Modeling Surround-Aware Contrast Sensitivity

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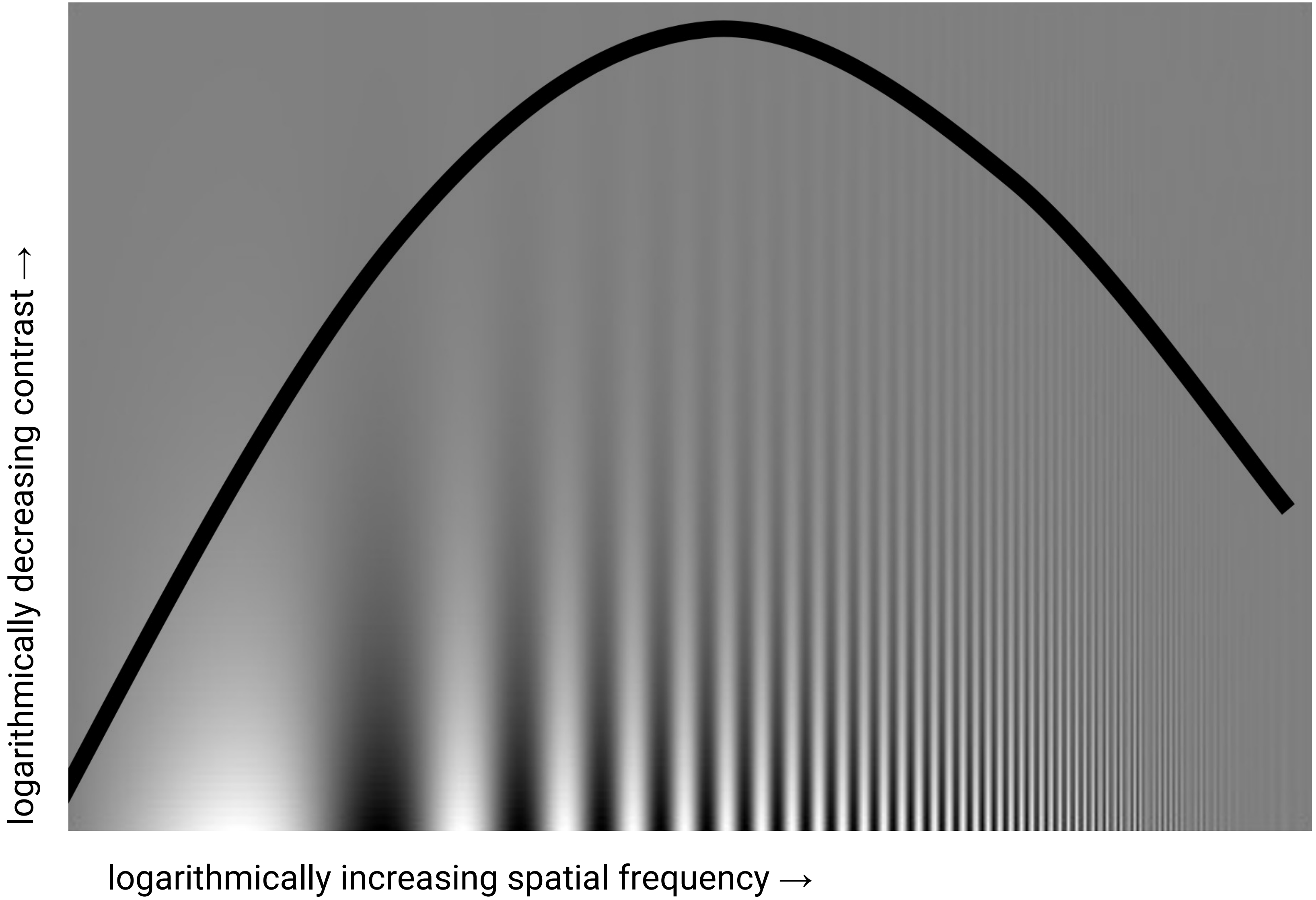
Contrast sensitivity function (CSF)



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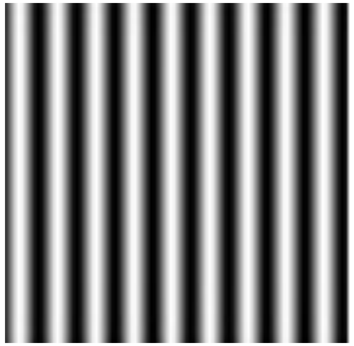
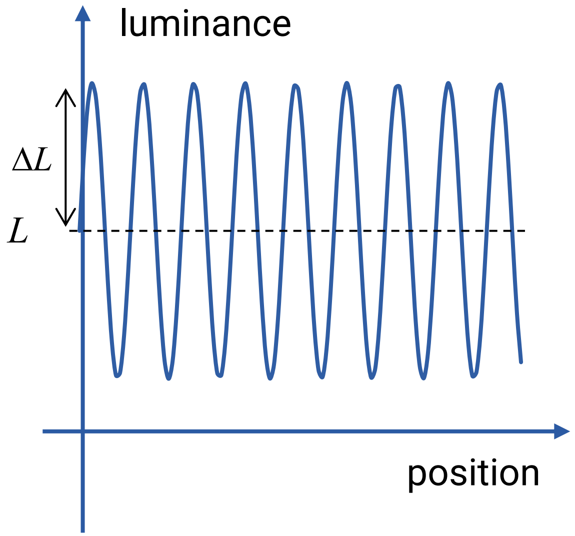


contrast $C = \frac{\Delta L}{L}$



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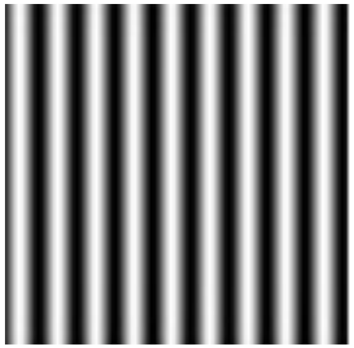

