



Natural Scene Statistics of Color and Range

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Motivation

- Color and range/depth play important roles in natural scenes and human vision systems.
- Perception of color and range/depth are related^{1,2}, but their joint statistics are unknown.
- Statistical relationships between color and range/depth could be used to
 - help understand how humans perceive 3D
 - improve image/video algorithms

¹Jordan et al., “Color as a source of information in the stereo correspondence process,” *Vision Research*, Dec. 1990

²Jordan and Bovik, “Using chromatic information in dense stereo correspondence,” *Pattern Recognition*, Apr. 1992

Contributions/Findings

- LIVE (Laboratory for Image and Video Engineering) Color+3D database 
- Statistical relationships and models between luminance/chrominance and range/disparity in natural scenes
- Improvement on computational stereo algorithms
- Posit that human vision systems could use these relationships in 3D perception.

Data Acquisition - LIVE Color+3D Database

- RIEGL-VZ400 laser scanner mounted with Nikon D700 digital camera

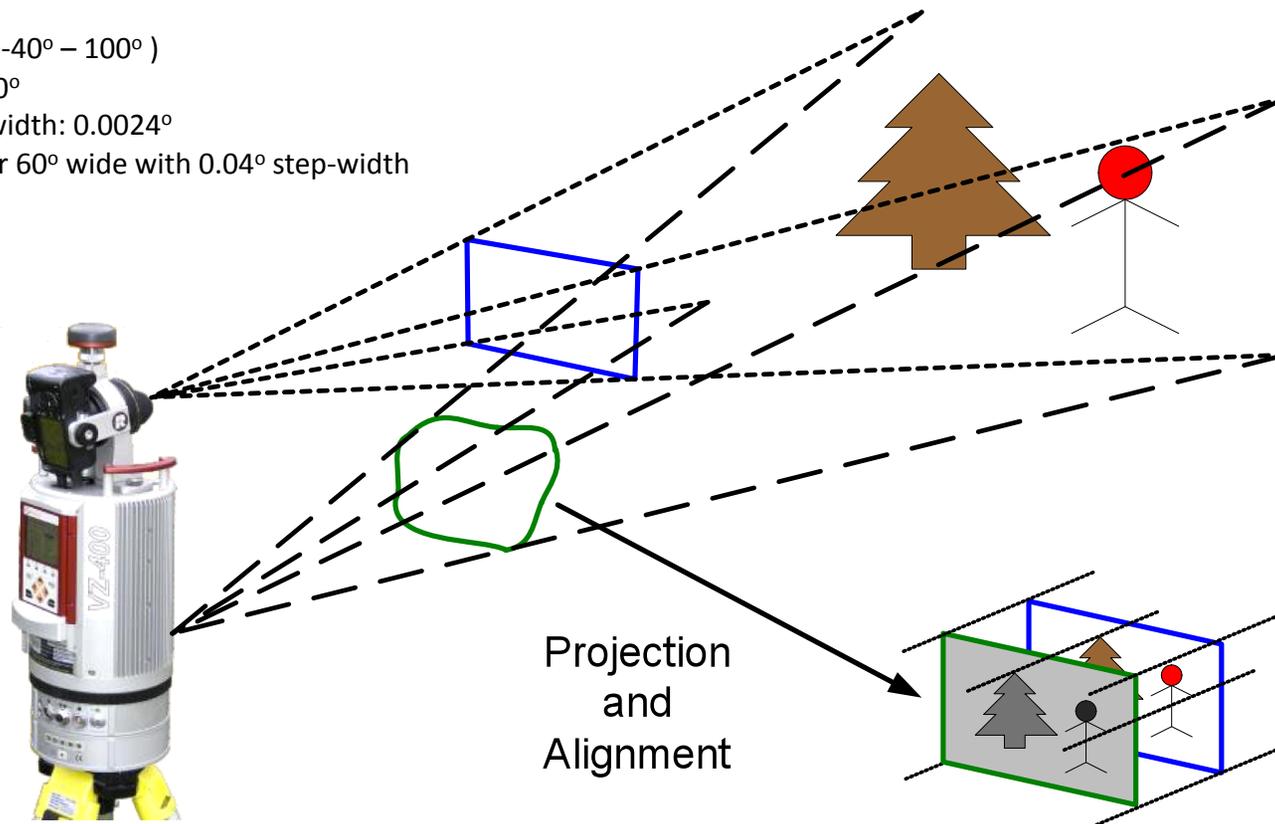
1.5 m – 600 m

Vertical: 100° ($-40^\circ - 100^\circ$)

Horizontal: 360°

Angular step-width: 0.0024°

Time: 2 min for 60° wide with 0.04° step-width



Data Acquisition - LIVE Color+3D Database

- RIEGL-VZ400 laser scanner mounted with Nikon D700 digital camera



Data Acquisition - LIVE Color+3D Database

- 12 sets of co-registered color images with ground-truth range maps
- High-definition resolution of 1280x720, 60°-by-33.75° field of view

Color Image

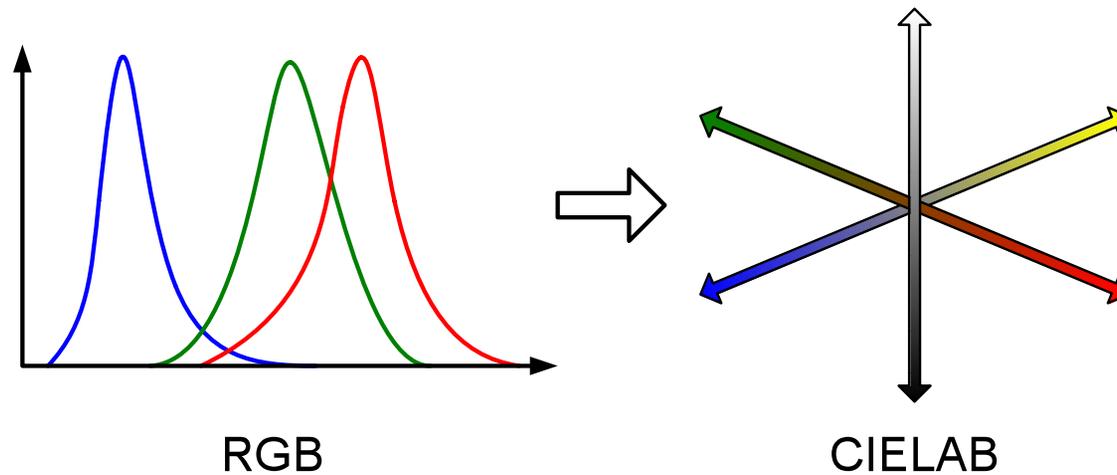


Range Map



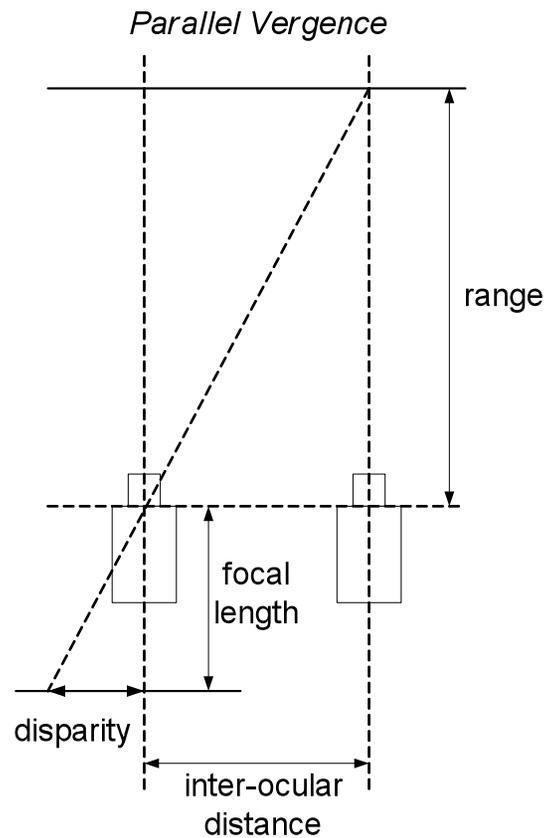
Analysis

- Transform RGB color images into a more perceptually relevant CIELAB color space.



