



SIGGRAPH2005

# Lightcuts: A Scalable Approach to Illumination

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# Lightcuts

- Efficient, accurate complex illumination



Environment map lighting & indirect  
Time 111s



Textured area lights & indirect  
Time 98s

(640x480, Anti-aliased, Glossy materials)



# Scalable

- Scalable solution for many point lights
  - Thousands to millions
  - Sub-linear cost

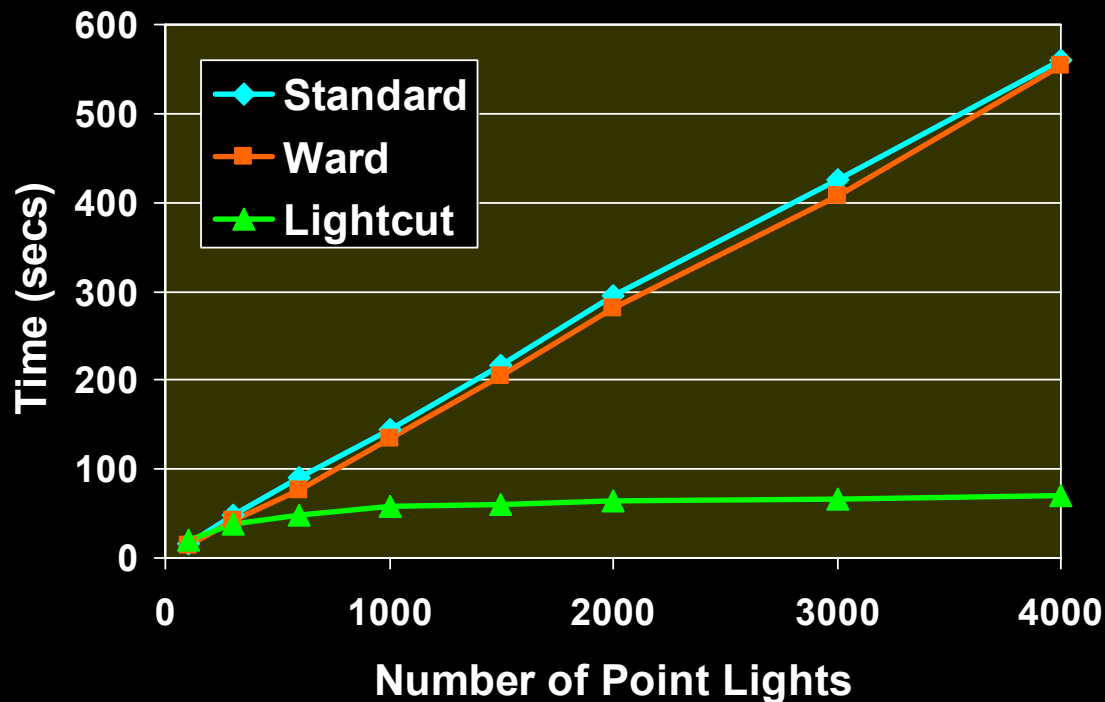


Tableau Scene



LIGHTCUTS

# Complex Lighting

- Simulate complex illumination using point lights
  - Area lights
  - HDR environment maps
  - Sun & sky light
  - Indirect illumination
- Unifies illumination
  - Enables tradeoffs between components



Area lights + Sun/sky + Indirect



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# Related Work

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- Hierarchical techniques
  - Hierarchical radiosity [eg, Hanrahan et al. 91, Smits et al. 94]
  - Light hierarchy [Paquette et al. 98]
- Many lights
  - [eg, Teller & Hanrahan 93, Ward 94, Shirley et al. 96, Fernandez et al. 2002, Wald et al. 2003]
- Illumination coherence
  - [eg, Kok & Jensen 92, Ward 92, Scheel et al. 2002, Krivanek et al. 2005]
- Env map illumination
  - [Debevec 98, Agarwal et al. 2003, Kollig & Keller 2003, Ostromoukhov et al. 2004]
- Instant Radiosity
  - [Keller 97, Wald et al. 2002]



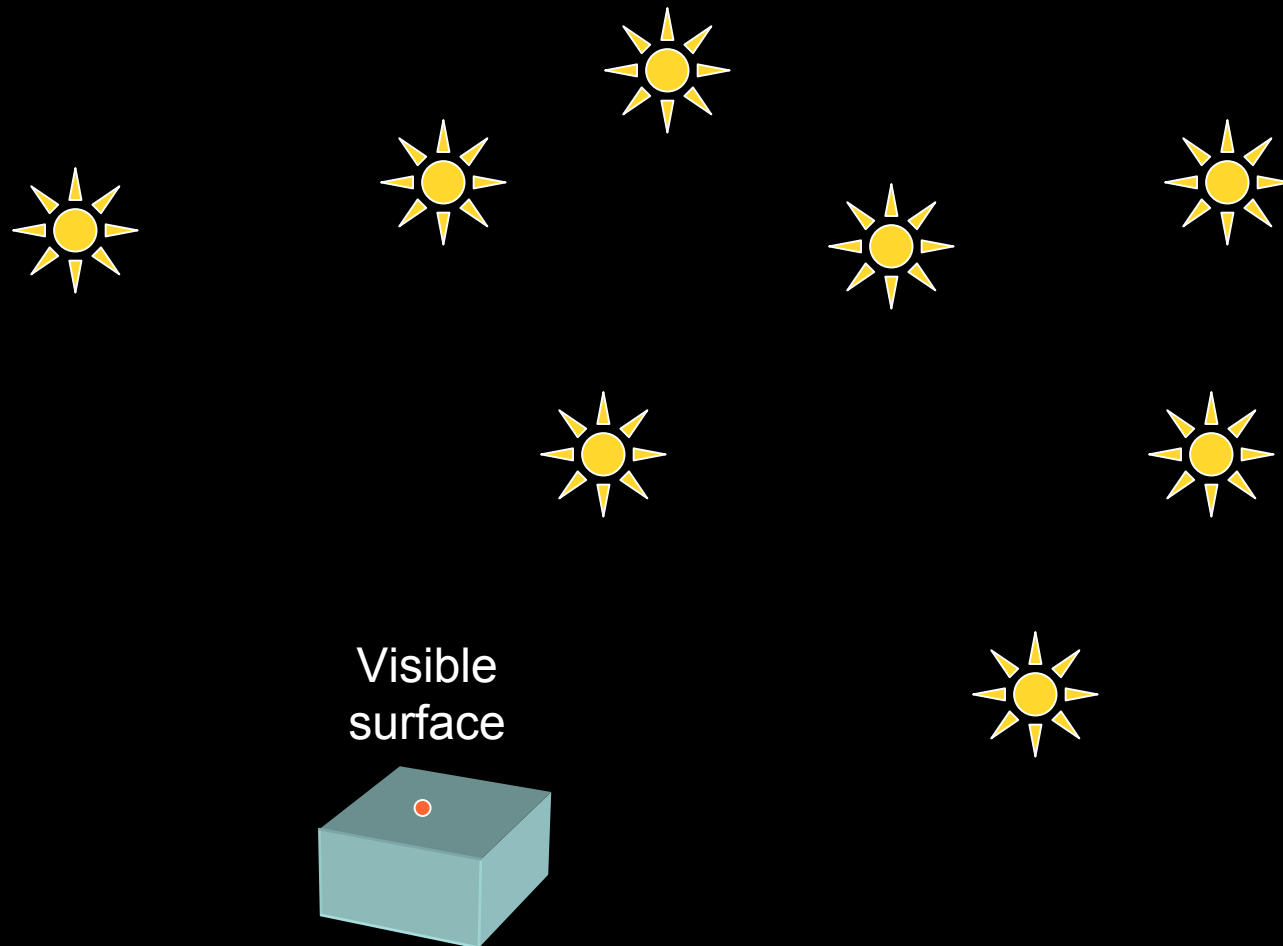
# Talk Overview

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- Lightcuts
  - Scalable accurate solution for complex illumination
- Reconstruction cuts
  - Builds on lightcuts
  - Use smart interpolation to further reduce cost

