Effects of image dynamic range on perceived surface gloss

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One of the defining characteristics of glossy surfaces is that they reflect images of their surroundings. High gloss surfaces produce sharp reflections that show all the features of the surround, while low gloss surfaces produce blurry reflections that only show bright "highlight" features. Due to the presence of light sources and shadows, the illumination field incident on a glossy surface can have high dynamic range. This means that the reflections can also have high dynamic range. However, in a conventional image of a glossy object, the high dynamic range reflections are compressed through tone mapping to make the images fit within the output range of the display. While the utility of conventional images demonstrates that the general characteristics of glossy objects are conveyed by tone-mapped images, an open question is whether the tone mapping process distorts the apparent gloss of the imaged object. We have conducted a series of experiments to investigate the effects of image dynamic range on perceived surface gloss. Using a custom-built high dynamic range display, we presented high dynamic range (HDR) and standard dynamic range (tone mapped, SDR) images of glossy objects in pairs and asked subjects to choose the glossier object. We tested objects with both simple and complex geometries and illuminated the objects with both artificial and natural illumination fields. We analyzed the results of the experiments using Thurstonian scaling, and derived common scales of perceived gloss for both the HDR and SDR object renderings. Our findings are that 1) limiting image dynamic range does change the apparent gloss of depicted objects - objects shown in SDR images were perceived to have lower gloss than identical objects shown in HDR images; 2) gloss differences are less discriminable in SDR images than in HDR images; and 3) surface geometry and environmental illumination modulate these effects.

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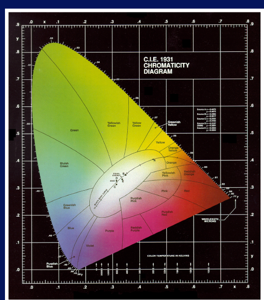
Describing material appearance

- color, gloss
- spectral, directional reflectance properties

Describing material appearance

color

gloss



colorimetry

?

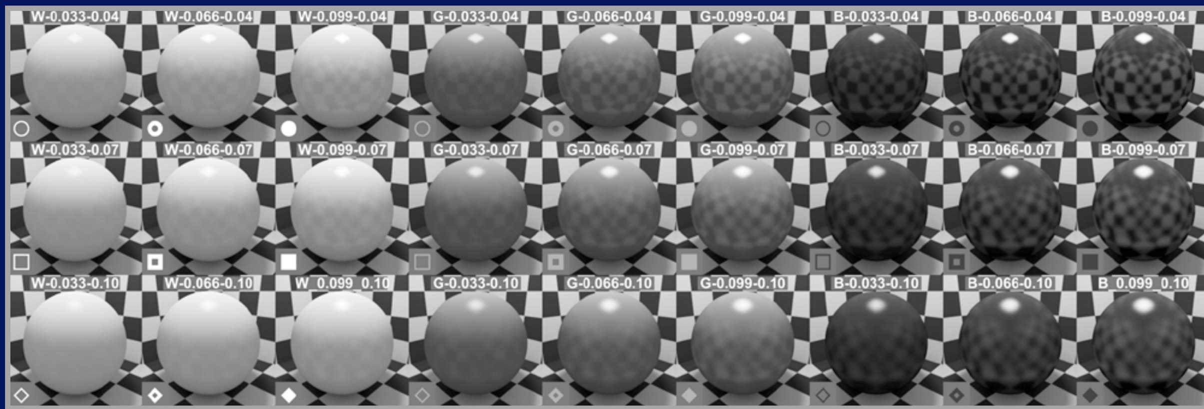
???imetry?

- useful systems for describing color
  - Munsell, XYZ, CIELab, ...
- nothing as systematic as colorimetry for gloss
  - Hunter (6 dimensions)
    - specular, contrast, DOI, haze, sheen, absence-of-texture
- Pellacini, F., Ferwerda, J.A., and Greenberg. D.P. (2000) Toward a psychophysically-based light reflection model for image synthesis. SIGGRAPH '00, 55-64.
  - study gloss perception
  - psychophysical model to relate physical reflectance and visual appearance

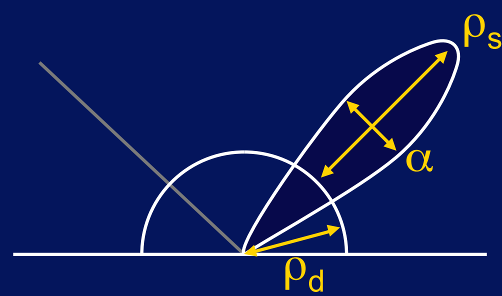
Experiments

- Experiment 1: defining gloss space
  - similarity judgments
  - multidimensional scaling (MDS)
  - dimensionality of gloss perception
  - perceptually meaningful axes
- Experiment 2: scaling gloss space
  - numerical rating
  - linear regression
  - place metrics on gloss axes
  - derive a psychophysical gloss model

