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Short Note

# Dust and light: predictive virtual archaeology

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**Abstract**

Computer graphics, and in particular high-fidelity rendering, make it possible to recreate cultural heritage on a computer, including a precise lighting simulation. Achieving maximum accuracy is of the highest importance when investigating how a site might have appeared in the past. Failure to use such high fidelity means there is a very real danger of misrepresenting the past. Although we can accurately simulate the propagation of light in the environment, little work has been undertaken into the effect that light scattering due to participating media (such as dust in the atmosphere) has on the perception of the site. In this paper we present the high-fidelity rendering pipeline including participating media. We also investigate how the appearance of an archaeological reconstruction is affected when dust is included in the simulation. The chosen site for our study is the ancient Egyptian temple of Kalabsha.


*Keywords:* Virtual archaeological reconstruction; High-fidelity visual appearance; Lighting simulation; Participating media

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## 1. Introduction

Lately archaeological reconstructions have become common in television documentaries, film and the publishing industries as part of presenting ancient cultures [9]. Recent advances in computer graphics, such as low cost, high performance hardware or tools for efficiently handling data sets from laser scanners [1] also enable virtual reconstructions to become a valuable tool for archaeologists as a way of recording, illustrating, analyzing and presenting the results [8]. However, if we are to avoid misleading representations of how a site may have appeared in the past, then the computer generated environments should not only look real, they must accurately simulate all the physical evidence from the site [2].

In this paper we consider how physically based participating media should be incorporated, as one part in the reconstruction process, when investigating how a site may have appeared in the past. We also investigate how the affect of participating media in the lighting simulation can alter the perception of a virtual reconstruction.

## 2. Background

The popularity of virtual archaeology has led to a significant number of virtual reconstructions ranging from non-photorealistic presentations, Quicktime VR images, realistic looking computer models, augmented reality applications and even full reconstructed urban environments [8]. Currently, many virtual reconstructions are limited because their level of realism cannot be validated. The generated images may look realistic, but their accuracy is not guaranteed, since they have no physical basis in reality. In order for the archaeologists to benefit from computer-generated models and use them in a predictive

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manner, they must accurately simulate all the physical evidence from the site being reconstructed [4]. The virtual reconstruction should not only be physically correct but also perceptually equivalent to the real scene it portrays [11].

### 2.1. Modeling the behavior of light

The goal of modeling the behavior of light is to simulate its interaction with the matter (the objects) in the scene, thus producing realistic renders while being able to predict the resulting intensity at any given point in the scene.

Physically based rendering methods allow us to calculate with accuracy the distribution of light in the scene. The Radiance Equation, introduced in computer graphics by [10] and solved by most global illumination algorithms can only be used if vacuum is the only medium in the scene, where the interaction of light is completely non-existent. But when rendering scenes that contain participating media the interaction between the light and particles floating in the medium has to be taken into account. A physically accurate lighting simulation of such media implies solving the Radiative Transfer Equation (RTE) [5], which is an integro-differential equation and noticeably more complex. Further details on the modeling of participating media can be found in Section 3.

## 3. Participating media

Light traveling through participating media interacts not only with the surface of the objects, but also with the medium itself (see Fig. 1). The atmosphere, for instance, contains particles, aerosols, dust, etc. and light interacts with all of them. The color of the sky, the loss of visibility in a foggy day, the so-called aerial perspective (loss of color perception with distance) are all effects of this interaction of light with the invisible particles of the atmosphere.

Fig. 1. Photograph of smoke in a medieval house in Sussex, showing the effects of participating media.

The most important effects of this interaction, mainly scattering, are spatial and angular spreading of the incoming light, which greatly varies our perception of the scenes. Effects such as glows around light sources or loss of color are due to the presence of these participating media, which causes light to be scattered while propagating.

To account for all those effects in the rendered images, the so-called integro-differential Radiative Transfer Equation (RTE) needs to be solved. This equation governs light transport in participating media, and is given by:

$$\frac{\partial L_\lambda(x,\vec{w})}{\partial x} = \alpha_\lambda(x) L_{e,\lambda}(x,\vec{w}) + \sigma_\lambda(x)\int_\Omega p_\lambda(x,\vec{w}',\vec{w}) L_\lambda(x,\vec{w}')\,\mathrm{d}\vec{w}' - \kappa_\lambda(x) L_\lambda(x,\vec{w}') \quad (1)$$

A much more detailed discussion appears in [7], including all the formulas and equations that lead to the Radiative Transfer Equation, as well as strategies to solve it.

The way participating media can influence perception can be obvious or more subtle. Objects might appear blurry and some detail might be lost. Light scattering and absorption are wavelength-dependent processes, so color perception will also be changed. Under certain conditions, participating media can also act as light sources themselves, or at least have a great influence in the contrasts and luminance gradients of a scene.

