Effects of Global Illumination Approximations on Material Appearance

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Global illumination rendering

- Required for accurate appearance, but slow

Global illumination rendering

- Fast GI algorithms are inaccurate

Overview

- VPL rendering (Instant Radiosity *[Keller 1997]*)
  - Fast & popular
  - Image artifacts & energy losses

- Impact of VPL rendering on visual fidelity
  - Systematic perceptual study

Related work

- 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

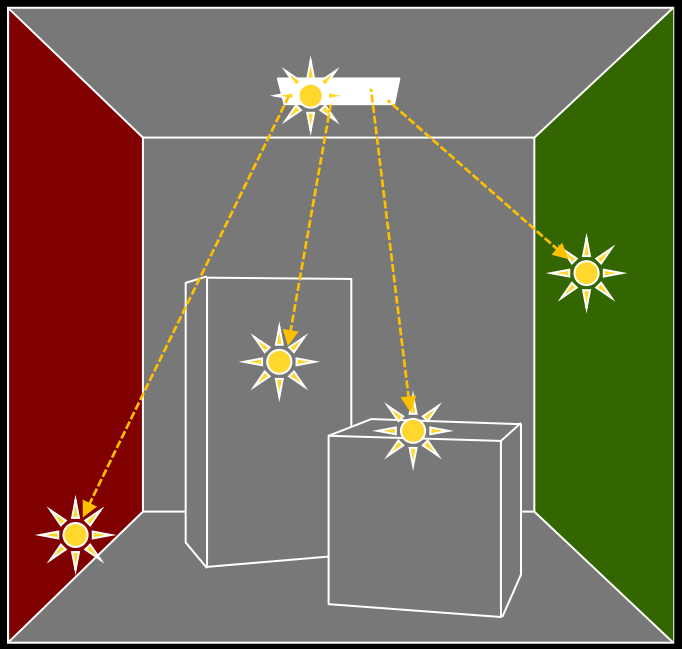
- Foundation of our work
  - Apply visual equivalence to VPL rendering

Related work – VPL rendering

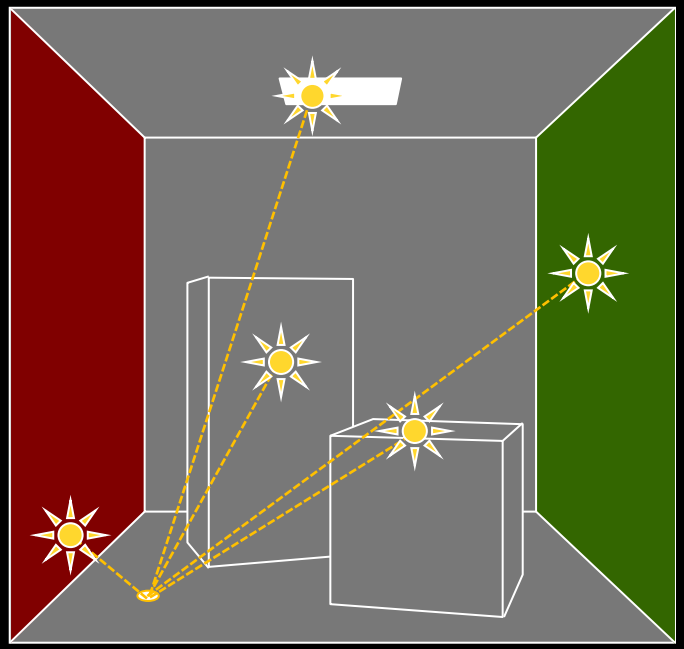
- Based on Instant Radiosity *[Keller 1997]*
- Approximate indirect illumination by

Virtual Point Lights (VPLs)

1. Generate VPLs



2. Render with VPLs



Related work – VPL rendering

1. Interactive GI *(≈ 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 *(≈ 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…

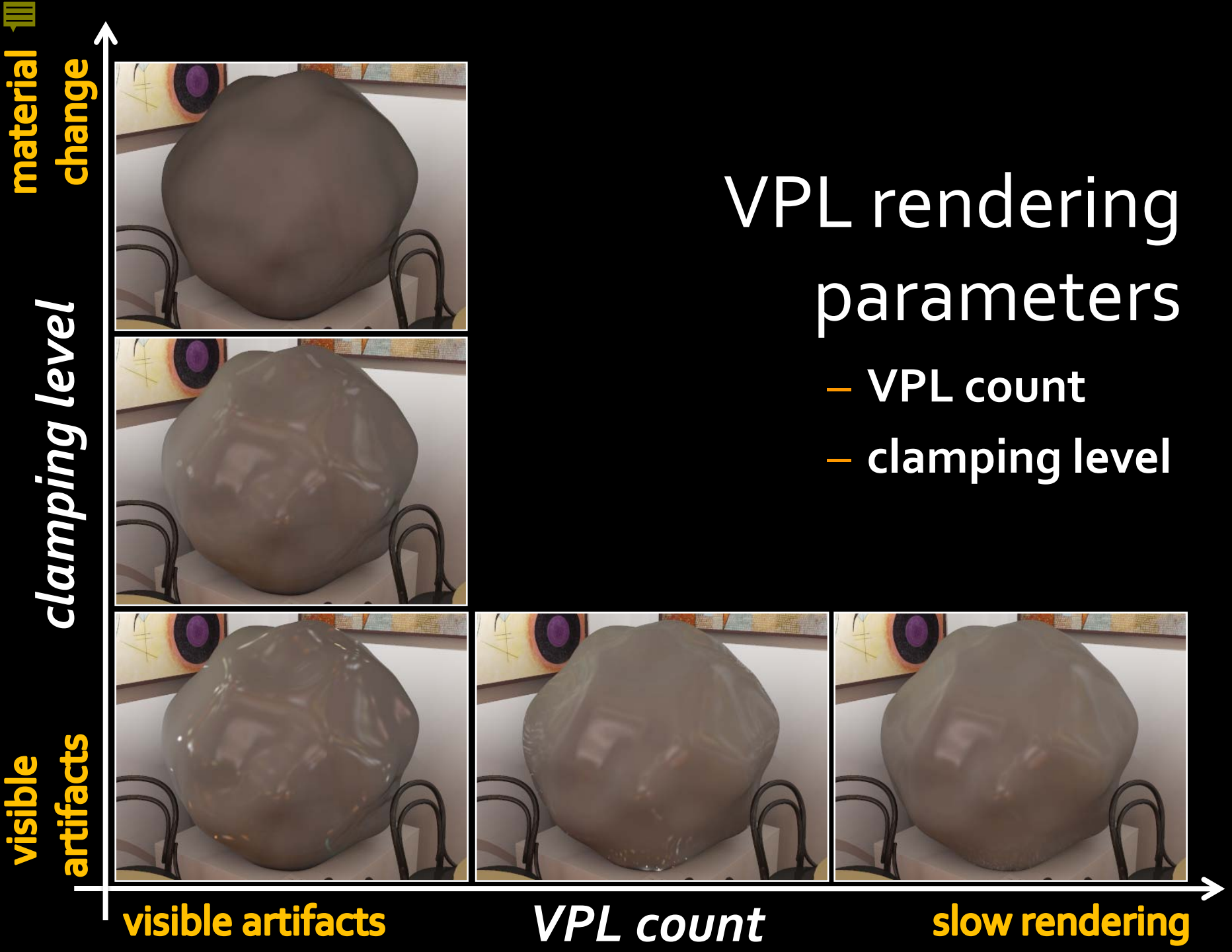
artifacts

material change

VPLs for high-fidelity rendering

- **Q:** When do VPL methods produce high-fidelity renderings?

- **A:** Systematic perceptual study
  - trade-offs : VPL parameters vs. visual fidelity



