The Shading Probe: Fast Appearance Acquisition for Mobile AR

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Problem Statement

- Realistic shading of virtual objects in an AR setting; e.g.:

[Aittala 2010]

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- Realistic shading of virtual objects in an AR setting; e.g.:
  - On mobiles

[Aittala 2010]

Shading Consistency

- Lighting and shading consistency is still a challenge in AR, as it requires:
  - An accurate estimate of real-world lighting
  - A compatible and realistic shading model
  - Modulating the shading of real-world objects to account for the virtual objects

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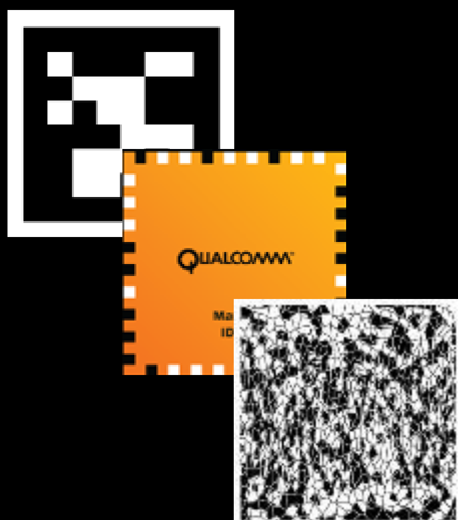
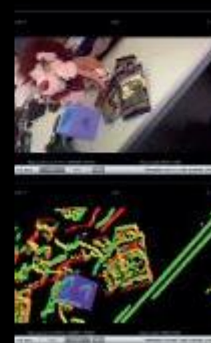
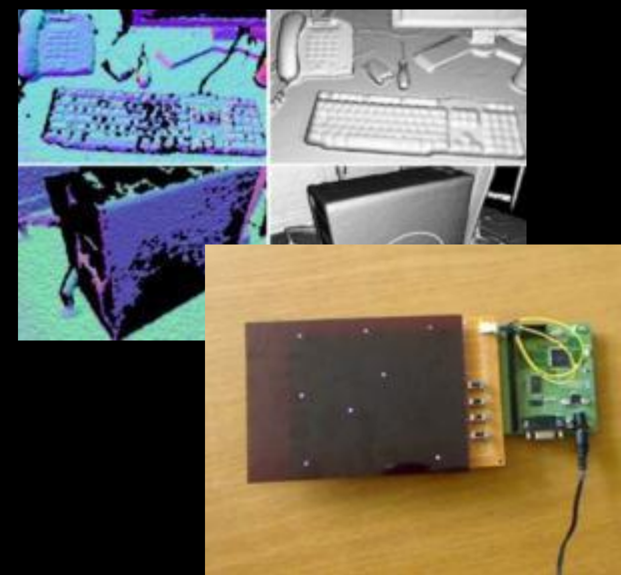
Augmented Reality

- Geometric calibration







[AR Toolkit]
[Qualcomm Vuforia]

[Schmalstieg and Hollerer 2013]
[Izadi et al. 2011]
[Kissling et al. 2012]

Augmented Reality

- Radiometric calibration
  - Estimating HDR incident lighting:
    - Chrome spheres [Debevec et al. 2002]
    - “Single-shot” light probes [Debevec et al. 2012]
    - Fish-eye cameras [Knecht et al. 2010]
  - LDR to HDR
    - Multiple LDR photographs [Debevec and Malik 2008]
    - Multi-orientation photographs [Szeliski and Shum 1997]
    - Videos [Diverdi et al. 2008]

Augmented Reality

- Realistic real-time rendering
  - PRT is coupled with complex shading models using the spherical harmonics representation of lighting [Nowrouzezahrai et al. 2011]
  - Shading is computed using Imperfect Shadow Maps [Knecht et al. 2011]
  - Shading is computed using Irradiance Caching and ray-tracing [Kan and Kaufmann 2013]
  - Etc.

Desktop-class hardware!

  - On mobiles via cloud?
    - Latency issues

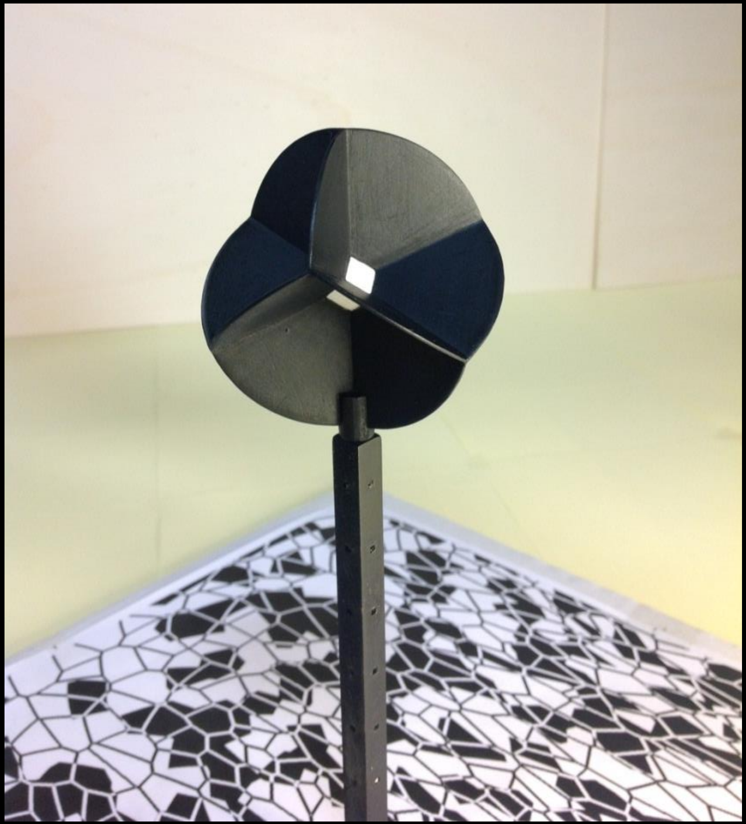
Augmented Reality

- Lighting and shading consistency has been traditionally solved by:
  - Incident illumination registration and capture
    - Using a reflective or diffuse sphere
  - Radiometric calibration
    - Temporally-stable HDR lighting estimation
  - Shading computation
    - Realistic light transport algorithms

