The Ancient Olympic Games: Being Part of the Experience

A. Gaitatzes, D. Christopoulos and G. Papaioannou

Foundation of the Hellenic World, Greece

Abstract
This paper presents the virtual reality applications that the Foundation of the Hellenic World has produced associated with the Olympic Games in ancient Greece. The separate virtual reality shows are presented in terms of interactivity and educational value. The technical aspects of the productions are next explained in detail, with an emphasis on character animation, dynamics and occlusion culling for surround screen projection environments. These techniques were mostly utilised in the recent production regarding the ancient pentathlon, where much effort has been made to recreate the feeling of the games and help the user/spectator be an interacting part of the edutainment activity.

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Additional Key Words and Phrases: Character Animation, Dynamics, Occlusion Culling.

1. Introduction

The undertaking of the 28th Summer Olympiad by Athens, the capital city of Greece, has spurred an increased interest for shows and complementary edutainment contributions to the games themselves. The Foundation of the Hellenic World (FHW) has prepared a series of thematic productions related to ancient Olympia and the Olympic Games, culminating with the highly interactive and accurate representation of ancient Olympia and the pentathlon (running, long jump, javelin, discus throwing and wrestling), whose final version was released just before the beginning of the Olympic Games. The high demand for interactive and entertaining productions, apart from simple walkthrough applications, however eye-catching [PGC03], has driven us to pursue an interaction model different from the classic navigator/inspector one. The virtual reality (VR) productions should be educational through creativity and active participation in events.

Some of the Olympic Games thematic applications have been running for quite some time and the feedback FHW has received has confirmed the preference of the spectators toward more "playable" environments where experimentation and first-hand experience is the most important channel leading to knowledge.

In the rest of the paper, section 2 provides the linking background and a brief insight to each one of the thematic applications, while section 3 explains the key points of the scientific and technological features related to the interactive shows and our effort to implement these in a surround screen projection environment.

2. The productions

In 2000, as the Olympic Games were returning to their birthplace, we decided to focus the new projects on the thematic region of the Olympic History and Games for the virtual reality productions that would open in the time period before the Olympic Games in Athens. Instead of focussing on only one production, where every concept and aspect of this glorious event would be explained and presented, a different approach was chosen. The event and its history would be approached by the creation of 4 projects. Each project would be complementary to the previous one and lead onto the next to finally conclude in a full-scale interactive representation of ancient Olympia and its Games.

A new production was released annually to the public, leading into a deeper understanding of the history of the Olympic Games and presenting the different aspects and impact in Greek culture and art.

Figure 1: *The Temple of Zeus at Olympia*

Starting from the first project, which was a simple presentation walkthrough, the following projects introduced new interactivity features and real-time graphics techniques to engage and captivate the visitor.

2.1. The temple of Zeus at Olympia

In the first production of the series the "Temple of Zeus at Olympia", visitors have the opportunity to admire the splendid temple itself as well as the sheer glory of the famous statue of Zeus, one of the seven wonders of the ancient world, of which nothing remains today (Figure 1). On the east pediment of the temple the myth of the origins of the Olympic Games is depicted, the chariots race between two kings. As the visitor approaches the temple the metopes come into view, portraying the twelve labours of Hercules, the famous hero son of Zeus. Walking on the backside of the temple on the west pediment, the visitor can marvel the battle between the people of Lapithes and Centaurs; the fight between Reason and Instinct.

In order to highlight places of interest in the virtual environment, an alternate navigation model was also employed. Even though the users have the freedom to move freely in the environment they also have the choice of a predefined path navigation model that assists them in making the experience more meaningful as the path highlights points of historic significance.

2.2. Olympic pottery puzzle

The study of ancient pottery has been a very important source of historical and archaeological information for understanding the life and culture in ancient Greece. Apart from the functional significance of the various types of pots, which give us clues about rituals and everyday life, the ink-paintings that cover many pot shards found at excavation sites, are priceless since they allow us to have an inside look into history. The goal of the Olympic pottery puzzle application was to educate the visitors about all this information, emphasizing on Olympic Athletic events in an entertaining and understandable way [RE00].

