Realistic Textures for Virtual Anastylosis

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Abstract

In the construction of 3D models of archaeological sites, especially during the anastylosis (piecing together dismembered remains of buildings), much more emphasis has been placed on the creation of the 3D shapes rather than on their textures. Nevertheless, the overall visual impression will often depend more on these textures than on the precision of the underlying geometry. This paper proposes a hierarchical texture modeling and synthesis technique to simulate the intricate appearances of building materials and landscapes. A macrotexture or "label map" prescribes the layout of microtextures or "subtextures". The system takes example images, e.g. of a certain vegetation landscape, as input and generates the corresponding composite texture models. From such models, arbitrary amounts of similar, non-repetitive texture can be generated (i.e. without verbatim copying). The creation of the composite texture models follows a kind of bootstrap procedure, where simple texture features help to generate the label map and then more complicated texture descriptions are called on for the subtextures.

1. Textures for Archaeological Sites

The 3D modeling and visualization of archaeological sites holds enormous promise for the public and archaeologists alike. For the former, a much more lively representation of ancient times is created. For archaeologists, 3D technology allows them to better assess the validity of different hypotheses.

So far, much work has gone into the development of flexible technology for the modeling of 3D shapes. This includes methods to capture in 3D the ruins as well as methods to recreate their original state through the Computer Aided Architectural Design (CAAD). Yet, the patterns by which the models of buildings and terrain are covered - their textures – are just as important for visual realism. We present an approach that can model and synthesize even complex textures, starting from an example photograph.

Although the approach is generic, the particular goals here are to produce textures for the simulation of building materials and landscape vegetation. Building materials of which ruins have been constructed usually have undergone serious erosion and have lost their original appearance. Hence, it is useful if the original appearance can be simulated as a texture that is mapped onto the CAAD models of the buildings. This is obviously a more veridical visualization than just mapping the ruin’s texture onto the model. The same goes for the terrain model. The existing vegetation may be very different from that prevailing in the era for which a site model is produced. Rather than mapping the existing texture onto the terrain model, one would like to cover it with texture that simulates the vegetation of that era.

2. Sagalassos as Testing Ground

We currently focus our efforts on the archaeological site of Sagalassos, located in present-day Turkey. The site is lying about 100 km to the north of Antalya. The excavation in Sagalassos is one of the largest ongoing archaeological projects in the Mediterranean. The project is lead by Prof. Marc Waelsens of the University of Leuven.

Sagalassos was one of the three most important cities of Pisidia. The city had thrived for about 1000 years, when it was finally abandoned after an earthquake in the 7th century AD. During this long period, it got under the military, political, and cultural influence of a series of foreign powers, including the Macedonians and the Romans. Of course, changes were not only of a political nature. Over time, architectural styles and techniques changed, and so did the gamut of building materials that were at the builders’ disposal. Probably even more noticeable were the changes in vegetation found near the site for different periods. Nowadays the mountain slopes
are not covered by "thorn-cushion steppe", a result of overgrazing. But at some point, the slope to the north of
the city was at least partially covered by cedar woods. Detailed knowledge is available about how these factors
changed during the centuries, thanks to thorough, multidisciplinary research within the scope of the
Sagalassos project [10].

Hence, when one creates 3D models of the site, the
choice of the right textures for the simulation of building
materials and vegetation is an important one and depends
on place and time. In summary, in our archaeological
applications, texture synthesis is used for two purposes:
1. Mapping landscape (esp. vegetation) texture onto
the terrain model of the site, where the texture is
dependent on the chosen era.
2. Mapping building material textures onto 3D CAAD
models of buildings, simulating their state in the absence
of erosion, or at different stages of erosion.

For all the applications of texture synthesis that have
been mentioned, a texture model is learnt from example
images. The texture model is very compact and can be
used to synthesize arbitrarily large patches of the texture.
Section 3 describes the basic texture analysis and
synthesis approach used for the relatively simple cases.
Then the paper moves on to the description of "composite
textures" in section 4, which are used to deal with the
synthesis of more complicated material and landscape
patterns. Section 5 concludes the paper.

3. Image-Based Texture Synthesis

Several powerful texture descriptions have been
proposed in the literature, all with their pros and cons ([1],
[3], [4], [6], [9], [11], [14]). The approach proposed here
is in line with the cooccurrence tradition (also see [4]),
which seems to offer a good compromise between
descriptive power and model compactness. Textures are
synthesized to mimic the pairwise statistics of their
example texture. This means that the joint probabilities of
the colors at pixel pairs with a fixed relative position are
approximated as closely as possible. Such pairs will be
referred to as cliques and pairs of the same type (same
relative position between the pixels) as clique types. This
is illustrated in Figure 1.