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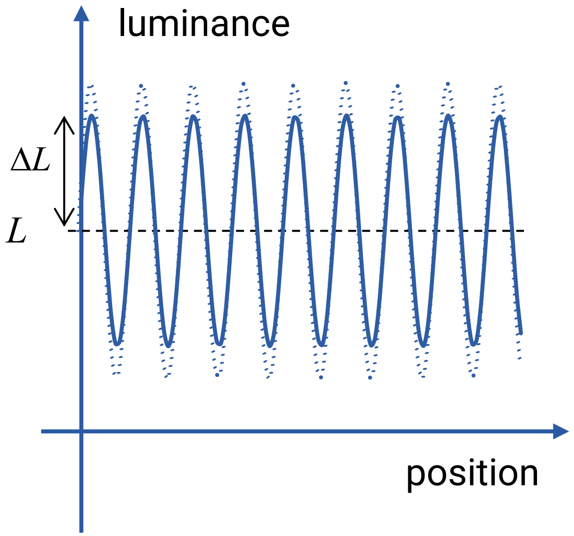

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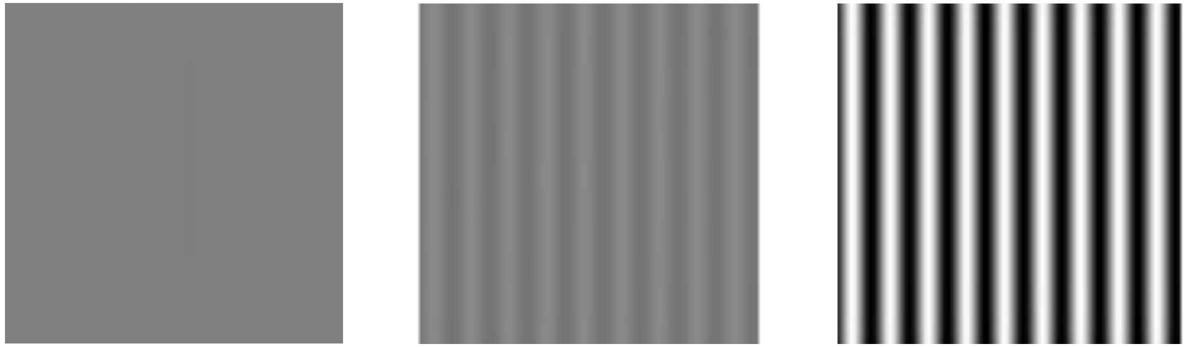

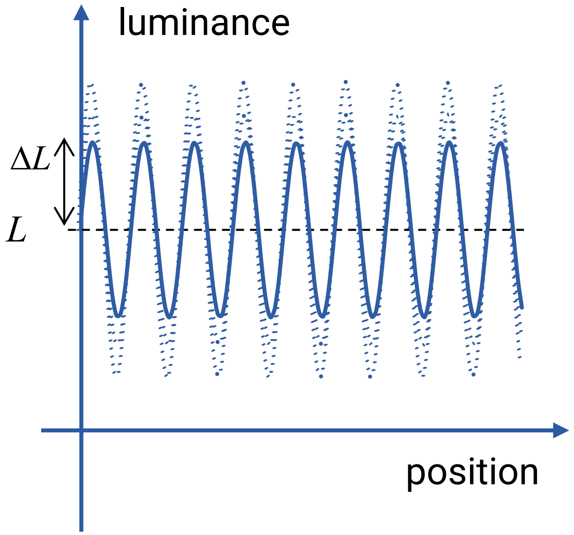

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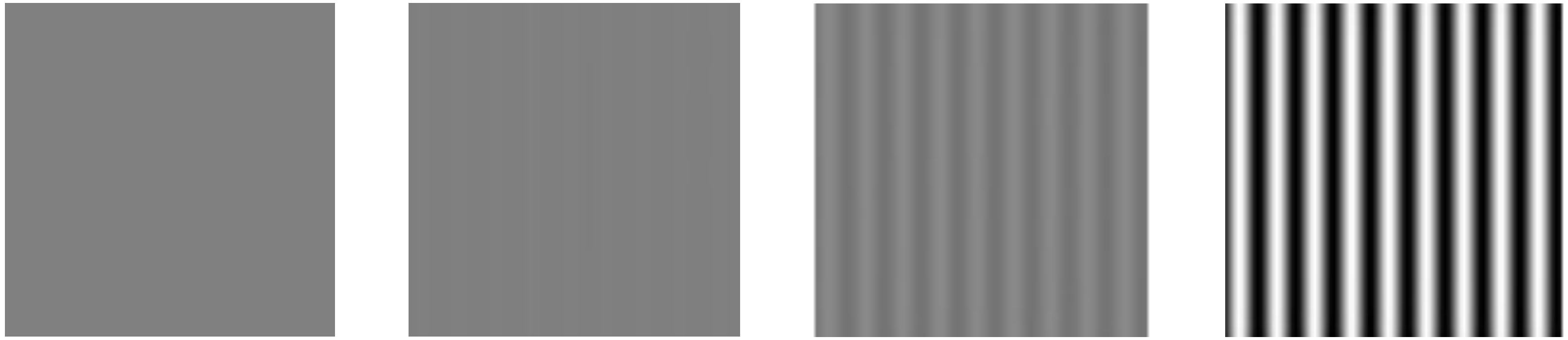
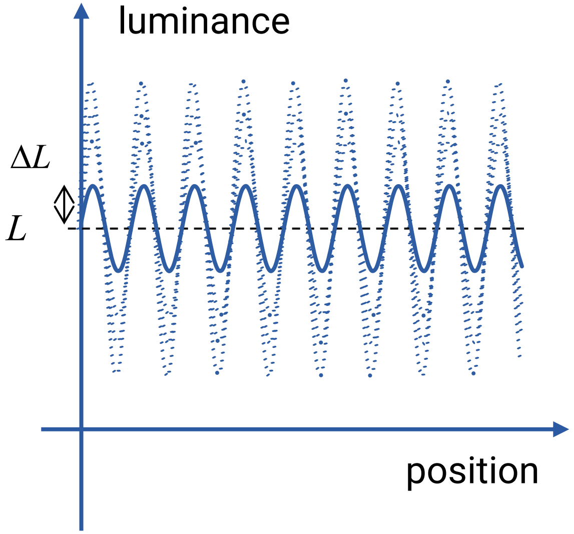
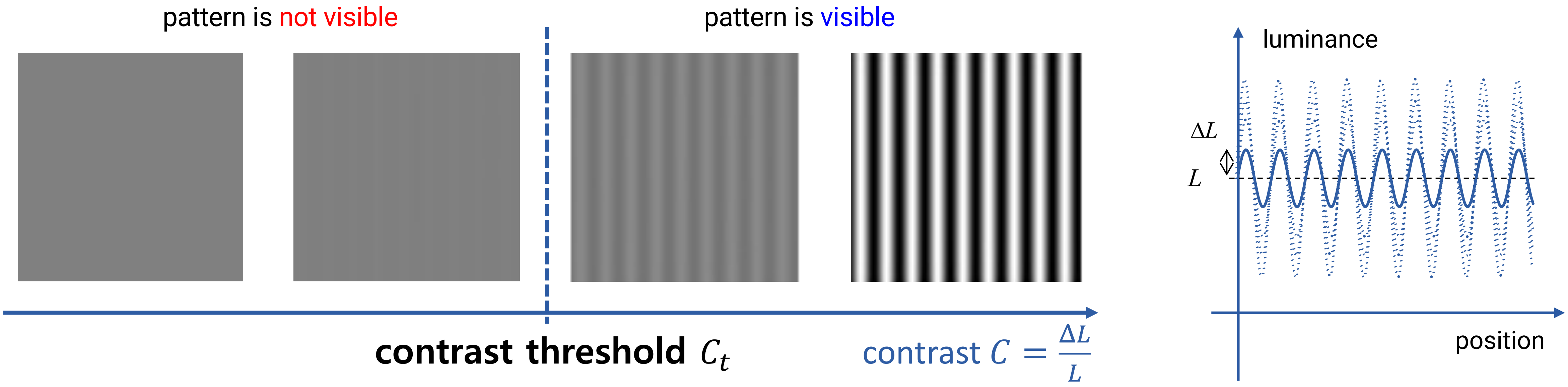
Contrast sensitivity function (CSF)



