VGA Write Mode 3
The Write Mode That Grows on You

Over the last three chapters, we've covered the VGA's write path from stem to stern—with one exception. Thus far, we've only looked at how writes work in write mode 0, the straightforward, workhorse mode in which each byte that the CPU writes to display memory fans out across the four planes. (Actually, we also took a quick look at write mode 1, in which the latches are always copied unmodified, but since exactly the same result can be achieved by setting the Bit Mask register to 0 in write mode 0, write mode 1 is of little real significance.)

Write mode 0 is a very useful mode, but some of VGA's most interesting capabilities involve the two write modes that we have yet to examine: write mode 1, and, especially, write mode 3. We'll get to write mode 1 in the next chapter, but right now I want to focus on write mode 3, which can be confusing at first, but turns out to be quite a bit more powerful than one might initially think.

A Mode Born in Strangeness

Write mode 3 is strange indeed, and its use is not immediately obvious. The first time I encountered write mode 3, I understood immediately how it functioned, but could think of very few useful applications for it. As time passed, and as I came to understand the atrocious performance characteristics of OUT instructions, and the importance of text and pattern drawing as well, write mode 3 grew considerably in my estimation. In fact, my esteem for this mode ultimately reached the point where
in the last major chunk of 16-color graphics code I wrote, write mode 3 was used more than write mode 0 overall, excluding simple pixel copying. So write mode 3 is well worth using, but to use it you must first understand it. Here's how it works.

In write mode 3, set/reset is automatically enabled for all four planes (the Enable Set/Reset register is ignored). The CPU data byte is rotated and then ANDed with the contents of the Bit Mask register, and the result of this operation is used as the contents of the Bit Mask register alone would normally be used. (If this is Greek to you, have a look back at Chapters 23 through 25. There's no way to understand write mode 3 without understanding the rest of the VGA's write data path first.)

That's what write mode 3 does—but what is it for? It turns out that write mode 3 is excellent for a surprisingly large number of purposes, because it makes it possible to avoid the bane of VGA performance, OUTs. Some uses for write mode 3 include lines, circles, and solid and two-color pattern fills. Most importantly, write mode 3 is ideal for transparent text; that is, it makes it possible to draw text in 16-color graphics mode quickly without wiping out the background in the process. (As we'll see at the end of this chapter, write mode 3 is potentially terrific for opaque text—text drawn with the character box filled in with a solid color—as well.)

Listing 26.1 is a modification of code I presented in Chapter 25. That code used the data rotate and bit mask features of the VGA to draw bit-mapped text in write mode 0. Listing 26.1 uses write mode 3 in place of the bit mask to draw bit-mapped text, and in the process gains the useful ability to preserve the background into which the text is being drawn. Where the original text-drawing code drew the entire character box for each character, with 0 bits in the font pattern causing a black box to appear around each character, the code in Listing 26.1 affects display memory only when 1 bits in the font pattern are drawn. As a result, the characters appear to be painted into the background, rather than over it. Another advantage of the code in Listing 26.1 is that the characters can be drawn in any of the 16 available colors.

**LISTING 26.1  L26-1.ASM**

: Program to illustrate operation of write mode 3 of the VGA.
: Draws 8x8 characters at arbitrary locations without disturbing
: the background, using VGA's 8x8 ROM font. Designed
: for use with modes 00h, 0Eh, 0Fh, 10h, and 12h.
: Runs only on VGAs (in Models 50 & up and IBM Display Adapter
: and 100% compatibles).
: Assembled with MASM
: By Michael Abrash
:
: stack segment para stack 'STACK'
: db  512 dup(?)
: stack ends
:
: stack segment para stack 'STACK'
: db  512 dup(?)
: stack ends
:
: VGA_VIDEO_SEGMENT equ  0a000h  ;VGA display memory segment
: SCREEN_WIDTH_IN_BYTES equ  044ah  ;offset of BIOS variable
: FONT_CHARACTER_SIZE equ  8  ;# bytes in each font char
:
: VGA register equates.
SC_INDEX equ 3c4h ;SC index register
SC_MAP_MASK equ 2 ;SC map mask register index
GC_INDEX equ 3ceh ;GC index register
GC_SET_RESET equ 0 ;GC set/reset register index
GC_ENABLE_SET_RESET equ 1 ;GC enable set/reset register index
GC_ROTATE equ 3 ;GC data rotate/logical function register index
GC_MODE equ 5 ;GC Mode register
GC_BIT_MASK equ 8 ;GC bit mask register index

