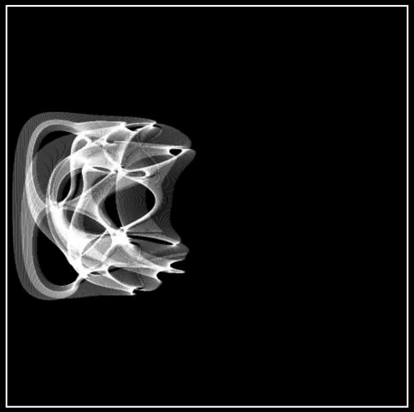
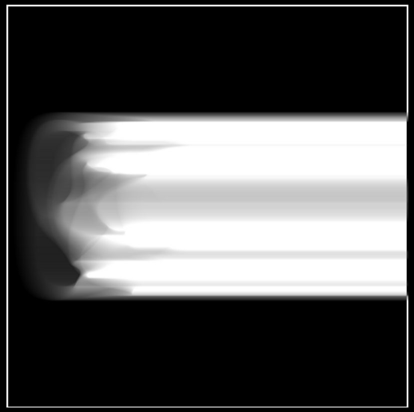
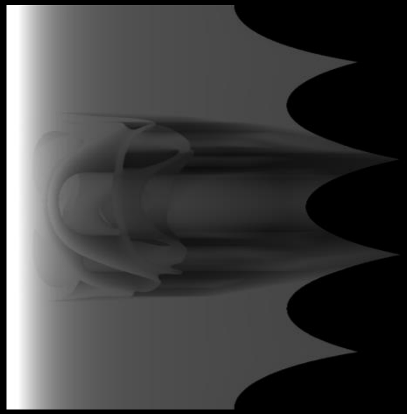
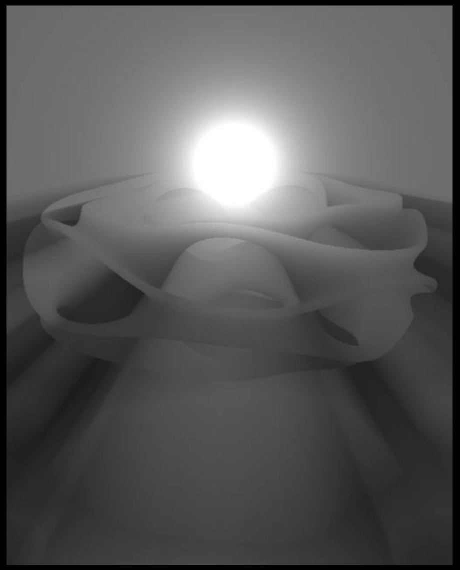
Voxelized Shadow Volumes

Chris Wyman
Department of Computer Science
University of Iowa

High Performance Graphics 2011

Problem: Visibility In Volumes

- Quickly solve the query:
  - Which points in volume see some point P?
- Example application: volumetric lighting
  - When integrating scattering with shadows
- Without loss of generality:
  - Use volume lighting for concrete examples
  - Our algorithm is not limited to this problem

The University of Iowa

Imagine: Want Volume Lighting

Creative Commons Image: Mila Zinkova

THE UNIVERSITY OF IOWA

Why Is This Hard?

- Alternatively:
  - Why not use shadow maps?
  - Why not use shadow volumes?

- After all, many propose just that:
  - Shadow volumes [Max86] [Biri06]
  - Shadow maps [Dobashi02] [Englehardt10] [Chen11]
  - Combine both [Wyman08] [Billeter10]

Why Is This Hard?

- Rendering without visibility:
  - [Sun et al. 05] takes << 1ms (~1000+ fps)
  - [Pegoraro et al. 09] takes < 3 ms (~300+ fps)

- Rendering with visibility:
  - [Chen et al. 11] takes 7-24 ms
  - [Billeter et al. 10] takes 9-100 ms
  - Older techniques even slower
  - Most slow with increased geometric complexity

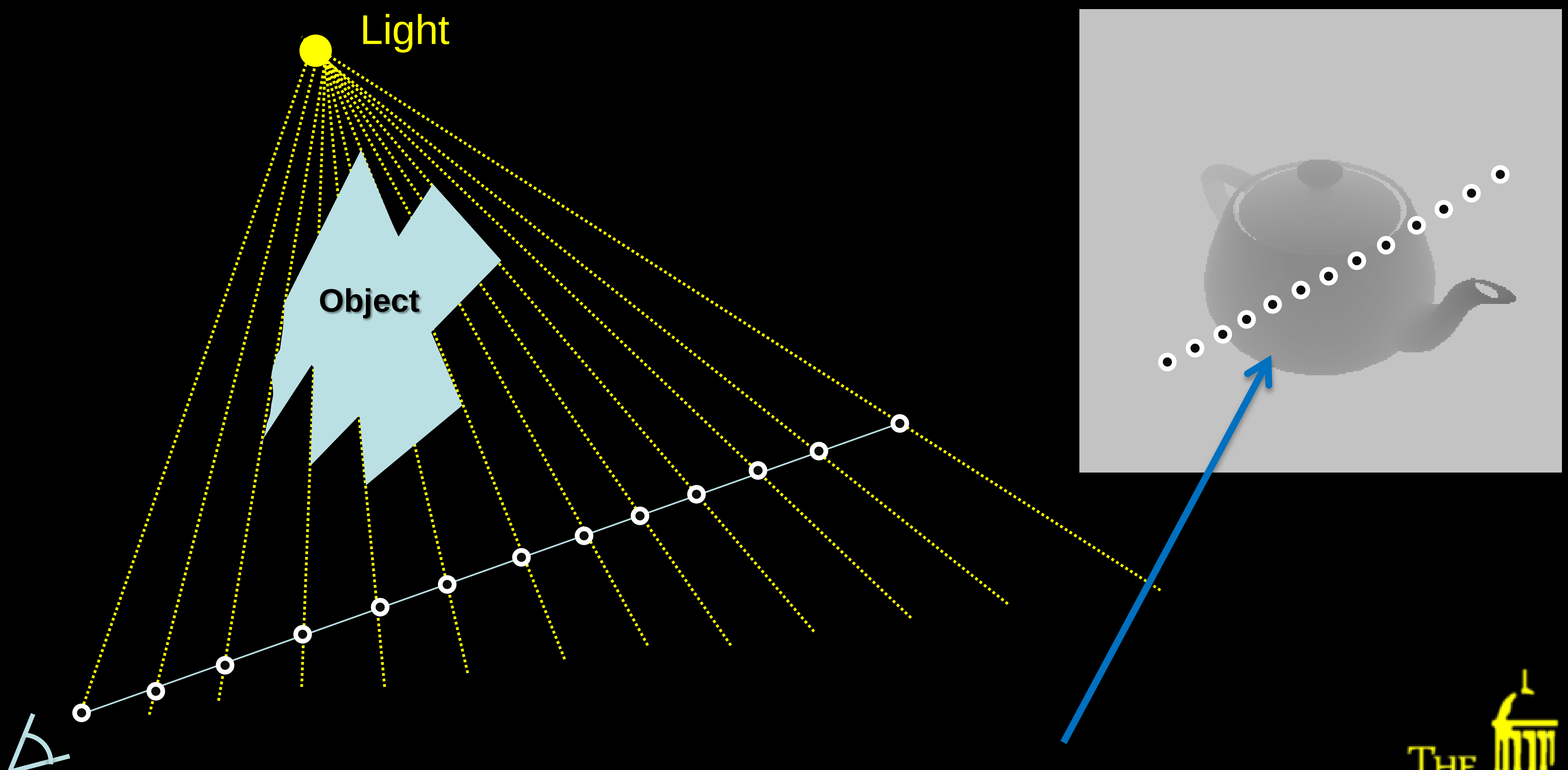
- Obviously, visibility is quite costly!

Why Is This Hard?

