions 3.0 and later, external commands can be preceded by a drive and/or path.



REPLACE

REPLACE 3.2
Update Files External

Purpose

Selectively adds or replaces files on a disk.

Syntax

REPLACE [*drive:*]*pathname* [*drive:*][*path*] [/A][/D][/P][/R][/S][/W]

where:

pathname	is the name and location of the source files to be transferred, optionally preceded by a drive; wildcard characters are permitted in the filename.
drive:path	is the destination for the file being transferred; filenames are not permitted in the destination parameter.
/A	transfers only those source files that do not exist at the destination (cannot be used with /S or /D).
/D	transfers only those source files with a more recent date than their destination counterparts (cannot be used with /A).
/P	prompts the user for confirmation before each file is transferred.
/R	allows REPLACE to overwrite destination read-only files.
/S	searches all subdirectories of the destination directory for a match with the source files (cannot be used with /A).
/W	causes REPLACE to wait for the disk to be changed before transferring files.

Description

The REPLACE utility allows files to be updated easily to more recent versions. REPLACE examines the source and destination directories and, depending on the switches used in the command line, selectively updates matching files or copies only those files that exist on the source disk but not the destination disk.

The *pathname* parameter (the source) specifies the name and location of the files to be transferred (optionally preceded by a drive); wildcards are permitted in the filename. The *drive:path* parameter (the destination) specifies the location of the files to be replaced and can consist of a drive, a path, or both. If only a drive is specified as the destination, REPLACE assumes the current directory of the disk in that drive. If the destination is omitted completely, REPLACE assumes the current drive and directory. The /S switch causes REPLACE to also search all subdirectories of the destination directory for files to be replaced.

The /A, /D, and /P switches allow selective replacement of files on the destination disk. When the /A switch is used, REPLACE transfers only those files on the source disk that do not exist in the destination directory. When the /D switch is used, REPLACE transfers only

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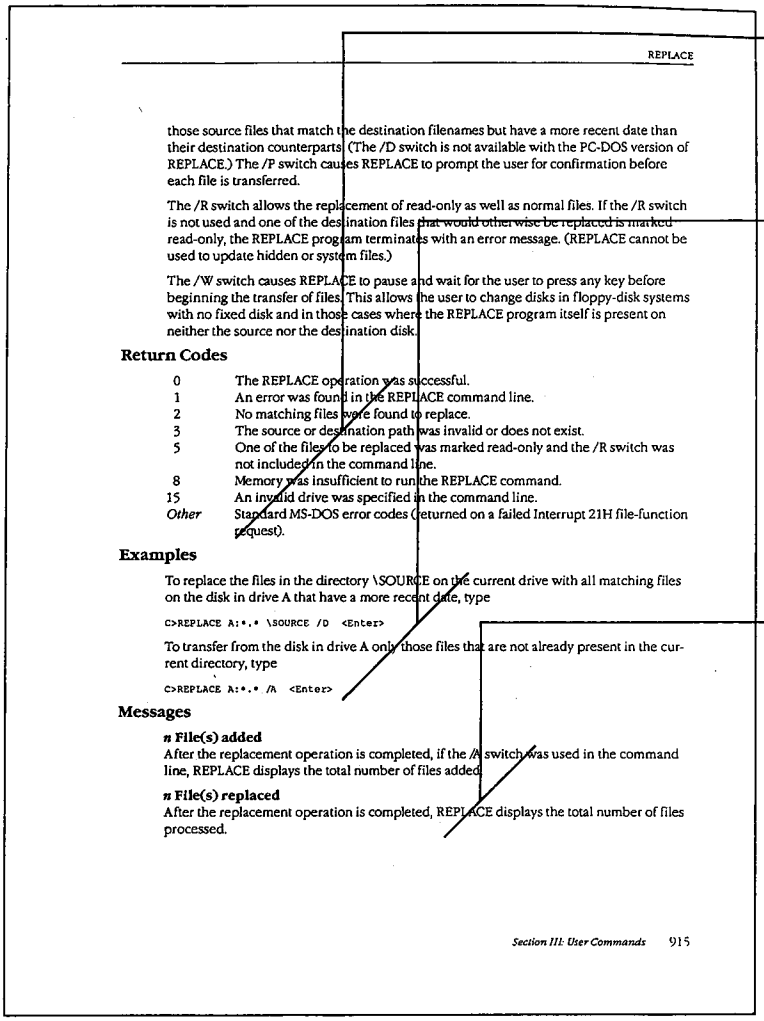
BELOW WHERE
A brief explanation of each command parameter and switch. Drives, paths, and filenames are always listed first, followed by the switches in alphabetic order. Any special position required for a filename or switch is shown in the syntax line and noted in the explanation.

DESCRIPTION
A detailed description of the command, including a full explanation of MS-DOS version dependencies, default values, possible interactions of command parameters and options, useful background information, and any applicable warnings.



REPLACE

those source files that match the destination filenames but have a more recent date than their destination counterparts. (The /D switch is not available with the PC-DOS version of REPLACE.) The /P switch causes REPLACE to prompt the user for confirmation before each file is transferred.

The /R switch allows the replacement of read-only as well as normal files. If the /R switch is not used and one of the destination files that would otherwise be replaced is marked read-only, the REPLACE program terminates with an error message. (REPLACE cannot be used to update hidden or system files.)

The /W switch causes REPLACE to pause and wait for the user to press any key before beginning the transfer of files. This allows the user to change disks in floppy-disk systems with no fixed disk and in those cases where the REPLACE program itself is present on neither the source nor the destination disk.

Return Codes

0	The REPLACE operation was successful.
1	An error was found in the REPLACE command line.
2	No matching files were found to replace.
3	The source or destination path was invalid or does not exist.
5	One of the files to be replaced was marked read-only and the /R switch was not included in the command line.
8	Memory was insufficient to run the REPLACE command.
15	An invalid drive was specified in the command line.
Other	Standard MS-DOS error codes (returned on a failed Interrupt 21H file-function request).

Examples

To replace the files in the directory \SOURCE on the current drive with all matching files on the disk in drive A that have a more recent date, type

```
C>REPLACE A:*.* \SOURCE /D  <Enter>
```

To transfer from the disk in drive A only those files that are not already present in the current directory, type

```
C>REPLACE A:*.* /A  <Enter>
```

Messages

***n* File(s) added**
After the replacement operation is completed, if the /A switch was used in the command line, REPLACE displays the total number of files added.

***n* File(s) replaced**
After the replacement operation is completed, REPLACE displays the total number of files processed.

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RETURN CODES
Exit codes returned by the command (if any) that can be tested in a batch file or by another program.

EXAMPLES
One or more examples of the command at work, including examples of the resulting output where appropriate. User entry appears in color; do not type the prompt, which appears in black. Press the Enter key (labeled Return on some keyboards) as directed at the end of each command line.

MESSAGES
An alphabetic list of messages that may be displayed when the command is used in MS-DOS version 3.2 (may vary slightly in earlier versions). Both messages generated by the command itself and applicable messages generated by MS-DOS are included. Following each message is a brief explanation of the condition that produces the message and, where appropriate, any action that should be taken.

Contents by Functional Group

The MS-DOS commands can be divided into several distinct groups according to the functions they perform. These are listed on the following pages.

Command	Action
System Configuration and Control	
BREAK	Set Control-C check.
COMMAND	Install secondary copy of command processor.
DATE	Set date.
EXIT	Terminate command processor.
PROMPT	Define system prompt.
SELECT	Configure system disk for a specific country.
SET	Set environment variable.
SHARE	Install file-sharing support.
TIME	Set system time.
VER	Display version.
Character-Device Management	
CLS	Clear screen.
CTTY	Assign standard input/output.
GRAFTABL	Load graphics character set.
GRAPHICS	Print graphics screen-dump program.
KEYB*xx*	Define keyboard.
MODE	Configure device.
PRINT	Print file (background print spooler).
File Management	
ATTRIB	Change file attributes.
BACKUP	Back up files.
COMP	Compare files.
COPY	Copy file or device.
DEL/ERASE	Delete file.
EDLIN	Create or modify text file (see also commands below).
FC	Compare files.
RECOVER	Recover files.
RENAME	Change filename.
REPLACE	Update files.
RESTORE	Restore backup files.
TYPE	Display file.
XCOPY	Copy files.

(more)

Command	Action
Filters	
FIND	Find string.
MORE	Display by screenful.
SORT	Sort file or character stream alphabetically.
Directory Management	
APPEND	Set data-file search path.
CHDIR	Change current directory.
DIR	Display directory.
MKDIR	Make directory.
PATH	Define command search path.
RMDIR	Remove directory.
TREE	Display directory structure.
Disk Management	
ASSIGN	Assign drive alias.
CHKDSK	Check disk status.
DISKCOMP	Compare floppy disks.
DISKCOPY	Copy floppy disks.
FORMAT	Initialize disk.
FDISK	Configure fixed disk.
JOIN	Join disk to directory.
LABEL	Display volume label.
SUBST	Substitute drive for subdirectory.
SYS	Transfer system files.
VERIFY	Set verify flag.
VOL	Display disk name.
Installable Device Drivers	
ANSI.SYS	ANSI console driver.
DRIVER.SYS	Configurable external-disk-drive driver.
RAMDRIVE.SYS	Virtual disk.
VDISK.SYS	Virtual disk.
System-Configuration File Directives	
BREAK	Configure Control-C checking.
BUFFERS	Configure internal disk buffers.
COUNTRY	Set country code.
DEVICE	Install device driver.
DRIVPARM	Set block-device parameters.
FCBS	Set maximum open files using File Control Blocks (FCBs).

