Perceptually Based Tone Mapping for Low-Light Conditions

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Purkinje Effect

Bright scene

Low-light => bluish

Key idea

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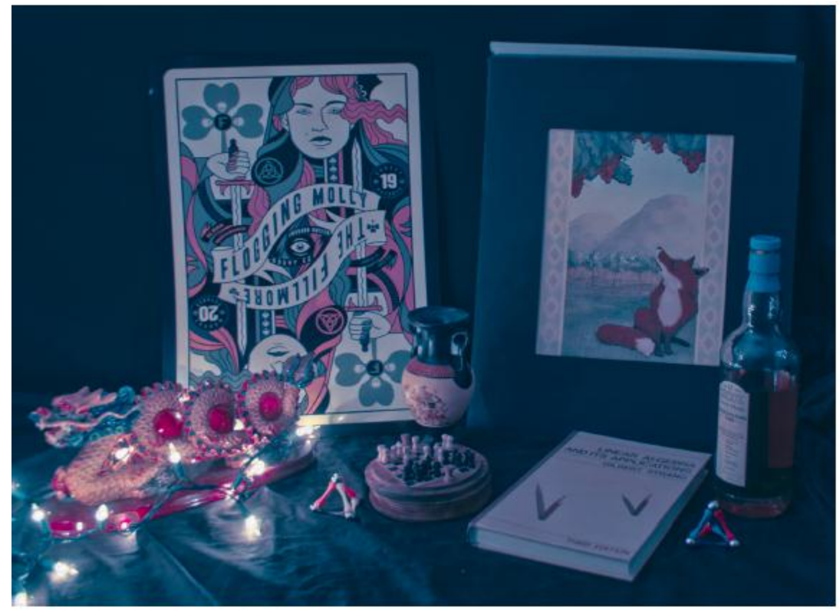
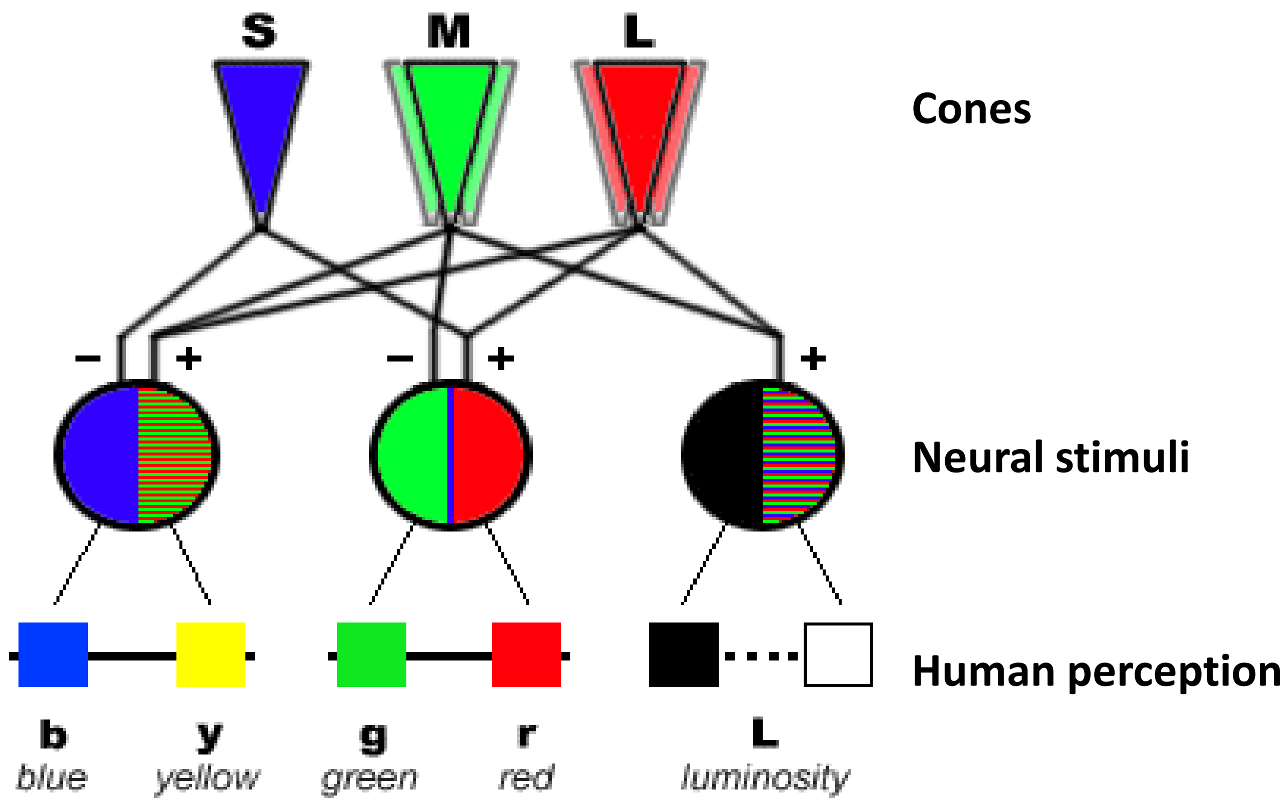