dseg segment para common 'DATA'
TEST_TEXT_ROW equ 69 :row to display test text at
TEST_TEXT_COL equ 17 :column to display test text at
TEST_TEXT_WIDTH equ 8 ;width of a character in pixels
TestString label byte
    db 'Hello, world!',0 ;test string to print.
FontPointer dd ? ;font offset
dseg ends

cseg segment para public 'CODE'
assume cs:cseg, ds:dseg
start proc near
mov ax, dseg
mov ds, ax

; Select 640x480 graphics mode.
;
    mov ax,012h
    int 10h

; Set the screen to all blue, using the readability of VGA registers to preserve reserved bits.
;
    mov dx, GC_INDEX
    mov al, GC_SET_RESET
    out dx, al
    inc dx
    in al, dx
    and al, 0f0h
    or al, 1 ;blue plane only set, others reset
    out dx, al
    dec dx
    mov al, GC_ENABLE_SET_RESET
    out dx, al
    inc dx
    in al, dx
    and al, 0f0h
    or al, 0fh ;enable set/reset for all planes
    out dx, al
    mov dx, VGA_VIDEO_SEGMENT
    mov es, dx ;point to display memory
    mov di, 0
    mov cx, 8000h ;fill all 32k words
    mov ax, 0ffffh ;because of set/reset, the value written actually doesn't matter
    rep stosw ;fill with blue

; Set driver to use the 8x8 font.
;
    mov ah, 11h ;VGA BIOS character generator function,
    mov al, 30h ;return info subfunction
mov bh, 3 ;get 8x8 font pointer
int 10h
call SelectFont
;
; Print the test string, cycling through colors.
;
mov si, offset TestString
mov bx, TEST_TEXT_ROW
mov cx, TEST_TEXT_COL
mov ah, 0 ;start with color 0

StringOutLoop:
    lodsb
    and al, al
    jz StringOutDone
    push ax ;preserve color
    call DrawChar
    pop ax ;restore color
    inc ah ;next color
    and ah, 0fh ;colors range from 0 to 15
    add cx, TEST_TEXT_WIDTH
    jmp StringOutLoop

StringOutDone:
;
; Wait for a key, then set to text mode & end.
;
mov ah, 1
int 21h ;wait for a key
mov ax, 3
int 10h ;restore text mode
;
; Exit to DOS.
;
mov ah, 4ch
int 21h

Start endp

; Subroutine to draw a text character in a linear graphics mode
; (ODh, OEh, OFh, 010h, 012h). Background around the pixels that
; make up the character is preserved.
; Font used should be pointed to by FontPointer.
;
; Input:
; AL = character to draw
; AH = color to draw character in (0-15)
; BX = row to draw text character at
; CX = column to draw text character at
;
; Forces ALU function to "move".
; Forces write mode 3.
;
DrawChar proc near
    push ax
    push bx
    push cx
    push dx
    push si
    push di
    push bp
    push ds
    push ax ;preserve character to draw in AL

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; Set up set/reset to produce character color, using the readability of VGA register to preserve the setting of reserved bits 7-4.

; mov dx, GC_INDEX
mov al, GC_SET_RESET
out dx, al
inc dx
in al, dx
and al, 0F0h
and ah, 0Fh
or al, ah
out dx, al

; Select write mode 3, using the readability of VGA registers to leave bits other than the write mode bits unchanged.

; mov dx, GC_INDEX
mov al, GC_MODE
out dx, al
inc dx
in al, dx
or al, 3
out dx, al

; Set DS:SI to point to font and ES to point to display memory.

; lds si, [FontPointer] ; point to font
mov dx, VGA_VIDEO_SEGMENT
mov es, dx ; point to display memory

; Calculate screen address of byte character starts in.

