Reconstruction and Lighting of Assyrian Palace Reliefs

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Abstract

We present a 3D scene of Assyrian stone reliefs from the Northwest Palace for a museum setting. Our scene includes 3D models of a stone relief that was scanned at the Yale University Art Gallery and reconstructed using structure from motion 3D reconstruction software.

This scene has a variety of features designed to enhance the experience of the viewer. Various lighting models such as torchlight and sunlight are meant to emulate the lighting in the era that these reliefs were created. The ability to toggle exaggerated shading allows the users to bring out more details in the reliefs, and the ability to integrate various coloring predictions for the relief into the scene is also available.

1 Introduction

The ancient city of Nimrud, located near the present-day city of Mosul, Iraq, was the capital of the Assyrian Empire from around 883 BC - 721 BC. The Northwest Palace was the royal residence and center of government during this period, and many rooms were decorated with intricate stone reliefs. As excavations of the palace have been carried out intermittently since 1845, these reliefs are now housed in many museums around the world. Two of these reliefs are currently on display in the Yale University Art Gallery.

In this paper, 3D scanning and reconstruction were carried out a relief depicting a genie watering a sacred tree. The aim of this paper was to create a 3D scene for a museum setting. By allowing the user to interact with different lighting models and coloring predictions, this scene was designed to allow the users to view the relief as it would have appeared about 3000 years ago. In addition, the scene is further enhanced using exaggerated shading to allow the users to bring out increased detail, in a non-photorealistic way, such that the users can more clearly see details that are not easily observable in real life.

2 Methods

The methodology for this paper can be split up into two components: creating the 3D scene and enhancing the scene.

2.1 Creating the 3D scene

This section details the tools and applications that were used to create the 3D scene and to reconstruct the 3D models.

2.1.1 Building the 3D scene framework

The 3D scene was built using the Three.js Application Programming Interface (API),
a JavaScript library that allows users to create and render 3D scenes using WebGL. One of the key features of the Three.js library is the ability for users to create 3D scenes that are rendered using highly realistic lighting models in real time. For instance, Three.js allows the user to create meshes that are rendered using a physically correct model of lighting. Specifically, the models of the stone relief in this paper were rendered with a physically based material, using Metallic-Roughness workflow.

2.1.2 Reconstructing a 3D model

For this scene, 3D models of the stone relief were created from an image set using structure from motion (SfM). Over 400 images, taken from various vantage points around the stone relief, were passed as input to SfM 3D reconstruction software applications. Multiple software applications such as ARC3D and Regard3D were used, with Regard3D yielding the best results from our particular image set. The resulting 3D mesh was then edited to remove any extraneous features.

2.1.3 Building the 3D room

The actual geometry of the room in the 3D scene was based on the floorplans of the Northwest Palace. In particular, the room was based on the floorplan for “Room S”, the room in the excavated palace that housed the stone reliefs on display in the Yale University Art Gallery. In the 3D scene, the walls of this room were textured with a simple limestone brick texture. Fig. 1 shows the floor plan for “Room S” as well as the location of the stone relief in “Room S”.

Fig. 1. The floorplan of Room S in the Northwest Palace. The red arrow points to the location of the stone relief used in this 3D scene. This figure was adapted from the CDLI website [1].

2.2 Enhancing the scene

This section details several additional features that were added to this 3D scene to enhance the experience of the viewers. By allowing users to change the coloring and lighting of the scene, this 3D scene provides the viewers with a more interactive and historically accurate rendering of the relief as compared to viewing the stone relief in person.

2.2.1 Lighting scenarios

At the time of the Assyrian Empire, these stone reliefs would likely have been viewed under much different lighting conditions compared to the modern indoor lighting found in most museums today. In addition to a uniform ambient lighting model, the 3D scene can also be lit by a torchlight model and a sunlight model. These models are designed to be more faithful to what would have been
the actual lighting conditions in the Northwest Palace.

As it is very probable that these reliefs would have been viewed using torchlight, one of the main lighting models in this 3D scene is a lighting model that tries to simulate the light from a torch. This lighting model is created by having multiple light sources in one small area to represent different parts of a torch’s fire. The intensity of these light sources is constantly incremented by small random amounts, leading to a flickering effect. In addition, the locations that the lights are pointing to constantly jitter, causing the size and directions of the shadows to constantly update.

It is also possible that the room that the reliefs were housed in was an open-roof room. In this situation, the reliefs would have been lit by sunlight. The sunlight model is designed to illuminate the scene from one direction. The location of this directional light in the scene can be adjusted by the user to mimic the sun at different times of the day.