(more)

Command	Action
System-Configuration File Directives *(continued)*	
FILES	Set maximum open files using handles.
LASTDRIVE	Set highest logical drive.
SHELL	Specify command processor.
STACKS	Configure internal stacks.
Batch-File Directives	
AUTOEXEC.BAT	System startup batch file.
ECHO	Display text.
FOR	Execute command on file set.
GOTO	Jump to label.
IF	Perform conditional execution.
PAUSE	Suspend batch-file execution.
REM	Include comment line.
SHIFT	Shift replaceable parameters.
EDLIN Commands	
linenumber	Edit line.
A	Append lines from disk.
C	Copy lines.
D	Delete lines.
E	End editing session.
I	Insert lines.
L	List lines.
M	Move lines.
P	Display in pages.
Q	Quit.
R	Replace text.
S	Search for text.
T	Transfer another file.
W	Write lines to disk.

ANSI.SYS

ANSI Console Driver

2.0 and later

External

Purpose

Allows the user to employ a subset of the American National Standards Institute (ANSI) standard escape sequences for control of the console.

Syntax

DEVICE=[*drive*:][*path*]ANSI.SYS

where:

drive:*path* is the drive and/or path to search for ANSI.SYS if it is not in the root directory of the startup disk.

Description

The ANSI.SYS file contains an installable character-device driver that supersedes the system's default driver for the console device (video display and keyboard). After ANSI.SYS is installed by means of a *DEVICE=ANSI.SYS* command in the CONFIG.SYS file of the disk used to start the system, programs can use a subset of the ANSI 3.64-1979 standard escape sequences to erase the display, set the display mode and attributes, and control the cursor in a hardware-independent fashion. (A supplementary set of escape sequences that are not part of the ANSI standard allows reprogramming of the keyboard.)

Programs that use ANSI.SYS for control of the screen can run on any MS-DOS machine without modification, regardless of its hardware configuration. However, most popular application programs for the IBM PC and compatibles circumvent ANSI.SYS and manipulate the video controller and its video buffer directly to achieve maximum performance.

The ANSI.SYS device driver detects ANSI escape sequences in a character stream and interprets them as commands to control the keyboard and display. An ANSI escape sequence is a sequence of ASCII characters, the first two of which must be the Escape character (1BH) and the left-bracket character (5BH). The characters following the Escape and left-bracket characters vary with the type of control function being performed; most consist of an alphanumeric code followed by a letter. In some cases this code is a single character; in others it is more than one character or a two-part string separated by a semicolon. Each ANSI escape sequence ends in a unique letter character that identifies the sequence; case is significant for these letters. The escape sequences supported by the ANSI.SYS driver are summarized in the tables on the following pages.

An escape sequence cannot be entered directly at the system prompt because each ANSI escape sequence must begin with an Escape character, and pressing the Esc key (or Alt-27 on the numeric keypad) causes MS-DOS to cancel the command line. There are three methods of executing ANSI escape sequences that do not require writing a program:

- Include the escape sequences in a PROMPT command.
- Enter the escape sequences into a word processor or text editor, save the file as an ASCII text file, and then execute the file by using the TYPE or COPY command (specifying CON as the destination for COPY) from the MS-DOS system prompt.
  (If the escape sequences are echoed on the screen when the file is executed, a *DEVICE=ANSI.SYS* command was not included in the CONFIG.SYS file when the system was turned on.)
- Place the escape sequences in a batch (.BAT) file as part of an ECHO command. When the batch file is executed, the sequences are sent to the console.

When escape sequences are entered using the PROMPT command, the Escape character is entered as $e. When escape sequences are entered using a word processor to create an ASCII text or batch file, the Escape character is usually entered by pressing the Esc key or by holding down the Alt key while typing 27 on the numeric keypad. (See the documentation provided with the word-processor for specific instructions.) In most cases, the escape character will appear in the word processor or text editor as a back-arrow character (←) or a caret–left bracket combination (^[).

Note: When the escape character is represented as ^[(as it is in EDLIN, for example), an additional left-bracket character must still be added to properly begin an ANSI escape sequence. Thus, the beginning of a valid ANSI escape sequence in EDLIN appears as ^[[.

The tables in this section use the abbreviation ESC to show where the ASCII escape character 27 (1BH) appears in the string.

Note: Case is significant for the terminal character in the string.

The following escape sequences control cursor movement:

Operation	Escape Sequence	Effect
Cursor Up	ESC[*number*A	Moves the cursor up *number* rows (1–24, default = 1). Has no effect if cursor is on the top row.
Cursor Down	ESC[*number*B	Moves the cursor down *number* rows (1–24, default = 1). Has no effect if cursor is on the bottom row.
Cursor Right	ESC[*number*C	Moves the cursor right *number* rows (1–79, default = 1). Has no effect if cursor is in the far right column.
Cursor Left	ESC[*number*D	Moves the cursor left *number* rows (1–79, default = 1). Has no effect if cursor is in the far left column.
Position Cursor	ESC[*row*;*column*H	Moves the cursor to the specified row (1–25, default = 1) and column (1–80, default = 1). If *row* is omitted, the semicolon before *column* must be specified.

(more)

Operation	Escape Sequence	Effect
Position Cursor	ESC[*row*;*column*f	Same as above.
Save Cursor Position	ESC[s	Stores the current row and column position of the cursor. Cursor can be restored to this position later with a Restore Cursor Position escape sequence.
Restore Cursor Position	ESC[u	Moves the cursor to the position of the most recent Save Cursor Position escape sequence.

The following two escape sequences are used to erase all or part of the display:

Operation	Escape Sequence	Effect
Erase Display	ESC[2J	Clears the screen and places the cursor at the home position.
Erase Line	ESC[K	Erases from the cursor position to the end of the same row.

The following escape sequences control the width and the color capability of the display. The use of any of these sequences clears the screen.

Operation	Escape Sequence	Effect
Set Mode	ESC[=0h	Sets display to 40 x 25 monochrome (text).
	ESC[=1h	Sets display to 40 x 25 color (text).
	ESC[=2h	Sets display to 80 x 25 monochrome (text).
	ESC[=3h	Sets display to 80 x 25 color (text).
	ESC[=4h	Sets display to 320 x 200 4-color (graphics).
	ESC[=5h	Sets display to 320 x 200 4-color (graphics, color burst disabled).
	ESC[=6h	Sets display to 640 x 200 2-color (graphics).

The following escape sequences control whether characters will wrap around to the first column of the next row after the rightmost column in the current row has been filled:

Operation	Escape Sequence	Effect
Enable Character Wrap	ESC[=7h	Sets character wrap.
Disable Character Wrap	ESC[=7l	Disables character wrap. (Note that the terminating letter is a lowercase L.)

The following escape sequence controls specific graphics attributes such as intensity, blinking, superscript, and subscript, as well as the foreground and background colors:

ESC[*attrib*;...;*attrib*m

where:

attrib is one or more of the following values. Multiple values must be separated by semicolons.

Value	Attribute	Value	Foreground Color	Value	Background Color
0	All attributes off	30	Black	40	Black
1	High intensity (bold)	31	Red	41	Red
2	Normal intensity	32	Green	42	Green
4	Underline (monochrome only)	33	Yellow	43	Yellow
5	Blink	34	Blue	44	Blue
7	Reverse video	35	Magenta	45	Magenta
8	Concealed (invisible)	36	Cyan	46	Cyan
		37	White	47	White

Note: Values 30 through 47 meet the ISO 6429 standard.

The following escape sequence allows redefinition of keyboard keys to a specified *string*:

ESC[*code*;*string*;...p

where:

code is one or more of the following values that represent keyboard keys. Semicolons shown in this table must be entered in addition to the required semicolons in the command line.

string is either the ASCII code for a single character or a string contained in quotation marks. For example, both 65 and "A" can be used to represent an uppercase A.

Key	Code			
	Alone	Shift-	Ctrl-	Alt-
F1	0;59	0;84	0;94	0;104
F2	0;60	0;85	0;95	0;105
F3	0;61	0;86	0;96	0;106
F4	0;62	0;87	0;97	0;107
F5	0;63	0;88	0;98	0;108
F6	0;64	0;89	0;99	0;109

(more)

Key	Code			
	Alone	**Shift-**	**Ctrl-**	**Alt-**
F7	0;65	0;90	0;100	0;110
F8	0;66	0;91	0;101	0;111
F9	0;67	0;92	0;102	0;112
F10	0;68	0;93	0;103	0;113
Home	0;71	55	0;119	–
Up Arrow	0;72	56	–	–
Pg Up	0;73	57	0;132	–
Left Arrow	0;75	52	0;115	–
Down Arrow	0;77	54	0;116	–
End	0;79	49	0;117	–
Down Arrow	0;80	50	–	–
Pg Dn	0;81	51	0;118	–
Ins	0;82	48	–	–
Del	0;83	46	–	–
PrtSc	–	–	0;114	–
A	97	65	1	0;30
B	98	66	2	0;48
C	99	67	3	0;46
D	100	68	4	0;32
E	101	69	5	0;18
F	102	70	6	0;33
G	103	71	7	0;34
H	104	72	8	0;35
I	105	73	9	0;23
J	106	74	10	0;36
K	107	75	11	0;37
L	108	76	12	0;38
M	109	77	13	0;50
N	110	78	14	0;49
O	111	79	15	0;24
P	112	80	16	0;25
Q	113	81	17	0;16
R	114	82	18	0;19
S	115	83	19	0;31
T	116	84	20	0;20
U	117	85	21	0;22
V	118	86	22	0;47
W	119	87	23	0;17
X	120	88	24	0;45

(more)

Key	Code			
	Alone	**Shift-**	**Ctrl-**	**Alt-**
Y	121	89	25	0;21
Z	122	90	26	0;44
1	49	33	–	0;120
2	50	64	–	0;121
3	51	35	–	0;122
4	52	36	–	0;123
5	53	37	–	0;124
6	54	94	–	0;125
7	55	38	–	0;126
8	56	42	–	0;127
9	57	40	–	0;128
0	48	41	–	0;129
–	45	95	–	0;130
=	61	43	–	0;131
Tab	9	0;15	–	–
Null	0;3	–	–	–

Examples

The following examples use ESC or $e to show where the ASCII escape character 27 (1BH) appears in the string. The PROMPT examples can be typed as shown, but for the examples that use ESC to denote the escape character, the actual escape character should be typed in its place.