Augmented Reality

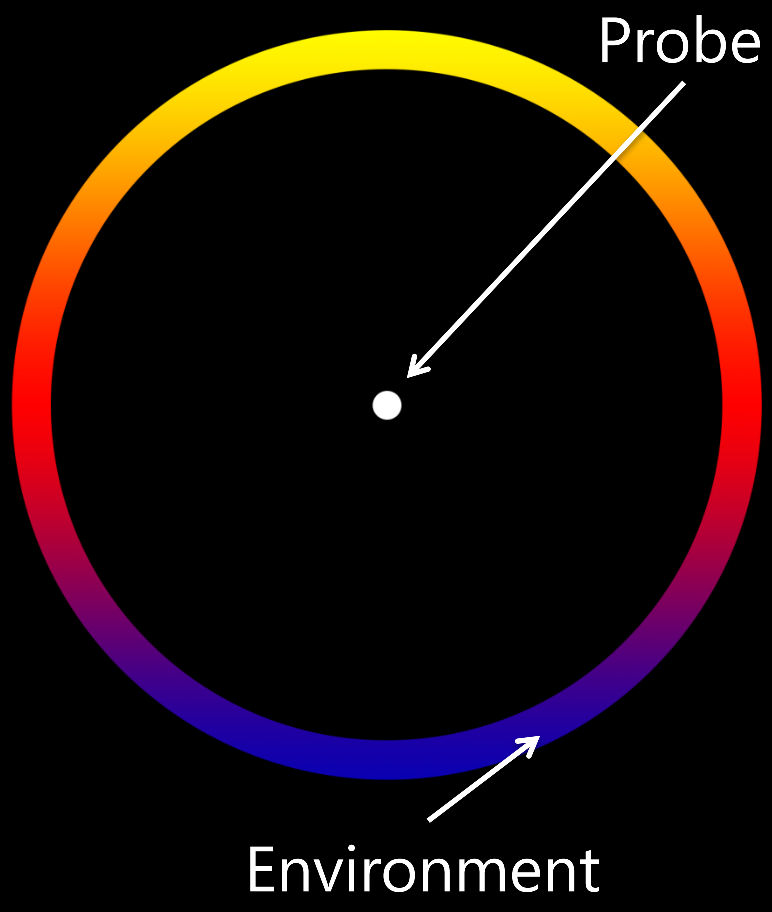
- Lighting and shading consistency has been traditionally solved by:
  - Incident illumination registration and capture
    - Using a reflective or diffuse sphere
  - Radiometric calibration
    - Temporally-stable HDR lighting estimation: costly & noisy
  - Shading computation
    - Realistic light transport algorithms: prohibitively costly

The Shading Probe



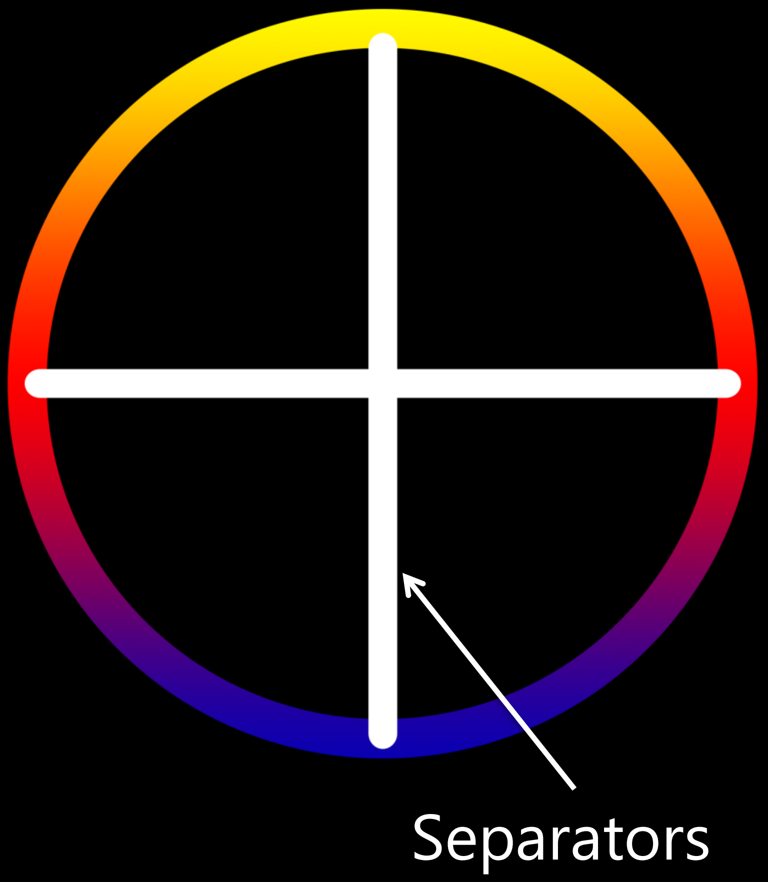
Intuition

- We want to:
  - Capture the environment cues
  - On a probe
  - Such that each point on the probe “sees” a different part of the environment



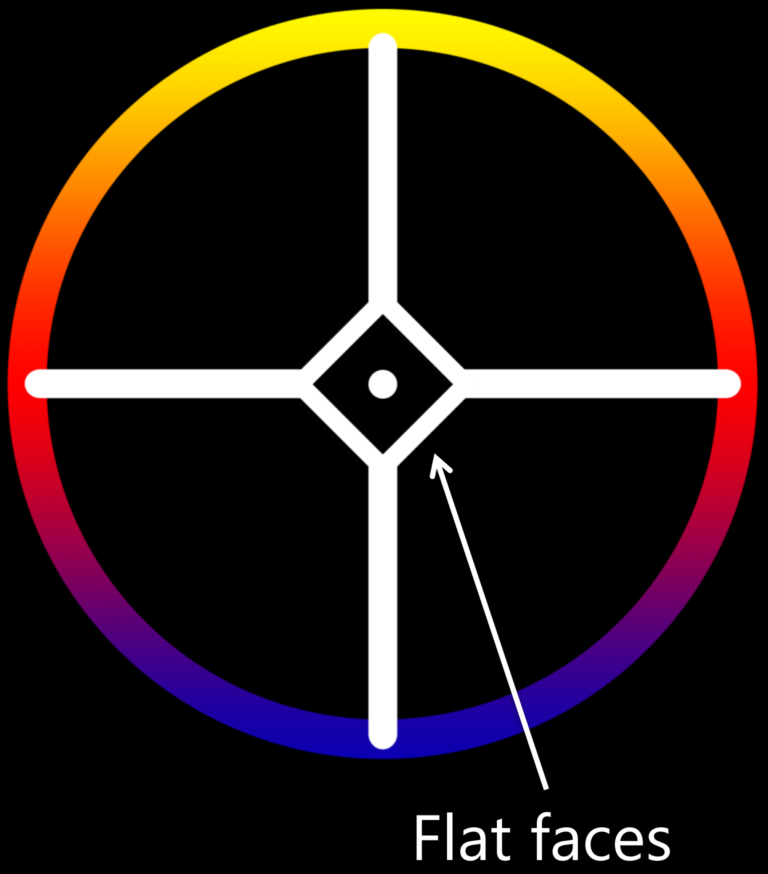
Intuition

- We can:
  - Introduce separators to split the environment into partitions



Intuition

- We can:
  - Introduce flat faces to “collect“ the incoming radiance from each partition



