Fast Local Approximation to Global Illumination

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Outline

- Motivation
- My Research
  - Shadows
  - Caustics
  - Diffuse Interreflections in Volumes
- Conclusions and Future Directions

Real World Illumination

Light bounces around a lot in the real world



Computer Graphics Lighting

- Able to achieve realistic images slowly
- Intuitively:
  - Photons work in parallel
  - CPU must work serially



Traditional techniques: Slow
(Cohen et al., Siggraph 87)

Interactive Computer Graphics

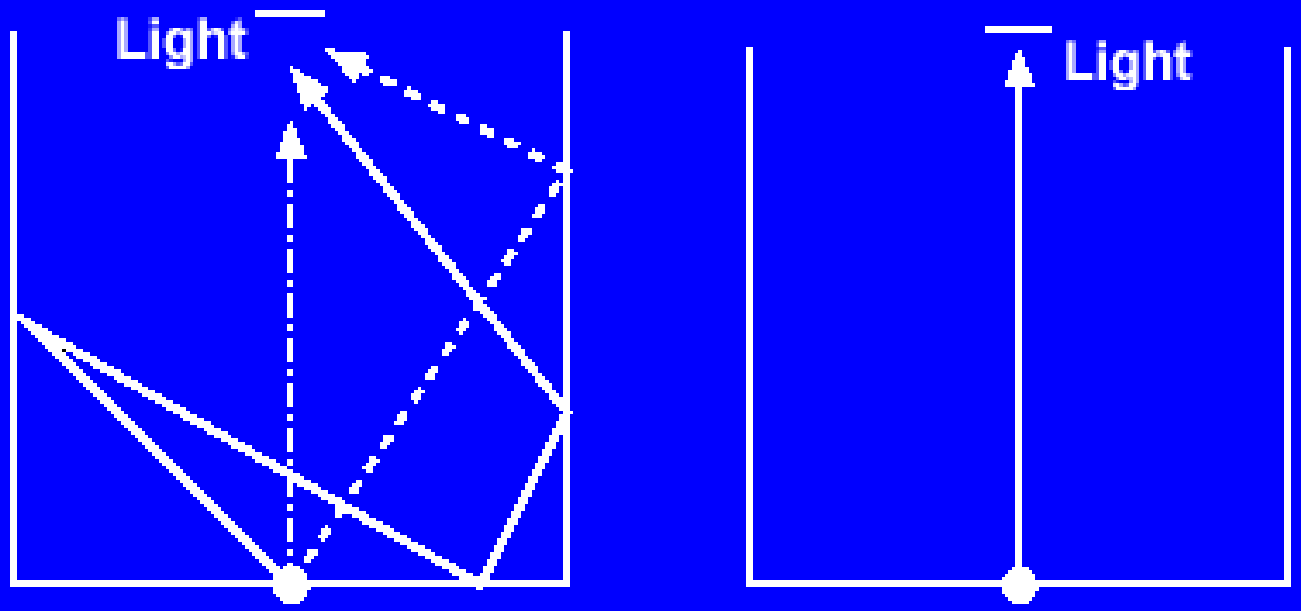
- Simplifications necessary for speed
- Interactive graphics
  - Definitions fall between 10 and 60 fps
  - Usually relies on specialized hardware



Goal: Full GI at 60+ fps

What is Global Illumination?

- Illumination at every point depends on illumination at every other point
  - "Global" information vs. "local" information



Missing in Local Models

- Visibility information
  - For shadows, reflections, color bleeding
- Integration
  - Area lights
  - Caustics
  - Light transport equations from physics:

$$L_{out}(x, \vec{\omega}) = L_{emit}(x, \vec{\omega}) + \int_{\Omega} \rho(x, \vec{\omega}, \vec{\omega}') L_{in}(x, \vec{\omega}')(\vec{\omega}' \cdot \vec{n}) d\vec{\omega}'$$