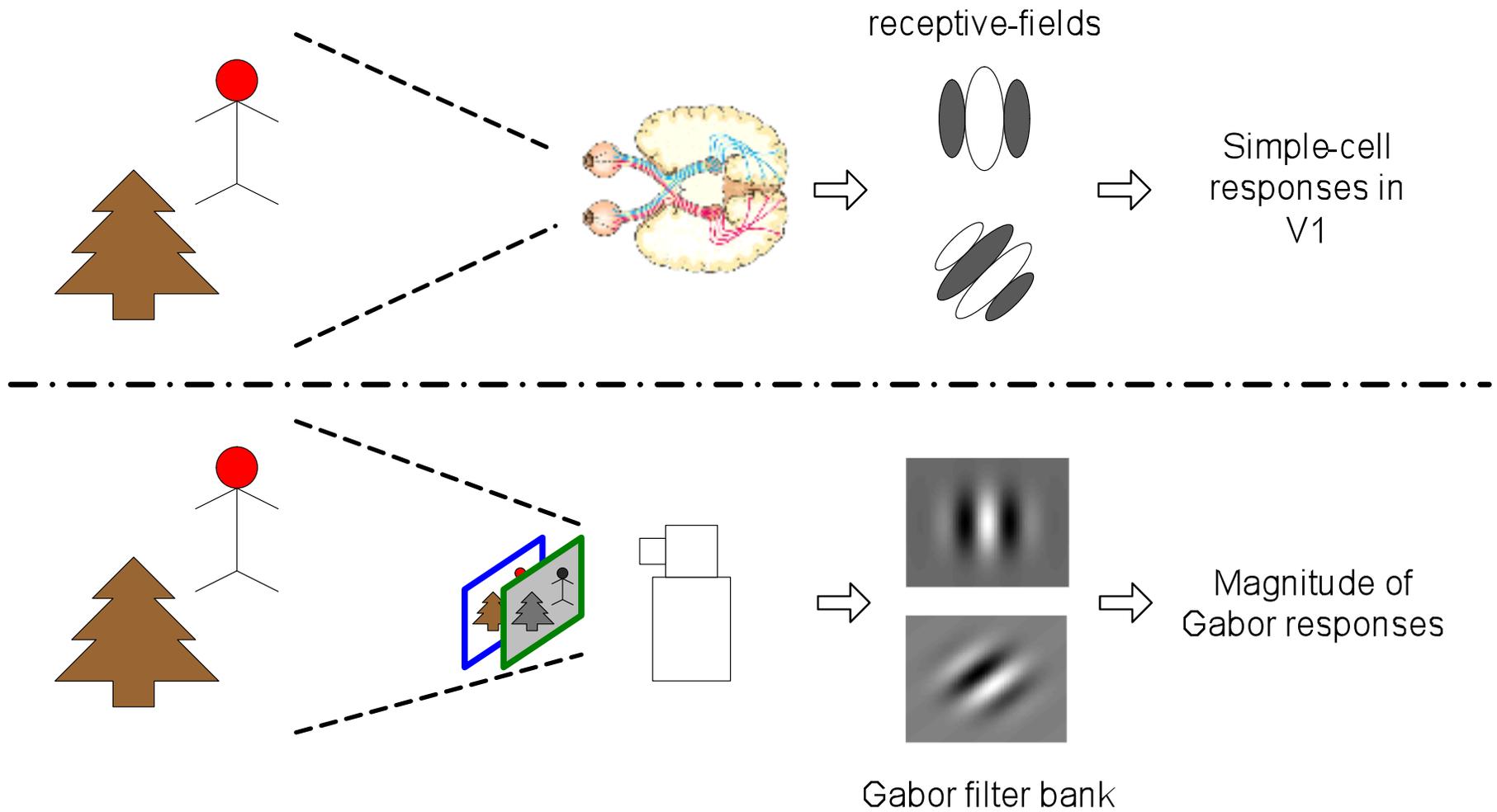
Analysis

- Convert ground-truth range maps into disparity maps.



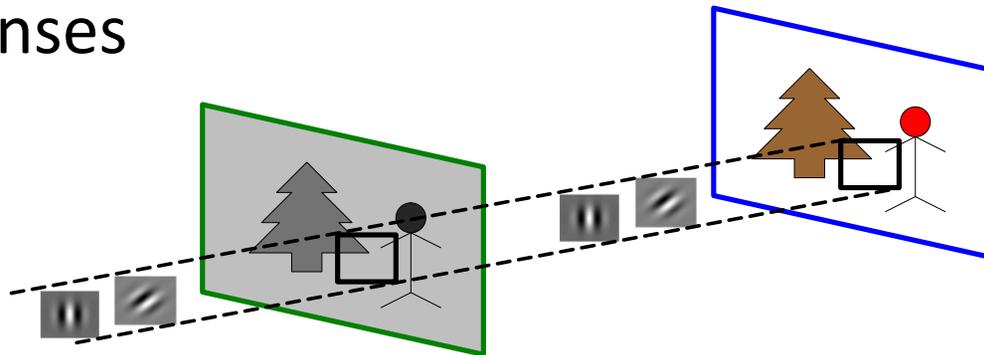
$$\frac{d_p}{f_c} = \frac{d_{io}}{R}$$
$$\Rightarrow d_p = f_c \frac{d_{io}}{R}$$

Analysis



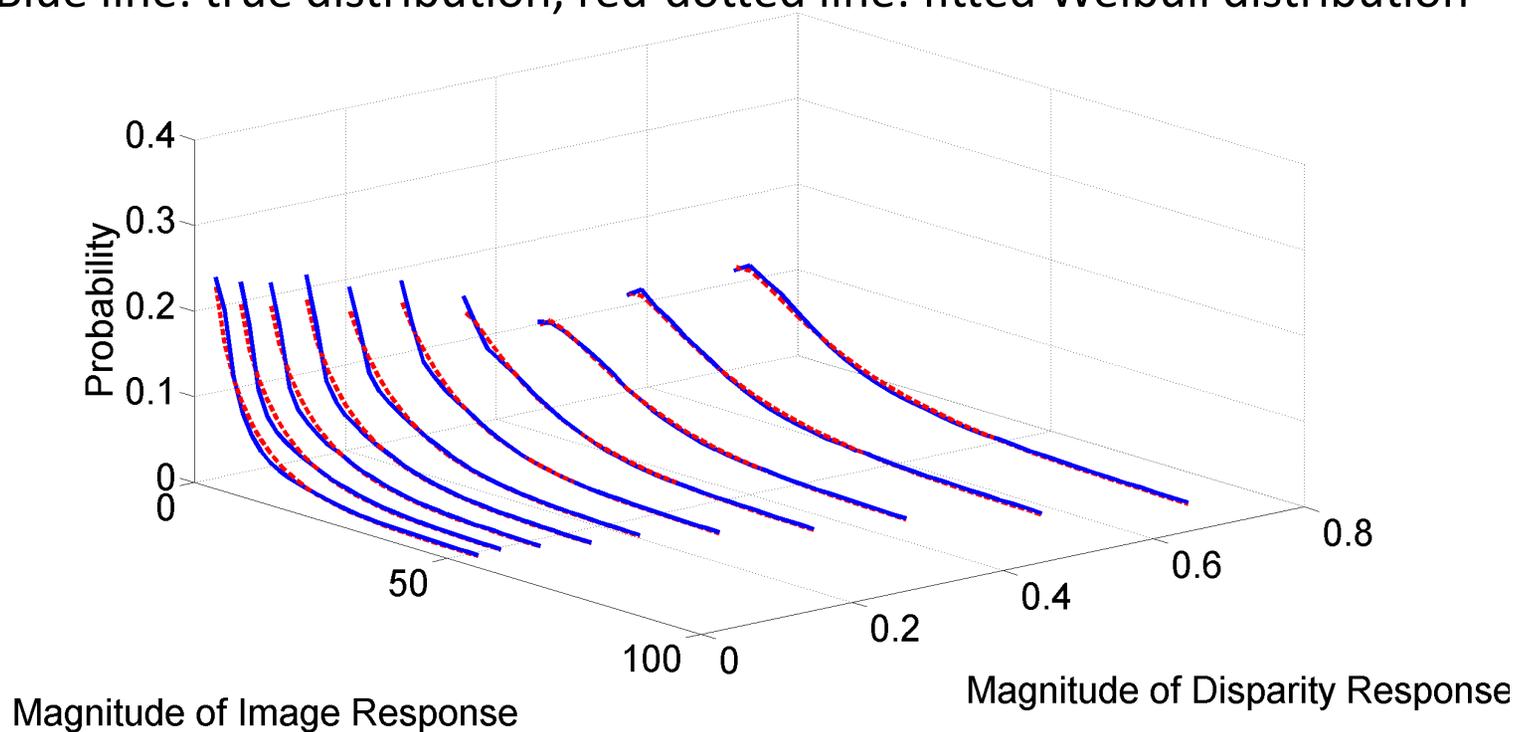
Analysis

- Marginal statistics and distribution
 - L^* , a^* , b^* responses
 - Disparity responses
- Conditional statistics and distribution
 - L^* , a^* , b^* responses conditioned on disparity responses