VPL rendering parameters

- VPL count
- clamping level

material change

clamping level

visible artifacts

visible artifacts

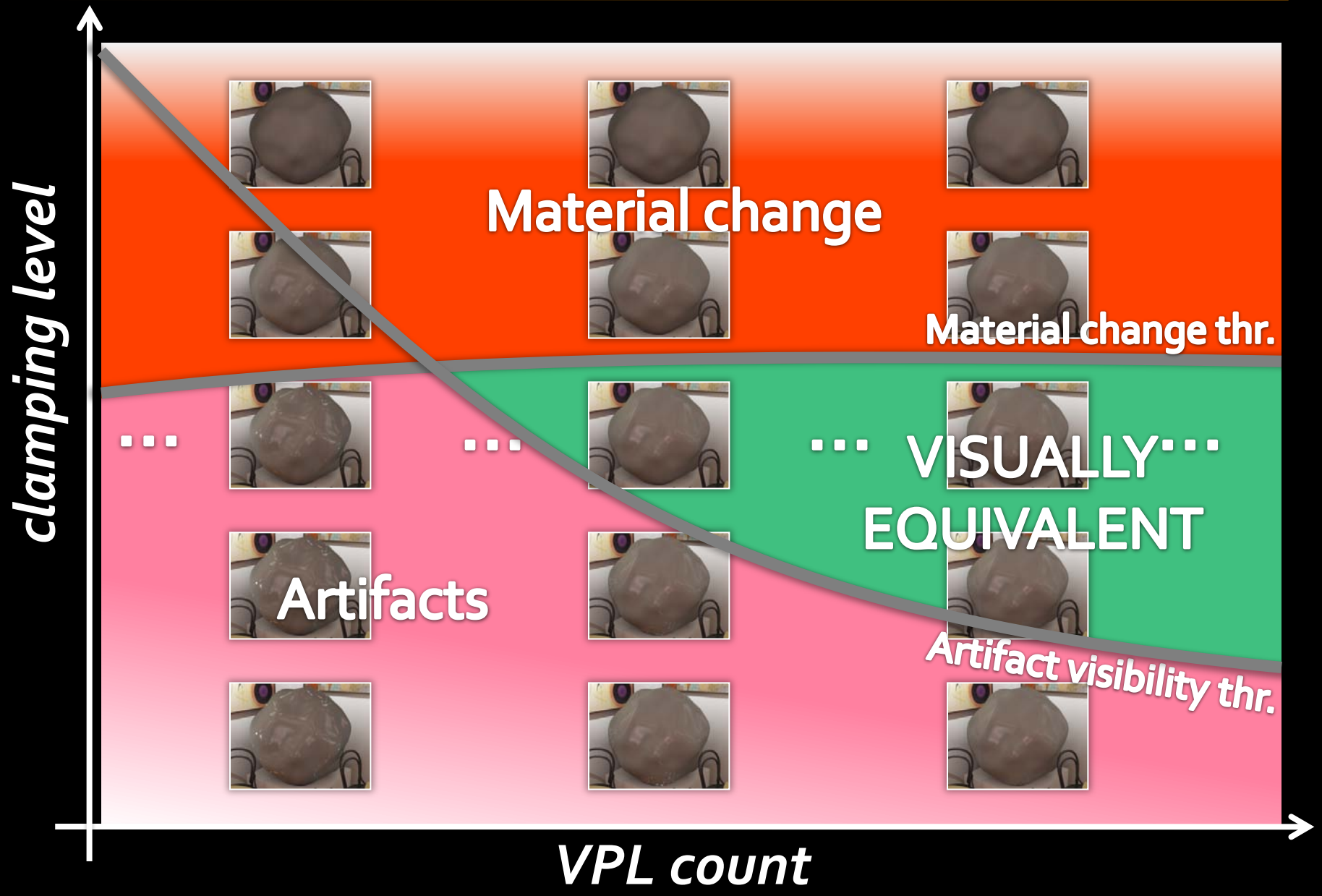
VPL count

slow rendering

VPL rendering parameters

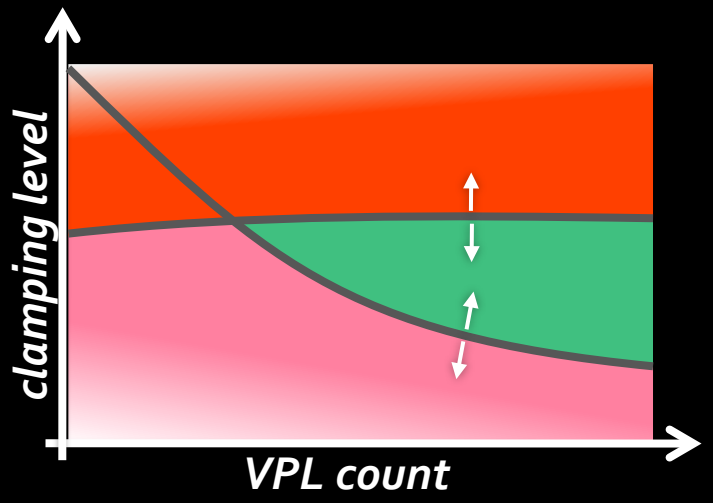
- **VPL count**
- **clamping level**

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: ρ_s α ρ_d

Test objects – Materials

	Metal Smooth	Metal Rough	Dielectric Black Smooth	Dielectric Black Rough	Dielectric Gray Smooth
ρ_s	0.22		0.033		

Ward-Dür BRDF: ρ_s α ρ_d **specular reflectivity**

Test objects – Materials

	Metal Smooth	Metal Rough	Dielectric Black Smooth	Dielectric Black Rough	Dielectric Gray Smooth
α	0.05	0.15			
ρ_s	0.22		0.033		

Ward-Dür BRDF: ρ_s α ρ_d **surface roughness**

Test objects – Materials

	Metal Smooth	Metal Rough	Dielectric Black Smooth	Dielectric Black Rough	Dielectric Gray Smooth
ρ_d	0.03				0.19
α	0.05	0.15			
ρ_s	0.22		0.033		

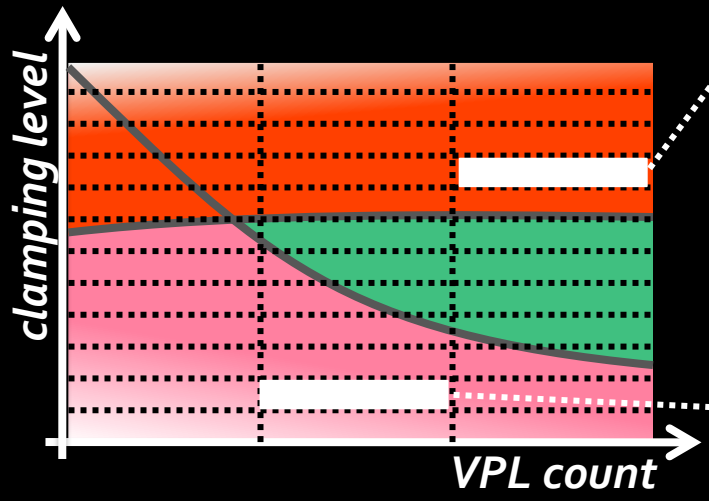
Ward-Dür BRDF: ρ_s α ρ_d **diffuse reflectivity**

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

1,000 (1k)

Interactive rendering

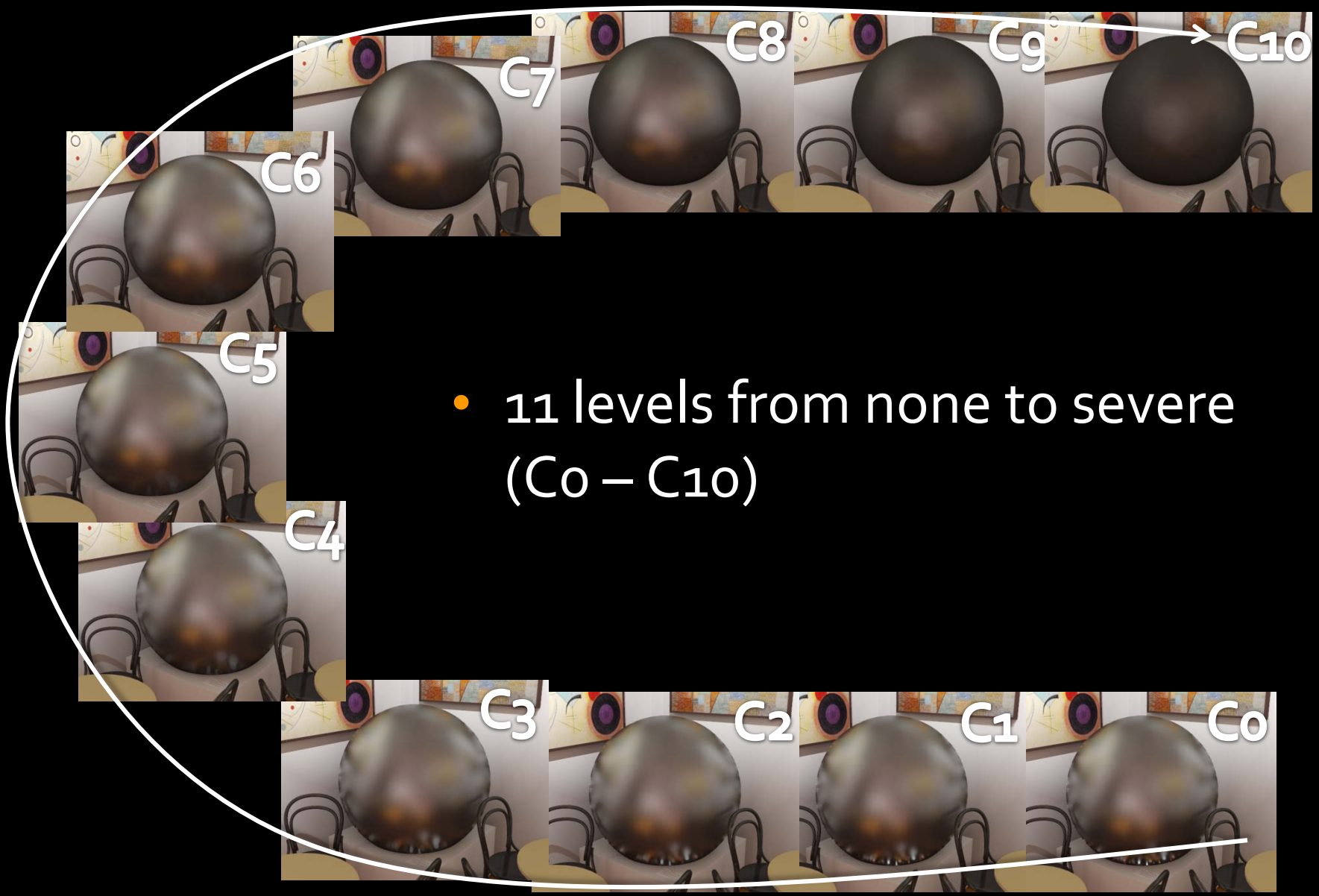
100,000 (100k)

Preview-quality rendering

5,000,000 (5M)