2.2.2 Exaggerated shading

This 3D model also implements a version of the exaggerated shading algorithm developed by Rusinkiewicz, et. al [2]. This algorithm is designed to bring out more detail in a mesh by adjusting the vertex normals of the mesh.

The general steps involved in this algorithm are quite straightforward. First, the vertex normals of the mesh are smoothed to various degrees. Then, a weighted average of these smoothed normals is taken, and the vertex normals of the mesh are replaced with these weighted averages. After this process, the updated lighting of the mesh reveals increased detail. This is particularly helpful with flat objects such as stone reliefs, as it brings out detail that would not be visible under any normal lighting condition.

2.2.3 Coloring

When the reliefs were created, they would have originally been almost entirely painted. However, in the millennia since the reliefs were produced, the vast majority of the paint has worn off. Part of this 3D scene is designed to incorporate fully colored meshes.

Using Blender, the mesh was split up into different groups of faces. Each one of these groups of faces was assigned a different material. Thus, different sections of the mesh could be colored different colors in line with the predicted colors of that region of the mesh. In addition, because each area is assigned its own material, it is very easy to switch between different sets of predicted colorings for the entire mesh.

3 Results

3.1 3D reconstructions

Two SfM 3D reconstruction software applications, ARC3D and Regard3D, were used to create 3D reconstructions of the stone reliefs. Of these two applications, the output produced by Regard3D yielded better results. While the output produced by ARC3D consisted mostly of several disjointed sets of faces, the output of Regard3D yielded a continuous, closed mesh, with only a few artefacts and extraneous features that needed to be removed. In addition, the mesh produced by Regard3D also included per-vertex coloring. As the output mesh had 218,238
vertices, this yielded a mesh with a very good color resolution. The resulting mesh can be seen in Fig. 2 below.

3.3 Torchlight model

The final torchlight model provided a relatively faithful simulation of the light cast by a fire. The color of the lighting was adjusted to be a warmer hue, and the lighting in this model is dynamic and constantly flickering in a manner similar to a fire. The appearance of this lighting model can be viewed in Fig. 4 below. However, it is important to note that while Fig. 4 displays the warm, orange hue of the torchlight model, it does not capture the effect that is produced by the flickering of the light.

3.2 Building the 3D room

Based on the floor plans of the Northwest Palace, a simple model of the 3D room was created. As seen below in Fig. 3, this room helps to situate the 3D model in a physical space.

3.4 Sunlight model

The sunlight model provided a simple lighting model that allows the user to light the scene from a single direction. One example of the lighting produced from the sunlight model in this scene can be viewed below in Fig. 5.
Fig. 5. Both images show the relief viewed using the sunlight model. The left-hand image shows the original relief while the right-hand image displays the relief using exaggerated shading. Note how the right-hand image shows increased detail and appears to have greater depth than left-hand image.

### 3.5 Exaggerated shading

The exaggerated shading of the model brought out increased detail in the mesh. In addition to improving the visibility of edges and features that were already prominent in the original model, the exaggerated shading also brought out details that were less obvious in the original model.

Fig. 5 shows how the exaggerated shading can bring out increased detail in the less noticeable regions of the original mesh. For instance, the exaggerated shading model greatly emphasizes the genie’s facial features and muscles. In particular, the genie’s ear and nose appear to have much more depth and 3D shape when viewed under exaggerated shading. In fact, even the edges that were obvious in the original mesh appear to have much more depth with the exaggerated shading.

### 3.6 Coloring

Using Blender, the mesh was split up by region into different materials. Fig. 6 below shows one way that the mesh could be split up into different regions.

Fig. 6. Each colored region is a different material.
4 Discussion

4.1 3D reconstructions

While the 3D reconstructions captured the likeness of the stone relief very accurately, the inadequate geometric resolution of these 3D meshes was a severe limitation. In fact, the meshes had very poor geometric resolution in the areas where there was cuneiform writing. At a distance, the 3D models appeared to have captured the appearance of the cuneiform characters; however, all this detail is actually derived from the per-vertex coloring. In fact, the areas of the mesh where the characters lay is much flatter than it initially appears.

Because these regions do not match the actual physical geometry of the stone reliefs, the performance of several other features of the 3D scene have been somewhat restricted. For instance, two of the affected features are the behavior of the shadows cast by the object onto itself and the effects produced by exaggerated shading.

4.2 Torchlight model

The final torchlight model produced an output that was similar to the light cast by a fire. However, it is important to note that the torchlight model created for this 3D scene was composed of many different components, each of which had its own tunable parameters. While the current values chosen for these parameters appeared to give a good output, there is still room for a finer tuning on the parameters.