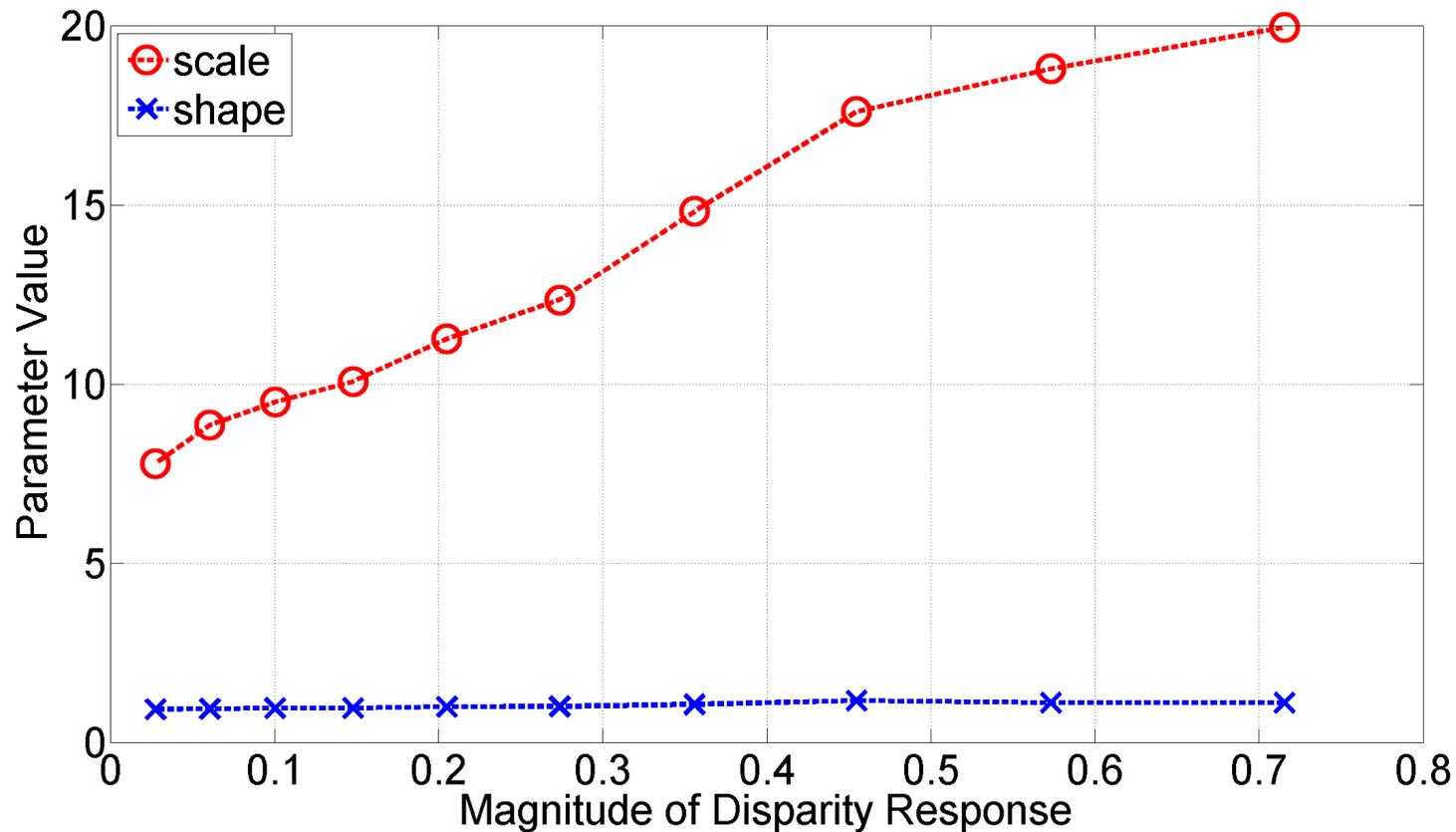


Conditional Distribution of Luminance Response on Disparity Response

- L* channel
- frequency = 5.87 (cycle/degree) , orientation = horizontal (0 degree)
- Blue line: true distribution, red-dotted line: fitted Weibull distribution

