Using MMX™ Instructions to Implement Alpha Blending

Information for Developers and ISVs

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1.0. INTRODUCTION

The Intel Architecture (IA) media extensions include single-instruction, multidata (SIMD) instructions. This application note presents an alpha blending filter used for imaging effects. Specifically, the alpha blending function \( \text{alphaB} \) demonstrates how the MMX technology shifting capability can be used to organize and calculate the output array efficiently.

2.0. OVERVIEW

Alpha blending is used for imaging effects to merge two images together, weighting one image more than the other. Alpha blending can be used for fading from one image to another or for creating a translucent effect. For example, it can be used to put a 'ghost' image in a picture, or to place a window in an image.

The equation for alpha blending is as follows:

\[
s[r,g,b] = \alpha \cdot p[r,g,b] + (1 - \alpha) \cdot q[r,g,b]
\]

where \( \alpha \) is the weighting factor, \( 0 \leq \alpha \leq 1 \), \( p \) and \( q \) are the input pixels, and \( s \) is the alpha blended pixel within the final image.

3.0. DATA STORAGE

The \( p \) array is made up of 32-bit elements. The lower 8 bits are the blue value of the pixel \( p_b \), the next 8 bits are the green value of the pixel \( p_g \), the next 8 bits are the red value of the pixel \( p_r \), and the upper 8 bits are the \( \alpha \) value. This pixel format was chosen for this application note since the \( p \) array is commonly the result of calculations to determine the proper RGB \( \alpha \) values.

The \( q \) array is made up of 15-bit values. The lower 5 bits are the blue value of the pixel \( q_b \), the next 5 bits are the green value of the pixel \( q_g \), and the upper 5 bits are the red value of the pixel \( q_r \). The resulting array \( s \) is made up of 15-bit values set up in the same order as the \( q \) array of pixels. This format, shown in Figure 1, was chosen for this application note since it is a common format for pixels already stored in a high color display buffer.

![Figure 1. Bit Arrangement for p, q, and s Pixels](image-url)
4.0. IMPLEMENTATION

The alpha blending equation was optimized for MMX technology as follows:

\[
\begin{align*}
  s &= \alpha * p + (1 - \alpha) * q \\
  s &= \alpha * p + q - \alpha * q \\
  s &= \alpha * (p - q) + q
\end{align*}
\]

Figure 2 shows a register diagram of the pixel calculations that are done in the main loop L3. The loop L3 occurs \( n \) times where \( n \) is the number of rows times the number of columns in the images \( p \) and \( q \). Before the start of loop L3, register MM0 contains the \( p \) pixel value and register MM7 contains the \( q \) pixel value for the current calculation. After the L3 loop occurs four times the four new \( s \) pixel values are stored over the old \( q \) pixel values.

*Figure 2. Program Flow of Main Loop*
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\[ aa = \alpha \]

\[
\begin{align*}
\text{MM7} & \quad \text{MM0} \quad \text{MM2, MM3, MM4} \\
00aa & \quad 00pr & \quad 00pg & \quad 00pb \\
\text{XX}XX & \quad \text{XX}XX & \quad \text{XX} & \quad \text{XX} qg qb \\
00aa & \quad 00aa & \quad \text{XX}XX & \quad \text{XX}XX \\
\text{PUNPCKHWD mm1, mm1} & \quad \text{PUNPCKHDQ mm1, mm1} & \quad \text{PAND mm2, maskr} & \quad \text{PSLLQ mm2, 25} \\
00aa & \quad 00aa & \quad 00aa & \quad 00aa \\
\end{align*}
\]

\[ \text{mm2, mm3, mm4 OR'd together} \]