To move the cursor to row 10, column 30 and display the string *Main Menu*, use the escape sequence

```
ESC[10;30fMain Menu
```

or

```
ESC[10;30HMain Menu
```

To move the cursor to row 5, column 10 and display the letter A (*ESC[5;10fA*), move the cursor down one row (*ESC[B*), move the cursor back one space and display the letter B (*ESC[DB*), move the cursor down one row (*ESC[B*), and move the cursor back one space and display the letter C (*ESC[DC*), use the escape sequence

```
ESC[5;10fAESC[BESC[DBESC[BESC[DC
```

To use ANSI escape sequences with the PROMPT command to save the current cursor position (*$e[s*), move the cursor to row 1, column 69 (*$e[1;69f*), display the current time using the PROMPT command's $t function, restore the cursor position (*$e[u*), and then

display the current path using the PROMPT command's $p function and display a greater-than sign using the PROMPT command's $g function, use the escape sequence

```
C>PROMPT $e[s$e[1;69f$t$e[u$p$g  <Enter>
```

To erase the display (*ESC[2J*), then move the cursor to row 10, column 30 and display the string *Main Menu* (*ESC[10;30fMain Menu*), use the escape sequence

```
ESC[2JESC[10;30fMain Menu
```

To move the cursor to row 5, column 40 (*ESC[5;40f*) and erase the remainder of the row starting at the current cursor position (*ESC[K*), use the escape sequence

```
ESC[5;40fESC[K
```

To move the cursor to row 3 (*ESC[3;f*), erase the entire row (*ESC[K*), move the cursor down one row (*ESC[B*), erase that entire row (*ESC[K*), move the cursor down one row and erase that entire row, use the escape sequence

```
ESC[3;fESC[KESC[BESC[KESC[BESC[K
```

To set the display mode to 25 rows of 80 columns in color (*ESC[=3h*) and disable character wrap (*ESC[=7l*), use the escape sequence

```
ESC[=3hESC[=7l
```

Note that ESC[=3h will also clear the screen.

To enable character wrap, use the escape sequence

```
ESC[=7h
```

To set the foreground color to black and the background color to blue (*ESC[30;44m*), clear the display (*ESC[2J*), then position the cursor at row 10, column 30 and display the string *Main Menu* (*ESC[10;30fMain Menu*), use the escape sequence

```
ESC[30;44mESC[2JESC[10;30fMain Menu
```

To (effectively) exchange the backslash and question-mark keys using literal strings to denote the keys, use the escape sequence

```
ESC["\";"?"pESC["?";"\"p
```

To exchange the backslash and question-mark keys using each key's ASCII value to denote the key, use the escape sequence

```
ESC[92;63pESC[63;92p
```

To restore the backslash and question-mark keys to their original meanings, use the escape sequence

```
ESC["\";"\"pESC["?";"?"p
```

or

```
ESC[92;92pESC[63;63p
```

To redefine the Alt-F9 key combination (*ESC[0;112*) so that it issues a CLS command (*;"CLS"*) plus a carriage return (*;13*) to execute the CLS command, then issues a DIR command piped through the SORT filter starting at column 24 (*;"DIR | SORT /+24"*) followed by another carriage return, use the escape sequence

```
ESC[0;112;"CLS";13;"DIR | SORT /+24";13p
```

To restore the Alt-F9 key combination to its original meaning, use the escape sequence

```
ESC[0;112;0;112p
```

APPEND

Set Data-File Search Path

3.2

External

Purpose

Specifies a search path for open operations on data files. (Also supported with some implementations of version 3.1, for use with networks.)

Syntax

APPEND [[*drive*:]*path*] [;[*drive*:]*path* ...]

or

APPEND ;

where:

path is the name of a valid directory, optionally preceded by a drive.

Description

APPEND is a terminate-and-stay-resident program that is used to specify a path or paths to be searched for data files (in contrast with the PATH command, which specifies a path to be searched for executable or batch files). The search path can include a network drive. If a program attempts to open a file and the file is not found in the current or specified directory, each path given in the APPEND command is searched.

If the APPEND command is entered with a path consisting of only a semicolon character (;), a "null" search path for data files is set; that is, no directory other than the current or specified directory is searched. This effectively cancels any search paths previously set with an APPEND command but does not free the memory used by APPEND.

An APPEND command without any parameters displays the current search path(s) for data files.

Note that a program cannot detect whether an opened file was found where it was expected (in the current or specified directory) or in some other directory specified in the APPEND command.

Warning: When an assigned drive is to be part of the search path, the ASSIGN command must be used before the APPEND command. Use of the ASSIGN command should be avoided whenever possible because it hides drive characteristics from those programs that require detailed knowledge of the drive size and format.

Examples

To cause the directories C:\SYSTEM and C:\SOURCE to be searched for a file during an open operation if the file is not found in the current or specified directory, type

```
C>APPEND C:\SYSTEM;C:\SOURCE  <Enter>
```

To display the current search path for data files, type

```
C>APPEND  <Enter>
```

MS-DOS then displays

```
APPEND=C:\SYSTEM;C:\SOURCE
```

To ensure that no directories other than the current or specified directory are searched during a file open operation, type

```
C>APPEND ;  <Enter>
```

Messages

APPEND / ASSIGN Conflict
APPEND was used before ASSIGN.

Incorrect DOS version
The version of APPEND is not compatible with the version of MS-DOS that is running.

No appended directories
The APPEND command had no parameters and no APPEND search path is active.

ASSIGN

Assign Drive Alias

3.0 and later

External

Purpose

Redirects requests for disk operations on one drive to a different drive. (Available with PC-DOS beginning with version 2.0.)

Syntax

ASSIGN [*x*=*y* [...]]

where:

x	is a valid designator (A, B, C, etc.) for a disk drive that physically exists in the system.
y	is a valid designator for the drive to be accessed by references to *x*.

Description

ASSIGN is a terminate-and-stay-resident program that redirects all references to drive *x* or files on drive *x* to drive *y*. The ASSIGN command is intended for use with application programs that require files to reside on drive A or B and have no provision within the program for changing those drives.

Multiple drive assignments can be requested in the same ASSIGN command line; the drive pairs must be separated with spaces, commas, or semicolons. Unlike the form in most other MS-DOS commands, the drive letters are not followed by colon characters (:). When a single drive is assigned, the equal sign is optional.

ASSIGN commands are not incremental. Each new ASSIGN command replaces assignments made with the previous ASSIGN command and cancels any assignments not specifically replaced. Entering ASSIGN with no parameters cancels all current drive assignments.

Warning: Use of the ASSIGN command should be avoided whenever possible because it hides drive characteristics from those programs that require detailed knowledge of the drive size and format; in particular, drives redirected with an ASSIGN statement should never be used with a BACKUP, RESTORE, LABEL, JOIN, SUBST, or PRINT command. ASSIGN can also defeat the checking performed by the COPY command to prevent a file from being copied onto itself. The FORMAT, SYS, DISKCOPY, and DISKCOMP commands ignore any drive reassignments made with ASSIGN.

With MS-DOS versions 3.1 and later, the SUBST command should be used instead of ASSIGN. For example, the command

```
C>ASSIGN A=C  <Enter>
```

should be replaced with the command

```
C>SUBST A: C:\  <Enter>
```

Examples

To redirect all requests for drive A to drive C, type

```
C>ASSIGN A=C  <Enter>
```

To redirect all requests for drives A and B to drive C, type

```
C>ASSIGN A=C B=C  <Enter>
```

To cancel all drive redirections currently in effect, type

```
C>ASSIGN  <Enter>
```

Messages

Incorrect DOS version
The version of ASSIGN is not compatible with the version of MS-DOS that is running.

Invalid parameter
One of the specified drive designators refers to a drive that does not exist in the system.

ATTRIB

Change File Attributes

3.0 and later

External

Purpose

Sets, removes, or displays a file's read-only and/or archive attributes.

Syntax

ATTRIB [+R¦–R] [+A ¦–A] [*drive*:]*pathname*

where:

+R	marks the file read-only.
–R	removes the read-only attribute.
+A	sets the file's archive flag (version 3.2).
–A	removes the file's archive flag (version 3.2).
pathname	is the name and location, optionally preceded by a drive, of the file whose attributes are to be changed or displayed; wildcard characters are permitted in the filename.

Description

Each file has an entry in the disk's directory that contains its name, location, and size; the date and time it was created or last modified; and an attribute byte. For normal files, bits 0, 1, 2, and 5 in the attribute byte designate, respectively, whether the file is read-only, hidden, or system and whether it has been changed since it was last backed up.

The ATTRIB command provides a way to alter the read-only and archive bits from the MS-DOS command level. If a file is marked read-only, it cannot be deleted or modified; thus, crucial programs or data can be protected from accidental erasure. A file's archive flag can be used together with the /M switch of the BACKUP command or the /M or /A switch of the XCOPY command to allow an incremental or selective backup of files from one disk to another.

If the ATTRIB command is entered with only a pathname, the current attributes of the selected file are displayed. An R is displayed next to the name of a file that is marked read-only and an A is displayed if the file has the archive flag set.

Examples

To make the file MENUMGR.C in the current directory of the current drive a read-only file, type

```
C>ATTRIB +R MENUMGR.C  <Enter>
```

To display the attributes of the file LETTER.DOC in the directory \SOURCE on the disk in drive D, type

```
C>ATTRIB D:\SOURCE\LETTER.DOC  <Enter>
```

MS-DOS then displays

```
R A      D:\SOURCE\LETTER.DOC
```

to indicate that the file is marked read-only and the archive flag has been set.

To set the archive flag on all files in the directory \SYSTEM on drive C and mark them as read-only, type

```
C>ATTRIB +A +R C:\SYSTEM\*.*  <Enter>
```

Messages

Access denied
ATTRIB cannot be used to alter or replace the attributes of a file in use across a network.

DOS 2.0 or later required
ATTRIB does not work with versions of MS-DOS earlier than 2.0.

Incorrect DOS version
The version of ATTRIB is not compatible with the version of MS-DOS that is running.