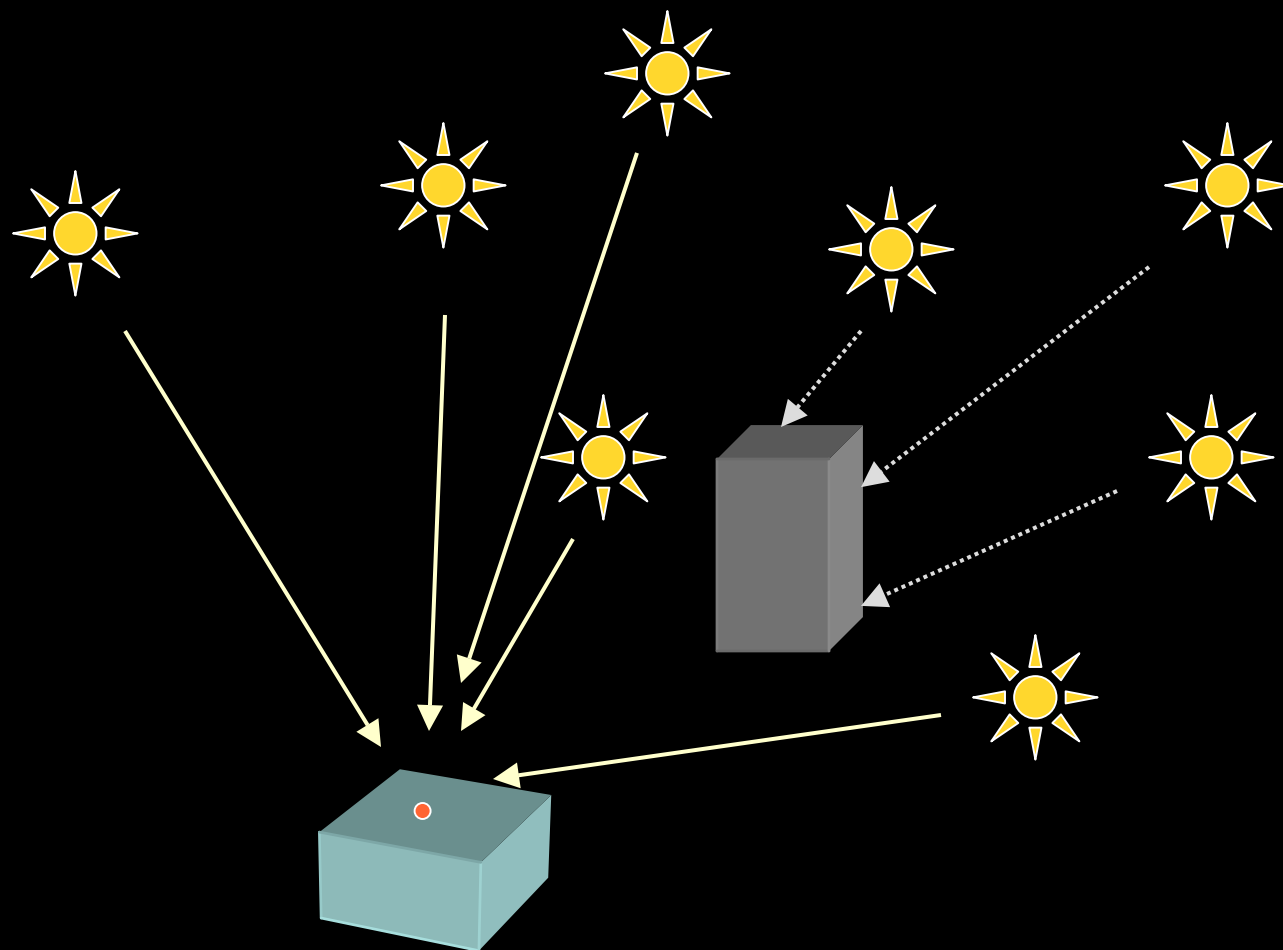


# Lightcuts Problem





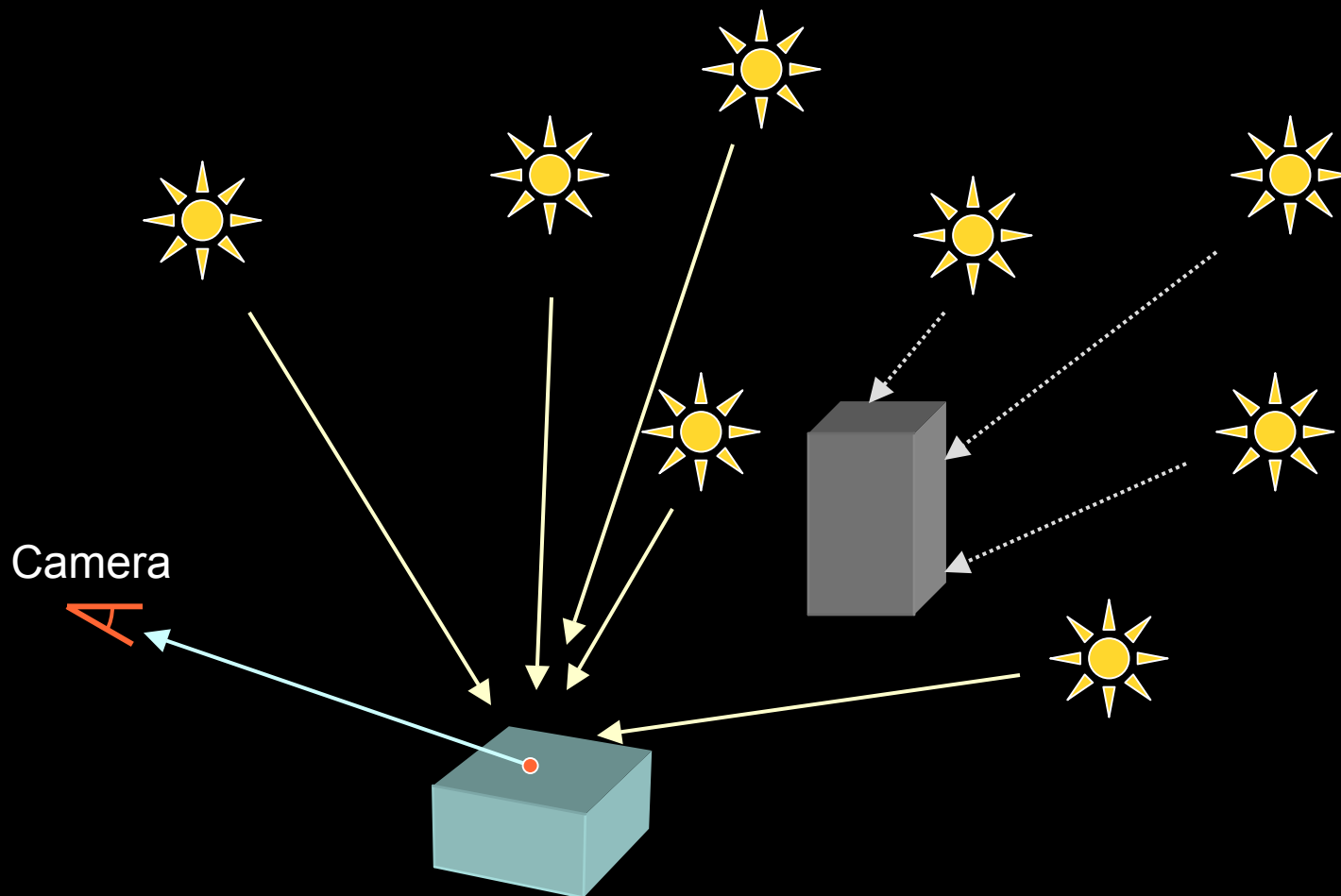
# Lightcuts Problem







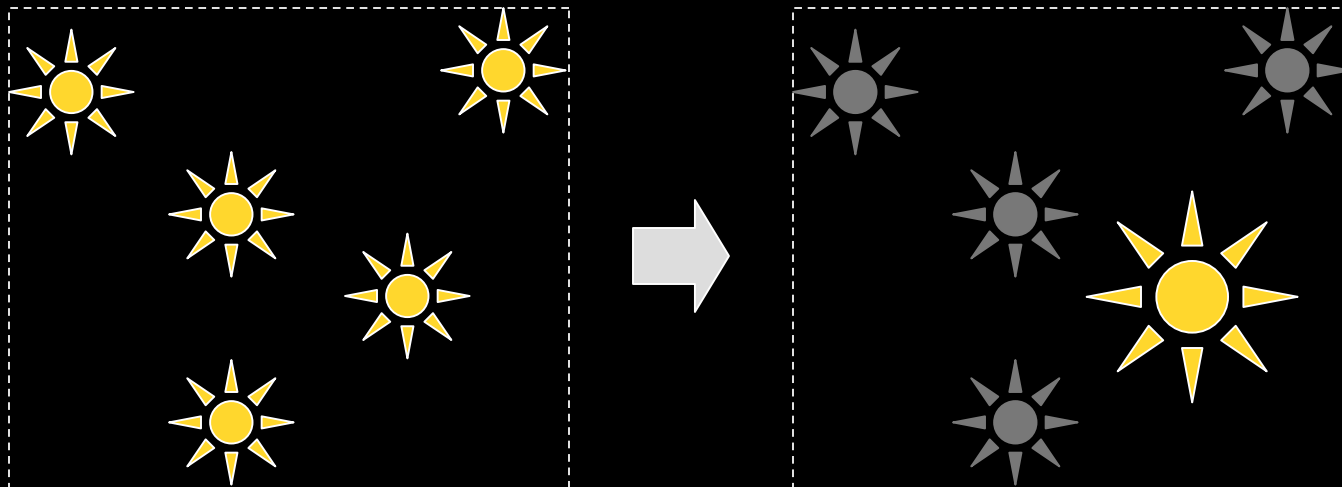
# Lightcuts Problem





# Key Concepts

- Light Cluster
  - Approximate many lights by a single brighter light (the representative light)

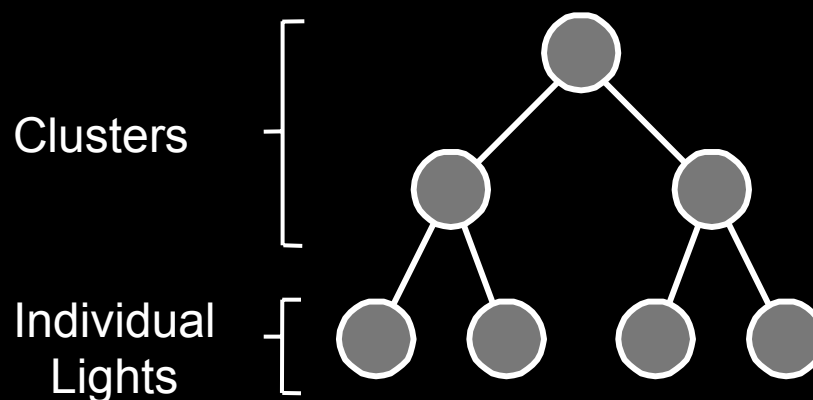




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# Key Concepts

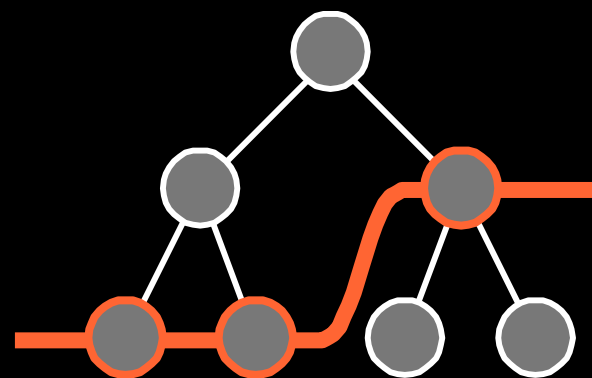
- Light Cluster
- Light Tree
  - Binary tree of lights and clusters





# Key Concepts

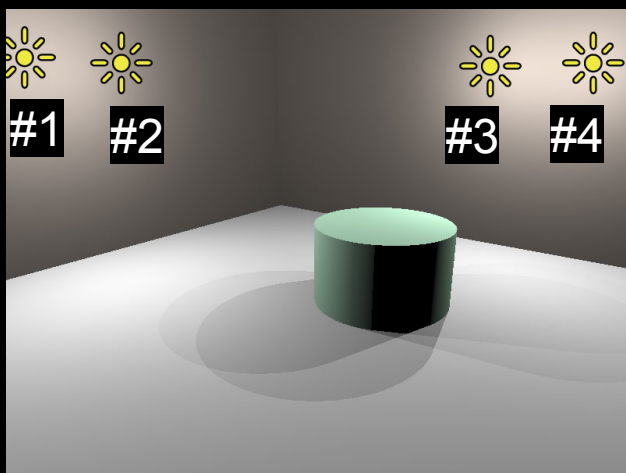
- Light Cluster
- Light Tree
- A Cut
  - A set of nodes that partitions the lights into clusters





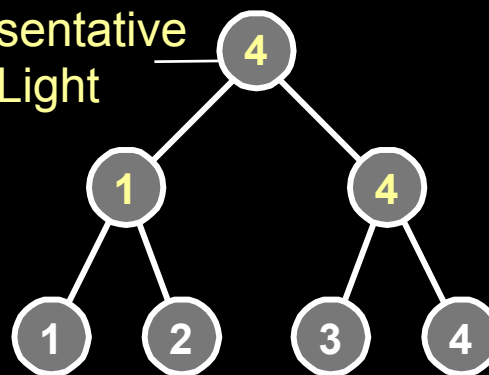
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# Simple Example



## Light Tree

Representative  
Light



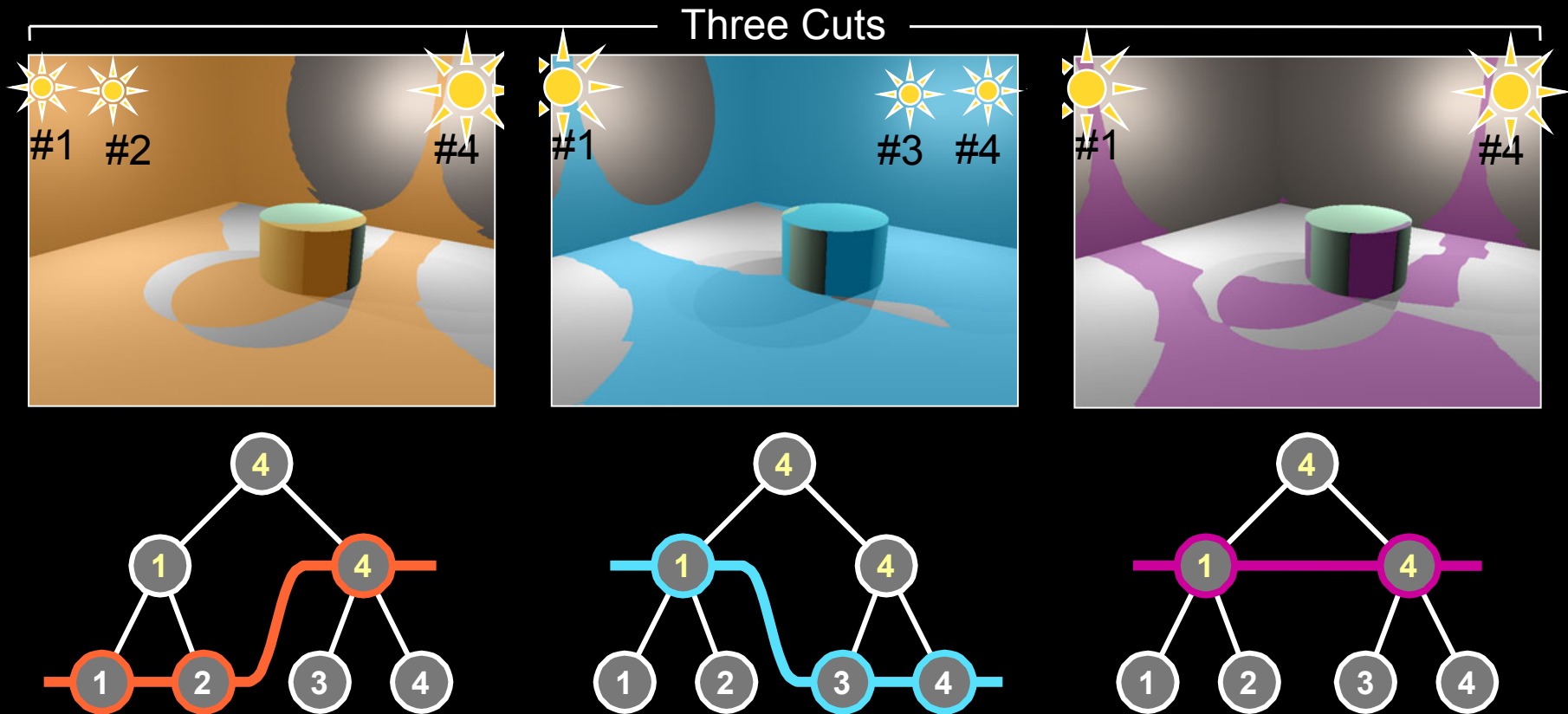
Clusters

Individual  
Lights



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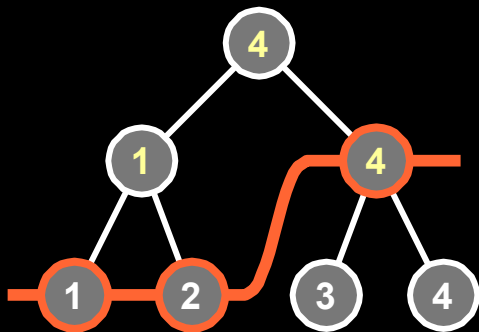
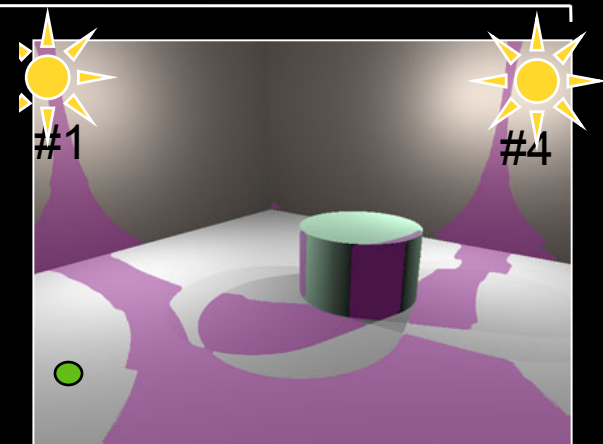
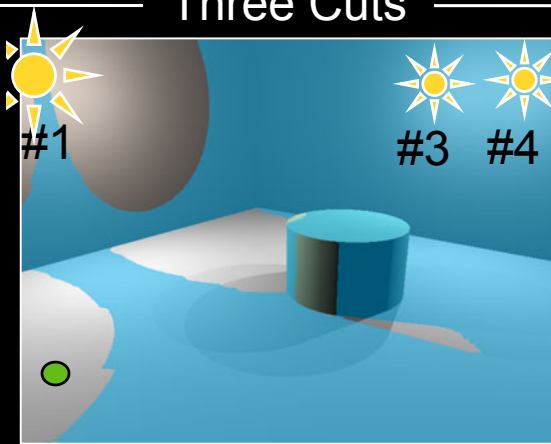
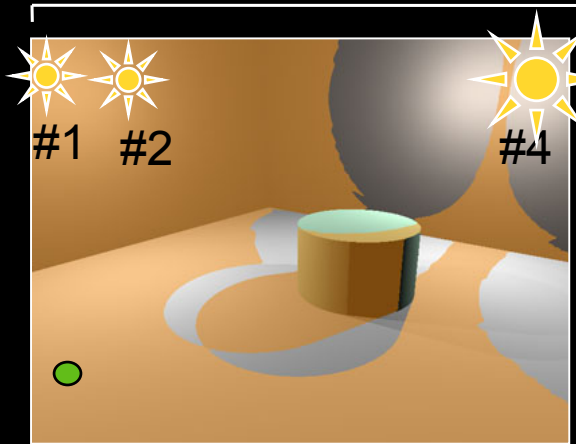
# Three Example Cuts