\[
\begin{align*}
\text{MM1} & \quad \text{PSUBW mm0, mm2} \\
0000 & \quad 0000 & \quad 0000 & \quad 0000 & \quad 0000 & \quad 0000 \\
\text{MULLW mm0, mm1} & \quad \text{PSLLW mm2, 8} & \quad \text{PADDW mm2, mm0} \\
0000 & \quad aa* & \quad pr & \quad -qr & \quad 00 & \quad pe & \quad -qe & \quad pp & \quad -qb \\
0000 & \quad aa* & \quad pr & \quad -qr & \quad 00 & \quad pe & \quad -qe & \quad pp & \quad -qb \\
\text{MM2} & \quad \text{MM3} & \quad \text{MM4} & \quad \text{MOVQ mm3, mm2} & \quad \text{MOVQ mm4, mm3} \\
0000 & \quad aa(pr-qr) & \quad +gr+0.5 & \quad aa(pg-qt) & \quad +gq+0.5 & \quad aa(pb-qt) & \quad +qb+0.5 \\
0000 & \quad aa(pr-qr) & \quad +gr+0.5 & \quad aa(pg-qt) & \quad +gq+0.5 & \quad aa(pb-qt) & \quad +qb+0.5 \\
0000 & \quad aa(pr-qr) & \quad +gr+0.5 & \quad aa(pg-qt) & \quad +gq+0.5 & \quad aa(pb-qt) & \quad +qb+0.5 \\
\text{MM2} & \quad \text{MM3} & \quad \text{MM4} & \quad \text{PSLLQ mm2, 15} & \quad \text{PSLLQ mm3, 26} \\
0000 & \quad 0000 & \quad 0000 & \quad 0000 & \quad 0000 \\
\text{PADDW mm2, mm0} & \quad \text{PAND mm2, maskrH} \\
0000 & \quad 0000 & \quad 0000 & \quad 0000 & \quad 0000 \\
\text{PSLLQ mm3, 26} & \quad \text{PAND mm3, maskgH} \\
0000 & \quad 0000 & \quad 0000 & \quad 0000 & \quad 0000 \\
\text{PSLLQ mm4, 37} & \quad \text{PAND mm4, maskbH} \\
0000 & \quad 0000 & \quad 0000 & \quad 0000 & \quad 0000 \\
\text{mm2, mm3, mm4 OR'd together and held in mm5 until 4 results calculated} \]

\[
\begin{align*}
\text{MM5} & \quad \text{MM4} \\
0000 & \quad 0000 & \quad 0000 \\
\end{align*}
\]
Notice how the $\alpha$ value is replicated to perform the transformation. In the equation, $\alpha$ must be multiplied by each component of the result of the $p-q$ calculation, namely $(p-q)_{\text{red}}$, $(p-q)_{\text{green}}$, and $(p-q)_{\text{blue}}$. To do this the $\alpha$ comes from the $p$ pixel and is replicated three times for use with each component. This can be accomplished by using the PUNPCKHWD and PUNPCKHDQ instructions with the same register specified for both inputs, as shown in Figure 3.

Figure 3. MMX Code Trick for Data Manipulation

\[
\begin{array}{c}
\text{aa} = \alpha \\
\text{MM1} \\
PUNPCKHWD \quad \text{mm1, mm1}
\end{array}
\begin{array}{cccc}
00aa & 00pc & 00pg & 00pb \\
\end{array}
\]

\[
\begin{array}{c}
\text{MM1} \\
PUNPCKHDQ \quad \text{mm1, mm1}
\end{array}
\begin{array}{cccc}
00aa & 00aa & XXXX & XXXX \\
\end{array}
\]

\[
\begin{array}{c}
\text{MM1} \\
PUNPCKHDQ \quad \text{mm1, mm1}
\end{array}
\begin{array}{cccc}
00aa & 00aa & 00aa & 00aa \\
\end{array}
\]

Approximately 92% of the instructions in the L1 loop are paired in the code presented in this paper. It might be possible to reduce the number of registers used in this loop to four so that the loop may be unrolled to improve the pairing. Also, the optimized technique used in Using MMX Instructions to Convert 24-Bit True Color Data to 16-Bit True High Color, Application Note AP-553 (Order number 243038) for the final packing of the result to 16-bit color format could be used to make the implementation more efficient. For these enhancements, the algorithm presented here would have to be reimplemented.
**5.0. PERFORMANCE**

The following cycle calculations were done by placing assembler tracing calls around both the C function call and the MMX function call that performs the alpha blending operation. The C code was compiled with a maximum speed compiler switch. The input images are 72x58 pixels. The code was traced, and the data file was used to generate a log file which contains the cycle information for each case.

For the scalar version of the alpha blending function:

- 936166 total cycles / 4176 pixels 224 cycles / pixel

For the MMX technology version of the alpha blending function:

- 118562 total cycles / 4176 pixels 28 cycles / pixel
6.0. CODE LISTING

;**************************************************************************/
;*              Copyright (c) 1996 Intel Corporation.
;*                      All rights reserved.
;**************************************************************************/
;**************************************************************************/
;*  File : alphammx.asm                                     Date : 3/4/96
;*;
;* Description:
;*
;*  This routine computes the alpha blending of two 8-bit RGB images as follows :
;*  s[r,g,b] = aa * p[r,g,b] + (1-aa) * q[r,g,b]
;*  IMPORTANT!!!
;*  This function requires that the total number of pixels in the image to be a multiple of 4, i.e. nx*ny = 4N
;*
;* Revision History:
;*  Name                    Date        Description
;*  ---------------------------------------------------------------------
;*;**************************************************************************/
title   alphaB
include iammx.inc
.486P
.model  flat,c
.data
zeros   dq       0h
roundf  dd  800080h,       80h
maskr   dd    7c00h,        0h
maskg   dd     3e0h,        0h
maskb   dd      1fh,        0h
maskrH  dd       0h, 7c000000h
maskgH  dd       0h,  3e00000h
maskbH  dd       0h,   1f0000h
.code
;------------------------------------------------------------------------
;       input:      p_ptr   pointer to array of [aa:8 pr:8 pg:8 pb:8]
;                   q_ptr   pointer to array of [qr:5 qg:5 qb:5]
;                   nx      number of rows
;                   ny      number of columns
;
;       output:     q_ptr   pointer to array of [sr:5 sg:5 sb:5]
alphaB  proc near C uses esi edi eax ebx ecx edx,
    p_ptr   : ptr dword,
    q_ptr   : ptr word,
    nx      : ptr word,
    ny      : ptr word
;------------------------------------------------------------------------

