Generic BRDF Sampling

A sampling method for Global Illumination

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Contents

1. Problem: efficient BRDF sampling
2. Solutions to BRDF sampling
3. Our sampling approach
4. Results for our solution

Contents

1 Problem: efficient BRDF sampling

2 Solutions to BRDF sampling

3 Our sampling approach

4 Results for our solution

Bidirectional Reflectance Distribution Function

BRDF function

- A BRDF describes the relation between the incoming and outgoing radiances at a given point on the surface.
- A function that represents the surface reflectance, given two directions $\mathbf{u}, \mathbf{v} \in \Omega$ and has values between 0 and ∞.
- Must be simmetric and energy conservative, to be *physically plausible*
- There are many reflectance models in Computer Graphics.

Radiance computation with the Monte Carlo Method

Monte Carlo Path Tracing Algorithm

- We use Monte Carlo to approximate the integral of the reflectance equation.

$$L_r(\mathbf{u}) = \int_{\Omega} f_r(\mathbf{u}, \mathbf{v})\, L_i(\mathbf{v})\, cos(\mathbf{v})\, d\sigma(\mathbf{v})$$

- On each point we take a chance to stop (absorption) or to reflect based on the reflectance properties of the surface (BRDF).
- We need a PDF to sample according to the integrand.

Probability Density Function

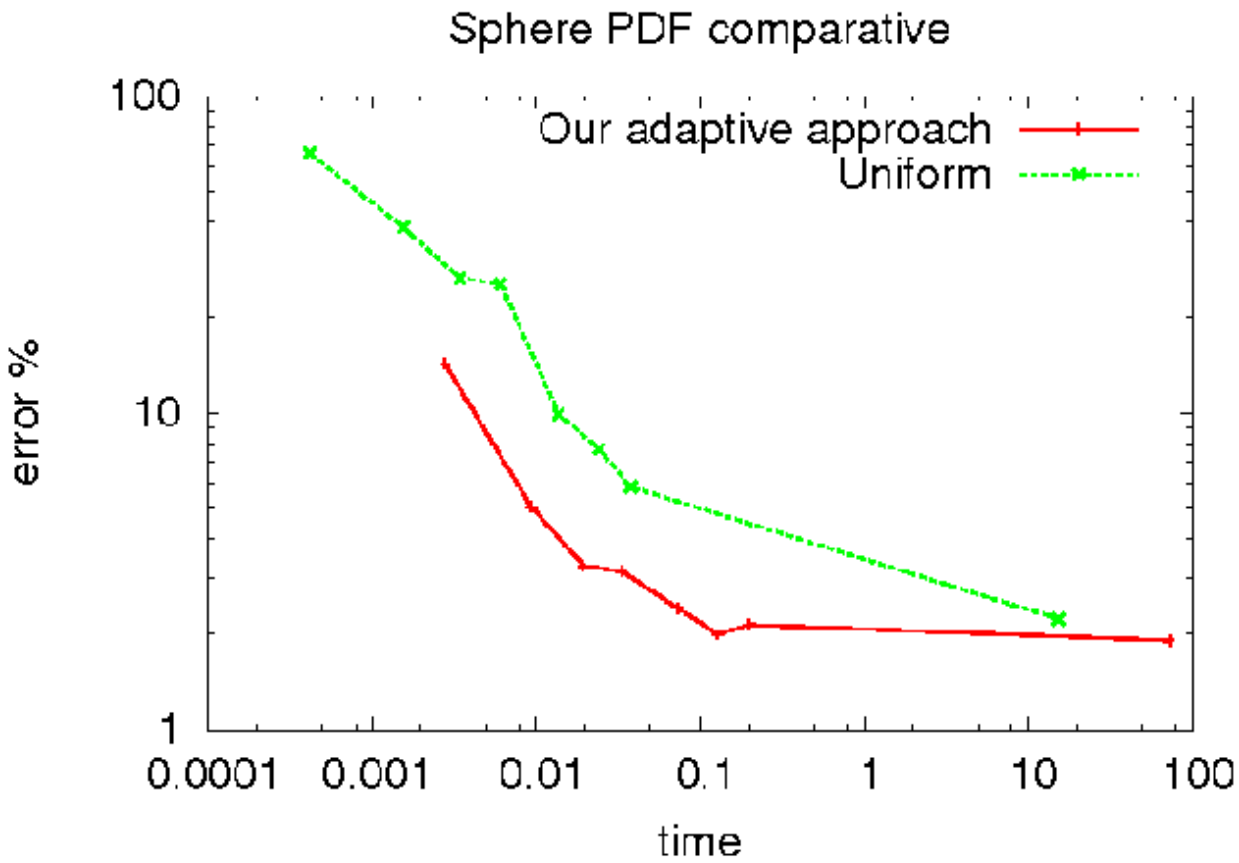
The PDF

