LOW-COST VISUAL SIMULATION: WORKSTATIONS OR IMAGE GENERATORS

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ABSTRACT

Advances in computer graphics and related technologies over the last several years have resulted in dramatic performance increases, numerous feature enhancements, and significant cost reductions for graphics computers. These factors, coupled with the heightened interest in virtual reality, have spurred the demand for low-cost visual simulation subsystems. The availability of relatively inexpensive graphics accelerators and workstations has helped fuel this demand with the promise of capabilities approaching those of special-purpose image generators. As the prices of traditional image generators fall and the capabilities of graphics workstations improve, the markets for these two product technologies will continue to converge. *Caveat emptor* applies for those not in tune with the rapidly blurring distinctions between general-purpose graphics workstations and special-purpose image generators.

Different kinds of simulation and training systems often require different capabilities and levels of visual simulation performance. This paper identifies typical selection criteria, including some that are common across many applications as well as those that are more specific to the simulator's intended use. Overall fidelity, realism, feature density, and other issues pertinent to the real-time simulation community are identified, and their trade-offs are discussed. These criteria are then used to compare the applicability of both special-purpose image generators and general-purpose graphics workstations to meeting different visual simulation requirements. This comparison provides a basis for specifying and selecting simulator visual systems in lieu of such esoteric metrics as polygon capacity. Understanding these issues and trade-offs will help those involved in the purchase of visual systems to make selection decisions that are not only cost effective but also meet the functional and performance needs of the end user.

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INTRODUCTION

Image generation systems used for low-cost visual simulation can be implemented with a variety of devices encompassing a wide range of price, performance, and capabilities. Such devices include more traditional special-purpose image generators, graphics workstations, and PCs equipped with high-performance graphics subsystems. As illustrated in Figure 1, there is presently a significant amount of overlap in the price and performance of these devices. Current trends in the industry indicate that these overlaps will continue to grow, further blurring the distinctions between these different systems.

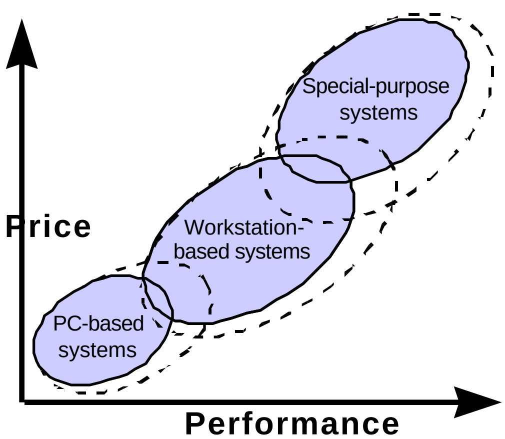

Figure 1. Current and future trend of overlap for image generation systems.

A survey of requirements for simulator visual systems will be presented, followed by a comparison of different capabilities of these different image generation systems. For the sake of clarity, the term "image generator" will refer to a generic subsystem that generates one or more video streams from a visual database under the control of a host simulation; it should be construed as neither a general-purpose graphics workstation nor as a special-purpose computer image generator. Furthermore, it should be understood that the host simulation may be either a computer external to the image generator or a processor integrated within the image generator.

REQUIREMENTS OF VISUAL SIMULATION

Simulation systems that use visual imagery impose, either explicitly or implicitly, requirements on the fidelity and functionality of the image generator. Some of these requirements are dependent upon the particular application of the simulator while others are more general in nature. These two categories of image generator requirements will be discussed in more detail below. Physical and environmental requirements, while also important, are beyond the scope of this paper and are not addressed.

General Requirements

The most important driver for the selection of an image generator is the level of fidelity—both spatial and temporal—required to provide the necessary visual cues. This covers requirements such as scene complexity, update rate, scene dynamics, and the size of the gaming areas.

Scene complexity or density is related to the polygonal, pixel, and texture capacity of the image generator. This may also impose requirements on level-of-detail control, so that the relative density of scene elements is distributed within the viewing plane (i.e. fewer but more detailed elements close to the observer and more but less detailed elements further away from the observer). Additionally, the level of scene density can affect the amount of data that must be stored in the image generator's memory, so that all of the elements within the observer's visible range can be viewed simultaneously.

