A Computational Model of Afterimages

Tobias Ritschel Elmar Eisemann
Télécom ParisTech (ENST) / CNRS, Paris

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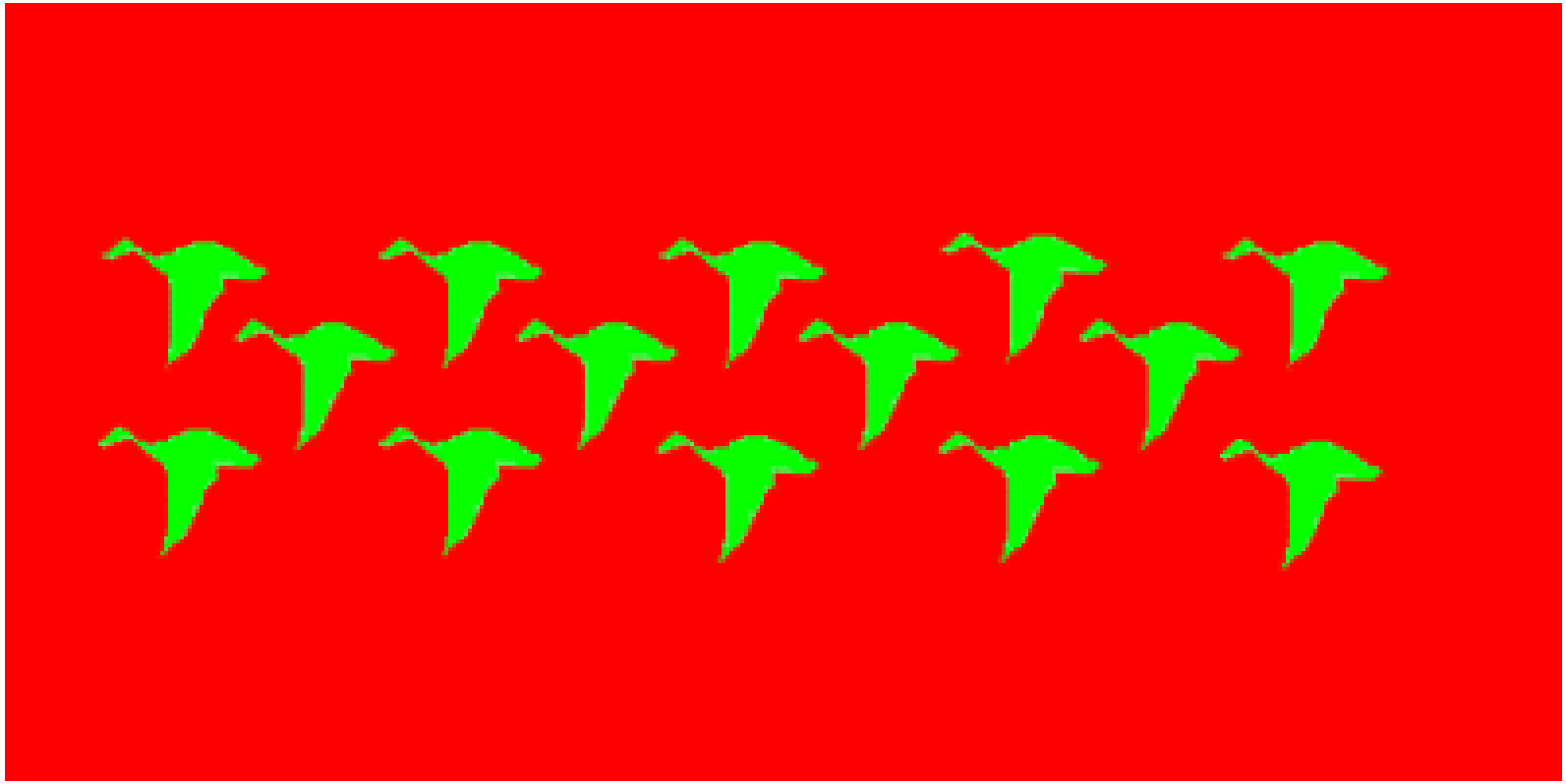


EXAMPLE

EXAMPLE

Cadik et al.: Evaluation of tone-mapping operatos, *Proc. Pacific Graphics* (2006)

MOTIVATION

HDR image

Changed HDR image

HDR Afterimages

LDR Afterimages

Our Afterimages

MOTIVATION

Division-by-maximum

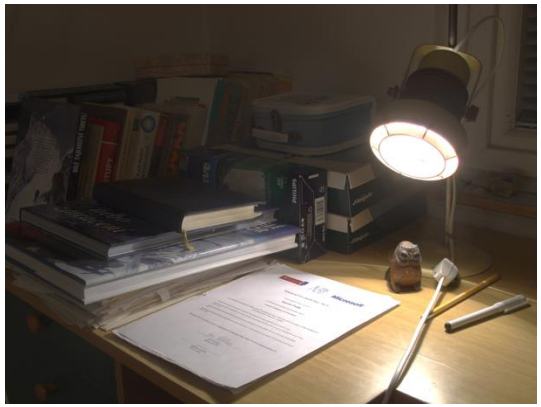
Clipping

Exponential

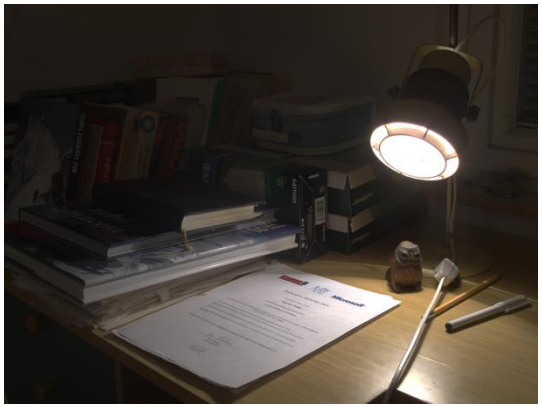
TONE MAPPING

Ward, 1992

Tumblin & Rushmeier 1993

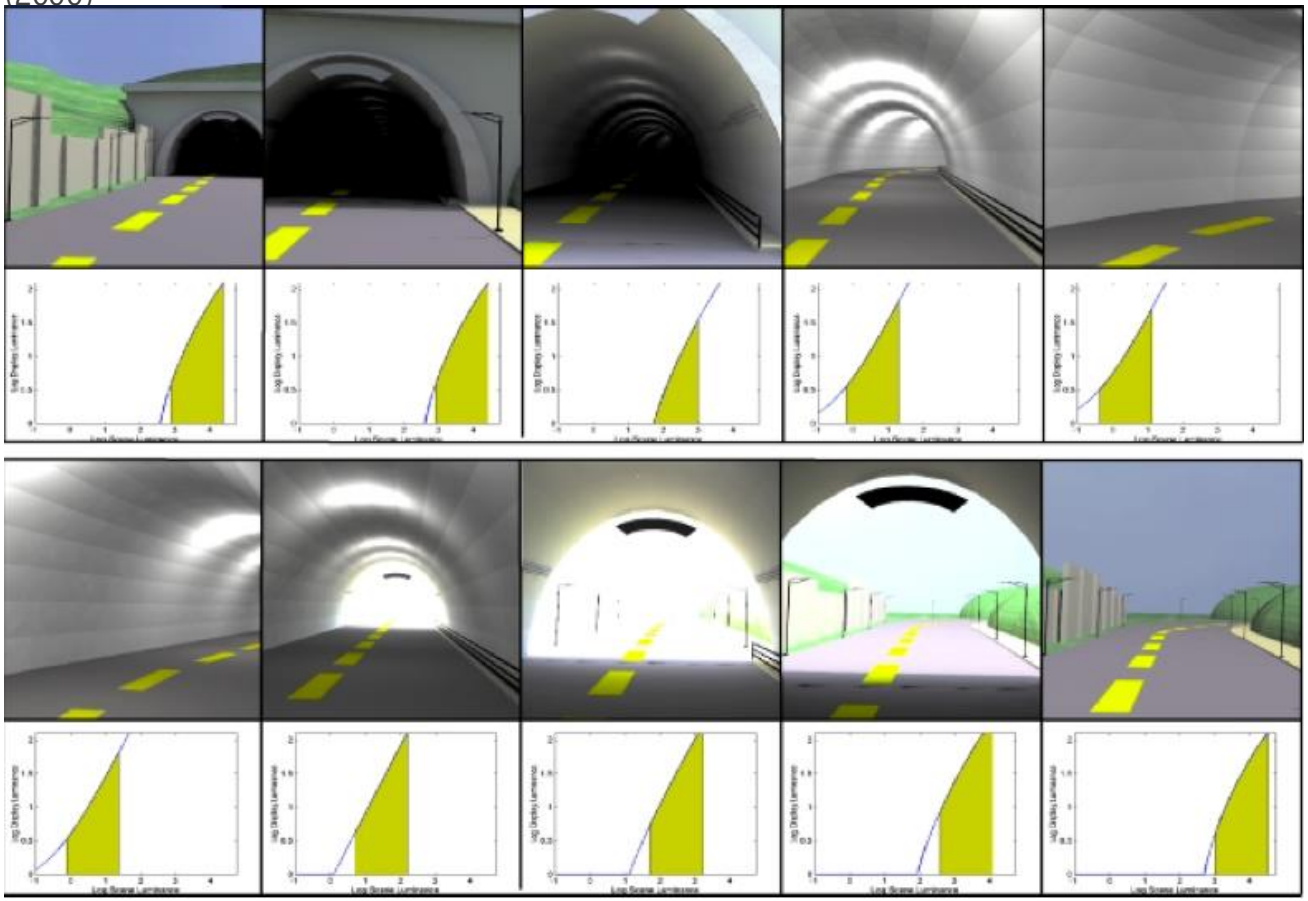


Ward et al. 1997



TONEMAPPING

Patanaik et al.: A multiscale model of adaptation and spatial vision for realistic image display, *Proc. SIGGRAPH* (2000)