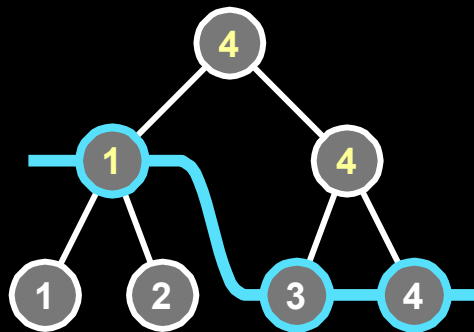


# Three Example Cuts

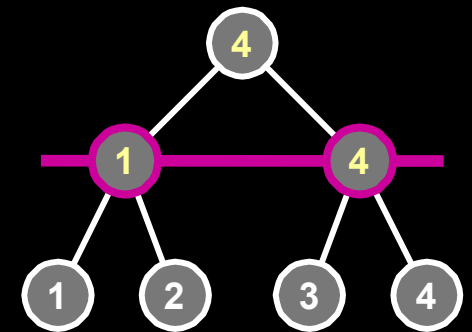
Three Cuts



Good



Bad

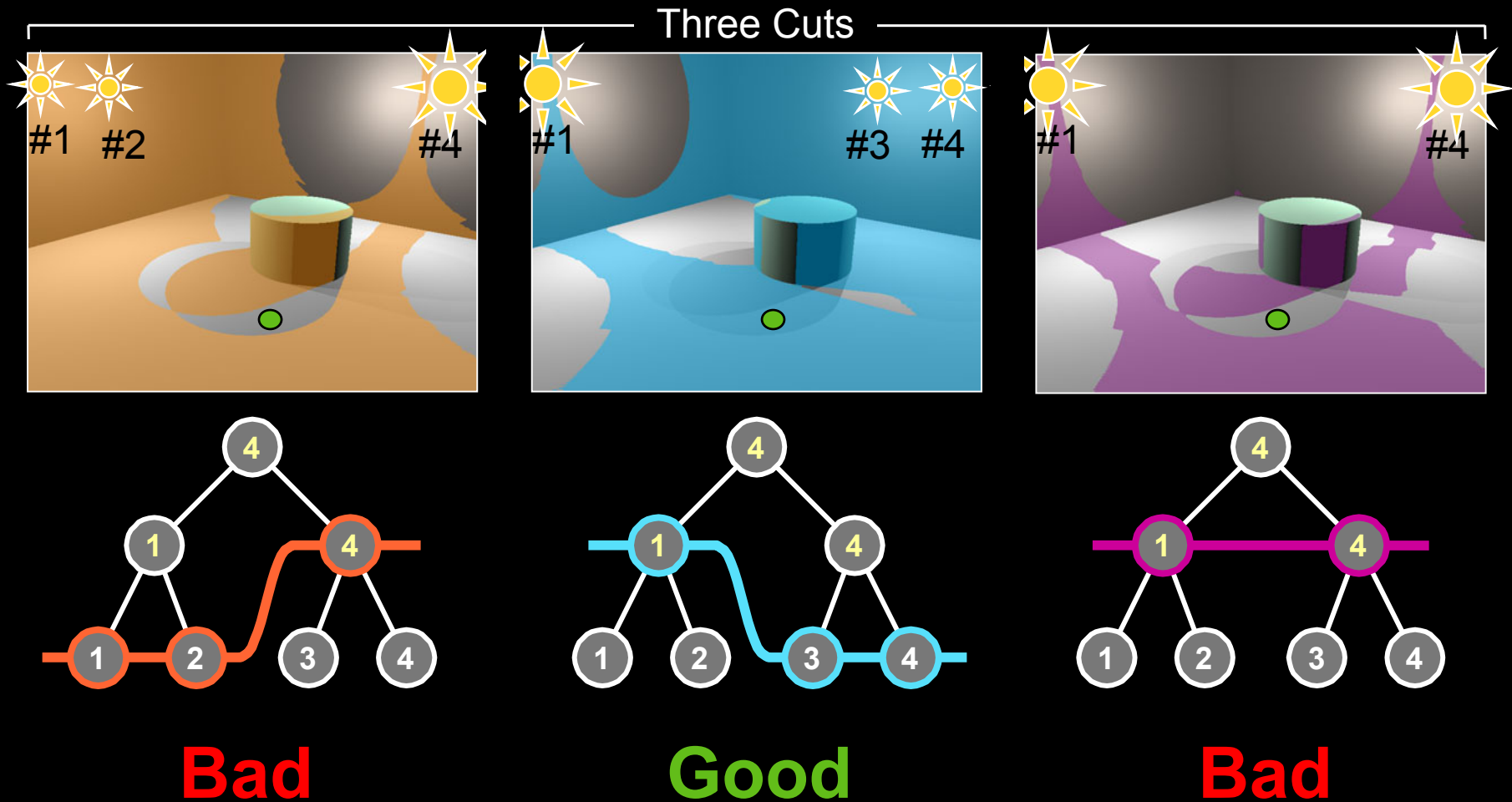


Bad



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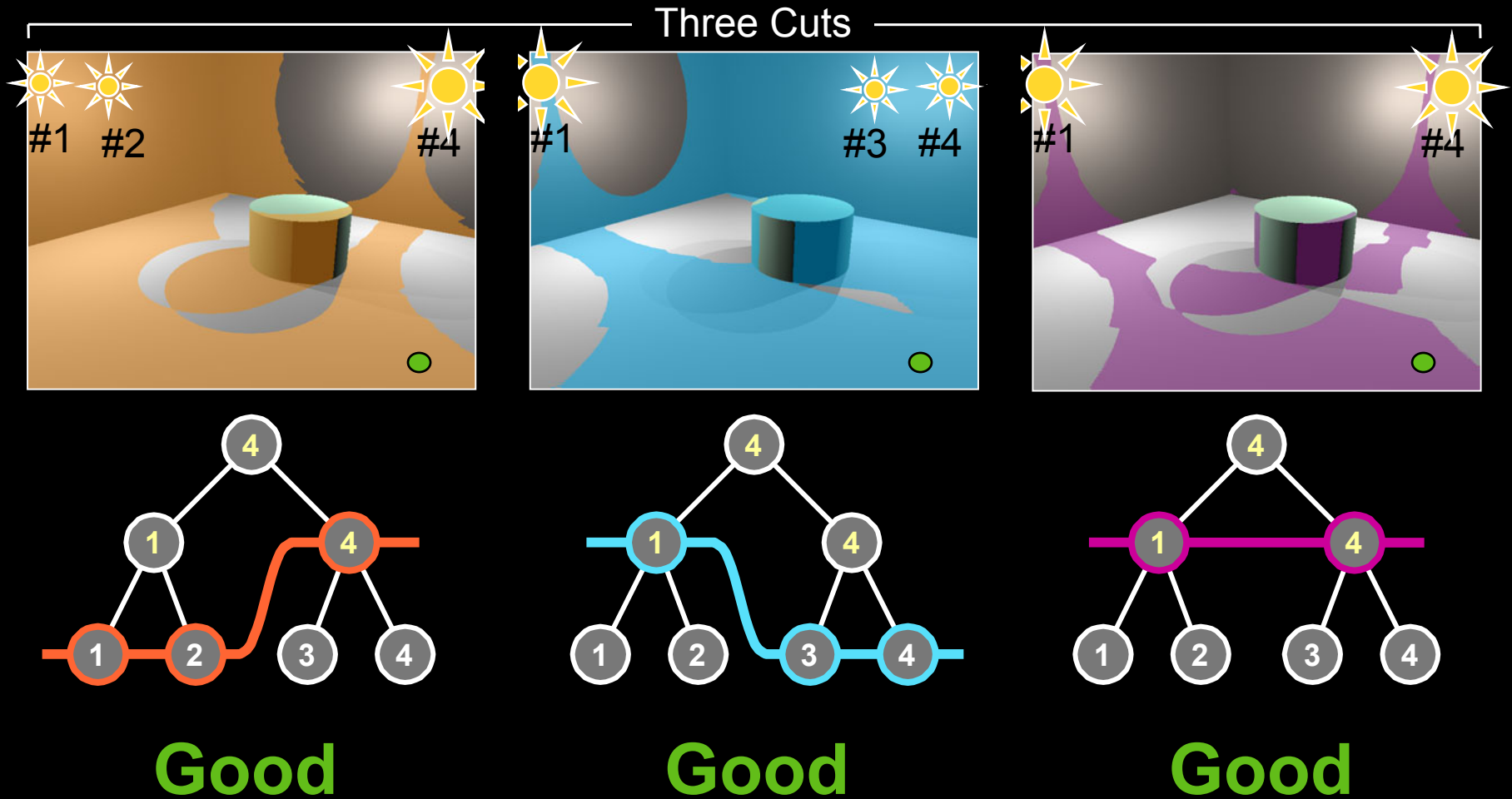
# Three Example Cuts







# Three Example Cuts





# Algorithm Overview

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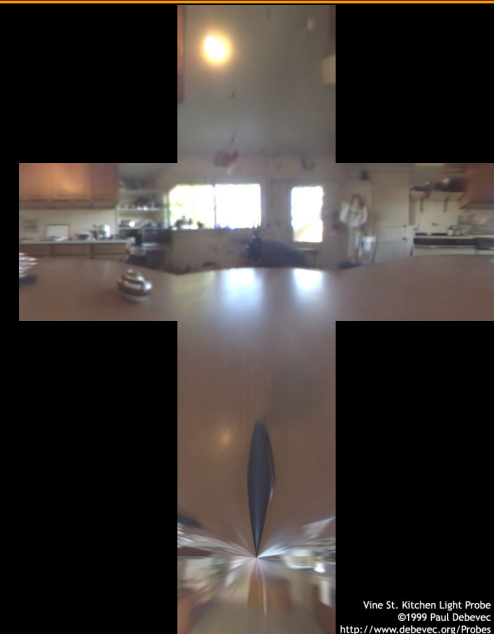
- Pre-process
  - Convert illumination to point lights
  - Build light tree
- For each eye ray
  - Choose a cut to approximate the illumination



LIGHTCUTS

# Convert Illumination

- HDR environment map
  - Apply captured light to scene
  - Convert to directional point lights using [Agarwal et al. 2003]
- Indirect Illumination
  - Convert indirect to direct illumination using Instant Radiosity [Keller 97]
    - Caveats: no caustics, clamping, etc.
  - More lights = more indirect detail





# Algorithm Overview

---

- Pre-process
  - Convert illumination to point lights
  - Build light tree
- For each eye ray
  - Choose a cut to approximate the local illumination
    - Cost vs. accuracy
    - Avoid visible transition artifacts



# Perceptual Metric

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- Weber's Law
  - Contrast visibility threshold is fixed percentage of signal
  - Used 2% in our results
- Ensure each cluster's error  $<$  visibility threshold
  - Transitions will not be visible
  - Used to select cut

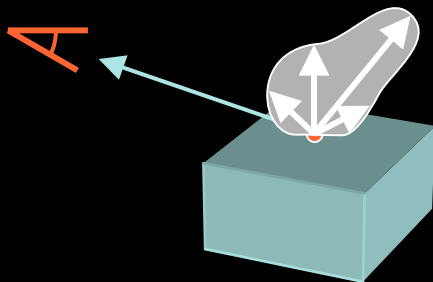


LIGHTCUTS

# Illumination Equation

$$\text{result} = \sum_{\text{lights}} M_i G_i V_i I_i$$

$M_i$  |  $G_i$  |  $V_i$  |  $I_i$   
 | | | |  
 Material term | Geometric term | Visibility term | Light intensity



Currently support diffuse, phong, and Ward

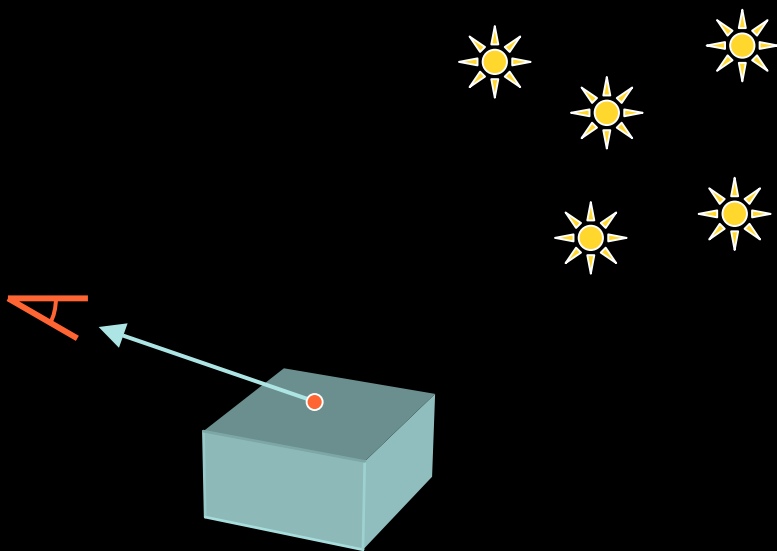


LIGHTCUTS

# Illumination Equation

$$\text{result} = \sum_{\text{lights}} M_i G_i V_i I_i$$

$M_i$  — Material term  
 $G_i$  — Geometric term  
 $V_i$  — Visibility term  
 $I_i$  — Light intensity