Figure 1. Dots represent pixels. Pixels connected by
lines represent cliques. Left: cliques of the same type,
right: cliques of different types

The texture model consists of statistics for a set of
different clique types. Just including all clique types as in
[3] is not a viable approach, instead a good selection
needs to be made. We have opted for an approach that
makes a selection to keep this set minimal, while on the
other hand draws the complete clique statistics of the
synthesized texture very close to that of the example
texture, even for the clique types that are not included in
the model [12]: an iterative procedure first synthesizes
texture based on the current clique set, then adds to the set
the clique type that yields the maximal difference between
reference statistics and current statistics. The procedure
stops as soon as the remaining differences is negligible.

In fact we do not work with the complete joint
probabilities of clique pixel intensities, but rather with
the histogram of intensity differences. In addition, the pure
intensity histogram is represented by a "singleton" clique
type.

A sketch of the texture model extraction algorithm is
as follows:
step 1: Collect the complete 2nd-order statistics for
the example texture, i.e. the statistics of all clique types.
After this step the example texture is no longer needed.
step 2: Generate an initial texture filled with
independent noise uniformly distributed in the range of
the example texture.
step 3: Collect the statistics for all clique types from
the current synthesized image.
step 4: For each clique type, compare the statistics
(intensity difference distribution) of the example texture
and the synthesized texture and calculate their Euclidean
distance.
step 5: Select the clique type with the maximal
distance. If this distance is less than a threshold, stop.
Otherwise add the clique type to the current (initially
empty) neighborhood system and all its statistical
characteristics to the current (initially empty) texture
parameter set.
step 6: Synthesize a new texture using the updated
neighborhood system and texture parameter set and go to
step 3.

After the 6-step analysis algorithm we have the final
neighborhood system of the texture and its statistical
parameter set. A more detailed description of this texture
modeling approach is given elsewhere [12]. In that paper
it is also explained how the synthesis step works. In this
section we demonstrate the use of this basic algorithm for
the synthesis of Sagalassos textures, and in the next
section we propose an extension towards "composite
textures", which we use for the synthesis of more
complicated textures.

In the case of Sagalassos, the method has mainly been
used for colored textures. For the modeling of colored
textures, clique types are added that combine intensities
of the different color bands.

The proposed algorithm produces texture models that
are very small compared to the complete 2nd-order
statistics extracted in step 1 and also compared to the
example image. Typically only 10 to 40 clique types are included and the model amounts from a few hundred to a few thousand bytes. Nevertheless, these models have proven effective for the synthesis of realistically looking textures of a wide variation.

Another important advantage of the method is that – in contrast to some of the most interesting alternatives, e.g. [1] – it avoids verbatim copying, i.e. no pieces of the example texture are taken as such and then spatially reorganized. Verbatim copying becomes particularly salient when large patches of texture need to be created.

Figure 2 shows a few examples of textures synthesized with our method for different building materials used at Sagalassos. The upper images are original textures of these materials (limestone). The images underneath show the results of texture synthesis based on models extracted from the originals. Figure 3 shows results for two types of vegetation found at modern Sagalassos. From left to right we show an original image, an image with a part cut out, and an image with this part filled in with synthetic texture for the particular vegetation. As can be seen, the synthetic texture blends in well.

The basic texture synthesis approach described in this section can handle quite broad classes of textures. Nevertheless, it has problems with capturing "composite textures": complex orderings of patches which themselves show textures (sometimes referred to as microtextures in the literature). This is why an extension towards a hierarchical approach – proposed in the next section – is necessary.

4. Composite Textures

Figure 4 shows part of the modern "thorn-cushion steppe" landscape found around Sagalassos (left). It consists of several ground cover types, like "rock", "green bush", "sand", etc., for which the corresponding segments are drawn in the right figure. If one were to directly model this composite ground cover as a single texture, the basic texture analysis and synthesis algorithm of the last section would not be able to capture its complexity (Figure 5). Therefore, a hierarchical version of the texture modeling approach is propounded, where a scene like this is first decomposed into the different composing elements, as shown in Figure 4 (right). The segments that correspond to different types have been given the same intensity (i.e. the same label). This segmentation has been done manually. Figure 6 shows the image patterns corresponding to the different segments.
the segments that s/he has defined, according to their labels. Similar ideas have independently been proposed [5], but our proposal automates the whole process, including the generation of the label map. In fact, the procedure is not quite as simple as presented here. In addition, non-stationary behavior near texture boundaries, where often rather smooth transitions can be found, has to be modeled. This is taken care of by the addition of clique types that have their heads and tails in different subtextures. A more detailed description of this extension is given in [13].

