



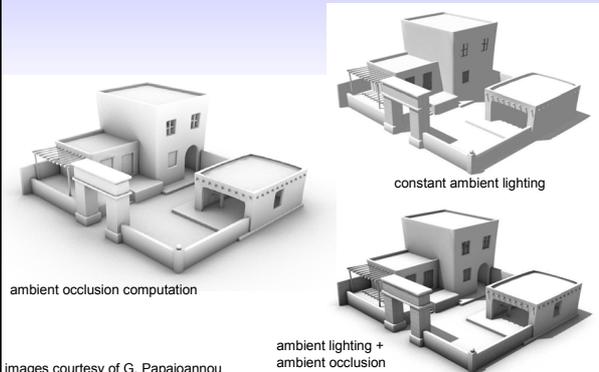
## Presampled Visibility for Ambient Occlusion

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## Ambient Occlusion Rendering

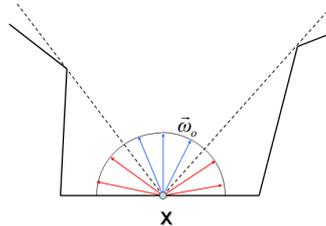


## Ambient Occlusion

$$A(x, \vec{n}) = \frac{1}{\pi} \int_{\Omega} V(x, \vec{\omega}_o) (\vec{\omega}_o \cdot \vec{n}) d\vec{\omega}_o$$

where:  $V(x, \vec{\omega}_o)$

is a function that maps distance from surface point  $x$  to the closest surface along direction  $\vec{\omega}_o$  to visibility values between  $[0.0, 1.0]$



## Previous Work

- Zhukov and Iones *et al.* in 1998
- Kontkanen *et al.* in 2005
- Zhou *et al.* in 2005
- Malmer *et al.* in 2005



## Introduction

- Brute force method:
  - For each sample on the receiver object
    - Cast rays towards the caster object
    - Accumulate the visibility of the sample
    - Paint the sample according to its visibility
- We propose:
  - Visibility pre-calculation step
  - Real-time computation step



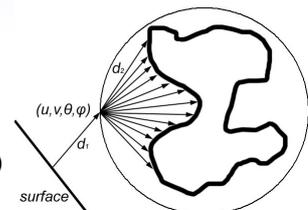
## Visibility Sampling

- Replace original ray-object intersection and distance measurement

with

- Ray-bounding sphere intersection ( $d_1$ )
- Bounding sphere to object intersection ( $d_2$ )

Pre-calculate and Store  $d_2$





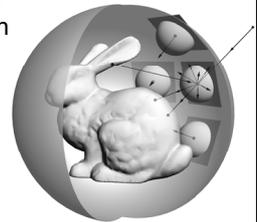
## Displacement Fields

- Require a 4 dimensional parameterization
  - 2 polar coordinates for the ray-sphere intersection point
  - 2 polar coordinates for the ray direction
- Displacement Fields are a set of distance maps that encode ray direction, one map for each intersection point on the sphere



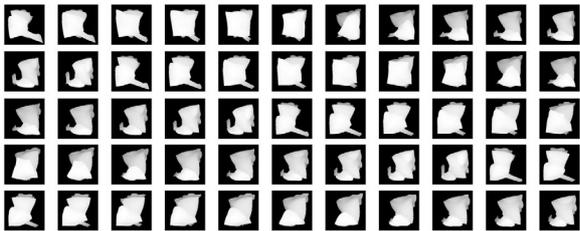
## Displacement Field Generation

- Pre-processing step:
  - Choose sample points on the bounding sphere of an object
  - Shoot rays from these samples towards the object
  - Store the computed distances into maps (displacement maps)



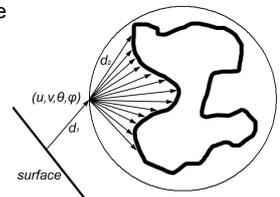
## Displacement Maps

- Maps of the bunny model using Concentric Map Sampling of Rays



## Displacement Fields

- Real-time step:
  - For each sample on the receiver object
    - Cast rays towards the bounding sphere of the object
    - Locate appropriate displacement map
    - Using the original ray direction, locate the recorded distance
    - Use total distance as distance to object



## Sample Points on a Sphere

- Requirements:
  - Samples must be evenly spaced on the surface of the sphere
  - The method must have an Inverse Function
- Methods:
  - Use Spherical Coordinates
  - Use Triangle Subdivision method by Mel Slater



## Sample Points on a Sphere

- Spherical Coordinates

Defined as

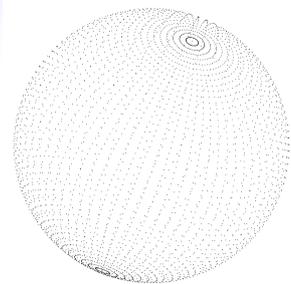
$$f(x, y, z) = (\sin \theta \cos \phi, \sin \theta \sin \phi, \cos \theta)$$

Inverse function

$$f^{-1}(\theta, \phi) = (\arccos z, \arctan y/x)$$

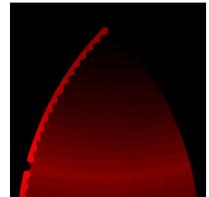
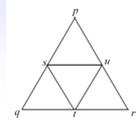
## Sample Points on a Sphere

- Spherical Coordinates
- Disadvantages:
  - Expensive Inverse function
  - Samples are concentrated at the poles of the sphere