contrast $C = \frac{\Delta L}{L}$



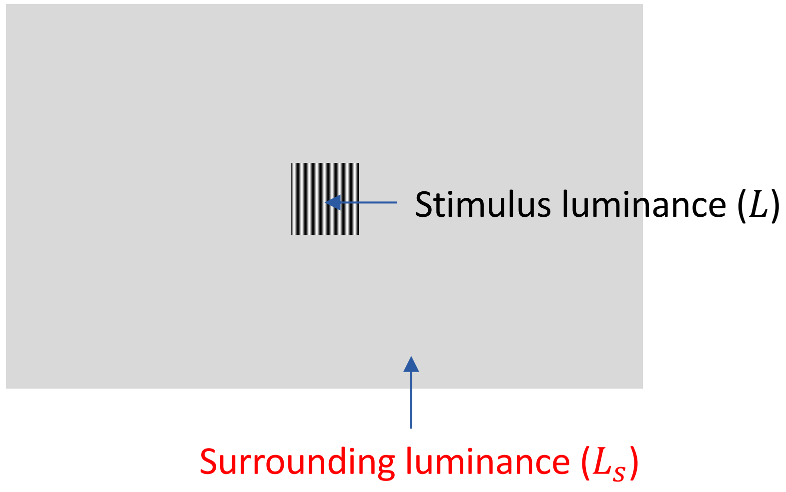
Contrast sensitivity function (CSF)



$$Contrast\ sensitivity = S = \frac{1}{C_t}$$

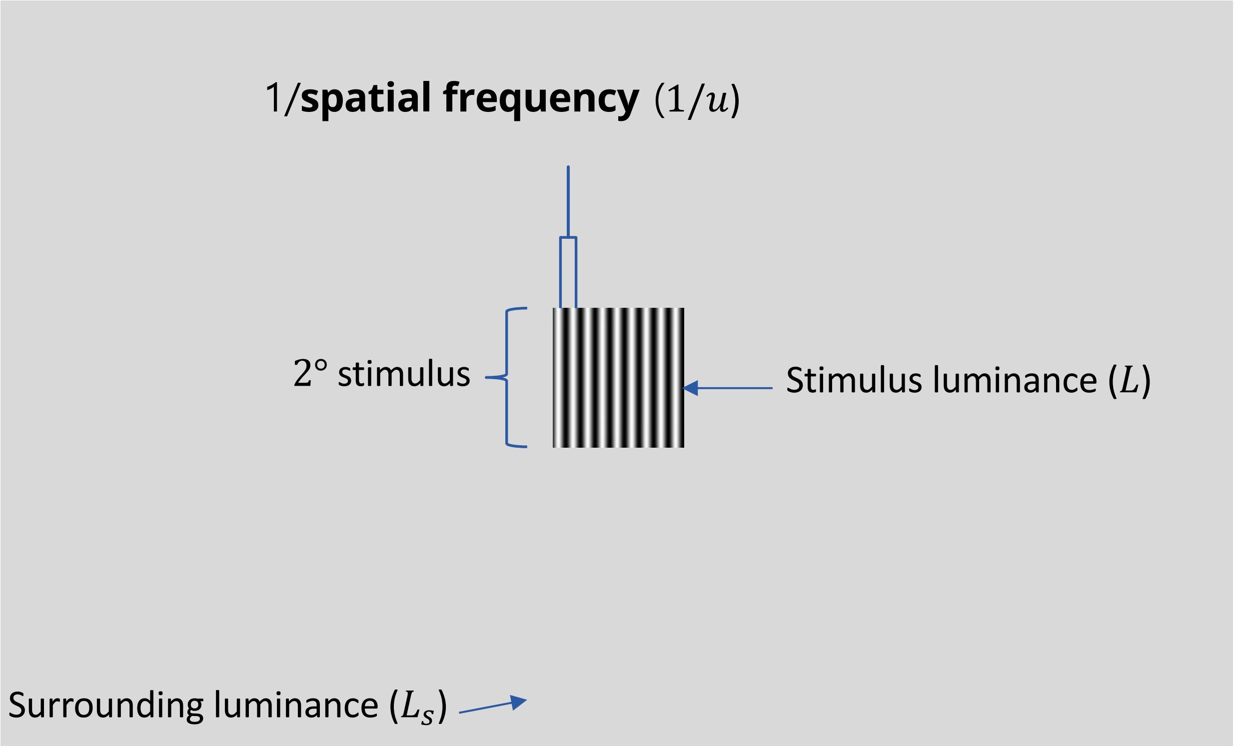
Related work

- Traditional CSF study
  - [Barten 1992], [Daly 1992]
  - → Limited luminance range
- CSF study on wide luminance range
  - [Mantiuk et al. 2011], [Wuerger et al. 2020]
  - → Do not consider both stimulus and surrounding luminance
- Surround-aware CSF
  - [Barten 2003]
  - → Old data (1973), airplane dashboards under specific viewing conditions



