# High Fidelity Rendering of the Interior of an Egyptian Temple

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## Abstract

The key factor in rendering of interior sceneries is how to treat the windows or other openings in the walls. The light, which is coming from these secondary light sources, may have significant impact on lighting conditions of interior sceneries and therefore it should be considered in rendering. Three window models, which can be used for rendering in Radiance, are described and compared in this paper. The aim is to find the most physically accurate way to reconstruct the lighting of the interior of an Egyptian temple or any other interior sceneries.

**Keywords:** secondary light source, window models, high fidelity graphics,

## 1    Introduction

Accurate light simulation is an important issue for archaeological reconstructions to obtain a realistic impression of a certain site in the past. This can be achieved by using appropriate lighting to the period, when the site was built. Accurate light simulation can have a major impact on the perception of historical sites and the decorations within them.

The site chose for this study is the ancient Egyptian temple of Kalabsha dating back to 30 BC. In 1963 this temple was moved in order to save it from the rising waters of Lake Nasser. A key feature in ancient Egyptian religion was the sun, so the temples would were built in a particular location and orientation. Therefore, in order to study the visual perception of the site, as it might have appeared when it was first built, a high fidelity reconstruction is needed.

Computer graphics enables us to recreate the temple as it was, based on the detailed measurements made in 1963 when moving the temple, and virtually place it back into its original location and orientation. By using the description of the sky in the original location in the past realistic depictions of these sites can be produced. This makes it possible to study how the sun lit particular parts of the temple at different times during the day. This can be used as a useful tool for Egyptologists to learn more about changes in perception.

The background of this project was that Egyptologists wanted to investigate the visual perception of an ancient Egyptian temple. One of the main questions was how the interior of the temple would have appeared when using lighting materials prevalent in ancient Egypt and how the sun would light the temple. The work on this project was started last year by Veronica Sundstedt, University of Bristol, but there were still some tasks (i.e. internal modelling of window holes, rendering of the interior, modelling the top of the pillars in more detail), which weren't solved. Hence this new study. This study should also investigate how the new location and orientation of the temple may have altered the visual perception of the temple.

Computer graphics is increasingly used by archeologists for interpretation of the past. It has long been used for tasks such as recording excavation plans, presenting the results of scientific analyses and illustrating artefacts. Lately, images generated by computers started to appear in television documentaries, film and publishing industries for presenting ancient cultures. Three-dimensional computer models can help archeologists to examine possible reconstructions and they can be also used in museums for presenting this information to the public.

Many archeological reconstructions are modeled and rendered in software that does not compute physically correct lighting. Such pictures can be useful in illustrations, but they are useless, when the study of the visual perception of a certain site is desired. When we want to study the effect of realistic lighting we should use only pictures, which are creating by using high fidelity graphics. This approach and the collaboration with Egyptologists makes it possible to create a model of the temple, place it back to its original location with original orientation, and illuminate it, as it was 2000 years ago.

The aim of this project is to investigate the visual perception of the interior of an ancient Egyptian temple and its decoration. In particular, how the interior may have appeared when we don't use any secondary light source. We consider only the Sun. Since the three-dimensional model of the temple was created during the previous work, it was not necessary to do that again. The existing model was used. To achieve the goal of this project the right technique for modeling the light, which was introduced through the holes in the walls had to be found.

## 2    Background

This section explains what high fidelity graphic means in this paper. It describes ideas and technology on which this    implementation    builds    and    it    contains    the

background theory of the lighting simulation and rendering system Radiance, which was used for this work.

## 2.1 High Fidelity Graphics

High fidelity graphics enables the rendering of images, which are perceptually similar to an original impression of a certain scenery [15]. The original in this case is the interior of the temple of Kalabsha in its old location and orientation. To produce a realistic impression is the paramount task in this work. The need for realism is one of the driving forces behind computer graphics research. It is important in many fields, and archeological reconstructions is one of them. Computer graphics enables us to study how the site would appear under the lightening conditions prevalent in a specific period of time. It is not possible to study it in reality, because many archeological sites are today illuminated with modern electric lighting. For achieving reality the correct spectral values of daylight and flame should be used to illuminate the site. By using the appropriate spectral data of the original light sources to illuminate a scene, the viewer can perceive a site in close approximation to what the original environment may have been.