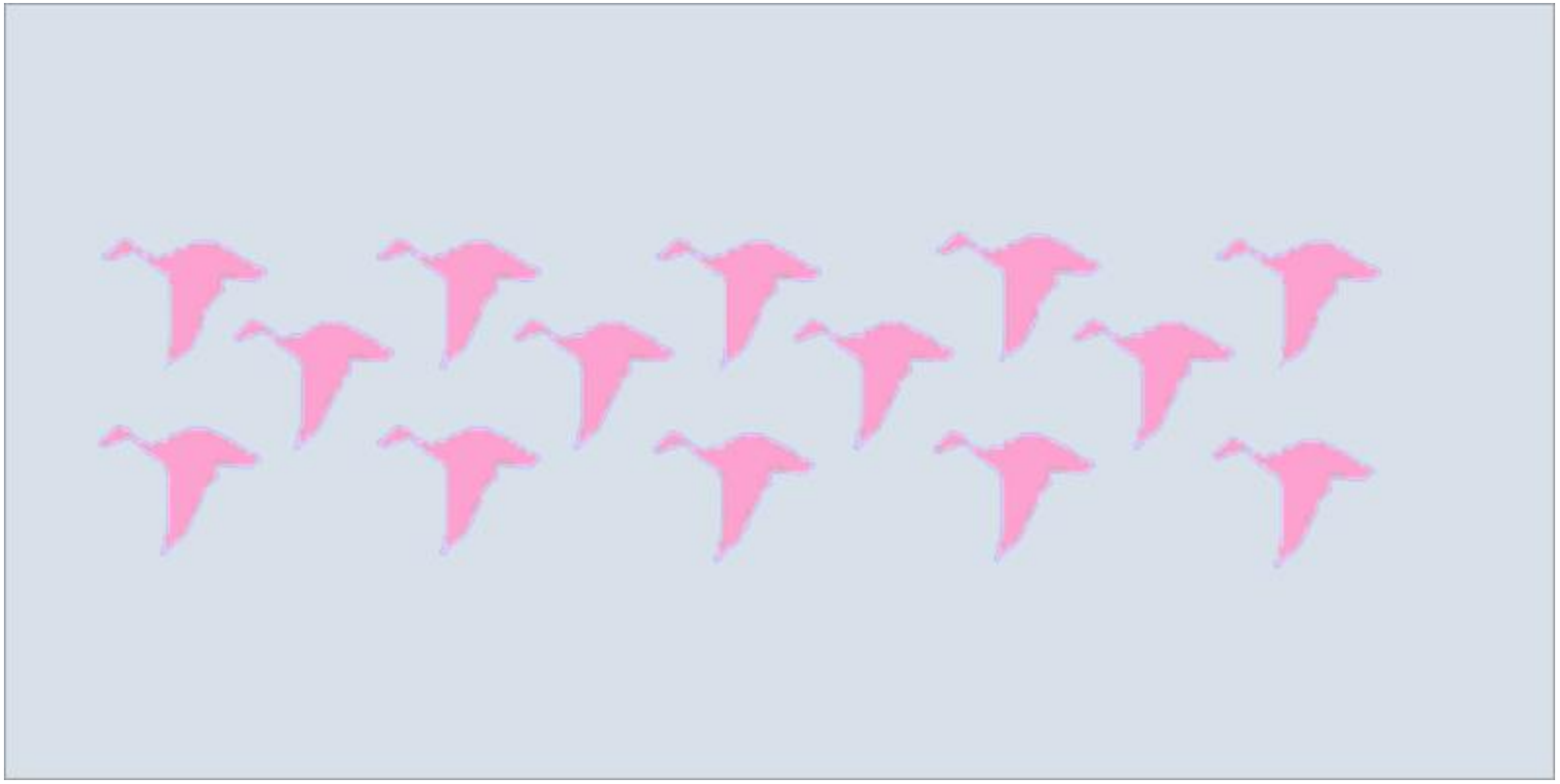
ADAPTATION

Pajak et al.: Visual maladaptation in contrast domain *Proc. SPIE* (2010)

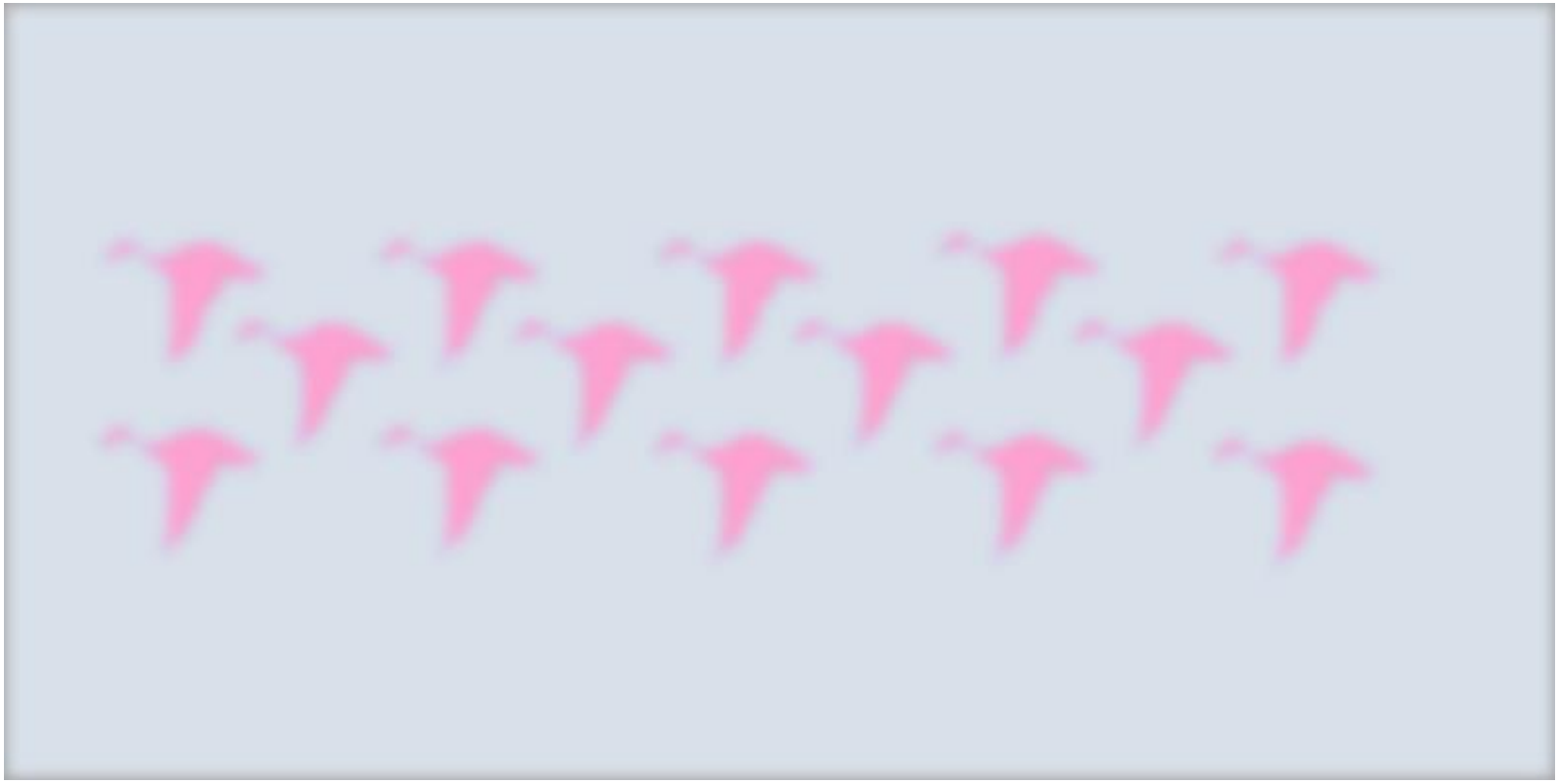
MALADAPTATION

Gutierrez et al.: Perception-based rendering: Eyes wide bleached, *Eurographics Short Papers* (2005)