Complex Shadows

- Lights often complex, with finite area







Complex Lighting



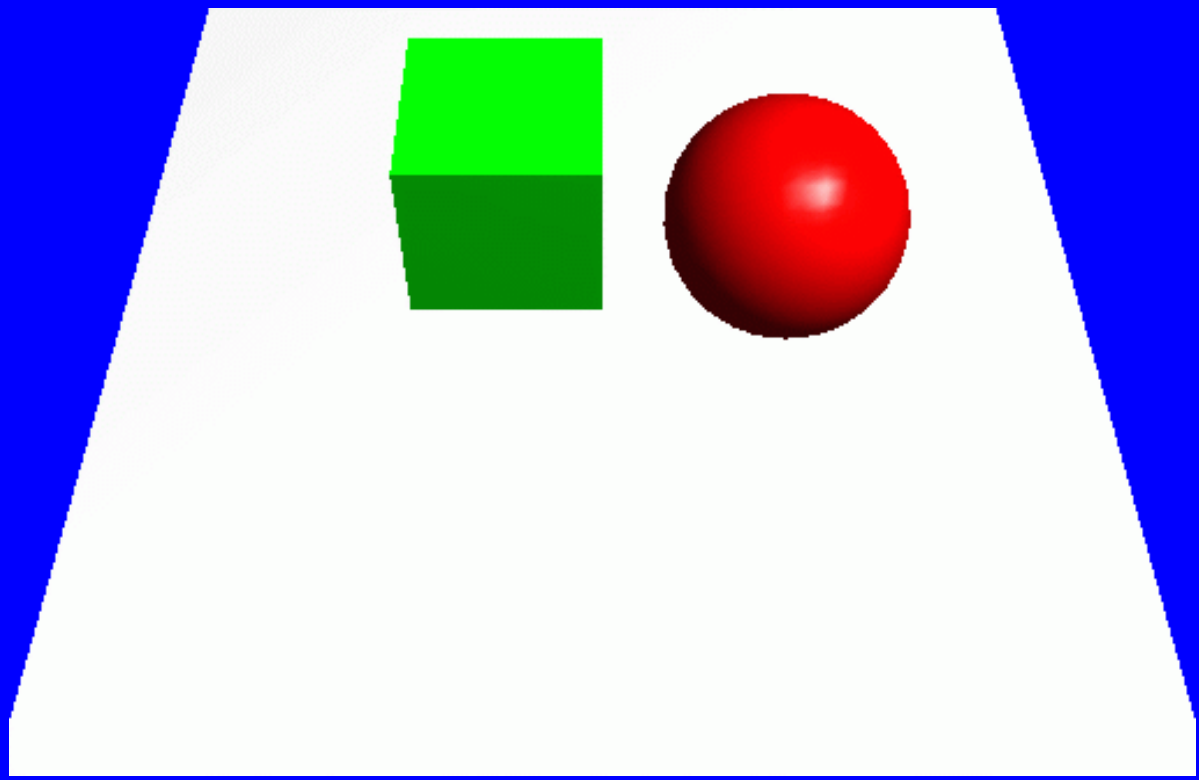






Importance of Global Info

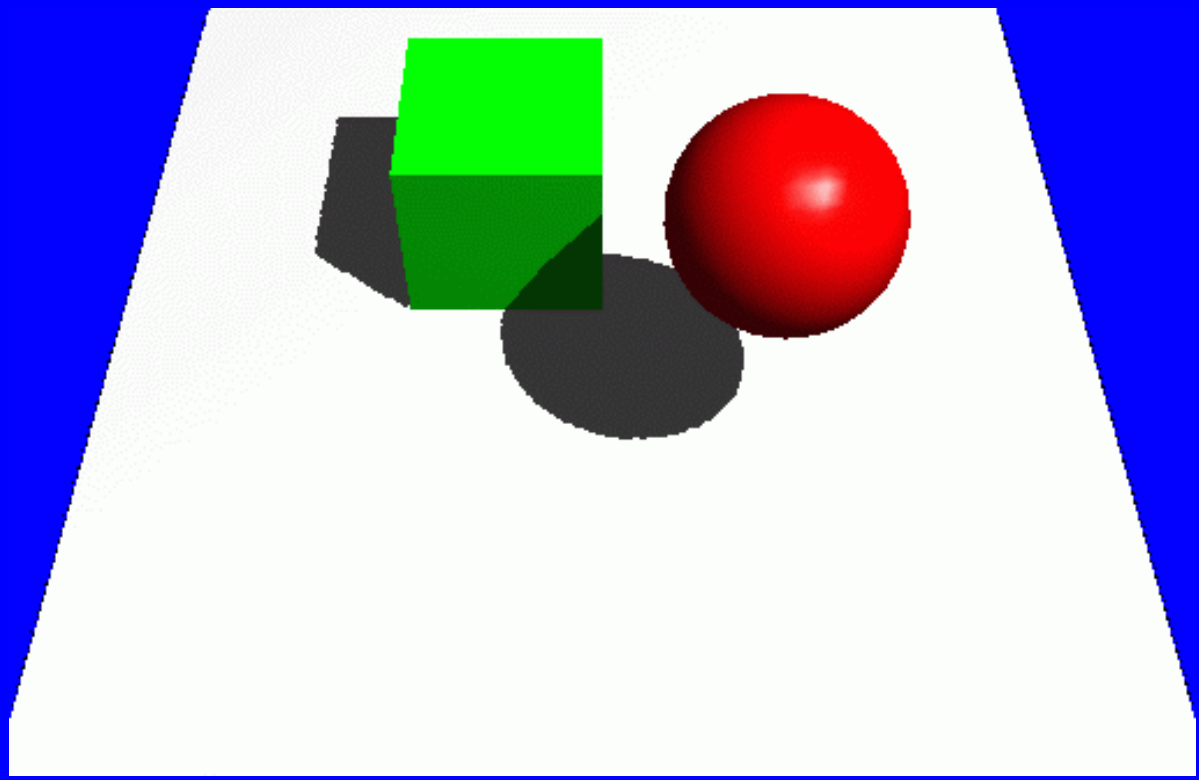
- Spatial relationship between objects



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Univ of Waterloo

Importance of Global Info

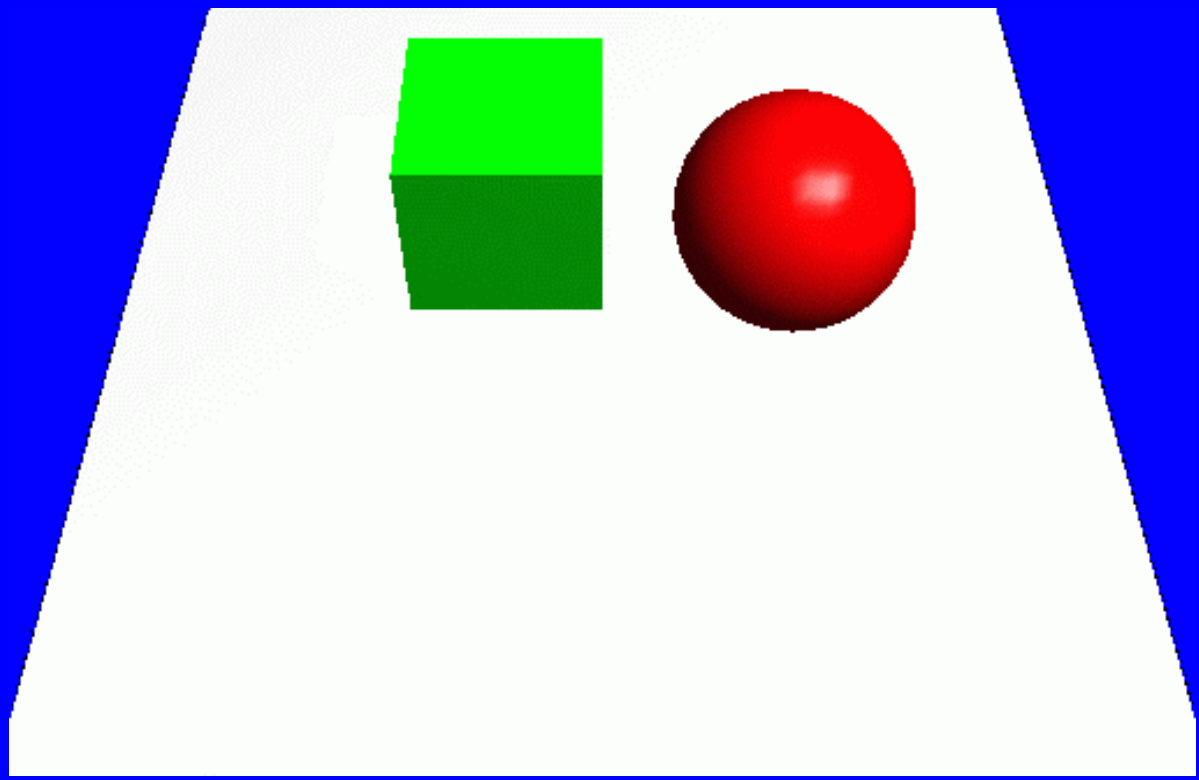
- Spatial relationship between objects



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Importance of Global Info

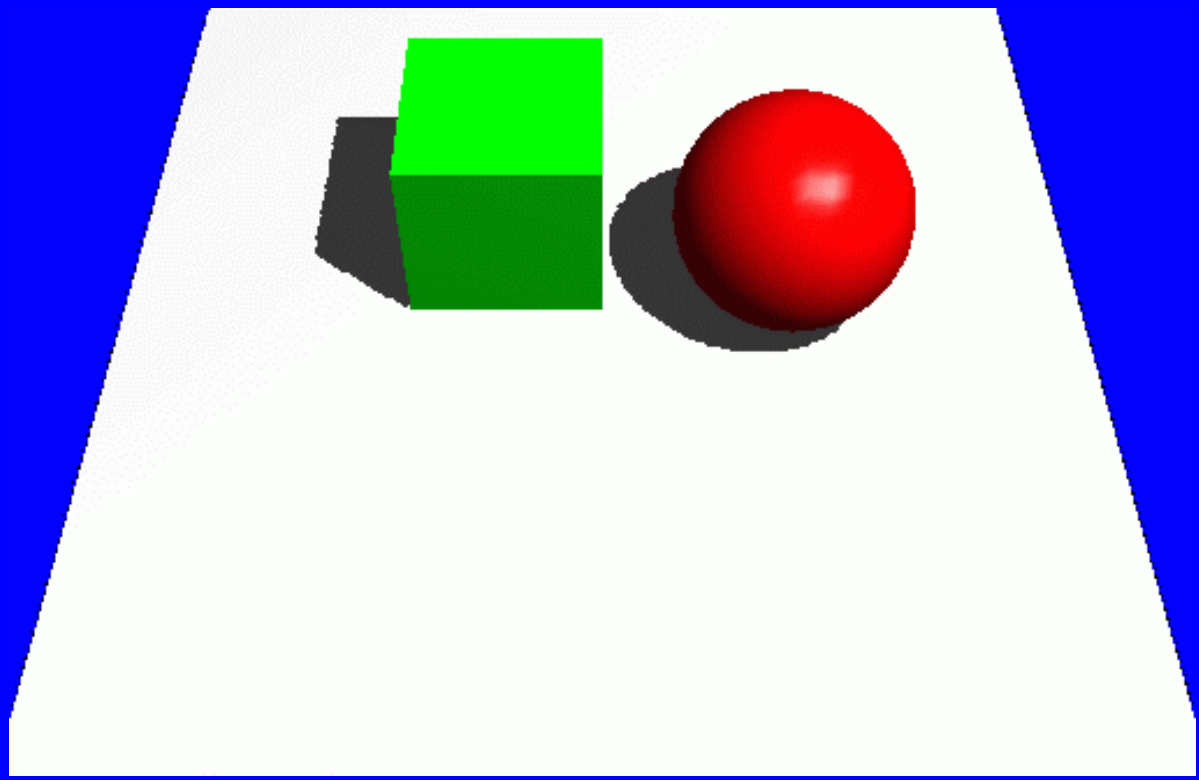
- Spatial relationship between objects



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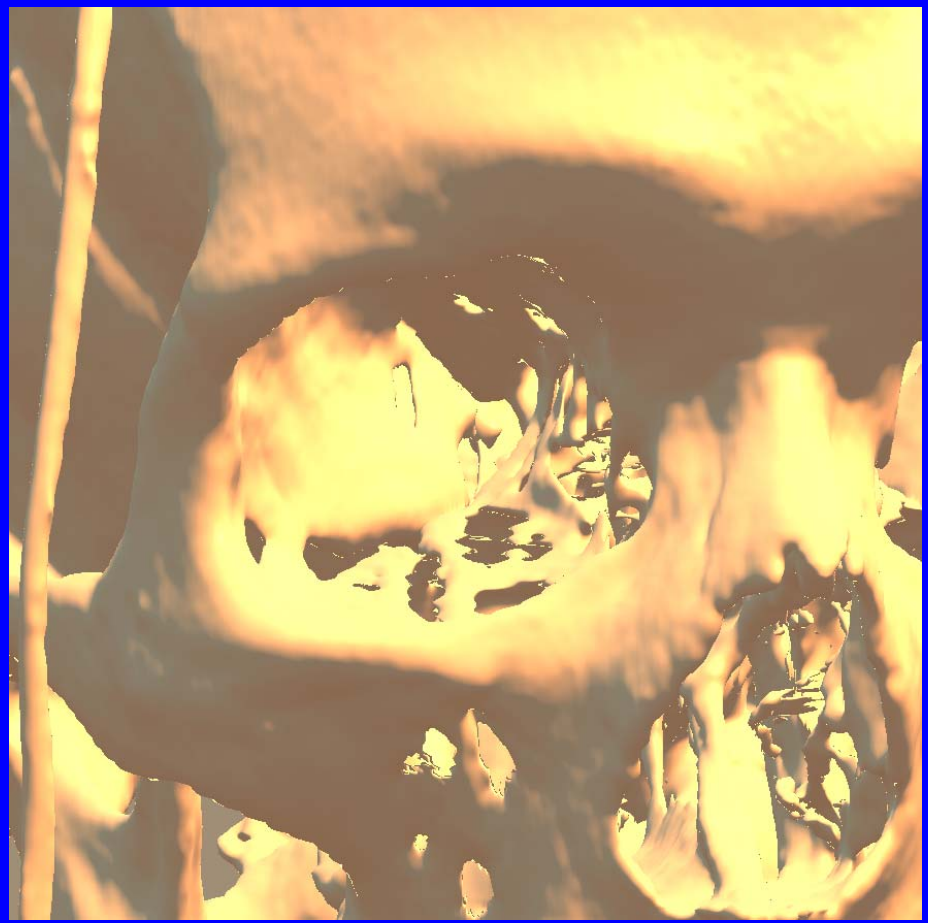
Importance of Global Info

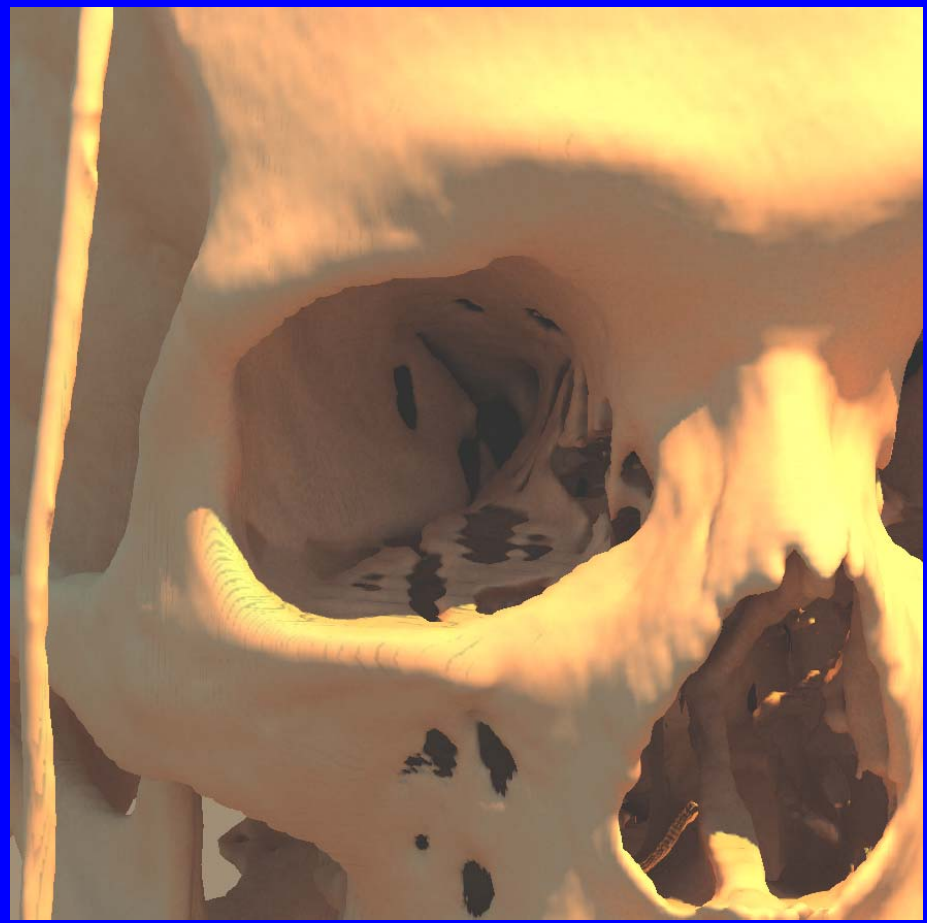
- Spatial relationship between objects



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Importance of Global Info





Approaches to Interactivity

- Graphics hardware (GPU) based
  - Specialized for graphics, but local models
  - Stream processor
  - Performance increasing faster than CPUs
- CPU based
  - General purpose processor
  - More flexibility

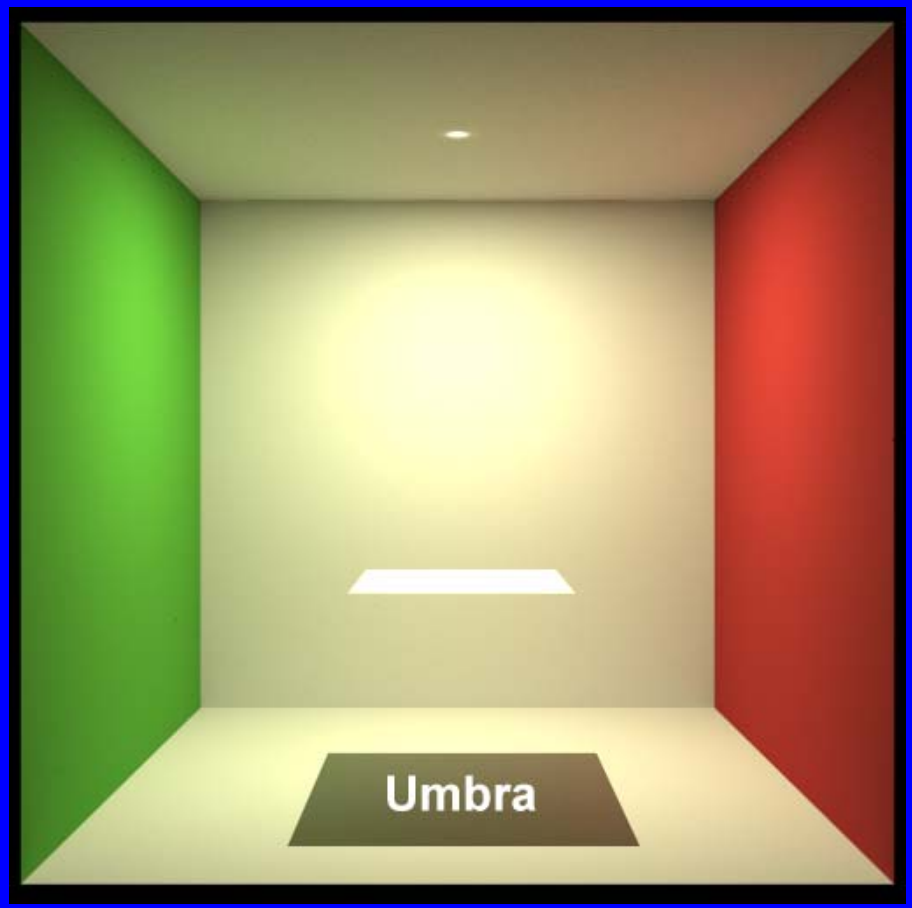
My Approach

- Approximate global illumination locally
  - Precompute and cache data
  - Can separate effects to render as needed
  - Requires simplifications
  - Better than local illumination
- Utilize resources as appropriate
  - Balance between CPU and GPU