Most modern 3D modeling packages are very powerful for modeling, but they are not so good for rendering. Light often does not interact in the rendering system in the same way, as it would do in a real environment. The results of rendering often look like a photorealistic image, but they are not true to reality. A different approach is used in special Lighting programs such as Radiance [5, 12]. These tools enable the user to render the scene with accurate lighting. For this project it is important to distinguish between photorealism and lighting simulation. Images, which look as real as a photograph, are products of photorealism. On the other hand the lighting simulation attempts to accurately reproduce how real light would spread through a certain environment. This is important because images, which look real, may still not be an appropriate representation of reality.

Rendering a three-dimensional computer model of a site with accurate lighting provides us with several advantages. Daylight simulation enables us to show how a site would have appeared at different times of the day (changing only a few parameters). This can be used by Egyptologists to study how the sun would have played on all parts of the site and how much light would have actually entered the interiors of the temple. We can create the model in which we can virtually restore parts of the temple, which have been damaged during the centuries. This is important, because otherwise we could not study how the sun would have lit original temple in reality. It is also possible to light the model with virtually reconstructed lights prevalent for a particular period, such as olive or sesame oil lamps. It is possible to view the site from new angles, which possibly is difficult in reality. The benefit of lighting simulation is also that

results not only look realistic, but in fact correspond to reality perceptually.

Nowadays realism typically means photorealism, i.e., the use of bellow described steps to render an image. At first it is necessary to create a model of the environment to depict in great detail. It is almost impossible to create a model, which is exactly the same as the original with respect to geometrical and in physical properties. However, this nevertheless would be important for an accurate interacting with light. Since we are not able to create a perfect model of the environment, we have to use some simplification. In photorealism we use the fact that human eye is not perfect and it cannot detect small differences between original and synthetic image. In photorealism the models with undetectable inaccuracies are good enough. Secondly, the accurate modeling of the light is important, i.e., properties of the light source and the propagation of light through the scene. Recreating the way in which the light moves throughout an environment precisely can create realistic images. Real environments can be also affected by other things, such as dust, fog or smoke. How real the computer graphic actually is, should be evaluated by the human response to an image, because in general software cannot compare reality and computer graphics in the same way as the human eye can do.

## 2.2 Radiance Lighting Simulation and Rendering System

Radiance is a lighting simulation and rendering system [5, 12]. It accurately simulates light behavior in virtual environments. This tool was developed at the Lawrence Berkley National Laboratory by Greg Ward. Initially it was developed as a research tool to investigate advanced rendering techniques for lighting design, then it evolved into a sophisticated tool used in both architecture and engineering. It differs from other rendering tools by its ability to predict reality. It produces numerical correct results and renderings that are indistinguishable from photographs [5].

There are two requirements for a valid lighting simulation: to solve correctly both the global and the local illumination problem. To solve the global illumination problem the program must compute how the light (from light sources) interacts with the synthetic objects in the scene. To solve this problem it is essential to accurately describe the indirect illumination, i.e., light which is not coming directly from a light source but has bounced diffusely one or more times off surfaces in the scene. Global illumination simulation is also used for soft shadows and color bleeding, i.e., how color of one surface in a scene affects the color on another surface. The local illumination model describes the physical properties of each surface in the scene, how the light is emitted, reflected and transmitted by each surface. There are two main techniques that enable the global illumination problem to be solved: ray tracing and radiosity [1, 3, 7]. Many lighting simulation programs are based on the simple radiosity method, which models the

surfaces as ideal Lambertian diffusers [3]. This simplification leads to more inaccuracies in the result. The best methods for solving the global illumination problem use specular and directional-diffuse reflection of the light as well, like in Radiance [5].