BLEACHING



QUALITATIVE: COLOR



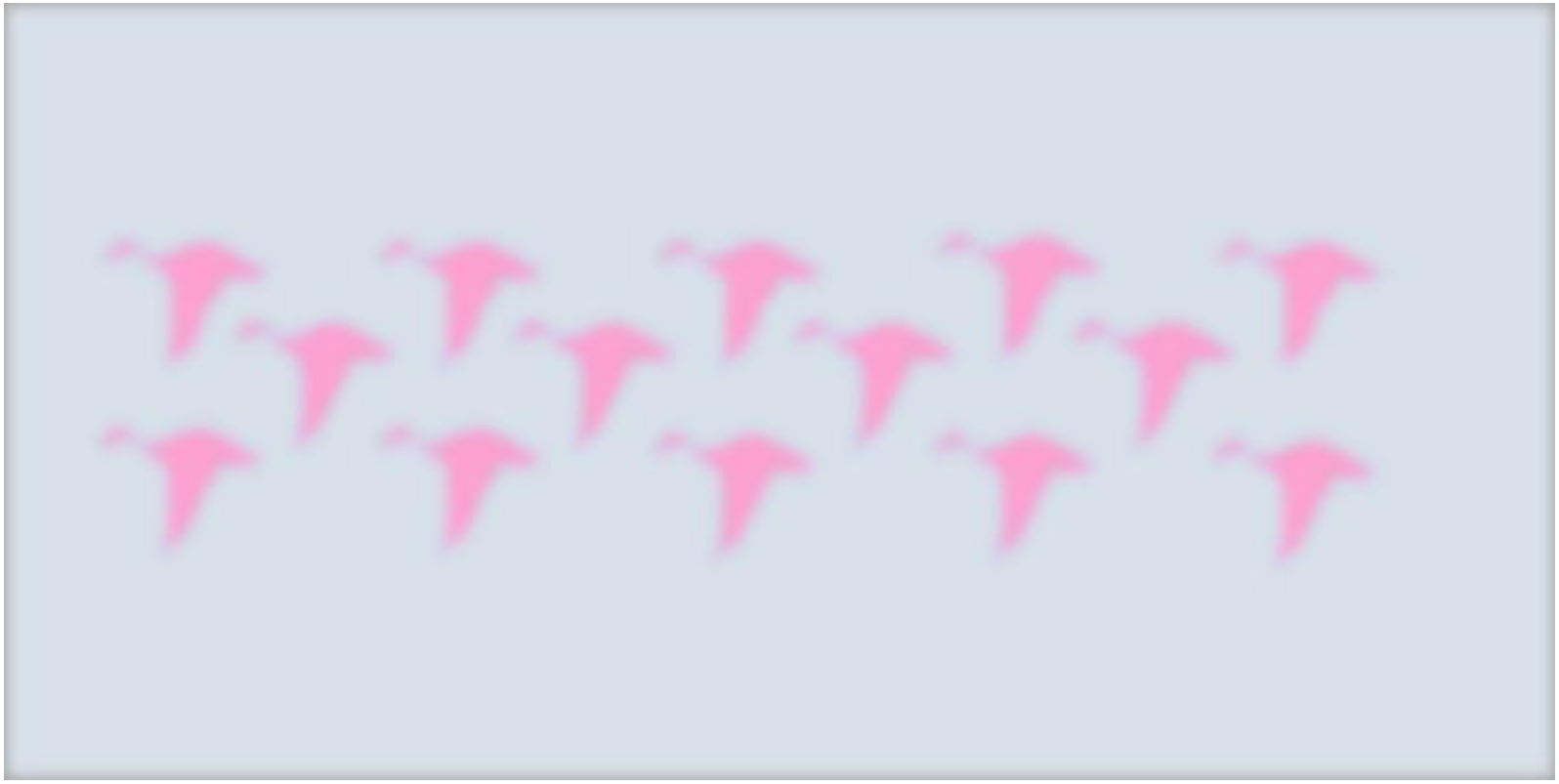
QUALITATIVE: BLUR 1

QUALITATIVE: LOSS

QUALITATIVE: LOSS

QUALITATIVE: LOSS

QUALITATIVE: GAIN

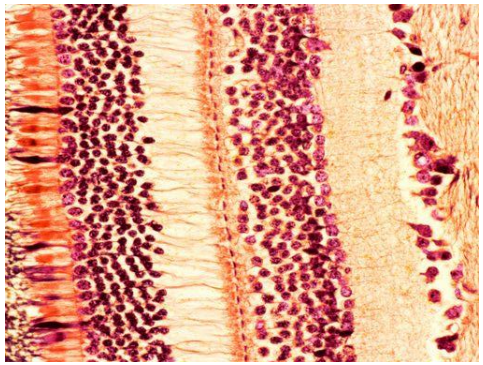


QUALITATIVE: BLUR 2

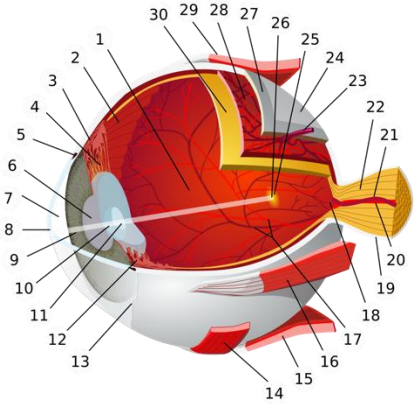
QUALITATIVE: BLUR 2

QUALITATIVE: BLUR 2

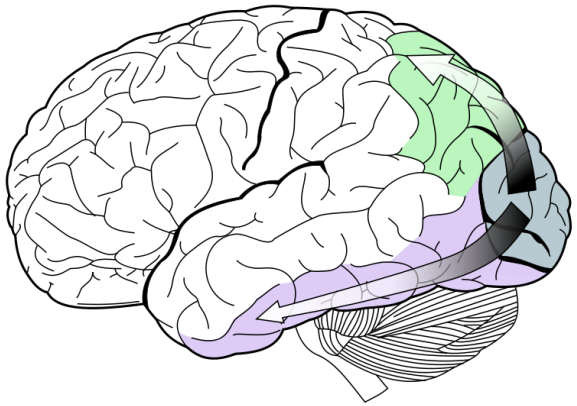
QUALITATIVE: BLUR 2



Retina

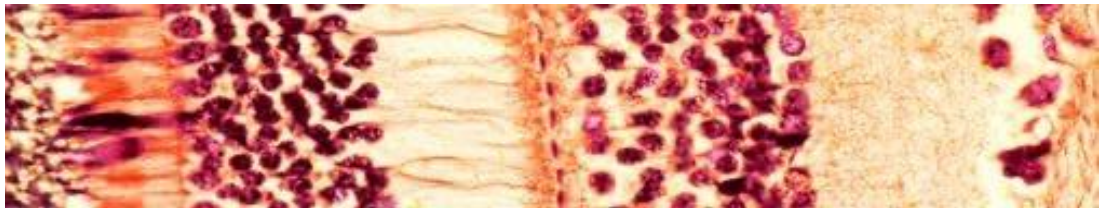


Eye

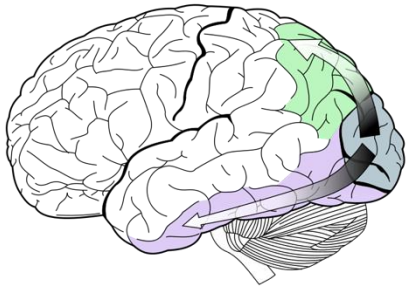


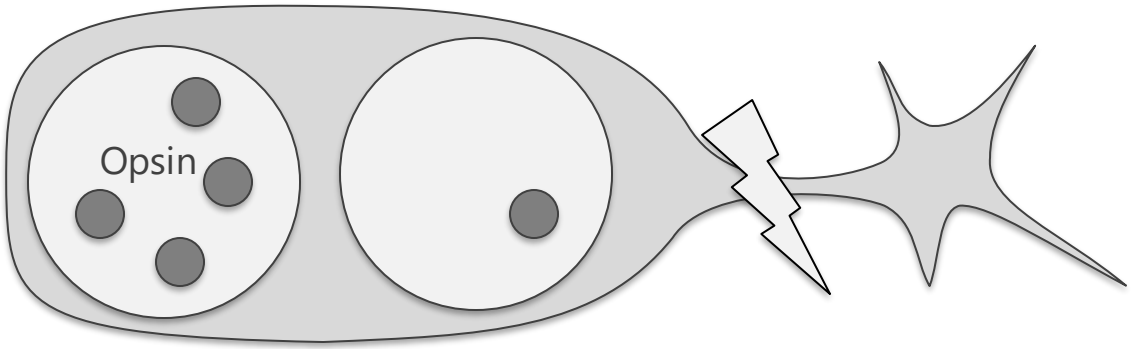
Visual cortex

HUMAN VISUAL SYSTEM

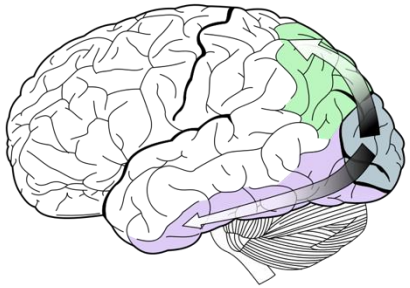


Retina



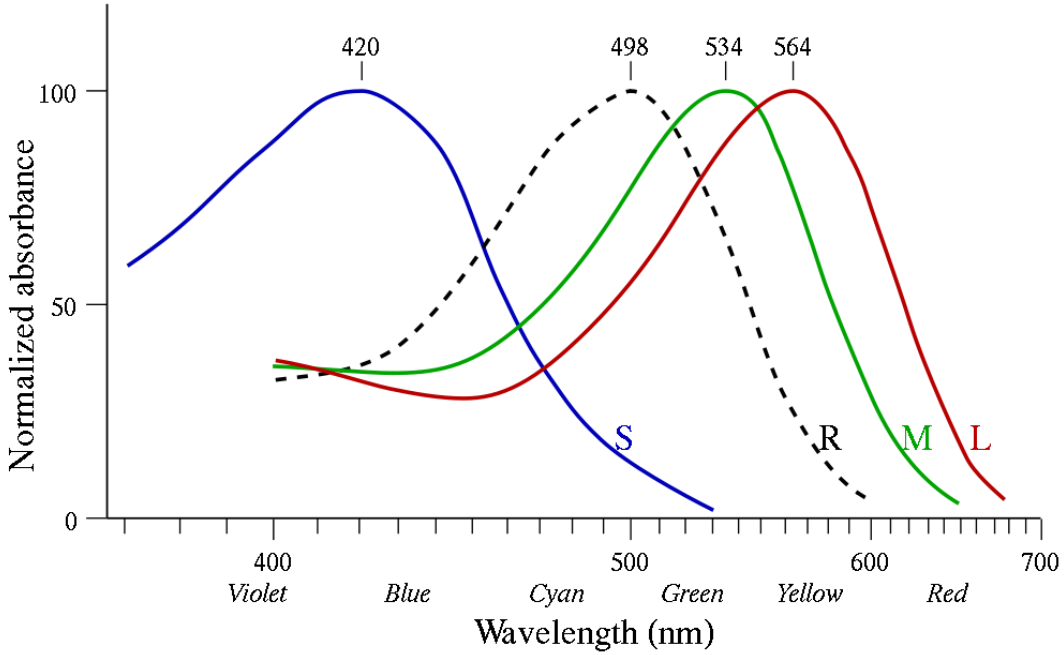


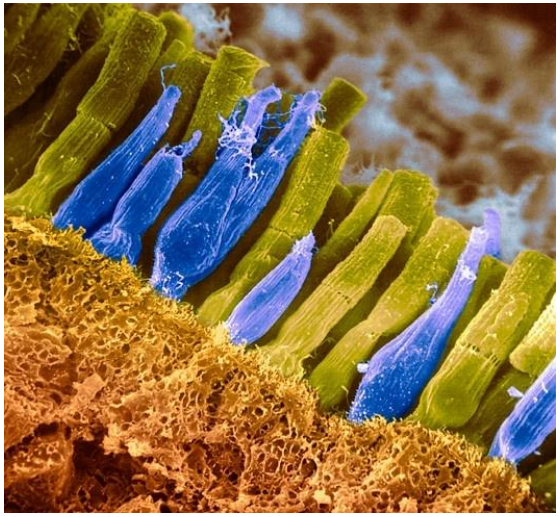
Photoreceptor cell



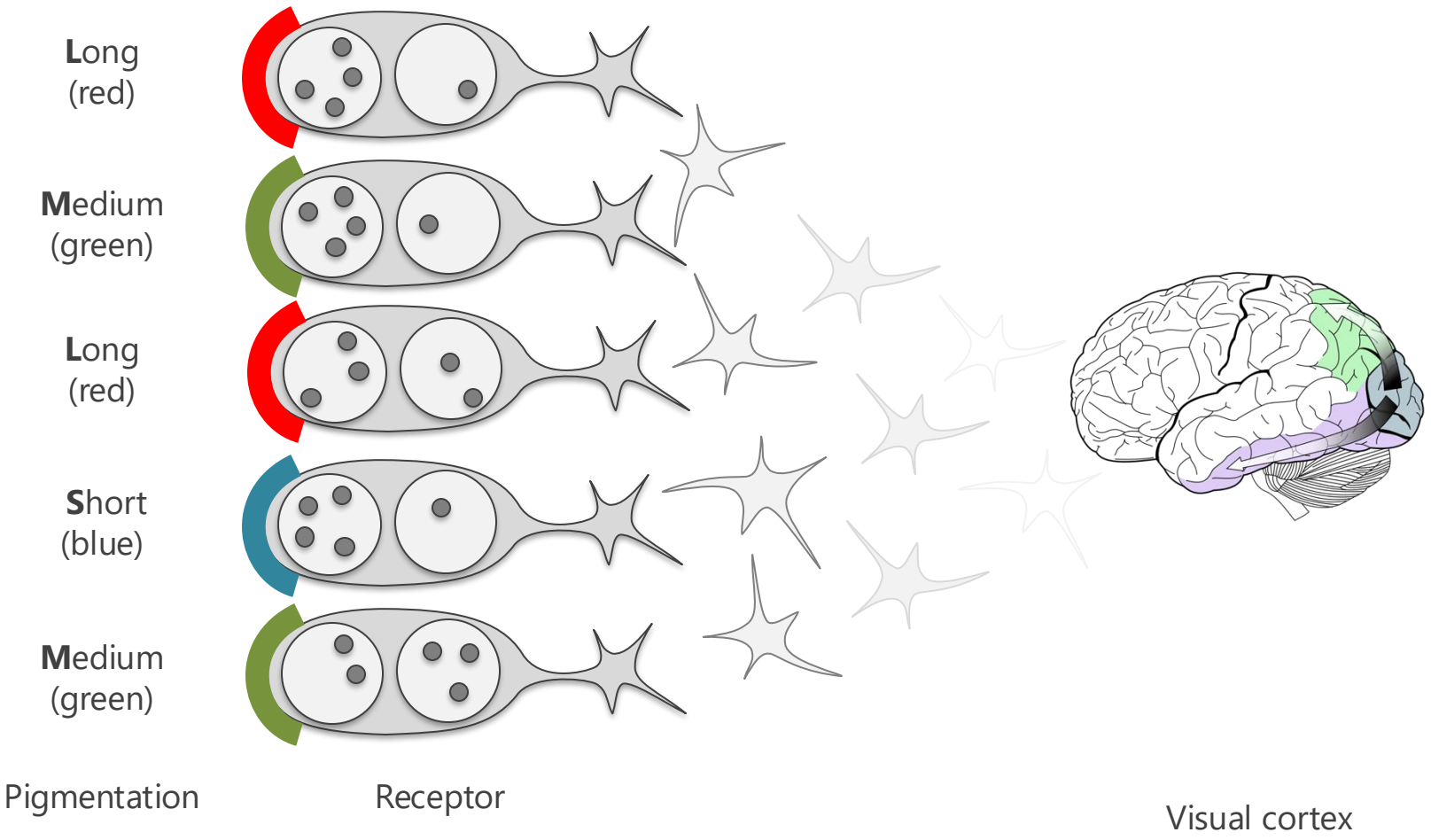
Visual cortex

BLEACHING