The image generator's update rate is how often the image is redrawn in the frame buffer, as opposed to the refresh rate, which how often the frame buffer is drawn on the display device. High update rates (usually equal to the refresh rate) are required in simulators where the observer and/or objects in the scene move at high angular velocities; this avoids an artifact known as multiple imaging (Moore, 1996). Fixed or deterministic update rates are generally required in simulators where there is a tight coupling between the visual system and other components such as a motion system or operator controls; varying update rates in such simulators can be a contributor to simulator sickness (Kennedy et. al, 1992).

The amount of dynamic elements in the scene is becoming a more important factor in image generator selection. Scene dynamics can take the form of geometric or texture animations, moving objects, dynamic sea states, and even terrain and features that can be affected by munitions or other actions. The image generator must be able to provide the desired functionality in sufficient quantities, and the host simulation interface must have sufficient bandwidth to control all of the dynamic elements.

The size of the gaming areas to be used affects the amount of on-line storage that must be available. Additionally, this also has an impact on the coordinate system used by the image generator and, perhaps, the entire simulator. For example, small area databases can use flat-earth (map projection) or local nadir coordinate systems, while large areas typically require geocentric or geodetic (lat-long) coordinates.

Another set of general requirements is involved with how the image generator is integrated with other simulator components. The three primary interfaces of an image generator are the display interface, the host interface, the visual database. (The physical/ environmental or facility interface will not be considered here.)

The display system typically requires only video signals from the image generator; however, the image generator may be required to support calligraphic, head- or eye-tracking, field extension, and other features of more complex displays. Video requirements are usually limited to the number of lines and pixels, timing information (e.g. horizontal and vertical refresh rates, blanking and sync times, etc.), and whether the video is interlaced or noninterlaced. Displays using curved screens may also require the image generator to perform distortion correction if this is not done by the projectors. Multiple-channel, mosaicked displays may necessitate soft edge blending between along the edges of the image generator's video outputs unless this is performed by the projectors or an external edge-blending device.

The interface between the image generator and the host simulation can usually be divided into the electrical interface and the data interface. When the host simulation is integrated within the image generator, the electrical interface requirements have already been satisfied. Otherwise, an electrical interface such as Ethernet™ or SCRAMNet™ must be specified such that both the host simulation and the image generator both support the interface and that the interface provides sufficient bandwidth to handle control and response information between the two subsystems. Because of the lack of standardization of the data interface between the host simulation and the image generator, software development is almost always required to integrate these two subsystems. Factors that can affect requirements include the existing software interfaces for the host simulator and the availability of an API to the image generator for the host simulator.

Image generators frequently use database formats that are proprietary and unique between different vendors and even across product lines from the same vendor. Fortunately, most vendors support common source formats, such as SIF and OpenFlight™, which can level the playing field among different image generator vendors. Factors which affect the requirements on this interface include existing databases that can or must be used or retrofitted, available database development resources (including both equipment and trained personnel), and database commonality with other simulators.

Application-specific Requirements

Image generators are used in a wide variety of simulation applications. While many of these applications share some of the same requirements, there are unique aspects to each that must be provided by the selected image generator.

Because of the high angular velocities encountered in normal cornering as well as a high degree of steering responsiveness, driving simulators are best suited with high, constant update-rate image generators. Multiple channels are almost always necessary to depict a wide forward field of view (critical for making 90° turns) and side and rear views. Coarse head or eye tracking may also be necessary in order to provide proper parallax cues in rear and side view mirrors.

Engineering simulators, such as those used to model and validate new designs, often require very low transport delays and constant update rates. In some cases, particularly if it is a hardware-in-the-loop simulation, the update rate may need to be very fast (in excess of 60 Hz).

Rotor-wing and fast fixed-wing aircraft simulators typically require fast update rates (e.g. 60 Hz) due to the types of maneuvering that they perform. In addition, sophisticated collision detection functions are frequently necessary because of the high vehicle velocities and low altitude flight profiles that are involved.