Radiance employs a light-backwards ray-tracing method, extended from the original algorithm introduced to computer graphics by Whitted in 1980 [10]. Since the original algorithm fails for diffuse interreflection between objects, which is usually approximated with a constant ambient term in the illumination equation for global illumination, Radiance is using a ray-tracing algorithm that is using a combination of deterministic and stochastic algorithms. Radiance uses an efficient algorithm for computing and caching indirect irradiance values over surfaces, while also providing more accurate and realistic light sources and surface materials. It recursively evaluates the following integral equation at each surface point, [5]:

$$L_r(\theta_r, \phi_r) =$$

$$L_e(\theta_r, \phi_r) + \iint L_i(\theta_i, \phi_i) f_r(\theta_i, \phi_i; \theta_r, \phi_r) |\cos \theta_i| \sin \theta_i \, d\theta_i \, d\phi_i$$

Where:

$\theta$    polar angle measured from the surface normal

$\phi$    azimuthal angle measured about the surface normal

$L_e(\theta_r, \phi_r)$    emitted radiance (watts/steradian/meter$^2$ in SI units)

$L_r(\theta_r, \phi_r)$    reflected radiance

$L_i(\theta_i, \phi_i)$    incident radiance

$f_r(\theta_i, \phi_i; \theta_r, \phi_r)$    bi-directional reflectance-transmittance distribution function (steradian$^{-1}$)

The radiance equation can be described as the value of a ray in a given direction, expressed in terms of luminance or radiance. The expression on the right-hand side sums the emitted radiation and the convolution of all incoming radiation with the reflectance-transmittance function for the surface, $f_r$. The function is defined recursively because the incident radiance at a point on a surface must be the emitted or reflected radiance at a point on a different surface. This equation captures the nature of the recursive ray tracing process [4].

Radiance uses a combination of deterministic and stochastic ray tracing. By combining of both approaches it is possible to obtain a balance between speed and accuracy.

To accelerate the solution, the integral is separated into those parts, which can be computed deterministically, and those that are better solved using stochastic methods. The direct component is computed by tracing rays to random locations on the light sources. The specular indirect component is computed by distributing rays about the mirror and transmission directions using uniform Monte Carlo sampling. Once these two prominent components are calculated, the diffusely interreflected component is computed by occasional evaluation of the integral at dynamically selected locations [5].

The key to calculating Equation 1 efficiently is removing any places where the incoming irradiance, $L_i$, or the surface reflectance, $f_r$, is large.

The ambient value approximates the global average of radiance over all directions and all points of interest in a scene. The ambient calculations in Radiance replace this global average with local averages based on indirect irradiance computations. It is more accurately referred to as a diffuse interreflection calculation [5].

## 2.3 The Site

The site chosen for this project is the temple of Kalabsha, one of the last temples that have been built for the ancient Egyptian gods. It is the largest freestanding temple of Lower Egyptian Nubia about 50 km south of Aswan. This temple was chosen because it is well documented since the temple was dismantled and moved in 1963. There are only few monuments that are so well documented, and it is possible to create a model of the monument without additional documentation work on site. Since the project focuses on how firelight and sunlight plays on a temple and its decorations, a site with both closed rooms and open architecture was desirable. The temple of Kalabsha is partly open to the sun and closed in other areas. It was also good if the site contained some polychrome (coloured walls) for the restoration process of the colours. Very small polychrome is preserved in Kalabsha itself so an attempt to make a reconstruction of the ancient polychrome palette had to be taken into consideration. For all these reasons the temple of Kalabsha was chosen. The temple is also unfinished which makes it a bit special to reconstruct.

The temple of Kalabsha dates back to the Roman Emperor Octavius Augustus 30 BC, but the colony of Talmis evidently dates back to at least the reign of Amenhotep II in 1427 -- 1400 BC [6]. The temple is dedicated to the fertility and Nubian Solar deity known as Mandulis. The walls of the temple are covered with text and inscriptions depicting Egyptian deities such as Isis and Osiris.