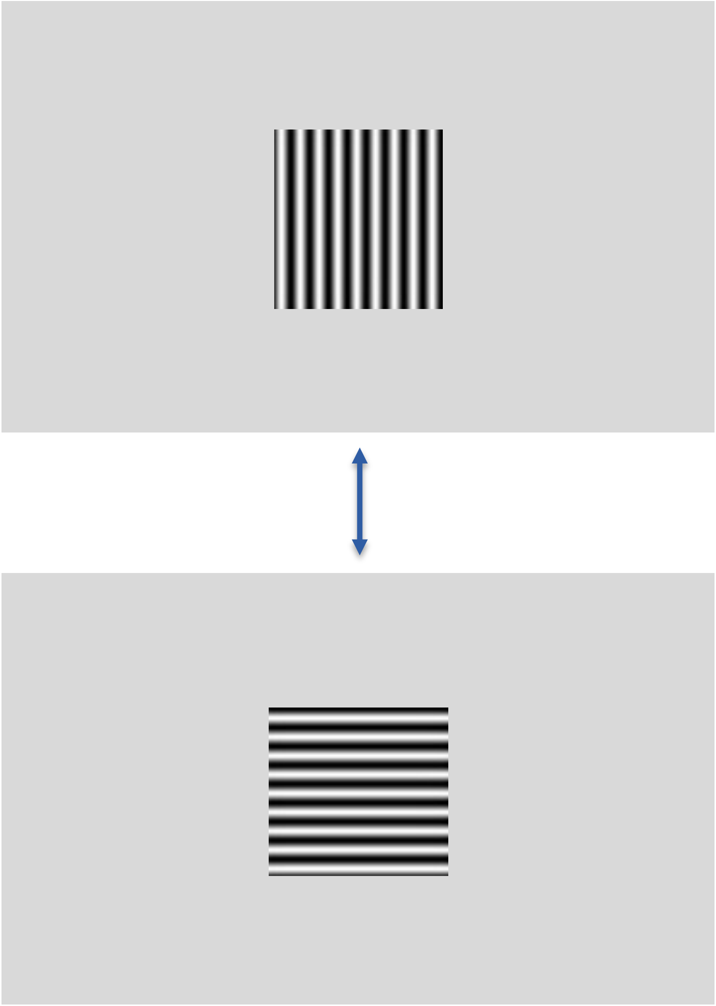
SIM2 HDR display

Experiment: stimuli



Experiment: variables

1. **direction** D
2. spatial frequency u
3. stimulus luminance L
4. surrounding luminance L_s

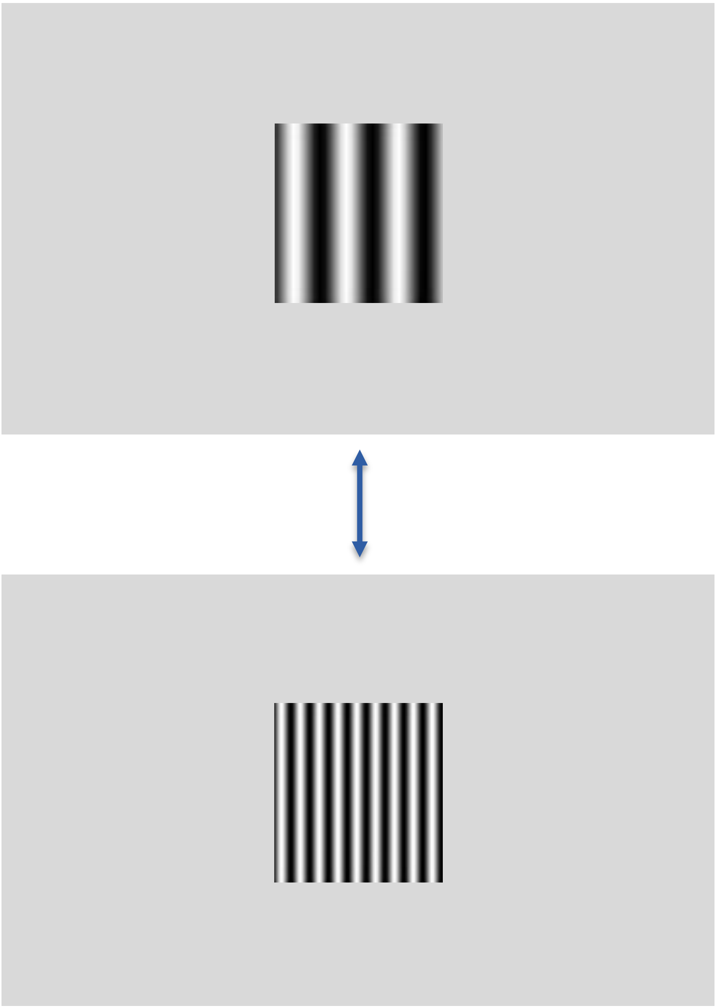


$D = \{\text{horizontal}, \text{vertical}\}$

Dataset will be available: http://vclab.kaist.ac.kr/egsr2021/

Experiment: variables

1. direction D
2. **spatial frequency u**
3. stimulus luminance L
4. surrounding luminance L_s

