The Reproduction of Specular Highlights on High Dynamic Range Displays

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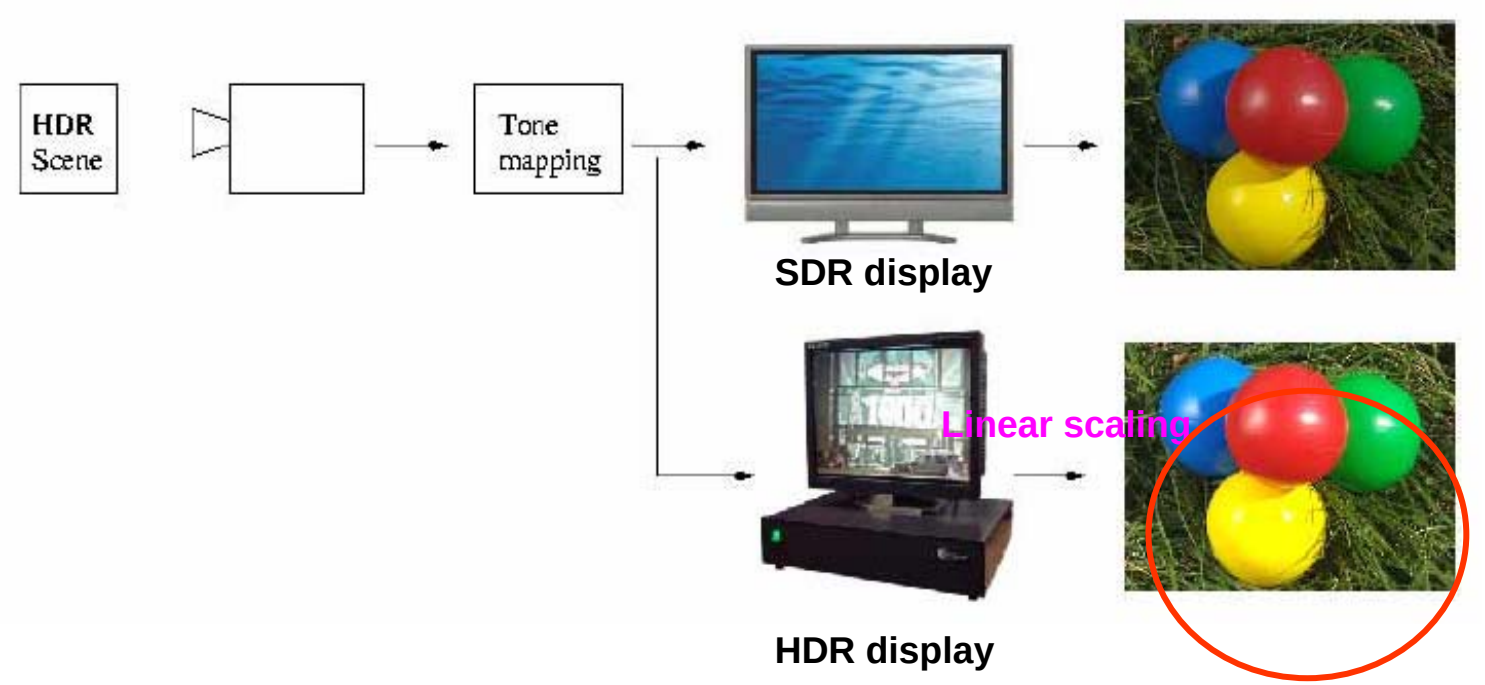
Abstract

- New issue in HDR display
  - Re-rendering of images that have been mapped to standard dynamic range (SDR) displays
- The proposal of tone scale function
  - Utilize the increase in dynamic range of HDR monitor to recreate the brightness of the clipped or compressed specular highlights
  - Achieve more natural looking images in HDR displays

Introduction

- The HDR monitor
  - Displaying simultaneously bright highlights and dark shadows
  - Facing with new problem of re-rendering the large amount of legacy images that are already mapped to SDR images
    - In SDR displays, specular highlights are badly reproduced due to strong luminance compression or clipping
    - As the highlights offer important visual cue about shape or realism, it is important to use part of dynamic range of HDR display

- The proposal of tone scale function to expand the luminance range, especially specular highlights

