



SIGGRAPH2010



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Apparent Display Resolution Enhancement for Moving Images

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MPI Informatik

Hans-Peter Seidel
MPI Informatik

Motivation



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A red square logo with white text and symbols.

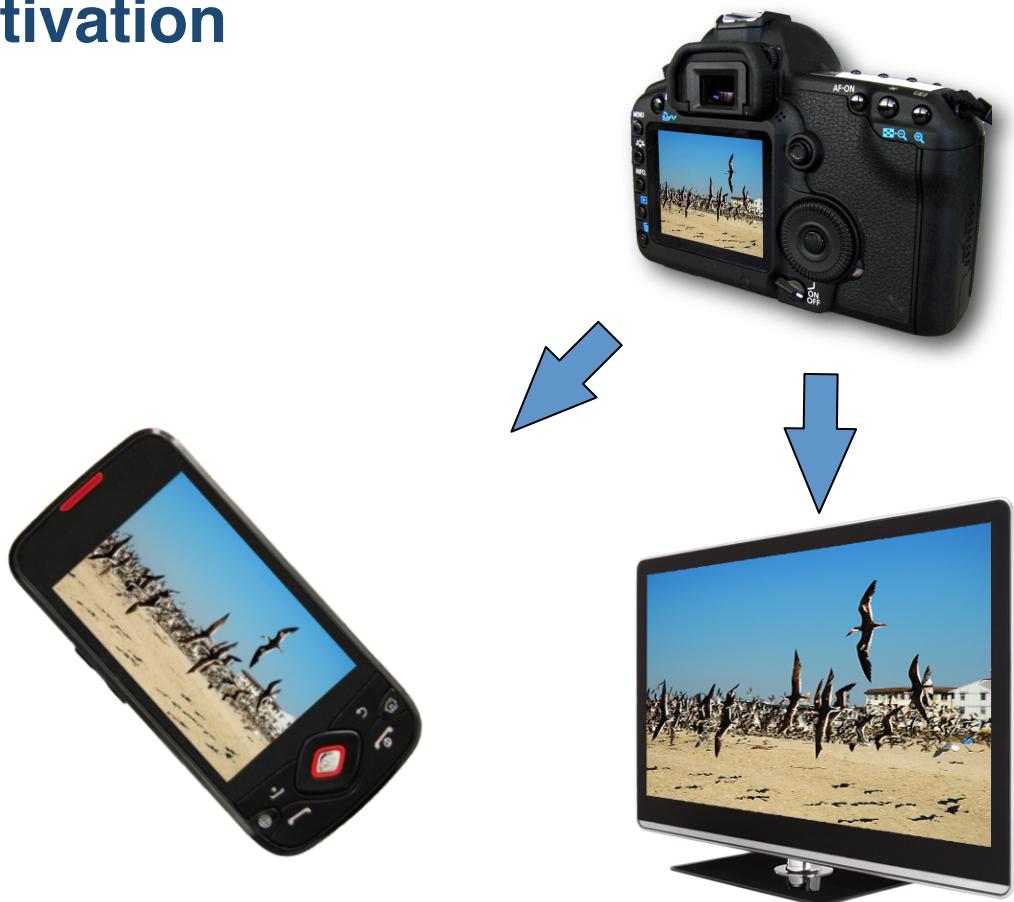


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A red and white graphic logo consisting of several vertical bars and a stylized 'T' shape.

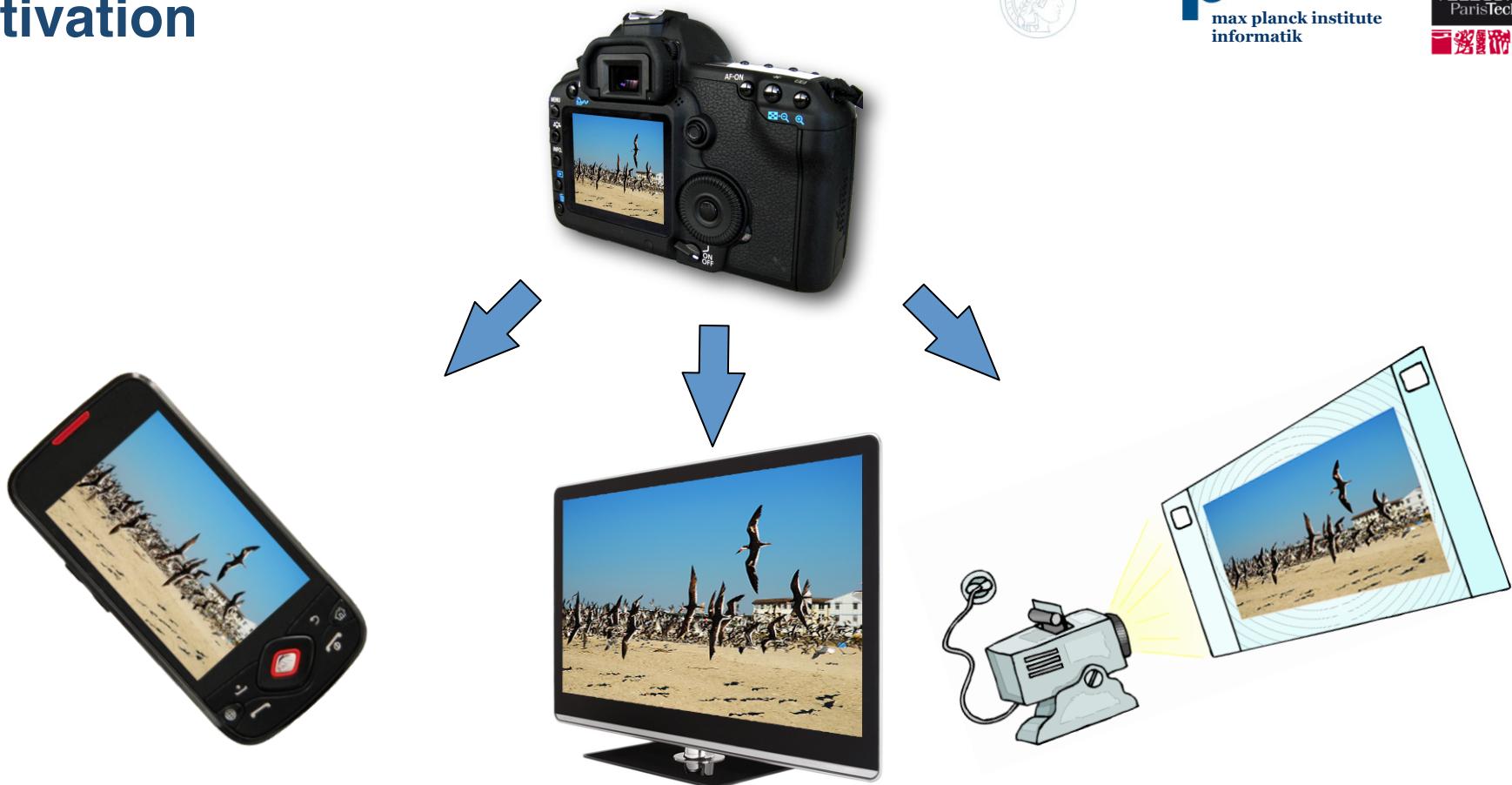


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source



display devices

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more than 10 MPix



source



display devices

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more than 10 MPix

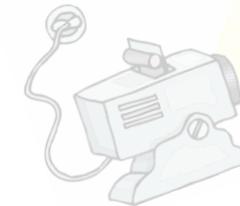


source

display devices

usually 2 MPix

up to 8MPix



Motivation



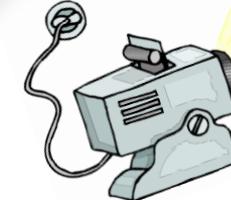
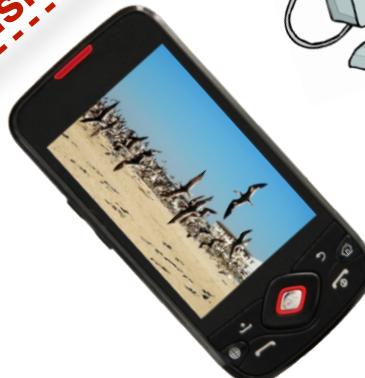
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resolution mismatch



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Photographs: > 10MPix



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Photographs: > 10MPix



Panoramas: > 50MPix



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Photographs: > 10MPix



Panoramas: > 50MPix



Gigapixel Photography:



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Photographs: > 10MPix



Gigapixel Photography:



Panoramas: > 50MPix



Computer generated: Unlimited



Previous work

Image resampling



high resolution image



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Previous work

Image resampling



high resolution image



take every n-th pixel



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Previous work

Image resampling



high resolution image



take every n-th pixel



aliasing problem



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Previous work

Image resampling



high resolution image



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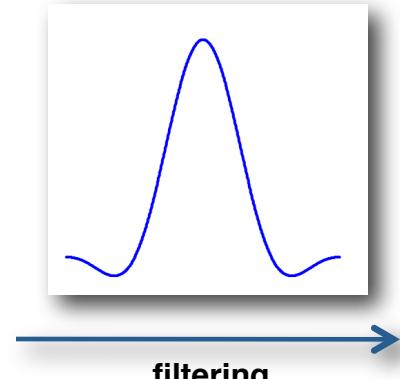
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Previous work

Image resampling



high resolution image



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“Lanczos Filtering in One and Two Dimensions”
[Duchon 1979]

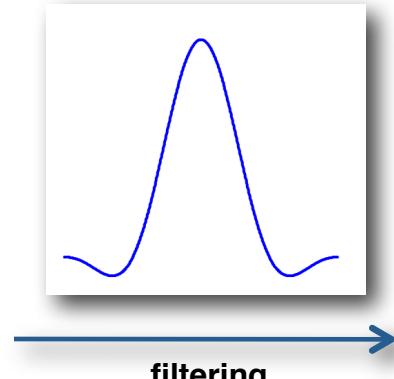
“Reconstruction Filters in Computer Graphics”
[Mitchell et al. 1988]

Previous work

Image resampling



high resolution image



“Lanczos Filtering in One and Two Dimensions”
[Duchon 1979]

“Reconstruction Filters in Computer Graphics”
[Mitchell et al. 1988]



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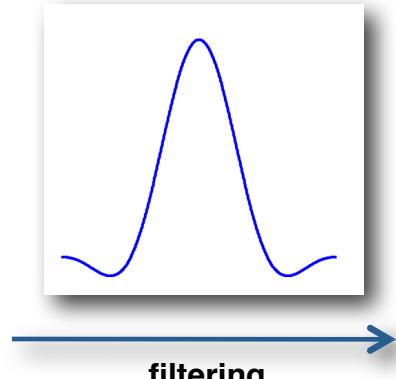


Previous work

Image resampling



high resolution image



downsampling



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TELECOM
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The logo of Telecom ParisTech, consisting of the word "TELECOM" above "ParisTech" and a red square containing a white stylized "T".

“Lanczos Filtering in One and Two Dimensions”
[Duchon 1979]

“Reconstruction Filters in Computer Graphics”
[Mitchell et al. 1988]

Motivation



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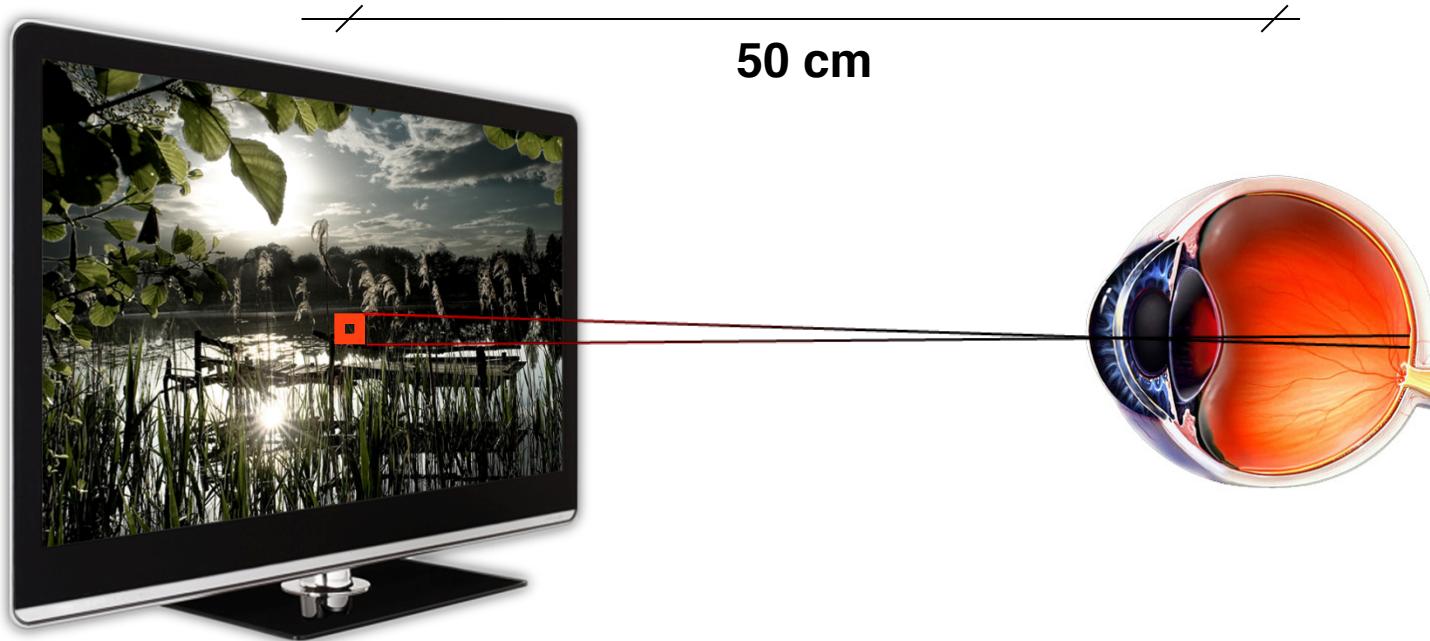


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TELECOM
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The logo of Telecom ParisTech, consisting of the word "TELECOM" above "ParisTech" and a red square containing a white graphic element.



1px → more than 9 receptors
(in the fovea region)

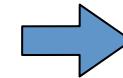
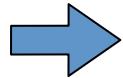
Motivation

Summary



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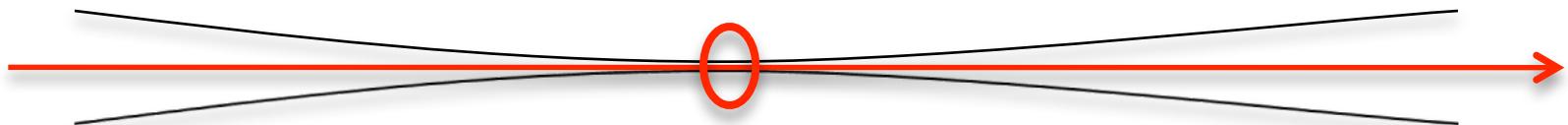
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easily ~50 MPix

~ 2-8 MPix

1px → > 9 receptors



Previous work

Color Matrix Displays



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“Optimal filtering for pattern displays”
[Platt 2000]

Previous work

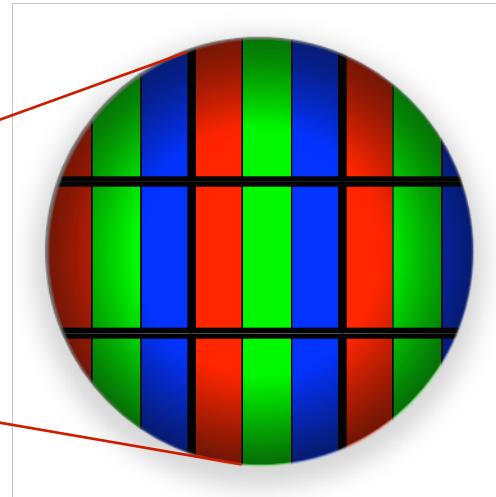
Color Matrix Displays



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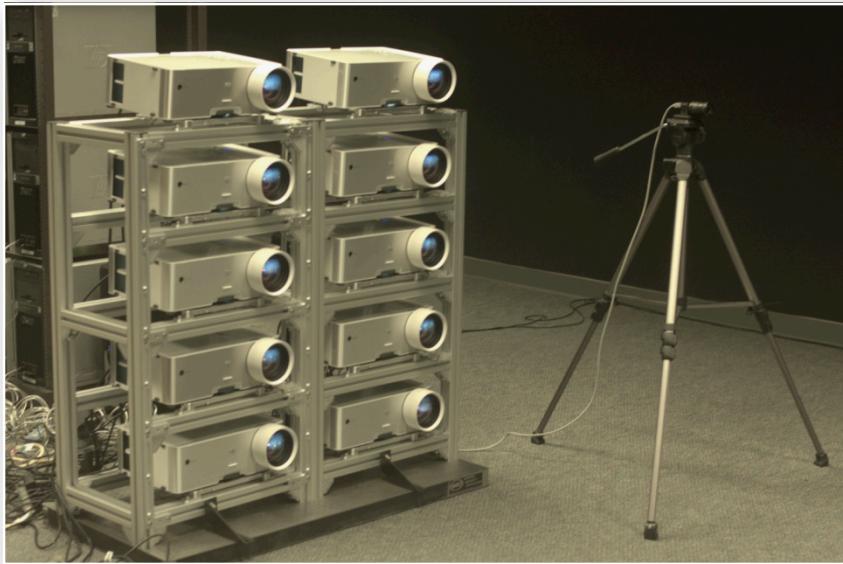
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“Optimal filtering for pattern displays”
[Platt 2000]

Previous work

Display Supersampling and Wobulation



“Display Supersampling”
[Damera-Venkata et al. 2009]

“Wobulation: Doubling the Addressed Resolution of Projection Displays”
[Allen et al. 2005]



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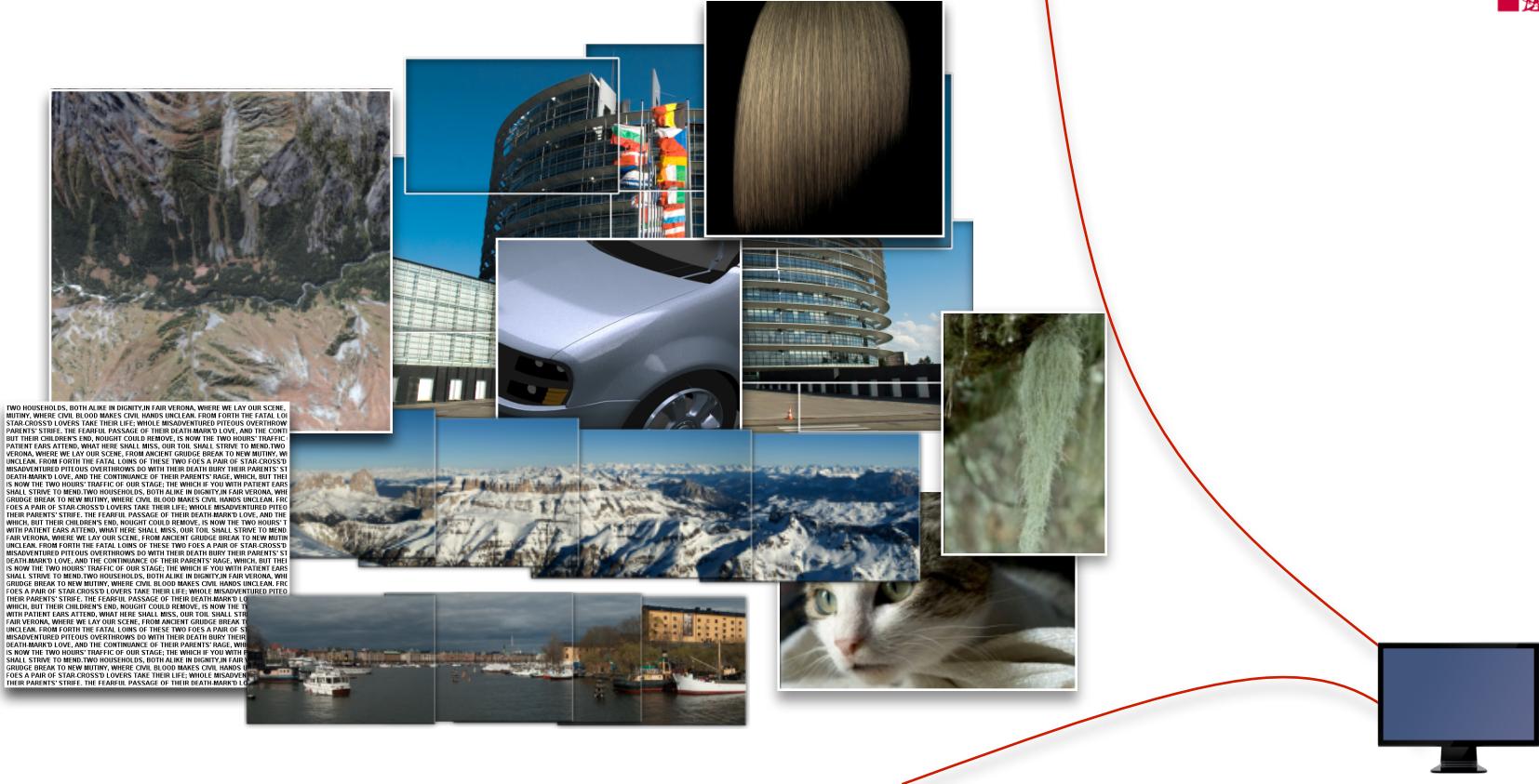




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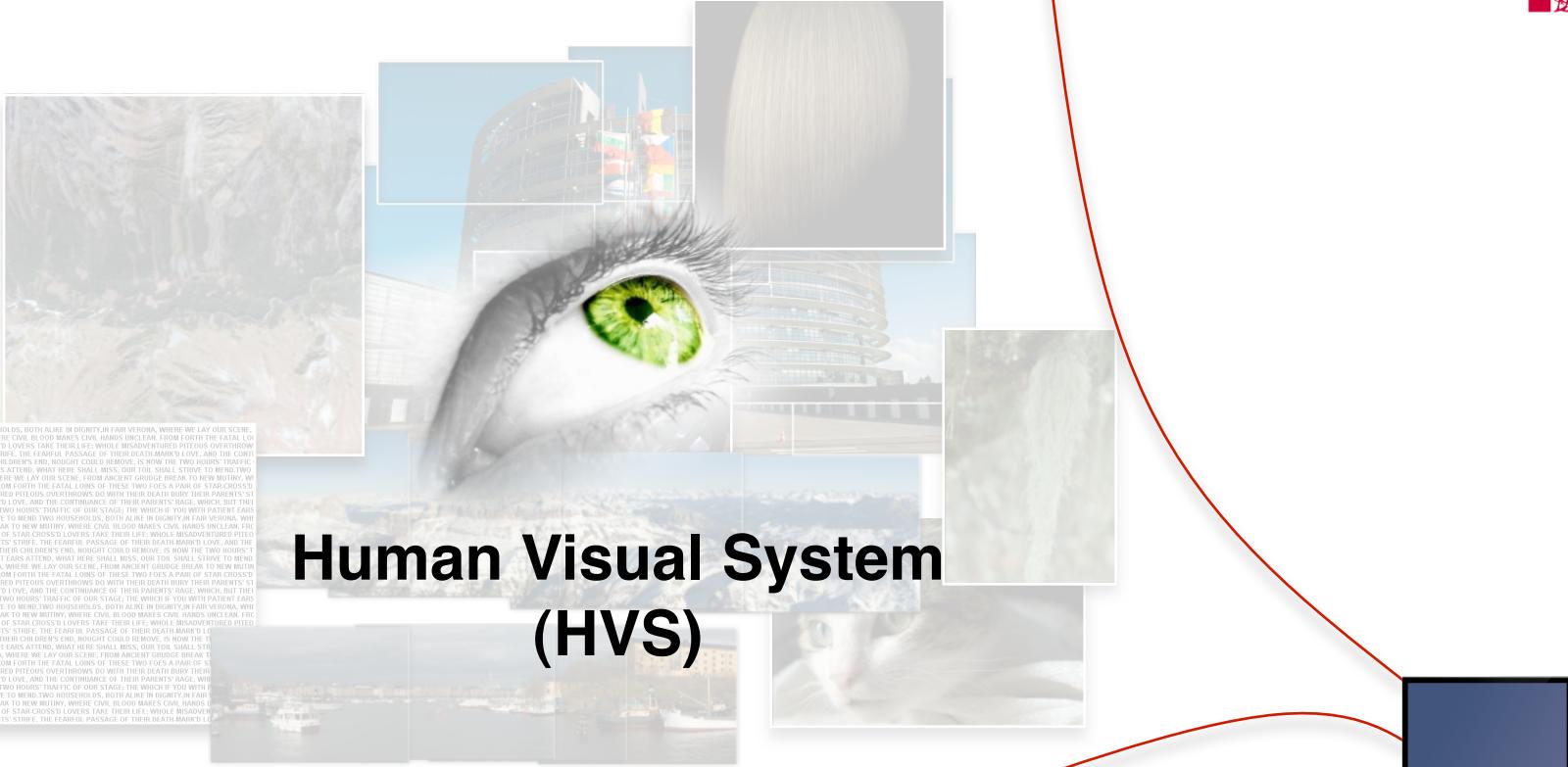


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Human Visual System (HVS)

Our goal



high resolution image



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Our goal



high resolution image



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Our goal



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high resolution image



Our goal



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Our goal



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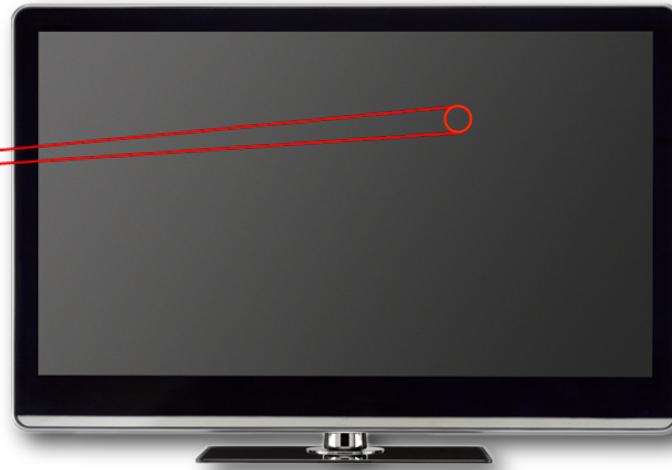
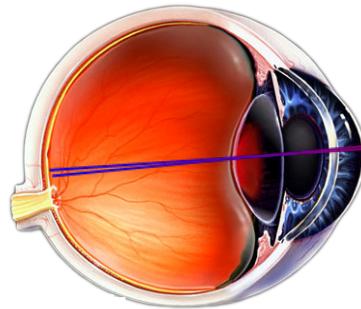
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Temporal domain - static case



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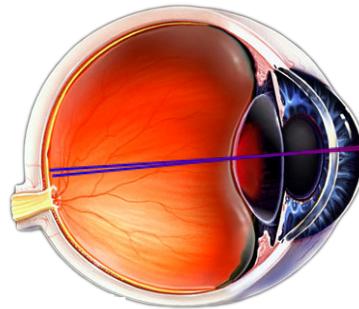
Temporal domain - static case



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Two red lines extend from the eye towards a computer monitor.