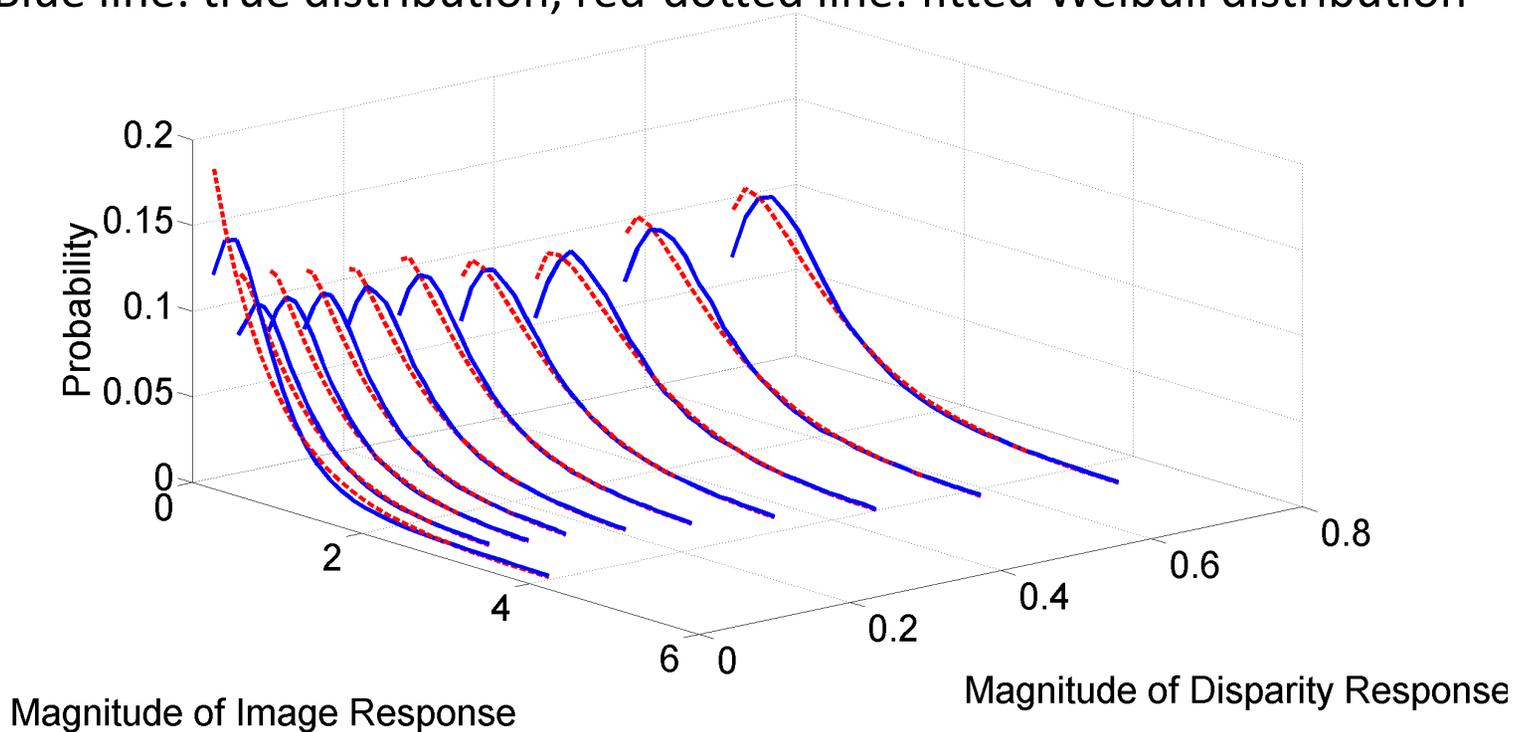


Plot of Weibull Parameters Fitting the Conditional Distribution

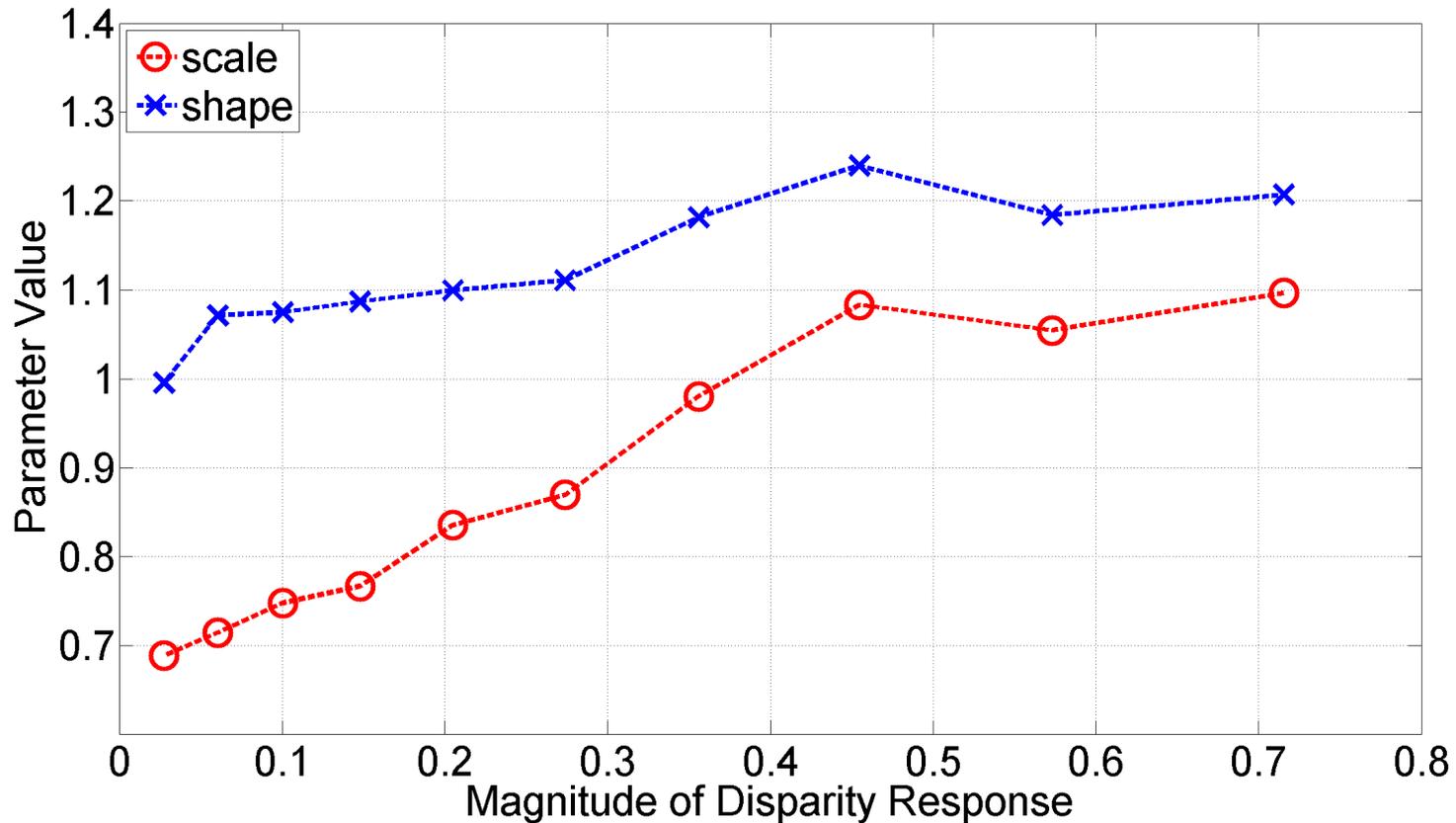


Conditional Distribution of Chrominance Response on Disparity Response

- a^* channel
- frequency = 5.87 (cycle/degree) , orientation = horizontal (0 degree)
- Blue line: true distribution, red-dotted line: fitted Weibull distribution

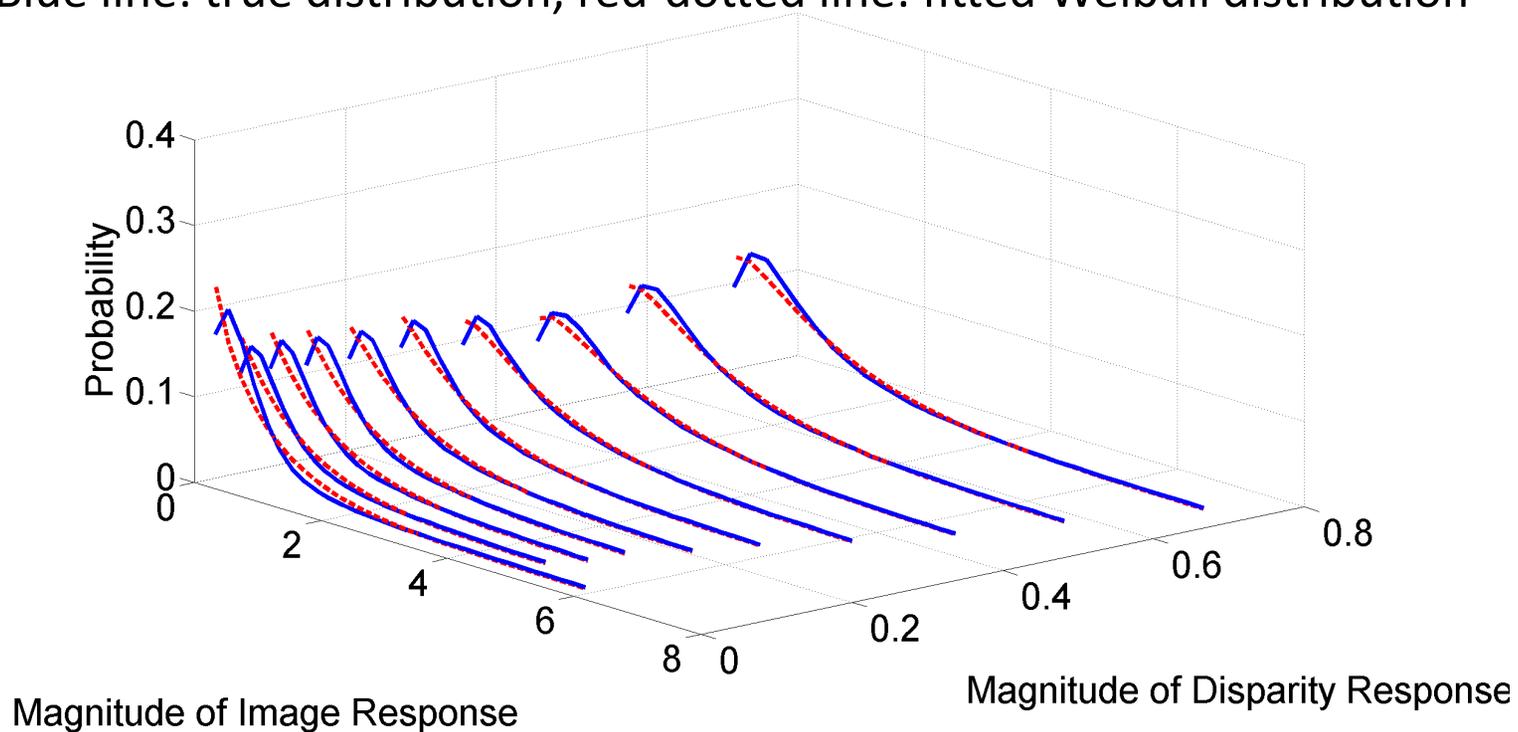


Plot of Weibull Parameters Fitting the Conditional Distribution

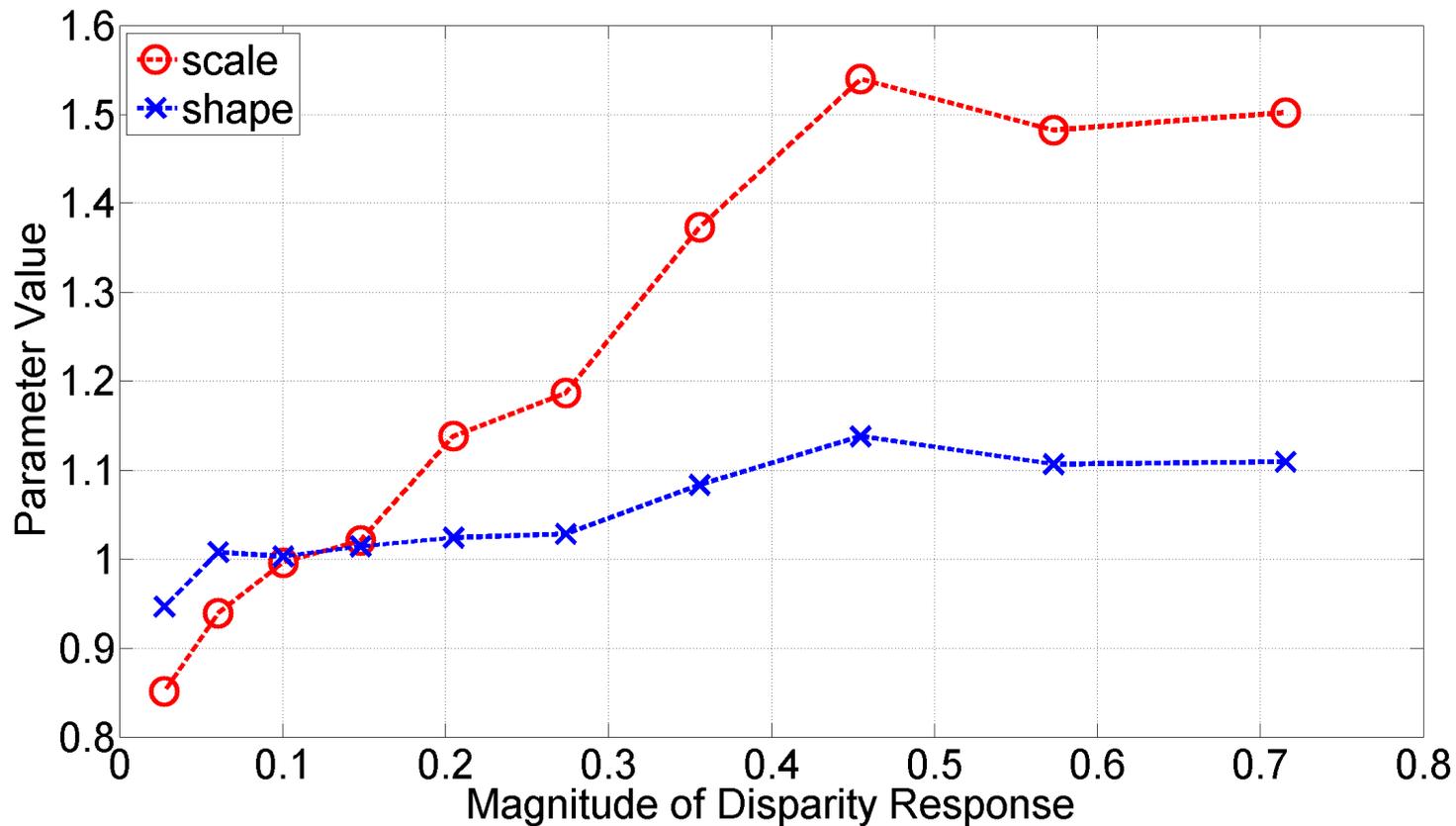


Conditional Distribution of Chrominance Response on Disparity Response

- b^* channel
- frequency = 5.87 (cycle/degree) , orientation = horizontal (0 degree)
- Blue line: true distribution, red-dotted line: fitted Weibull distribution



