



HAL
open science

How does lateral inhibition shape the response to moving stimuli ?

Bruno Cessac

► **To cite this version:**

Bruno Cessac. How does lateral inhibition shape the response to moving stimuli?. Latin Americal Summer School in Computational Neuroscience (LACONEU), Valparaiso, Chile, Jan 2025, Valparaiso (Chile), Chile. hal-04920942

HAL Id: hal-04920942

<https://inria.hal.science/hal-04920942v1>

Submitted on 30 Jan 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

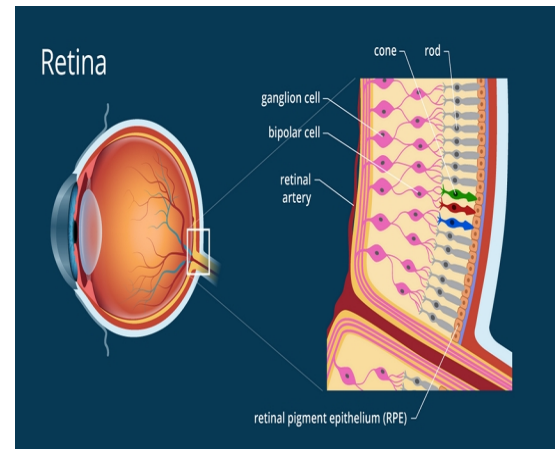
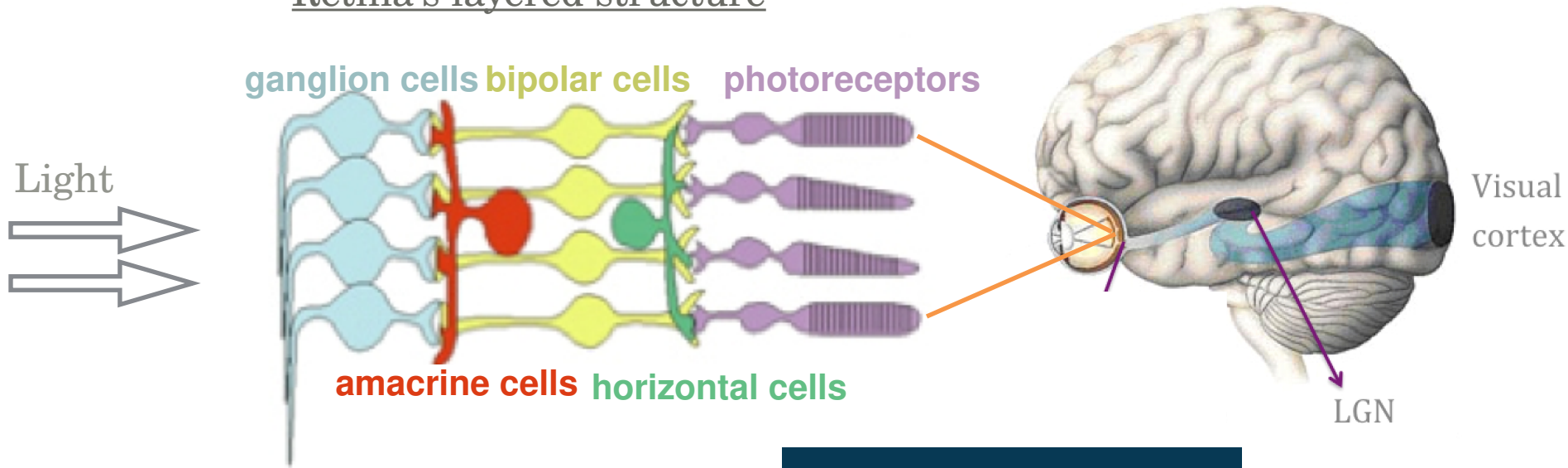
How does lateral inhibition shape the response to moving stimuli ?

B. Cessac, Université Côte d'Azur, INRIA,
Biovision team and Neuromod Institute
Sophia Antipolis, France



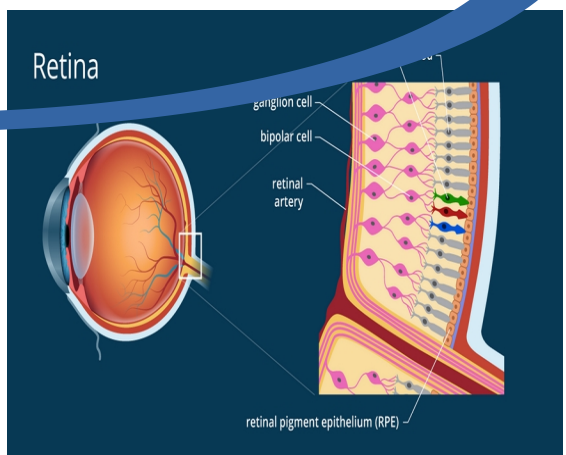
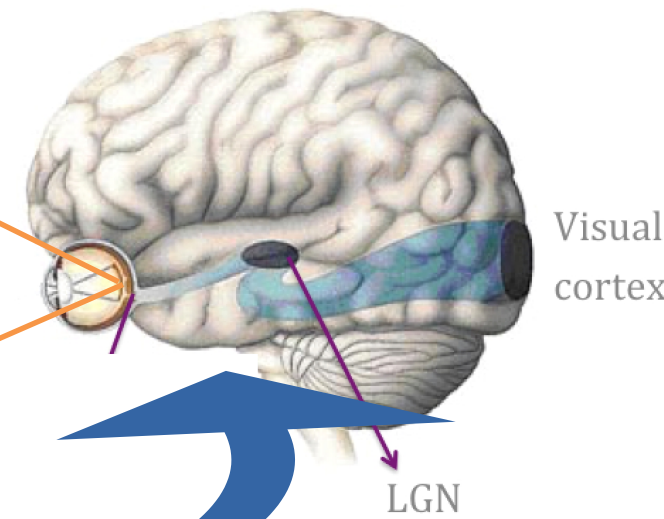
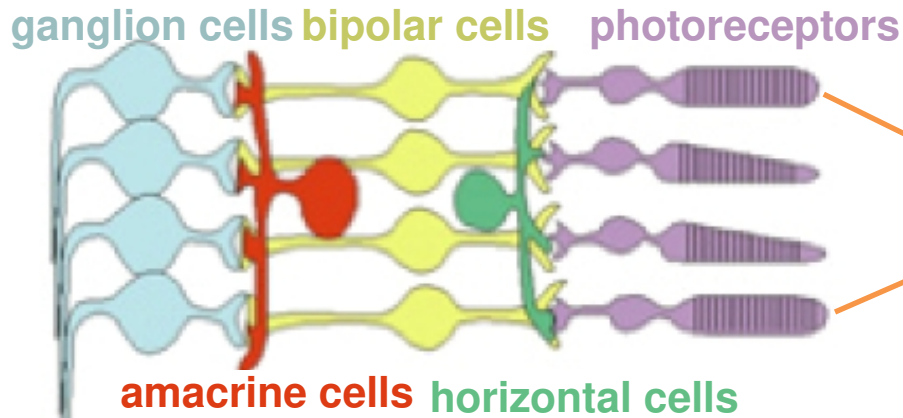
The visual system

Retina's layered structure



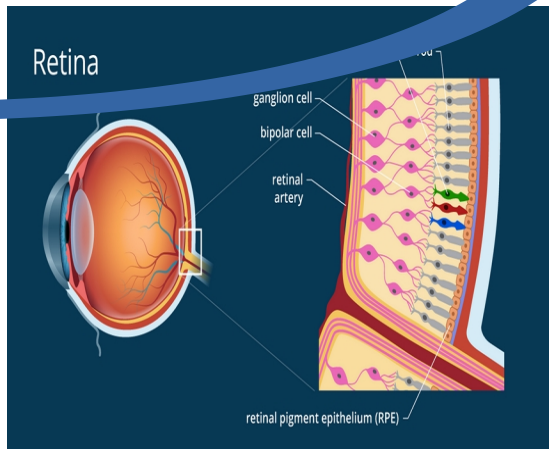
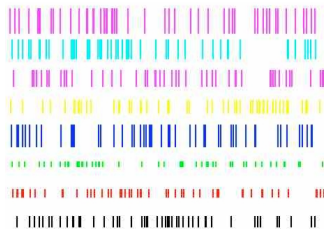
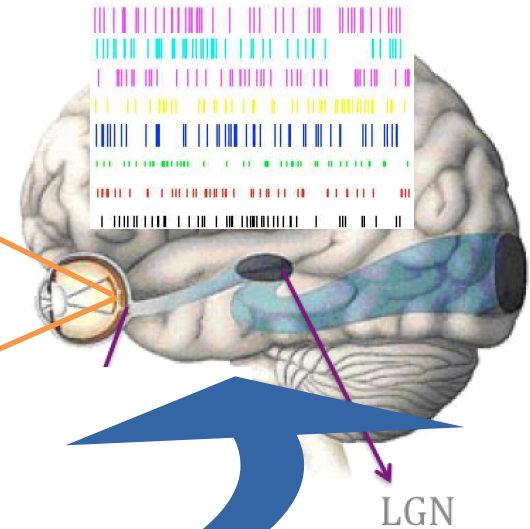
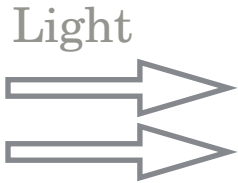
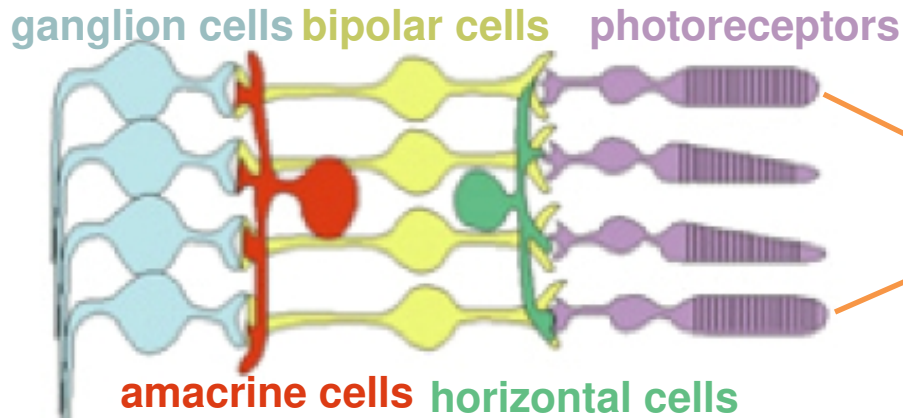
The visual system

Retina's layered structure



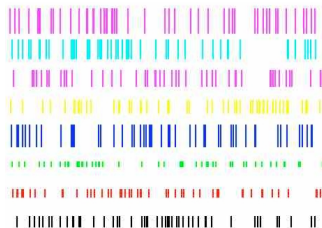
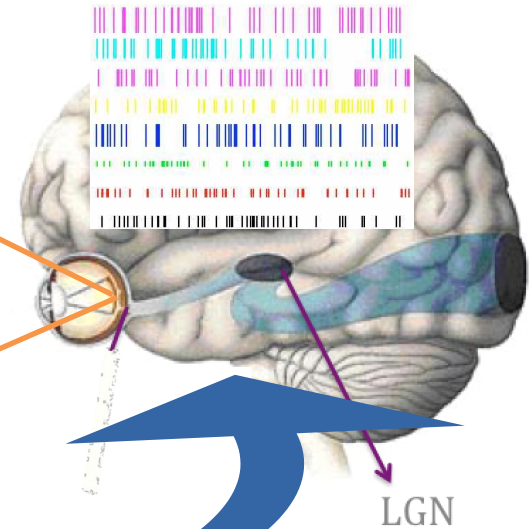
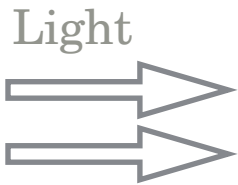
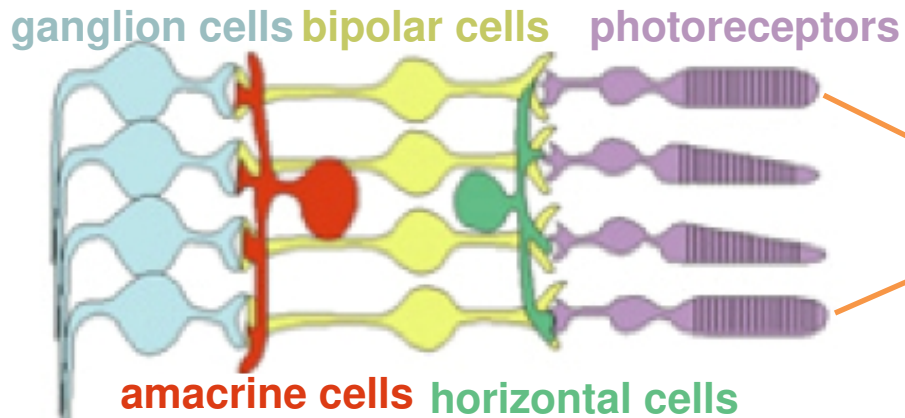
The visual system

Retina's layered structure



The visual system

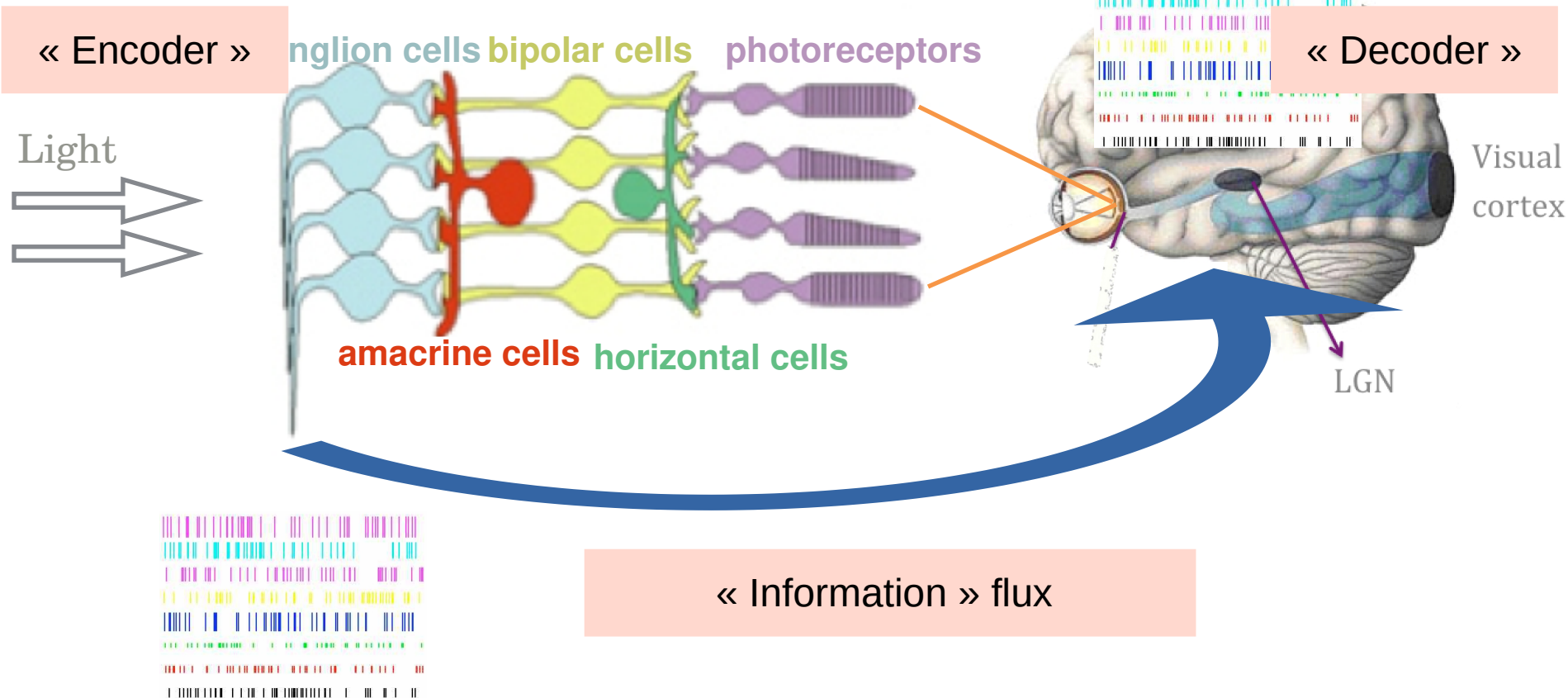
Retina's layered structure



« Information » flux

The visual system

Retina's layered structure



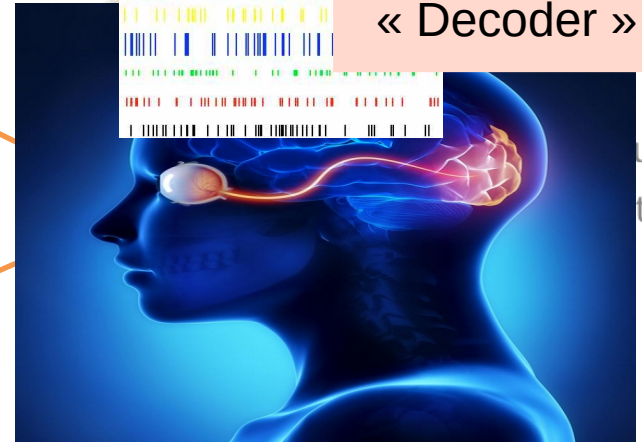
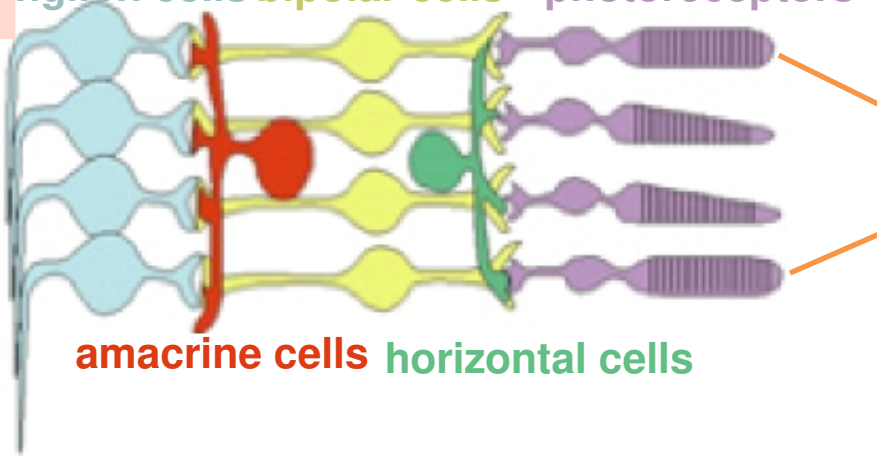
The visual system

Retina's layered structure

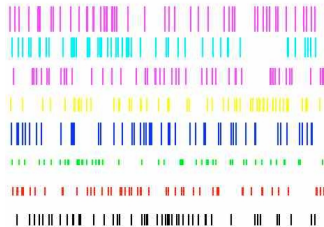
« Encoder »

ganglion cells bipolar cells photoreceptors

« Decoder »