High-quality rendering

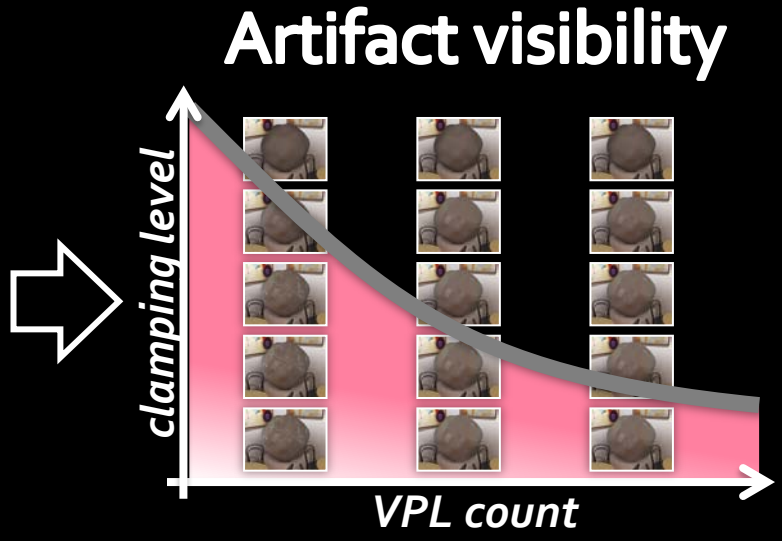
Stimulus images – Clamping level



- 11 levels from none to severe (C0 – C10)

Experiment 1: Artifact visibility

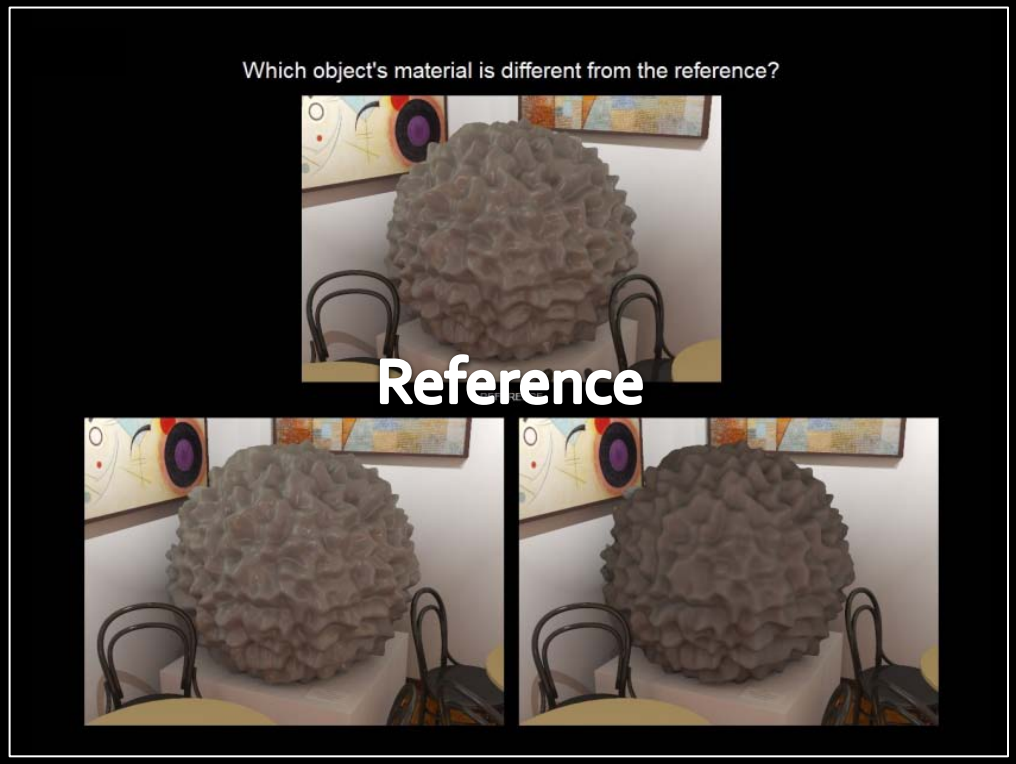
Select the image that has the artifacts.

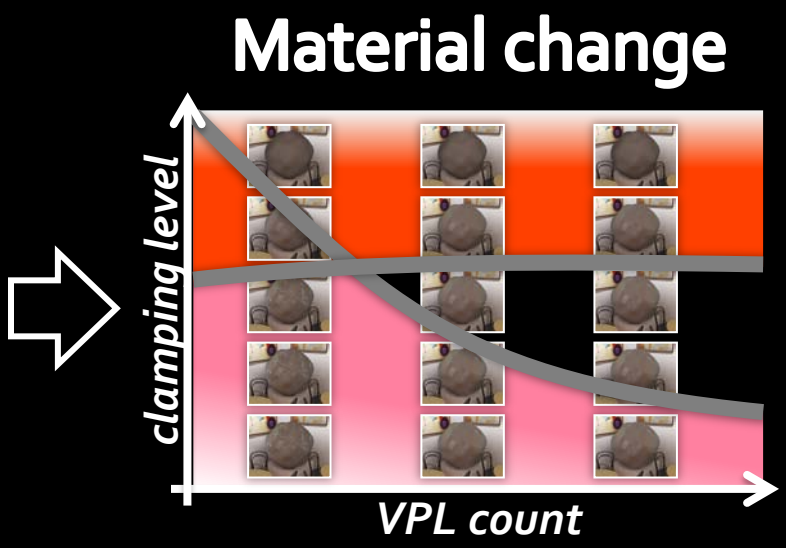


- Standard two-alternative forced choice method
- 480 trials, 12 participants

Experiment 2: Material change

Which object's material is different from the reference?