Plot of Weibull Parameters Fitting the Conditional Distribution



Application and Demonstration

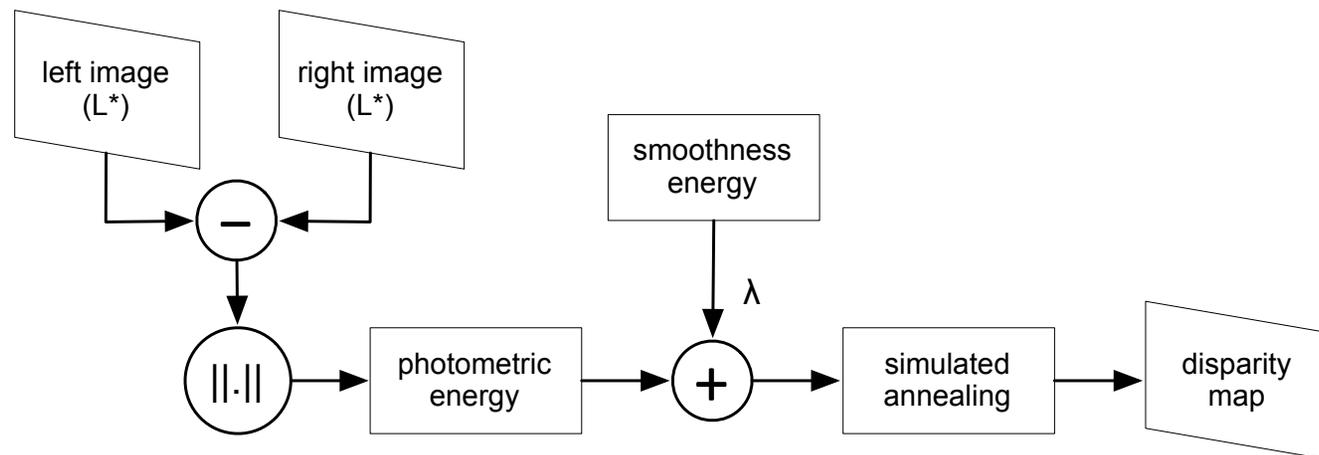
- Improvement on computational stereo algorithms
 - Application to Bayesian stereo algorithm
- Co-occurrence of luminance and range edges in natural scenes

Application to Bayesian Stereo Algorithm

- Given the left and right images, compute the disparity map.
- Formulation
 - Canonical model

$$Pr(D|(I_L, I_R)) \propto Pr((I_L, I_R)|D)Pr(D)$$

$$\Rightarrow E = E_p + \lambda E_s$$

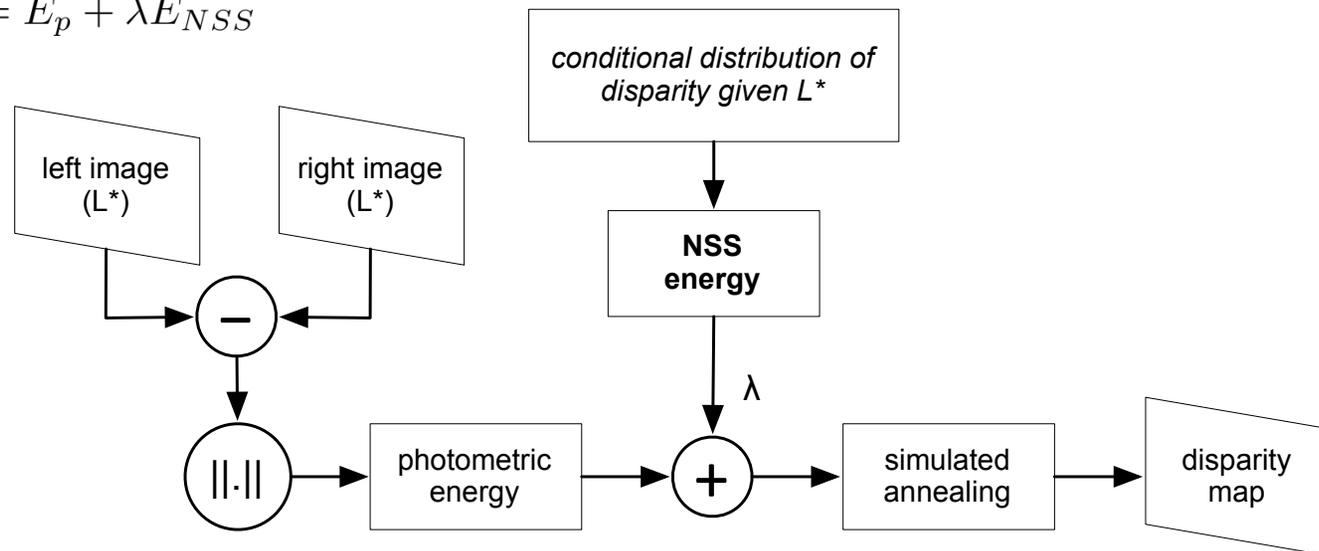


Application to Bayesian Stereo Algorithm

- Given the left and right images, compute the disparity map.
- Formulation
 - Previous NSS (natural scene statistics) model¹

$$Pr(\tilde{D} | (I_L, I_R), \tilde{I}_L) \propto Pr((I_L, I_R) | \tilde{D}, \tilde{I}_L) Pr(\tilde{D} | \tilde{I}_L)$$

$$\Rightarrow E = E_p + \lambda E_{NSS}$$



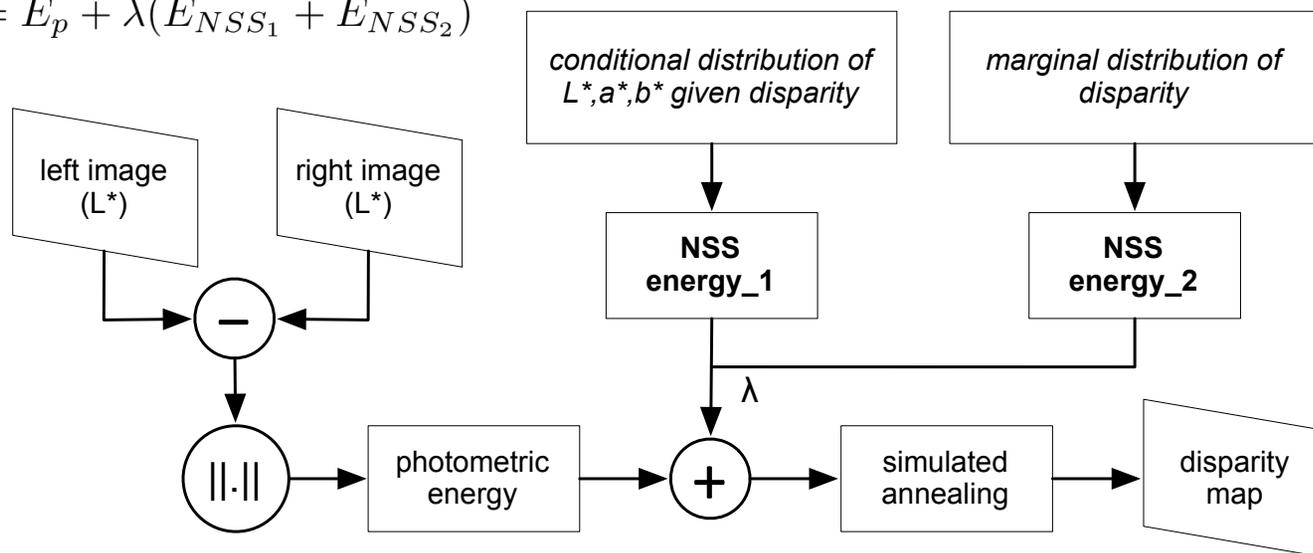
¹Liu et al., "Statistical modeling of 3D natural scenes with application to Bayesian stereopsis," *Image Processing, IEEE Transaction on*, to be published.