- Uniform sampling is simple but produces high variance (noise)
- It is preferable to generate more samples where the function has higher values (not uniform).
- Importance sampling is better when the PDF is closer to the integrand.

Key point

If we assume no information about the incomming radiance, is preferable to sampling proportional to the BRDF fuction.

Uniform vs Importance Sampling



Contents

1 Problem: efficient BRDF sampling

2 Solutions to BRDF sampling

3 Our sampling approach

4 Results for our solution

Two Sampling Approaches

Direct Sampling

- BRDFs based on cosine lobe: Lafortune, Phong, Blinn, etc.
- Cosine-Lobe based sampling does not applies well to every BRDF model.

Generic Sampling

- Independient of the BRDF: Poulin-Fournier, Phong, Lafortune, Torrance-Sparrow, He, Strauss, Schlick, Oren-Nayar, Minnaert, Ward, Ashikhmin, Beard-Maxwell, Coupled, etc.

Key point

There is no way to define a specific PDF for each BRDF model.

Approximate Sampling

Tabular BRDF

- Densely sampled tabular representations of BRDFs (off-line)
- Store distribution for dense set of views [Matusik03]
- Sampling using numerical inversion of the CDF.

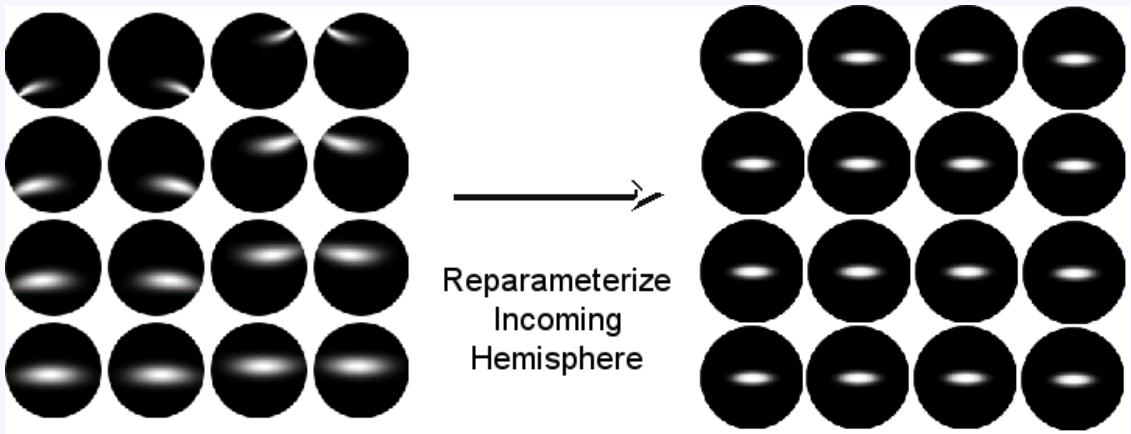
Drawback

- Expensive: The total size of this set of CDFs + the BRDF can quickly become prohibitively large.
- Aliasing if an insufficient number of slices are stored

