Diplomarbeitspräsentation

Realistic Rendering in Mobile Augmented Reality

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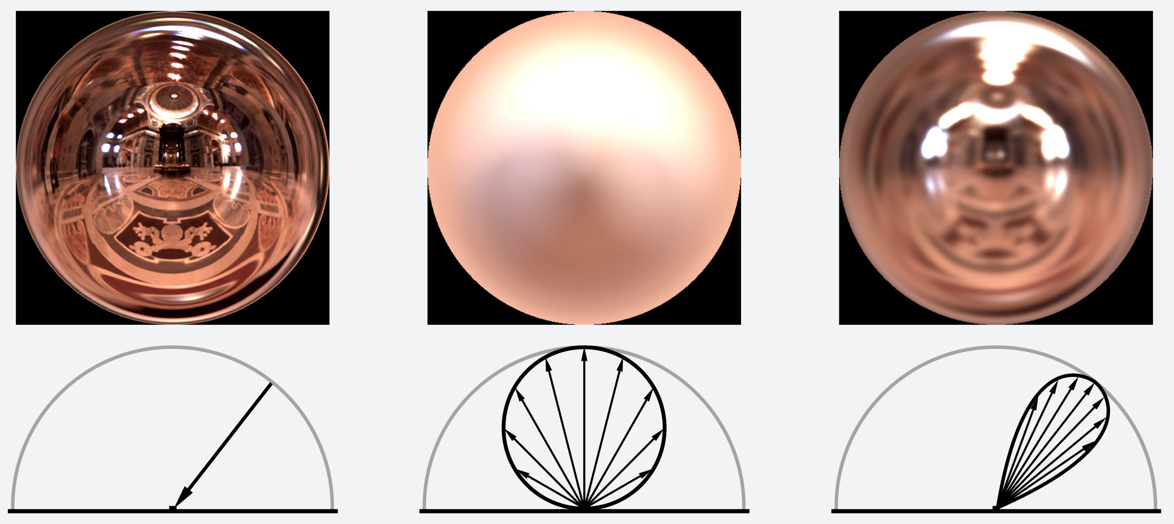
Context, Motivation, Approach

Augmented Reality (AR) combines a view of the real world in real-time with computer-generated data. Some mobile applications require a high degree of visual coherence. It is desirable to achieve realistic rendering without additional hardware. Our technique can achieve this goal, requiring only a single commodity mobile device for the steps:

- Capture real world illumination in an environment map
- Prepare the captured illumination information for high quality rendering by computing an irradiance and multiple reflection maps via different methods:
  1. Accurate calculation, 2. MIP-mapping based approximation, 3. Calculation via sphercial harmonics
- Rendering an Augmented Reality scene, where virtual objects are shaded via image-based lighting (IBL)

Environment, Irradiance, and Reflection Maps

Environment M.	Irradiance Maps	Reflection Maps
store incoming radiance values[1]	store reflected irradiance values	store reflected radiance values

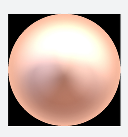
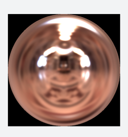


Based on a bidirectional reflectance distribution function (BRDF), reflected irradiance and radiance values can be calculated by weighted accumulation of the incoming radiance values. The results are stored in textures and can be used to simplify the rendering equation (1) to the form depicted in (2) when using the Phong BRDF.

The Rendering Equation

$$L_o(x,\vec{\omega}) = L_e(x,\vec{\omega}) + \int_{\Omega} L_i(x,\vec{\omega}')f_r(x,\vec{\omega},\vec{\omega}')\ \cos\theta\ d\vec{\omega}' \qquad (1)$$

