

# Enhanced Table Lookup Performance

## Using the MPC5500 Signal Processing Engine (SPE)

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### 1 Introduction

Lookup tables are often used to store data in a multi-dimensional array format. These tables provide a means to capture the dynamic behavior of a system and allow it to be expressed as a predetermined set of data points (called breakpoints<sup>1</sup>). The breakpoints are used to store the input-output mapping of the system. That is, for each input value, there are one or more associated output values, depending on the number of dimensions in the array.

In many automotive applications, table lookups comprise a large percentage of the overall execution time of the application, typically 10-20%. The tables used for these functions are two dimensional and have relatively few breakpoints. Traditional search methods such as binary search or hash functions do not work well on small tables. Usually a simple iterative search and compare loop is used to find a corresponding breakpoint for a given input value.

1. These breakpoints should not be confused with the term breakpoint as used in a software debugger.

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This application note describes the operation and performance results for an optimized table lookup function and compares execution time with a more typical search function. The optimized function is written in assembly using the PowerPC 32-bit Book E instruction set with the Signal Processing Engine (SPE) and its related instructions.

Example code is included for both the typical and optimized lookup functions and the optimized function example may be built into an application with minimal modification.

## 2 Function Overview

The lookup table is a set of values or breakpoints consisting of an input or x value and a corresponding output or y value. The relationship of each discrete input to output value pair usually represents a continuous function where y is some function of x, or  $f(x) = y$ .

To generate a return value y, the table lookup function takes the input and attempts to find a matching x value:

- If the input value is less than the first x value or greater than the last x value, the function uses the appropriate end point y value as the output.
- If a matching x value is found, the corresponding y value is returned.
- If neither of the first two conditions are met, the function finds the two nearest x values above and below the input value, and determines the slope of the function between those two points (i.e. is  $Y_{LOW}$  greater than or less than  $Y_{HIGH}$ ?) Then, [Equation 1](#) is used to perform a linear interpolation and approximate a y value.

**Eqn. 1**

$$Y = Y_{LOW} + \frac{((input - X_{LOW}) \cdot (Y_{HIGH} - Y_{LOW}))}{(X_{HIGH} - X_{LOW})}$$

$Y$	– Interpolated return value.
$input$	– input x value.
$X_{LOW}$	– The nearest x value in the table that is less than the input value.
$Y_{LOW}$	– The y value associated with $X_{LOW}$ .
$X_{HIGH}$	– The nearest x value in the table that is greater than the input value.
$Y_{HIGH}$	– The y value associated with $X_{HIGH}$ .

The functions are called with a pointer to the appropriate table, and an input x value and return a 16-bit value.

## 3 Table Format

The table may have a variable number of entries, but the total number of entries must be a multiple of four. A table entry is defined as one x y pair.

As discussed in [Section 1](#), there are two example lookup functions, a typical iterative search function written in C, and an optimized function written in assembly using SPE instructions. The following sections define the required formats and contents of the table data for each of the function types.

**NOTE**

While the table structure and format differs for the C and assembly versions of the lookup table, the size of the tables and the data values are identical to insure valid performance comparisons.

### 3.1 General Requirements

The following are requirements for the lookup data tables used in this application note:

- All x and y table entries should be unsigned, fixed point numbers.
- The lookup table should have each x entry in order of increasing magnitude. That is, x1 must be less than x2, x2 must be less than x3, etc.
- Every x value must have a corresponding y value.
- Each table must be a global data structure.

### 3.2 Table Data for C Function

The table data for the C lookup function is shown in [Figure 1](#). The first byte (lowest memory address of the table) contains the number of table entries. Following that byte, there is a one byte pad to align the first table entry pair on the appropriate memory boundary. Following that are the x y pairs of the table.

Offset	16-bits	
0x00	0xC	0x0
0x02	x1	
0x04	y1	
0x06	x2	
0x08	y2	
...	...	
0x2E	x12	
0x30	y12	

Number of x/y pairs

**Figure 1. C Function Table Memory Layout**

### 3.3 Table Data for Optimized assembly Function

In order to take advantage of the SPE instruction set used in the assembly functions, the table data must be organized in memory to accommodate the use of 64-bit operands found in many SPE instructions. The memory layout for the SPE assembly function lookup table is shown in [Figure 2](#).

In the SPE optimized version of the data table the following rules apply:

- Each table entry must be two bytes in length.
- Each data vector can hold any number of entries; however, in order to avoid an alignment exception error, the total number of table entries must be a multiple of 4.

- Dummy values can be stored in the table if the data has a number of breakpoints that is not a multiple of four.
- The x values must be stored in ascending order.
- The y values must be interleaved as shown in [Figure 2](#).
- The second and fourth 16-bit values of the table must contain the offset to the first y value from the base address of the table.

Offset	32-bits	
0x00	0x0	0x20
0x04	0x0	0x20
0x08	x1	x2
0x0C	x3	x4
0x10	x5	x6
0x14	x7	x8
0x18	x9	x10
0x1C	x11	x12
0x20	Y1	Y3
0x24	Y2	Y4
0x28	y5	y7
0x2C	y6	y8
0x30	y9	y11
0x34	y10	y12

**Figure 2. Assembly Function Table Memory Layout**

## 4 Lookup Algorithms

This section provides a comparison of the actual algorithms used in the lookup routines.

