THE MOTOROLA ALTIVEC™ TECHNOLOGY

Wesley F. Miaw

Computer Science Division-EECS
University of California
Berkeley, CA 94720

December 10, 1999

Abstract

Traditionally, advancements in microprocessor speed have been gained by increasing clock speed, which is a measurement of how fast a microprocessor can execute instructions. However, recent design efforts have focused upon increasing the number of instructions that can be executed simultaneously. When more instructions can be executed at the same time, a microprocessor's speed increases without requiring an increase in clock speed. To increase speed without increasing the clock speed, Motorola's AltiVec technology was designed to allow a microprocessor to apply a single computation to many pieces of data at the same time. Additionally, the AltiVec technology is designed to manipulate large pieces of data and is optimized to perform complex calculations. As a result, the low-cost Motorola MPC7400 microprocessor, which incorporates AltiVec, can be used to replace the expensive specialized chips previously used to perform complex calculations upon large data. Applications targeted by AltiVec, such as network hardware and audio/video production, are already benefiting from this technology. As the industry advances, the capabilities of the AltiVec technology will play an ever increasing role in improving computing speed.

1.0 Introduction

Since the introduction of the microprocessor, computers have become smaller, faster, and more powerful at an incredible rate. A consumer microprocessor's speed is traditionally measured by the microprocessor's clock speed. In order to perform calculations, the processor generates electrical pulses. The time required to generate a single pulse is called a cycle. Clock speed is measured in Hz (cycles per second, or pulses generated per second) [1]. Today a consumer computer starts at clock speeds of around 300 MHz (million cycles per second).

As the industry has evolved, clock speed has become less important and microprocessor architects have begun to focus on other areas of the microprocessor's design. Traditionally, a microprocessor is able to perform one calculation per cycle. More advanced microprocessors are able to perform several calculations per cycle. As a result, a microprocessor with a slower clock speed but more advanced design can be faster than a microprocessor with a faster clock speed but less advanced design.

Increasing a microprocessor's speed without increasing its clock speed is also important for the microprocessor's stability. Microprocessors with high clock speeds must be constructed of hardware that is capable of rapidly generating pulses and that can deal with fast moving electrical signals. When the hardware is unable to reliably generate pulses at a high rate or the hardware is not equipped to handle so many signals each second, errors will occur. Therefore, increasing the microprocessor speed without increasing the clock speed does not lead to microprocessor instability.

One area of microprocessor design that has recently become a hot topic in the industry is vector calculation optimization. Many software applications today make extensive use of vector calculations, and improving the execution rate of these calculations can have a profound impact on performance. Motorola is one of the latest companies to release a microprocessor optimized for these calculations. The name of their vector calculation technology is AltiVec.

This paper will explain the AltiVec technology and illustrate some benefits already experienced by users of this technology.

2.0 Background

Traditionally, calculations involving large amounts of data or complex computations were handled by specialized hardware such as ASIC (application-specific integrated circuit) chips [2]. ASIC chips are designed for a specific application and can perform the duties unique to that application very well [3]. However, a particular ASIC chip is limited to the application it was designed for and is therefore more expensive and less useful than a "general" purpose chip.

ASIC chips are used in many applications, including MPEG-2 file format decoders for DVD-Video playback, anti-lock breaking systems in automobiles, and Dolby Digital receiv-