The "Olympic Pottery Puzzle" exhibit was created using the above aspects as guidelines and a constructivist's approach to interaction [PRS*94] (Figure 2). The user must re-assemble a number of ancient vases putting together pot shards. The users are presented with a colour-coded skeleton of the vessels with the different colours showing the correct position of the pieces. They then try to select one piece at a time from a heap and place it in the correct position on the vase. When they finish the puzzle, the painting on the vase comes to life, presenting an animation of one of the ancient Olympic contests. Being a highly interactive exhibit, different object selection mechanisms had to be employed to make the process as natural and simple to use. From a technical perspective, much effort was directed towards the realistic, highly detailed representation of vases and the simulation of their material properties like specularity and glossiness, using

Figure 2: *The Olympic pottery puzzle*

multi-pass rendering techniques.

Although no large stunning worlds or ancient cities were simulated, this exhibit still captivates the visitors of all ages, giving them the opportunity to interact with the vases intuitively. Completing the 3D assemblage puzzle with the help of VR equipment, helps them learn some important historical facts about the vases and the Olympic contests, as well as have a glimpse of the restoration procedure of earthenware. The reanimation of the depicted athletes was made in 2D (planar video overlays), preserving the colours and character of the ancient Greek ink paintings. This, in turn, helped the visitors perceive the Olympic contests and any information regarding the Olympic Games in antiquity from the perspective of an ancient Greek artist, something the public responded enthusiastically to. The Olympic pottery puzzle is suitable for presentation in both single-screen and surround screen projection systems.

2.3.   Feidias' Workshop

After the successful launch of the first interactive application regarding the Olympics, it was important to build on the positive feedback and winning concepts and create an experience, which would bring the visitor one step closer to Olympia. In this VR exhibit, visitors engage themselves in another marvel of ancient Greek art, the creation of *golden ivory statues*. Golden ivory statues are regarded as the masterpieces of Greek sculpture, and were admired as such even at the time of their creation. Only statues of Gods and heroes were made using this technique.

"Feidias' Workshop" (Figure 3) is a highly interactive virtual experience that takes place at the construction site of the 15-meter-tall golden ivory statue of Zeus, one of the seven wonders of the ancient world. The famous sculptor Feidias and his team of artisans built the statue in this workshop. Zeus' statue was afterwards dismantled and transferred to its designated location in the most important temple at Olympia, the Temple of Zeus.

The visitors enter the two-storey-high workshop and come in sight of an accurate reconstruction of an unfinished version of the famous statue of Zeus and walk among the sculptor's tools, scaffolding, benches, materials, and moulds used to construct it. The visitors take the role of the sculptor's assistants and actively help finish the creation of the huge statue, by using virtual tools to apply the necessary materials onto the statue, process the ivory and gold plates, apply them onto the wooden supporting core and add the finishing touches. Interaction is achieved using the navigation wand of the VR system, onto which the various virtual tools are
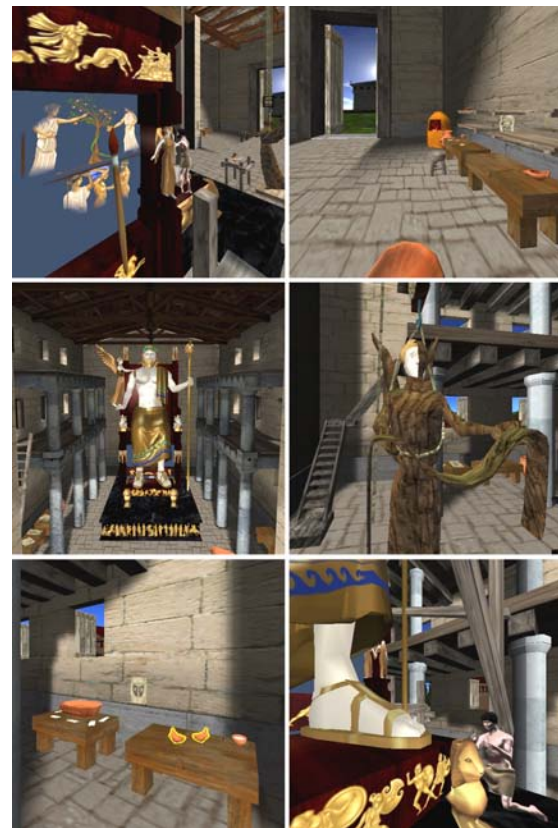

Figure 3: *Feidias' workshop: A creative approach to interactive edutainment*

attached. Using these tools the user helps finish the work on the statue, learning about the procedures, materials and techniques applied for the creation of these marvelous statues. The various workers and Feidias himself are displayed using *image-based rendering* techniques in the form of animated impostors [PGC03]. This technique was chosen because of its low polygon count since the detail of the other models in the scene was high. In order to provide additional depth cues for the interaction and better image realism, shadows were incorporated using precomputed lightmaps.