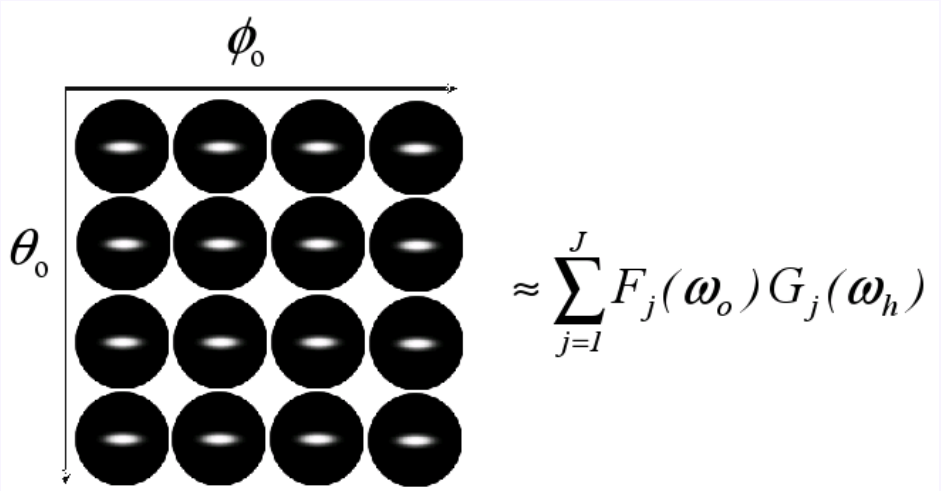
Approximate Sampling

Factorization of the BRDF [Lawrence et al. 2004]

- Based on numerical approximation of the BRDF times the cosine term.
- Compact: BRDF is factorized into 2D and 1D pieces (low dimension).
- Effective sampling of view-independent 1D functions.



Approximate Sampling



Key limitations

- The PDF is not exactly proportional to BRDF.
- Samples the set of directions in the sphere. Some samples must be rejected.
- Not all functions factorize efficiently.

Contents

1 Problem: efficient BRDF sampling

2 Solutions to BRDF sampling

3 Our sampling approach

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Adaptive Sampling of the BRDF

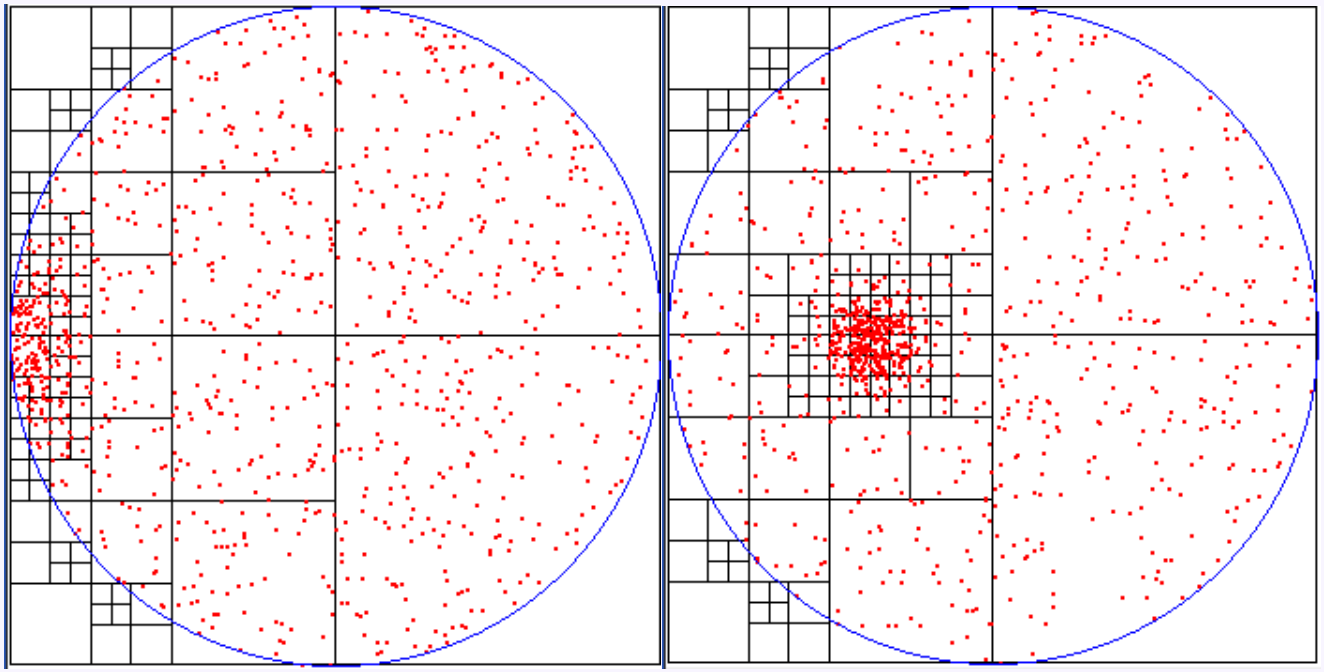
Key Idea

- Sampling random directions for arbitrary BRDF functions.
- Optimized rejection sampling algorithm.

