White Paper

Benefits of VPro™ Graphics Architecture with 12-Bit Component Support

How Additional Color Precision Enhances Realism and Workflow Productivity

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1.0 Introduction

The many unique hardware features of the high-performance SGI VPro graphics architecture available in the Silicon Graphics® Octane2™ visual workstation, Silicon Graphics Fuel™ visual workstation, and the InfinitePerformance™ graphics in the SGI® Onyx® 3000 series make these systems well suited to applications that require high-quality images without compromising performance. This paper describes how one of these industry-leading features, the 12-bit-per-component deep-pixel support, can be used within applications to improve both image quality and workflow productivity. This support for 12-bit-per-component color precision is found not only within the frame buffer used for image display but also throughout the entire OpenGL® hardware rendering pipeline.

2.0 Architectural Overview

2.1 OpenGL on a Chip™

A departure from traditional SIMD graphics systems, the VPro graphics architecture consists of only two principal ASICs: OpenGL on a Chip for transformation and rasterization and a back-end video ASIC that combines the pixel streams from the raster unit and outputs the resulting pixel data to the DAC(s). This single-chip OpenGL 1.2 design implements the full OpenGL 1.2 geometry pipeline, including transformation, lighting, and clipping, as well as the OpenGL 1.2 ARB_imaging pipeline in a single ASIC. This ASIC then interfaces to the display back-end chip via a dedicated onboard bus and to the rest of the system via a 16-bit 800MB-per-second bidirectional XTALK interface. A high-level diagram of the VPro architecture is shown in figure 1. In this diagram, the following components of the VPro architecture are shown:

- CFIFO: Deep-command FIFO to buffer command streams
- GFE: Graphics front end to process OpenGL graphics instructions
- XFORM: Transform engine
- RTS: Rasterization, texture, and shading engine

Unlike other SIMD architectures, the single-chip design of the VPro graphics architecture does not have the strip length, context switch, or other interchip communication drawbacks. Lighting is fully hardware-accelerated for both per-vertex and per-pixel shading. Texturing features include 2D and 3D textures, borders, post-texture lookup tables, and post-texture specular highlights.

3.0 Configurable Graphics Memory

In another departure from traditional graphics systems, the VPro graphics architecture is built around a pool of configurable graphics memory. As such, all buffers, in addition to texture memory and the CFIFO, are allocated from this single large graphics memory pool as illustrated in figure 2. This pool of onboard SDRAM, which can be as large as 128MB, provides flexible buffer management for all types of applications. Specific capabilities include:

- Allocation of color buffers with a maximum depth of 48-bit RGBA for applications such as film compositing, CAD styling, and imaging that require high color precision
- Drawable buffers with a maximum addressable area of 4096x4096, which allows large imaging operations common in many application areas such as film,

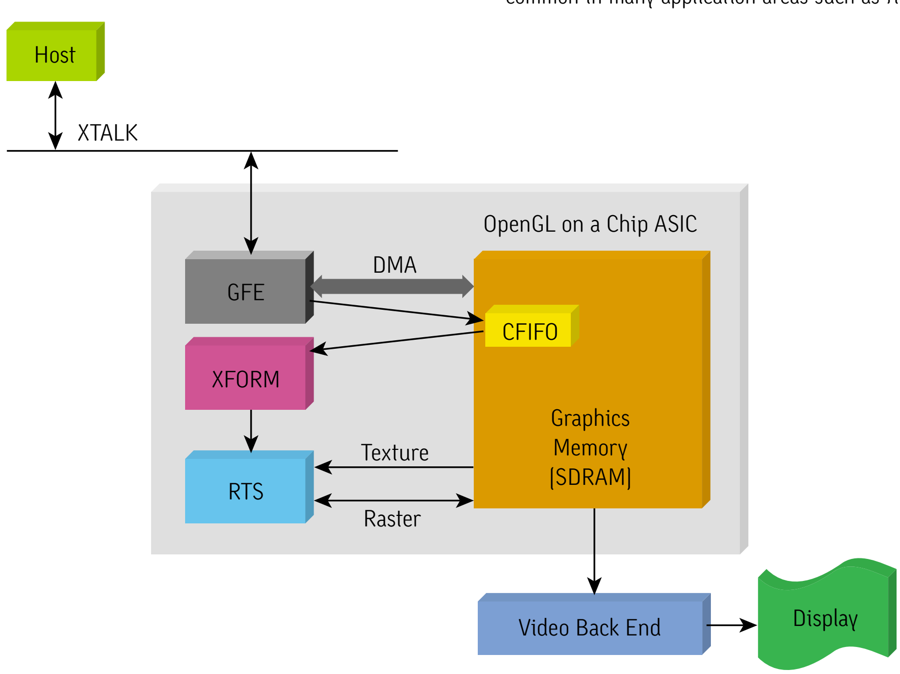

Fig. 1. VPro Architecture

HDTV, and scientific visualization to be performed with ease
- Allocation of texture objects with a maximum dimension of 32,768 with the constraint that the texture, including all mipmap levels, must fit in available graphics memory; this, combined with nonblocking asynchronous texture download, provides fast manipulation of large images as texture data
- A hardware accumulation buffer with up to 24-bit-per-component precision RGBA
- 3D textures for fast rendering of volumetric data sets
- 48-bit texture lookup table for very fast and accurate interaction with volume-rendered data sets