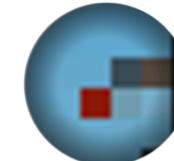
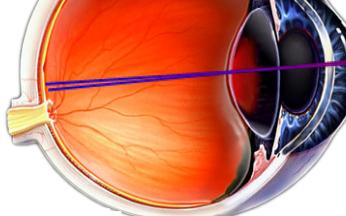
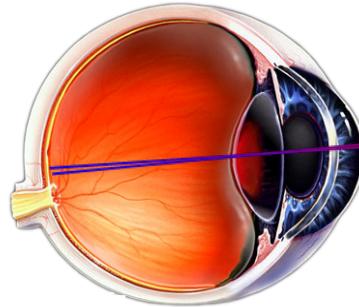


Temporal domain - static case



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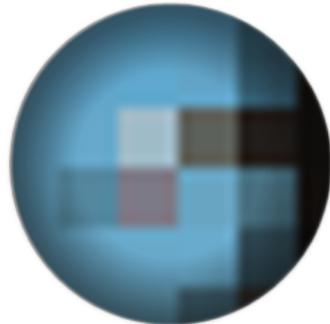
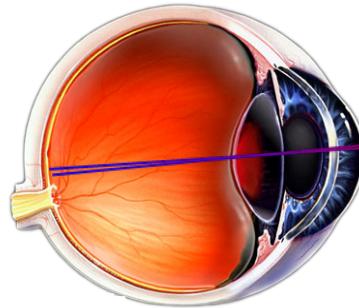


Temporal domain - static case



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result on retina



Temporal domain - temporal case



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Temporal domain - temporal case



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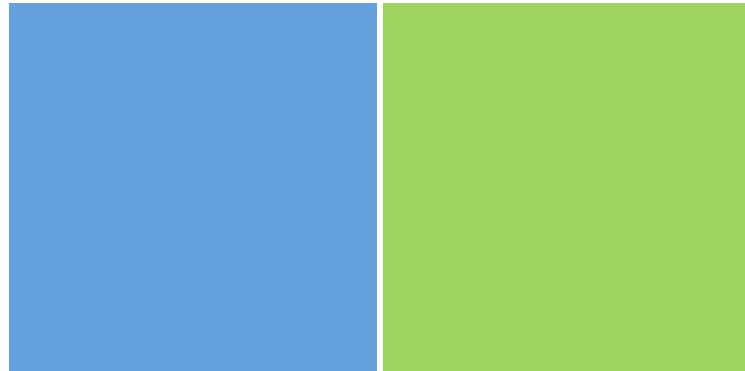


Temporal domain



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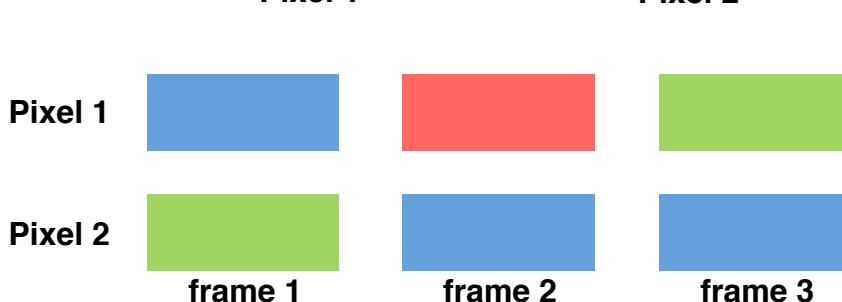
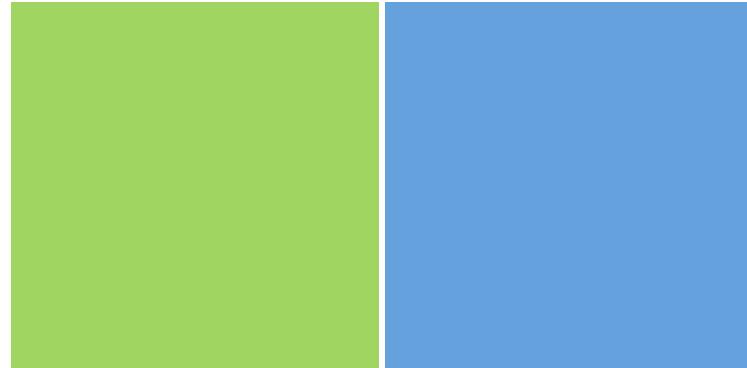
Pixel 1

Pixel 2

Pixel 1

Pixel 2

Temporal domain

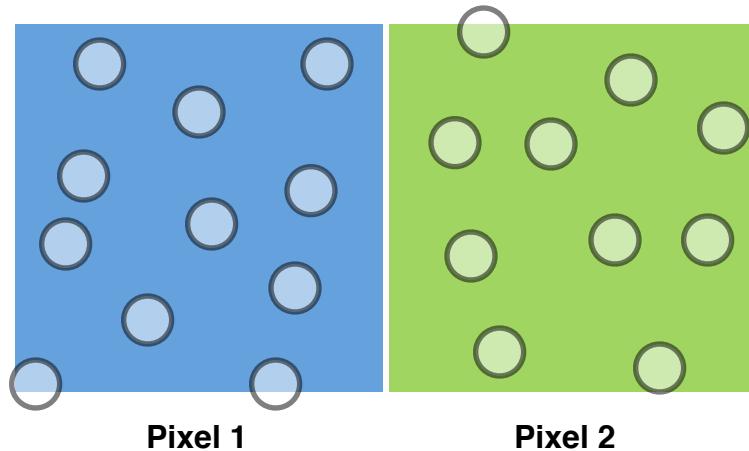


Temporal domain – static case



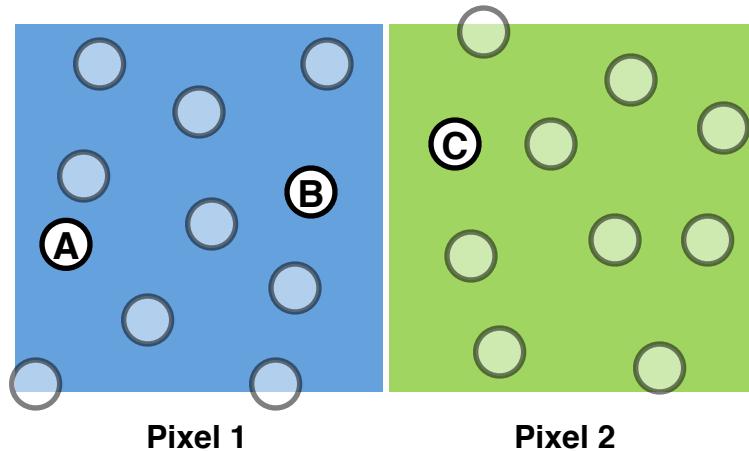
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○ → receptor

Temporal domain – static case



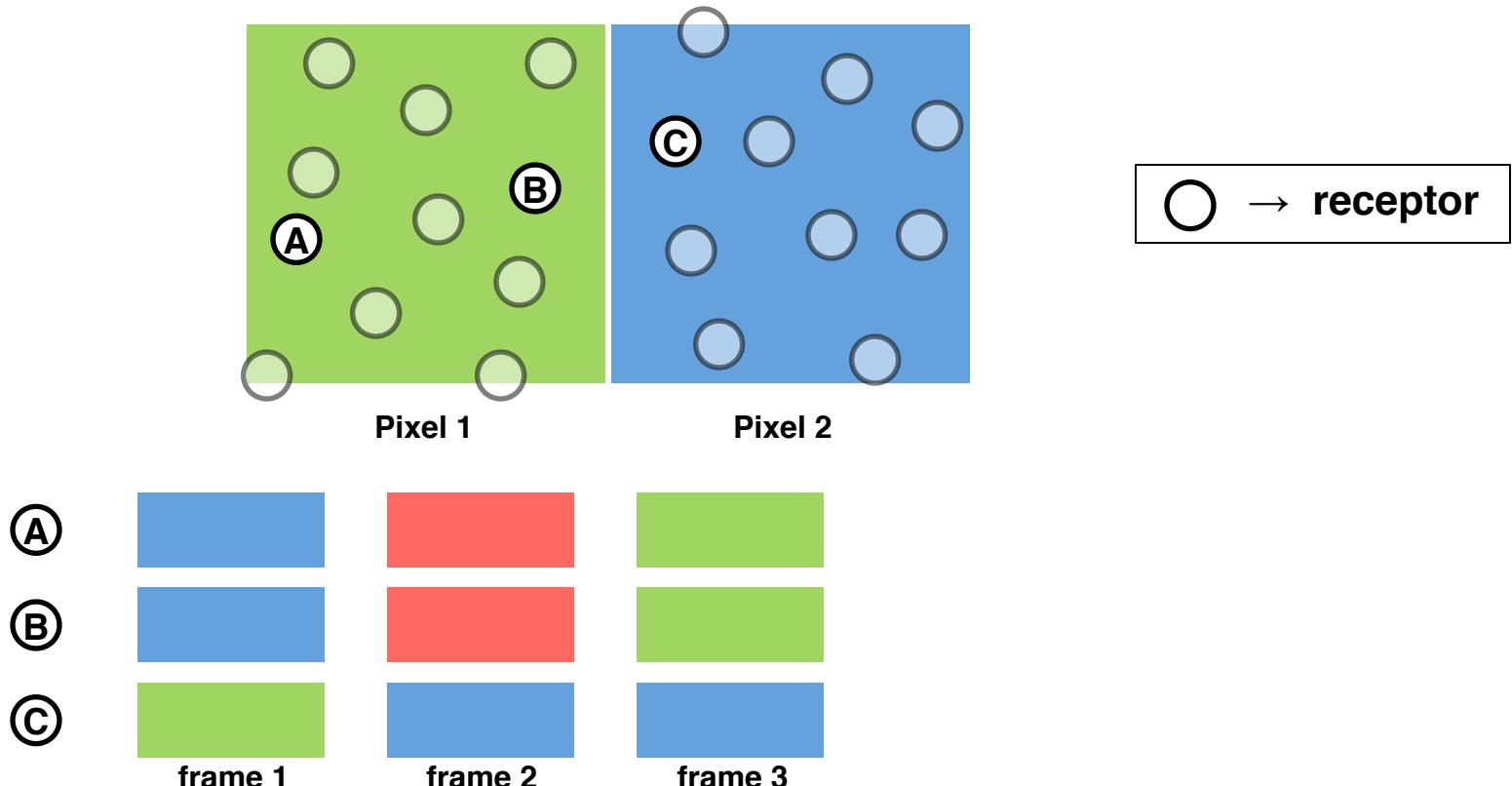
○ → receptor

Ⓐ

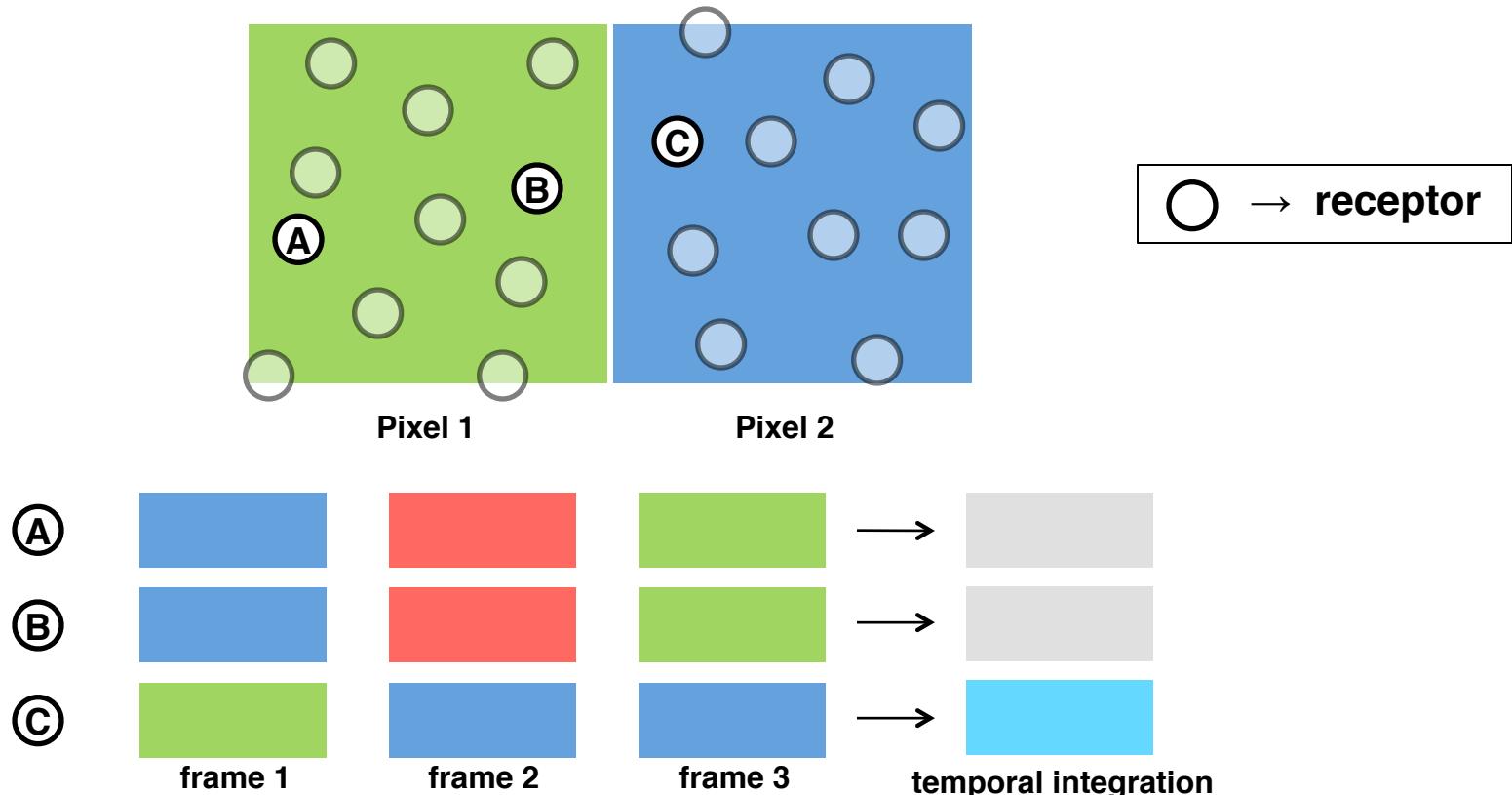
Ⓑ

Ⓒ

Temporal domain – static case



Temporal domain – static case



Temporal domain - temporal case



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Temporal domain - temporal case

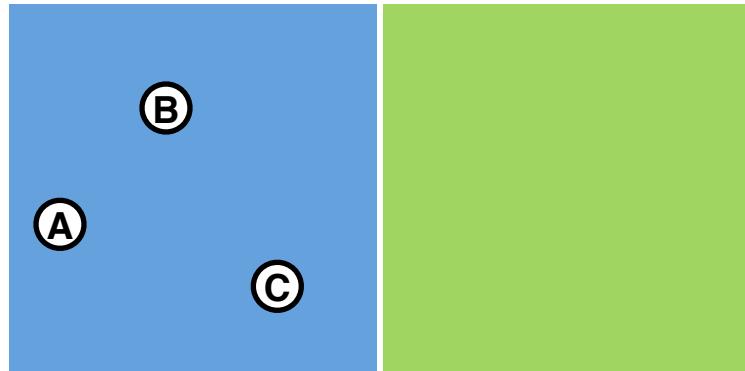


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Temporal domain - dynamic case



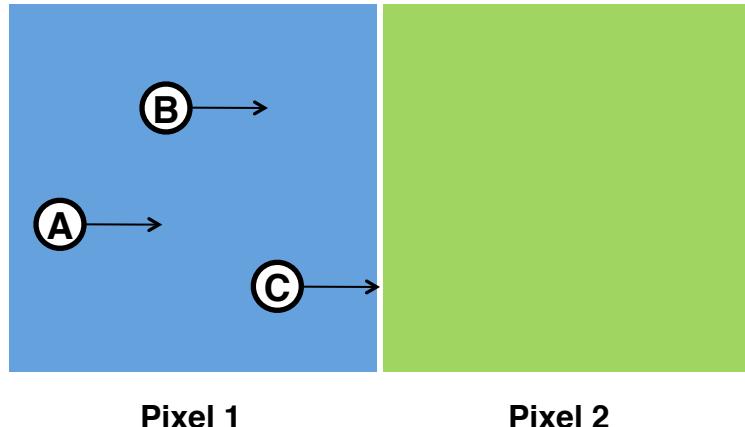
 → receptor

(A)

(B)

(C)