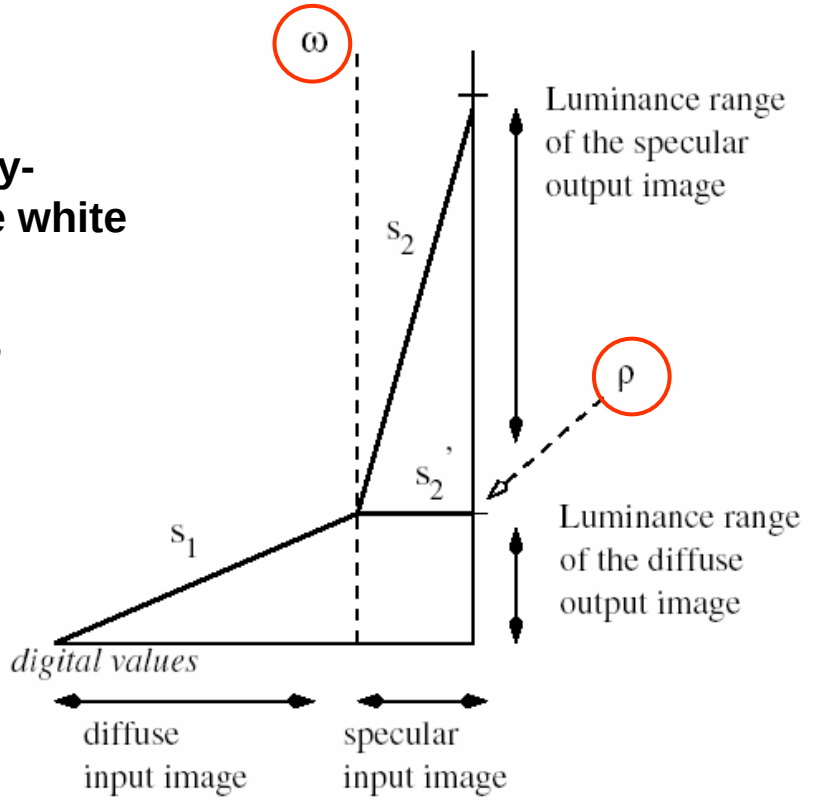


The Tone Scale Function

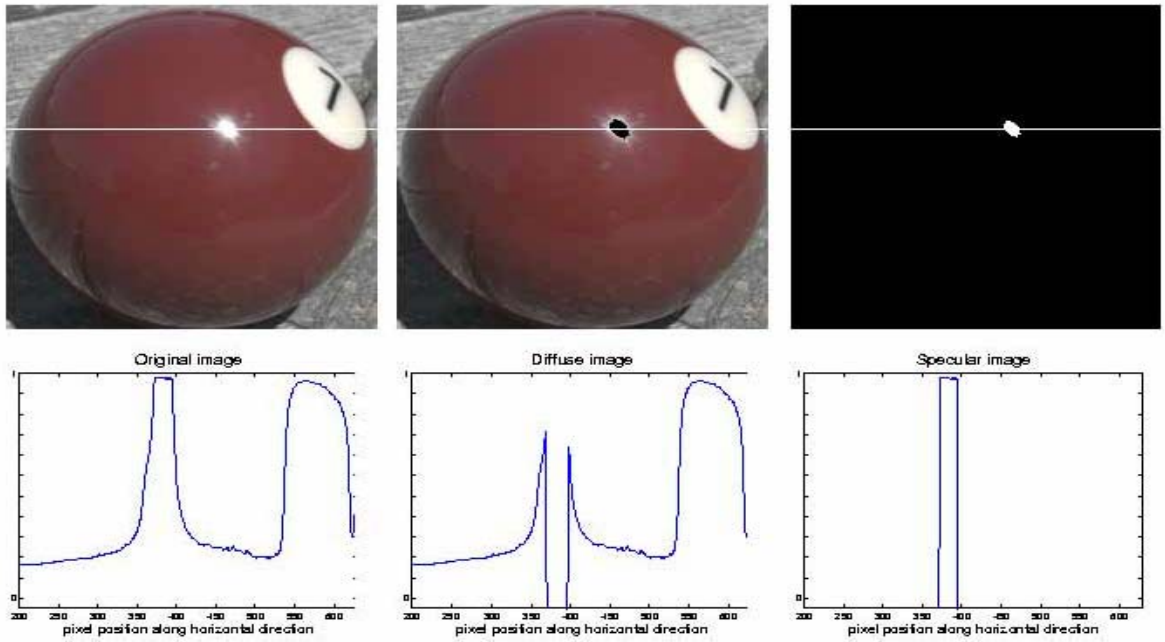
- The shape of tone scaling function
  - Composed of two slopes to adjust the tone of diffuse image and specular image