Intuition

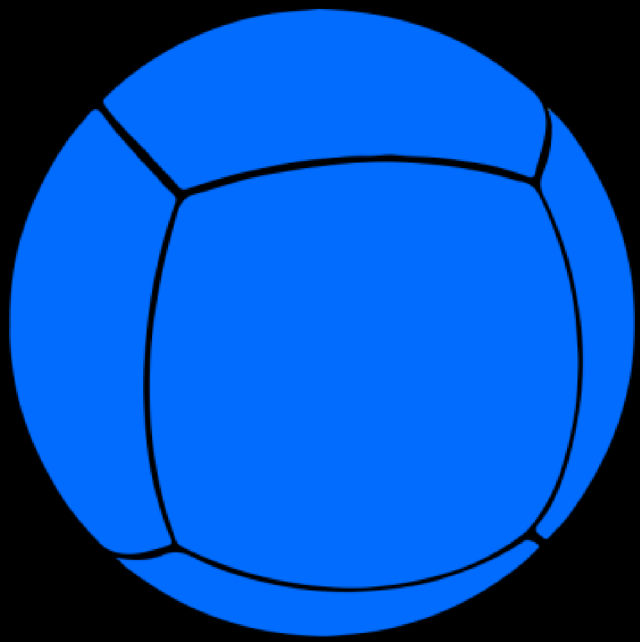
- We can:
  - Color the separators black to cancel out interreflections

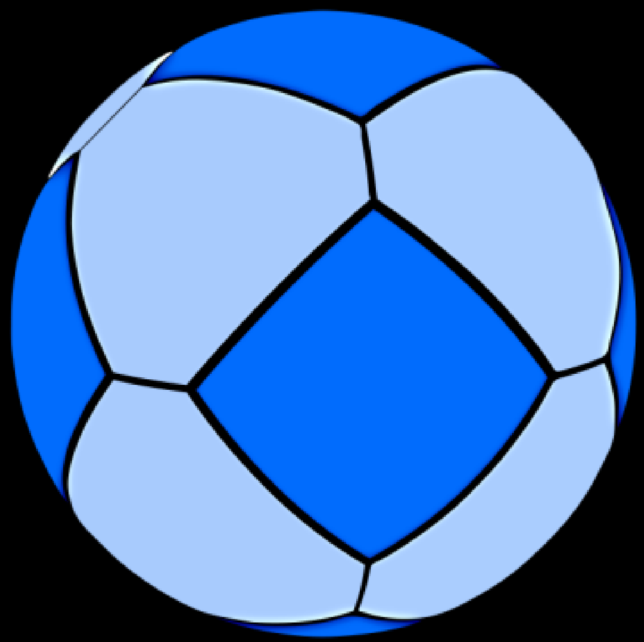
Design

- We propose a family of probe designs that:
  - Bin the sphere of directions
  - Induce an orthogonal piecewise-constant spherical basis set
- Allows us to capture basis-convolved illumination directly
  - As an LDR signal
  - Ready to be fed into a PRT framework

Scenario Optimisation

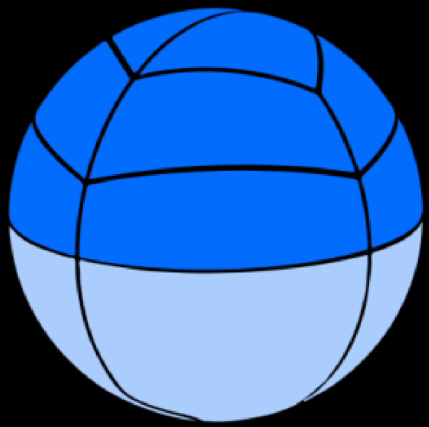
- General case
  - Approximately-uniformly partitioned (Spherical Voronoi diagram)
  - 6D and 14D



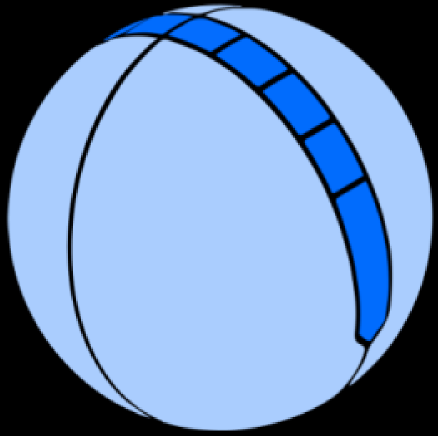


Scenario Optimisation

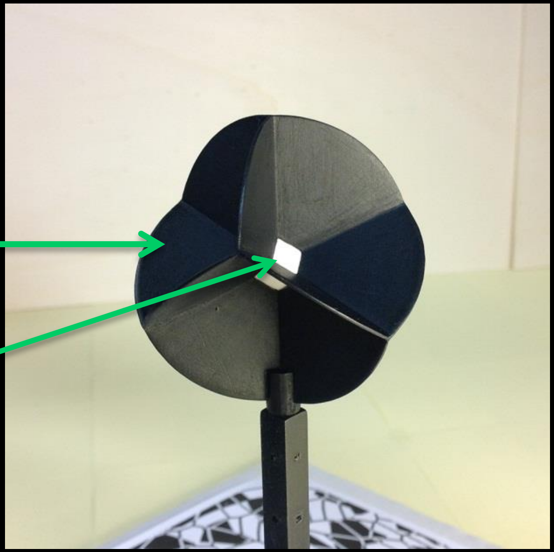
- Indoor
  - Assume most light originates from above



- Outdoor
  - Tracks sun path
  - Using date and location
  - High-frequency shadows