Temporal domain - dynamic case



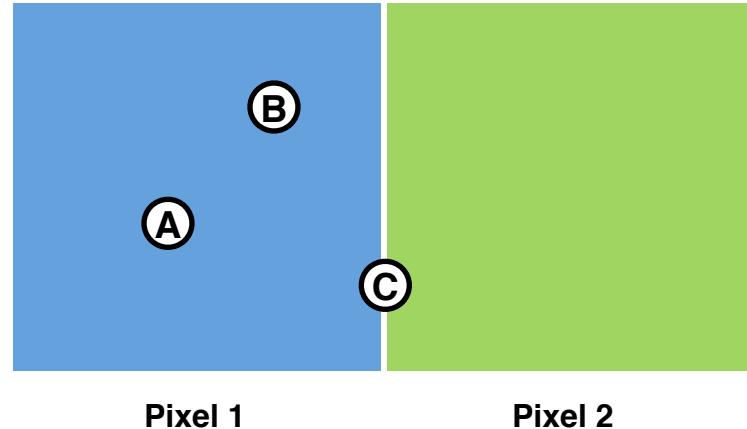
○ → receptor

Ⓐ

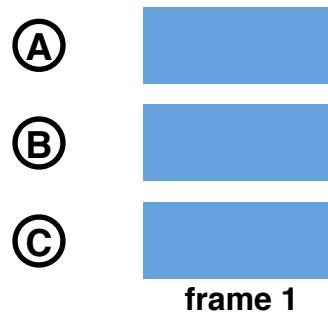
Ⓑ

Ⓒ

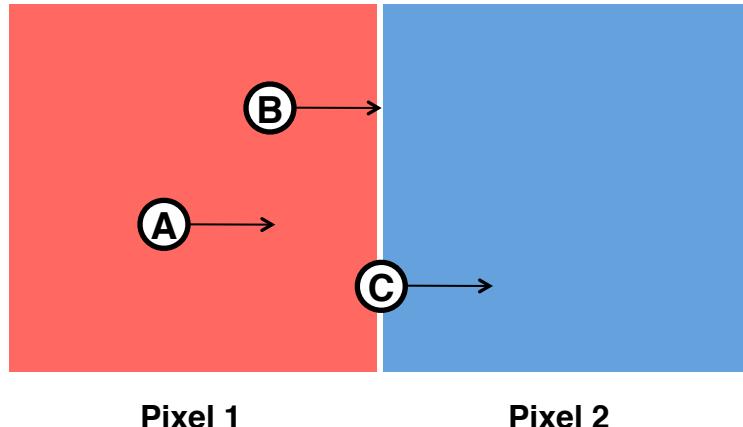
Temporal domain - dynamic case



○ → receptor



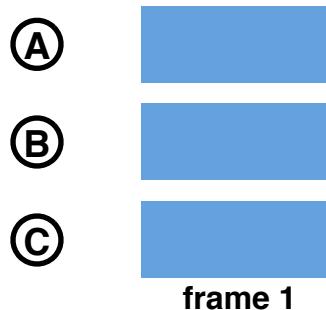
Temporal domain - dynamic case



○ → receptor

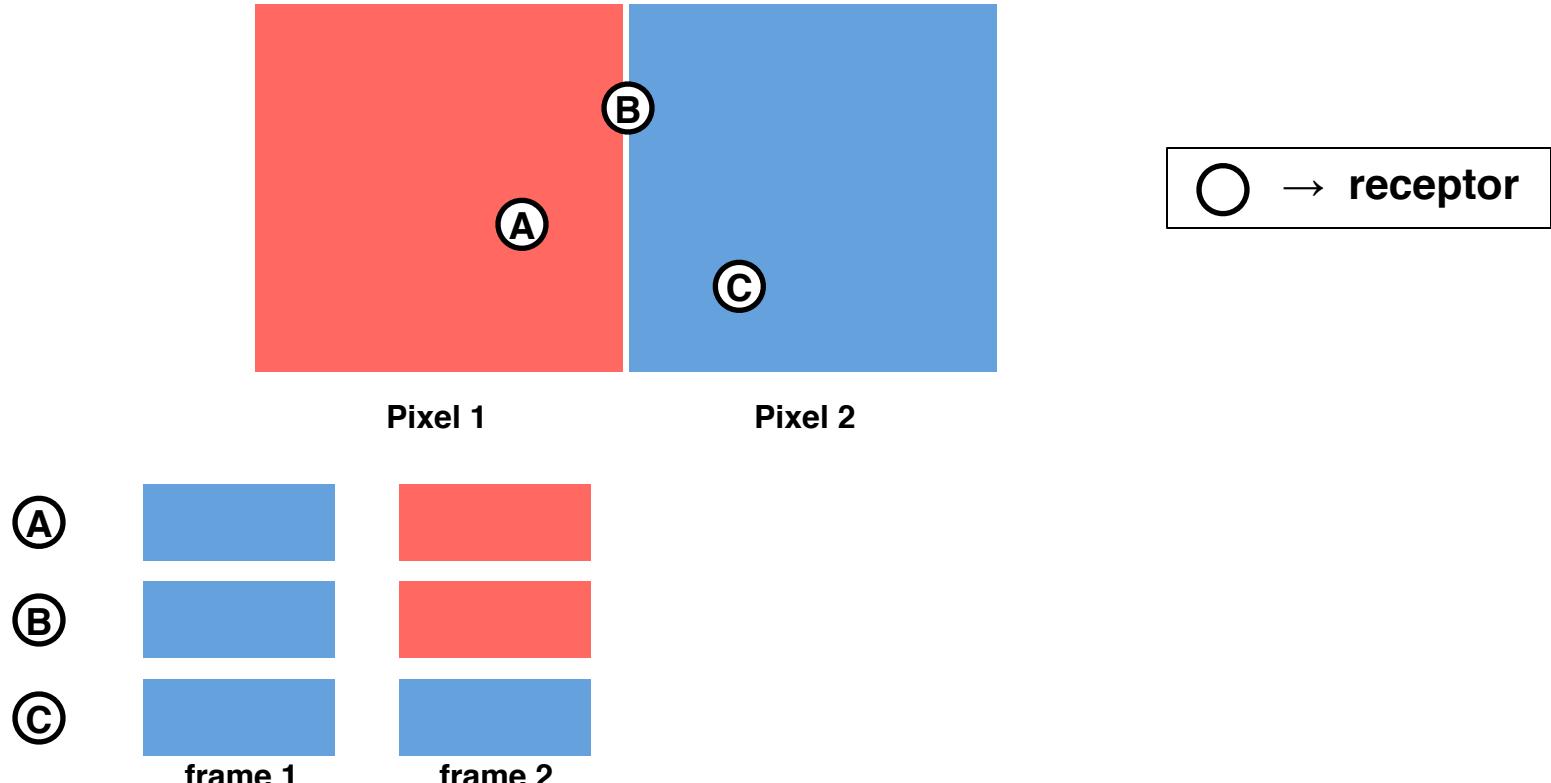
Pixel 1

Pixel 2

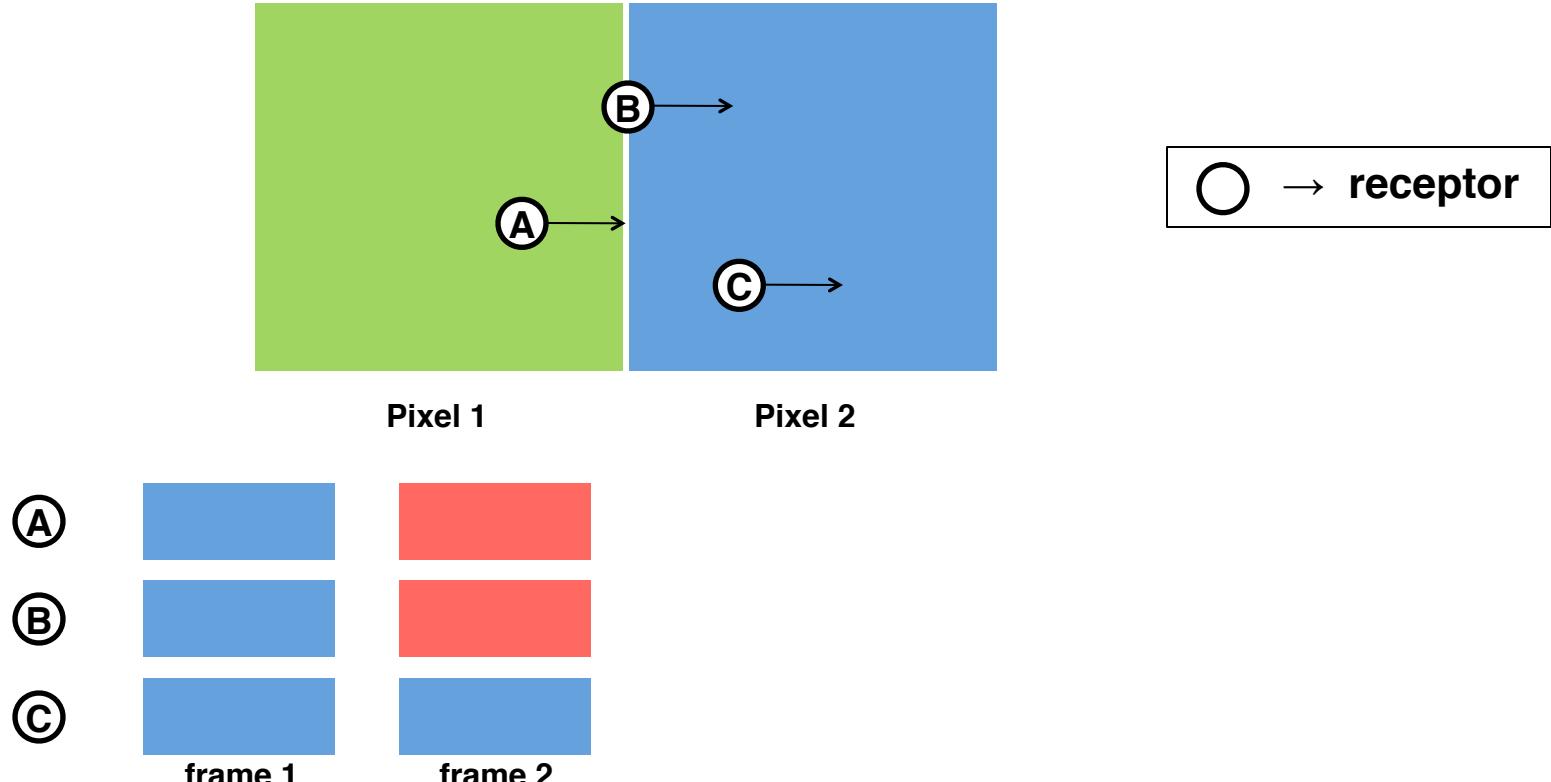


frame 1

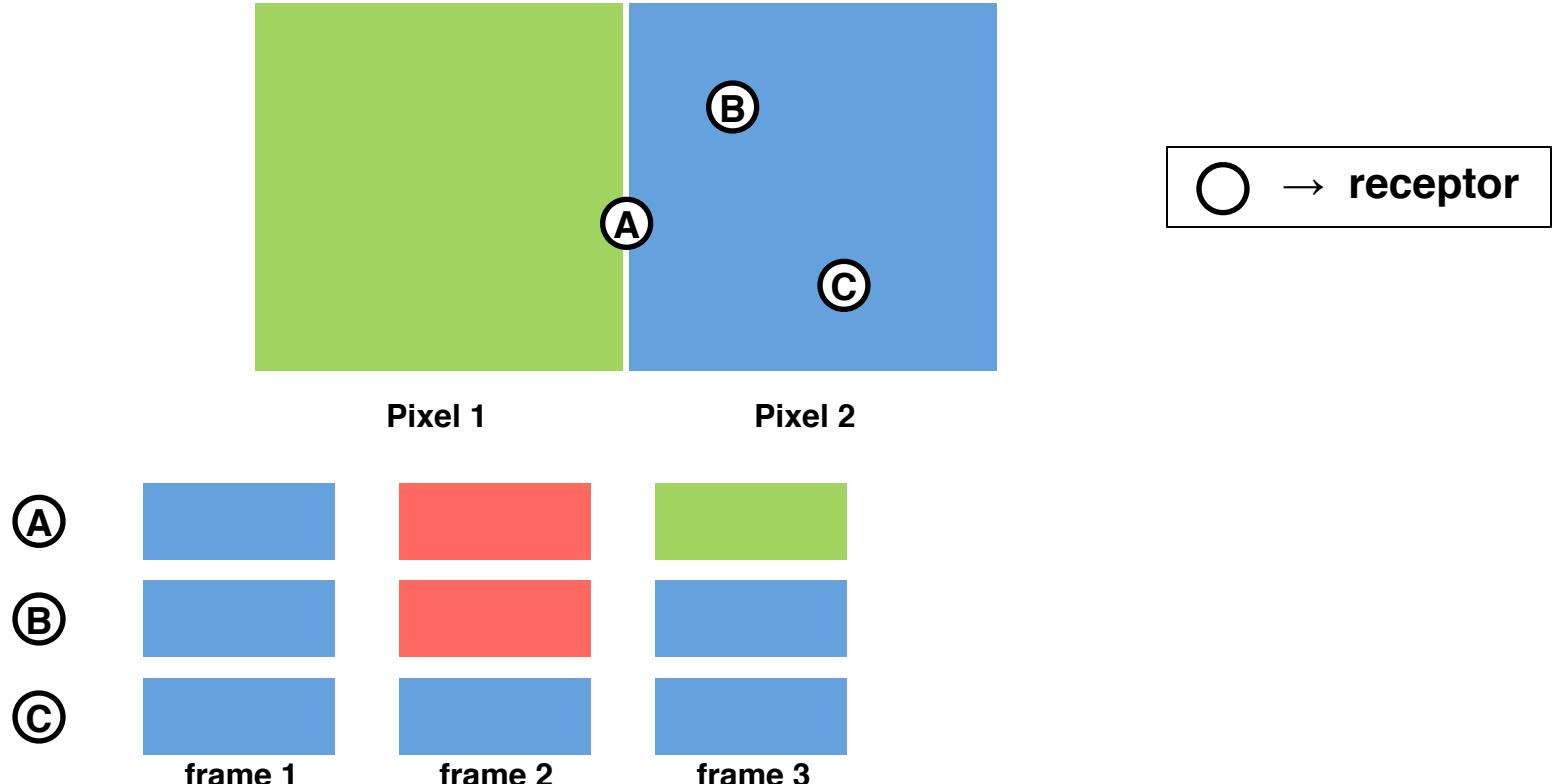
Temporal domain - dynamic case



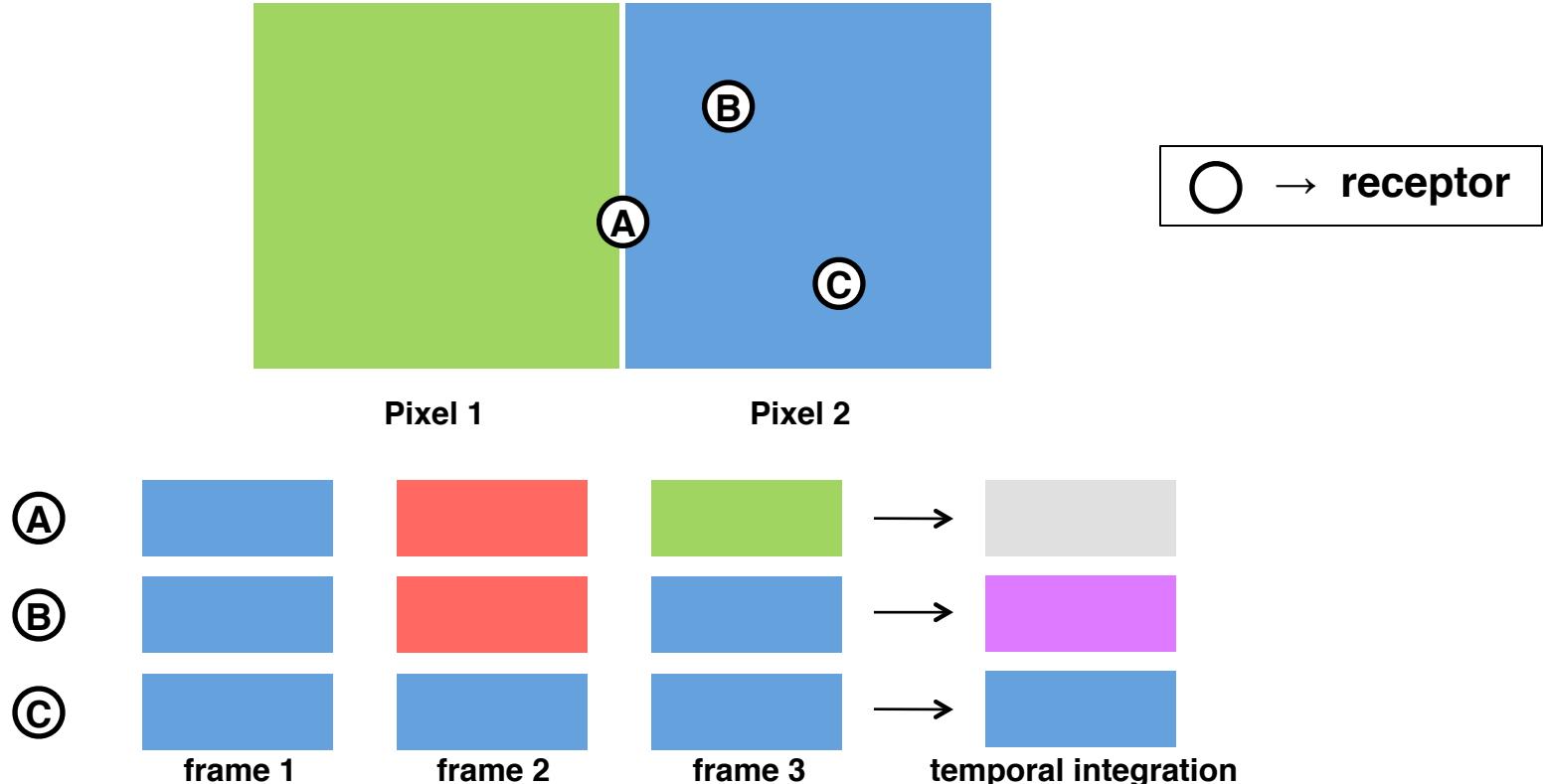
Temporal domain - dynamic case



Temporal domain - dynamic case



Temporal domain - dynamic case

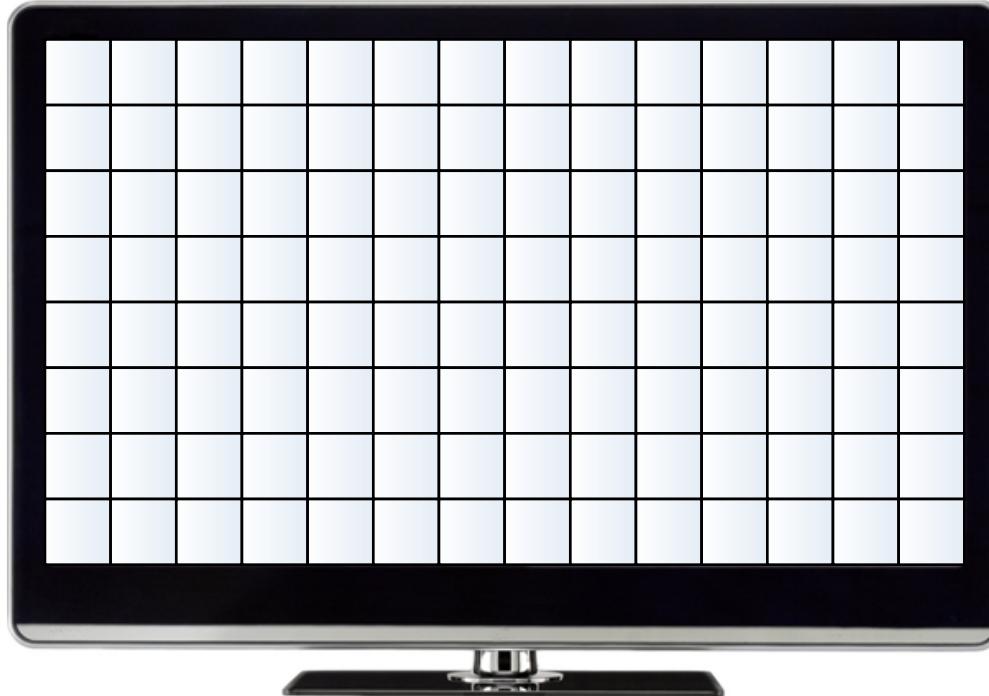


Temporal Integration Model



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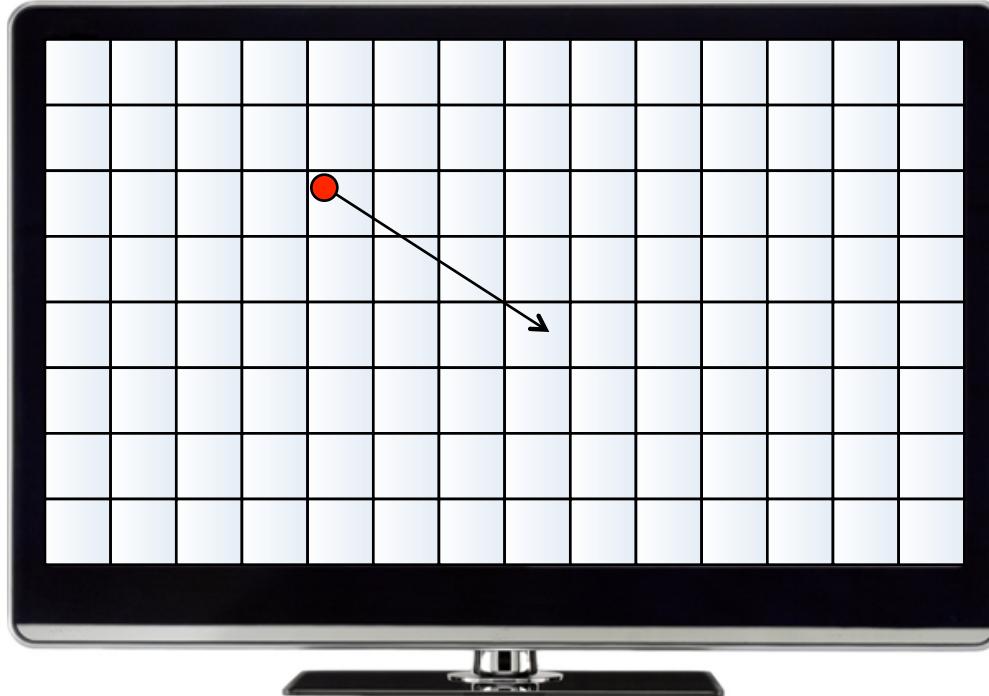


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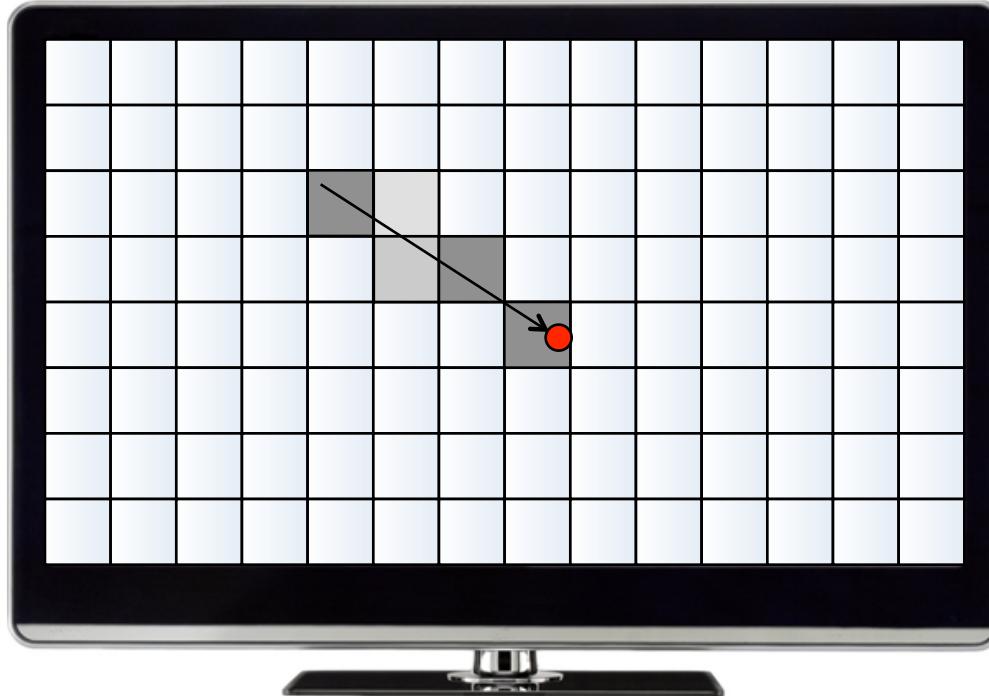


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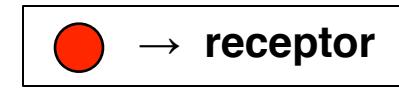
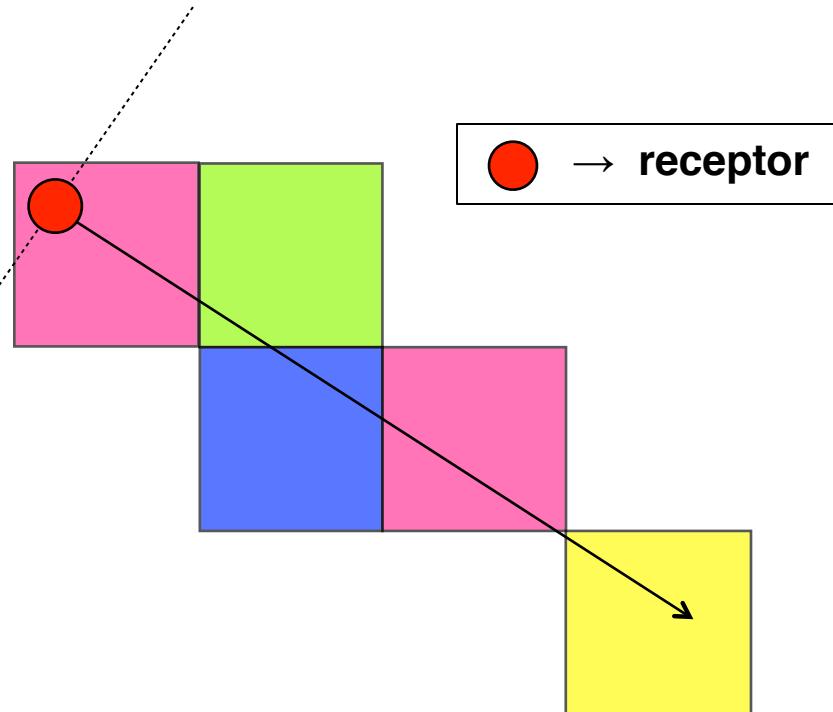
Temporal Integration Model



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Receptor signal:



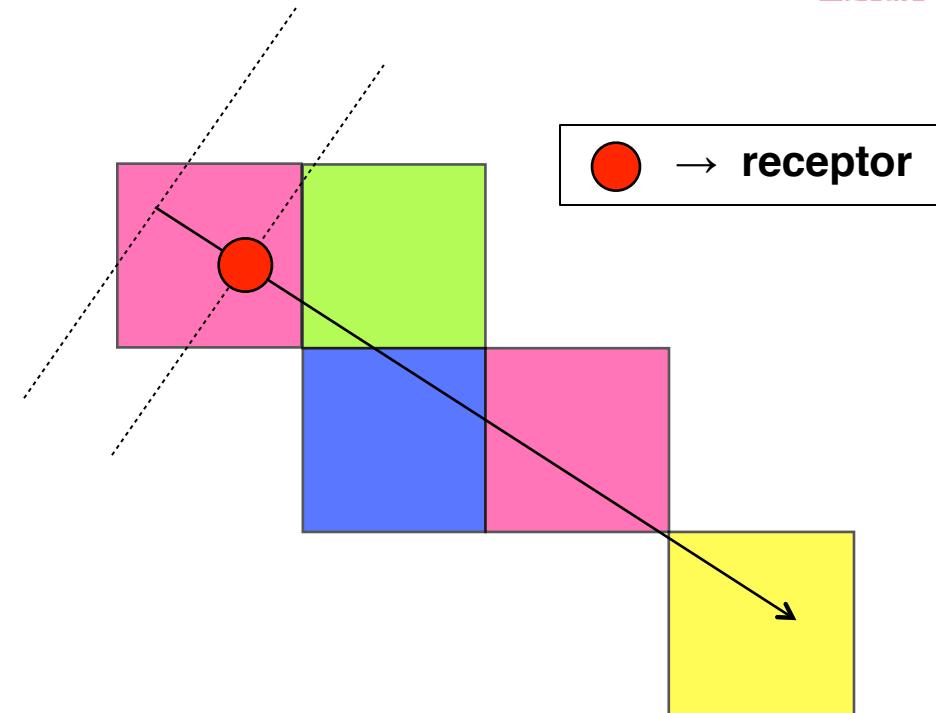
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Receptor signal:



→ receptor

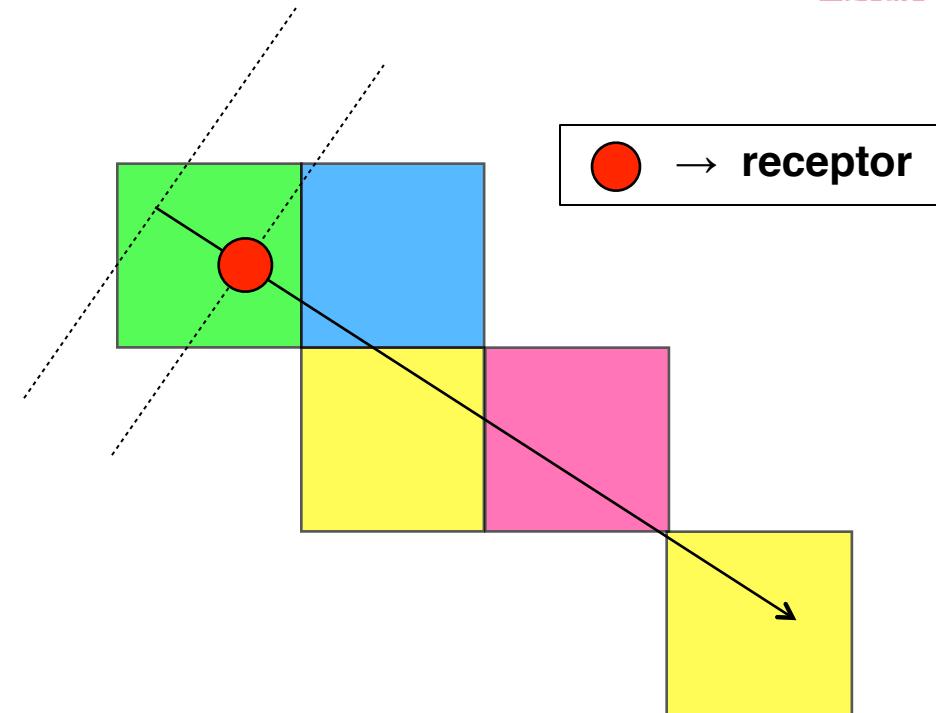
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Receptor signal:



→ receptor

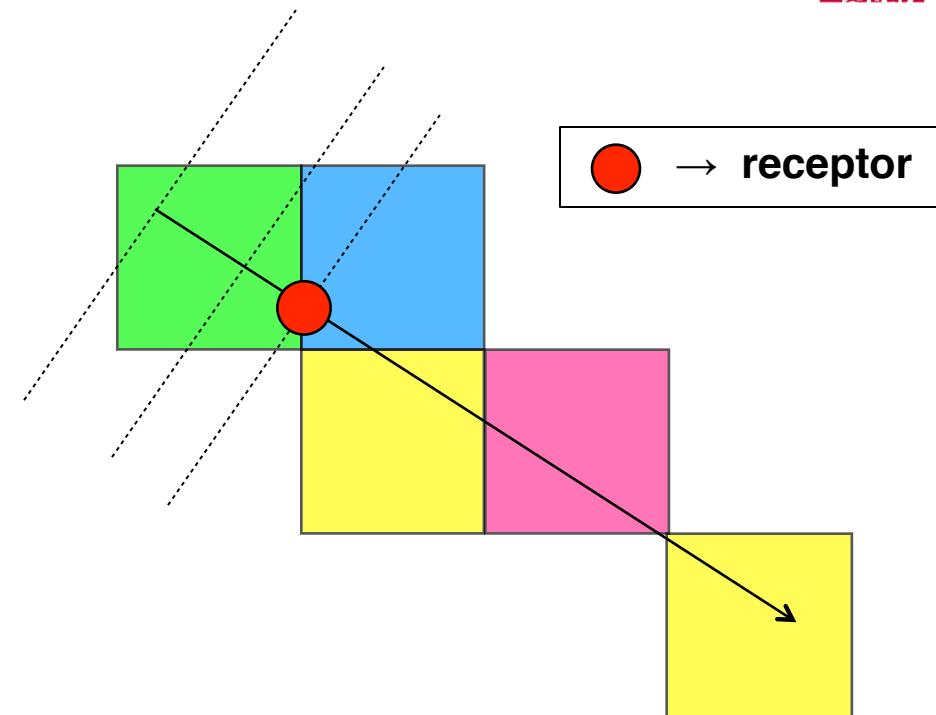
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Receptor signal:



→ receptor

Temporal Integration Model

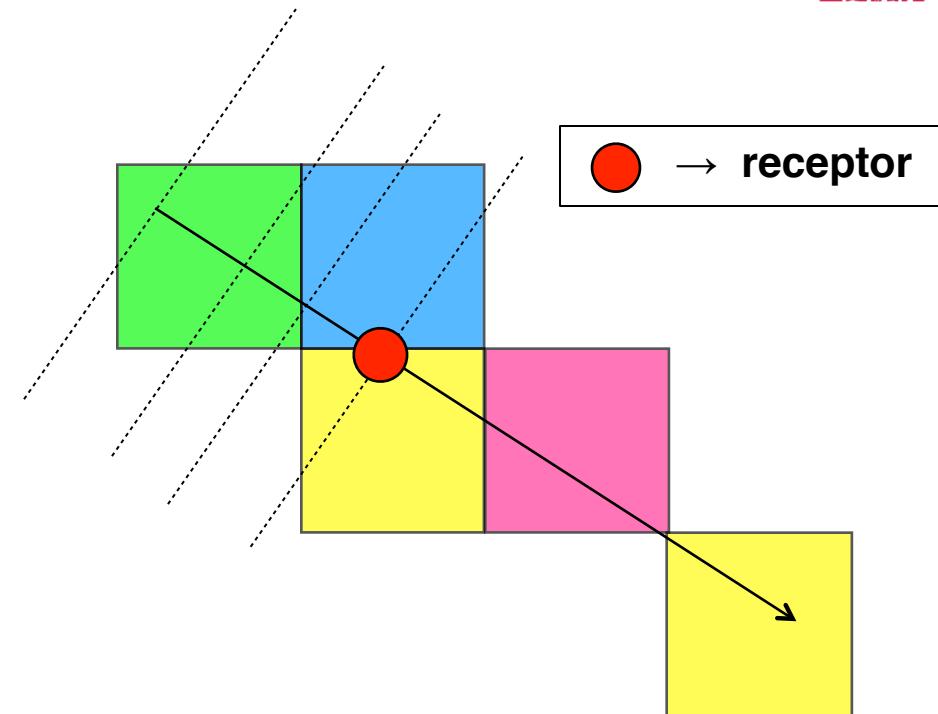
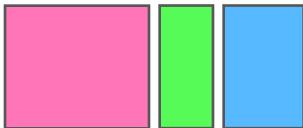


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Receptor signal:



→ receptor

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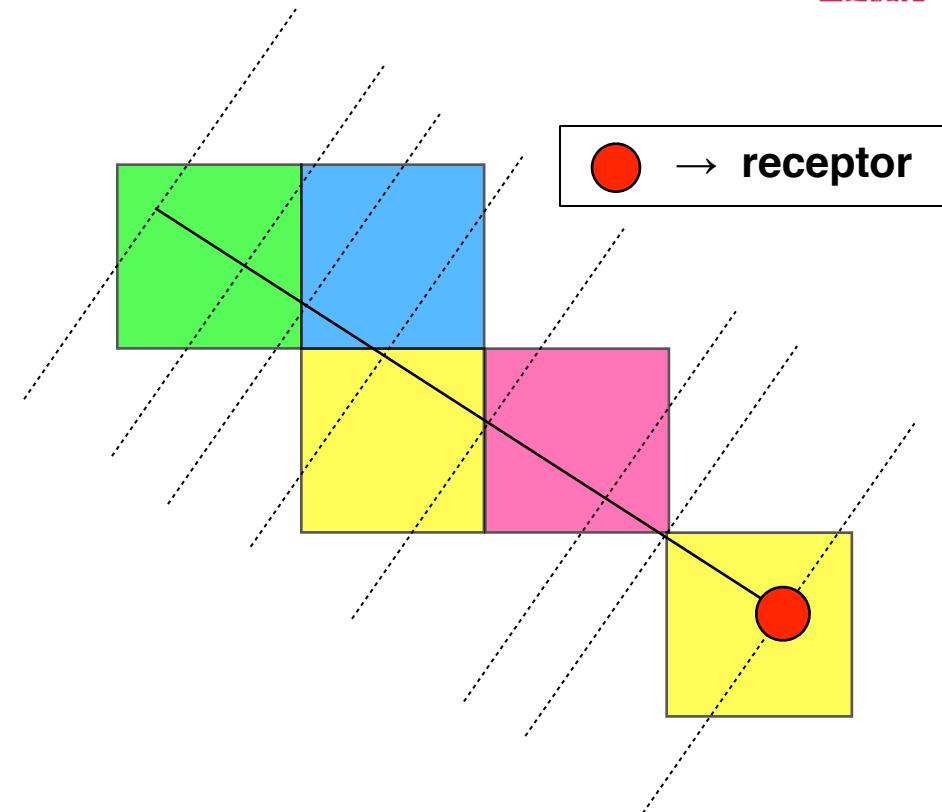


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Receptor signal:



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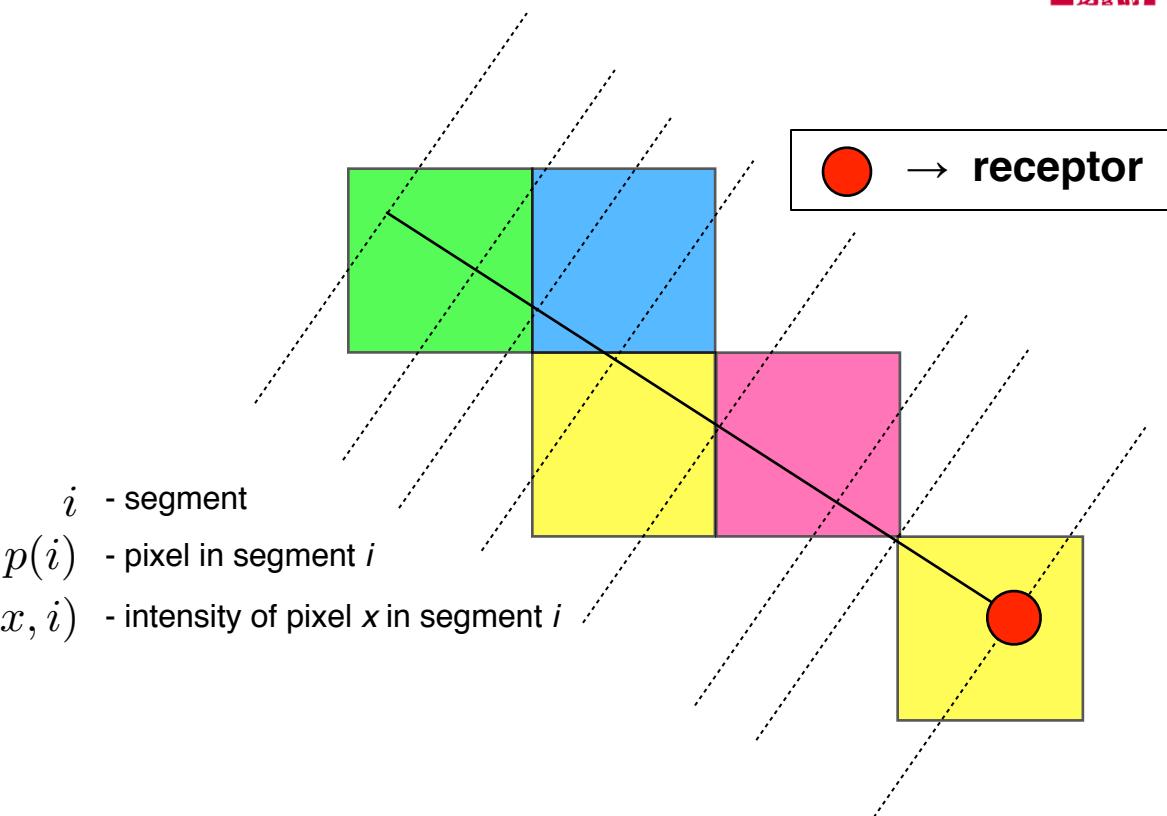
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Receptor signal:



$$\sum_{i=0}^N w_i I(p(i), i)$$

i - segment
 $p(i)$ - pixel in segment i
 $I(x, i)$ - intensity of pixel x in segment i



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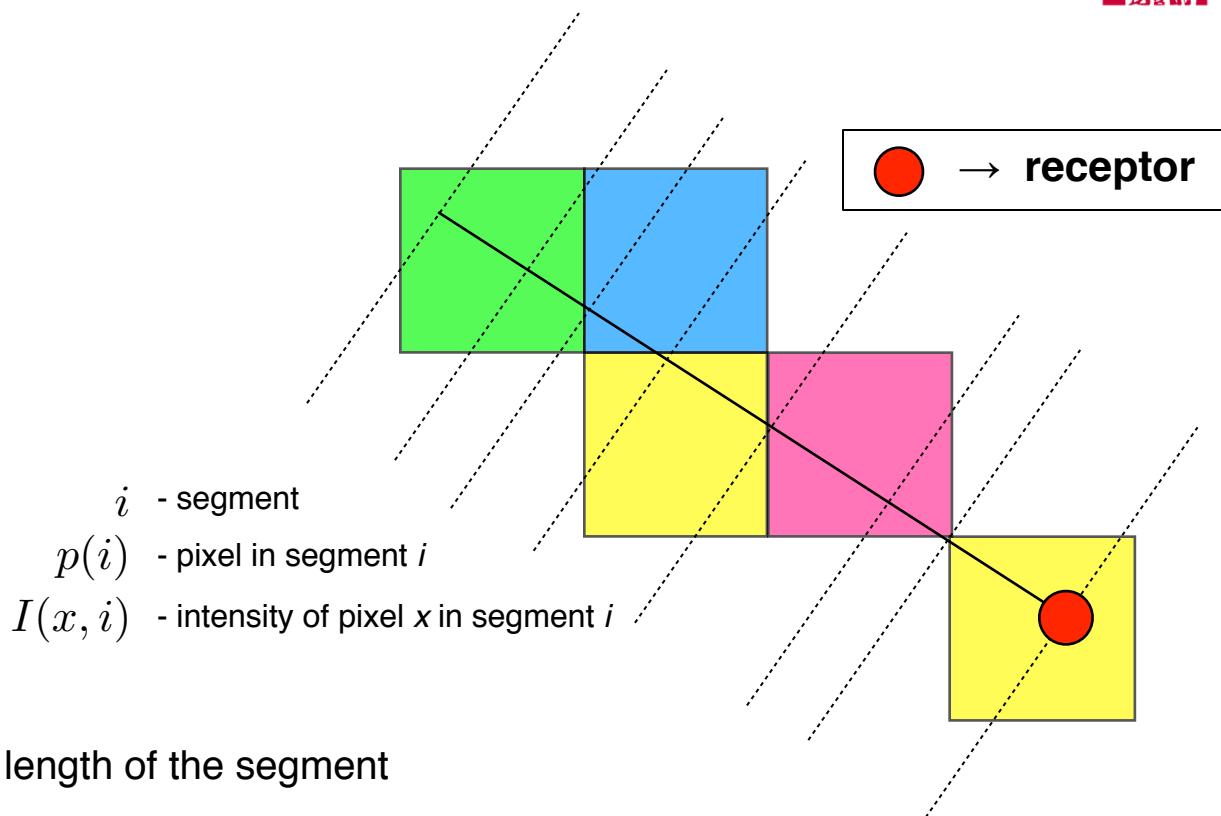
Receptor signal:



$$\sum_{i=0}^N w_i I(p(i), i)$$

w_i - weights proportional to the length of the segment

i - segment
 $p(i)$ - pixel in segment i
 $I(x, i)$ - intensity of pixel x in segment i

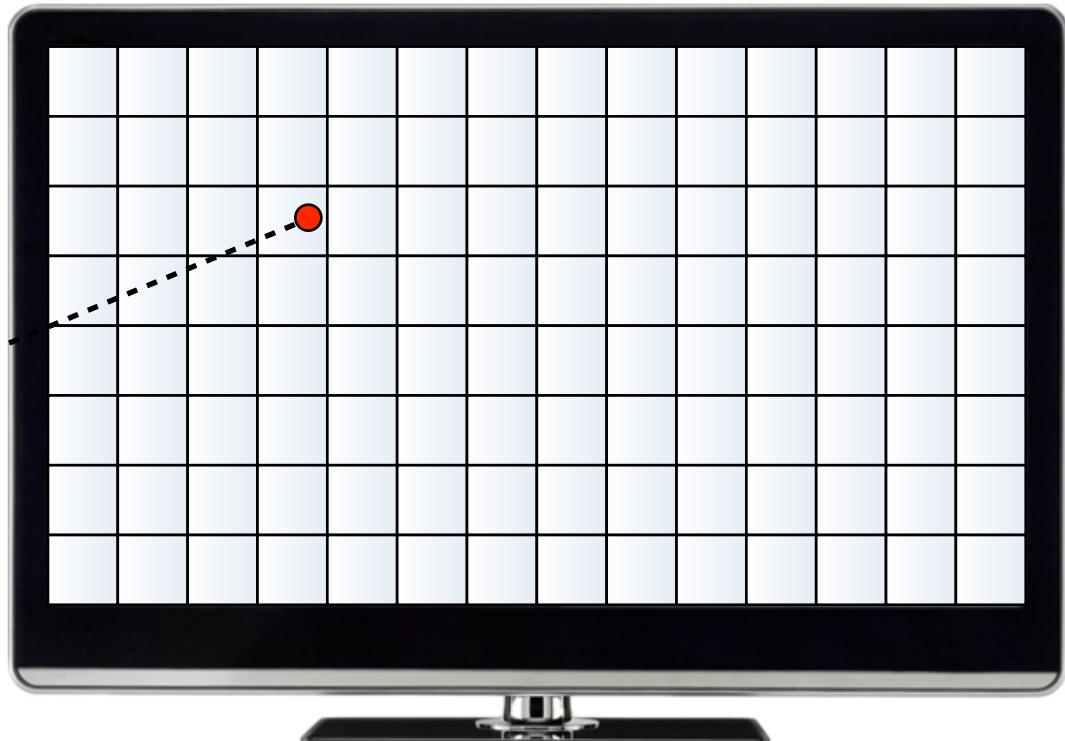


Prediction of retina image



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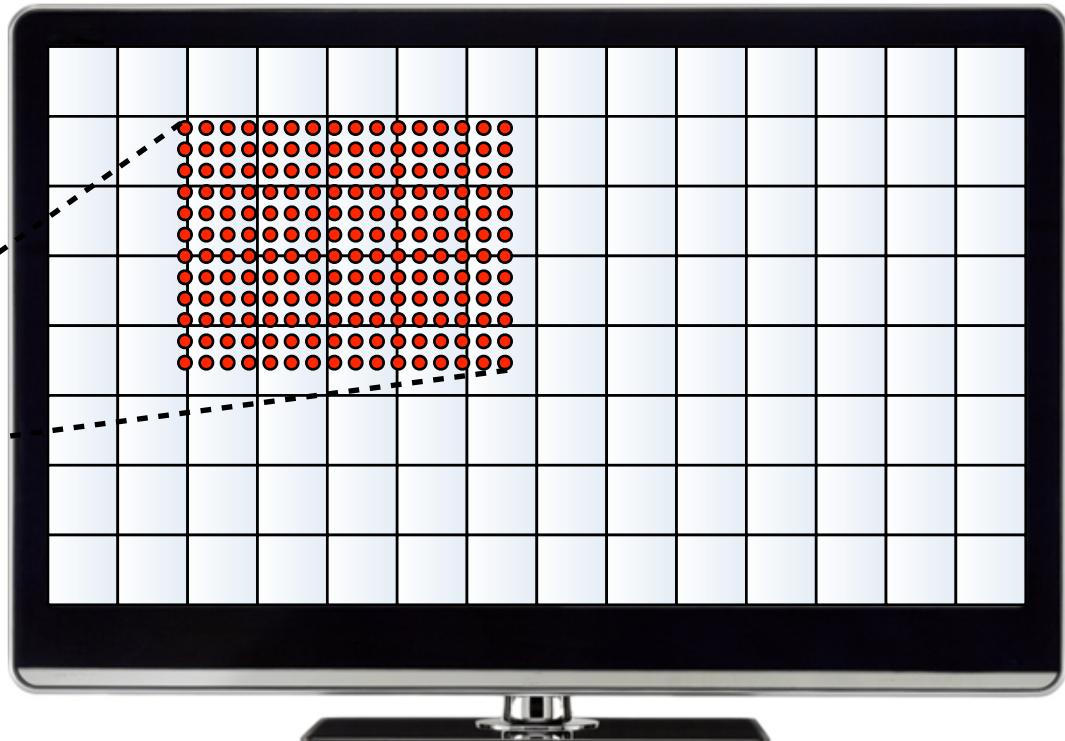
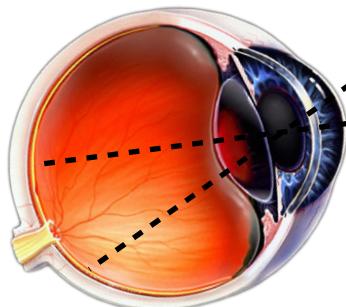


Prediction of retina image



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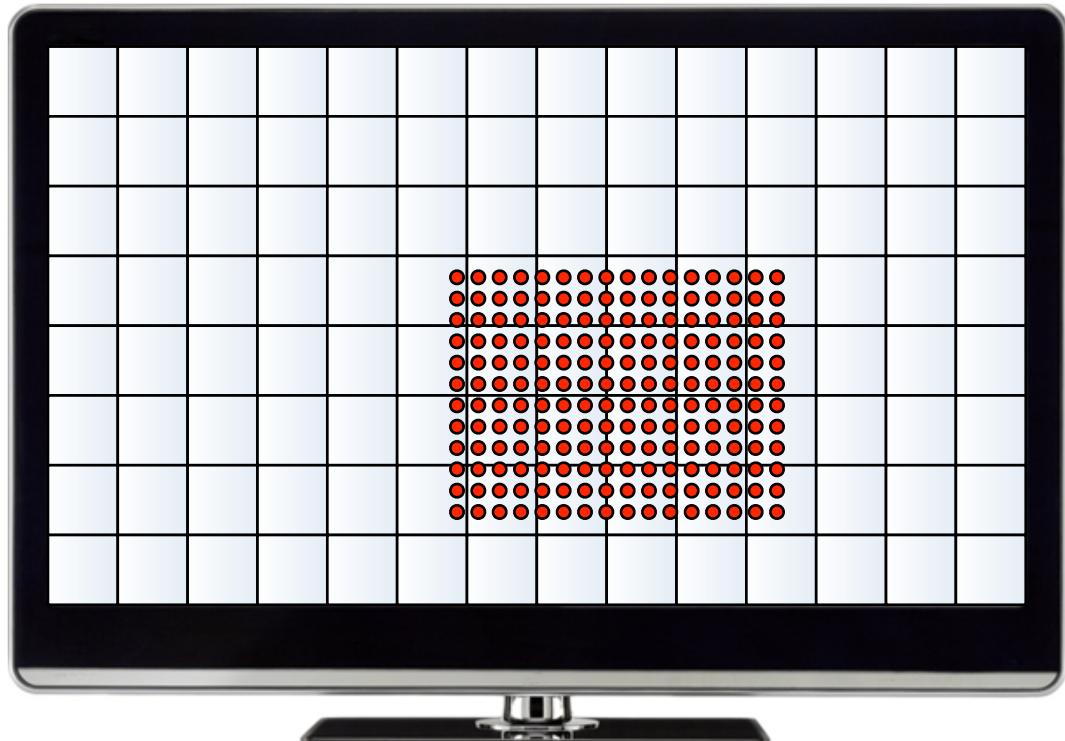
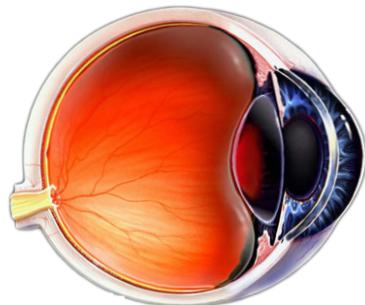


Prediction of retina image



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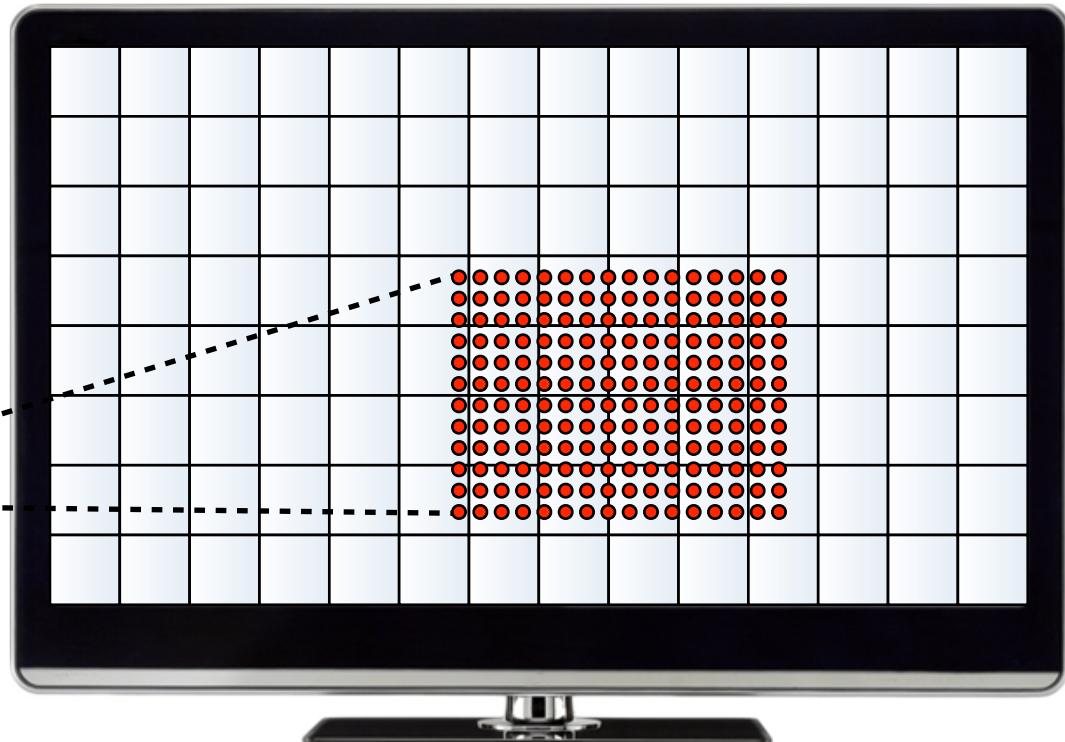
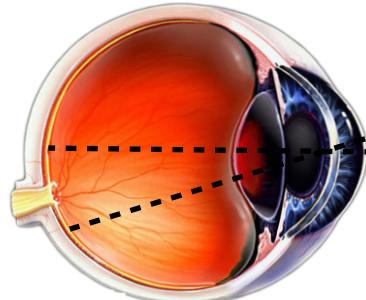
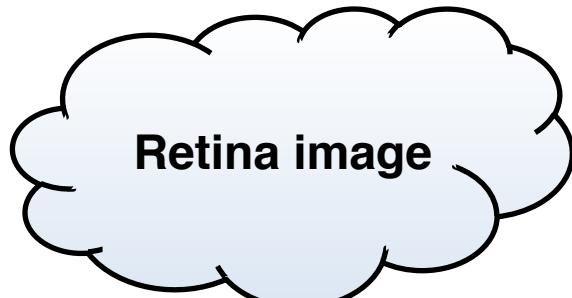