This architecture also permits operations on all buffers, including off-screen rendering buffers and the accumulation buffer, to run at full hardware speeds because all the graphics memory is local to the graphics subsystem. Another benefit of this design is that copies between buffers and textures are performed onboard and, as a result, are extremely fast.

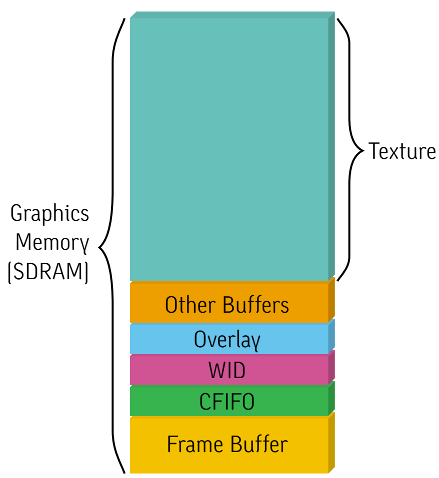

Fig. 2. Configurable Graphics Memory

4.0 12-Bit Component Support

4.1 Buffer Support

The VPro graphics architecture, where all buffers and texture memory are allocated from a single large configurable graphics memory pool, permits color buffers to be allocated with a maximum depth of 48-bit RGBA with a 96-bit hardware-accelerated accumulation buffer. This feature, previously available only on very high end graphics platforms such as InfiniteReality®, provides support for RGBA12 data formats for unprecedented color resolution and image quality on the desktop. Buffers with deeper pixels store results with higher precision.

In RGBA mode, when a buffer is allocated, a specific number of bitplanes is reserved for each of the R, G, B, and A color components. The number of bitplanes allocated per component depends on the pixel format chosen by the application. RGBA values from an application are then mapped into the number of bits available for each component. The number of available bits determines the total number of colors available. As a result, more bits available means more colors available for higher-quality results. A typical graphics system with 8 bits per component supports 16 million addressable colors with 256 discrete alpha values. Compare this with the 68 billion addressable colors with 4,096 discrete alpha values available with the 12-bit-per-component RGBA feature of the Octane2 and Silicon Graphics Fuel visual workstations as illustrated in figure 3.

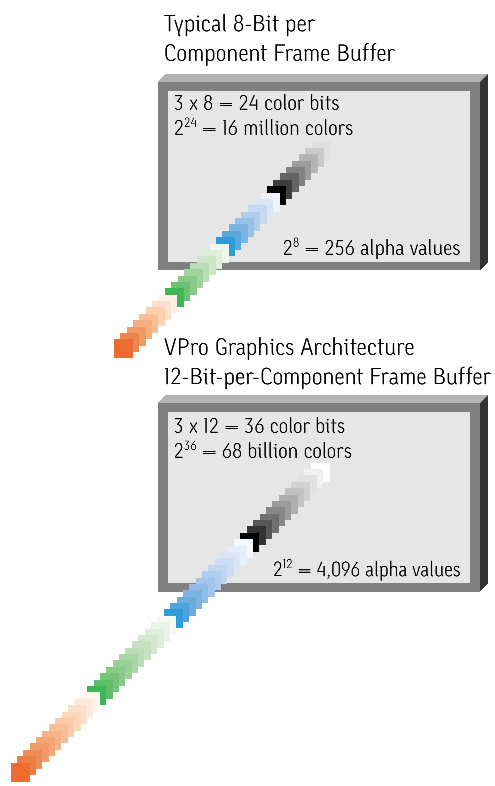

Fig. 3. VPro Graphics Supports 68 Billion Colors

4.2 Pipeline Support

Buffer support for 12-bit-per-component RGBA alone is not enough for a high-quality imaging system. The paths between the various stages in the rendering pipeline must also be at least 12 bits wide to accommodate the intermediate results of rendering calculations and prevent the introduction of anomalies into an image by truncating the results to fewer bits.

In the VPro graphics architecture, the complete OpenGL rendering pipeline runs with 12-bit-per-component or greater pixel precision from the geometry stage through rasterization.* VPro also implements the complete OpenGL 1.2 ARB_imaging subset in hardware, with 12-bit-per-component or greater pixel precision. As a result, the Silicon Graphics Octane2 visual workstation and the Silicon Graphics Fuel visual workstation provide unparalleled rendering quality in desktop systems, and the SGI Onyx 3000 series with InfinitePerformance graphics offers exceptional color quality at a new level of affordability and price/performance for an advanced graphics system.