Stimuli

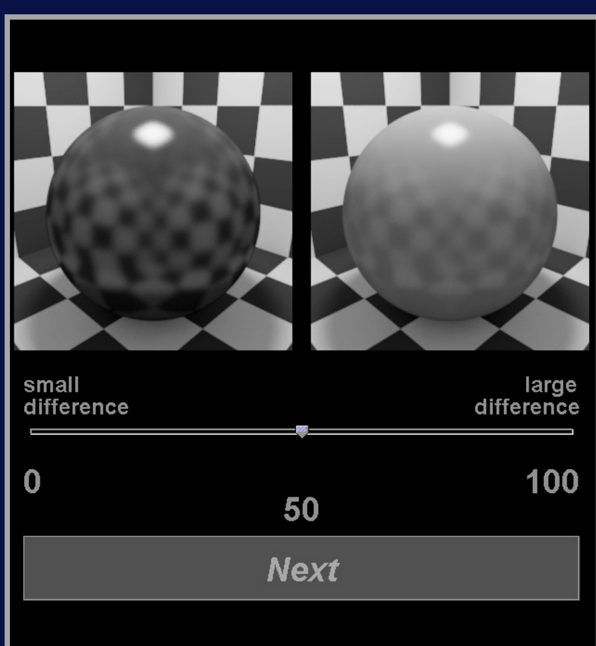


- latex paints
- wide gloss range
- measured BRDF data
- Ward model (ρ_d, ρ_s, α)
- 3 levels of each param.
- physically-based rendering
- sigmoid tone mapping



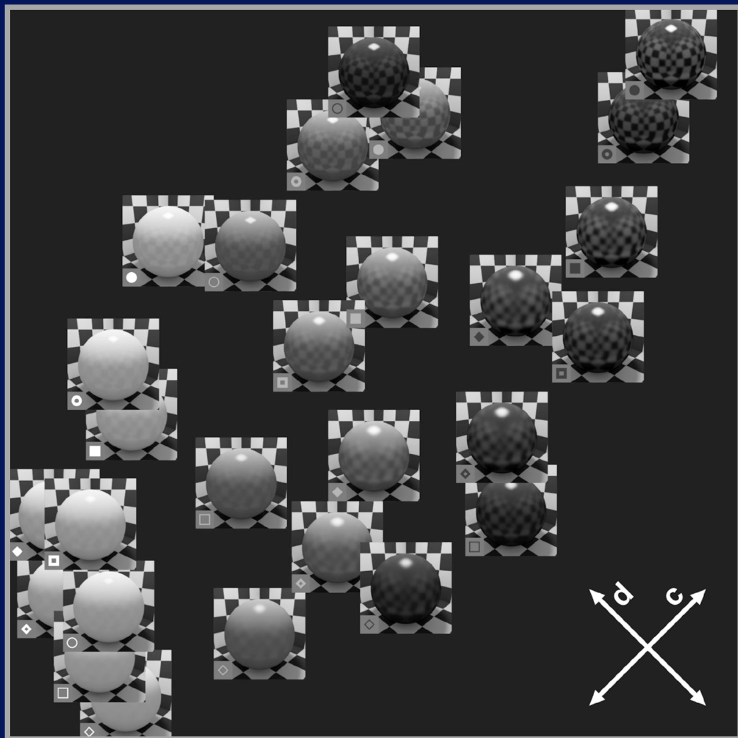
$$\rho(\theta_i, \phi_i, \theta_o, \phi_o) = \frac{\rho_d}{\pi} + \rho_s \times \frac{\exp[-\tan^2 \delta / \alpha^2]}{4\pi\alpha^2 \sqrt{\cos\theta_i \cos\theta_o}}$$

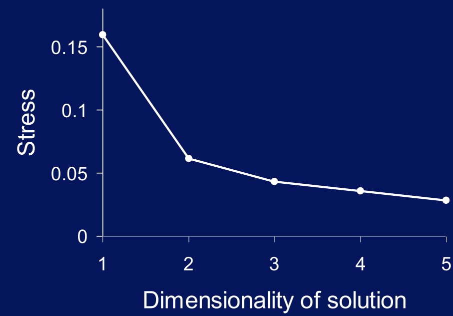
Experiment 1: dimensions of gloss space



- 9 subjects
- pair comparison
- similarity judgments
  - "How different in gloss are the two spheres?"
- analysis:
  - multidimensional scaling (MDS)