## 4. Case study: the Temple of Kalabsha

The ancient Egyptian temple of Kalabsha was chosen as a case study for our virtual reconstruction, given that the sun was a key feature of Egyptian religion and the dust levels in Egypt are high [14,15]. Using predictive light scattering it is possible to study the perception of the site when the sun's rays entering the temple are being scattered by dust particles. The temple of Kalabsha is one of the last temples to have been built for the ancient Egyptian gods. It is also the largest free-standing temple of Lower Egyptian Nubia located about 50 km south of Aswan. The temple is built of sandstone masonry and dates back to the Roman Emperor Octavius Augustus, 30 BC. Although, the site it was built upon evidently dates back to the colony of Talmis at least the reign of Amenhotep II in 1427–1400 BC [12]. The temple was dedicated to the Nubian fertility and solar deity known as Mandulis and the walls are covered with text and inscriptions depicting Egyptian deities such as Isis and Osiris. The temple was originally built at Kalabsha (Talmis) but with the construction of the Aswan High Dam in 1959, it became apparent that the temple would disappear under the rising waters of the Nile. In order to save the monument it was decided that Kalabsha was going to be dismantled and moved to a new site.

## 5. Creating the virtual temple

The first task in the virtual reconstruction process was to create a highly detailed geometric model of the temple of Kalabsha. Fortunately, when the temple was dismantled, it was very well documented, including detailed drawings and measurements, so that it could subsequently be physically reconstructed. A three-dimensional geometrical model was created based on these architectural plans, visual measurements and historical literature [13,16] using the Alias Maya modeling package. The model took two people several weeks to model, with the more intricate parts, for example the tops of the columns, taking the majority of the time. Although a more detailed model could have been captured if laser scanning would have been undertaken, the model currently consists of ~2.6 million polygons. For the purpose of studying the sunlight entering the temple this model is sufficiently detailed. Furthermore we were able to validate the geometry of our model with real measurements taken at the site.

Equally important to the geometric model, is the representation of the materials, which determines how the light interacts with the geometry. In fact a key problem in creating the model was not so much the geometry, which was well documented when the site was dismantled, but determining the texture and surface properties of the stone. Measurements taken during a site visit in January 2003 confirmed the Lambertian nature of the stone and thus we assumed a predominantly diffuse material. It was therefore not necessary to determine their precise BRDF using samples and a sophisticated device such as a gonioreflectometer. The results found in [3] were used as a basis for our simulations. The materials were modeled directly in Lucifer without any significant loss of accuracy. Lucifer is a spectral renderer, which can handle participating media in a physically based manner, described in-depth in [6].

Fig. 2 shows two side-by-side comparisons of the temple as it stands today and the virtual reconstruction.

## 6. Results and conclusions

This paper has presented considerations that should be addressed when creating a virtual reconstruction including a participating medium. An example was presented using a reconstruction of the ancient Egyptian temple of Kalabsha. One of the benefits with a high fidelity reconstruction is that it enables archaeologists to experiment with different hypotheses. For

Fig. 2. Real temple today and its virtual reconstruction. Top, the Pylon (main entrance); bottom, the pillars by the Pylon.

Fig. 3. Simulation of the interior of one of the chambers. Top left: without participating media. Top right: including participating media. Bottom left: real picture of a slit. Bottom middle: simulation without participating media. Bottom right: simulation with participating media.

example it is possible to study how different lighting conditions might have affected how the site was used. Sun simulations in combination with an accurate geometric model also allow the Egyptologists to study how sunlight would have entered the temple with and without dust.

By knowing the carefully chosen co-ordinates of the original location of the Kalabsha temple, we could place the computer model back virtually to where it was originally built. To study how participating media alters the perception of the Kalabsha Temple, we have chosen one of the inner three chambers. A sun simulation was made, including participating media in the form of suspended dust particles. To produce the simulations we used Lucifer [7]. The images have been rendered on a 4 GHz CPU with 1 GB of RAM, at PAL resolution (720 × 512 pixels), with an adaptive antialiasing of up to four rays per pixel. Obviously, including or not participating media greatly affects rendering times, from less than a minute per frame without it, to an average of 34 minutes per frame including it. In the absence of participating media, all the space between the light sources and the geometry is ignored, and light only interacts with the surfaces of the objects in the scene. With participating media, on the contrary, light−matter interactions (with the atmosphere in this case) occur even as light travels from the source to the objects, and computations of such interactions need to be performed at each incremental step. On the other hand, Lucifer is a physically based renderer, and no speed-up strategies are adopted if they compromise the quantifiable accuracy of the results. Other production-based renderers could cut many corners in the computations, reducing rendering times at the cost of physical accuracy.

