Authentic Illumination of Archaeological Site Reconstructions

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Abstract

Computer reconstructions of heritage sites provide us with a means of visualising past environments, allowing us a glimpse of the past that might otherwise be difficult to appreciate. However, it is essential that these reconstructions incorporate all the physical evidence for the site, otherwise there is a very real danger of misrepresenting the past. A key feature when reconstructing past environments is authentic illumination. This paper discusses some key issues which must be considered when reconstructing the past.

Introduction

Today the interior of our buildings are lit by bright and steady light, but past societies relied on daylight and flame for illumination. Our perception of an environment is affected by the amount and nature of light reaching the eye. A key component in creating the authentic and engaging virtual environments of the past must, therefore, include the accurate modeling of the visual appearance of the environment illuminated by daylight and flame [DC01, SCM04]. Furthermore, in many graphics applications, including virtual archaeology, it is assumed that light travels through a non participating medium, normally clear air or a vacuum. For a great majority of synthesised images, this is a satisfactory assumption. However, in some situations it is necessary to include the participating media such as fog, smoke, or dust to provide the required level of realism within the images. In archaeological sites in particular, the materials used to provide interior light, including candles and wood fires would have caused smoke, which might have significantly affected visibility in these environments [Rus95, SGG*06].

In addition, the range of luminance levels in the real world are typically far larger than can be adequately displayed on a computer monitor. Thus some form of tone mapping operator (TMO) is needed that can careful map the set of real luminances to those that can be displayed on a low contrast ratio display or printed, or better still, novel high dynamic range (HDR) devices should be considered. These HDR devices are capable of displaying contrast ratios of approximately 4 or 5 orders of magnitude [SWW03].

Background

Virtual archaeology is now regularly used to portray a vast number of ancient sites, and there are even conference series devoted to this topic, including Computer Application in Archaeology [Caa] and VAST: International Symposium on Virtual Reality, Archaeology and Cultural Heritage (which incorporates the Eurographics Symposia on Graphics and Virtual Heritage) [Vas06]. However, the question of realism in virtual archaeology remains the subject of much discussion, for example [Spi88, Rei91,Mol92, MR95, Rya96, FSR97, RR97, Gil99, Bat00, Eit00, Kan00, Mar01, CD02] .To date there are in fact very few reconstructions that attempt to authentically represent how a site may have been appeared in the past. Failure to include as much of the physical evidence that may have affected the perception of a site, runs the real danger of the virtual reconstruction actually misrepresenting the past.

Key Issues

In this section we present some of the key issues which must be considered when undertaking a high-fidelity reconstruction of a past environment.

Authentic Illumination

Before the advent of modern lighting, illumination within ancient environments was dependent on daylight and flame. Highly accurate daylight models have been developed for computer graphics, including [PSI93, PSS99, WS98]. Of particular use is the Radiance program gensky which produces a Radiance scene description derived from the Commission Internationale de l'Eclairage (CIE) standard sky distribution at the given date and local standard time [WS98]. This allows the month, day, time, latitude, longitude and meridian of sites to be specified to see how they would be lit during a specific time of a day. Figure 1 shows the Egyptian temple of Kalabsha as it appeared at 9am on the 21 January 2003, and as it may have appeared at 9am on 21 January 30BC [SCM04].

Figure 1. *Daylight at the Temple of Kalabsha at 9am on 21 January (a) photograph 2003 (b) daylight simulation 30BC [SCM04]*

For the dark interior of ancient environments, some form of firelight was necessary. The fuel used for this fire directly affects the visual appearance of these interiors and any objects within them [DC01]. Furthermore, flames are not static and their flicker may create patterns and moving shadows that further affect how objects lit by these flames might look. Thus any realistic flame-lit environment should not only incorporate the accurate spectral profile of the fuel being burnt, but also the manner in which the flame may move over time [Rac96, RC03, BLR*06]. The acquisition of valid experimental data is thus of vital importance as the material used may have had a significant influence on the perception of the ancient environment [DCB02]. Experimental archaeology techniques should be used to build a variety of reconstruction candles and oils for lamps using authentic materials. Detailed spectral data of each flame type can then be gathered using, for example a spectoradiometer. Such a device is able to measure the emission spectrum of a light source from 380nm to 760nm, in 5nm wavelength increments. This gives an accurate breakdown of the emission lines generated by the combustion of a particular fuel. Figure 2 shows the spectral profile for a beeswax candle.

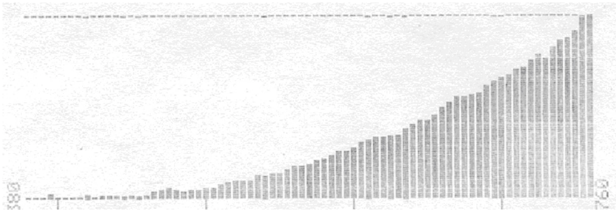

Figure 2. *Spectral profile of a beeswaxcandle [RC03]*

This wavelength information can subsequently be incorporated into a physically based renderer, such as the lighting simulation system, Radiance [WS98] with spectral rendering, which has been shown to yield highly realistic images [MCT*00, RB04]. Figure 3 shows a reconstruction of part of the horse frieze from the prehistoric site of Cap Blanc, France [RCS*01]. Figure 3(a) shows the horse illuminated by a simulated 55W incandescent bulb (as in a low power floodlight), which is how visitors view the actual site today. Figure 3(b), on the other hand, shows the lighting simulation of the horse illuminated by an animal fat tallow candle as it may have been viewed 15,000 years ago. As can be seen the difference between the two images is significant with the candle illumination giving a warmer glow to the scene, as well as increasing the shadows.