### 4.1 C-Based Algorithm

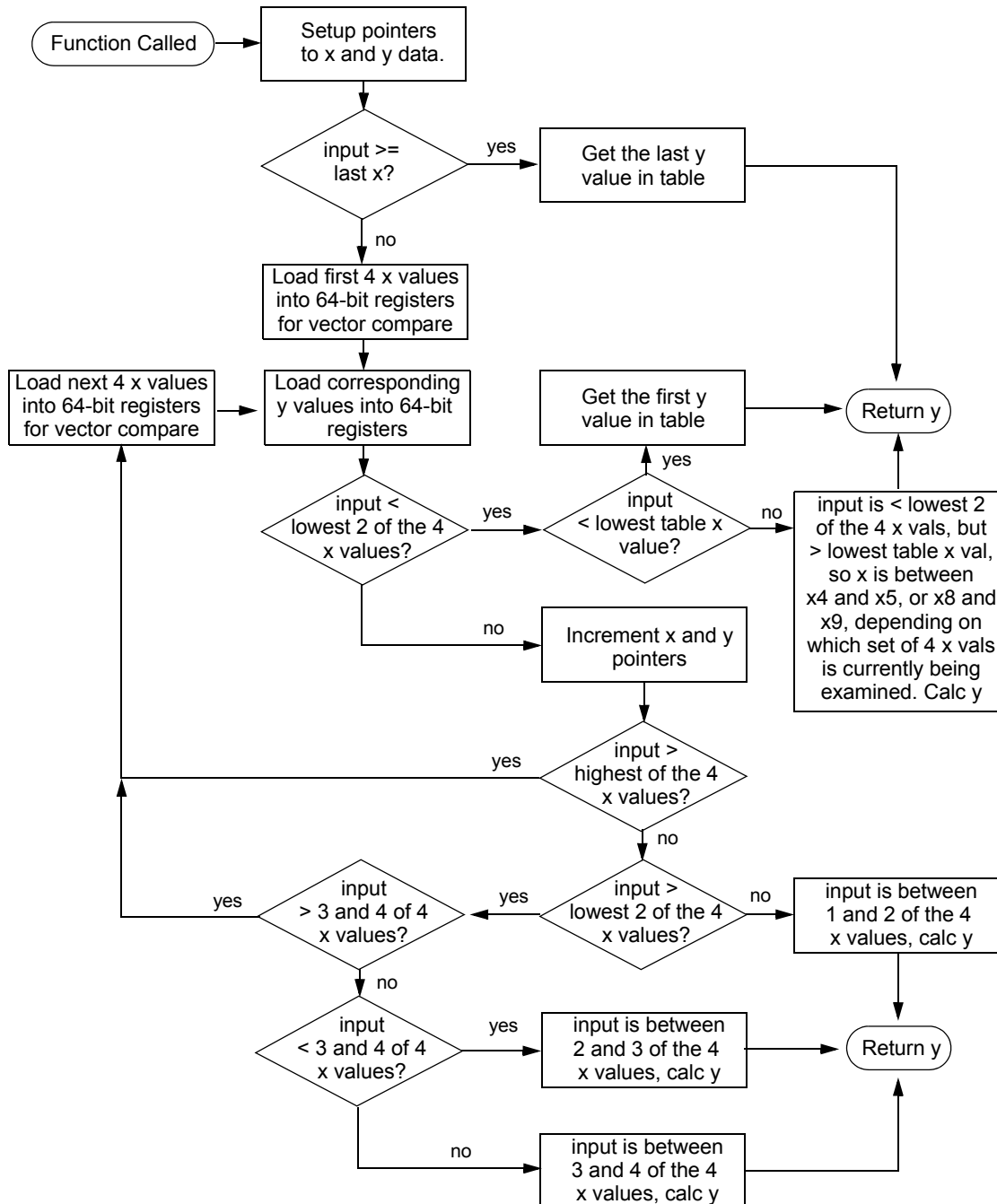
The non-optimized C code lookup functions do not use SPE instructions to perform table lookups, but rather a traditional iterative search algorithm. This type of algorithm is essentially a simple increment and compare loop, where the farther into a table the match is located, the longer the execution time that is required. This is a well known search algorithm and the details are not discussed in this application note. A code listing for the C code can be found in [Section A.2](#).

### 4.2 SPE Optimized Algorithm

The SPE optimized lookup algorithm is coded in assembly, and due in part to the unique way that the SPE instructions are implemented, is not easily understood by a simple inspection of the code listing. The inherent advantage of the SPE optimized function is that it utilizes 64-bit registers to perform tests or compares on two values simultaneously. The following section and diagram details the steps of the SPE

enhanced algorithm. Each related code segment is followed by an explanation of the purpose of the operation(s). The code listing includes line numbers to simplify referencing. Referencing the table data layout (see [Section 3.3](#)) will aid in understanding the following algorithm. A complete listing of the SPE based code can be found in [Section A.1](#).

## 4.2.1 Flow Diagram



## 4.2.2 Code Analysis

This section provides a line by line analysis of the SPE based table lookup function.

```
1 unsigned short var_table_lookup_asm( unsigned short *DataPtr, unsigned short Input)
```

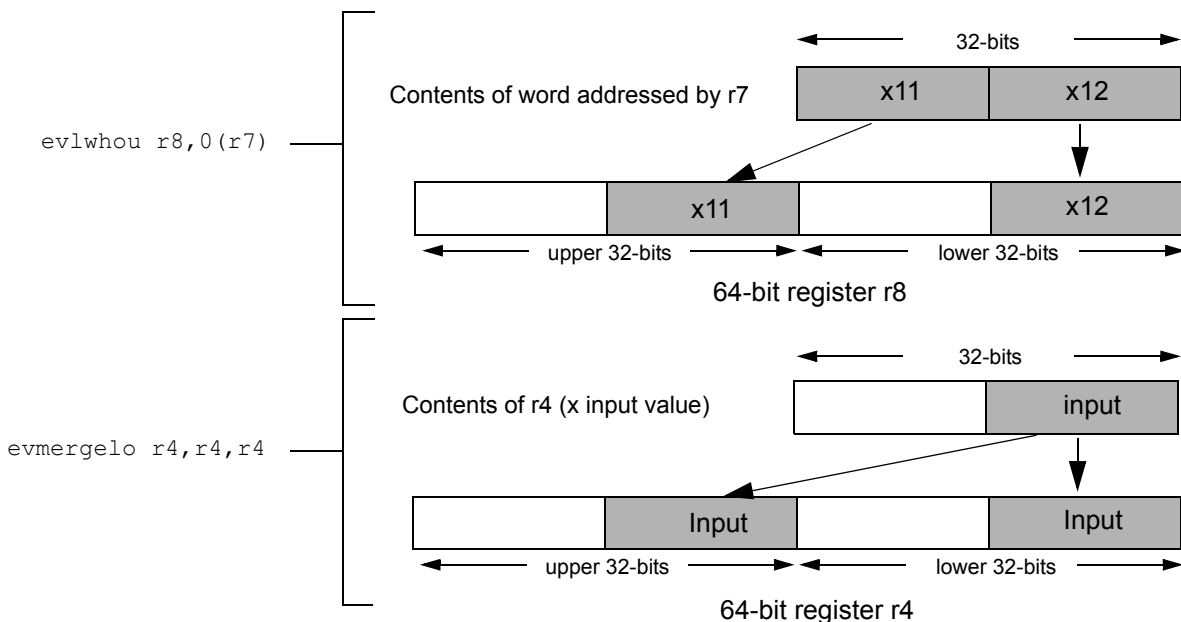
Line 1 is the actual function declaration. This function is called with two args, a pointer to the relevant data table (\*DataPtr), and the input x value (Input). Notice that it returns an unsigned 16-bit value.

```
{
/*Set up X and Y data pointers*/
2  asm("lhz      r12,8(r3)      "); // initialize r12 to first X val
3  asm("lwz      r5,0(r3)      "); // Put the y-offset (from table entry) value in r5
4  asm("addi     r6,r5,-8      "); // Put the number of data points times 2 in r6
5  asm("add      r5,r3,r5      "); // Set r5 to the address of the first Y value
                                   // r5 = r3 (table address) + r5 (y-offset)
6  asm("addi     r7,r5,-4      "); // r7 = address of word holding last two x values
```