This VR production presents an accurate reconstruction of a populated and active workshop, with interactive and educational value. The learning by doing concept worked well and increased the visitors' interest and active participation in the VR show. Visitors are amazed with the techniques and level of craftsmanship involved in the building of such large-scale statues, facts that are mostly unknown to people at large. The use of the CAVE-like environment helps support the large scale and proportions of the workshop and the statue of

Zeus. The positive feedback we got from the incorporation of characters, led us to the conclusion that the public was especially interested in the way of life and working habits of people in ancient Greece. The use of animated representation of characters helped the audience understand, participate and immerse themselves into the experience, giving them a reference point of interest.

2.4. A walk through Ancient Olympia

In our most recent VR production "A Walk through Ancient Olympia", the user, apart from visiting the historical site, learns about the ancient games themselves by interacting with athletes in the ancient game of pentathlon (Figure 4).

We are at the end of the 2nd century BC. The day breaks and in front of us appears the majestic sanctuary of Zeus in ancient Olympia. In antiquity the Olympic Games took place here, while today it hosts the lighting of the Olympic flame. The visitors can wonder around and visit the buildings and learn their history and their function: the Heraion, the oldest monumental building of the sanctuary dedicated to the goddess Hera, the temple of Zeus, a model of a Doric peripteral temple with magnificent sculpted decoration, the Gymnasium, which was used for the training of javelin throwers, discus throwers and runners, the Palaestra, where the wrestlers, jumpers and boxers trained, the Leonidaion, which was where the official guests stayed, the Bouleuterion, where athletes, relatives and judges took a vow that they would upheld the rules of the Games, the Treasuries of various cities, where valuable offerings were kept, the Philippeion, which was dedicated by Philip II, king of Macedonia, after his victory in the battle of Chaeronea in 338 BC and the Stadium, where most of the events took place.
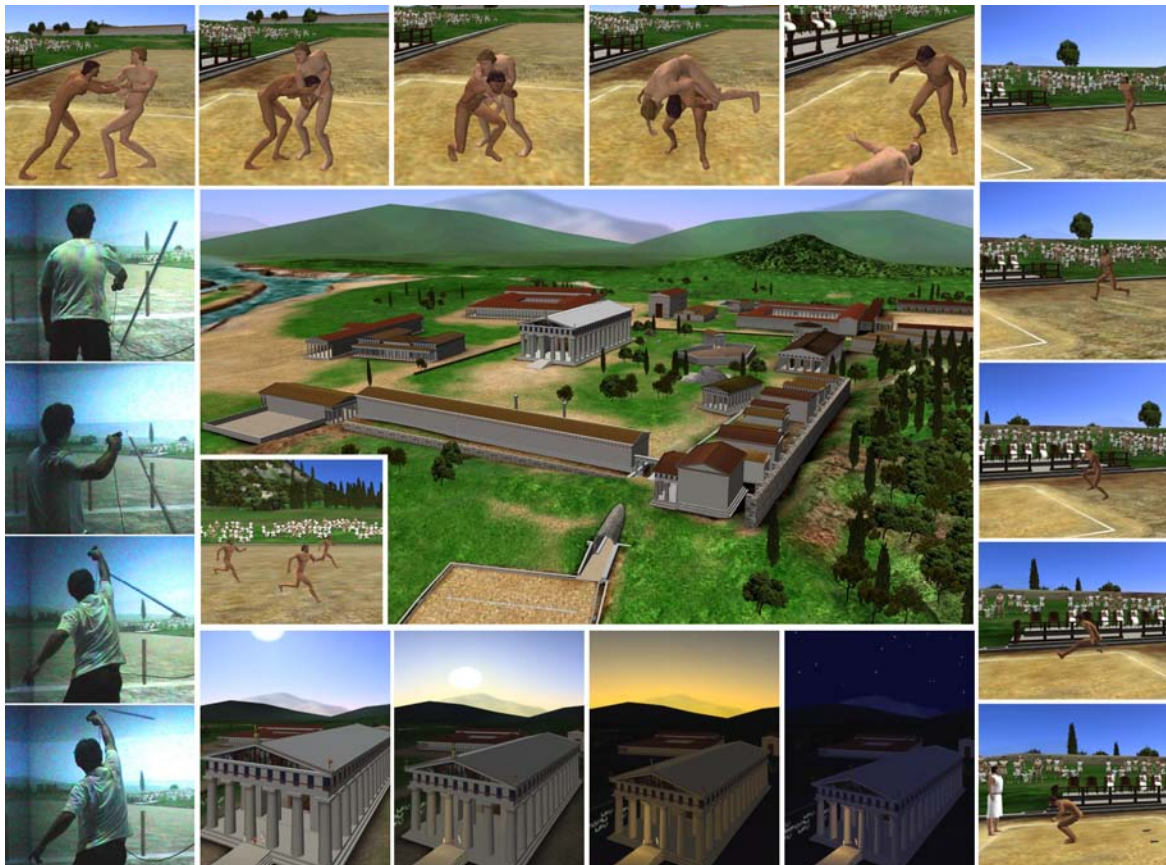