Match human vision in low-light conditions

Human vision

- Bright scene: dominated by cones (photonic vision)
- Dark scene: dominated by rod (scotopic vision)
- In between? Low-light vision (mesopic vision)
  - rod and cones all contributes (4D-> 3D)
  - This is why we perceived color change in low-light
  - Cameras do not have this mechanism!

Opponent color model in photopic vison

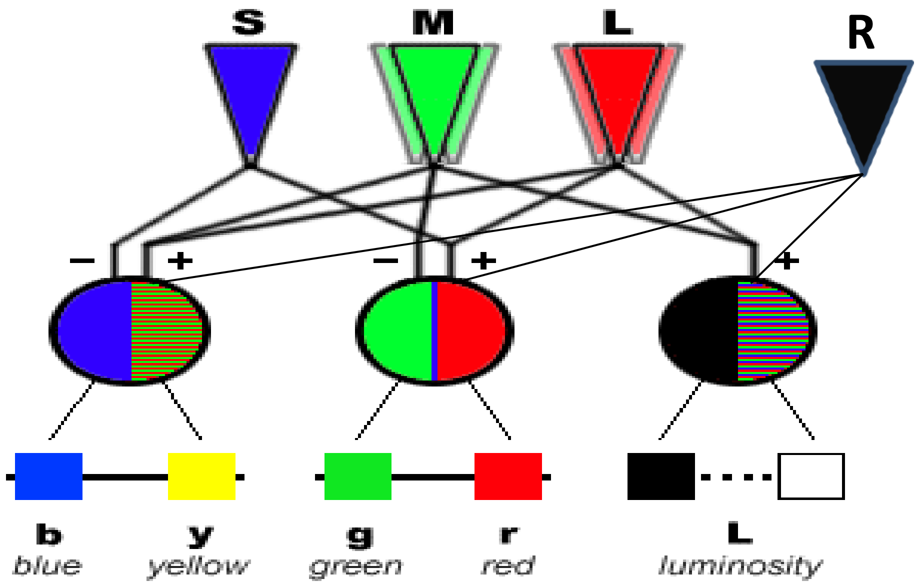


$$o_{\text{Red/Green}} = \hat{q}_{\text{Medium}} - \hat{q}_{\text{Long}}$$

$$o_{\text{Blue/Yellow}} = \hat{q}_{\text{Short}} - (\hat{q}_{\text{Long}} + \hat{q}_{\text{Medium}})$$

$$o_{\text{Luminance}} = \hat{q}_{\text{Long}} + \hat{q}_{\text{Medium}}$$

Low light vision



Neural stimuli diffs

$$
\begin{cases}
\Delta o_{\mathrm{Red/Green}} = x\,\kappa_1 \left(\rho_1 \dfrac{g_{\mathrm{Medium}}}{m_{\max}} - \rho_2 \dfrac{g_{\mathrm{Long}}}{l_{\max}} \right) q_{\mathrm{Rod}} \\[2ex]
\Delta o_{\mathrm{Blue/Yellow}} = y \left(\rho_3 \dfrac{g_{\mathrm{Short}}}{s_{\max}} - \rho_4 \left(\alpha \dfrac{g_{\mathrm{Long}}}{l_{\max}} + (1-\alpha) \dfrac{g_{\mathrm{Medium}}}{m_{\max}} \right) \right) q_{\mathrm{Rod}} \\[2ex]
\Delta o_{\mathrm{Luminance}} = z \left(\alpha \dfrac{g_{\mathrm{Long}}}{l_{\max}} + (1-\alpha) \dfrac{g_{\mathrm{Medium}}}{m_{\max}} \right) q_{\mathrm{Rod}}
\end{cases}
\tag{12}
$$