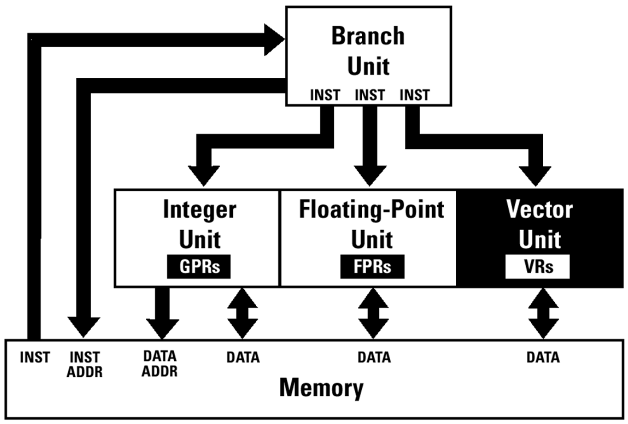
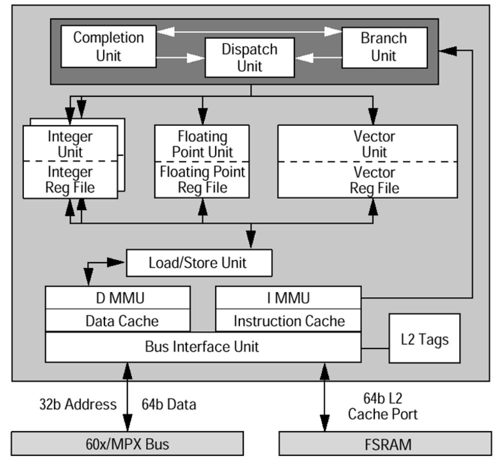


Figure 1. High-level structural overview for PowerPC with AltiVec technology

(Source: Sam Fuller, Motorola's AltiVec™ Technology - White Paper)

Figure 2: Motorola MPC7400 Block Diagram



(Source: Motorola MPC7400 PowerPC™ Microprocessors)

ers for high quality sound signal processing. In each of these applications, a specific chip was designed and produced to perform the required function. However, the ASIC designed for anti-lock breaking systems cannot be used to process high quality Dolby Digital sound signals. If a “general” purpose microprocessor could be used instead of an ASIC, specialized chips would not need to be designed and produced.

Recent "general" purpose microprocessors, including the Intel Pentium® III and AMD Athlon™ along with the Motorola MPC7400 PowerPC (called the G4 in Power Macintosh computers), contain integrated circuitry that provides a level of performance previously requiring specialized hardware [2]. Before the addition of the AltiVec vector unit to the PowerPC microprocessor line, all instructions were processed by the integer unit or the floating-point unit (FPU). These two coprocessors perform integer and floating-point (non-integer real numbers) calculations respectively. The AltiVec unit performs calculations on vectors, or lists, of integers or floating point numbers.

The addition of the AltiVec vector unit is described by the diagrams below. Figure 1 illustrates the previous PowerPC structural overview with the addition of the Vector Unit coprocessor. Figure 2 is a block diagram of the Motorola MPC7400 microprocessor.

3.0 SIMD Explained

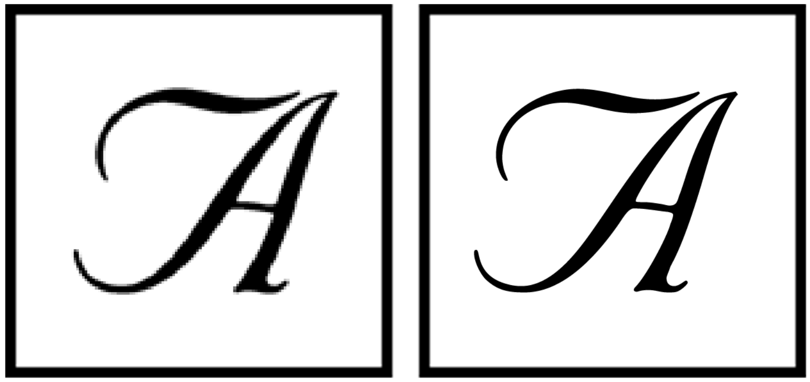
In order to perform vector calculations, the MPC7400 microprocessor uses SIMD (Single Instruction, Multiple Data) to process up to 20 instructions per clock cycle. Sixteen of these 20 possible instructions can be executed by the AltiVec vector unit each clock cycle. Before the advent of SIMD, each calculation required its own instruction. For example, calculating 3 + 5 followed by 12 + 8 would require two separate instructions. If integer addition was implemented with SIMD, the microprocessor could be told to perform both calculations with a single instruction instead of with two separate instructions.