Our approach

- Directions in Ω are projected into a unit disc of domain $[-1,1]^2 \Longrightarrow$ cosine term is implicit in our PDF.
- A quadtree data structure represent the BRDF adaptively.
- Leaf nodes represent exactly the BRDF function.
- Rejection sampling is performed on leafs with bounded average number of trials.

Adaptive Sampling of the BRDF



Benefice

Using rejection sampling with an adaptive subsivision of the domain, the samples density is exactly proportional to the BRDF.

Representation of an Adaptive PDF

The Data Structure

The Adaptive PDF is represented as a *quadtree* for each BRDF and for any given direction $\mathbf{u}$.

1. Split original domain $\mathcal{D}^2$ into N disjoints regions $R_1, R_2, \ldots, R_n \subseteq \mathcal{D}^2$.
2. We subdivide a node if there is enough variability in the function so more detail is needed.

$$n_{max} \frac{I_i}{V_i} \geq 1$$

Representation of an Adaptive PDF

Optimal Rejection Sampling

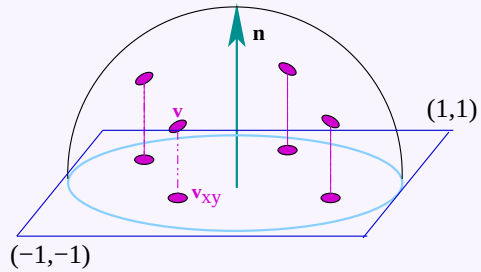
- The number of times the main loop is executed is a known geometric distribution.
- The average number of trials is a parameter of our algorithm $n_{max} = 2$.
- We guarantee a probability for accepting a sample of $I_i/V_i \geq 0.5$.

Sampling the Adaptive PDF

How to generate a random direction

1. Traverse the *quadtree* and randomly select a leaf node, with associated region R_i.
2. Perform rejection sampling on R_i, get $\mathbf{s}_{xy}$.
3. Project $\mathbf{s}_{xy}$ onto Ω, obtain $\mathbf{s}$.
4. Pdf value for this sample is:

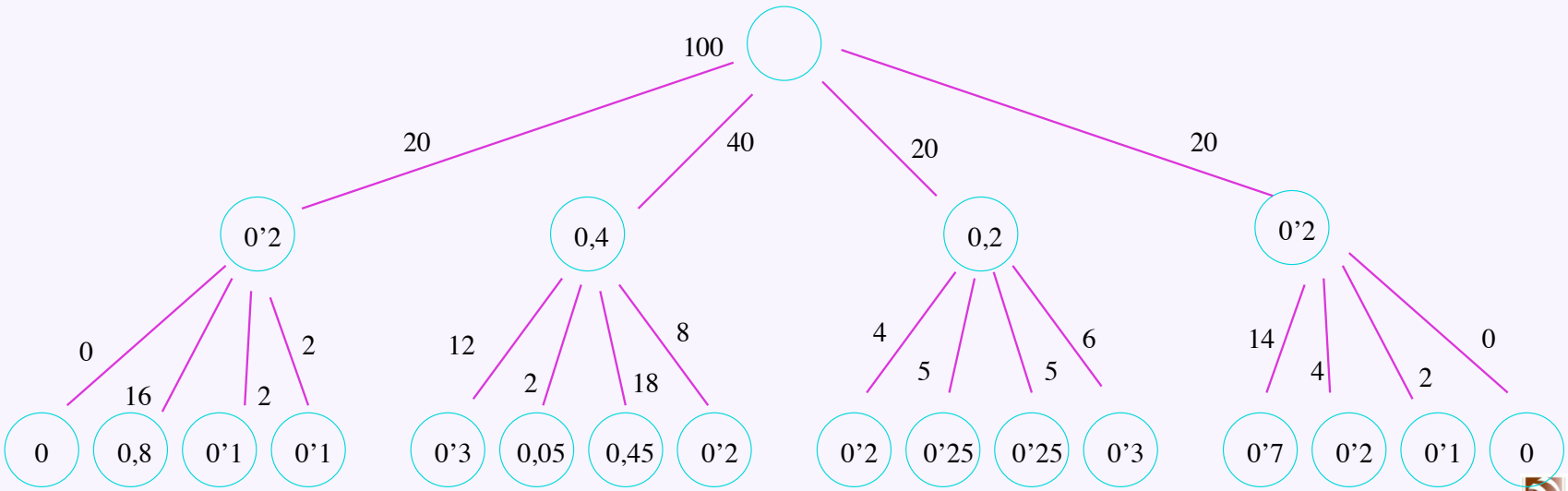
$$q_{\mathbf{u}}(\mathbf{s}) = prob(\mathbf{s}_{xy})\, p_{\mathbf{u}}(R_i)\xi\chi$$