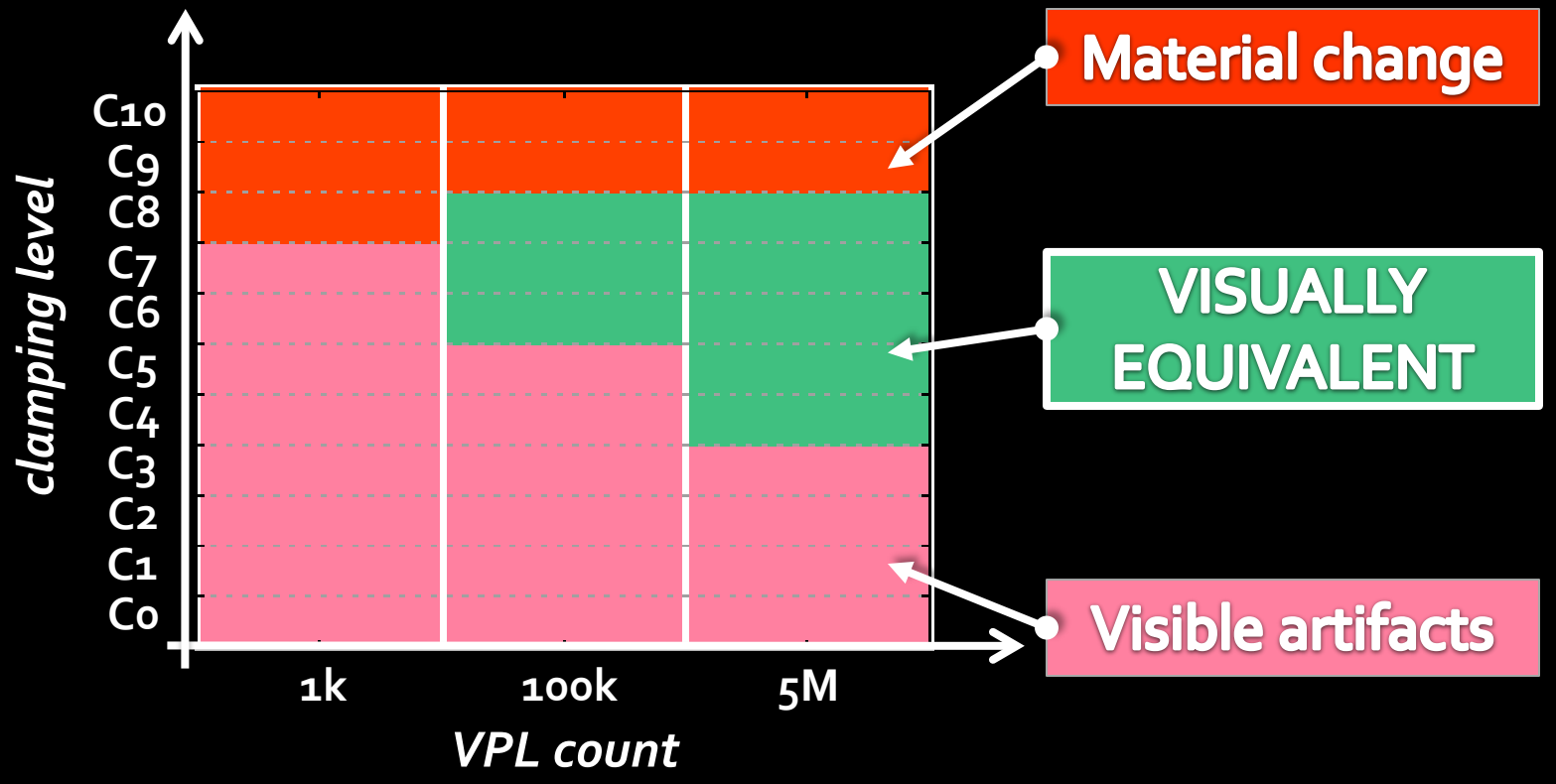




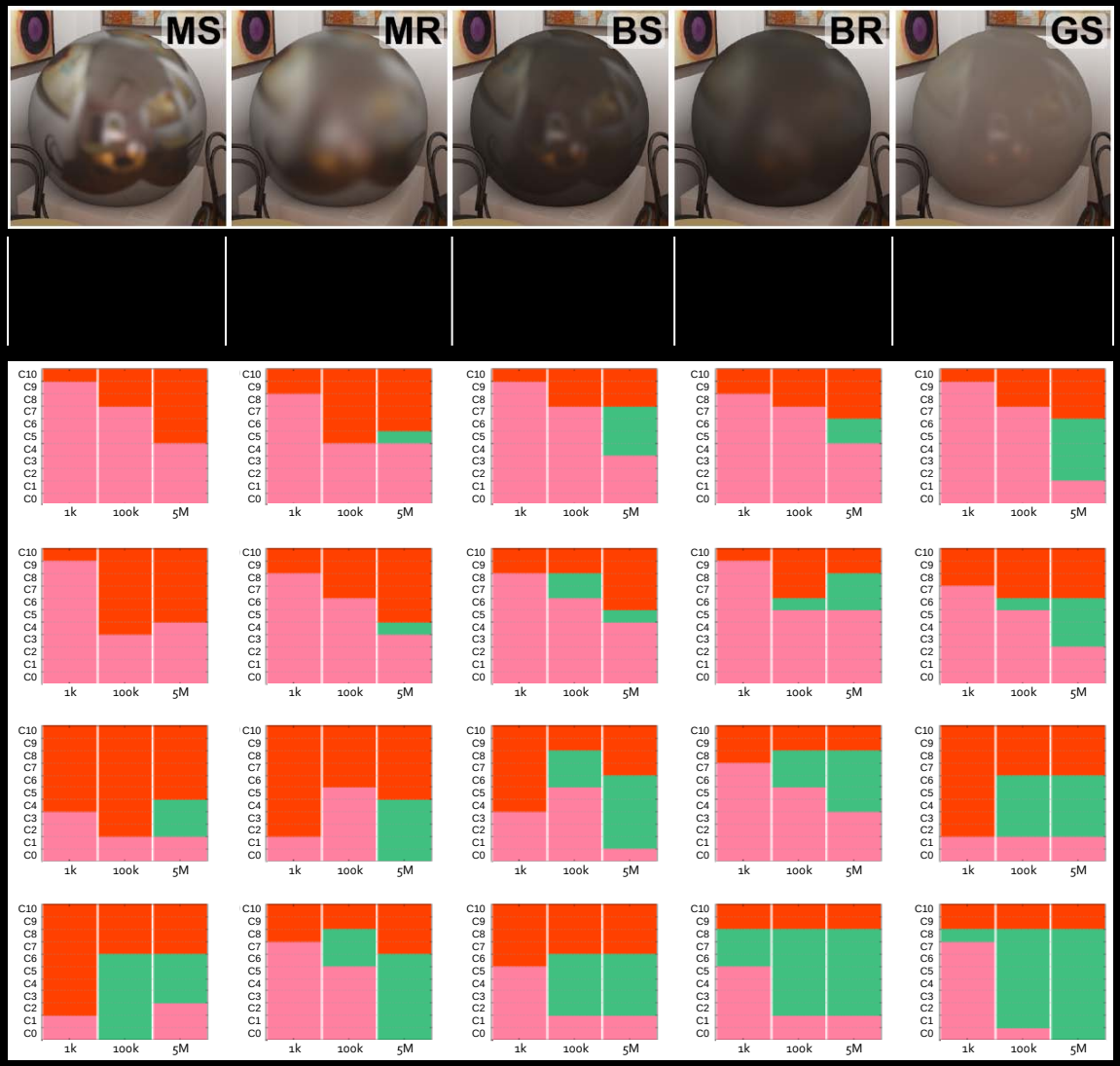
- Standard two-alternative forced choice method
- 520 trials, 14 participants

Data analysis

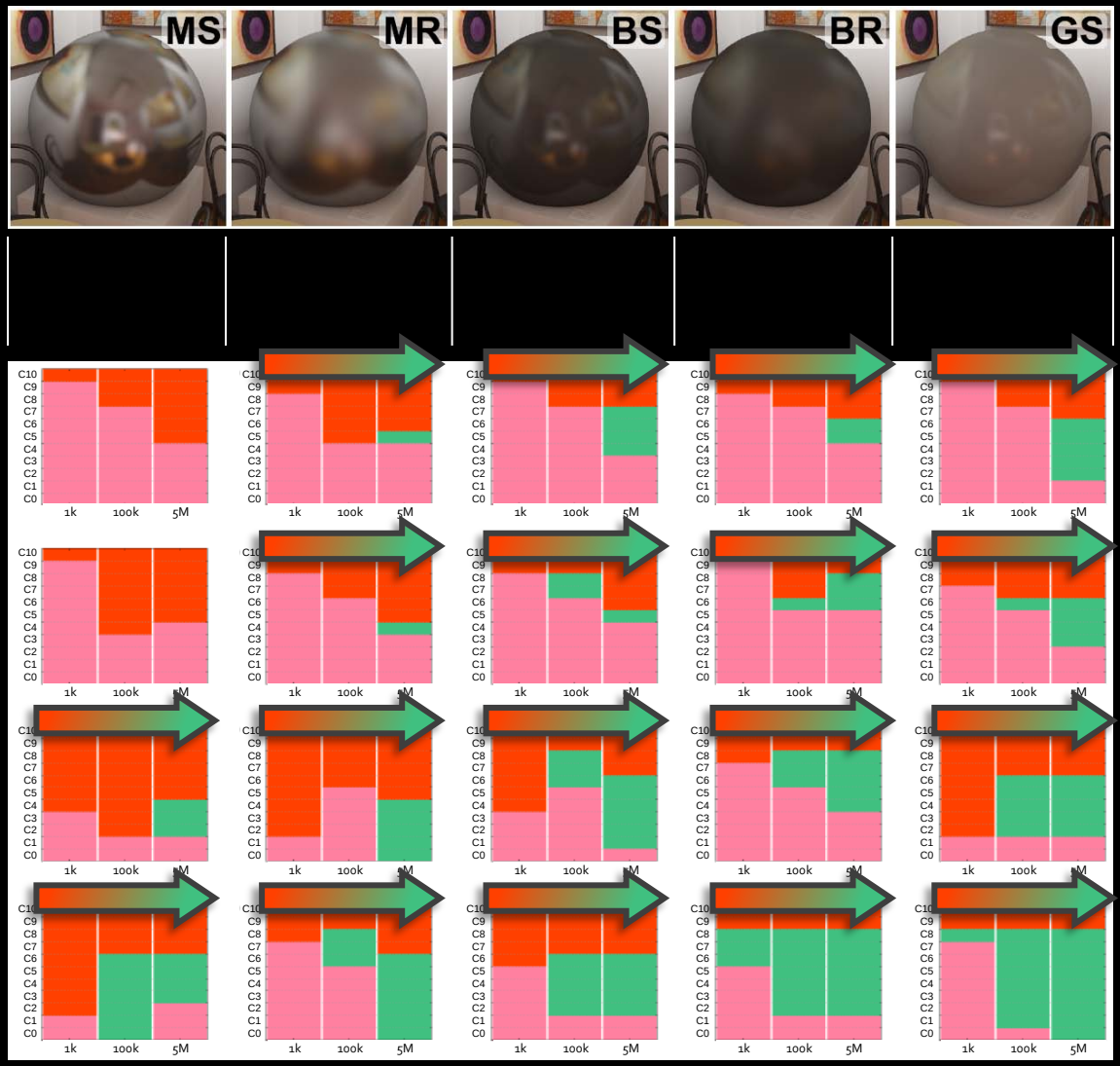
- Extract thresholds from subjects' answers
  - Standard 75% 2 AFC threshold criterion