Method Overview

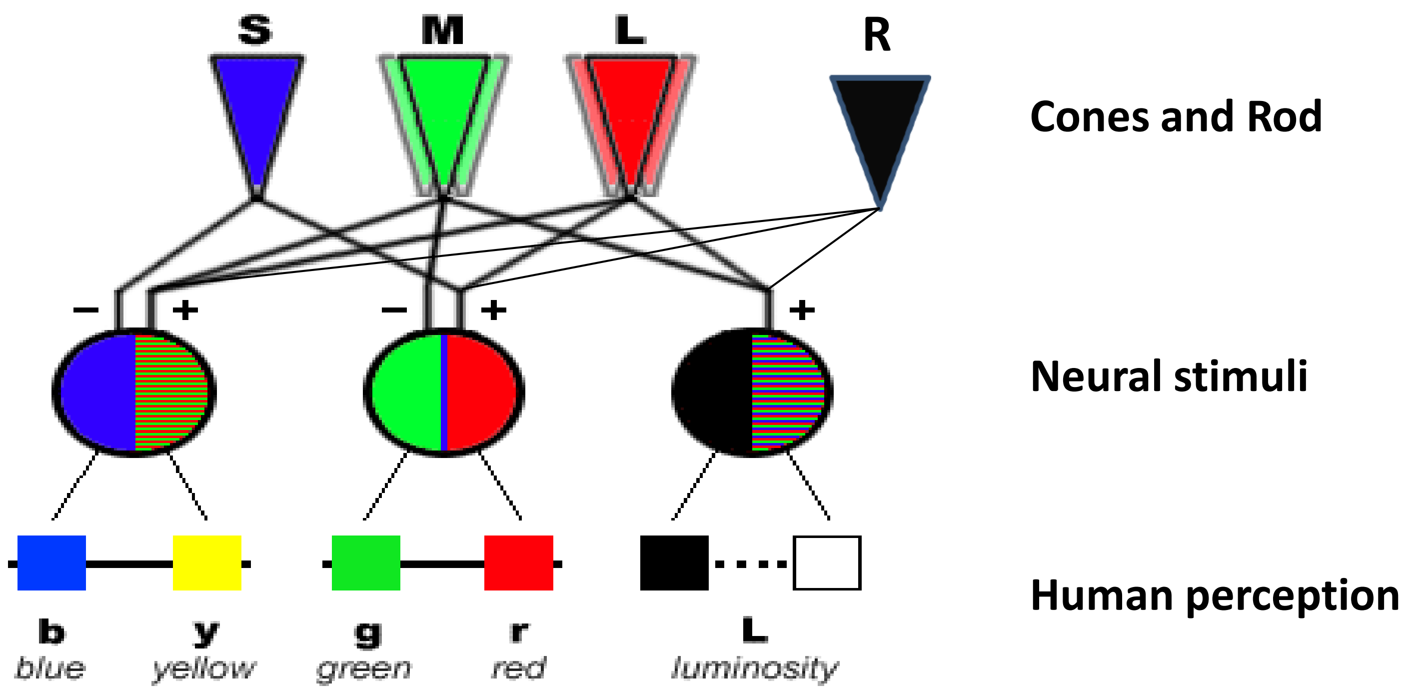
- The only work apply human vision model to deal with Purkinje effect in images
- Flow
  - Acquiring Spectral Images to estimate LMSR response
  - Compute nerual stimuli difference due to rod
  - Convert neural stimuli back to RGB

Acquiring Spectral Images

- LMSR response: $q_n = \int_{\Omega} \mathcal{E}_n(\lambda)\,\mathcal{R}(\lambda)\,\mathrm{d}\lambda$

  LMSR response — LMSR spectral sensitivity

- Each pixel is represented by a spectral function R(λ)
- Take snapshot of the same scene with 10 band pass filters
- Cubic B-spline curve fitting to get R(λ)