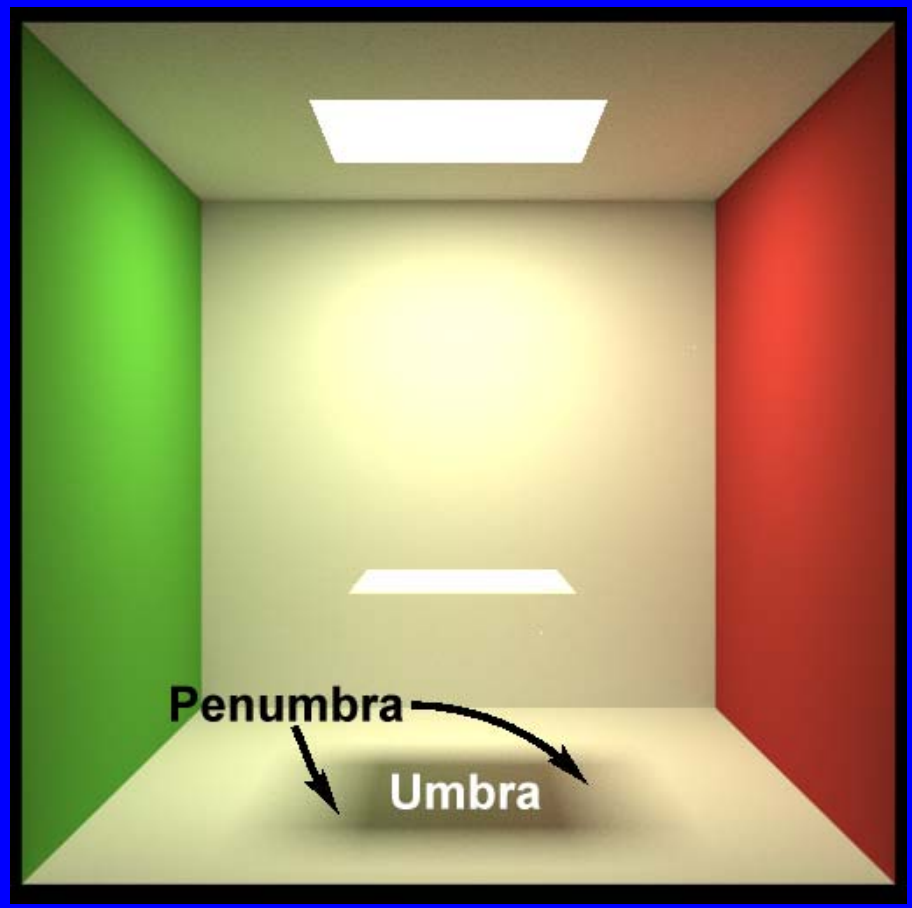
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Anatomy of a Soft Shadow



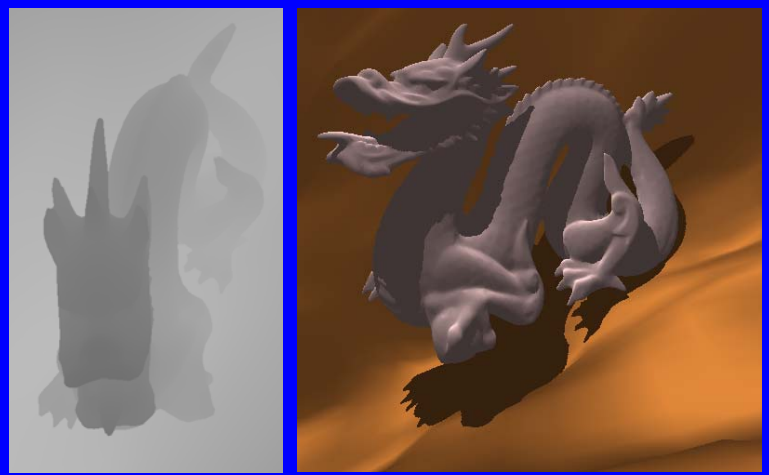
Hard Shadow

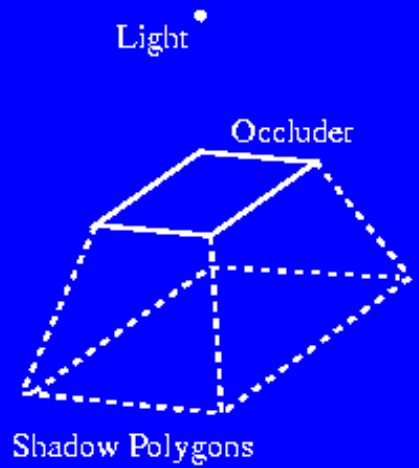


Soft Shadow

Interactive Hard Shadows

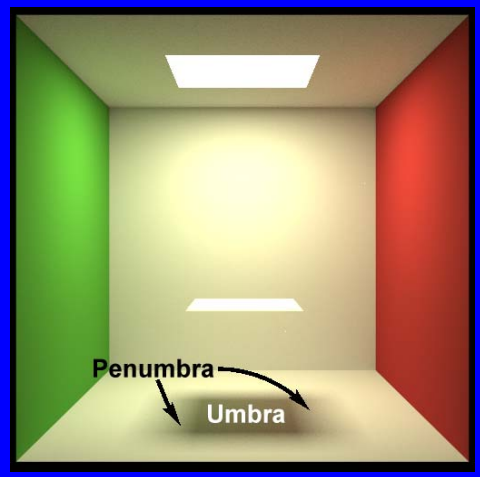
- Two common approaches:
  - Image based technique
  - Object based technique





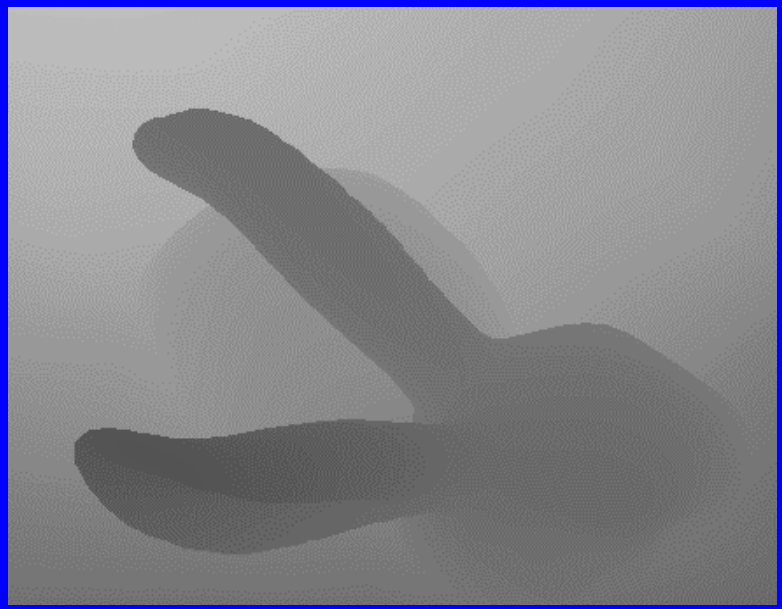
Approach to Shadows



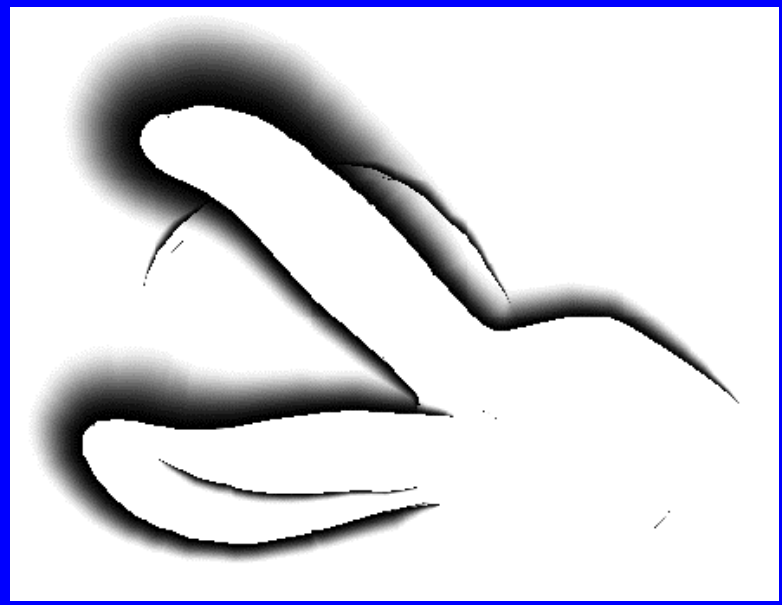


- Assume:
  - Approximate shadow umbra with hard shadow
  - Object silhouettes remain constant over light surface

Key Insight



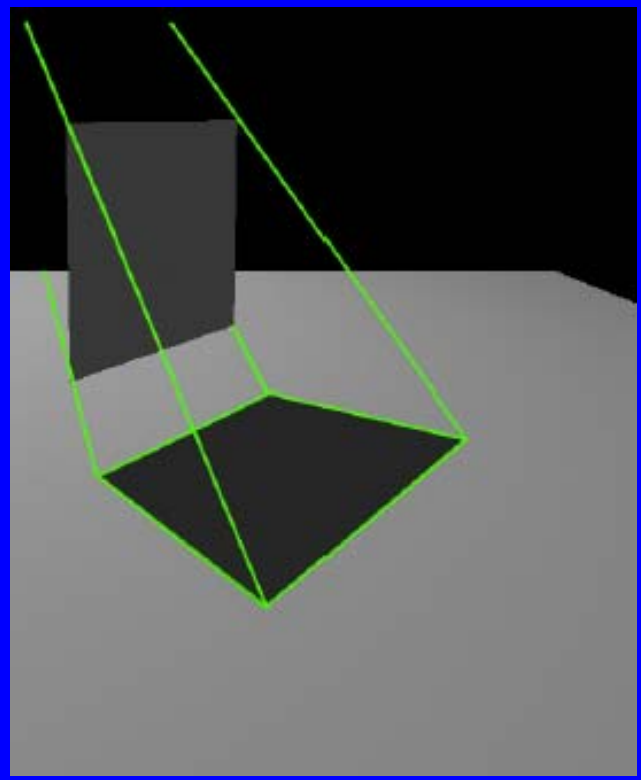
Shadow map stores depth information from light