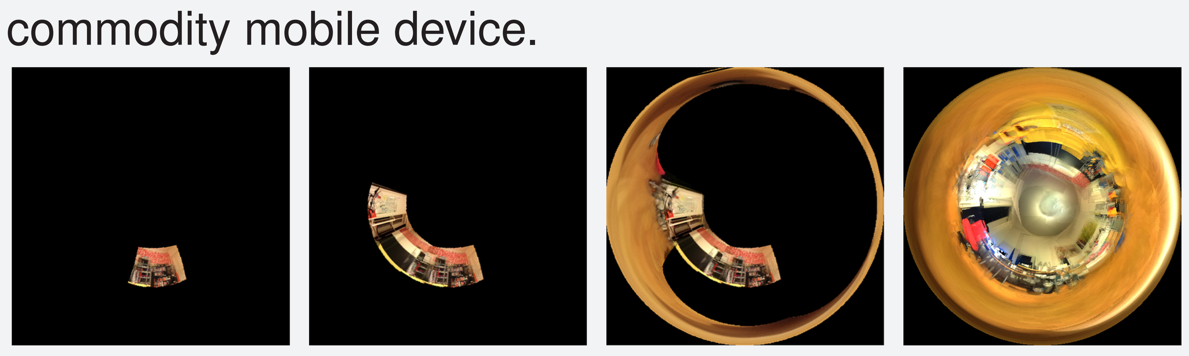
Simplification with Phong BRDF-convolved irradiance and reflection maps

$$L_o(x,\vec{\omega}) = L_e(x,\vec{\omega}) + k_d \cdot$$  $$+ k_s \cdot$$  (2)

where x is a point, $\vec{\omega}$ a direction, L_o is the outgoing radiance, L_e the emitted radiance, the integral is the sum of radiance received from all directions, and $\cos\theta$ is the light attenuation.

Environment Map Capturing

We are using a technique by Kán [Kán, 2015] to capture the full sphere of light in high dynamic range (HDR) with a commodity mobile device.



The mobile device's inertial measurement unit (IMU) is used to determine its orientation. Multiple camera images are accumulated to create the full environment map in HDR by using inverse camera response functions and the camera's exposure time. When a new camera image is merged with the already captured data, feature matching is applied to improve quality. [Kán, 2015]

Accurate Calculation

This method for calculating the irradiance and reflection maps computes the accurate results. To calculate the irradiance or radiance of one texel, the algorithm iterates over all other texels in the input environment map and accumulates their contribution weighted by the BRDF.

Bounds optimization:
The quadratic runtime-complexity of this method results in high performance demands. We describe an approach which optimizes the bounds for texture-lookup in the input map to increase the performance for reflection map calculation in exchange for a small quality tradeoff. The higher the specular shininess coefficient is, the narrower the bounds can be chosen.

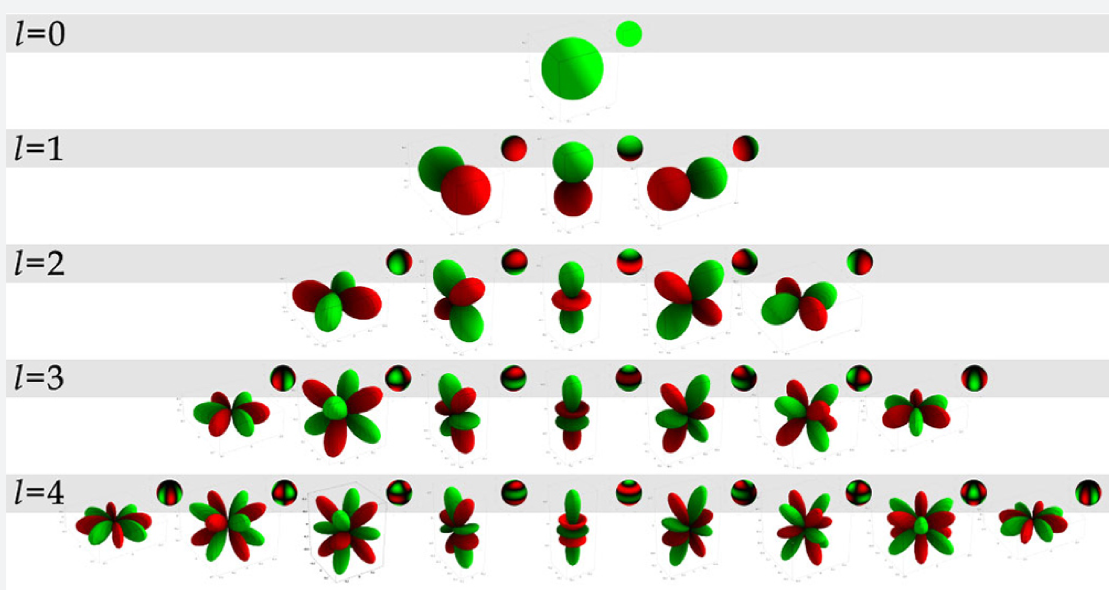
MIP-mapping Based Approximation

This method strives to maximize the performance of irradiance and reflection maps calculation by creating an approximation to the accurate results. The approximation is calculated by MIP-mapping the input environment map and selecting an appropriate MIP-map level for each reflection map's specular shininess coefficient which appears similar to the corresponding Phong BRDF-based accurate result.