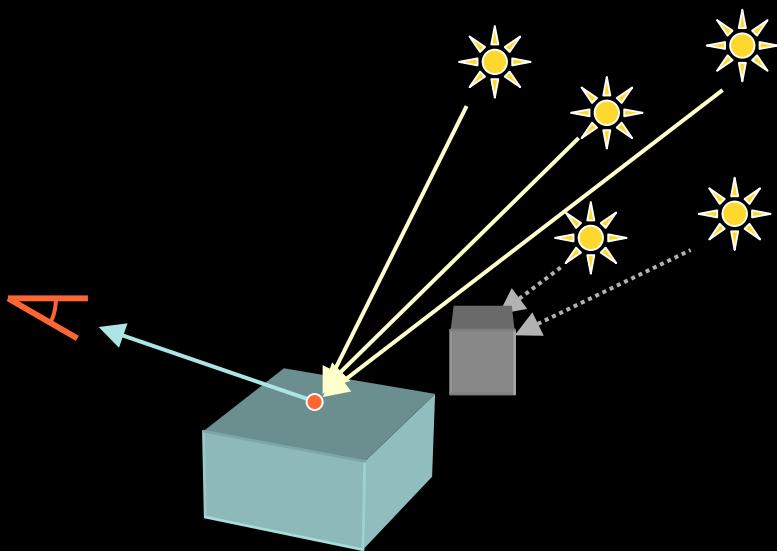




# Illumination Equation

$$\text{result} = \sum_{\text{lights}} M_i G_i V_i I_i$$

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 $G_i$  — Geometric term  
 $V_i$  — Visibility term  
 $I_i$  — Light intensity



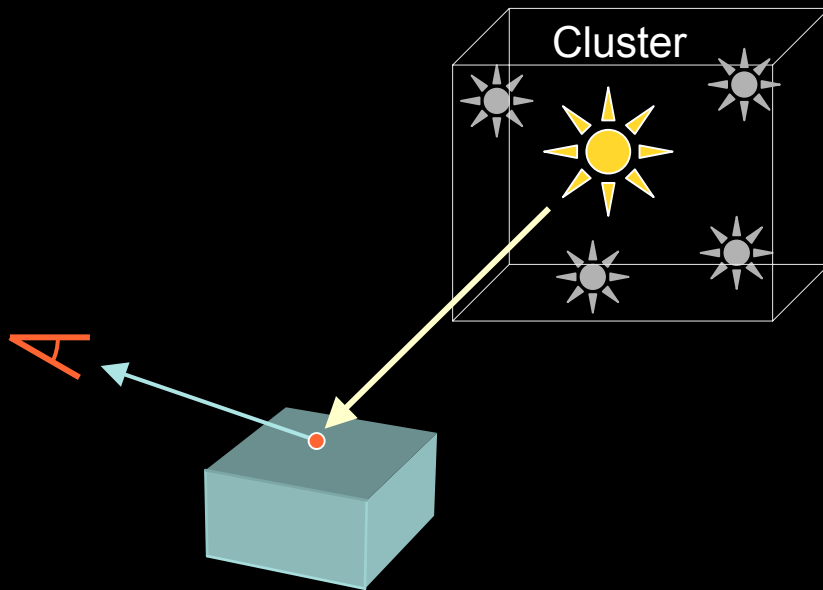




# Cluster Approximation

$$\text{result} \approx M_j G_j V_j \sum_{\text{lights}} I_i$$

$j$  is the representative light

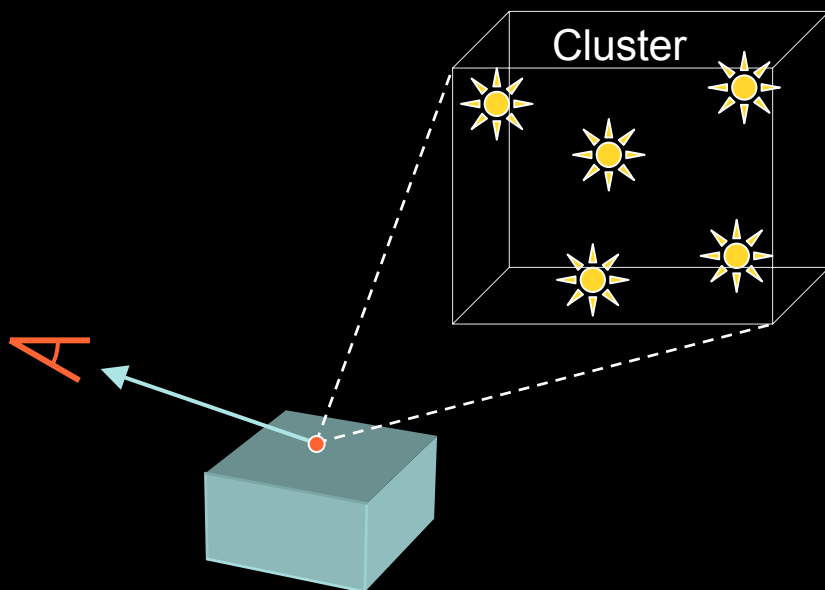




# Cluster Error Bound

$$\text{error} \leq M_{\text{ub}} G_{\text{ub}} V_{\text{ub}} \sum_{\text{lights}} I_i$$

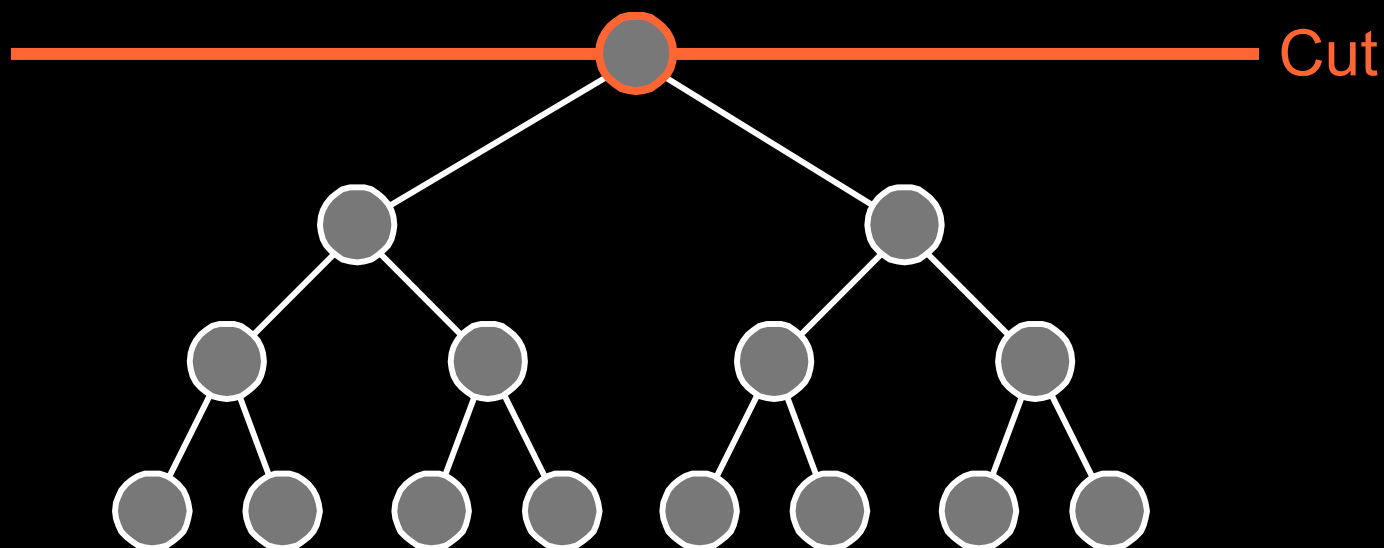
- Bound each term
  - Visibility  $\leq 1$  (trivial)
  - Intensity is known
  - Bound material and geometric terms using cluster bounding volume





# Cut Selection Algorithm

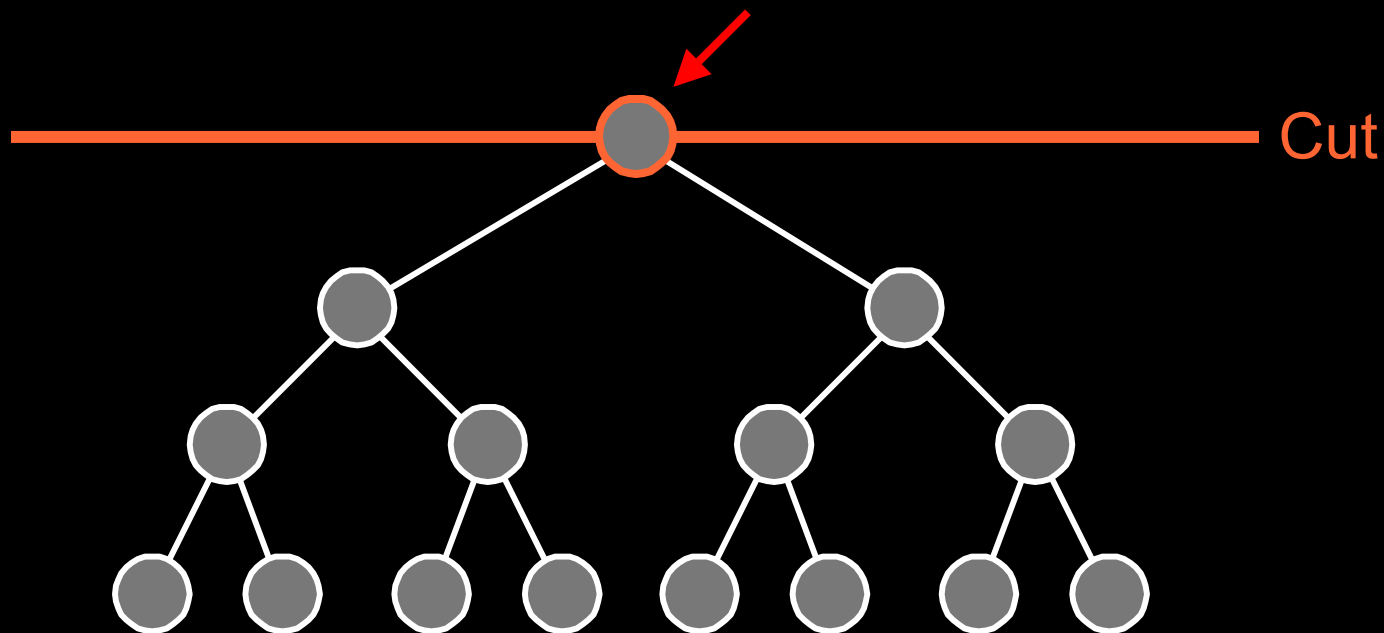
- Start with coarse cut (eg, root node)





# Cut Selection Algorithm

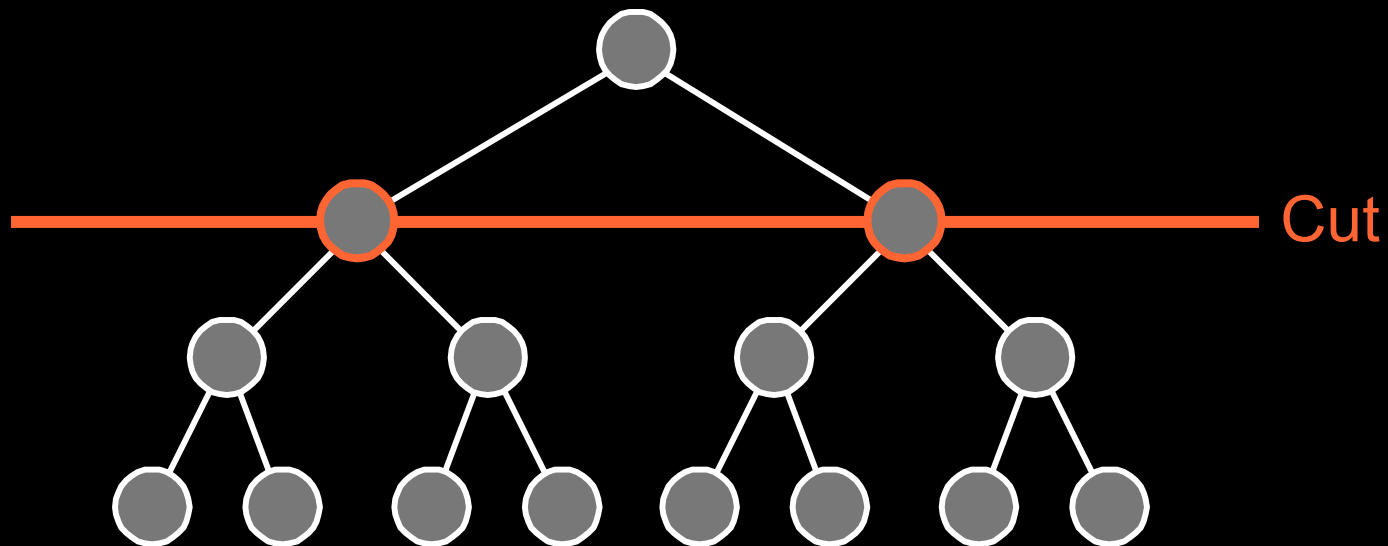
- Select cluster with largest error bound





