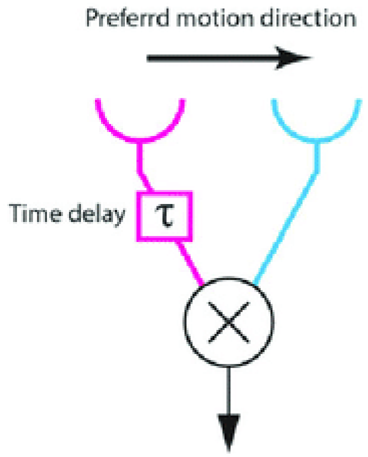
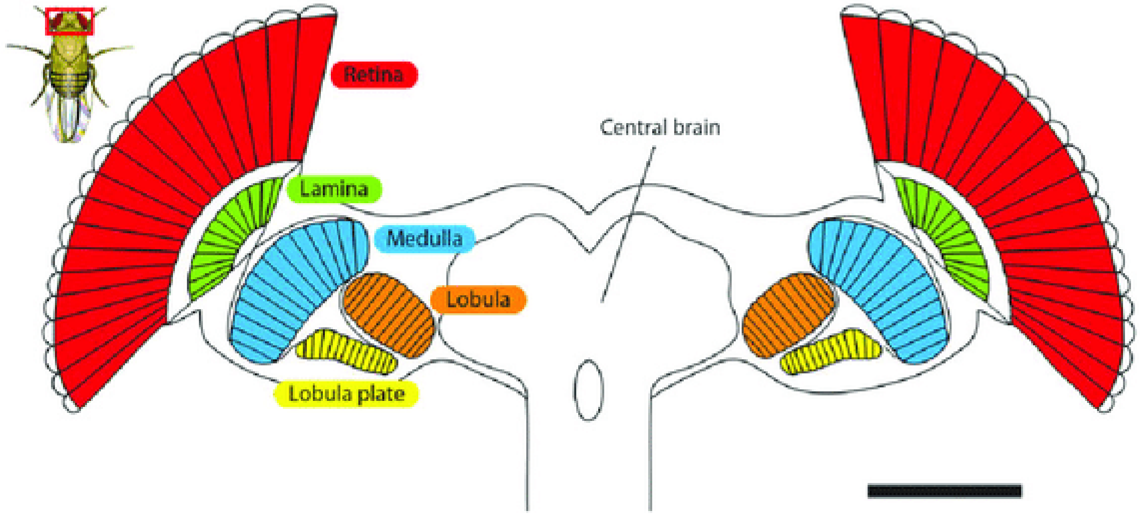
Insect-Inspired Motion Detection System





Speaker: Wei-Tse Kao
Advisor: Chung-Chuan Lo
Date: 2019.11.28

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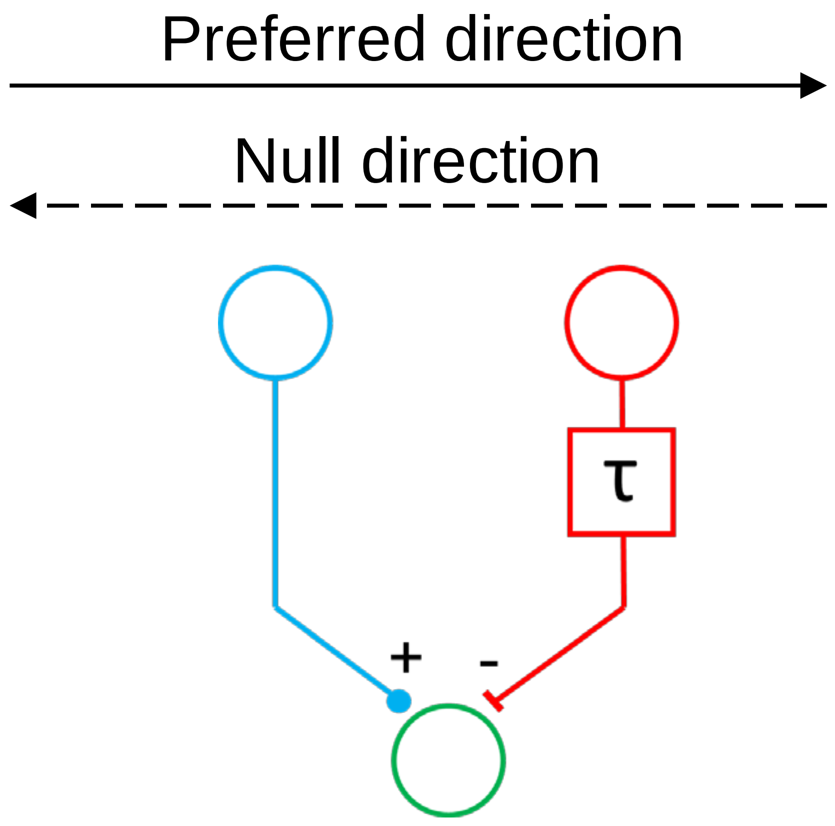
Motion vision: How we detect a moving object?

Introduction : motion detection in biological system

- Modeling the neuron connectivity in retina and visual cortex.
- Response in preferred direction.
- Principles of visual motion detection :
  - Two inputs
  - Non-linear Interaction (time delay)
  - Asymmetry



Barlow–Levick

Motion detection in biological system

- Modeling the neuron connectivity in retina and visual cortex.
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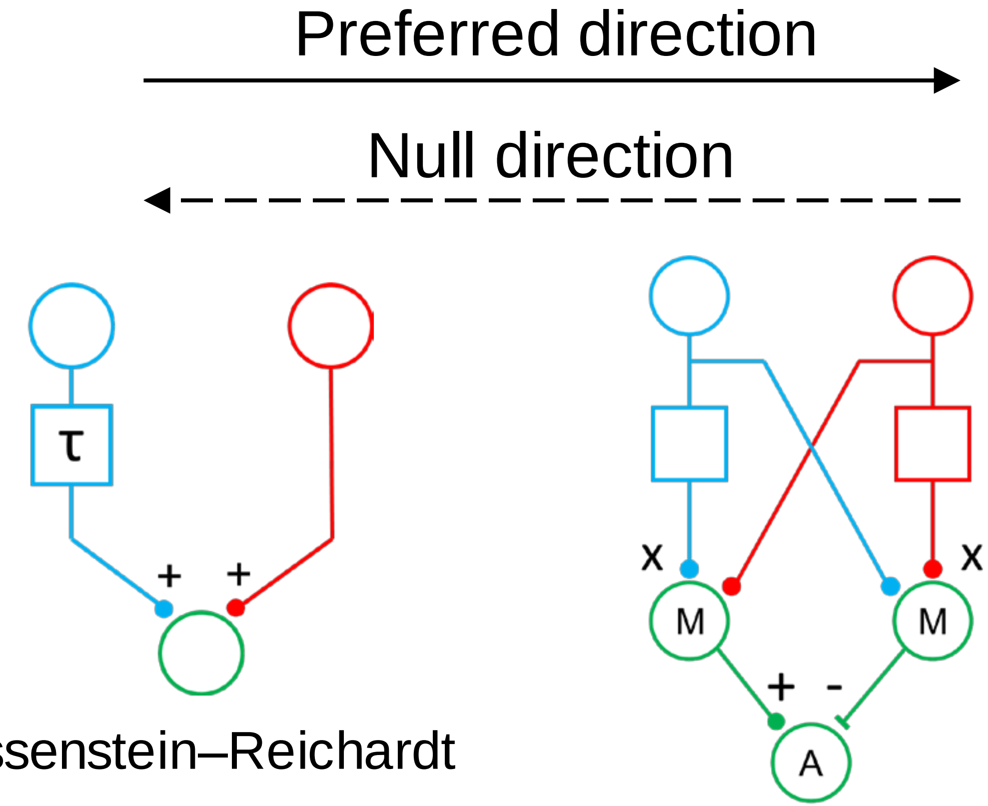
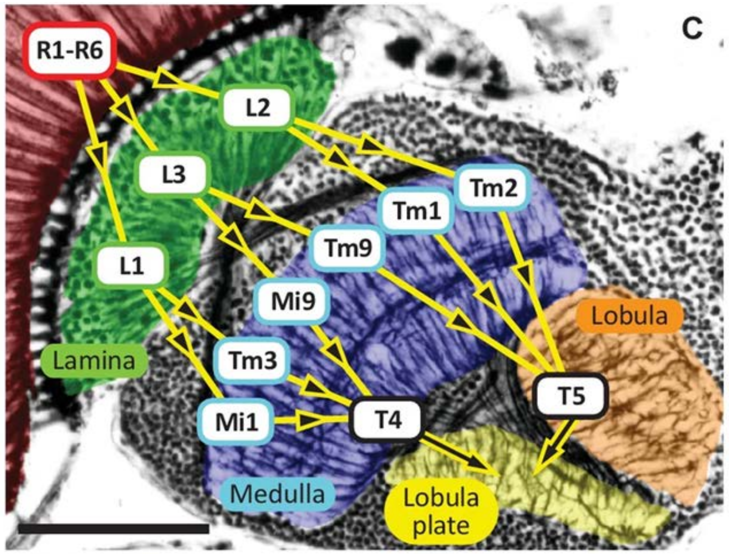


Hassenstein–Reichardt

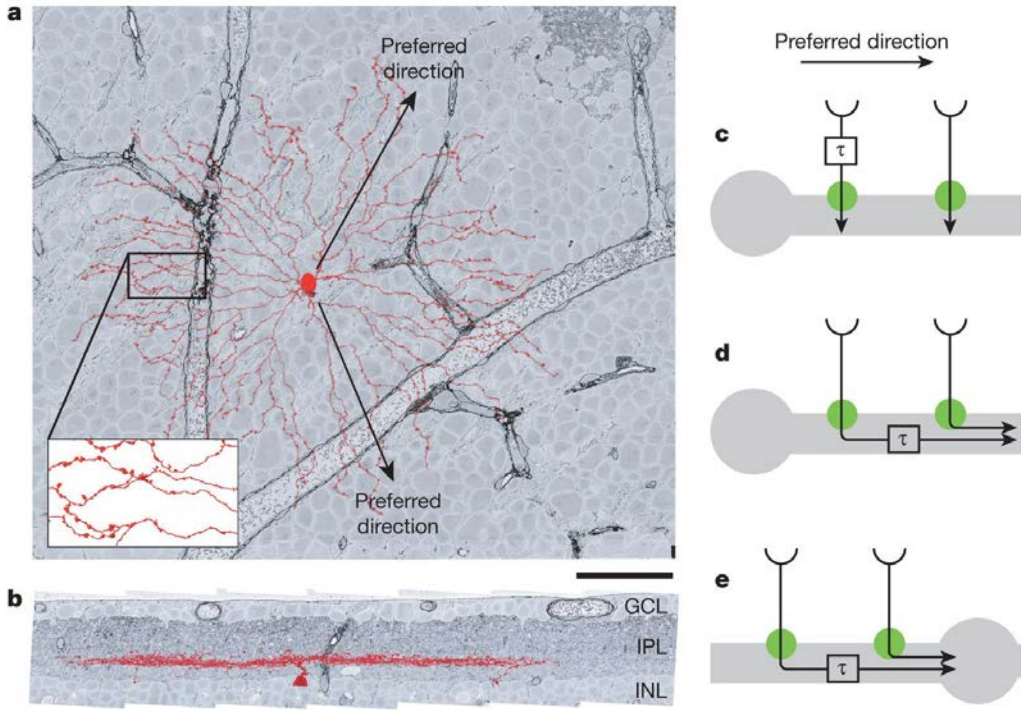
Full Hassenstein–Reichardt

Motion detection in biological system

- Evidence found in fly optic lobe and rabbit retina.

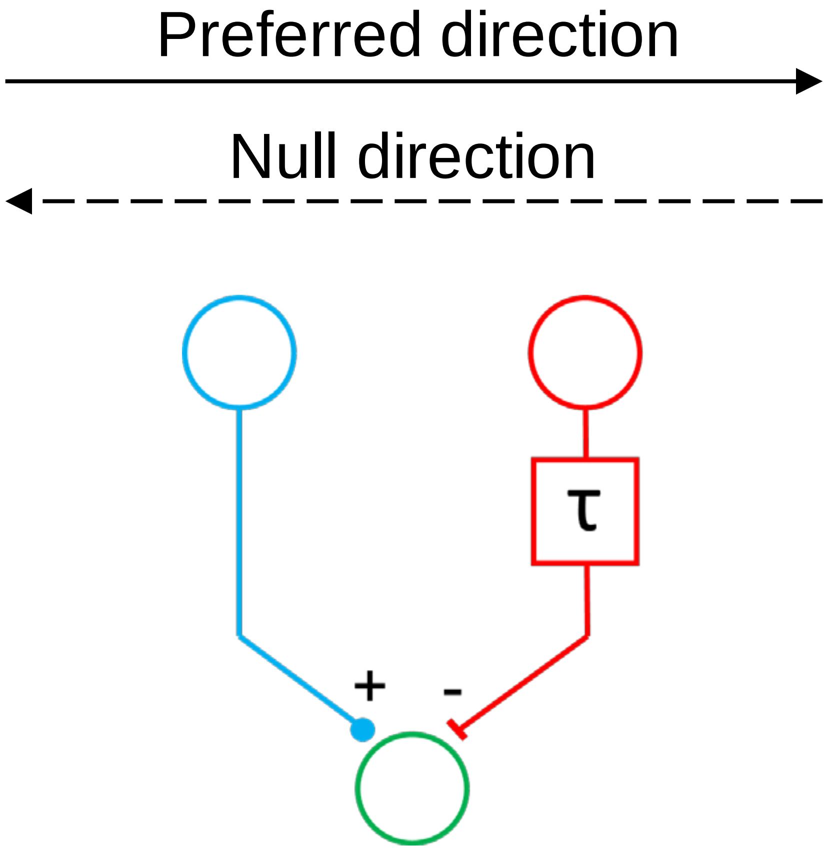


Takemura, Shin-ya, et al. Elife 6 (2017)