Adaptive Sampling of the BRDF

Optimizations

- We store n quadtrees for n incident angles in a preprocess step.
- We traverse the quadtre once to get N random directions.



Contents

1 Problem: efficient BRDF sampling

2 Solutions to BRDF sampling

3 Our sampling approach

4 Results for our solution

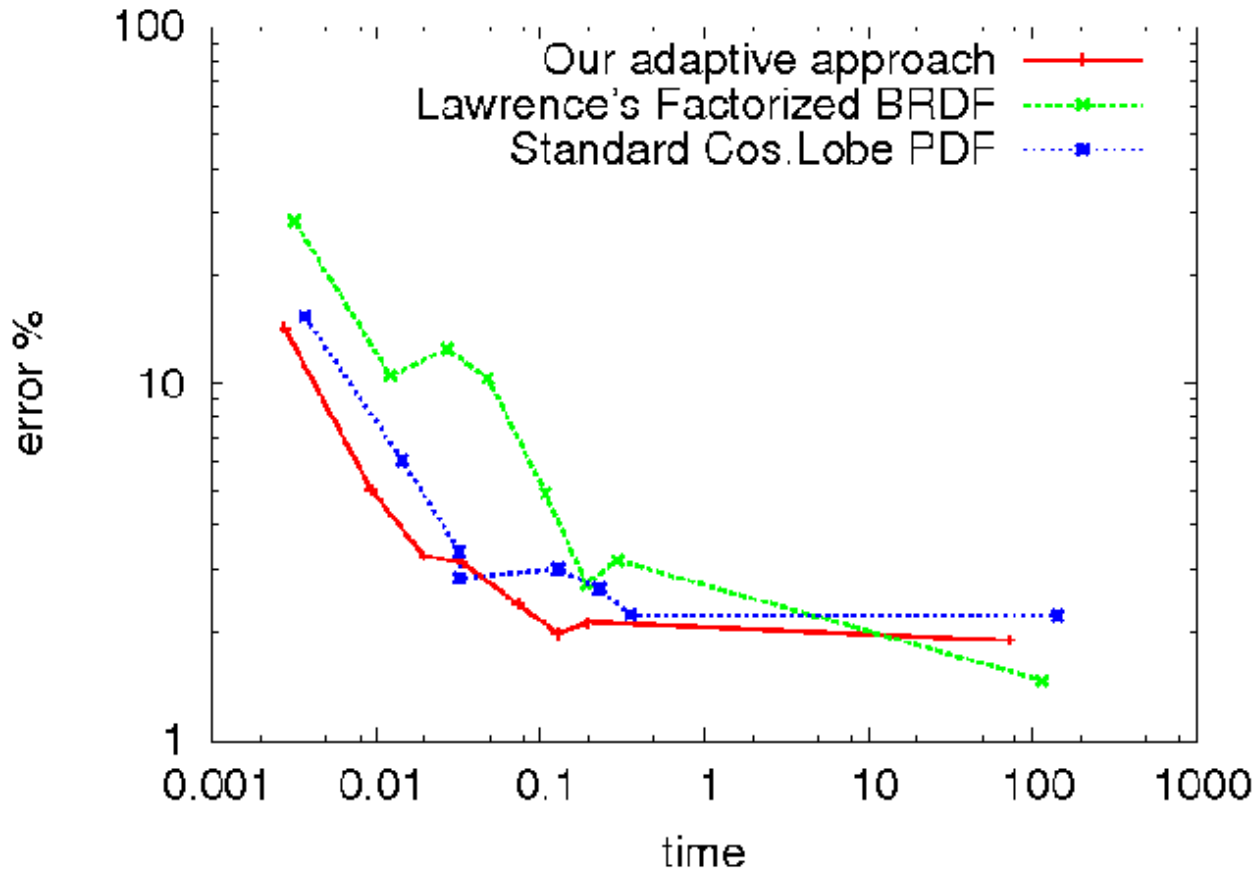
Results for our solution

Precomputation Cost

Ashikhmin	51.4	BeardMaxwell	15.5
Blinn	8.7	Coupled	22.6
He	102.7	Lafortune	6.6
Lewis	6.9	Minnaert	7.3
Oren-Nayar	10.5	Phong	6.9
Poulin-Fournier	35.5	Schlick	13.2
Strauss	10.9	Torrance-Sparrow	8.3
Ward	20.7		