Lines 2 through 6 perform several operations to setup up the required pointers into the data structure as indicated by the code comments. The PowerPC EABI dictates that when this function is called, r3 holds the address of the data structure, and r4 holds the input value.

```
7  asm("evlwhou   r8,0 (r7)     "); // 64-bit r8 now holds next to last x and last x
                                   // values
8  asm("evmergelo  r4,r4,r4     "); // move r4[0:31] to r4[32:63]
```

Lines 7 and 8 perform SPE operations to setup up for a compare as shown below.



```
9  asm("cmp      1,r8,r4       "); // bounds check (input >= last x value?)
10 asm("bc       4,4,toohigh   "); // if > or = last x, then input is out of bounds
```

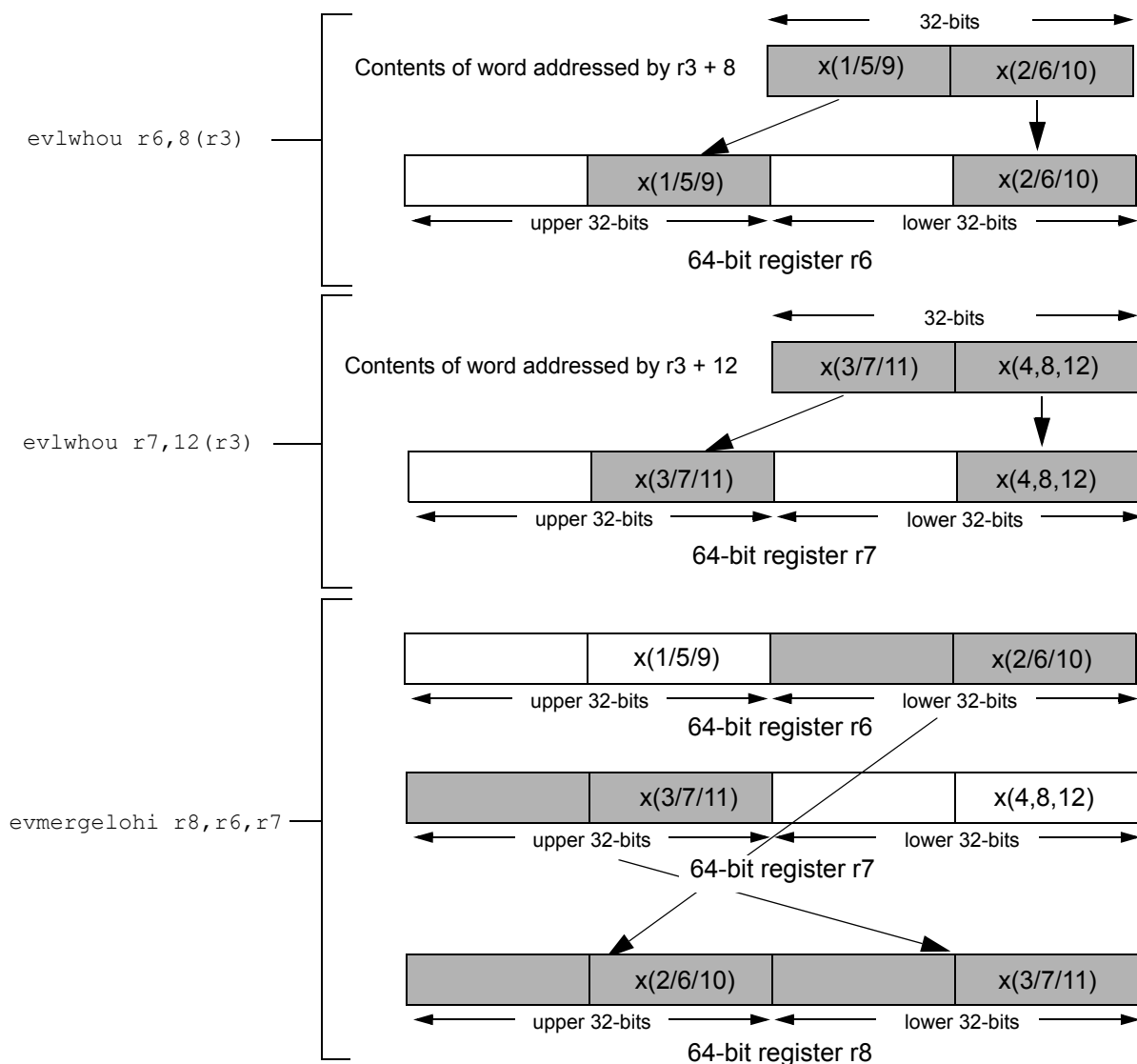
Line 9 compares the input value in the lower 32-bits of r4 with the maximum x value which is in the lower 32-bits of r8. If the input is greater than or equal to the last x value, the code branches to the label toohigh.

```
/* Pre-load 4 x-values to compare with input. Note that the first time through this loop
```

```

64-bit registers r6 and r7 hold x1, x2, x3, and x4. The second time through this loop, if
necessary, they will hold x5, x6, x7, and x8, and the last time through this loop, if
necessary, they will hold x9, x10, x11 and x12. */
11 asm("Loop:");
12 asm("evlwhou      r6,8 (r3)   "); // r6[0:31]=x(1/5/9), r6[32:63]=x(2/6/10)
13 asm("evlwhou      r7,12 (r3)  "); // r7[0:31]=x(3/7/11), r7[32:63]=x(4/8/12)
14 asm("cmp          1,r7,r4     "); // Early Check input > r7[32:63]? result in CR1
15 asm("evmergelohi   r8,r6,r7   "); // r8[0:31]=x2/x6/x10 ,r8[32:63]=x3/x7/x11
    
```