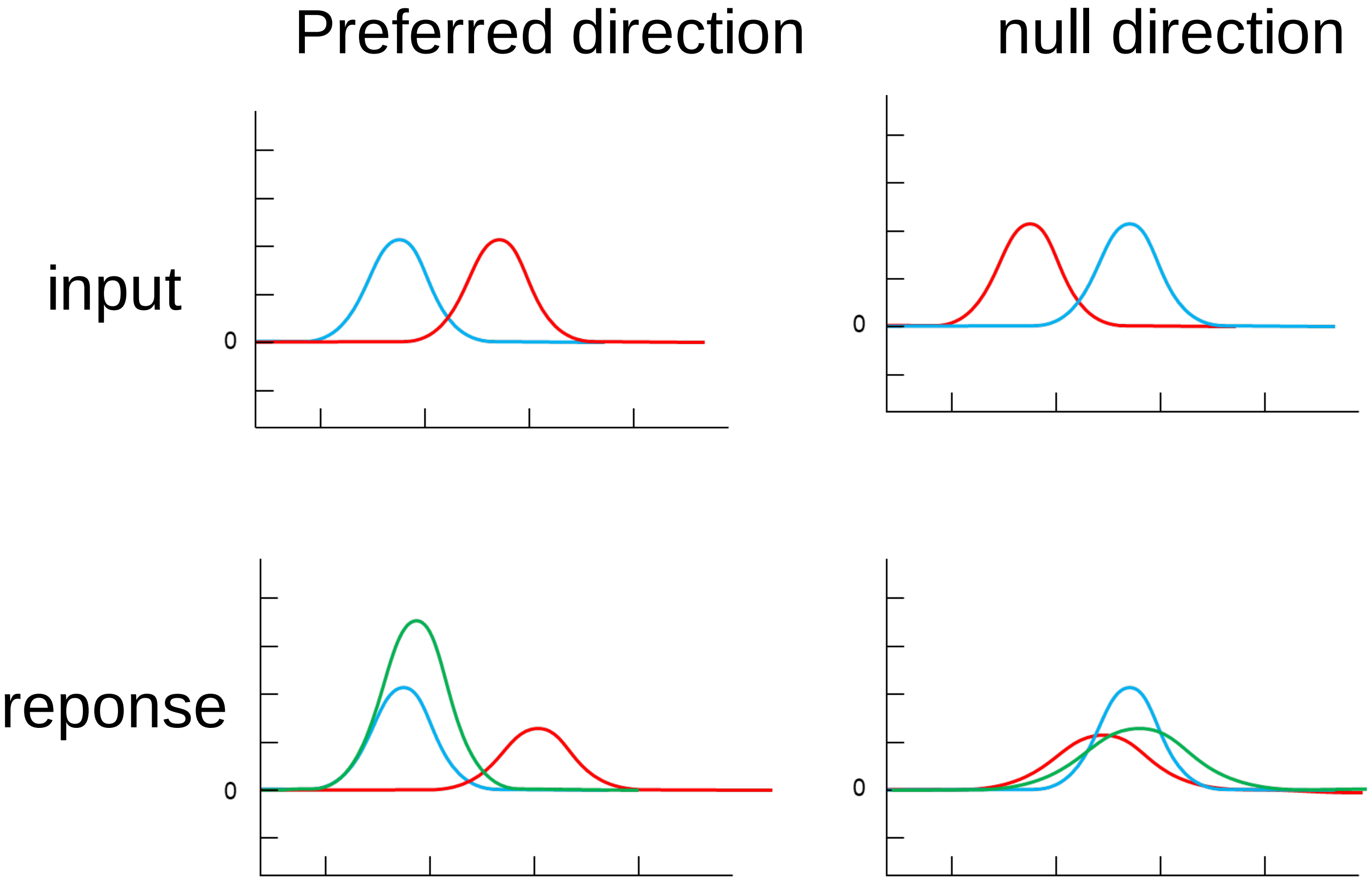


Kim, J. S., et al *Nature* (2014).

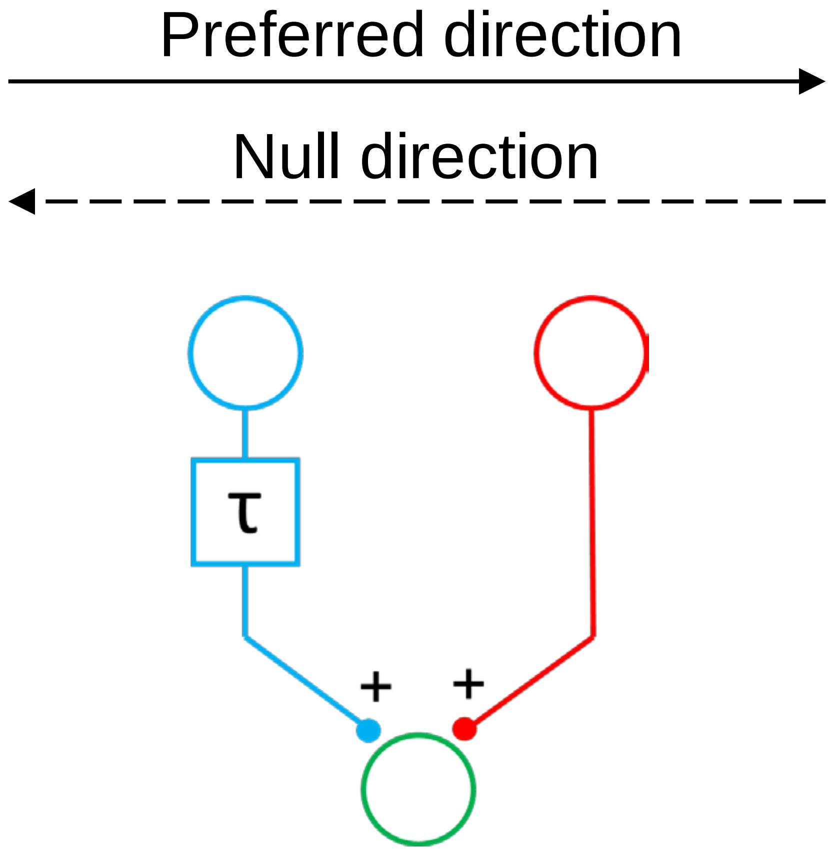
Motion detection model and its response



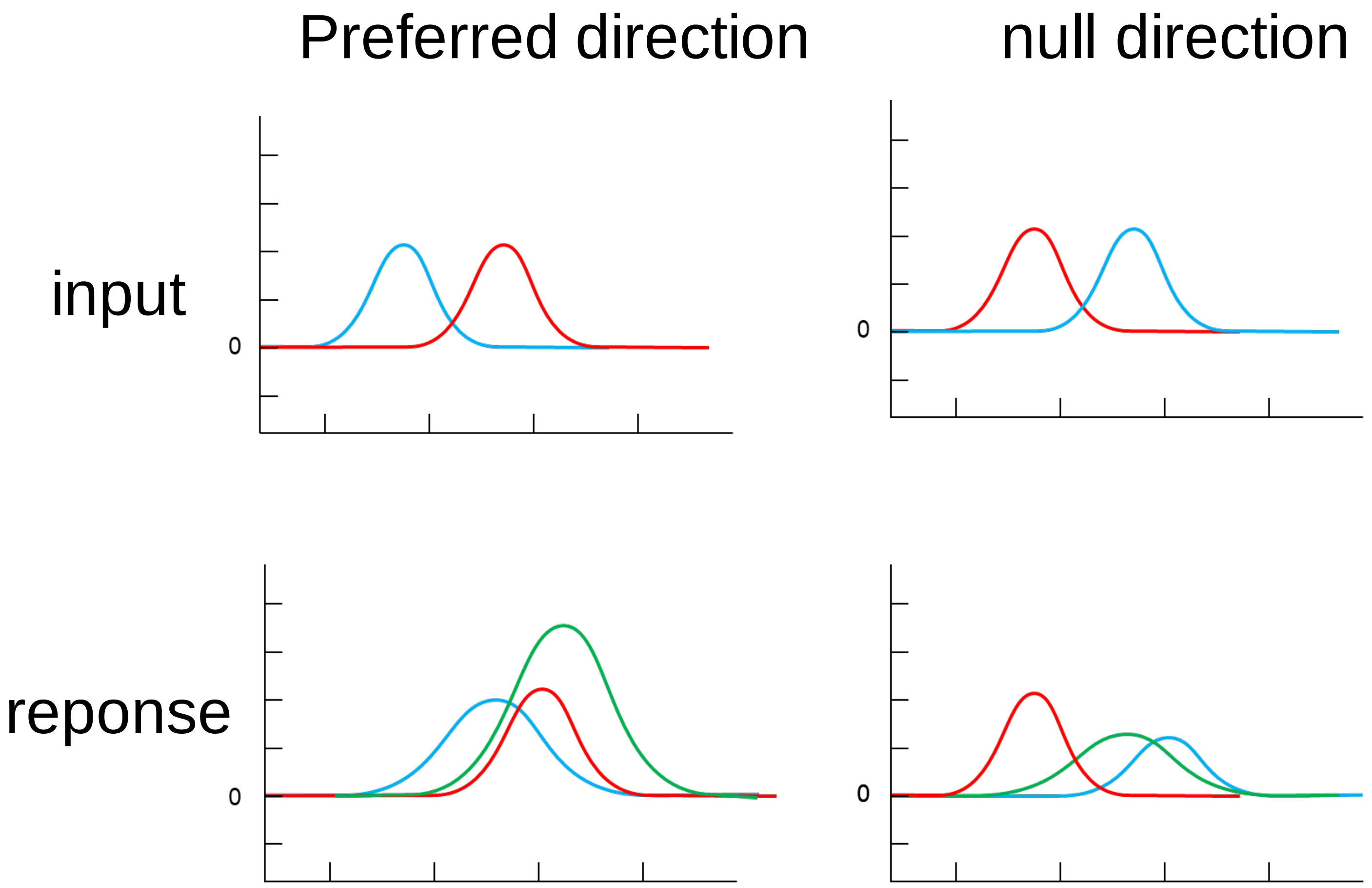
Barlow–Levick



Motion detection model and its response



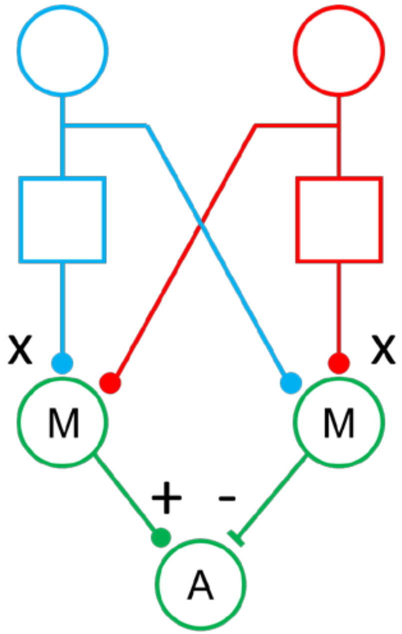
Hassenstein–Reichardt



Motion detection model and its response

Preferred direction

Null direction

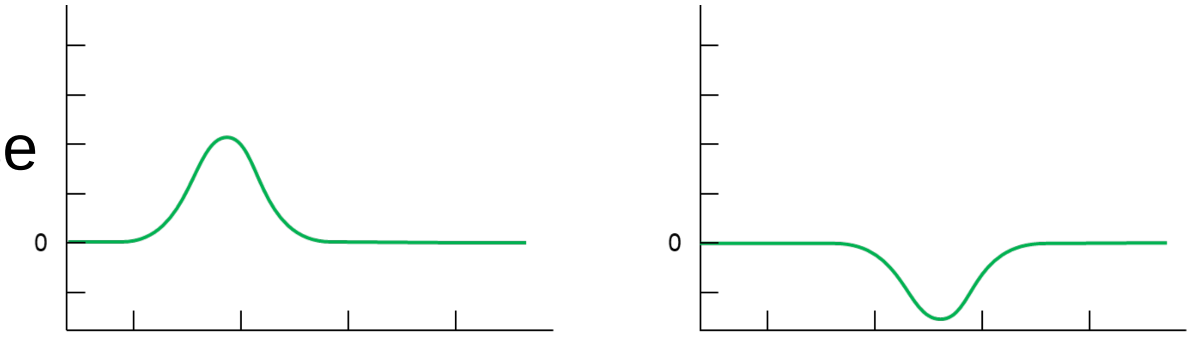


Full Hassenstein–Reichardt

Preferred direction

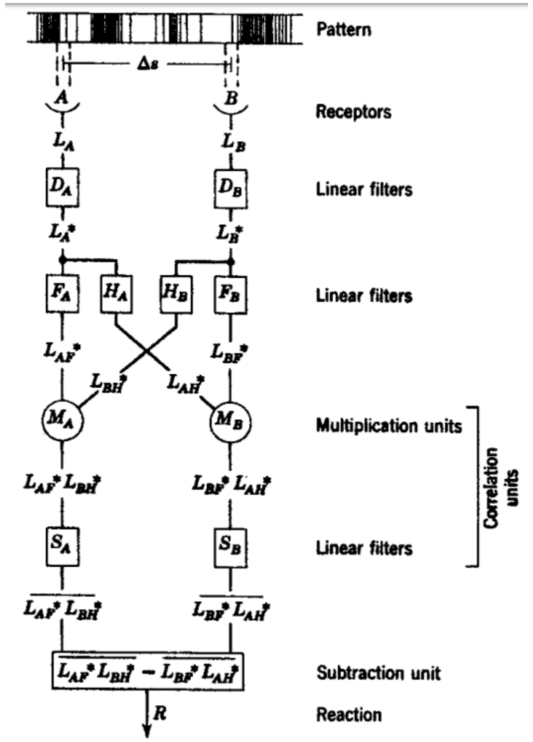
null direction

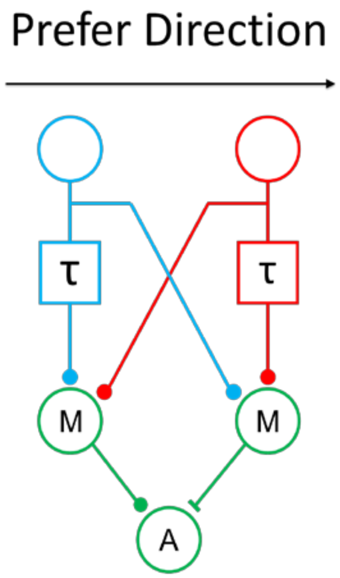
reponse



Reichardt-Hassenstein Model (1956)

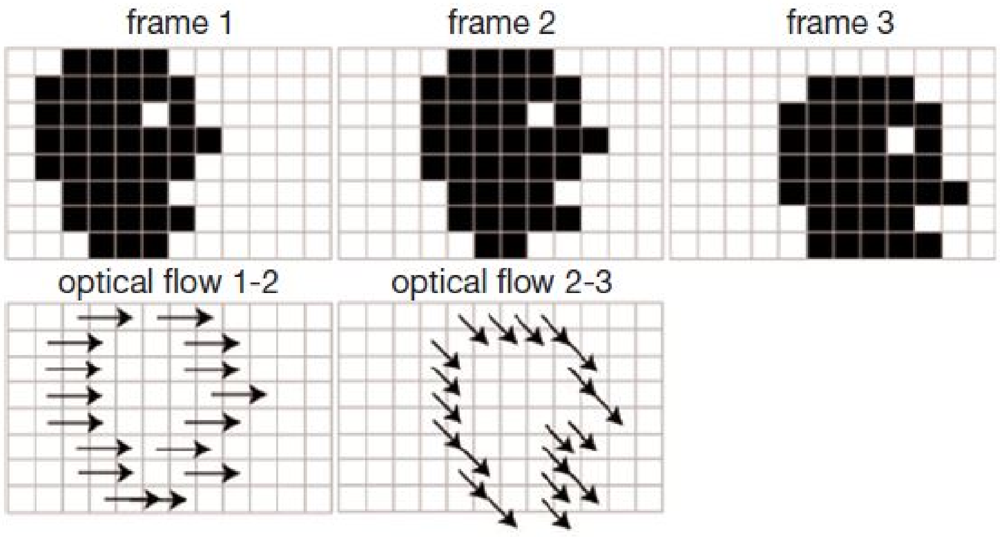
- Detect correlation between the two adjacent points.
- Consists of two symmetrical subunits.
- Computed by following processing steps:
  - Time delay with low-pass filter.
  - Multiplication other subunit.
  - Compute correlation by subtractor.