Start up times in seconds for some BRDF models. In average: 20.71 seconds for 90 quadtrees.

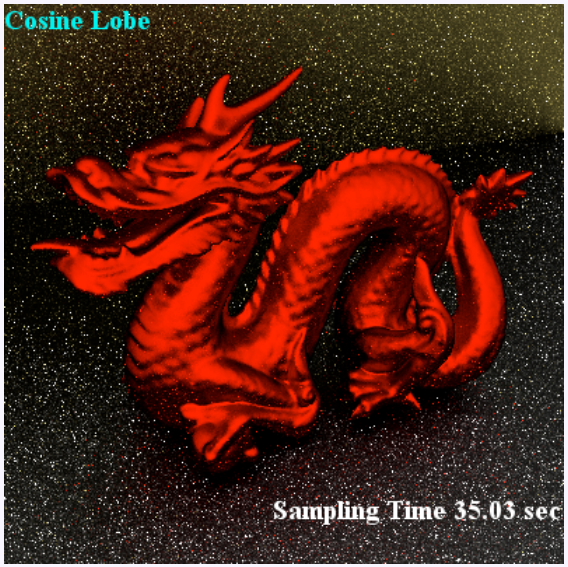
Results: relative error versus sampling time

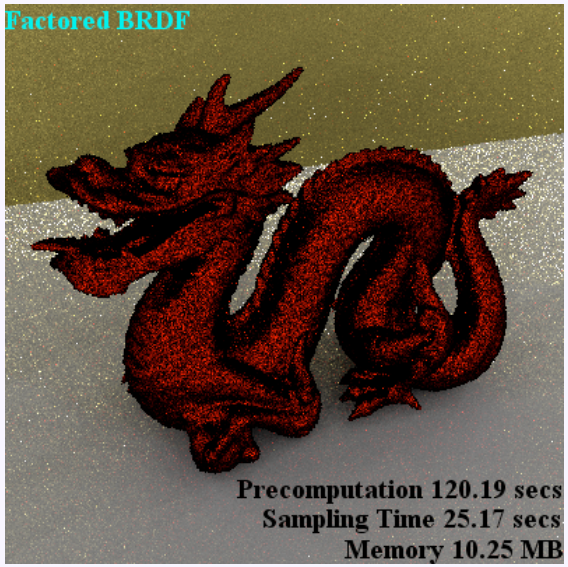


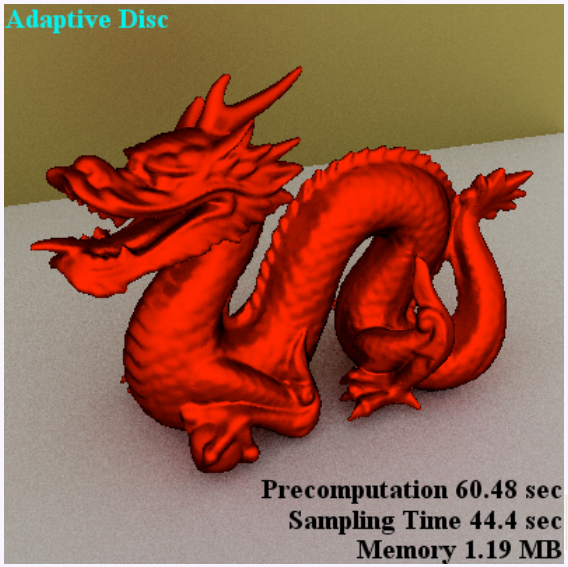
Results: images

Dragon with 100 samples

- BRDF instances: Oren-Nayar, Strauss and Lafortune.
- No manual selection of any parameter is needed with our sampling approach.







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Thank you for your attention