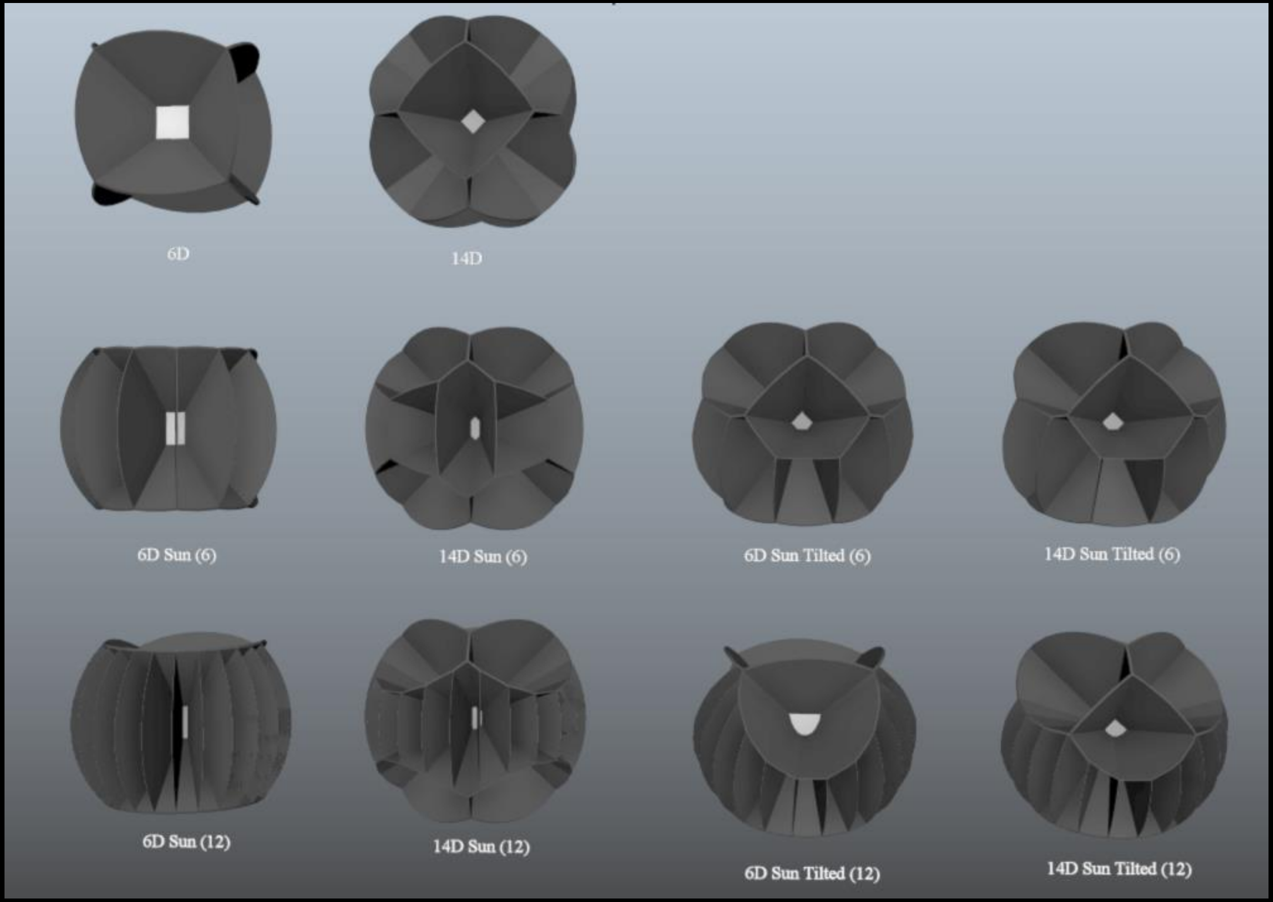
Probe Geometry



- Two parts
- Outer shell
  - Bins spherical visibility
  - Black to suppress indirect light
- Kernel
  - Faces capture basis-convolved illumination
  - White indoors
  - Grey outdoors (HDR Sun)

Probe Geometry

- Automatically generated from partition directions using CSG
- Manufactured by 3D printing

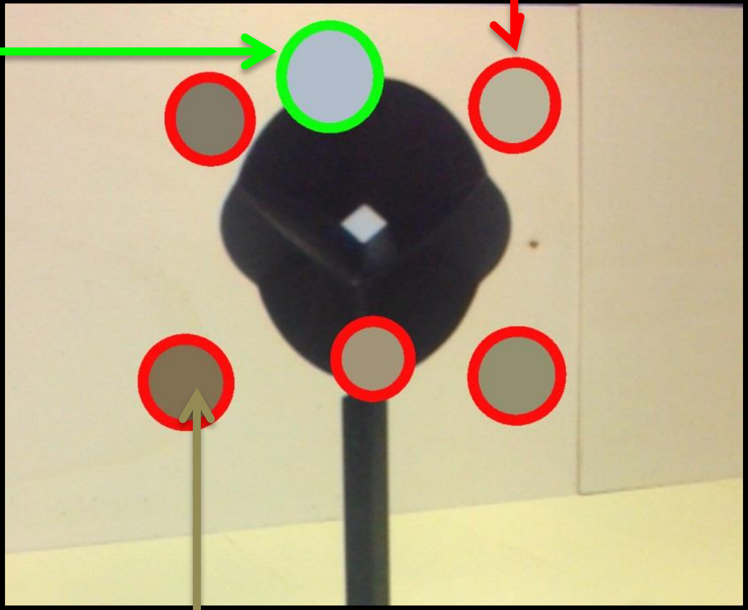


Acquisition

- Requires capturing one shading value for each of the n faces of the kernel
- User rotates camera around the probe
  - Samples are captured automatically
- Captured radiance samples are linearised
  - Inverting camera gamma
  - The only processing done for lighting capture

Acquisition Process

- Sphere outline indicates visibility from camera
  - Occluded
  - Visible

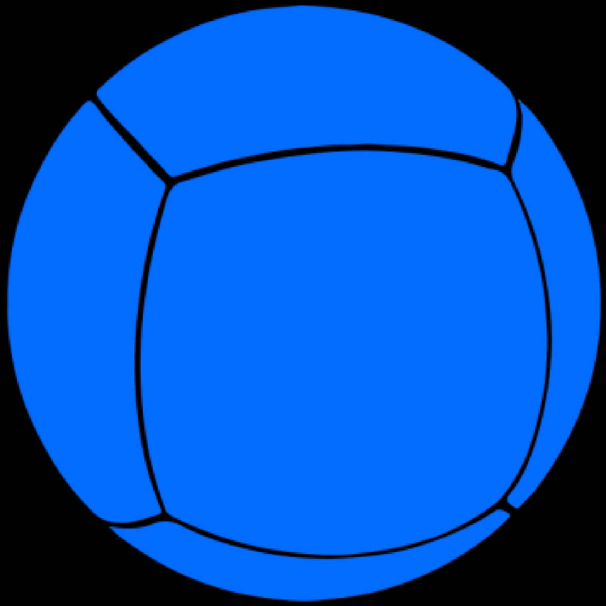


- Sphere fill indicates captured shading


Calibration: Translation
Calibration: Rotation
Calibration: Scale
Basic functions
Data Capture
Hide

Rendering

- Probe induces a piece-wise approximately constant orthogonal spherical basis set
  - Each partition i corresponds to a basis: $b_i(\omega)$
  - $b_i(\omega) = \cos(n_i, \omega)^+ V_i(\omega)$
    - Where $V_i(\omega) = 1$ if ω is in the partition P_i
    - And 0 otherwise