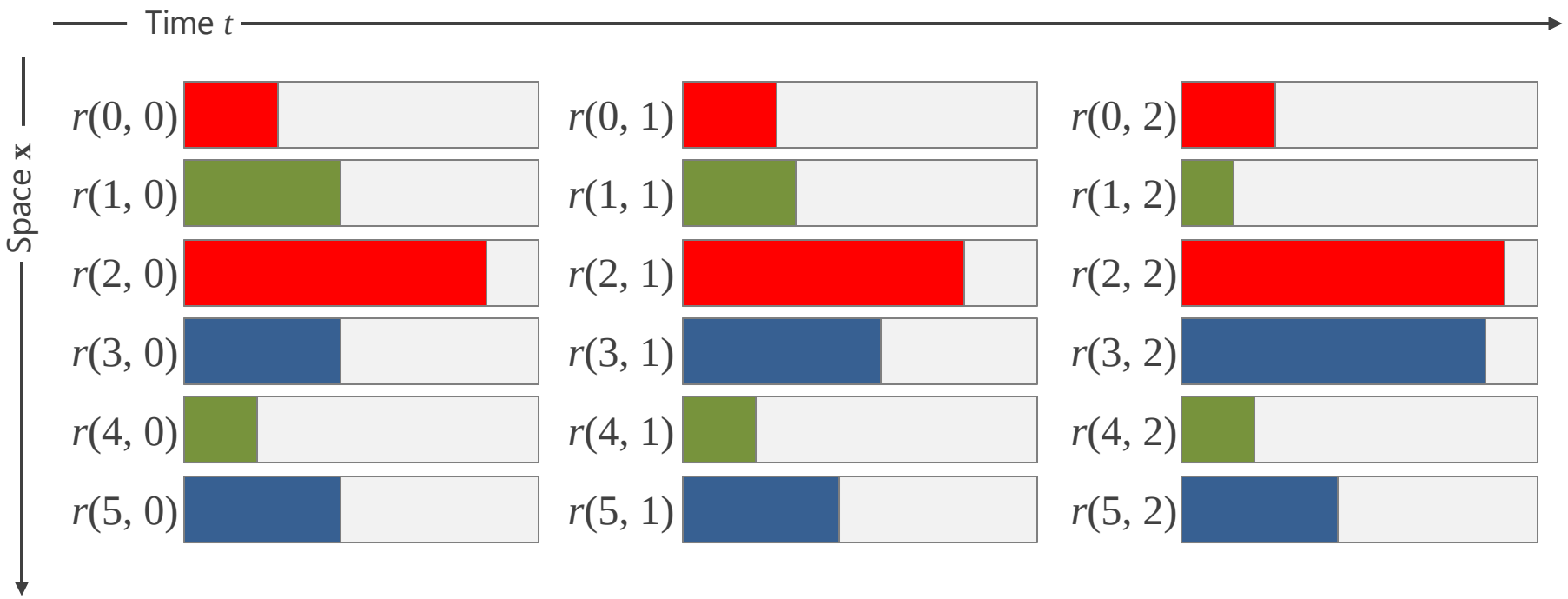
PHOTORECEPTORS


Long
(red)
Medium
(green)
Long
(red)
Short
(blue)
Medium
(green)
Pigmentation
Receptor
Visual cortex

BLEACHING

$\dot{r}(\mathbf{x}, t)$

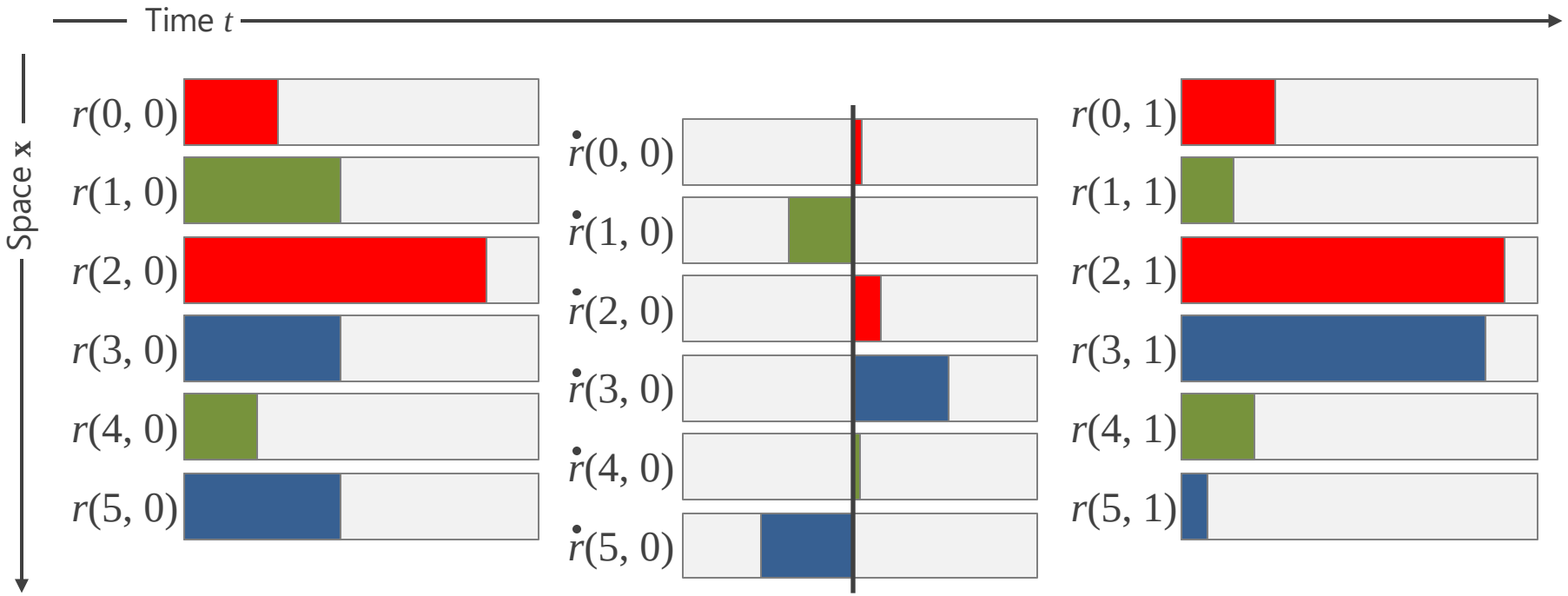
Concentration of opsin in space $\mathbf{x}$ and time t



RECEPTOR KINETICS

$r(\mathbf{x}, t)$
Concentration of opsin in space $\mathbf{x}$ and time t

$\dot{r}(\mathbf{x}, t)$
Change of opsin concentration in space $\mathbf{x}$ and time t

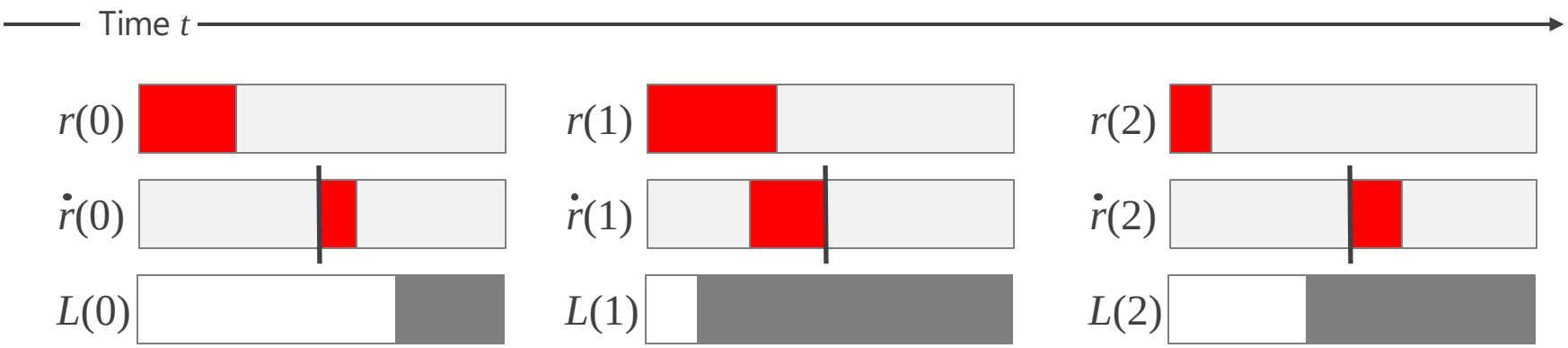


RECEPTOR KINETICS

$r(t)$
Concentration at time t

$\dot{r}(t)$
Change concentration at time t

$L(t)$
Retinal radiance [Trolands]



RECEPTOR KINETICS

$r(t)$
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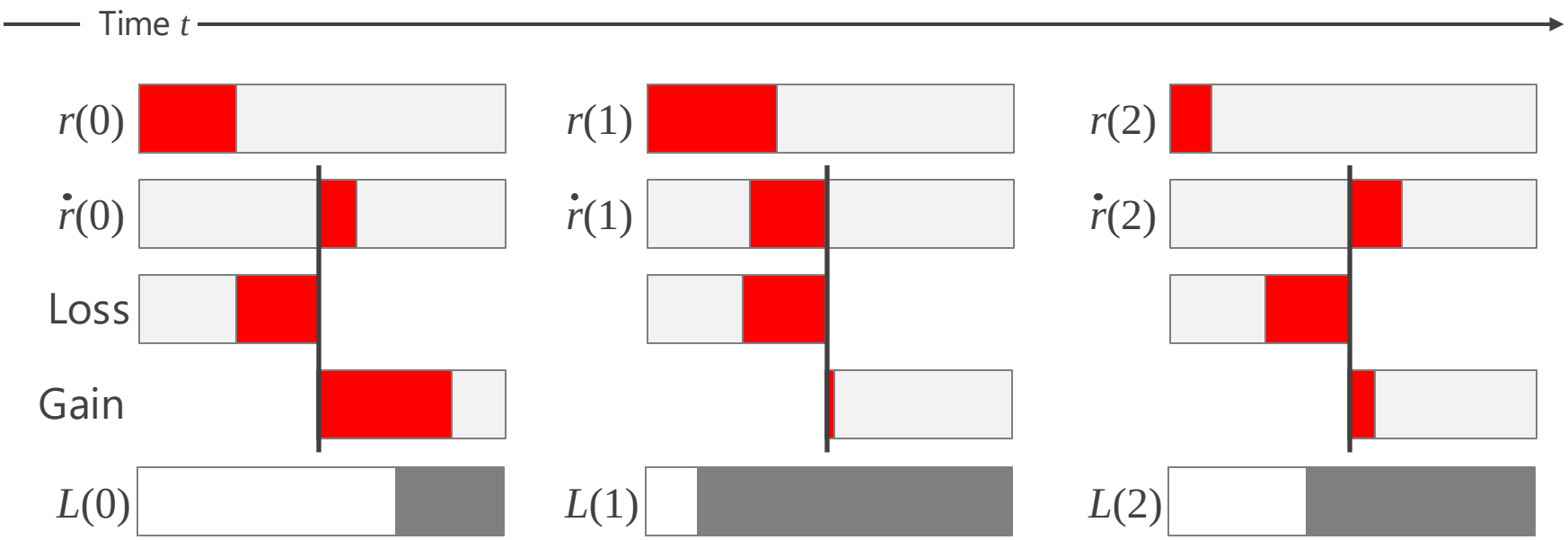