- Both SMs and SVs designed for surfaces
  - Shadow volumes scale more naturally
    - As they bound regions
    - Require significant fill rate
    - Fill rate increases with higher frequency shadows
  - Shadow maps simply sample more
    - Sample at points in volume, not just on surfaces
    - Leads to ***incoherent*** memory access
    - Leads to ***redundant*** memory access

The University of Iowa

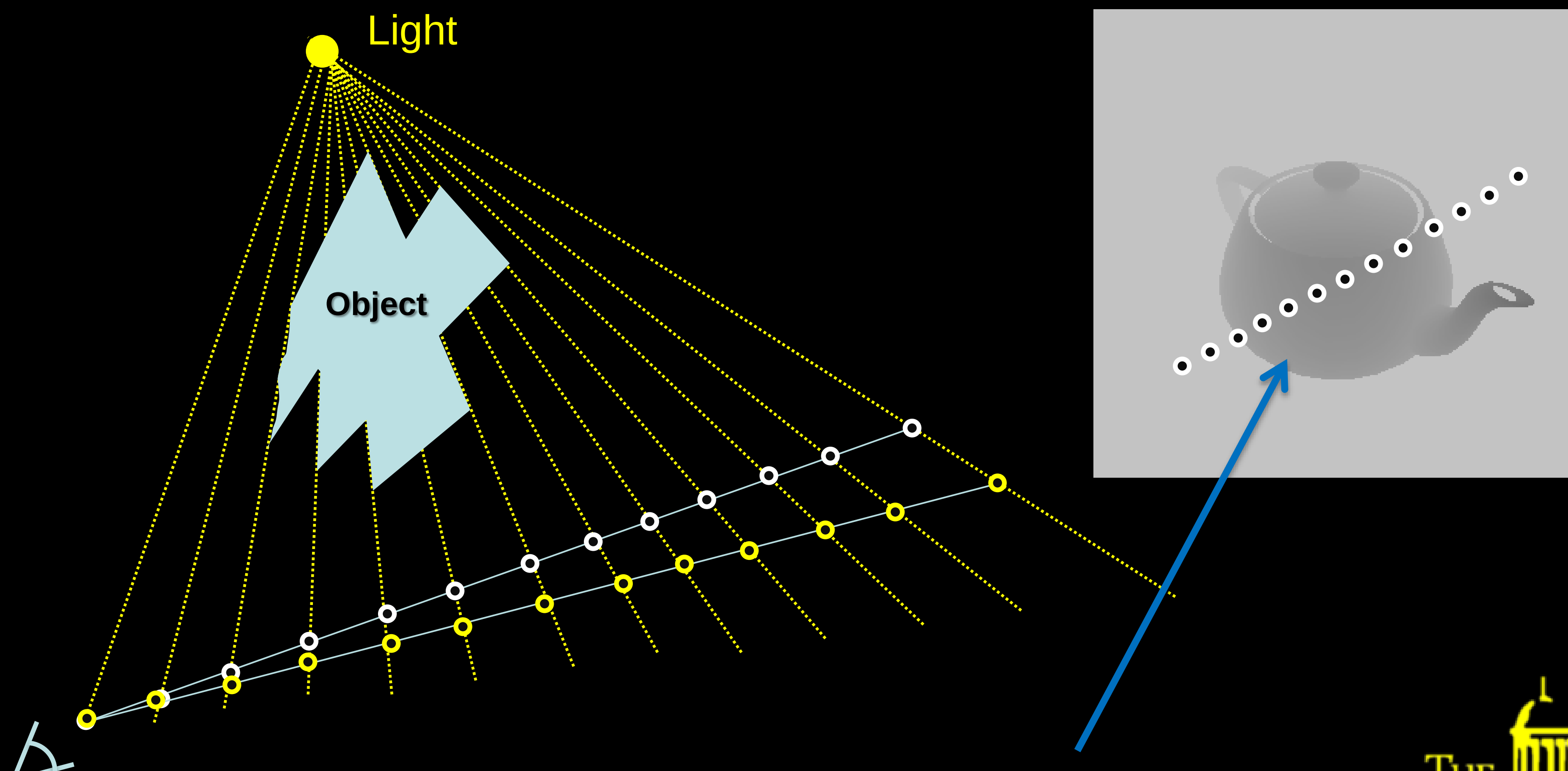
Why Is This Hard?



Shadow map samples likely have poor cache coherence.

The University of Iowa

Why Is This Hard?



Independently computed samples along adjacent rays look into ***same*** set of shadow map texels. And there is no guarantee values are still in the texture cache.

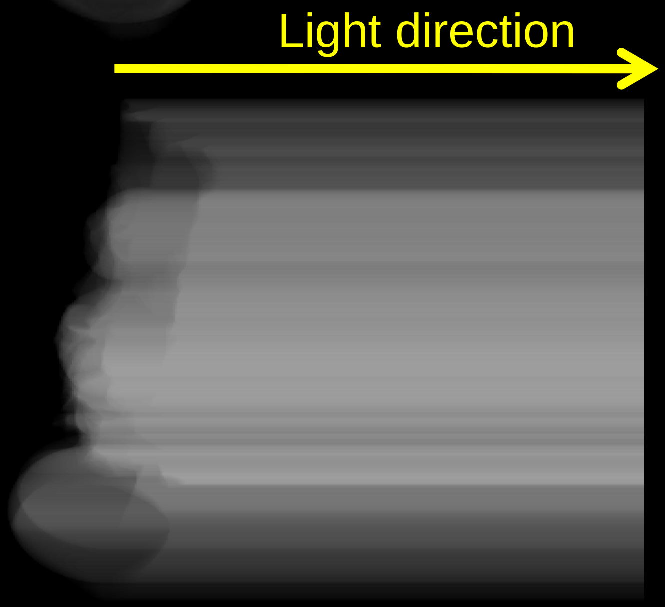
Voxelized Shadow Volume Goals

- Develop a *cache coherent* visibility lookup
  - Eye ray lookups should be efficient
  - Lookups for nearby eye rays near in texture
- Eliminate redundancy between lookups
  - Less important
  - But falls out naturally

What Are VSVs? (The Basics)

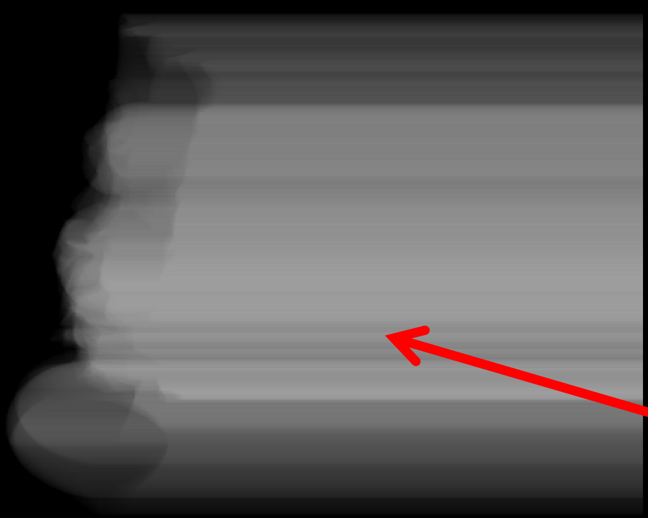
- Imagine voxelizing
  - To 3D voxel grid

- Parallel scan
  - Along a grid axis
  - Use an bitwise OR



What Are VSVs? (The Basics)

- Each pixel corresponds to:
  - Set of binary voxels, where
    - 1 → inside geometry
    - 0 → outside geometry



- Each pixel corresponds to:
  - Set of binary voxels, where
    - 1 → inside shadow volume
    - 0 → outside shadow volume

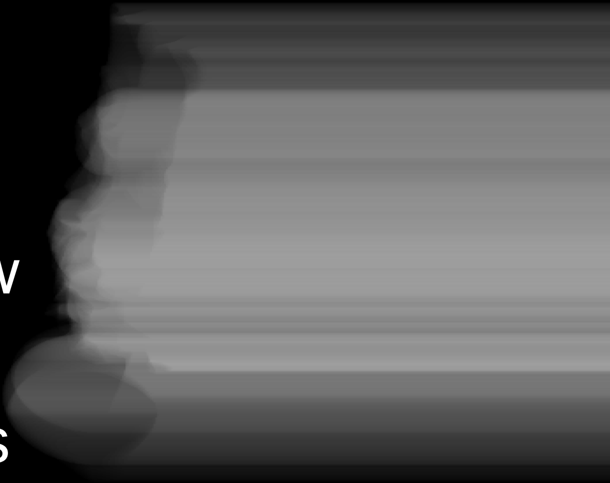
A *voxelized shadow volume*!