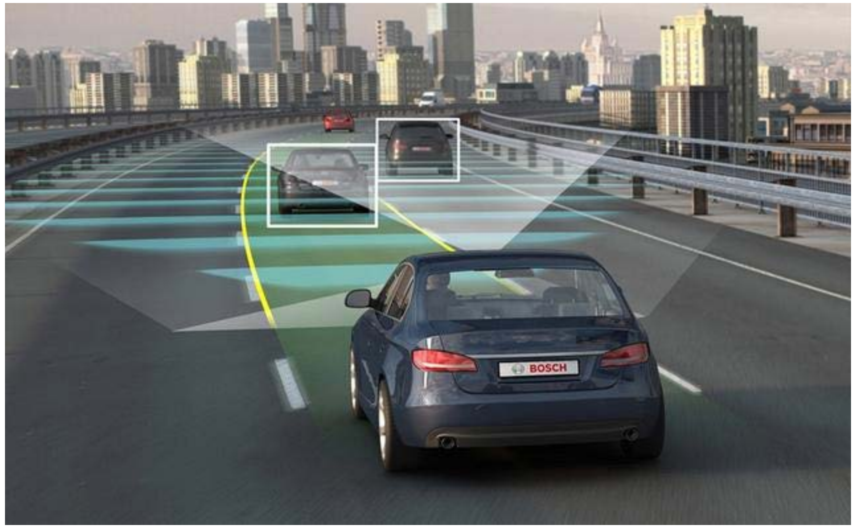
Introduction: Optical Flow

- Optical Flow (OF) describes the relative motion field caused by camera relative to the objects.
- Calculate the motion between two image frames.
- Widely use in robotic navigation control, video processing.



Motivation

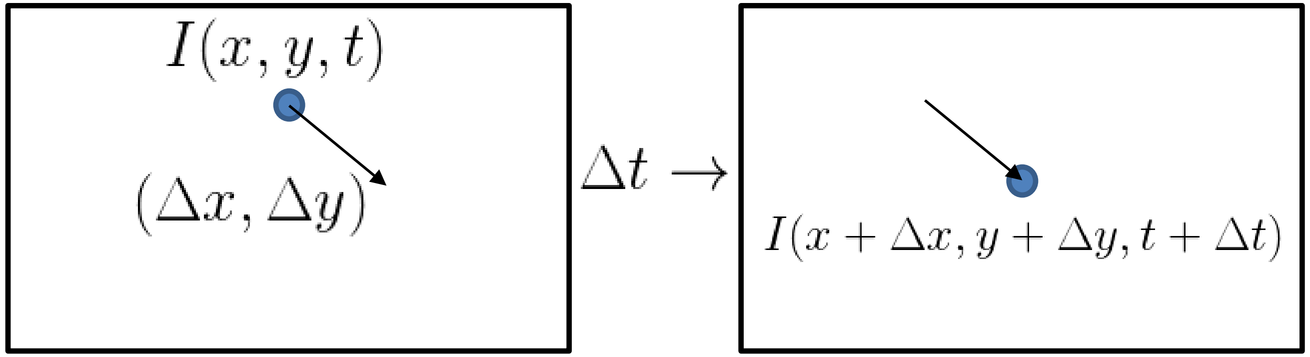
- Investigate the difference between motion detection model and optical flow.
- Design a low power consumption motion estimation method.



Preliminary: Lucas-Kanade method

- Brightness constancy constraint:
  - Constraint equation:

$$I(x, y, t) = I(x + \Delta x, y + \Delta y, t + \Delta t)$$

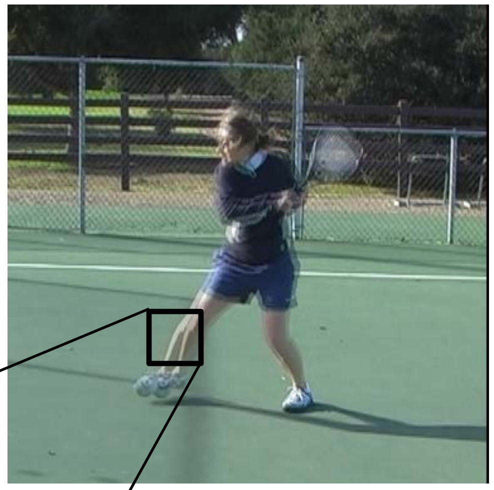


  - Take Taylor expansion:

$$I(x + \Delta x, y + \Delta y, t + \Delta t) = I(x, y, t) + \frac{\partial I}{\partial x}\Delta x + \frac{\partial I}{\partial y}\Delta y + \frac{\partial I}{\partial t}\Delta t$$

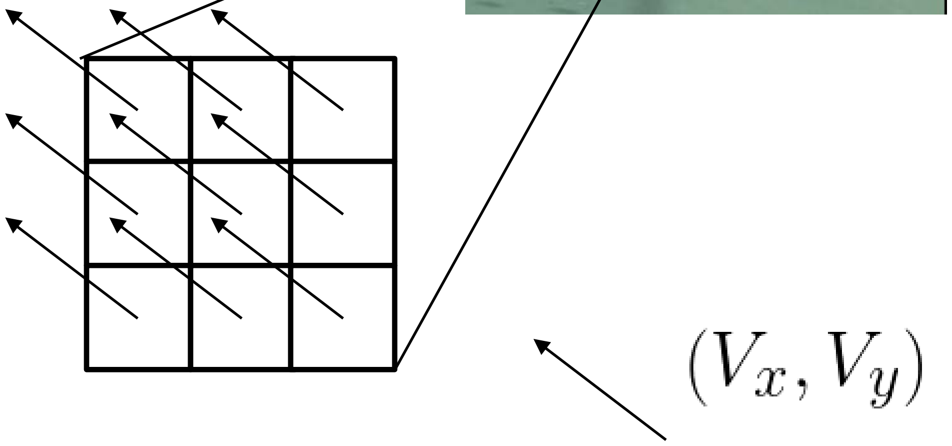
$$\boxed{I_x V_x + I_y V_y = -I_t}$$

Lucas–Kanade method



- Assumption: The flow is essentially constant in a local neighbourhood of the pixel.

$$I_x(q_1)V_x + I_y(q_1)V_y = -I_t(q_1)$$
$$I_x(q_2)V_x + I_y(q_2)V_y = -I_t(q_2)$$
$$\vdots$$
$$I_x(q_n)V_x + I_y(q_n)V_y = -I_t(q_n)$$



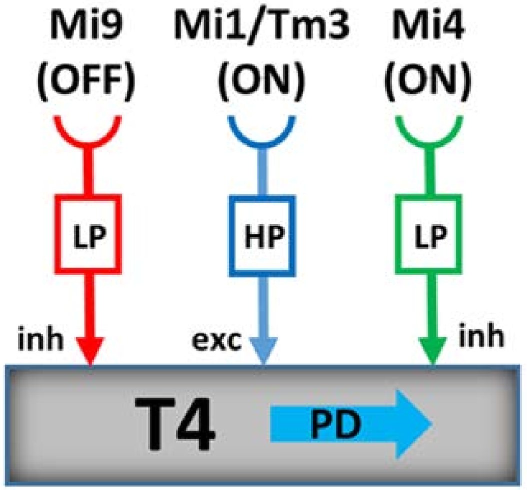
- Solved by least squares method.

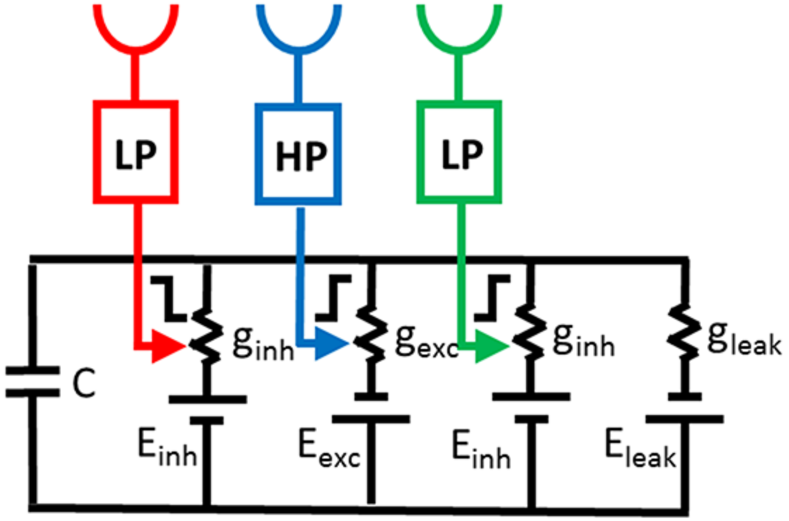
$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \sum_i I_x(q_i)^2 & \sum_i I_x(q_i)I_y(q_i) \\ \sum_i I_y(q_i)I_x(q_i) & \sum_i I_y(q_i)^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i I_x(q_i)I_t(q_i) \\ -\sum_i I_y(q_i)I_t(q_i) \end{bmatrix}$$

Preliminary: Borst's Model(2018)

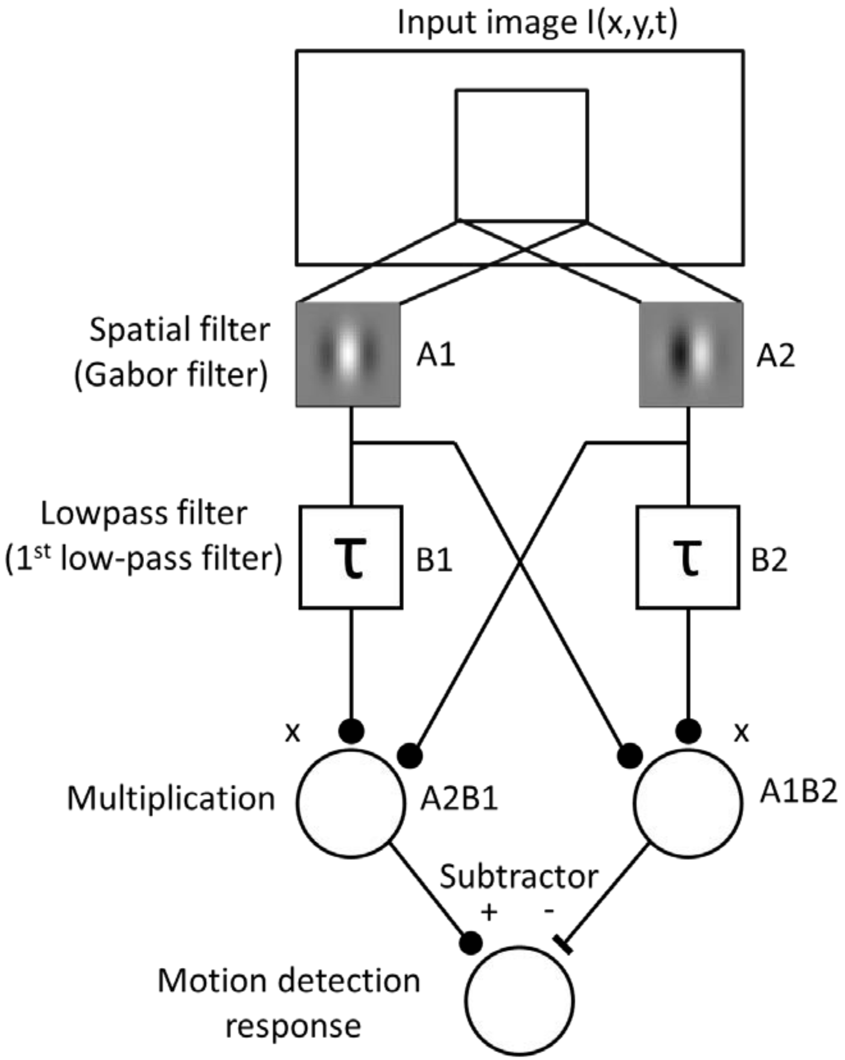
- Biophysics model base on connectome data.
- Describe as a passive membrane circuit.
- Visual signal process through high-pass and low-pass filter.

$$V_m = \frac{E_{exc} g_{exc} + E_{inh} g_{inh}}{g_{exc} + g_{inh} + g_{leak}}$$



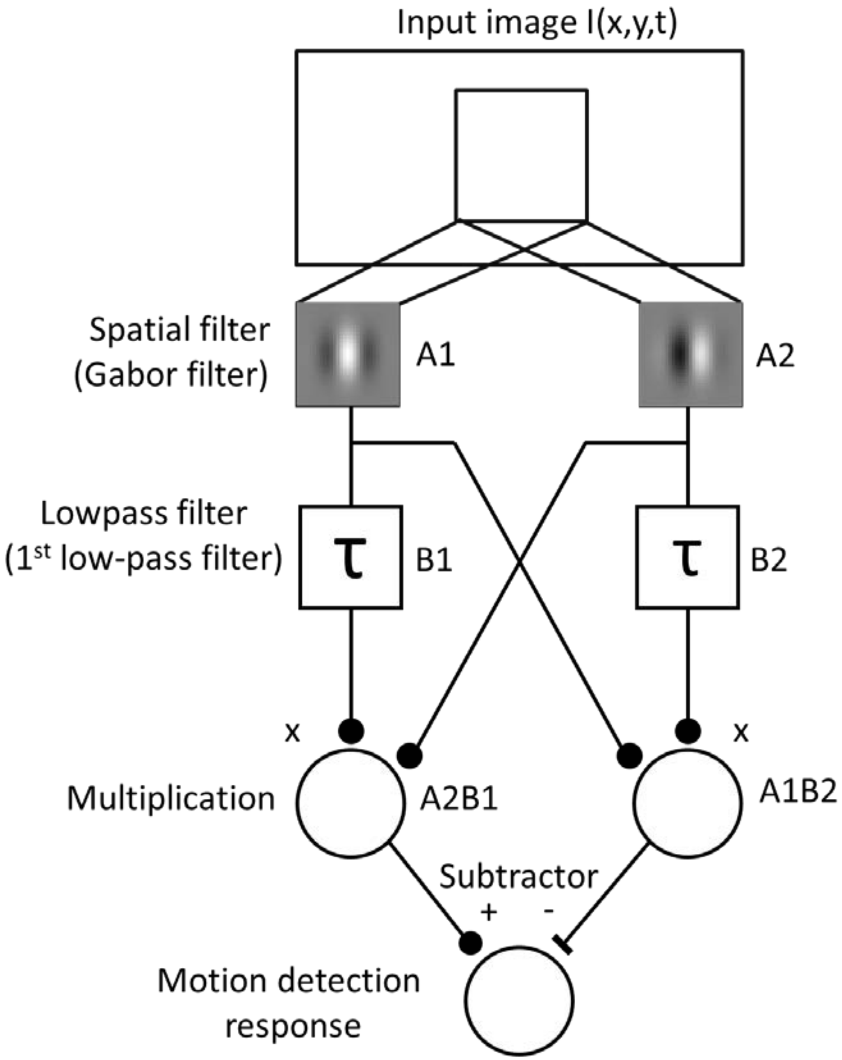


Spatial-temporal filter Reichardt (STR) model

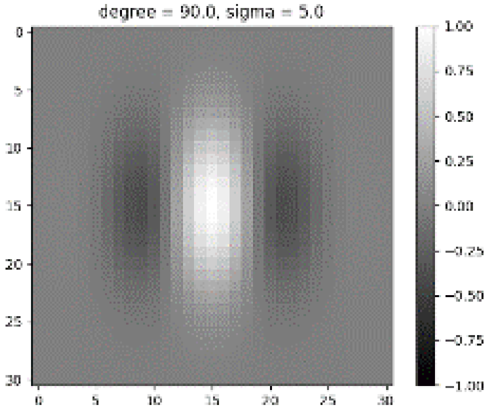


- (1) Spatial filter with Gabor filter.
- (2) Time-delay by 1st low-pass filter.
- (3) Correlation by multiplication.
- (4) Subtractor to computer motion response.