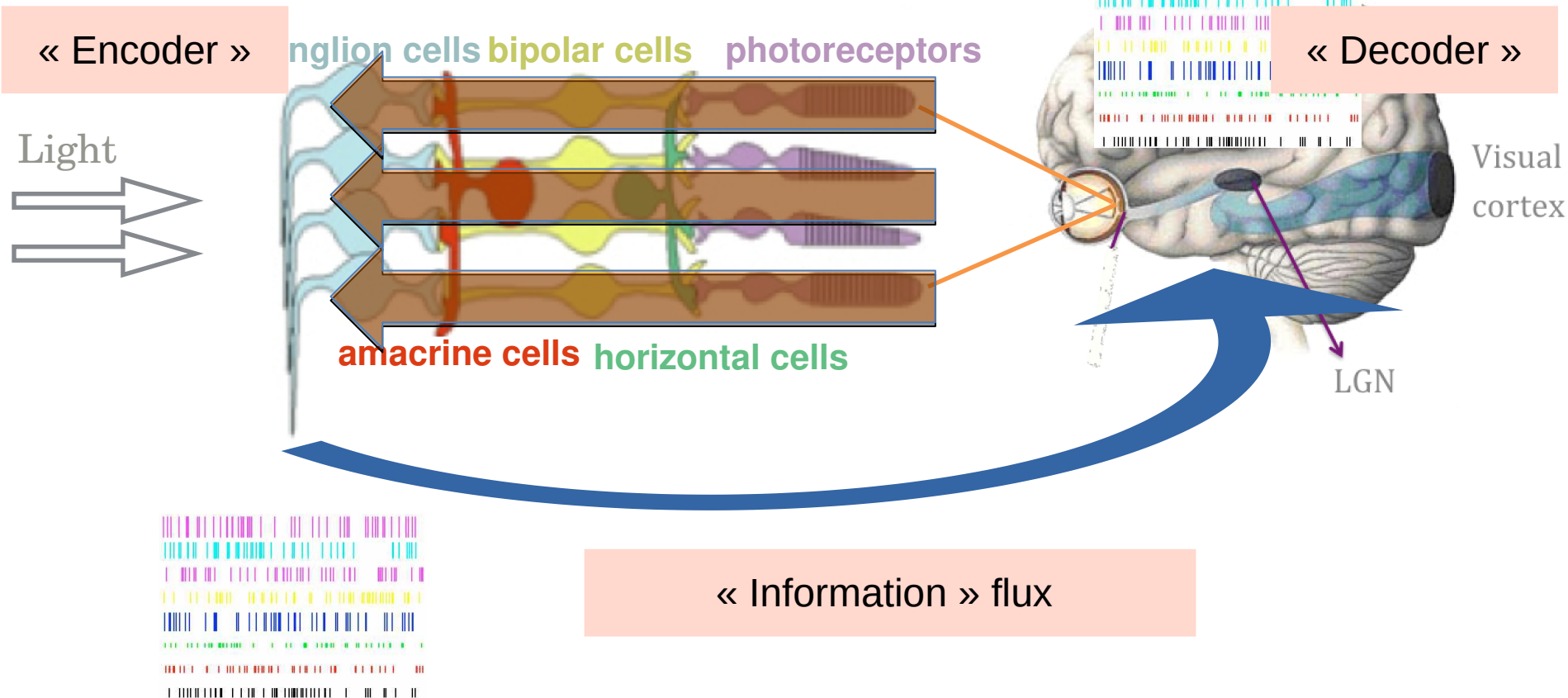
ual
tex



« Information » flux

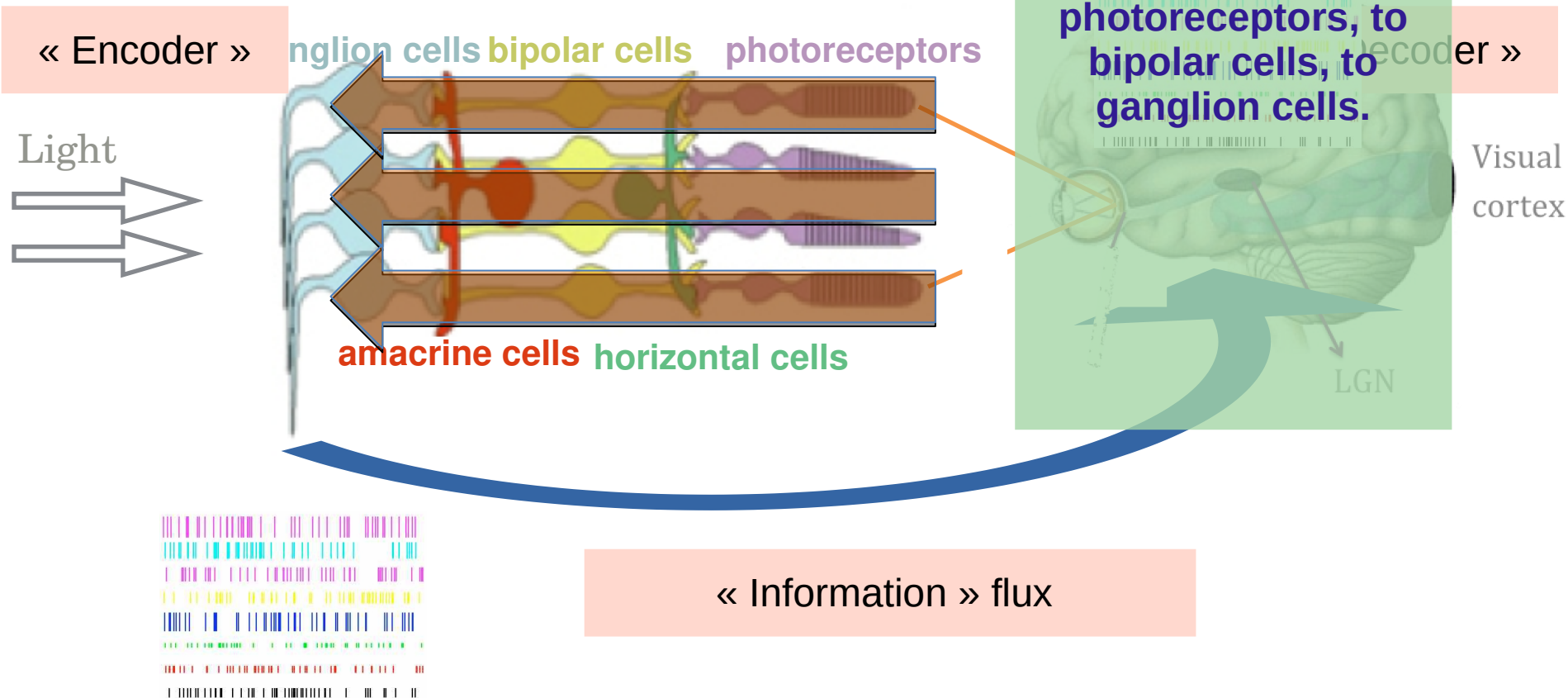
The visual system

Retina's layered structure



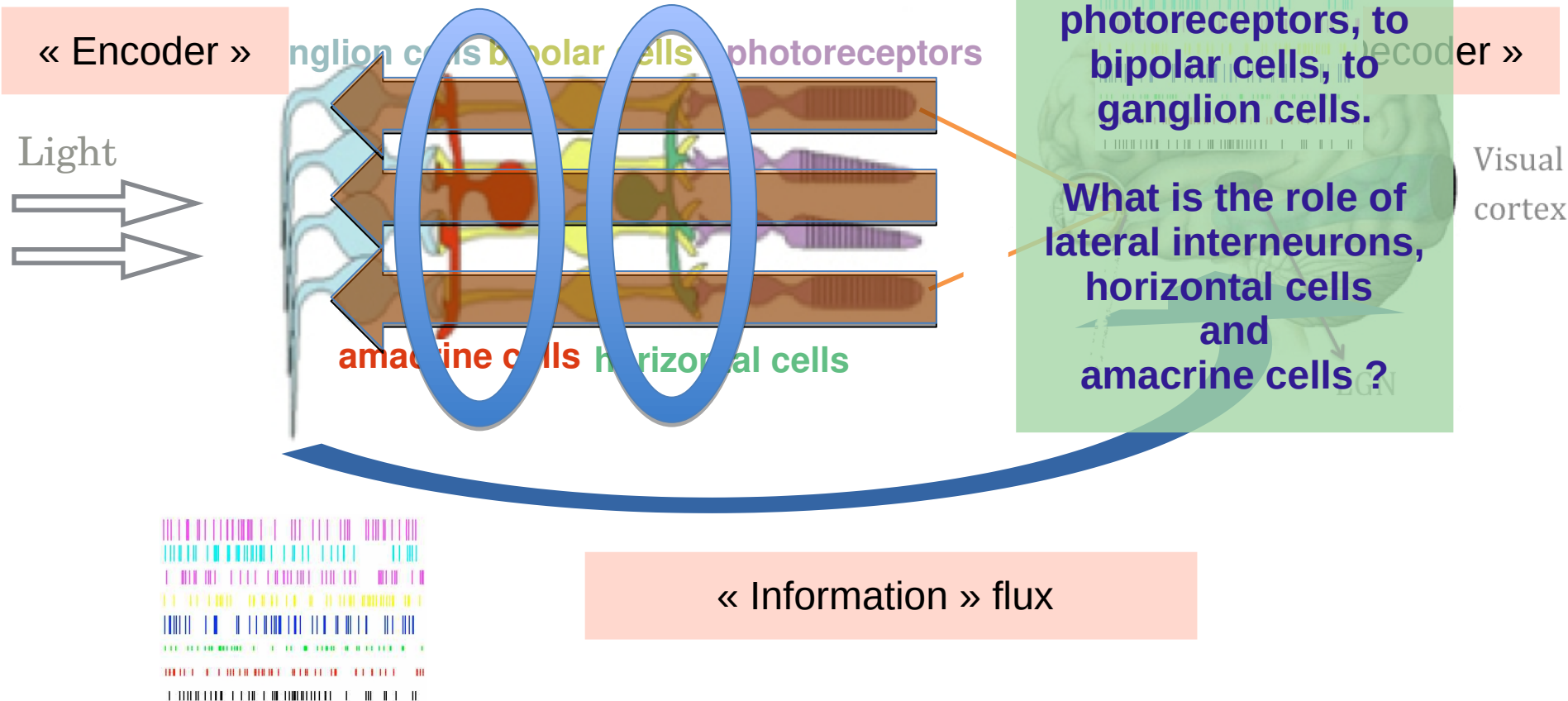
The visual system

Retina's layered structure



The visual system

Retina's layered structure

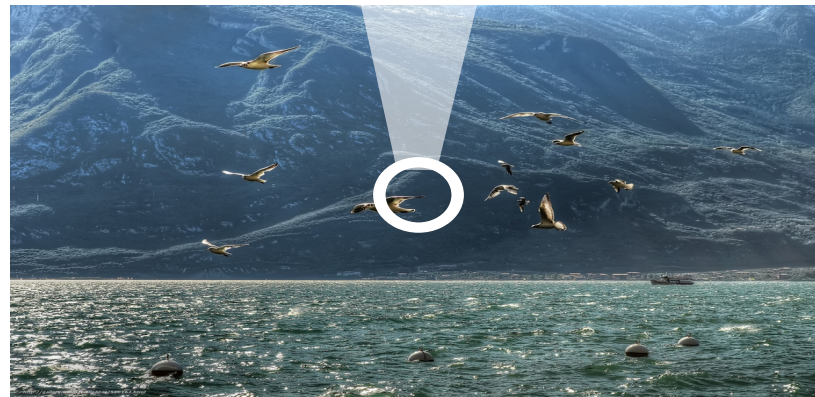
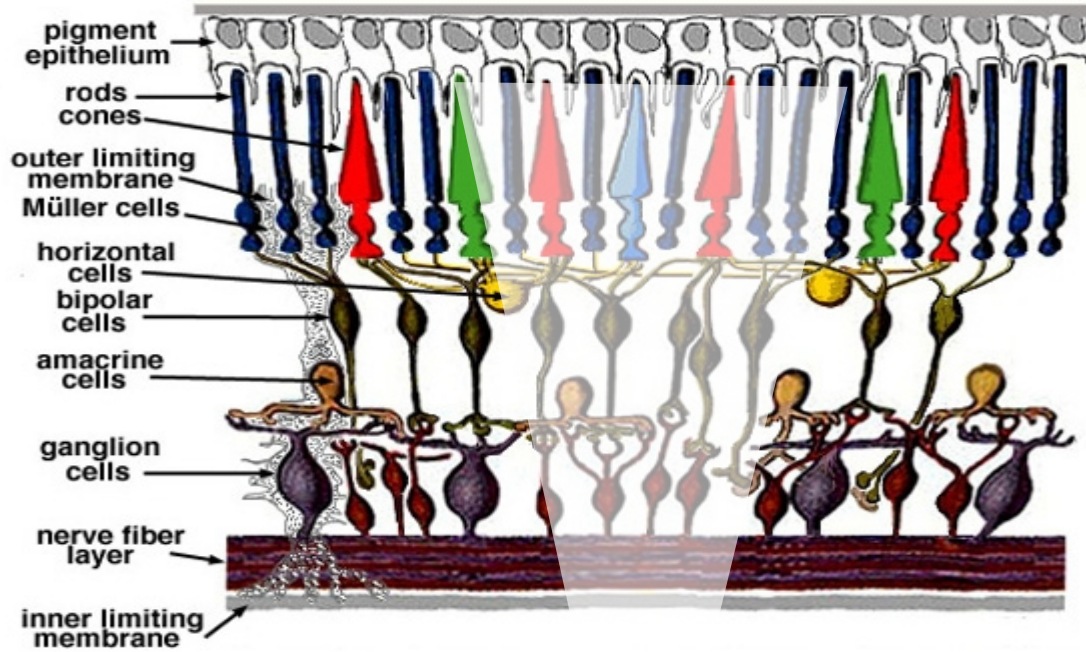


Receptive Field



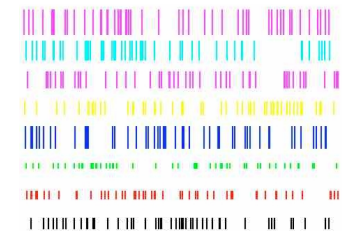
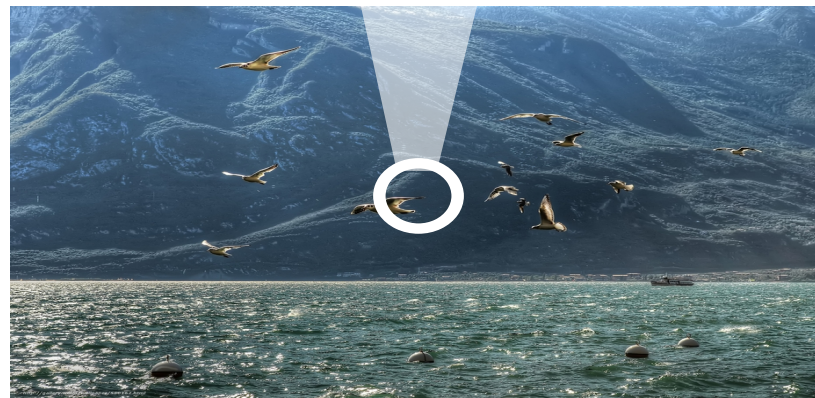
Receptive Field

Source : <http://webvision.med.utah.edu/>

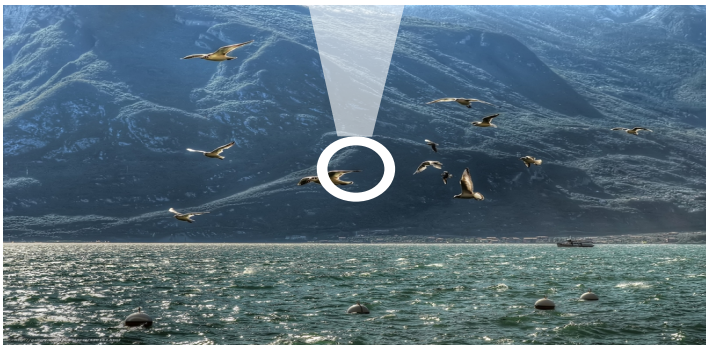
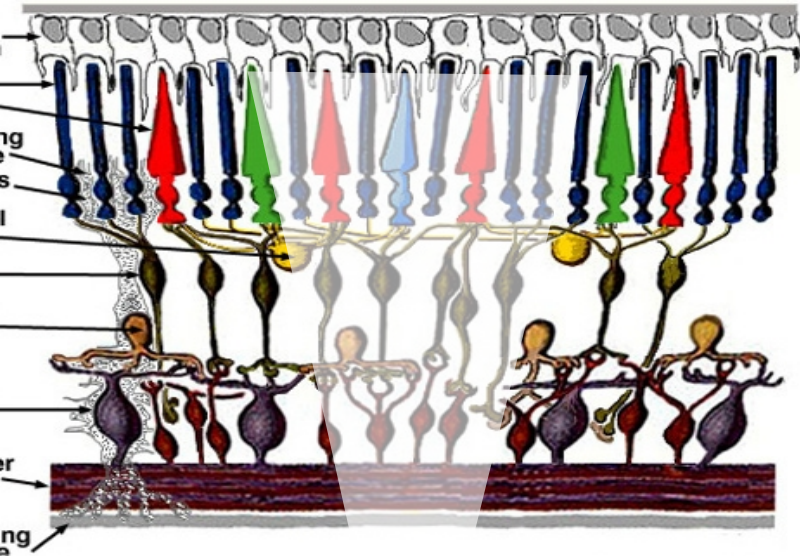


Receptive Field

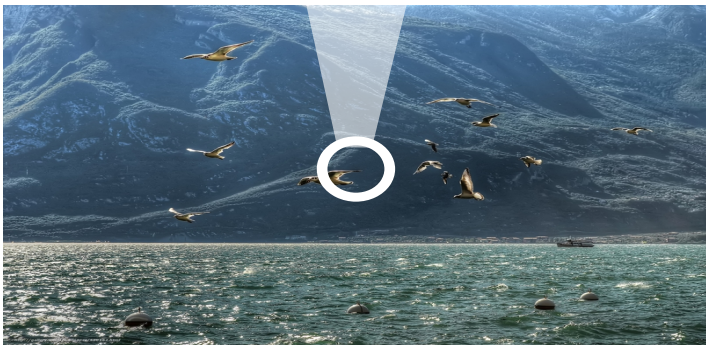
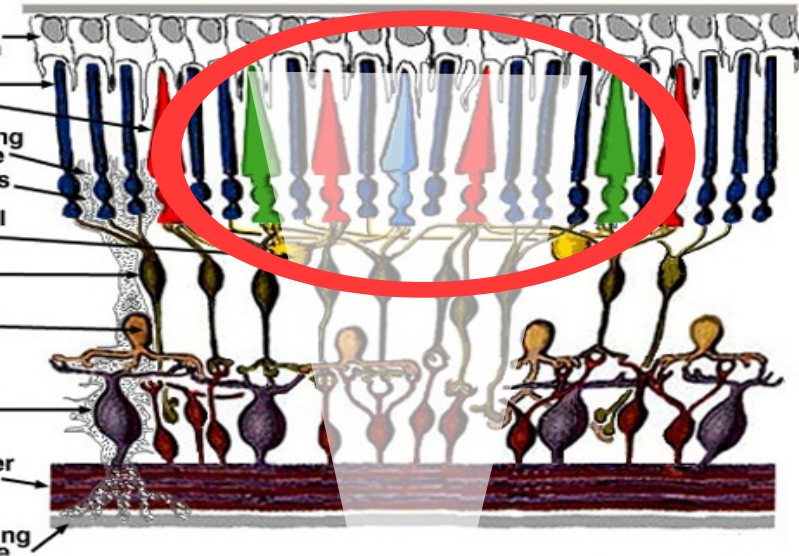
Source : <http://webvision.med.utah.edu/>