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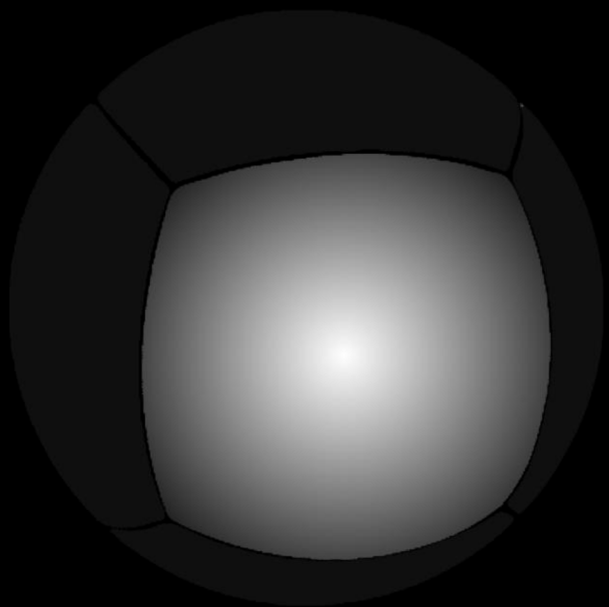
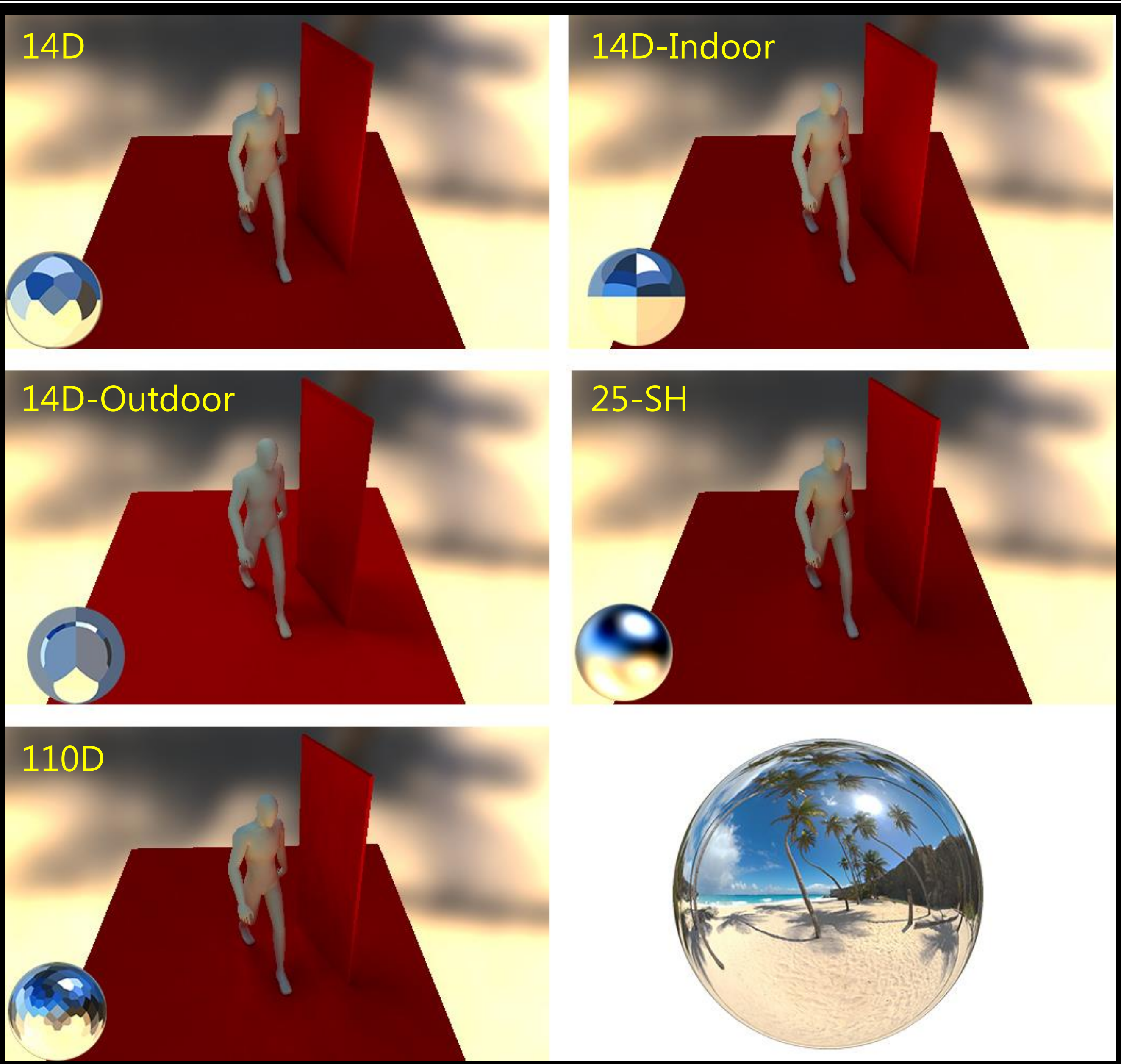


Rendering

- Rendering uses diffuse PRT
  - Transport pre-computed using probe's induced basis
  - Lighting basis coefficients are the captured shading samples (* a constant factor)