The three rooms have only got small windows high up on each wall for light to enter through them. This makes these rooms especially interesting since there is practically no direct sunlight entering there, and thus the participating medium plays a key role in the transport of light throughout the scene. Photographs from other sites with similar architecture, see Fig. 3 (bottom left), show how the sunlight scatters through participating media when entering the chambers, greatly altering the visual sensation they provoke. Fig. 3 shows a close up of one of the modeled windows, with (bottom right) and without (bottom middle) participating media. It is evident how the sun's rays play a key role in the perception of the scene. Fig. 4 shows some frames of an animation of sunlight through a slit. The complete animation can be downloaded from http://www.cs.bris.ac.uk/»alan/kalabsha/. Fig. 3 also shows the difference in how the interior of the Kalabsha temple might look with and without taking into account participating media. The presence of participating media in the simulation (dust from the sandy environment of the temple) creates a whole new luminance distribution and, what is more important, a very different gradient distribution, thus changing dramatically the perception of brightness. Colors and details are almost indistinguishable in the background, since the eye is adapted to the higher luminance levels of the foreground.

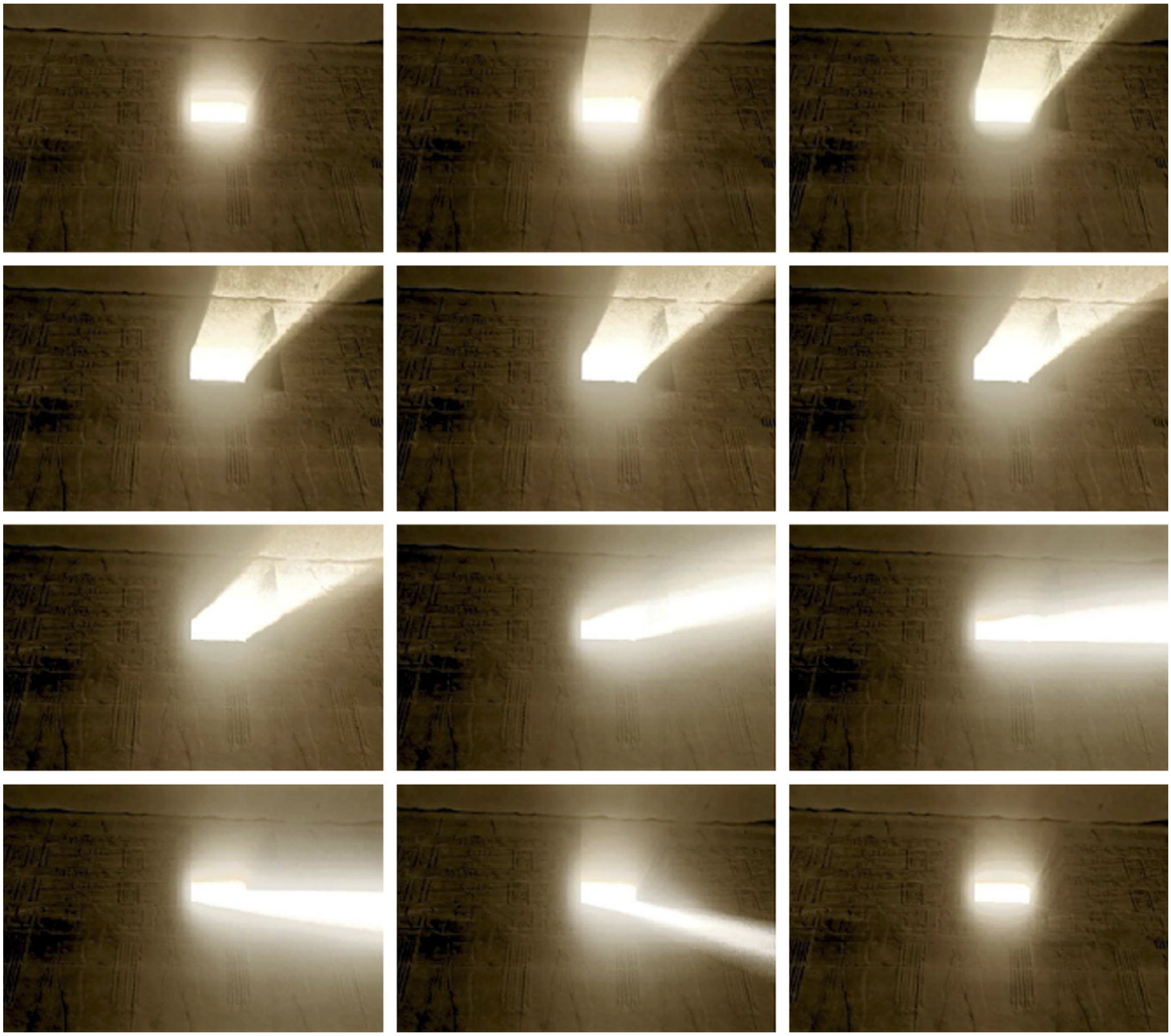

Fig. 4. Several frames of our animation of sunlight through the slit, at different times of the day.

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