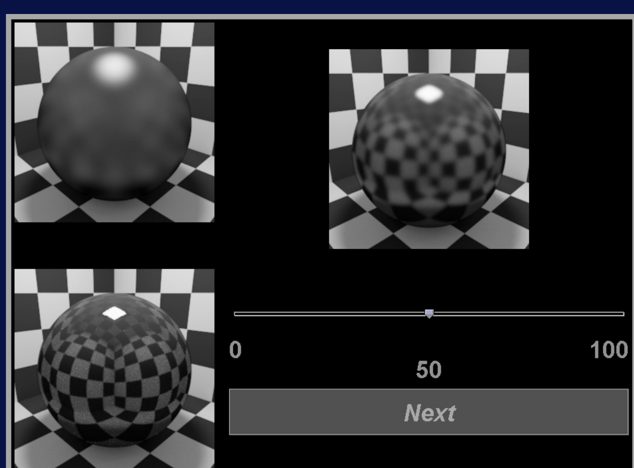
Experiment 1: results





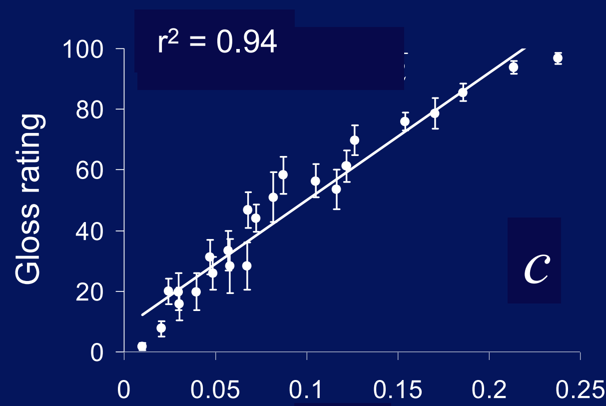
- dimensions:
  - c = contrast gloss (contrast of reflected image)
  - d = DOI gloss (sharpness of reflected image)
- confirmation of Hunter from first principles?

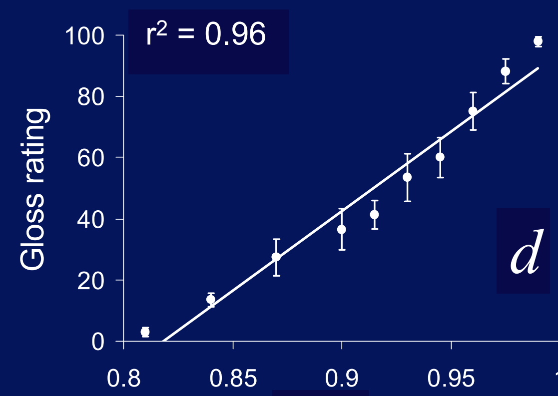
Experiment 2: scaling gloss space



- 9 subjects
- stimuli varied along c & d axes
- numerical rating procedure
  - "How glossy is the test sphere?"
- analysis
  - regression on ratings