ω **: normalized code value (a linearly-encoded) of the maximum diffuse white**

ρ **: percentage of the maximum display luminance allocated to** ω



- An example of an image segmentation into its specular and diffuse componets
  - The specular image : contains specular highlights
  - The diffuse image : the rest of image



The definition of tone scaling function

– Varying the ρ- parameter to test the visual experiment

$$f(\Lambda(p)) = \begin{cases} s_1 \cdot \Lambda(p) & if\ \Lambda(p) \le \omega \\ s_1 \cdot \omega + s_2(\Lambda(p) - \omega) & if\ \Lambda(p) > \omega \end{cases}$$

where

$s_1 = \rho / \omega$

$s_2 = (1-\rho)/(\Lambda_{\max} - \omega)$

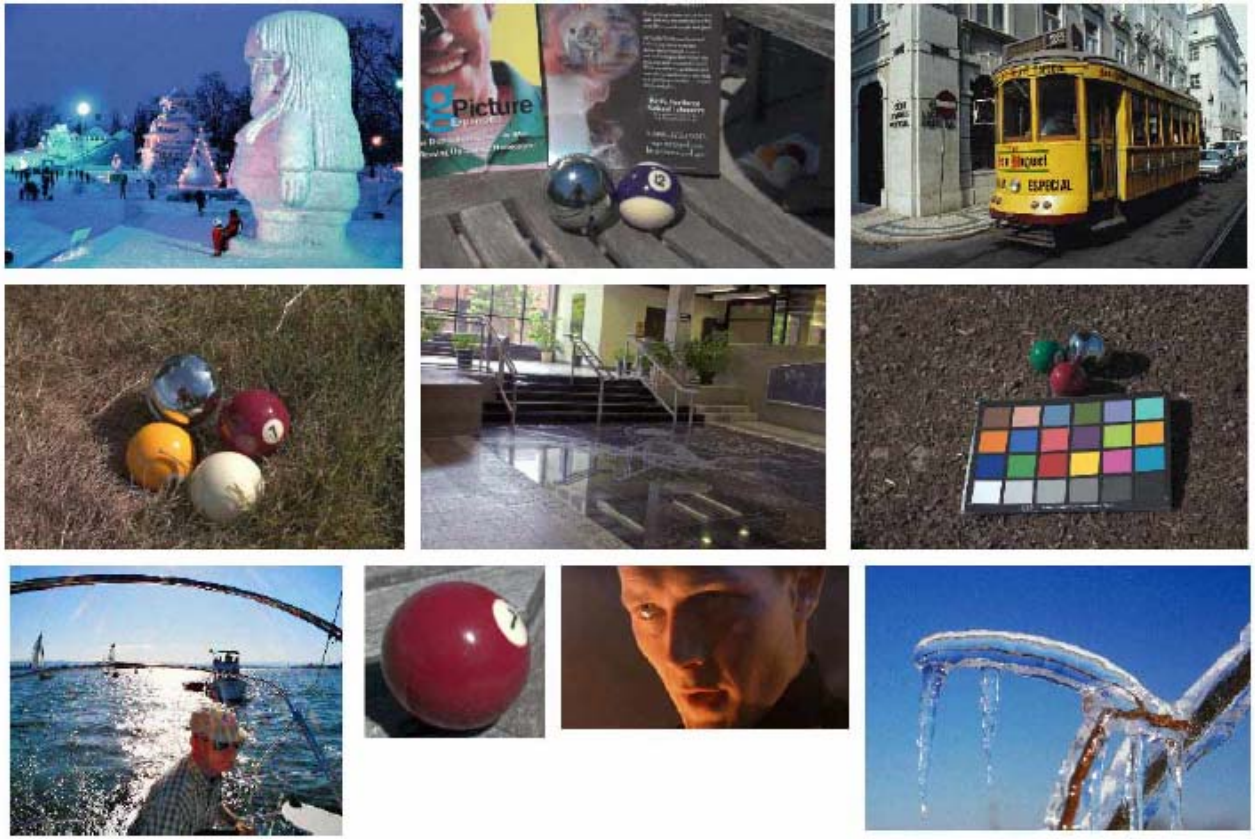
Λ : *normalized luminance*

p : *a pixel in the image*

$\Lambda_{\max}$: *maximum digital value of the input image*

Stimuli preparation

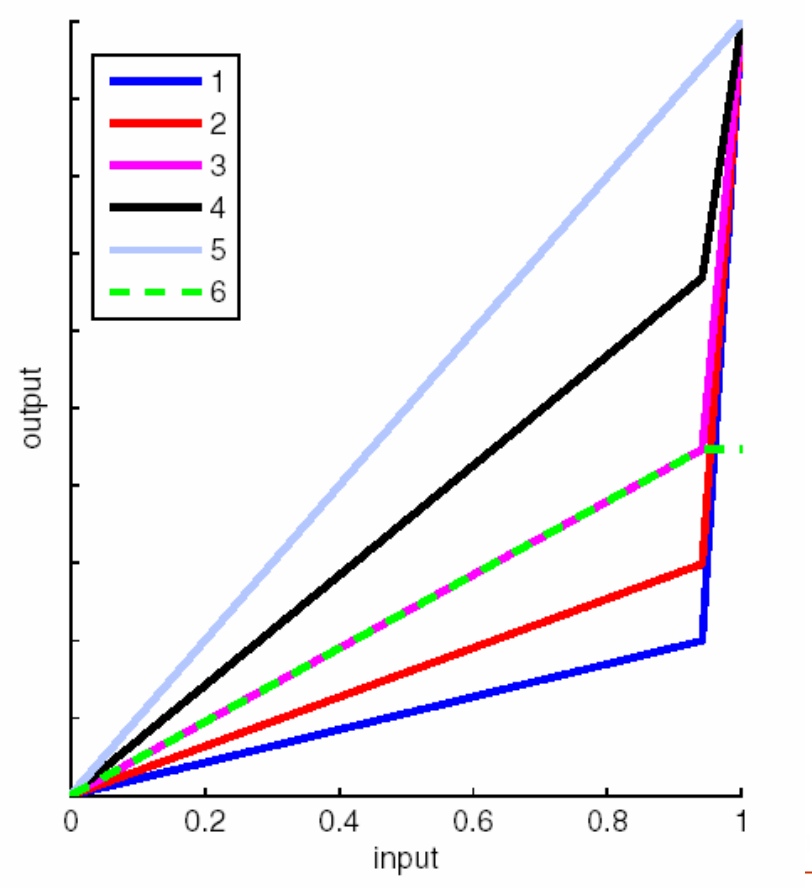
- The set of images containing specular highlights



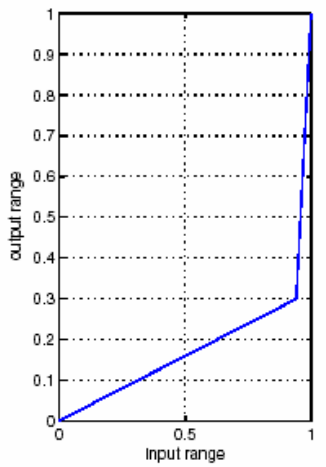
