# TensorTextures

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Figure 1: Frames from the "Treasure Chest" animation. The coin collection in the box is a TensorTexture mapped on a planar surface. Seen from different viewpoints (images 1–3) and under different illuminations (3–5), the TensorTexture appears to have considerable 3D relief.

## 1. Introduction

TensorTextures is a new image-based texture mapping technique. It is a generative model that, from a sparse set of example images, learns the interaction between viewpoint, illumination, and geometry, which determines surface appearance, including complex details such as self-occlusion and self-shadowing. As Fig. 1 illustrates, although the coins appear to have considerable 3D relief under continuously varying viewpoint and illumination, the collection of coins in the box is actually a synthesized TensorTexture mapped onto a planar surface.

TensorTextures stems from a recently proposed multilinear (i.e., tensor) algebra approach to the analysis of image ensembles [Vasilescu and Terzopoulos 2002]. Here, we apply the approach to ensembles of images of textured surfaces. Given such an ensemble, our algorithm learns an approximation to the bidirectional texture function (BTF) [Dana et al. 1999], which describes the appearance of the textured surface under various viewpoints and illuminations. A generalization of the well-known BRDF, the BTF is a function of six variables $(x, y, \theta_v, \phi_v, \theta_i, \phi_i)$, where $(x, y)$ are pixel coordinates, $(\theta_v, \phi_v)$ is the viewpoint direction, and $(\theta_i, \phi_i)$ is the illumination direction.

Unlike the method of [Malzbender et al. 2001] our technique estimates the complete BTF, including variations not only in illumination, but also in viewpoint. Unlike the BTF synthesis method of [Tong et al. 2002], our technique is purely image based—it avoids the nontrivial problem of 3D geometric microstructure estimation.

## 2. TensorTextures Algorithm

The TensorTextures algorithm starts by organizing an ensemble of texture images acquired under different viewpoints and illuminations as 3-mode array, or data tensor $\mathcal{D}$, which indexes the images according to pixel $(x, y)$, viewpoint $(\theta_v, \phi_v)$, and illumination $(\theta_i, \phi_i)$ indices.

Applying a multilinear generalization of the conventional matrix singular value decomposition (SVD), known as an $N$-mode SVD [Vasilescu and Terzopoulos 2002], with $N = 3$, the data tensor $\mathcal{D}$ is then decomposed into the (3-mode) product of a core tensor (which is analogous to the SVD eigenvalue matrix) and three orthogonal matrices. The columns of these matrices are eigenvectors that encode the observed variation in the texture image ensemble across the viewpoint, illumination, and pixel modes of $\mathcal{D}$.

Our TensorTextures algorithm represents the BTF as a multilinear combination of basis vectors that are expressed as the product of the core tensor and the pixel orthogonal matrix. Fig. 2 illustrates TensorTexture bases for the coins texture and a corn texture.

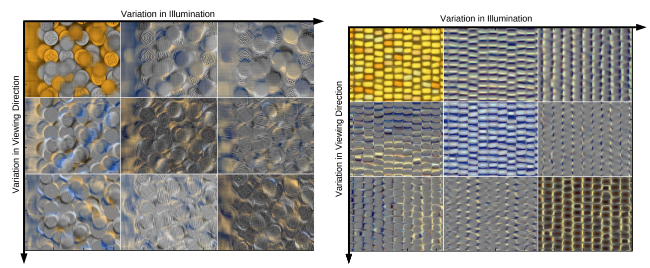


Figure 2: TensorTexture bases for coins (left) and corn (right).

Our algorithm can quickly synthesize textures for arbitrary viewpoints and illuminations as a product of the TensorTexture basis with interpolated viewpoint and illumination representations.

## 3. Results

We have employed our TensorTextures algorithm to synthesize (from 777 sample images) the coins and corn TensorTextures featured in the "Treasure Chest" (Fig. 1) and "Scarecrow" (Fig. 3) animations.


Figure 3: "Scarecrow Quarterly." The corn cob is a TensorTexture mapped on a cylinder.

## References

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