High-order Wavelets for Hierarchical Refinement in Inverse Rendering

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http://nick.feed-back.be/hierarchHighOrderWav/

Problem

It is common to use factored representation of visibility, lighting and BRDF in inverse rendering. Current techniques use Haar wavelets to calculate these triple product integrals efficiently. Haar wavelets are an ideal basis for the piecewise constant visibility function, but suboptimal for the smoother lighting and material functions. How can we leverage compact high-order wavelet bases to improve efficiency, memory consumption and accuracy of an inverse rendering algorithm?

Previous Work

- Triple product Haar wavelet integrals for all-frequency relighting[1,2]
- Hierarchical refinement of reflectance[3]
- Hierarchical splitting of wavelet coefficients[4,5,6]

Motivation

- Previous triple product methods only render at low frame rates (< 15 fps) for large models (> 100.000 polygons). If triple product integrals can be efficiently calculated for higher-order wavelets, the reduction in coefficients will reduce the number of calculations, therefore improving performance and memory usage. Some BRDFs can be stored 5x more compactly.
- Current inverse rendering algorithms rely on solving large systems of bilinear equations. We propose a hierarchical refinement algorithm that exploits the tree structure of the wavelet basis. By only splitting at interesting nodes in the hierarchy, large portions of less important coefficients can be skipped.

Overview

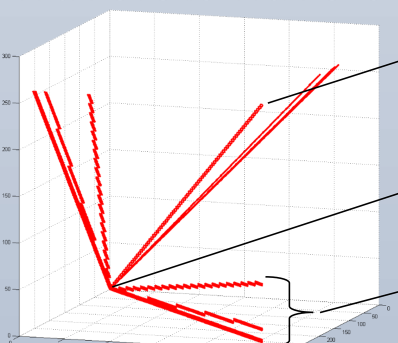
Triple product integral

- *Solving the rendering equation as a triple product integral:*

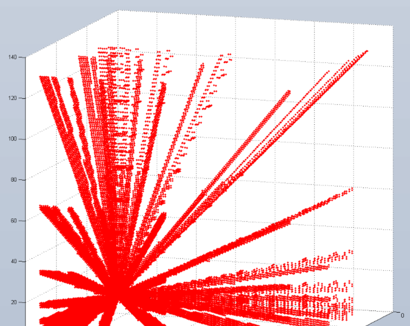
$$B(x,\omega_o) = \sum_i \sum_j \sum_k V_i \tilde{L}_j \rho_k \int_\Omega \Psi_i(\omega_i)\Psi_j(\omega_i)\Psi_k(\omega_i)d\omega_i$$

- 3 factors: V_i visibility, $\tilde{L}_j$ environment map in local frame, ρ_k BRDF
- Preprocess binding coefficients $\int_\Omega \Psi_i(\omega_i)\Psi_j(\omega_i)\Psi_k(\omega_i)d\omega_i$
- High-order wavelets have overlapping support → more complex tensor

Haar binding coefficient tensor. Notice the simple structure and how the simple cases from Ng[1] can be identified.



Coiflet binding coefficient tensor. Cases cannot trivially identified anymore.



- Our method exploits the hierarchical nature and vanishing moments of wavelets, resulting in fast calculation of a sparse tensor.