Invalid number of parameters
More than two attributes were used before the pathname.

Invalid path or file not found
The file named in the command line or one of the directories in the given path does not exist.

Syntax error
An invalid attribute was supplied or the attribute was not properly placed before the pathname in the command line.

BACKUP

Back Up Files

2.0 and later

External

Purpose

Creates backup copies of files, along with the associated directory information necessary to restore the files to their original locations.

Syntax

BACKUP *source destination* [/A] [/D:*date*] [/L:*filename*] [/M] [/P] [/S] [/T:*time*]

where:

source	is the location (drive and/or path) and, optionally, the name of the files to be backed up; wildcard characters are permitted in the filename.
destination	is the drive to receive the backup files.
/A	adds the files to existing files on the destination disk without erasing the destination disk.
/D:*date*	backs up only those files modified on or after *date*.
/L:*filename*	creates a log file with the specified name in the root directory of the disk being backed up. If *filename* is not specified, BACKUP creates a file named BACKUP.LOG and places the log entries there. Use of the /L:*filename* switch may cause loss of IBM compatibility.
/M	backs up only those files modified since the last backup.
/P	packs the destination disk with as many files as possible, creating subdirectories, if necessary, to hold some of the files. Use of the /P switch causes loss of IBM compatibility.
/S	backs up the contents of all subdirectories of the source directory.
/T:*time*	backs up only those files modified on or after *time*.

Note: Not all switches are supported by all implementations of MS-DOS.

Description

The BACKUP command creates a backup copy of the specified file or files, transferring them from either a floppy disk or a fixed disk to another removable or fixed disk. The backup file is in a special format that includes information about the original file's location in the directory structure. Files created by BACKUP can be restored to their original form only with the RESTORE command.

BACKUP can back up a single file or many files in the same operation. If only a drive letter is given as the source, all the files in the current directory of that disk are backed up. If only a path is given as the source, all the files in the specified directory are backed up. If the /S switch is used, all the files in the current or specified directory are backed up, and

the files in all its subdirectories as well. If both a path and a filename are entered as the source, the specified file or files in the named directory are backed up.

If the source file is marked read-only, the resulting backup file will also be marked read-only. If the source file's archive bit is set, it will be cleared for both the source and the destination files. BACKUP also backs up hidden files; the files will remain hidden on the destination disk.

If the destination disk is a floppy disk, its previous contents are erased as part of the backup operation (unless the /A switch is included in the command line and the destination disk has already been used as a backup disk—that is, the disk contains a valid BACKUPID.@@@ file). If the files being backed up do not fit onto a single floppy disk, the user will be prompted to insert additional disks until the backup operation is complete.

If the destination disk is a fixed disk, the backed-up files are placed in a directory named \BACKUP. If a \BACKUP directory already exists on the fixed disk, any files previously contained in it are erased as part of the backup operation (unless the /A switch is included in the command line and the destination disk has already been used as a backup disk—that is, the \BACKUP directory contains a valid BACKUPID.@@@ file). Other files on the destination fixed disk are not disturbed.

A control file named BACKUPID.@@@ is placed on every floppy disk onto which files are backed up or in the /BACKUP directory if the files are backed up onto a fixed disk. The BACKUPID.@@@ file has the following format:

Byte	Value	Use
00H	00 or FFH	Not last floppy disk/last floppy disk
01–02H	*nn*	Floppy disk number in low-byte/high-byte decimal format
03–04H	*nnnn*	Full year in low-byte/high-byte order
05H	1–31	Day of the month
06H	1–12	Month of the year
07–0AH	*nnnn*	Standard MS-DOS system time if the /T:*time* switch was used; otherwise 0
0B–7FH	00	Not used

Each backed-up file also has a 128-byte header added to it when it is created. The header has the following format:

Byte	Value	Use
00H	00 or FFH	Not last floppy disk/last floppy disk on which this file resides
01H	*nn*	Floppy disk number
02–04H	00	Not used

(more)

Byte	Value	Use
05–44H	*nn*	File's full pathname, except for drive designator
45–52H	00	Not used
53H	*nn*	Length of the file's pathname plus one
54–7FH	00	Not used

The /T:*time*, /D:*date*, and /M switches allow incremental or partial backups. The /T:*time* switch excludes files modified or created before a certain time and should be used in the form of the COUNTRY command in effect. For the USA, the format is /T:*hh:mm:ss*. (The /T:*time* switch is not supported in all implementations of BACKUP.) The /D:*date* switch excludes files modified or created before a certain date and should be used in the form of the COUNTRY command in effect. For the USA, the format is /D:*mm-dd-yy*. The /M switch selects only those files that have been modified since the last backup operation.

The /L:*filename* switch causes a log file to be created on the source disk. This file includes the name of each file backed up, the time and date, and the number of the destination disk that received that backup file. If *filename* is omitted, the name defaults to BACKUP.LOG. Use of the /L:*filename* switch can cause compatibility problems between MS-DOS and PC-DOS because the backup log file may match the search pattern and be backed up, too, resulting in an extra file on the backup disk.

The /P switch causes backup files to be packed as densely as possible on the destination disk. When many short files are being backed up to floppy disks, the number of files that fit on the destination disk may exceed the number of entries that will fit in the destination's root directory. If the /P switch is included in the command line, subdirectories are created on the destination disk as needed to use the disk space more effectively. The /P switch is not supported under PC-DOS; backup disks created with the /P switch will not be compatible with IBM's BACKUP and RESTORE commands.

Warning: BACKUP should not be used on disk directories or drives that have been redirected with an ASSIGN, JOIN, or SUBST command.

Return Codes

0 Backup operation was successful.
1 No files were found to back up.
2 Some files were not backed up because of sharing conflicts (versions 3.0 and later).
3 Backup operation was terminated by user.
4 Backup operation was terminated because of error.

Examples

To back up the file REPORT.TXT in the current directory on the current drive, placing the backup file on the disk in drive A, type

```
C>BACKUP REPORT.TXT A:  <Enter>
```

To back up all the files in the subdirectory B:\V2\SOURCE, placing the backup files on the disk in drive A, type

```
C>BACKUP B:\V2\SOURCE A:  <Enter>
```

To back up all the files with extension .C in the directory \V2\SOURCE on the current drive, placing the backup files on the disk in drive A, type

```
C>BACKUP \V2\SOURCE\*.C A:  <Enter>
```

To back up all the files with the extension .ASM from the current directory on the current drive and from all its subdirectories, placing the backup files on the disk in drive A, type

```
C>BACKUP *.ASM A: /S  <Enter>
```

To back up all the files that have been modified since the last backup from all the subdirectories on drive C, placing the backup files on the disk in drive A, type

```
C>BACKUP C:\ A: /S /M  <Enter>
```

To back up all the files with the extension .C from the directory C:\V2\SOURCE that were modified on or after October 16, 1985, placing the backup files on the disk in drive A, type

```
C>BACKUP C:\V2\SOURCE\*.C A: /D:10-16-85  <Enter>
```

Messages

*****Backing up files to drive *X*: *****
Diskette Number: *n*
This informational message informs the user of the progress of the BACKUP command.

*****Last file not backed up *****
The destination drive does not have enough space to back up the last file.

*****Not able to back up file *****
One of the system calls used by BACKUP failed unexpectedly; for example, a file could not be opened, read, or written.

Cannot create Subdirectory BACKUP on drive *X*:
Drive *X* is full or its root directory is full.

DOS 2.0 or later required
BACKUP does not work with versions of MS-DOS earlier than 2.0.

Error trying to open backup log file
Continuing without making log entries
The /L switch was used and BACKUP is unable to create the backup log file.

Files cannot be added to this diskette
unless the PACK (/P) switch is used
Set the switch (Y/N)?
The root directory of the destination disk is full and a subdirectory must be created to hold the remaining files. Respond with *Y* to cause BACKUP to create a subdirectory and continue backing up files into it; respond with *N* to return to MS-DOS.

Incorrect DOS version
The version of BACKUP is not compatible with the version of MS-DOS that is running.

Insert backup diskette in drive *X*:
Strike any key when ready
This message prompts the user to insert a disk to receive the backup files into the specified destination drive.

Insert backup diskette *n* in drive *X*:
Strike any key when ready
The files being backed up will not fit onto a single floppy disk; this message prompts the user to insert the next floppy disk. Multiple-floppy-disk backup disks should be labeled and numbered to match the number displayed in this message.

Insert backup source diskette in drive *X*:
Strike any key when ready
This message prompts the user to insert the floppy disk to be backed up into the specified source drive.

Insert last backup diskette in drive *X*:
Strike any key when ready
This message prompts the user to insert the final disk that will receive the backup files into the specified destination drive.

Insufficient memory
Available system memory is insufficient to run the BACKUP program.

Invalid argument
One of the switches specified in the command line is invalid or is not supported in the version of BACKUP being used.

Invalid Date/Time
An invalid date or time was given with the /D:*date* or /T:*time* switch.

Invalid drive specification
The source or destination drive specified in the command line is not available or is not valid.

Invalid number of parameters
At least two parameters, the source and the destination, must be specified in the command line; a maximum of seven switches can be specified after the source and destination.

Invalid parameter
One of the switches supplied in the command line is invalid.

Invalid path
The path specified as the source is invalid or does not exist.

Last backup diskette not inserted
Insert last backup diskette in drive *X*:
Strike any key when ready
The backup disk inserted as the last backup disk was not the correct disk. Insert the correct disk.

No space left on device
The destination disk is full.

No such file or directory
The source specified is invalid or does not exist.

Source and target drives are the same
The disks specified as the source and destination disks are identical.

Source disk is Non-removable
The disk containing the files to be backed up is a fixed disk.

Target can not be used for backup
The disk specified as the destination disk is damaged or the /A switch was used in the command line and the disk does not contain a valid BACKUPID.@@@ file.

Target disk is Non-removable
The disk that will contain the backed-up files is a fixed disk.

Target is a floppy disk

or

Target is a hard disk
This informational message indicates which type of disk was specified as the destination disk.

