



# Effects of Global Illumination Approximations on Material Appearance

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# Global illumination rendering

- Required for accurate appearance, but slow



scene: Autodesk | rendering: Edgar Velázquez-Armendáriz

# Global illumination rendering

- Fast GI algorithms are inaccurate



scene: Autodesk | rendering: Edgar Velázquez-Armendáriz



# Overview

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- VPL rendering (Instant Radiosity [*Keller 1997*])
  - Fast & popular
  - Image artifacts & energy losses
  
- Impact of VPL rendering on visual fidelity
  - Systematic perceptual study

# Related work

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- Perceptually-based rendering
  - Visible Difference Predictor  
*[Mitchell 87, Bolin and Meyer 95/98, Myszkowski 02, ...]*
  - Illumination components  
*[Stokes et al. 04; Debattista et al 05]*
  - Higher-level processing  
*[Yee et al. 01, O'Sullivan et al. 04]*
  - Material appearance  
*[Pellacini et al. 00; Westlund and Meyer 01; Fleming et al. 03; Khan et al. 06; Vangorp et al. 07/08]*
  - Visual Equivalence *[Ramanarayanan et al. 2007] ...*

# Related work – Visual equivalence

- Visually equivalent =
  - Same scene appearance
  - Visibly different



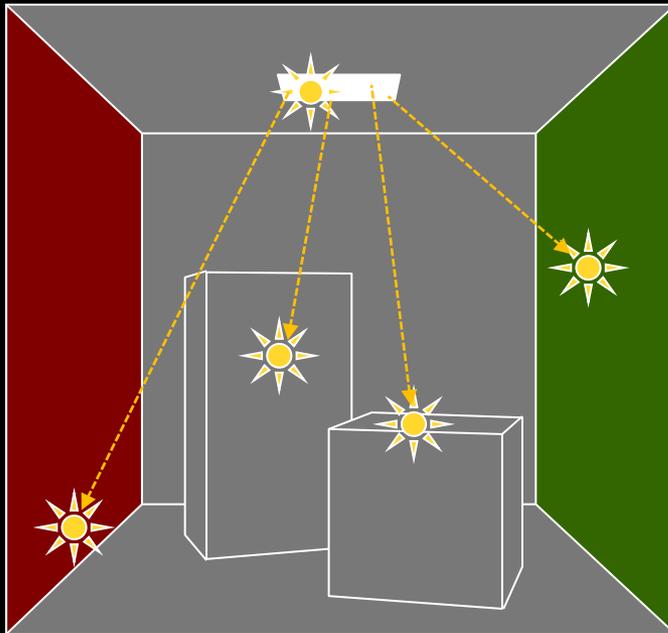
- Foundation of our work
  - Apply visual equivalence to VPL rendering

# Related work – VPL rendering

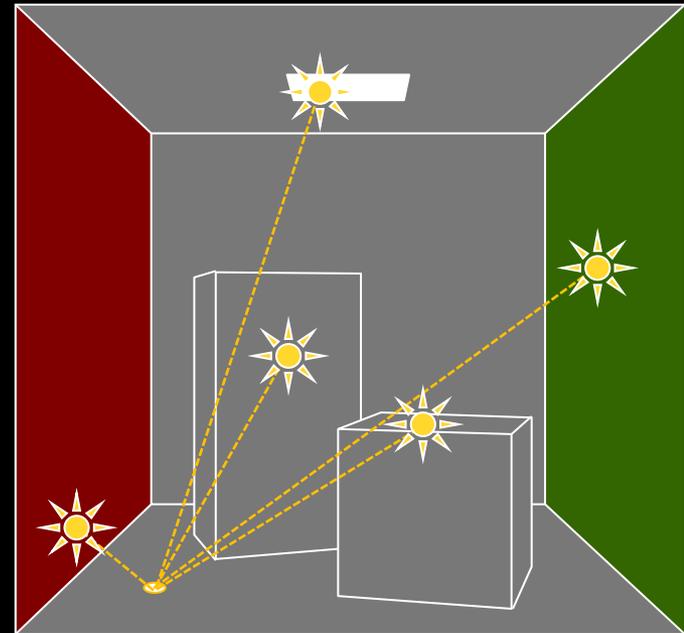
- Based on Instant Radiosity [Keller 1997]
- Approximate indirect illumination by

## Virtual Point Lights (VPLs)

### 1. Generate VPLs



### 2. Render with VPLs



# Related work – VPL rendering

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1. Interactive GI ( $\approx 1,000$  VPLs)

*[Wald et al. 02; Segovia et al. 07; Laine et al. 07; Ritschel et al. 08; Dong et al. 09; Yu et al. 09; ...]*

2. Preview-quality ( $\approx 100,000$  VPLs)

*[Hašan et al. 07/09]*

3. High-quality ( $> 1,000,000$  VPLs)

*[Walter et al. 05/06]*

# VPL rendering is fast, but...



**artifacts**

**material change**



# VPLs for high-fidelity rendering

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- **Q:** When do VPL methods produce high-fidelity renderings?
- **A:** Systematic perceptual study
  - trade-offs : VPL parameters vs. visual fidelity