While not needing high update rates due to relatively slow movement, maritime simulation often poses its own set of application-unique requirements. Three-dimensional dynamic sea states and a mechanism for correlated ship motion are frequently required, and realistically depicted surf and shore effects are highly desirable.

Multiple sensors and many dynamic features are typical requirements of gunnery and tactical training simulators. Most of these systems need thermal and light-intensified imagery simulations for weapon sights and night vision devices in addition to the typical out-the-window imagery. Scenes depicting many moving vehicles, smoke and fire, weapon firing effects, and the effects of weapons on vehicles, terrain, and features are becoming necessities rather than luxuries.

The simulation of space-based vehicles require, among other things, many moving and articulated objects. Models depicting the Earth and an accurate star field are necessary, and the use of geocentric coordinates is also frequently needed.

This sampling of different simulator applications illustrates the diverse requirements that image generators must meet. To meet the requirements of a particular application, trade-offs are frequently necessary; rarely can a single image generator perform well in every situation. By having a complete and thorough understanding of what is required in an image generator, an intelligent and informed selection can be made.

COMPARING GRAPHICS WORKSTATIONS WITH SPECIAL-PURPOSE IMAGE GENERATORS

Image generation systems are most often used in applications requiring interactive or real-time visual or sensor simulation. In this context, interactive is used to mean that the imagery is updated frequently enough that a user can interact with the object depicted in what appears to be a smooth fashion. This typically involves update rates from 15 to 60 Hz, depending upon the situation.

Applications that involve cues other than visuals (particularly motion) or ones in which the operator controls and the visual scene are tightly coupled usually require what is termed real-time visual simulation. Real-time simulation is a more rigid specification in which the imagery must not only be updated at interactive rates but that the update rate must also be kept constant or deterministic. A lack of determinism in updating the visual scene (i.e. asynchrony within the visual subsystem) can contribute to simulator sickness (Kennedy et. al, 1992).

Interactive visual simulation has been dominated by the use of graphics workstations, and the use of graphics-equipped PCs is fast becoming the standard. Special-purpose image generators have been used for these applications, predominantly because the distinction between requirements for interactive versus real-time is far from clear. Until recently, real-time visual simulation has been the unique domain of special-purpose image generation systems; however, many graphics workstations and even some high-performance PC-based graphics systems are beginning to encroach on what was once an exclusive market.

The following sections compare and contrast some of the capabilities and functionality of general-purpose graphics devices and special-purpose image generators. These comparisons are by no means intended to be exhaustive; rather, they attempt to characterize some of the more vital differences and provide a framework for selection criteria geared towards a specific user application. Comparisons of specific graphics and image generation products are generally available (Computer Graphics Systems Development, 1995; Computer Graphics Systems Development, 1996; IMAGE, 1996).

Performance Specifications

The most often encountered performance specification by which both interactive and real-time graphics systems are compared is polygon throughput. Because of the different heritage of workstations as opposed to special-purpose image generators, their polygon throughputs are frequently specified differently; thus, a direct comparison cannot be made without first taking into account several factors. Features such as shading, texturing, antialiasing, and nominal polygon size must be considered with an equal footing between the devices being compared. Furthermore, the effect of other capabilities such as the number of moving objects or height-above-terrain returns on polygon processing should be considered.

Pixel capacity is a second performance measure that is used to characterize image generators. Pixel throughput takes into account the update rate, number and computed resolution of display outputs, and the average number of computations per pixel needed to depict the scene. This latter measure depends greatly upon the architecture of the image generator. Unoptimized z-buffer architectures require computations for each polygon that subtends a pixel (or subpixel) on the screen; conversely, polygon sorting (either off-line or on-the-fly) can reduce this computational load significantly. Archdeacon (1996) proposes a suite of benchmarks for evaluating the pixel and polygon performance of API-based graphics systems for use in simulation applications.

Other performance specifications that should be considered are the amount of on-line geometry and texture capacity, geometry and texture paging rates, degree of antialiasing, number of levels of transparency, and countless other measures.

General Fidelity Issues

Image generation systems are often expected to have capabilities that extend beyond the standard graphics function of rendering large quantities of shaded, textured, antialiased polygons. Depicting various environment conditions and providing a dynamic scene are key capabilities required for visual simulation.