Figure 4: *Screenshots and live capture from the production "A Walk through Ancient Olympia".*

In addition, the public can interact virtually with 3D digital representations of Olympian athletes in the ancient pentathlon, including the 200-meter sprint, the discus throwing, the long jump, the javelin throwing and wrestling. Instead of just observing the games the visitors take place in them. They pick up the discus or the javelin and they try their abilities in throwing them towards the far end of the stadium. Excited about the interaction they ask when will they be able to interact with the wrestler one on one. A role-playing model of interaction with alternating roles was tried here with pretty good success as the visitors truly immersed in the environment wish they could participate in more games.

Finally, decorated with red ribbons in his hands and legs, the glorious winner makes the tour of triumph holding a palm leaf in his hand while the spectators give him a standing ovation. The Games come to an end.

3.   Production technology

From a technical point of view, the productions of FHW are presented on two VR systems, both using projective viewing technology [GCR01]. The larger system is a CAVE-like ReaCTor™ immersive display, consisting of four 3m × 3m projection walls (3 rear-projected viewing walls and a top-projected floor). An 8-processor SGI® Onyx2™ drives the four projectors through four InfiniteReality2™ graphics subsystems, in active stereo. A maximum number of 10 visitors and a museum educator enter the immersive cube, all wearing stereo shutter glasses and the show is controlled by the guide via a 6-degrees-of-freedom tracked joystick (wand). The museum educator also wares a hat with an attached 6DOF sensor for the head position and orientation tracking, which affect the perspective projection on each wall.

The smaller VR system consists of an ImmersaDesk™ R2 rear projection tilted screen driven in active stereo by an SGI® Octane2™. 6DOF head and hand tracking are provided via a head-mounted tracker and a tracked joystick. This system, having a lesser immersive effect and also a much slower computing system, is used mostly for lightweight applications. The large interactive VR shows are run in the surround-screen projection environment.

In terms of software technology, we have built our own game engine, Enhanced Visualisation System (EVS) [PGC03], [PIA*98], [GCR01], which uses SGI's OpenGL Performer™ scene-graph library [RH94], but also pure OpenGL for the rendering and VRCO's® CAVELib™ for the tracking input. As natural interaction requires the presence of familiar and realistic representations not just of visual aspects of the virtual world, but also of actions and procedures, important techniques and features such as character animation and

dynamics have been incorporated in the VR engine and are discussed below.

3.1.   Character animation

Real-time character animation in simulated virtual environments has progressed rapidly over the last years. This development has also been reflected by the changes of the visual style in virtual environment applications. Originally, game characters have been either hand-drawn or computer generated 2D images. For simple walkthroughs or small applications these techniques might be satisfactory. When the experience is to be enriched with interaction in active environments where people should explore and participate in close interaction with virtual people, the use of 3D animated characters, with recognizable and natural features, gestures and fluid motion, is essential.

The animation technique, which has established itself as the defacto way in bringing articulated models to life in real-time 3D environments, is *skeletal animation* combined with *soft skinning*. Skeletal animation was developed for the animation of articulated (e.g. humaniform) objects, in order to simplify the animator's work and make the animated forms more life-like and naturally moving [Wood00]. It is an improvement over previously used animation techniques like kinematics on hierarchical articulated objects [WW93] or morphing of character meshes. These techniques had a number of drawbacks like visible seams and gaps or high memory usage, absence of flexibility and interpolation problems.