Seems Too Simple…

- Why has it never been done?
  - Need to scan along grid axis → very limiting
- But, if possible… What advantages?
  - Voxelization & render resolution independent
  - Voxelization occurs in different pass
  - Implies:
    - Shadow volume fill rate decouples from geometric complexity & screen resolution

Seems Too Simple…

- Other advantages?
  - Lookup logistics:
    - One “pixel” (at right) gives shadow visibility at many volume samples
    - Store 128 binary visibility samples in a texel on GPU
    - Significantly reduces lookups for dense visibility sampling
    - Used anywhere visibility needed



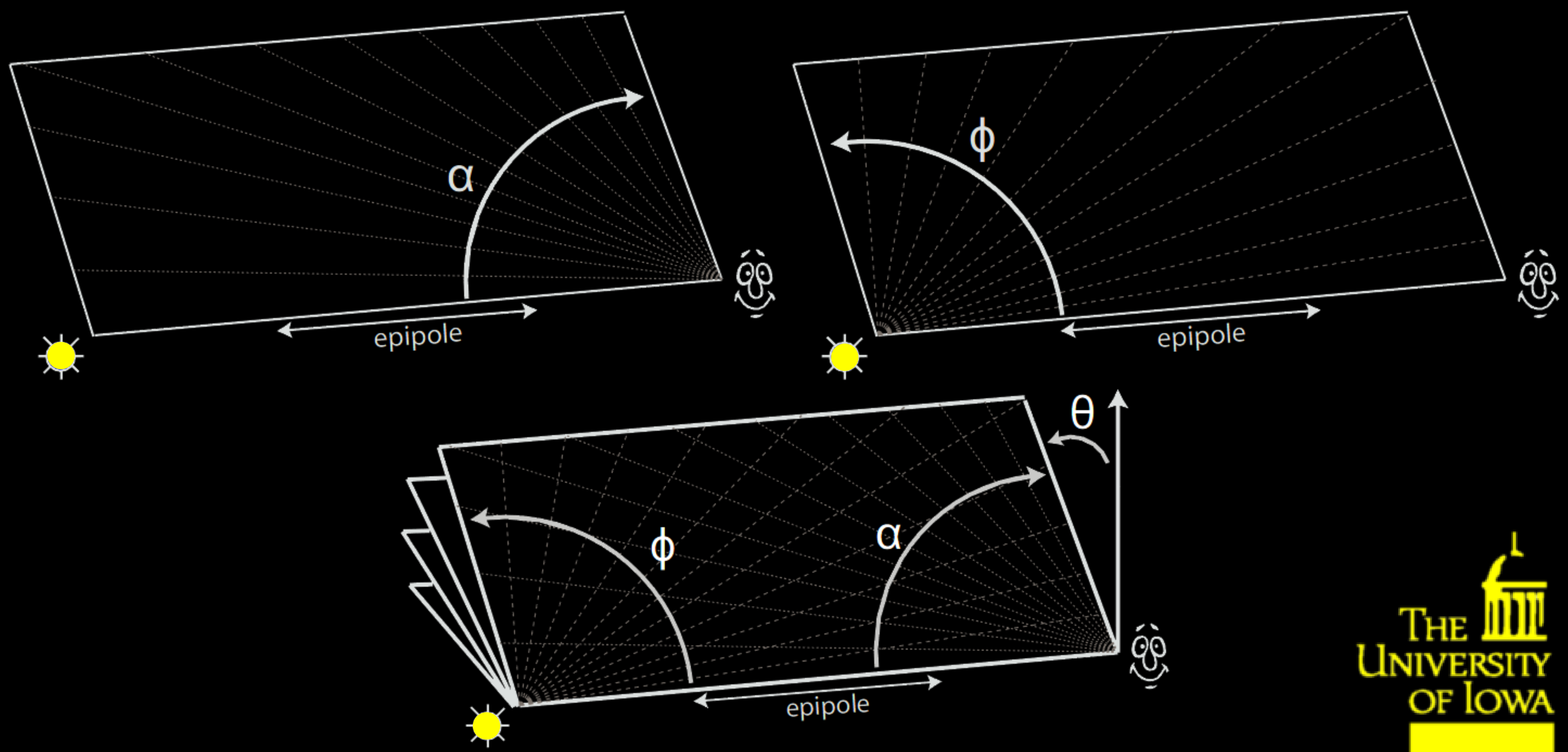
How Do We Generalize?

- Need parallel scan to run along grid axis
  - I.e., light direction runs along axis
  - Similar idea from ray tracing literature
    - [Hunt 08] Perspective-space accel structures
- Need per-pixel lookup along grid axis
  - To stash row of visibility samples in a texel
  - Done frequently in GPU computing
    - [Eisemann 06] Screen-space voxel grid
- Novel: Need them simultaneously

The University of Iowa

Creating VSVs

- We propose *epipolar space voxelization*



Creating VSVs

- Straightforward parameterization:

Given eye-space light and vertex position: `esLPos`, `esVPos`

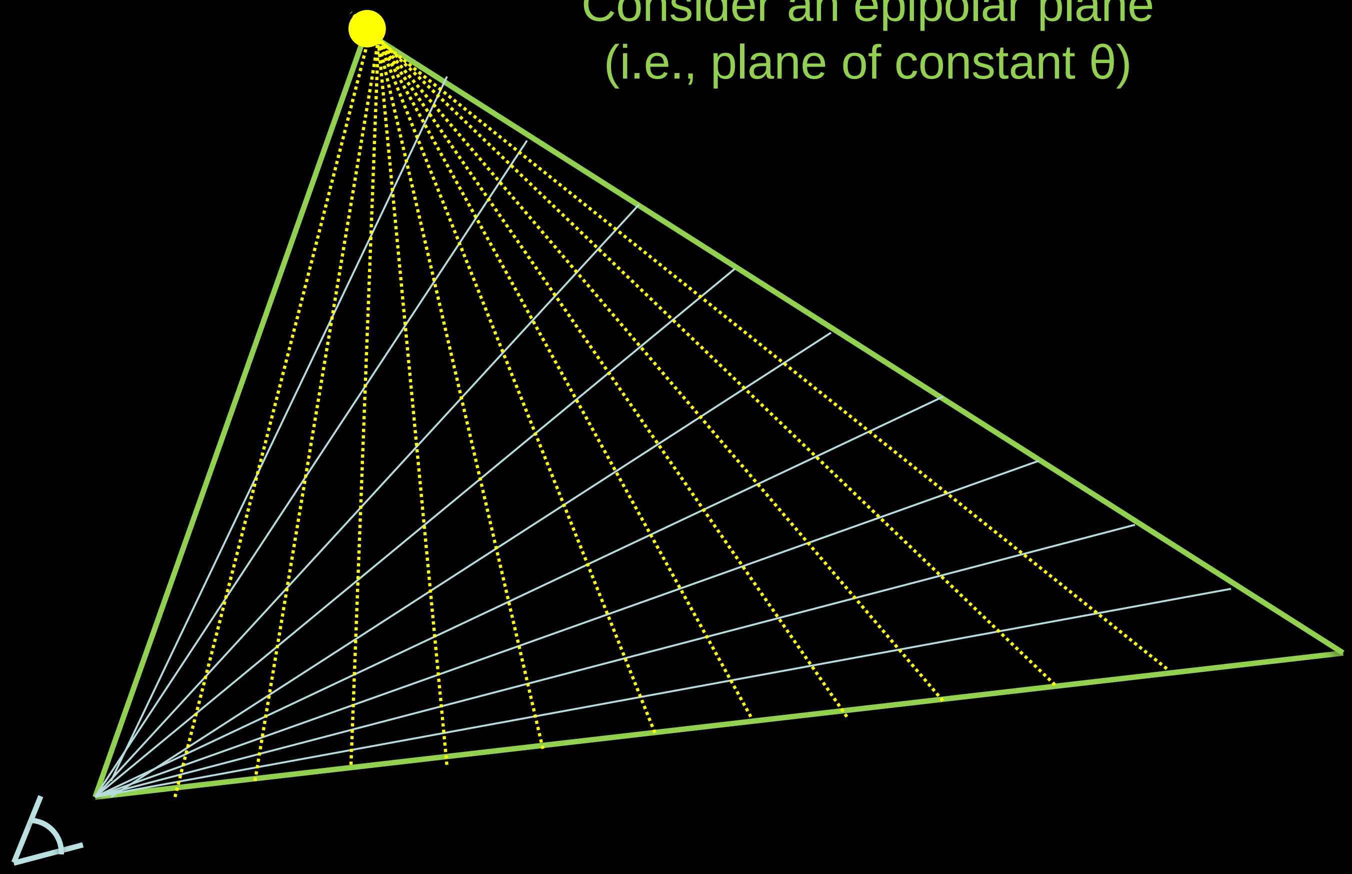
```
vec3 toLight = normalize( esLPos );
vec3 toVert = normalize( esVPos );
vec3 upVec = normalize( cross( toLight, vec3(0,0,-1) ) );
vec3 forwardVec = cross( upVec, toLight );

float α = acos( dot( toLight, toVert ) );
float θ = atan( dot( forwardVec, toVert ), dot( upVec, toVert ) );
float φ = acos( dot ( -toLight, normalize(esVPos-esLPos) ) );
```