material  
change

clamping level

visible  
artifacts



# VPL rendering parameters

- VPL count
- clamping level

visible artifacts

VPL count

slow rendering



material  
change

clamping level

visible  
artifacts



# VPL rendering parameters

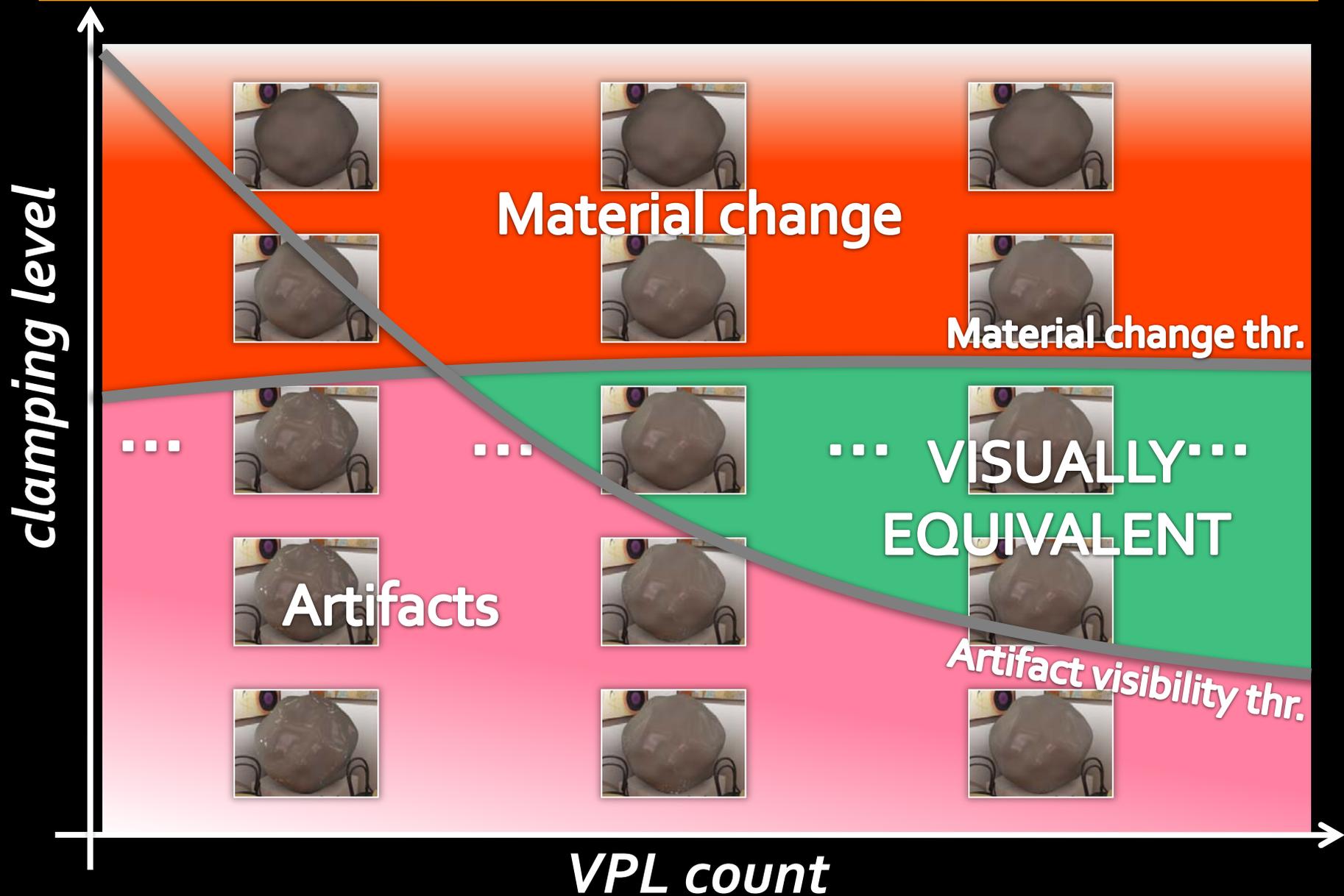
- VPL count
- clamping level

visible artifacts

VPL count

slow rendering

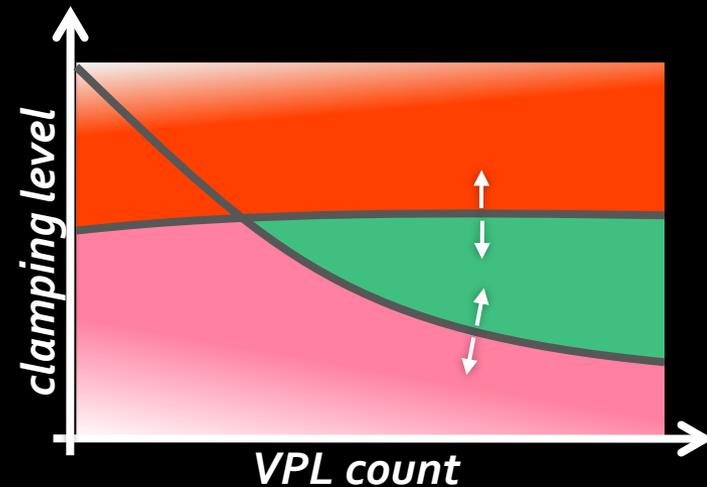
# Space of rendering parameters



# Psychophysical experiments

- How are the thresholds affected by

- shape complexity?
- material?
- illumination?



- Outline

- Experiment design
- Results & validation
- Applications

# Test objects – Shape complexity



- Same as [Ramanarayanan et al. 07]
- G0 ... sphere
- G1-G3 ... bumpy spherical objects

# Test objects – Materials



Metal  
Smooth

Metal  
Rough

Dielectric  
Black  
Smooth

Dielectric  
Black  
Rough

Dielectric  
Gray  
Smooth

Ward-Dür BRDF:  $\rho_s$   $\alpha$   $\rho_d$

# Test objects – Materials



Metal  
Smooth

Metal  
Rough

Dielectric  
Black  
Smooth

Dielectric  
Black  
Rough

Dielectric  
Gray  
Smooth

$\rho_s$  0.22

0.033

Ward-Dür BRDF:  $\rho_s$   $\alpha$   $\rho_d$

specular reflectivity

# Test objects – Materials



Metal  
Smooth

Metal  
Rough

Dielectric  
Black  
Smooth

Dielectric  
Black  
Rough

Dielectric  
Gray  
Smooth

$\alpha$  0.05

0.15

$\rho_s$  0.22

0.033

Ward-Dür BRDF:  $\rho_s$   $\alpha$   $\rho_d$

surface roughness

# Test objects – Materials



Metal  
Smooth

Metal  
Rough

Dielectric  
Black  
Smooth

Dielectric  
Black  
Rough

Dielectric  
Gray  
Smooth

$\rho_d$

0.03

0.19

$\alpha$

0.05

0.15

$\rho_s$

0.22

0.033

Ward-Dür BRDF:  $\rho_s$   $\alpha$   $\rho_d$  diffuse reflectivity

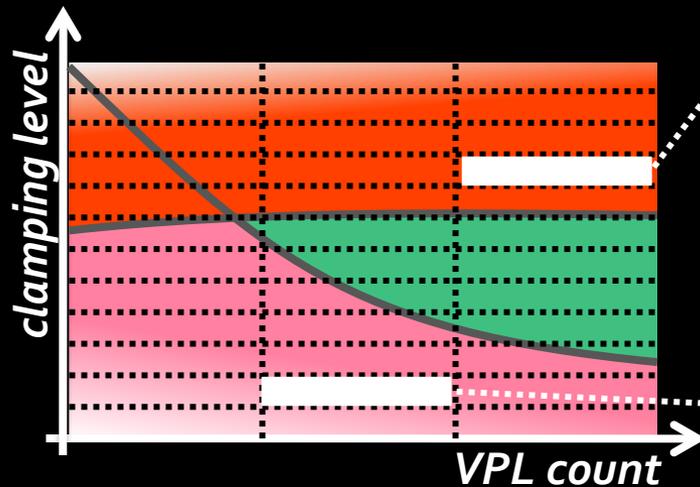
# Scene

- Art gallery café
- Studied object on a pedestal



# Stimulus images

- Different VPL rendering parameters
  - 3 VPL counts
  - 11 clamping levels



# Stimulus images – VPL count

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1,000 (1k)

Interactive  
rendering



100,000 (100k)

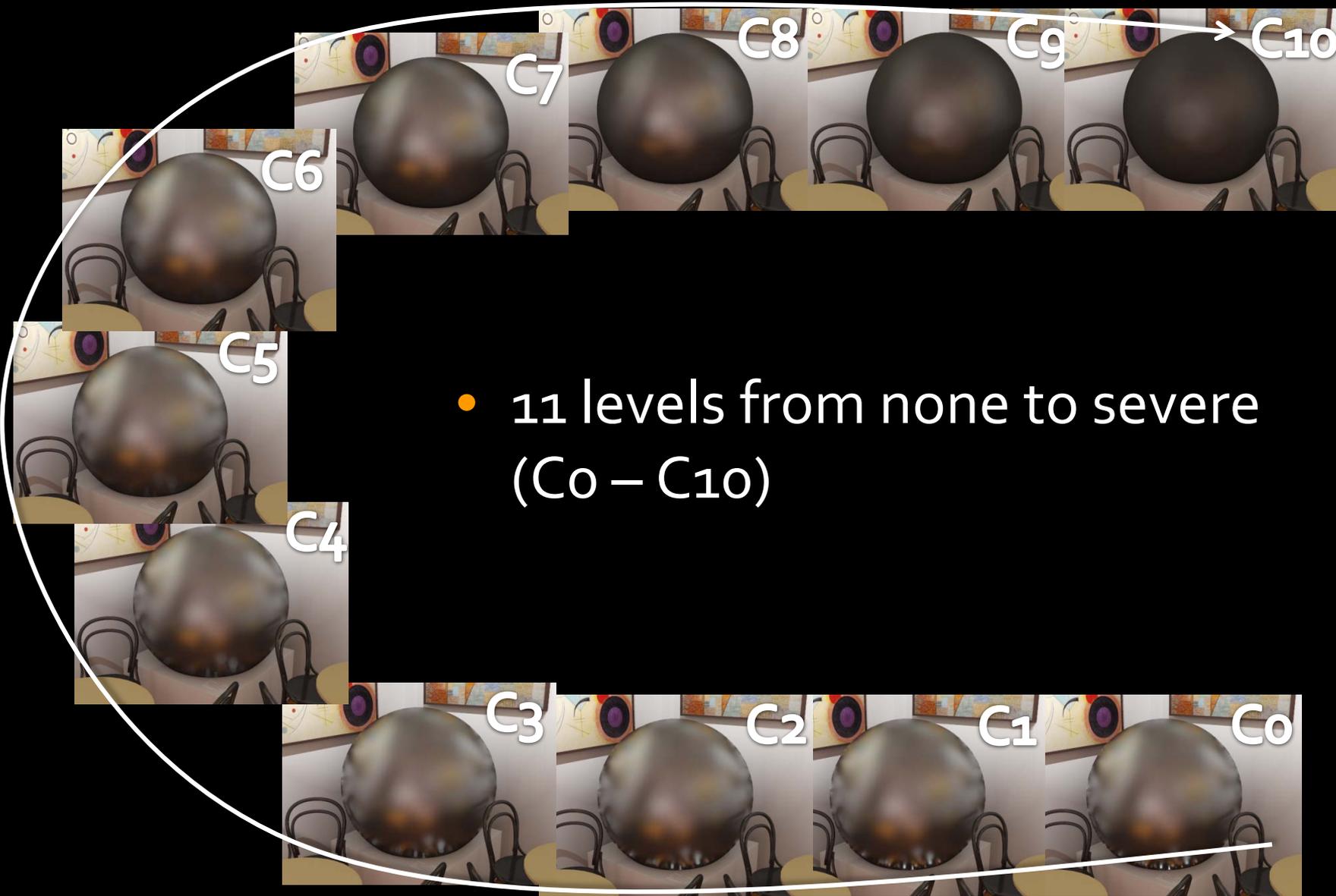
Preview-quality  
rendering



5,000,000 (5M)