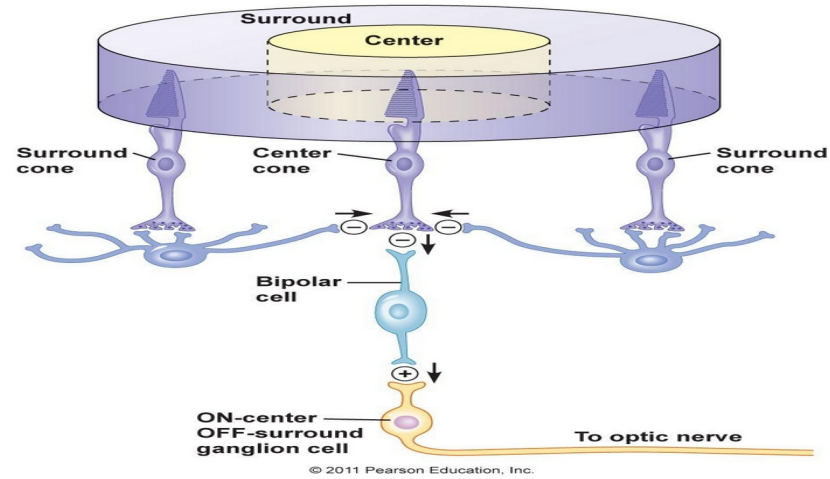
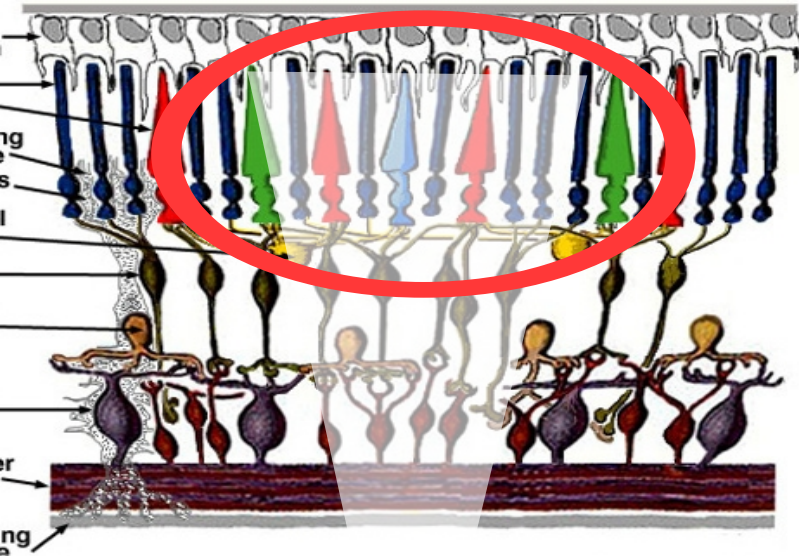
Receptive Field



Receptive Field



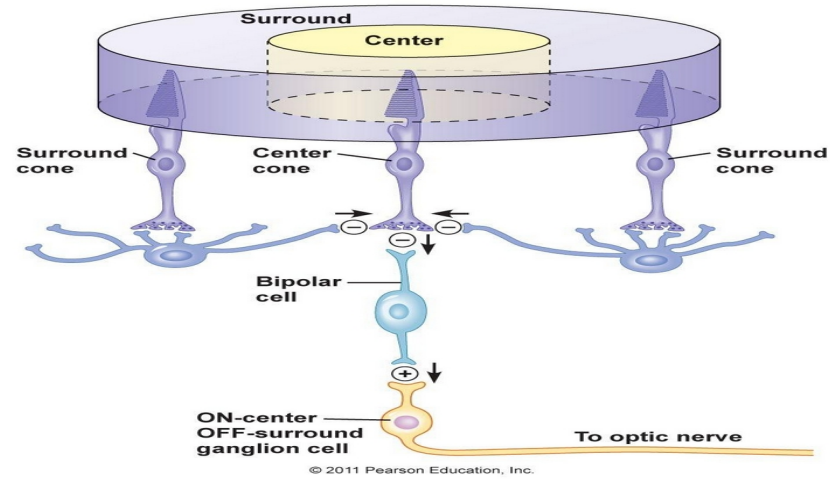
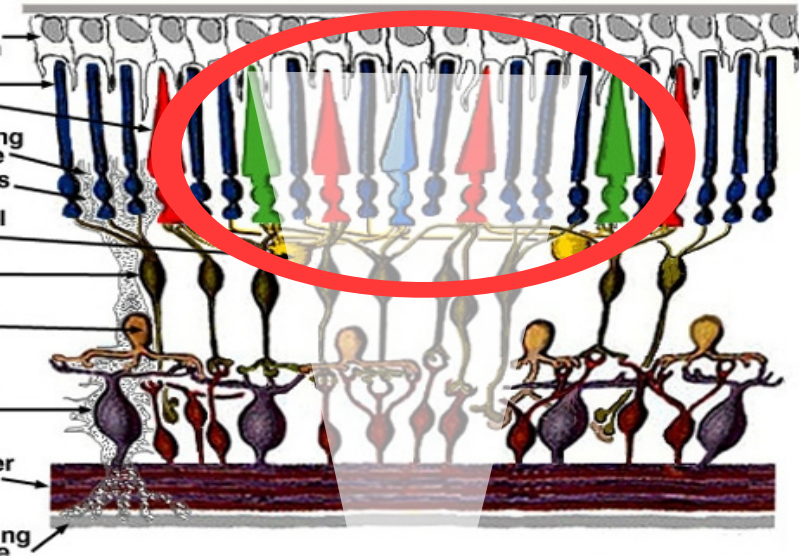
Receptive Field



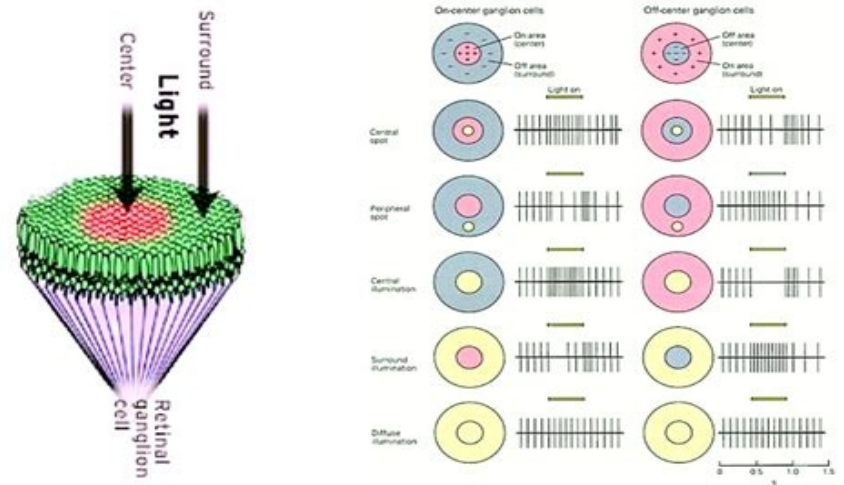
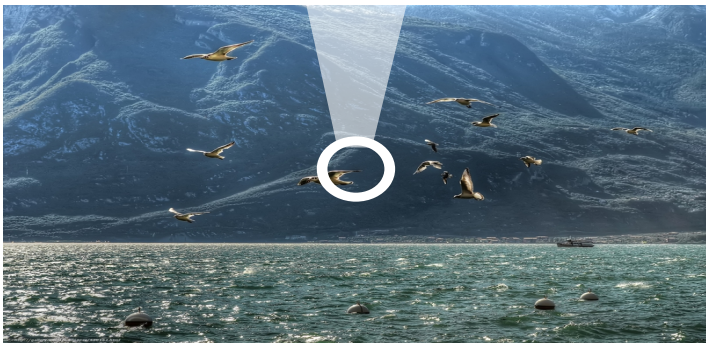
Source: <https://www.pinterest.com/>



Receptive Field

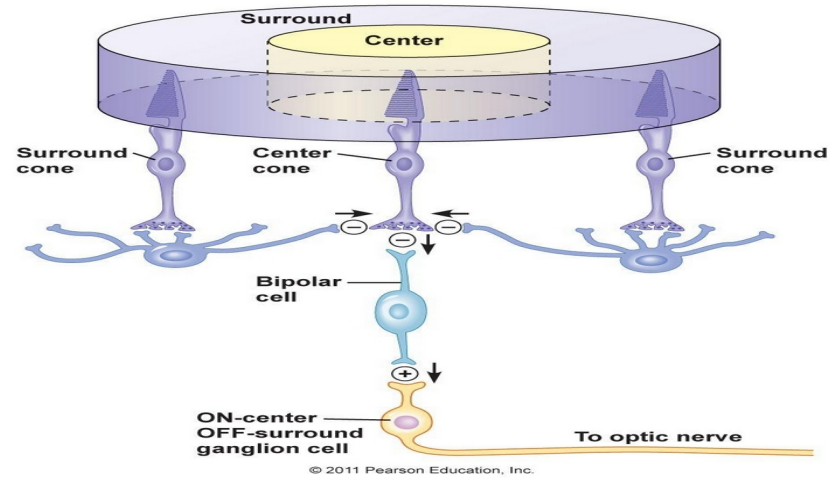
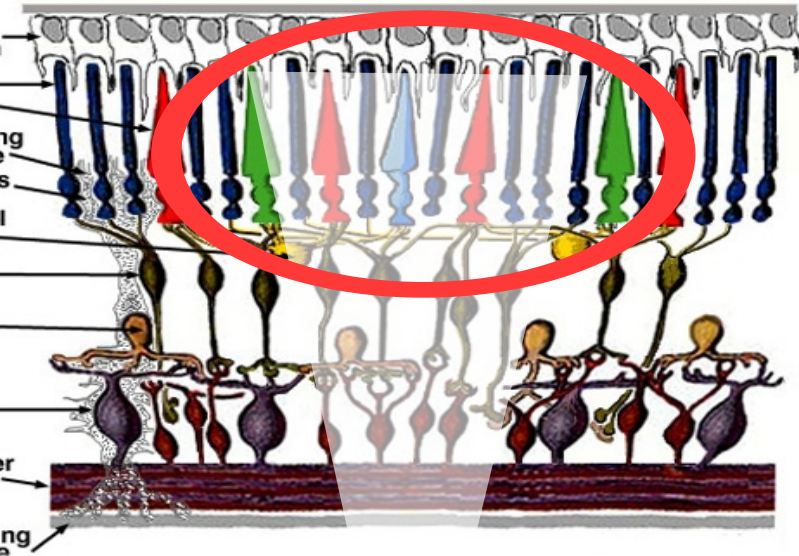


Source: <https://www.pinterest.com/>

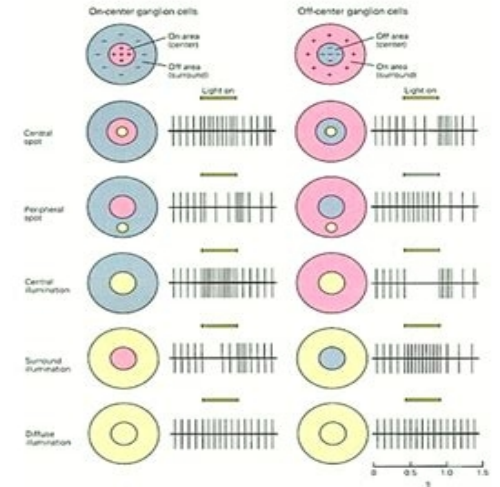
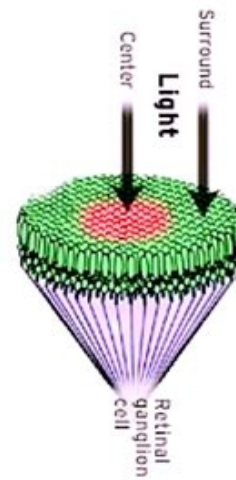
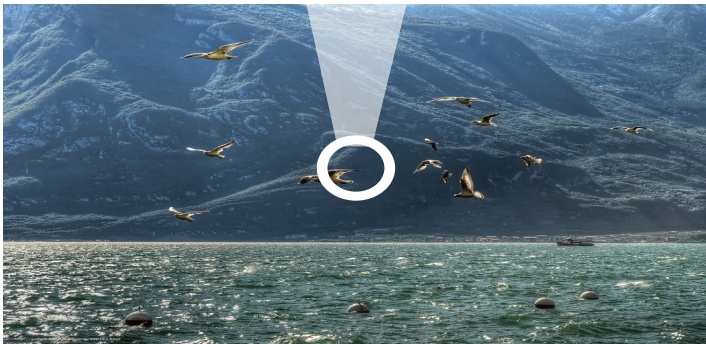


Source: <https://project.inria.fr/keops/>

Receptive Field

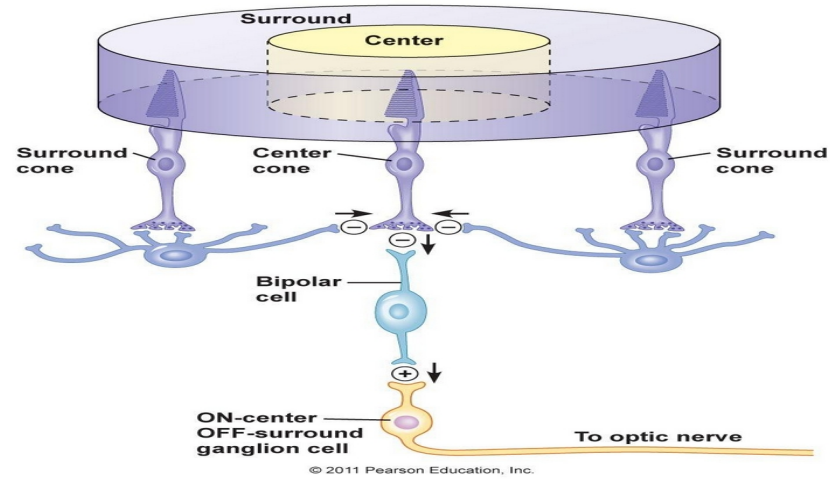
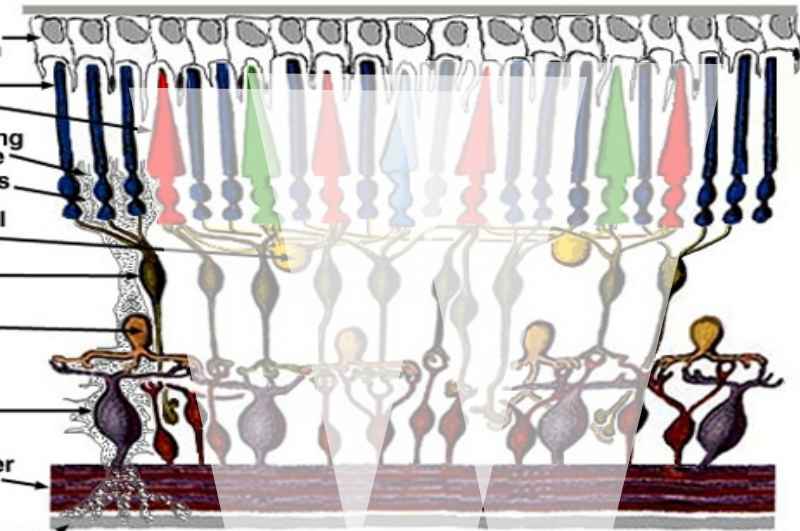


Source: <https://www.pinterest.com/>

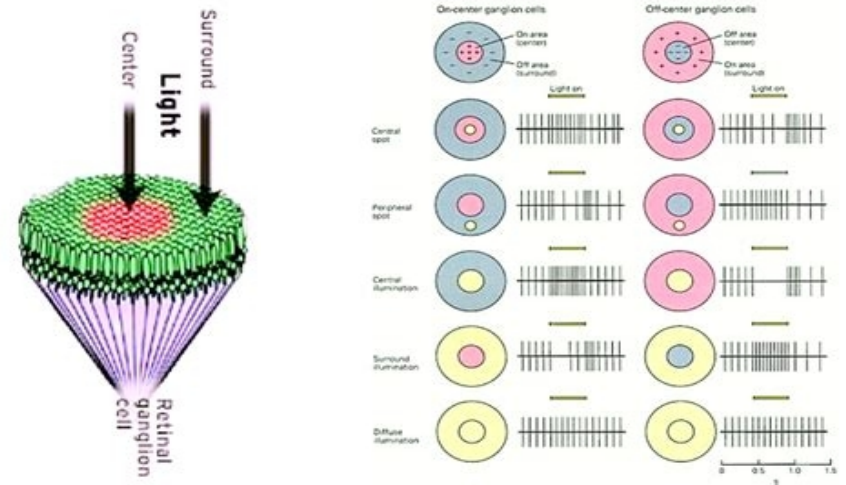


Source: <https://project.inria.fr/keops/>

Receptive Field



Source: <https://www.pinterest.com/>

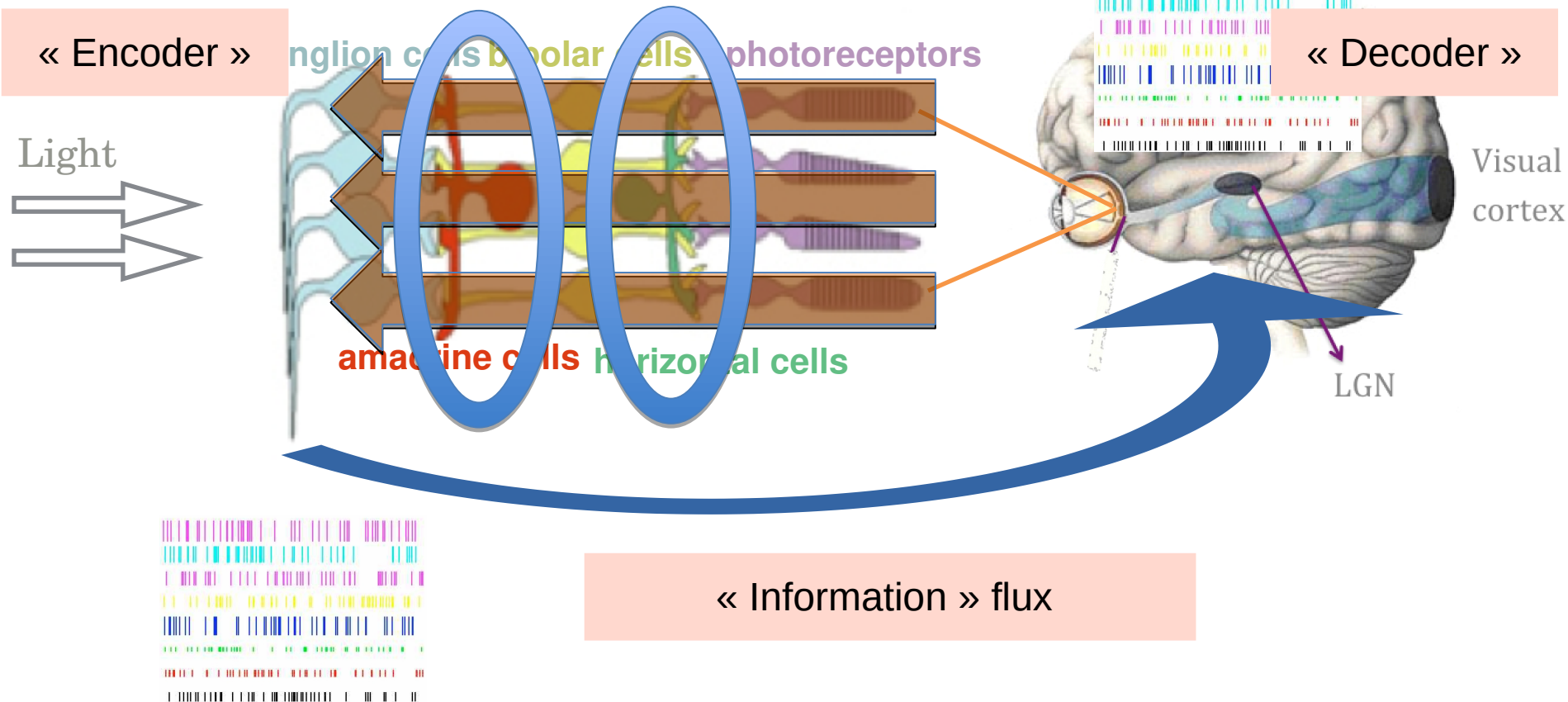


Source: <https://project.inria.fr/keops/>

How does lateral inhibition shape the response to moving stimuli ?