Skeletal animation uses an endoskeleton, a hierarchic structure of *joints* and *bones*, which drives a *skin*, a vertex mesh representing the outer shell of the object. A bone is simply a transformation matrix, determining its position in relation to its parent bone to which it is connected via a joint (Figure 5). All the bones of the articulated object form together the skeleton. Only the skeleton is explicitly animated by recursively traversing the hierarchic data structure starting from the root bone, passing down the transformation of the parent objects to their children and concatenating the passed-down and local rigid transformations. The bones in turn implicitly animate the skin and its vertices. Using soft skinning, each vertex of the mesh can be influenced by more than one bones [Wood00], effectively mimicking the way a bone in a real body would affect the skin of a living being. Memory usage for skeletal animation is small and requires a significantly lower amount of information to be stored when compared to the other techniques. Animation data can also be generated on the fly using techniques like *inverse kinematics* [WW93], and applied to the model in real-time.
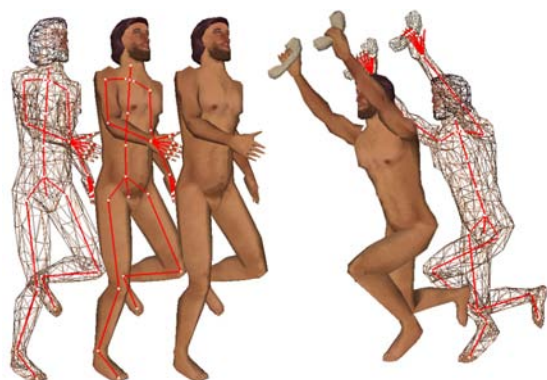
Figure 5: *Character animation using bones and soft skinning*

For our recent VR production "A Walk through Ancient Olympia" the skeletal animation technique was implemented for animating the various characters and athletes (Figure 4). Using the *Cal3D* animation framework library [Cal3D], specialized EVS rendering and simulation nodes were created which allowed us to incorporate skeletal animations from commercial modelling and animation software into our framework. Besides the playback of animations, the ability to blend and mix multiple animations was implemented for advanced animation control, generating smooth transitions between the animations and dispensing with extra transition animation cues.

Automatic generation of LOD versions of the Cal3D mesh are generated during the export phase, which can be shown at runtime for any animated model. Cloth and hair simulation, although still experimental, can be incorporated using the mass-spring model. In order to make memory usage more efficient, model instancing was implemented in cases where animation, mesh, and material data are shared. Initially, a set of *core models* is created, from which *instance models*, representing one specific instance of the model with its own animation state, are subclassed. A core model consists of all mesh, skeleton and animation data, while an instance model has its own animation state but inherits all other data from the core model.

Due to the fact that models also have to interact with the environment by picking and dropping other objects, a mechanism for attachment and detachment of other scene objects on the characters was implemented.

Although the animation system worked perfectly for the last project there are some shortcomings that have to be addressed concerning control of the animation sequences. Currently, there is no option to specify automatically what action should be taken when an action has ended or specify the number of times the animation should cycle, since only "cycle constantly" or "cycle only once" modes are currently supported.

3.2. Newtonian dynamics

One of the challenges in the "Walk through Ancient Olympia" was to be able to actively participate in at least one of the games (Figure 4). Considering the difficulty to move in a CAVE when surrounded by spectators, we decided to implement such interaction for the discus and javelin throwing games, which are relatively static. Both games required that the user take hold of an object and send it flying through the scene under the influence of forces in a controllable manner. The object would collide, bounce off and exchange energy with other geometry. For this purpose we used Newtonian dynamics, a well-known and extensively studied motion model for rigid bodies and their response to collisions [Ebe04].

3.2.1 EVS dynamics implementation. In the EVS implementation of dynamics, special geometric nodes, the dynamics objects, can be "hooked" to or "unhooked" from force fields at run-time. These objects govern their motion themselves under the influence of the forces they are presently attached to, unless they take part in one or more dynamic simulations. In the second case, the simulation node reports collisions, manages friction and dumping constraints, calculates the exchange of energy between objects (not necessarily all dynamic) participating in the simulation and estimates new linear and rotational speed and momentum for the objects.

For the moment, dynamic objects are controlled only by one hard constraint vital to our applications: grabbing. Once a dynamic object is grabbed, the differential rotational part of the user's hand (wand) transformation is applied at each frame to the dynamic object first. The force-related differential matrix is then applied and finally, the positional part of the wand motion. In this order, the trajectory defined by the current forces and the wand influence are disassociated.