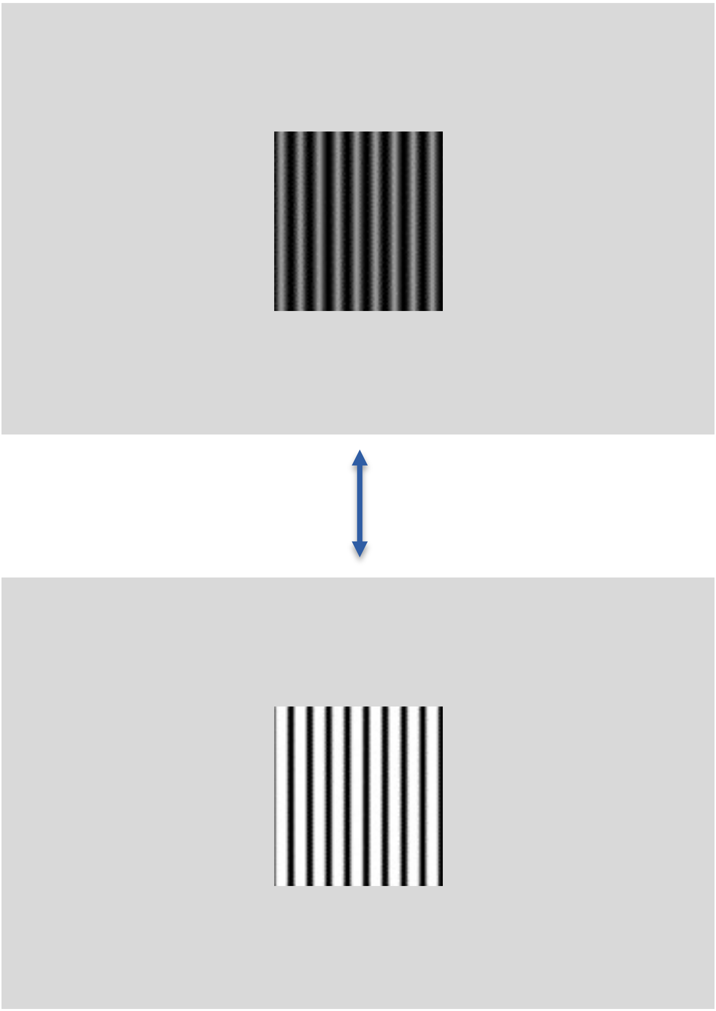


$$u = \{1.3, 2.5, 5.0, 10.1, 20.2\}\text{cycles/degree}$$

Dataset will be available: http://vclab.kaist.ac.kr/egsr2021/

Experiment: variables

1. direction D
2. spatial frequency u
3. **stimulus luminance L**
4. surrounding luminance L_s

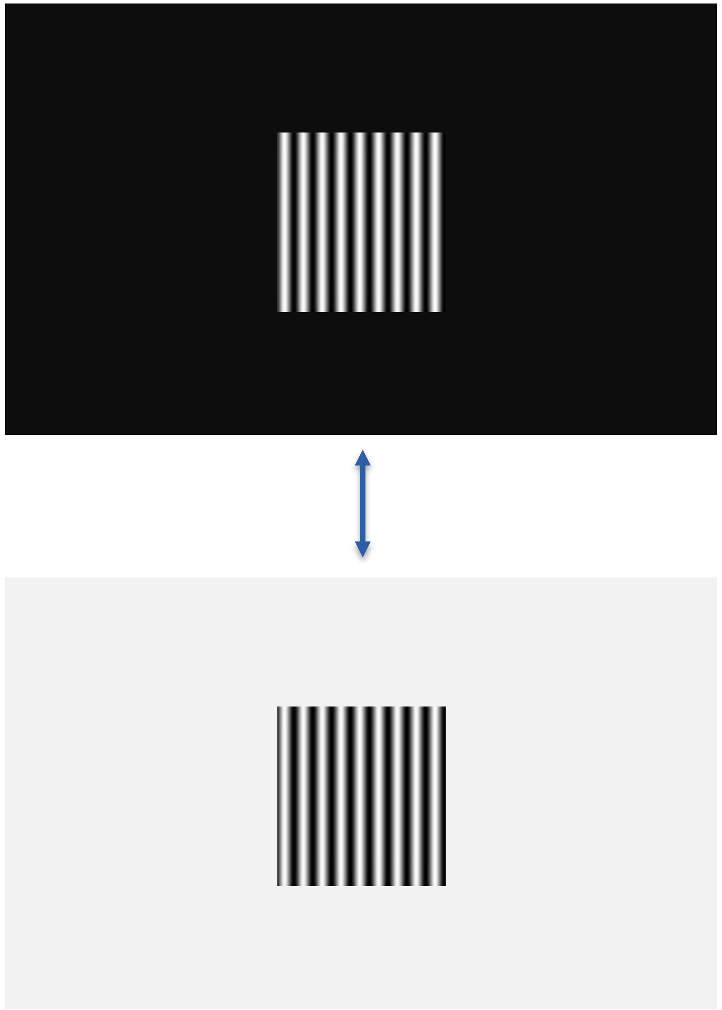


$$L = \{0.6, 3.0, 30, 300, 1050\}\mathrm{cd/m^2}$$

Dataset will be available: http://vclab.kaist.ac.kr/egsr2021/

Experiment: variables

1. direction D
2. spatial frequency u
3. stimulus luminance L
4. **surrounding luminance L_s**