Results: Synthetic Input



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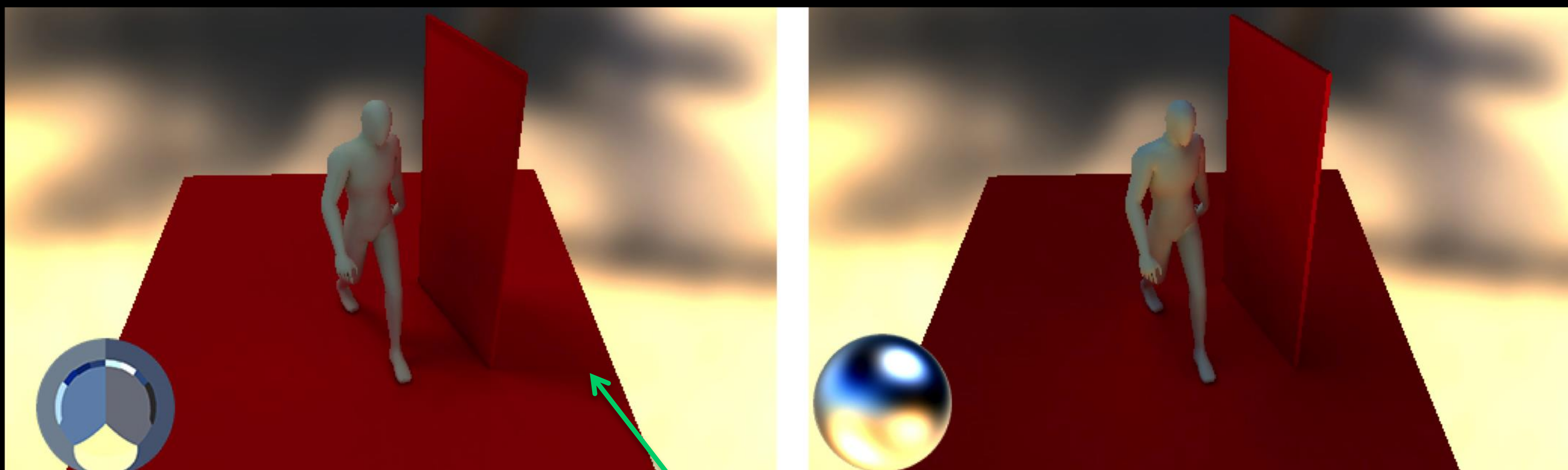
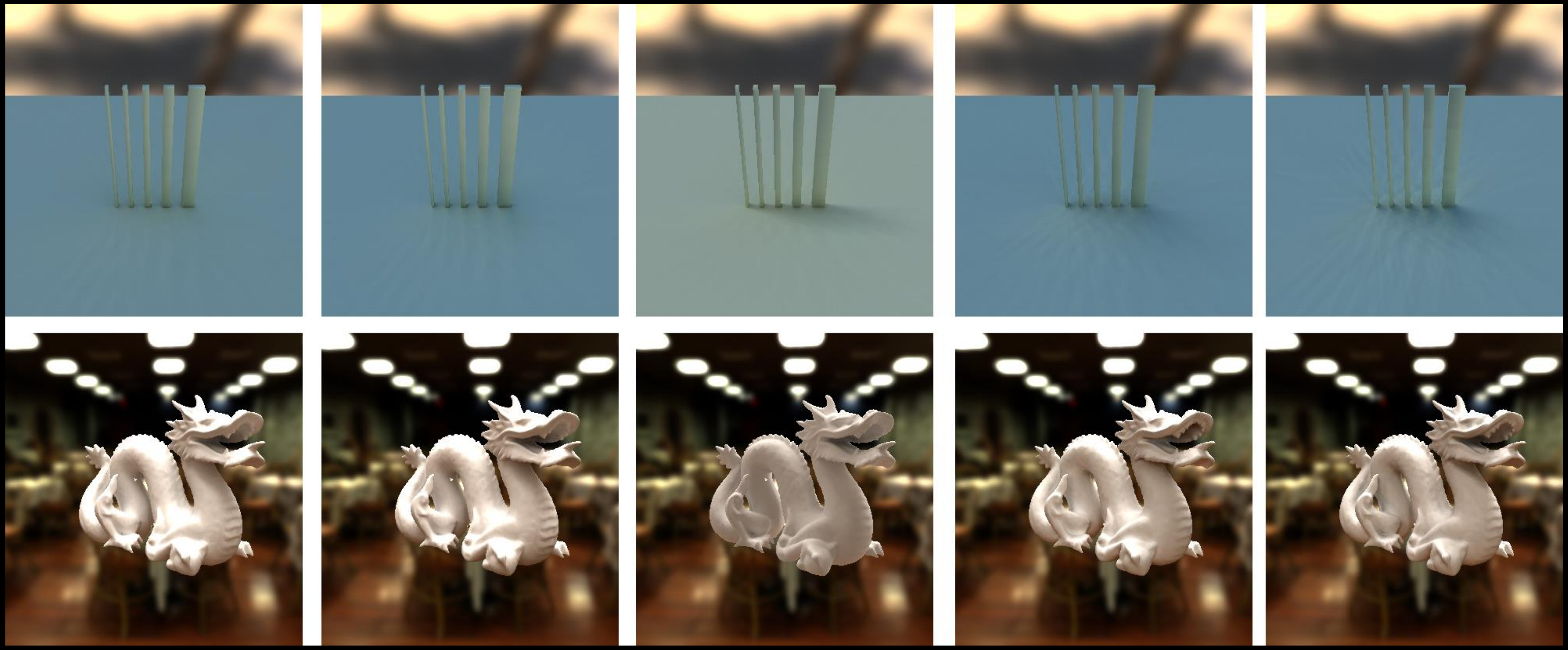