Depending on which iteration through the loop this is, lines 12 through 15 load the  $x(1/5/9)$ ,  $x(2/6/10)$ ,  $x(3/7/11)$  and  $x(4/8/12)$  values into vectors as shown below, in preparation for a vector compare with the input value. Note that after these operations a vector compare can be made on  $x1$  and  $x2$  ( $r6$ ),  $x2$  and  $x3$  ( $r8$ ), or  $x3$  and  $x4$  ( $r7$ ). The  $x(\text{loop } 1/\text{loop } 2/\text{loop } 3)$  designation indicates which value  $x$  takes depending on the loop iteration. Similarly, a  $y(\text{loop } 1/\text{loop } 2/\text{loop } 3)$  designation indicates the  $y$  value depending on the loop iteration. As an example, the second time through the loop, the  $x$  values will be  $x5$ ,  $x6$ ,  $x7$  and  $x8$ .



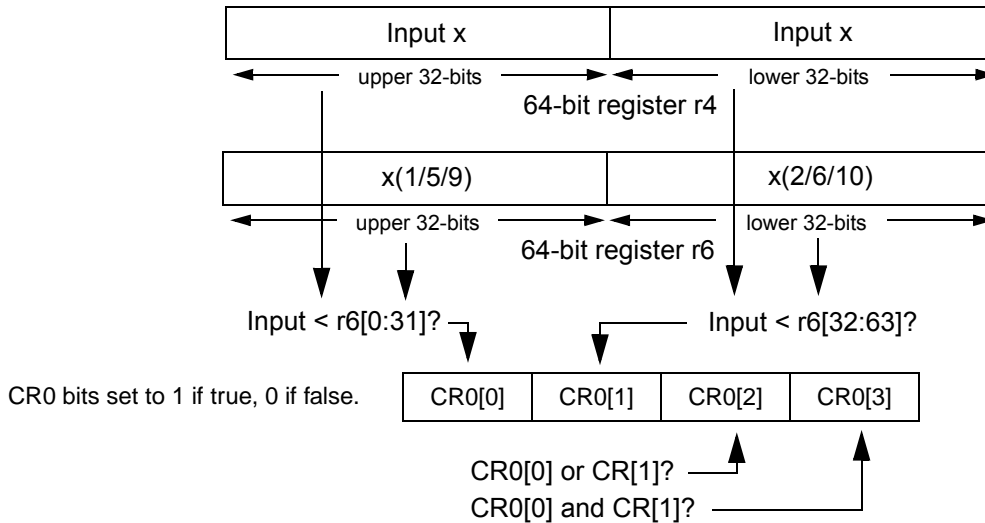
## Lookup Algorithms

```

/* Check the input against current x value pair in r6 */
16 asm("evcmplts    0,r4,r6    ");    // compare input to current pair of x values in r6,
                                     // result in CR0

```

Line 16 performs a vector compare of r4 to r6, which now holds  $x(1/5/9)$  and  $x(2/6/10)$ . The results of this compare are captured in the CR0 register as shown in the following diagram. Note that this single vector compare instruction provides information that can be used for several conditional branches later in the algorithm.



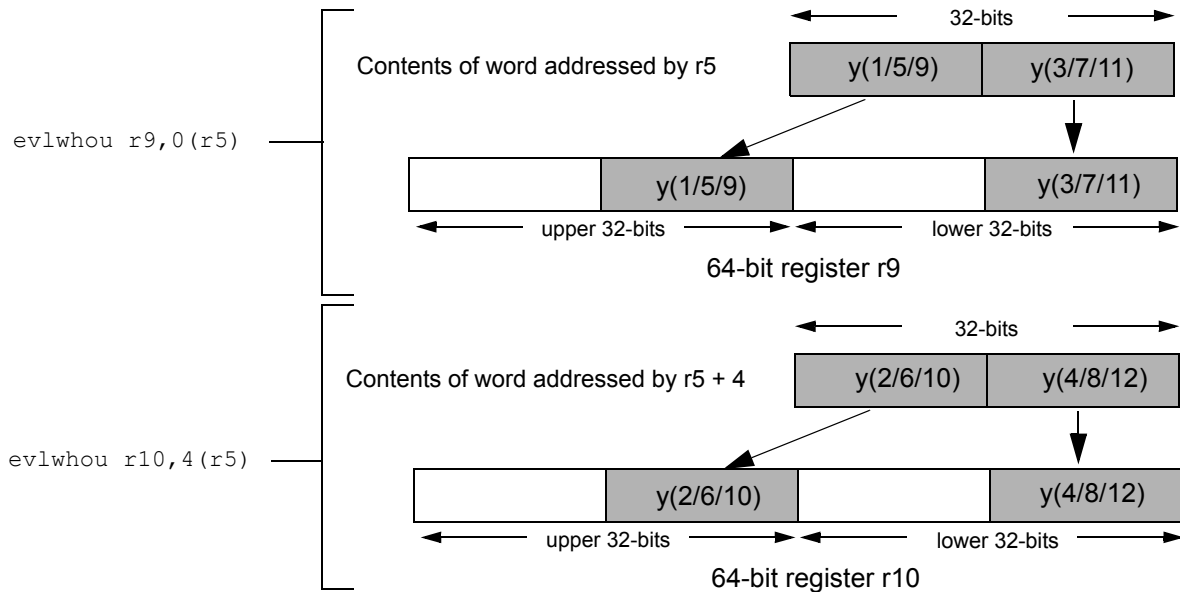
```

/* load the related y values in r9 and r10 */
17 asm("evlwhou    r9,0 (r5)    ");    // r9[0:31]=y1/y5/y9 , r9[32:63]=y3/y7/y11
18 asm("evlwhou    r10,4 (r5)   ");    // r10[0:31]=y2/y6/y10 , r10[32:63]=y4/y8/y12
19 asm("bc         12,3,BackGrd2");    // is input < both r6 x values?, if so branch

```

Lines 17 and 18 move  $y(1/5/9)$ ,  $y(3/7/11)$ , and  $y(2/6/10)$ ,  $y(4/8/12)$  into r9 and r10 respectively (r5 holds the address of the first y value) as shown in the following diagram. These values are needed later to calculate a return value so are loaded now. The results of the input value compare in line 16 are still in CR0 at this point, and now a conditional branch is made in line 19 based on the value in CR0[3]. If the input value is less than both  $x(1/5/9)$  and  $x(2/6/10)$ , the branch is taken, if not execution continues inline.