$$L_s = \{0.6, 3.0, 30, 300, 1050\}\mathrm{cd/m^2}$$

Dataset will be available: http://vclab.kaist.ac.kr/egsr2021/

Measurement

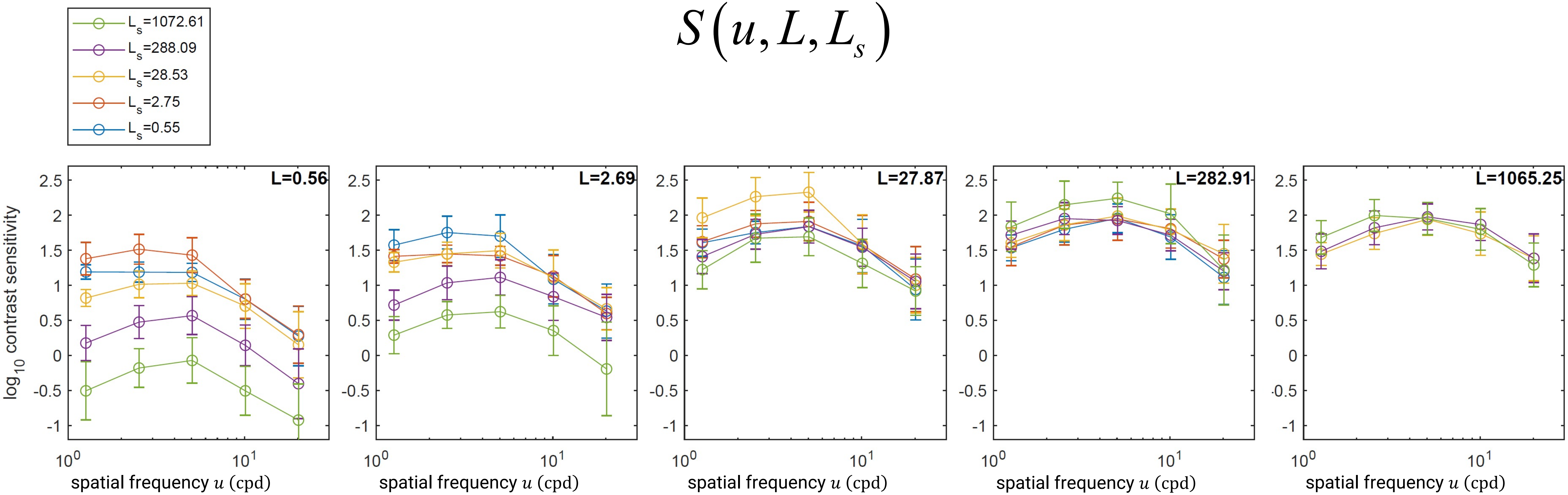
$$S\left(D, u, L, L_s\right)$$

Notations

u	spatial frequency
L	stimulus luminance
L_s	surrounding luminance

Measurement

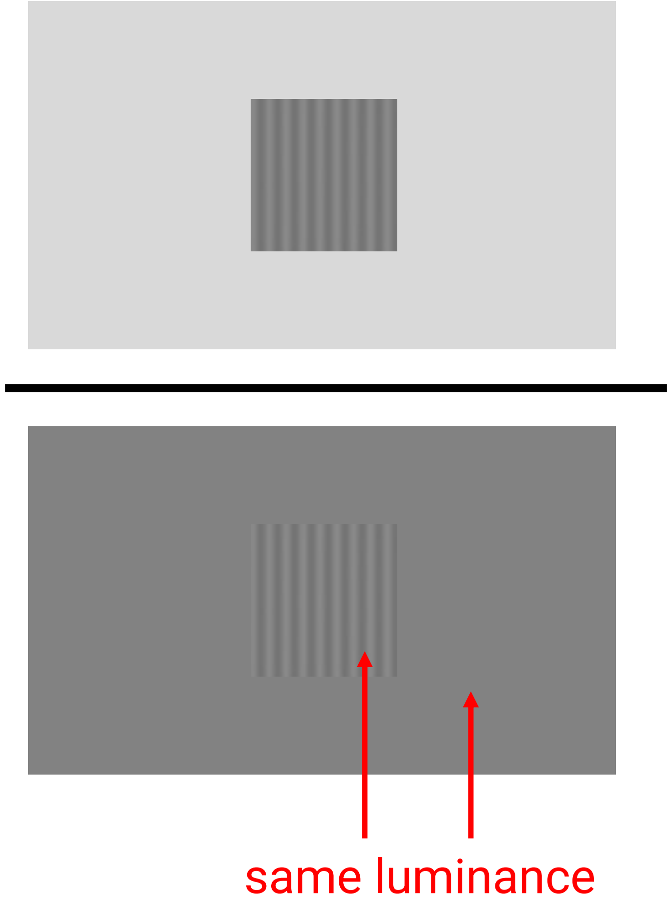
$$S(u, L, L_s)$$



Modeling

relative sensitivity R

$$R = \frac{S(u, L, L_s)}{S(u, L, L_s = L)} =$$



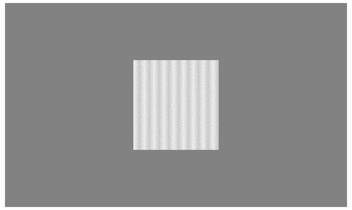
Notations	
u	spatial frequency
L	stimulus luminance
L_s	surrounding luminance
R	relative sensitivity

Modeling

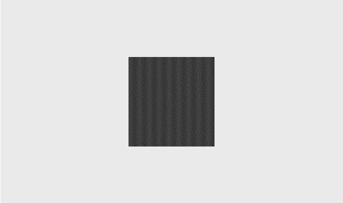
- Major dependency about $\frac{L_s}{L}$:

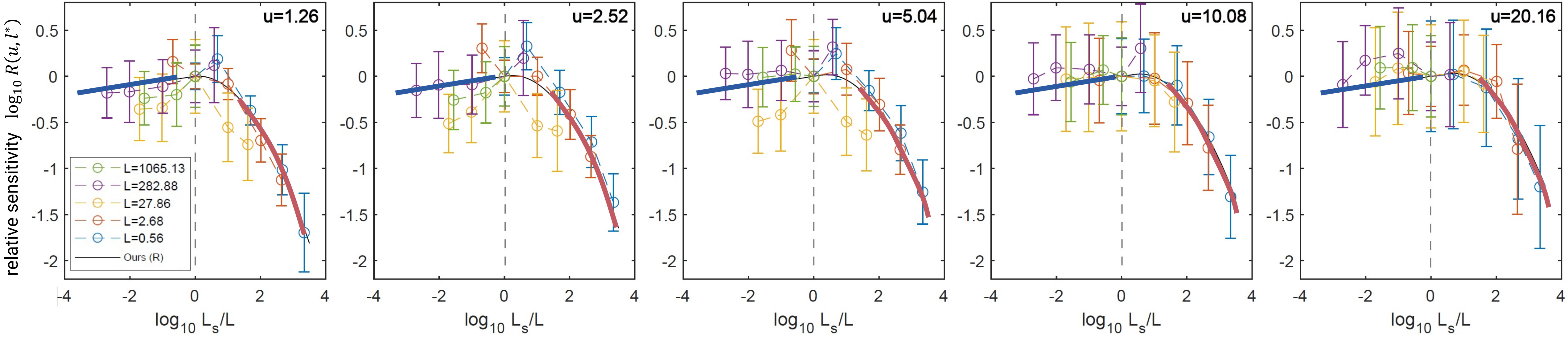
$$\log_{10} R\left(u, l^* = \log_{10}\frac{L_s}{L}\right) = -a\left(l^*\right)^2 + bl^* - a\left(l^* + c\right)\left|l^* + c\right| + ac\left|c\right|$$