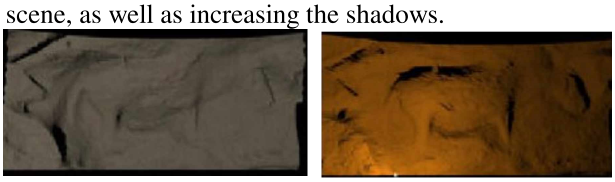

Figure 3. *Cap Blanc horse frieze lit by (a) simulated modern light (b) simulated animal tallow candle [CGH00]*

Using such a high-fidelity virtual reconstruction it was also possible to explore the intriguing possibility as to whether the dynamic nature of flame, coupled with the careful use of three-dimensional structure of the carving, may have been used by our prehistoric ancestors to create animations in the cave art sites of France, 15,000 years ago [CGH00]. We will, of course, never know for certain whether the artists of the Upper Palaeolithic were in fact creating animations 15,000 years ago. However, the reconstructions show that shadows created by the moving flame do indeed appear to give the horse motion.

Participating Media

Participating media, such as smoke, dust and fog were a major part of many past environments. Thus, when reconstructing these sites, it is important to take into account how the light scatters as it passes through the medium [SGG*05]. Four new types of interaction can occur: emission, absorption, in-scattering and ou-scattering. Furthermore, the coefficients that govern these interactions are wavelength-dependent. Figure 4 shows the inner sanctuary of the Egyptian temple of Kalabsha lit with, and without the ever present dust from the desert location. Desert dust is made up of more than a hundred different types of particles, each oriented in random directions [Kah03], and as figure 4 clearly shows, failure to include this dust in the reconstruction can significantly affect the perception of the resultant environment.

Figure 4. *Illumination within the Inner sanctuary of Kalabsha with and without the ever present dust. Image courtesy of Diego Gutierrez, University of Zaragoza*

Eye Adaptation

Although humans are capable of seeing a huge range of light intensities, from daylight levels of around $10^8 cd/m^2$ to night luminances of about $10^{-6} cd/m^2$, the cells of our visual system have a much more limited response range. We deal with this large luminance range by eye adaptation. Dark adaptation occurs whenever there is a decrease in ambient illumination, for example when we enter a dark room from a brighter environment, or switch the light off. Light adaptation happens when there is a sudden increase in illumination levels. During dark adaptation the human visual system recovers sensitivity which is experienced as temporary blindness, whereas when we undergo light adaptation we experience a loss in the system's sensitivity which allows us to see at the higher illumination levels. The time-course of light and dark adaptation is well known and it is different for the cones and rods [HF86]. An eye-adaptation process should also be capable of simulating important effects such as colour sensitivity and visual acuity variation. Furthermore, the visual system is not static and will dynamically adapt to an environment [LSC04]. Figure 5 shows dark adaptation for a medieval house environment.

Figure 5. *Simulating dark adaptation. In frame 2 the candles are blown out and at first our visual system experiences a loss of visibility as our visual system has yet to recover and become sensitive to such low light levels. After some time (this is mainly a function of pre-adapting luminance and pre-adapting time), sensitivity increases allowing us to recover some visibility. Note that we the brightness of the image have been increased for illustration purposes.[LSC04]*

Validation

Finally, validation should be a fundamental part of any virtual archaeology approach. In [RC03] a real reference scene, containing various geometrical objects was constructed and compared to the computer reconstruction of this test environment, figure 6. In this way the visual characteristics of the real and virtual candle flames including the shadows and the illumination could be directly compared. Concentric circles were added at the base of the "floor", to make more accurate measurements and observations. This validation step helped improve the fidelity of the virtual flame used in the subsequent reconstruction of Knossos, figure 7(b).

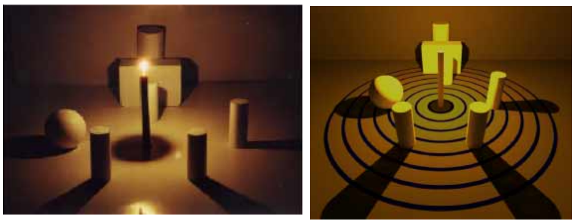

Figure 6: *Validation between real and virtual scene*

Figure 7. *Throne room of Knossos lit by (a) modern lighting (b) beeswax candles [RC03].*

Conclusions

There is no doubt that computers have had a major impact on archaeology, enabling multi-dimensional aspects of cultural heritage to be investigated as never before. As more sites and artefacts are modeled on computer and presented to a wide audience, great care should be taken to ensure that the computer reconstructions and subsequent perception of the site must take into account all aspects of the illumination. This must include the material used for the fuel, the presence of any participating media, and finally, the actual retinal response to the light to ensure that we generate a high-fidelity image. Furthermore, we don't just want to generate a photo-realistic image, that is an image equivalent to a photograph of the environment, but rather an image which is the equivalent to what a human observer would see if actually standing in the real environment in the past, a so called "*there-realistic*" image.

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