Experiment results



Trends – VPL count

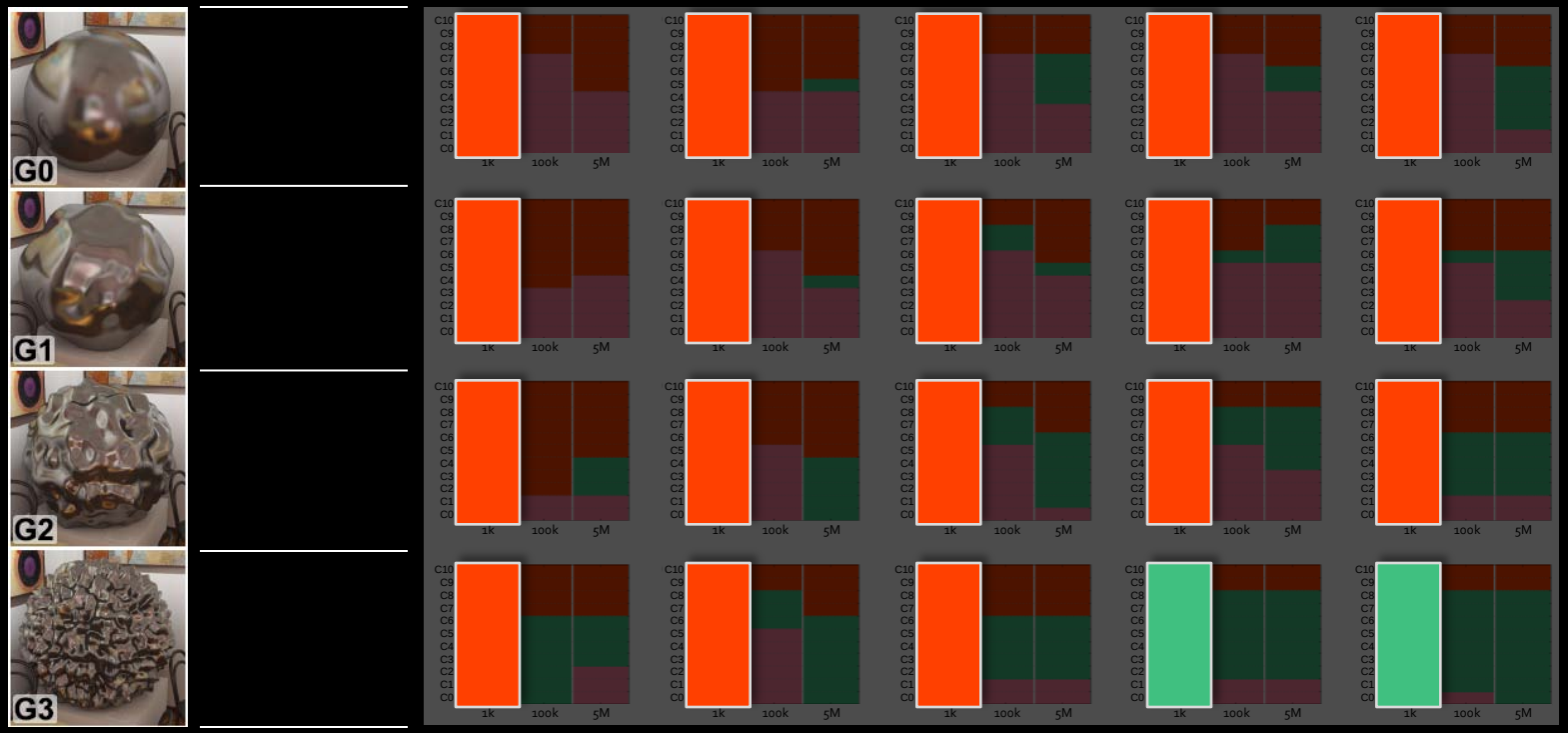


Trends – VPL count

Trends – VPL count

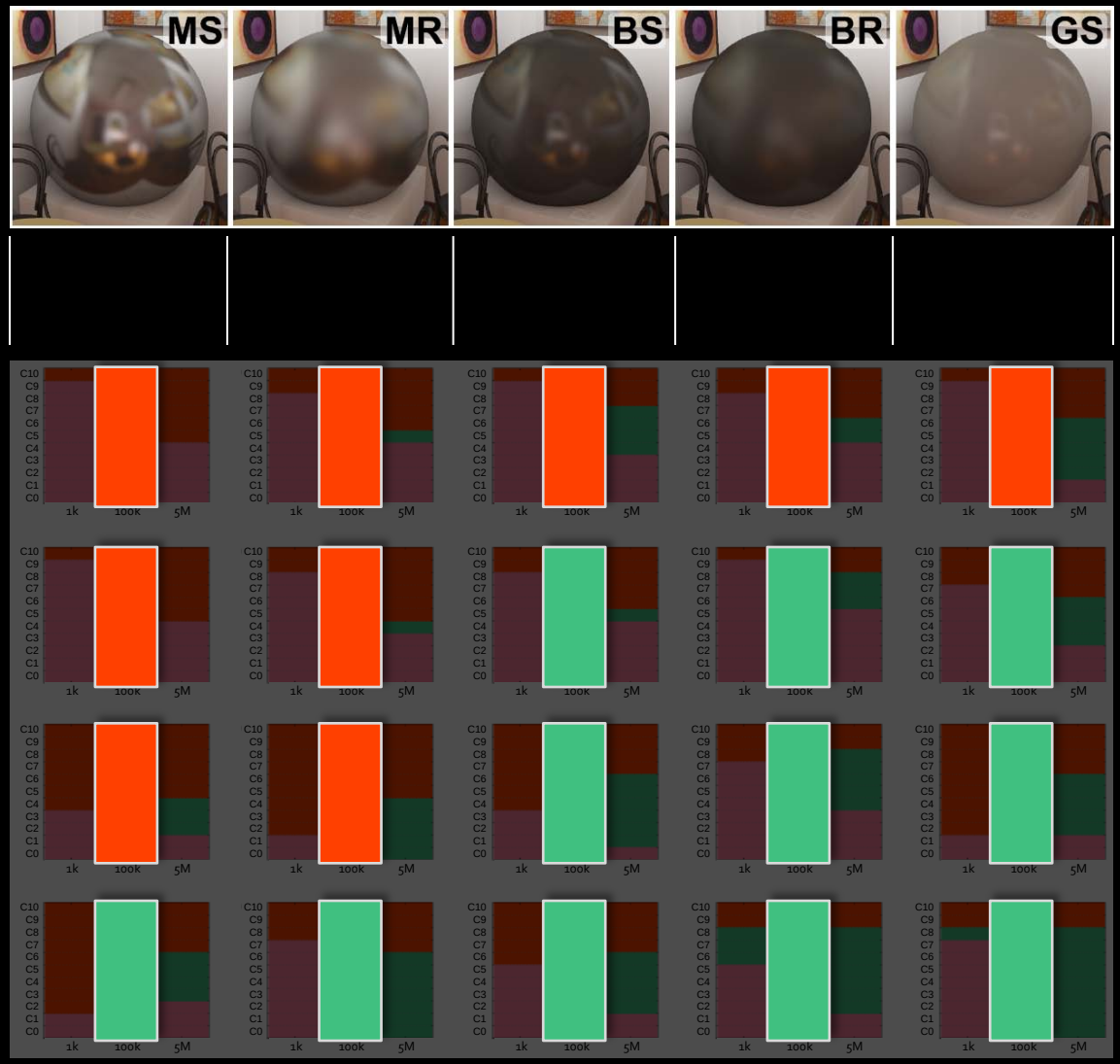
1k VPLs

… mostly insufficient



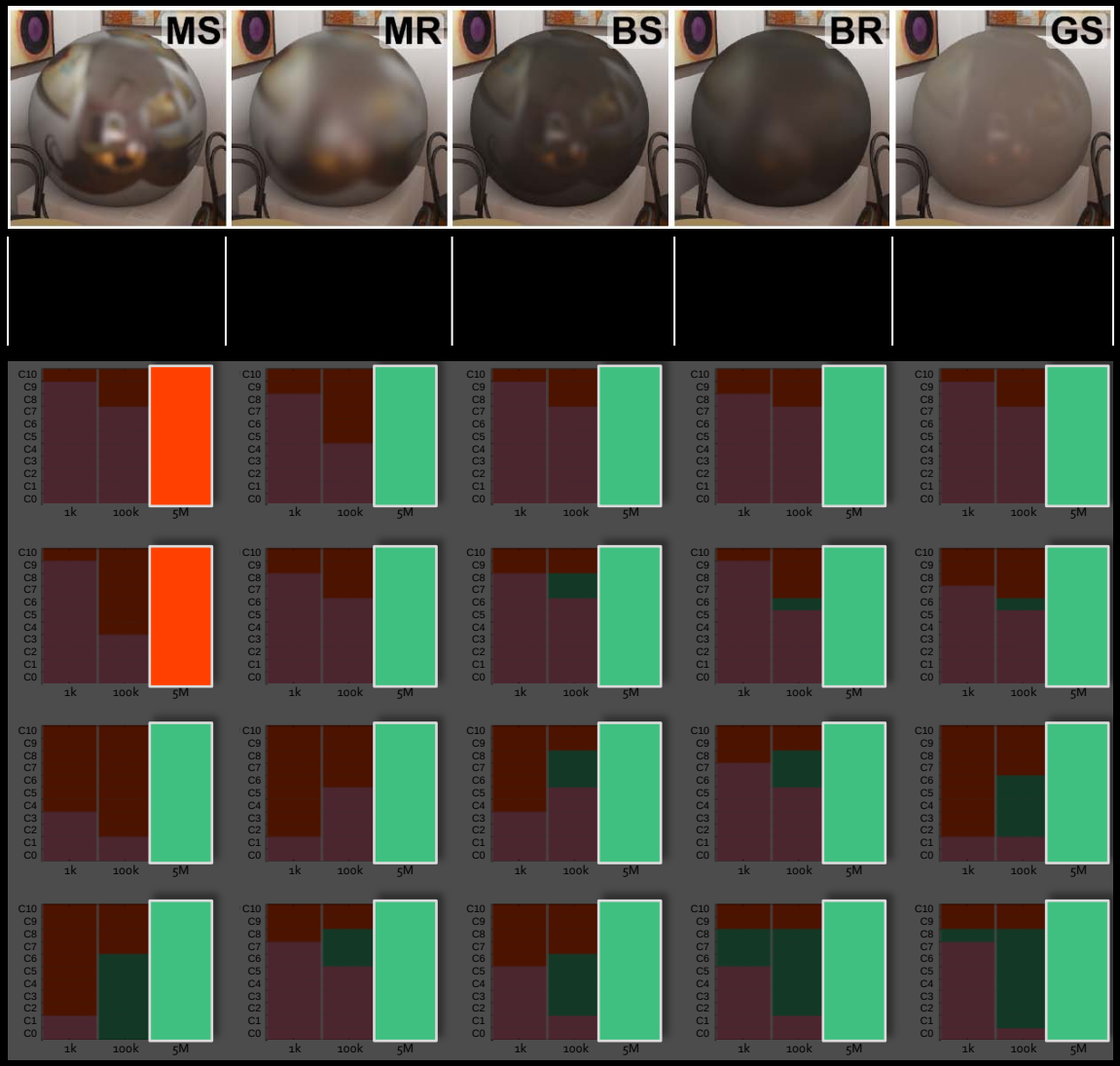