14D-Outdoor

25-SH

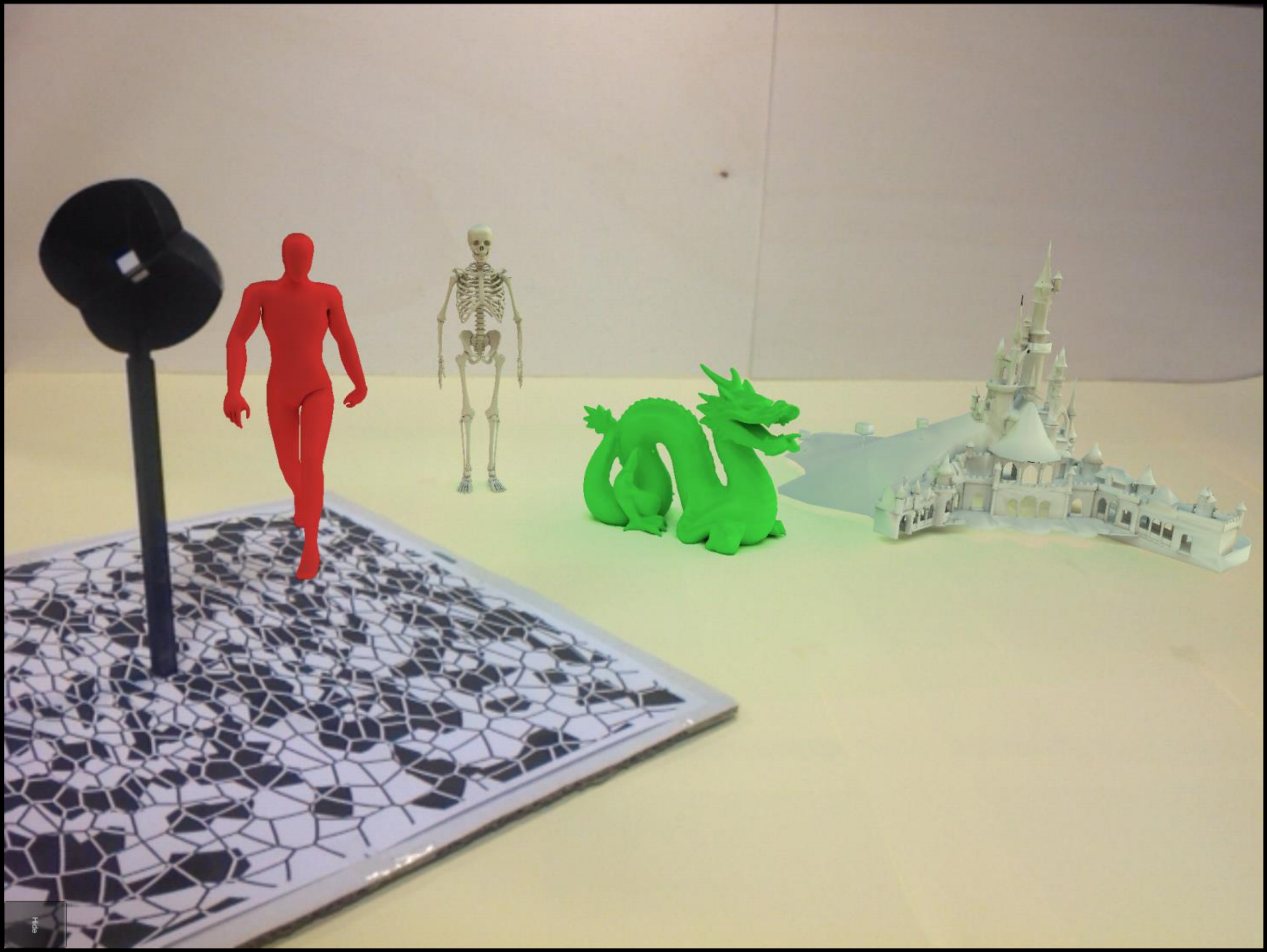
High frequency shadows

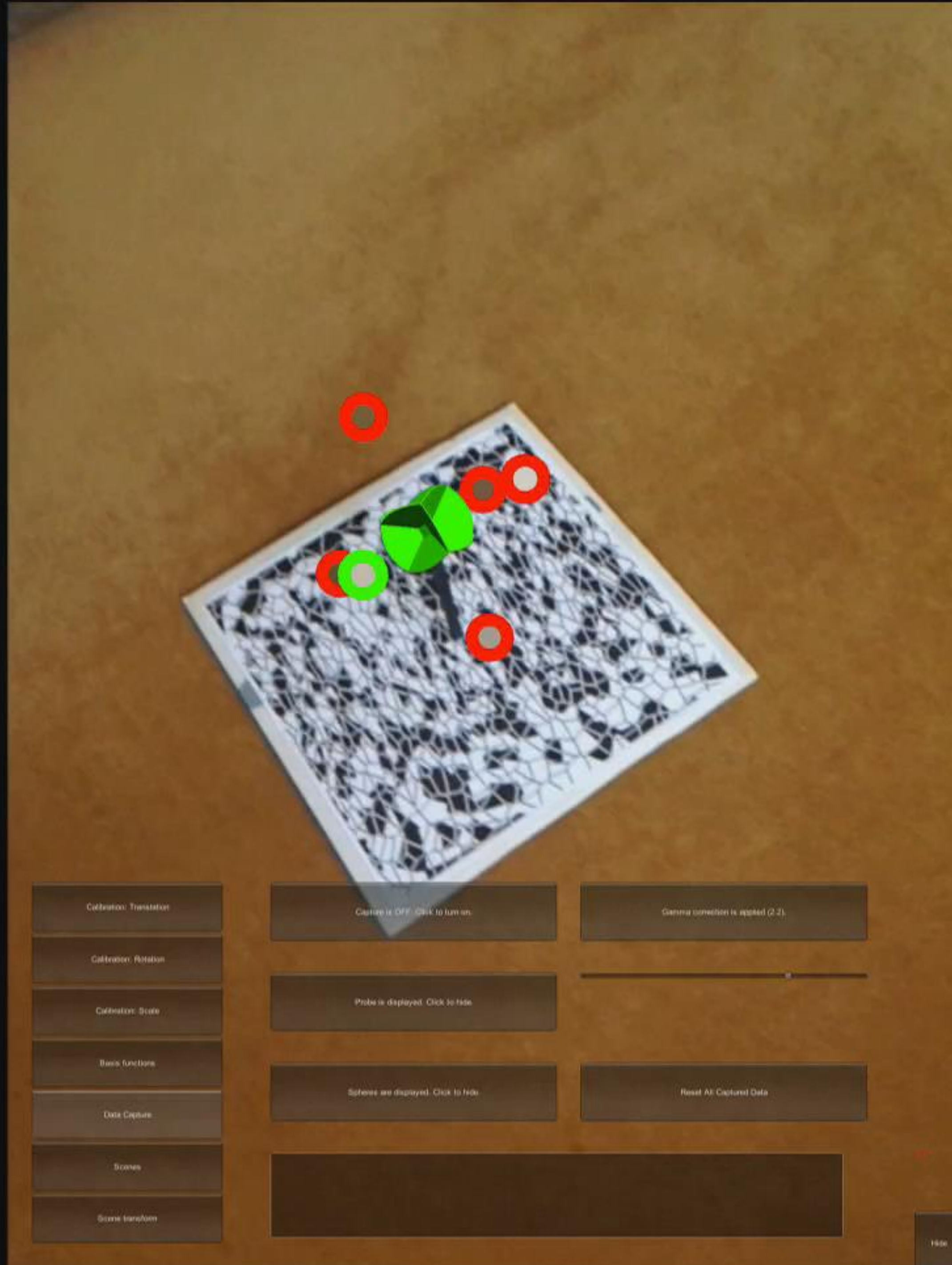
Results: Synthetic Input



14D 14D-Indoor 14D-Outdoor 25-SH 110D

Results: Real Input



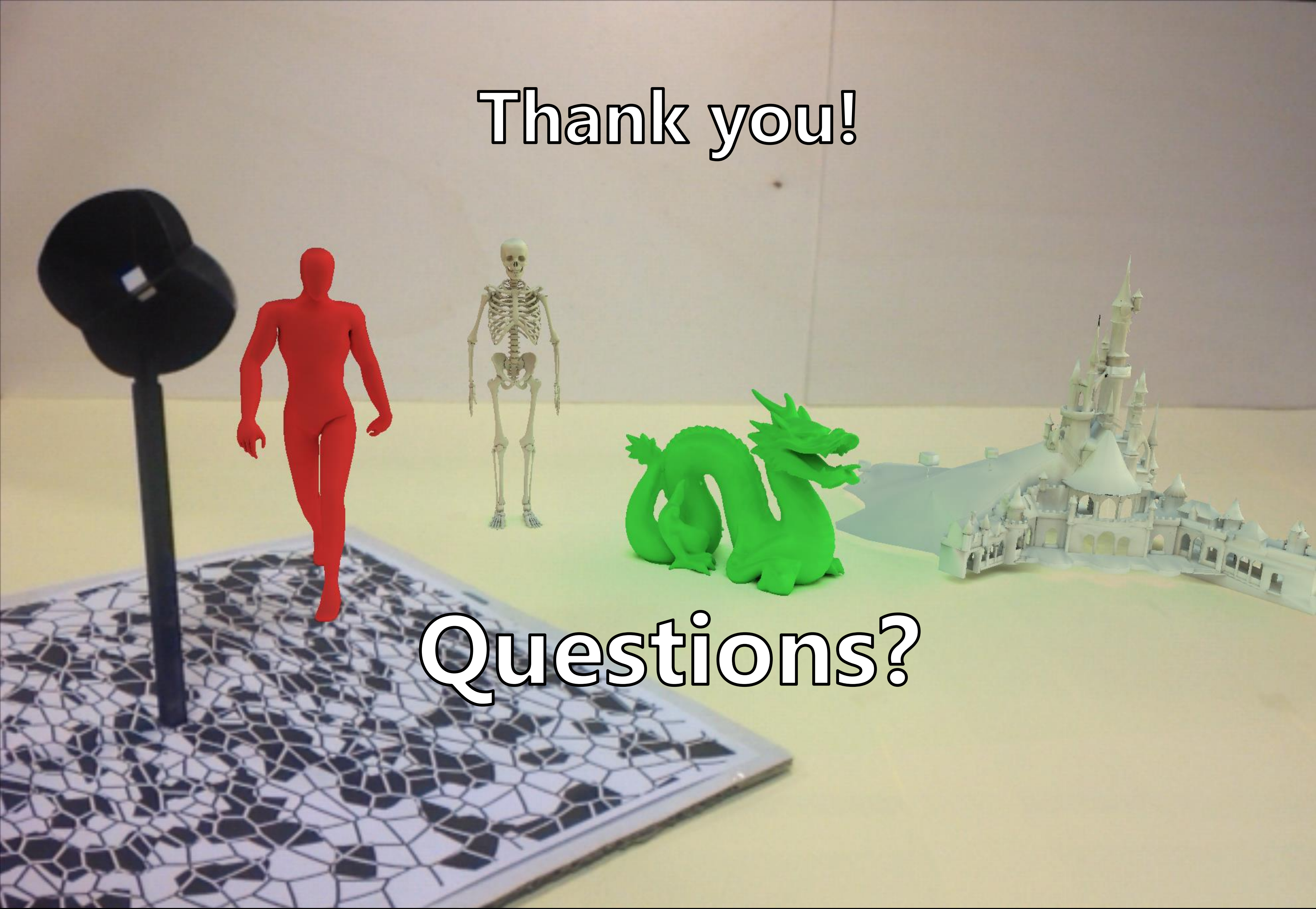

Calibration: Translation
Calibration: Rotation
Calibration: Scale
Basis functions
Data Capture
Scenes
Scene transform
Capture is OFF. Click to turn on.
Probe is displayed. Click to hide.
Spheres are displayed. Click to hide.
Gamma correction is applied (2.2).
Reset All Captured Data
Hide

Limitations

- In the discretisation limit, such a probe becomes specular
  - Only diffuse reflectance remains possible within reasonable computation and memory constraints
- Inherits limitations of PRT
  - Requires pre-computation
- Probe's induced basis set not closed under rotation

Future Work

- Glossy probe
  - Material reflectance lobe used as basis
  - No need for outer shell
  - Requires precise control over glossiness
- Improving tracking accuracy