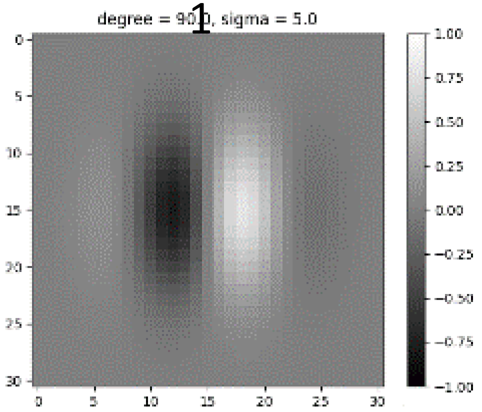
Spatial filter – Gabor function



A1



A2
1



$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = \exp(-\frac{x'^2 + \gamma^2 y^2}{2\sigma^2}) \cos(2\pi \frac{x'}{\lambda} + \psi)$$

λ: sinusoidal wave
θ: orientation of Gabor function.
ψ: the phase of sinusoidal function
σ: standard deviation of the Gaussian function
γ: ellipticity

Spatial-temporal filter Reichardt (STR) model

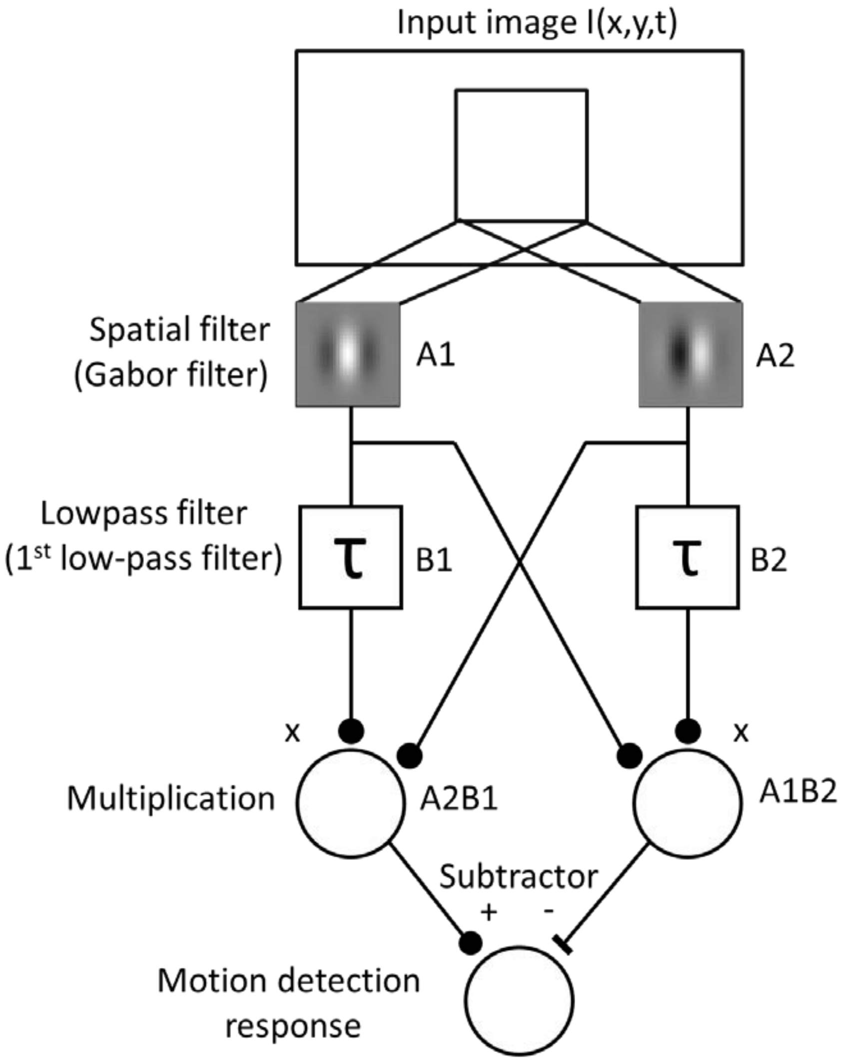


Image processed by Gabor filter

$$A(x, y, t) = I(x, y, t) * g(x, y)$$

temporal filter – 1st lowpass filter

$$B(t) = A(t)/\tau + (1\tau)B(t-1)$$

Multiplication and Subtractor

$$R(t) = A_2(t) \cdot B_1(t) - A_1(t) \cdot B_2(t)$$

Design a STR model with velocity selectivity

- Low-pass filter have cutoff frequency

$$f_c = \frac{1}{2\pi\tau_a}$$

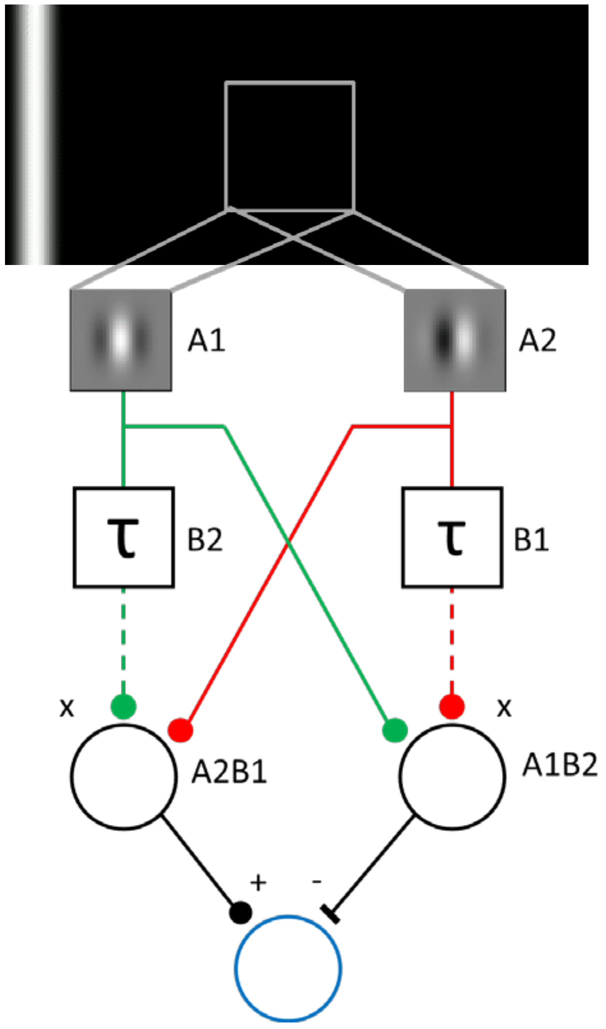
- In digital filter time constat

$$\tau_a = \frac{T_s(1-\tau)}{\tau}$$

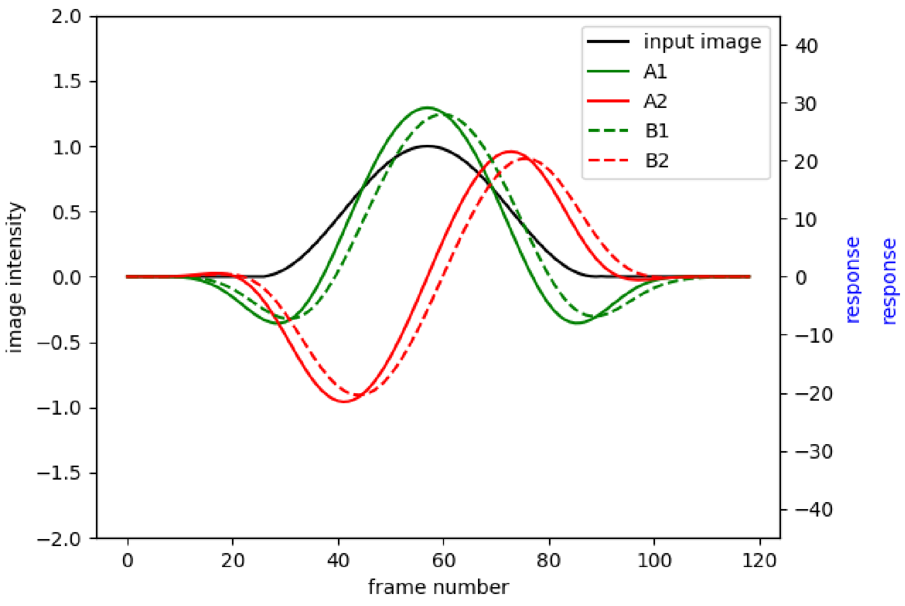
- Velocity $v = \dfrac{f_t}{f_x}$ STR model with velocity selectivity $v = \dfrac{\lambda_g \tau}{2\pi T_s(1-\tau)}$