Trends – VPL count

100k VPLs

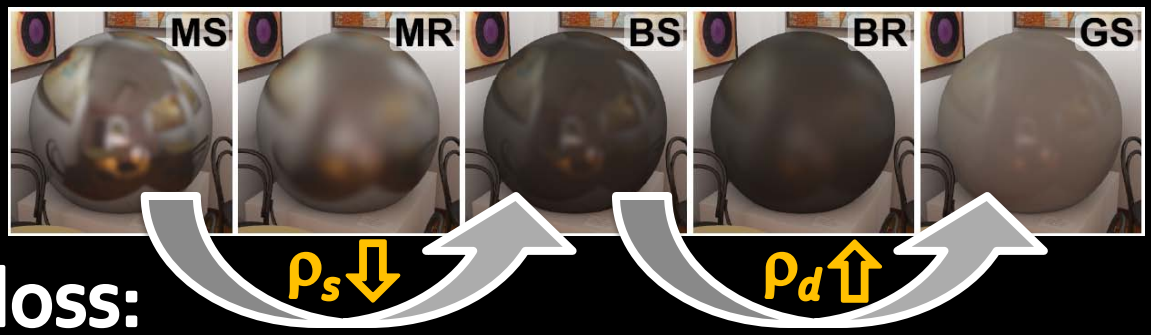


Trends – VPL count

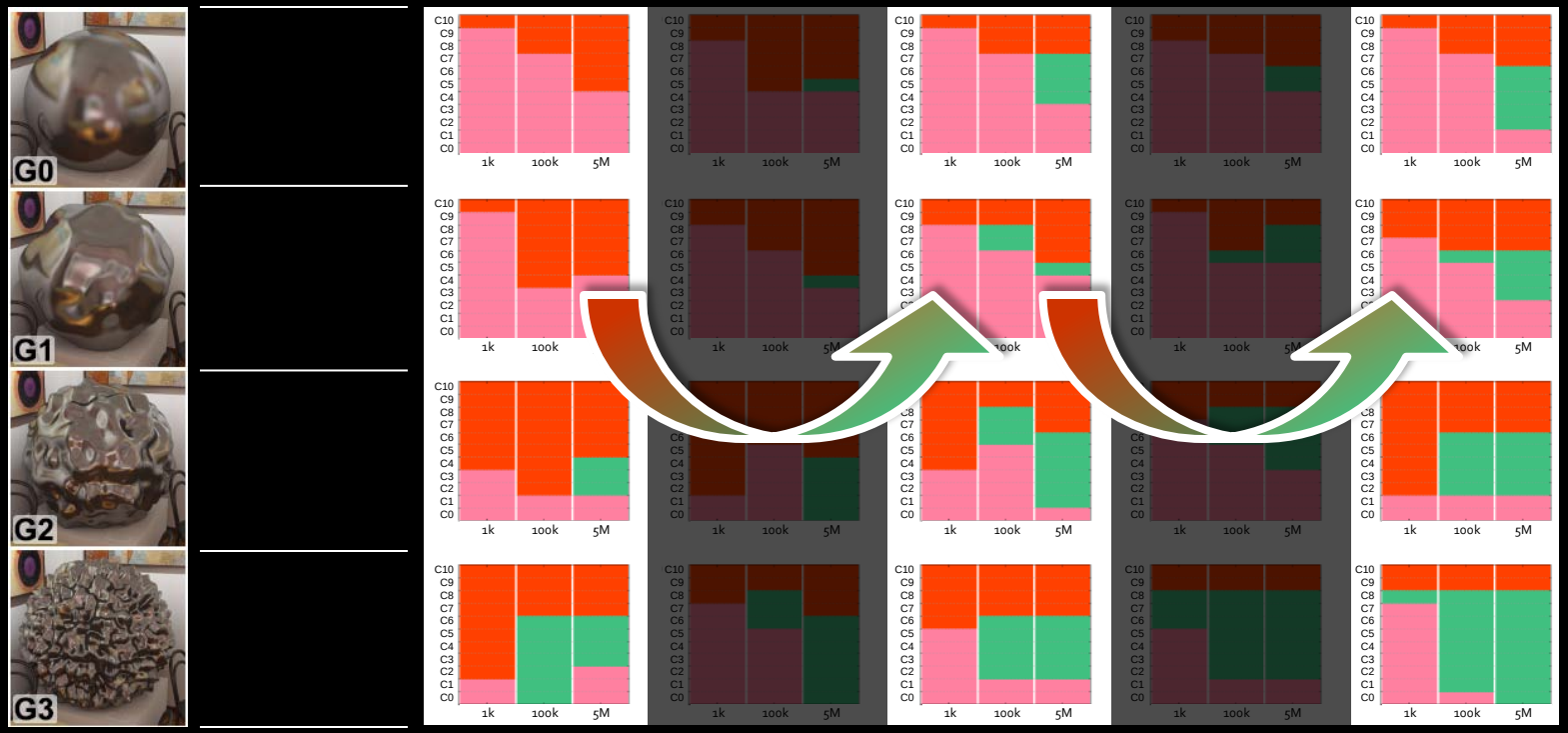
5M VPLs



Trends – Material contrast gloss



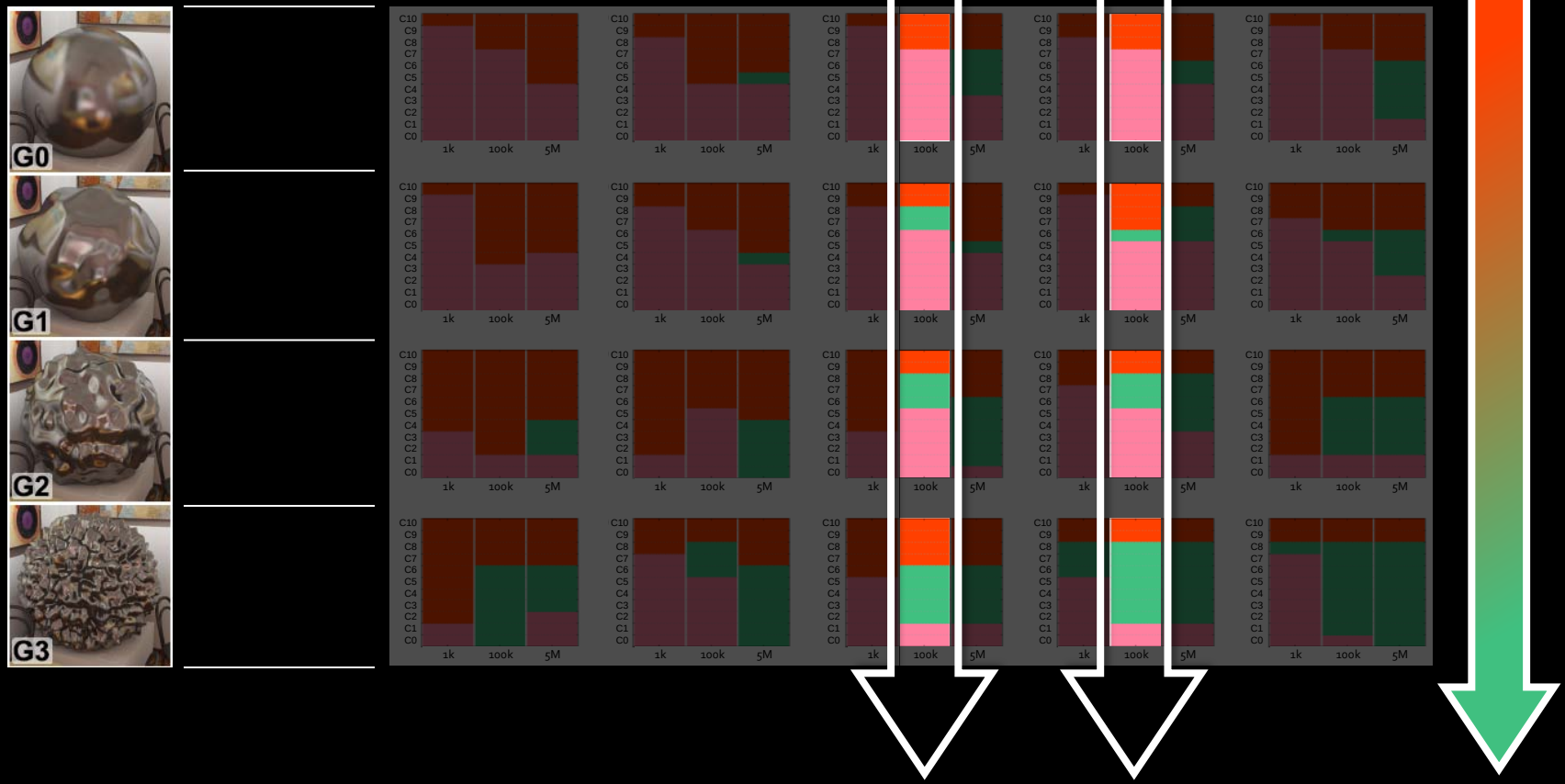
contrast gloss:



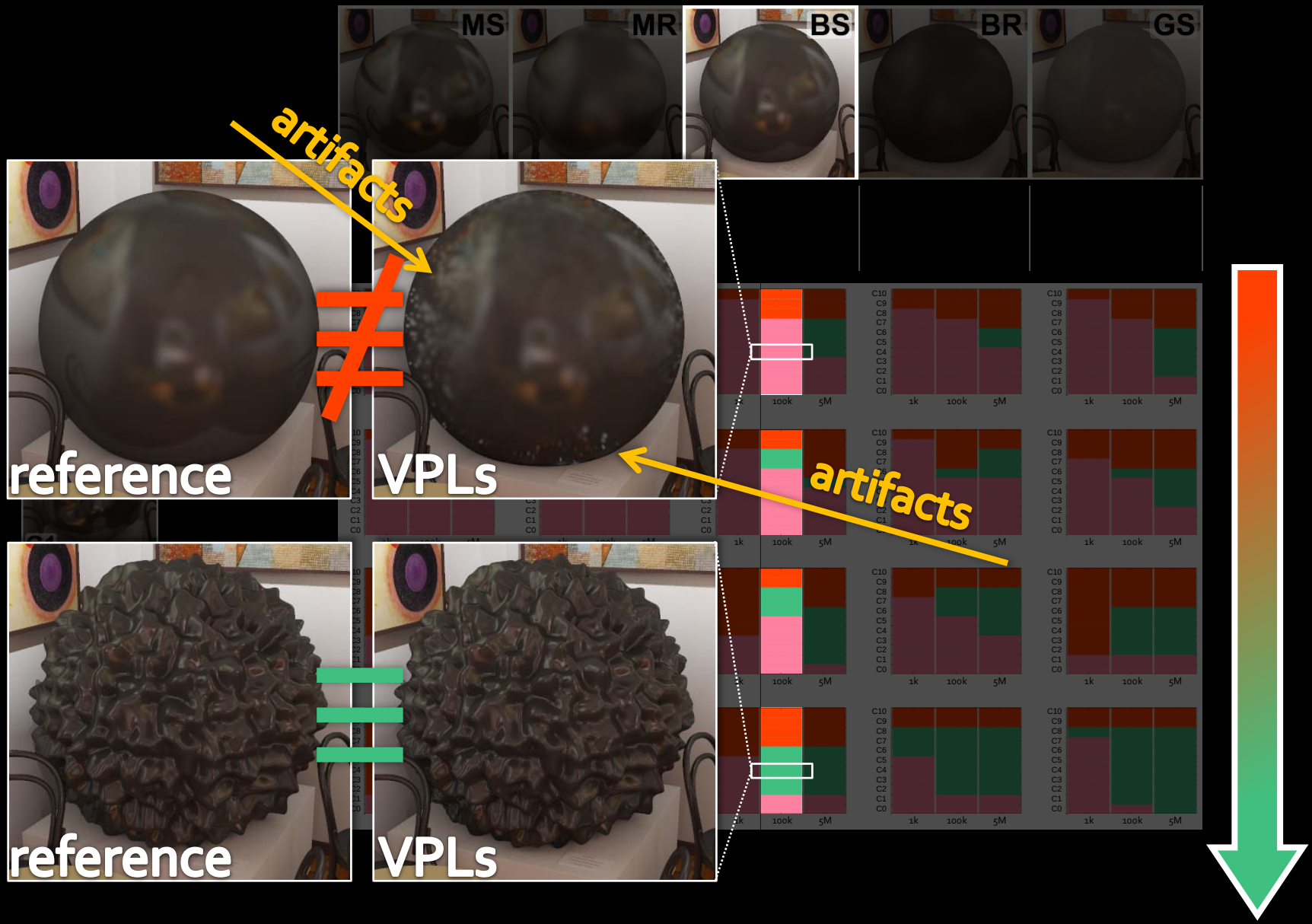
lower contrast gloss → greater equivalence

Trends – Shape complexity

complex shape → greater equivalence

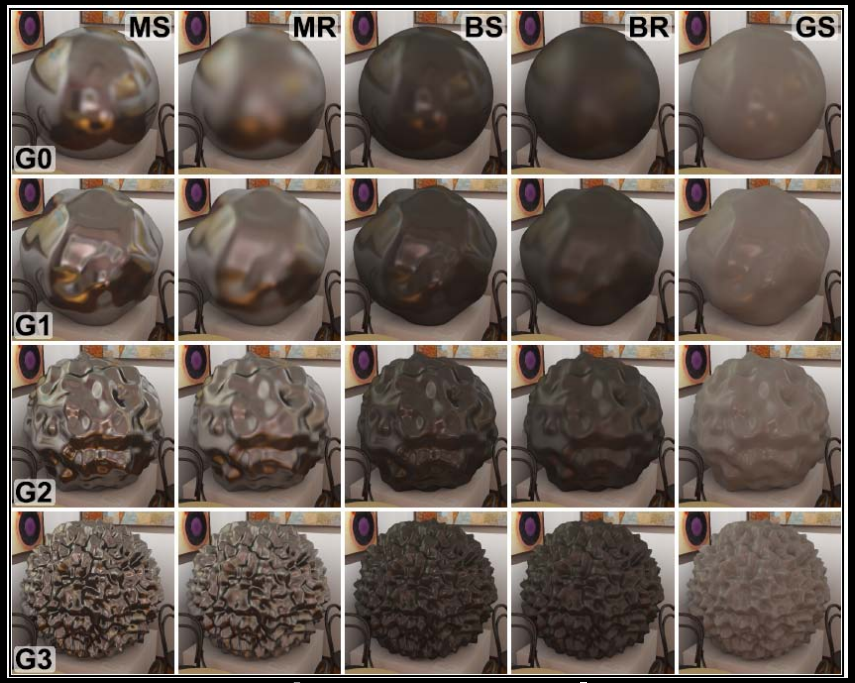


Trends – Shape complexity

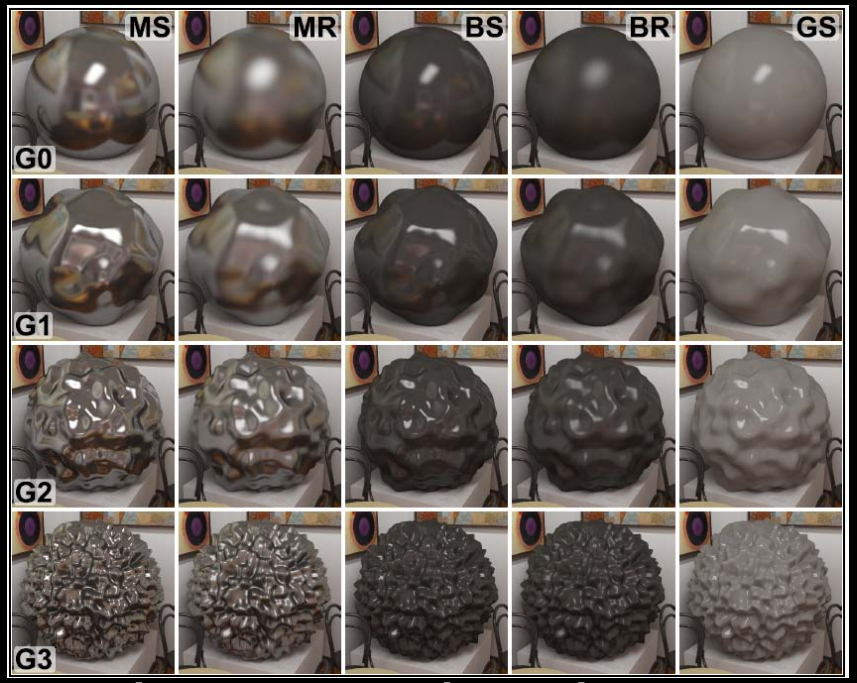


Trends – Illumination

- 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)

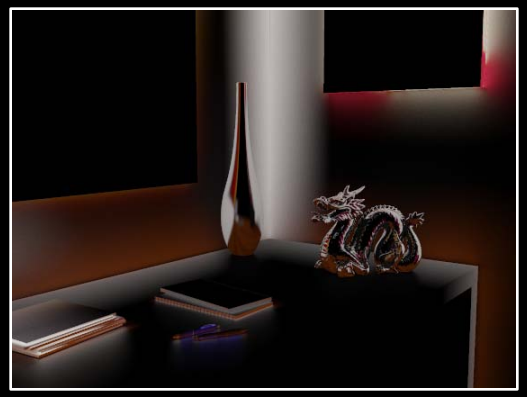
   - Most forgiving material
   - Need more than 1k VPL to achieve equivalence

Applications

- Per-object clamping
- Luminance normalization

Application – Per-object clamping

- Energy compensation [Kollig & Keller 04]


+

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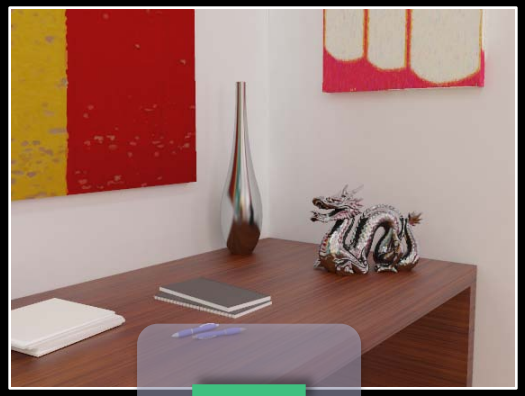
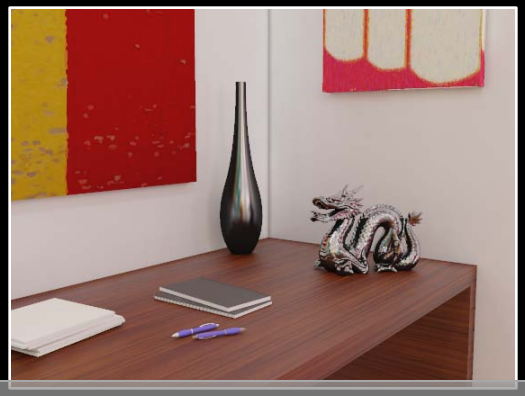


