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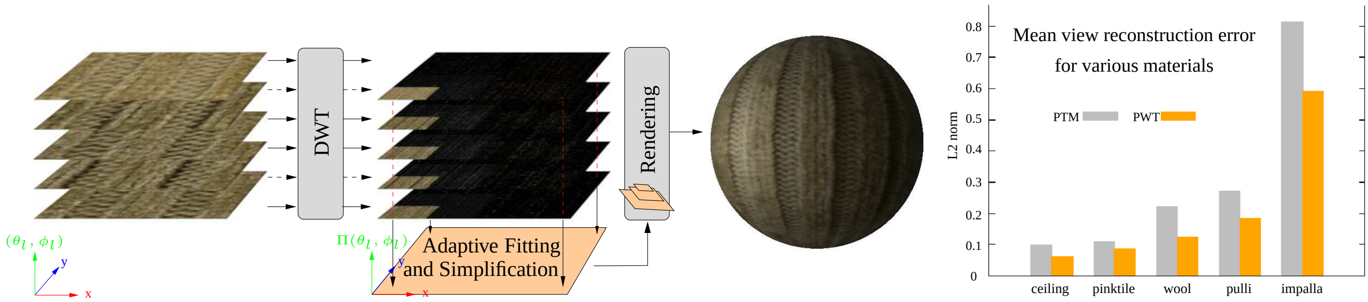

Figure 1: *(a) The general pipeline to generate a Polynomial Wavelet Tree from a BTF (b) error of reconstruction PWT versus PTM*

1 Introduction

Bidirectional Texture Functions (*BTF*) currently offer the highest quality representation for the appearance of complex real-world materials (see Figure 1). However, *BTF* acquisition leads to a huge amount of data and thus cannot be used as is. In a pixelwise approximation, working with light varying material for each eye direction is more convenient since *BTF* include strong parallax effects arised from high depth varying materials. The light transition is smooth and can be fitted with approximation functions but the multiplicity of physical effects captured during acquisition leads to errors in approximated data [Malzbender et al. 2001; Meseth et al. 2004; Filip and Haindl 2004]. Usually, a finer fitting is found with a multi-scale approximation since data are decomposed into varying importance sets to drive locally the complexity of approximation functions. In this paper, we present a new kind of factorization for compressing *BTF*, called the *Polynomial Wavelet Tree* (*PWT*). The key idea is to separate directional and spatial variations by projecting the spatial *BTF* domain onto a wavelet domain and to approximate the resulting light-dependent wavelet coefficients with varying degree polynomial functions that spans the lighting directions. Our method improves upon previous polynomial approximations and is designed for high quality materials rendering using GPU.

2 Polynomial Wavelet Tree

The *BTF* is a six dimensional function of $(x, y) \in \mathbb{R}^2$ the spatial coordinates, $(\theta_v, \phi_v) \in \mathbb{S}^2$ the viewpoint directions and $(\theta_l, \phi_l) \in \mathbb{S}^2$ the light directions. Our method consists in decomposing the BTF to an adaptive structure generated with three steps (see Figure 1). The first one is a projection of the *BTF* onto a wavelet basis. Then, wavelet coefficients are factorized using a polynomial approximation. Finally, the *PWT* is rendered with an efficient pre-computed GPU algorithm.

Wavelets for *BTF* Multi-resolution wavelet analysis decompose a function into a low resolution part and a set of coefficients that capture details from higher resolutions. We found enough to apply the wavelet expansion in spatial dimensions only to use the good properties of a wavelet decomposition: energy compaction and decorrelation. We use Wavelet Packets to decompose images into small subbands and then, to compute statistical informations about the contribution of a subband in the original data. Note that while a geometric wavelet decomposition can be applied in direction space subject to data resampling, this can lead to inaccurate approximation.

Adaptive Data fitting Fitting wavelet coefficients instead of data themselves is more efficient because low frequency transitions are smooth and higher frequency coefficients can be quantized with less importance. We choose to use varying degree bivariate polynomials along the light directions, (θ_l, ϕ_l), to approximate the data and, in this way, make the light direction space continuous. First, light space is projected onto a better suited space for data fitting $(\theta_l, \phi_l) \mapsto \Pi(\theta_l, \phi_l)$, where $\Pi(\theta_l, \phi_l) \in \mathbb{R}^2$ is a paraboloid parameterization of the light hemisphere [Heidrich and Seidel 1998]. The data fitting process is computed on each node of the decomposition tree (i.e. per pixel) for a fixed point of view along the parameterized light directions using *Singular Value Decomposition*. The polynomial degree is chosen per subband according to its level of importance found during statistical analysis. The polynomial coefficients in the wavelet decomposition tree describe the *PWT*. A simplification of the *PWT* is done in a post-process by excluding minor contribution branches of the tree (i.e. smallest importance subbands) according to a quality criterion, a fixed amount of energy, or a size criterion.

Rendering The inverse Wavelet Transform is partially precomputed on polynomial coefficients and resulting textures are stored in a mipmap texture. Note that, in this way, our GPU data structure is independent of the wavelet basis and thus makes it possible to use high degree wavelet basis. Moreover, hardware texture filtering can be used for minification (embedded in our representation) and magnification. The synthesis of a pixel is done in one pass: n texture access ($n < 3$, degree of bivariate polynomial) per pixel and few arithmetic operations for fixed view and light directions. Each viewpoint is stored using this method. Interpolation between viewpoints is done using a paraboloid map to store barycentric weights of intermediate view directions.

3 Results

The quality of our approximation outperforms existing solutions (see Figure 1 (b)) and, thanks to adaptive *PWT* simplification, the size of the data is less than fifty percent that of *PTM*. The synthesis remains efficient with a partial reconstruction of the first levels of the *PWT* and avoids aliasing with a better low resolution approximation than classical mipmap generation. Last, *PWT* is not limited to *BTF* and can be applied on any spatially varying material representation. Note that polynomial approximation is not robust on specular materials. However, our method is independent of any approximation scheme and, therefore, better approximation functions could be used.

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