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PREFERRED MODEL OF ADAPTATION TO DARK FOR VIRTUAL REALITY HEADSETS

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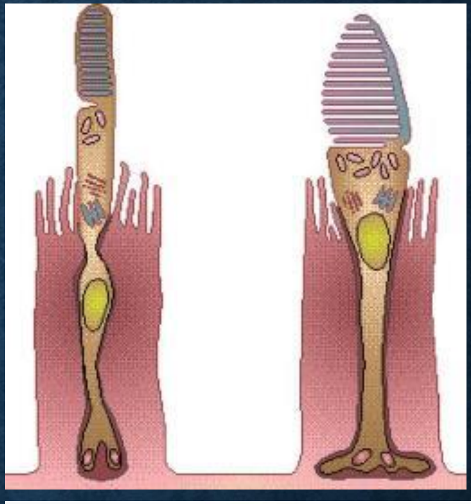
ADAPTATION TO DARKNESS

- Visual adaptation allows seeing objects both in dark and bright conditions
- Adaptation level is constantly changing which has to be calculated in real-time
- Implementing adaptation mechanism would improve VR experience



Rod and cone

HTC Vive VR Goggles

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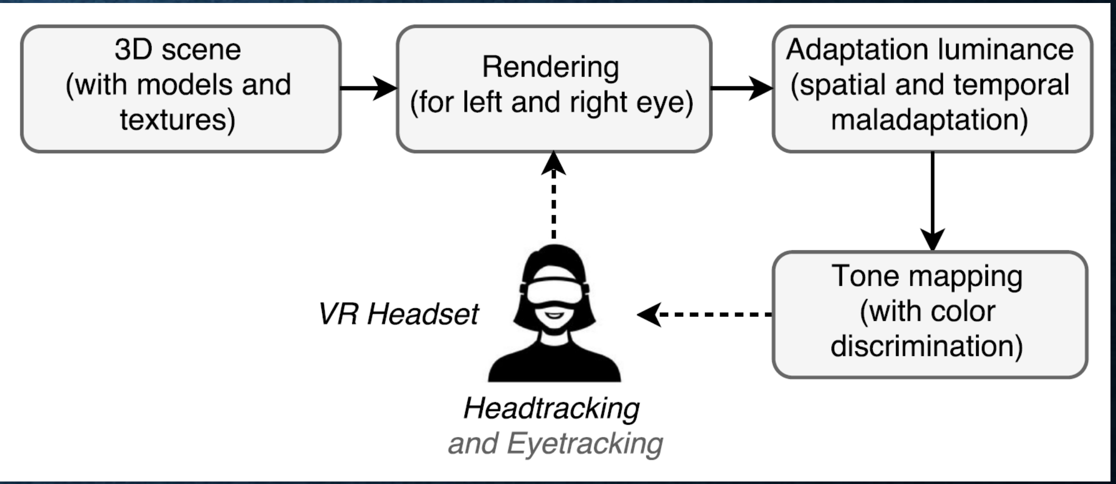
IMPLEMENTATION DETAILS

- Environment rendered using OpenGL 4.0 API
- Testing performed on five different scenes
- Render result after each individual step is stored in HDR image
- Adaptation calculation is based on current and previous frame