- Satisfies our constraints:
  - One axis (constant α) parallel to view rays
  - One axis (constant Φ) parallel to light rays

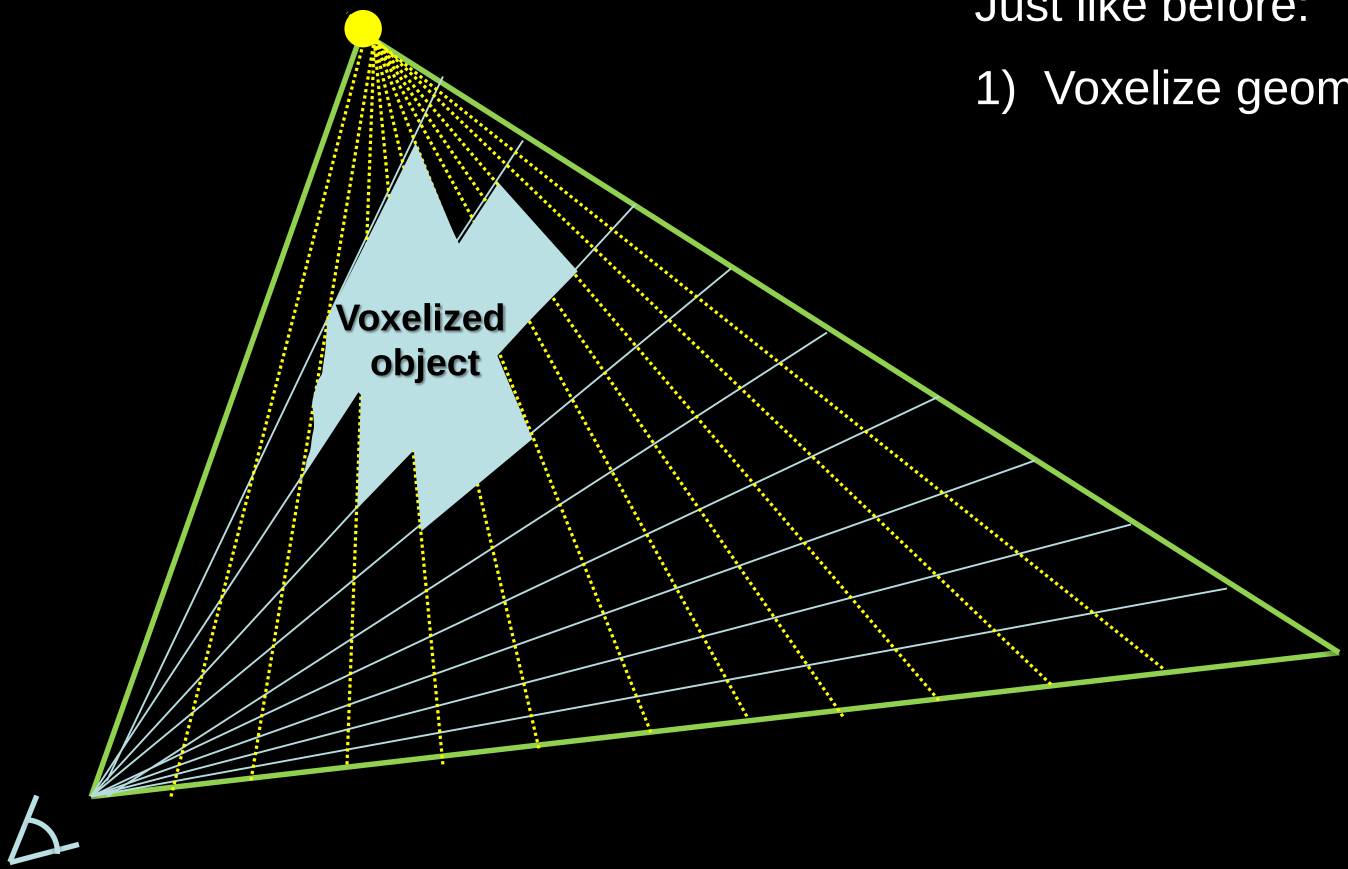
THE UNIVERSITY OF IOWA

Creating VSVs

Consider an epipolar plane
(i.e., plane of constant θ)



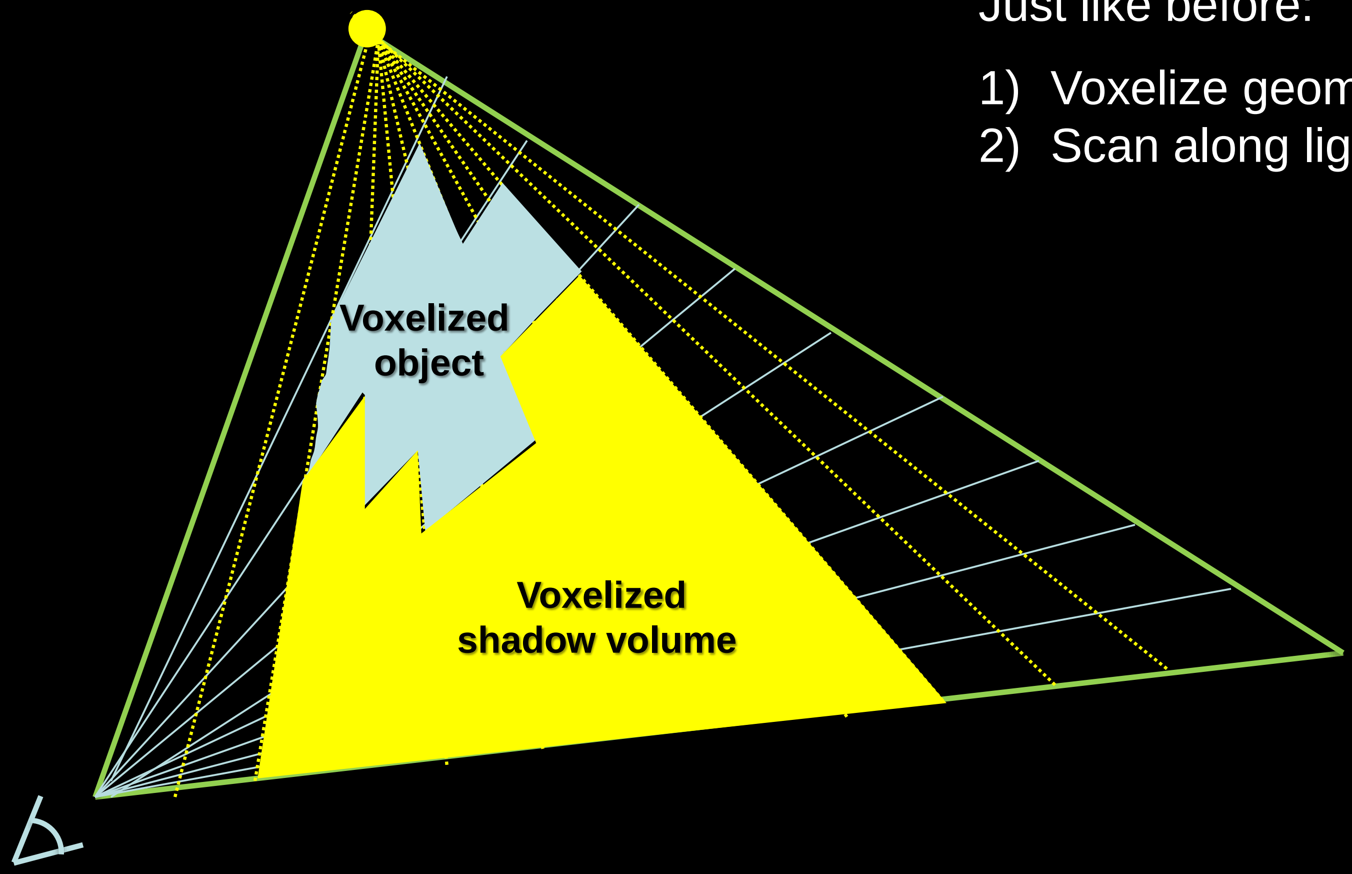
Creating VSVs



Just like before:

1) Voxelize geometry

Create VSVs



Just like before:

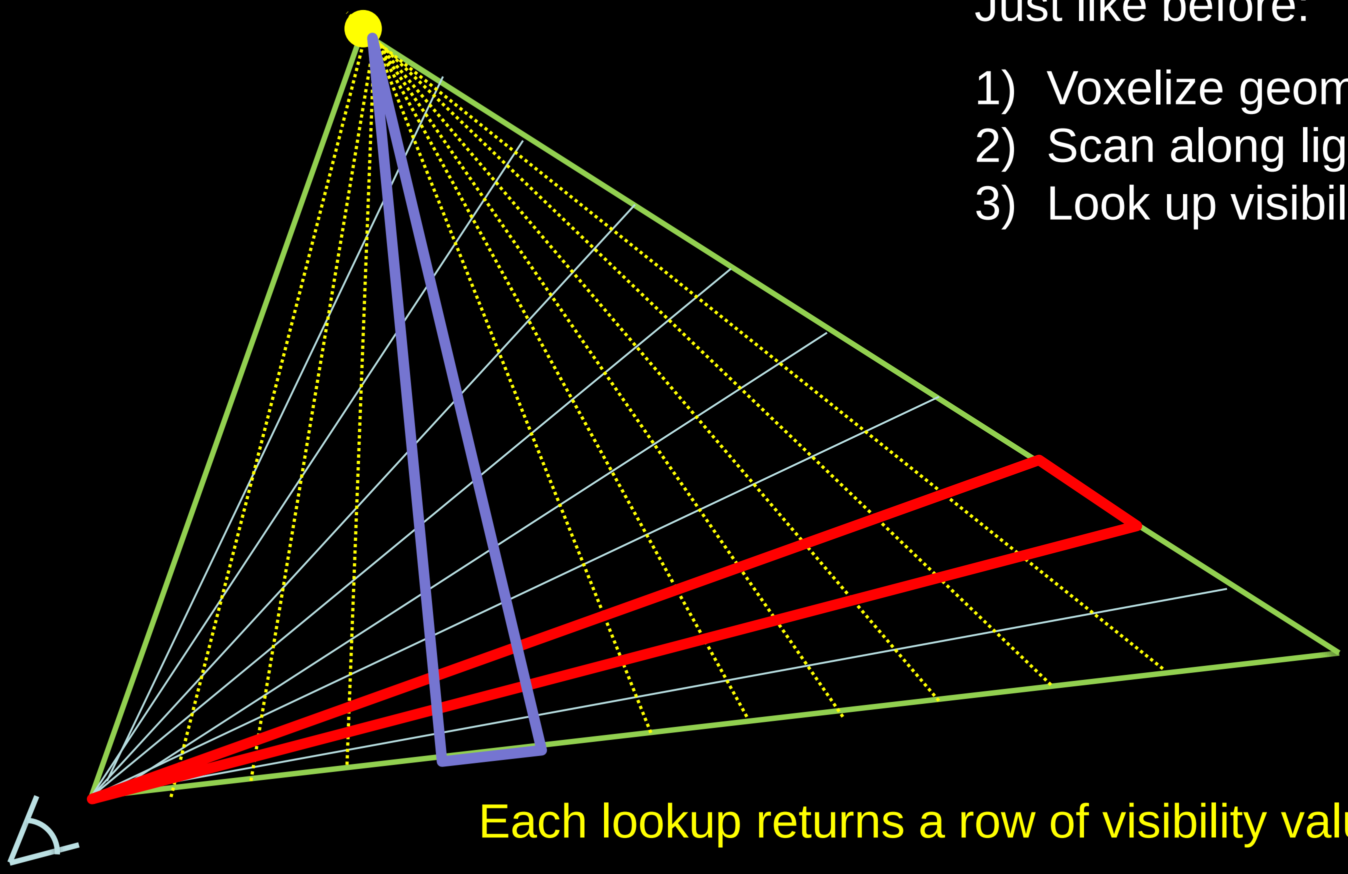
1) Voxelize geometry
2) Scan along light axis

THE UNIVERSITY OF IOWA

Using Voxel Shadow Volumes

Just like before:

1) Voxelize geometry
2) Scan along light axis
3) Look up visibility

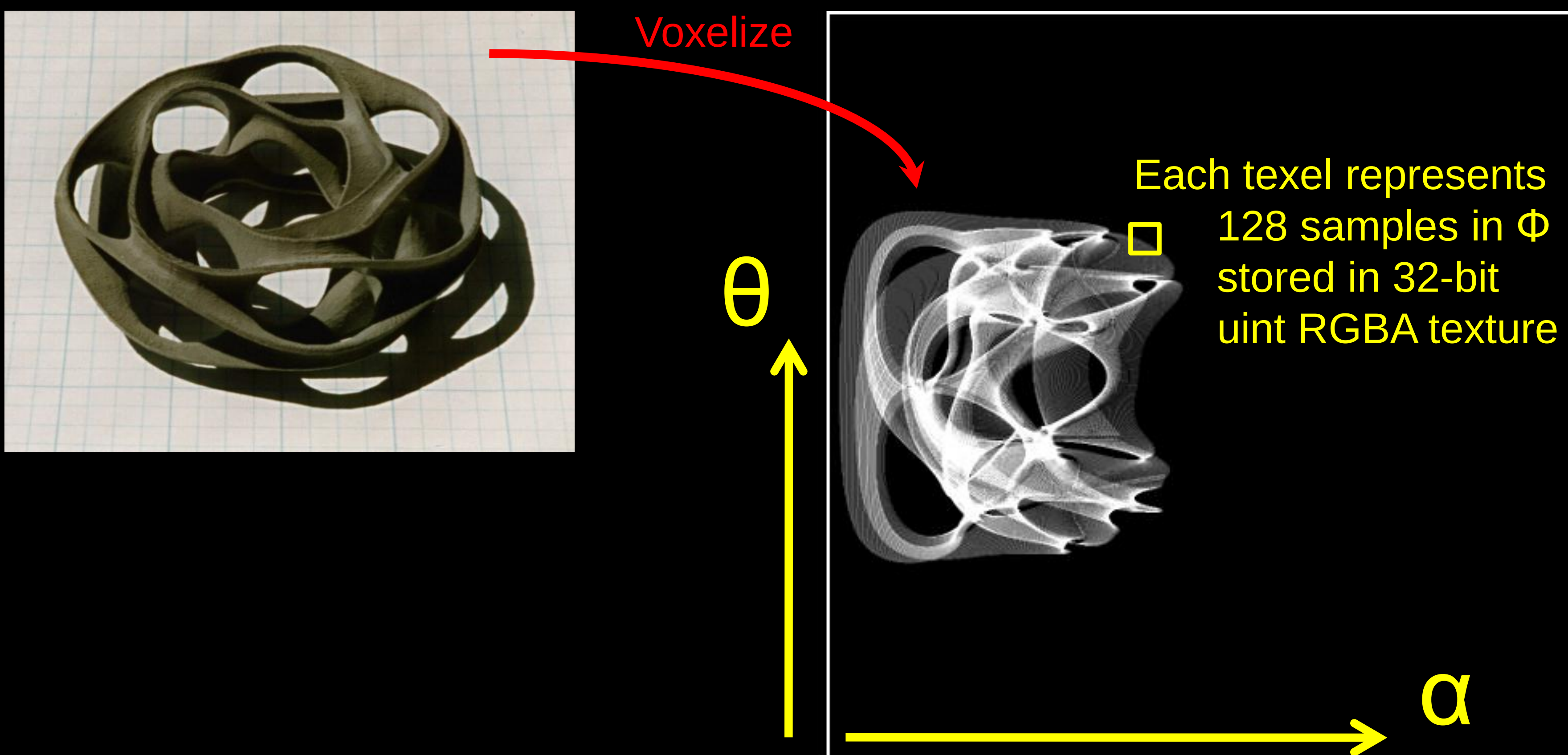


Each lookup returns a row of visibility values (red)