RECEPTOR KINETICS

$r(t)$
Concentration at time t

$\dot{r}(t)$
Change concentration at time t

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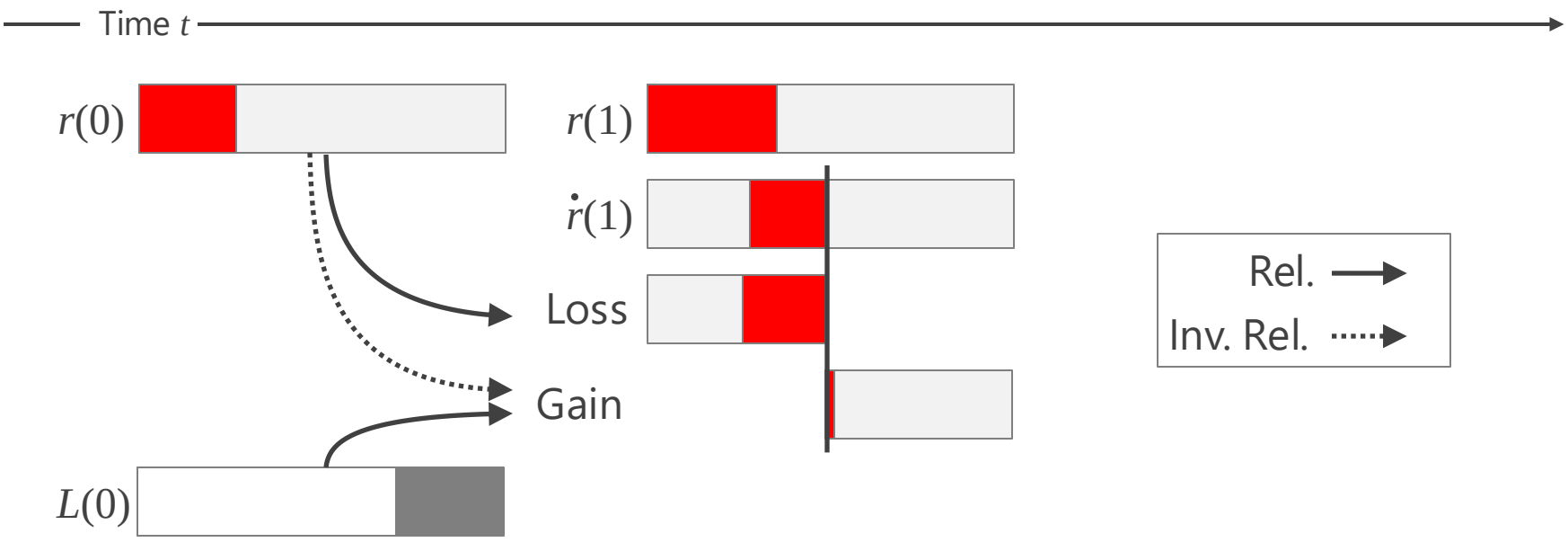
Retinal radiance [Trolands]

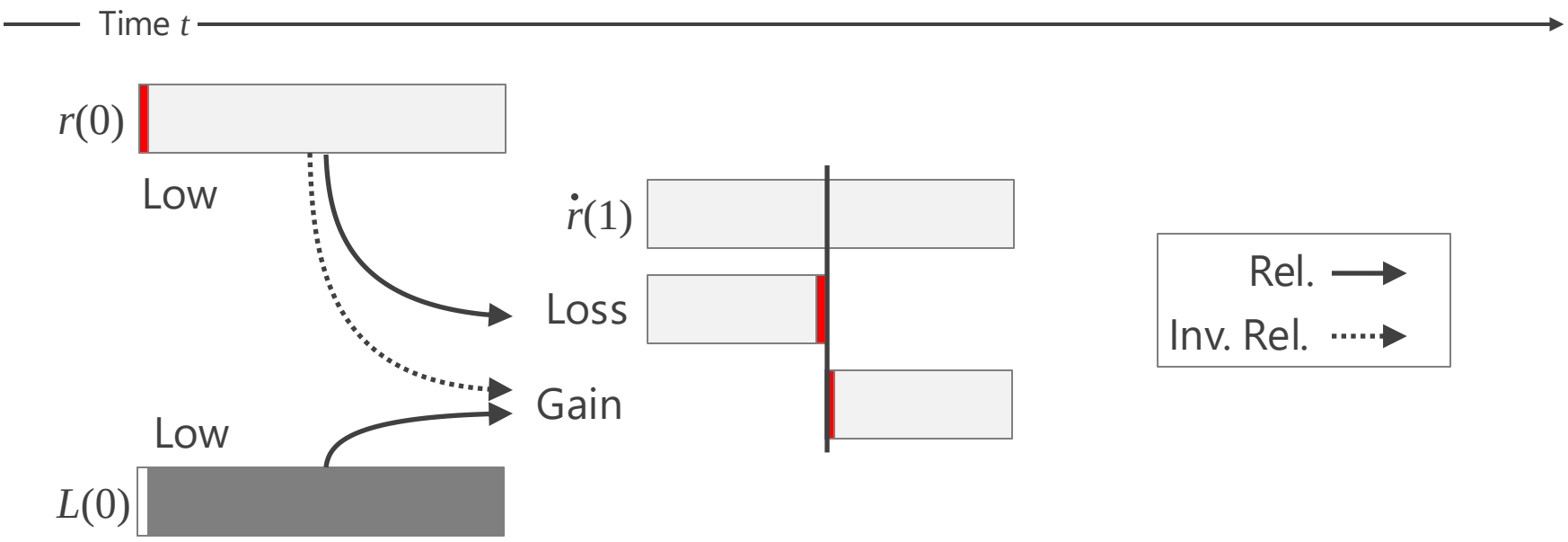


RECEPTOR KINETICS

$r(t)$
Concentration at time t

$\dot{r}(t)$
Change concentration at time t

$L(t)$
Retinal radiance [Trolands]

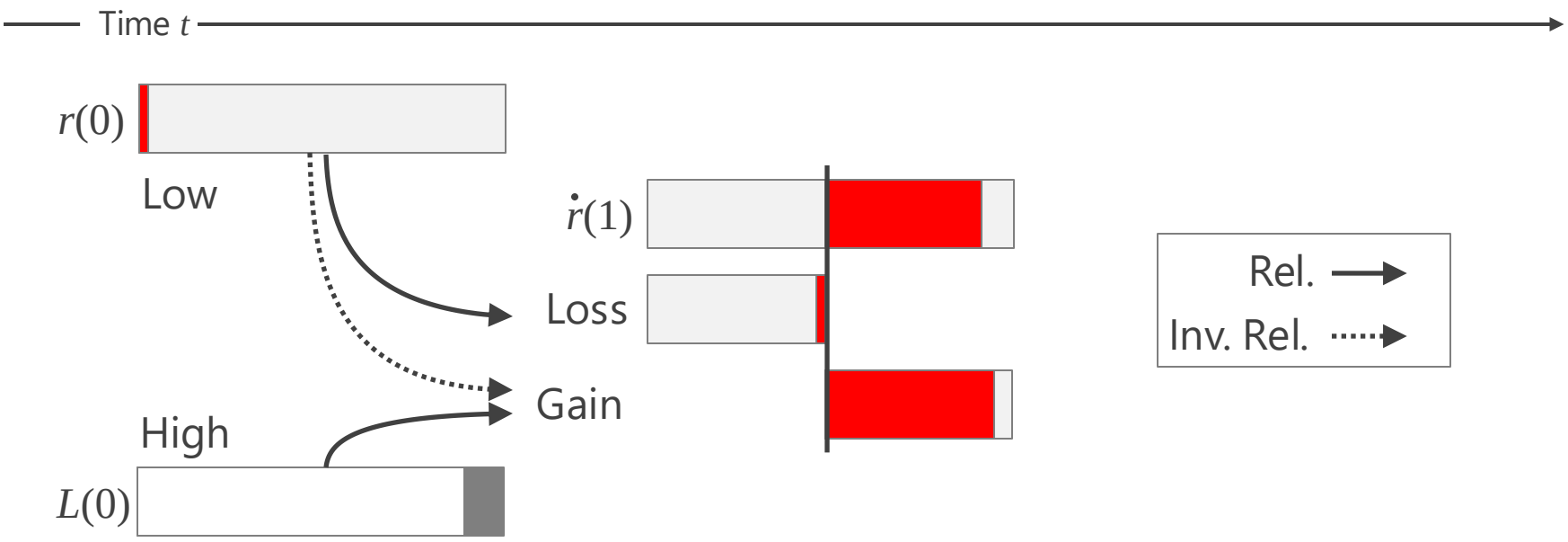


RECEPTOR KINETICS

$r(t)$
Concentration at time t

$\dot{r}(t)$
Change concentration at time t

$L(t)$
Retinal radiance [Trolands]

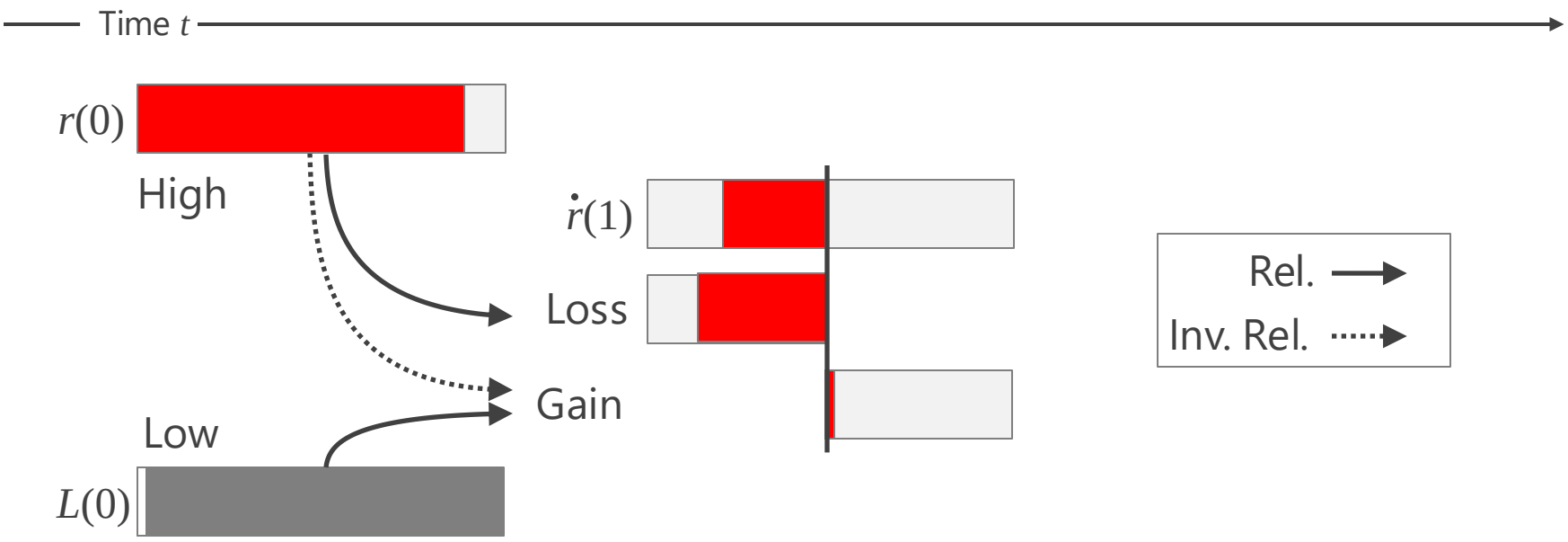


RECEPTOR KINETICS

$r(t)$
Concentration at time t

$\dot{r}(t)$
Change concentration at time t

$L(t)$
Retinal radiance [Trolands]