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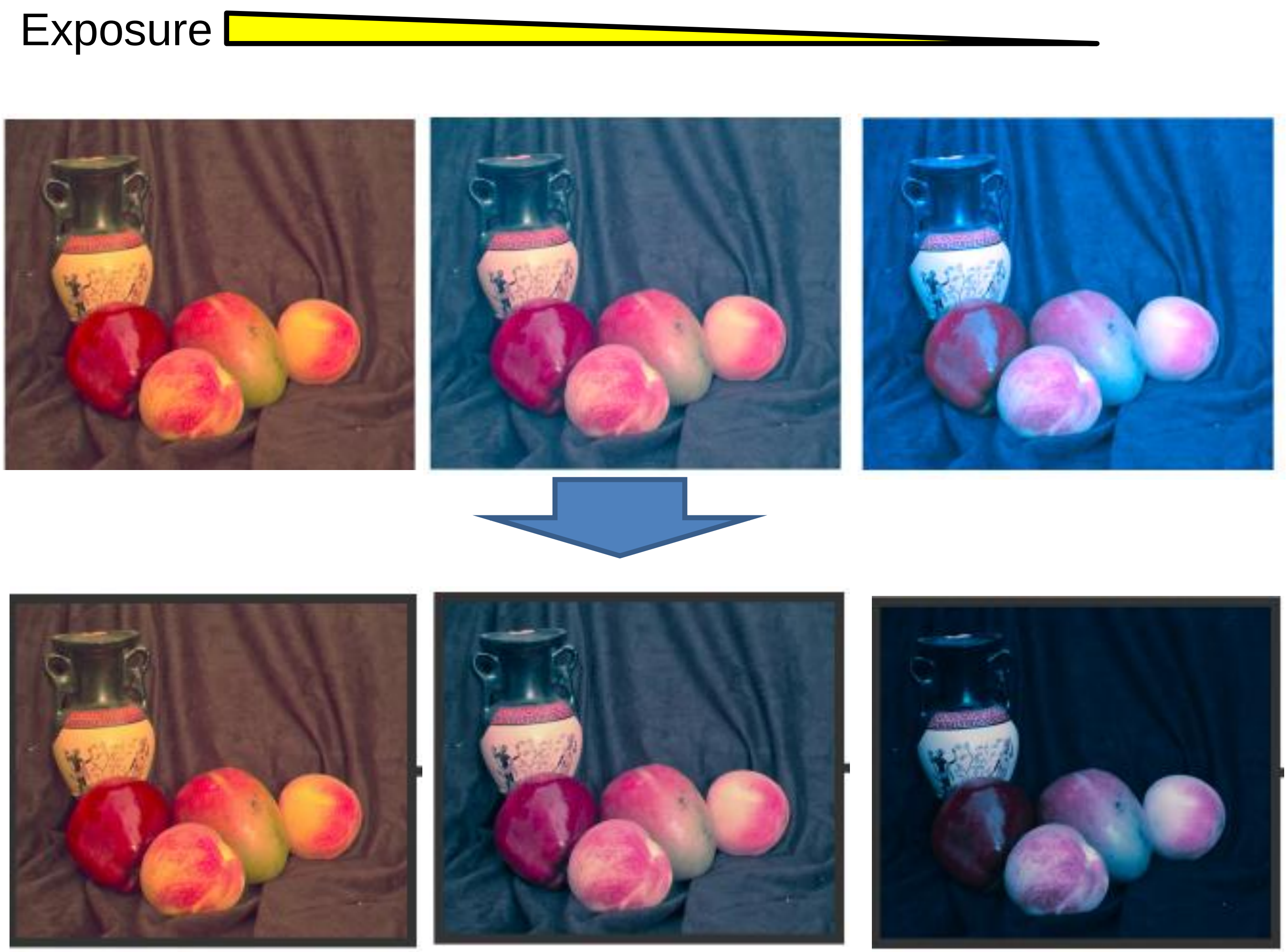
\end{cases}
\tag{12}
$$

Convert back to RGB image

- Compute RGB values best represent the neural stimulus
- Apply standard HDR range compression first
- Looks weird (a low light image with full range)
- Suppress pixel value by mesopic factor w
  - w=0 -> fully photonic, w>1 -> fully scotopic

$$\acute{P} = P * \max(1 - w(1-\gamma), \gamma), \qquad \gamma \in [0.25, 0.5]$$

Result (Range Compression)



Results

Results

Results

Images copyright Adam Kirk and James O'Brien. Painting untitled by Susan Kim.

Approximation of Non-Spectral Images

- Spectral images are hard to acquired
- Build a RGB->LMSR mapping matrix by data trained from spectral images
- Apply that mapping to RGB images to create approximated LMSR value

Results (Non-Spectral Image)

Original image "Foggy Night" copyright Jack Tumblin, Northwestern University.