Penumbra map stores penumbra intensity for regions outside hard shadow

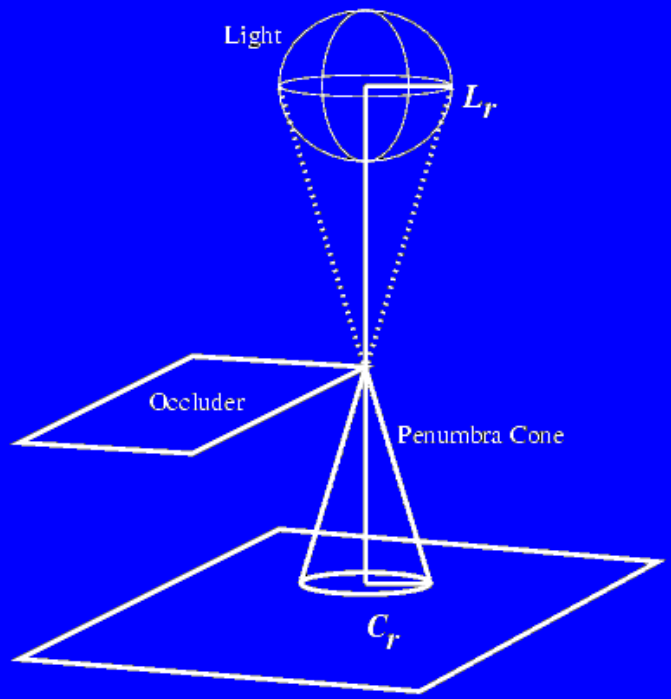
Creating the Penumbra Map

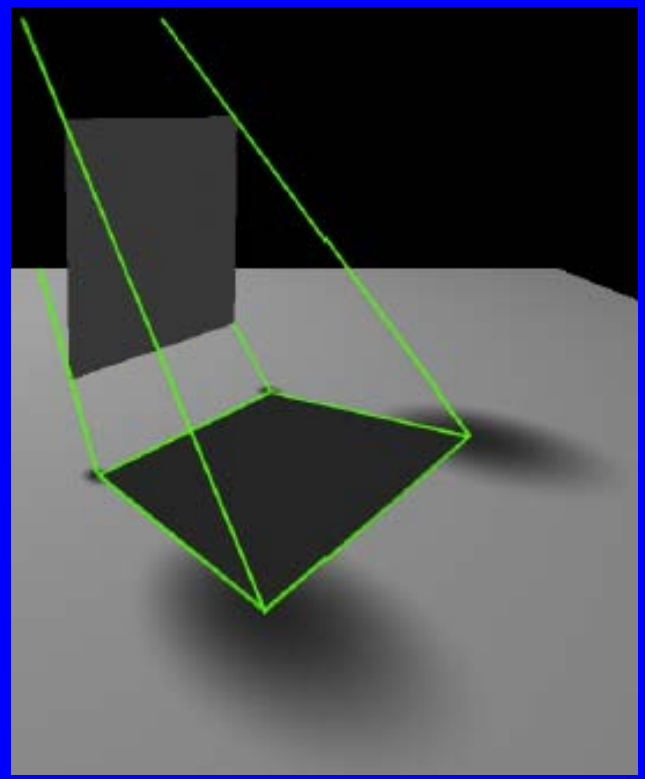
- Compute hard shadow
- Find silhouettes from light's center



Creating the Penumbra Map

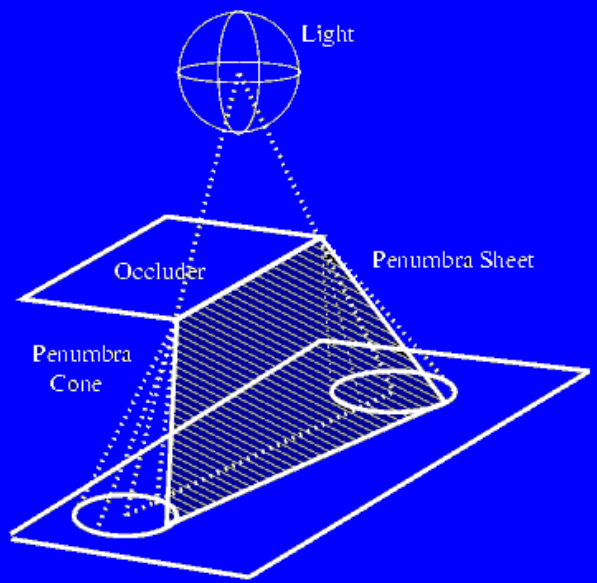
- Compute cones at silhouette vertices

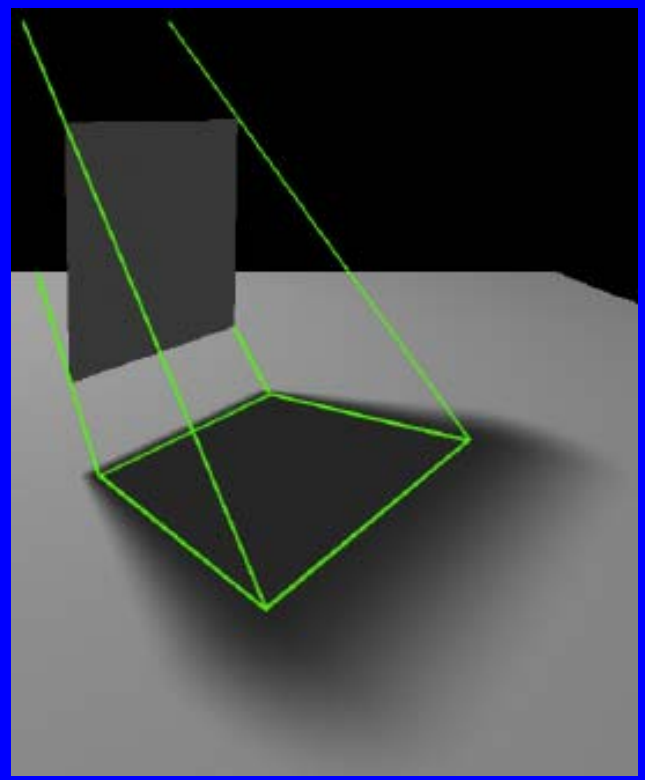




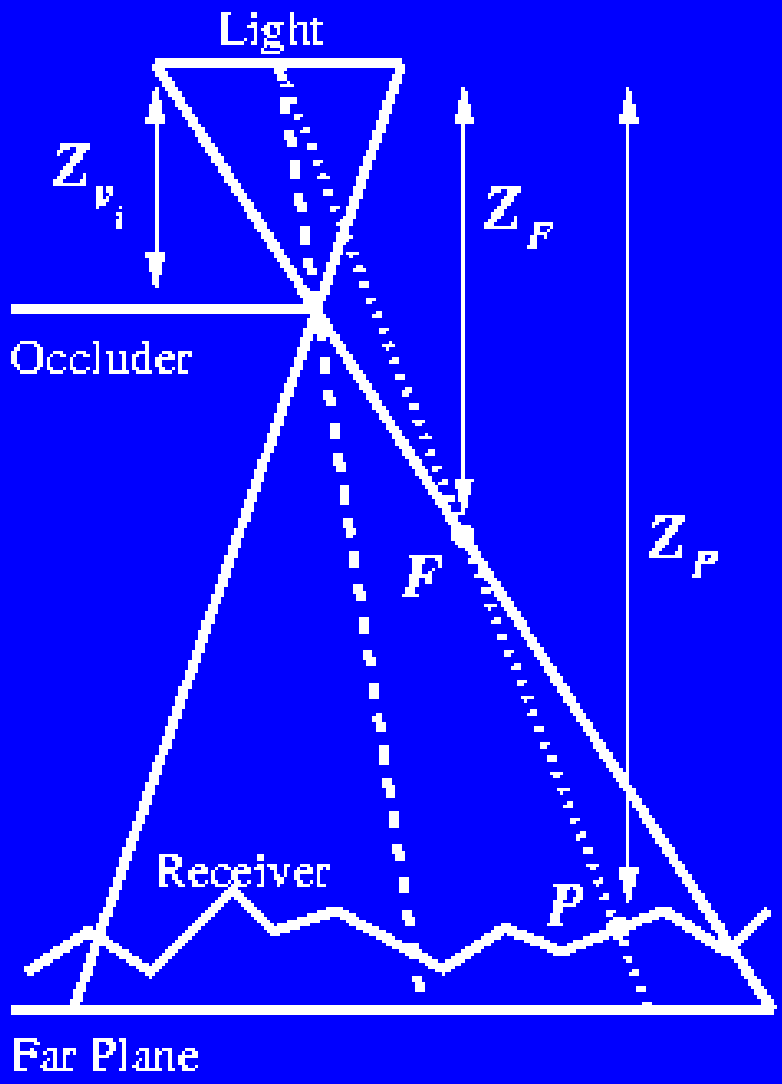
Creating the Penumbra Map

- Connect cones with sheets at silhouette edges





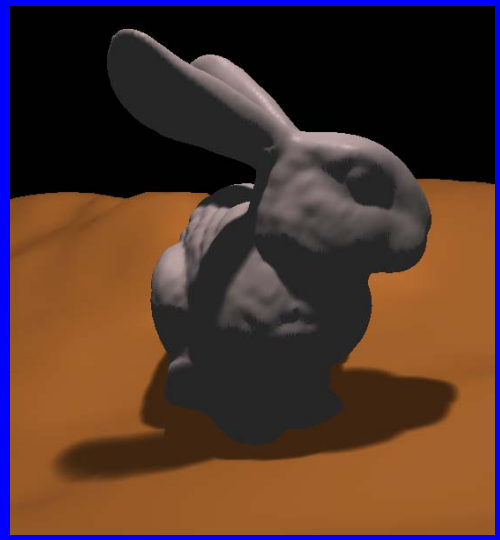
Why This Works



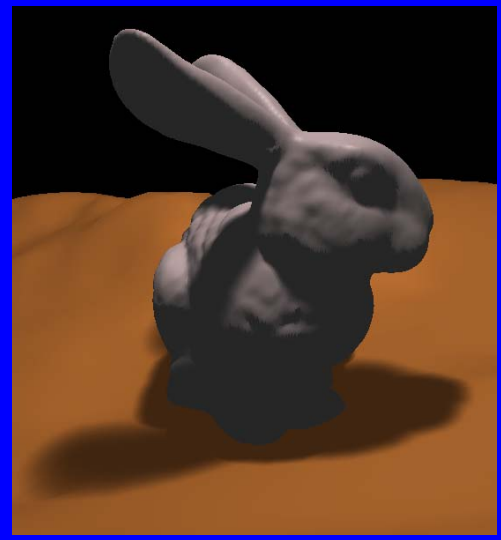
Results (Shadows)



Hard shadow



Soft shadow



Larger light

- Runs interactively (~18 frames per second)
- Simplify model for shadows

Results (Shadows)



Shadow Map



Hard shadows



Soft Shadows



Penumbra Map

Runs at ~15 frames per second

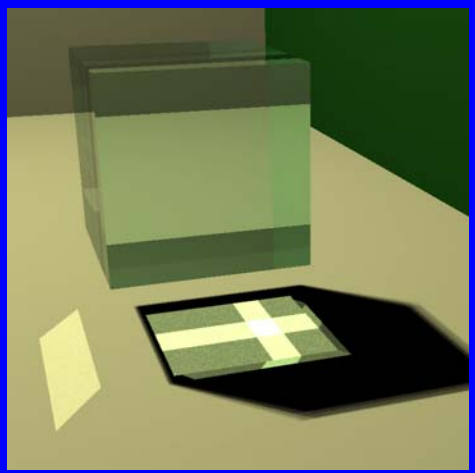
Demo

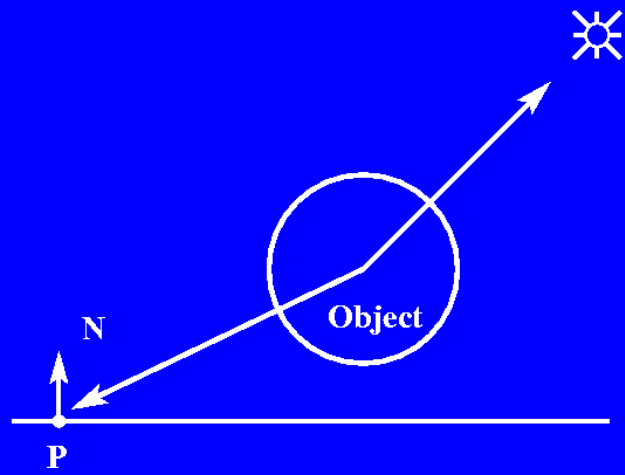
Outline

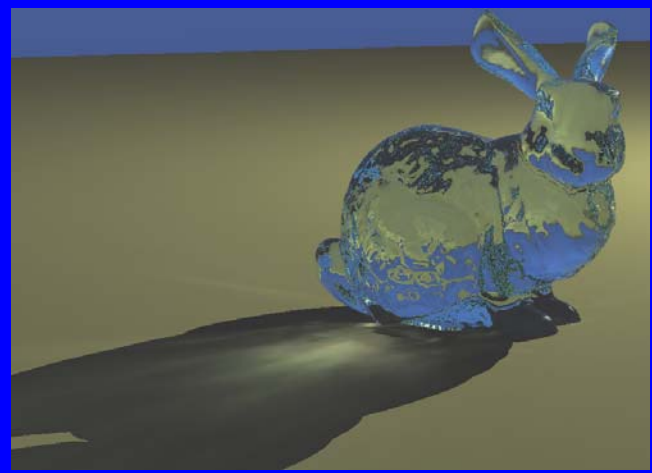
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  - ***Caustics***
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Caustic Behavior