Implementation diagram

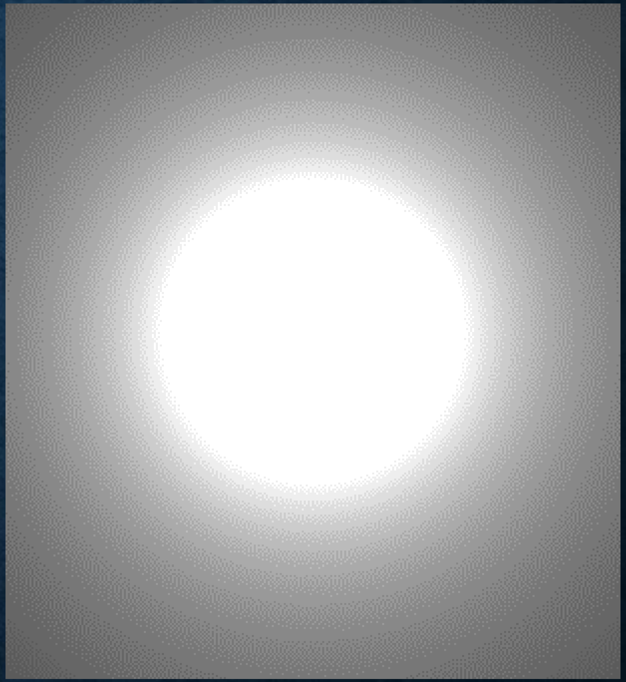
SPATIAL EXTENT OF VISUAL ADAPTATION

- Adaptation luminance computed based on gaze position

- Values are based on the gaze-dependent contrast sensitivity function [*Peli et al.*]

- The highest visible frequency for the **eccentricity** d is equal:

$f_c(d) = 43.1 \cdot \frac{E}{E+d}$ [Vangorp et al.]

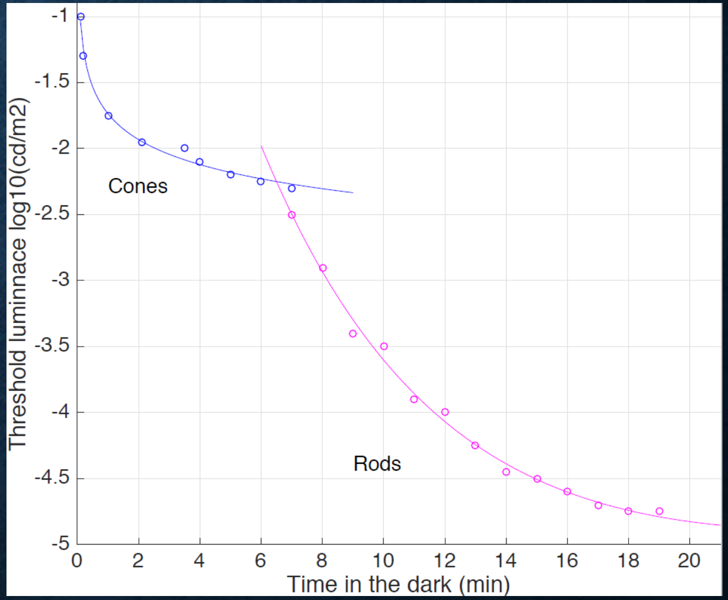


Visible frequency mask

TEMPORAL ADAPTATION IN HVS

- Adaptation to dark consists of two phases for both photoreceptor types
- Cones adaptation allows to quickly adjust to small contrast differences; rods adaptation takes longer but reaches very low visible threshold
- Adaptation luminance can be calculated using Weber's law through TVI function [*Woodworth at al.*]

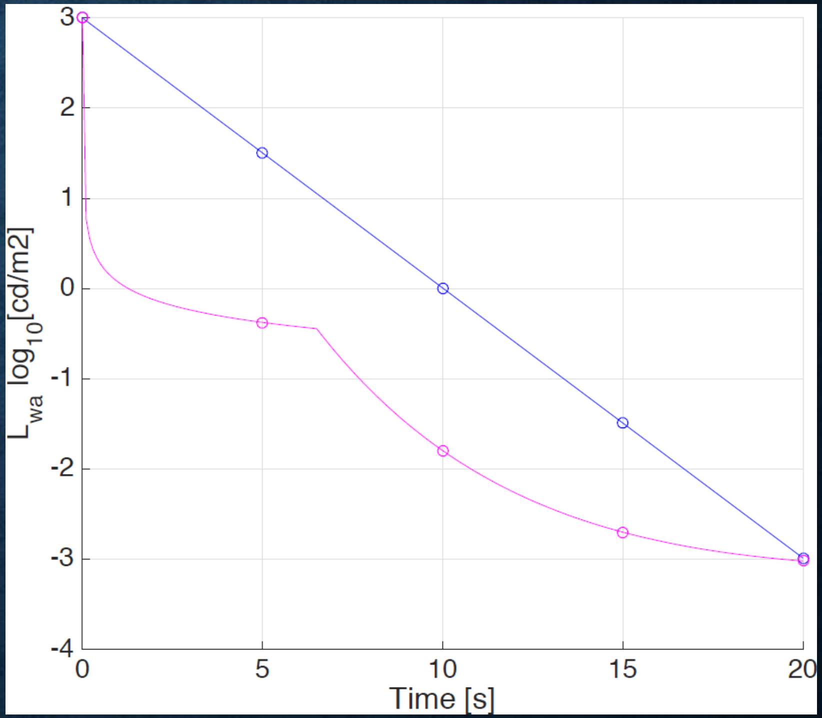
$$\begin{cases} \Delta L_{cone} = 5.659 * t^{-0.051} - 7.431, \\ \Delta L_{rod} = -5.766 * e^{-0.0053*t} + 9.694 * e^{-0.1648*t} \end{cases}$$