Internal response and output -Prefer direction

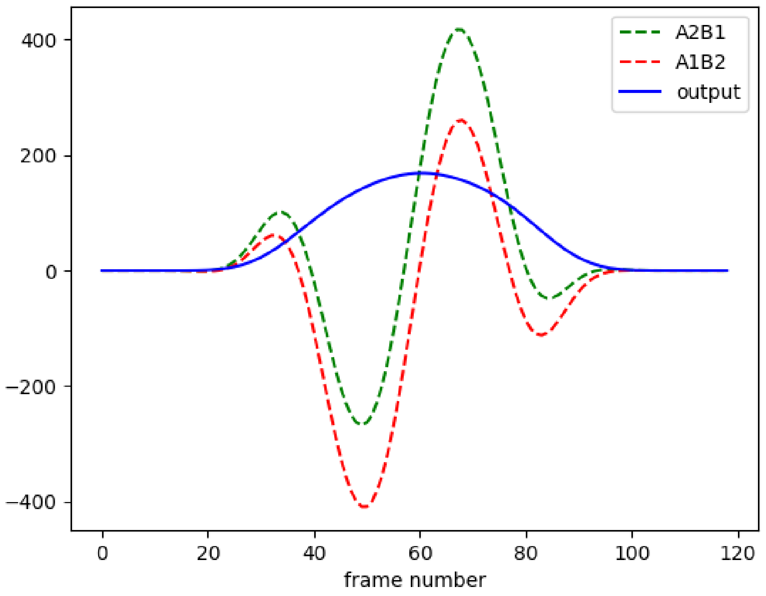
Visual stimuli input



Internal response

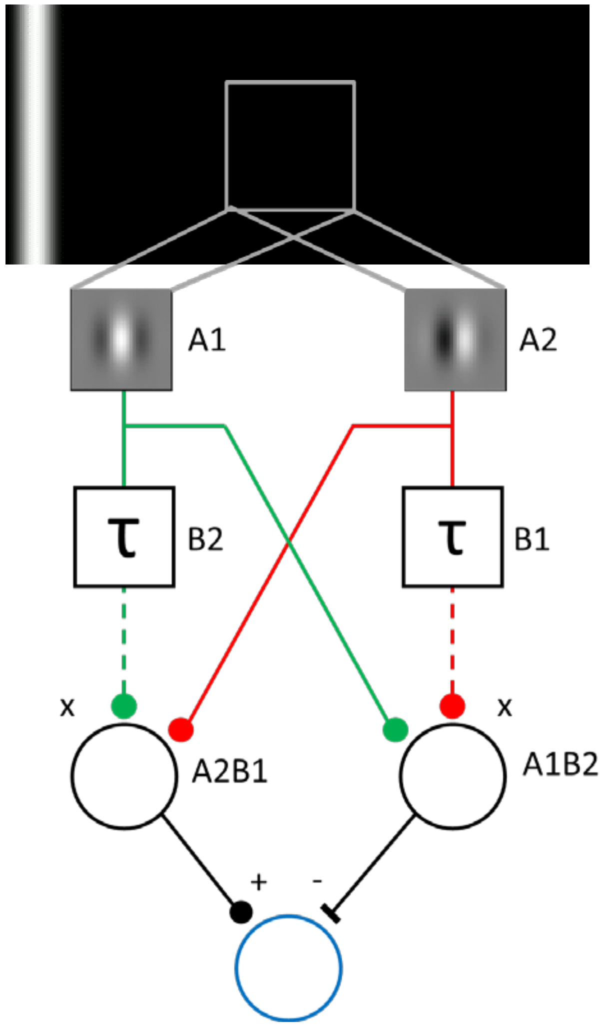


output

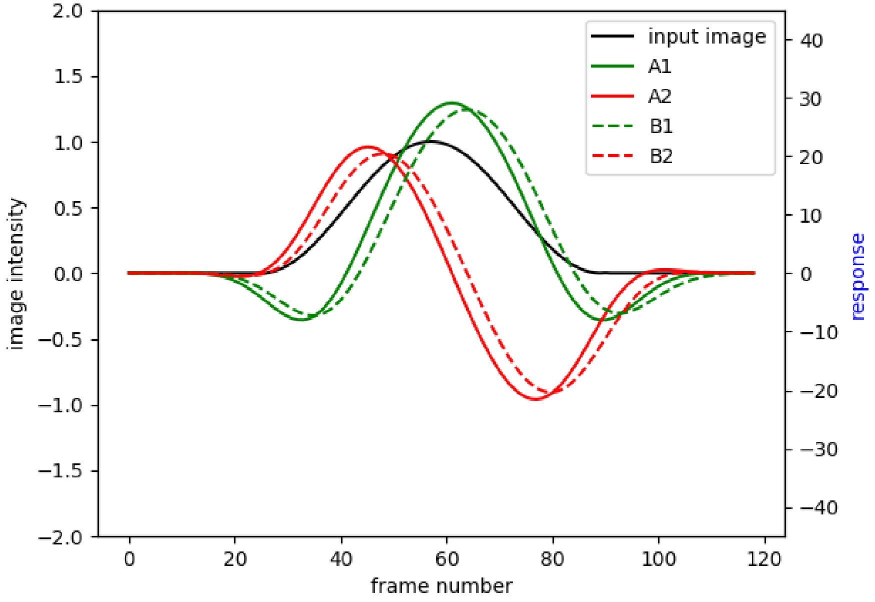


Internal response and output -null direction

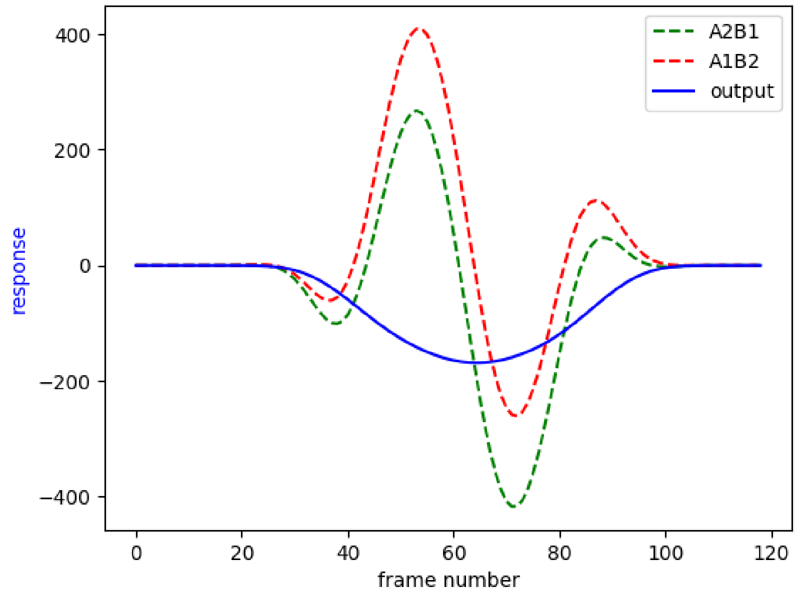
Visual stimuli input



Internal response

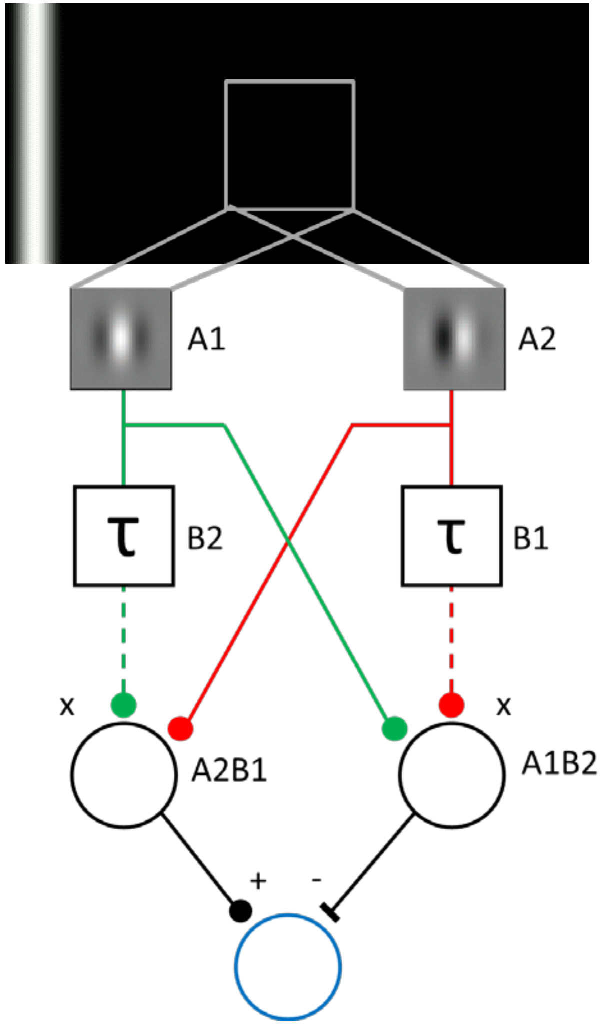


output

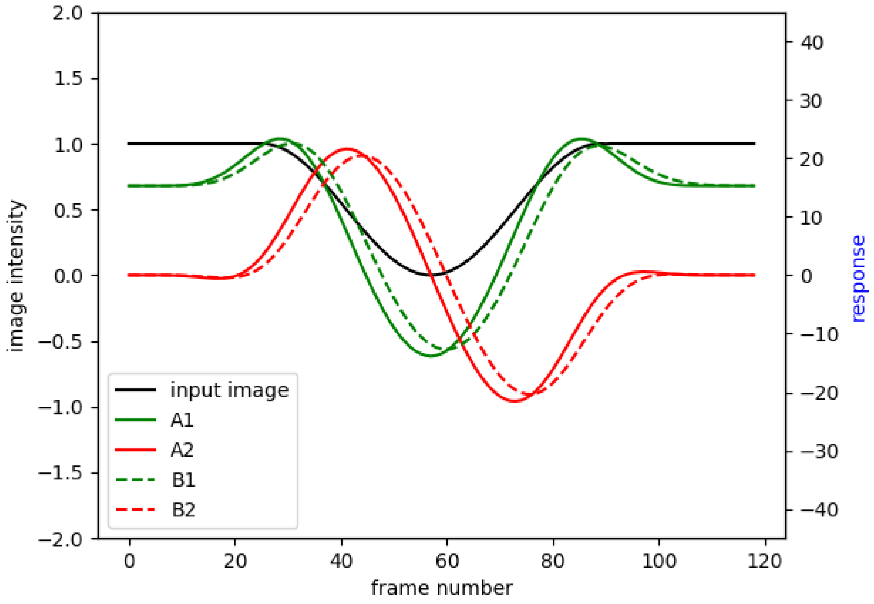


Internal response and output -Prefer direction

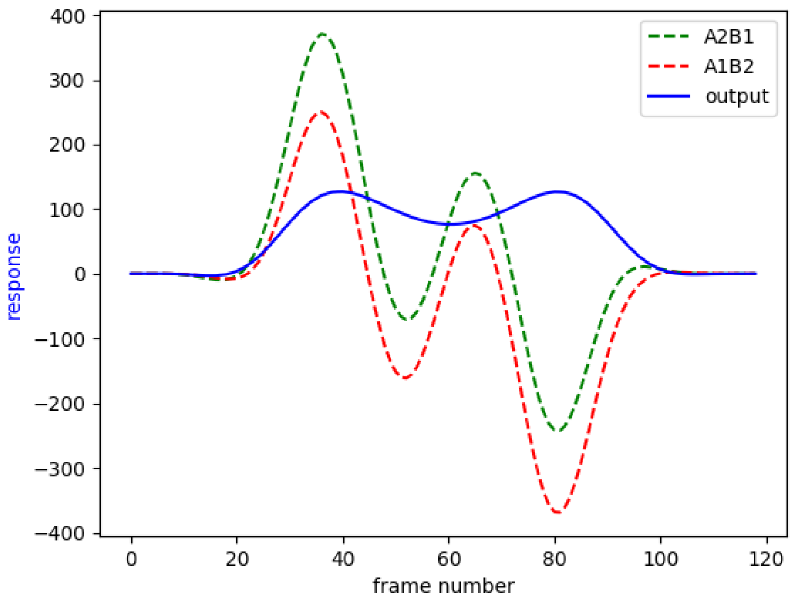
Visual stimuli input



Internal response

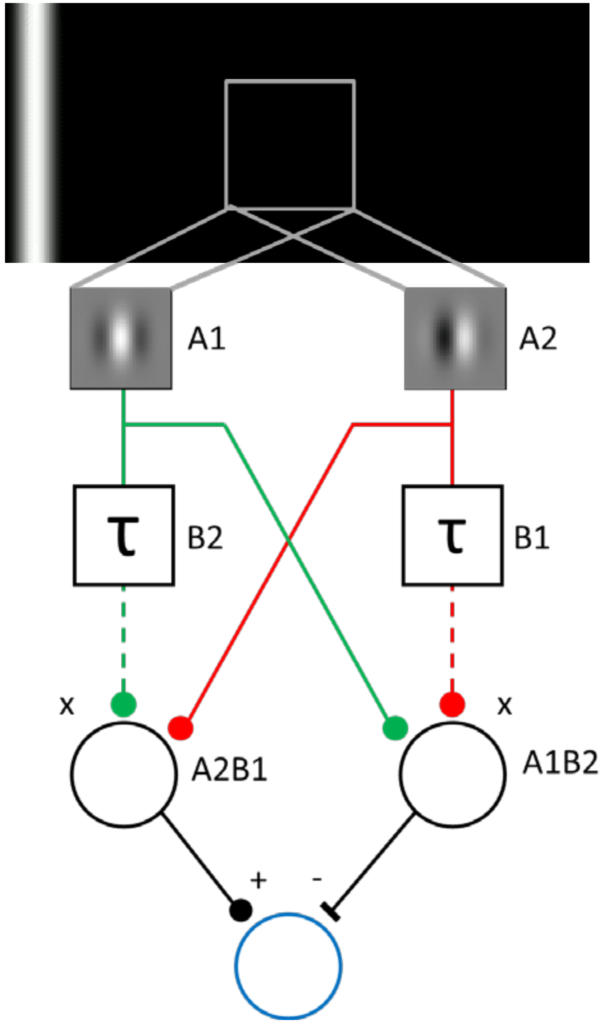


output

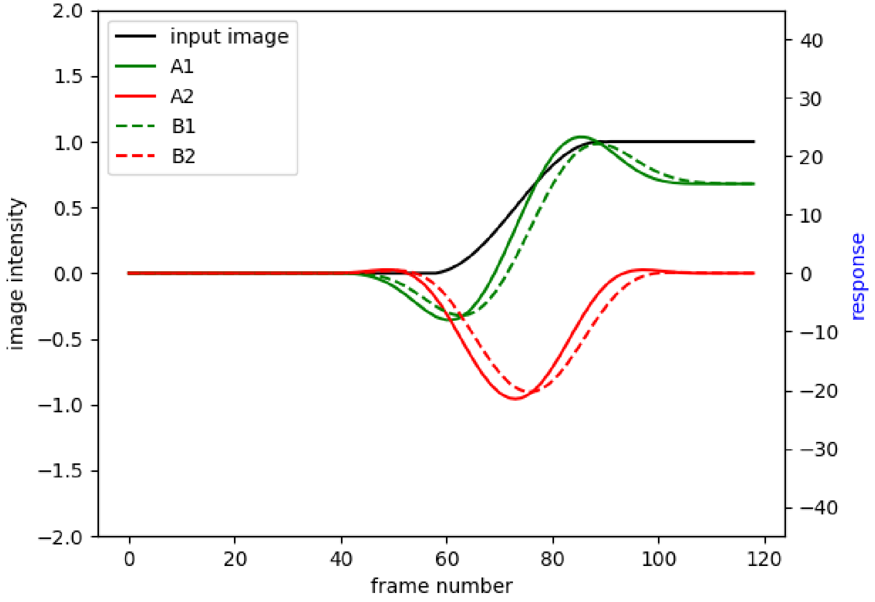


Internal response and output -Prefer direction

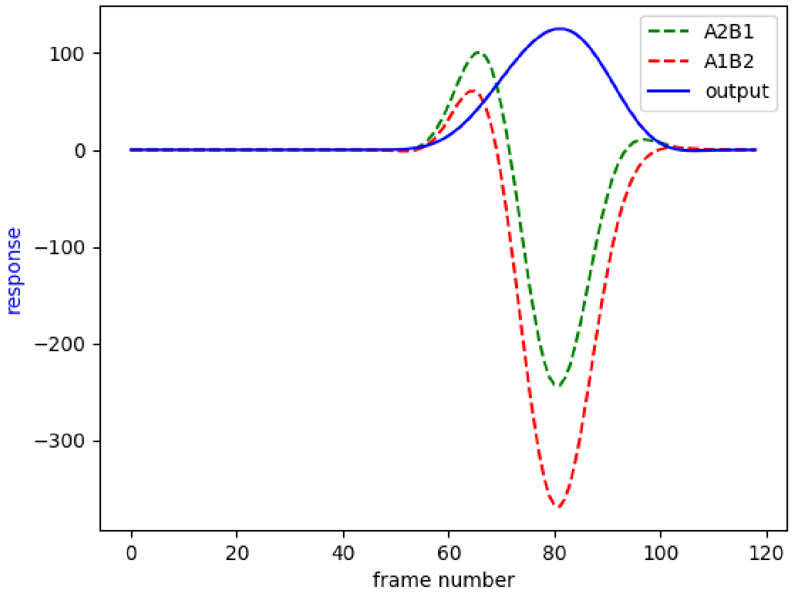
Visual stimuli input



Internal response



output

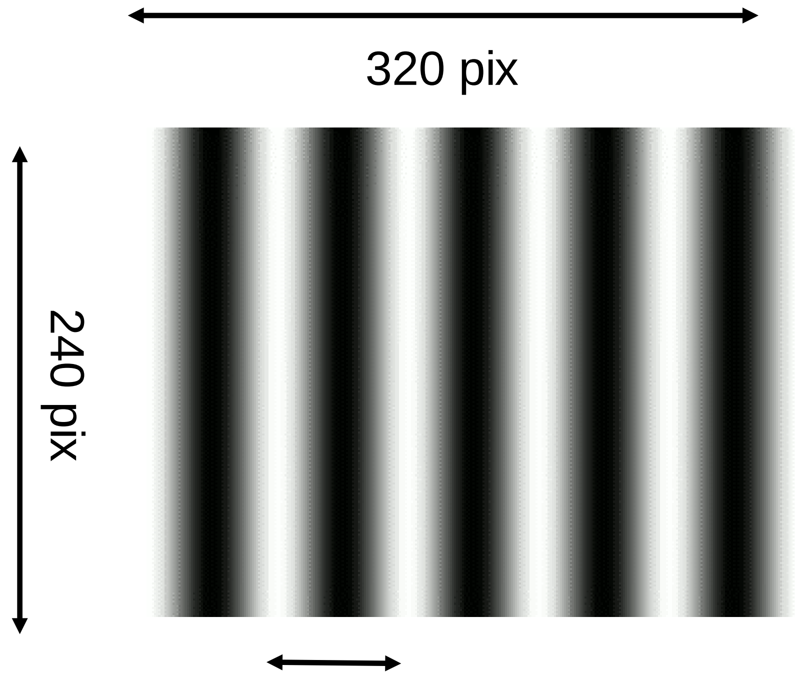


Visual Stimulus Method

- We apply 320 x 240 sine grating video.
- Velocity (pixel per frame) equals the temporal frequency divided by the spatial frequency.

$$v = \frac{f_t}{f_x}$$

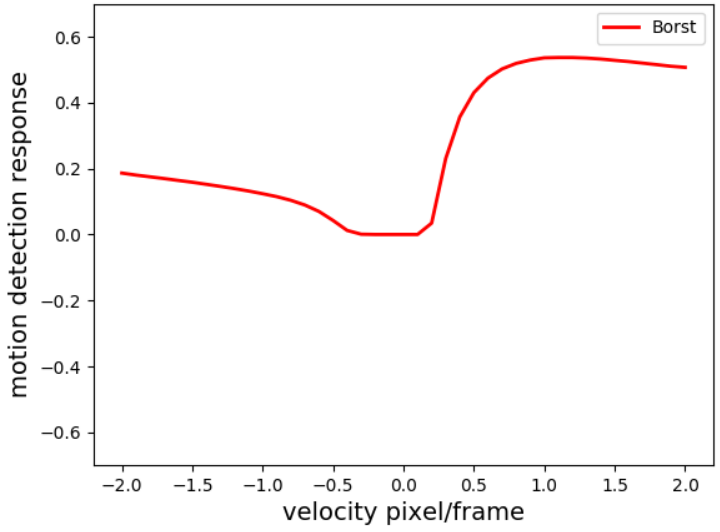
	Range
temporal frequency (f_t)	2^{-10}~2^{-1}(1/frame)
spatial frequency (f_x)	2^{-7}~2^{-2}(1/pixel)
velocity(v)	2^{-6}~2^{4}(pixel/frame)