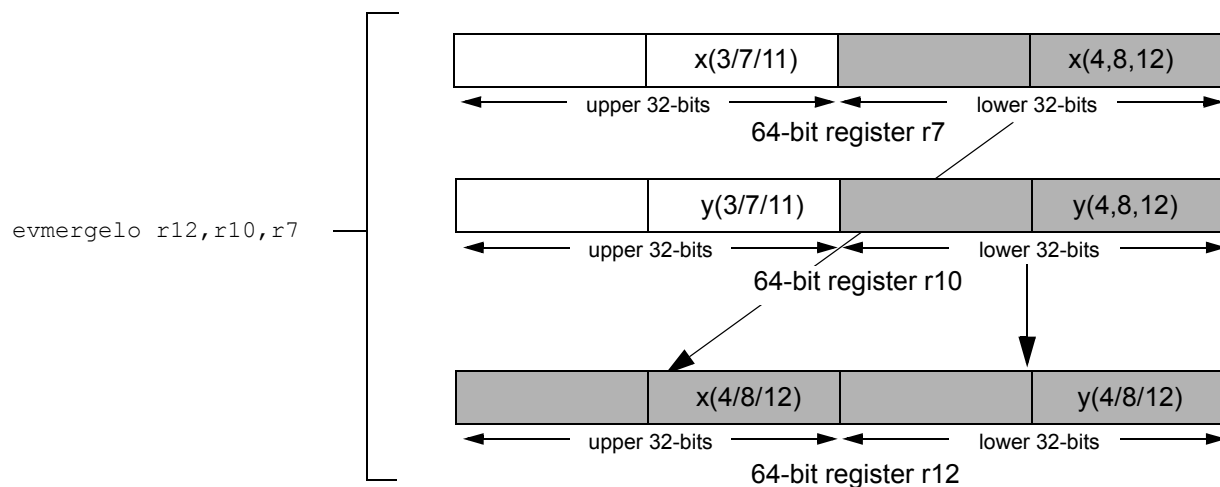




```

20 asm("evmerge10    r12,r10,r7    "); // else save r7[32:63] and r10[32:63] in case input
21 asm("addi         r3,r3,8        "); // is between r7[32:63] and the next greater x value.
22 asm("addi         r5,r5,8        "); // increment x pointer in case input > r7[32:63]
23 asm("bc           12,4,Loop      "); // increment y pointer in case input > r7[32:63]
                                     // if (input > r7[32:63]) get next four x values to
                                     // compare
    
```

As shown in the following diagram, line 20 saves x(4/8/12) and y(4/8/12) in case the input value is between one of the three 'groups' of four x values being examined in 64-bit registers r6 and r7, i.e. x input is greater than x4, but less than x5 or greater than x8, but less than x9. Lines 21 and 22 increment the x and y pointers in case the input x value is greater than x(4/8). Line 23 checks to see if the input is greater than all four x values and if so, branches to `Loop` to get the next four x values in the table.



## Lookup Algorithms

```
24 asm("evsubfw      r11,r9,r10   "); // else r11[0:31]=(y2/y6/y10 - y1/y5/y9),
                                     // and r11[32:63]=(y4/y8/y12 - y3/y7/y11),
                                     // this is (y high-y low)
25 asm("bc           4,1, comp     "); // if(input > x1/x5/x9 & x2/x6/x10) branch
```

Line 24 calculates the difference between y high, and y low for each of the four y values in 64-bit registers r9 and r10. These values are used later during calculation of the return value. Line 25 does a compare of  $x(1/5/9)$  and  $x(2/6/10)$ , and if the x input value is greater than both a branch is taken to comp.

```
/* If no branch was taken, input is known to be between x(1/5/9) and x(2/6/10) so a return
   value is interpolated. */
26 asm("evsubfw      r4,r6,r4      "); // r4 = r4-r6 (input - xlow)
27 asm("evmergehi    r4,r0,r4      "); // r4[0:31]-->r4[32:63]
28 asm("evmergehi    r11,r0,r11    "); // r11[0:31]-->r11[32:63] (y high-y low)
29 asm("mullw        r4,r4,r11     "); // (input-Xlow) * (Yhigh-Ylow)
30 asm("evsubfw      r8,r6,r8      "); // (xhigh-Xlow), r8[0:31]=(X2-X1)
31 asm("evmergehi    r8,r0,r8      "); // r8[0:31]-->r8[32:63]
32 asm("divw         r4,r4,r8      "); // 32 bit quotient
33 asm("evmergehi    r9,r0,r9      "); // r9[0:31]-->r9[32:63]
34 asm("add          r3,r4,r9      "); // return answer in r3
35 asm("b            return_y     ");
```

If the branch in line 25 was not taken, the input x value is known to be between  $x(1/5/9)$  and  $x(2/6/10)$  so beginning at line 26, a return value is interpolated based on the formula in [Equation 1](#) on Page 2 and returned to the calling function.

```
/* Checking if input is between x3/x7/x11 and x4/x8/x12 */
36 asm("comp:");
37 asm("evcmltbs     0,r4,r7       "); // input< r7 (input< x3/x7/x11 or input< x4/x8/x12),
                                     // result in CR0
38 asm("bc           4,1, Loop     "); // if(input > x3/x7/x11 & x4/x8/x12) get more x values
39 asm("bc           12,3,BackGrd1 "); // if(input < x3/x7/x11 & x4/x8/x12) branch.
```

