Using MMX™ Instructions to Get Bits From a Data Stream

Information for Developers and ISVs

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1.0. INTRODUCTION

The Intel Architecture (IA) media extensions include single-instruction, multi-data (SIMD) instructions. This application note presents examples of code that exploit these instructions. Specifically, the \texttt{getbits} function presented here illustrates how to use the new MMX\textsuperscript{TM} instructions (\texttt{PSRLQ} and \texttt{PSLLQ}) to manipulate a data stream. The performance improvement relative to traditional IA code can be attributed primarily to the much faster shift instructions. Whereas the IA shift instruction (\texttt{SHIFT}) takes four cycles on a Pentium\textsuperscript{®} processor, the MMX instruction (\texttt{PSHIFT}) takes only one cycle. The performance gain is also due to the fact that the MMX instructions operate on 64-bit values instead of the 32-bit values operated on by the scalar shift instructions.
2.0. GETBITS FUNCTION

In applications such as the Moving Pictures Expert Group (MPEG) applications, the data is organized in a bit stream in big-endian order. The user requires a variable number of bits from this bitstream. The getbits function performs these tasks to access the requested data:

1. The function gets the user-specified number of bits from the multimedia register, MM0, and returns them in the integer register, EAX.

2. When all the bits in MM0 have been used, getbits jumps to the new64bit code. This code refreshes MM0, filling it with bits from a buffer of finite length. getbits then returns the requested bits in the eax register.

3. When there are no more bits in the buffer, getbits jumps to the do_refill code, which places a finite number of bits from the input stream into the buffer.

2.1. Getbits Core

Figure 1 illustrates the basic MMX code flow needed for the getbits core. Basically, MM2 (a copy of MM0) shifts the desired bits all the way to the least significant part of the register. Register MM0 is updated so that these returned bits are removed.

The core of the getbits function is listed in Example 1. Recall that the multimedia register, MM0, contains the bits that will be retrieved by getbits.

The first three lines determine how many bits the user requests and if there are enough valid bits in the MM0 register. Assuming that MM0 contains enough valid bits for this call of getbits, the branch in line 4 is not taken.

![Figure 1. Getbits Core Diagram](image)

**Example 1. Getbits Core**

```
getbits:
1  MOV   eax, DWORD PTR bit_count ; Number of valid bits in MM0
2  MOV   ecx, 4[ESP]           ; Parameter. How many bits to read
3  SUB   eax, ecx             ; Do we have enough bits in MM0
4  JL    new64bit            ; If not get new 64 bits
5  movd  MM3,64_minus_index[ecx*4] ; MM3 = 64 - number of needed bits
6  movq  MM2,MM0             ; make a copy of the bits
7  movd  MM1,ecx             ; number of bits to read
8  psrlq  MM2,MM3            ; MM2 now has valid bitstream in
                              ; least significant part
```
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9  mov  BYTE PTR bit_count,al ; Update number of valid bits
10  movd  eax,MM2 ; move the result into eax
11  psllq  MM0,MM1 ; throw away those bits
12  ret

The big-endian to little-endian conversion is already performed. See Section 2.2. new64bit Code. The relevant bits are currently in the most significant part of MM0. These bits are copied to MM2 (line 6). The bits in MM2 are shifted to the right so that they are now in the least significant part of the register (lines 5 and 8). The bits can then be loaded to the EAX register (line 10). The bits that were just loaded to EAX are then discarded at the most significant edge of MM0 (shift to left in lines 7 and 11). Line 9 updates the number of valid bits in MM0.

The read from a 64-bit MMX register takes only eight cycles, including the two cycles for the RET instruction. If the application uses this core piece of the getbits function as a macro, the two-cycle overhead for the return is saved. Of course, this means an extra 42 bytes of code size each time this macro is called.

In addition, if another register can be spared, then the number of requested bits can be passed to the macro in the ECX register, or another similar register. The code may then take as few as four cycles (another instruction or a pair of instructions could execute during the free cycle). The restructured code is listed in Example 2.