Experiment 2 results



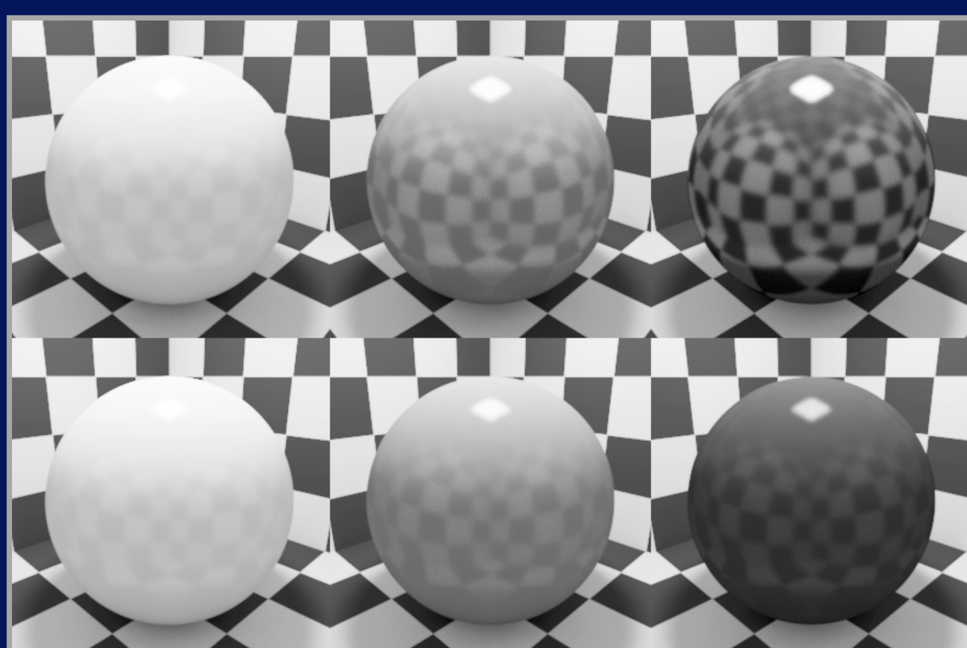


$$c = \sqrt[3]{\rho_s + \rho_d/2} - \sqrt[3]{\rho_d/2}$$

$$d = 1 - \alpha$$

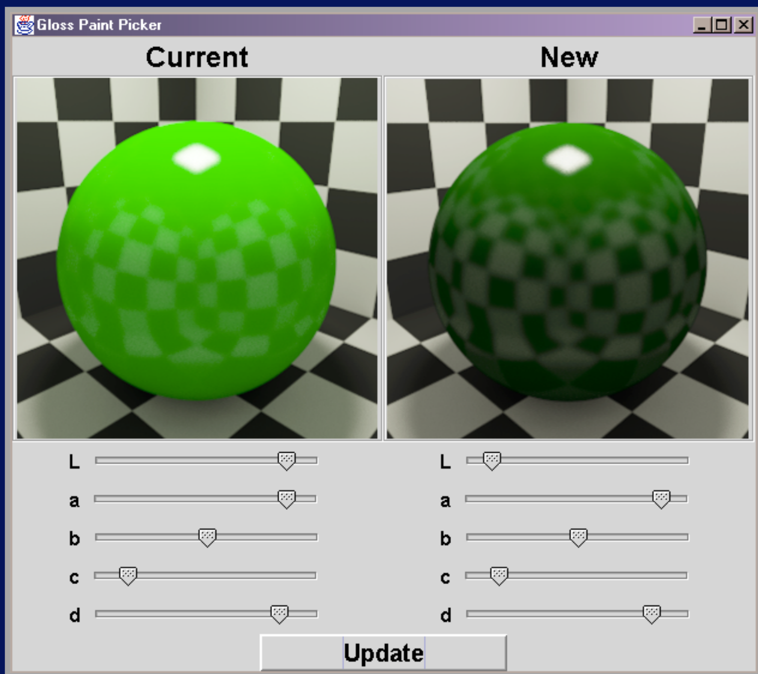
- a psychophysical gloss model
- relates physical reflectance and visual appearance

Gloss matching



- top row: same physical gloss properties ($\rho_s = 0.099$, $\alpha = 0.04$)
- bottom row: same visual gloss properties ($c = 0.057$, $d = 0.96$)

Describing material appearance



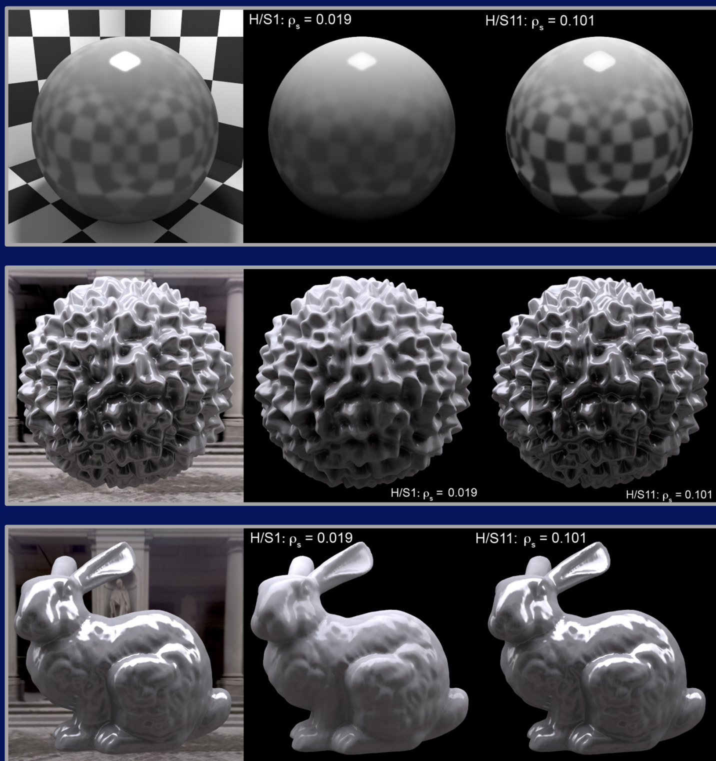
- 5 parameters
- color (CIELab)
  - lightness (L)
  - chroma (a,b)
- gloss
  - contrast gloss (c)
  - DOI gloss (d)
- perceptually meaningful space
- allows integrated description of material appearance
- caveat: tone mapped (SDR) images