; pop ax ; get back character to draw in AL
push ds ; point to BIOS data segment
sub dx, dx
mov ds, dx
xchg ax, bx
mov di, dx:[SCREEN_WIDTH_IN_BYTES] ; retrieve BIOS screen width
pop ds
mul di ; calculate offset of start of row
push di ; set aside screen width
mov di, cx ; set aside the column
and cl, 0111b ; keep only the column in-byte address
shr di, 1
shr di, 1
shr di, 1 ; divide column by 8 to make a byte address
add di, ax ; and point to byte

; Calculate font address of character.

; sub bh, bh ; assumes 8 bytes per character; use
shl bx, 1 ; a multiply otherwise
shl bx, 1 ; offset in font of character
add si, bx ; offset in font segment of character

; Set up the GC rotation. In write mode 3, this is the rotation of CPU data before it is ANDed with the Bit Mask register to
: form the bit mask. Force the ALU function to "move". Uses the
: readability of VGA registers to leave reserved bits unchanged.
:
```
mov   dx, GC_INDEX
mov   ax, GC_ROTATE
out   dx, ax
inc   dx
in    ax, dx
and   ax, 0eOh
or    ax, cl
out   dx, ax
```
: Set up BH as bit mask for left half, BL as rotation for right half.
:
```
mov   bx, 0ffffh
shr   bh, cl
neg   cl
add   cl, 0
shl   bl, cl
```
: Draw the character, left half first, then right half in the
: succeeding byte, using the data rotation to position the character
: across the byte boundary and then using write mode 3 to combine the
: character data with the bit mask to allow the set/reset value (the
: character color) through only for the proper portion (where the
: font bits for the character are 1) of the character for each byte.
: Wherever the font bits for the character are 0, the background
: color is preserved.
: Does not check for case where character is byte-aligned and
: no rotation and only one write is required.
:
```
mov   bp, FONT_CHARACTER_SIZE
mov   dx, GC_INDEX
pop   cx               ; get back screen width
dec   cx
dec   cx                ; -2 because do two bytes for each char
```
```
CharacterLoop:
```
: Set the bit mask for the left half of the character.
:
```
mov   al, GC_BIT_MASK
mov   ah, bh
out   dx, ax
```
: Get the next character byte & write it to display memory.
: (Left half of character.)
:
```
mov   al, [si]           ; get character byte
mov   ah, es:[di]       ; load latches
stosb                    ; write character byte
```
: Set the bit mask for the right half of the character.
:
```
mov   al, GC_BIT_MASK
mov   ah, bl
out   dx, ax
```
: Get the character byte again & write it to display memory.
: (Right half of character.)

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The key to understanding Listing 26.1 is understanding the effect of ANDing the rotated CPU data with the contents of the Bit Mask register. The CPU data is the pattern for the character to be drawn, with bits equal to 1 indicating where character pixels are to appear. The Data Rotate register is set to rotate the CPU data to pixel-align it, since without rotation characters could only be drawn on byte boundaries.

As I pointed out in Chapter 25, the CPU is perfectly capable of rotating the data itself, and it’s often the case that that’s more efficient. The problem with using the Data Rotate register is that the *OUT* that sets that register is time-consuming, especially for proportional text, which requires a different rotation for each character. Also, if the code performs full-byte accesses to display memory—that is, if it combines pieces of two adjacent characters into one byte—whenever possible for efficiency, the CPU generally has to do extra work to prepare the data so the VGA’s rotator can handle it.

At the same time that the Data Rotate register is set, the Bit Mask register is set to allow the CPU to modify only that portion of the display memory byte accessed that the pixel-aligned character falls in, so that other characters and/or graphics data won’t be wiped out. The result of ANDing the rotated CPU data byte with the contents of the Bit Mask register is a bit mask that allows only the bits equal to 1 in the original
character pattern (rotated and masked to provide pixel alignment) to be modified by the CPU; all other bits come straight from the latches. The latches should have previously been loaded from the target address, so the effect of the ultimate synthesized bit mask value is to allow the CPU to modify only those pixels in display memory that correspond to the 1 bits in that part of the pixel-aligned character that falls in the currently addressed byte. The color of the pixels set by the CPU is determined by the contents of the Set/Reset register.