As a result, a microprocessor with SIMD at a lower clock speed can perform more calculations in less time than a microprocessor without SIMD at a much higher clock speed. Current versions of the MPC7400 can operate at clock speeds up to 450 MHz. A comparable microprocessor without SIMD would need to operate at a clock speed roughly 20 times greater, or at 9 GHz (billions of cycles per second). Modern processors can only be taken up to 1 GHz before becoming unstable and bringing the clock speed up that high requires very specific conditions that are not easy to attain. Since microprocessors cannot reach extremely high clock speeds, SIMD provides an alternative mechanism for increasing the speed at which a microprocessor can execute instructions.

4.0 AltiVec Technology

AltiVec is a short vector parallel architecture. Each vector processed contains either 4, 8, or 16 elements and these elements are processed in parallel with SIMD. Each element of a vector is a datum to which the computation will be applied. In the above example which calculated 3 + 5 and 12 + 8 the numbers 3, 5, 12, and 8 are the vector elements. The vector lengths supported by AltiVec are much shorter than vectors supported by supercomputers. Short vectors are more effective for the applications targeted by Motorola's AltiVec technology. Only very complex calculations, such as the simulation of proteins folding, require calculations on vectors hundreds of elements long.

Figure 3:



Aliased Antialiased

Since AltiVec can handle up to 128 bits of data at a time, AltiVec supports parallel computations of:

- 16-way parallelism (16 element vectors) for 8-bit data
- 8-way parallelism (8 element vectors) for 16-bit data
- 4-way parallelism (4 element vectors) for 32-bit data

The AltiVec instructions that can be performed on these vectors fall into four major classes: intra-element arithmetic, intra-element non-arithmetic, inter-element arithmetic, and inter-element non-arithmetic [4]. Intra-element computations are performed independently of data external to the vectors, while inter-element computations rely upon external data.

Some examples of intra-element arithmetic operations are addition, multiplication, max, and average. Some examples of intra-element non-arithmetic operations are comparisons, bit shifts, and rotations. Comparisons include less-than or greater-than. Bit shifts move the bits in a binary number to the left or right. For example, the binary number 0100 shifted one place to the right is 0010. Rotations are useful for the display of three-dimensional objects. Very often, it is helpful to be able to view a three dimensional object displayed on a computer screen from many different angles. Since the data defining the object is only stored with respect to one viewpoint, rotations must be applied to this data to display an image of the object as viewed from a different viewpoint.

Inter-element arithmetic operations perform sum of products and sum across. Sum of products is very useful for dot products, the most common vector operation. The dot product of two vectors is the sum of the products of each element of the first vector with the corresponding element of the second vector. The sum across operation sums the elements of a vector. Inter-element non-arithmetic operations perform various powerful algebraic computations. One of the most powerful operations is the permute operation. This operation provides the ability to very quickly reorganize data before or after performing computations. Of special interest is the capability of inter-element non-arithmetic operations to be applied to 128-bit data. Intra-element arithmetic, intra element non-arithmetic, and inter-element arithmetic operations are limited to 32-bit data [2].

5.0 AltiVec Applications

Motorola is targeting AltiVec at applications that require high-bandwidth and powerful computational capabilities. These applications include high-end modems, speech processing systems, image and video processing systems, and network hardware.

The most visible use of AltiVec is by Apple Computer in their Power Macintosh G4 computer product line. These computers are available for purchase by the typical consumer but are powerful enough to serve as advanced image, video, and audio workstations. Adobe Photoshop is one image manipulation application that has been optimized for use on the Power Macintosh G4. With the AltiVec technology, Photoshop can perform complex image manipulations much faster than before.

Antialiasing is one area in which Photoshop that benefit from AltiVec. Aliasing is what causes certain images displayed on a computer screen to appear with “jagged” edges that do not smoothly blend into the image’s surroundings. Antialiasing is a software technique used to reduce the visual effects of aliasing. Aliased and antialiased examples of the letter A are shown in Figure 3.