If the code reaches the comp label at line 36, the x input value is now checked to see if it is less than  $x(3/7/11)$  and/or  $x(4/8/12)$ . The results of this compare are in CR0. If the input is greater than both these x values, a branch is taken in line 38 to Loop to get the next set of four x values. If the input x value is less than both of these x values it must be between x2 and x3 so execution branches at line 39 to BackGrd1 to interpolate a y value.

```
/*At this point X input is known to be between x3/x7/x11 and x4/x8/x12 so a return
   value is interpolated. */
40 asm("subf         r4,r8,r4      "); // r4 = r4 -r8 (input-xlow)
41 asm("mullw        r4,r4,r11     "); // (input-Xlow)*(Yhigh-Ylow)
42 asm("subf         r8,r8,r7      "); // (Xhigh-Xlow), r8[32:63]= x(4/8/12) - x(3/7/11)
43 asm("divw         r4,r4,r8      "); // 32 bit quotient
44 asm("add          r3,r4,r9      "); // return answer in r3
45 asm("b            return_y     ");
```

If neither branch in lines 38 and 39 were taken, the input x value is between  $x(3/5/7)$  and  $x(4/8/12)$ . The code starting at line 40 interpolates a y value and returns it to the calling function.

```
/*At this point X input is known to be between x2/x6/x10 & x3/x7/x11 so a return
   value is interpolated. */
46 asm("BackGrd1:");
47 asm("evmergehi    r10,r0,r10    "); // r10[0:31]-->r10[32:63]= Y2
48 asm("subf         r4,r6,r4      "); // compute (input-Xlow)
49 asm("subf         r9,r10,r9     "); // (Yhigh-Ylow) or (Y3-Y2)
50 asm("mullw        r4,r9,r4      "); // (input-Xlow)*(Yhigh-Ylow)
```

```

51 asm("subf      r8,r6,r8      "); // (Xhigh-Xlow), r8[32:63]=(Y3-Y2)
52 asm("divw      r4,r4,r8      "); // 32 bit quotient
53 asm("add       r3,r4,r10     "); // return answer in r3
54 asm("b         return_y      ");

```

If the branch in line 39 was taken, the input x value is between  $x(2/6/10)$  and  $x(3/7/11)$ . The code starting at line 47 interpolates a y value and returns it to the calling function.

```

/* Input is less than the current x values in r6, so it's either too low,
   or between x4 and x5, or between x8 and x9.*/
55 asm("BackGrd2:");
56 asm("evmergehilo r4,r9,r4      "); // r9[0:31]=Yhigh r4[32:63]=input

```

If the branch in line 19 was taken, the input x value is less than  $x(1/5/9)$  and  $x(2/6/10)$ . If the input x value is not lower than the first x value, the code starting at line 57 interpolates a y value and returns it to the calling function. Line 63 does a compare of the input x value and the lowest possible x table value (x1). If it is less than x1, the code branches to `toolow`.

```

57 asm("evsubfw    r5,r12,r4      "); // else, compute (Yhigh-Ylow) and (input-Xlow)
58 asm("evmergehi  r10,r0,r5      "); // r4[0:31]-->r10[32:63]
59 asm("mullw      r10,r5,r10     "); // (Yhigh-Ylow)*(input-Xlow)
60 asm("evmergehi  r6,r0,r6      "); // r6[0:31]-->r6[32:63]
61 asm("subf      r8,r12,r6      "); // (Xhigh-Xlow), r8[32:63]=(X5-X4)
62 asm("divw      r10,r10,r8      "); // 32 bit quotient
63 asm("cmp       1,r4,r12       "); // Bounds Check is input < first x value
64 asm("bc        12,4,toolow    "); // if true, then input out of bounds
65 asm("evmergehi  r3,r0,r12     "); // r12[0:31]-->r12[32:63]
66 asm("add       r3,r10,r3      "); // return answer in r3
67 asm("b         return_y      ");

/* OUT OF BOUNDS */
68 asm("toolow:");
69 asm("evmergehi  r3,r0,r4      "); // merge contents of r4[0:31]-->r10[32:63]
70 asm("b         return_y      ");

```

If the code branched to `toolow` from line 64, the code beginning at line 69 returns the lowest y value, or y1.

```

71 asm("toohigh:");
72 asm("evlwhoux   r3,r6,r7      "); // r6 = last y value

73 asm("return_y:");
74 return;
}

```

If the code branched to `toohigh` from line 10, the code beginning at line 72 returns the highest y value, or y12.

## 5 Results

Using a test table with a range of input x values the following results were obtained. On average the SPE based lookup code was 41% faster.

**Table 1. Test Results**

Input x	C code		SPE code		SPE Execution vs C Code
	y returned	time <sup>1</sup>	y returned	time <sup>1</sup>	
0x210A	0xBCCC	175	0xBCCC	107	- 39%
0x3F0A	0x9EC6	201	0x9EC6	111	- 45%
0x4325	0x9AAA	201	0x9AAA	111	- 45%
0x5A35	0x8397	226	0x8397	132	- 42%
0x6428	0x799B	227	0x799B	133	- 41%
0x7555	0x686D	240	0x686D	145	- 40%
0x8765	0x5658	253	0x5658	137	- 46%
0x9875	0x4543	266	0x4543	160	- 40%
0xA985	0x3438	279	0x3438	159	- 43%
0xBA95	0x2308	292	0x2308	171	-41%
0xCB05	0x128B	305	0x128B	163	-47%
0xDC78	0x1116	90	0x1116	67	-26%
				Average	-41%

NOTES:

<sup>1</sup> Timebase counts

## 6 Summary

As shown in the preceding section, the SPE enhanced routine is significantly faster than the non-optimized C function. The performance improvement comes from the ability to perform parallel (vector) operations on multiple sets of data, and by minimizing the number of memory accesses needed per operation. Also, comparing multiple sets of data enables faster search processing. Other optimization techniques were also used, such as loop unrolling and scheduling instructions out of order to minimize pipe line stalls.