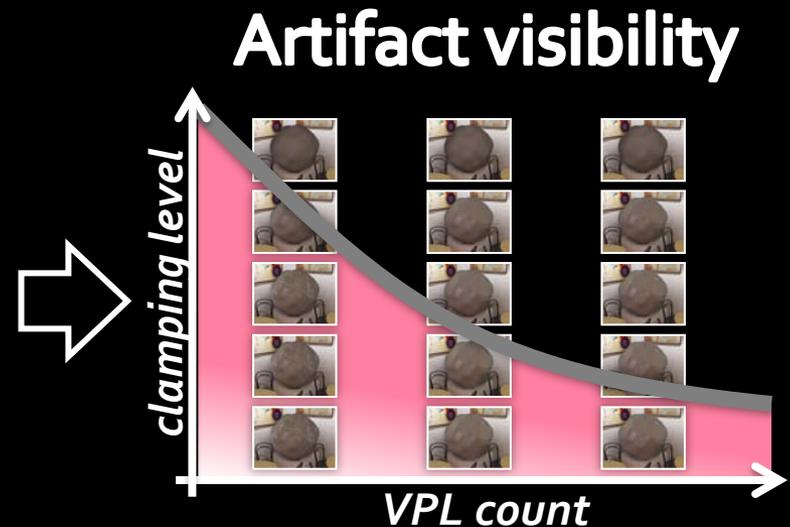
High-quality  
rendering

# Stimulus images – Clamping level



# Experiment 1: Artifact visibility

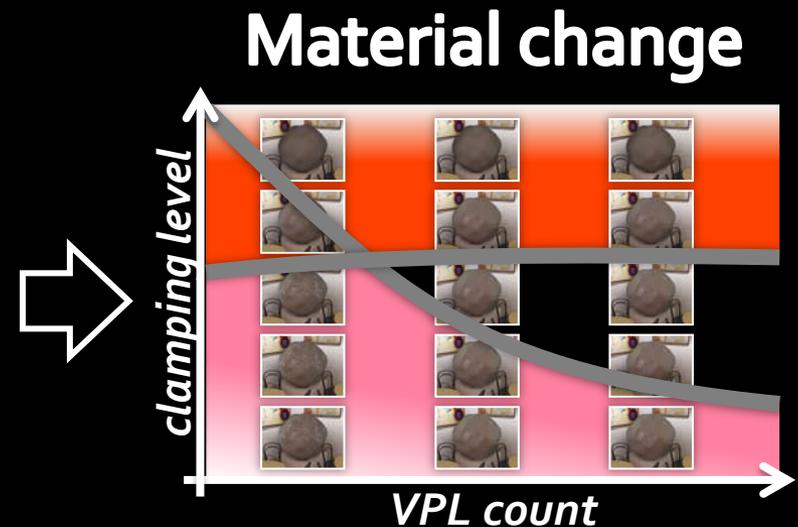
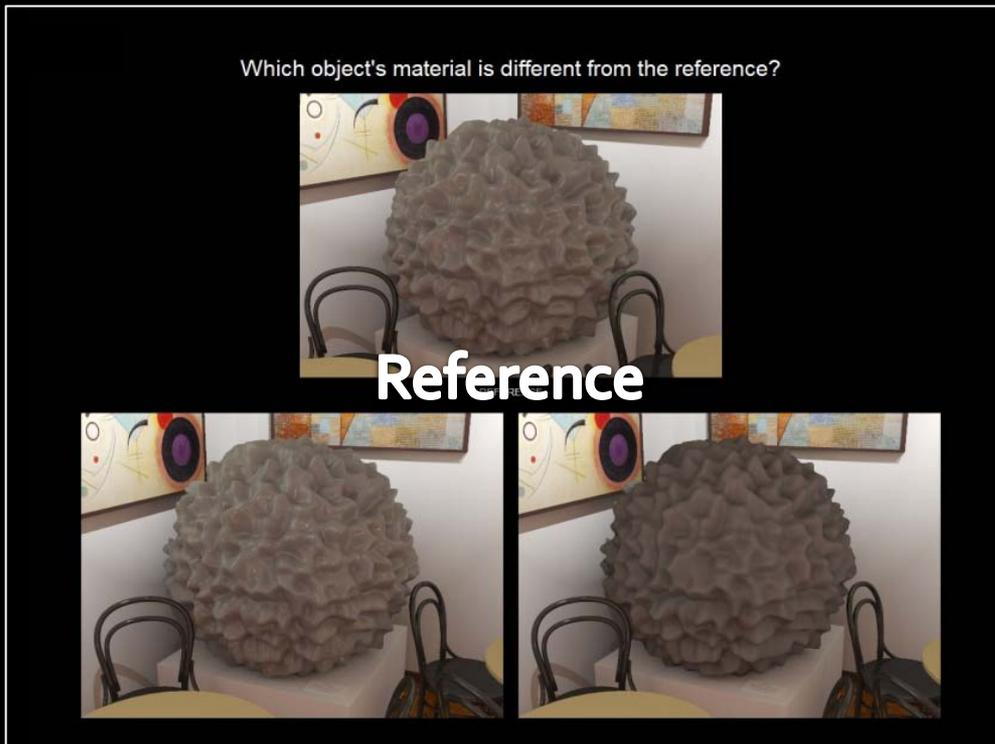
Select the image that has the artifacts.



- Standard two-alternative forced choice method
- 480 trials, 12 participants

# Experiment 2: Material change

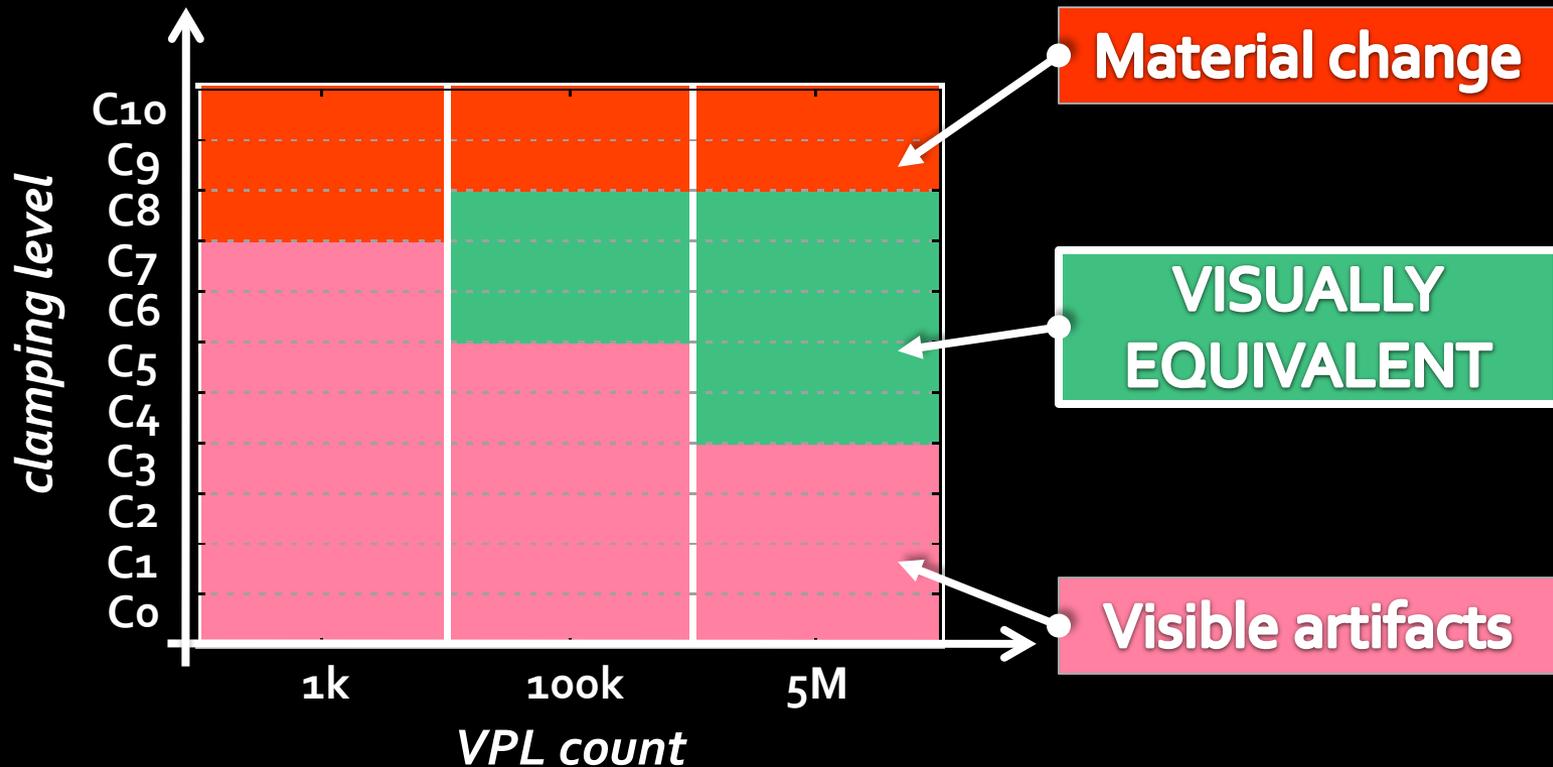
Which object's material is different from the reference?