Linear when



Quadratic when





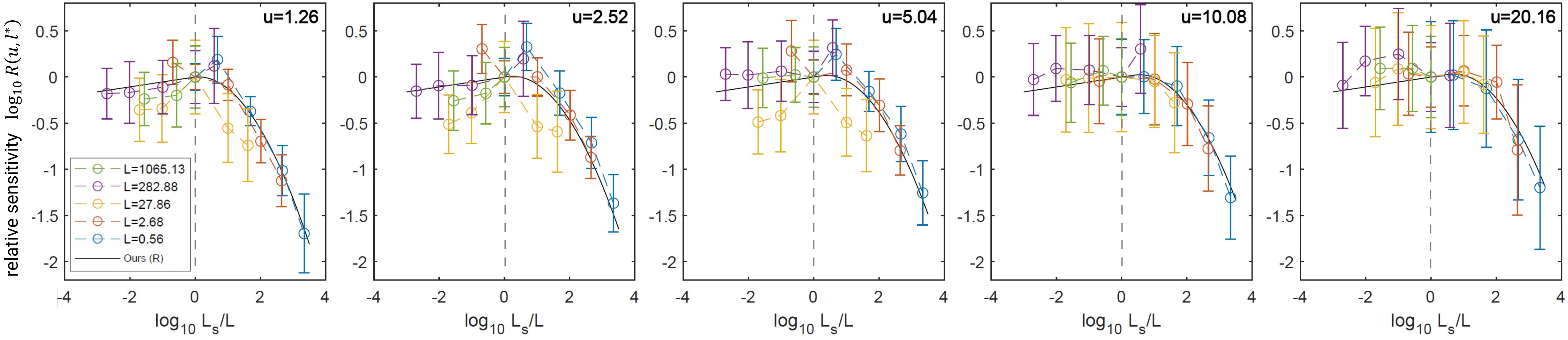
Modeling

- Major dependency about $\frac{L_s}{L}$:

$$\log_{10} R\left(u, l^* = \log_{10}\frac{L_s}{L}\right) = -a\left(l^*\right)^2 + bl^* - a\left(l^* + c\right)\left|l^* + c\right| + ac\left|c\right|$$

- Minor dependency about u:

Model $b\left(u; q_1, q_2, q_3\right)$ and $c\left(u; p_1, p_2\right)$ as simple decreasing functions of u



Modeling

relative sensitivity $$R = \frac{S(u, L, L_s)}{S(u, L, L_s = L)}$$ surround-aware CSF

Notations

u	spatial frequency
L	stimulus luminance
L_s	surrounding luminance
R	relative sensitivity

Modeling

$$\underbrace{S(u, L, L_s)}_{\text{surround-aware CSF}} = \underbrace{R\left(u, \frac{L_s}{L}\right)}_{\text{relative sensitivity}} \underbrace{\boxed{S(u, L, L_s = L)}}_{\text{remaining part}}$$

Notations

u	spatial frequency
L	stimulus luminance
L_s	surrounding luminance
R	relative sensitivity

- The remaining part is the same as a traditional CSF $S(u, L)$
- Use Barten'92 CSF model $S_B(u, L)$
  - Barten'92 CSF has been used for HDR application such as popular Dolby perceptual quantizer
  - Backward compatibility of our model to renown model

Modeling

- Full model (9 params.)

$$S(u,L,L_s) = \boxed{R\left(\cancel{u}, \frac{L_s}{L}; a, p_1, p_2, q_1, q_2, q_3\right)} \boxed{S_B\left(u, L; \cancel{\sigma_0, \eta}, k\right)}$$

novel function

Barten'92 model with parameter fitting

- Practical model (4 params.)

$$S(u,L,L_s) = \boxed{R_p\left(\frac{L_s}{L}; a, b, c\right)} \boxed{\lambda S_B^O(u,L)}$$

novel function

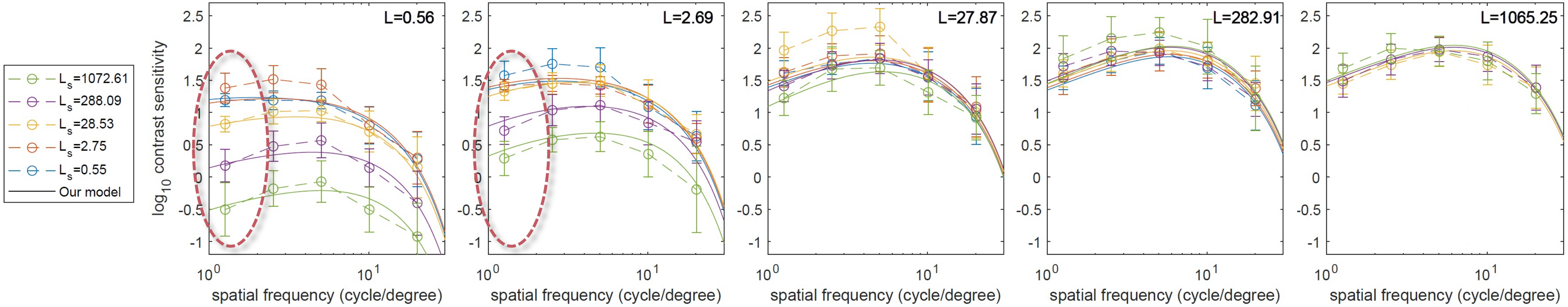
Barten'92 model with scale adjusting constant λ