  - 3D model-based tracking for anisotropic probes
  - Embedding markers within unused probe geometry
- Handling high-frequency light transport


Thank you!
Questions?

Rendering: Details

- The shading of a flat patch *i* is $S_i =$

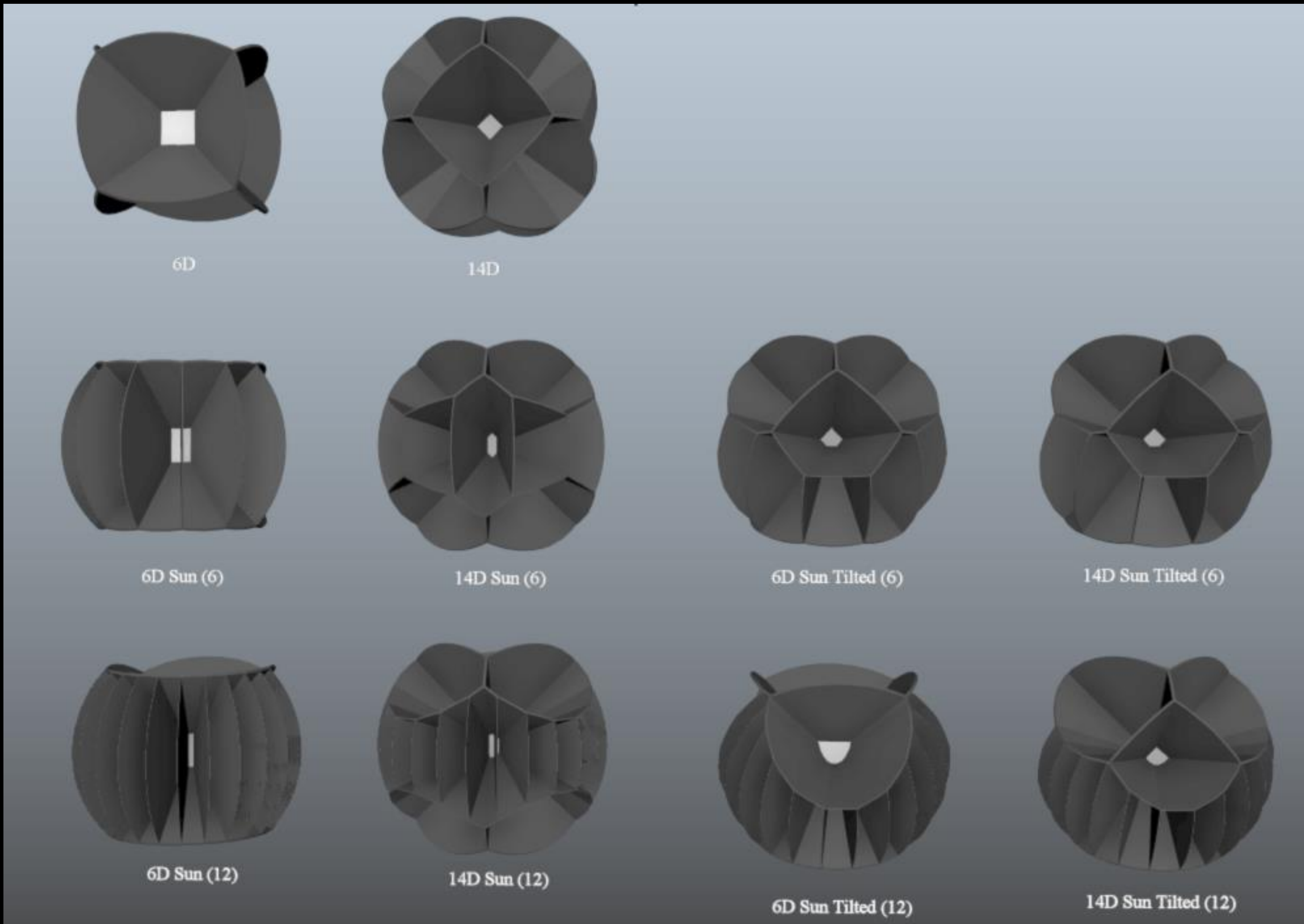
$$= L(n_i, V_i) = \frac{\rho}{\pi} \int_\Omega L_{in}(\omega) V_i(\omega)(n_i \cdot \omega)^+ d\omega$$

$$= \frac{\rho}{\pi} \int_\Omega L_{in}(\omega)(n_i \cdot \omega)^+ d\omega$$

- Assuming $L_{in}(\omega)$ is cst. across the *i*-th partition, we denote it by $L_{in(i)}$ and re-arrange the equation to yield it

- We define the (orthonormalised) basis function $b_i(\omega)$ which corresponds to partition *i*, such that $L_{in(i)}$ becomes the coefficient for the basis b_i

Probe Geometry: Zoomed in



Probe Geometry: Details

- Geometry is automatically generated from partition directions (CSG):
  - Shell = Sphere – generalized cones of partition boundaries
  - Kernel = Sphere – aligned planes with partition directions