The temple was designed in a style that is typical for Ptolemaic period with pylon (part 4 on the following plan of the temple of Kalabsha, figure 1), courtyard (1), hypostyle hall and three-room sanctuary. In this case the Pylon is offset, which creates a trapezoid in the courtyard beyond. The courtyard, which is just inside the pylon, had columns on three sides in the past. The upper stories of the pylon can be reached by staircases, which are at either end of the courtyard. There is a good view of Lake Nasser from the top of the pylon. The gateway of the temple is 9.70 meters high. On top of this gateway there are inscriptions of the disk of the sun and scenes of the king giving sacrifices and praying. The small rooms in the surrounding wall were used for storage.
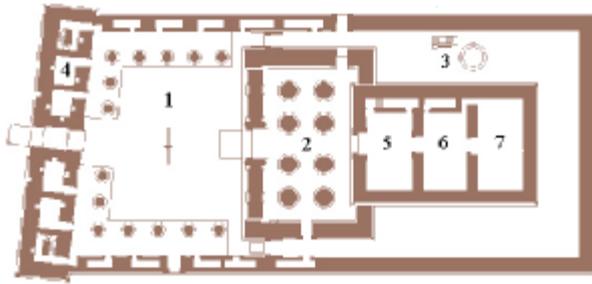
Figure 1: Drawing of the temple of Kalabsha
The main parts of the temple: courtyard (1), the hypostalle hall (2), nilometer (3), pylon (4), the pronaos (5), the naos (6), the adyton (7).

In the hypostalle (2) hall there is an entrance to the three inner chambers. First one is the pronaos (5), second one is the naos (6), or sanctuary where statues of gods were located, and the last one is adyton (7), which is the innermost or secrete shrine [14]. Inside the surrounding wall there is also nilometer (3), which was used to collect sacred water to the gods.

There are two further elements of religious importance that remain outside the enclosure wall. This wall is narrowly enclosured by another (outer) enclosure wall. The Mamisi, where the sacred birth of the Pharaoh is venerated, is at the South West angle of this latter enclosure. And finally one complete element of the earlier temple is preserved, the so-called Ptolemaic Chapel. The first enclosure wall is meant to bind an area of 66.08 m x 33.04 m [2, 11]. The original overall height of the Pylon was probably 16.25 m. The complex is built in sandstone masonry.

The focus of this work is on the three inner chambers. The aim of this project is to find how the inner chambers are lit by sunlight (coming through small windows in each room and from the hypostalle hall).

# 3   Rendering in Radiance

The model used for rendering in this project was created by Veronica Sundstedt in last year of her final project [8]. It was created in Alias|Wavefront's 3D modeling software called Maya [9, 13]. Since this project is an extension to the work of Veronica Sundstedt, the model was used with her agreement.

The Radiance programs have no graphical user interface and are accessed from the command line with many options. The rendering pipeline for making 2D images from a 3D model can be divided into following few steps:

Model -> Compile -> Render -> Filter -> Display

The radiance program uses simple text files for scene descriptions. It is quite difficult to write scene description files even for simple environments and for such a complex scene like a whole temple it basically is

impossible. Fortunately, there exist modeling programs, which can export the scene description into Radiance's obj file format, and Maya is one of them. All objects of the scene in Maya must be made out of triangulated polygons before the .obj-file can be created. The radiance package contains the *obj2rad* command, which converts the .obj-file into a Radiance scene description.

To assign a final material for each object is a bit more complicated. The final material of a face is determined by a material, which is assigned to this face in Maya from the start. If the material blinn1 is assigned to a face in Maya it will get the name blinn1SG in the .rad-file, when it is exported. The mapfile.map file describes what material in the material.rad file this face will be mapped to. The material for the surfaces will be assigned based on the mapping rules file given in the -m option in *obj2rad* command. If no original is assigned in Maya the face will get the default material [8]. The original files mapfile.map and material.rad created by Veronica Sundstedt were used for this project.

Before we start to render a scene, the following files should be prepared: a description of a scene, material and light source description and mapfile.map file. From these files it is possible to create a file with an octree, which is used by the rendering process in Radiance. Following commands can be used:

*% obj2rad -m mapfile.map scene.obj > scene.rad*

*% oconv material.rad scene.rad >scene.oct.*

The first command converts the .obj-file into a Radiance input file format and the second command creates an octree from the description of a scene and of all materials used in the scene. Suitable parameters for rendering and a desirable view can be found by using the interactive program *rview* for scene viewing.