Weather effects are important in many applications, and even the most simple ones can benefit from some of the more basic capabilities. Pixel-level fog and haze attenuates the horizon (important for flight simulation cueing) and can be an effective means of masking the edge of the database. Other effects include cloud decks, layered fog, and volumetric smoke. These capabilities are typically available in some form on special-purpose image generators and some workstations but are less often found on PC-based systems.

The control of many moving scene elements can be a key selection factor. This can include independent moving objects (such as other vehicles), articulated components, animations, and sea states. These features are available on nearly every image generation platform. Because of their flexible architectures, some workstations offer some more advanced capabilities such as procedural effects.

Lighting effects are used to provide additional scene realism and usually is available as additional light sources and/or light lobe patterns. Light sources can be used to depict effects such as searchlights or flares, while lobe patterns can be used as landing lights on aircraft or ground vehicle headlights. These advanced lighting effects are available on most workstations and special-purpose image generators (usually with some processing penalty) but are not common on PC platforms.

Support of Multiple Simulations

In many situations, multiple channels of imagery are needed to support different display channels. Examples of this are multiple-channel, wide field-of-view displays and multiple gunsights. Many special-purpose image generators provide this capability, and this is also available on some graphics workstations. The ability of the image generator to generate multiple display outputs without duplicating the entire hardware path is highly desirable for several reasons. Such a system not only provides a cost-effective solution but also ensures (or at least increases the likelihood) that the various display channels stay synchronized and also reduces the required bandwidth between the image generation system and the simulation host.

Almost all image generation systems are able to provide imagery that depicts the virtual environment in the visual or “out-the-window” domain. Other image-based simulations, such as those of infrared (or thermal) and light intensification devices, may also be required, particularly in military applications. The simulation of these devices can be as simple as changing the colors of objects in the scene or may have sensor-specific data encoded and processed on the fly.

The ability of the image generator to provide the required level of fidelity of sensor simulation should be given due consideration where it is applicable. Some special-purpose image generators and graphics workstations provide sensor processing as an option. Alternatively, sensor-specific image generators can be integrated with the system; however, this approach requires additional bandwidth to and from the simulation host and may present database correlation problems.

Integration with Visual Databases

Many of the capabilities of an image generator are related to how it interacts with the database. Some of these features include geometry and texture paging, load management, and dynamic terrain and objects.

Paging geometry from disk allows the image generator to traverse databases much larger than what can be stored in the environment memory or display list. Texture paging allows high-resolution, geospecific textures (such as satellite imagery or aerial photographs) to be mapped to terrain and features for highly recognizable, extremely detailed databases. Nearly all special-purpose image generators are able to page geometry, and texture paging is usually available as an option if it is not standard. These capabilities are not as common on workstation and PC graphics systems, but are becoming more available.

Load management is an integral part of an image generator’s ability to maintain a constant update rate by controlling polygon and pixel processing loads. Geometric level of detail is typically used to keep polygon processing within the image generator’s throughput capacity; pixel load management techniques tend to vary widely between manufacturers. These capabilities are fairly standard on special-purpose image generators; workstation and PC graphics systems usually have geometry level of detail but few have any form of pixel load management.

As visual simulation applications have become more sophisticated, the desire has grown for databases that can be affected by actions of the user. This capability is of extreme importance in the ground warfare community, where the destruction of buildings and bridges and cratering of roads provide important cues for training. The ability to modify the on-line database seems to be more widely available on graphics workstations (which tend to have more flexible processing architectures) than on special-purpose image generators or PC graphics systems (which are usually optimized for static databases).

Integration with Display Systems

A visual system that uses simple CRT or rear-projection monitors need not have a display-savvy image generator. More complex display systems such as partial- or full-dome projectors, head- or eye-tracking, calligraphic and field-extended displays, and mosaicked displays may place additional requirements on the image generator.

Projected display systems usually require some form of distortion correction and, if the display channels are mosaicked, edge blending. These capabilities are rapidly finding their way into the projectors themselves; if the display system does not support either or both of these features, they are more likely to be found on special-purpose image generators than on workstations or PCs. Alternatives include third-party black boxes that can provide some of this functionality.