mov     esi, p_ptr              ; esi = p
xor     eax, eax                ; eax = 0
mov     edi, q_ptr              ; edi = q
xor     ecx, ecx                ; ecx = 0
mov     ax, word ptr nx         ; ax = nx
mov     cx, word ptr ny         ; cx = ny
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```
imul    eax, ecx              ; eax = nx*ny
L1:     movq    mm7, mmword ptr [edi] ; mm7 = qqq4 qqq3 qqq2 qqq1
        pxor    mm5, mm5             ; mm5 = 0000 0000 0000 0000
L2:     movq    mm6, mmword ptr [esi] ; mm6 = a2r2 g2b2 a1r1 g1b1
        movq    mm0, mm6             ; mm0 = xxxx xxxx aarr ggbg
        add    esi, 8                ; esi += 8
L3:     punpcklbw mm0, mmword ptr zeros ; mm0 = 00aa 00rr 00gg 00bb
        movq    mm2, mm7             ; mm2 = 0000 0000 0000 0000
        pand    mm2, maskr           ; mm2 = 0000 0000 0000 qqqq
        movq    mm1, mm0             ; mm1 = xxxx xxxx aarr ggbg
        movq    mm3, mm7             ; mm3 = 0000 0000 0000 0000
        punpckhwd mm1, mm1           ; mm1 = xxxx xxxx xxxx qqqq
        pand    mm3, maskg            ; mm3 = xxxx xxxx xxxx 0qqq
        movq    mm4, mm7             ; mm4 = xxxx xxxx xxxx 0qqq
        psllq    mm2, 25              ; mm2 = 0000 0000 0000 0000
        movq    mm4, mm7             ; mm4 = 0000 0000 0000 0000
        psllq    mm3, 14              ; mm3 = 0000 0000 0000 0000
        pand    mm4, maskkb           ; mm4 = 0000 0000 0000 0000
        punpckhwdq mm1, mm1           ; mm1 = xxxx xxxx xxxx xxxx
        por     mm2, mm3              ; mm2 = xxxx xxxx xxxx xxxx
        psllq    mm4, 3               ; mm4 = 0000 0000 0000 0000
        por     mm2, mm4              ; mm2 = xxxx xxxx xxxx xxxx
        psrlq    mm6, 32              ; mm6 >>= 32
        psllw    mm0, mm2             ; mm0 = p - q
        psllw    mm2, 8               ; mm2 = 0000 qr00 qg00 qb00
        paddw    mm2, roundf          ; mm2 = q + round'd factor
        pmullw    mm0, mm1            ; mm0 = (p-q)*aa
        psrlq    mm5, 16              ; mm5 >>= 16
        pslrq    mm7, 16              ; mm7 >>= 16
        nop
        paddw    mm2, mm0              ; mm2 = (p-q)*aa+q + round'd factor
        movq    mm0, mm6              ; mm0 = xxxx xxxx aarr ggbg
        movq    mm3, mm2              ; mm3 = mm2
        psllq    mm2, 15              ; mm2 = rrxx xxxx xxxx xxxx
        movq    mm4, mm3              ; mm4 = mm3
        psllq    mm3, 26              ; mm3 = xggx xxxx xxxx xxxx
        pand    mm2, maskrH           ; mm2 = rr00 0000 0000 0000
        psllq    mm4, 37              ; mm4 = xxbb xxxx xxxx xxxx
        pand    mm3, maskgH           ; mm3 = 0ggg 0000 0000 0000
        por     mm5, mm2              ; mm5 = sss0 0000 0000 0000
        pand    mm4, maskbH           ; mm4 = 0000 0000 0000 0000
        por     mm5, mm3              ; mm5 = ssss SSSS SSSS SSSS
        por     mm5, mm4
        dec    eax                    ; -- eax
        test    eax, 1
        jnz     L3
        test    eax, 2
        jnz     L2
        movq    mmword ptr [edi], mm5 ; save 4 alpha blended words in q
        cmp    eax, 0
        je      L4
        add    edi, 8                ; edi += 8
        jmp    L1
L4:     emms
        ret
alphaB  endp
end
```