The highest-quality pictures can be produced by rendering program *rpict*. There are many parameters that can be set for rendering with *rpict* and it is not trivial to find most suitable values for them. The result of *rpict* is not generally viewed until the rendering calculation is complete and the output has to be passed through *pfilt* for antialiasing and exposure adjustment. Here is an example of the *rpict* command, which uses an octree of a scene and myview file that contains description of desirable view:

*% rpict -vf myview -av .5 .5 .5 scene.oct >scene.pic*

The output can be filtered by:

*% pfilt -x /2 -y /2 scene.pic > scenefil.pic*

It is not necessary to run all these commands individually to create a rendered image. By creating a control file, it is possible to leave the details of running the right commands with the right options in the right order to the Radiance executive program, *rad*. *Rad* pays attention to

file-modified times in deciding whether or not the octree needs to be rebuilt or other files need to be updated. *Rad* also improves rendering time and quality by optimizing parameter values based on qualitative information in the control file instead of relying on defaults. The control file usually has the .rif extension and it contains a list of variable assignments. Here is an example of running rad program:

*% rad scene.rif > scene.pic*

For this project the approach with control file was used.

## 3.1 Rendering of an Interior Scenery

The aim of this project was to investigate, how the sun could light the interior of the temple (three inner chambers) through the windows and the doors (entrance door from hypostalle hall). For achieving this goal it was necessary to create a description of the sky and to find the right way how to represent the windows and doors.

### 3.1.1 Sky Description

The sun was an important key feature in ancient Egyptian religion and it affected the positions and orientations of the temples. Computer graphics enables us to place the computer model back into its original position and orientation and study how the sun would affect the temple in its original location.

The daylight component is based on resources that are built into Radiance. The data are derived from Commission Internationale de l'Eclairage (CIE) standards that closely model daylight observations that have been collected by scientists and engineers for decades. To produce a sky description a Radiance program *gensky* can be used. This command creates a Radiance scene description for the CIE standard sky distribution at the given date and local standard time. As parameters the values of month, day, time, latitude, longitude and meridian could be specified. The values used for this project were values for old location in Talmis:

Latitude: 23.5500
Longitude: 32.8667
Altitude (meters): 172
Lat (DMS): 23° 33' 0N
Long (DMS): 32° 52' 0E

All images presented in this project were created with sky description for 2, January, 10:00am.

### 3.1.2 Windows Representation

The windows (or other holes) in the walls usually act as secondary light sources in the scene and there are a few ways to model them. In this project three of them were used and compared.

At first all windows and the entrance door were modeled as a hole in the geometry and they weren't considered as a secondary light sources. There were no special files with description of the windows or of the material used for windows created for this approach. Different parameters for rendering were tried to find how they affect the final result.

Secondly, the windows were represented as secondary light sources without using mkillum. The mkillum is a program, which takes a prepared scene description and an octree and computes light source distribution for each surface, replacing them with secondary sources whose contributions can by computed more efficiently by rpict. A new file with the description of the inner surface of the window and the new material used for this face had to be created. The new material was derived from illum material, which is designed for secondary light sources, with using a special function, which calculates the distribution of light from the window only from the description of the sky.

Finally, the mkillum was used for all windows and entrance doors. For this case the description of inner surface of the window is needed. The difference between this and previous approach is that mkillum considers the outside geometry when it calculates the distribution of a light from specified surfaces.

For the descriptions of the windows and door it was necessary to find the co-ordinates of the inner vertices. The description cannot be created by exporting the .obj-files, because this approach create two triangulates for the window face and for input to mkillum we need one polygon. Therefore the values were found in Maya model by using create polygon tool and snap-to-point function.

## 4 Results

At first all three methods for windows representation were tested for the most inner room of the chambers of the temple. For this test the reduced model was used, which contained only the description of these three rooms and of the sky and ground. The outside geometry wasn't considered. The results in this case for all three types of windows representation were almost the same, with no noticeable differences. Therefore if we do not consider the outside geometry, there is no reason to use mkillum. But in reality, when the sun simulation is created, it is necessary to consider the outside geometry; otherwise the result is only a rough approximation of the reality.

Secondly, a series of images of the first inner room was created, at least one image for each type of windows representation. In this case the scene contained the whole temple. Images created with different technique were also compared with Mean Square Error (MSE) method (some of the results are shown in a table at the end of this chapter).

For the first approach (holes in the walls) the results were very bad at the beginning. There were no shadows in the images, so they looked very flat. After changing

some parameters (ab – ambient bounces and ad – ambient divisions) for rendering the results were better, but there still were some obvious errors.