Prediction of retina image



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Prediction of retina image

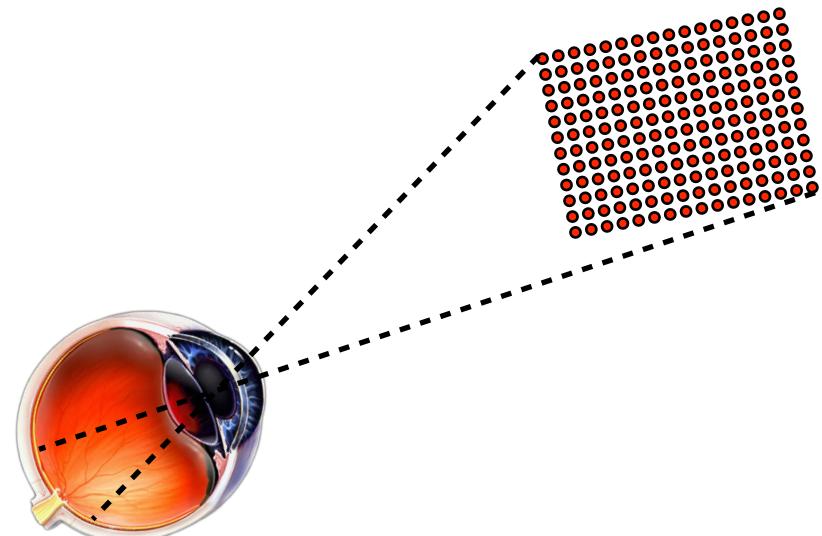


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Assumptions:

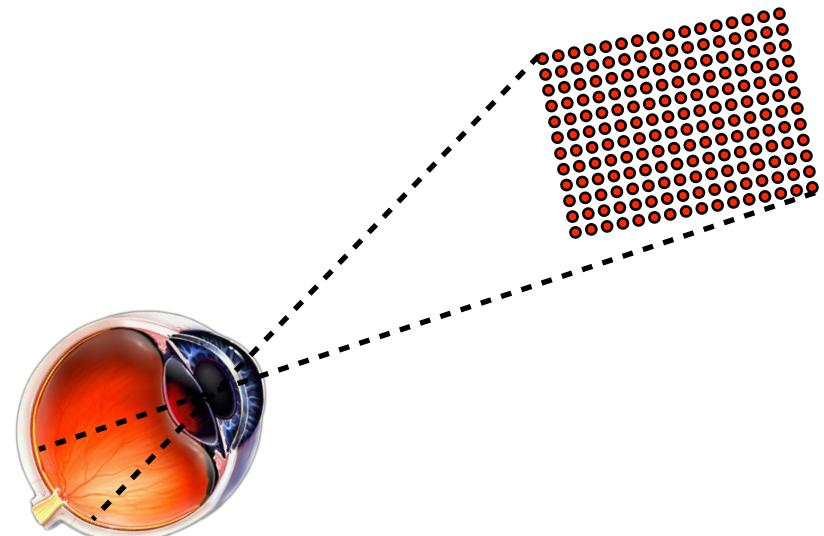


Prediction of retina image



Assumptions:

- Eye is tracking perfectly



Prediction of retina image



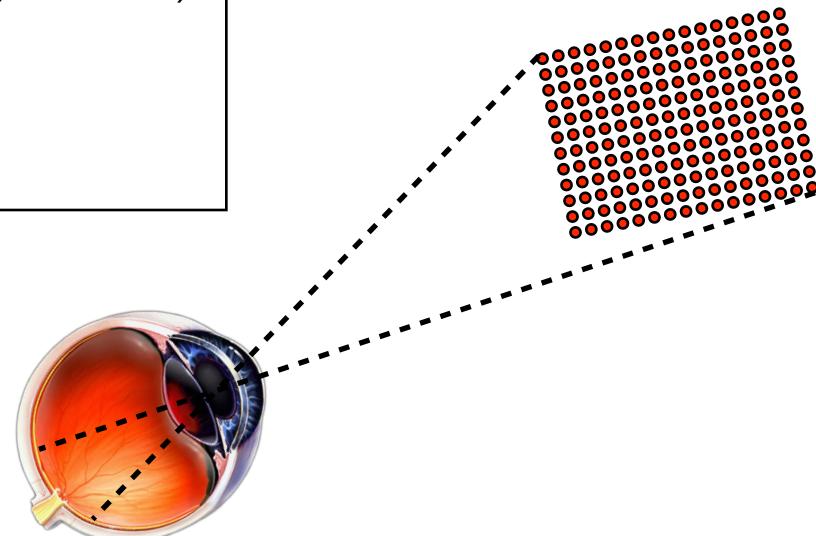
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Assumptions:

- Eye is tracking perfectly
 - HVS is trained to track (*smooth pursuit eye motion*)
0.625 - 2.5 deg/s - perfect
up to 7 deg/s - very good
 - switching and initialization fast

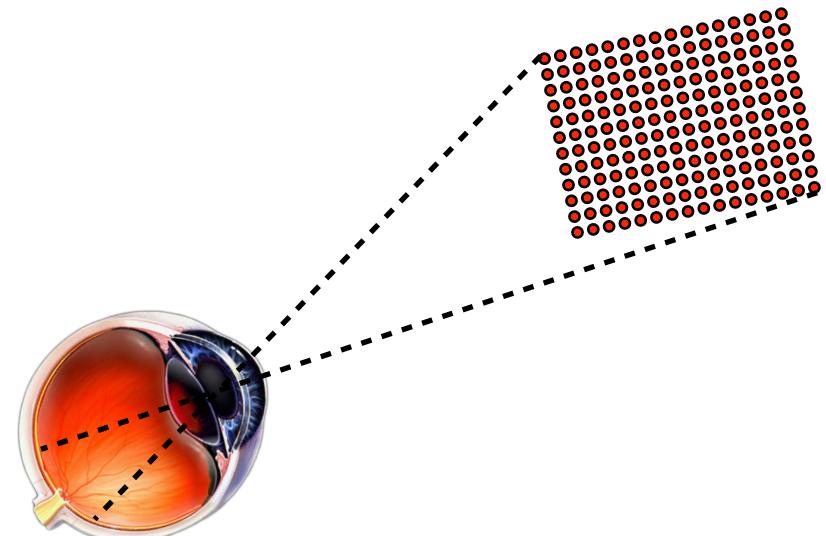


Prediction of retina image



Assumptions:

- Eye is tracking perfectly **OK**
- Retina represented as a grid of photoreceptors

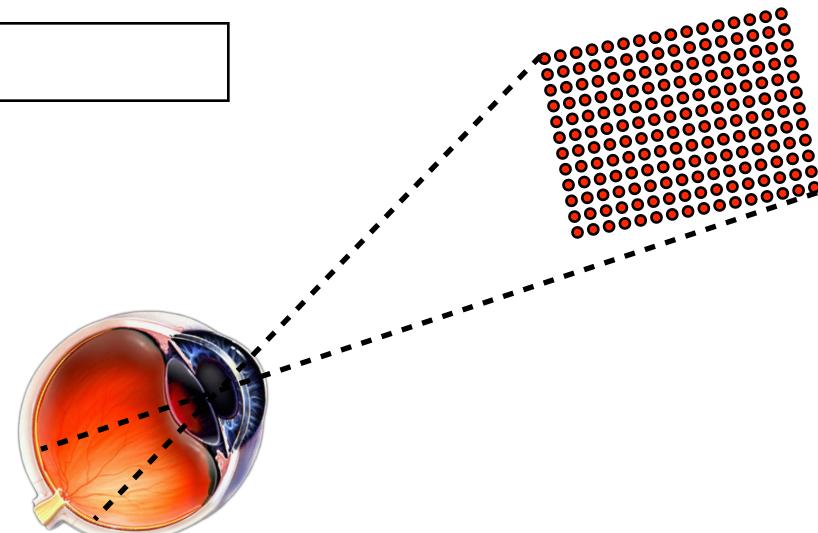


Prediction of retina image



Assumptions:

- Eye is tracking perfectly **OK**
- Retina represented as a grid of photoreceptors
 - should be dense enough

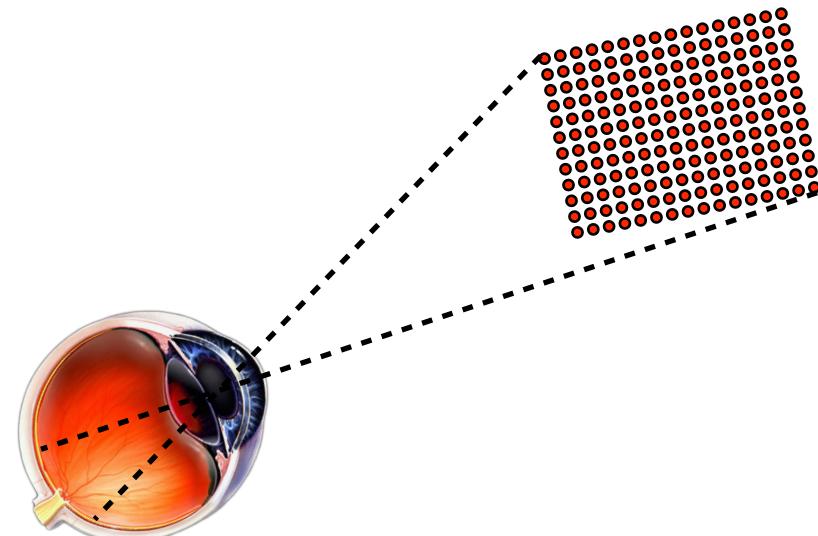


Prediction of retina image



Assumptions:

- Eye is tracking perfectly **OK**
- Retina represented as a grid of photoreceptors **Reasonable**
- Temporal filter assumed to be a box filter

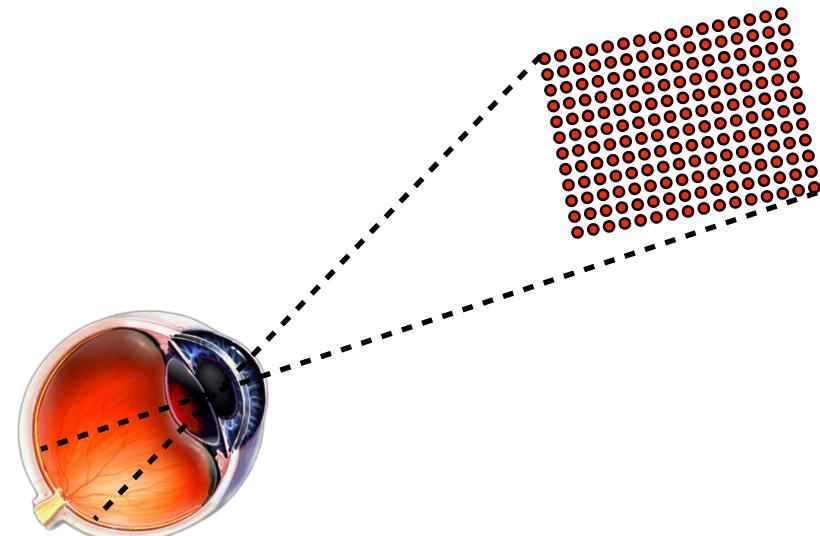


Prediction of retina image



Assumptions:

- Eye is tracking perfectly **OK**
- Retina represented as a grid of photoreceptors **Reasonable**
- Temporal filter assumed to be a box filter
- Simple display and eye optics model

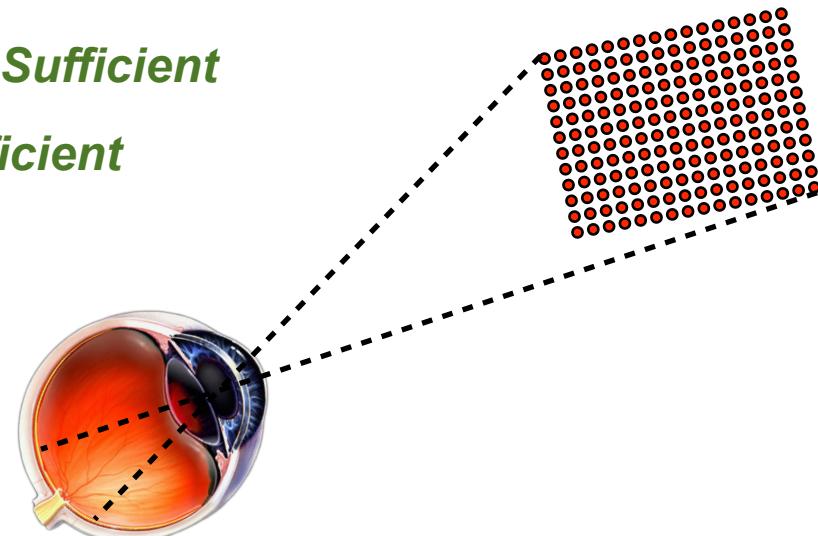


Prediction of retina image



Assumptions:

- Eye is tracking perfectly *OK*
- Retina represented as a grid of photoreceptors *Reasonable*
- Temporal filter assumed to be a box filter *Sufficient*
- Simple display and eye optics model *Sufficient*



Prediction in equations



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subimages

Prediction in equations



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A red square logo with white stylized letters.



subimages

integration
model



Prediction in equations

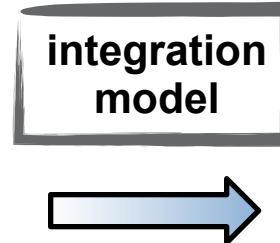


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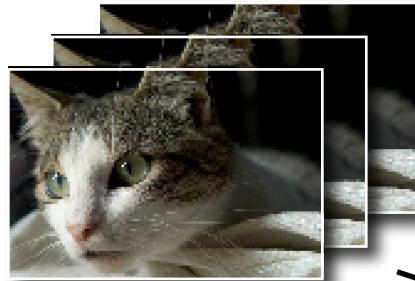


Prediction in equations



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$$\sum_{i=0}^N w_i I(p(i), i) \quad \left(\begin{array}{c} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{array} \right)$$



retina image

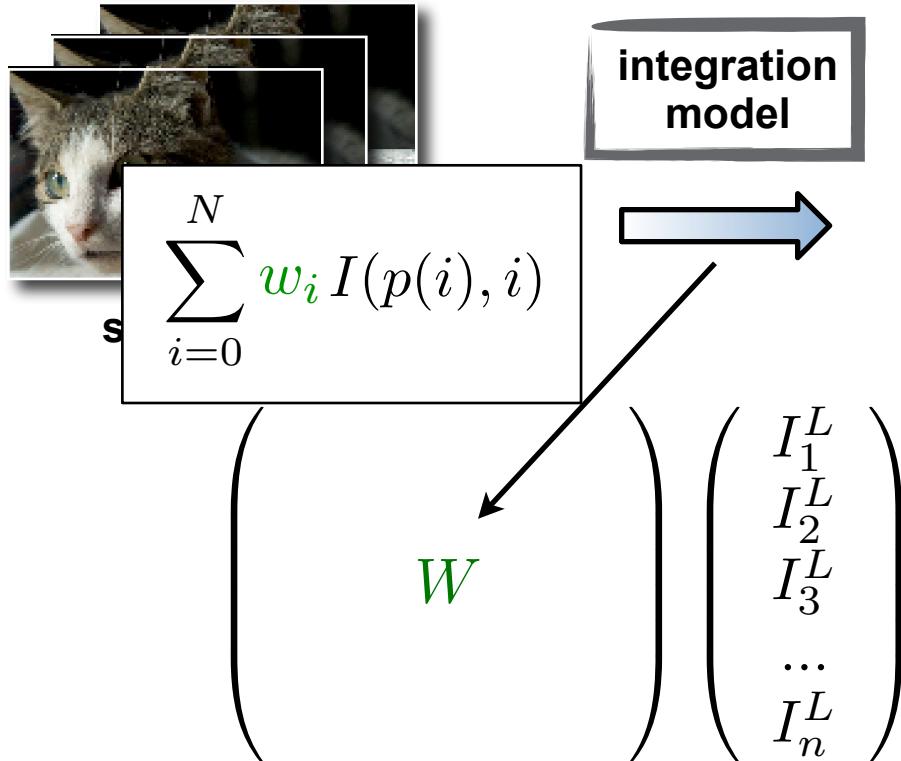
$$= \left(\begin{array}{c} I_1(1, 1) \\ I_1(2, 1) \\ \dots \\ I_1(m, k) \\ I_2(1, 1) \\ \dots \\ I_n(m, k) \end{array} \right)$$

Prediction in equations



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Prediction in equations



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retina image

$$\begin{pmatrix} W \end{pmatrix} \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

Prediction in equations



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model



retina image

$$\begin{pmatrix} w_{1,1}, w_{1,2}, \dots, w_{n,m} \\ W \end{pmatrix} \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \vdots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

Prediction in equations



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integration
model



retina image

$$\begin{pmatrix} w_{1,1}, w_{1,2}, \dots, w_{n,m} \end{pmatrix} W \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \vdots \\ I_n^L \end{pmatrix} = \begin{pmatrix} i_{x,y} \\ I^H \end{pmatrix}$$

prediction for one receptor

$$\sum_{i=0}^N w_i I(p(i), i)$$

Optimization problem



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model



retina image

$$\left(\begin{array}{c} \\ \\ \\ \\ W \end{array} \right) \left(\begin{array}{c} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{array} \right) = \left(\begin{array}{c} \\ \\ \\ \\ I^H \end{array} \right)$$

Optimization problem



$$\begin{pmatrix} W \end{pmatrix} \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

Optimization problem



$$\begin{pmatrix} W \end{pmatrix} \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

Optimization problem



$$\text{integration model} \rightarrow \begin{pmatrix} W \end{pmatrix} \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

Optimization problem

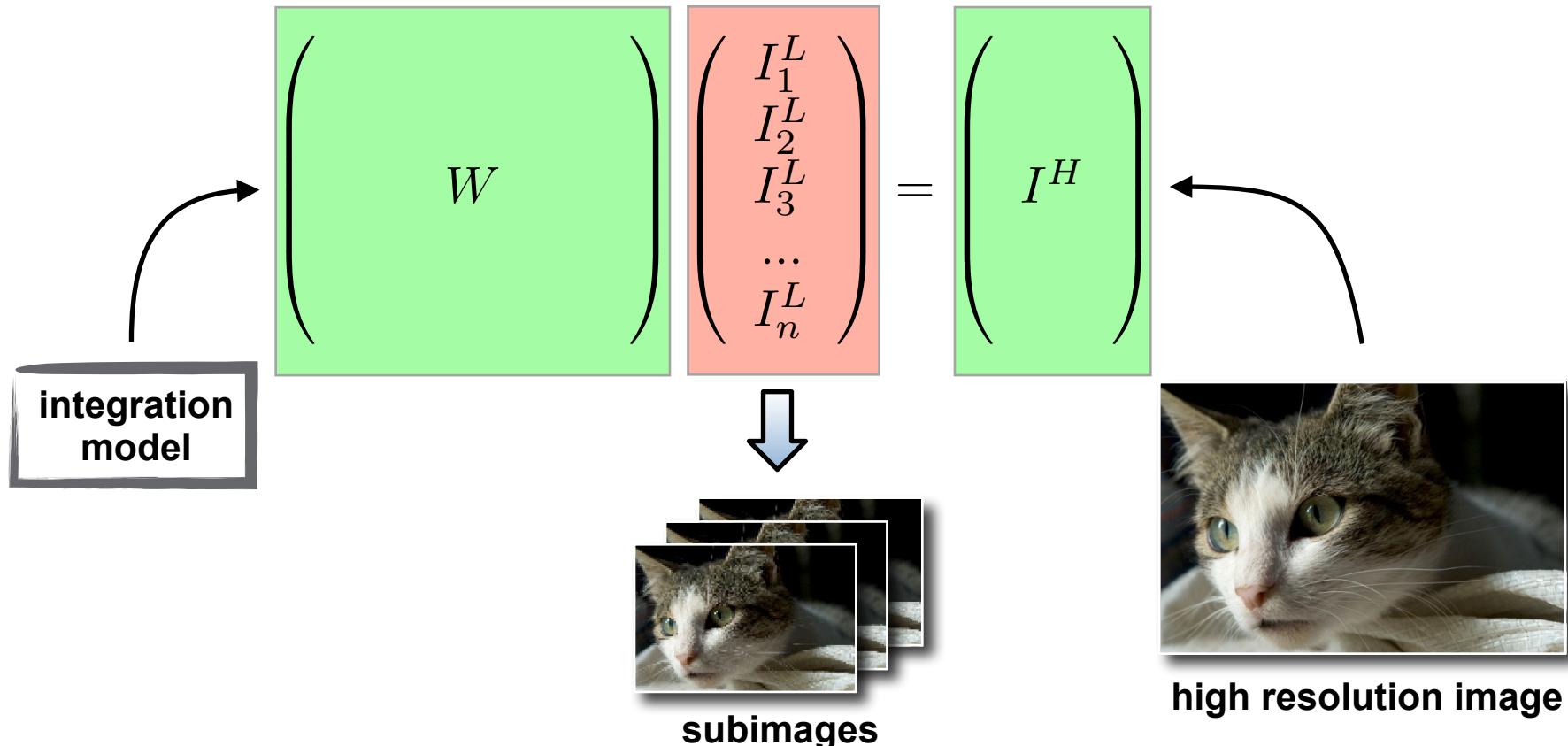


$$\text{integration model} \rightarrow \begin{pmatrix} W \end{pmatrix} \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix} \leftarrow \text{high resolution image}$$



high resolution image

Optimization problem



Optimization problem



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$$\begin{pmatrix} W \end{pmatrix} = \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

Optimization problem



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$$\begin{pmatrix} W \end{pmatrix} \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

We solve it with least square method

Optimization problem



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$$\begin{pmatrix} W \end{pmatrix} \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

Optimization problem



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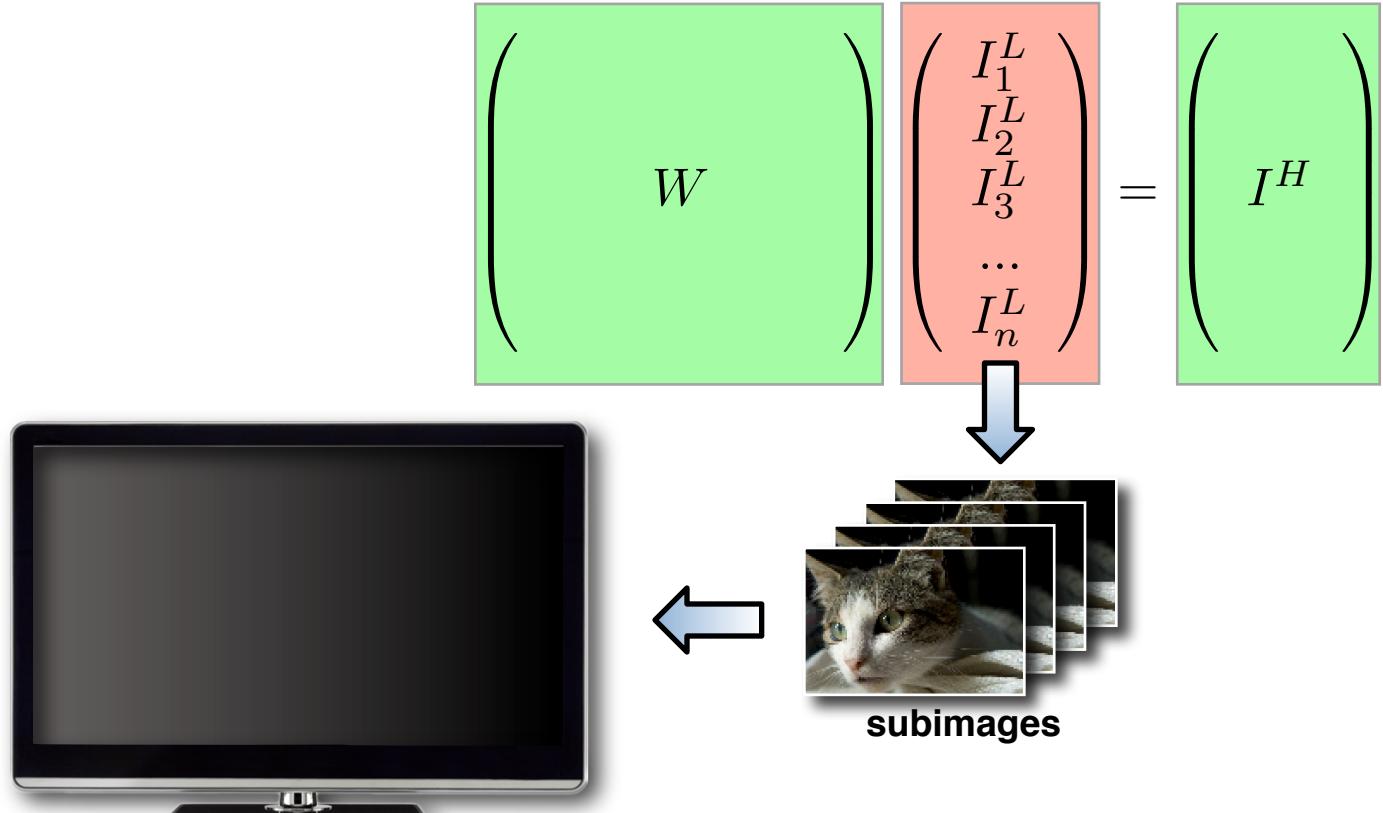
$$\begin{pmatrix} W \end{pmatrix} = \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} \begin{pmatrix} I^H \end{pmatrix}$$