EVS supports various types of force fields, including wand-controlled and transformable ones. The actual throwing action uses a wand-controlled force field (duration of application and direction), combined with a conventional linear field for the gravity.

The collision detection is handled by the dynamics simulation node, which uses the ColDet freeware library for this purpose [ColDet]. This collision detection system cannot report multiple contact points or edges, but it still works sufficiently well for our demands and is very fast. In some cases though, it causes instabilities or a wrong behaviour when handling marginal contacts

(objects may stop instead of pivoting on the contact edge and falling away).

3.2.2. Aerodynamics. An issue that has arisen in the javelin throwing game was the inability of the spear's body to align itself correctly with its trajectory. The airflow has little effect on the discus, being heavy and uniformly dense. This is not the case for the javelin though, which is heavily influenced by the air. In order to address this problem, we have added an adjustable aerodynamics bias to the rotational part of the dynamics object transformation. What it does is that it slowly corrects the object's rotational matrix so that its primary axis becomes aligned with the sum of applied forces.

In more detail, at initialisation time, the principal axes of an object are extracted from a random sampling of the object's surface vertices and they correspond to the eigenvectors of the covariance matrix of the sample set (second order central moments) [LD89], [Ebe04]. The largest primary axis is the eigenvector that corresponds to the largest eigenvalue. At each frame, a corrective transformation matrix $\mathbf{R}_{Bias}$ is multiplied to the time-differential rotation matrix (Figure 6):

$$\mathbf{R}_{Bias} = \mathbf{R}_{\theta, \vec{r}}$$

$$\theta = bias \cdot \frac{\pi}{2} \left\| \vec{a}_1 \times \vec{F}_{norm} \right\| \tag{1}$$

$$\vec{r} = \begin{cases} \vec{a}_1 \times \vec{F}_{norm} \Big/ \left\| \vec{a}_1 \times \vec{F}_{norm} \right\|, & \theta \neq 0 \\ (1,0,0), & \theta = 0 \end{cases}$$

where *bias* is the amount of aerodynamic influence, $\vec{r}$ is the axis of rotation, $\vec{a}_1$ is the transformed primary axis and $\vec{F}_{norm}$ is the total applied force direction.

When objects travel a long way airborne, the above adjustment helps rectify the orientation of a lightweight object relative to its trajectory.

3.3. Occlusion culling for open environments

As graphics cards have a limit to the fill rate and triangle count the application can pump into them, culling – or non-visible geometry elimination - is used extensively in large 3D worlds in order to minimize the geometry sent for rendering in the graphics card. In occlusion culling, [CCSD03], geometry that is hidden behind objects closer to the camera point, is discarded before being subject to depth sorting algorithms. Shadow culling [HMC*97], uses predefined occlusion proxies (occluders), which consist of simplified (and usually convex) polygonal versions of actual rendered geometry, such as rectanglular barriers, in order to efficiently block geometry hidden behind them. Shadow culling is best
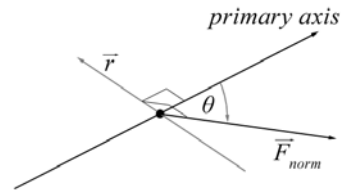

Figure 6: *Aerodynamics correction computation*

suited for our outdoor sparse environments as compared to other techniques, most of which are targeted for dense or indoor scenes.

In each frame, a semi-infinite convex frustum is created for each (convex) occluder polygon, the cap of the semi-infinite frustum being the occluder polygon itself and the sides connecting the each edge with the viewpoint. The bounding boxes of the geometry to be rendered are compared for containment with these frusta. If a bounding box resides completely within all frusta, then the object it contains is hidden. This process is performed in a hierarchical manner, discarding whole sub-trees of a 3D scene graph prior to forwarding the geometry to the rendering engine. Careful construction and placement of the occluders [PGC03], results in high hidden geometry elimination and a considerable speedup, especially for enclosed environments.

3.3.1 Solid occluders. In the case of outdoor scenes, like Olympia, where the static geometry is often blocky (buildings) but scattered and sparse, simple occlusion culling is not very effective due to the partial occlusion phenomenon (see Figure 7): Two or more adjoining planar occluders may partially hide a distant object but the combined occlusion area of them may hide it completely. This object cannot be eliminated if the frustum for each occluder is created separately, and the joining of frusta is an expensive operation.