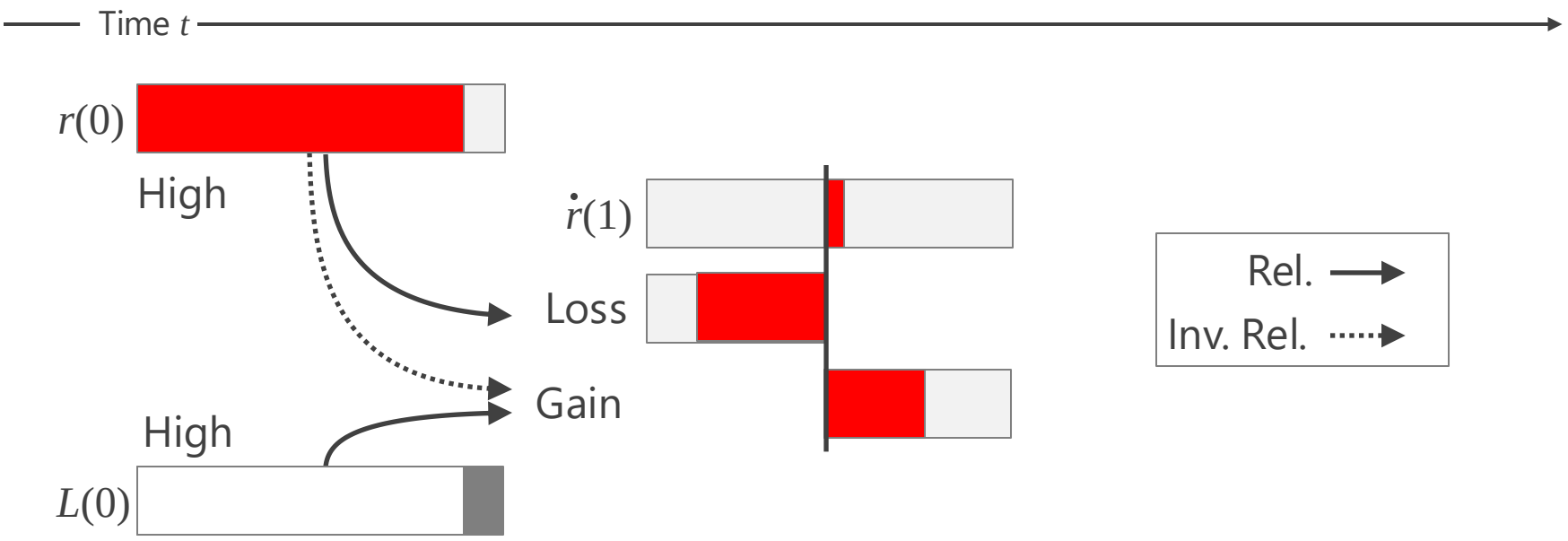


RECEPTOR KINETICS

$r(t)$
Concentration at time t

$\dot{r}(t)$
Change concentration at time t

$L(t)$
Retinal radiance [Trolands]

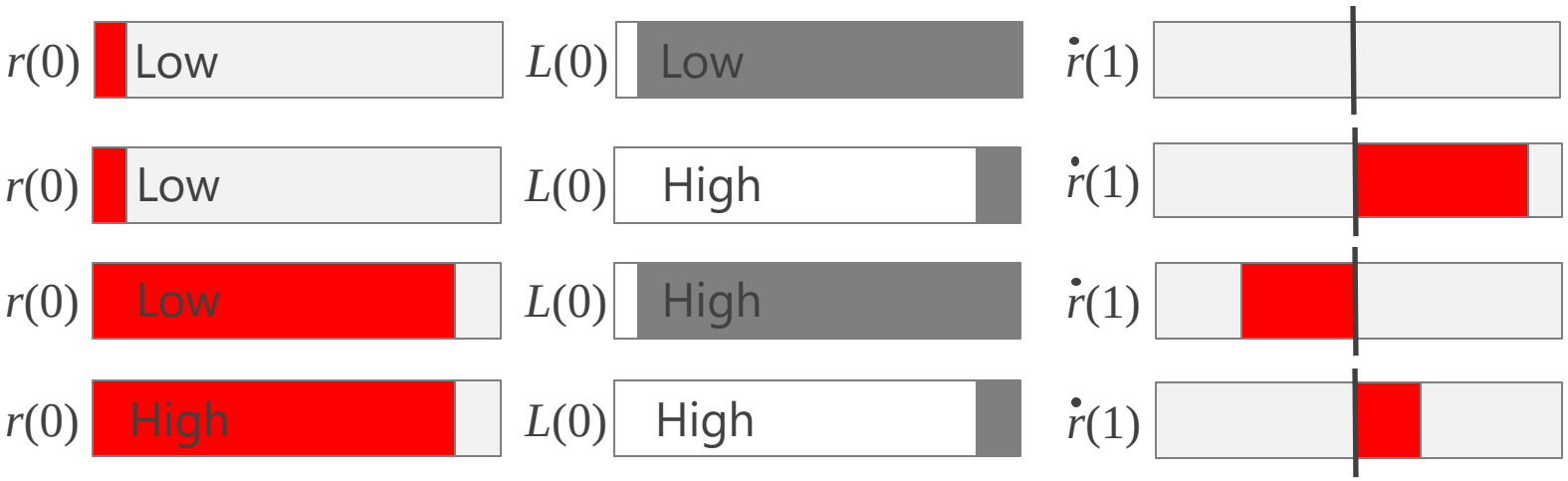


RECEPTOR KINETICS

$r(t)$
Concentration at time t

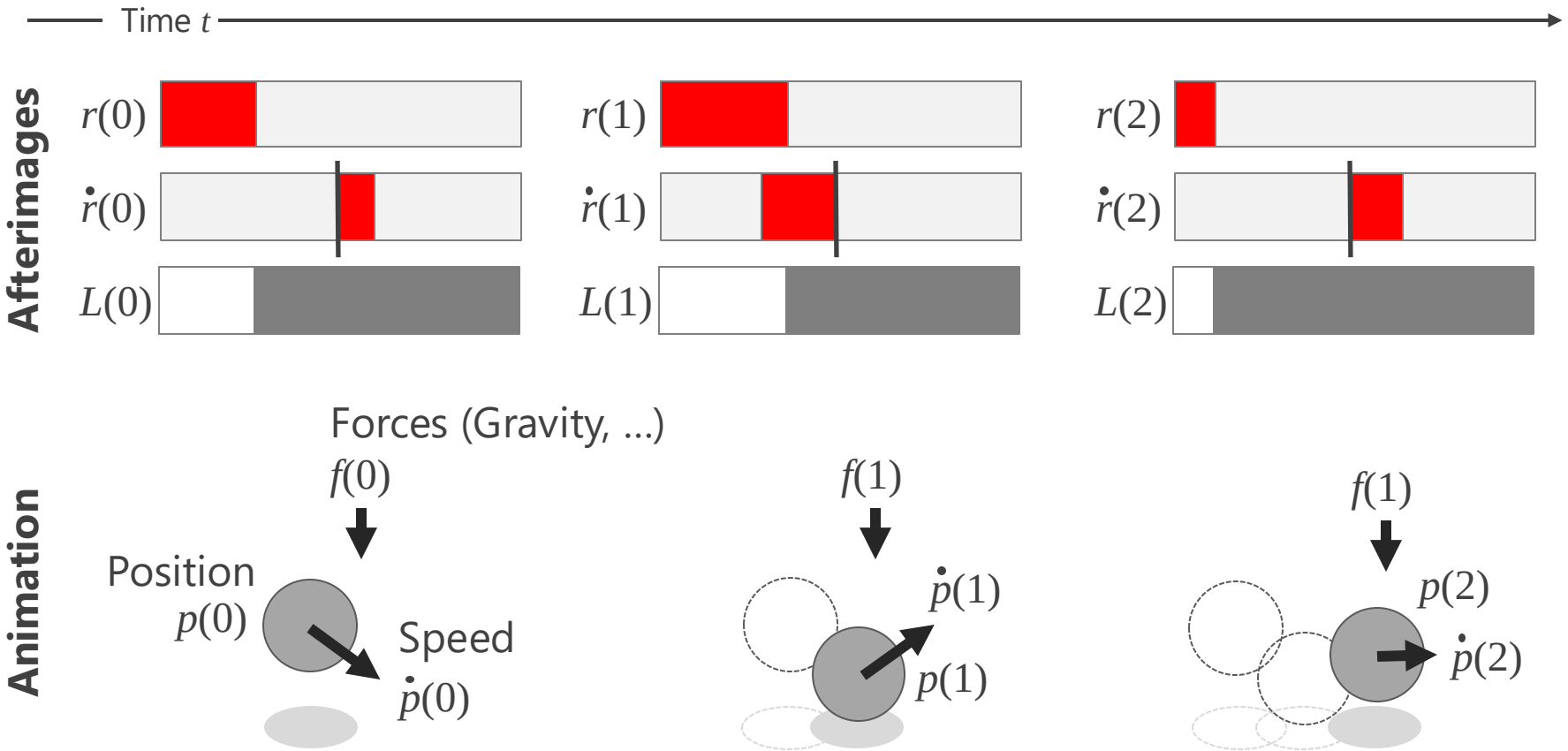
$\dot{r}(t)$
Change concentration at time t

$L(t)$
Retinal radiance [Trolands]

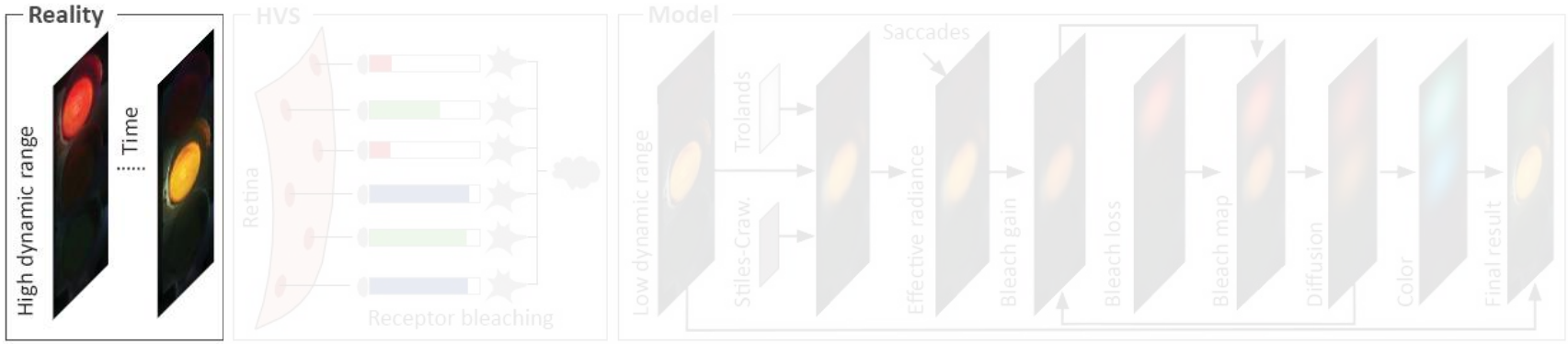


$$\dot{r}(\mathbf{x}, t) = c_a L(\mathbf{x}, t)(1 - r(\mathbf{x},t)) - c_d r(\mathbf{x},t)$$