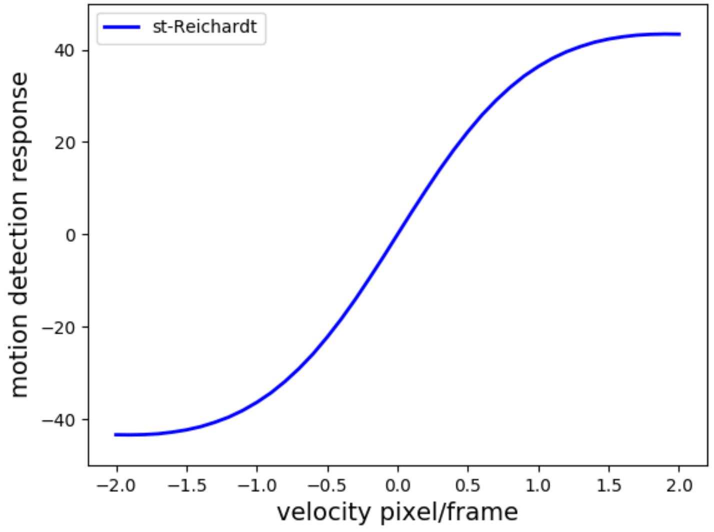
$$f_x = \frac{1}{\lambda}$$

Linearity of each method

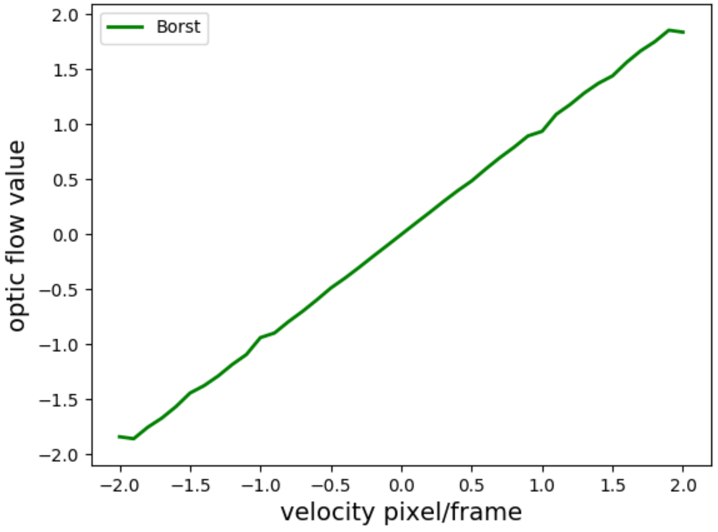
Borst’s model



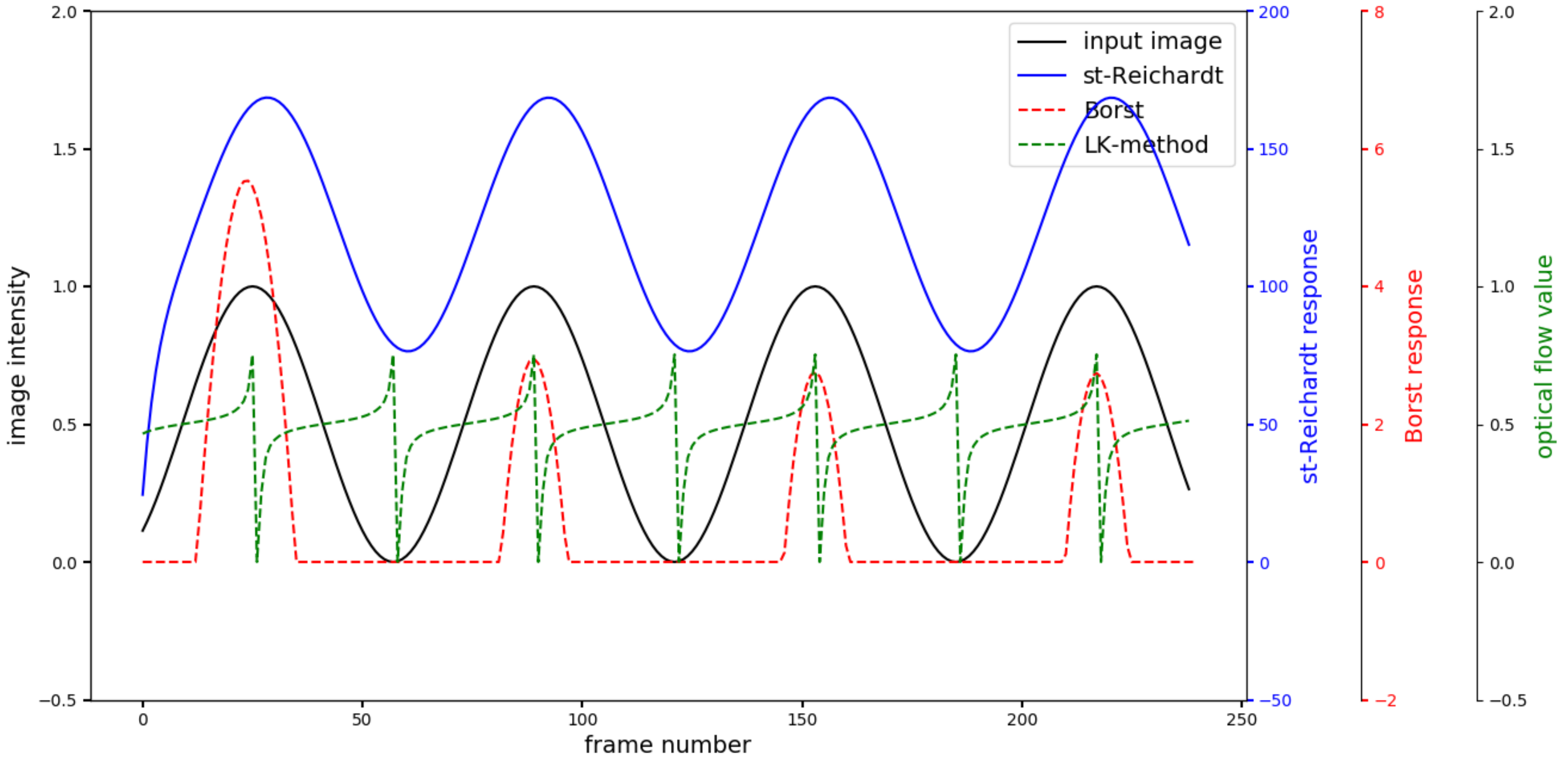
Reichardt model



LK-method model



Response of each method



Working dynamic range of each method

Borst’s model

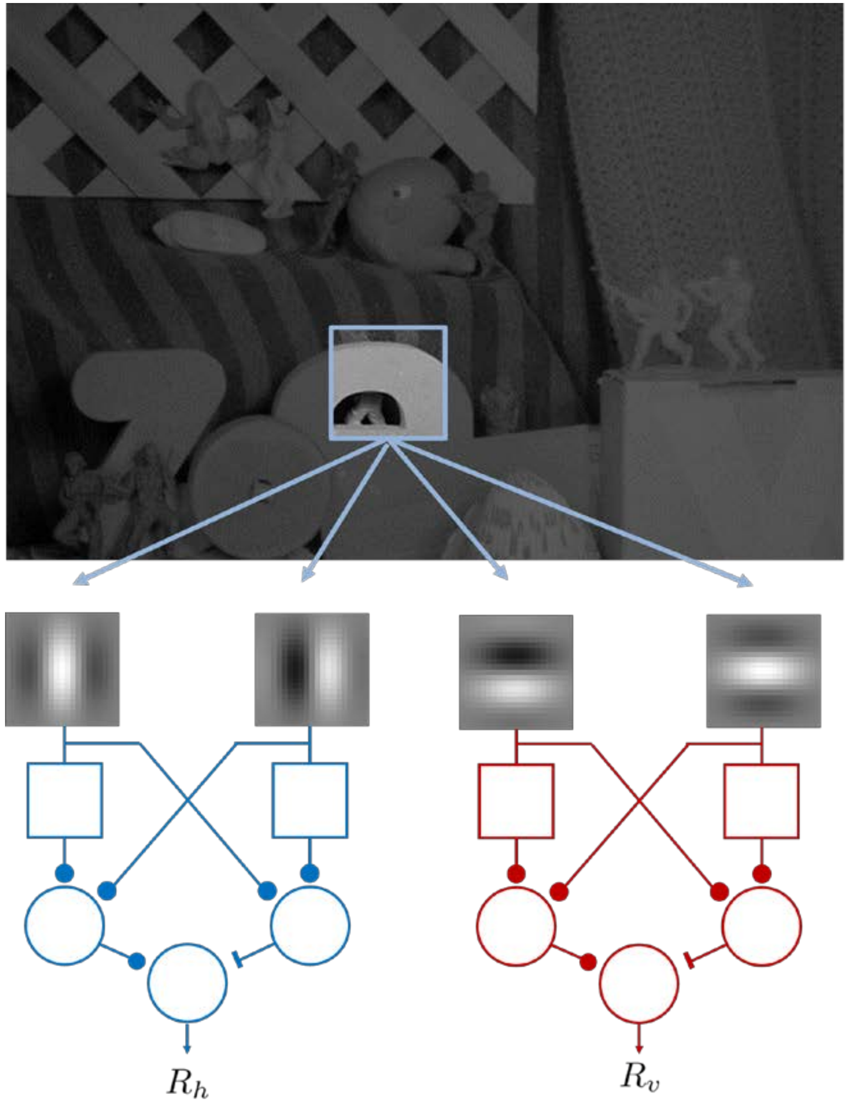
Reichardt model

LK-method model

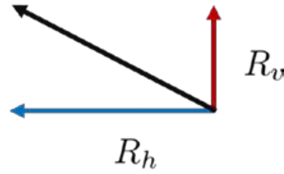
Velocity selectivity of STR model

Testing with real image sequence

- Use two STR model to estimate vertical and horizontal motion



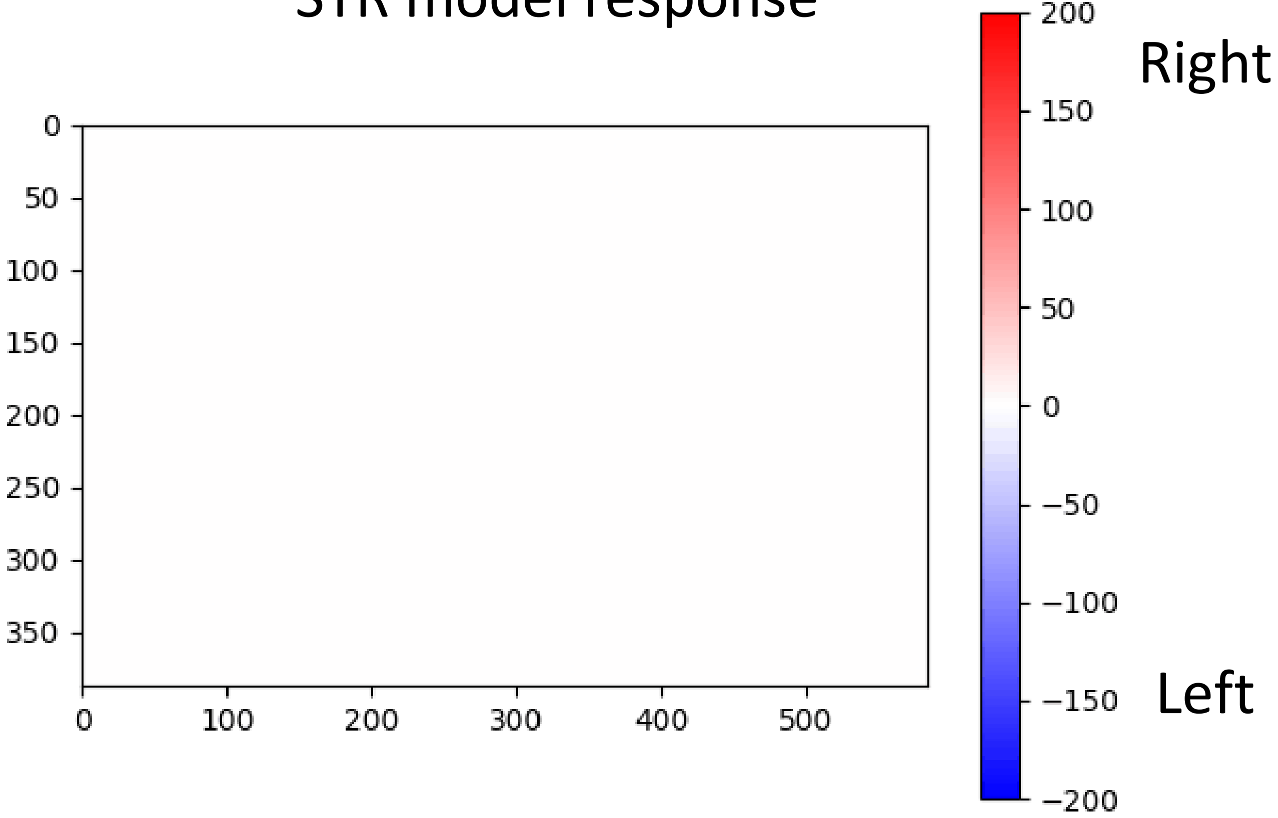
Motion estimation



Motion detection with real image

Original image

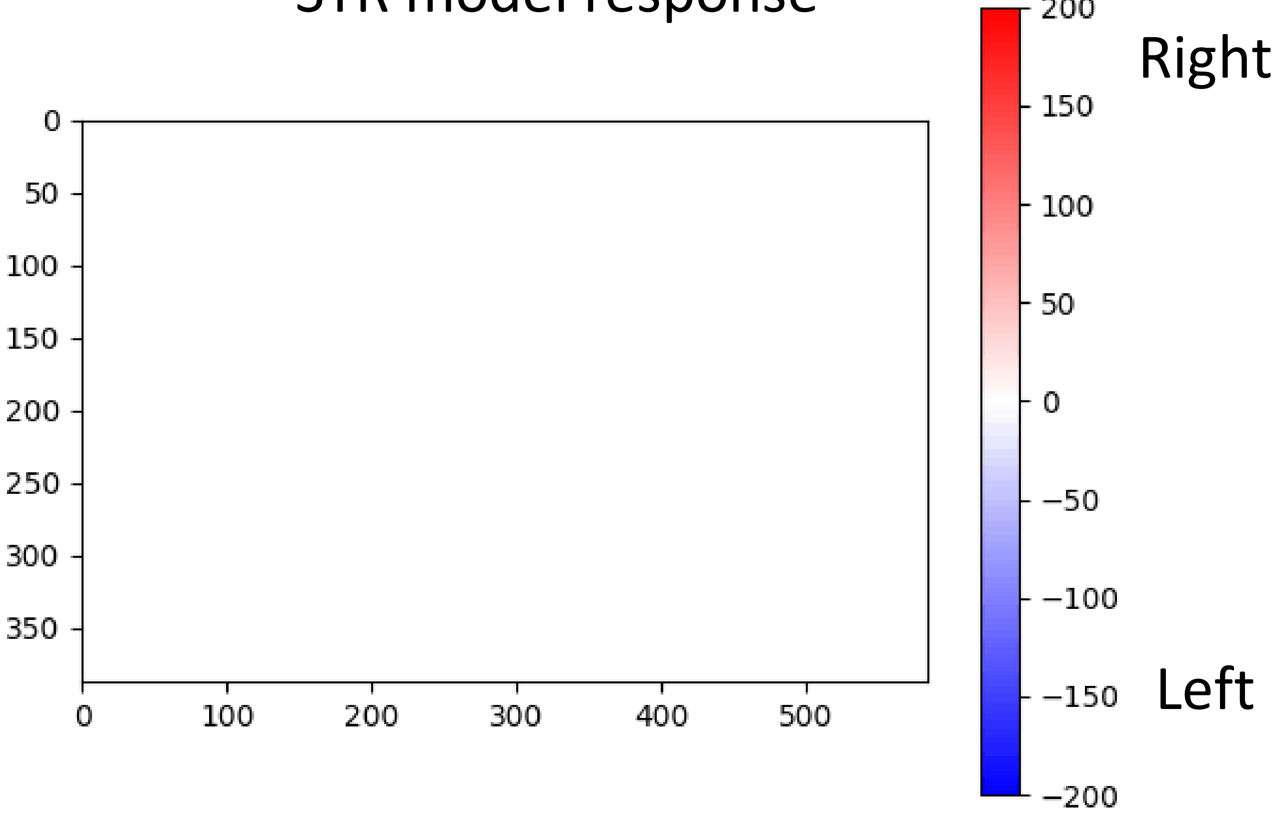
STR model response



Motion detection with real image

Original image

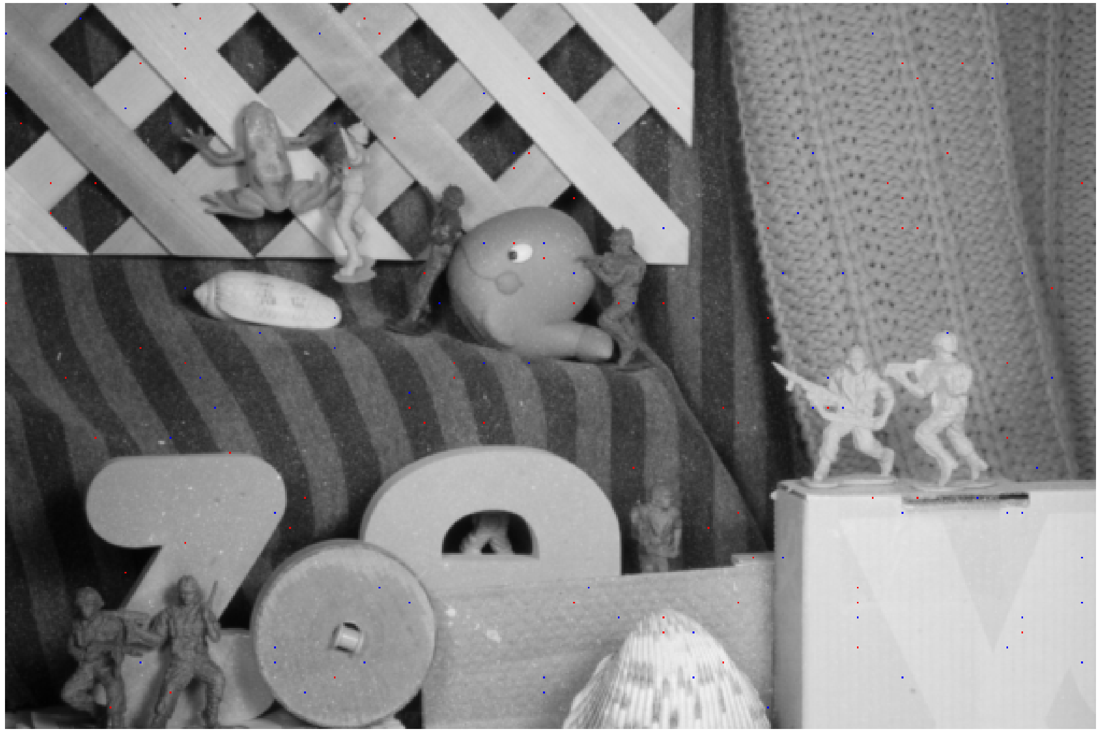
STR model response



Motion detection with real image

Original image

STR model response



Time complexity analyze

A m x n image with window size w

Solution of Lucas-Kanade method:

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \sum_i I_x^2 & \sum_i I_x I_y \\ \sum_i I_y I_x & \sum_i I_y^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i I_x I_t \\ -\sum_i I_y I_t \end{bmatrix}$$