Postfiltering, one antialiasing method, “smoothes” the edges of an image by calculating the correct color for each pixel (dot of color) as the weighted average of the surrounding pixels. The average is weighted because closer surrounding pixels contribute more to the average than distant surrounding pixels [5]. In the antialiased letter A above, the pixels at the edge of the A have been recalculated as varying shades of gray to blend in with the white surroundings.

Bilinear filtering, one of the algorithms used by Photoshop to perform postfiltering, looks at the four pixels surrounding a point in the image. Each pixel is defined by four pieces of data called channels: red, green, blue, and alpha. The red, green, and blue channels specify how much of each respective color is contained in the pixel while the alpha channel specifies the transparency of the pixel [6]. The following equations are used to calculate the weighted average color of the four surrounding pixels.

$$R = w0R0 + w1R1 + w2R2 + w3R3$$
$$G = w0G0 + w1G1 + w2G2 + w3G3$$
$$B = w0B0 + w1B1 + w2B2 + w3B3$$
$$A = w0A0 + w1A1 + w2A2 + w3A3$$

where

Bx = blue value of pixel x
Gx = green value of pixel x
Rx = red value of pixel x
Ax = alpha value of pixel x
wx = weight of pixel x

AltiVec can be used to execute in parallel the multiplications of each pixel's weight with the channel values of that pixel. For example, the multiplication of w0 with R0, G0, B0, and A0, only requires a single instruction. As a result the four equations above can be solved with only four multiplication instructions instead of sixteen [5].

6.0 Conclusion

AltiVec technology is one implementation of the latest trend in microprocessor design: simultaneous execution of vector calculations. The need for vector calculations is increasing as computers are used in more diverse areas to perform complex computations. Previously, complex vector computations required specialized hardware, but recent generations of "general" purpose microprocessors have integrated circuitry to handle such computations. “General” purpose microprocessors are less expensive and can be used in more applications than a specialized chip. In conjunction with SIMD, AltiVec provides high-bandwidth, complex computational power without sacrificing general purpose capabilities.

7.0 References

1. *What Is...clock speed (a definition)*. whatis?com™. whatis.com Inc. http://www.whatis.com/clockspe.htm, 1999.

2. Fuller, Sam. *Motorola’s AltiVec™ Technology - White Paper*. Motorola, Inc. http://www.motorola.com/SPS/PowerPC/teksupport/teklibrary/papers/altivec_wp.pdf, 1999.

3. *What Is...ASIC (a definition)*. whatis?com™. whatis.com Inc. http://www.whatis.com/asic.htm, 1999.

4. *AltiVec Technology Fact Sheet*. Motorola, Inc. http://www.mot.com/SPS/PowerPC/library/fact_sheet/7400_fs.pdf, 1999.

5. *Antialiasing Implemented Using Streaming SIMD Extensions*. Intel Corporation. ftp://download.intel.com/design/perftool/cbts/appnotes/ap806/a_alias.pdf, 1999.

6. Weinman, Lynda. Designing Web Graphics 2. Indianapolis: New Riders Publishing, 1997, pp. 61, 135.

8.0 Secondary Sources

1. *Apple - Products - Power Mac G4*. Apple Computer, Inc. http://www.apple.com/powermac/processor.html, 1999.

2. *Motorola MPC7400 PowerPC™ Microprocessors*. Motorola, Inc. http://www.mot.com/SPS/PowerPC/library/fact_sheet/7400_fs.pdf, 1999.

3. *Motorola’s New MPC7400 Microprocessor Delivers Quantum Performance Leap*. Motorola, Inc. http://www.mot.com/SPS/PowerPC/library/press_releases/7400_pr.html, 1999.

4. Stamos, Alex “Dr. Penguin”. *The G4 Processor: Under the Hood*. Thresh’s FiringSquad. http://www.firingsquad.com/hardware/g4processor/default.asp, 1999.