$$l_{rad} = l_{max} - \log_2\left(\min\left(\max(s/2,4),N\right)\right) \qquad (3)$$

We select the MIP-map level for reflection maps like shown in equation (3), where l_{max} is the maximum MIP-map level, s is the specular shininess coefficient, and N is the side length of the texture. For irradiance maps, we use the third to highest level, which is sized 4 x 4 pixels.

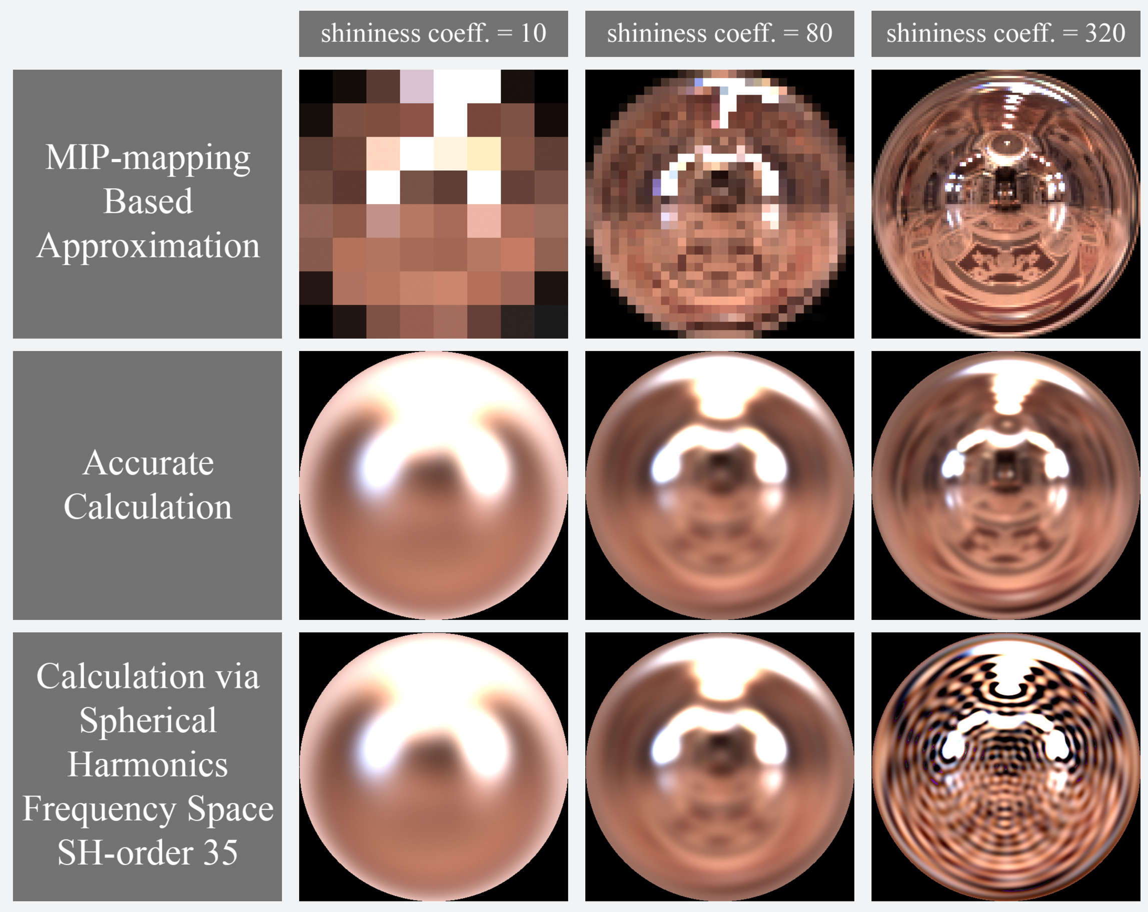
Calculation via SH Frequency Space



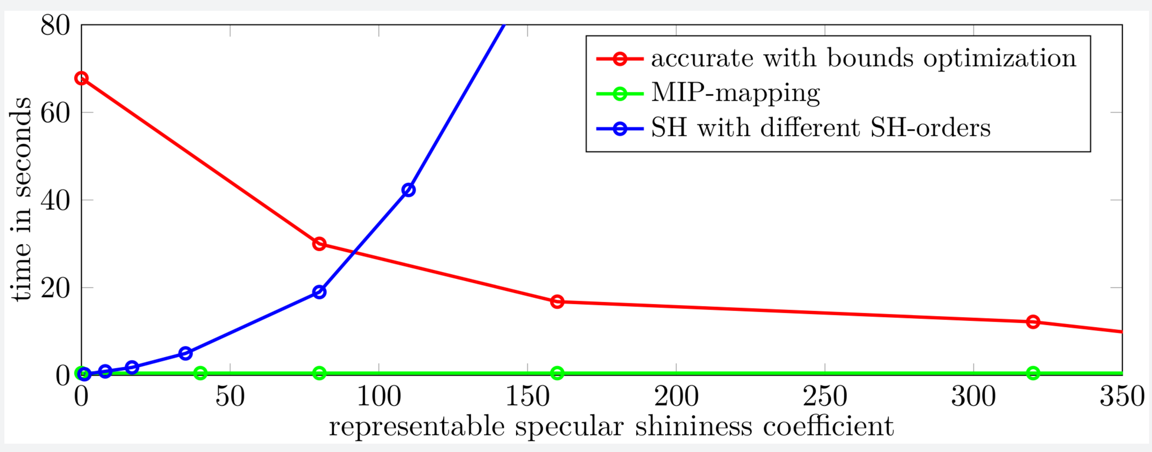
This method transforms the input environment map into its spherical harmonics (SH) frequency space representation by using the SH basis functions. SH basis functions are defined on the surface of a sphere and are arranged in frequency bands which are shown in the figure[2], where l is the band index. While SH basis functions on the lower bands capture slow changes over the sphere, functions on higher bands capture finer details of the input environment map. The number of basis functions increases in quadratic relation to the band index and at some level, the computations have to be stopped due to the computational complexity, ignoring all further higher SH bands.

Transforming an input environment map into SH frequency space yields a set of SH coefficients. Using *spherical convolution* between those and the SH coefficients of the Phong BRDF, irradiance and reflection maps can be calculated in SH frequency space via multiplication which corresponds to a convolution in the spatial domain.

Results