the time complexity is $O(5mnw^2)$

For a STR model, calculating Gabor filter with window size w, the the time complexity is $O(4mnw^2)$

Discussion

- Drawback:
  - Brightness contrast effect the accuracy of detection model .
  - Low frame rate cause the distortion
- Different from optical flow, motion detection model response at a rage of spatiotemporal frequency.
- Have higher efficiency, suitable parallel computing.

Acknowledgement

Thanks for listening!

Speaker: Wei-Tse Kao
Advisor: Chung-Chuan Lo
Date: 2019.12.23

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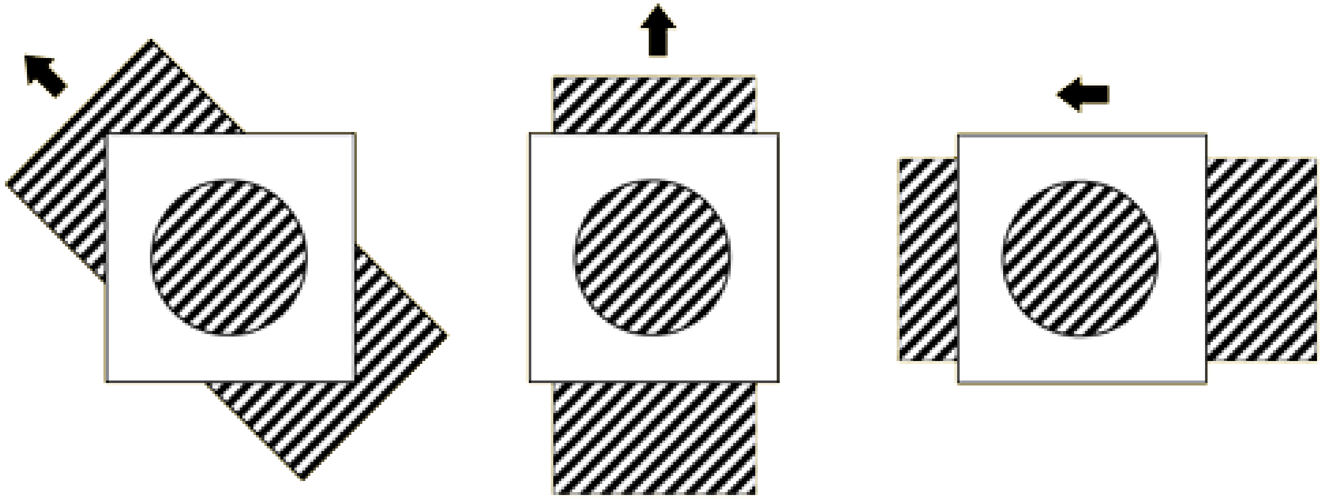
Limitation of optical Flow: Aperture Problem

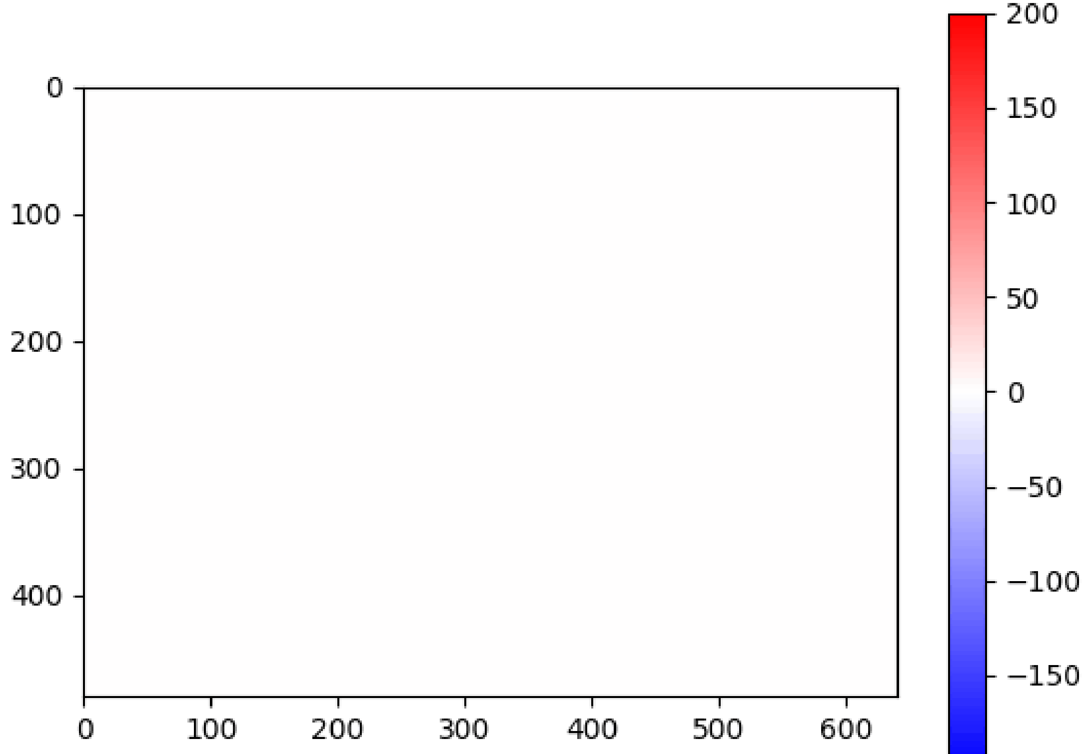
- The motion of a one-dimensional spatial structure cannot be determined unambiguously if it is viewed through a small aperture.



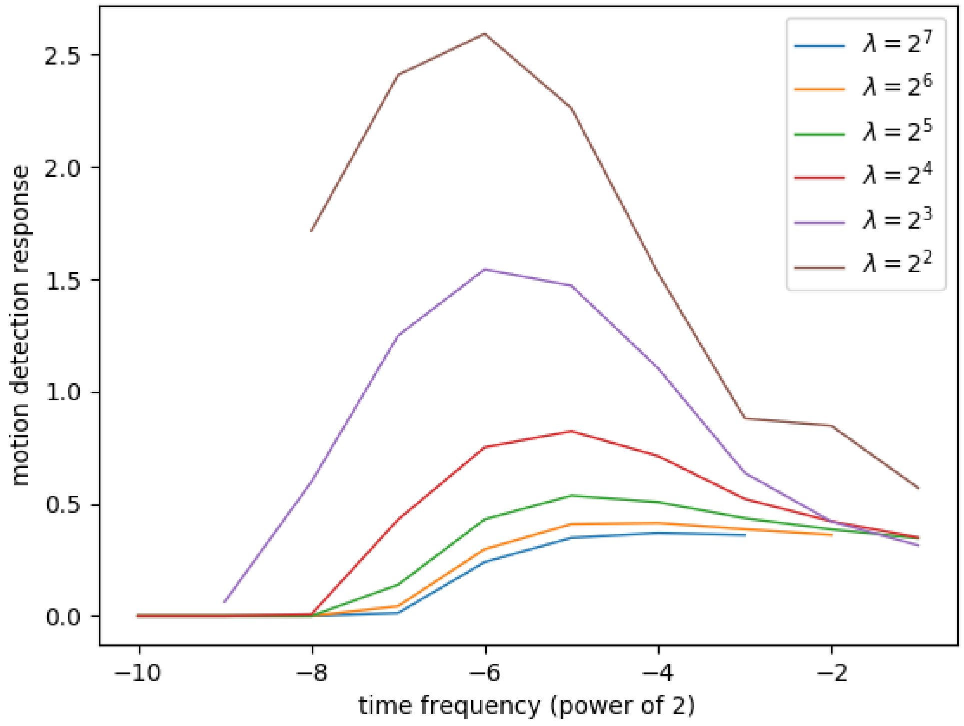
Motion detection with real image

Original image

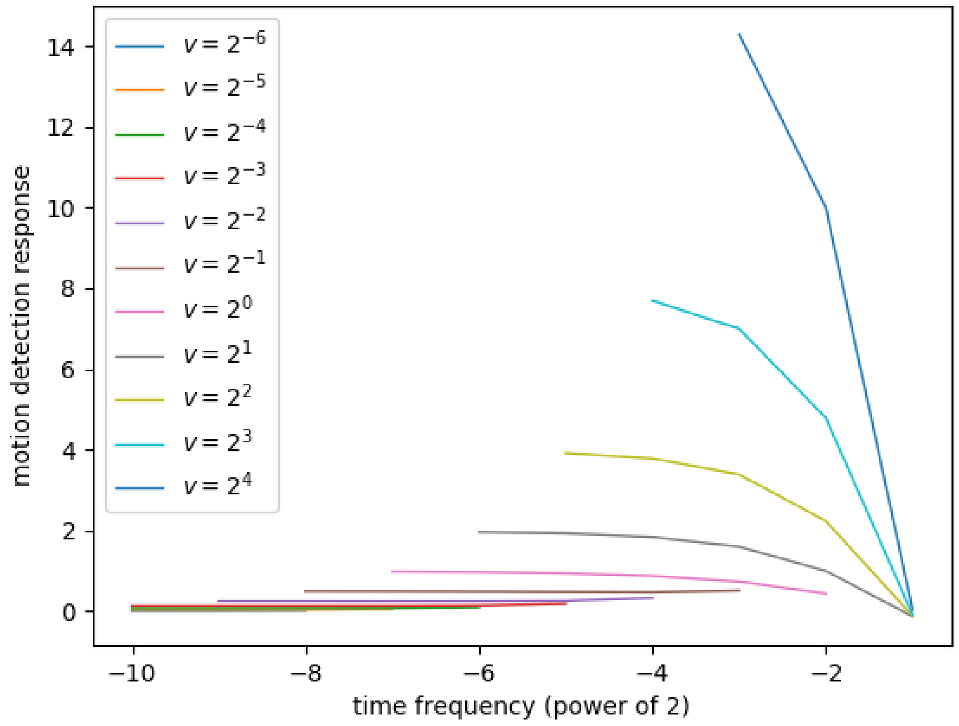
RH model response



Result 1: Motion Detection V.S. Optical Flow (wavelength)