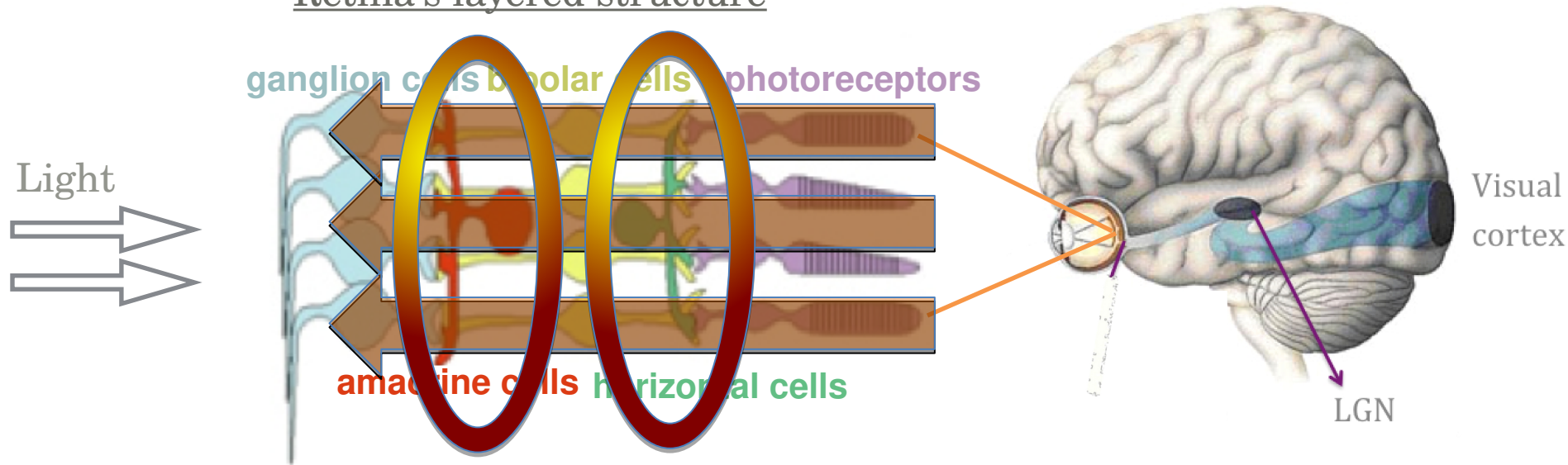
How does lateral inhibition shape the response to moving stimuli ?

Retina's layered structure



How does lateral inhibition shape the response to moving stimuli ?

Retina's layered structure



What happens if one enhances the lateral inhibition with drugs ?

Clozapine N Oxide (CNO) increases the activation level of amacrine cells (in genetically modified mice).

How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).

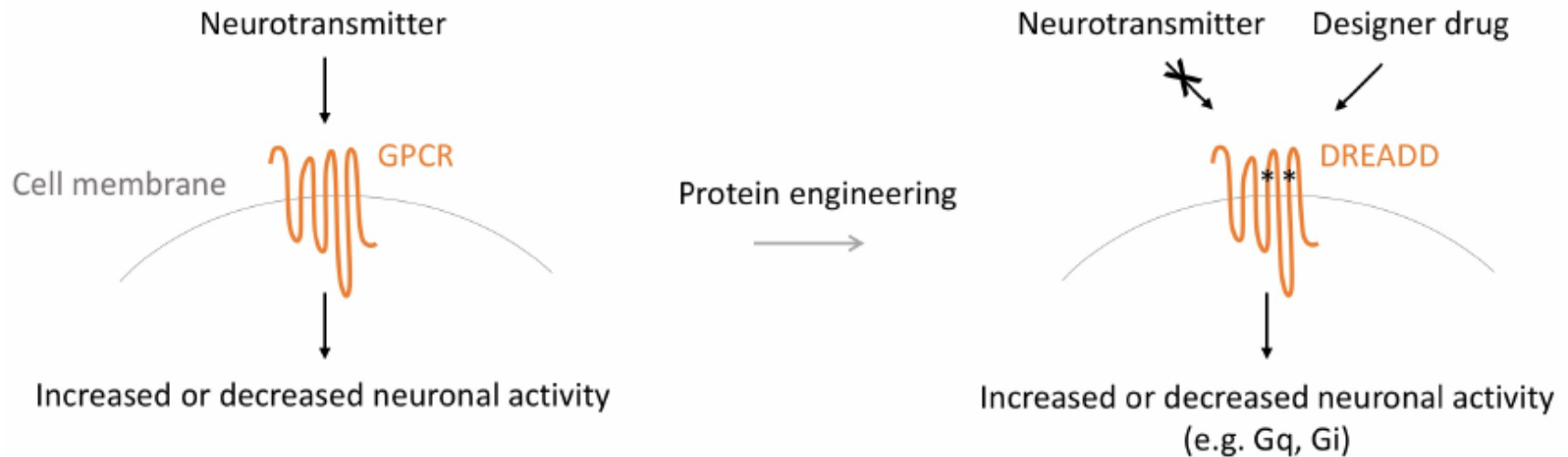
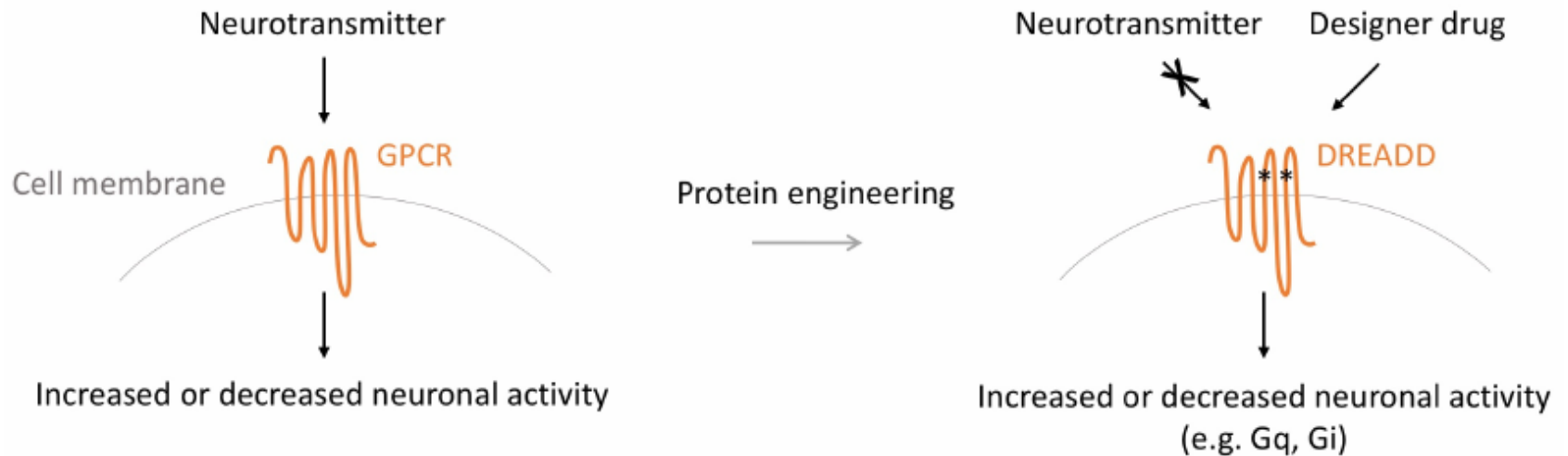


Figure 3.1. Designer Receptor Exclusively Activated by Designer Drugs. *Left.* Neurotransmitters bind to G protein-coupled receptors (GPCRs) of the membrane, which leads to a change in the activity of the neuron. *Right.* An engineered version of GPCRs, called DREADDs, responds only to a specific biologically inert chemical (a designer drug), hence allowing us to control neuronal activity. Source: <https://benchling.com/pub/dreadds>

How does lateral inhibition shape the response to moving stimuli ?

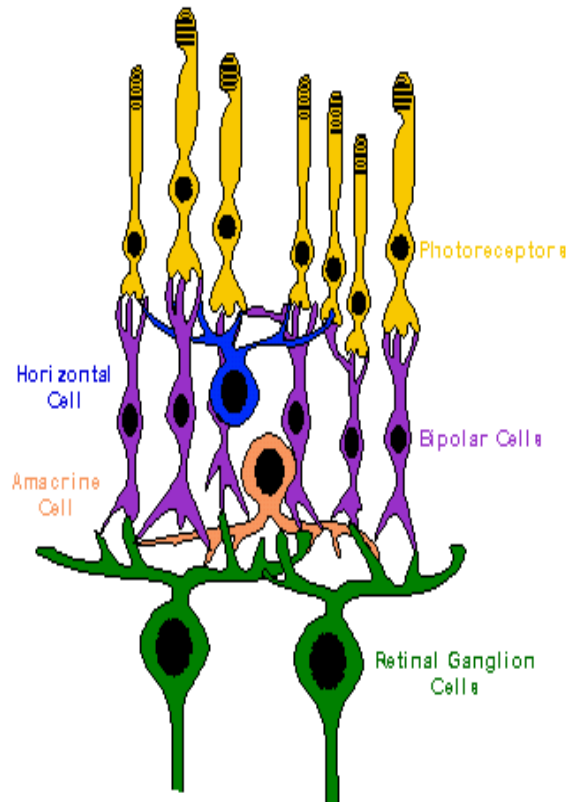
How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



DREADDs can be excitatory (hM3Dq - release of calcium from organelles leading to increase of intracellular concentration of free calcium, leading to membrane depolarisation and higher neuronal excitability), or inhibitory (hM4Di - opening of potassium channels, leading to membrane hyperpolarisation and neuronal silencing).

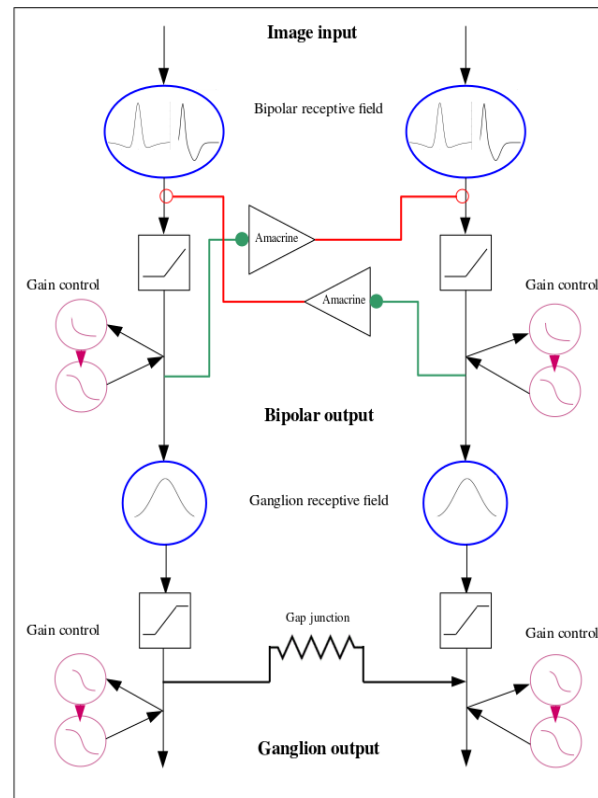
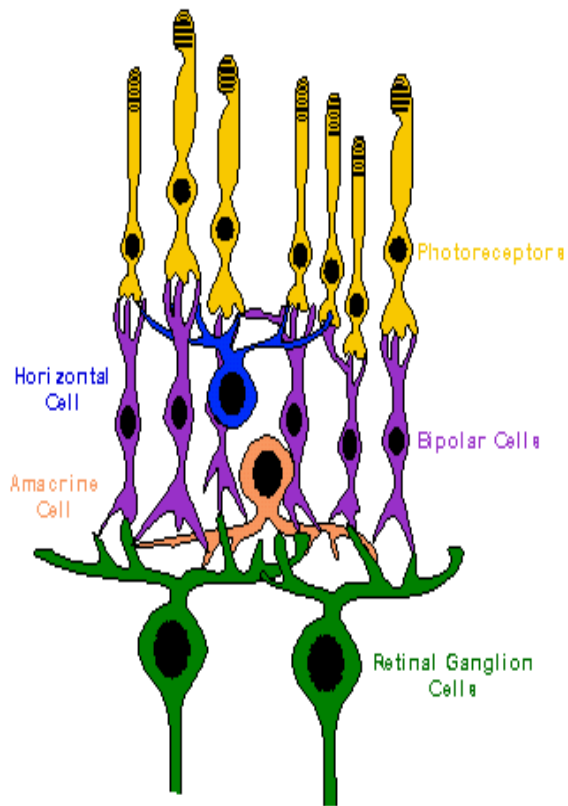
How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



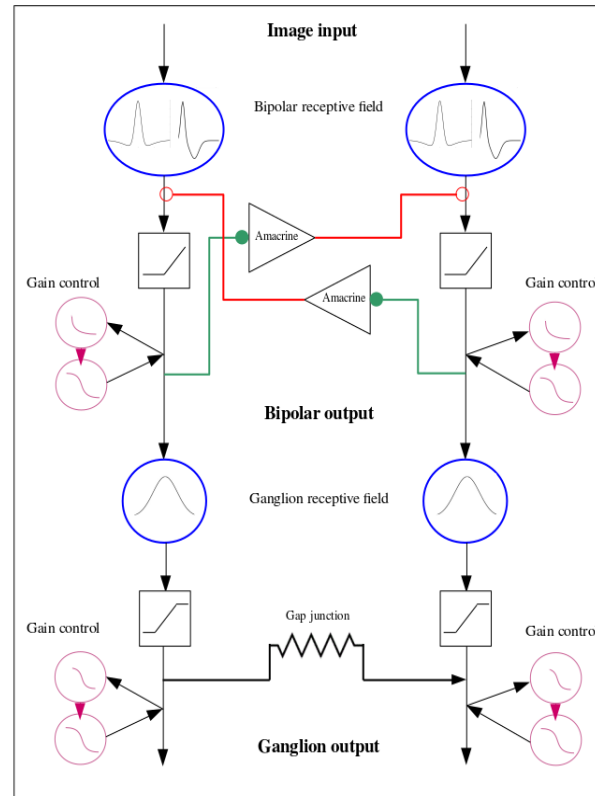
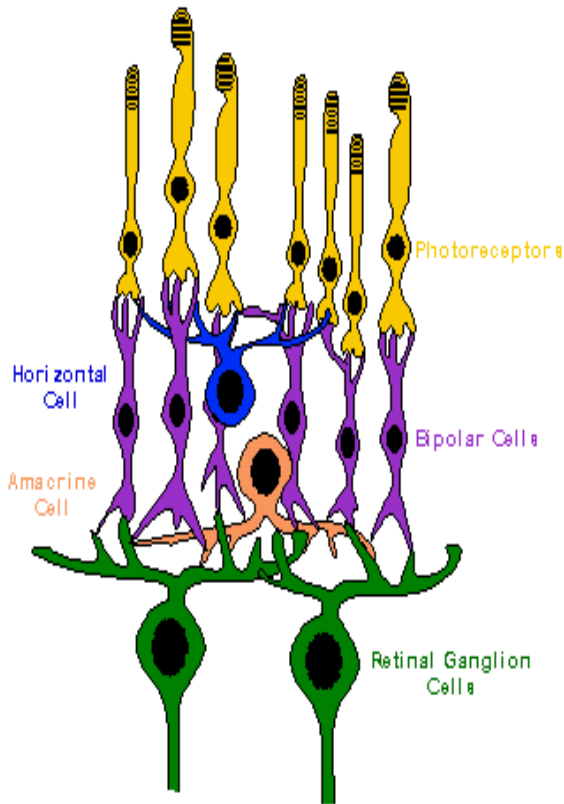
How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



- Bipolar voltage :

$$\frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t)$$

- External drive :

$$F_{B_i}(t) = \frac{\mathcal{V}_i^{(drive)}}{\tau_{B_i}} + \frac{d}{dt} \mathcal{V}_i^{(drive)}$$

- Amacrine voltage :

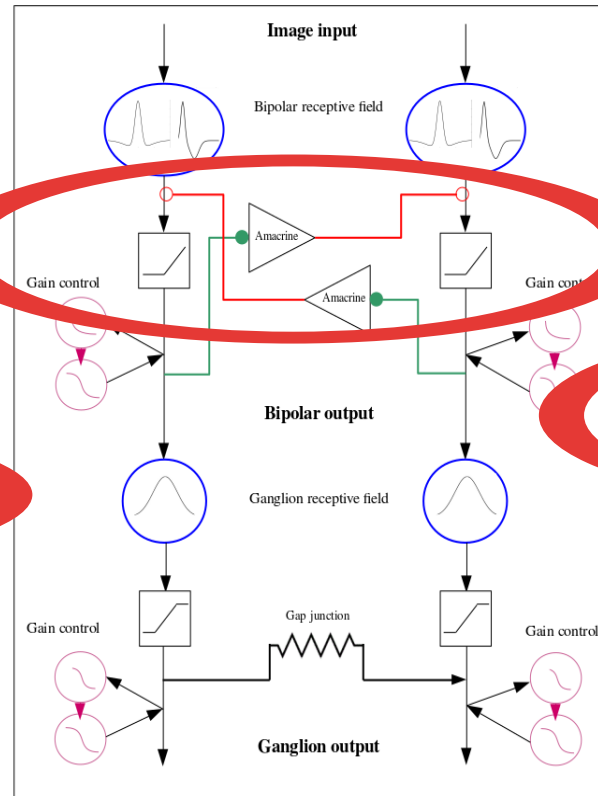
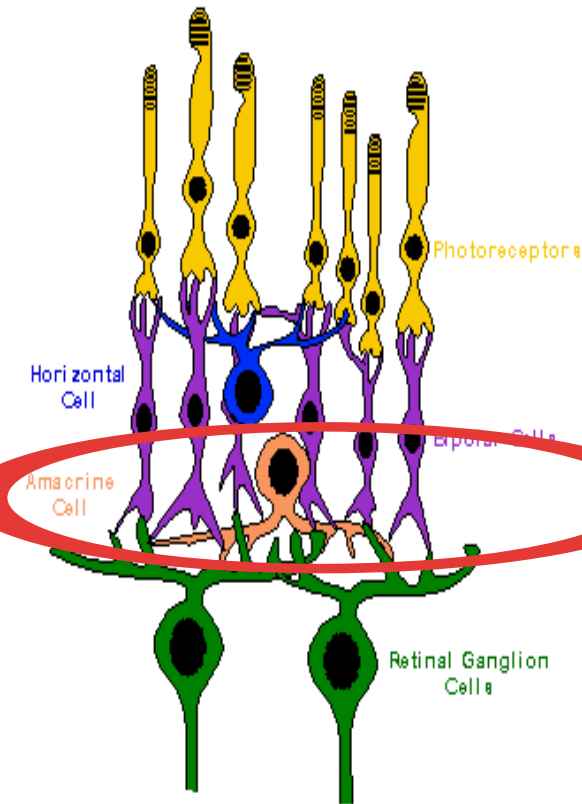
$$\frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_A$$