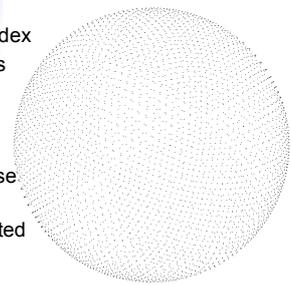
## Sample Points on a Sphere

- Triangle Subdivision Method
  - Generation
    - Start with a triangle
    - Bisect each of the three sides to generate 4 new triangles
    - Project the new vertices on the unit sphere
  - Render the triangles in a map, associating their coordinates with a colour value



## Sample Points on a Sphere

- Triangle Subdivision Method
  - Query
    - Pick correct colour index to map into coordinates
- Advantages:
  - Has constant time inverse function
  - Samples evenly distributed
  - GPU friendly

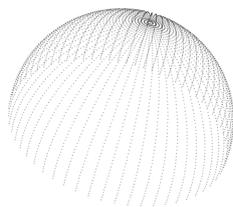


## Ray Parameterization

- Need to sample ray directions both from
  - the receiver object (initial visibility sample directions)
  - the intersection point towards the object (directional distance parameterization)

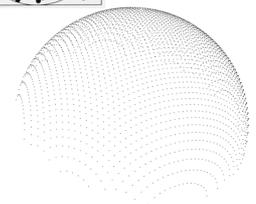
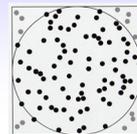
## Sample a Hemisphere of Rays

- Spherical Coordinates
- Advantages:
  - Samples are concentrated at the cap of the hemisphere
  - Produce a good cosine term
- Disadvantage:
  - Samples are not equally spaced



## Sample a Hemisphere of Rays

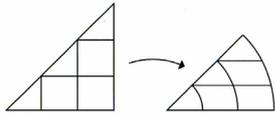
- Rejection Sampling
  - Uniformly sample points inside the  $[-1, 1]^2$  square
  - Reject the samples that fall outside the unit disk.
- Disadvantage:
  - 21.5% of samples are rejected



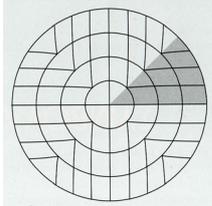


## Sample a Hemisphere of Rays

- Concentric Map Sampling
  - Introduced by Shirley *et al.* in 1997
  - Sample points inside the  $[-1, 1]^2$  square are uniformly mapped to the unit disk

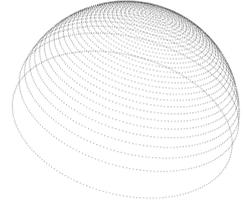
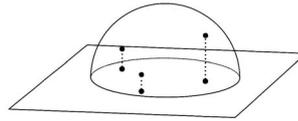


Wedges on the square are mapped into pie-shaped slices of the circle



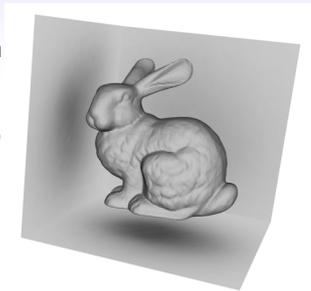
## Sample a Hemisphere of Rays

- Concentric Mapping Sampling
  - Now use Malley's method to generate the cosine-weighted samples
  - Project the samples from the disk onto the hemisphere



## Results

- Reference Image
  - Ray Casting
  - 256 rays cast from each vertex of the receiver object (3x33x33 vertices)



## Results

Maps of size 64 x 64

1122 Maps using Uniform sampling

1090 Maps using Concentric map sampling

Sampling of 256 rays

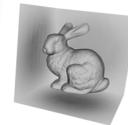
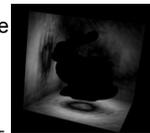


Image differences between the Reference image and the corresponding map method



Exaggerated by a factor of 5



## Results

- Casting 256 rays using concentric map sampling distribution, from receiver object
- Used 4226 samples on the bounding sphere



32x32

Secs: 0.10826

Error: 0.67720



64x64

0.11118

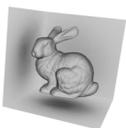
0.63150



128x128

0.11504

0.62090



256x256

0.12190

0.61850



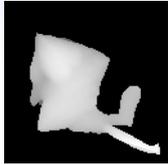
## Results

	Lemon Tree	Bunny	Igea	Multiple Objects
Model				
Triangles	26,300	39,000	67,200	142,300
Rays cast	836,352	836,352	836,352	26,444,800
Ray casting time	196.20 s	331.10 s	616.35 s	4,286.8 s
Pre-processing (4226 / 32x32)	99.54 s	54.79 s	243.76 s	334.6 s
AO calculation	0.240 s	0.228 s	0.204 s	4.692 s



## Optimizations – Storage

- 128x128 displacement maps



8-bits



16-bits

RMS Error: 0.125525



difference image exaggerated by a factor of 50



## Optimizations – Visibility Map

- 8-bit, 128x128 maps



displacement map



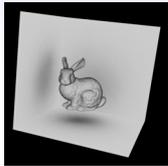
visibility map

87.5 % savings in texture space

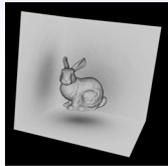


## Optimizations

- 8-bit, 128x128 maps



using displacement map



using visibility map

RMS Error: 2.947292



difference image exaggerated by a factor of 5



## Current Work

- GPU Implementation
- Application to Ray Tracing



## Videos

- tire model
- bunny model
- dragon model



## Thank you