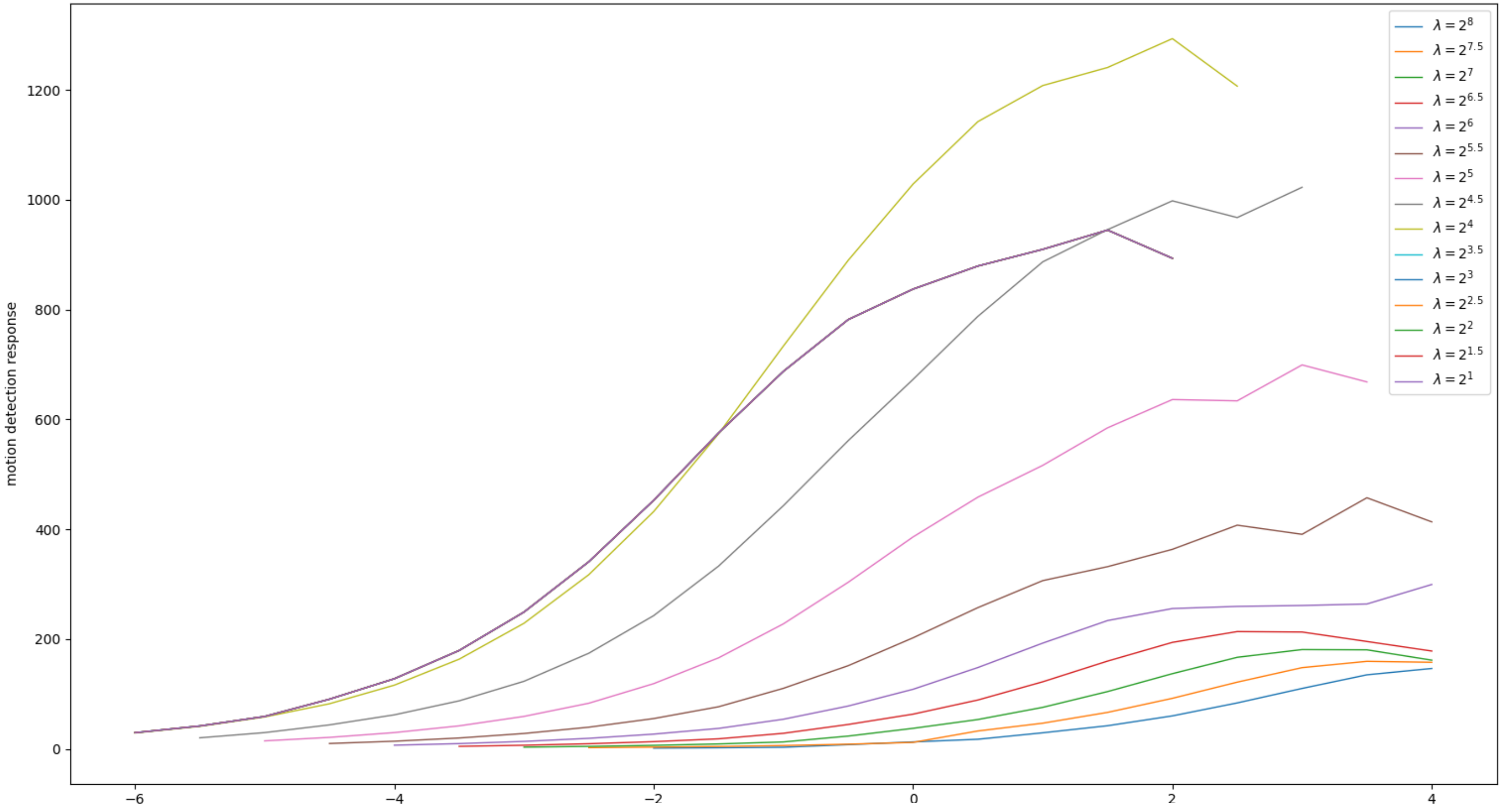
Borst's model



Normal flow

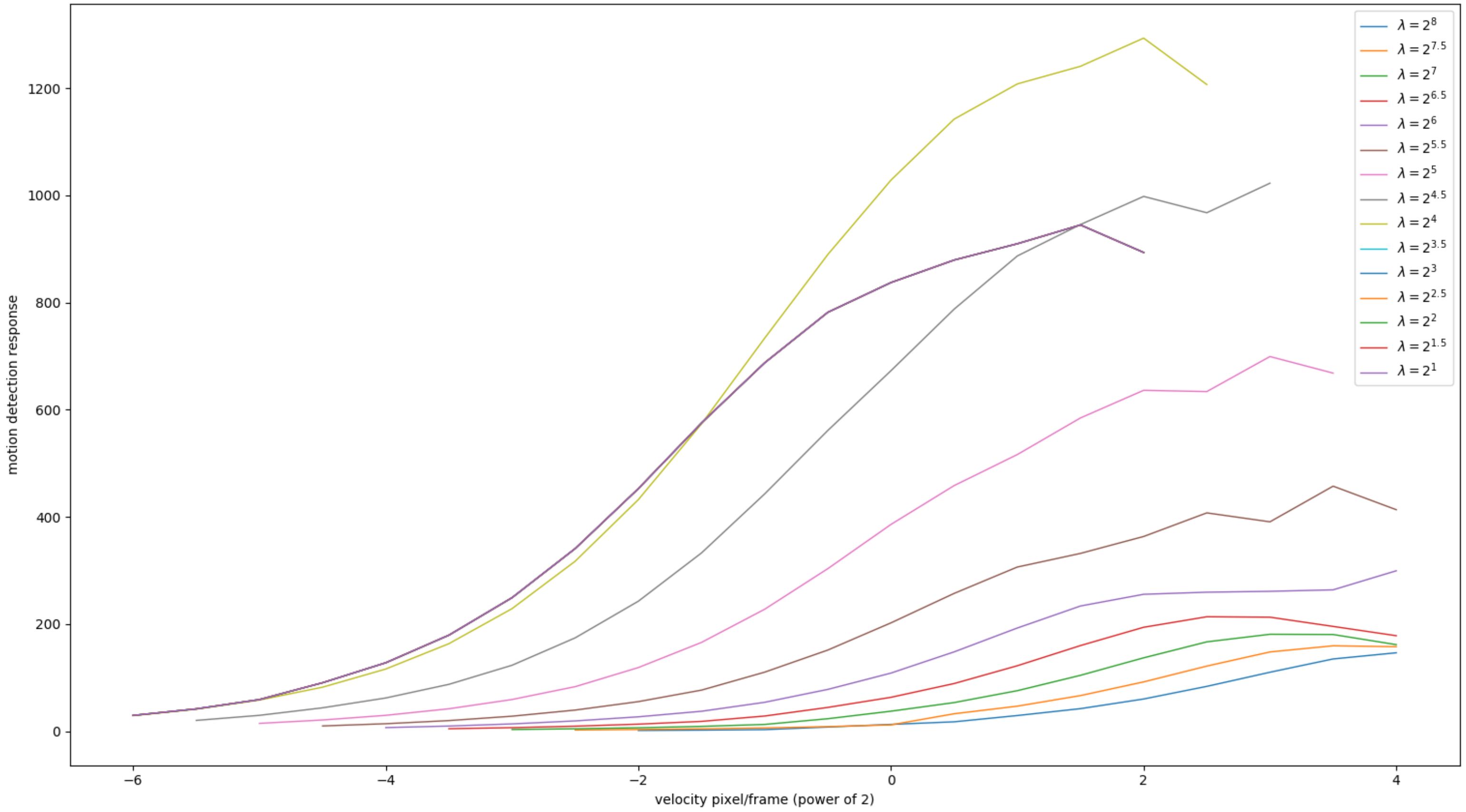
Result 1: Motion Detection V.S. Optical Flow (wavelength)

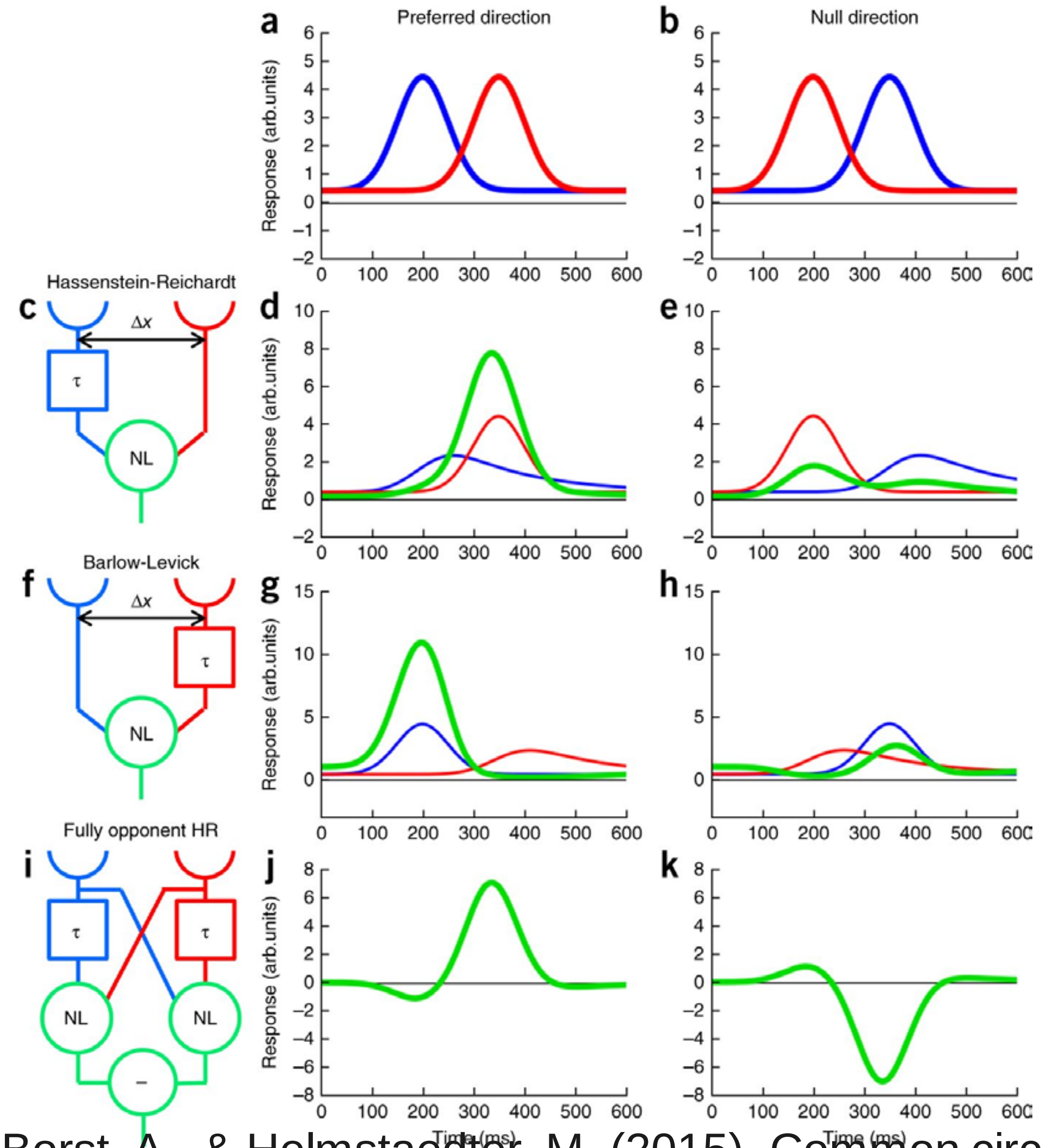
Response



Velocity (pixel/frame power of 2)

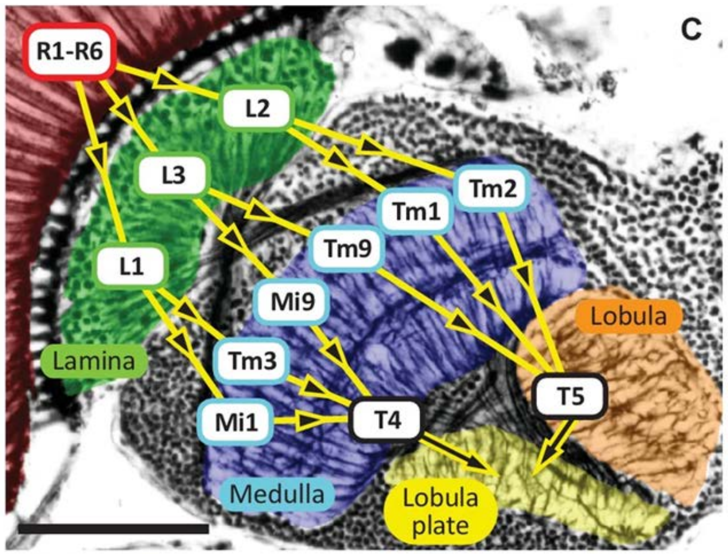
Result 1: Motion Detection V.S. Optical Flow (wavelength)



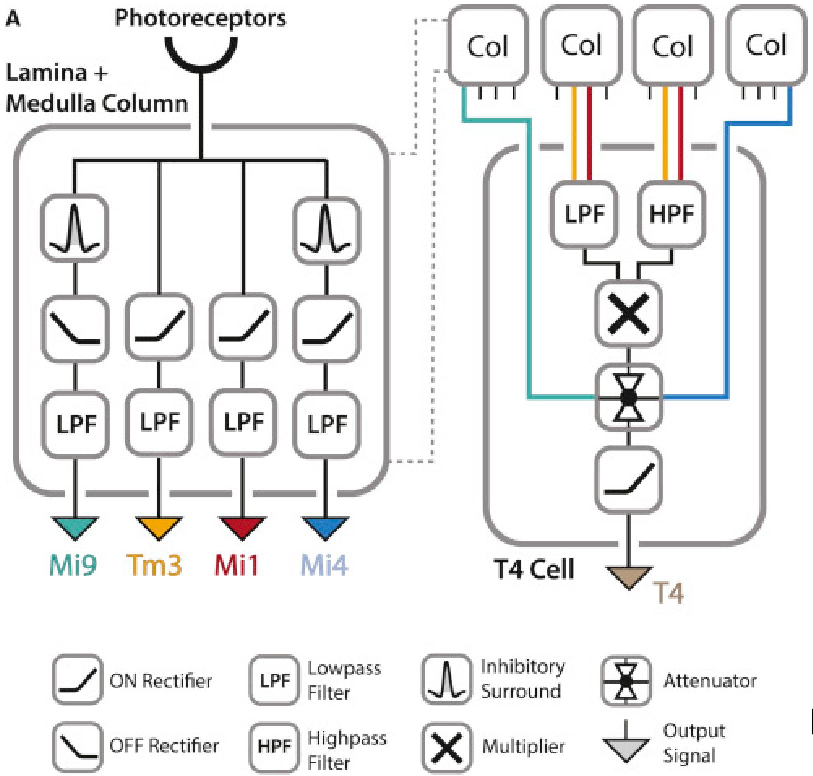


Borst, A., & Helmstaedter, M. (2015). Common circuit design in fly and mammalian motion vision. *nature neuroscience*, *18*(8), 1067.

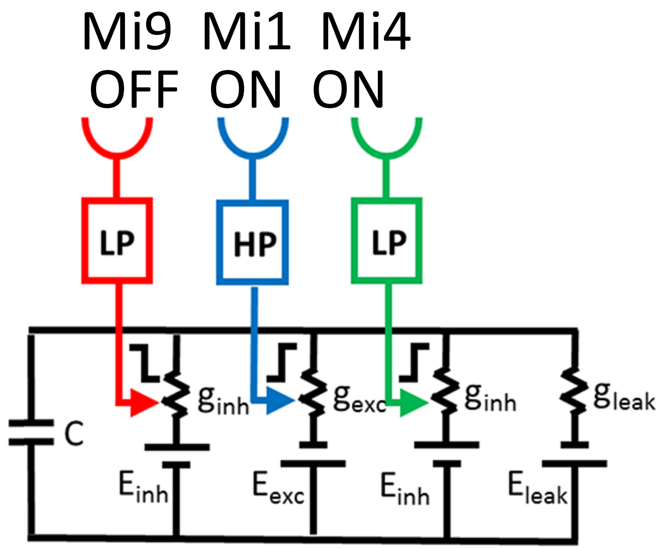
Motion Detection Model: Borst(2018) and Strother, et al(2017).



Takemura, Shin-ya, et al. Elife 6 (2017)



Strother, A. et al. *Neuron*, **14(6)** (2017).



Borst, A. et al. *PLoS computational biol*, **14(6)** (2018).