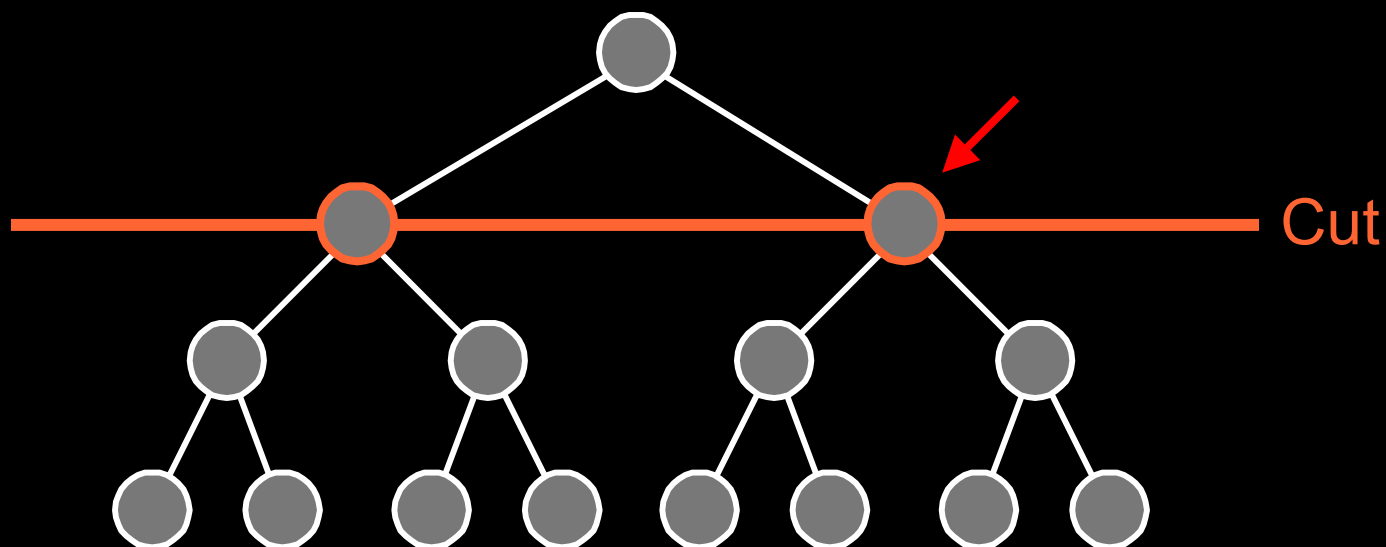
# Cut Selection Algorithm

- Refine if error bound  $> 2\%$  of total



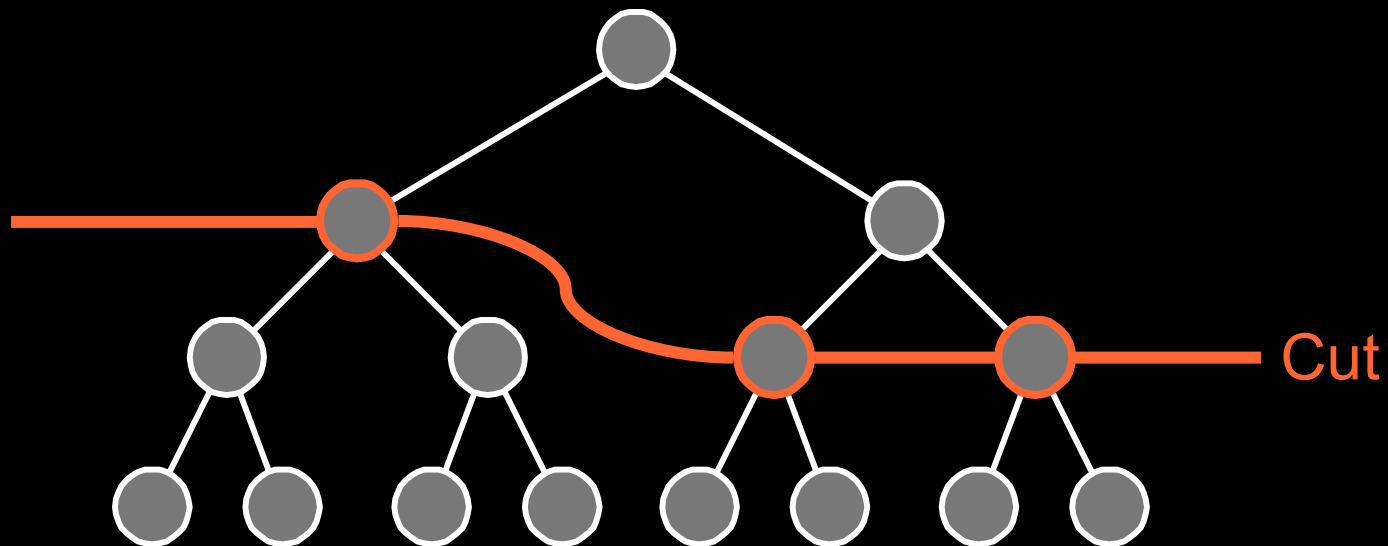


# Cut Selection Algorithm



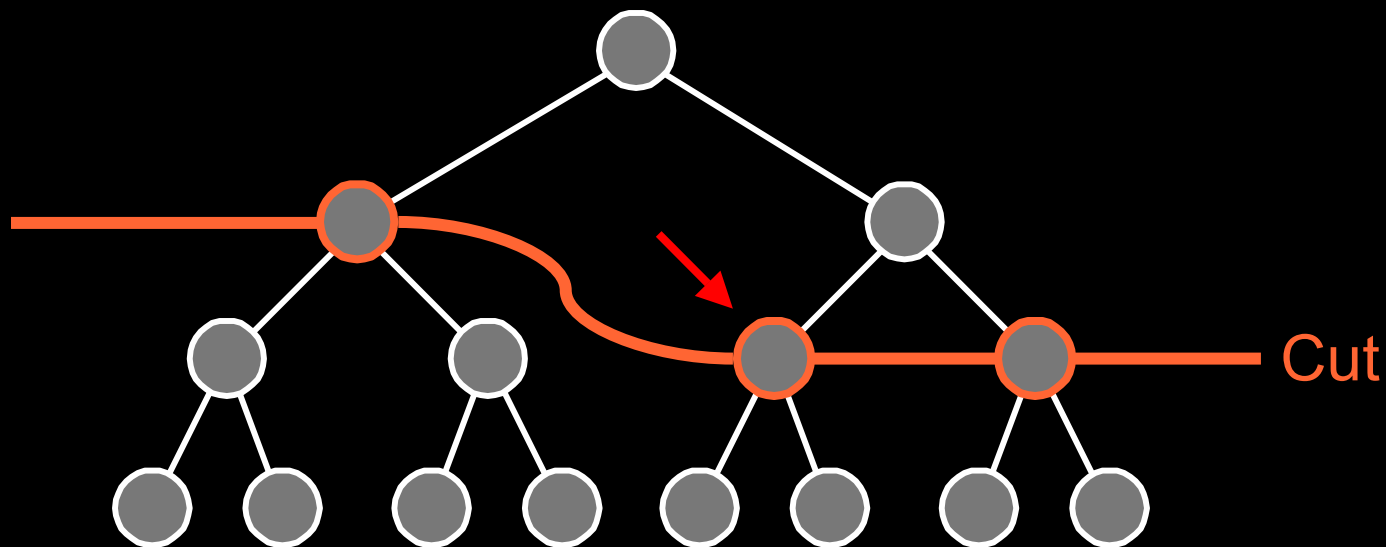


# Cut Selection Algorithm





# Cut Selection Algorithm

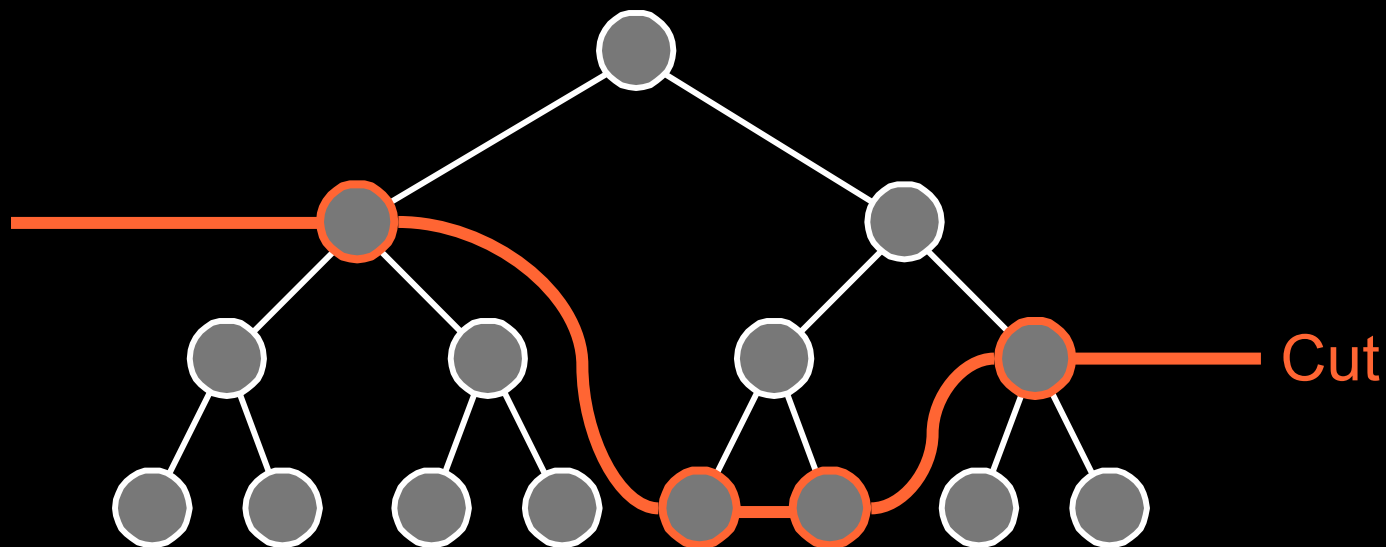






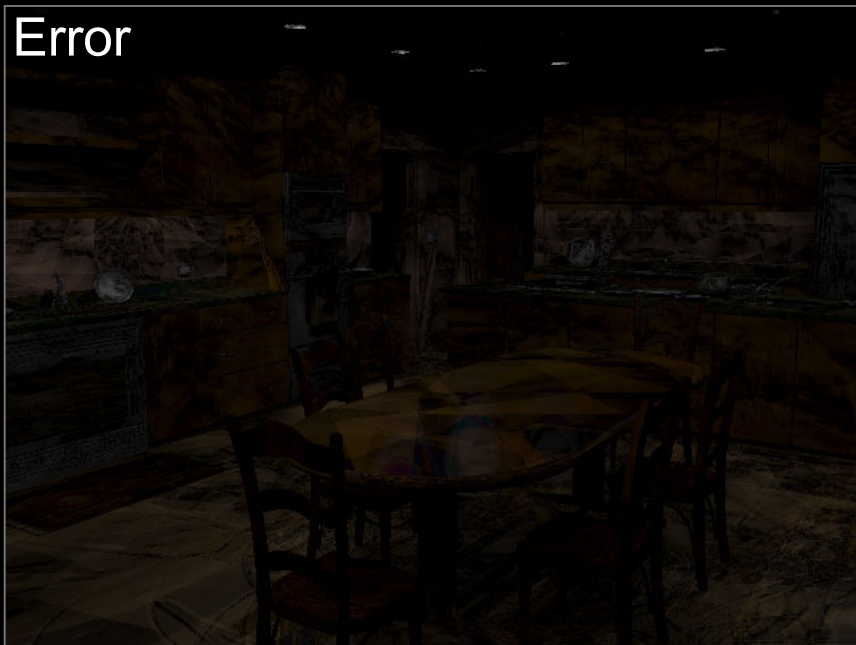
# Cut Selection Algorithm

- Repeat until cut obeys 2% threshold





Kitchen, 388K polygons, 4608 lights (72 area sources)



Kitchen, 388K polygons, 4608 lights (72 area sources)



# Combined Illumination



Lightcuts 128s

4 608 Lights  
(Area lights only)



Lightcuts 290s

59 672 Lights  
(Area + Sun/sky + Indirect)



# Combined Illumination



Lightcuts 128s

4 608 Lights  
(Area lights only)

Avg. 259 shadow rays / pixel



Lightcuts 290s

59 672 Lights  
(Area + Sun/sky + Indirect)

Avg. 478 shadow rays / pixel  
(only 54 to area lights)



# Lightcuts Recap

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- Unified illumination handling
- Scalable solution for many lights
  - Locally adaptive representation (the cut)
- Analytic cluster error bounds
  - Most important lights always sampled
- Perceptual visibility metric

Lightcuts implementation sketch, Petree Hall C, ~4:30pm



# Talk Overview

---

- Lightcuts
  - Scalable accurate solution for complex illumination
  
- Reconstruction cuts
  - Builds on lightcuts
  - Use smart interpolation to further reduce cost



# Reconstruction Cuts

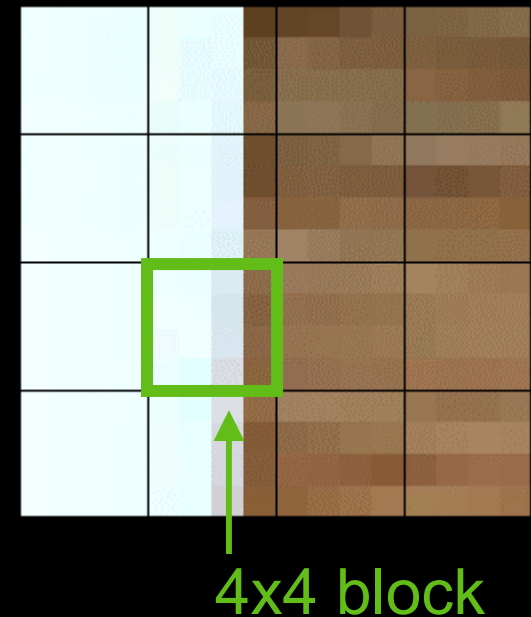
- Subdivide image into blocks
  - Generate samples at corners
- Within blocks
  - Interpolate smooth illumination
  - Use shadow rays when needed to preserve features
    - Shadow boundaries, glossy highlights, etc.
- Anti-aliasing
  - (5-50 samples per pixel)