Dynamic range and material appearance

- glossy surfaces reflect light sources
- occlusions produce shadows
- creates high dynamic range (HDR) scenes/images
- tone mapping compresses highlight/shadow values

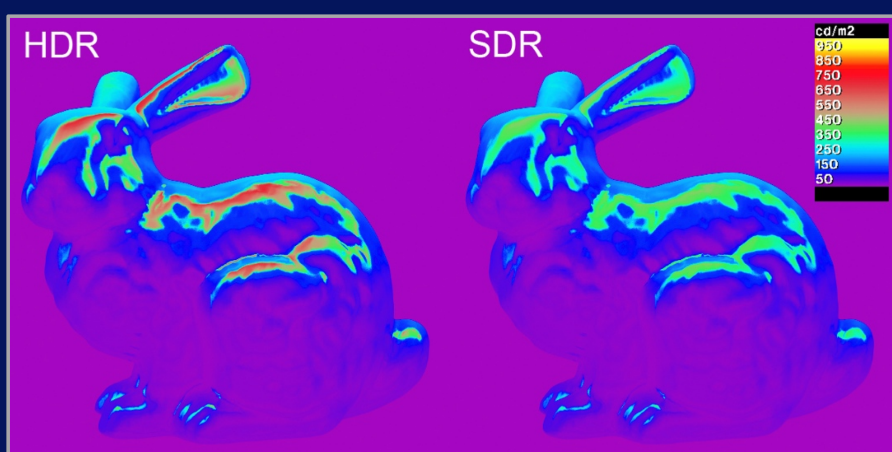
- effects of image dynamic range on material appearance?

Stimuli



- 3 objects
  - ball, blob, bunny
  - effects of geometry
- glossy gray paint
  - ρ_d = 0.19, α = 0.04
  - ρ_s = (0.019 - 0.101) in 11 steps
- checkerboard, Uffizi environments
- rendered w/ Radiance
- 600x600 HDR images

Test image sets

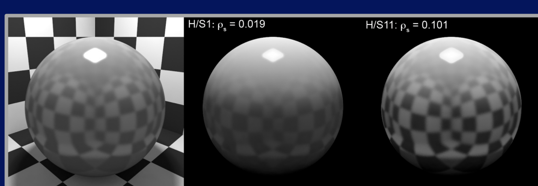


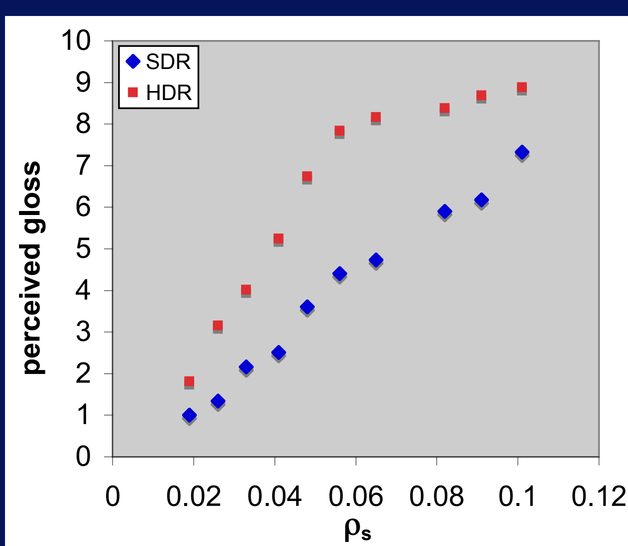
- HDR, SDR image sets
- HDR set scaled from display max (760 cd/m^2)
- SDR set tone mapped with 160:1 sigmoid

Procedure

- HDR display, dark room, 10° images
- full randomized pair-comparison within objects
  - HDR/HDR, HDR/SDR, SDR/SDR
  - "Which object is glossier?"
- 23 (mostly expert) subjects