Visible luminance threshold in time domain

OUR MODEL OF TEMPORAL ADAPTATION

- Magenta line corrensponds to our adaptation model, based on HVS (*perceptual*)
- Blue line is a simplified adaptation, linear in log domain (*linear*)
- The model had to be adjusted for game environment: time had to be shortened, luminance boundaries tightened



Perceptual and *linear* adaptation model

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LINEAR VS. PERCEPTUAL MODEL

TONE MAPPING

- Adaptation results have to be transformed according to HVS and display limitations
- We use Ward's tone reproduction operator which purpose is to match just-noticable difference between world and display observers
- TVI functions are computed separately for rods and cones
- Final tone mapping values range from photopic, through mesopic, to scotopic vision

$$L_d = m * L_w$$

$$m = t(L_{da})/t(L_{wa})$$

$$\log t_s(L_a) = \begin{cases} -2.86 & if \log L_a \leq -3.9 \\ \log L_a - 0.395 & if \log L_a \geq -1.4 \\ (0.405 \log L_a + 1.6)^{2.18} & \\ -0.72 & otherwise. \end{cases}$$

$$\log t_p(L_a) = \begin{cases} -0.72 & \text{if} \log L_a \leq -2.6 \\ \log L_a - 1.255 & if \log L_a \geq 1.9, \\ (0.249 \log L_a + 0.65)^{2.7} & \\ -0.72 & otherwise, \end{cases}$$

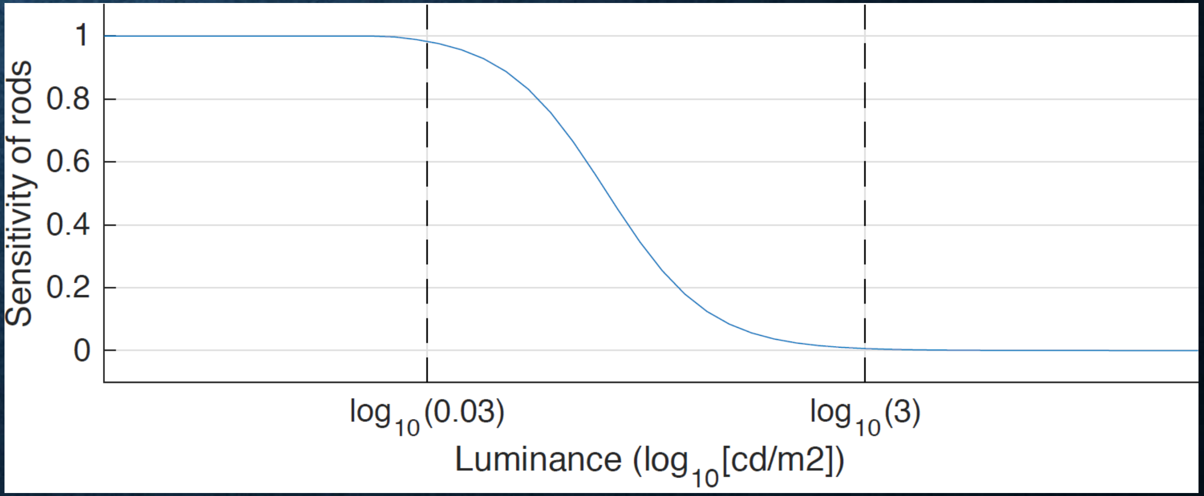
$$t(L_{wa}) = (1 - k(L_{wa})) * t_p(L_{wa}) + k(L_{wa}) * t_s(L_{wa})$$