# A Source Code Listing

## A.1 var\_table\_lookup\_asm( )

```
// Copyright (c) 2006, Freescale.
//
// -----
// RELEASE HISTORY
// VERSION  DATE          AUTHOR          DESCRIPTION
// 1.0      2006-7-6      Bill Terry      Initial release
// -----
// PURPOSE: This function processes two dimensional table lookups on 16-bit table entries.
//
// NOTE:     Maximum number of table entries must be a multiple of 4.
//
// -----

/*****
 * r3 [32:63] = base address of table
 * r4 [32:63] = input value
 *****/

unsigned short var_table_lookup_asm( unsigned short  *DataPtr, unsigned short Input)
{
    /* Set up x and y data pointers */
    asm("lhz      r12,8(r3)      "); // initialize r12 to first X val
    asm("lwz      r5,0(r3)       "); // load offset to y values in r5
    asm("addi     r6,r5,-8       "); // Put the number of data points x 2 in r6
    asm("add      r5,r3,r5       "); // Set r5 to the address of the first Y value
    asm("addi     r7,r5,-4       "); // decrement y pointer to last x value (Bnds Checking)
    asm("evlwhou  r8,0 (r7)      "); // r8 = last x value  (Bnds Checking)
    asm("evmergelo r4,r4,r4      "); // r4[32:63] --> r4[0:31]
    asm("cmp      1,r8,r4        "); // Bounds check (input > last x value?)
    asm("bc       4,4,toohigh    "); // if > or = last x, then input is out of bounds (CR

    /* Pre-load 4 x-values to compare with input. Note that the first time through this loop
    64-bit registers r6 and r7 hold x1, x2, x3, and x4. The second time through this loop
    (if necessary) they will hold x5, x6, x7, and x8, and the last time through this loop
    (if necessary) x9, x10, x11 and x12. */
    asm("Loop:");
    asm("evlwhou  r6,8 (r3)      "); // r6[0:31]=x1/x5/x9, r6[32:63]=x2/x6/x10
    asm("evlwhou  r7,12 (r3)     "); // r7[0:31]=x3/x7/x11, r7[32:63]=x4/x8/x12
    asm("cmp      1,r7,r4        "); // Early Check input > r7[32:63]? result in CR1
    asm("evmergelohir8,r6,r7     "); // r8[0:31]=x2/x6/x10 ,r8[32:63]=x3/x7/x11

    /* Check the input against current x value pair in r6 */
    asm("evcmplts 0,r4,r6       "); // compare input to current pair of x values in r6,
    // result in CR0

    /* load the related y values in r9 and r10 */
    asm("evlwhou  r9,0 (r5)      "); // r9[0:31]=y1/y5/y9 ,r9[32:63]=y3/y7/y11
    asm("evlwhou  r10,4(r5)      "); // r10[0:31]=y2/y6/y10 ,r10[32:63]=y4/y8/y12
    asm("bc       12,3,BackGrd2  "); // is input < both r6 x values?, if so branch
    asm("evmergelo r12,r10,r7     "); // else save r7[32:63] and r10[32:63] in case input
    // is between r7[32:63] and the next greater x value.
    asm("addi     r3,r3, 8       "); // increment x pointer in case input > r7[32:63]
    asm("addi     r5,r5, 8       "); // increment y pointer in case input > r7[32:63]
    asm("bc       12,4,Loop      "); // if (input > r7[32:63]) get more values to compare
    asm("evsubfw  r11,r9,r10     "); // else r11[0:31]=(y2/y6/y10 - y1/y5/y9),
    // and r11[32:63]=(y4/y8/y12 - y3/y7/y11), this is (y
```

## Summary

```

// high-y low)
asm("bc          4,1, comp      "); // if(input > x1/x5/x9 & x2/x6/x10) branch

/* At this point X input is known to be between r6[0:31] and r6[32:63] so a return
value is interpolated. */
asm("evsubfw     r4,r6,r4      "); // r4 = r4-r6 (input - xlow)
asm("evmergehi   r4,r0,r4      "); // r4[0:31]-->r4[32:63]
asm("evmergehi   r11,r0,r11     "); // r11[0:31]-->r11[32:63] (y high-y low)
asm("mullw       r4,r4,r11      "); // (input-Xlow) * (Yhigh-Ylow)
asm("evsubfw     r8,r6,r8      "); // (xhigh-Xlow), r8[0:31]=(X2-X1)
asm("evmergehi   r8,r0,r8      "); // r8[0:31]-->r8[32:63]
asm("divw        r4,r4,r8      "); // 32 bit quotient
asm("evmergehi   r9,r0,r9      "); // r9[0:31]-->r9[32:63]
asm("add         r3,r4,r9      "); // return answer in r3
asm("b          return_y");

/* Checking if input is between x3/x7/x11 and x4/x8/x12 */
asm("comp:");
asm("evcmlpls    0,r4,r7       "); // input< r7 (input< x3/x7/x11 or input < x4/x8/x12),
// result in CR0
asm("bc          4,1, Loop     "); // if (input > x3/x7/x11 & x4/x8/x12) get more x values
asm("bc          12,3,BackGrd1 "); // if (input < x3/x7/x11 & x4/x8/x12) see if input is
// between x2/x6/x10 & x3/x7/x11

/*At this point X input is known to be between x3/x7/x11 and x4/x8/x12 so a return
value is interpolated. */
asm("subf        r4,r8,r4      "); // r4 = r4 -r8 (input-xlow)
asm("mullw       r4,r4,r11      "); // (input-Xlow)*(Yhigh-Ylow)
asm("subf        r8,r8,r7      "); // (Xhigh-Xlow), r8[32:63]=(X40-X3)
asm("divw        r4,r4,r8      "); // 32 bit quotient
asm("add         r3,r4,r9      "); // return answer in r3
asm("b          return_y");

/*At this point X input is known to be between x2/x6/x10 & x3/x7/x11 so a return
value is interpolated. */
asm("BackGrd1:");
asm("evmergehirl0,r0,r10      "); // r10[0:31]-->r10[32:63]= Y2
asm("subf        r4,r6,r4      "); // compute (input-Xlow)
asm("subf        r9,r10,r9     "); // (Yhigh-Ylow) or (Y3-Y2)
asm("mullw       r4,r9,r4      "); // (input-Xlow)*(Yhigh-Ylow)
asm("subf        r8,r6,r8      "); // (Xhigh-Xlow), r8[32:63]=(Y3-Y2)
asm("divw        r4,r4,r8      "); // 32 bit quotient
asm("add         r3,r4,r10     "); // return answer in r3
asm("b          return_y");

/* Input is less than the current x values in r6, so it's either too low,
or between x4 and x5, or between x8 and x9.*/
asm("BackGrd2:");
asm("evmergehilr4,r9,r4      "); // r9[0:31]=Yhigh r4[32:63]=input
asm("evsubfw     r5,r12,r4     "); // else, compute (Yhigh-Ylow) and (input-Xlow)
asm("evmergehi   r10,r0,r5     "); // r4[0:31]-->r10[32:63]
asm("mullw       r10,r5,r10     "); // (Yhigh-Ylow)*(input-Xlow)
asm("evmergehi   r6,r0,r6      "); // r6[0:31]-->r6[32:63]
asm("subf        r8,r12,r6     "); // (Xhigh-Xlow), r8[32:63]=(X5-X4)
asm("divw        r10,r10,r8     "); // 32 bit quotient
asm("cmp         1,r4,r12      "); // Bounds Check, is input < first x value
asm("bc          12,4,toolow   "); // if true, then input out of bounds
asm("evmergehi   r3,r0,r12     "); // r12[0:31]-->r12[32:63]
asm("add         r3,r10,r3     "); // return answer in r3
asm("b          return_y");

/* OUT OF BOUNDS */