# Image Subdivision

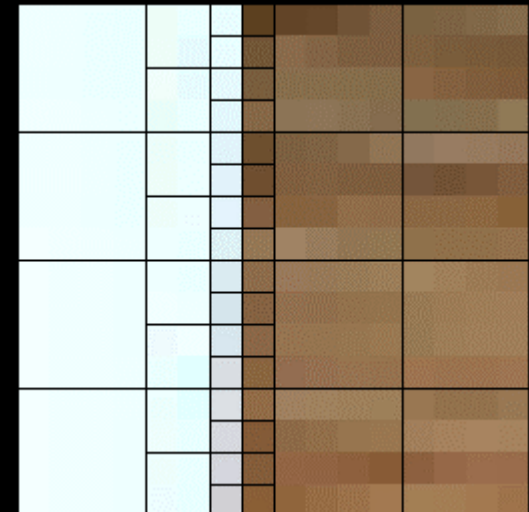
- Divide into max block size (4x4 blocks)





# Image Subdivision

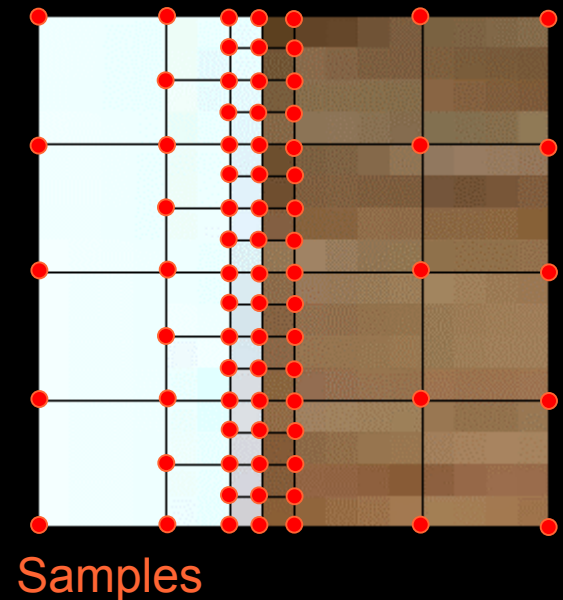
- Divide into max block size (4x4 blocks)
- Trace multiple eye rays per pixel
- Subdivide blocks if needed
  - Based on material, surface normal, and local shadowing configuration





# Image Subdivision

- Divide into max block size (4x4 blocks)
- Trace multiple eye rays per pixel
- Subdivide blocks if needed
  - Based on material, surface normal, and local shadowing configuration
- Compute samples at corners

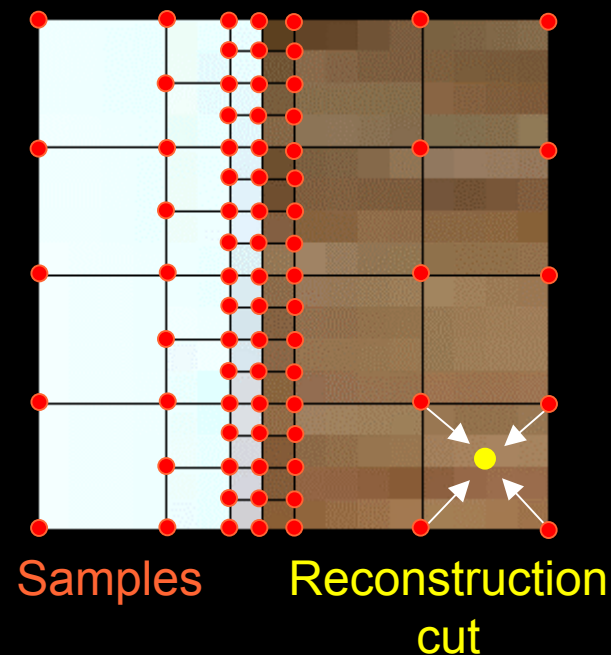




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# Image Subdivision

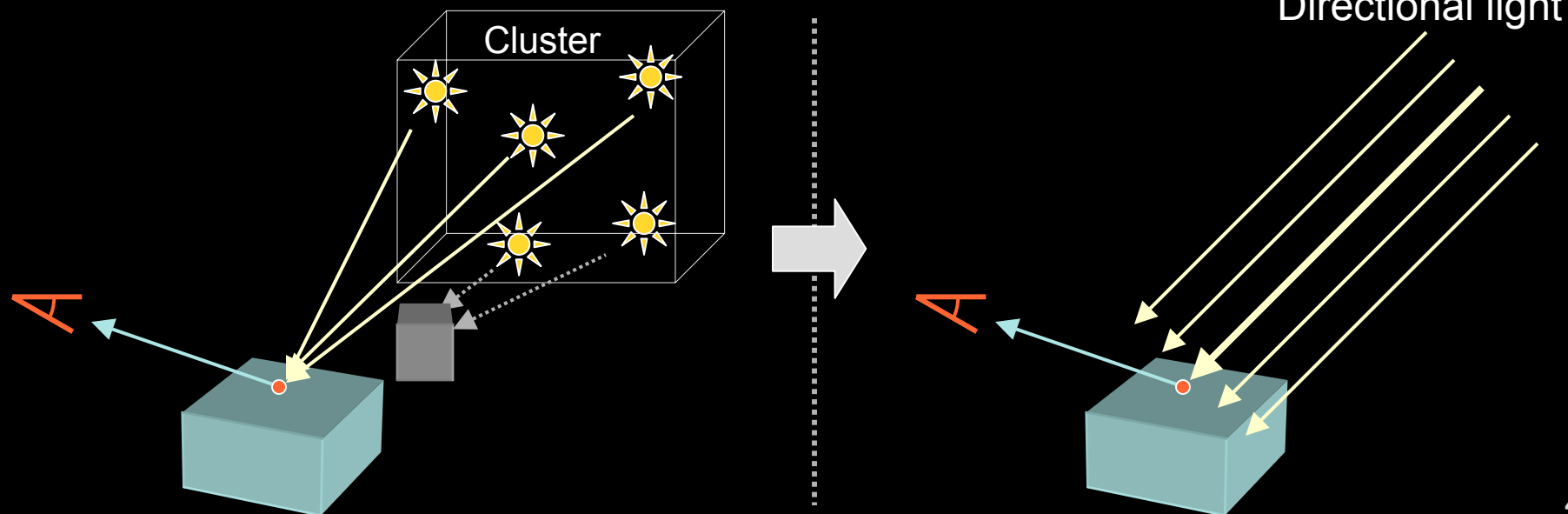
- Divide into max block size (4x4 blocks)
- Trace multiple eye rays per pixel
- Subdivide blocks if needed
  - Based on material, surface normal, and local shadowing configuration
- Compute samples at corners
- Shade eye rays using reconstruction cuts





# Sample Construction

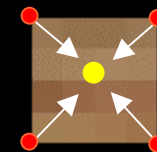
- Compute a lightcut at each sample
- For each node on or above the cut
  - Create impostor light (directional light)
  - Reproduce cluster's effect at sample