To overcome this taxing limitation, we decided to use convex solid occluders, such as boxes and cylinders as proxies for large isolated structures (Figure 7). A convex solid when projected on a plane is guaranteed to produce a convex polygon. The convex frustum of the projected polygon is the union of the frusta that would be generated from the individual planes of the solid occluder, thus bypassing the need to merge frusta in order to avoid partial occlusion.

For each frame, the solid occluder frustum is generated as follows. The view dependent silhouette of the solid occluder is extracted by connecting the edges belonging to adjacent polygons, which are not both visible or hidden simultaneously:
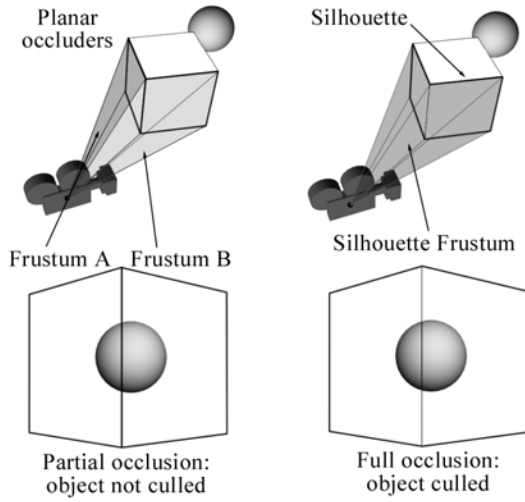
Figure 7: *Comparison between polygonal and solid occluders in shadow culling.*

$$edge(tr_i, tr_j) \in Silhouette \Leftrightarrow$$
$$\left[\vec{N}_i \cdot (\bar{P}_{i0} - \bar{C}) \right] \cdot \left[\vec{N}_j \cdot (\bar{P}_{j0} - \bar{C}) \right] \leq 0 \qquad (2)$$

where $\vec{N}_k$ is the normal vector of triangle tr_k, $\bar{P}_{k0}$ the triangle's first point and $\bar{C}$ the viewpoint.

The Silhouette edges do not lie on the same plane in general. Therefore, we must select a cap (near plane) for the semi-infinite frustum, based on the relative position of the viewer and the silhouette points. If the near plane is too close, the frustum solid angle may become too large, resulting in the false elimination of partially hidden geometry. Similarly, choosing a plane near the average of the silhouette points can be a disastrous selection for elongated solid occluders in the view direction. We chose to fix the near plane of the frustum to the furthest point of the silhouette from the viewer. This clipping plane's normal vector is the average directional vector between the viewpoint and the silhouette points:

$$\vec{N}_{near} = \sum_{i=0}^{K-1}\left(\bar{S}_i - \bar{C}\right) \Bigg/ \left\| \sum_{i=0}^{K-1}\left(\bar{S}_i - \bar{C}\right) \right\| \qquad (3)$$

where $\bar{S}_i$ is the *i*-th point out of the *K* silhouete vertices.

3.3.2 Occluder selection. As Hudson et al.[HMC*97] suggest, a scene may contain too many occluders for the engine to be able to test each object against each one of them. In our case, Olympia contains more than 200 occluder planes and solids. Therefore, an optimal set of occluders has to be selected for each frame at run-time in order to keep the number of "active" occluder primitives to a minimum. For this task, a "score" or optimization function f_{planar} has to be devised that takes into account the solid angle of the frustum. Hudson et al. use the area-angle approximation presented by Coorg and Teller [CT97]:

$$f_{planar} = \frac{-A\vec{N} \cdot \vec{V}}{\left\| \vec{V} \right\|^2} \qquad (4)$$

where *A* is the area of a planar occluder, $\vec{N}$ is its normal vector and $\vec{V}$ is the vector from the viewpoint to the centre of the occluder. We use the criterion in eq. (4) for planar occluders. For solid occluders we use an approximation formula which depends on the projection on the viewplane of the solid occluder's volume *Vol* and the squared distance of the occluder from the viewpoint:

$$f_{solid} = \frac{Vol}{\left\| \vec{V} \right\|} \cdot \left\| \vec{V} \right\|^{-2} = \frac{Vol}{\left\| \vec{V} \right\|^3} \qquad (5)$$

Keep in mind that the optimisation function for the solid occluders does not depend on angular attributes as the near plane of the constructed frustum always faces the centre of projection (see eq. (3)). f_{planar} and f_{solid} are balanced and do not need further biasing to become compatible.