- Light focused off specular objects
- Eight dimensional function
- Approximation acceptable





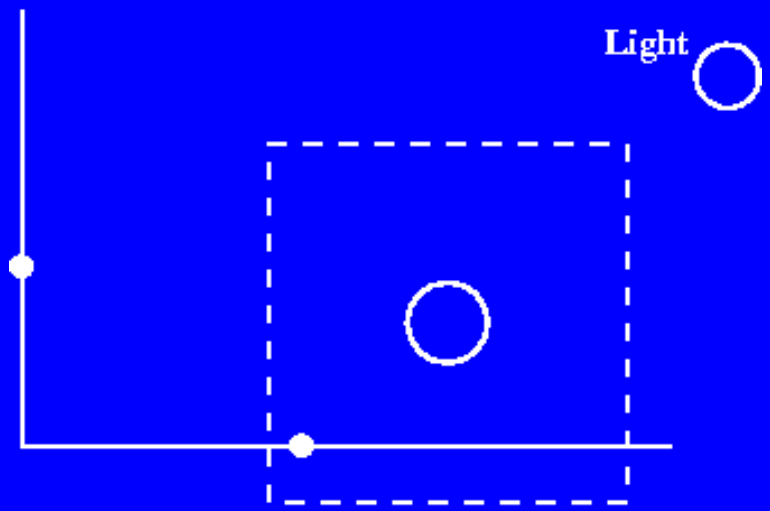


Observations About Caustics

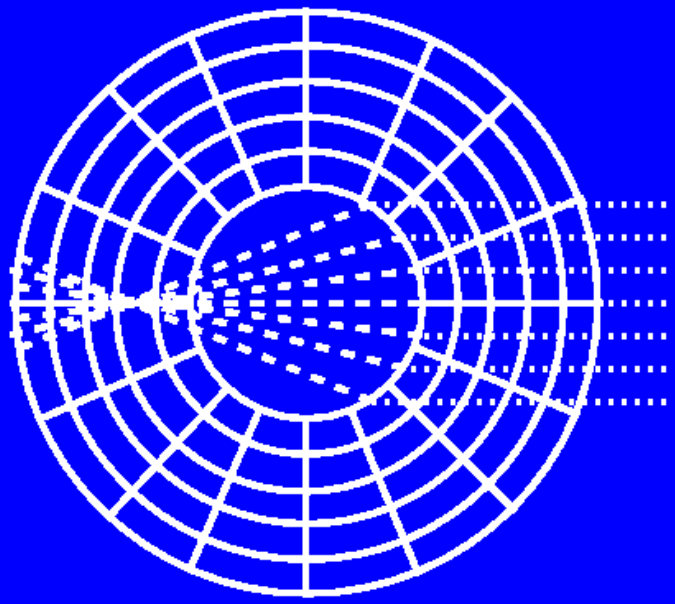
- Light direction more important than distance
- Light far away similar to directional light
- Caustics associated with objects

Assumptions

- Directional light, not point light
- Sample caustic in finite region
- Compute caustic for one orientation N_p



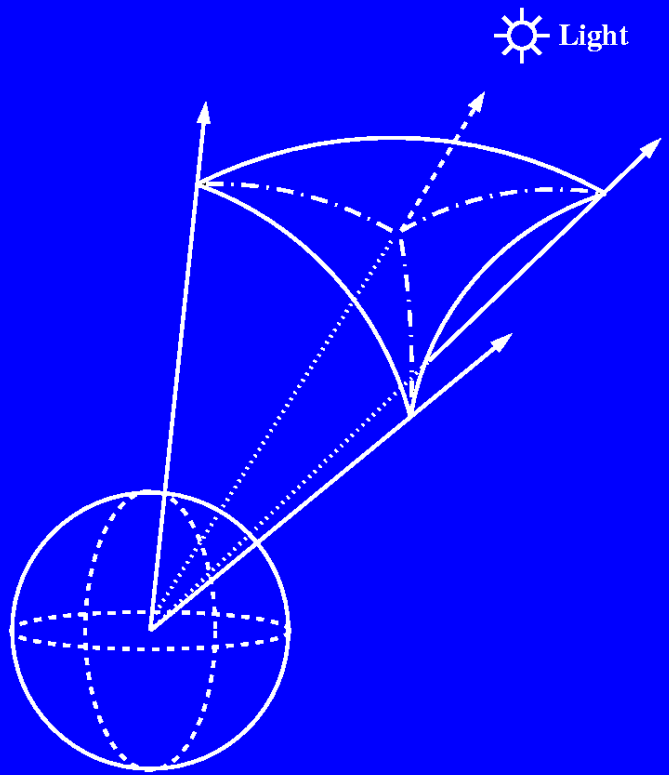
Sampling

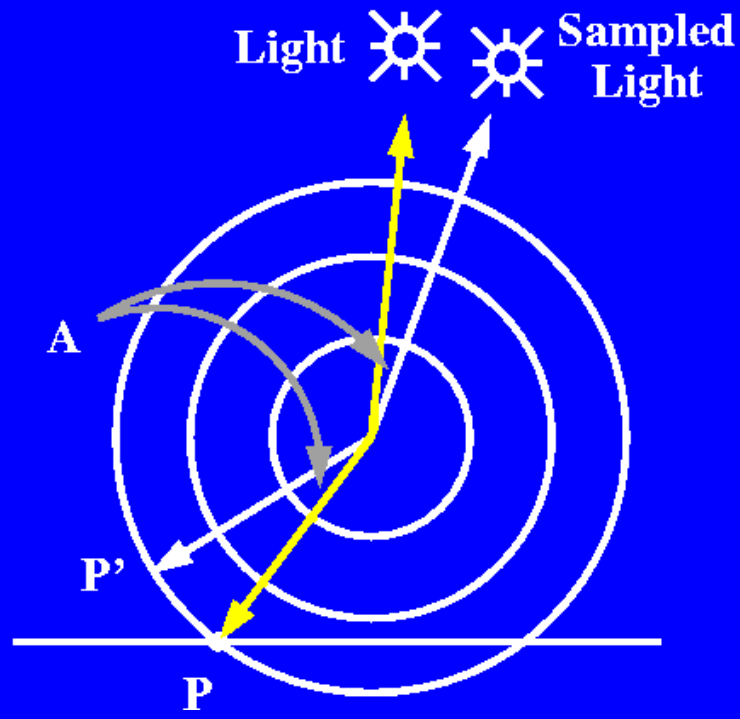


- Examined methods for best sampling
- Examined multi-res and compression schemes for lowering memory usage

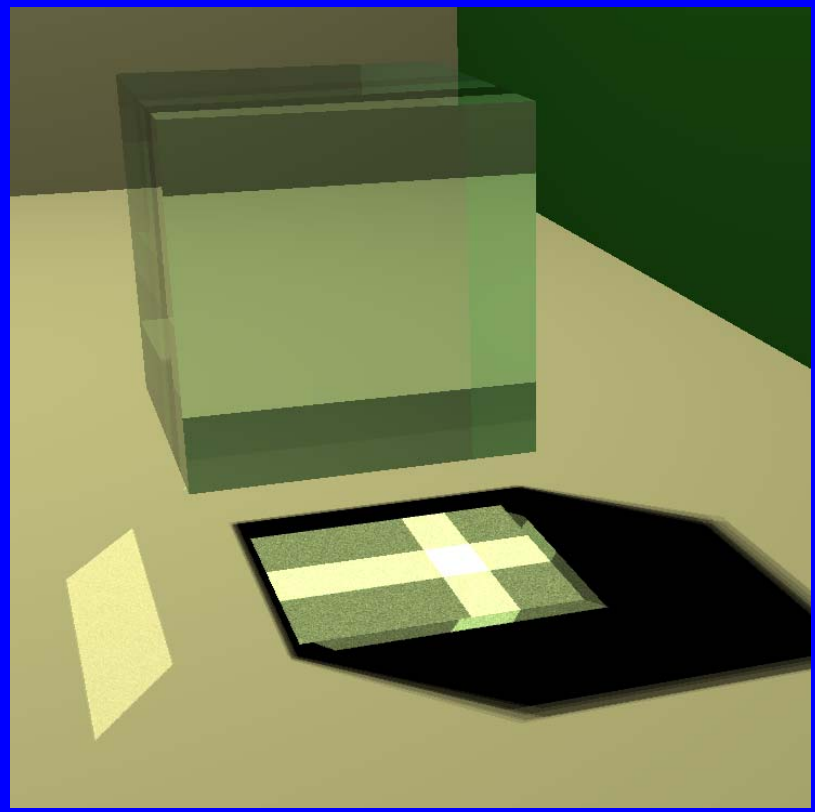
Rendering

- Ways of interpolating this 5D data
  - Sampled in complex space

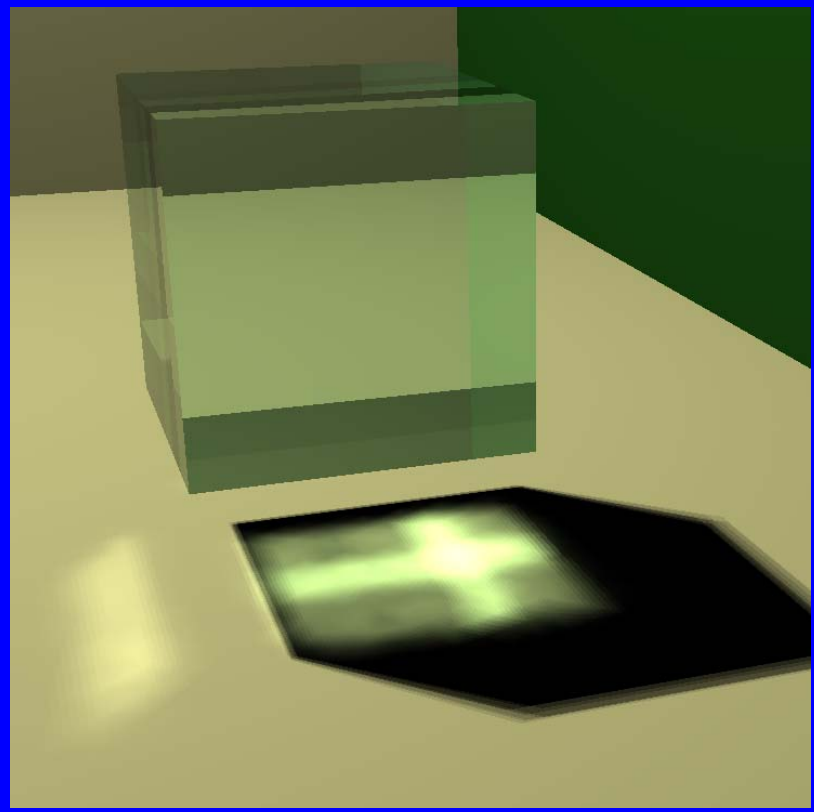




Results (Caustics)



Photon map
(4 seconds for just caustics)



My approach
(12+ frames per second)

Results (Caustics)