5.0 Applications

5.1 Modeling and Animation

The additional color precision available with the 12-bit-per-component frame buffer in the VPro graphics architecture brings enhanced realism to the digital content-creation process. This enhanced realism translates directly into increased workflow productivity. Visual effects, which previously required a time-consuming software render to preview, can now be viewed in real time as they are created.

5.2 Blending

In the process of creating digital content, blending is utilized to create special effects such as surface transparency. This technique, also known as alpha blending, uses the A value in the RGBA quartet to determine how the new color for a pixel is to be combined with the current pixel color. Without blending operations, each new pixel color simply would overwrite the old one in the frame buffer. Thus, by combining the two colors using an alpha-blend equation, a portion of the original color will show through. In the VPro graphics architecture, these blending calculations are performed with 12 bits of precision per component versus the only 8 bits available on a typical desktop graphics system. As a result, the Silicon Graphics Octane2 and Silicon Graphics Fuel visual workstations have 16 times the alpha precision of a typical desktop system, with 4,096 discrete alpha values compared with only 256 discrete alpha values available on a typical desktop system. This yields more realistic results that are much closer to those that will be obtained during the final software render performed when going to tape or film.

5.3 Lighting

In the graphics rendering pipeline, lighting calculations of final vertex color values are performed in 3D prior to the viewport transformation to 2D coordinates. These final color values calculated by the XFORM unit, within the VPro graphics architecture, have 12 bits of precision per color component. As a result, applications that utilize the graphics subsystem hardware to calculate lighting effects will produce higher-quality images on SGI® systems with the VPro graphics architecture than on typical graphics systems that support only 8 bits of precision per color component. Again, this technology provides more realistic results without needing to software render. This improves the workflow by reducing the time required to complete a project.

5.4 Film Compositing

The support for RGBA12 in the Silicon Graphics Octane2 visual workstation, Silicon Graphics Fuel visual workstation, and the SGI Onyx 3000 series with InfinitePerformance graphics provides several benefits for high-end film and video compositing applications. Digital compositing combines multiple images from various sources such as human-generated elements, computer-generated images, and scanned images from film or video into a single image.

5.5 Color Space Conversion

The most common type of material used in digital compositing is live-action footage scanned or digitized from film or video. Film and video content captured for use in compositing is typically stored in 16-bit YUV422 format to economize disk-space usage. However, compositing operations are generally performed in RGBA. This requires a color space conversion from YUV422 to RGBA.

The color space conversion between YUV422, a nonlinear color space, into linear RGBA can produce banding in dark-colored regions of an image if an insufficient color resolution is used. In the past, in order to maintain the required 10–12 bits of color information per component, the color space conversion was performed in software on the host CPU. With the VPro graphics architecture, the color space conversion can now be performed quickly and easily in the 12-bit-per-component on-chip graphics-imaging pipeline using the color matrix functionality of OpenGL.

5.6 Attached Alpha

Typical graphics systems support only RGBA8, or if they do support more bits of precision per color component, they support only RGBA with 10 bits of precision for RGB and 2 bits of precision for alpha. Or, if they do support 12 bits of precision per component like the MXE graphics subsystem previously available on

* In the case of lighting, although the VPro XFORM unit computes in 32-bit floating point, certain limited-precision approximations are used. The accuracy of these approximations is variable depending upon the input data.

Silicon Graphics® Octane®, they support RGB12 with 12 bits of color information available for RGB only with no alpha channel at all. These shortcomings require compositing systems to implement one of two solutions to work around this problem:

- Maintain alpha component values in a separate buffer
- Premultiply the RGB data by alpha and perform compositing operations using these premultiplied images; this technique is known as Porter-Duff compositing

Both of these solutions have disadvantages. In the case where alpha data is maintained in a separate buffer, there is increased overhead connected with having to maintain this alpha buffer in addition to the buffer of RGB data. In the case where images are premultiplied with alpha, once the color channels are modified by alpha, a specific brightness is established for each color channel; as a result, the brightness of any color channel can no longer be modified without taking the value in the alpha channel into account. This is specifically a problem when color-correcting an image. Premultiplied images need to be unmultiplied before applying a color-correction operation.

The VPro graphics architecture solves this problem by providing direct hardware support for RGBA12 pixel data. In addition to the 12 bits of precision per color channel, there is an alpha channel with 12 bits of precision. The alpha channel information no longer must be maintained separately or premultiplied into the color channels.