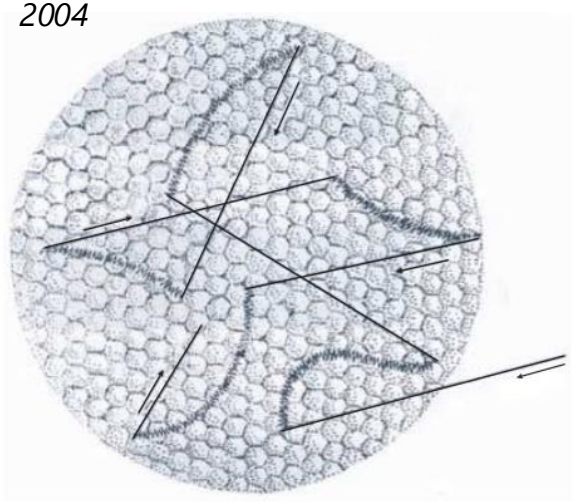
RECEPTOR KINETICS



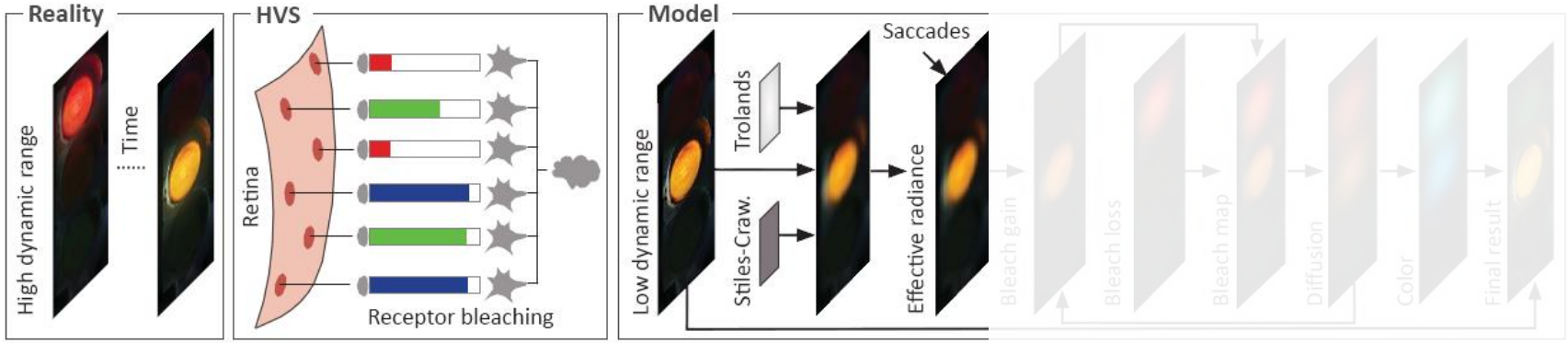
WHY KINETICS?



Martinez-Conde et al.: The role of fixational eye movements in visual perception. *Nature Rev. Neurosc. 5(3), 2004*

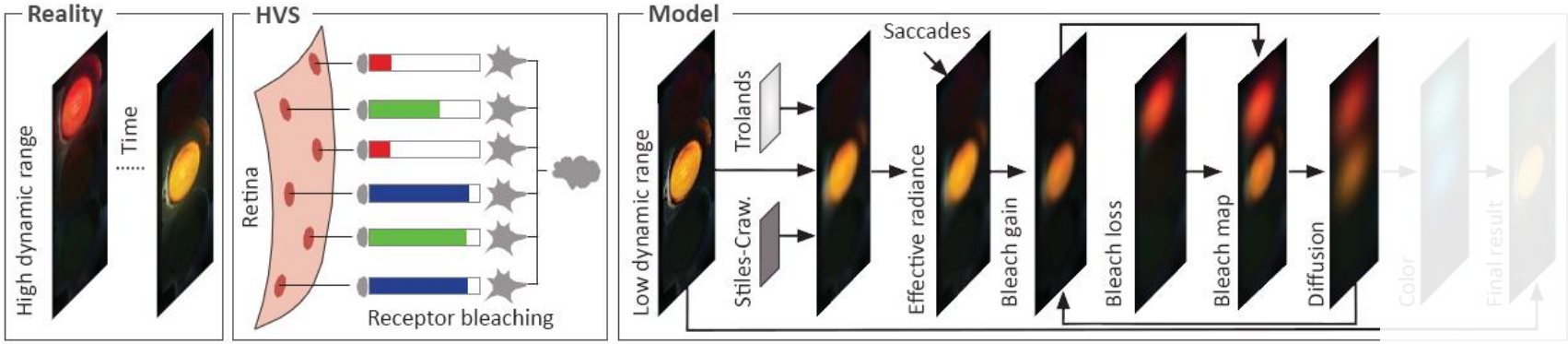


EFFECTIVE RADIANCE

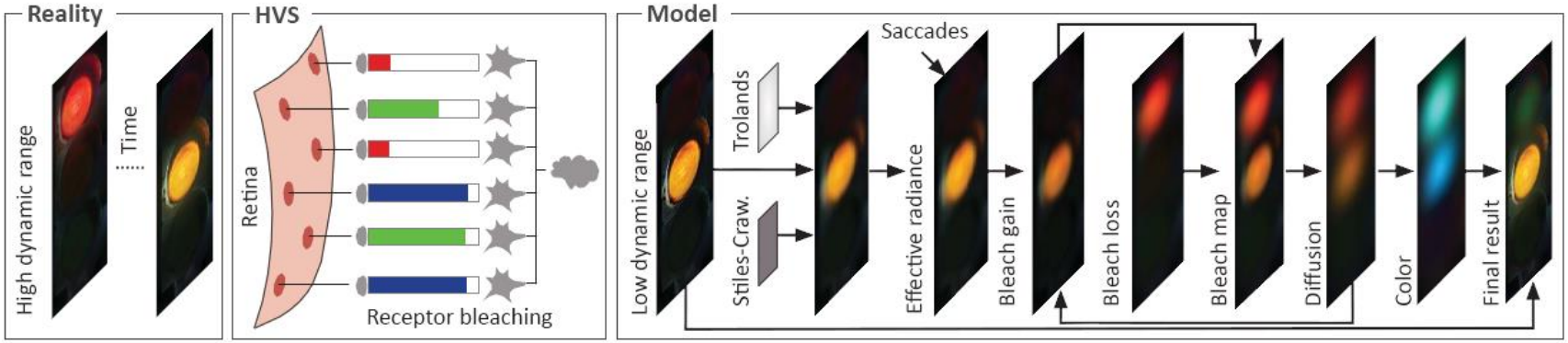


$$
\begin{aligned}
&\textbf{for } i = 1 \ldots n \\
&\quad \textbf{for each } r_j \text{ in } \mathcal{R} \text{ parallel} \\
&\qquad \dot{r}_j \leftarrow c_\mathrm{a} \mathcal{L}_j (1 - r_j) - c_\mathrm{d} r_j \\
&\qquad r_j \leftarrow r_j + \tfrac{s}{n} \dot{r}_j \\
&\quad \textbf{for each } r_j \text{ in } \mathcal{R} \text{ parallel} \\
&\qquad r_j \leftarrow \texttt{convolve}(\mathcal{R}, \mathcal{N}_\sigma)_j
\end{aligned}
$$

(GPU) SOLVER


Reality
High dynamic range
Time
HVS
Retina
Receptor bleaching
Model
Low dynamic range
Trolands
Stiles-Craw.
Saccades
Effective radiance
Bleach gain
Bleach loss
Bleach map
Diffusion
Color
Final result