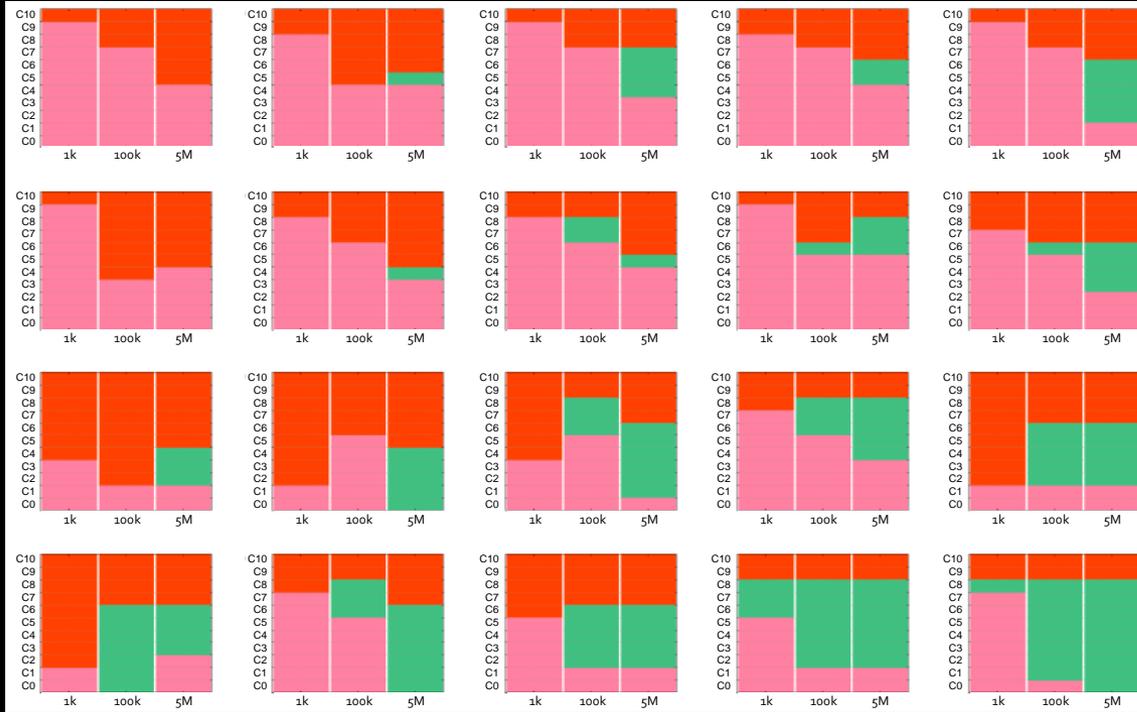
- Standard two-alternative forced choice method
- 520 trials, 14 participants

# Data analysis

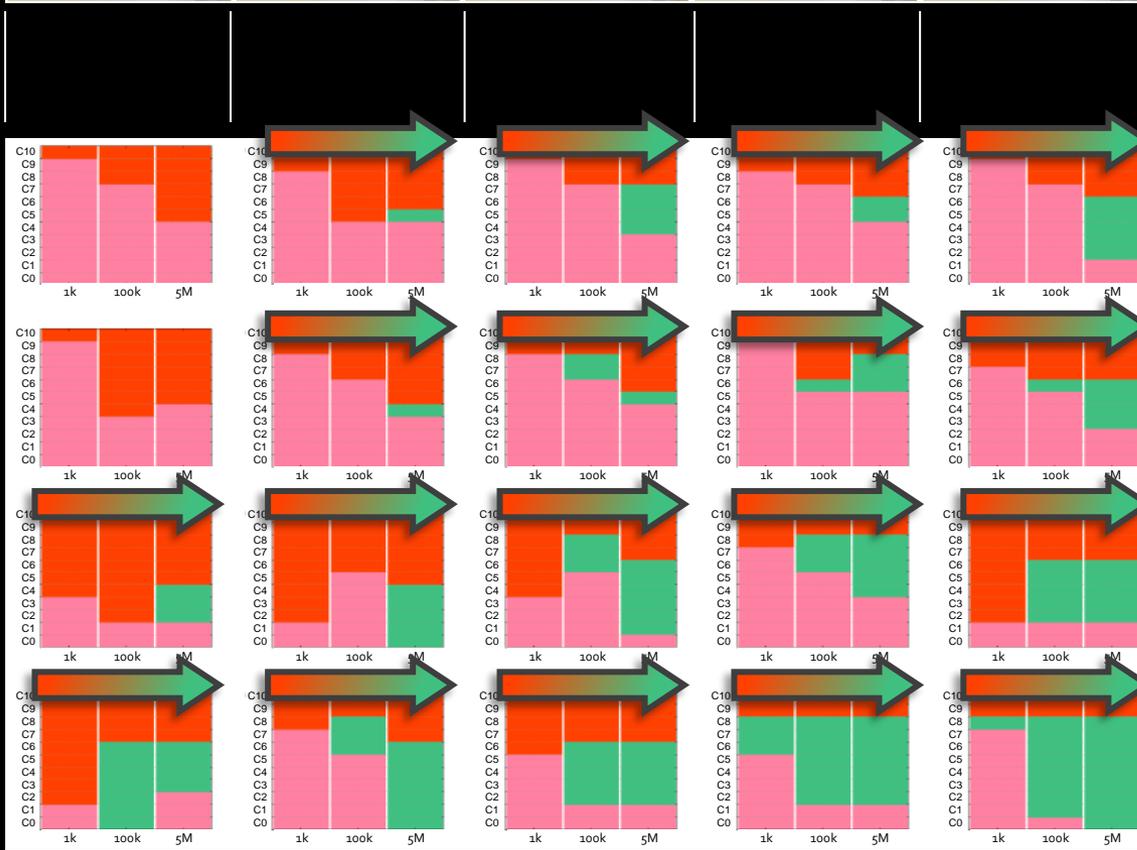
- Extract thresholds from subjects' answers
  - Standard 75% 2 AFC threshold criterion