Application to Bayesian Stereo Algorithm

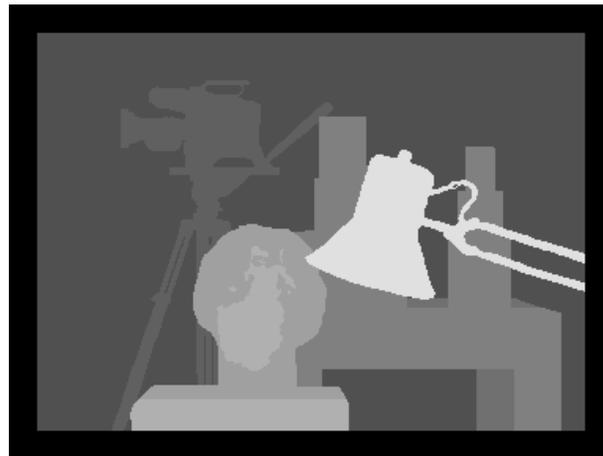
- Given the left and right images, compute the disparity map.
- Formulation
 - Gabor-based NSS model by this work

$$Pr(\tilde{D} | (I_L, I_R), \tilde{I}_L) \propto Pr((I_L, I_R) | \tilde{D}, \tilde{I}_L) Pr(\tilde{I}_L | \tilde{D}) Pr(\tilde{D})$$

$$\Rightarrow E = E_p + \lambda(E_{NSS_1} + E_{NSS_2})$$



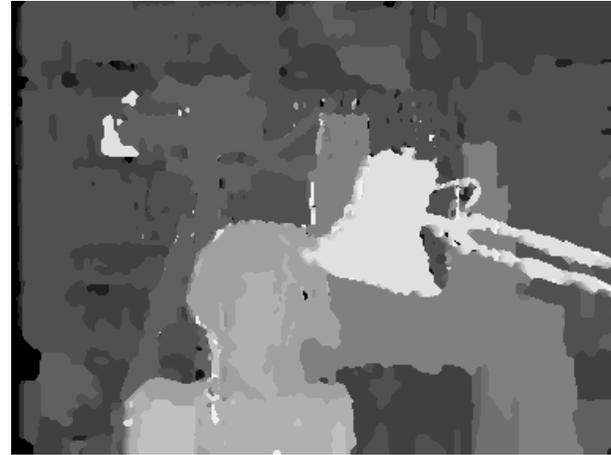
Ground-truth: “Tsukuba”



Visual Comparison



Canonical



Previous NSS

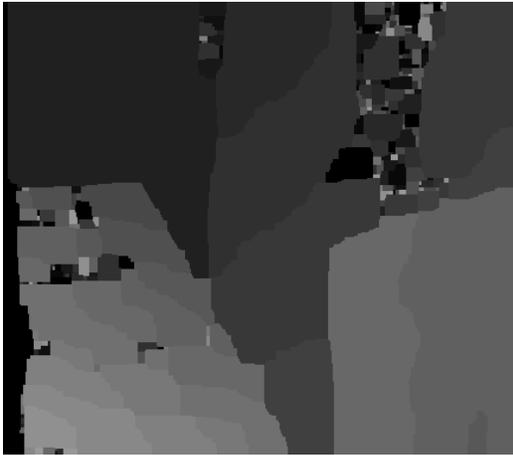


Gabor-based NSS

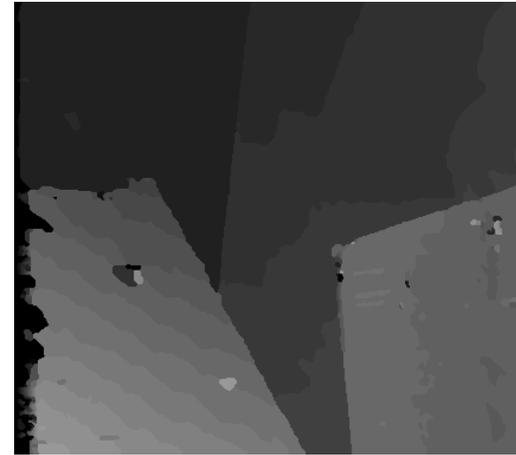
Ground-truth: “Venus”