- The tone scales used in the experiment
  - Four different ρ
  - Linear scaling
  - Clipped version

Table 1: Tone scales used in the experiment.

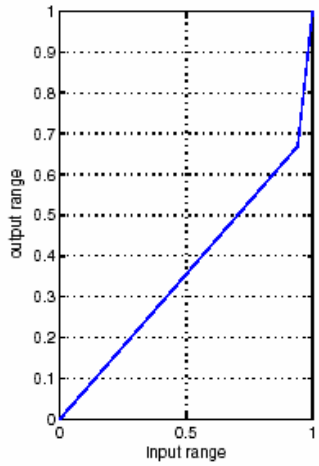
	1	2	3	4	5	6
ρ	0.2	0.3	0.47	0.67	lin.	0.47 clipped



- For the non-clipped tone scales
  - The more luminance range is allocated to the diffuse image, the brighter the image appears
  - The smaller luminance range allocated to the diffuse image causes the image to look dimmer



Small range allocated to diffuse image



Large range allocated to diffuse image

- A smoothing technique to remove unnatural contours
  - Adding a smoothing step to our algorithm to reduce the discontinuity in the tone scale function
- The generation of pairs of tone-scaled images
  - Presenting the image in pairs computed by different tone scale to observers, where its left/right position is chosen randomly
    - If the number of tone scale is 6, then the number of pairs is 15