Example 2. Restructured getbits Core

getbits:
1  sub  edi,ecx ; Are there enough bits in MM0
2  jnl  continue ; If there are, then continue
3  call  new64bit ; If not, get new 64 bits
4  jmp  out ; finished
continue:
5  movd  MM3,64_minus_index[ecx*4] ;MM3 = 64 - number of requested bits
6  movq  MM2,MM0 ; make a copy of the bits
7  movd  mm1,ecx ; number of bits to read
8  psrlq  MM2,MM3 ; MM2 has valid bitstream in least significant part
                  ;(free cycle)
                  ;(free cycle)
10  movd  eax,MM2 ; move the result into eax
11  psllq  MM0,MM1 ; throw away those bits
out:

2.2. new64bit Code

The new64bit code is performed when there are not enough bits available in MM0. This code (as illustrated in Figure 2) calculates the number of requested bits less the number of bits remaining in MM0. A temporary copy of the bits remaining in MM0 is made. Then, another 64 bits are obtained from the bitstream (in two 32-bit halves that are converted to little endian at the start of the refill code). The remaining bits are prepended to these bits. After the requested bits are returned in the EAX register, MM0 contains the remaining part of the new 64 bits (the new bits are appended to the previously remaining bits).

The code is listed in Example 3.
Actual statistics from a sample MPEG1 audio application shows that an average of 4.86 bits are requested each time `getbits` is called. This means that an average of once every 13.17 calls to `getbits`, 64 more bits are read from the buffer into MM0.

**Example 3. new64bit Code**

```assembly
; mm2 has remaining bits from old group
; mm4 has new 64 bits
; eax has -(number of bits we missed in old group), (negative)
1 add eax, 64 ; ecx has number of requested bits
2 movd mm3, _64_minus_index[ecx*4] ; eax = 64 - # of bits we missed in old group
3 psrlq mm2, mm3 ; MM3 = 64 - number of requested bits
4 movd mm3, eax ; mm2 has remaining bits in least significant part with room for new bits to right of it
5 movq mm0, mm4 ; mm3 = 64 - # of bits we missed in old group
6 psrlq mm4, mm3 ; bits to right of it
7 mov _bit_count, eax ; mm4 = new bits we now need in least significant part
8 por mm2, mm4 ; Save bit count for next time
9 movd mm1, _64_minus_index[4*eax] ; mm2 = remaining bits
10 movd eax, mm2 ; combine remaining bits with the bits
11 psllq mm0, mm1 ; from new word
12 por mm2, mm4 ; # of bits we missed in old group
13 movd eax, mm2 ; return bits in eax
14 psllq mm0, mm1 ; remove the bits we just read from mm0
```

**2.3. do_refill Code**

When the 64-bit aligned input buffer is empty, the `getbits` function performs the `do_refill` code. The `do_refill` code resets the values of `buf_pointer` (pointer to input buffer) and the `EndBuf` (pointer to end of buffer). If the application assumes that the buffer is never empty (for example, perhaps the buffer is filled at the end of every frame) the two-cycle overhead of testing for end of buffer can be saved.

The `do_refill` code reads new data from the input stream every 64 bits. The current 64 bits are stored in MM0. Therefore, other functions should not modify the contents of MM0.
3.0. PERFORMANCE GAINS

This section details the performance improvement as compared with traditional scalar code. There is approximately a 2X performance gain for the MMX optimized code version for typical MPEG Audio code.

3.1. Scalar Performance

The scalar version of the `getbits` function executes in 18 cycles (if there are enough bits in the 32-bit register). In case of a jump to the `new32bit` code (with a mispredicted branch it must be called more often since it retrieves only 32 bits), the code takes 38 cycles to execute, plus an additional five cycles (for the misprediction) to read another 32 bits.

Assuming 4.86 bits per read (see Section 2.2), the 32-bit register is refilled approximately every 6.58 reads. Total `getbits` execution time (on average) therefore is:

\[(18 \times (6.58-1) + (38+5)) / 6.58 = 21.8 \text{ cycles}\]

3.2. MMX™ Code Performance

The MMX optimized code version of the `getbits` function executes in eight cycles (if there are enough bits in MM0). The speedup can be attributed to several factors:

The MMX code uses 64-bit registers, rather than the 32-bit registers used by scalar code.

By using a 64-bit read, the cost of the mispredicted branch is reduced by half, compared to the scalar code with a 32-bit read.

In case of a jump to the `new64bit` code, the `getbits` function takes 19 cycles to execute, plus an additional five cycles (for the misprediction) to read another 64-bit value.