# Experiment results

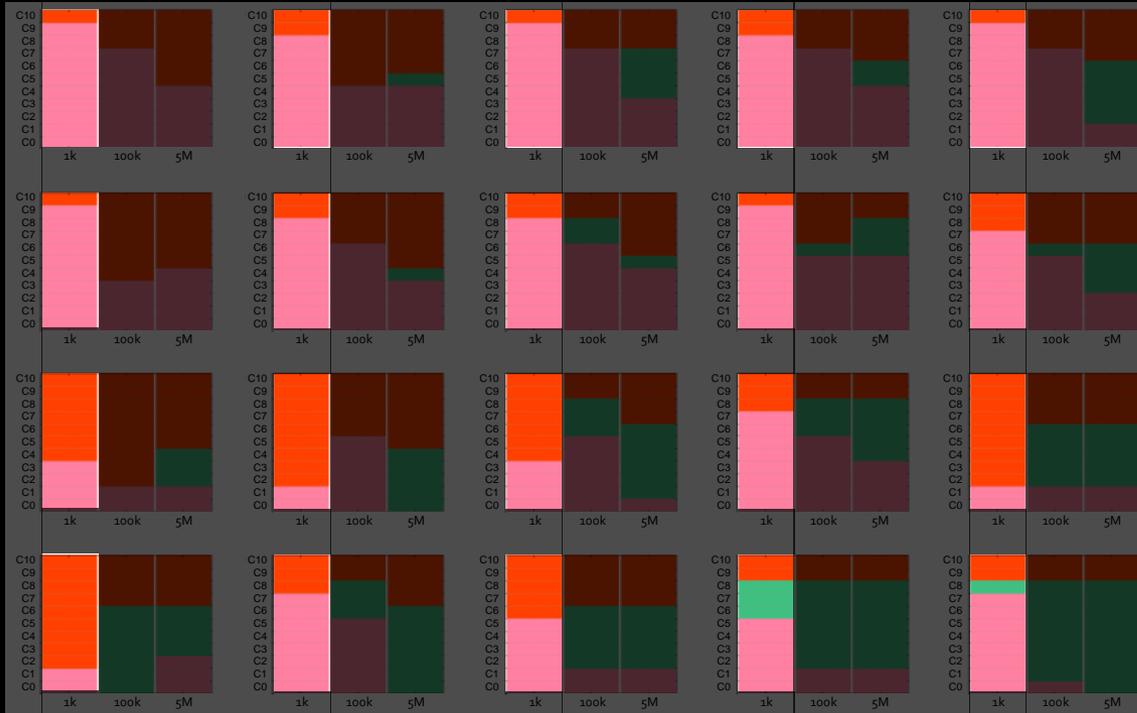


# Trends – VPL count



# Trends – VPL count

1k  
VPLs

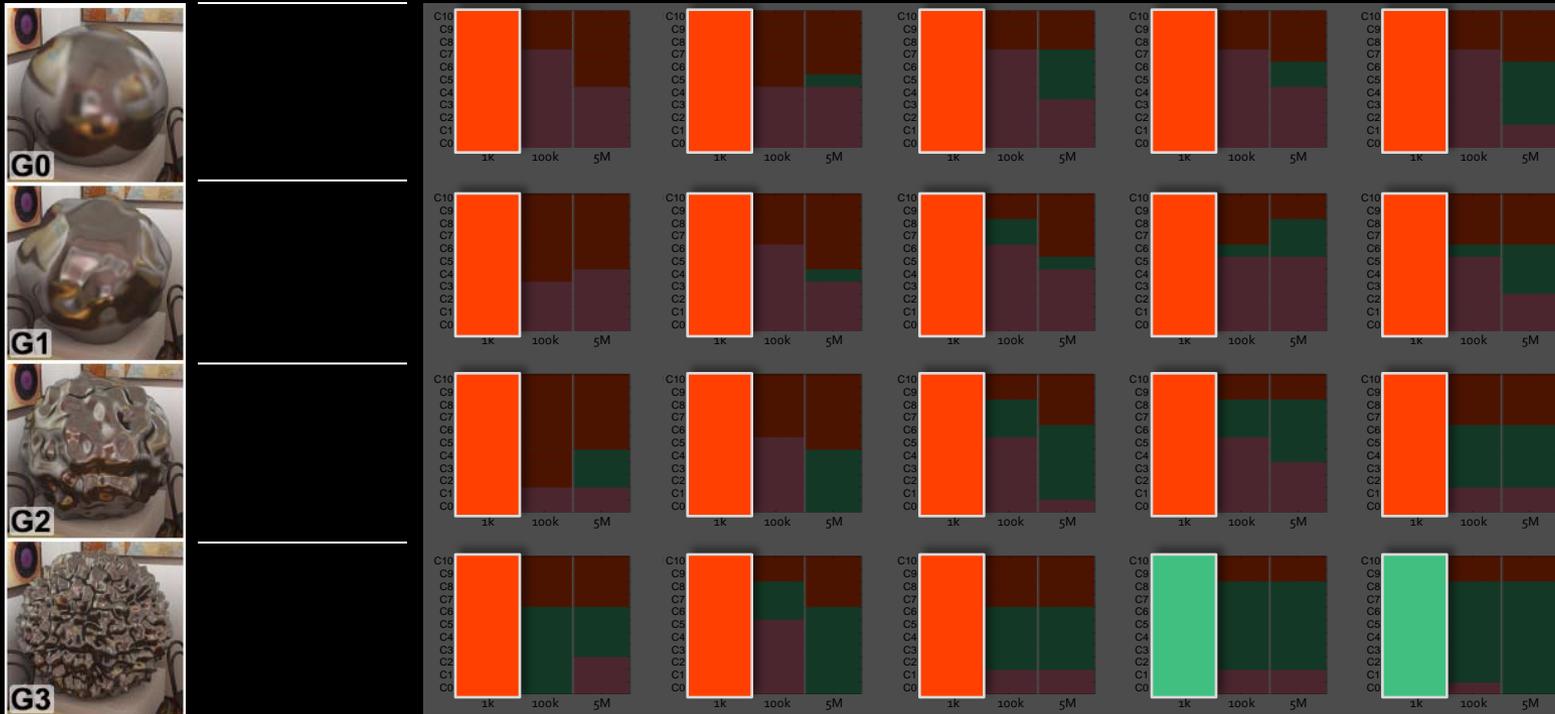


# Trends – VPL count

1k  
VPLs

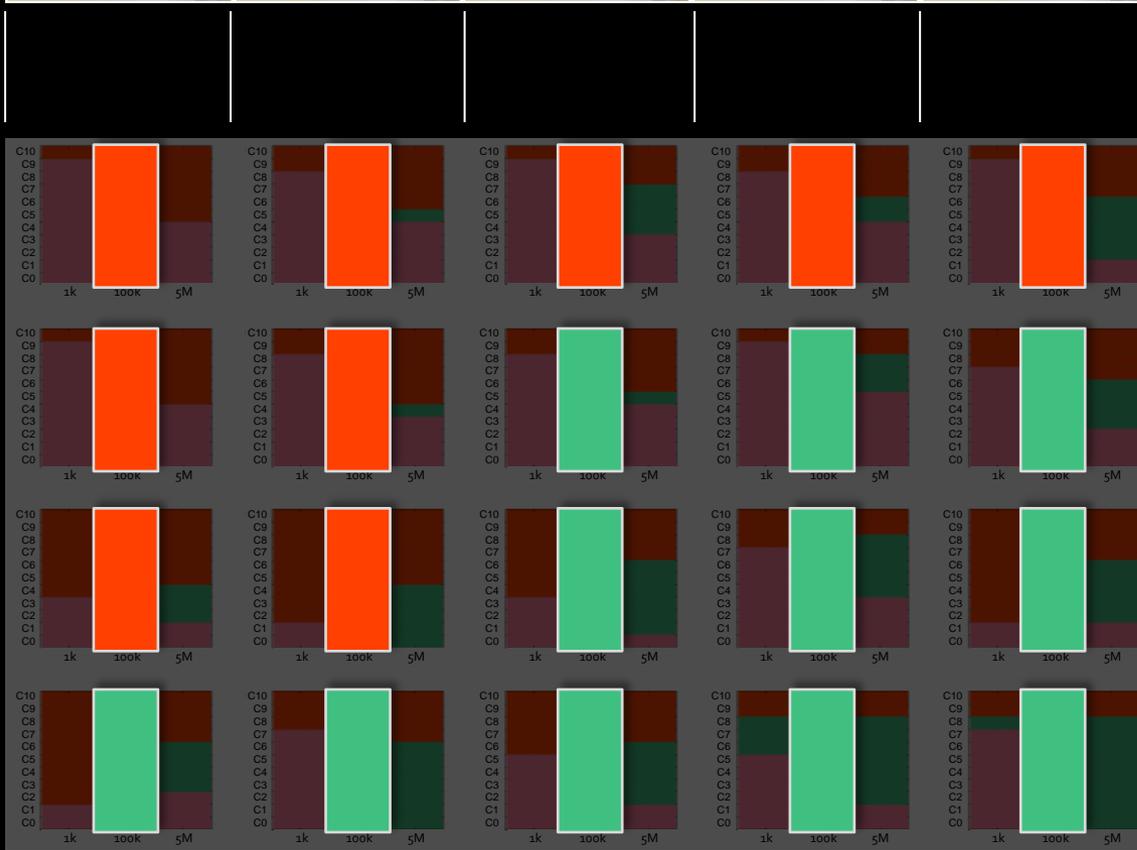