Optimization problem



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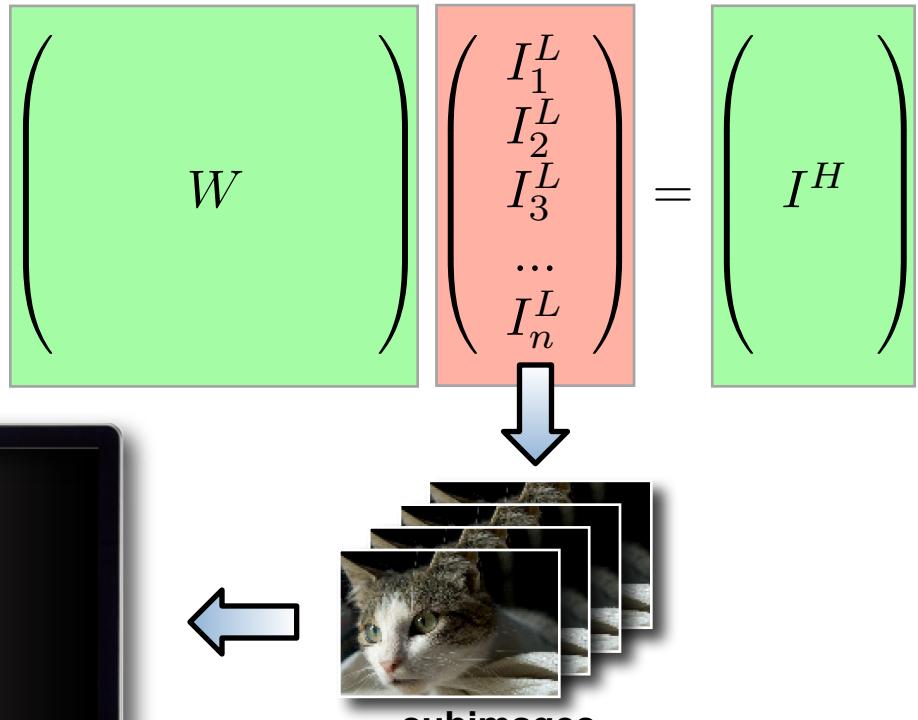
Optimization problem



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We cannot display arbitrary values
→ System needs to be constrained



Optimization problem



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We cannot display arbitrary values
→ System needs to be constrained

$$\begin{pmatrix} W \end{pmatrix} = \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix} = \begin{pmatrix} I^H \end{pmatrix}$$

“A reflective Newton method for minimizing a quadratic function subject to bounds on some of the variables”
[Coleman et al. 2005]

Optimization results



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Display



time

Optimization results



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Display

THE HOUSEHOLDS, BOTH ALIKE IN DIGNITY, IN
MUTINY, WHERE CIVIL BLOOD MAKES CIVIL HAD
STAR-CROSS'D LOVERS TAKE THEIR LIFE; WHI
PARENTS' STRIFE. THE FEARFUL PASSAGE OF
BUT THEIR CHILDREN'S END, NOUGHT COULD I
PATIENT EARS ATTEND, WHAT HERE SHALL M
VERONA, WHERE WE LAY OUR SCENE, FROM A
UNCLEAR, FROM FORTH THE FATAL LOINS OF
MISADVENTURED PITEOUS OVERTHROWS DO
DEATH-MARK'D LOVE, AND THE CONTINUANCE
IS HOW THE TWO HOURS' TRAFFIC OF OUR ST
SHALL STRIVE TO MEND. TWO HOUSEHOLDS, I
GRUDGE BREAK TO NEW MUTINY, WHERE CIVI
FOES A PAIR OF STAR-CROSS'D LOVERS TAKE
THEIR PARENTS' STRIFE. THE FEARFUL PASSA
WHICH, BUT THEIR CHILDREN'S END, NOUGHT
WITH PATIENT EARS ATTEND, WHAT HERE SH
FAIR VERONA, WHERE WE LAY OUR SCENE, FR
UNCLEAN, FROM FORTH THE FATAL LOINS OF

time

integration



Predicted image on the retina

TWO HOUSEHOLDS, BOTH ALIKE IN DIGNITY, IN
MUTINY, WHERE CIVIL BLOOD MAKES CIVIL HAD
STAR-CROSS'D LOVERS TAKE THEIR LIFE; WHI
PARENTS' STRIFE. THE FEARFUL PASSAGE OF
BUT THEIR CHILDREN'S END, NOUGHT COULD I
PATIENT EARS ATTEND, WHAT HERE SHALL M
VERONA, WHERE WE LAY OUR SCENE, FROM A
UNCLEAR, FROM FORTH THE FATAL LOINS OF
MISADVENTURED PITEOUS OVERTHROWS DO
DEATH-MARK'D LOVE, AND THE CONTINUANCE
IS HOW THE TWO HOURS' TRAFFIC OF OUR ST
SHALL STRIVE TO MEND. TWO HOUSEHOLDS, I
GRUDGE BREAK TO NEW MUTINY, WHERE CIVI
FOES A PAIR OF STAR-CROSS'D LOVERS TAKE
THEIR PARENTS' STRIFE. THE FEARFUL PASSA
WHICH, BUT THEIR CHILDREN'S END, NOUGHT
WITH PATIENT EARS ATTEND, WHAT HERE SH
FAIR VERONA, WHERE WE LAY OUR SCENE, FR
UNCLEAN, FROM FORTH THE FATAL LOINS OF

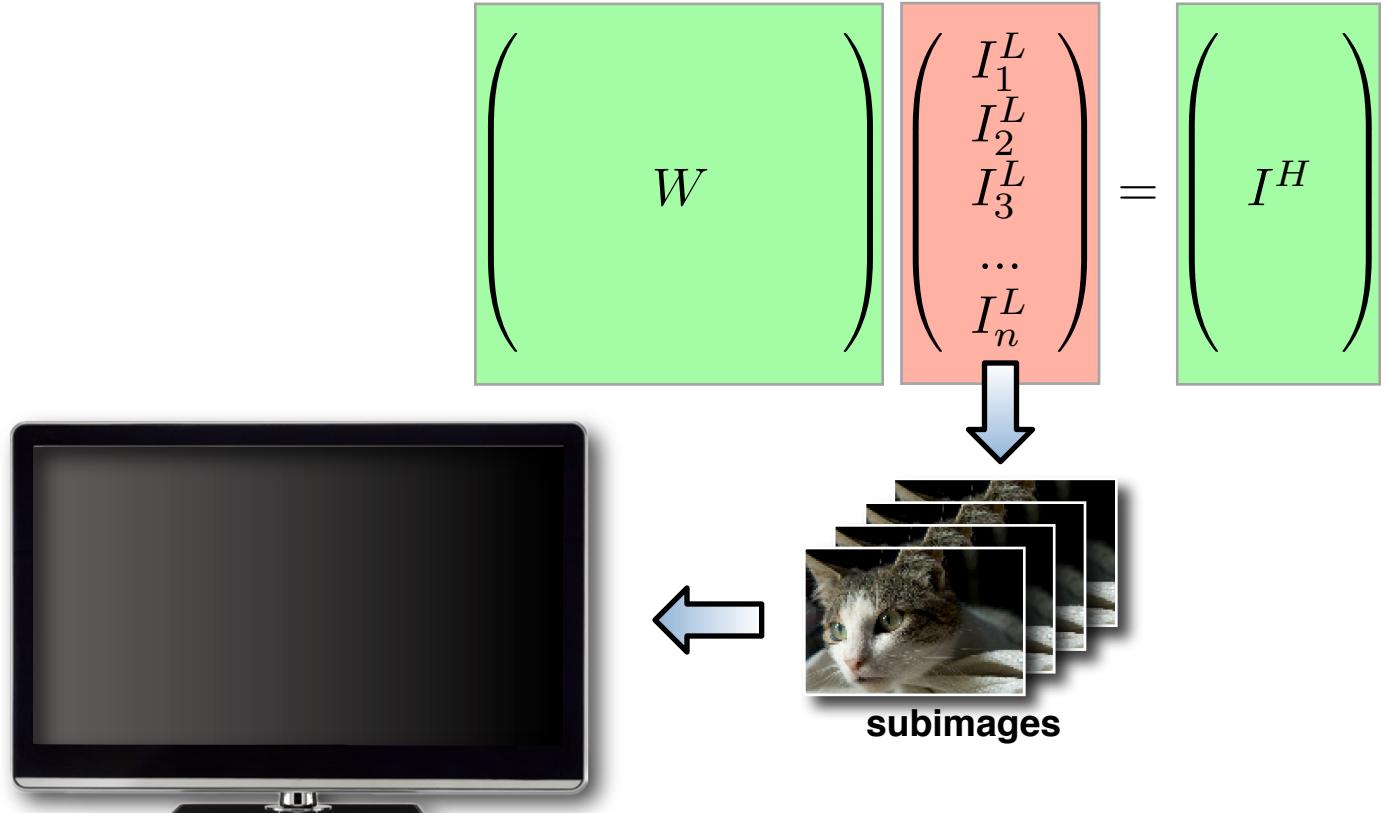
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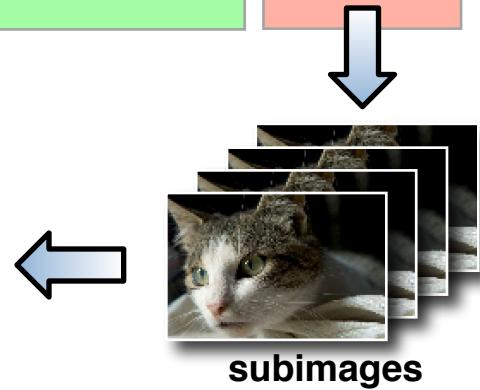
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Human Visual System



$$\begin{pmatrix} W \end{pmatrix} = \begin{pmatrix} I_1^L \\ I_2^L \\ I_3^L \\ \dots \\ I_n^L \end{pmatrix}$$

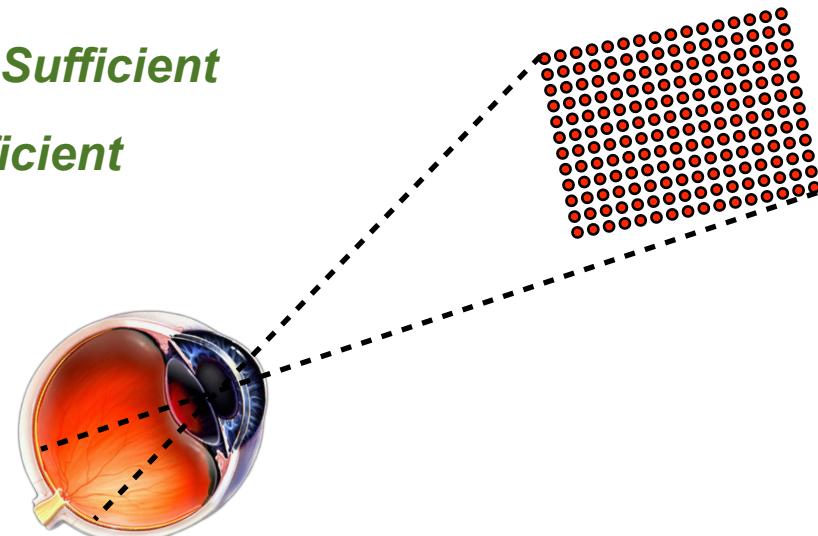


Prediction of retina image



Assumptions:

- Eye is tracking perfectly *OK*
- Retina represented as a grid of photoreceptors *Reasonable*
- Temporal filter assumed to be a box filter *Sufficient*
- Simple display and eye optics model *Sufficient*

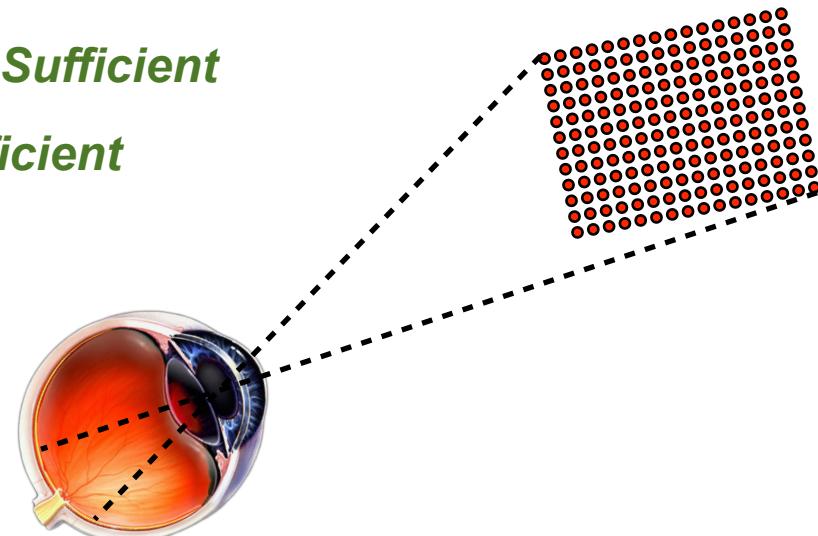


Prediction of retina image



Assumptions:

- Eye is tracking perfectly *OK*
- Retina represented as a grid of photoreceptors *Reasonable*
- Temporal filter assumed to be a box filter *Sufficient*
- Simple display and eye optics model *Sufficient*
- All frames are fused

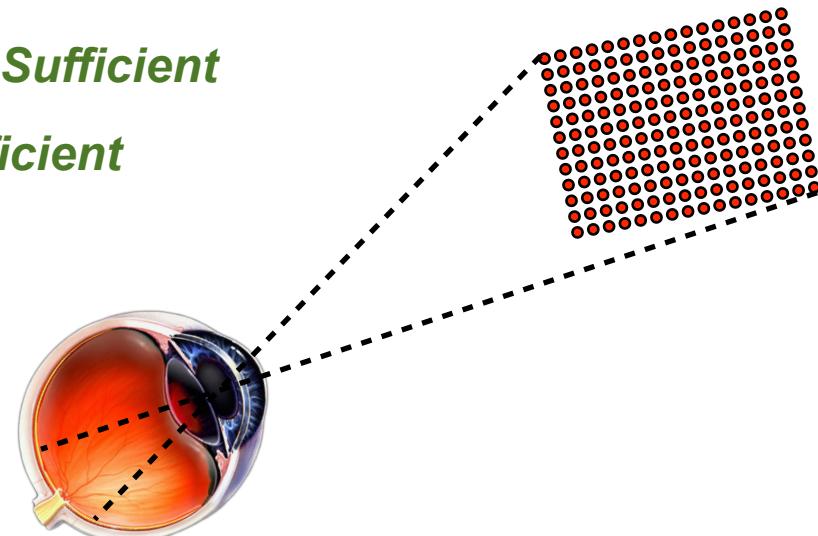


Prediction of retina image



Assumptions:

- Eye is tracking perfectly **OK**
- Retina represented as a grid of photoreceptors **Reasonable**
- Temporal filter assumed to be a box filter **Sufficient**
- Simple display and eye optics model **Sufficient**
- All frames are fused **We will solve it**



Fusing frames



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Fusing frames



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Fusing frames



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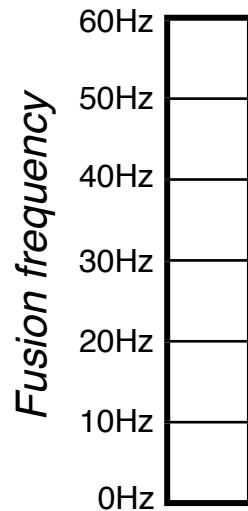
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When do we start fusing the subimages?

Fusion frequency

Fusion frequency depends on:



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Fusion frequency



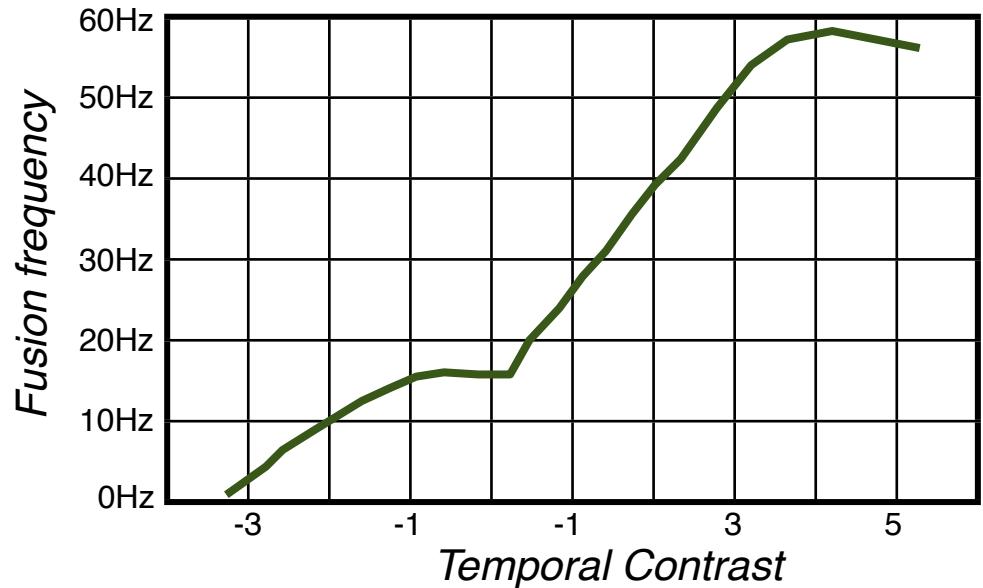
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Fusion frequency depends on:

- temporal contrast



Critical Flicker Frequency - Hecht and Smith's data from
Brown J. L. *Flicker and Intermittent Simulation*

Fusion frequency

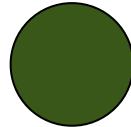


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Fusion frequency depends on:

- temporal contrast
- spatial extent of the pattern

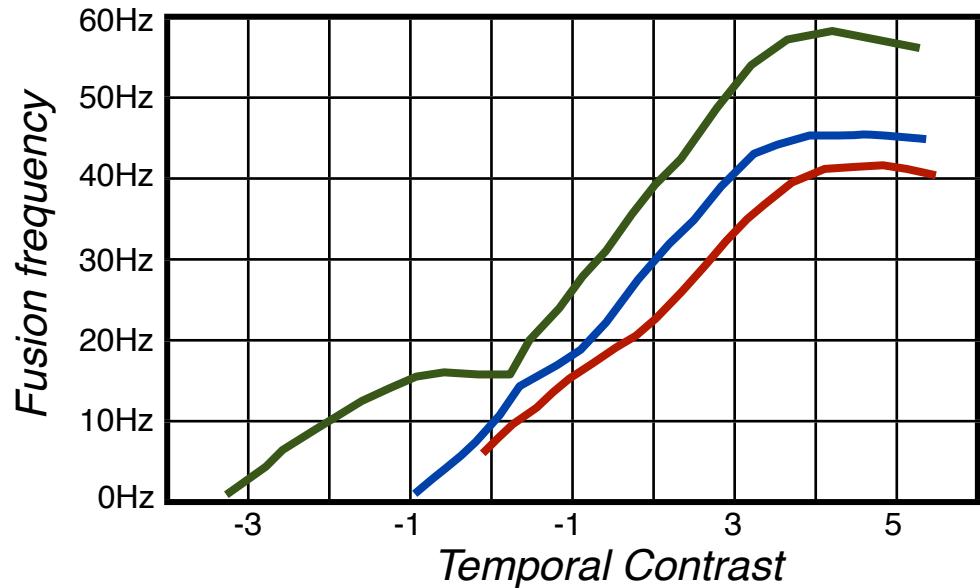


19 deg



2 deg

● 0.3 deg



Critical Flicker Frequency - Hecht and Smith's data from
Brown J. L. *Flicker and Intermittent Simulation*

Fusion frequency

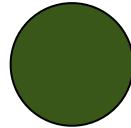


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Fusion frequency depends on:

- temporal contrast
- spatial extent of the pattern



19 deg

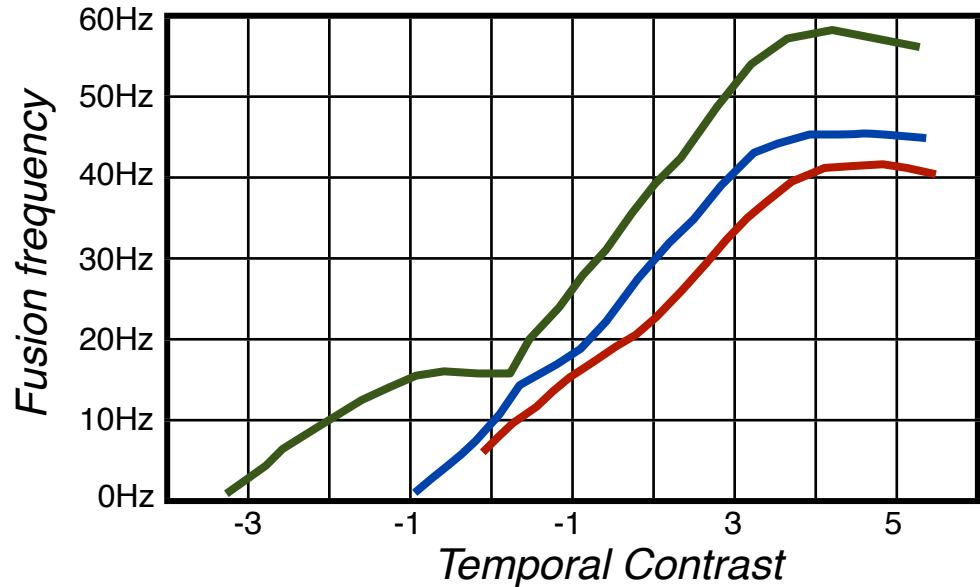


2 deg

● 0.3 deg



40Hz



Critical Flicker Frequency - Hecht and Smith's data from
Brown J. L. *Flicker and Intermittent Simulation*



120 Hz display
(common for 3D applications)



40Hz - 3 subimages

120 Hz display
(common for 3D applications)



120 Hz display
(common for 3D applications)

40Hz - 3 subimages

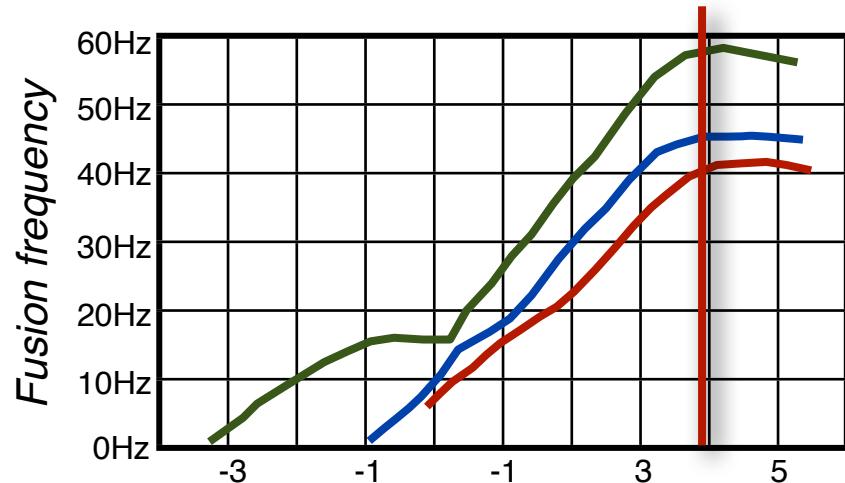
- fine details are fused
- bigger not necessary



120 Hz display
(common for 3D applications)

40Hz - 3 subimages

- fine details are fused
- bigger not necessary

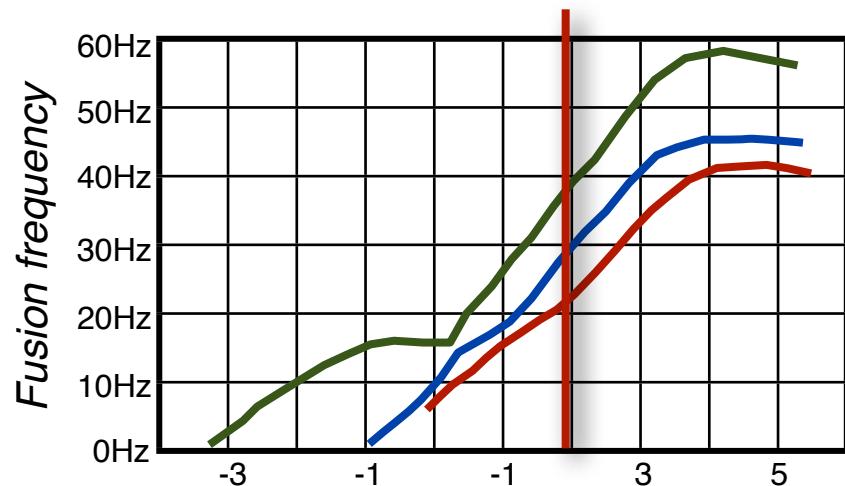




120 Hz display
(common for 3D applications)

40Hz - 3 subimages

- fine details are fused
- bigger not necessary

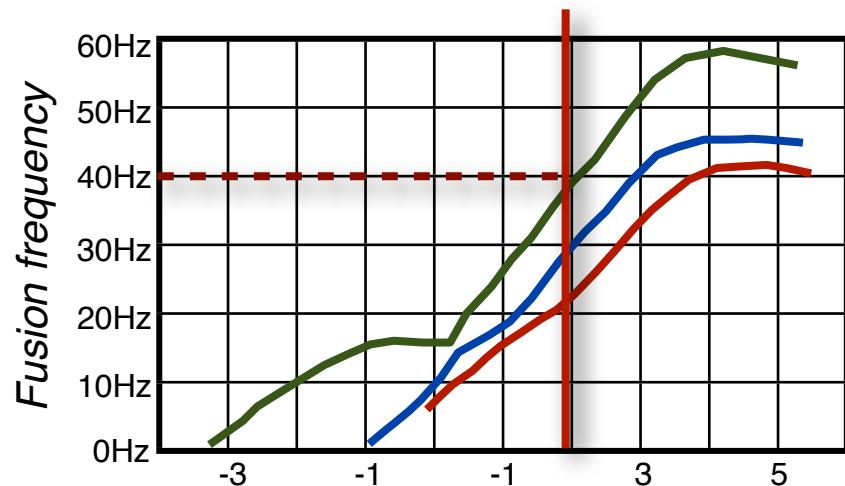




120 Hz display
(common for 3D applications)

40Hz - 3 subimages

- fine details are fused
- bigger not necessary



Flickering reduction



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Flickering reduction



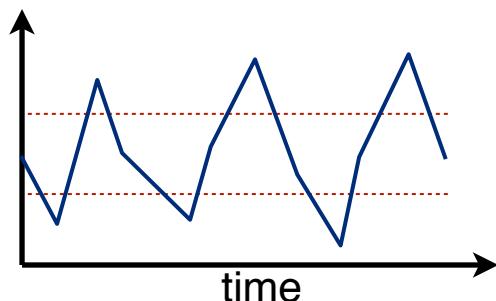
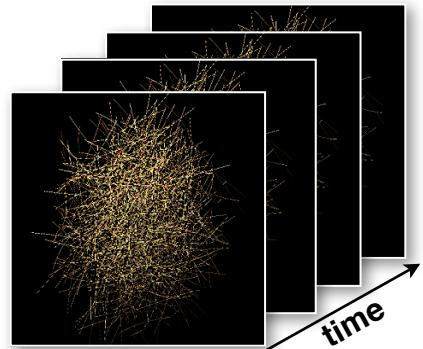
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subimages