The MIP-mapping results are very inaccurate in general, especially for lower specular shininess coefficients. For computing the accurate results shown in the middle row we did not apply the bounds optimization. The SH results have been generated with the basis functions from the first 34 SH bands (SH-order 35). While for low specular shininess coefficients they are very close to the accurate results, ringing artefacts emerge for higher specular shininess coefficients due to lost details which the set of SH basis functions was unable to capture.



Our performance analysis shows that SH are fast and have low error rates for specular shininess coefficients between 1 and 100 or even higher, depending on the light probe. For high specular shininess coefficients, the accurate method with bounds optimization performs better in terms of speed and quality above a certain threshold. MIP-mapping computes in real-time.

AR rendering result[3] using IBL with irradiance and reflection maps generated from the map shown in section *Environment Map Capturing*, and light mapping.

AR rendering results[4] using IBL for a metallic material using reflection maps of different specular shininess coefficients in each image. The maps were generated from two different light probes with the accurate method.

References

- Kán, Peter 2015.
  Interactive HDR Environment Map Capturing on Mobile Device. *In EUROGRAPHICS 2015 Short papers,* pages 29–32, Eurographics Association.

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[1] Base environment map *St. Peter's Basilica, Rome* by Paul Debevec, Light Probe Image Gallery, http://www.pauldebevec.com/Probes
[2] Adapted from Robin Green, Spherical Harmonic Lighting: The Gritty Details. In Archives of the Game Developers Conference, volume 56, 2003
[3] Dragon 3D model from the The Stanford 3D Scanning Repository, http://graphics.stanford.edu/data/3Dscanrep/
[4] 3D Model *Challenger* by Unity Technologies, *The Blacksmith: Characters*, Unity Asset Store, http://u3d.as/hjn