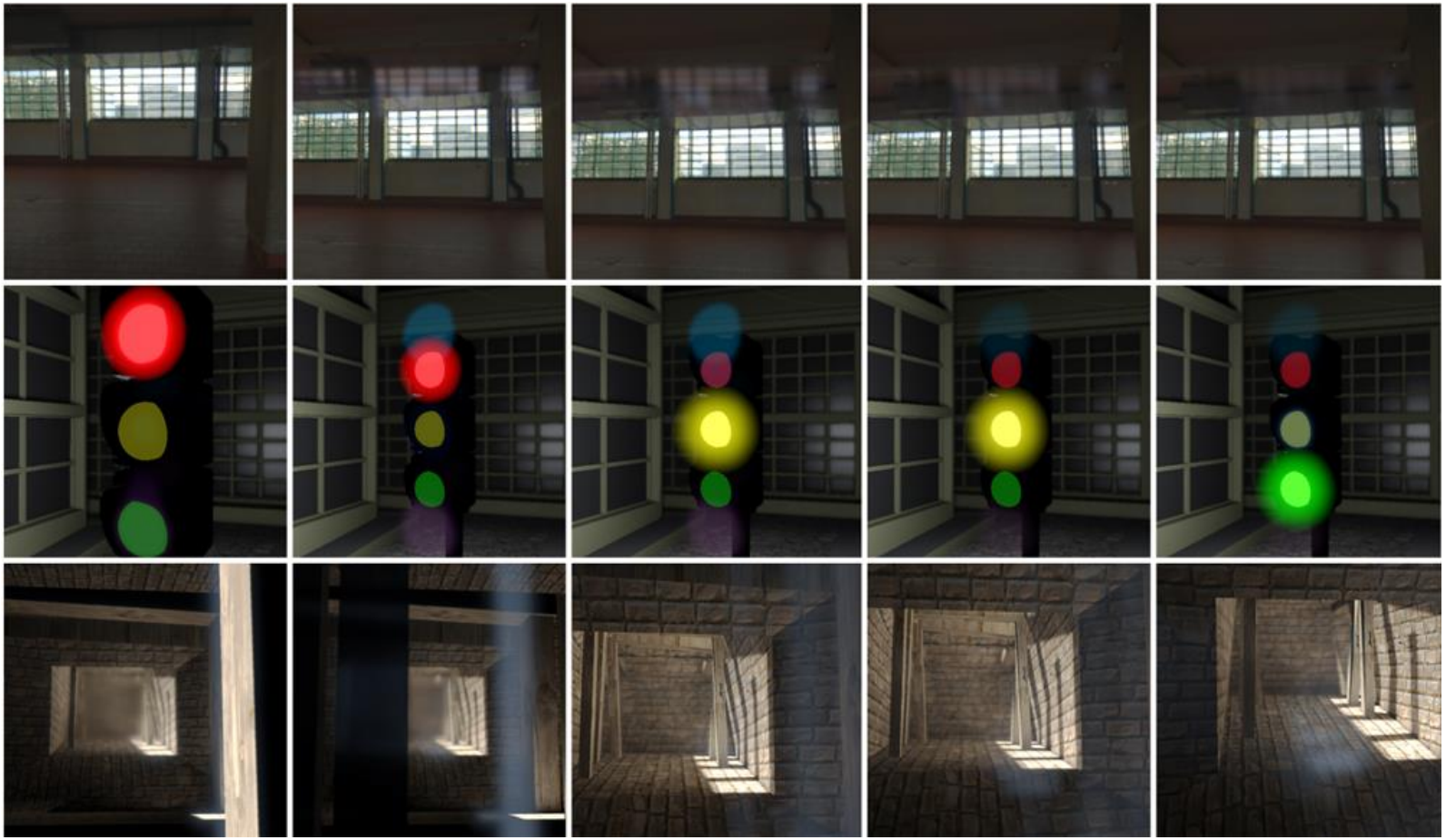
DIFFUSION



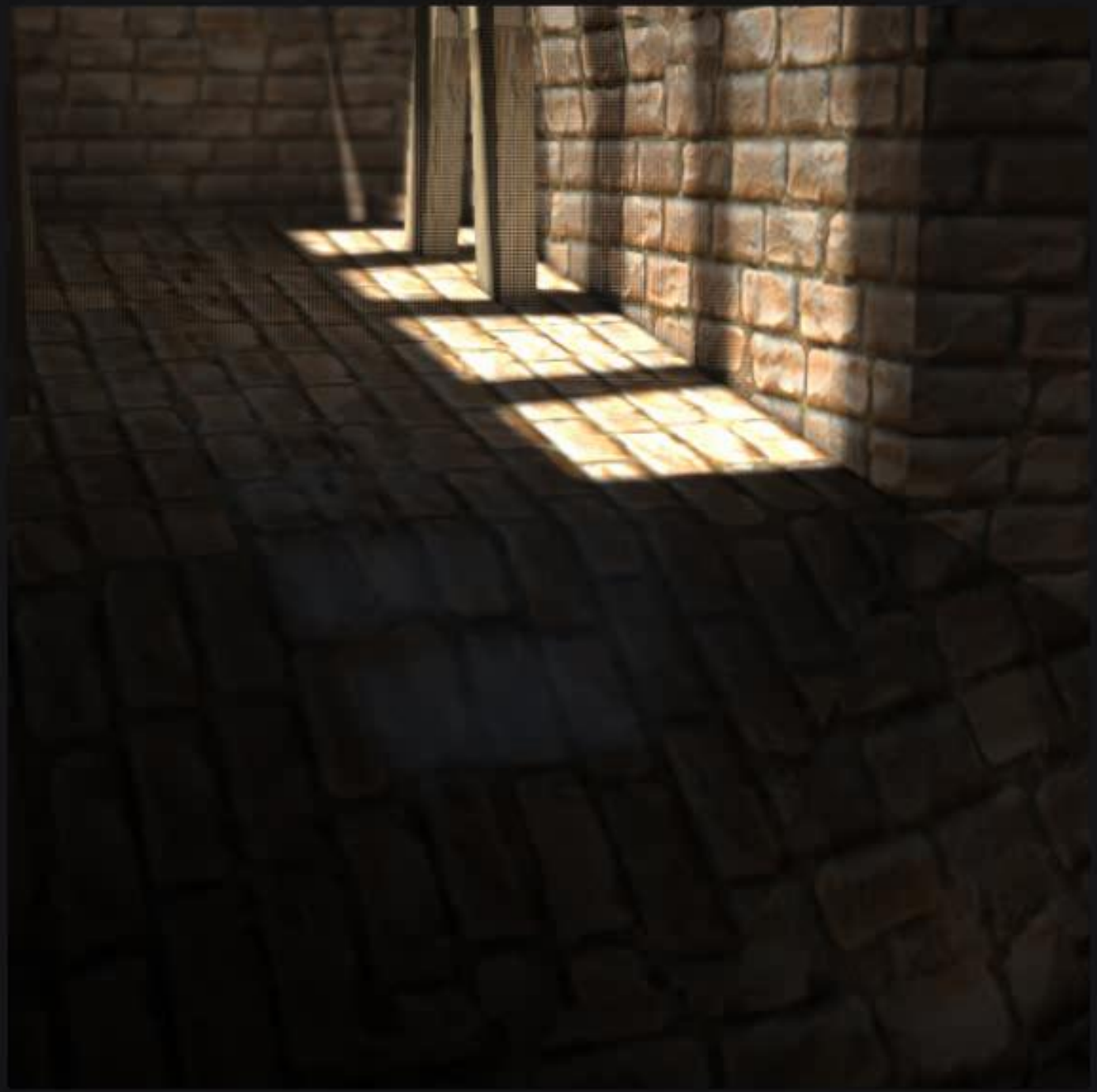
COMPOSITING

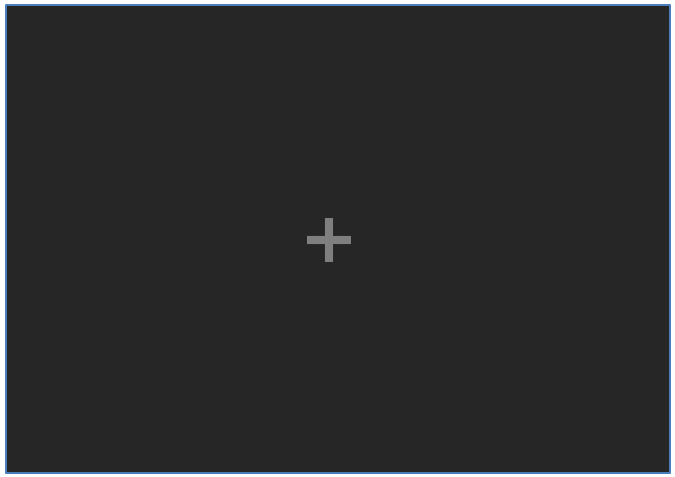
Shuey: The flight of colors. Am J Psych 35(4)

FLIGHT OF COLORS



RESULTS



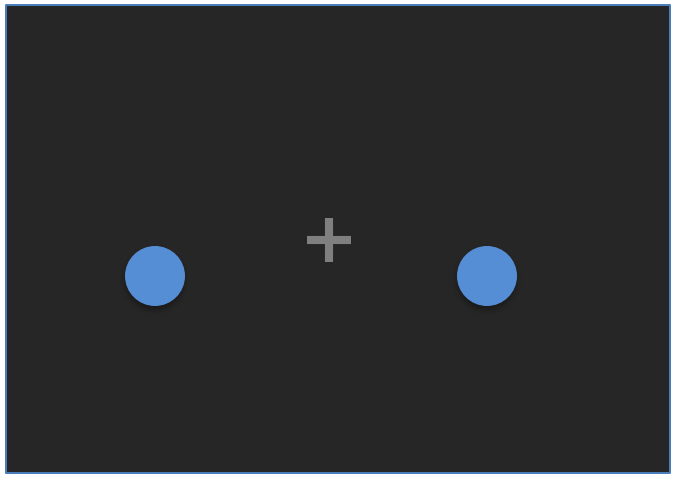


Samsung RZ 2233 display

120 Hz
1680 x 1920

250 cd/m^2 (high)

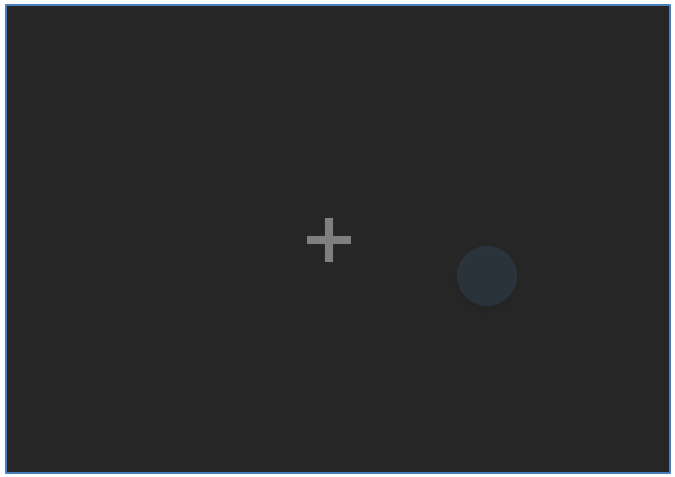
STUDY 1



2-Answer forced-choice

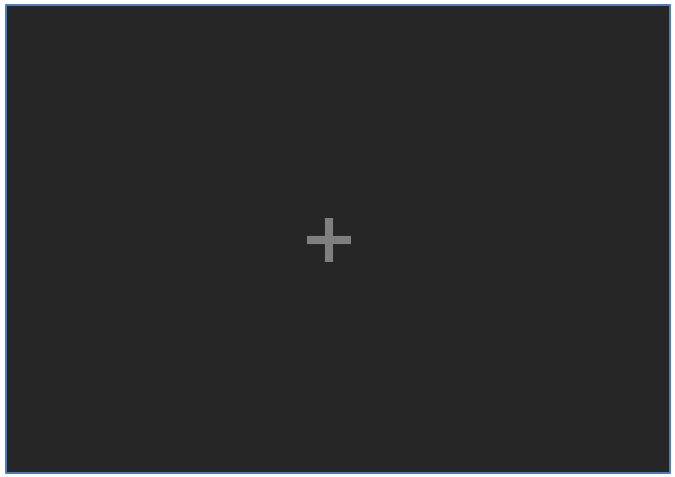
Two circular patches
200 ms

STUDY 1



Afterimages close-to-threshold:
Get faint very quick

STUDY 1



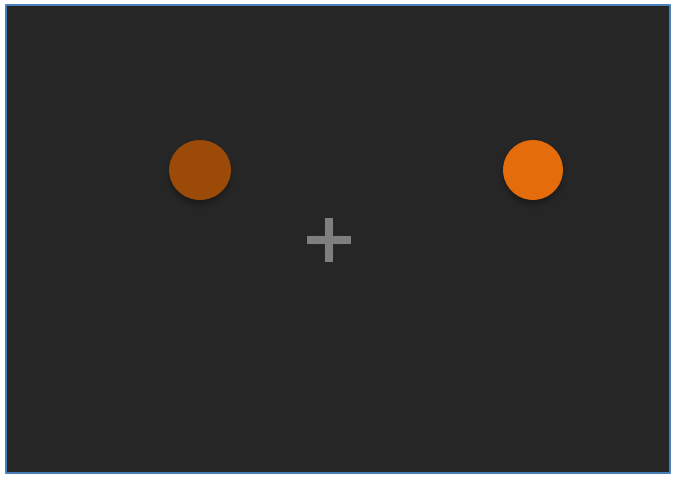
Result

9 subjects
2700 trials

57.3 % Afterimages was brighter

(Significant, but …)

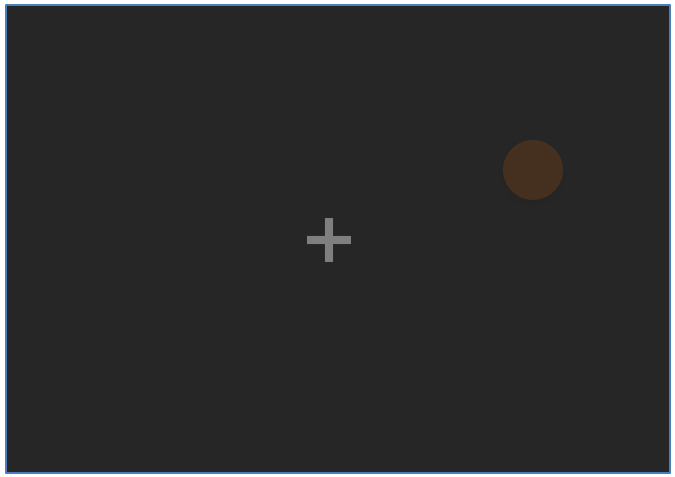
STUDY 1



Adjustment

Two circular patches
200 ms

STUDY 2



Afterimages close-to-threshold:
Get faint very quick

STUDY 2

STUDY 2

Result

6 subjects
42 trials

Avg. factor	1.83
Std. dev.	0.23

STUDY 2

- Computational model of afterimages
- Empirical but also well-grounded in retinal kinetics
- A simple shader with a texture
- Study to validate that it is perceived brighter
- Future work:
  - Eye tracking
  - Proper colors
  - More after-effects

CONCLUSION

Acknowledgements

Hans Brettel	Télécom ParisTech
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David Pajak	Nvidia
Karol Myszkowski	MPI Informatik
Sirko Straube	

THANK YOU!