Whew. It sounds complex, but given an understanding of what the data rotator, set/reset, and the bit mask do, it’s not that bad. One good way to make sense of it is to refer to the original text-drawing program in Listing 25.1 back in Chapter 25, and then see how Listing 26.1 differs from that program.

It’s worth noting that the results generated by Listing 26.1 could have been accomplished without write mode 3. Write mode 0 could have been used instead, but at a significant performance cost. Instead of letting write mode 3 rotate the CPU data and AND it with the contents of the Bit Mask register, the CPU could simply have rotated the CPU data directly and ANDed it with the value destined for the Bit Mask register and then set the Bit Mask register to the resulting value. Additionally, enable set/reset could have been forced on for all planes, emulating what write mode 3 does to provide pixel colors.

The write mode 3 approach used in Listing 26.1 can be efficiently extended to drawing large blocks of text. For example, suppose that we were to draw a line of 8-pixel-wide bit-mapped text 40 characters long. We could then set up the bit mask and data rotation as appropriate for the left portion of each bit-aligned character (the portion of each character to the left of the byte boundary) and then draw the left portions only of all 40 characters in write mode 3. Then the bit mask could be set up for the right portion of each character, and the right portions of all 40 characters could be drawn. The VGA’s fast rotator would be used to do all rotation, and the only OUTs required would be those required to set the bit mask and data rotation. This technique could well outperform single-character bit-mapped text drivers such as the one in Listing 26.1 by a significant margin. Listing 26.2 illustrates one implementation of such an approach. Incidentally, note the use of the 8×14 ROM font in Listing 26.2, rather than the 8×8 ROM font used in Listing 26.1. There is also an 8×16 font stored in ROM, along with the tables used to alter the 8×14 and 8×16 ROM fonts into 9×14 and 9×16 fonts.

**LISTING 26.2 L26-2.ASM**

; Program to illustrate high-speed text-drawing operation of
; write mode 3 of the VGA.
; Draws a string of 8×14 characters at arbitrary locations
; without disturbing the background, using VGA's 8×14 ROM font.
; Designed for use with modes 0Dh, 0Eh, 0Fh, 10h, and 12h.
; Runs only on VGAs (in Models 50 & up and IBM Display Adapter
; and 100% compatibles).
; Assembled with MASM
; By Michael Abrash

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stack segment para stack 'STACK'
  db  512 dup(?)
stack ends
;
VGA_VIDEO_SEGMENT equ 0a000h ;VGA display memory segment
SCREEN_WIDTH_IN_BYTES equ 044ah ;offset of BIOS variable
FONT_CHARACTER_SIZE equ 14 ;# bytes in each font char
;
; VGA register equates.
;
SC_INDEX equ 3c4h ;SC index register
SC_MAP_MASK equ 2 ;SC map mask register index
GC_INDEX equ 3ceh ;GC index register
GC_SET_RESET equ 0 ;GC set/reset register index
GC_ENABLE_SET_RESET equ 1 ;GC enable set/reset register index
GC_ROTATE equ 3 ;GC data rotate/logical function
; register index
GC_MODE equ 5 ;GC Mode register
GC_BIT_MASK equ 8 ;GC bit mask register index
;
dseg segment para common 'DATA'
TEST_TEXT_ROW equ 69 ;row to display test text at
TEST_TEXT_COL equ 17 ;column to display test text at
TEST_TEXT_COLOR equ 0fh ;high intensity white
TestString label byte
  db 'Hello, world!',0 ;test string to print.
FontPointer dd ? ;font offset
dseg ends
;
cseg segment para public 'CODE'
  assume cs:cseg, ds:dseg
start proc near
  mov ax,dseg
  mov ds,ax

  ; Select 640x480 graphics mode.
  ;
  mov ax,012h
  int 10h

  ; Set the screen to all blue, using the readability of VGA registers
  ; to preserve reserved bits.
  ;
  mov dx,GC_INDEX
  mov al,GC_SET_RESET
  out dx,al
  inc dx
  in al,dx
  and al,0f0h
  or al,1 ;blue plane only set, others reset
  out dx,al
  dec dx
  mov al,GC_ENABLE_SET_RESET
  out dx,al
  inc dx
  in al,dx
  and al,0f0h
  or al,0fh ;enable set/reset for all planes
  out dx,al
  mov dx,VGA_VIDEO_SEGMENT