Notations

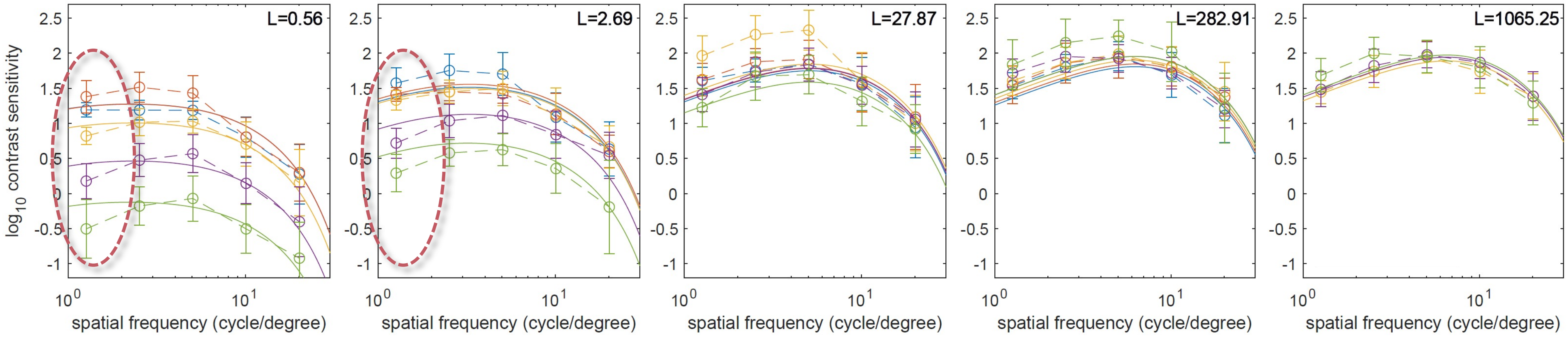
u	spatial frequency
L	stimulus luminance
L_s	surrounding luminance
R, R_p	our full, practical model of relative sensitivity, resp.
S_B, S_B^O	Barten'92 CSF model w/, w/o parameter fitting, resp.
$a, p_{1,2}, q_{1,2,3}, \sigma_0, \eta, k$	fitting parameters for full mo del
a, b, c, λ	fitting parameters for practic al model

Modeling: results

- Full model (9 params.): RMSE = 2.69dB Generalization error = 1.34dB



- Practical model (4 params.): RMSE = 3.16dB Generalization error = 0.95dB



Applications

Algorithms based on surround-aware CSF $S(u, L, L_s)$, instead of existing CSF $S(u, L)$

where L_s is computed as the adaptation level of given scene

- HDR tone mapping
  - Mantiuk et al. [2008]
- HDR video compression
  - HEVC codec with *transfer functions* [Miller et al. 2013]
- Visual difference predictor (HDR-VDP)
  - HDR-VDP 2-2 [Narwaria et al. 2015]

HDR tone mapping: Mantiuk'08 vs. Ours

Mantiuk et al. [2008]
(based on Daly [1992] CSF)

HDR tone mapping: Mantiuk'08 vs. Ours

HDR tone mapping: Mantiuk'08 vs. Ours

HDR tone mapping: Barten’03 vs. Ours

Equipped surround-aware CSFs

HDR tone mapping: Barten’03 vs. Ours

Equipped surround-aware CSFs

HDR tone mapping: Barten'03 vs. Ours

Equipped surround-aware CSFs

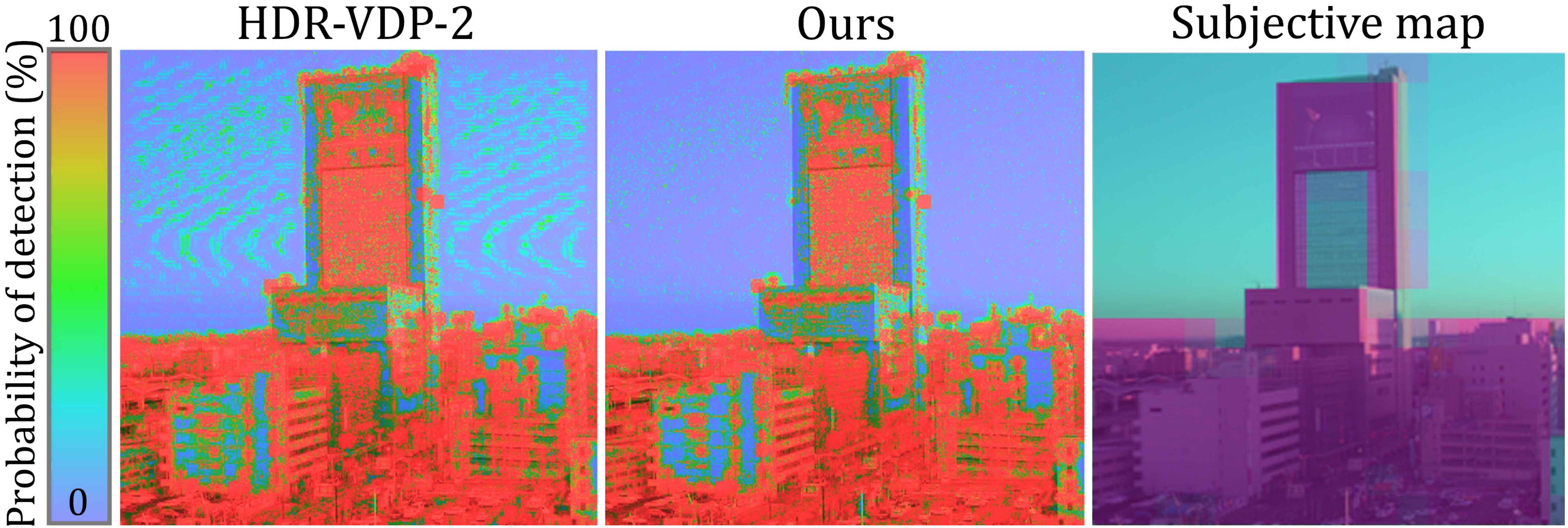
HDR video compression

Bit rate: 2,497,838 kbps.
(original)

Showgirl

Original HDR video

Visual difference predictor (HDR-VDP)



Mantiuk et al. [2011] CSF vs. Our surround-aware CSF

Conclusion

- Psychophysical experiment using a state-of-the-art HDR display
- Accounting for both stimulus and surrounding luminance
- Full and practical surround-aware CSF models
- Presenting three HDR applications using our CSF model

Thank you