Hierarchical refinement scheme

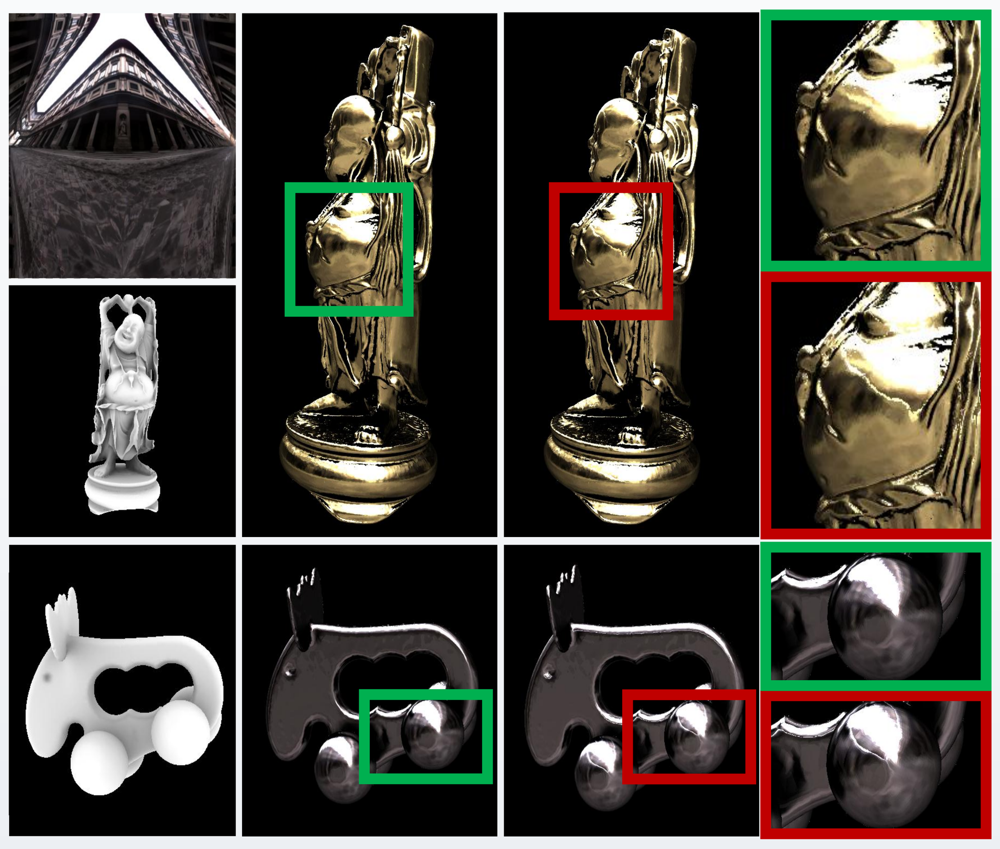
- The key of this algorithm is only splitting nodes of the wavelet tree that contribute to the solution of the system M:

```
M: initialize system to solve at root node of wavelet tree
repeat
    K: set of possible nodes for refinement
    for k ∈ K do
        concatenate k to M: M = M|M_k
        if rank(M) ≠ full then remove k from K
        end if
    end for
    Solve M for L̃
until no splits left
```

- It is critical to use high-order wavelets for this, as Haar wavelet can only introduce high frequencies which lead to blockiness.