Head- and eye-tracked display systems can provide parallax cues and higher resolution through area-of-interest insets. This requires tight integration between the tracking device, the display system, and the image generator to minimize lags between head and eye position and orientation, location of the projected image, and the scene depicted. Furthermore, dynamic distortion correction may be necessary to depict the scene correctly as the eyepoint moves. Because of the variety of devices available, the responsibility for integration of the tracking device, display system, and image generator varies widely. Workstation and PC-based systems tend to have more choices of lower fidelity products, while a limited number of choices in a broader fidelity range are usually available for special-purpose image generators.

Calligraphic and field-extending display systems are not often used in low-cost systems. When these features are required, however, few PCs, workstations, or low-cost special-purpose image generators support such capabilities.

Integration with Simulation Host

The simulation host issues commands to and receives feedback from the image generator over some communications link. It is not only necessary that this communication be somehow synchronized but that the necessary level of control and feedback functions be made available.

Communication between the image generator and host simulation is generally either asynchronous or synchronous. When communicating asynchronously, the host sends commands to the image generator without regard for the phase difference between their processing frames; the image generator might perform some form of extrapolation on position and orientation commands to compensate for this phase difference. When the host simulation and the image generator are synchronized, the phase difference between the two is typically constant and minimized. Synchronous communication reduces the overall system transport delay through the visual subsystem and provides an increased level of update rate determinism. The types of communication between the host simulation and the image generator vary between different vendors and the various communication methods and protocols.

Some applications require that the image generator provide feedback to the host simulation about the environment or events that occur. Some examples include reporting height above terrain, intervisibility of two objects, range finding, and collision detection. These capabilities are usually available in some form on most image generators, although capacities and functions vary widely. This is important to know if image generators from different vendors are being used together (such as in a networked simulation system) to avoid or minimize correlation problems. It is also important to understand the performance of such functions (e.g. latency, number of reports per update frame, communication bandwidth required) and their impact on other performance parameters (like polygon processing).

Non-technical Issues

Special-purpose image generators are available from several vendors and are usually sold as an integrated combination of hardware and software and may even include integrated host simulation and/or display systems. In contrast, hardware and software components from different vendors must frequently be integrated for image generation systems based upon graphics workstations or PC-based graphics subsystems. This latter approach provides a great deal of flexibility and scalability with the added risk of integration difficulties and supportability issues (e.g. who is responsible for solving what may be a system-level problem). These issues may be difficult to quantify, but they should be seriously considered when preparing selection criteria for a visual system

CONCLUSIONS

PCs with high-performance graphics subsystems, graphics workstations, and special-purpose image generators have each been designed to serve different purposes, but all can be used in visual simulation. Each of these devices has its own strengths and weaknesses, and these must be assessed carefully against the requirements of the application and environment in which it will be used.

PC-based systems can often provide the most cost effective solution because the commodity nature of most of the hardware involved. This same factor that makes such systems so inexpensive also limits their applicability in visual simulation; however, in situations they can be used, PCs with interactive and/or real-time graphics are difficult to compete against. Because they are so prolific, development systems and experienced developers are almost always readily available.

Graphics workstations have long been used for interactive visualization and are now becoming sufficiently enabled for real-time applications. While they are more expensive than PC-based systems, these workstations are often more robust both in terms of hardware and software. Like the PCs, graphics workstations also provide the capability of being used as an application development platform and can often be used for database development as well.

Special-purpose image generators have taken severe blows in what was once the exclusive marketplace of high-end interactive and real-time simulation. They have remained competitive, however, due to decreased prices from increased use of off-the-shelf components and a rich set of capabilities resulting from the tightly focused market orientation.

As the market for low-cost visual systems continues to expand, manufacturers and integrators of image generation systems will step up their competition. The distinctions between the various levels of product offerings will further blur, posing more difficult choices to a wider range of consumers. To make informed and cost-effective choices from among a broad line of products, it is important for decision-makers to understand the complex range of issues involved in the specification and selection of image generators.

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