23 kB



90 kB



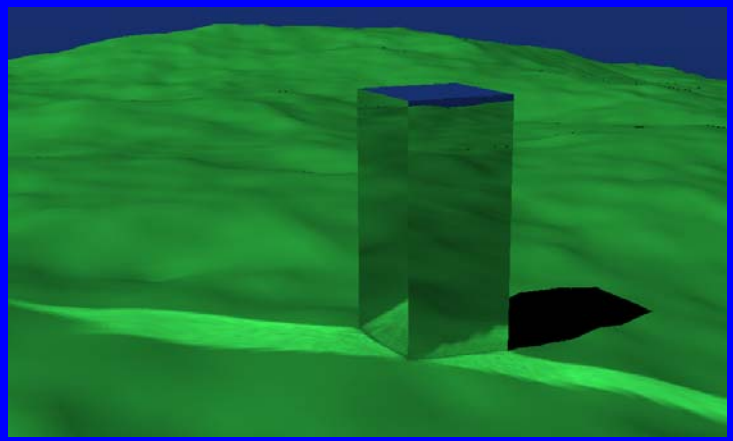
360 kB

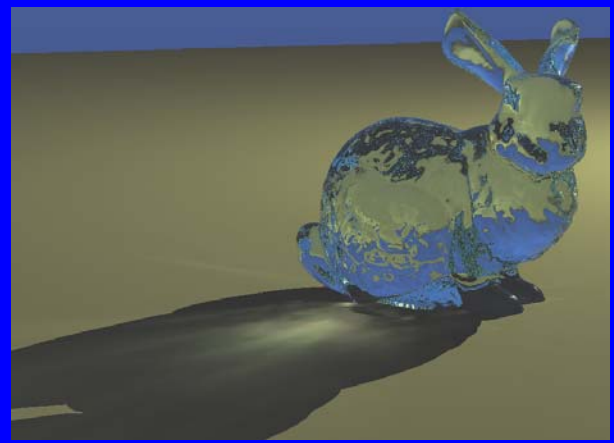


1440 kB

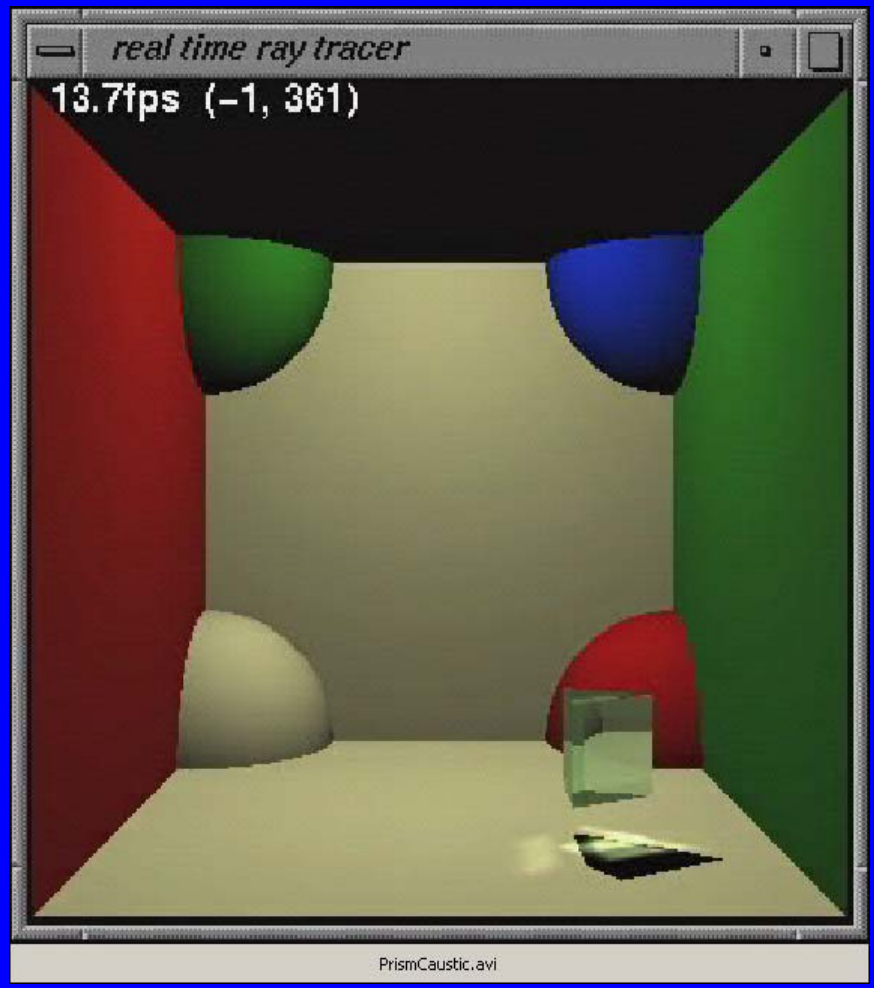


Photon Map (2 sec for just caustic)





Video

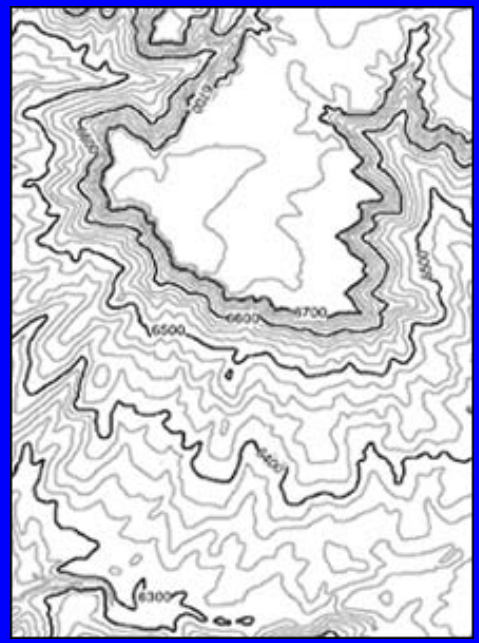


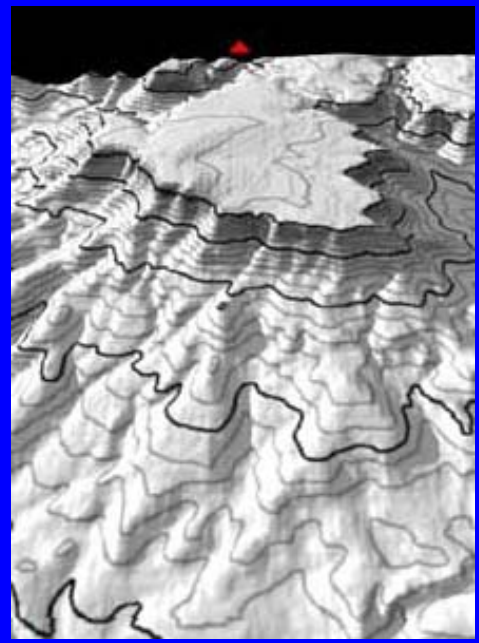
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Volumetric Data

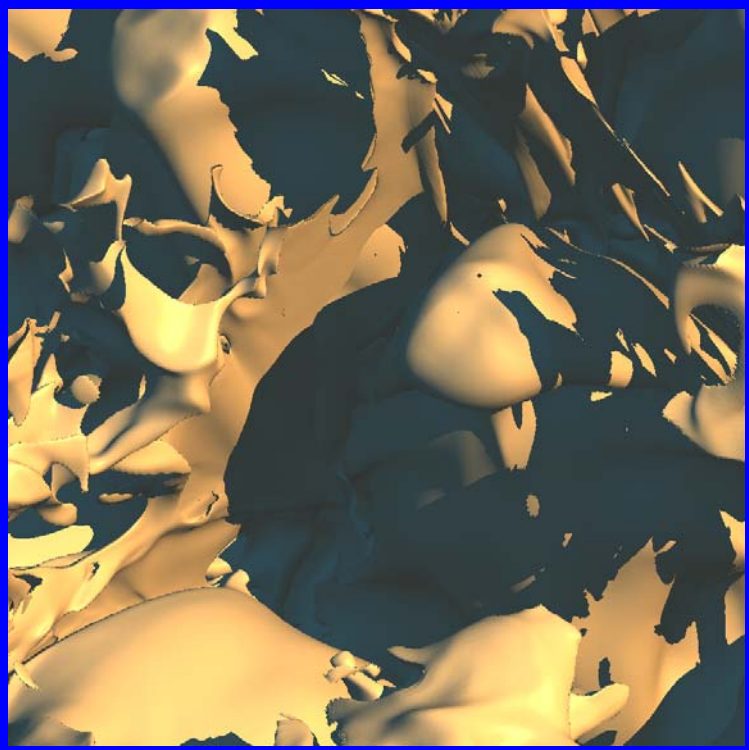
- Typically from scans or simulations
- Value at every point in space
- Can explore by visualizing isosurfaces

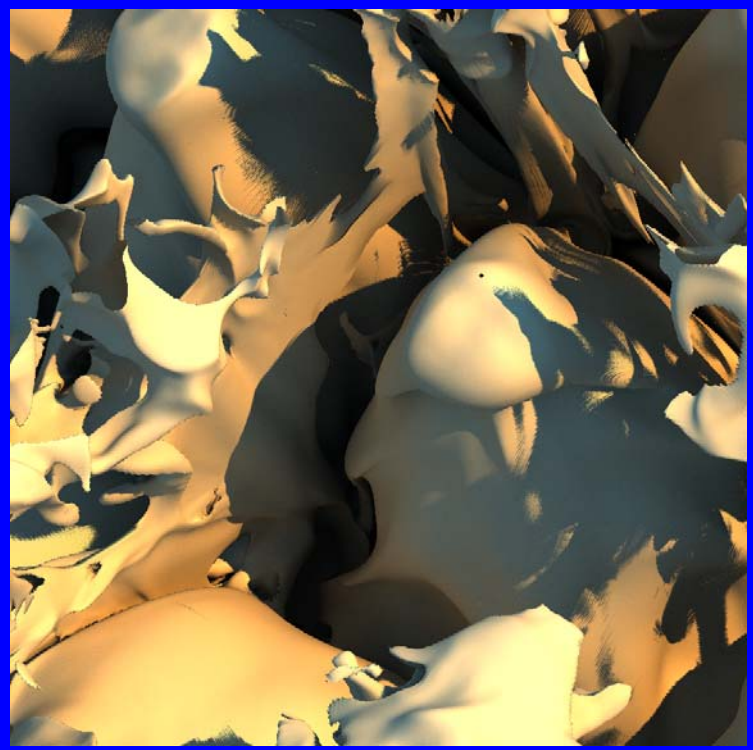




Illumination of Isosurfaces

- Recent work allows large scale interactive exploration
- Current interactive volume apps use local models



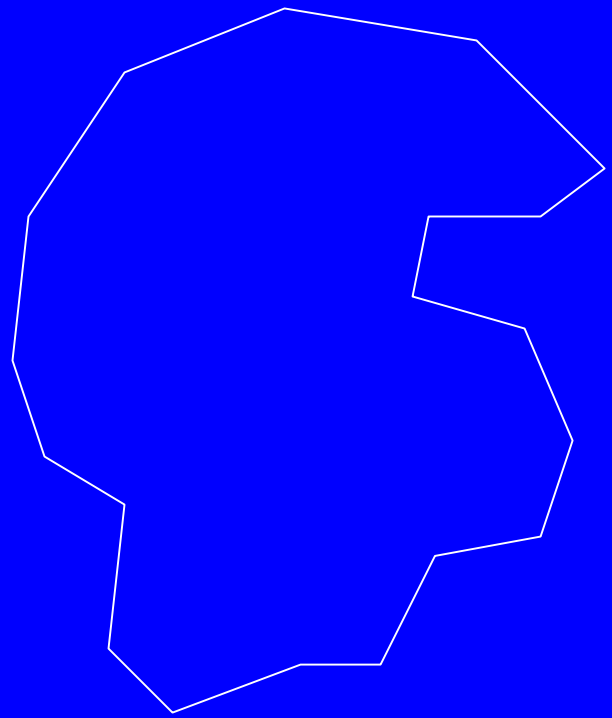


Our Approach

- Store illumination in a volume
  - Data & illumination value at each point
    - Data & GI samples need not coincide
  - GI computed on isosurface through sample
  - Precompute or lazily compute GI values
- Interpolate to correct surface