clamping (VPL) compensation (PT)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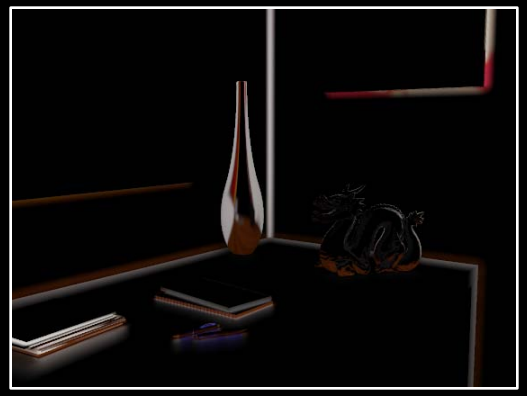
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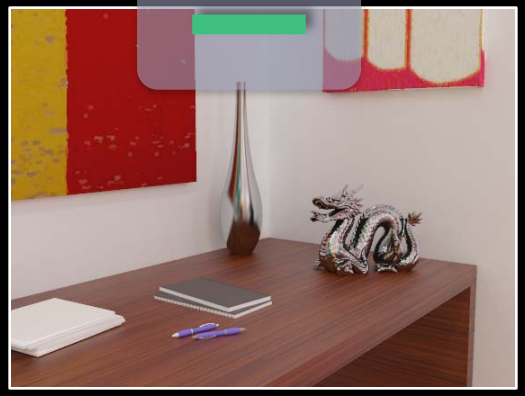
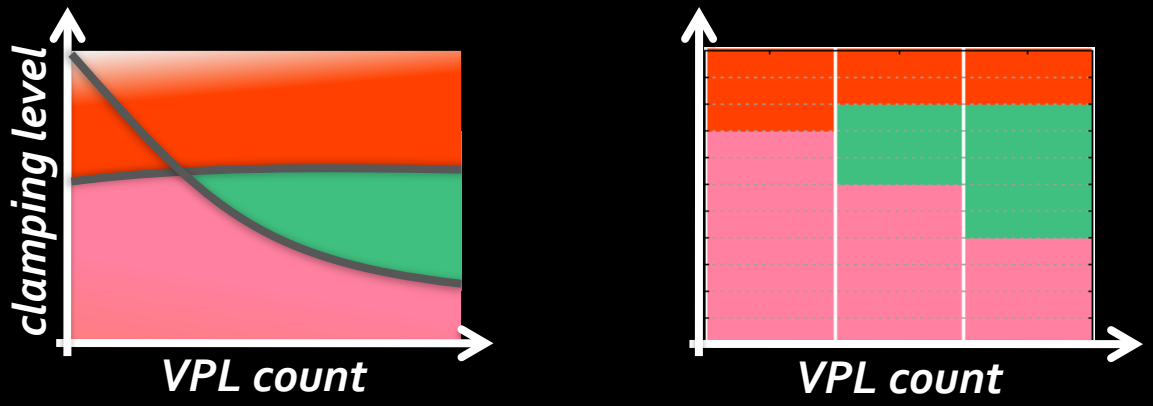


Less clamping for diffuse & complex objects → **Less work, 2x speedup**

Summary of results

- Visual equivalence in space of VPL parameters



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

Conclusions

- 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

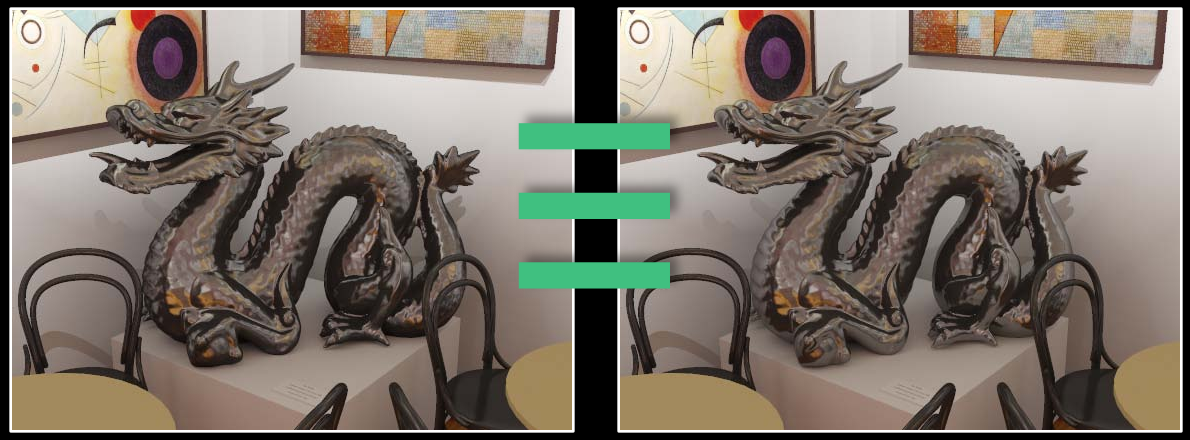
- Model for visual equivalence in VPL rendering
- Effects of accurate direct illumination
  - Ambiguity between artifacts and highlights
- Scalable & equivalent VPL methods

Acknowledgements

- Marie Curie Fellowship PIOF-GA-2008-221716
- NSF CAREER 0644175
- NSF CPA 0811680
- Intel
- Microsoft

- Experiment participants

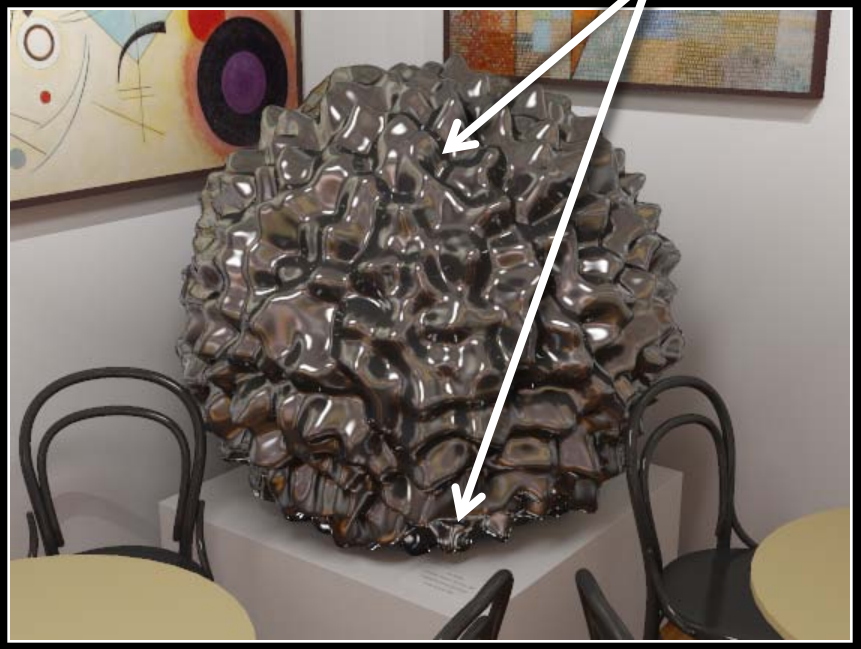
Thank you



Additional Slides

Ambiguity: highlights vs. artifacts

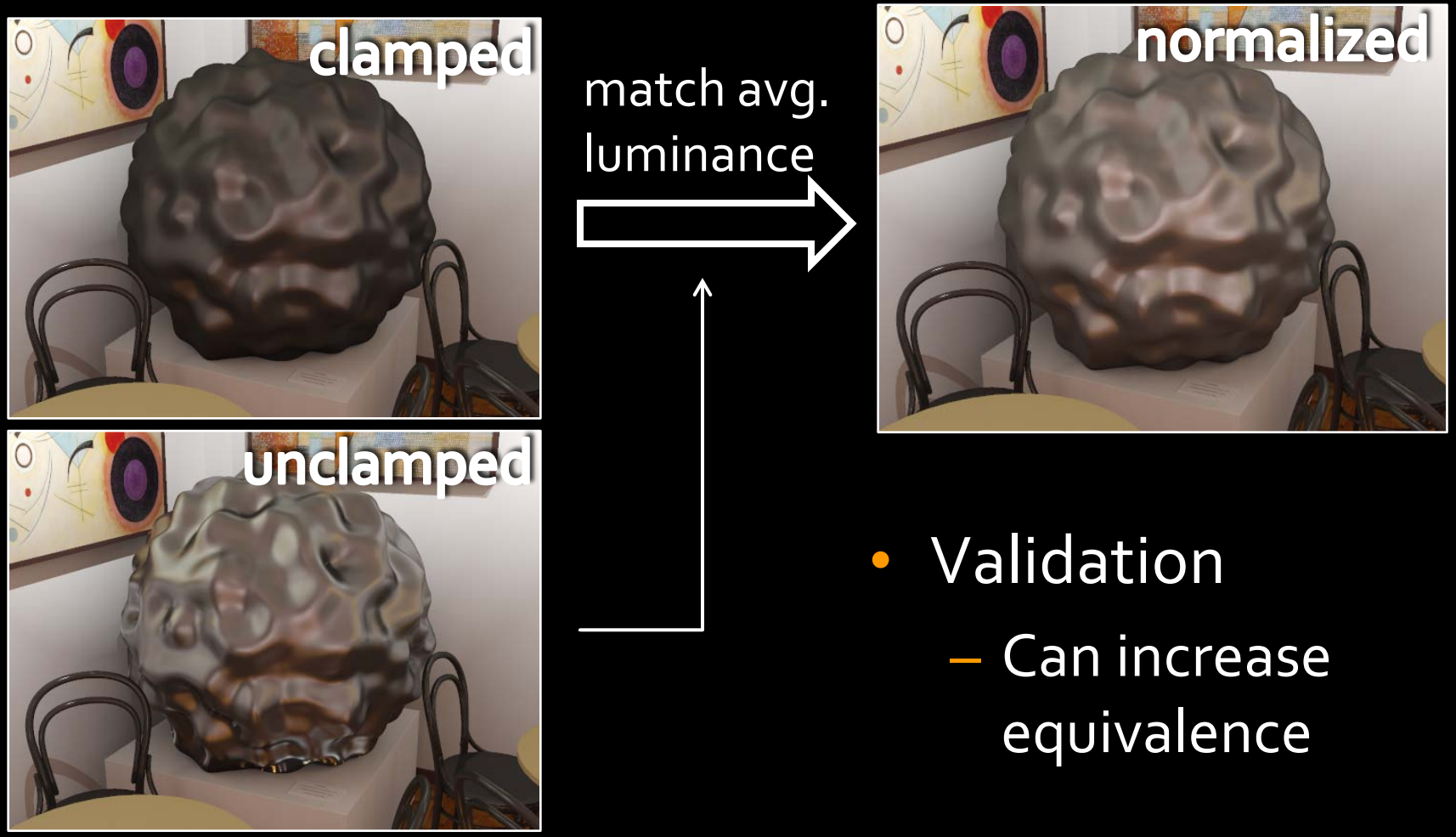
indirect-only



direct-and-indirect

Apps: Luminance normalization

- Re-introduce energy removed by clamping



- Validation
  - Can increase equivalence

Apps: Luminance normalization

Trends – Material roughness

rougher → greater equivalence