COLOUR DISCRIMINATION

- In scotopic range colours are not visible – it has to be modelled additionally
- We model the rods sensitivity with the sigmoidal function [*Hunt and Gainer*]
- The final image is a weighted sum of pure luminance value and RGB output from tone mapping:

$$LDR_{RGB} = \sigma * L_d + (1 - \sigma) * \frac{HDR_{RGB}}{L_w} * L_d.$$

$$\sigma = \begin{cases} 1 & L_w < 0.03\ cd/m^2, \\ 0 & L_w > 3\ cd/m^2, \\ \frac{0.07}{0.069 + 1.409 * e^{4.267 * L_w}} & otherwise. \end{cases}$$



Rods senstivity in luminance domain

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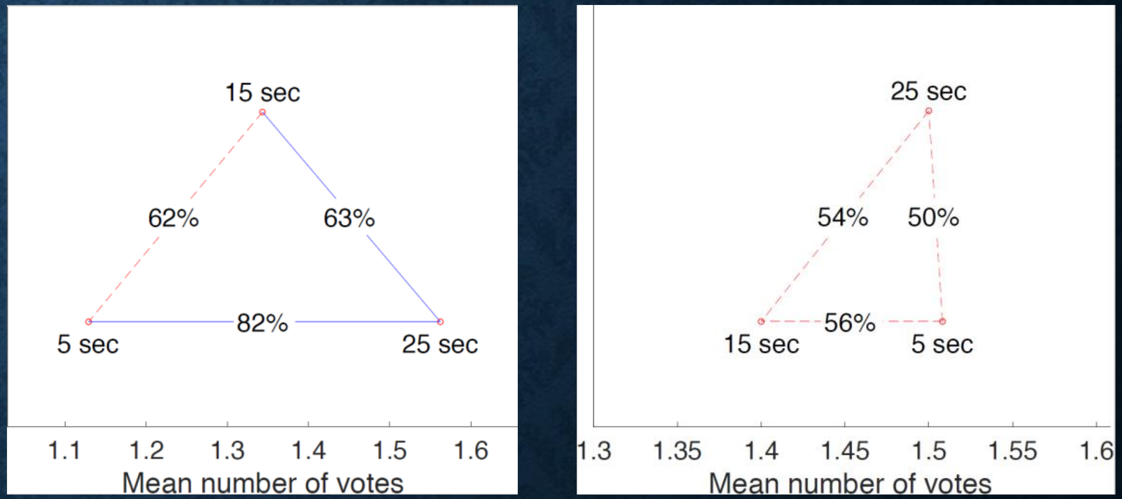
TONE MAPPING & COLOUR DISCRIMINATION

EXPERIMENT EVALUATION

- We performed an experiment to select a better adaptation model and to choose which speed of adaptation feels the most natural
- Participants were able to freely look in a VR environment in which we performed dark adaption simulation
- First experiment: participants were asked to choose the preferred model (*linear* or *perceptual*)
- Second experiment: participants choose which adaptation time was best for each method separately (5, 15 or 25 seconds)
- Experiments were performed on five scenes, with fixed gaze position at the centre
- 15 participants aged 19-23 took the experiment

EXPERIMENT RESULTS

- Linear vs perceptual: 68 vs 32 votes ($p = 0.35$)
- Significant preference for 25 seconds long *linear* adaptation
- *Perceptual* experiment didn't show statistical advantage of any of the given timings



Ranking graphs illustrating the statistical significance of the experiment testing a preferred adaptation time for the *linear* (left) and *perceptual* (right) formulas.

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CONCLUSIONS AND FUTURE WORK

- We designed a model of visual adaptation to dark suitable for VR headsets
- Model takes into consideration photoreceptors capabilities and the gaze position
- Participants in general preferred simplified model which would lead to performance improvements

Future work:

- Use of higher quality displays with better colour representation and pixel density
- Improve the model by additional HVS features, such as visual acuity

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THANK YOU FOR YOUR ATTENTION!

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