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mov es, dx ; point to display memory
mov di, 0
mov cx, 8000h ; fill all 32k words
mov ax, 0ffffh ; because of set/reset, the value ; written actually doesn't matter
rep stosw ; fill with blue

; Set driver to use the 8x14 font.
;
mov ah, 11h ; VGA BIOS character generator function.
mov al, 30h ; return info subfunction
mov bh, 2 ; get 8x14 font pointer
int 10h
call SelectFont

; Print the test string.
;
mov si, offset TestString
mov bx, TEST_TEXT_ROW
mov cx, TEST_TEXT_COL
mov ah, TEST_TEXT_COLOR
call Drawstring

; Wait for a key, then set to text mode & end.
;
mov ah, 1
int 21h ; wait for a key
mov ax, 3
int 10h ; restore text mode

; Exit to DOS.
;
mov ah, 4ch
int 21h
Start endp

; Subroutine to draw a text string left-to-right in a linear
; graphics mode (0DH, 0EH, 0FH, 010h, 012h) with 8-dot-wide
; characters. Background around the pixels that make up the
; characters is preserved.
; Font used should be pointed to by FontPointer.
;
; Input:
; AH - color to draw string in
; BX - row to draw string on
; CX - column to start string at
; DS:SI - string to draw
; Forces ALU function to "move".
; Forces write mode 3.
;
DrawString proc near
push ax
push bx
push cx
push dx
push si
push di
push bp
push ds

exit
DrawString endp
; Set up set/reset to produce character color, using the readability
; of VGA register to preserve the setting of reserved bits 7-4.
;
mov   dx, GC_INDEX
mov   al, GC_SET_RESET
out   dx, al
inc   dx
in    al, dx
and   al, 0f0h
and   ah, 0fh
or    al, ah
out   dx, al

; Select write mode 3, using the readability of VGA registers
; to leave bits other than the write mode bits unchanged.
;
mov   dx, GC_INDEX
mov   al, GC_MODE
out   dx, al
inc   dx
in    al, dx
or    al, 3
out   dx, al
mov   dx, VGA_VIDEO_SEGMENT
mov   es, dx        ;point to display memory

; Calculate screen address of byte character starts in.
;
push  ds             ;point to BIOS data segment
sub   dx, dx
mov   ds, dx
mov   di, ds:[SCREEN_WIDTH_IN_BYTES]       ;retrieve BIOS
                                          ; screen width
pop   ds
mov   ax, bx         ;row
mul   di              ;calculate offset of start of row
push  di              ;set aside screen width
mov   di, cx          ;set aside the column
and   cl, 0111b       ;keep only the column in-byte address
shr   di, 1
shr   di, 1
shr   di, 1           ;divide column by 8 to make a byte address
add   di, ax          ;and point to byte

; Set up the GC rotation. In write mode 3, this is the rotation
; of CPU data before it is ANDed with the Bit Mask register to
; form the bit mask. Force the ALU function to "move". Uses the
; readability of VGA registers to leave reserved bits unchanged.
;
mov   dx, GC_INDEX
mov   al, GC_ROTATE
out   dx, al
inc   dx
in    al, dx
and   al, 0e0h
or    al, cl
out   dx, al

; Set up BH as bit mask for left half, BL as rotation for right half.

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; Draw all characters, left portion first, then right portion in the succeeding byte, using the data rotation to position the character across the byte boundary and then using write mode 3 to combine the character data with the bit mask to allow the set/reset value (the character color) through only for the proper portion (where the font bits for the character are 1) of the character for each byte. Wherever the font bits for the character are 0, the background color is preserved. Does not check for case where character is byte-aligned and no rotation and only one write is required.