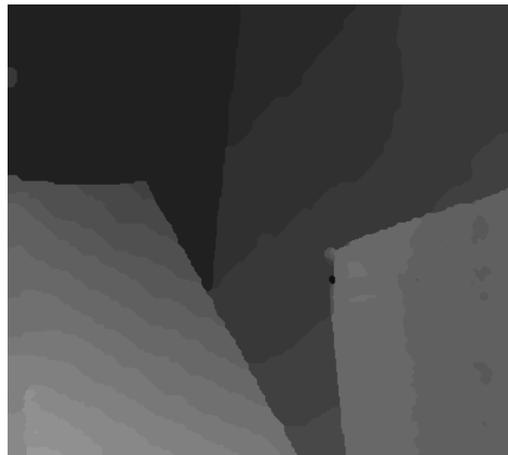
Visual Comparison



Canonical



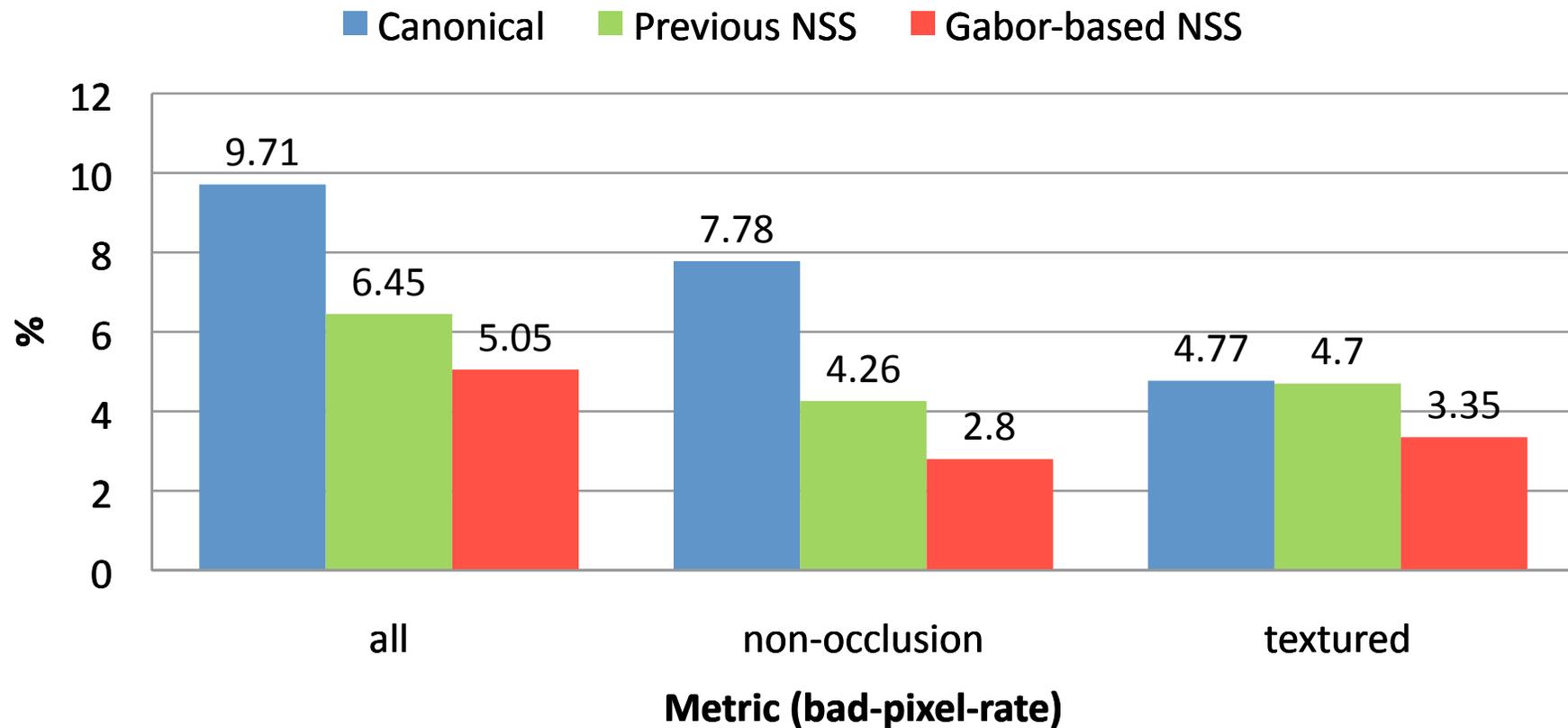
Previous NSS



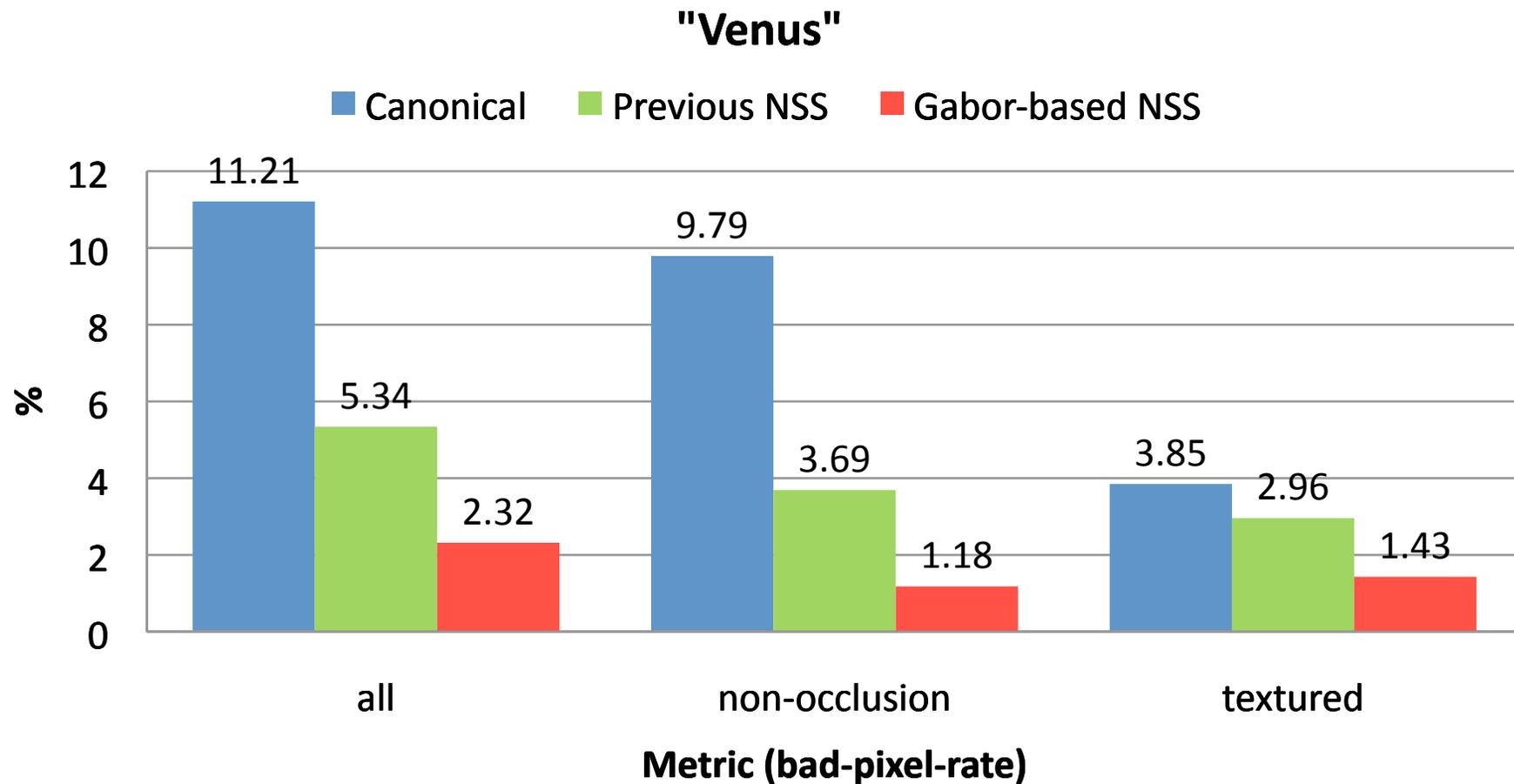
Gabor-based NSS

Numerical Comparison

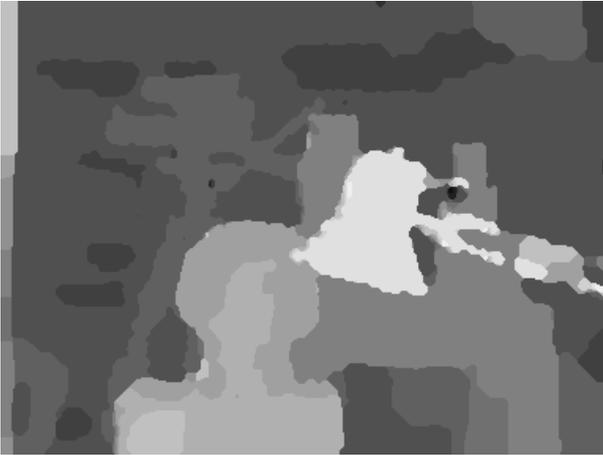
"Tsukuba"



Numerical Comparison



Visual Comparison between with/without Chrominance Information



Only Luminance

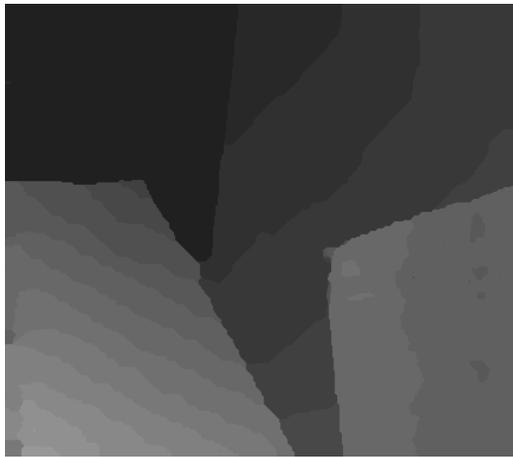


Only Chrominance

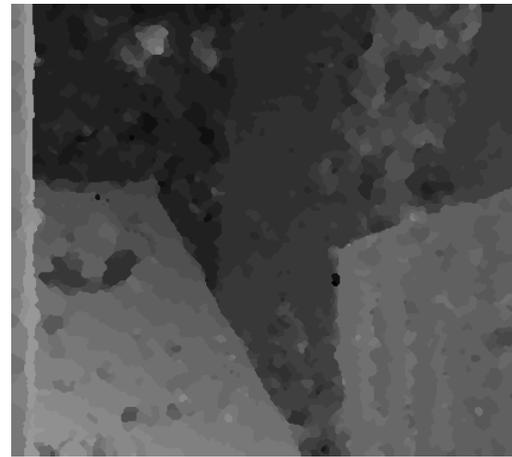


Both

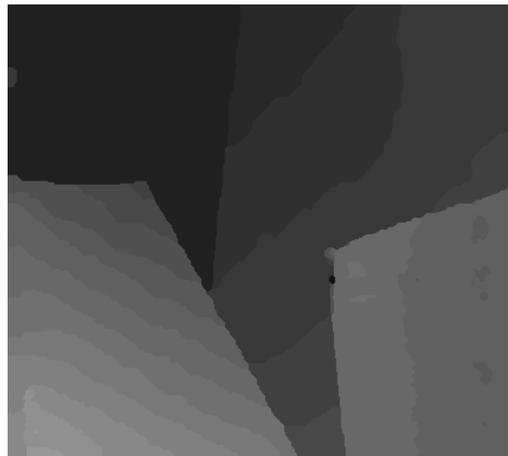
Visual Comparison between with/without Chrominance Information