Too many open files
Too many files are open. Increase the value of the FILES command in the CONFIG.SYS file.

Unable to erase *filename*
BACKUP is unable to erase an older version of a backed-up file because the file is read-only or is in use by another program.

Warning! Files in the target drive
***X*:\root directory will be erased**
Strike any key when ready
The destination is a floppy-disk drive and this message warns the user that all files in its root directory will be erased before the backup operation.

Warning! Files in the target drive
C:\BACKUP directory will be erased
Strike any key when ready
BACKUP is ready to begin backing up files to the \BACKUP directory on drive C. All existing files in the \BACKUP directory will be deleted. Press Crtl-Break to terminate the backup operation or press any key to continue.

Warning! No files were found to back up
No files were found on the source disk in the current or specified directory or no files were found matching the filename supplied.

BATCH

1.0 and later

System Batch-File Interpreter

Internal

Purpose

Sequentially executes commands stored in a batch file (a text-only file with a .BAT extension).

Syntax

filename [[*parameter1* [*parameter2* [...]]]]

where:

filename	is the name of the batch file to be executed, without the .BAT extension. (The filename is always %0 in the list of replaceable parameters.)
parameter1	is the filename, switch, or string that is the value of the first replaceable parameter (%1).
parameter2	is the filename, switch, or string that is the value of the second replaceable parameter (%2). As many additional replaceable parameters can be specified as the command line will hold.

Description

A batch file is an ASCII text file that contains one or more MS-DOS commands. It is a useful way to perform sequences of frequently used commands without having to type them all each time they are needed. When a batch file is invoked by entering its name, the commands it contains are carried out in sequence by a special batch-file interpreter built into COMMAND.COM. Additional information entered in the batch-file command line can be passed to other programs by means of replaceable parameters (*see below*).

A batch file must always have the extension .BAT. The file can contain any number of lines of ASCII text; each line can contain a maximum of 128 characters. Batch files can be created with EDLIN or another text editor or with a word processor in nondocument mode. (Formatted document files cannot be used as batch files because they contain special control codes or escape sequences that cannot be processed by the batch-file interpreter.) Batch files can also be created with the MS-DOS COPY command by specifying the CON device (keyboard) as the source file and the desired batch-file name as the destination file. For example, after the command

```
C>COPY CON MYFILE.BAT  <Enter>
```

each line that is typed will be placed into MYFILE.BAT. This form of the COPY command is terminated by pressing Ctrl-Z or the F6 key, followed by the Enter key.

The commands in a batch file can be any combination of internal MS-DOS commands (such as DIR or COPY), external MS-DOS commands (such as CHKDSK or BACKUP), the names of other programs or batch files, or the following special batch-file directives:

Command	Action
ECHO	Displays a message on standard output (versions 2.0 and later).
FOR	Executes a command on each of a set of files (versions 2.0 and later).
GOTO	Transfers control to another point in a batch file (versions 2.0 and later).
IF	Conditionally executes a command based on the existence of a file, the equality of two strings, or the return code of a previously run program (versions 2.0 and later).
PAUSE	Waits for the user to press a key before executing the remainder of the batch file.
REM	Allows comment lines to be placed in batch files for internal documentation.
SHIFT	Provides access to more than 10 command-line parameters (versions 2.0 and later).

These special batch commands are discussed individually, with examples, in the following pages.

A batch file is executed by entering its name, without the .BAT extension, in response to the MS-DOS prompt. The system's command processor, COMMAND.COM, searches the current directory and then each directory named in the PATH environment variable for a file with the specified name and the extension .COM, .EXE, or .BAT, in that order. If a .COM or .EXE file is found, it is loaded into memory and receives control; if a .BAT file is found, it is assumed to be a text file and is passed to the batch-file interpreter. (If two files with the same name exist in the same directory, one with a .COM or .EXE extension and the other with a .BAT extension, it is not possible to execute the .BAT file—the .COM or .EXE file is always loaded instead.)

If the disk that contains a batch file is removed before all the commands in the batch file are executed, COMMAND.COM will prompt the user to replace the disk so that the batch file can be completed. Execution of a batch file can be terminated by pressing Ctrl-C or Ctrl-Break, causing COMMAND.COM to issue the message *Terminate batch job? (Y/N)*. If the user responds with *Y*, the batch file is abandoned and COMMAND.COM displays its usual prompt.

The input redirection (<), output redirection (> or >>), and piping (¦) characters have no effect when they are used in a command line that invokes a batch file. However, they can be used in individual command lines *within* the file.

Ordinarily, if a batch file includes the name of another batch file, control passes to the second batch file and never returns. That is, when the commands in the second batch file are completed, the batch-file interpreter terminates and any remaining commands in the first

batch file are not processed. However, a batch file can execute another batch file without itself being terminated by first loading a secondary copy of the system's command processor. To accomplish this, the first batch file must contain a command of the form

COMMAND /C *batch2*

where *batch2* is the name of the second batch file. When all the commands in the second batch file have been processed, the secondary copy of COMMAND.COM exits and the first batch file continues where it left off. (*See* USER COMMANDS: COMMAND for details on the use of the /C switch with COMMAND.COM.)

A batch file can be made more flexible by including replaceable parameters inside the file. A replaceable parameter takes the form *%n*, where *n* is a numeral in the range 0 through 9. Replaceable parameters simply hold places in the batch file for filenames or other information that the user will supply in the command line when the batch file is invoked.

When a batch file is interpreted and a command containing a replaceable parameter is encountered, the corresponding value specified in the batch-file command line is substituted for the replaceable parameter and the command is then executed. The %0 replaceable parameter is replaced by the name of the batch file itself; parameters %1 through %9 are replaced sequentially with the remaining values specified in the command line. If a replaceable parameter references a command-line entry that does not exist, the parameter is replaced with a null (zero-length) string.

For example, if the batch file MYBATCH.BAT contains the single line

```
COPY %1.COM %2.SAV
```

and is executed by entry of

```
C>MYBATCH FILE1 FILE2  <Enter>
```

the actual command that is carried out is

```
COPY FILE1.COM FILE2.SAV
```

(The SHIFT batch command makes it possible to use more than 10 replaceable parameters. *See* USER COMMANDS: BATCH:SHIFT)

An environment variable is a special case of a replaceable parameter. If the SET command is used in the form

SET *name=value*

to add an environment variable to the system's environment block, the string *value* will be substituted for the string *%name%* wherever the latter is encountered during the interpretation of a batch file. This capability is available only in versions 2.x, 3.1, and 3.2.

BATCH: AUTOEXEC.BAT

1.0 and later

System Startup Batch File

Description

The AUTOEXEC.BAT file is an optional batch file containing a series of MS-DOS commands that automatically execute when the system is turned on or restarted.

When the system's default command processor, COMMAND.COM, is first loaded, it looks in the root directory of the current drive for a file named AUTOEXEC.BAT. If AUTOEXEC.BAT is not found, COMMAND.COM prompts the user to enter the current time and date and then displays the MS-DOS copyright notice and command prompt. If AUTOEXEC.BAT is found, COMMAND.COM sequentially executes the commands within the file. No prompts to enter the time and date are issued unless the TIME and DATE commands are explicitly included in the batch file; no copyright notice is displayed.

Typical uses of the AUTOEXEC.BAT file include

- Running a program to set the system time and date from a real-time clock/calendar located on a multipurpose expansion board (IBM PC, PC/XT, or compatibles only)
- Using the MODE command to configure a serial port or to redirect printing
- Executing SET commands to configure environment variables
- Setting display colors on a color monitor (if the command *DEVICE=ANSI.SYS* has been included in the CONFIG.SYS file)
- Installing terminate-and-stay-resident (TSR) utilities
- Using the PATH command to tell COMMAND.COM where to find executable program files if they are not in the current drive and/or directory
- Defining a custom prompt using the PROMPT command
- Invoking an application program such as a database, spreadsheet, or word processor

A secondary copy of the command processor can also be loaded from within the AUTOEXEC.BAT file. If this copy of COMMAND.COM is loaded with the /P switch, it too searches for an AUTOEXEC.BAT file on the current drive and processes the file if it is found. This feature can be useful for performing special operations. For example, on very old PCs that are unable to start from a fixed disk, a secondary copy of the command processor can be used to make the fixed disk's copy of COMMAND.COM the copy used by the system from that point on (at the expense of some system memory). If the AUTOEXEC.BAT file containing the lines

```
C:
COMMAND C:\ /P
```

is stored on the floppy disk in drive A when the system is turned on or restarted, the first line of the file causes drive C to become the current drive; then the second line

permanently loads a secondary copy of COMMAND.COM from drive C and instructs COMMAND.COM to reload its transient portion from the root directory of drive C when necessary. This in turn triggers the execution of the AUTOEXEC.BAT file on the fixed disk to perform the actual system configuration. Because the transient part of COMMAND.COM will be reloaded from the fixed disk when necessary, rather than from the floppy disk, system performance is improved considerably.

Example

The following example illustrates several common uses of the AUTOEXEC.BAT file to configure the MS-DOS system at startup time. (The line numbers are included for reference and are not part of the actual file.)

```
1    ECHO OFF
2    SETCLOCK
3    PROMPT $p$g
4    MD D:\BIN
5    COPY C:\SYSTEM\*.* D:\BIN > NUL
6    PATH=D:\BIN;C:\WP\WORD;C:\MSC\BIN;C:\ASM
7    APPEND D:\BIN;C:\WP\WORD;C:\ASM
8    SET INCLUDE=C:\MSC\INCLUDE
9    SET LIB=C:\MSC\LIB
10   SET TMP=C:\TEMP
11   MODE COM1:9600,n,8,1,p
12   MODE LPT1:=COM1:
```

Line 1 causes the batch-file processor to operate silently; that is, the commands in the batch file are not displayed on the screen as they are executed.

Line 2 runs a utility program called SETCLOCK, which reads the current time and date from a real-time clock chip on a multifunction board and sets the system time and date accordingly.

Line 3 configures COMMAND.COM's user prompt so that it displays the current drive and directory.