# Reconstruction Cut

- Top-down traversal of light tree
  - Comparing impostors from nearby samples



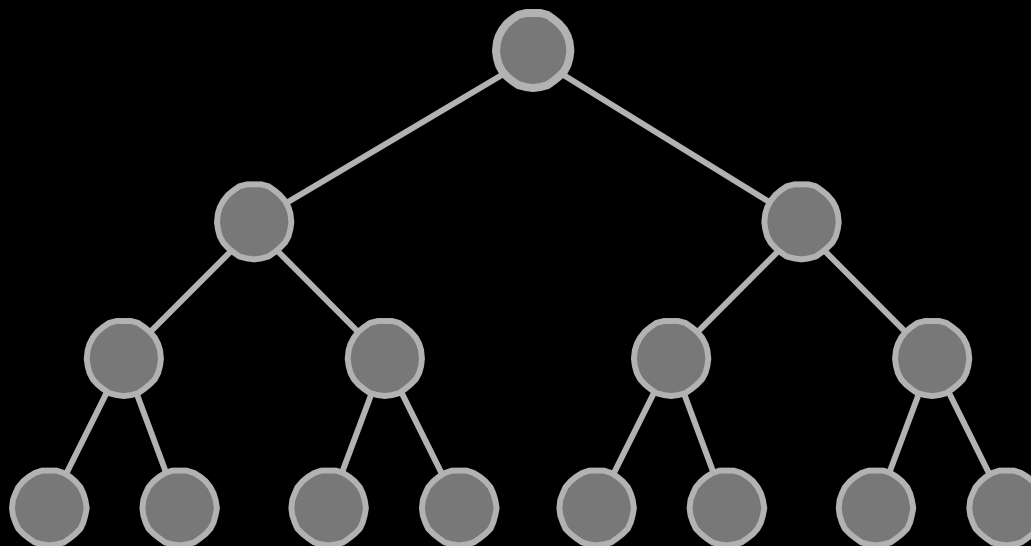
Not visited

Recurse

Occluded

Interpolate

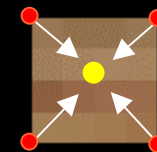
Shadow ray





# Reconstruction Cut

- Recurse if samples differ significantly



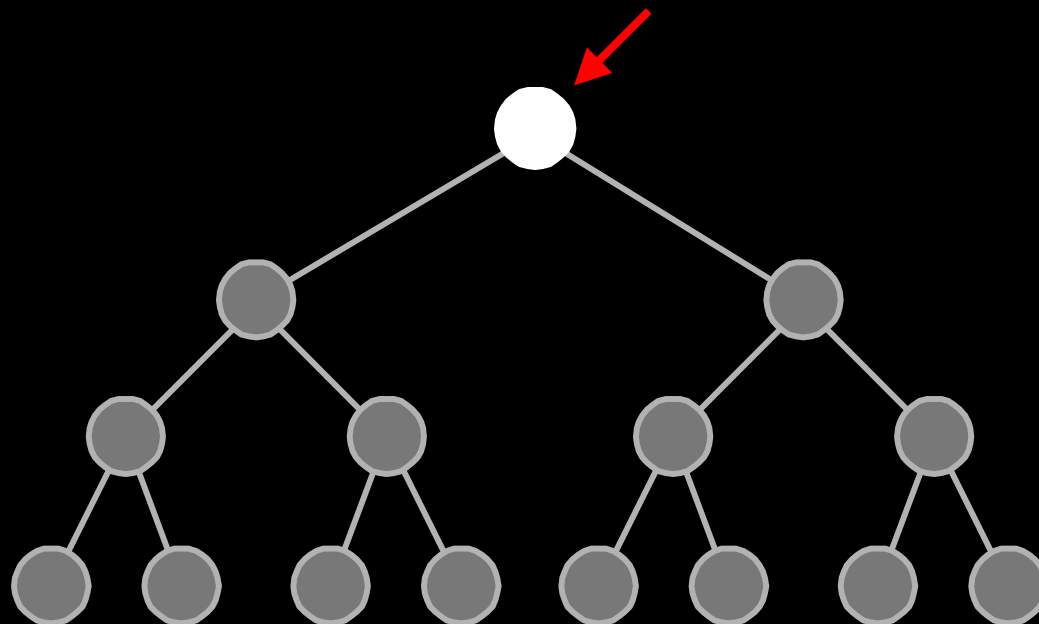
Not visited

Recurse

Occluded

Interpolate

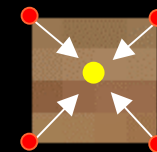
Shadow ray





# Reconstruction Cut

- Discard if cluster occluded at all samples



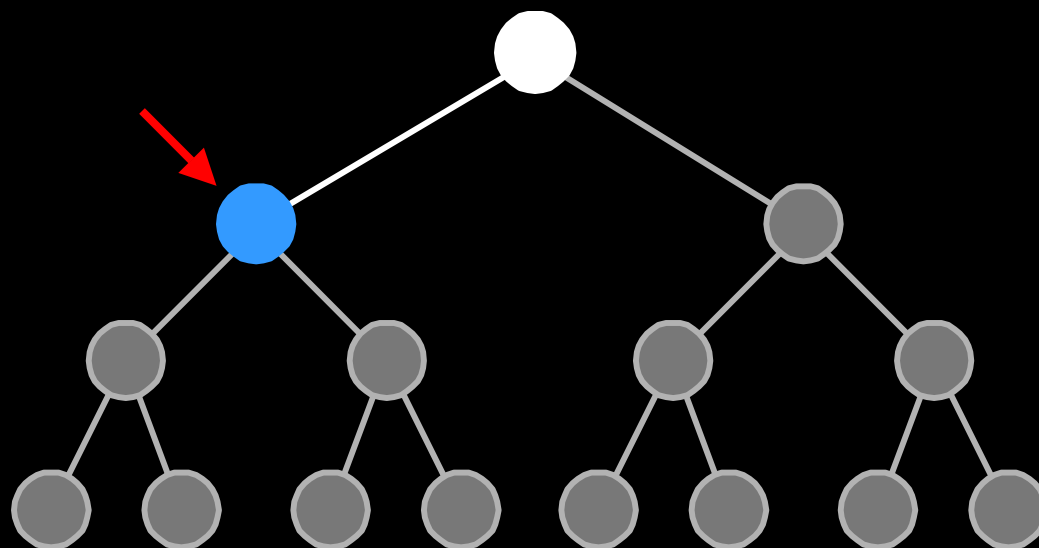
Not visited

Recurse

Occluded

Interpolate

Shadow ray

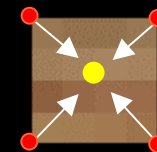






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# Reconstruction Cut



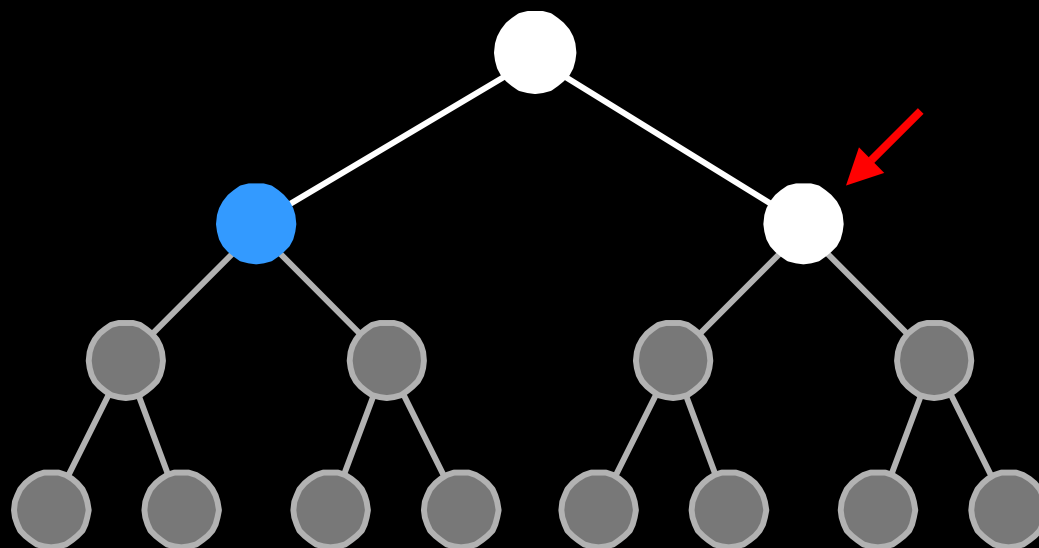
Not visited

Recurse

Occluded

Interpolate

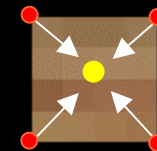
Shadow ray





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# Reconstruction Cut



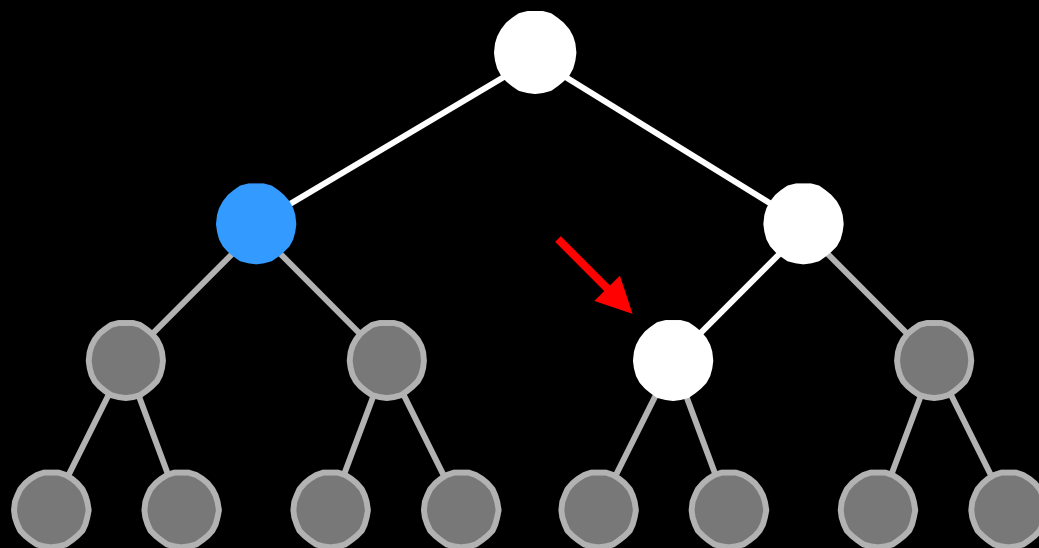
Not visited

Recurse

Occluded

Interpolate

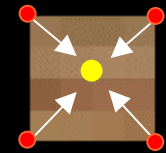
Shadow ray





# Reconstruction Cut

- Interpolate if sample impostors are similar



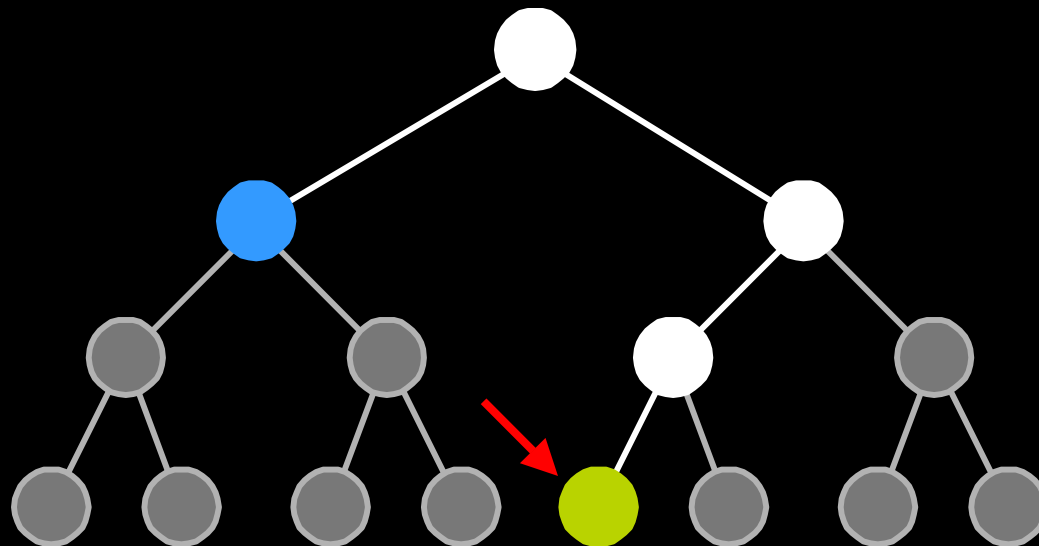
Not visited

Recurse

Occluded

Interpolate

Shadow ray

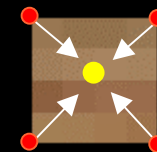




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# Reconstruction Cut

- If cluster contribution small enough, shoot shadow ray to representative light
  - Lightcut-style evaluation



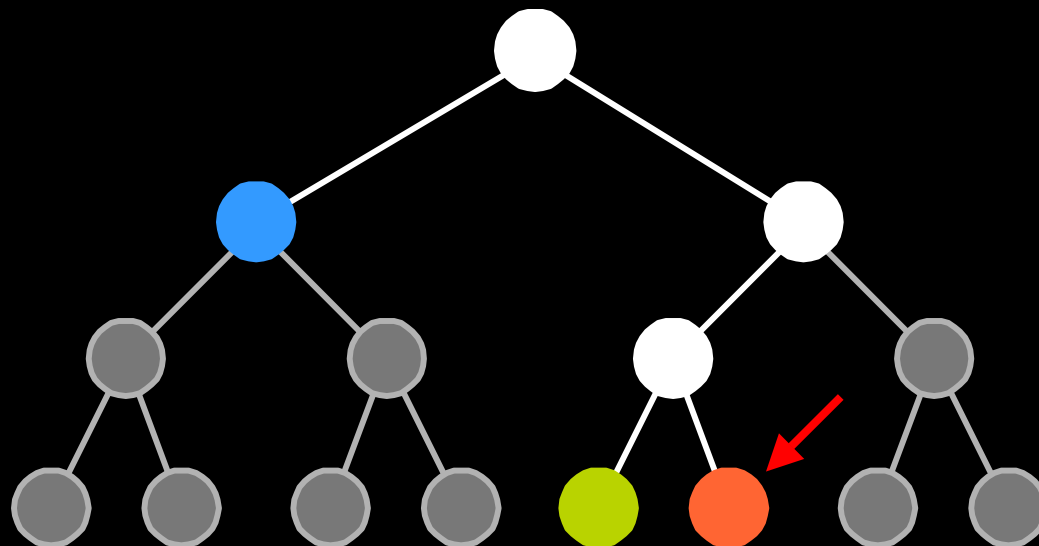
Not visited

Recurse

Occluded

Interpolate

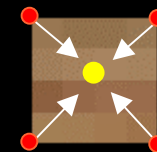
Shadow ray





LIGHTCUTS

# Reconstruction Cut



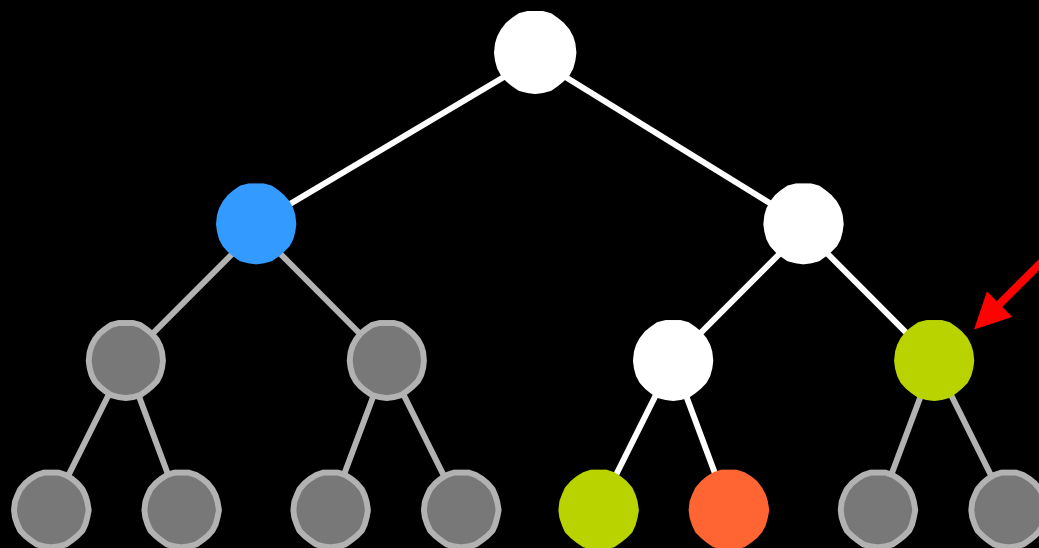
Not visited

Recurse

Occluded

Interpolate

Shadow ray





Temple, 2.1M polygons, 505 064 lights, (Sun/sky+Indirect)



Temple, reconstruction cut block size



# Result Statistics

- Temple model (2.1M polys, 505064 lights)

Cut type	Avg. shadow rays per cut
Lightcut	373
Reconstruction cut	9.4

Image algorithm	Avg. eye rays per pixel	Image time
Lightcuts only	1	225s
Combined (anti-aliased)	5.5	189s





Grand Central, 1.46M polygons, 143464 lights, (Area+Sun/sky+Indirect)

Avg. shadow rays per eye ray 46 (0.03%)



Tableau, 630K polygons, 13 000 lights, (EnvMap+Indirect)

Avg. shadow rays per eye ray 17 (0.13%)



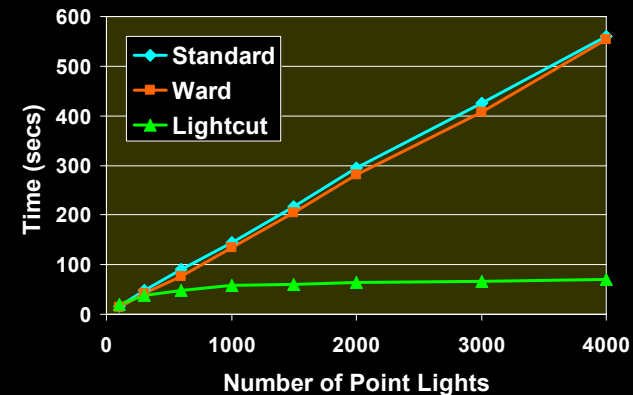
Bigscreen, 628K polygons, 639 528 lights, (Area+Indirect)  
Avg. shadow rays per eye ray 17 (0.003%)



LIGHTCUTS

# Conclusions

- Lightcuts
  - Scalable, unified framework for complex illumination
  - Analytic cluster error bounds & perceptual visibility metric
- Reconstruction cuts
  - Exploits coherence
  - High-resolution, anti-aliased images





LIGHTCUTS

# Future Work

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- Visibility bounds
- More light types
  - Spot lights etc.
- More BRDF types
  - Need cheap tight bounds
- Other illumination types
  - Eg, caustics



# Acknowledgements

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- National Science Foundation grant ACI-0205438
- Intel corporation for support and equipment
- The modelers
  - Kitchen: Jeremiah Fairbanks
  - Bigscreen: Will Stokes
  - Grand Central: Moreno Piccolotto, Yasemin Kologlu, Anne Briggs, Dana Gettman
  - Temple: Veronica Sundstedt, Patrick Ledda, and the graphics group at University of Bristol
  - Stanford and Georgia Tech for Buddha and Horse geometry



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# The End

- Questions?