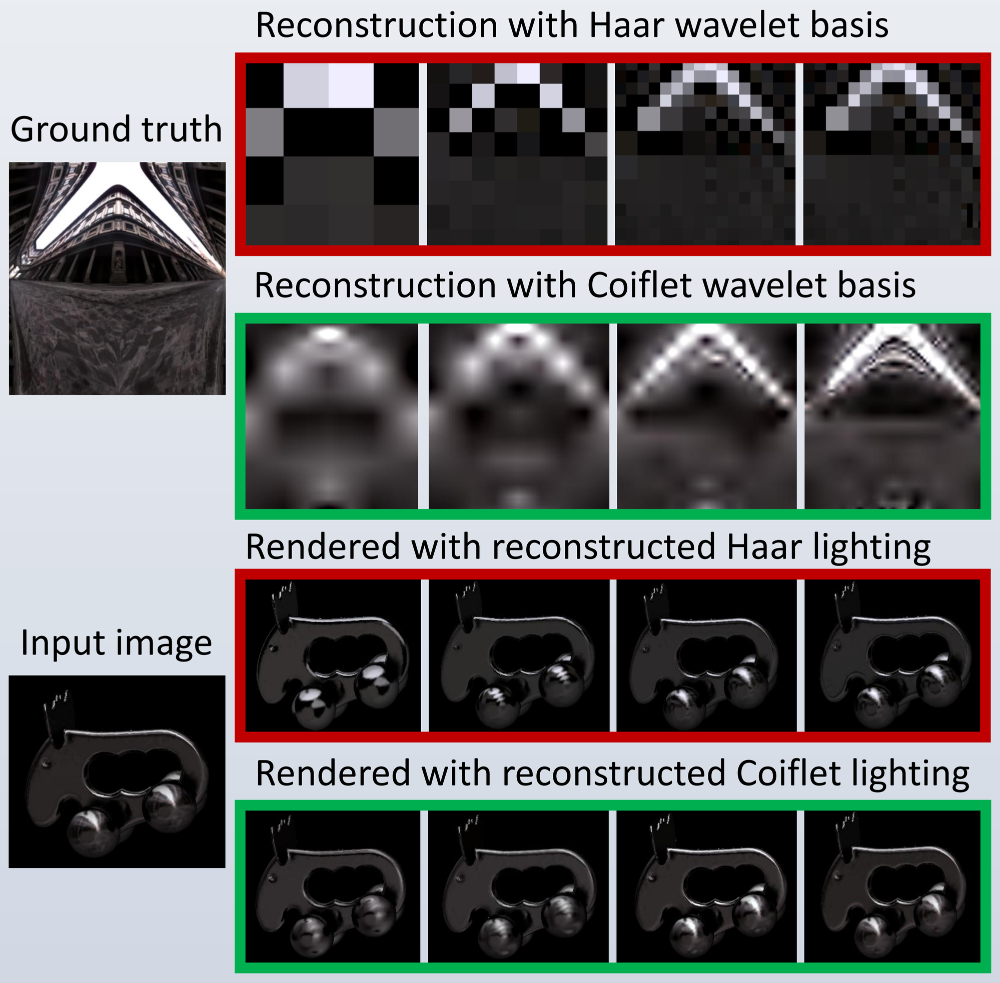
Results

Forward Rendering with high-order wavelets



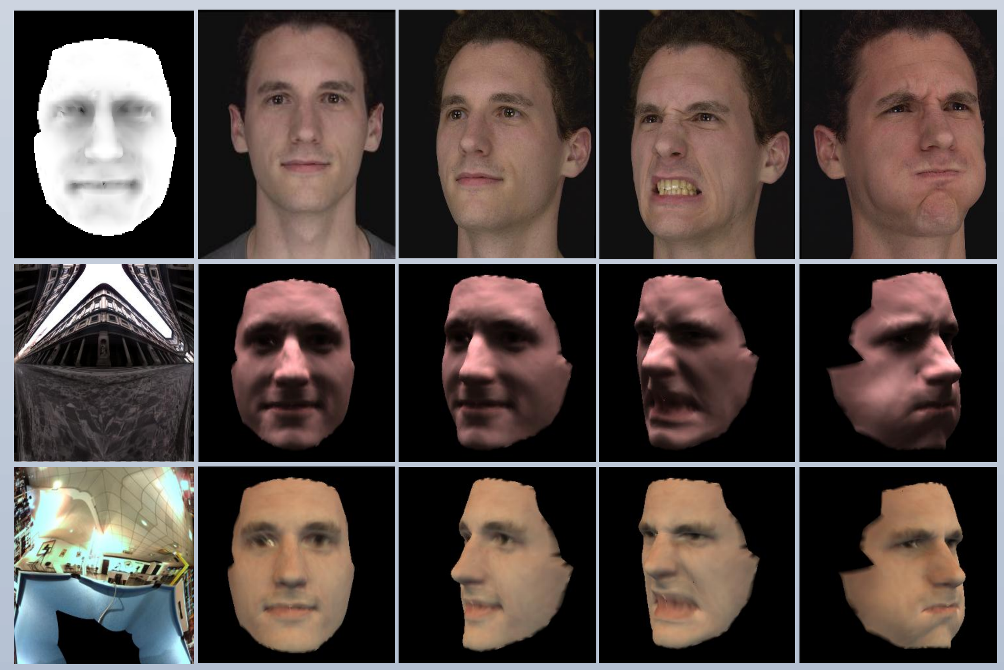
Quality comparison for two different datasets. Leftmost column: environment map and meshes. Two central columns: rendering with optimal wavelet basis (green) versus Haar basis (red). Rightmost column: Zoomed images to compare quality. Our method produces better quality with up to 5x reduction in coefficients.

Hierarchical Refinement



Here, a hierarchical refinement scheme is used to estimate the lighting environment map. Step-by-step, the most interesting coefficients on a certain detail level are added to the sparse wavelet tree, based on a splitting criterium. Reconstructions for both Haar and the smoother Coiflet wavelet bases are shown. Haar has a tendency to introduce disturbing high frequencies around edges.

Inverse Rendering



Reconstruction of a temporal face dataset under different lighting conditions. Lighting and materials are estimated with the hierarchical refinement method.

Ray traced occlusion maps, BRDF slices and lighting environment map are combined in the triple product integral calculation.

References

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