The psychovisual experiment

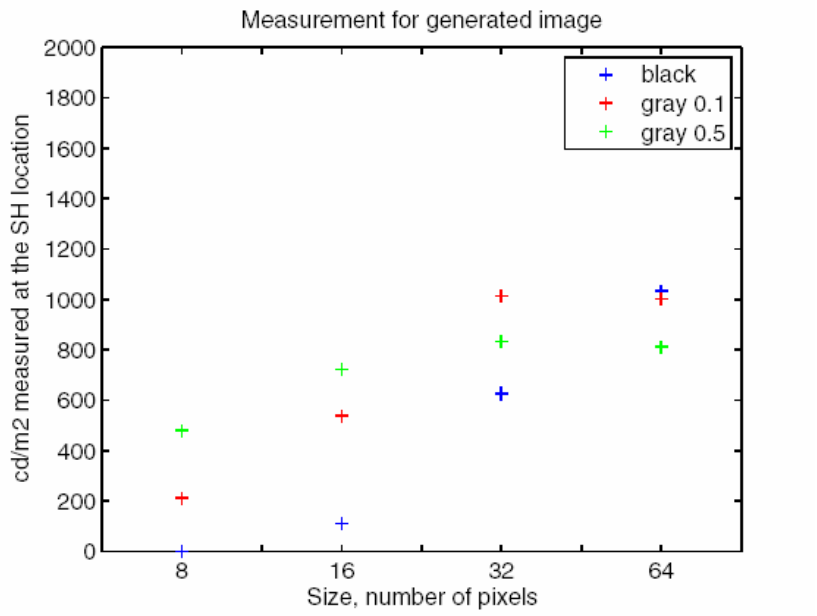
- Procedure
  - Observers : naïve observers (14), experts (6)
  - Display : Brightside's 37'' HDR monitor
  - Viewing angle : 33 degree
  - For each image of the test set, 15 pairs were presented, then the 15 pairs of next image are shown
  - Asking the observers which image looks more natural

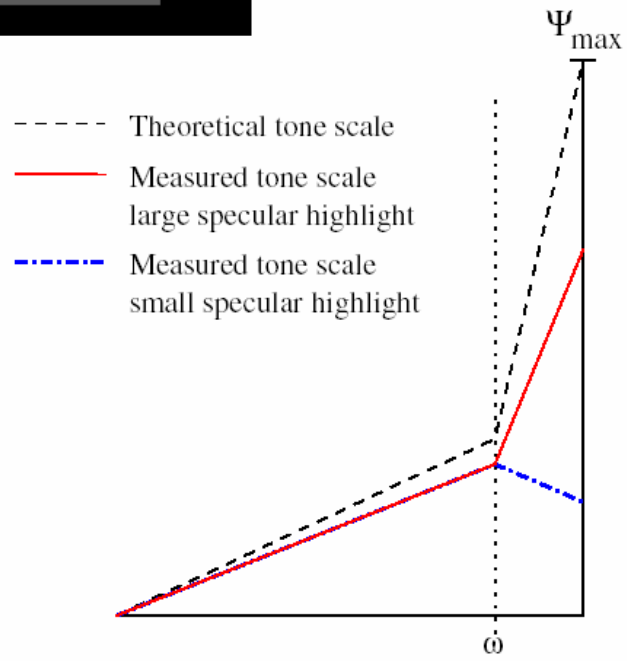
Measurements performed on the HDR display

- Displaying and measuring a large white patch to obtain the maximum displayed luminance of HDR monitor
  - For very small bright areas, this measured value cannot be reached due to the cross-talk that the luminance measured at one LED position is not only due to one LED but also to remaining light emitted by neighboring LEDs

→ **The measured luminance at screen differ from what is intended by the tone scale function applied to the image**

- Measuring white patches of varying sizes and backgrounds
  - Based on our measurements, the diameter of a specular highlights must be more than 16 pixels