Figure 7 shows one example for both procedures. Note that the right image has been created fully automatically and arbitrary amounts of such texture can be generated, enough to cover the terrain model with never-repeating, yet detailed texture. As mentioned before, the fact that this approach doesn’t use verbatim copying of parts in the example images has the advantage that no disturbing repetitions are created.

A similar approach can generate textures of the more complicated types of marbles and limestones that were used as building materials. Currently, we focus on the virtual reconstruction of the fountain building, erected at the upper agora, during the reign of Marcus Aurelius (161-180 AD). Figure 8 shows a crude reconstruction.

It is an ideal kind of monument to combine different technologies. A large part of the building has been preserved. Passive, structure from motion techniques [8] have been used to build a 3D model of the friezes, for instance. Figure 9 shows two views of this 3D model. Note the nice Medusa head carvings. This model will be used to reproduce a detailed model of the building, as it was in its intact state.

The monument was also decorated with several statues. For the creation of their 3D model, a portable 3D camera was used, that is based on a structured light technique [15]. Figure 10 shows the model of Dionysos statue.

In a building like this "Nymphaeum", about 10 differently colored stones were combined to give splendid effects. If one wants to recreate the original appearance of this building and others in the monumental center of the city, such textures need to be shown in their full complexity.

Figure 11 shows an example of a limestone (pink-gray breccia) (a), which has a kind of patchy structure. The different parts do not only have different colors, but also a substructure (microtexture) of their own. The overall breccia texture is too difficult to be modeled well by our basic algorithm, as shown in (b). This image is the texture generated from a single model. As for the landscapes, we can follow the composite texture approach. First, the original limestone image is manually segmented, whereupon texture models are generated for the different parts. An automatically generated, synthetic result is shown in (c). Figure 12 and Figure 14 show an example of the use of such textures. Several pillars are shown with their simulated, original appearance.

Figure 6. Manual segmentation of the Sagalassos terrain texture shown in Figure 4. Left: segments corresponding to 1-green bush, 2-rock, 3-grass, 4-sand, 5-yellow bush. Right: left-over regions are grouped into an additional class corresponding to transition areas

Ongoing work aims at an important, further step in the automation of composite texture learning. In the given examples, the textures were segmented by hand to generate an example label map. The potential of the composite texture approach would clearly increase substantially if also this first step could be automated. At first sight this seems like a chicken-and-egg problem, as it seems necessary to have good subtexture models before the segmentation could be done. However, as extensive experiments by Paget [7] have shown, texture features used for segmentation can be simpler than those needed for synthesis. In fact, Paget even demonstrated that the optimal complexity of features for segmentation is lower than that for synthesis. Hence, a kind of bootstrapping procedure seems possible, where an initial segmentation is based on simpler color and filter bank outputs. These features are segmented on the basis of a clique partitioning algorithm, described in [2]. This step generates a label map and indicates where different subtextures have to be learned from. Synthesis is then as before, using the much more sophisticated subtexture models. This allows the system to synthesize textures completely automatically from an example image.

Figure 13 shows some results. Both scenes on the left are landscapes photographed in the Sagalassos region. The textures on the right have been generated from these, without any human interaction. The one in the top row was automatically segmented into 2 regions, which in this case amounted to the brownish soil and the green tree canopies. The landscape in the bottom row is more complex. It was automatically segmented into three regions: grass, bush, and rock fragments. Note how the synthetic image for the latter (bottom right image in the
figure) manages to keep the overall spatial arrangement correct. This is due to the fact that the basic synthesis method makes a distinction between head and tail pixels in the handling of the cliques. As a consequence, the label map will concentrate the same subtextures at the top and the bottom of the image as in the case of the example image.

Figure 7. Synthetically generated Sagalassos landscape textures. Left: based on a manually drawn label map. Right: based on an automatically generated label map

Figure 8. Schematic overview of the Nymphaeum of Sagalassos' upper agora

Figure 9. Two views of the 3D frieze model, obtained through structure from motion techniques based on images taken with a hand-held camera

5. Conclusions and Future Work

We have focused on a texture synthesis method and its extension towards composite textures. This texture synthesis work is aimed at simulating intricate textures such as those of building materials and vegetation types. An advantage of the methods is that they work from example images as input. In the case of composite textures, a segmentation has to be produced manually once, or this could be generated automatically. Further enhancing the automatic segmentation is another topic of current investigations. So is the enhanced modeling of interactions between subtextures and their positions within label maps. An advantage of the proposed methods is that they don’t yield verbatim copying of parts of the example textures. Such copies quickly become very salient as several of them appear in larger patches of textures. Moreover, the texture models are very compact and storage of the example images is not required.

Figure 10. Left: view of the untextured model of a Dionysos statue. Right: same model with its texture

Figure 11. Pink-gray breccia. (a) original, (b) synthesized as a single texture, (c) as a composite texture
References