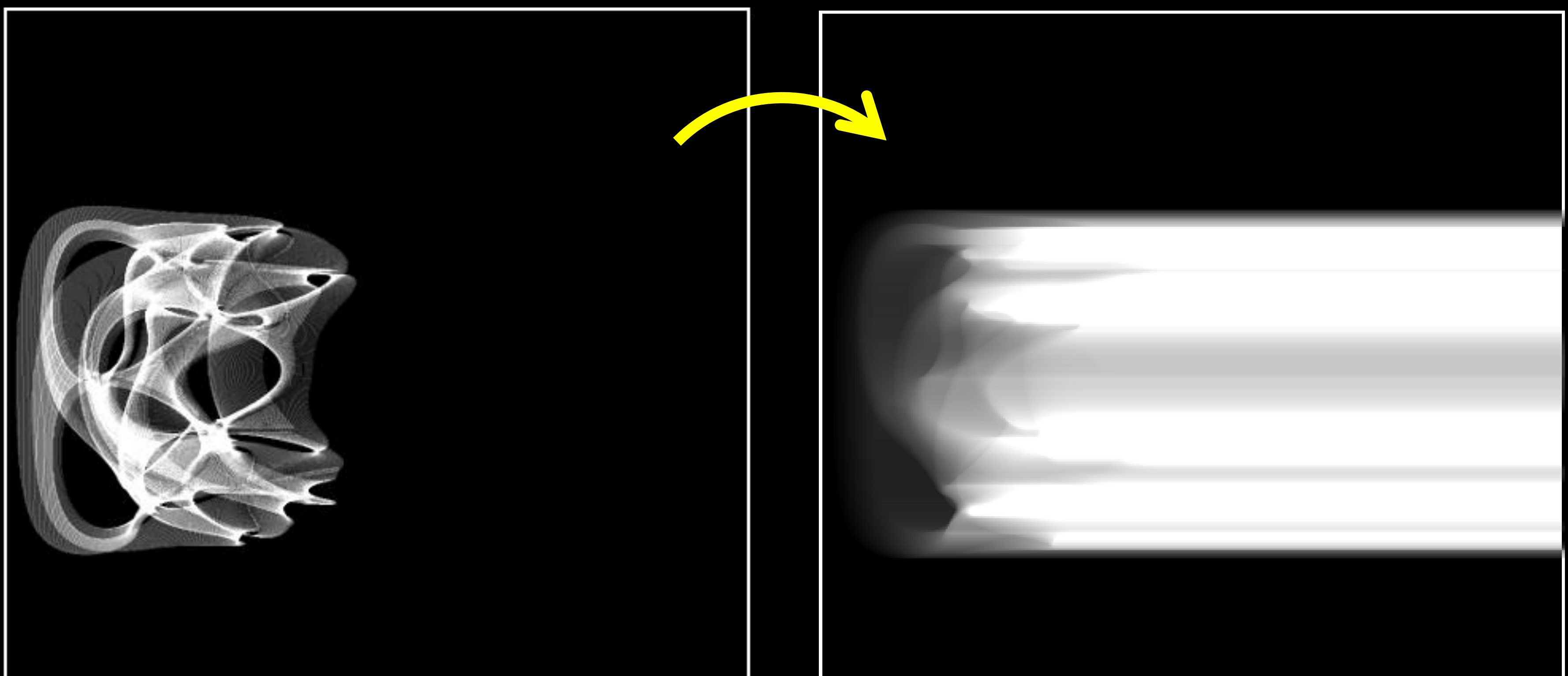
Each bit returned in lookup corresponds to visibility at one sample (blue) along view ray.

VSV Implementation

- Map epipolar space into a 2D GPU texture

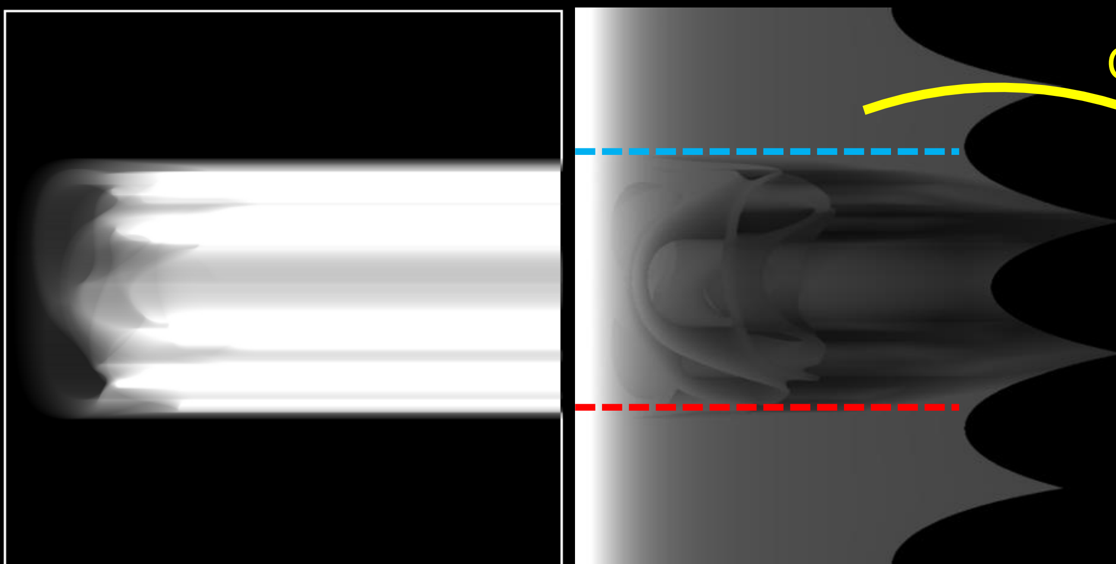


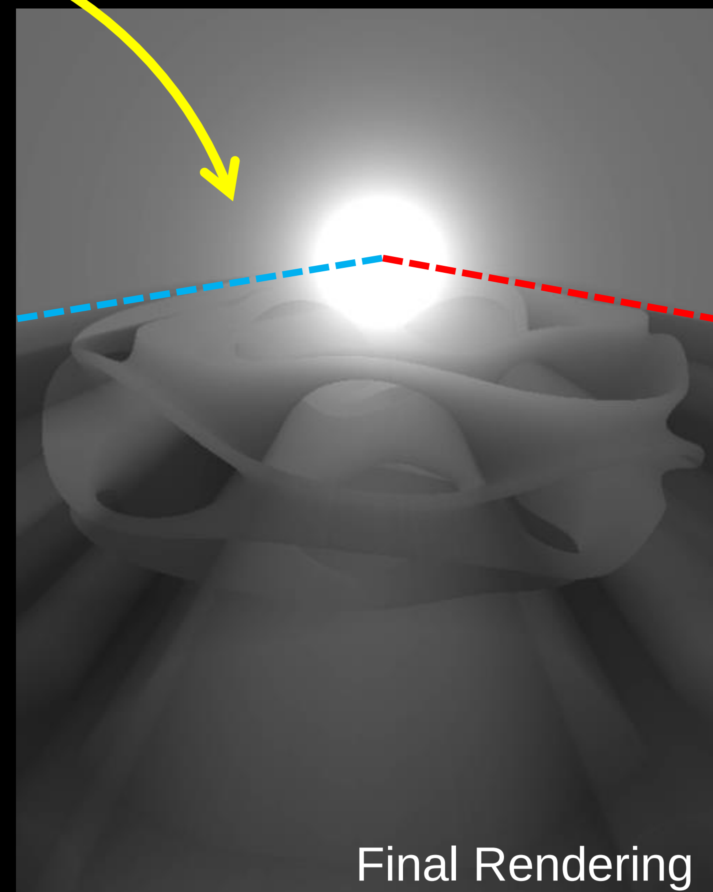
VSV Implementation



Perform a parallel scan (prefix sum) along the α axis using a bitwise OR, rather than a + operator, to create the VSV.

VSV Implementation





Lookup visibility at every pixel and use in desired application

(Note: We ***do not*** compute scattering in epipolar space. This computation is for clarity of explanation)

Tricky Details

- How to voxelize into epipolar space?
  - Paper proposes 3 approaches:
    - [Eisemann 06] screen space voxelization
      - Blazing fast, requires watertight models
      - Requires fixes to handle epipolar singularities
    - [Schwarz 10] conservative voxelization
      - Significantly slower, better quality for thin geometry
      - Requires fixes to handle epipolar singularities
    - Resampling shadow map to epipolar space
      - Similar to approach used by [Chan 11]
      - Blazing fast, naively handles all singularities.