Figure 2: First room rendered with first method with default parameters





Figure 3: The first room rendered with first method with changed parameters
(left ab=2, right ab=2, ad=2048)

The images produced with the second representation of the windows were much better. There were no obvious errors in the results and they did not seem to be wrong. But with this approach there are still some inaccuracies, because the outside geometry is not considered. The results will still be the same, whether there is outside geometry or not.
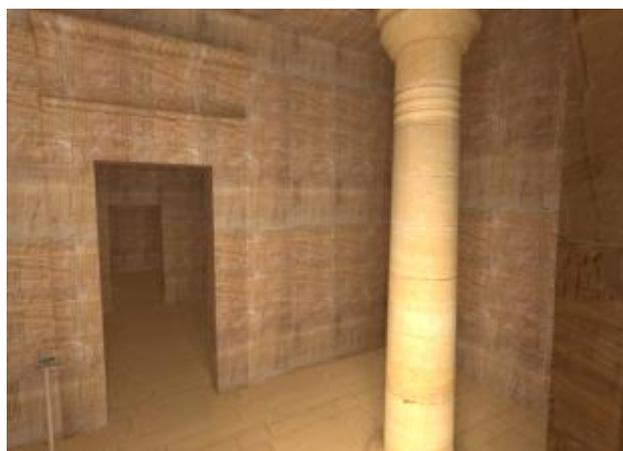


Figure 4: First room rendered with the second method

Since the first two methods did not produce sufficiently realistic images, the third method was tried. In this case, the mkillum program was used to calculate the light distributions for the inner surfaces of each window and of the entrance doors. First results were again not very good and a bit flat, but after changing some parameters the results were satisfactory. The mkillum program was created for the scenes that break the assumptions in the Radiance indirect calculation, which is that indirect illumination sources are more or less uniformly distributed. The temple of Kalabsha is a classic example of such scene, because the hypostalle hall creates quite complicated outside geometry. The images created with using mkillum seem to be most realistic, and it should be the method used to model the windows and doors for rendering in Radiance.
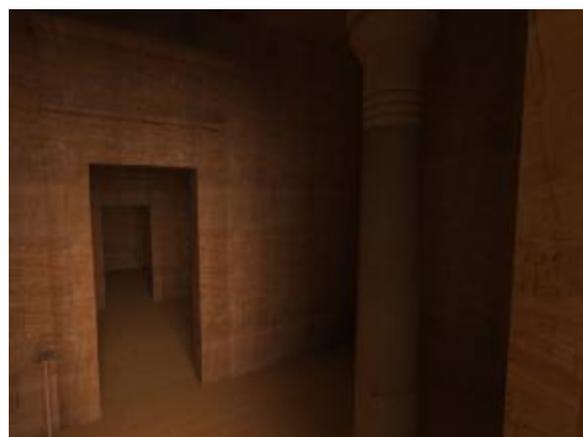


Figure 5: The first room rendered with using mkillum and with changed parameters (ab=2)

The following table shows values of MSE for the image of the first inner room created using mkillum (third method, figure 5) and for images of the first inner room created by other techniques (figure 2, 3, 4):

| | first method | first method with ab=2 | first method with ab=2 and ad=2048 | second method |
|---|---|---|---|---|
| MSE | 93,49 | 7,33 | 6,05 | 4972,80 |





Figure 6: The third room rendered with using mkillum only for the entrance door and with using mkillum for entrance door and for all windows. MSE between these images: 25,05

## 5 Conclusion

This paper describes a high fidelity reconstruction of interior of an ancient Egyptian temple. The project focused on the rendering of interiors of a chosen site. The paper describes alternative approaches how the interior should be rendered. It discuss different ways how to model the windows and doors for rendering in Radiance. The advantages of each method are described in this paper and a comparison of all methods is given. The most suitable method (using mkillum for rendering of interior sceneries) was found.

With this method it is possible to create images in high quality that are closest to reality from all created images. This enables archaeologists to study how far the sunlight would have reached into the temple. For example we can study if the windows were positioned in order to light something special in the temple. It is also possible to investigate the visual perception of the interior of a chosen site.



Figure 7: The view from hypostalle hall towards the inner rooms rendered with using mkillum for the entrance doors into first room.

## Acknowledgements

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