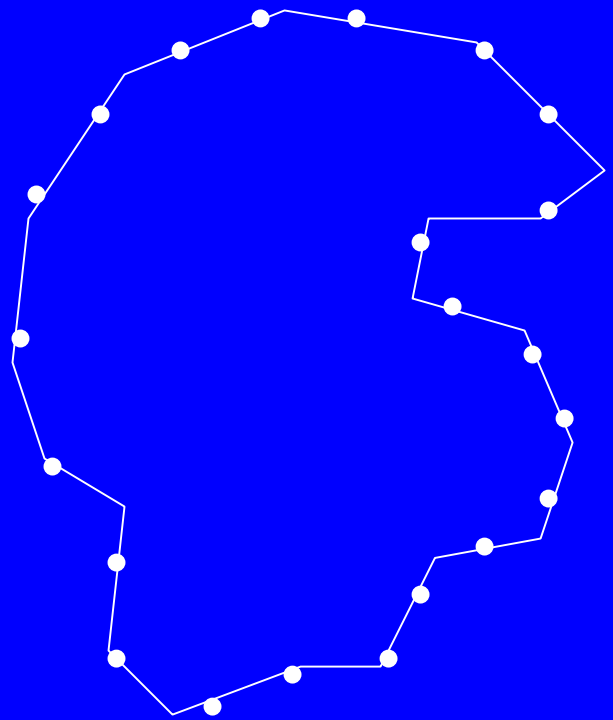
Computing Illumination

- Back in 2D:
  - Isosurface



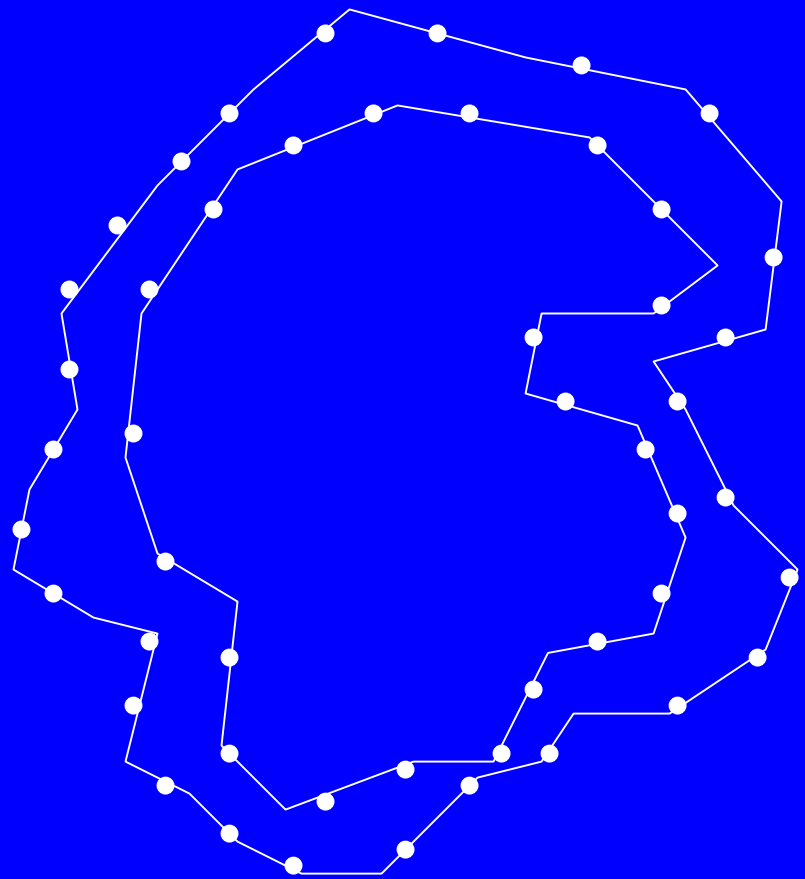
Computing Illumination

- Back in 2D:
  - Isosurface
  - Sample illum



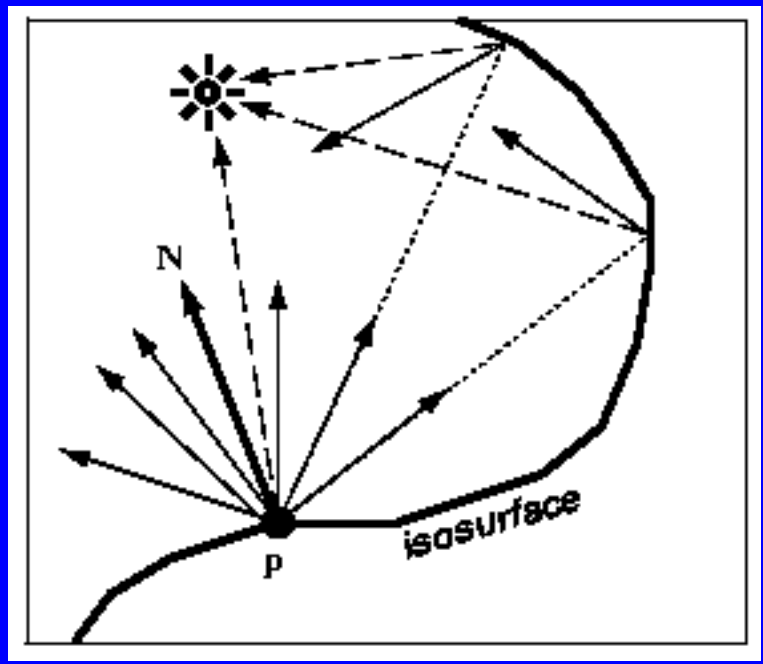
Computing Illumination

- Back in 2D:
  - Isosurface
  - Sample illum
  - Repeat for all isosurfaces



Computing Illumination

- Compute on uniform grid
- Illumination for isosurface computed same as polygonal surface



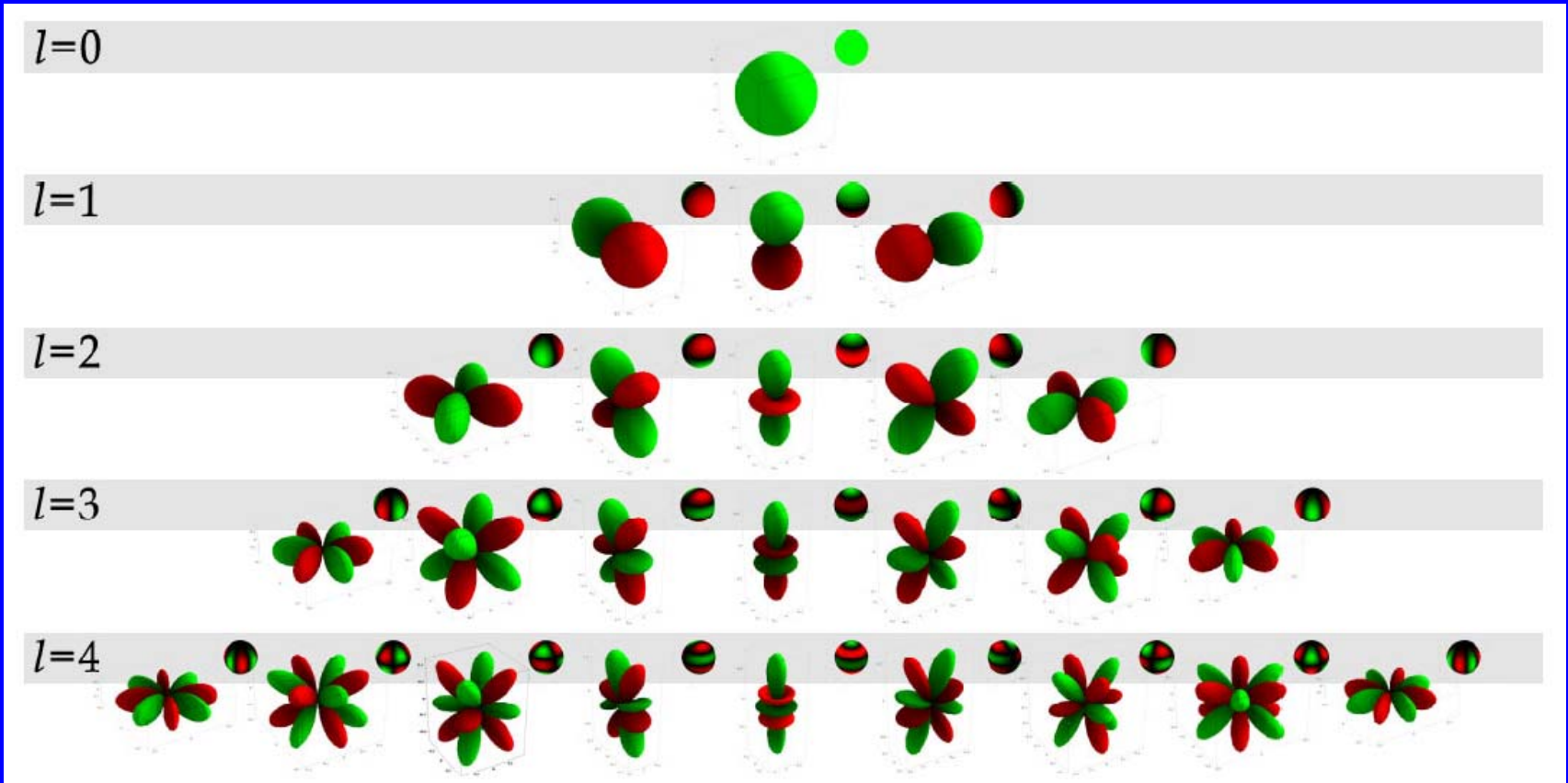
Data Representation

- Single color
  - 3 bytes per sample
  - Static illumination (irradiance)
- Spherical harmonics
  - 300 bytes per sample (5^{th} order)
  - Dynamic illumination
  - Lose high frequency information

Spherical Harmonic Basics

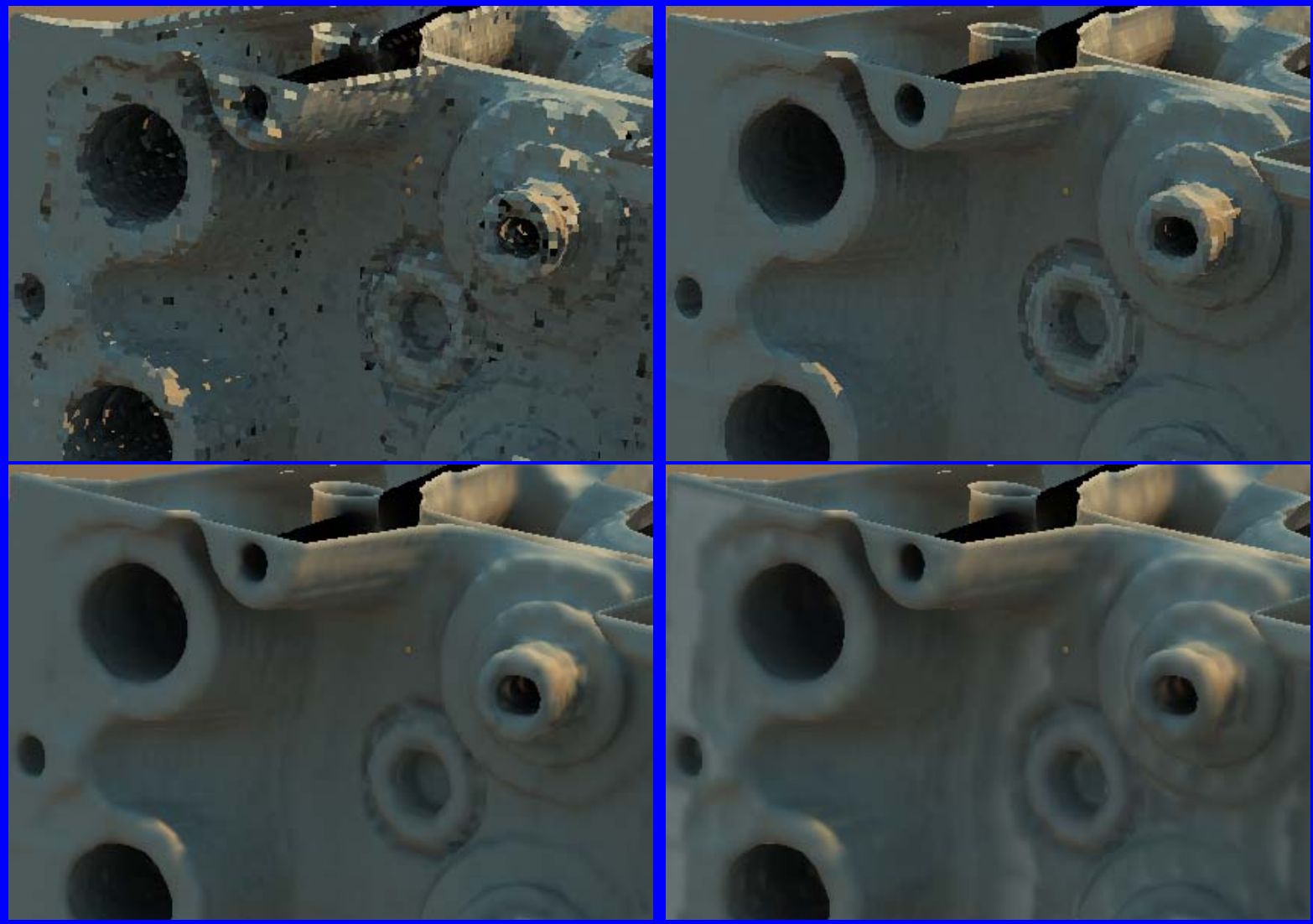
- Orthonormal basis over the sphere
- Analogous to Fourier
- Integral of 2 projected functions reduces to a dot product
- Rotate projected function using matrix multiply