- local flickering
- improved resolution



Flickering reduction

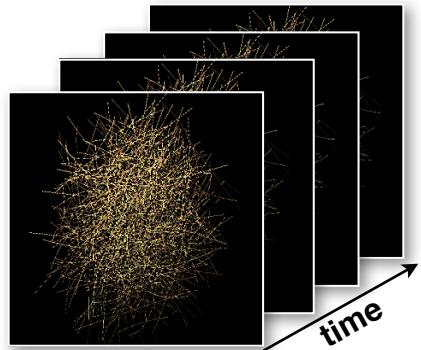


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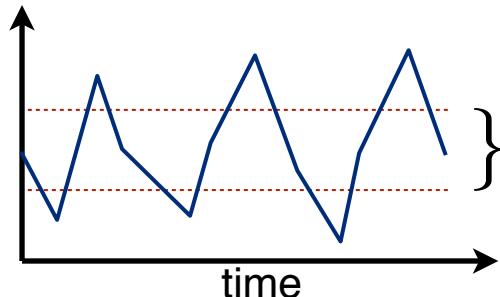
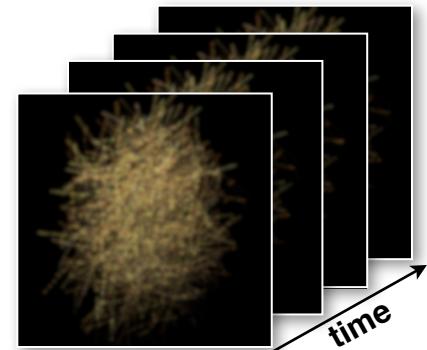
- local flickering
- improved resolution



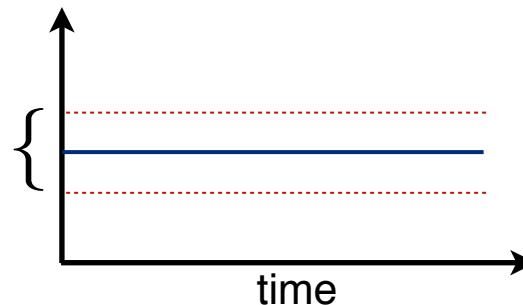
standard solution

(e.g., Lanczos)

- no flickering
- low resolution



fusion at 40Hz



Flickering reduction

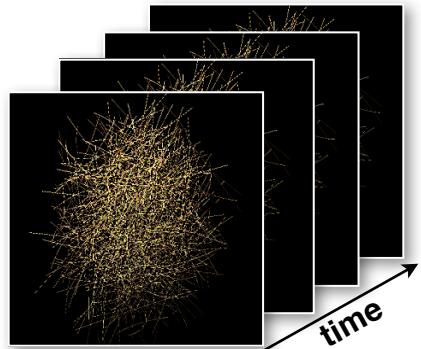


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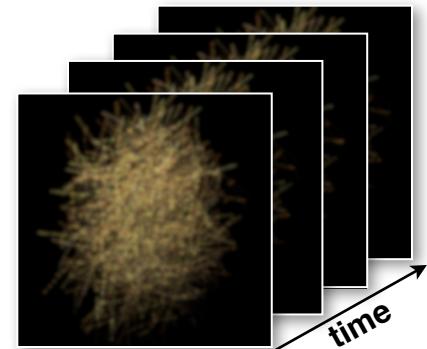
- local flickering
- improved resolution



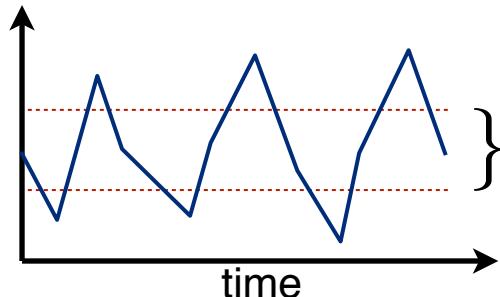
standard solution

(e.g., Lanczos)

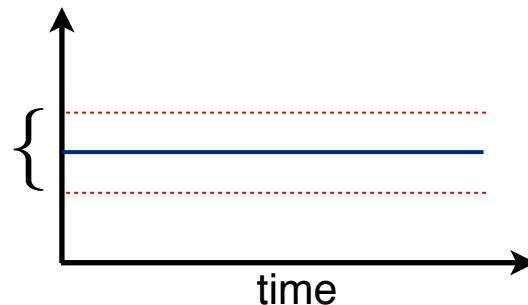
- no flickering
- low resolution



blending



fusion at 40Hz



Flickering reduction

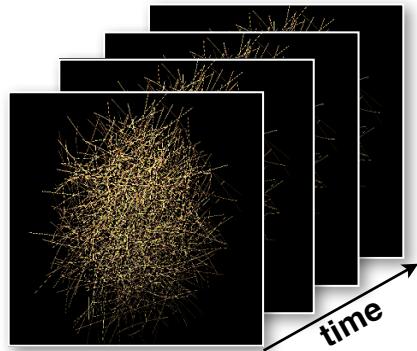


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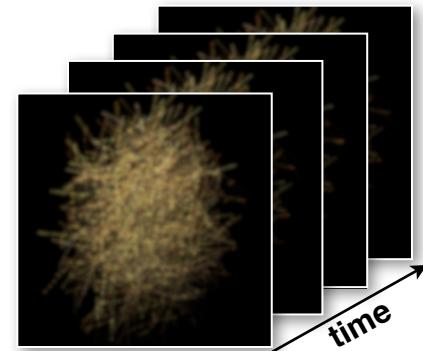
- local flickering
- improved resolution



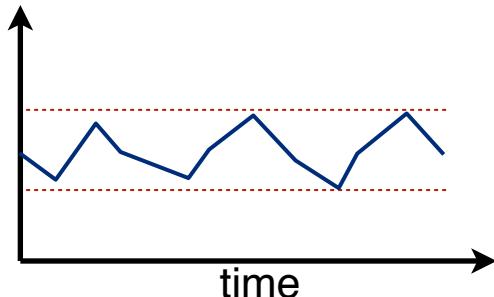
standard solution

(e.g., Lanczos)

- no flickering
- low resolution



blending



Flickering reduction

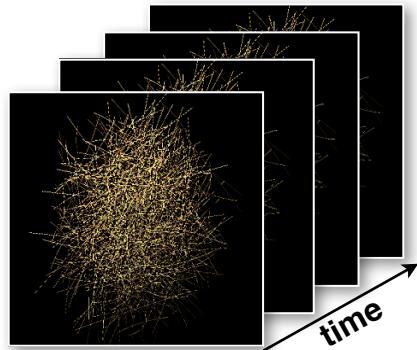


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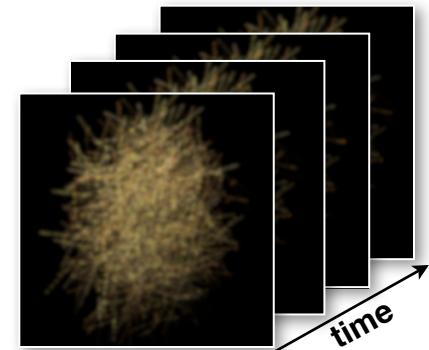
- local flickering
- improved resolution



standard solution

(e.g., Lanczos)

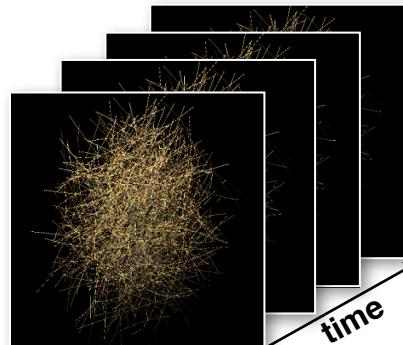
- no flickering
- low resolution



blending

final solution

- no flickering
- improved resolution



Flickering reduction

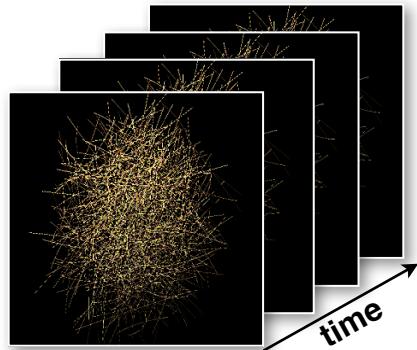


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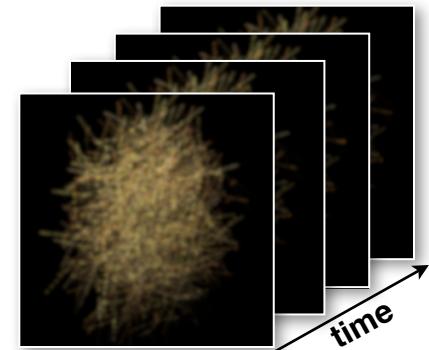
- local flickering
- improved resolution



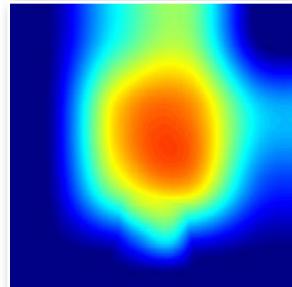
standard solution

(e.g., Lanczos)

- no flickering
- low resolution



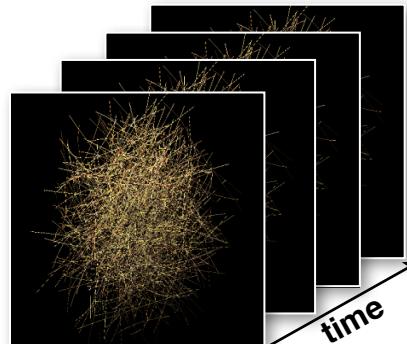
blending



reduction map

final solution

- no flickering
- improved resolution



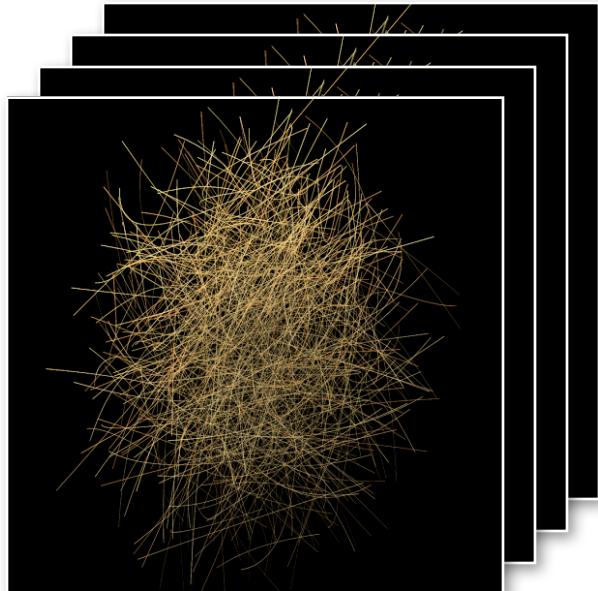
Flickering reduction



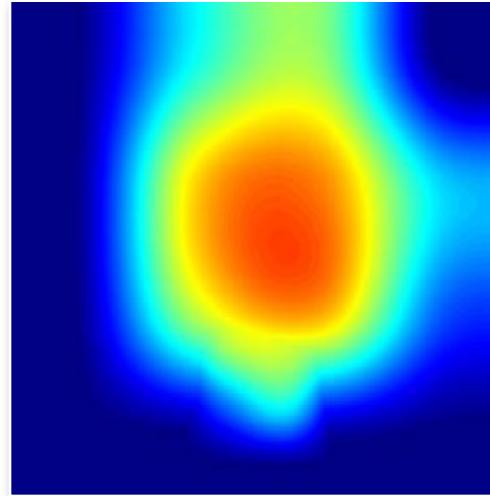
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subimages



contrast reduction map

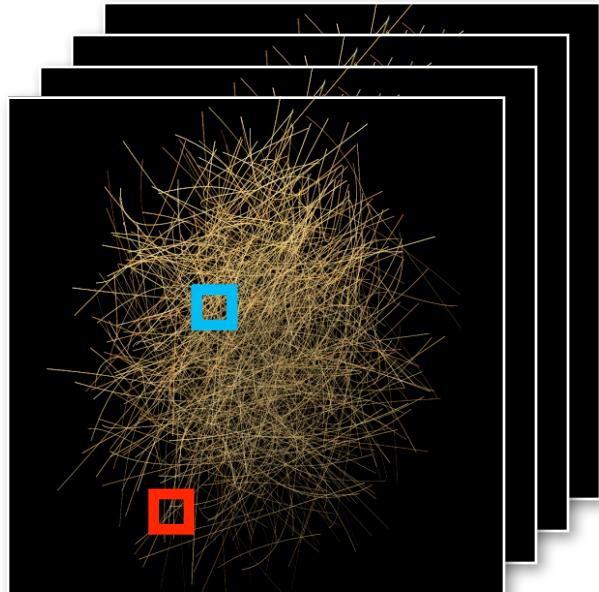


Flickering reduction

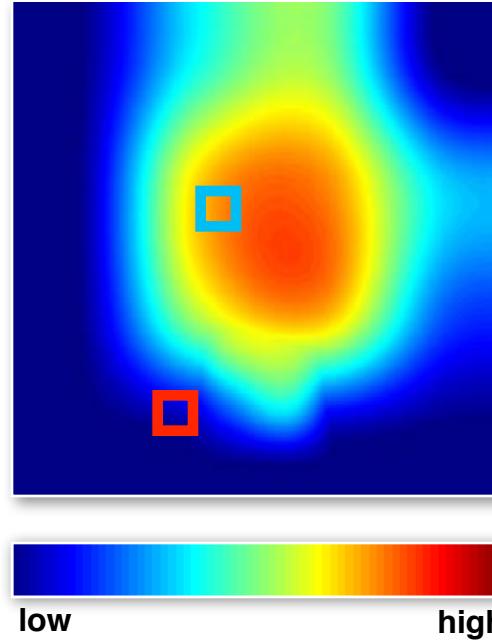
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contrast reduction map

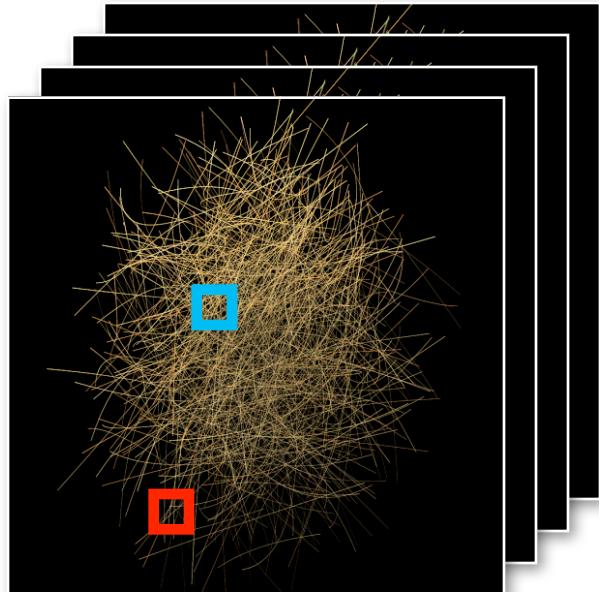


Flickering reduction

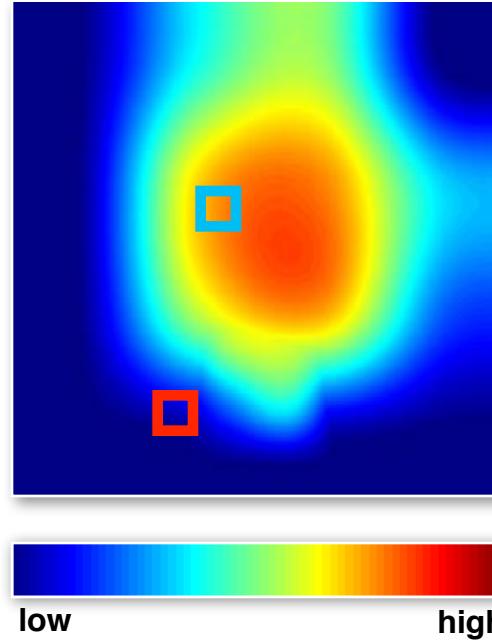
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contrast reduction map

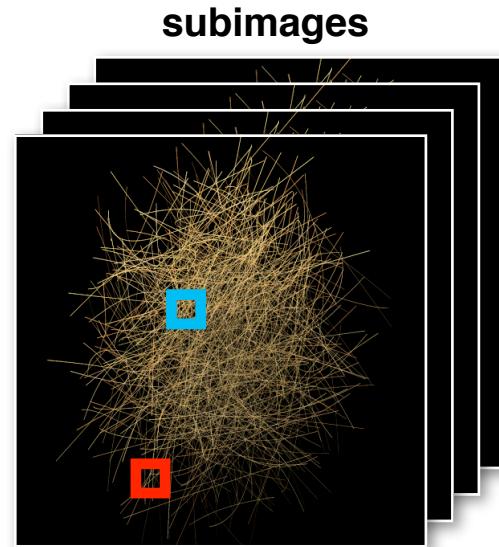


Flickering reduction

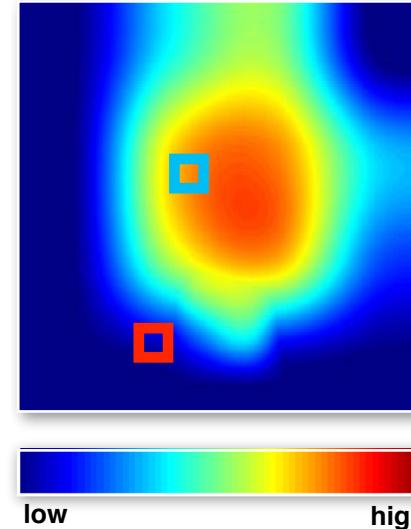


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contrast reduction map



The reduction map: How much we need to reduce temporal contrast

“Effects of luminance and external temporal noise on flickering sensitivity
as a function of stimulus size at various eccentricities”

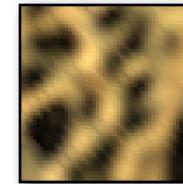
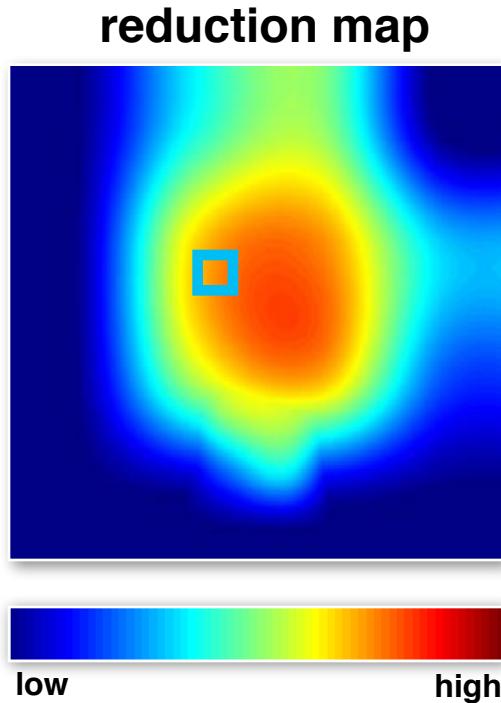
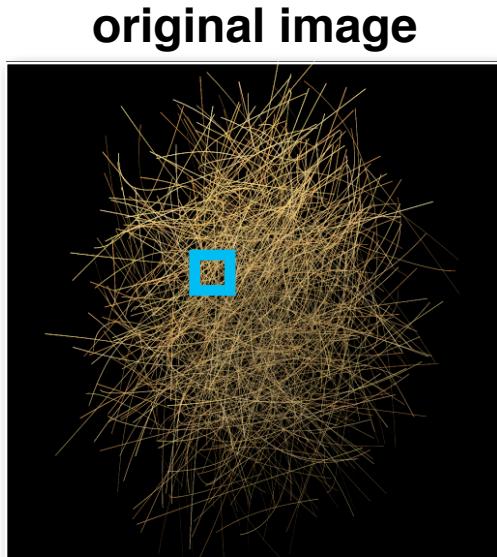
[Mäkelä et al. 1994]

Flickering reduction

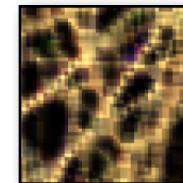


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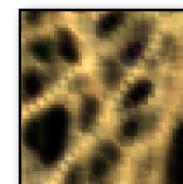
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Downsampling



Our
before reduction



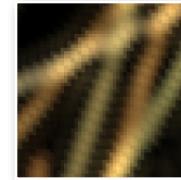
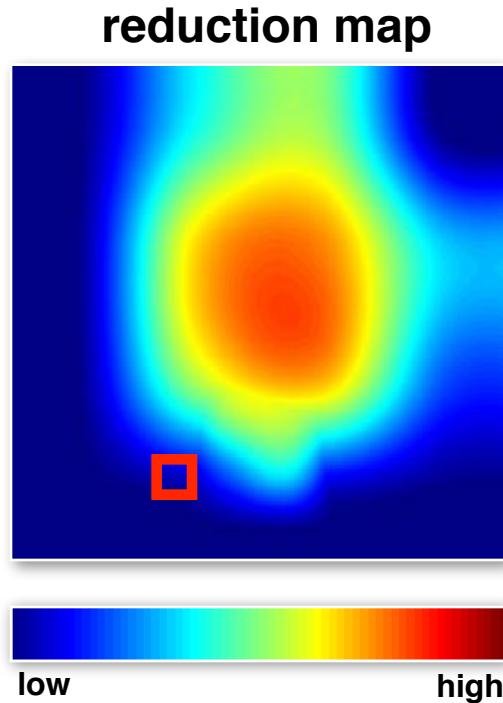
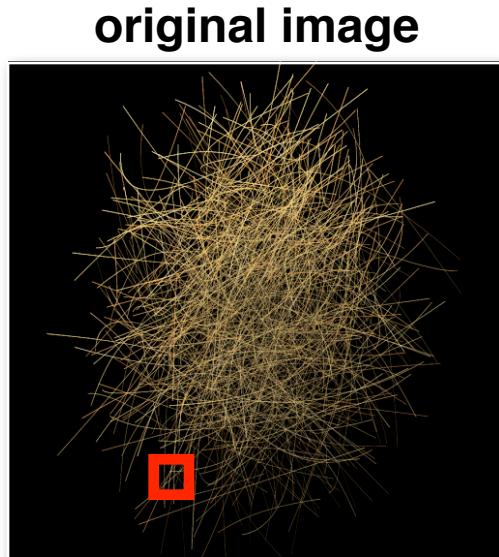
Our
after reduction

Flickering reduction



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Downsampling



Our
before reduction

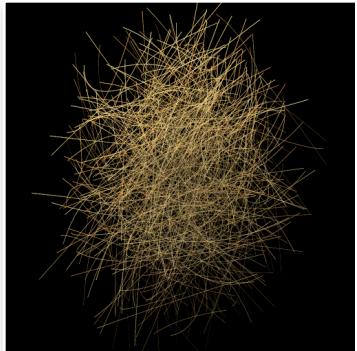


Our
after reduction

Full pipeline



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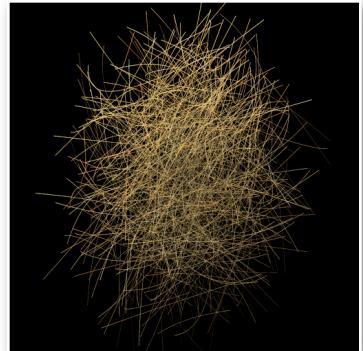
high resolution image