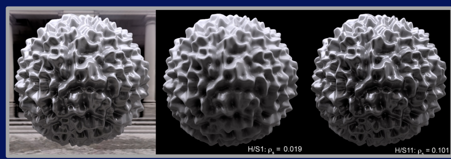
Results: ball

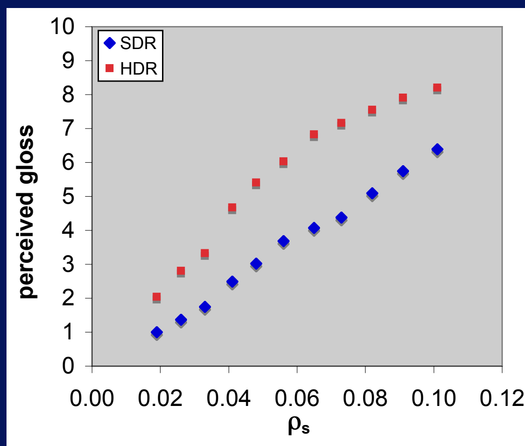


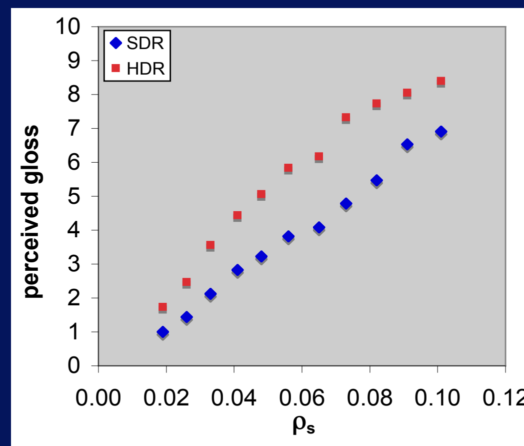


- Thurstonian scaling to derive perceived gloss
- monotonic increase in perceived gloss with ρ_s
- objects shown in HDR images always seen as glossier than SDR counterparts
- slope of HDR curve is high for low ρ_s, becomes compressive for high ρ_s

Results: blob, bunny

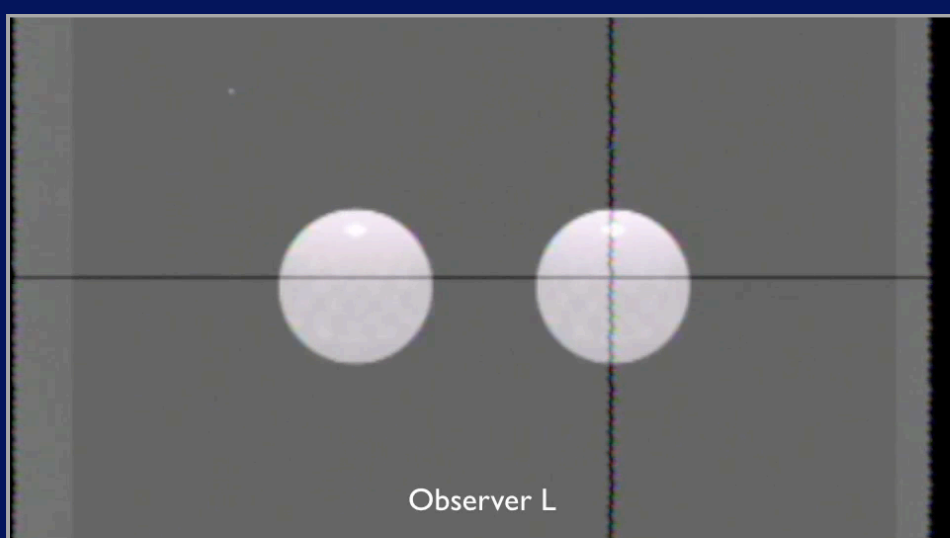






- HDR renderings consistently perceived as glossier
- less distinct compression with more complex objects, real-world illumination

Work in progress



- eye movements during gloss discrimination task
- where do people look? highlights? reflections? shadows?
- effects of geometry, illumination

Conclusions and future work

- image dynamic range does affect how glossy objects are perceived
  - are HDR images better representations?
  - need for ground truth studies
- specular intensity does appear to be a source of information about gloss
  - how does it integrate with other sources (e.g. c,d)?
  - multidimensional gloss model
- people employ different strategies, use different information when discriminating gloss
  - effects of geometry, material, illumination
  - individual differences, perceptual learning

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