Spherical Harmonic Basics



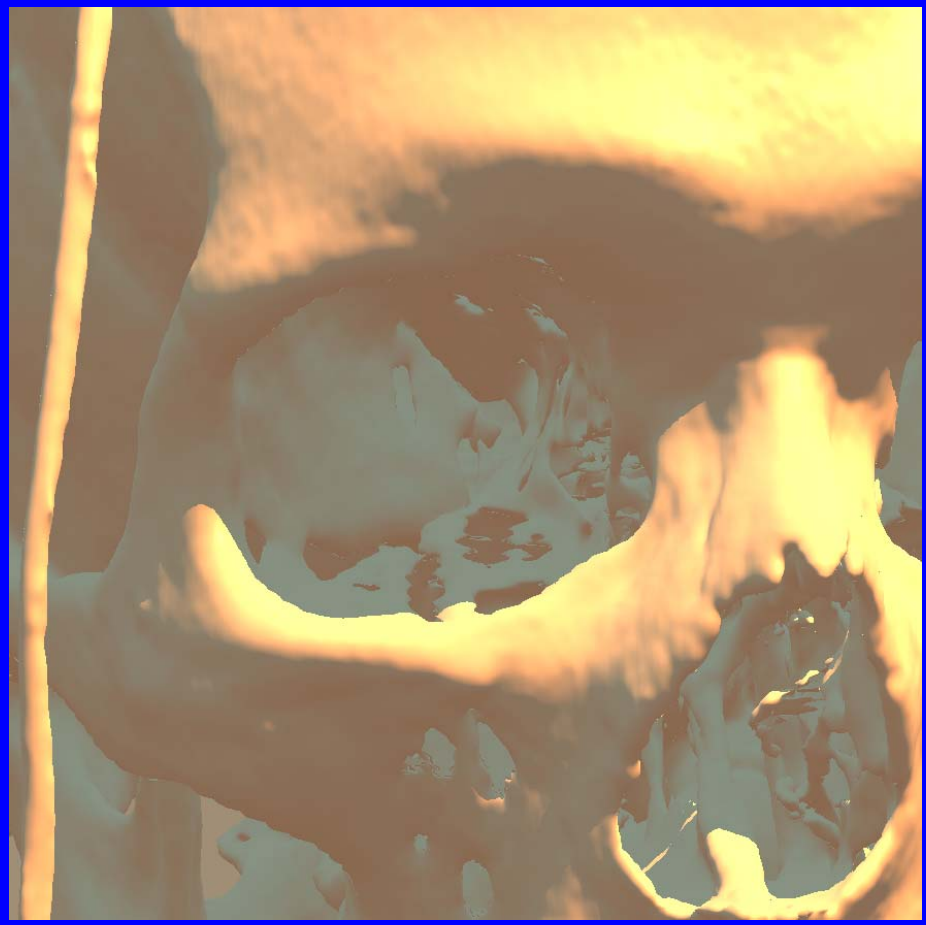
Robin Green, Sony Computer Entertainment

Interpolation

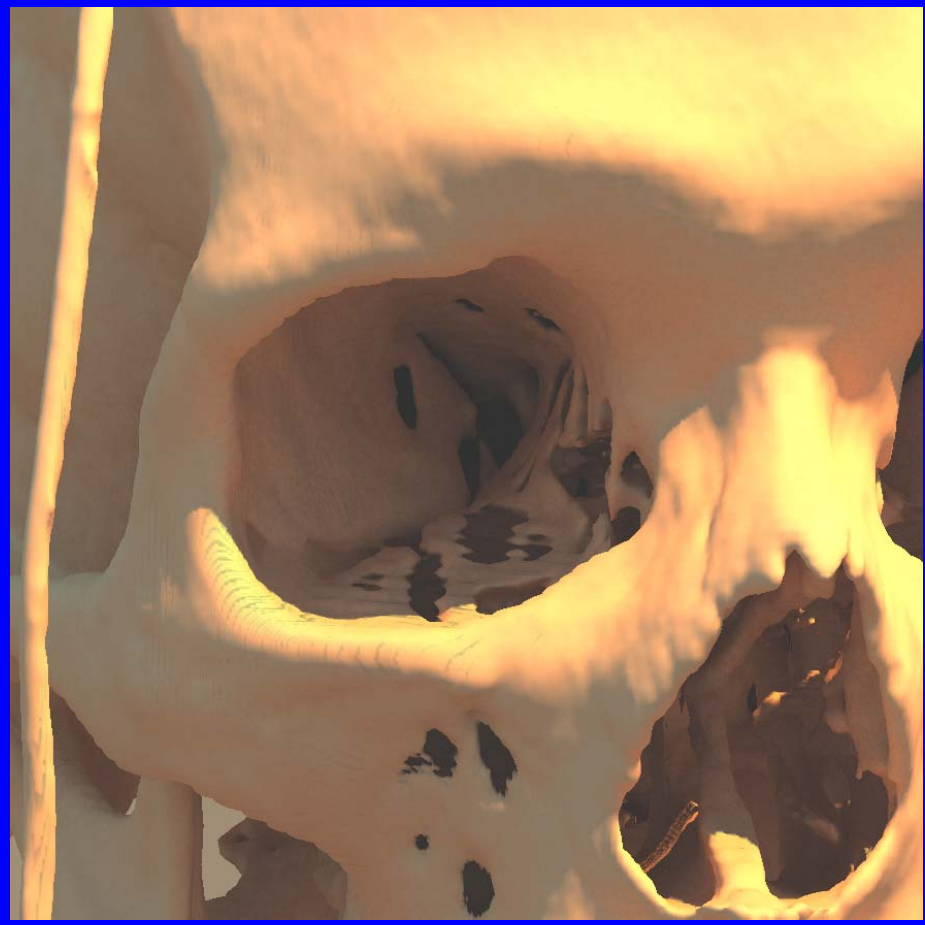


Implementation

- Implemented first in interactive raytracer
  - About 10% slower than Phong w/o shadows
  - About 75% faster than Phong with shadows
  - SH about 25% slower than irradiance samples
- Also implemented in OpenGL



Phong
(Local model with shadows)



Diffuse global illumination
using our approach

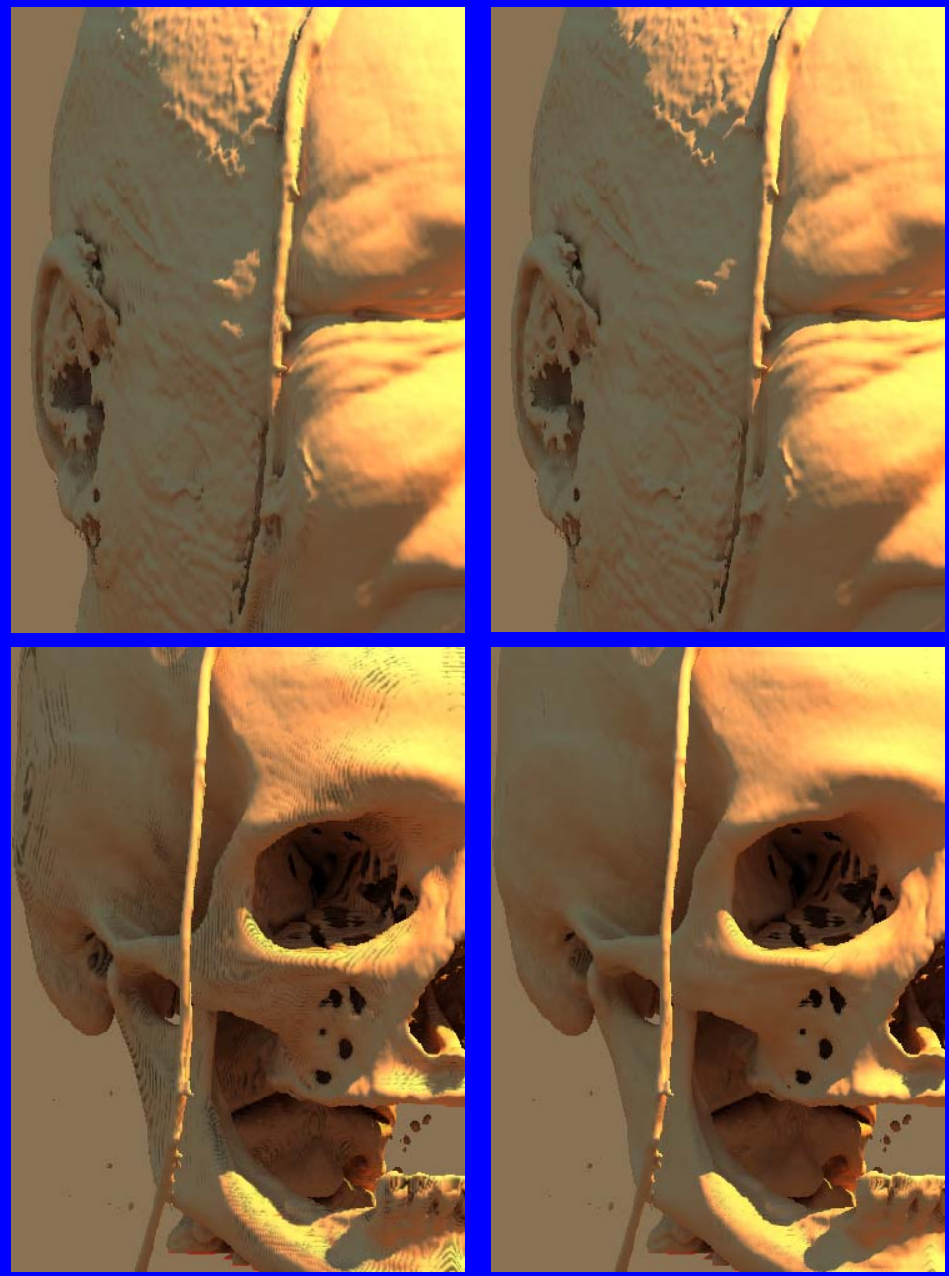


Pathtraced (~80min), 10000 spp



My approach, ~15-20 fps

- Sampling density affects results
- Usually same resolution as volume sufficient
- Areas where isovalue changes quickly need more samples



1x resolution

8x resolution

Video



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Conclusions

- Local caching gives interactivity for GI
- Tradeoff between
  - Accuracy
  - Memory consumption
  - Rendering time
- Tailor data representation to application
- Simple methods produce good results

Limitations

- Interpolation issues
  - Inherent to solution
- Simplifications
  - Limit applicability
  - Cannot always use all global information

Future Work

- Near term
  - Extensions of current work
  - What approximations are best for user perception?
  - Balance between GPUs and CPUs

Future Work

- Goal: realistic rendering at 60+ fps
- Long term
  - Combine interactive GI effects and still maintain interactivity
  - Interactive realistic material rendering

Questions?