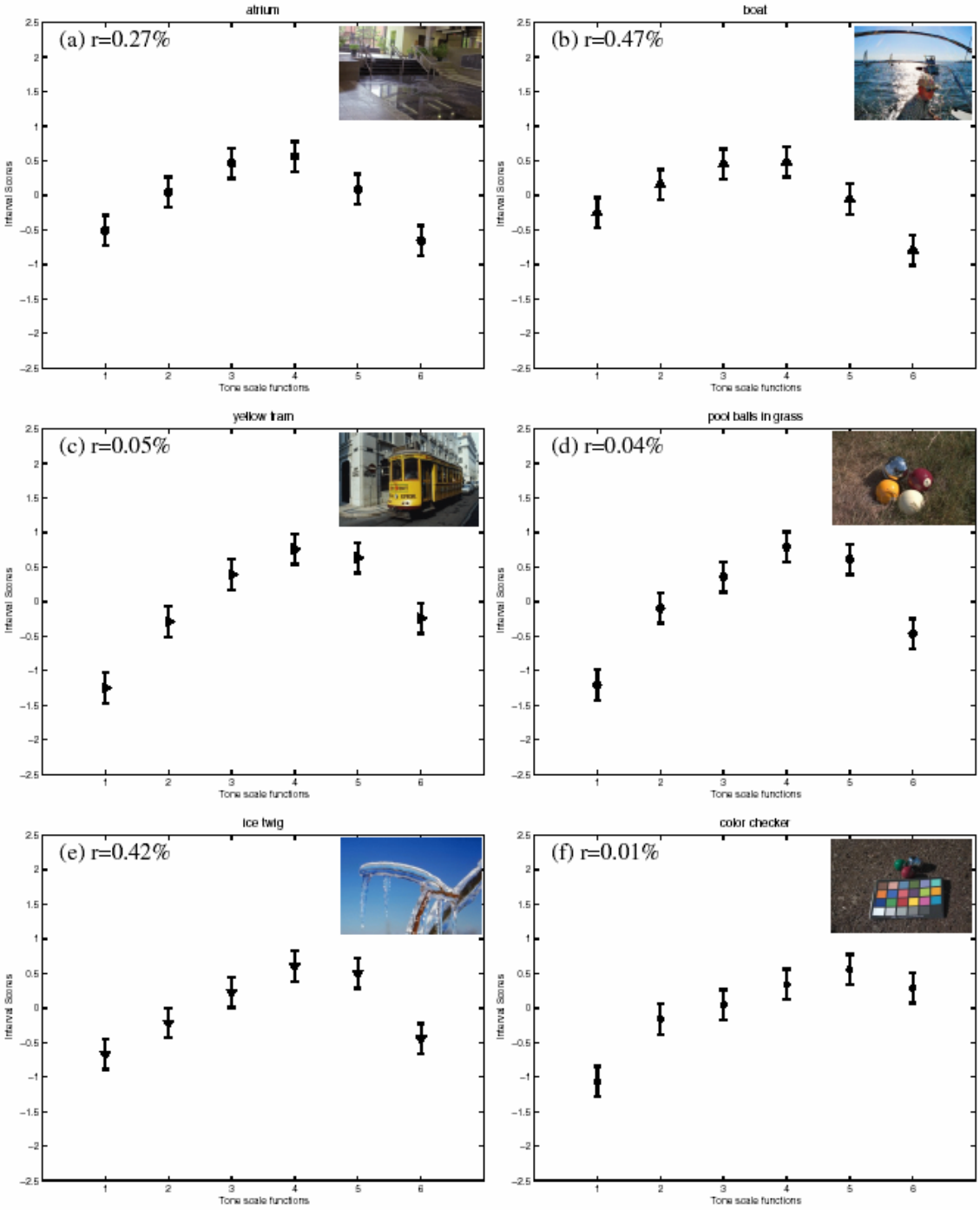




Result

- Statistical analysis
  - Applying the Thurstones's law of comparative judgment Case V to convert the paired comparison observer data into an interval scale of preference
    - Calculating the z-scores and 95%-confidence intervals from such data
  - Calculating the percentage of specular pixels in each image

$$r = \frac{N_{specular}}{N}$$


atrium
(a) r=0.27%
boat
(b) r=0.47%
yellow tram
(c) r=0.05%
pool balls in grass
(d) r=0.04%
ice twig
(e) r=0.42%
color checker
(f) r=0.01%
Interval Scores
Tone scale functions

Conclusion

- Focusing on the conversion of SDR images into images that can be displayed on an HDR monitor
  - Proposing the tone scale function to improve the realism of specular highlights
  - It is preferable not to use the entire dynamic range for the diffuse component of the input image despite of the reduction in mean brightness