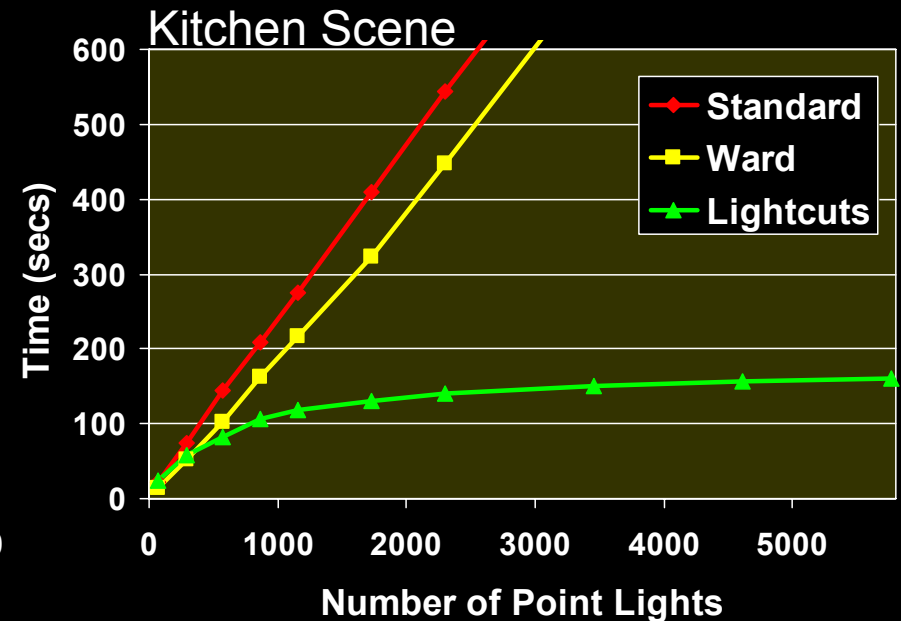
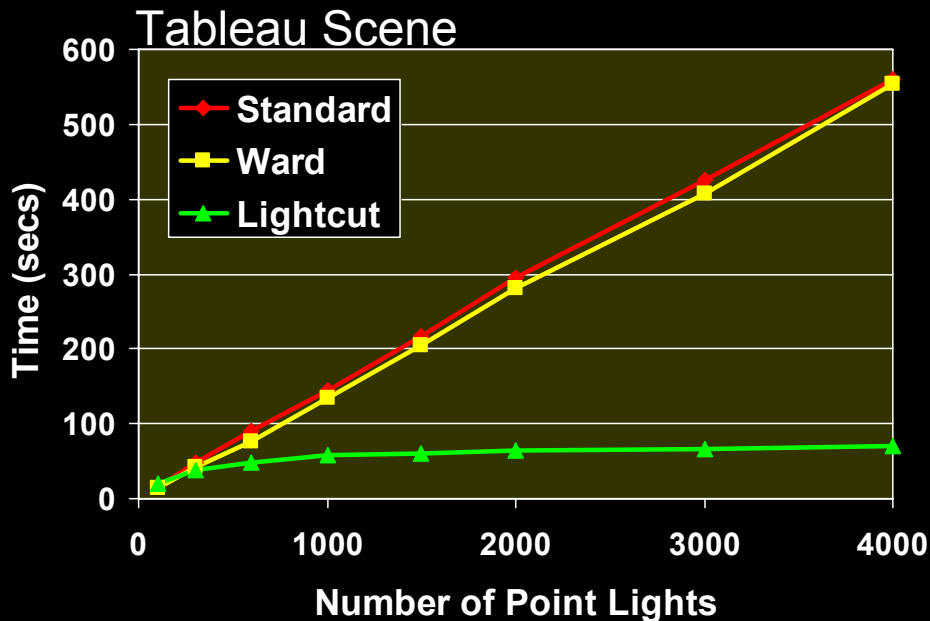


Lightcuts implementation sketch, Petree Hall C, ~4:30pm



# Scalable

- Scalable solution for many point lights
  - Thousands to millions
  - Sub-linear cost





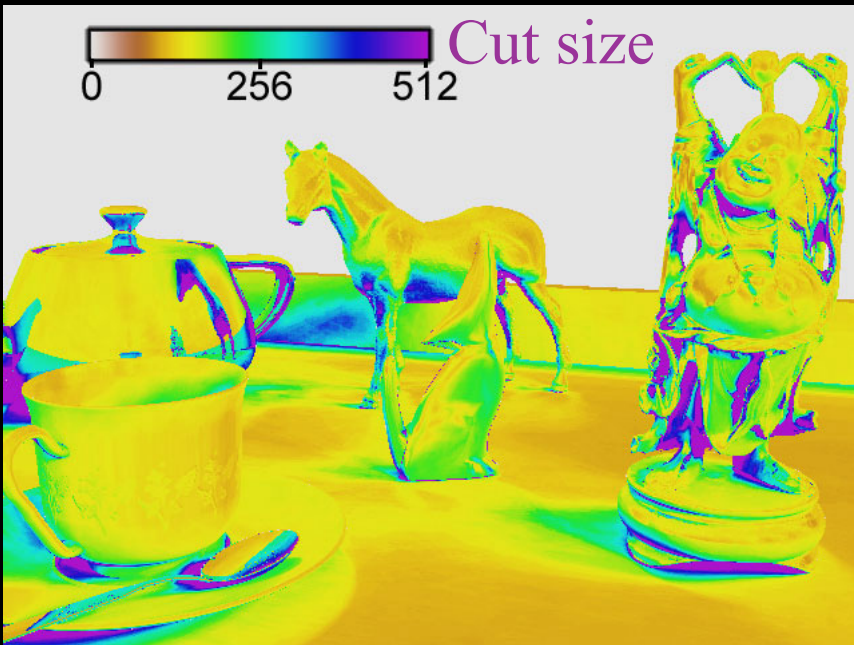
Lightcuts



Reference



Cut size

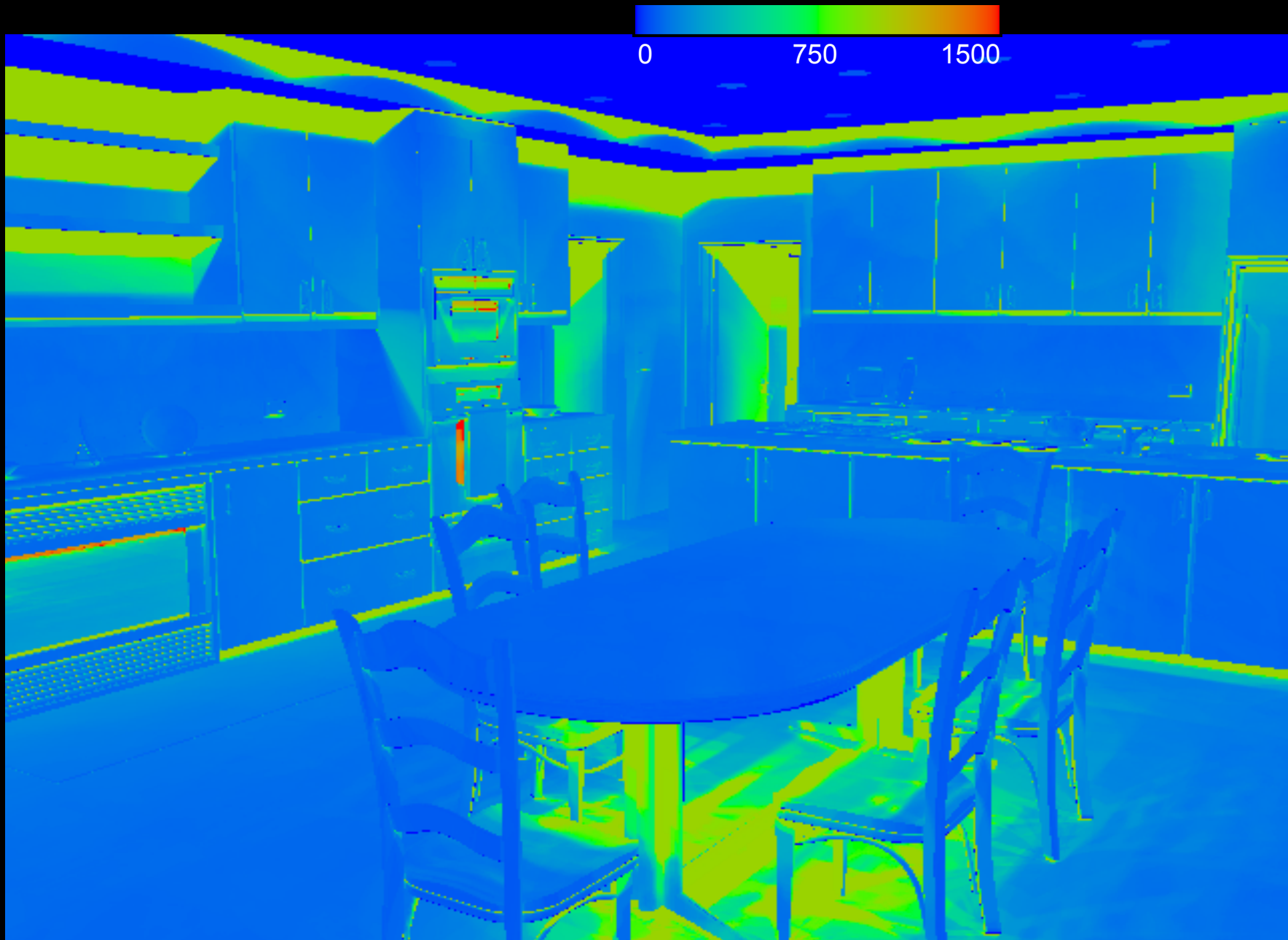


Error x 16





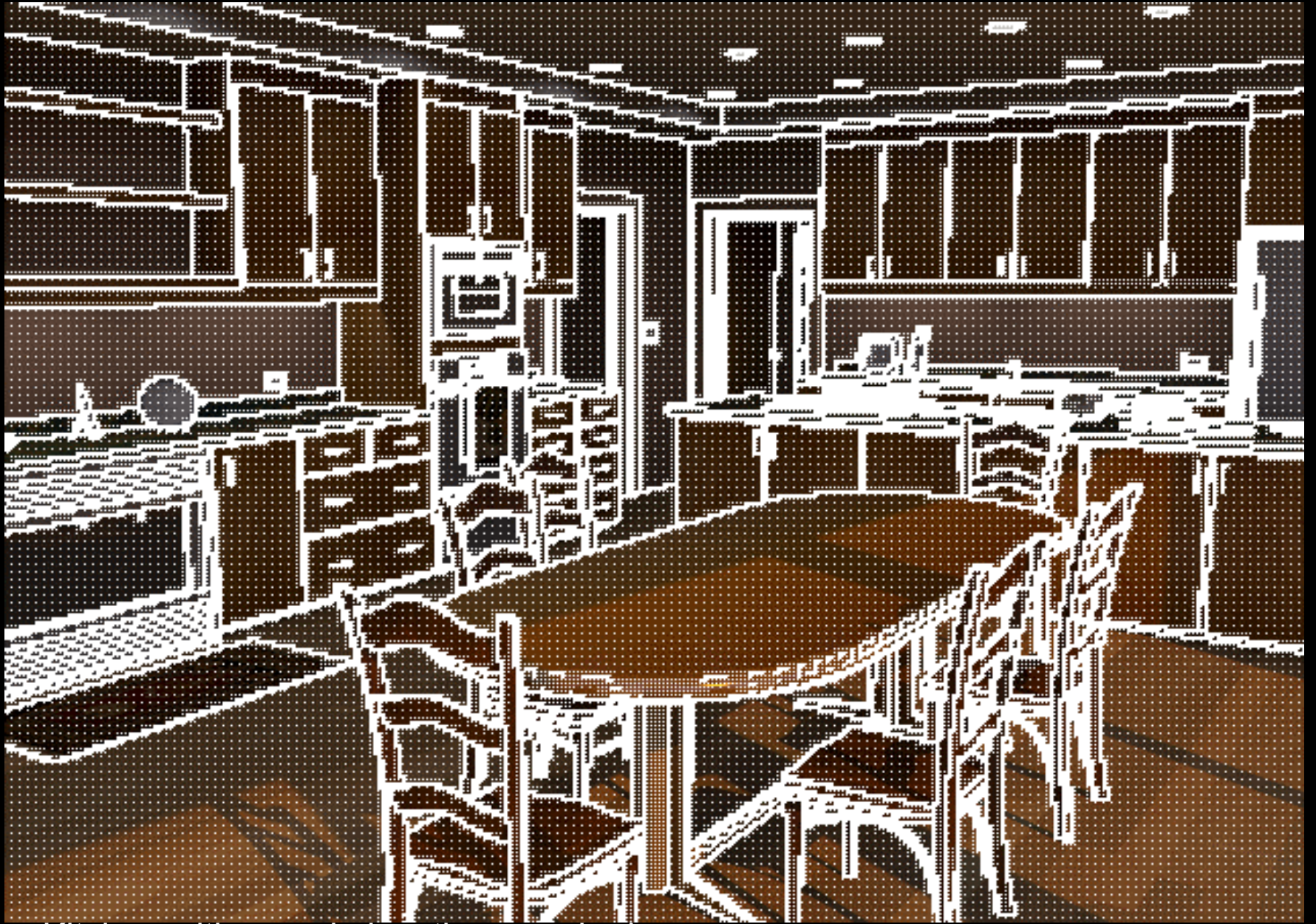
Kitchen, 388K polygons, 59,672 Lights



Kitchen, shadow ray false color



Tableau, shadow ray false color



Kitchen with sample locations marked



# Types of Point Lights

- Omni
  - Spherical lights
- Oriented
  - Area lights, indirect lights
- Directional
  - HDR env maps, sun&sky