The effectiveness of the solid occluders becomes apparent when moving among the buildings, especially at ground level and at inspection distance (near). Planar occluders would mostly produce partial occlusion when not facing the main sides of the buildings straight on. Most of the time we view the blocky buildings from odd angles and that is where the solid occluders provide a unified contiguous frustum to take into account all sides at once.

3.4. Skylight illumination model

Most realistic rendering in VR has dealt with indoor scenes or has focused on objects and buildings. However, outdoor scenes differ from indoor scenes in two important aspects, other than geometry: most of their illumination comes directly from the sun and sky; and the distances involved make the effects of air "aerial perspective" visible. A *Skylight Illumination Model*, once incorporated into the framework, captures and simulates the visual aspects and results of these phenomena. It changes sunlight position and colour from

the pale red of dawn to the bright yellow of midday and back again. It determines the colour and brightness of the sky throughout the day and it cues us to the distance of objects by shifting their colours. All these effects vary not only based on time of day, but also depending on weather, pollution and other factors.

Traditionally, outdoor VR applications would model these phenomena using Skydomes or Skyboxes, texture-mapped with static high-resolution sky and cloud renderings. In our latest outdoor simulation of ancient Olympia, a sky simulation from sunrise to sunset and nightfall was needed. Therefore, the implementation of a Skylight model was necessary.

The analytic model of [PSS99] was implemented with some modifications regarding the colour conversion algorithm to produce more dramatic sunsets/sunrises and the incorporation of a nightfall simulation with rendering of stars and moon (Figure 4).

An EVS node was created which constructs the dome geometry takes as input the sun position and weather conditions and finally, draws the dome, computing the colours for every vertex with analytic formulas. The colour and intensity of the sun is also computed and all underlying geometry is lit by its computed light attributes. The sun is implemented as a standard OpenGL light source. Indirect skylight illumination, caused by the atmospheric scattering of light, is simulated by additional light sources placed in the perimeter of the scene. These light sources are linked to the simulation and their intensity and colour is controlled to match their respective position in the skylight simulation.

In some cases, one might be satisfied with the colour and intensity of the skylight but the lighting on the objects might be too low. Brightening the skylight, causes the lighting on the objects to get higher, but the intensity and colour of the skylight also changes. Manually adjusting the lighting is achieved by introducing more peripheral light sources into the simulation, which only affect underlying geometry.

Unfortunately, the vertex colours computed from the initial illumination model are in Yxy CIE colour space and had to be converted first to XYZ tristimulus values and then to RGB [WS00]. By tweaking the original conversion matrix from XYZ to RGB to a different colour whitepoint setting, an increase in the vividness of the colours at sunset/sunrise is achieved, providing more dramatic results. The initial implementation proposed in [PSS99] only computed values during the day. To overcome this limitation, at nightfall, the sky and sunlight colours get interpolated to a standard night bluish colour. During the night, stars and the moon are faded in, implementing a fast and easy night sky model.

All the weather parameters and the position of the sun can be animated to produce smooth animations of sunset or sunrise along with changes in weather conditions.

The skylight model enhanced greatly the natural and realistic appearance of the scenery and decreased production time and resources on the graphics card since no time consuming rendered images had to be generated and loaded into texture memory. Since the specific model was created for real-time use, it had little impact on the frame rate of the application. Not only were the visitors excited with the virtual world by its vivid and beautiful imagery but the skylight effect also allowed cinematic introductions and endings to be realized.

4. Conclusions

As the curtain of the ATHENS 2004 Olympic Games came down, the odyssey of creating this series came to an end, confirming and outlining once again the importance of combining interactivity, storyboard with culture, advanced graphics and social interest points. All these key factors lead to the success and embracement of this series of applications from the public. Encouraged from the visitor numbers (approx. 7500) during the summer of the Olympiad and their positive feedback, we feel convinced that we succeeded in the challenge of bringing Ancient Olympia to the public and comfortable in undertaking and pushing future projects into new directions.

Finally, below follow a few highlight quotes from our guest book:

"What a great exhibition – both the real and the virtual. Keep up the good work" – *T. Berners-Lee (inventor of the world-wide web).*

"Today, on my third visit, I admired very much the new 3D program of Olympia" – *J. Rogge, President of International Olympic Committee.*

"I was astounded with my visit to the Temple of Zeus. I would like to express my admiration and sincere congratulations" – *I. Skoularikis, mayor of Olympia.*

Acknowledgements

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