Line 4 creates a directory named \BIN on drive D, which in this case is a RAMdisk that was created by an entry in the system's CONFIG.SYS file.

Line 5 copies all the programs in the \SYSTEM directory on drive C to the \BIN directory on drive D. The normal output of this COPY command is redirected to the NUL device—in effect, the output is thrown away—to avoid cluttering the screen.

Line 6 sets the search path for executable files and line 7 sets the search path for data files. Note that the RAMdisk directory D:\BIN is specified as the first directory in the PATH command; therefore, if the name of a program is entered and it cannot be found in the current directory, COMMAND.COM will look next in the directory D:\BIN. This strategy allows commonly used programs (in this example, the programs in the \SYSTEM directory that were copied into D:\BIN) to be located and loaded quickly.

Lines 8 through 10 add the environment variables INCLUDE, LIB, and TMP to the system's environment. These variables are used by the Microsoft C Compiler and the Microsoft Object Linker.

Line 11 configures the first serial communications port (COM1) and line 12 causes program output to the system's first parallel port (LPT1) to be redirected to the first serial port. This pair of commands allows a serial-interface Hewlett Packard LaserJet printer to be used as the system list device.

Note: Depending on the version of MS-DOS in use, some commands in this example may not be available or may support different options. See the individual command entries for more detailed information.

BATCH: ECHO

2.0 and later

Display Text

Internal

Purpose

Displays a message during the execution of a batch file and controls whether or not batch-file commands are listed on the screen as they are executed.

Syntax

ECHO [ON¦OFF¦*message*]

where:

ON	enables the display of all subsequent batch-file commands as they are executed.
OFF	disables the display of all subsequent batch-file commands as they are executed.
message	is a text string to be displayed on standard output.

Description

Each command line of a batch file is ordinarily displayed on the screen as it is executed. The ECHO command has a dual usage: to control the display of these commands and to display a message to the user.

ECHO is used with ON or OFF to enable or disable the display of commands during batch-file processing. If the ECHO command is used with no parameter, the current status of the batch processor's ECHO flag is displayed. Note that the ECHO flag is always forced on at the start of any batch-file processing, even if that batch file was invoked by another batch file.

The ECHO command is not limited to batch files; an ECHO command can also be issued at the command prompt. ECHO OFF entered at the command prompt prevents the prompt from subsequently being displayed. ECHO ON entered interactively restores the display. If ECHO is entered interactively without a parameter, the current status of the ECHO flag is displayed.

ECHO can also be followed by a message to be sent to standard output regardless of the status of the ECHO flag (on or off). Note that if ECHO is on, two copies of the message are actually displayed, the first copy preceded by the word *ECHO*. ECHO *message* is frequently used to display prompts and informative text during the execution of a batch file because text following REM or PAUSE commands is not displayed if ECHO is off.

ECHO *message* can also be used to build lists or other batch files dynamically while the batch file is executing. For example, the messages in the following ECHO commands are used to build the file STARTUP.BAT:

```
ECHO CHKDSK > STARTUP.BAT
ECHO DIR /W >> STARTUP.BAT
ECHO PROMPT $p$g >> STARTUP.BAT
```

The first ECHO command causes the message *CHKDSK* to be redirected to the file STARTUP.BAT. The second and third ECHO commands cause the messages *DIR/W* and *PROMPT pg* to be appended to the existing contents of STARTUP.BAT. The completed STARTUP.BAT file contains the following:

```
CHKDSK
DIR /W
PROMPT $p$g
```

Note: When the pipe symbol (¦) is used in *message*, the symbol and any characters following it are ignored until a redirection symbol (<, >, or >>) is encountered, at which point the redirection symbol and the remaining characters are recognized. For example, if the line

```
ECHO DIR ¦ SORT > STARTUP.BAT
```

was placed in a batch file and subsequently executed, the only characters echoed to the file STARTUP.BAT would be *DIR*; the pipe symbol and the characters between it and the redirection symbol > would be ignored.

Examples

To disable the display of each batch-file command as it is executed, include the following line as the first line in the batch file:

```
ECHO OFF
```

To display the message *Now formatting disk* on standard output, include the following line in the batch file:

```
ECHO Now formatting disk
```

To display the current status of the ECHO flag, include the following line in the batch file:

```
ECHO
```

If the ECHO flag is currently off, MS-DOS displays:

```
ECHO is off
```

To echo a blank line to the screen with versions 2.x, type a space after the ECHO command and press Enter. To echo a blank line with versions 3.x, type the ECHO command and a space, then hold down Alt and type 255 on the numeric keypad; finally, release the Alt key and press Enter.

Messages

ECHO is off

or

ECHO is on

If the ECHO command is entered without a parameter, one of these lines is displayed to give the current status of the batch processor's ECHO flag.

BATCH: FOR

2.0 and later

Execute Command on File Set

Internal

Purpose

Executes a command or program for each file in a set of files.

Syntax

FOR %%*variable* IN (*set*) DO *command* (batch processing)

or

FOR %*variable* IN (*set*) DO *command* (interactive processing)

where:

variable	is a variable name that can be any single character except the numerals 0 through 9, the redirection symbols (<, >, and >>), and the pipe symbol (|); case is significant.
set	is one or more filenames, pathnames, character strings, or metacharacters, separated by spaces, commas, or semicolons; wildcard characters are permitted in filenames.
command	is any MS-DOS command or program except the FOR command; the variable name %%*variable* (or %*variable* in interactive mode) can be part of the command.

Description

The FOR command allows sequential execution of the same command or program on each member of a set of files.

The *set* parameter can contain multiple filenames (including wildcards), pathnames, character strings, or metacharacters such as the replaceable parameters %0 through %9. Each of the following lines is an example of a valid set:

```
(FILE1.TXT %1 %2 B:\PROG\LISTING?.TXT)
(A:\%1 A:\%2 C:\LETTERS\*.TXT C:MEMO?.*)
(%PATH%)
```

Each filename from *set* is assigned in turn to %*variable* and then the specified command or program is executed. (When the FOR command line is executed in a batch file, the leading percent sign of %%*variable* is removed, leaving %*variable*.) If a filename in *set* contains wildcards, each matching file is used before the batch processor goes on to the next member of *set*.

Note: In versions 2.x, *set* can consist only of a list of single filenames, a single filename with wildcard characters, or a combination of single filenames and metacharacters. In versions 3.x, however, all combinations of these are allowed in the same set.

The FOR command can also be used interactively at the MS-DOS prompt to perform a single command on several files without entering the same command for each file. When FOR is used in this manner, only one percent sign (%) should be used before the dummy alphabetic variable; in this case, the percent sign is not removed during processing. When the FOR command is used interactively, environment variables such as %PATH% cannot be used as part of the filename set.

Examples

To view all the files with the extension .TXT in the current directory, include the following line in the batch file:

```
FOR %%X IN (*.TXT) DO TYPE %%X
```

To perform the same function interactively, type

```
C>FOR %X IN (*.TXT) DO TYPE %X  <Enter>
```

To copy up to nine files to the disk in drive A, specifying the names of the files in the batch-file command line, include the following line in the batch file:

```
FOR %%Y IN (%1 %2 %3 %4 %5 %6 %7 %8 %9) DO COPY %%Y A:
```

(Recall that %0 is the name of the batch file.)

To execute successive batch files under the control of one batch file, use the /C switch with COMMAND, as in the following batch-file line:

```
FOR %%Z IN (BAT1 BAT2 BAT3) DO COMMAND /C %%Z
```

Message

FOR cannot be nested
The command or program performed by a FOR command cannot be another FOR command.

BATCH: GOTO

2.0 and later

Jump to Label

Internal

Purpose

Transfers program control to the batch-file line following the specified label.

Syntax

GOTO *name*

where:

name is a batch-file label declared elsewhere in the file in the form *:name*.

Description

The GOTO command causes the batch-file processor to transfer its point of execution to the line following the specified label. If the label does not exist in the file, execution of the batch file is terminated with the message *Label not found*.

A batch-file label is defined as a line with a colon character (:) in the first column, followed by any text (including spaces but not other separator characters such as semicolons or equal signs). Only the first eight characters following the colon are significant; spaces are not counted in the eight characters.

Examples

The GOTO command is frequently used in combination with the IF and SHIFT batch commands to perform some action based on the return code from a program. For example, the following batch file will back up a variable number of files or directories, whose names are specified in the batch-file command line, to a floppy disk in drive A. The batch file accomplishes this by executing the BACKUP program with successive pathnames specified in the command line until BACKUP returns a nonzero (error) code. Control is then transferred to the label *:DONE*, and the batch file is terminated.

```
1   ECHO OFF
2   :START
3   BACKUP %1 A:
4   IF ERRORLEVEL 1 GOTO DONE
5   SHIFT
6   GOTO START
7   :DONE
```

Note that the batch file includes two labels, *:START* and *:DONE*, in lines 2 and 7, respectively. It also includes two GOTO commands, in lines 4 and 6. (The line numbers in the listing above are included only for reference and are not present in the actual batch file.) If the condition in line 4 is true (the BACKUP program returned an exit code of 1 or higher), the remainder of line 4 is executed and program control passes to the *:DONE* label in

line 7. If the condition is false, program control passes to line 5, the SHIFT command is executed, and program control goes to line 6, where the GOTO statement returns program control to line 2.

Message

Label not found
The specified label does not exist in the batch file.

BATCH: IF

2.0 and later

Perform Conditional Execution

Internal

Purpose

Tests a condition and executes a command or program if the condition is met.

Syntax

IF [NOT] *condition command*

where:

condition is one of the following:

ERRORLEVEL *number*
The condition is true if the exit code of the program last executed by COMMAND.COM was equal to or greater than *number*. Note that not all MS-DOS commands return explicit exit codes.

string1==string2
The condition is true if *string1* and *string2* are identical after parameter substitution; case is significant. The strings cannot contain separator characters such as commas, semicolons, equal signs, or spaces.