Full pipeline

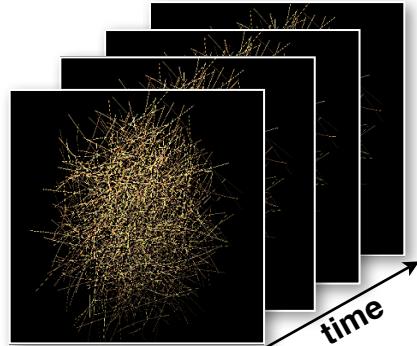
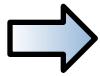


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high resolution image



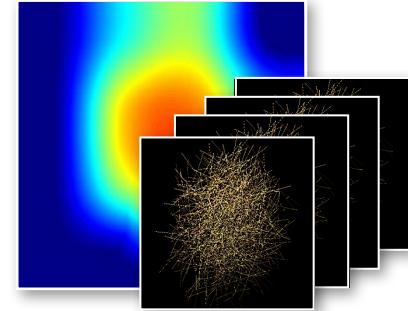
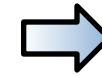
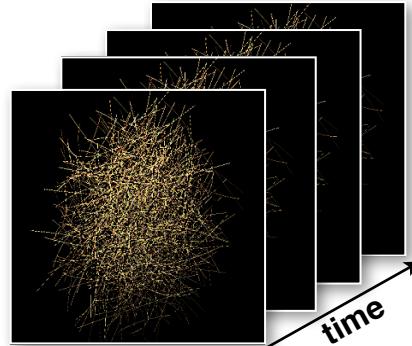
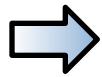
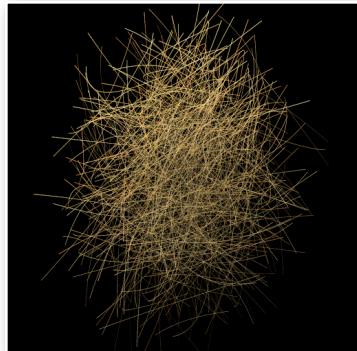
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Full pipeline



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Full pipeline

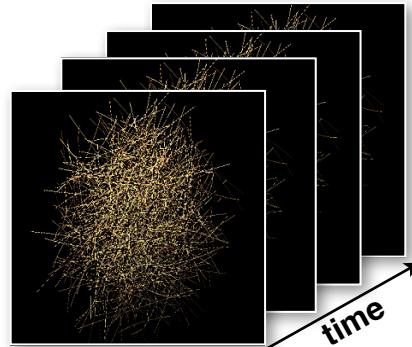


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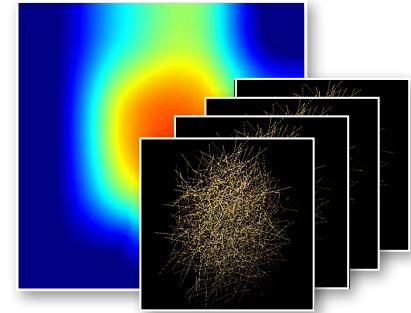
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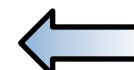
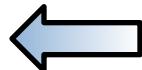
high resolution image



subimages



flickering reduction

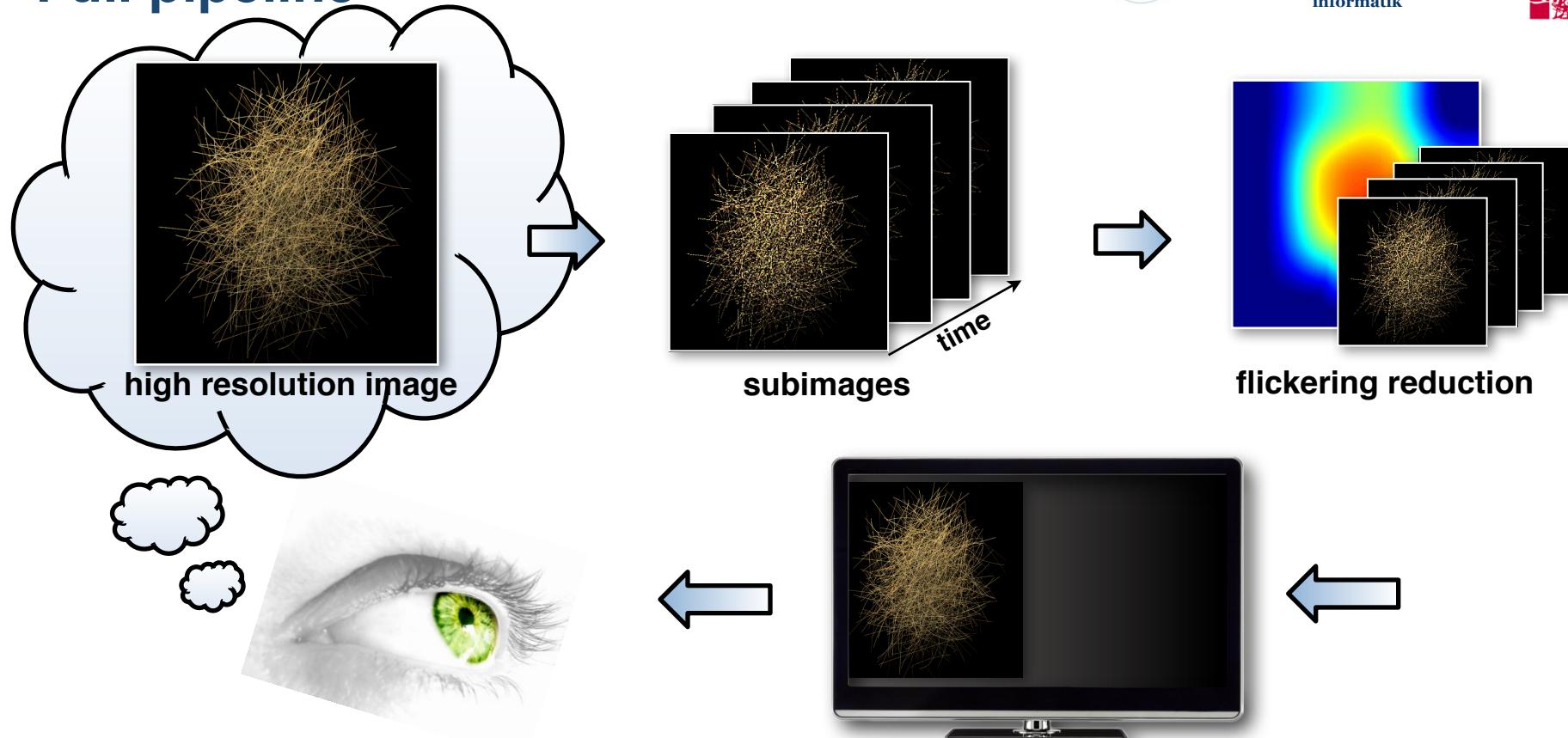


Full pipeline



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Experiments

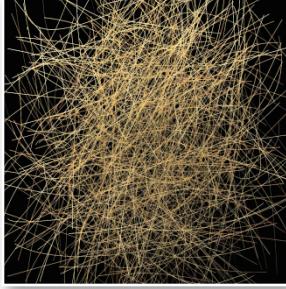


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Experiments

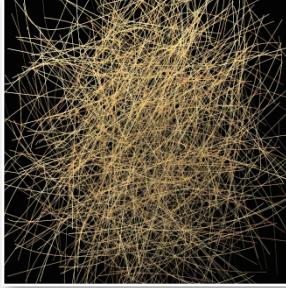
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- 5 images - detailed photographs and rendering

Experiments

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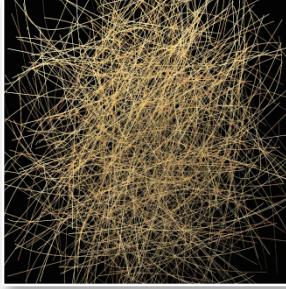
- 5 images - detailed photographs and rendering
 - different velocities

Experiments



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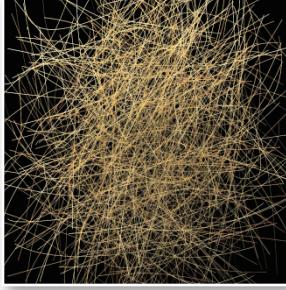
- 5 images - detailed photographs and rendering
- different velocities
- decomposition into 3 subimages

Experiments



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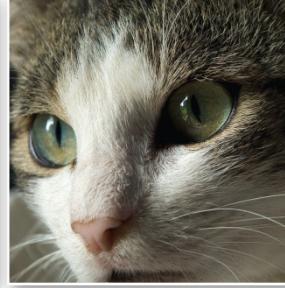
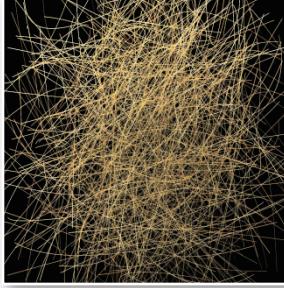
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- 5 images - detailed photographs and rendering
- different velocities
- decomposition into 3 subimages
- 14 participants

Experiments

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- 5 images - detailed photographs and rendering
 - different velocities
 - decomposition into 3 subimages
 - 14 participants
 - comparison to Lanczos and Mitchell downsampling

Experiments

Our vs. Static case



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our



standard downampling

Experiments

Our vs. Static case



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Our vs. static case



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Experiments

Our vs. static case



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our



standard downsampling

All participants preferred our solution

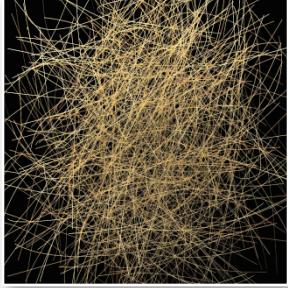
Experiments

Our vs. Lanczos



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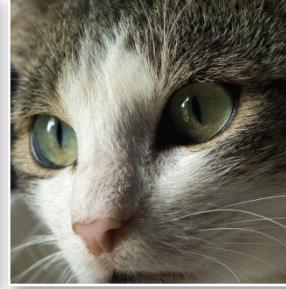
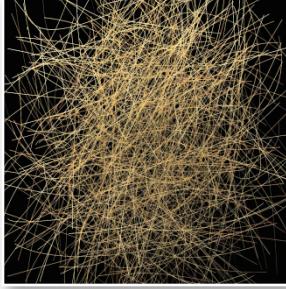


- compare to moving image
- each frame downsample separately
 - ➡ slightly different information over time

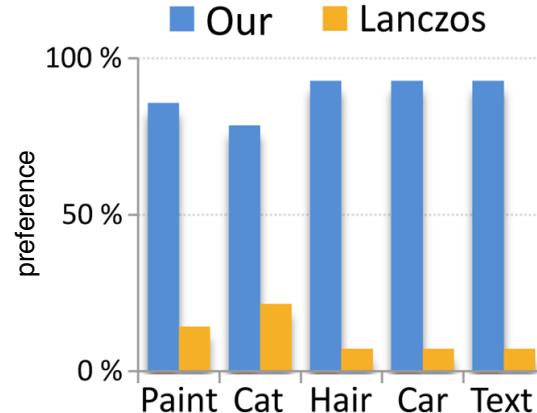
Experiments

Our vs. Lanczos

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- compare to moving image
 - each frame downsample separately
 - slightly different information over time



Experiments

Lanczos scale 3:1



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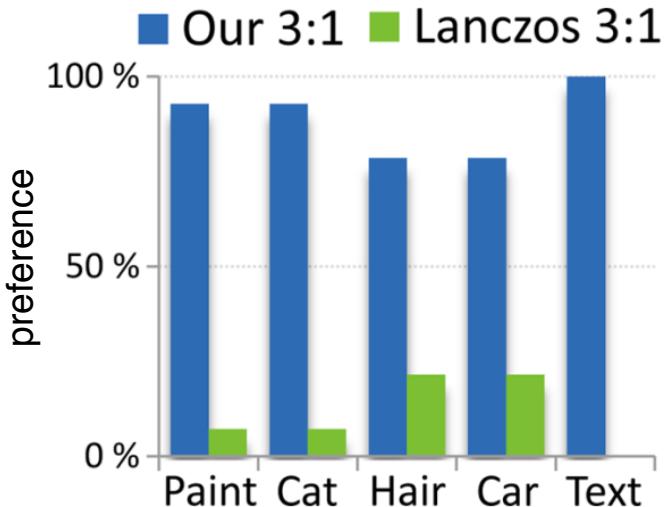


Our / Lanczos
in scale 3:1

Original

Experiments

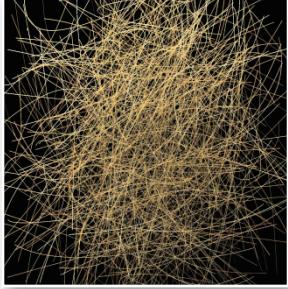
Lanczos scale 3:1



Experiments

Our vs. Mitchell

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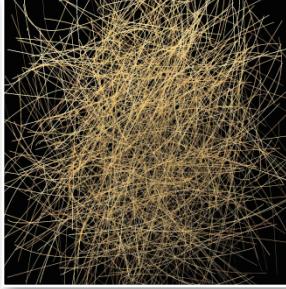
Mitchell downsampling

- participants adjusted parameters to match high resolution image

Experiments

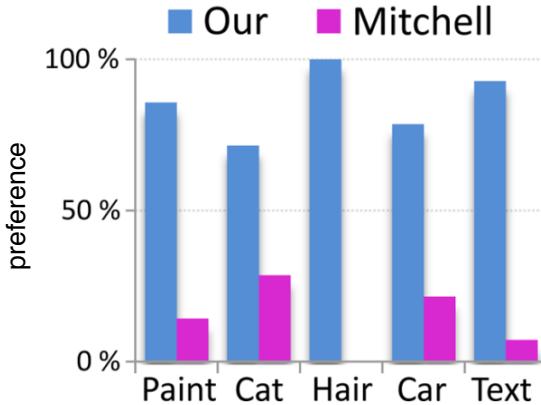
Our vs. Mitchell

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Mitchell downsampling

- participants adjusted parameters to match high resolution image



Results

Alphabet

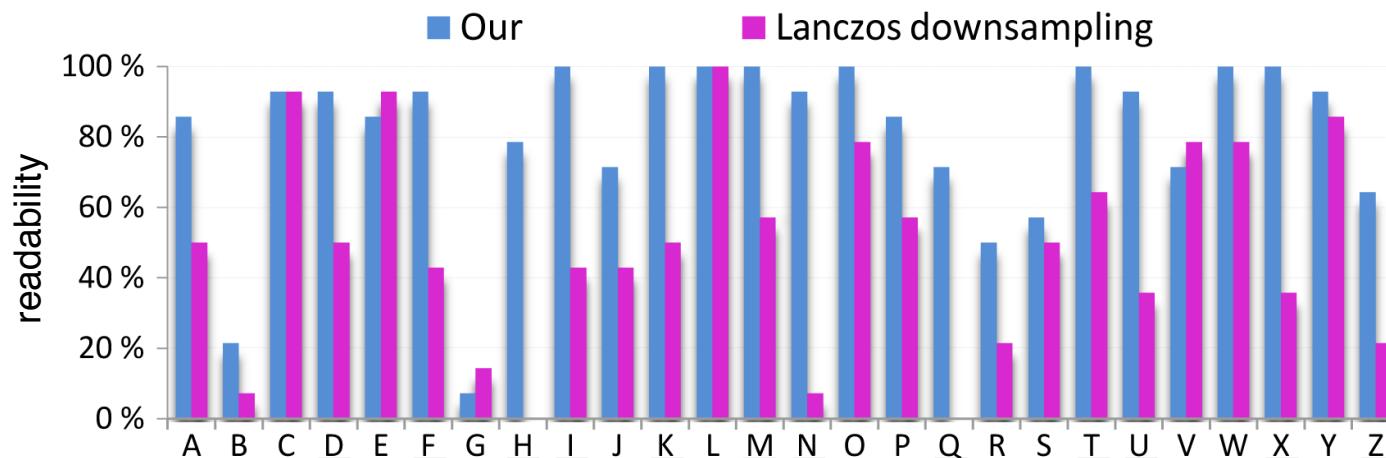


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A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Size: 2 x 3 pixels



Results

Alphabet

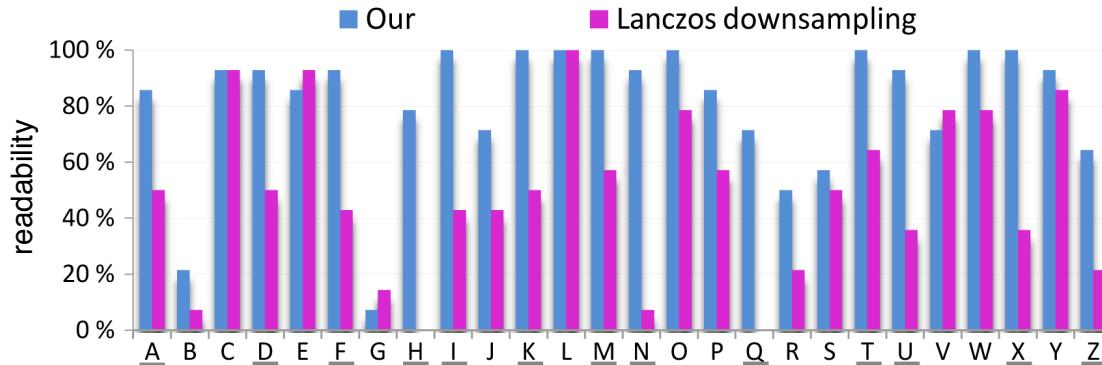


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A B C D E F G H I J K L M N O P Q R S T U W V X Y Z

Size: 2 x 3 pixels



Applications:

- scrolling text or maps on low resolution devices
- stock tickers, news headlines

Experiment (small)

Rendering



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Experiment (small)

Rendering



- 2 highly detailed rendering
- 5 participants
- comparison to Lanczos



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Experiment (small)

Rendering



- 2 highly detailed rendering
- 5 participants
- comparison to Lanczos

Result:
all subjects preferred our solution

Limitations



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Limitations



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- The resolution improvement is velocity dependent

Limitations



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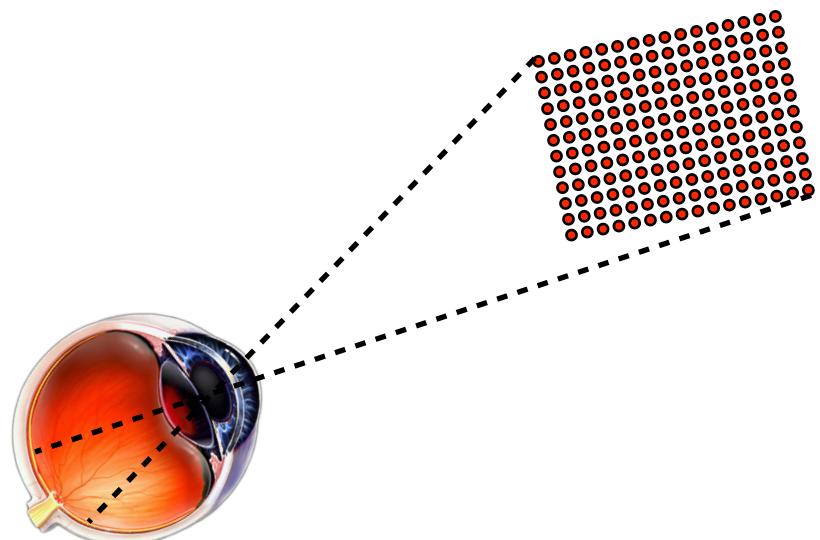
- The resolution improvement is velocity dependent
- For complex motion optimization of whole sequence is required

Conclusions



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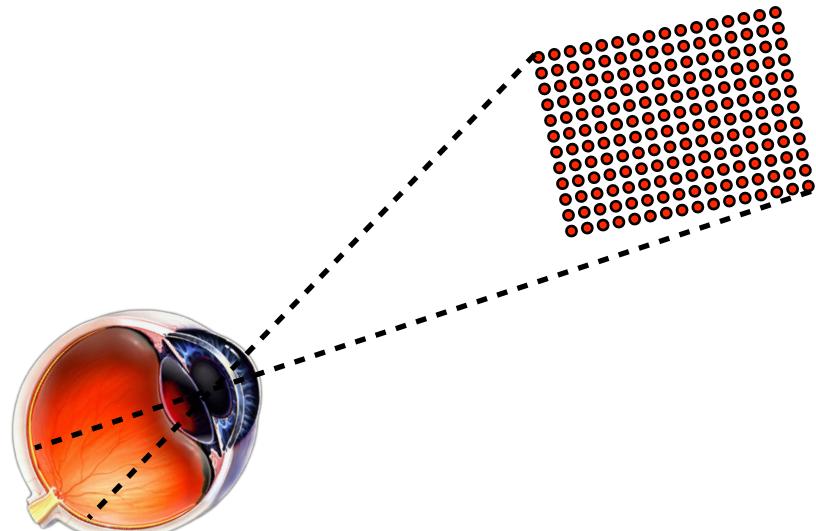
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Conclusions



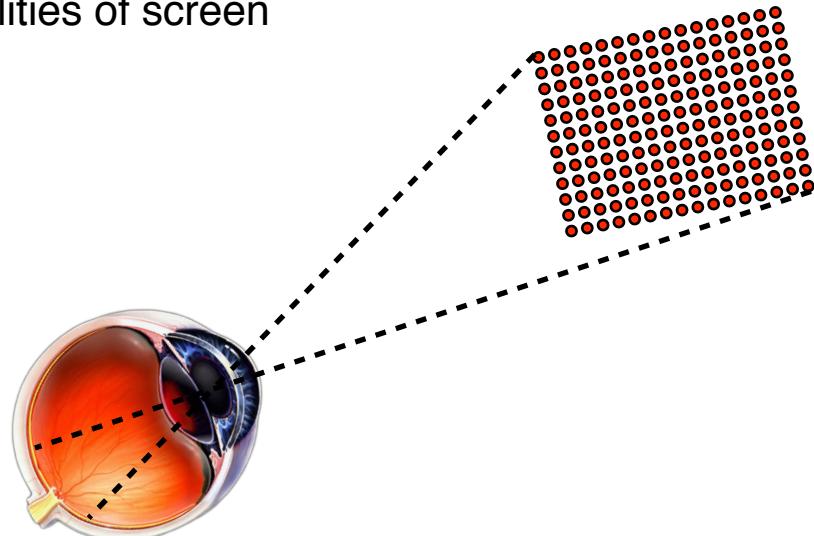
- We presented apparent resolution enhancement using human perception



Conclusions



- We presented apparent resolution enhancement using human perception
- We can show resolution beyond physical capabilities of screen



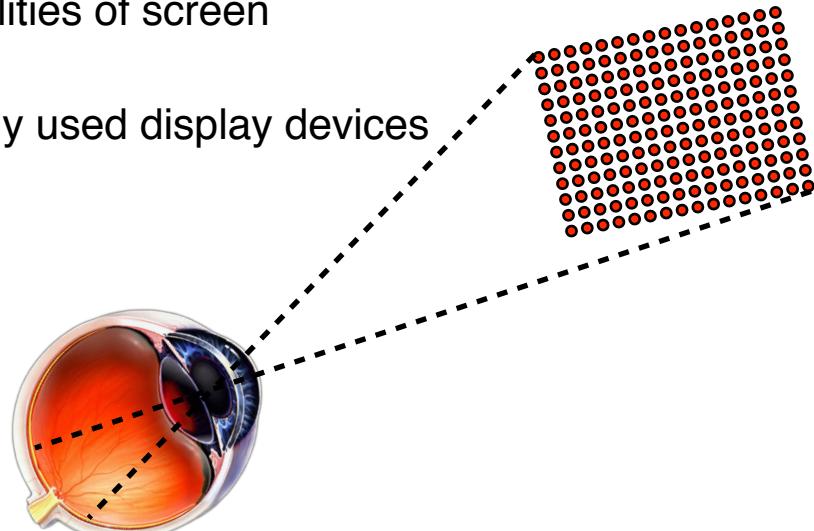
Conclusions



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- We presented apparent resolution enhancement using human perception
- We can show resolution beyond physical capabilities of screen
- Our method works with whole range of commonly used display devices



Acknowledgments



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We would like to thank:

Acknowledgments



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We would like to thank:

- Reinhard Klein, Rafał Mantiuk and Robert Strzodka for helpful discussions

Acknowledgments



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SIGGRAPH2010

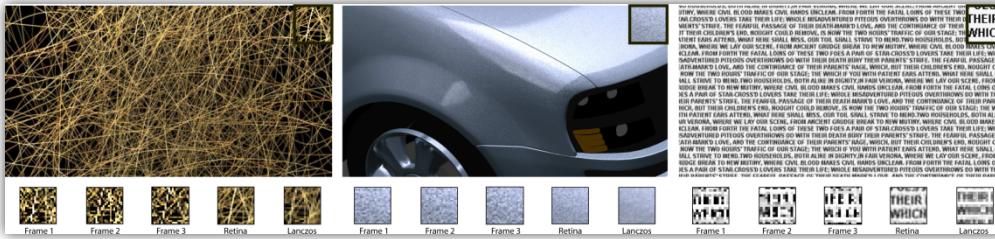


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Apparent Display Resolution Enhancement for Moving Images

Piotr Didyk, Elmar Eisemann, Tobias Ritschel, Karol Myszkowski, Hans-Peter Seidel



Thank you!

Additional materials: <http://www.mpii.de/resources/ResolutionEnhancement/>