The main parameters for this lighting model were the number of lights in the torchlight, the speed of the flickering, the magnitude of light direction jittering, and the kind of noise used for the flickering and the jittering. These parameters play an important role in illuminating the scene and perturbing the shadows in the scene. However, because the geometry of the meshes were not as fine as desired, the shadows cast from the object onto itself exhibited poor performance. Thus, the number of lights and magnitude of light direction jittering, parameters which only affected the motions of the shadows, did not have a real effect on the appearance of the scene.

Thus, the main parameters that were adjusted to optimize the appearance of the scene were the speed of the flickering and the type of noise used for the flickering. The speed of the flickering was tested at several different values, and a final value was chosen based on what appeared most similar to flickering in an actual fire. The two types of noise that were tested were Perlin noise and random noise from built-in JavaScript random number generator. In the end, the default random number generator gave better results for light flickering.

While the parameters for the number of lights and magnitude of light direction jittering were largely unused in the final model of the torchlight, a toy example demonstrating the effect of moving shadows in a scene lit by firelight is included in the accompanying materials to this paper. Perlin noise appeared to work better for the light direction jittering.

4.3 Sunlight model

While the sunlight model provided a simple interface for the user to adjust the location of the sun in the sky, the model was not very effective. The main reason for this was because the directional
lighting model did not account for indirect lighting. Because the relief was a flat object attached to wall, the lack of indirect lighting meant that the relief was only illuminated when the directional light was directly targeting the object.

4.4 Exaggerated shading

The exaggerated shading model was successful in bringing out details in the mesh that were not previously visible. However, due to the lack of a high-quality mesh, there were not enough faces and vertices in the areas with the cuneiform characters for the exaggerated shading model to bring out the characters.

The current implementation of the scene requires the users to pre-smooth the mesh normals needed for the exaggerated shading algorithm using some other software. Nonetheless, it is quite straightforward to adjust the weighting of the different sets of normals and to add additional smoothed meshes.

4.5 Coloring

While it is possible to divide the mesh into multiple regions using Blender, there were a couple drawbacks with this methodology. First, Blender is not designed to work with meshes with a large number of vertices and faces. This issue was assuaged by using mesh decimation to greatly decrease the number of vertices/faces in the mesh.

In addition, the regions were divided up based on what appeared to be the most logical. While it is possible that the selected regions were all colored a different color, it would be necessary to consult experts in Assyrian reliefs in order to produce the more accurate coloring of these meshes.

5 Future work

5.1 Producing higher quality meshes

Many of the features of this scene would have been improved if we had access to a better quality model. In the future, doing 3D scanning with a handheld 3D scanner or another attempt at using structure from motion could result in acquiring higher quality meshes.

One advantage to creating a template for producing high quality meshes using structure from motion from image sets would be the ability to acquire additional meshes for this scene by just asking peer institutions to follow this template.

5.2 Displaying coloring predictions

We would have to consult art historians to get accurate predictions of what experts in these reliefs believe the different regions of the mesh would have been colored. If the experts believed that multiple hypotheses were valid, the 3D scene could allow the user to toggle between these different color predictions.

5.3 Gathering physical data

The scene could be made to be more physically accurate by incorporating physical data. This would be the most relevant for rendering materials such as painted stone which would have different lighting properties depending on the ingredients used in the paint. In addition, the light from a torch could be recorded to serve as a basis for the torchlight model.

5.4 Automatic segmentation of mesh

Our current implementation requires the user to divide the mesh up manually into different materials using Blender. One
future direction would be to develop mesh segmentation algorithms that would automatically divide the relief models into the relevant regions for coloring.

5.5 Optimization of parameters

Most of the different features in this scene have parameters that can be further optimized to provide viewers with the best experience. For instance, the torchlight model could be tweaked to match data gathered from a physical torch. Furthermore, there are still many parameters in the exaggerated shading model that could be tested, which could help to bring out even more detail in the scene.

6 Conclusion

We have presented a 3D scene of Assyrian stone reliefs from the Northwest Palace. This scene has been designed to enhance the experience of the viewer by providing multiple lighting options similar to the original lighting that the reliefs would have been viewed under. In addition, the exaggerating shading option allows the users to bring out more details in the relief.

This paper marks a novel way to present to museum viewers a more authentic depiction of what these stone reliefs would have looked like at the time they were originally on display in the Northwest Palace. We have outlined a workflow for creating scenes for Nimrud stone reliefs that could also be applied to other artifacts and monuments in the field of cultural heritage.

In our future work, we plan on integrating authentic color predictions into the 3D scene. By coupling the colored meshes with the realistic lighting models, we hope to be able to present an even more accurate model of what the reliefs would have looked like to our viewers.

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8 References