EXIST *pathname*
The condition is true if the specified file exists. The pathname can include metacharacters.

command is the command or program to be executed if the condition is true.

Description

The IF command provides conditional execution of a command or program in a batch file. When *condition* is true, IF executes the specified command, which can be another IF command, any other MS-DOS internal command, or a program. When *condition* is not true, MS-DOS ignores *command* and proceeds to the next line in the batch file. The sense of any condition can be reversed by preceding the test or expression with NOT.

Examples

To branch to the label *:ERROR* if the file LEDGER.DAT does not exist, include the following line in the batch file:

```
IF NOT EXIST LEDGER.DAT GOTO ERROR
```

To branch to the label *:ONEPAR* if the batch-file command line does not contain at least two parameters, include the following line in the batch file:

```
IF "%2"==""GOTO ONEPAR
```

or

```
IF %2~==~ GOTO ONEPAR
```

Note that the existence of a replaceable parameter can be determined by concatenating it to another string. In the first example, quotation marks are concatenated on either side of the replaceable parameter; if %2 doesn't exist, *"%2"=="* evaluates to *""=="*, which is true and will allow *GOTO ONEPAR* to be executed. In the second example, a tilde character is concatenated to the end of the replaceable parameter; if %2 doesn't exist, the argument becomes ~==~.

To copy the file specified by the first replaceable batch-file parameter to drive A only if it does not already exist on the disk in drive A, include the following line in the batch file:

```
IF NOT EXIST A:%1 COPY %1 A:
```

To branch to the label *:DONE* if the first replaceable batch-file parameter exists in the \PROG directory on drive C *and* in the \BACKUP directory on drive C, include the following line in the batch file:

```
IF EXIST C:\PROG\%1 IF EXIST C:\BACKUP\%1 GOTO DONE
```

Messages

Bad command or filename
The command following the condition in the IF statement was misspelled, does not exist, or was represented by a replaceable parameter that was not supplied in the command line that invoked the batch file.

Syntax error
The condition specified in the IF statement cannot be tested.

BATCH: PAUSE

1.0 and later

Suspend Batch-File Execution

Internal

Purpose

Displays a message, suspends execution of a batch file, and waits for the user to press a key.

Syntax

PAUSE [*message*]

where:

message is a text string to be displayed on standard output.

Description

The PAUSE command displays the message *Strike a key when ready...* and suspends execution of a batch file until the user presses a key. This command can be used to allow time for the operator to change disks, change the type of forms on the printer, or take some other action that is necessary before the batch file can continue.

If the batch processor's ECHO flag is on when the PAUSE command is executed, the entire line containing the PAUSE statement is displayed on the screen so that the optional message is visible to the user. The message *Strike a key when ready...* is then displayed on a new line and the system waits. Note that *Strike a key when ready...* is *always* displayed, even if the ECHO flag is off. When the user presses a key, execution of the batch file resumes.

Note: Redirection symbols should not be used within *message*. They prevent the message *Strike a key when ready...* from being displayed on the screen.

If the user presses Ctrl-C or Ctrl-Break while a PAUSE command is waiting for a key to be pressed, a prompt is displayed that gives the user the opportunity to terminate the execution of the batch file. This same message is displayed whenever the user presses Ctrl-C or Ctrl-Break during the execution of a batch file; however, using PAUSE commands supplemented by appropriate ECHO commands at strategic points within a batch file provides the user with clearly defined breakpoints for terminating the file.

Examples

To display the message *Put an empty disk in drive A* and then wait until the user has pressed a key, include the following line in the batch file:

```
PAUSE Put an empty disk in drive A
```

When this line of the batch file is executed, if the ECHO flag is on, the user sees the following messages on the screen:

```
C>PAUSE Put an empty disk in drive A
Strike a key when ready . . .
```

If the ECHO flag is off, only the message *Strike a key when ready...* appears.

To display the message without the prompt and command, the PAUSE command can be used immediately after an ECHO command, as follows:

```
ECHO OFF
CLS
ECHO Put an empty disk in drive A
PAUSE
```

This batch file will display the following message on the screen:

```
Put an empty disk in drive A
Strike a key when ready . . .
```

Note that the message must be included in an ECHO command. With ECHO off, a PAUSE message is not displayed.

BATCH: REM

1.0 and later

Include Comment Line

Internal

Purpose

Designates a remark, or comment, line in a batch file.

Syntax

REM [*message*]

where:

message is any text.

Description

The REM command allows inclusion of remarks, or comments, within a batch file. Remarks are often used to document the purpose of other commands within the file for the benefit of those who may wish to modify the file later.

If the ECHO flag is on, remarks are displayed on the screen during the execution of a batch file. Thus, remarks can also be used to provide information, guidance, or prompts to the user; however, the ECHO and PAUSE commands are more suitable for these purposes.

REM can also be used alone to insert blank lines in a batch file to improve readability. (If ECHO is on, the word *REM* will still be displayed.)

Note: The redirection symbols (<, >, and >>) and piping character (¦) produce no meaningful results with the REM command and should not be used.

Example

To document a batch file's revision history with the internal comment *This batch file last modified on 6/18/87*, include the following line in the batch file:

```
REM This batch file last modified on 6/18/87
```

BATCH: SHIFT

2.0 and later

Shift Replaceable Parameters

Internal

Purpose

Changes the position of the replaceable parameters in a batch-file command line, thereby allowing more than 10 replaceable parameters.

Syntax

SHIFT

Description

Ordinarily only 10 replaceable parameters (%0 through %9, where %0 is the name of the batch file) can be referenced within a batch file. The SHIFT command allows access to additional parameters specified in the command line by shifting the contents of each of the previously assigned parameters to a lower number (%1 becomes %0, %2 becomes %1, and so on). The previous contents of %0 are lost and are not recoverable. The eleventh parameter in the batch-file command line is then moved into %9. This allows more than 10 parameters to be specified in the batch-file command line and subsequently processed in the batch file.

Example

The following batch file will copy a variable number of files, whose names are entered in the batch-file command line, to the disk in drive A:

```
ECHO OFF
:NEXT
IF "%1"=="" GOTO DONE
COPY %1 A:
SHIFT
GOTO NEXT
:DONE
```

BREAK

2.0 and later

Set Control-C Check

Internal

Purpose

Sets or clears MS-DOS's internal flag for Control-C checking.

Syntax

BREAK [ON|OFF]

Description

Pressing Ctrl-C or Ctrl-Break while a program is running ordinarily terminates the program, unless the program itself contains instructions that disable MS-DOS's Control-C handling. As a rule, MS-DOS checks the keyboard for a Control-C only when a character is read from or written to a character device (keyboard, screen, printer, or auxiliary port). Therefore, if a program executes for long periods without performing such character I/O, detection of the user's entry of a Control-C may be delayed. The BREAK ON command causes MS-DOS to also check the keyboard for a Control-C at the time of each system call (which slows the system somewhat); the BREAK OFF command disables such extended Control-C checking. The default setting for BREAK is off.

If the BREAK command is entered alone, the current status of MS-DOS's internal BREAK flag is displayed.

Examples

To display the current status of the MS-DOS internal flag for extended Control-C checking, type

```
C>BREAK  <Enter>
```

MS-DOS displays

```
BREAK is off
```

or

```
BREAK is on
```

depending on the status of the BREAK flag.

To enable extended checking for Control-C during disk operations, type

```
C>BREAK ON  <Enter>
```

Messages

BREAK is on

or

BREAK is off
Extended Control-C checking is enabled or disabled, respectively. These messages occur in response to a BREAK status check.

Must specify ON or OFF
An invalid parameter was supplied in a BREAK command.

CHDIR or CD

2.0 and later

Change Current Directory

Internal

Purpose

Changes the current directory or displays the current path of the specified or default disk drive.

Syntax

CHDIR [*drive*:][*path*]

or

CD [*drive*:][*path*]

where:

drive is the letter of the drive for which the current directory will be changed or displayed, followed by a colon. Note that use of the *drive* parameter does not change the currently active drive.

path is one or more directory names, separated by backslash characters (\), that define an existing path.

Description

The CHDIR command, when followed by an existing path, is used to set the working directory for the default or specified disk drive.

The *path* parameter consists of the name of an existing directory, optionally followed by the names of existing subdirectories, each separated from the next by a backslash character. If *path* begins with a backslash, CHDIR assumes that the first named directory is a subdirectory of the root directory; otherwise, CHDIR assumes that the first named directory is a subdirectory of the current directory. The special directory name .. , which is an alias for the parent directory of the current directory, can be used as the path.

When CHDIR is entered alone or with only a drive letter followed by a colon, the full path of the current directory for the default or specified drive is displayed.

CD is simply an alias for CHDIR; the two commands are identical.

Examples

To change the current directory for the current (default) disk drive to the path \V2\SOURCE, type

```
C>CD \V2\SOURCE  <Enter>
```

To display the name of the current directory for the disk in drive D, type

```
C>CD D:  <Enter>
```

To return to the parent directory of the current directory, type

```
C>CD ..  <Enter>
```

Messages

Invalid directory
One of the directories in the specified path does not exist.

Invalid drive specification
An invalid drive letter was given or the named drive does not exist in the system.

CHKDSK

Check Disk Status

1.0 and later

External

Purpose

Analyzes the allocation of storage space on a disk and displays a summary report of the space occupied by files and directories.

Syntax

CHKDSK [*drive*:][*pathname*] [/F] [/V]

where:

drive	is the letter of the drive containing the disk to be analyzed, followed by a colon.
pathname	is the location and, optionally, the name of the file(s) to be checked for fragmentation; wildcard characters are permitted in the filename.
/F	repairs errors (versions 2.0 and later).
/V	"verbose mode," reports the name of each file as it is checked (versions 2.0 and later).

Description

The CHKDSK command analyzes the disk directory and file allocation table for consistency and reports any errors. If the /V switch is included in the command line, the name of each file processed is displayed as the disk is being analyzed.