... mostly insufficient



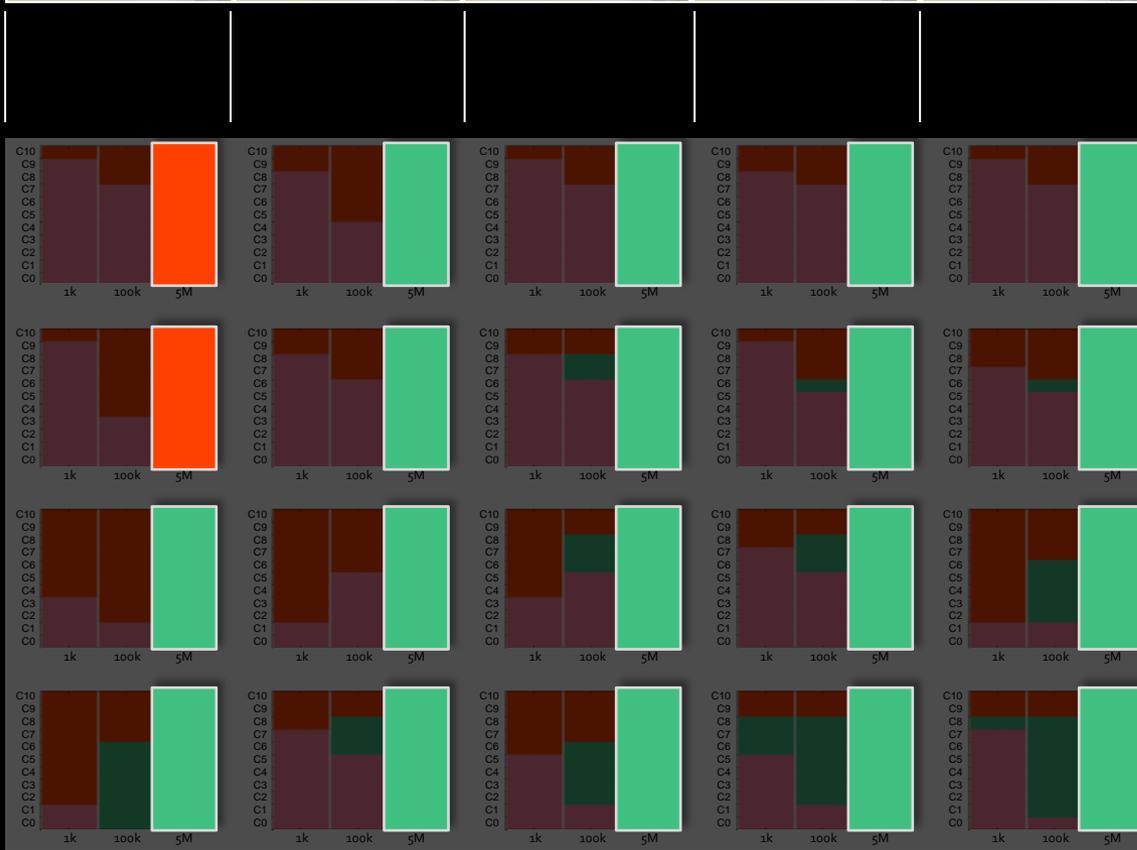
# Trends – VPL count

100k  
VPLs



# Trends – VPL count

5M  
VPLs



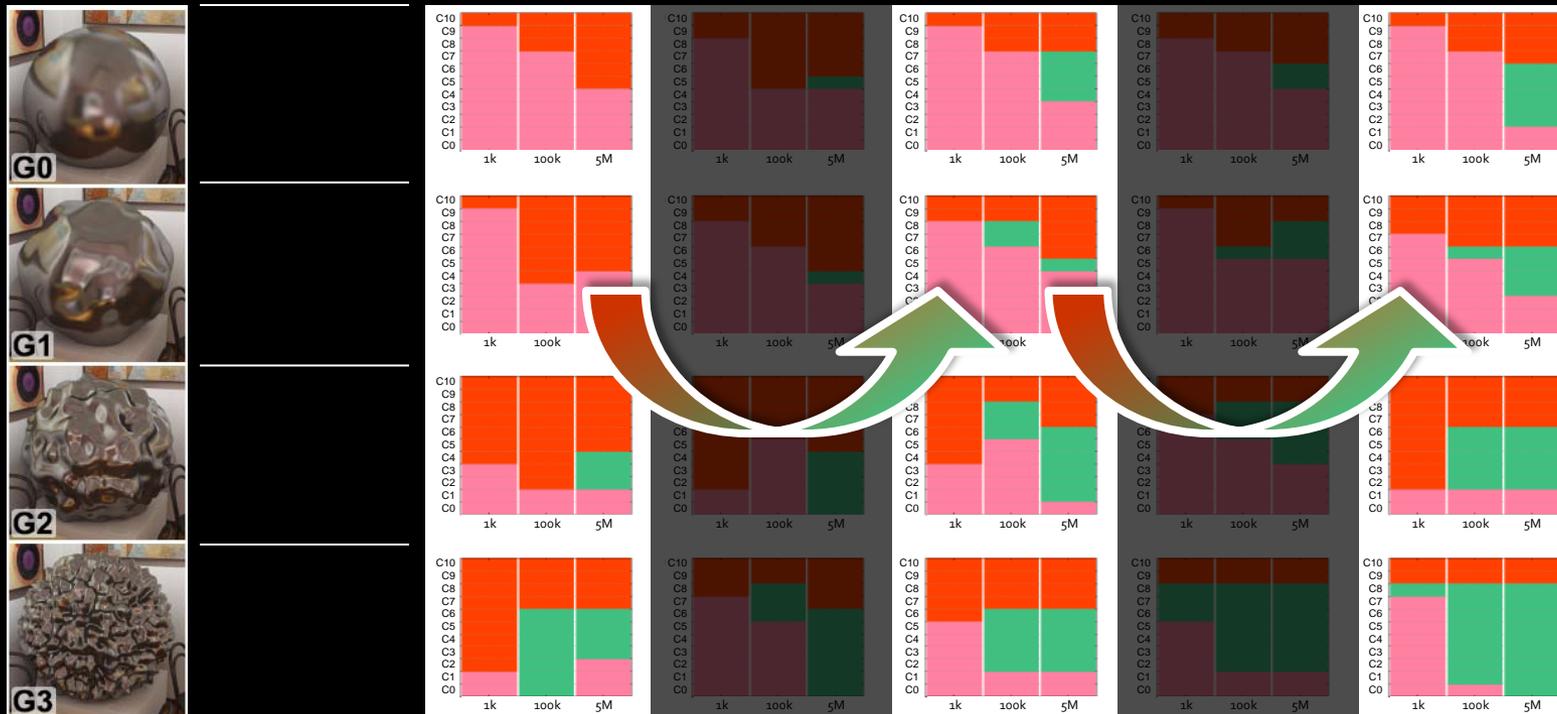
# Trends – Material contrast gloss



contrast gloss:

$\rho_s \downarrow$

$\rho_d \uparrow$

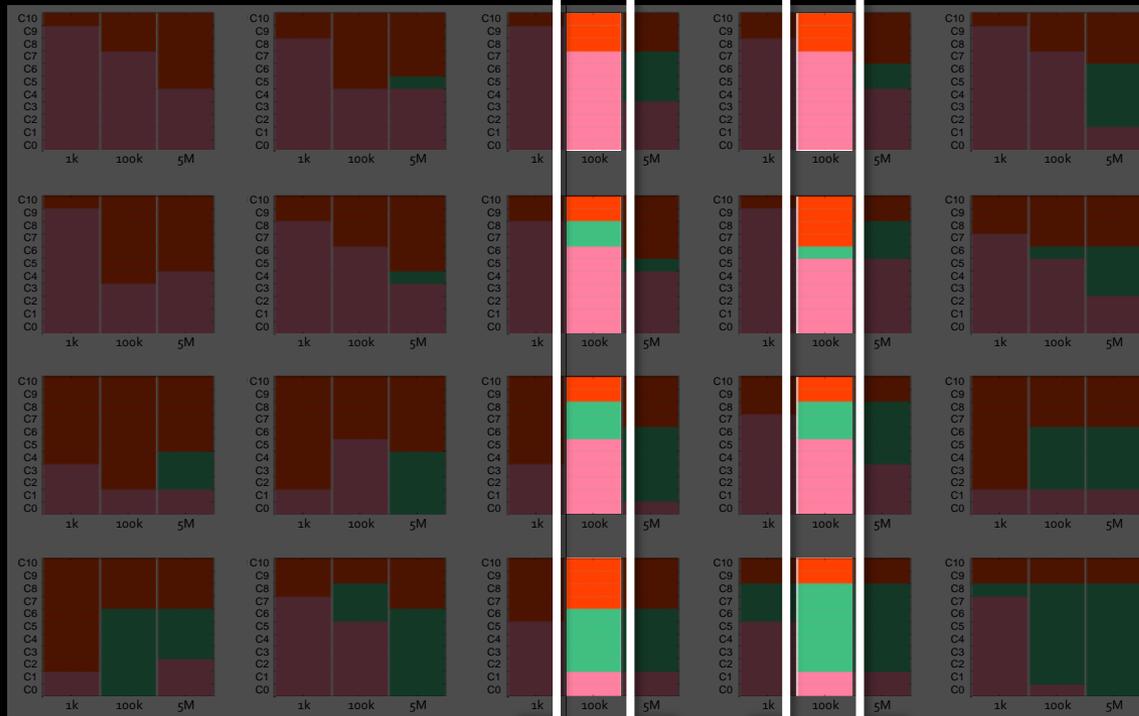


lower contrast gloss → greater equivalence

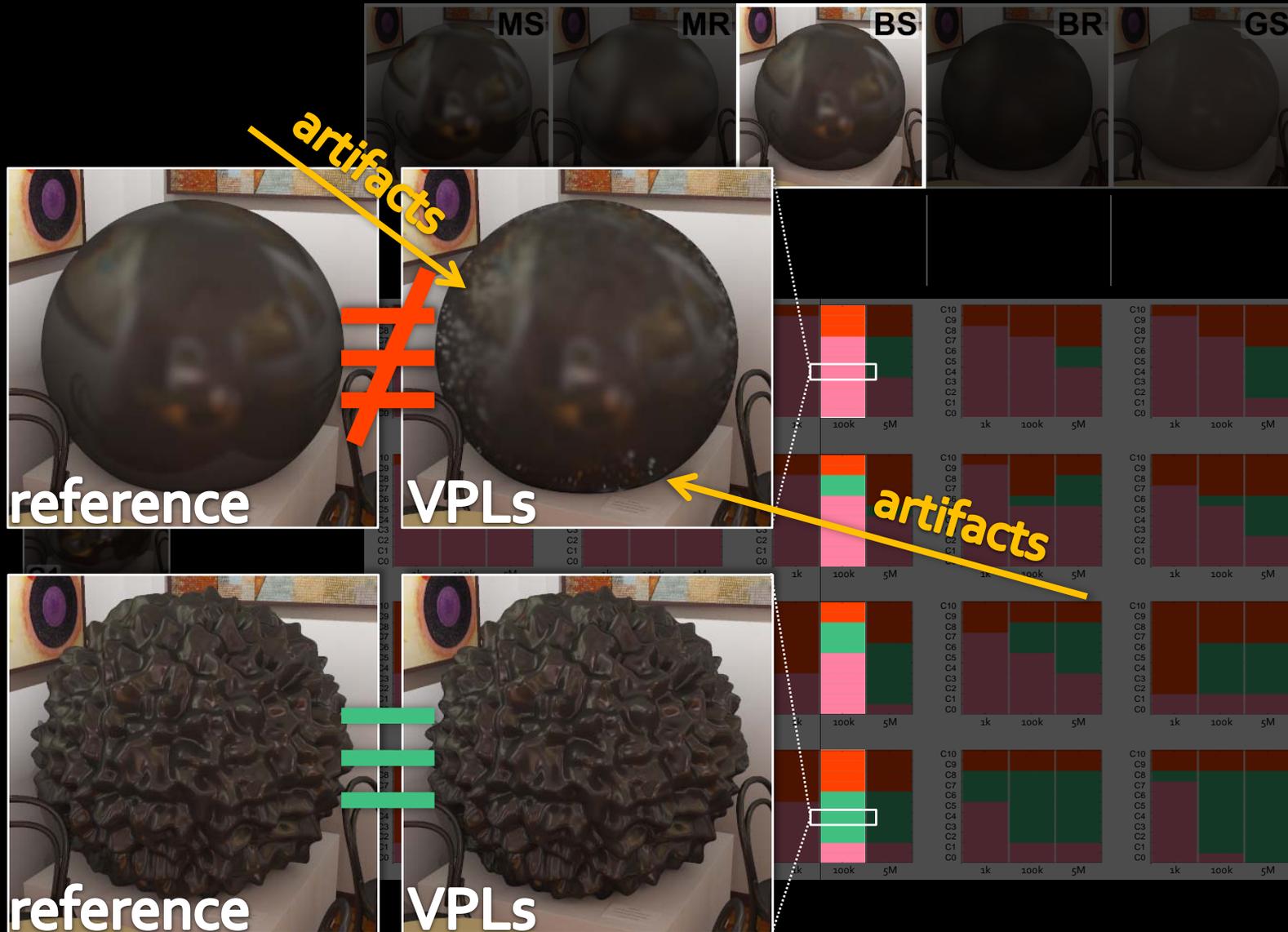
# Trends – Shape complexity



complex shape → greater equivalence

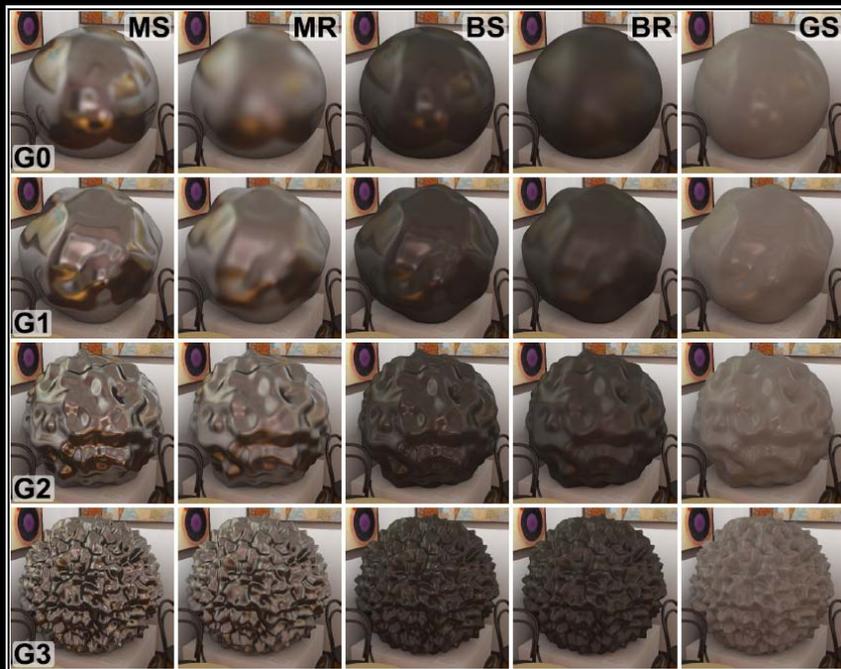


# Trends – Shape complexity

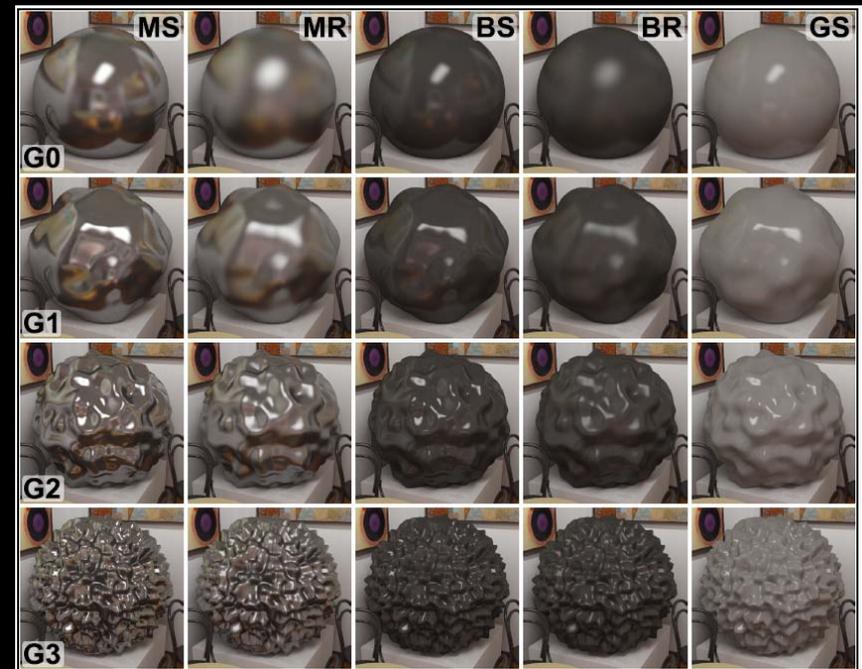


# Trends – Illumination

- Does accurate direct illumination help preserve material appearance?
  - No significant improvement measured
  - Further investigation needed



indirect-only



direct-and-indirect

# Validation

1. Real-world geometry
  - Trends confirmed



2. New material (diffuse)



- Most forgiving material
- Need more than 1k VPL to achieve equivalence



# Applications

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- Per-object clamping
- Luminance normalization