; Draw the left portion of each character in the string:

pop cx ; get back screen width
push si
push di
push bx

; Set the bit mask for the left half of the character.

mov dx, GC_INDEX
mov ax, GC_BIT_MASK
mov bx, bh
out dx, ax
LeftHalfLoop:
lodsb
and ax, al
jz LeftHalfLoopDone
call CharacterUp ; point to next character location
inc di
jmp LeftHalfLoop
LeftHalfLoopDone:

; Draw the right portion of each character in the string.

inc di ; right portion of each character is across byte boundary

; Set the bit mask for the right half of the character.

mov dx, GC_INDEX
mov ax, GC_BIT_MASK
mov bx, bl
out dx, ax
RightHalfLoop:
lodsb
and ax, al
jz RightHalfLoopDone
call CharacterUp
inc di ; point to next character location
jmp RightHalfLoop

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RightHalfLoopDone:

: pop ds
: pop bp
: pop di
: pop si
: pop dx
: pop cx
: pop bx
: pop ax
: ret

DrawString endp

; Draw a character.
; Input:
; AL = character
; CX = screen width
; ES:DI = address to draw character at

CharacterUp proc near

push cx
push si
push di
push ds

; Set DS:SI to point to font and ES to point to display memory.
lds si,[FontPointer] ;point to font

; Calculate font address of character.

mov bi,14 ;14 bytes per character
mul bl
add si,ax ;offset in font segment of character

mov bp.FONT_CHARACTER_SIZE
dec cx ; -1 because one byte per char

CharacterLoop:

lodsb ;get character byte
mov ah,es:[di] ;load latches
stosb ;write character byte

; Point to next line of character in display memory.

add di,cx

dec bp
jnz CharacterLoop

pop ds
pop di
pop si
pop cx
ret

CharacterUp endp

; Set the pointer to the font to draw from to ES:BP.

SelectFont proc near

mov word ptr [FontPointer].bp ;save pointer
In this chapter, I've tried to give you a feel for how write mode 3 works and what it might be used for, rather than providing polished, optimized, plug-it-in-and-go code. Like the rest of the VGA's write path, write mode 3 is a resource that can be used in a remarkable variety of ways, and I don't want to lock you into thinking of it as useful in just one context. Instead, you should take the time to thoroughly understand what write mode 3 does, and then, when you do VGA programming, think about how write mode 3 can best be applied to the task at hand. Because I focused on illustrating the operation of write mode 3, neither listing in this chapter is the fastest way to accomplish the desired result. For example, Listing 26.2 could be made nearly twice as fast by simply having the CPU rotate, mask, and join the bytes from adjacent characters, then draw the combined bytes to display memory in a single operation. Similarly, Listing 26.1 is designed to illustrate write mode 3 and its interaction with the rest of the VGA as a contrast to Listing 25.1 in Chapter 25, rather than for maximum speed, and it could be made considerably more efficient. If we were going for performance, we'd have the CPU not only rotate the bytes into position, but also do the masking by ANDing in software. Even more significantly, we would have the CPU combine adjacent characters into complete, rotated bytes whenever possible, so that only one drawing operation would be required per byte of display memory modified. By doing this, we would eliminate all per-character OUTs, and would minimize display memory accesses, approximately doubling text-drawing speed.

As a final note, consider that non-transparent text could also be accelerated with write mode 3. The latches could be filled with the background (text box) color, set/reset could be set to the foreground (text) color, and write mode 3 could then be used to turn monochrome text bytes written by the CPU into characters on the screen with just one write per byte. There are complications, such as drawing partial bytes, and rotating the bytes to align the characters, which we'll revisit later on in Chapter 55, while we're working through the details of the X-Sharp library. Nonetheless, the performance benefit of this approach can be a speedup of as much as four times—all thanks to the decidedly quirky but surprisingly powerful and flexible write mode 3.

**A Note on Preserving Register Bits**

If you take a quick look, you'll see that the code in Listing 26.1 uses the readable register feature of the VGA to preserve reserved bits and bits other than those being modified. Older adapters such as the CGA and EGA had few readable registers, so it was necessary to set all bits in a register whenever that register was modified. Happily, all
VGA registers are readable, which makes it possible to change only those bits of immediate interest, and, in general, I highly recommend doing exactly that, since IBM (or clone manufacturers) may well someday use some of those reserved bits or change the meanings of some of the bits that are currently in use.