- Coupled dynamics :

$$\begin{cases} \frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t), & i=1 \dots N \\ \frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_A, & j=1 \dots N, \\ \frac{dV_{G_k}}{dt} = -\frac{1}{\tau_{G_k}} V_{G_k} + \sum_{i=1}^{N_B} W_{G_k}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \sum_{j=1}^{N_A} W_{G_k}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + \zeta_G, & k=1 \dots N. \end{cases}$$

How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



- Bipolar voltage :

$$\frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t)$$

- External drive :

$$F_{B_i}(t) = \frac{\gamma_i^{(drive)}}{\tau_{B_i}} + \frac{d}{dt} \gamma_i^{(drive)}$$

- Amacrine voltage :

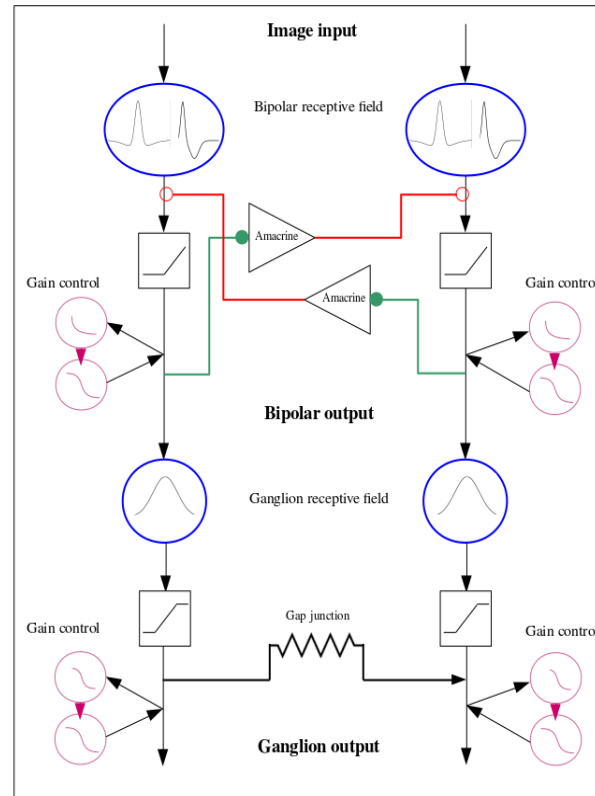
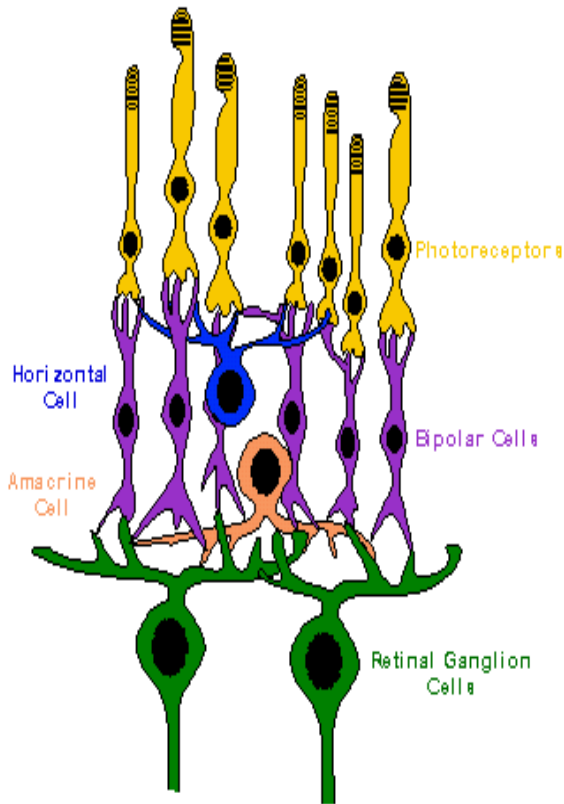
$$\frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_{A_j}$$

- Coupled dynamics :

$$\begin{cases} \frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t), & i=1 \dots N \\ \frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_{A_j}, & j=1 \dots N, \\ \frac{dV_{G_k}}{dt} = -\frac{1}{\tau_{G_k}} V_{G_k} + \sum_{i=1}^{N_B} W_{G_k}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \sum_{j=1}^{N_A} W_{G_k}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + \zeta_{G_k}, & k=1 \dots N. \end{cases}$$

How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



- Bipolar voltage :

$$\frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t)$$

- External drive :

$$F_{B_i}(t) = \frac{\mathcal{V}_i^{(drive)}}{\tau_{B_i}} + \frac{d}{dt} \mathcal{V}_i^{(drive)}$$

- Amacrine voltage :

$$\frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_A$$

- Coupled dynamics :

$$\begin{cases} \frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t), & i=1 \dots N \\ \frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_A, & j=1 \dots N, \\ \frac{dV_{G_k}}{dt} = -\frac{1}{\tau_{G_k}} V_{G_k} + \sum_{i=1}^{N_B} W_{G_k}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \sum_{j=1}^{N_A} W_{G_k}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + \zeta_G, & k=1 \dots N. \end{cases}$$

How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).

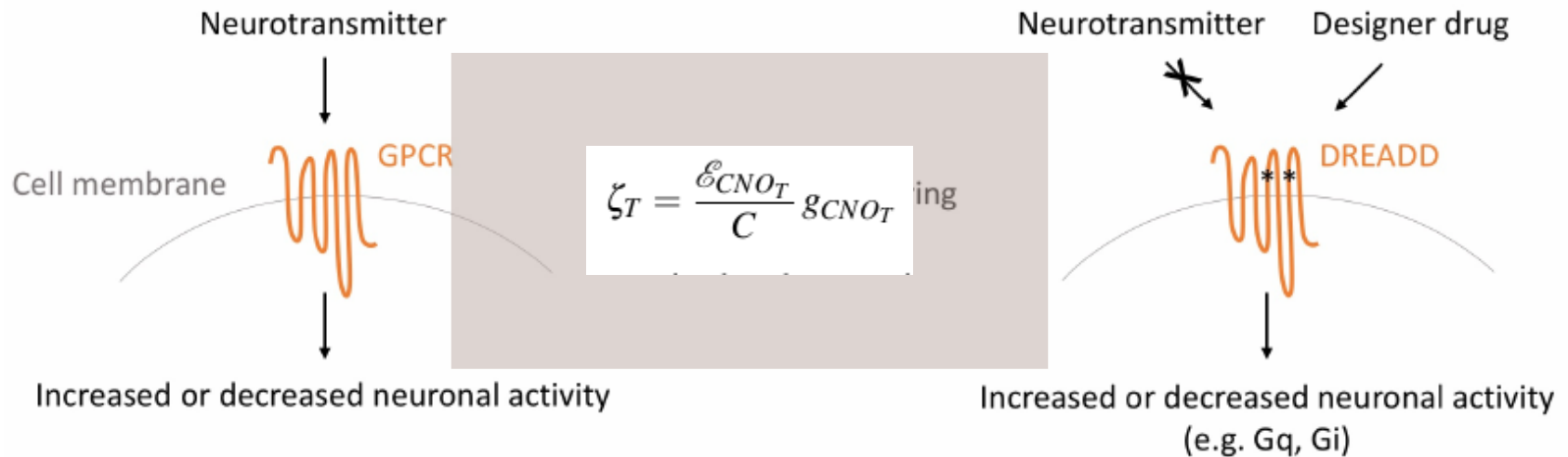
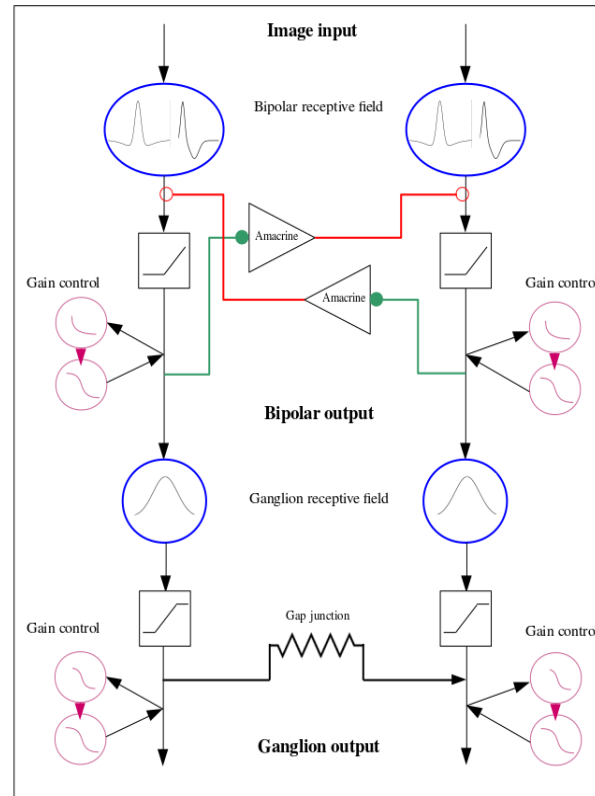
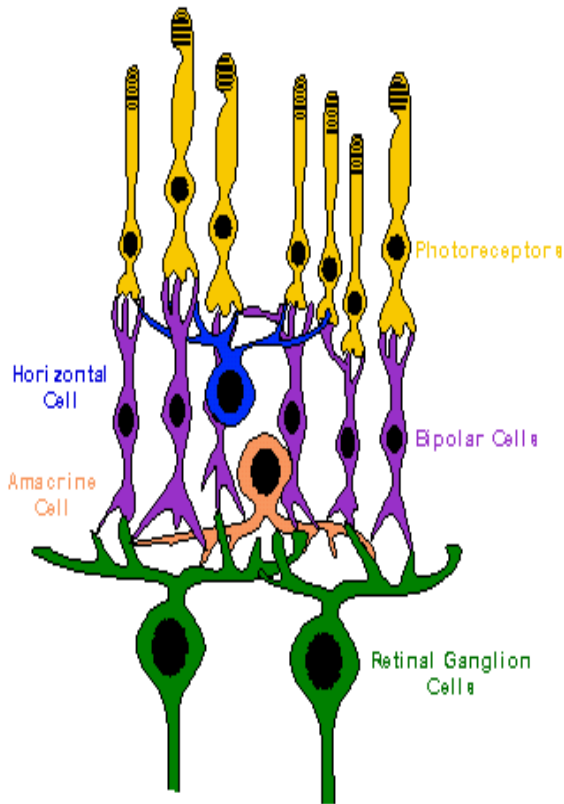


Figure 3.1. Designer Receptor Exclusively Activated by Designer Drugs. *Left.* Neurotransmitters bind to G protein-coupled receptors (GPCRs) of the membrane, which leads to a change in the activity of the neuron. *Right.* An engineered version of GPCRs, called DREADDs, responds only to a specific biologically inert chemical (a designer drug), hence allowing us to control neuronal activity. Source: <https://benchling.com/pub/dreadds>

How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



- Bipolar voltage :

$$\frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t)$$

- External drive :

$$F_{B_i}(t) = \frac{\mathcal{V}_i^{(drive)}}{\tau_{B_i}} + \frac{d}{dt} \mathcal{V}_i^{(drive)}$$

- Amacrine voltage :

$$\frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_A$$

- Coupled dynamics :

$$\begin{cases} \frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t), & i=1 \dots N \\ \frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_A, & j=1 \dots N, \\ \frac{dV_{G_k}}{dt} = -\frac{1}{\tau_{G_k}} V_{G_k} + \sum_{i=1}^{N_B} W_{G_k}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \sum_{j=1}^{N_A} W_{G_k}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + \zeta_G, & k=1 \dots N. \end{cases}$$

How does lateral inhibition shape the response to moving stimuli ?

How specific classes of retinal cells contribute to vision : a computational model, Evgenia Kartsaki, PhD, 2022

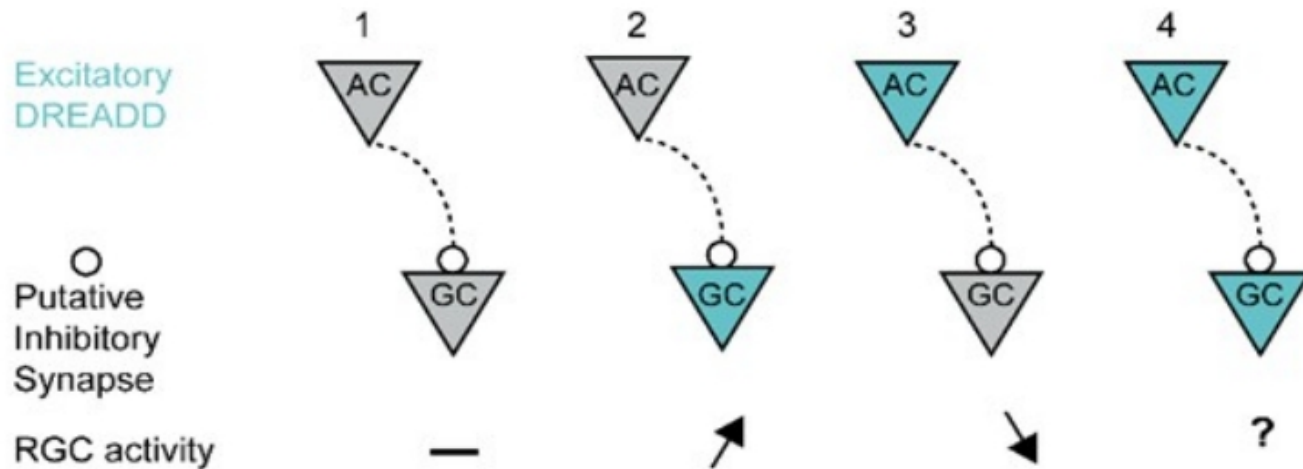
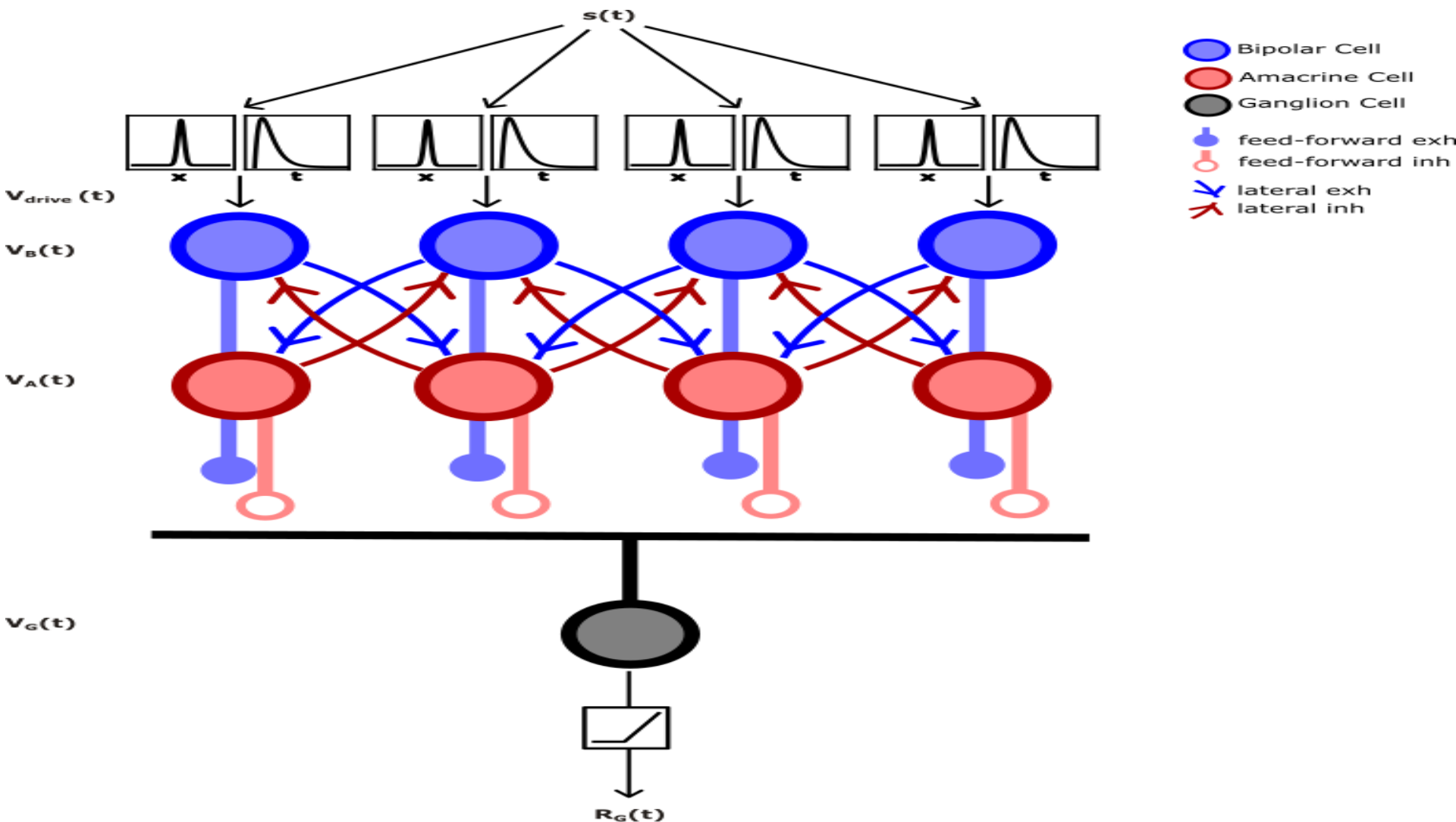
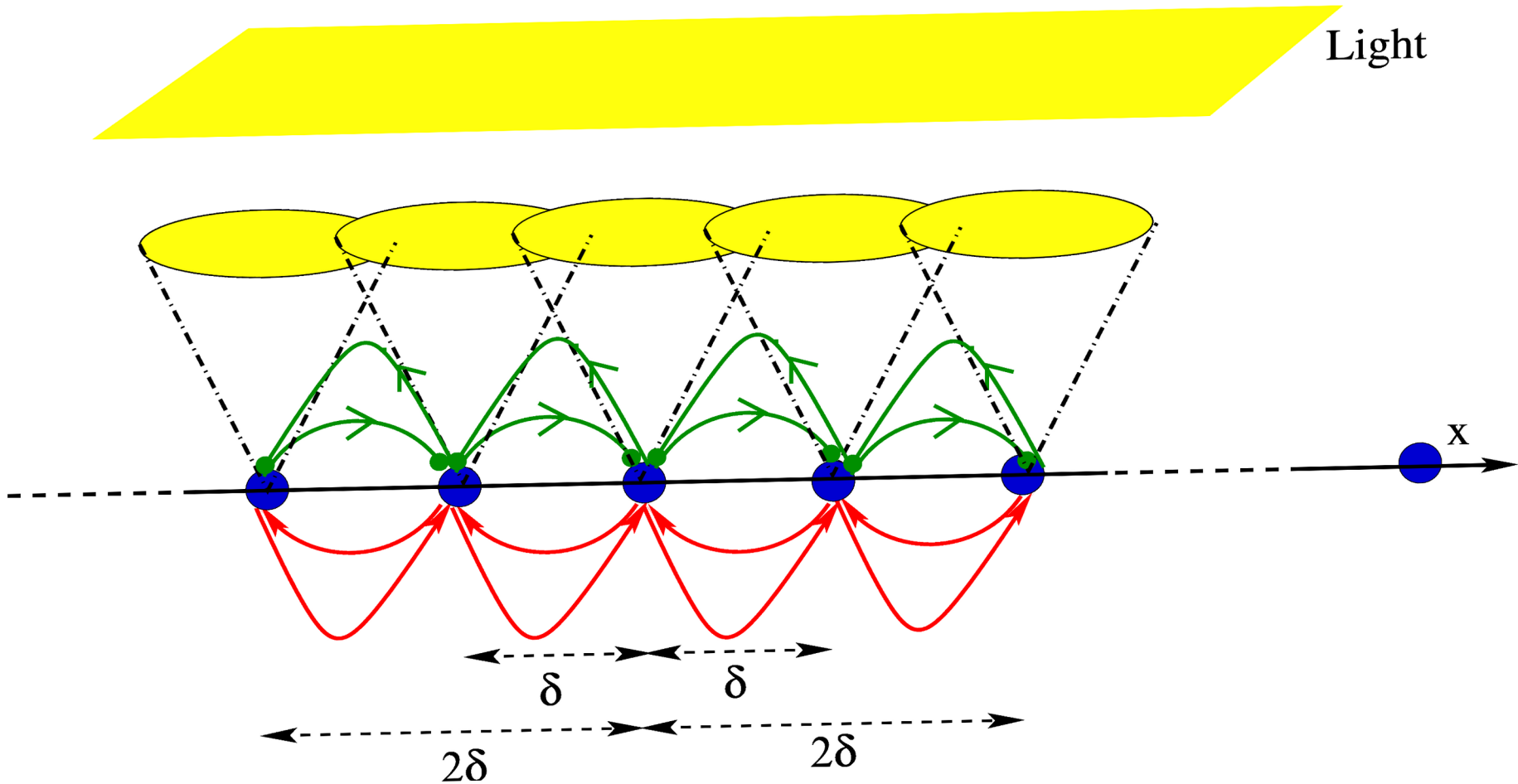


Figure 3.7. Potential scenarios of DREADD activation. 1. ACs and RGCs do not express DREADDs, thus there is no change in the spiking activity of the RGCs. 2. Only RGCs express DREADDs, so DREADD activation is triggering increased RGC firing. 3. Only ACs express DREADDs, so DREADD activation causes an increase of the putative inhibitory effect of ACs on RGCs, resulting in decreased RGC firing. 4. Both ACs and RGCs express DREADDs, therefore DREADD activation triggers an excitatory direct effect on RGCs and an inhibitory indirect effect via ACs on RGCs. The net effect is not clear on experimental grounds. Figure Courtesy Dr. Hilgen.