Again, assuming 4.86 bits per read (see Section 2.2), the 64-bit MM0 register is refilled approximately every 13.17 `getbits` calls. Therefore, on average, the total execution time is:

\[(8 \times (13.17-1) + (19+5)) / 13.17 = 9.2 \text{ cycles}\]

It takes 9.2 cycles to finish the MMX technology version of the `getbits` call. The performance gain is almost 2.4X over that of typical MPEG Audio code.

With the Pentium® Pro processor, the misprediction penalty is much higher. The performance gain relative to scalar code will therefore be even greater.

Note that this analysis assumes 100 percent misprediction on the branch.
4.0. GETBITS FUNCTION: CODE LISTING

```
486P

ASSUME ds:FLAT, cs:FLAT, ss:FLAT
EXTRN refill_buffer:PROC
DATA SEGMENT PARA PUBLIC USE32 'DATA'
ALIGN 16
64_minus_index dd 64,63,62,61,60,59,58,57,56,55,54,53,52,51,50,49,48,47,46,45,44,43,42,41,40,39,38,37,36,35,34 dd
33,32,31,30,29,28,27,26,25,24,23,22,21,20,19,18,17,16,15,14,13,12,11,10,9,8,7,6,5,4,3,2,1
EXTRN _buf_pointer:DWORD
EXTRN _end_buf:DWORD
EXTRN _bit_count:DWORD
DATA ENDS
_TEXT SEGMENT DWORD PUBLIC USE32 'CODE'
PUBLIC _getbits
_getbits:
    mov eax, DWORD PTR _bit_count ; Number of valid bits in MM0
    mov ecx, 4[ESP]               ; Parameter. How many bits should we
                                   ; read.
    sub eax,ecx                   ; Do we have enough bits in MM0
    jf new64bit                   ; If not get new 64 bits
    movd MM3, _64_minus_index[ecx*4] ;MM3 = 64 - number of needed bits.
    movq MM2,MM0                   
    movd mm1,ecx                   ; # of bits to read
    psrlq MM2,MM3                  ; MM2 now has valid bitstream in least
                                   ; significant part
    mov BYTE PTR _bit_count,al    ; Update number of valid bits.
    mov eax,MM2                    ; move the result into eax
    psllq MM0,MM1                  ; throw away those bits
    ret

new64bit:
    movd MM3, _64_minus_index[ecx*4] ;MM3 = 64 - number of requested bits
                                   ;(for shifting)
    movq MM2,MM0                   ; copy left over bits
    mov edx, DWORD PTR _buf_pointer ;pointer to bitstream
    mov ecx, DWORD PTR _end_buf    ;read pointer to end of buffer
    add edx,8                      ;update the pointer
    add eax,64                     ;eax = 64- # of bits we missed in old
                                   ;group
    cmp edx,ecx                     ;do we have another qword to read
    mov DWORD PTR _buf_pointer,edx  ;save new value
    mov ecx,[edx-8]                 ;read next qword (dword here)
    mov edx,[edx-4]                 ;(dword here)
    jge refill                      ;do_refill

refill:
    ; now convert from bigendian to little and
    ; but make use of left over bits (MM2) before using these
    bswap edx                      ;swapping the first 32 bit
    bswap ecx                      ;swapping the second 32 bit
    movd mm4,ecx                   ;second 32 bit in mm4
    psrlq mm2,mm3                  ;mm2 has remaining bits in least
                                   ;significant part with room for new
                                   ;bits to right of it
    movd mm1,edx                   ;move first 32 bit
    psllq mm4,32                   ;shift second 32 bit to upper part of
                                   ;register
    movd mm3,eax                   ;mm3 gets the shift counter
```
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por mm4,mm1  ;combine the 64 swapped data into mm4
movq mm0,mm4  ;save new word in mm0 for next time
psrlq mm4,mm3  ;mm4 = new bits we now need in least
mov bit_count,eax  ;significant part
por mm2,mm4  ;Save bit count for next time
mov mm1,_64_minus_index[4*eax]  ;combine remaining bits with the bits
movd eax,mm2  ;from new word
psllq mm0,mm1  ;return bits in eax
RET

do_refill:
    PUSH EAX
    PUSH EDX
    PUSH ECX
    CALL _refill_buffer
    POP ECX
    POP EDX
    POP EAX
    JMP refill

_TEXT ENDS
END