After analyzing the disk, CHKDSK displays a summary of the disk and RAM space used and available. The disk-space report includes

- Total disk space in bytes
- Number of bytes allocated to hidden files
- Number of bytes contained in directories
- Number of bytes contained in user files
- Number of bytes contained in bad (unusable) sectors
- Number of available bytes on the disk

(Hidden files are files that do not appear in a directory listing. A bootable MS-DOS or PC-DOS disk always contains two hidden files—MSDOS.SYS and IO.SYS or IBMDOS.COM and IBMBIO.COM, respectively—that contain the operating system. A volume label, if present, counts as a hidden file. In addition, some application programs create hidden files for copy protection or other purposes.)

Directory errors detected by CHKDSK include

- Invalid pointers to data areas
- Bad file attributes in directory entries

- Damage to a portion of the directory that makes it impossible to check one or more paths
- Damage to an entire directory that makes the files contained in that directory inaccessible

File allocation table (FAT) errors detected by CHKDSK include

- Defective disk sectors in the FAT
- Invalid cluster (disk allocation unit) numbers in the FAT
- Lost clusters
- Cross-linking of files on the same cluster

If the /F switch is included in the command line, CHKDSK will attempt to repair errors in disk allocation and recover as much data as possible. Because repairs usually involve changes to the disk's file allocation table that may cause a loss of information, the user is prompted for confirmation. Lost clusters are collected into files in the root directory with names of the form FILE*nnnn*.CHK.

If the command line contains a file specification, CHKDSK will examine all files that match the specification and report on their fragmentation—that is, on whether or not their sectors are contiguous on the disk. (Fragmented files can degrade the performance of the system because of the time required to move the drive head back and forth across the disk to reach the various parts of the file.) Files on a floppy disk can be collected into contiguous sectors by copying them to an empty floppy disk. Files on a fixed disk can be collected into contiguous sectors by backing them all up to floppy disks, erasing all files and subdirectories on the fixed disk, and then restoring the files from the floppy disk.

Warning: CHKDSK should not be used on a network drive or on a drive created or affected by an ASSIGN, JOIN, or SUBST command.

Examples

To check the disk in the current drive, type

```
C>CHKDSK  <Enter>
```

If CHKDSK finds no errors, a report such as the following is displayed:

```
Volume HARDDISK    created Jun 8, 1986 9:34a

 21204992 bytes total disk space
    38912 bytes in 3 hidden files
   116736 bytes in 53 directories
 17055744 bytes in 715 user files
    20480 bytes in bad sectors
  3973120 bytes available on disk

   655360 bytes total memory
   566576 bytes free
```

Note that the line containing the volume name and creation date does not appear if the disk has not been assigned a volume name.

If CHKDSK finds errors, a message such as the following is displayed:

```
Errors found, F parameter not specified.
Corrections will not be written to disk.

10 lost clusters found in 3 chains.
Convert lost chains to files  (Y/N)?
```

A *Y* response at this point does not convert the lost chains to files; to do this, enter the CHKDSK command again with the /F switch specified.

To correct any allocation errors found by the CHKDSK command, type

```
C>CHKDSK /F  <Enter>
```

In this example, CHKDSK displays its usual report, followed by an error message:

```
Volume HARDDISK    created Jun 8, 1986 9:34a

 21204992 bytes total disk space
    38912 bytes in 3 hidden files
   116736 bytes in 53 directories
 17055744 bytes in 715 user files
    20480 bytes in bad sectors
  3973120 bytes available on disk

   655360 bytes total memory
   566576 bytes free

10 lost clusters found in 3 chains.
Convert lost chains to files (Y/N) ?
```

A *Y* response causes CHKDSK to recover the lost chains of clusters into files in the root directory, giving the files the names FILE0000.CHK, FILE0001.CHK, FILE0002.CHK, and so on. An *N* response causes CHKDSK to free the lost chains of clusters without saving the contents to files.

To check all files in the directory C:\SYSTEM with the extension .COM for fragmentation, type

```
C>CHKDSK C:\SYSTEM\*.COM  <Enter>
```

CHKDSK displays its usual report, followed by a list of fragmented files:

```
Volume HARDDISK    created Jun 8, 1986 9:34a

 21204992 bytes total disk space
    38912 bytes in 3 hidden files
   116736 bytes in 53 directories
 17055744 bytes in 715 user files
    20480 bytes in bad sectors
  3973120 bytes available on disk

   655360 bytes total memory
   566576 bytes free

C:\SYSTEM\ALUSQ.COM
   Contains 2 non-contiguous blocks.

C:\SYSTEM\EJECT.COM
   Contains 4 non-contiguous blocks.
```

Messages

. Does not exist.

or

.. Does not exist.
The . (alias for the current directory) or the .. (alias for the parent directory) entry is missing.

filename* Is cross linked on cluster *n
Two or more files have been assigned the same cluster. Make a copy of both files on another disk and then delete them from the disk containing the error. One or both of the resulting files may contain information belonging to the other file.

***x* lost clusters found in *y* chains.**
Convert lost chains to files (Y/N)?
Clusters have been identified that are not assigned to any existing file. If the /F switch was included in the original command line, respond with *Y* to convert the lost clusters to files in the root directory of the disk with names of the form FILE*nnnn*.CHK. If desired, the recovered clusters can then be returned to the free-disk-space pool by erasing the .CHK files.

Allocation error, size adjusted.
The size of the file indicated in the disk directory is not consistent with the number of clusters allocated to the file. If the /F switch was included in the command line, the file is truncated to the size indicated in the disk directory.

All specified file(s) are contiguous.
The clusters belonging to the specified file(s) are allocated contiguously (without fragmentation).

Cannot CHDIR to *pathname*
tree past this point not processed.
The tree directory structure of the disk being checked cannot be traveled to the specified directory. This message indicates severe damage to the disk's directories or files.

Cannot CHDIR to root
Processing cannot continue.
In traversing the tree directory structure of the disk being checked, CHKDSK was unable to return to the root directory. This message indicates severe damage to the disk's directories or files.

Cannot CHKDSK a Network drive
The drive containing the disk to be checked has been assigned to a network.

Cannot CHKDSK a SUBSTed or ASSIGNed drive
The drive containing the disk to be checked has been substituted or assigned.

Cannot recover . entry, processing continued.
The special directory entry . (alias for the current directory) is defective.

Cannot recover .. entry,
Entry has a bad attribute

or

Cannot recover .. entry,
Entry has a bad link

or

Cannot recover .. entry,
Entry has a bad size
The special directory entry .. (alias for the parent directory of the current directory) is defective due to a bad attribute, link, or size.

CHDIR .. failed, trying alternate method.
While checking the tree structure, CHKDSK was unable to return to the parent directory of the current directory. It will attempt to return to that directory by starting over at the root directory and searching again.

Contains *n* non-contiguous blocks.
The clusters assigned to the specified file are not allocated contiguously on the disk.

Directory is joined
CHKDSK cannot process directories that have been joined using the JOIN command. Use the JOIN /D command to unjoin the directories, then run CHKDSK again.

Directory is totally empty, no . or ..
The specified directory does not contain the usual aliases for the current and parent directories. This message indicates severe damage to the disk's directories or files. Delete the directory and recreate it.

Disk error reading FAT *n*

or

Disk error writing FAT *n*
One of the file allocation tables for the disk being checked contains a defective sector. MS-DOS will use the alternate FAT if one is available. It is advisable to copy all the files on the disk containing the defective sector to another disk.

Errors found, F parameter not specified.
Corrections will not be written to disk.
Errors were found on the disk being checked, but the /F switch was not included in the command line.

File allocation table bad drive *X*:
The disk is not an MS-DOS disk. Repeat CHKDSK with the /F option; if this message is displayed again, reformat the disk.

File not found.
CHKDSK was unable to find the specified file.

First cluster number is invalid, entry truncated.
The directory entry for the specified file contains an invalid pointer to the disk's data area. If the /F switch was included in the command line, the file is truncated to a zero-length file.

General Failure error reading drive *X*:
The format of the disk being checked is not compatible with MS-DOS or the disk has not been formatted for use by MS-DOS.

Has invalid cluster, file truncated.
The file directory contains an invalid pointer to the disk's data area. If the /F switch was included in the command line, the file is truncated to a zero-length file.

Incorrect DOS version
The version of CHKDSK is not compatible with the version of MS-DOS that is running.

Insufficient memory
Processing cannot continue.
The computer does not have enough memory to contain the tables necessary for CHKDSK to process the specified disk.

Insufficient room in root directory.
Erase files in root and repeat CHKDSK.
The root directory is full and does not have room for the entries for recovered files. Delete some files from the root directory of the disk being checked and rerun the CHKDSK program.

Invalid current directory
Processing cannot continue.
The directory structure of the disk is so badly damaged that the disk is unusable.

Invalid drive specification
The CHKDSK command contained an invalid disk drive.

Invalid parameter
One of the switches in the command line is invalid.

Invalid sub-directory entry.
The directory name specified in the command line does not exist or is invalid.

Path not found.
One of the directories in the path specified in the command line does not exist or is invalid.

Probable non-DOS disk
Continue (Y/N) ?
The disk being checked was not formatted by MS-DOS or the file allocation table has been severely damaged or destroyed.

Unrecoverable error in directory.
Convert directory to file (Y/N)?
The specified directory is damaged and unusable. If the /F switch was included in the original command line, respond with *Y* to convert the damaged directory to a file in the root directory of the disk with a name of the form FILE*nnnn*.CHK. If desired, the .CHK file can then be deleted. Any files that were previously reached through the damaged directory will be lost.

CLS

Clear Screen

2.0 and later

Internal

Purpose

Clears the video display.

Syntax

CLS

Description

The CLS command clears the video display and displays the current prompt.

In some implementations of MS-DOS, proper operation of the CLS command may require installation of the ANSI.SYS console driver with a *DEVICE=ANSI.SYS* command in the CONFIG.SYS file.

Examples

To clear the screen, type

```
C>CLS  <Enter>
```

To save the ANSI escape sequence used by the CLS command (ESC[2J) into a file named CLEAR.TXT, type

```
C>CLS > CLEAR.TXT  <Enter>
```