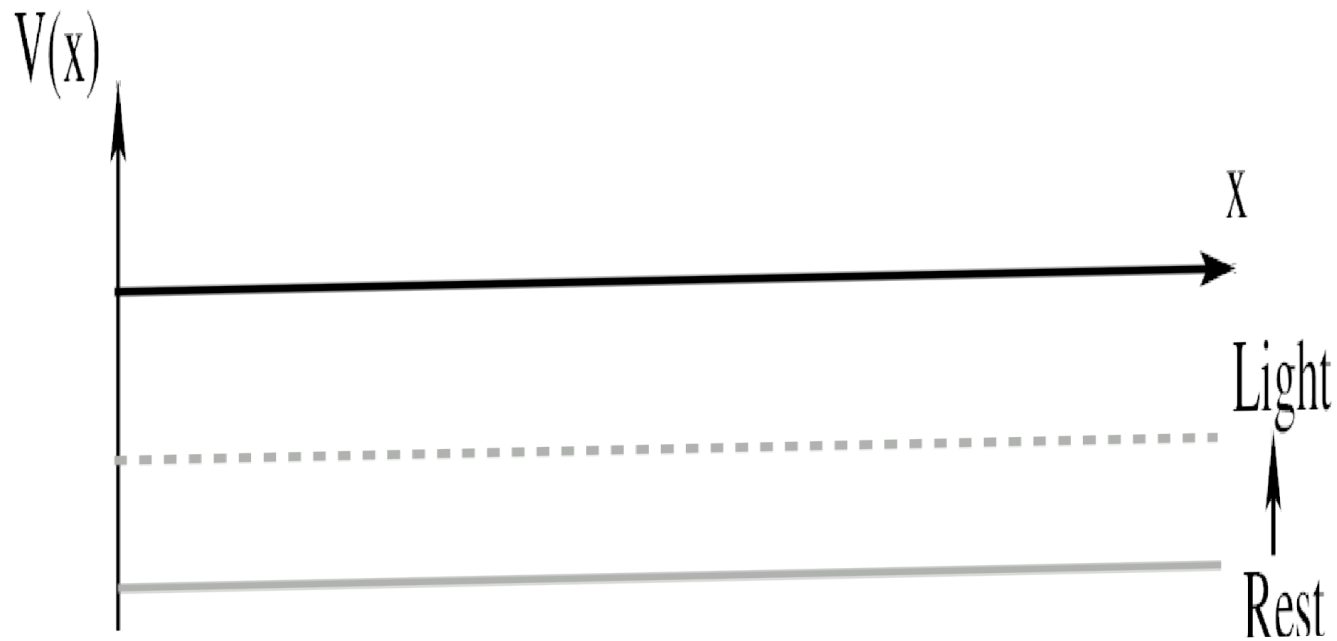
How does lateral inhibition shape the response to moving stimuli?



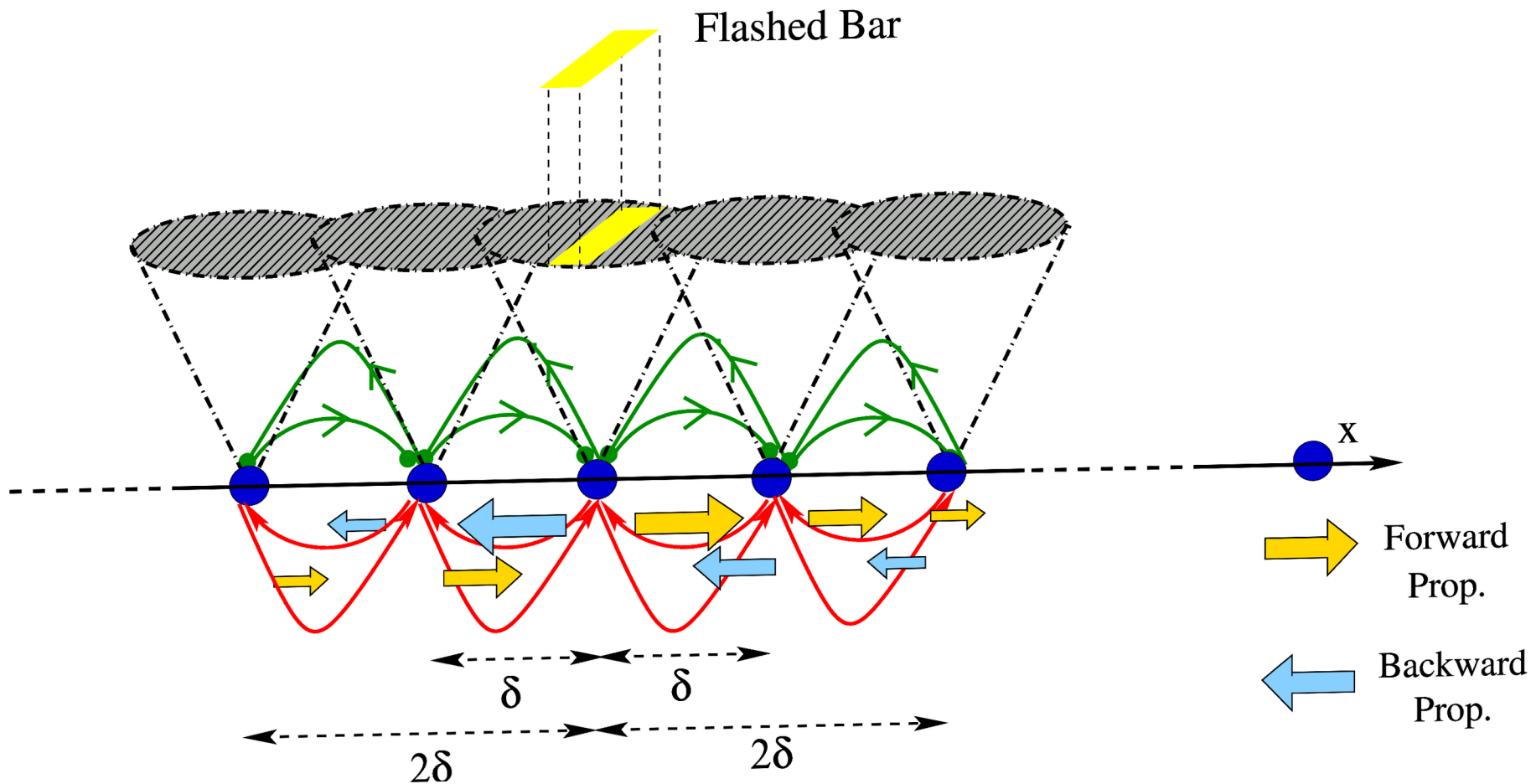
How does lateral inhibition shape the response to moving stimuli ?



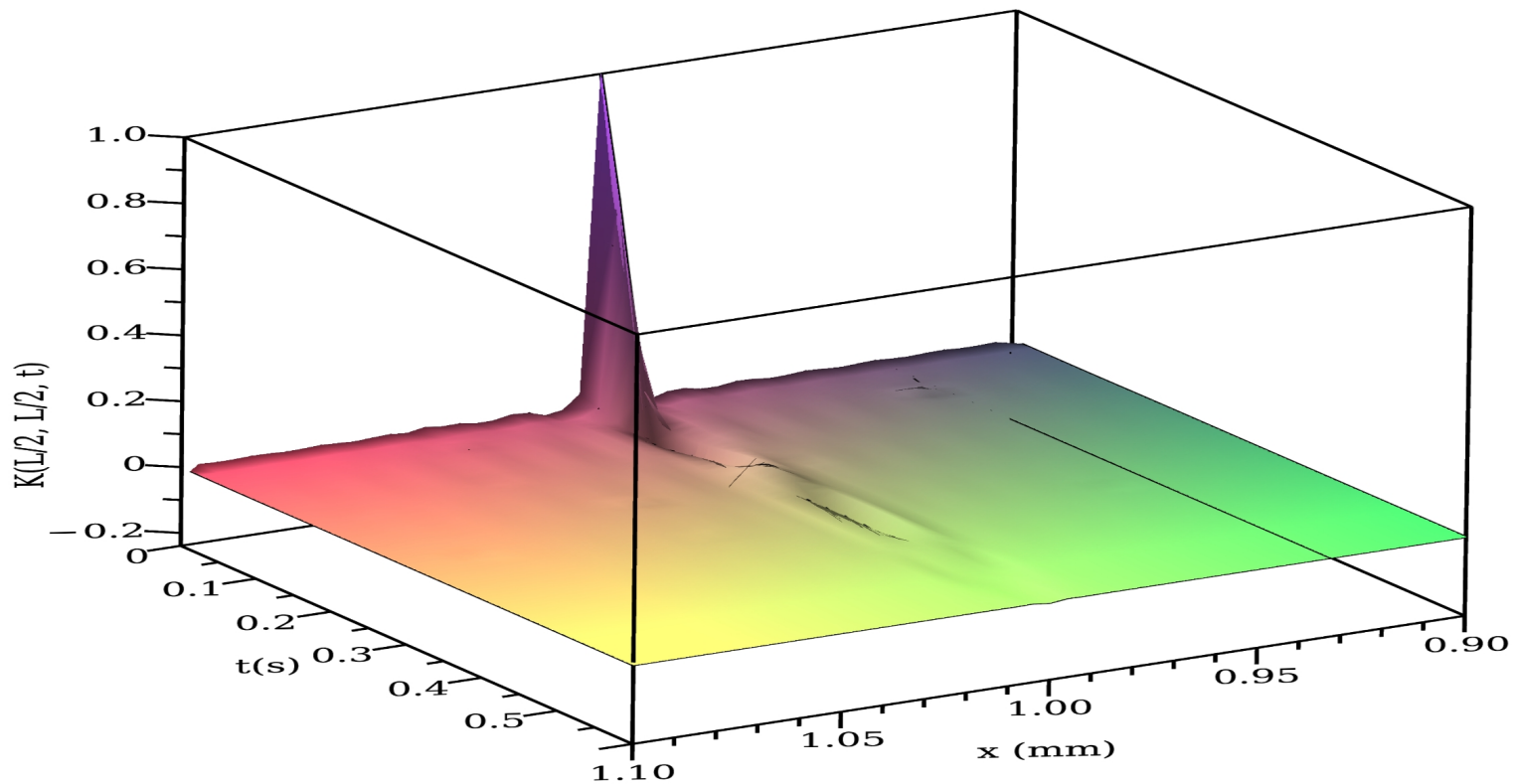
How does lateral inhibition shape the response to moving stimuli ?



How does lateral inhibition shape the response to moving stimuli ?

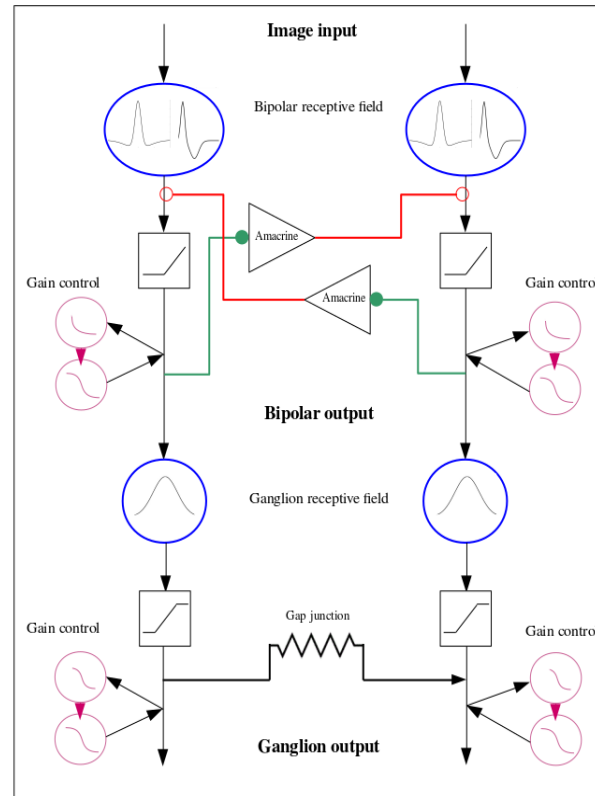
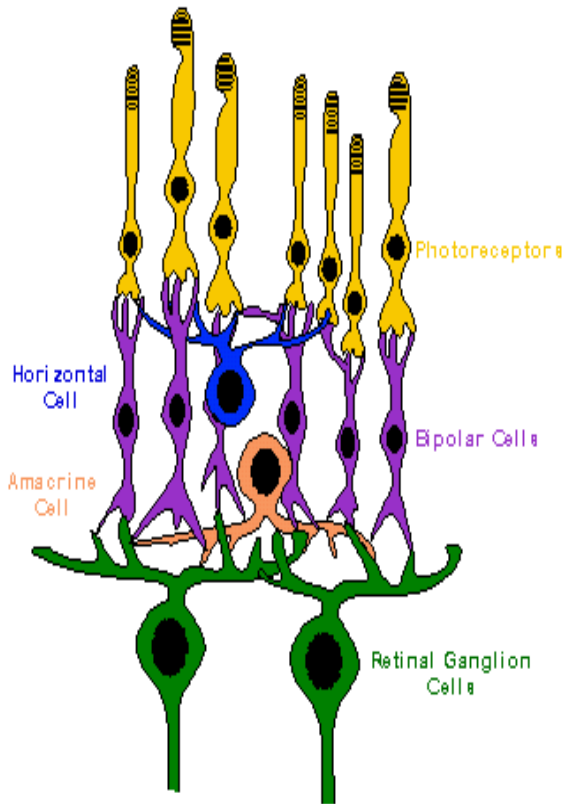


How does lateral inhibition shape the response to moving stimuli ?



How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



- Bipolar voltage :

$$\frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t)$$

- External drive :

$$F_{B_i}(t) = \frac{\gamma_i^{(drive)}}{\tau_{B_i}} + \frac{d}{dt} \gamma_i^{(drive)}$$

- Amacrine voltage :

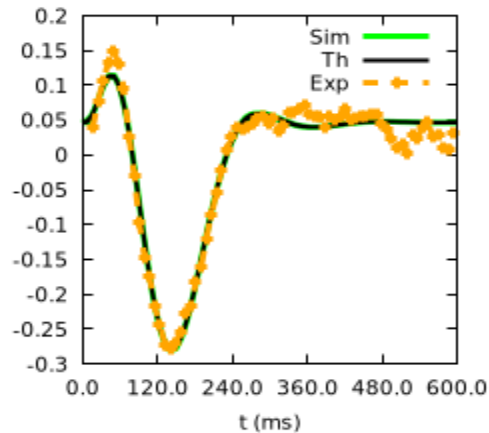
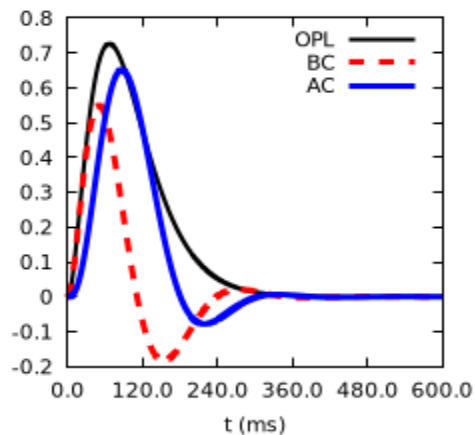
$$\frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_A$$

- Coupled dynamics :

$$\begin{cases} \frac{dV_{B_i}}{dt} = -\frac{1}{\tau_{B_i}} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + F_{B_i}(t), & i=1 \dots N \\ \frac{dV_{A_j}}{dt} = -\frac{1}{\tau_{A_j}} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \zeta_A, & j=1 \dots N, \\ \frac{dV_{G_k}}{dt} = -\frac{1}{\tau_{G_k}} V_{G_k} + \sum_{i=1}^{N_B} W_{G_k}^{B_i} \mathcal{N}^{(B)}(V_{B_i}) + \sum_{j=1}^{N_A} W_{G_k}^{A_j} \mathcal{N}^{(A)}(V_{A_j}) + \zeta_G, & k=1 \dots N. \end{cases}$$

How does lateral inhibition shape the response to moving stimuli ?