Only Luminance

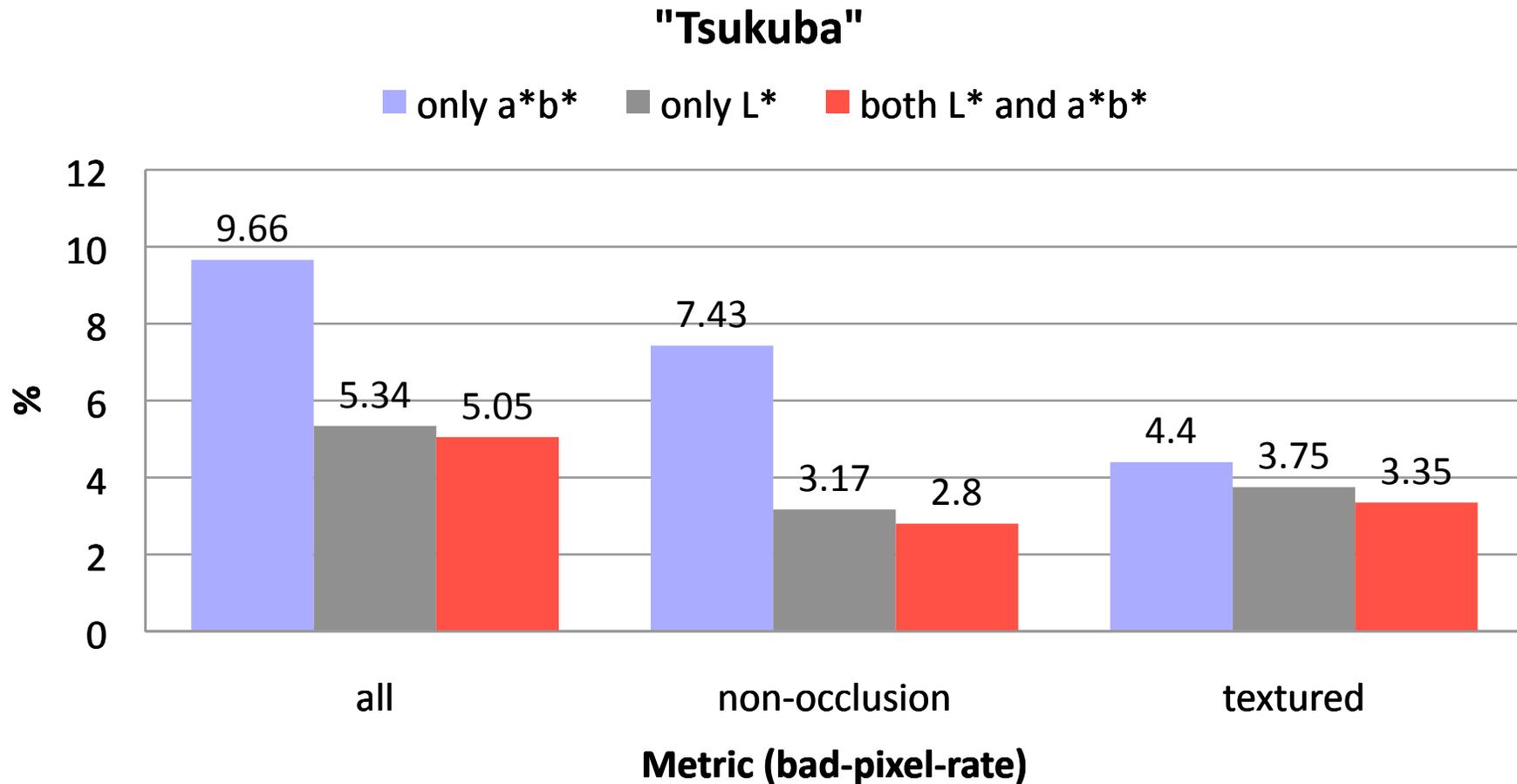


Only Chrominance

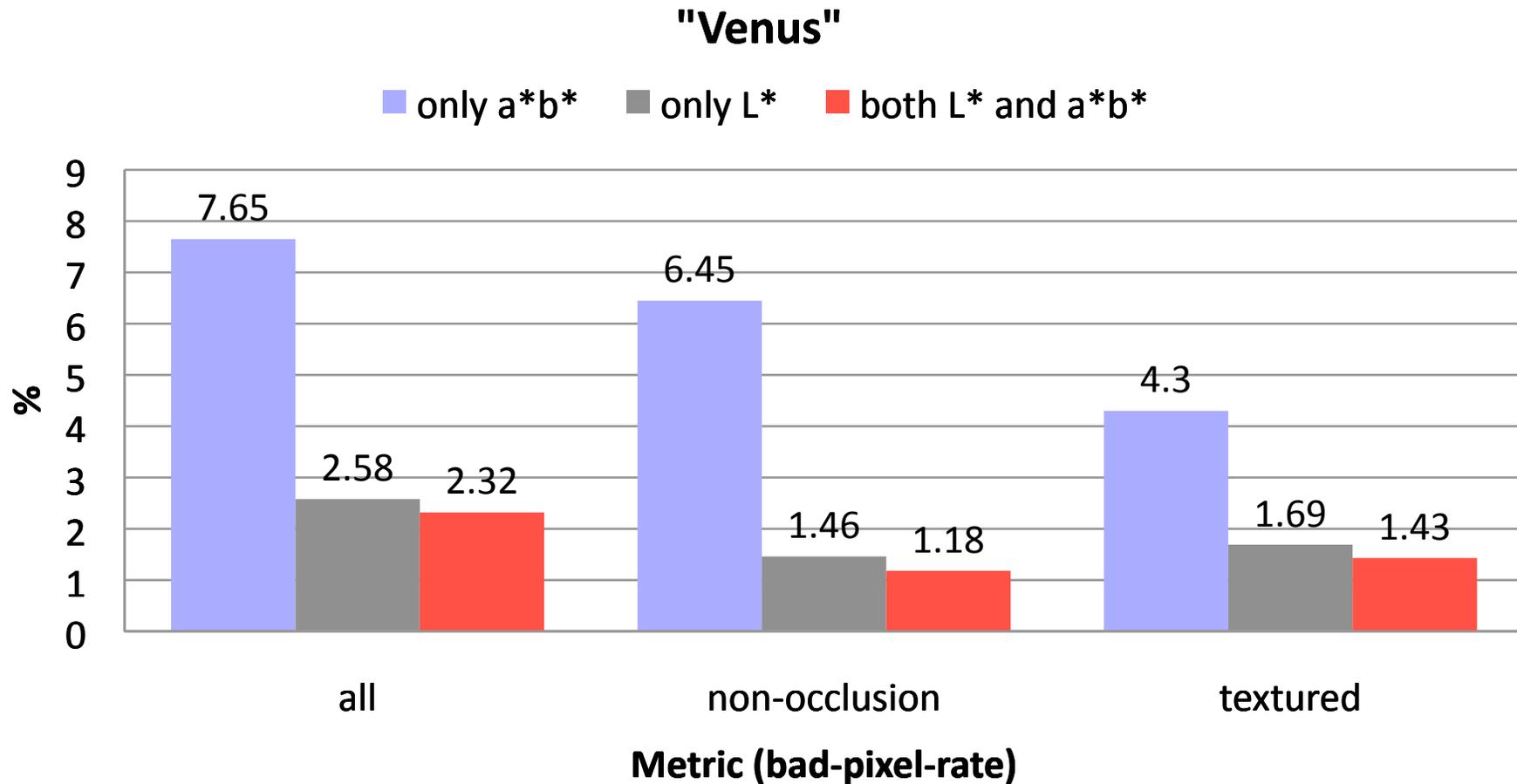


Both

Numerical Comparison between with/without Chrominance Information

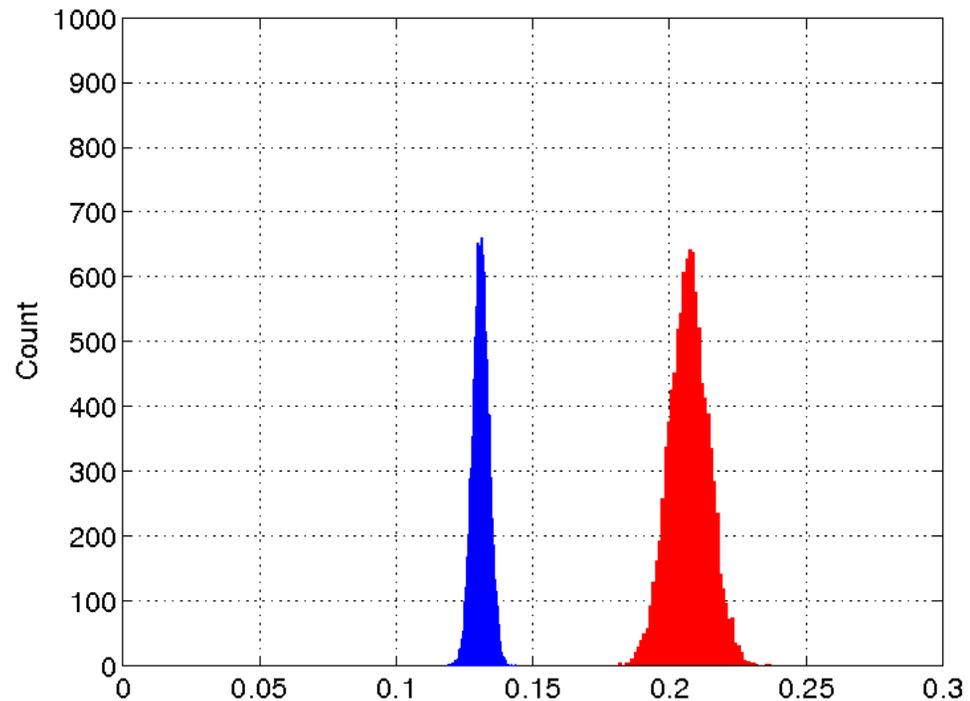


Numerical Comparison between with/without Chrominance Information



Co-occurrence of Luminance and Range Edges

- Given the prior information that there is a luminance edge, the probability of finding a range edge increases.



Sampling distribution of unconditional and conditional probability of range edges

Conclusion

- We built the LIVE 3D+Color database with high-definition resolution color images and co-registered range maps.
- The statistical models between luminance/chrominance and range/disparity in natural scenes are developed, and we demonstrated that they are
 - helpful in understanding human 3D perception.
 - useful in application to Bayesian stereo algorithms.

Acknowledgement

- Thanks to LIVE members for contributing to this work.
 - Application to Bayesian stereo algorithm
 - Yang Liu 
 - Co-occurrence of luminance/chrominance and range edges
 - Anish Mittal 
 - Michele Saad 
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