```

```
asm("toolow:");
asm("evmergehi r3,r0,r4      "); // merge contents of  r4[0:31]-->r10[32:63]
asm("b      return_y      ");
asm("toohigh:");
asm("evlwhoux  r3,r6,r7      "); // r6 = last y value
```

```
asm("return_y:");
return;
```

```
}
```

## A.2 var\_table\_lookup\_c( )

```
//-----
// C based table lookup code
//-----
```

```
unsigned short var_table_lookup_c( unsigned short *tbl_ptr, unsigned short in_value )
{
    unsigned char  num_XYpairs;      // number of x-y pairs
    unsigned short y_high;           // upper bound of the y value
    unsigned short y_low;            // lower bound of the y value
    unsigned short y_input_diff;     // difference between y_low and the Y value from the
                                     // input.
    unsigned short y_return;         // return value
    unsigned short x_input_diff;     // difference between input and the lower bounding X
                                     // value
    unsigned short x_diff;           // difference between the bounding X values
    unsigned short x_val;            // x value pointed at by x_ptr
    unsigned short *x_ptr;           // pointer to the current x_val

    /* get the count of xy pairs and check if 0 */
    if (num_XYpairs = *((unsigned char *) tbl_ptr) )
    {
        if (in_value <= *(tbl_ptr + 1)){ /* is the input <= first x? */
            y_return = *(tbl_ptr + 2); /* if so, return first y */
        }
        else if (in_value >= *(tbl_ptr + ((num_XYpairs * 2) - 1))){
            /* is the input >= last x? */
            y_return = *(tbl_ptr + (num_XYpairs * 2)); /* if so, return last y */
        }
        else {
            /* if neither above, it must be in the middle */
            x_ptr = tbl_ptr + 1; /* move ptr to first entry */

            /* search up through the X points to find which two X entries input is between */
            while( *x_ptr <= in_value)
                x_ptr+=2;

            x_val = *x_ptr;
            y_low = (unsigned short) *(x_ptr - 1);

            if (in_value == (unsigned short) *(x_ptr - 2)){
                y_return = y_low;
            }
            else {
                /* Determine the difference between the input and the lower bounding X value */
                x_input_diff = (in_value - *(x_ptr - 2));

                /* Determine the difference between the bounding X values */
                x_diff = (x_val - *(x_ptr - 2));
            }
        }
    }
}
```

## Summary

```
y_high = (unsigned short) *(x_ptr + 1 );

if (y_high > y_low){
    /* if Slope is positive find the increase for the change in input then add
    it to the y_low value */
    y_input_diff = ((unsigned short) ((y_high - y_low) * x_input_diff)) / x_diff;
    y_return = (unsigned short) y_low + y_input_diff;
}
else {
    /* if Slope is negative find the decrease for the change in input then subtract
    it from the y_low value */
    y_input_diff = ((unsigned short) ((y_low - y_high) * x_input_diff)) / x_diff;
    y_return = (unsigned short) y_low - y_input_diff;
}

return(y_return);
}
else {
    /* return first Y value if Count == 0 */
    return(*(tbl_ptr + 2));
}
}
```

## A.3 Tables

/\* This table holds the data for the c-based table lookup function \*/

```
unsigned short table_var_c[]={
    0x0c00,    // header, first byte is number of x-y pairs
    0x110a,    // x1
    0xccc8,    // y1
    0x2214,    // x2
    0xbbc2,    // y2
    0x331e,    // x3
    0xaaB5,    // y3
    0x4428,    // x4
    0x99A6,    // y4
    0x5532,    // x5
    0x889f,    // y5
    0x663c,    // x6
    0x7784,    // y6
    0x7746,    // x7
    0x667c,    // y7
    0x8850,    // x8
    0x556c,    // y8
    0x995A,    // x9
    0x445d,    // y9
    0xaa64,    // x10
    0x3359,    // y10
    0xbb6e,    // x11
    0x222d,    // y11
    0xcc78,    // x12
    0x1116};   // y12
```

/\* This table holds the data for the SIMD-based table lookup function \*/

```
unsigned short table_var_asm[]={
    { 0x0000,    // first four entries are the header
      0x0020,    // offset to start of y vals
      0x0000,
      0x0020,
```



```

0x110a , // x1
0x2214, // x2
0x331e, // x3
0x4428, // x4
0x5532, // x5
0x663c, // x6
0x7746, // x7
0x8850, // x8
0x995a, // x9
0xaa64, // x10
0xbb6e, // x11
0xcc78, // x12

0xccc8, // y1 - Note the 'interleaved' order of the y data that allows
0xaaB5, // y3   the efficient use of the 64-bit SIMD instructions.
0xbbc2, // y2
0x99a6, // y4
0x889f, // y5
0x667c, // y7
0x7784, // y6
0x556c, // y8
0x445d, // y9
0x222d, // y11
0x3359, // y10
0x1116}; // y12

```



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