Results (Non-Spectral Image)

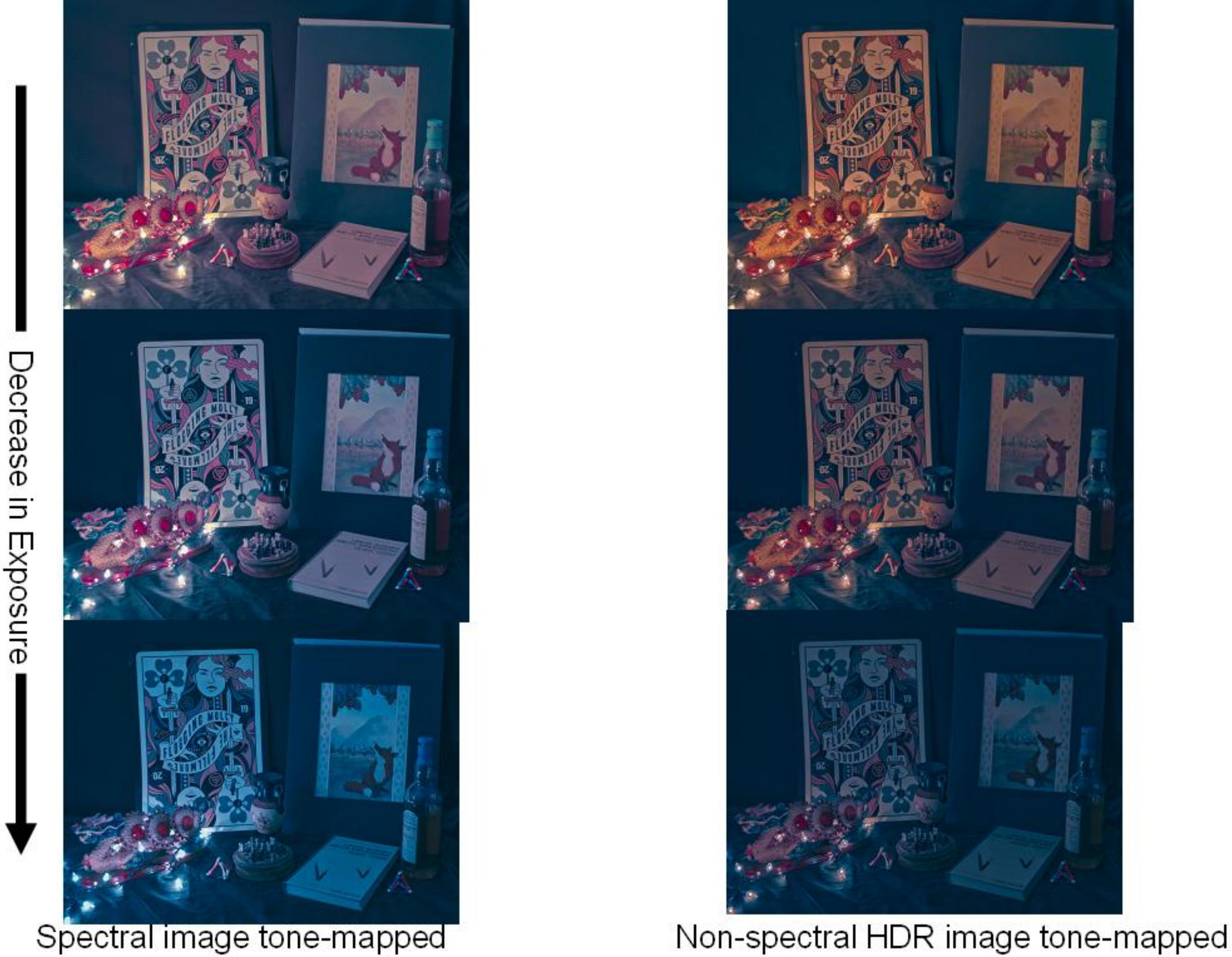
Thanks

?

Discussion

- Differences/Alternatives

-What happens when using RGB input images instead of multiple spectual images?


Decrease in Exposure
Spectral image tone-mapped
Non-spectral HDR image tone-mapped

Discussion

– How do the two methods compare?

– Does the approximate work well?
Why or why not?

– Do the results fit your perception?

- Other techniques?

Discussion

- Limitations?

  - Focus only on interplay between rods and cones in early stage of vision

  - Other adaptive mechanisms not incorporated

- Additional effects not modeled

Discussion

- Future works

  - Apply method to all sort of light intensities

  - Predict actual viewer experiences

  - Apply to videos