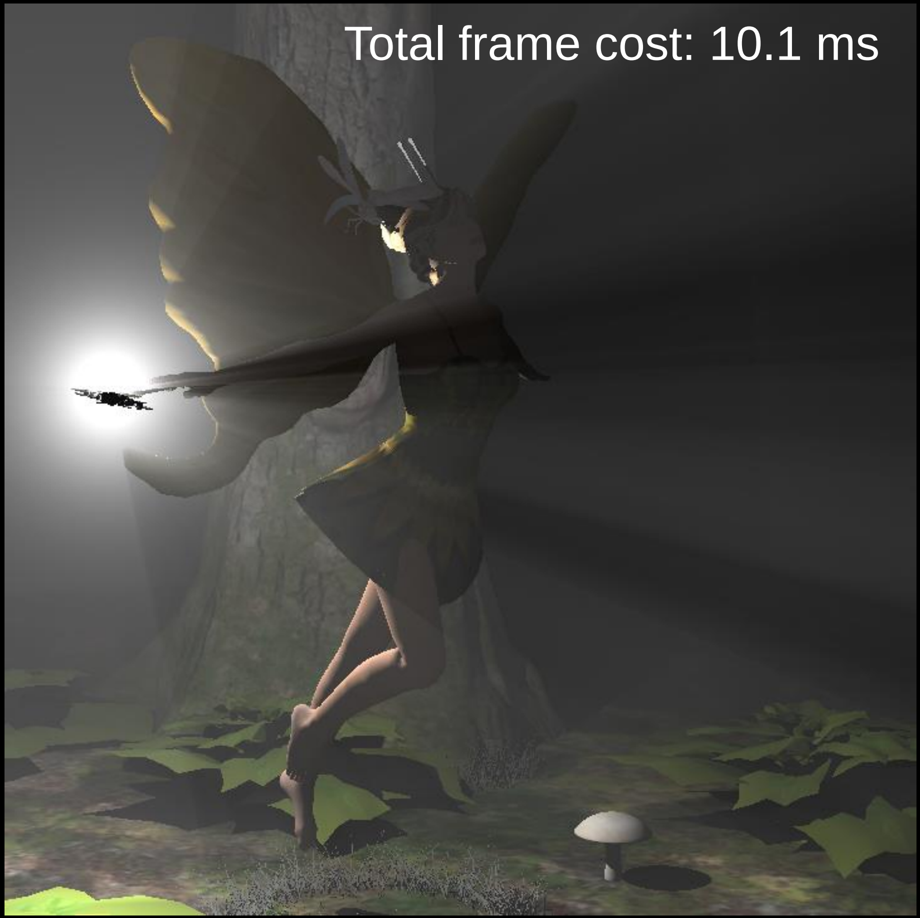
Tricky Details

- See paper for details on first 2 methods

- Voxelization via resampling:
  - For each (θ_i, Φ_j) in epipolar space
    - Create the light ray in direction (θ_i, Φ_j)
    - Locate the corresponding shadow map texel
    - Lookup nearest surface, compute its α_{ij} value
    - Set the bit at $(\theta_i, \Phi_j, \alpha_{ij})$

Results

(Reported on a GeForce 580 GTX, 512 x 2048 x 512 voxel volume)

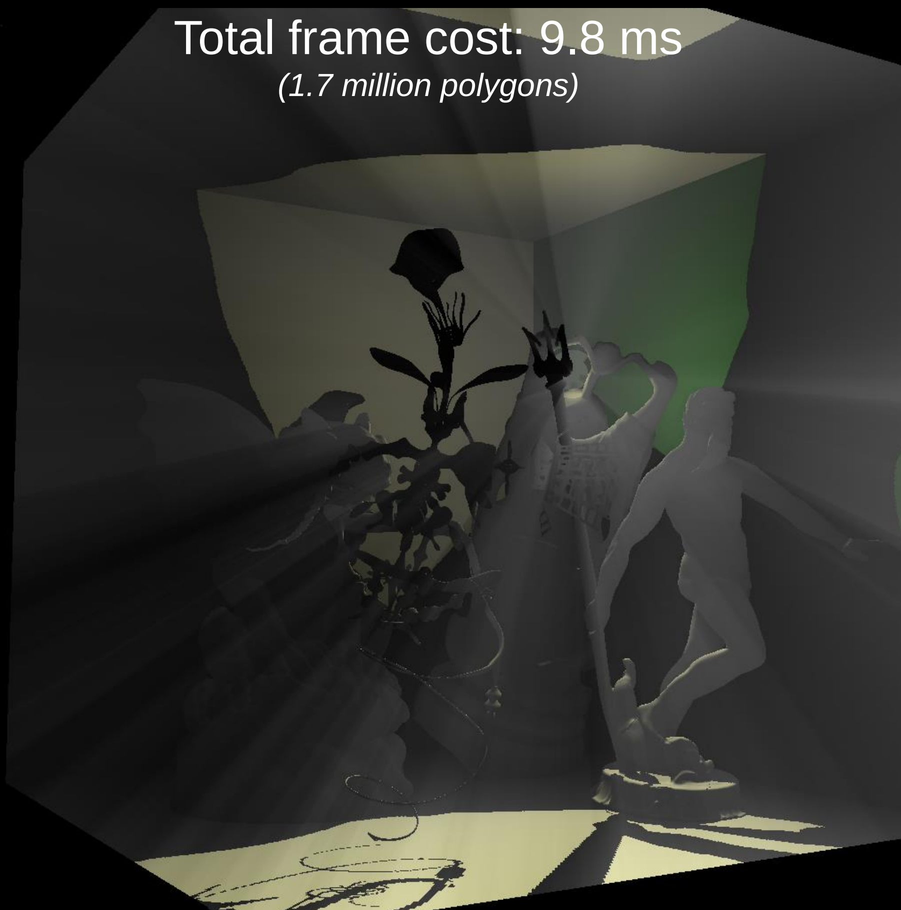


Shadow map: 0.8 ms
Voxelization: 3.1 ms Other rendering: 3.5 ms
Parallel scan: 2.7 ms

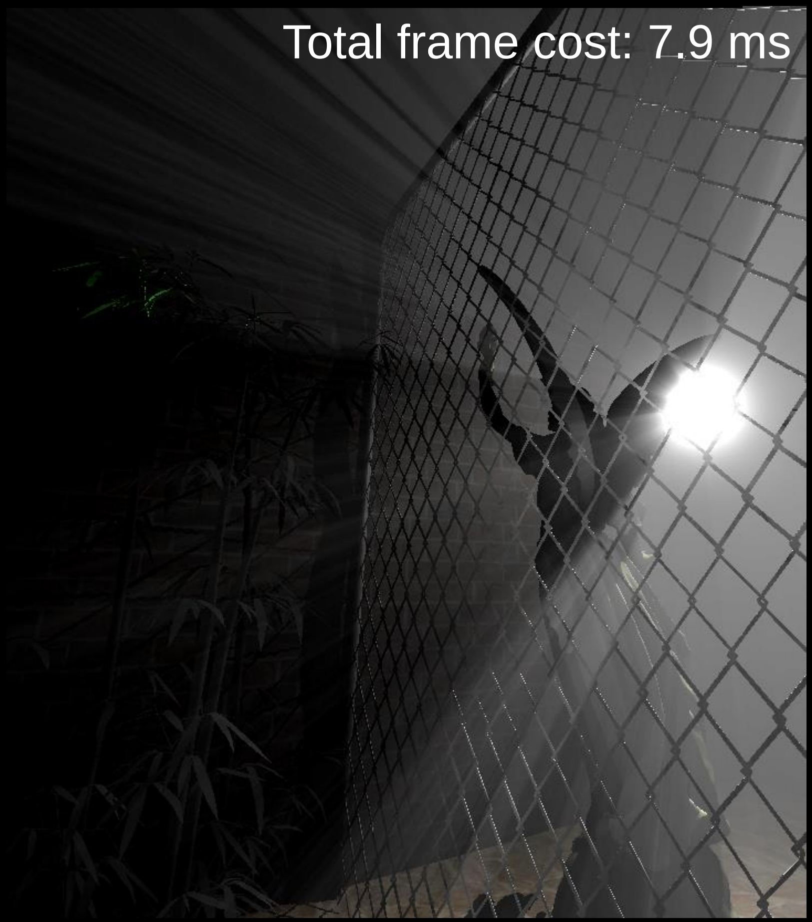
Shadow map: 0.3 ms
Voxelization: 1.4 ms Other rendering: 1.9 ms
Parallel scan: 2.7 ms