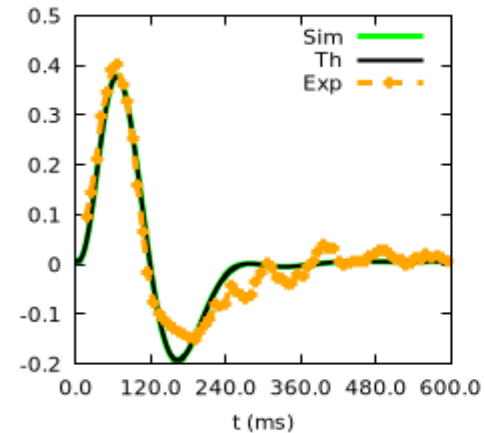
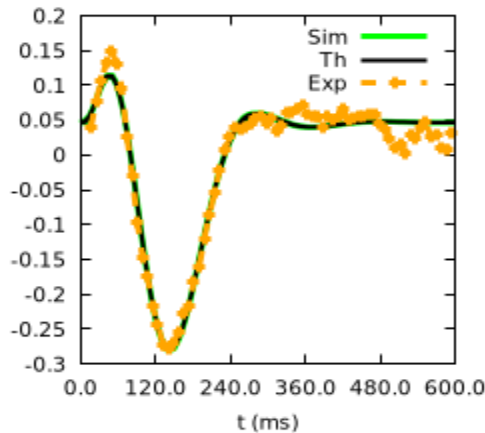
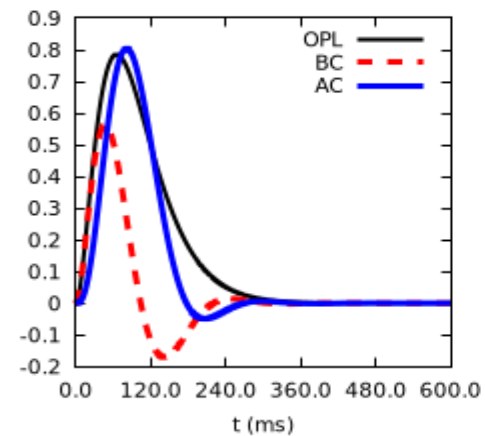
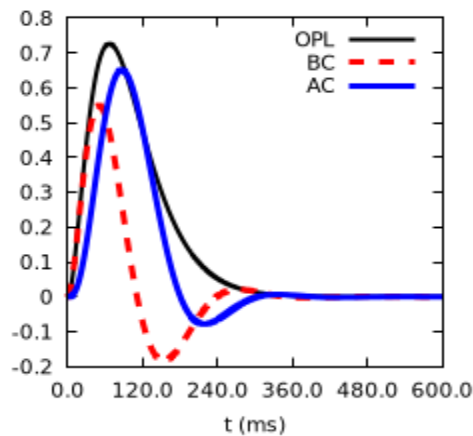
How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



Control condition

How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).

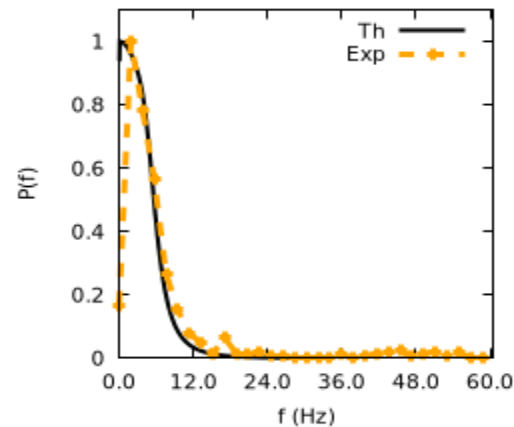
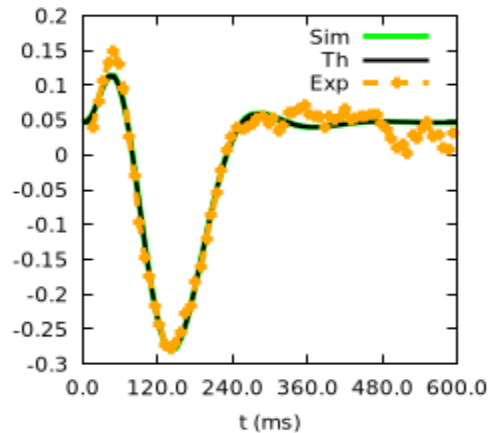
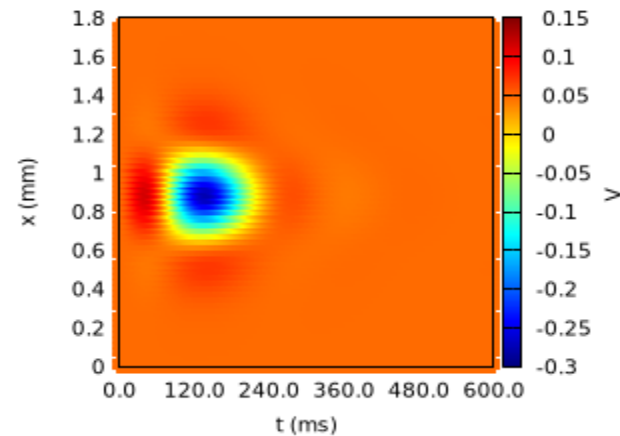
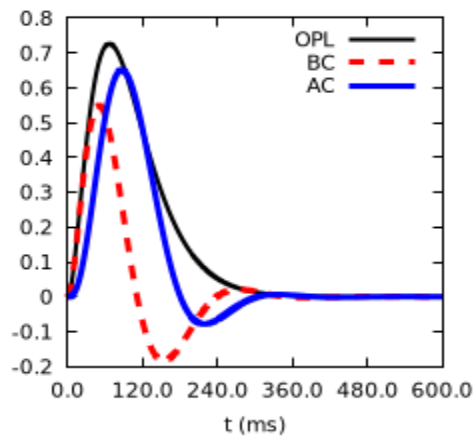


Control condition

CNO

How does lateral inhibition shape the response to moving stimuli ?

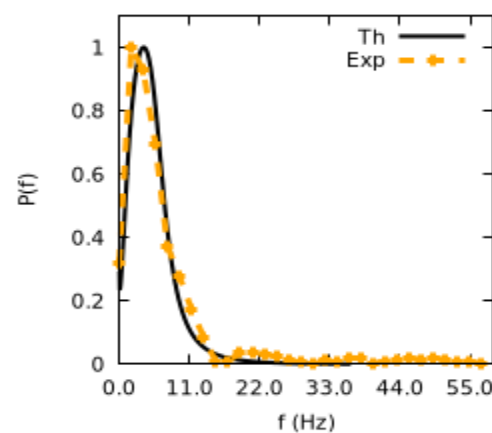
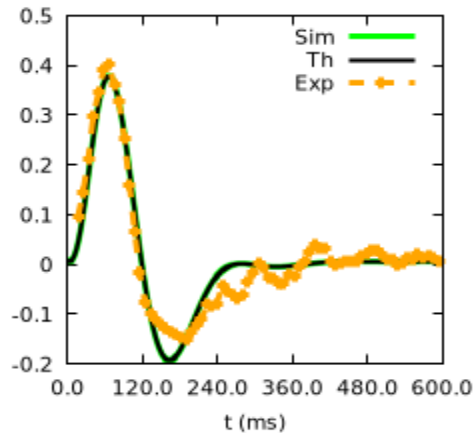
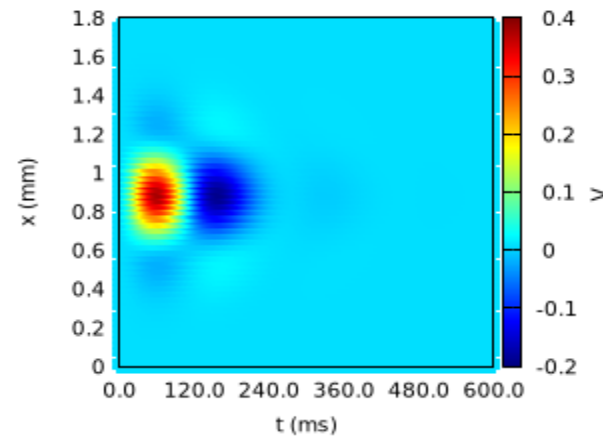
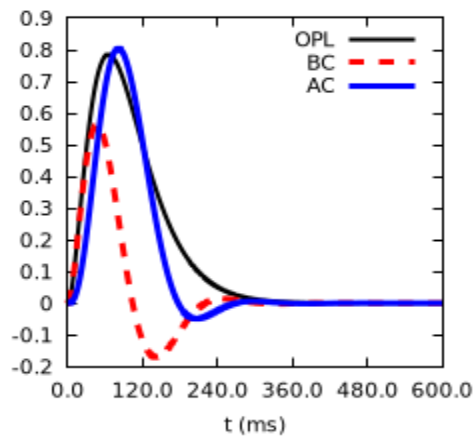
How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



Control condition

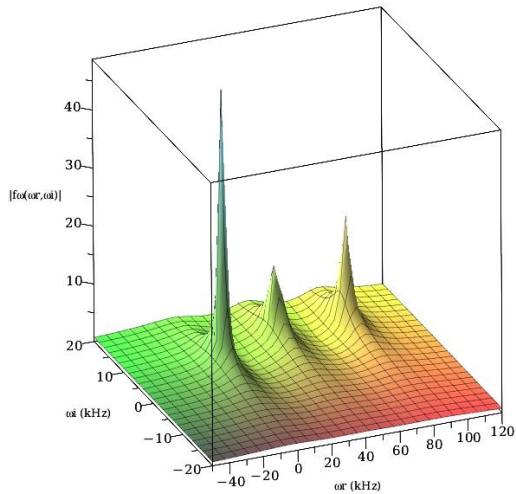
How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



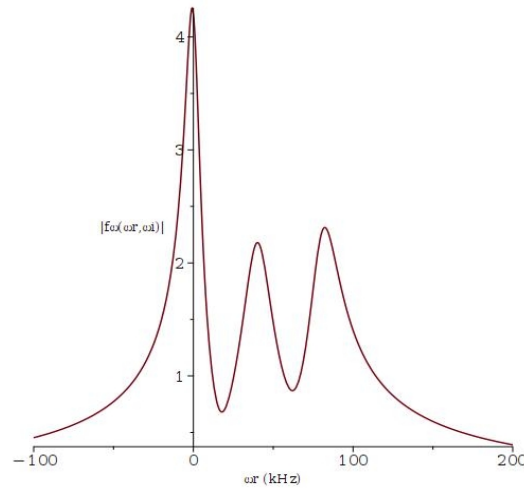
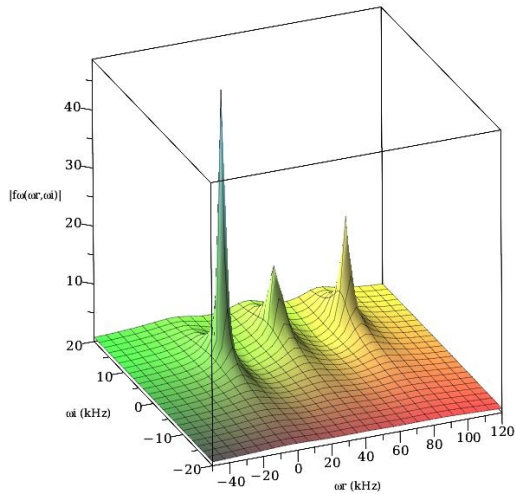
Resonances, poles, and Fourier transform

$f(\omega)$: Meromorphic function in the complex plane



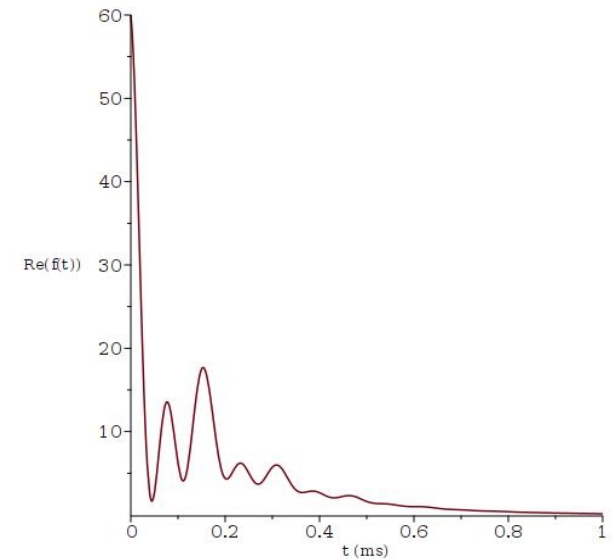
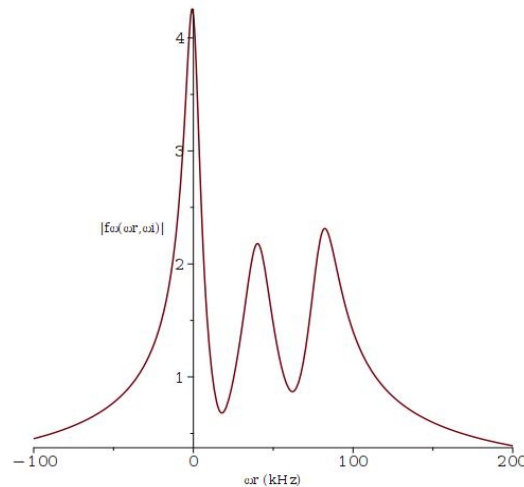
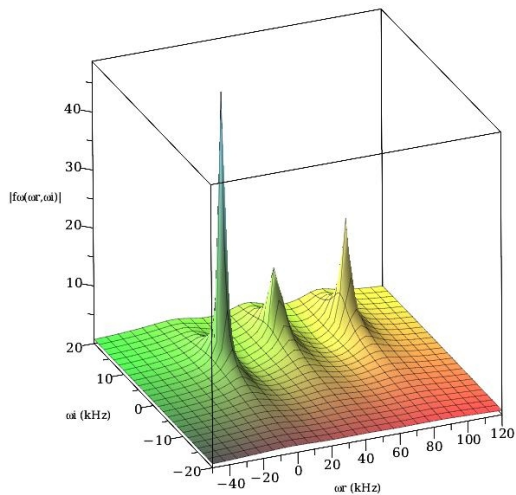
Resonances, poles, and Fourier transform

$f(\omega)$: Meromorphic function in the complex plane



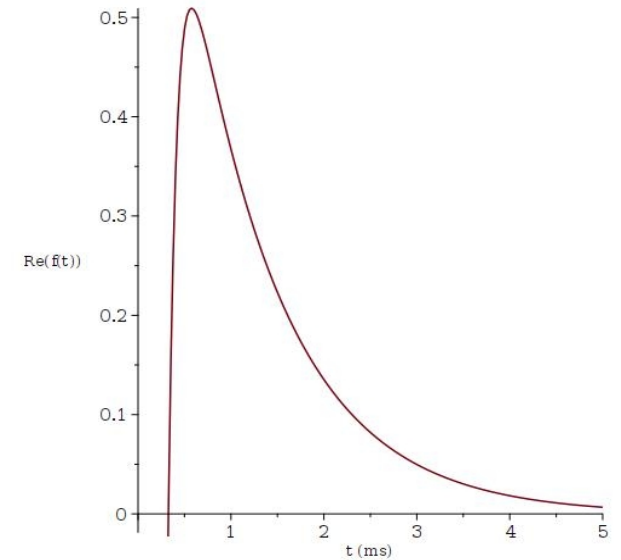
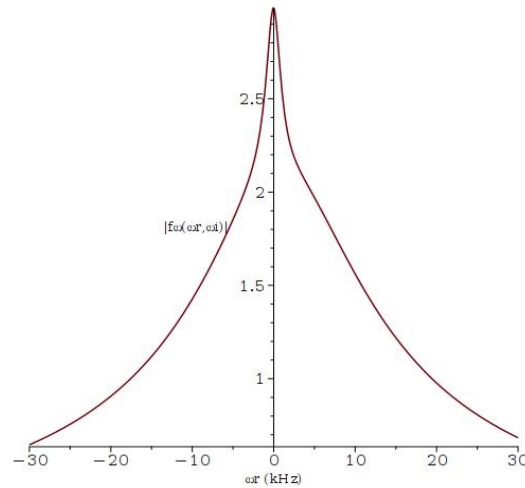
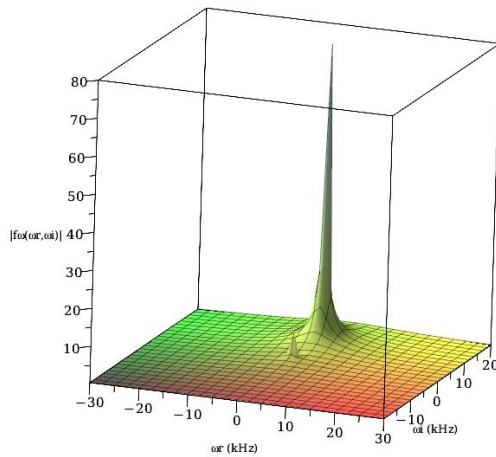
Resonances, poles, and Fourier transform

$f(\omega)$: Meromorphic function in the complex plane



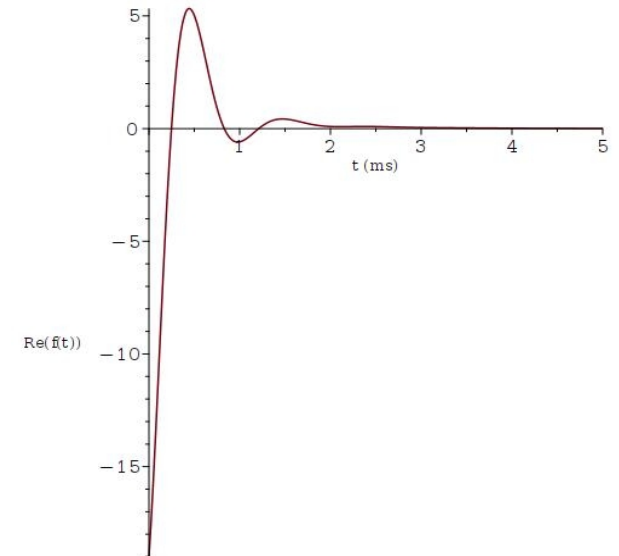
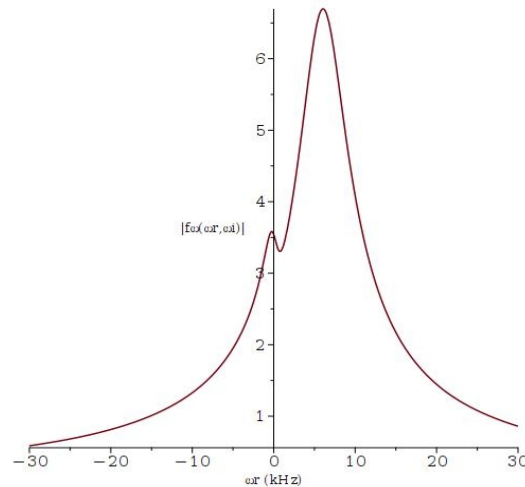
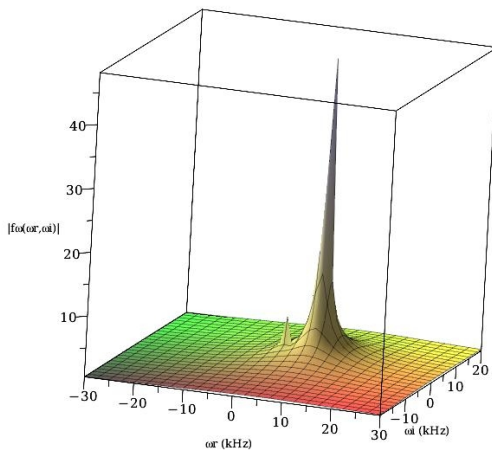
Resonances, poles, and Fourier transform

From resonances to monophasic profile

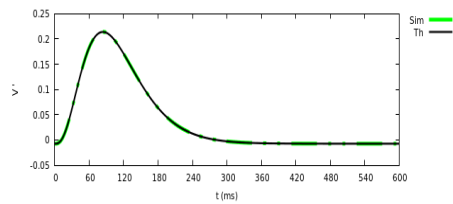
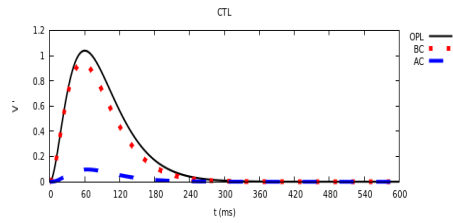


Resonances, poles, and Fourier transform

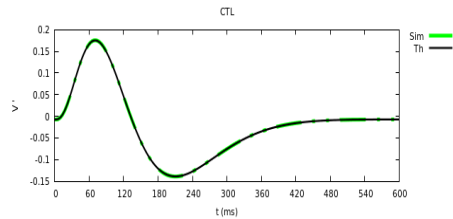
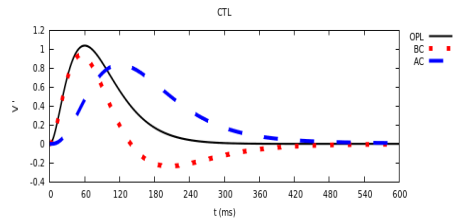
From resonances to polyphasic profile



How does lateral inhibition shape the response to moving stimuli ?