5.7 Frame Buffer Compositing

Digital compositing typically involves combining two or more images by using OpenGL blending operations via one or more passes through the graphics frame buffer. In the past, this has typically been performed either by blackbox systems or in software on general computer systems because computer graphics hardware did not offer significant bits of precision per color component.

The VPro graphics architecture, however, supports 12 bits of precision per color component along with 12 bits of alpha channel data combined with 12 bits or more of precision between stages of the OpenGL rendering pipeline. This permits digital compositing operations to be performed quickly and easily, directly in the frame buffer.

6.0 Manufacturing

In the manufacturing market, the color precision available with the 12-bit-per-component frame buffer in the VPro graphics architecture provides a desktop computing platform that offers the most accurate visual representations of numerical data of any available desktop system. When combined with design software from leading application vendors, the Silicon Graphics Octane2 visual workstation, the Silicon Graphics Fuel visual workstation, or the SGI Onyx 3000 series with InfinitePerformance graphics forms a complete manufacturing solution. This solution improves the design workflow and reduces the time to market for a new product.

6.1 CAD Styling

For CAD styling applications, the 12-bit-per-component capability translates into a more accurate understanding of surface contours. Surface details can now be viewed interactively without the need to prerender models. On SGI systems with the VPro graphics architecture with 12 bits of precision per color component, this interactivity shortens development time by eliminating the time required to produce high-quality renderings of models and reducing the need for physical prototypes.

6.2 Finite Element Analysis

Finite element analysis applications rely on the color precision of the graphics system to accurately reflect the data and provide a precise visual representation of the numerical results. In applications of this type, data variations are shown graphically by varying the color over a range. With 68 billion addressable colors versus only 16 million on typical desktop workstations, the Silicon Graphics Octane2 and Silicon Graphics Fuel visual workstations provide high-quality images that are easily reviewed and understood. As a result, engineering decisions can be made more quickly, reducing product development time.

7.0 Imaging

Imaging applications that require high color precision will benefit from the 12-bit-per-component graphics frame buffer in the VPro graphics architecture. This, combined with the 12-bit-per-component hardware pipeline for OpenGL imaging operations, will produce the highest quality results available in a desktop system.

7.1 Medical Imaging

Medical imaging is another application area that will benefit from the 12-bit-per-component resolution available with the VPro graphics architecture. In recent years, the science of medical imaging has moved toward a digital representation with the goal of efficient image transfer and archiving as well as the easy manipulation of visual diagnostic information in ways that improve the usefulness of the data, such as image enhancement and volume rendering.

In the case of medical imaging, the 12-bit component values in the frame buffer combined with the 12 bits or more of precision in the OpenGL rendering pipeline set the SGI systems with VPro graphics apart from the competition.

Medical imaging data is acquired from a variety of sources, including magnetic resonance imaging and computed tomography with a typical resolution of 10–12 bits of gray level. This data is typically stored in 16-bit values for alignment purposes before being converted to luminance alpha or RGBA for display.

On typical systems, with 8-bit-per-component pixel depth and 8-bit data paths, the data is then jammed into 8 bits such that 4 significant bits of data are lost. This decimation of the data produces an effect known as quantization. Because the data paths are only 8 bits wide, the resulting data loss is then magnified as additional operations are performed on the data by the graphics subsystem. These operations include convolutions for filtering and sharpening, color lookup table operations for adjustment of the color contrast between layers, and fast Fourier transforms. On systems with the VPro graphics architecture, the data fits nicely into the 12-bit-per-component buffers without loss of precision. All subsequent imaging operations are then performed with 12 bits or more of precision between them to preserve the results. This translates into a final result that is accurate and without data loss.

7.2 Geospatial Imaging

Geospatial imaging is another application area that will benefit from the 12-bit-per-component deep pixels available with the VPro graphics architecture. For image exploitation applications, decimation to 8 bits is no longer necessary with the full 12-bit RGBA or 16-bit luminance alpha support throughout the rendering pipeline. Hardware support in the imaging pipeline for convolutions, with kernel sizes up to 7x7, provides quick sharpening operations. The up to 104MB of texture memory available, combined with hardware support for subtextures and asynchronous texture download, makes SGI systems with the VPro graphics architecture well suited for large roaming and sight-model applications. The combination of these features produces large, high-quality interactive images for an increased understanding of the terrain. The result is an improved workflow that makes decision making easier.

8.0 Conclusion

The VPro graphics architecture delivers 12-bit-per-component deep pixel support for unprecedented color resolution and image quality. This support for 12-bit-per-component color precision is found not only within the frame buffer used for image display but also throughout the OpenGL hardware rendering pipeline. This high color precision prevents the introduction of anomalies that result from truncating the results of rendering calculations to fewer bits. Applications can take advantage of this industry-leading color precision to improve both image quality and workflow productivity.

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3289 (3/29/02) J13937