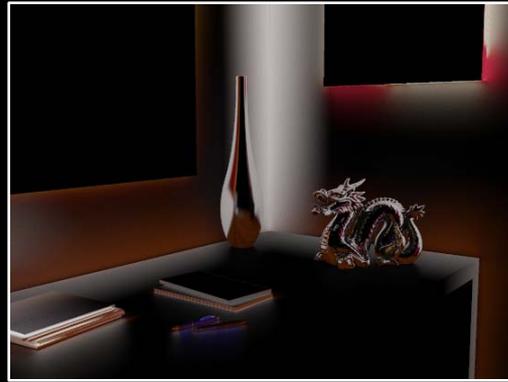
# Application – Per-object clamping

- Energy compensation [Kollig & Keller 04]



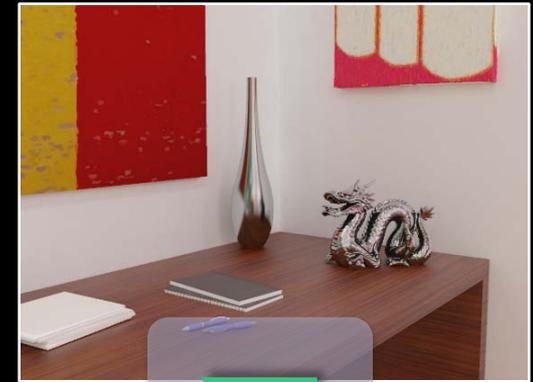
clamping (VPL)

+



compensation (PT)

=



+



=



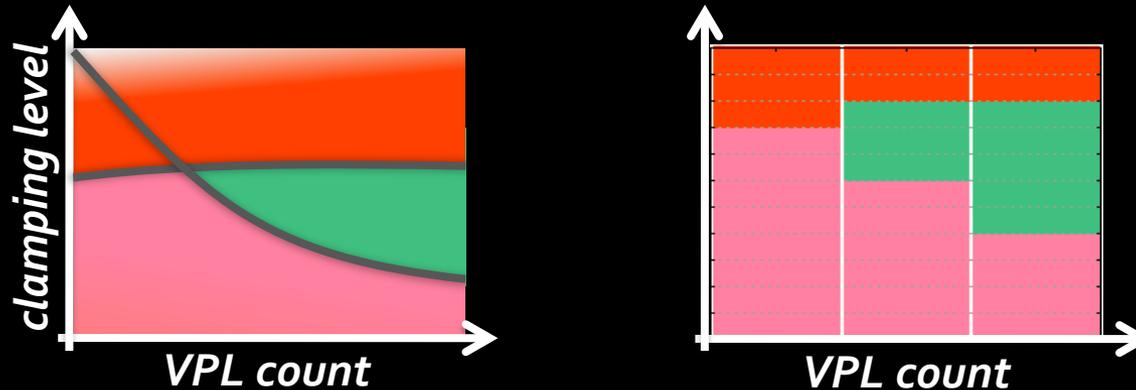
Less clamping for  
diffuse &  
complex objects



Less work,  
2x speedup

# Summary of results

- Visual equivalence in space of VPL parameters



- Trends in equivalence
  - VPL count
  - Shape complexity
  - Contrast gloss decrease



# Conclusions

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- Adequacy of VPL methods for high fidelity rendering
- Take-home messages
  - VPL methods produce equivalent renderings for a wide range of scene settings
  - 1k VPLs used in interactive apps → no equivalence
  - Smooth metal & simple shape → no equivalence
- Solid perceptual foundation for VPL methods



# Future work

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- Model for visual equivalence in VPL rendering
- Effects of accurate direct illumination
  - Ambiguity between artifacts and highlights
- Scalable & equivalent VPL methods

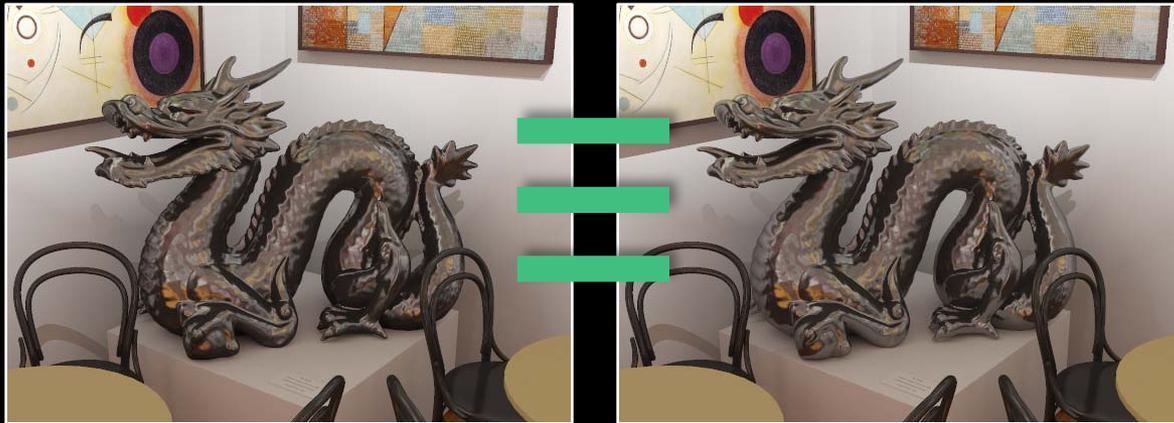
# Acknowledgements

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- NSF CAREER 0644175
- NSF CPA 0811680
- Intel
- Microsoft
  
- Experiment participants

# Thank you

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# Additional Slides

# Ambiguity: highlights vs. artifacts

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highlights  
or artifacts?



**indirect-only**



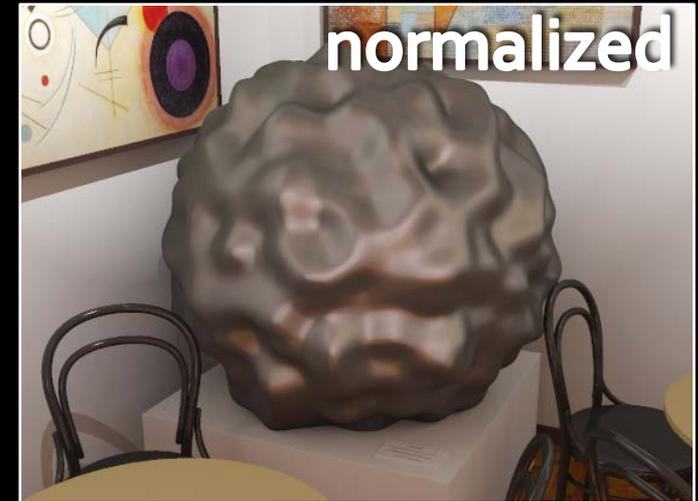
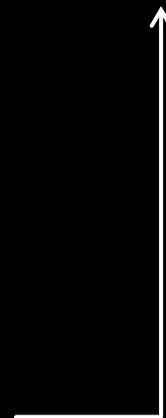
**direct-and-indirect**

# Apps: Luminance normalization

- Re-introduce energy removed by clamping



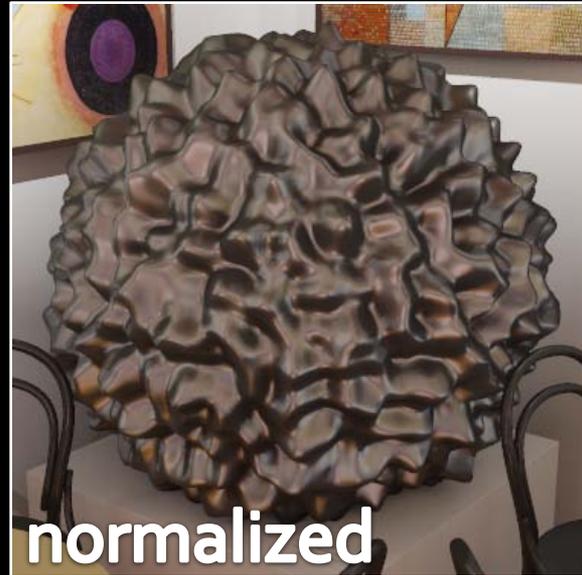
match avg.  
luminance



- Validation
  - Can increase equivalence

# Apps: Luminance normalization

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# Trends – Material roughness



rougher → greater equivalence