Results

(Reported on a GeForce 580 GTX, 512 x 2048 x 512 voxel volume)



Shadow map: 2.6 ms
Voxelization: 1.9 ms Other rendering: 2.6 ms
Parallel scan: 2.7 ms



Shadow map: 1.1 ms
Voxelization: 2.0 ms Other rendering: 2.1 ms
Parallel scan: 2.7 ms

Video / Demo

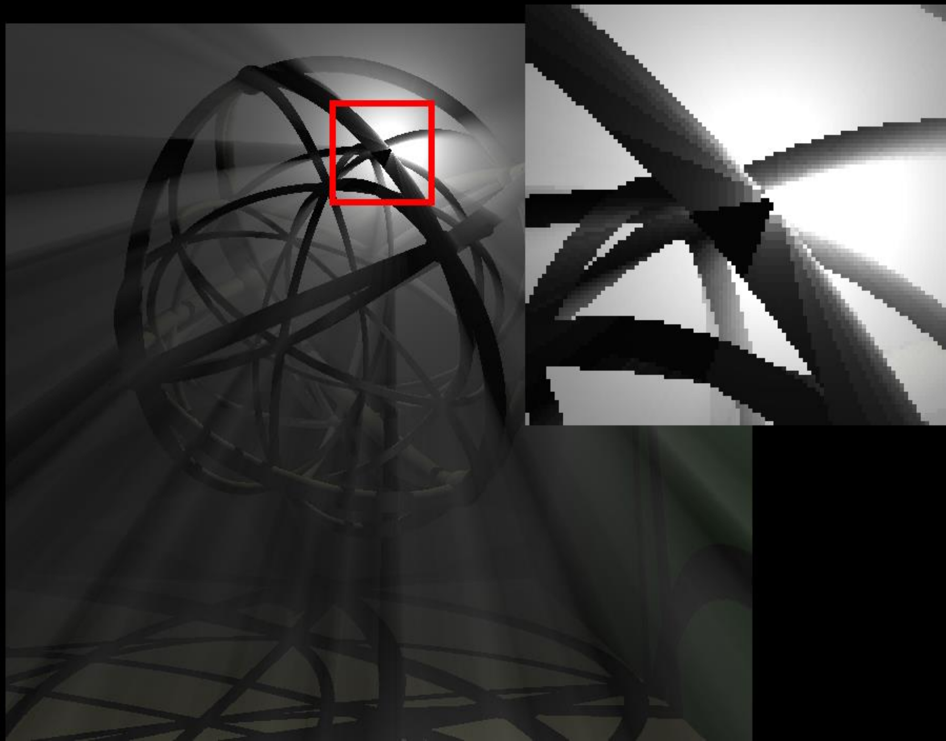
Aliasing Issues

- Aliasing occurs, as with all sampling
  - Can focus on important samples
    - Paper talks about selecting good α, Φ, and θ ranges
  - Can do adaptive sampling
    - Paper explores briefly, but more work needed
  - Can brute force by adding more samples
    - Our performance → 512 x 2048 x 512 volumes
    - Parallel scan decreases roughly linearly in size
  - Filtering in epipolar space
    - Perhaps similar to PCF, needs more exploration.

THE UNIVERSITY OF IOWA

Aliasing Issues

- Our worst aliasing occurs @ singularity
  - Geometry seen occluding light
  - Geometry seen behind light (less problematic)



Summary

- Proposed *voxelized shadow volumes* for visibility queries
  - Voxelize using a new epipolar space parameterization
  - Prefix sum along light rays in epipolar space
  - Gives a discrete sampling of shadow volumes
  - Lookup 128 binary visibility samples with single texture lookup

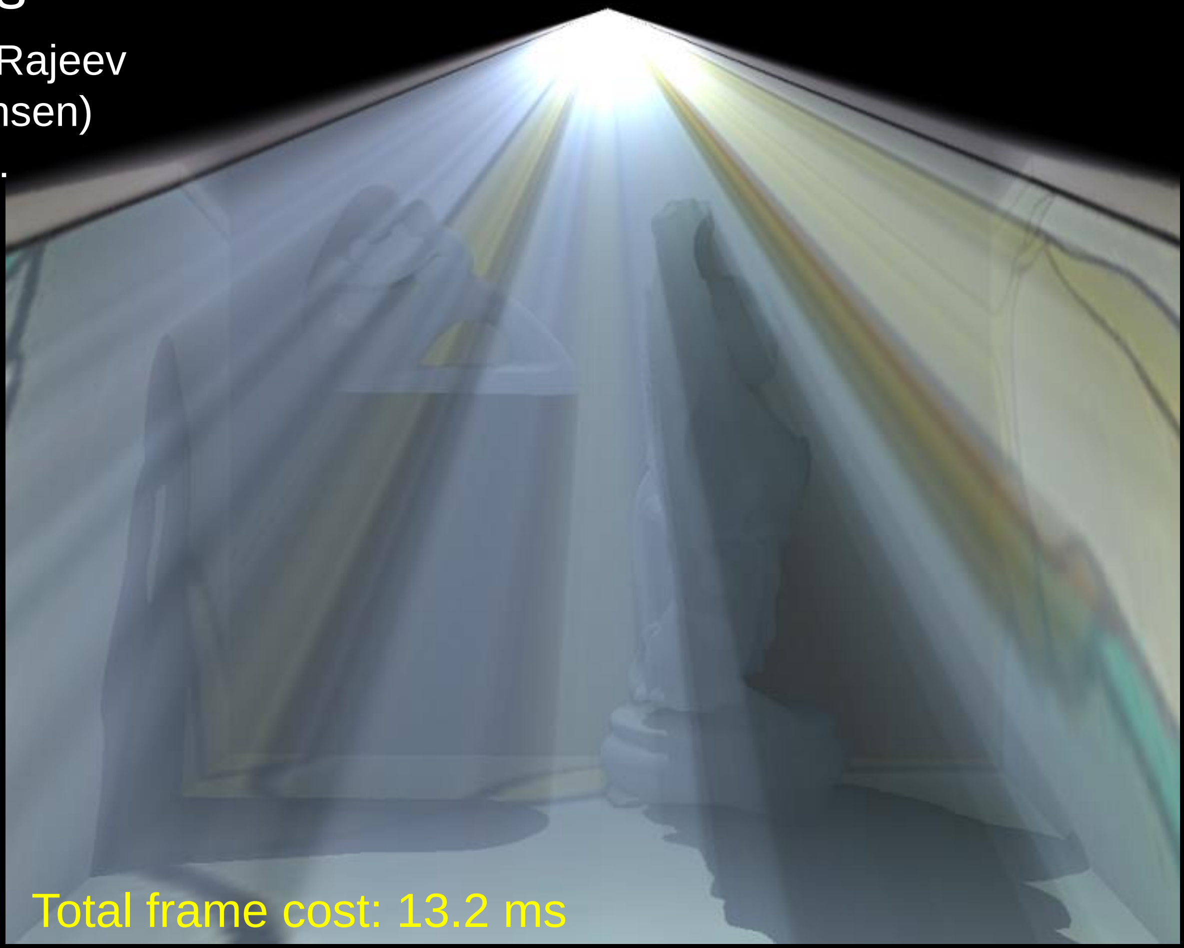
- Advantages
  - Decouples geometric complexity & visibility cost
  - Cache coherent lookups
  - Drop into existing participating media techniques for visibility

- Disadvantages
  - Some aliasing near singularity
  - Some care in implementation details for robustness (see paper)

Acknowledgements

- People who have listened to this idea in progress
  - My students (Greg Nichols, Rajeev Penmatsa, and Thomas Hansen) and too many others to list…
- Funding sources:
  - DARPA: HR001-09-1-0027
  - ARO: W911NF-10-1-0338
- Hardware donations:
  - NVIDIA Corporation

The University of Iowa



Comparison To Ground Truth