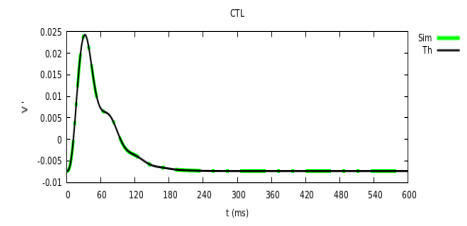
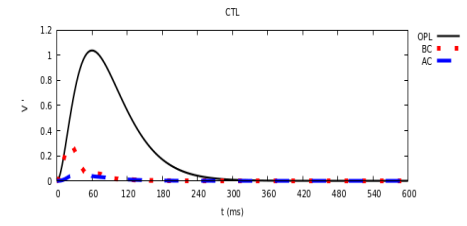
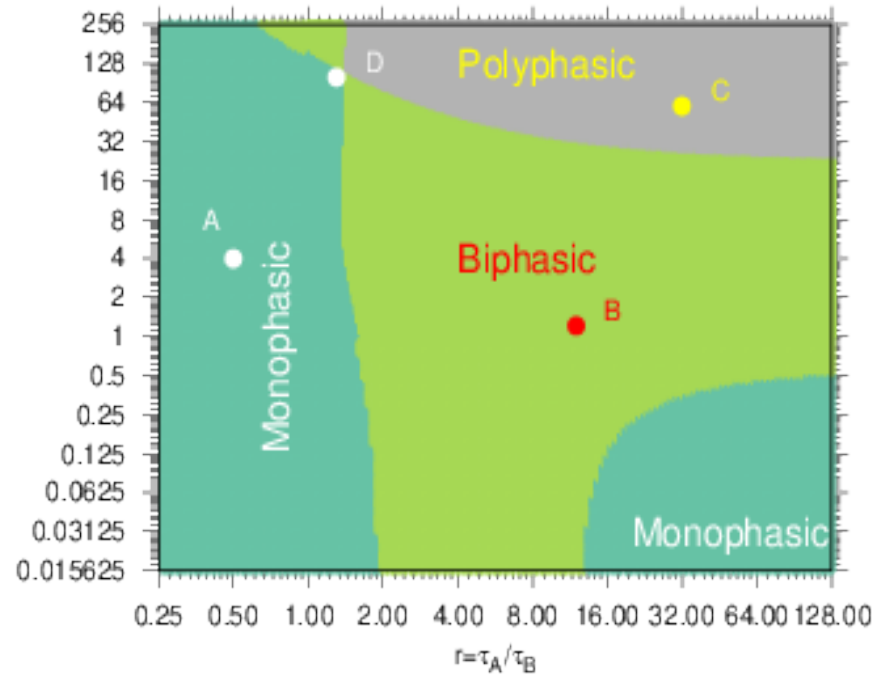


A

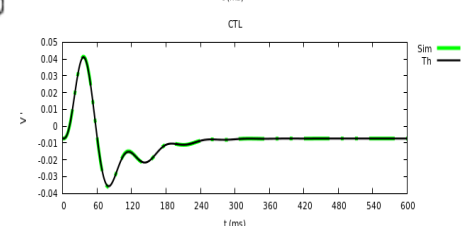
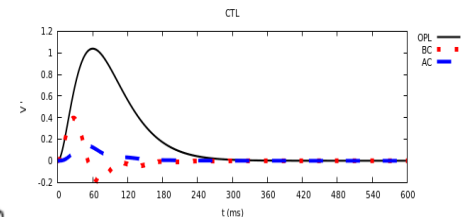


B

$$s = \bar{w} / \bar{w}^+$$



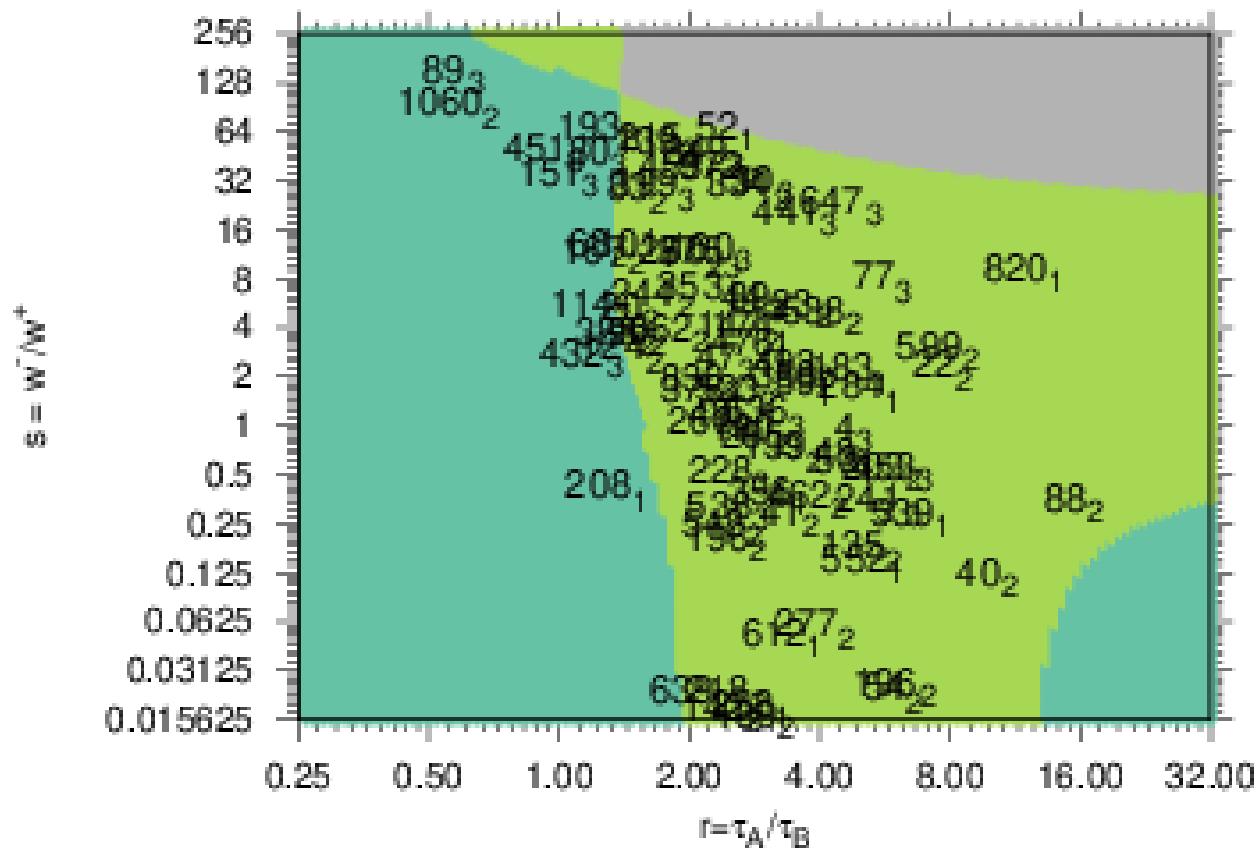
D



C

How does lateral inhibition shape the response to moving stimuli ?

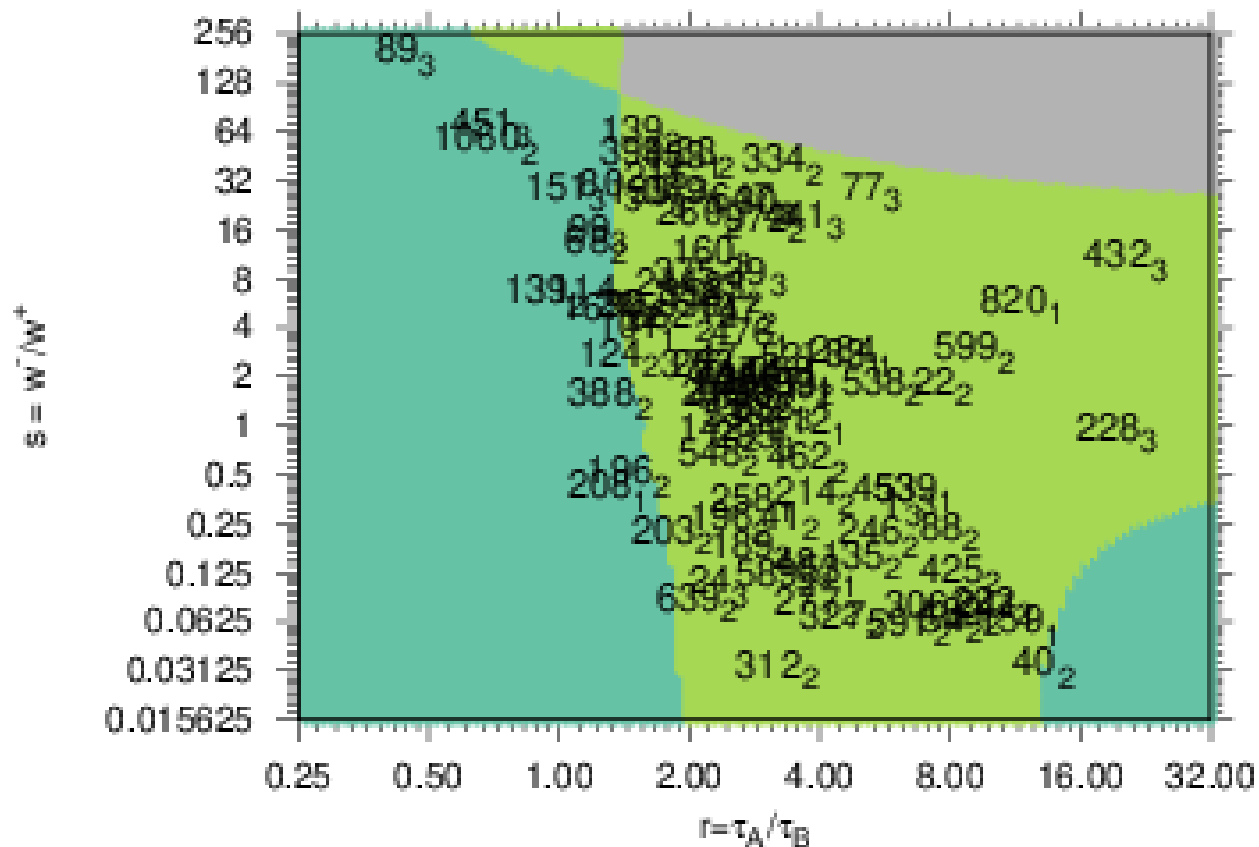
How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).



Control condition

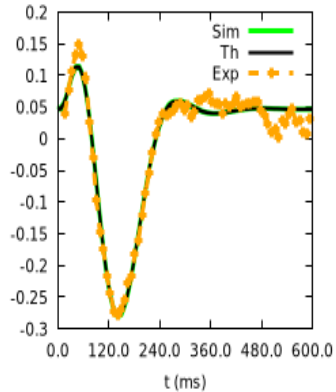
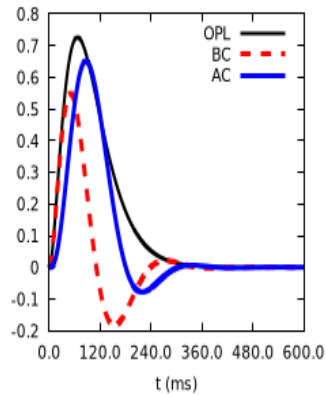
How does lateral inhibition shape the response to moving stimuli ?

How does the inner retinal network shape the ganglion cells receptive field : a computational study, E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, Neural Computation, 2024, 36 (6).

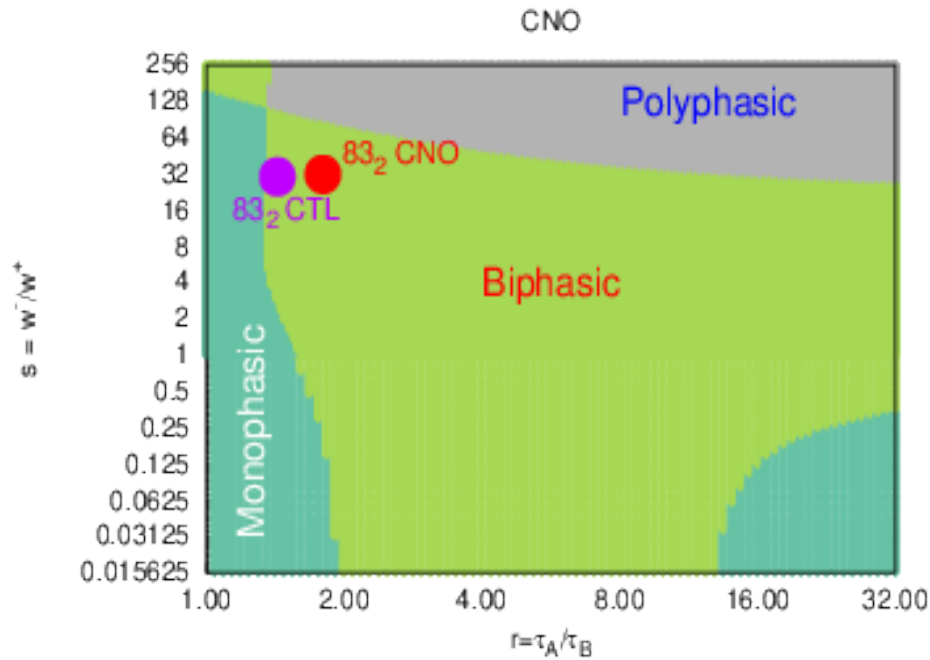


Application of CNO (Clozapine N Oxide)

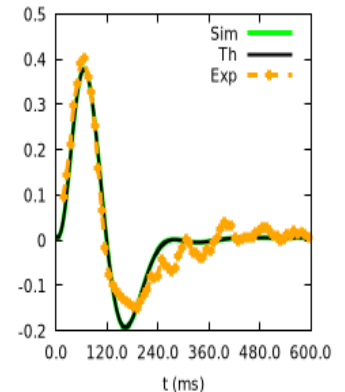
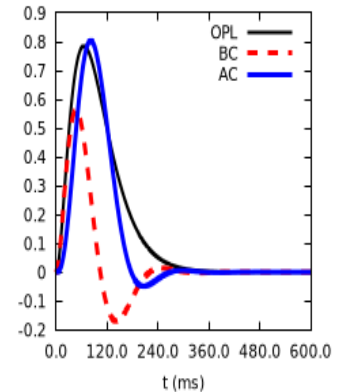
How does lateral inhibition shape the response to moving stimuli ?



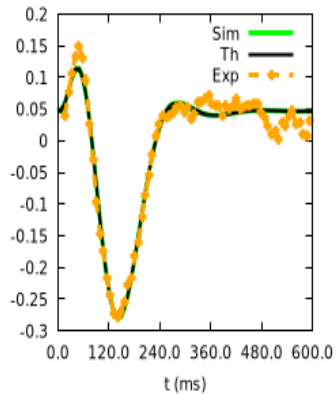
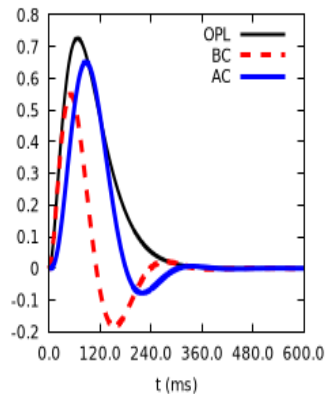
Control condition



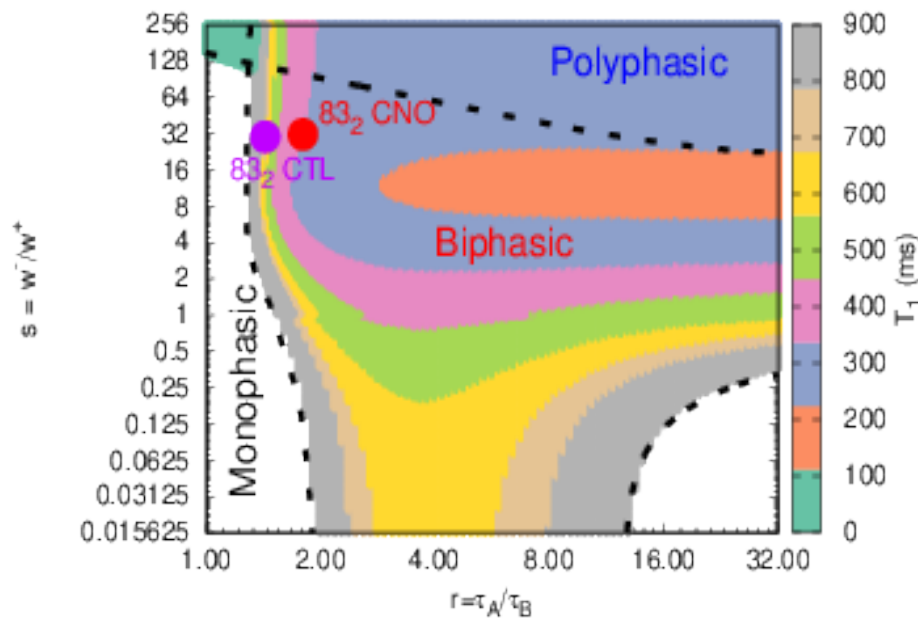
CNO



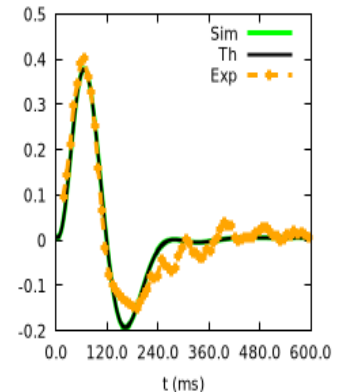
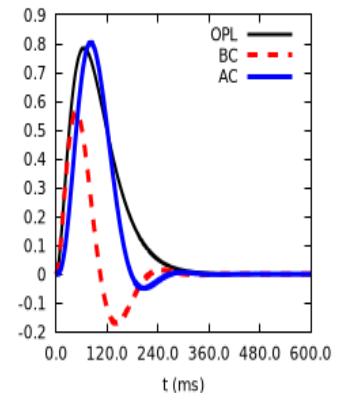
How does lateral inhibition shape the response to moving stimuli ?



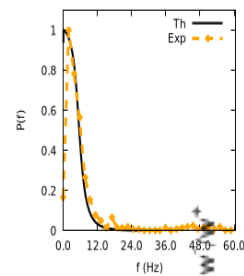
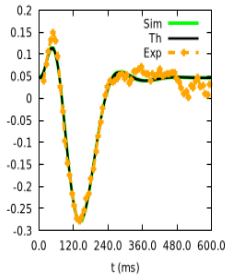
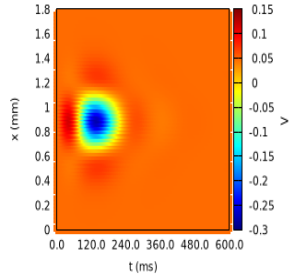
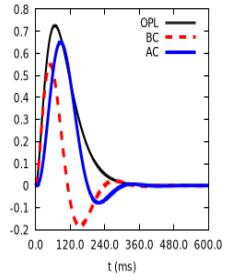
Control condition



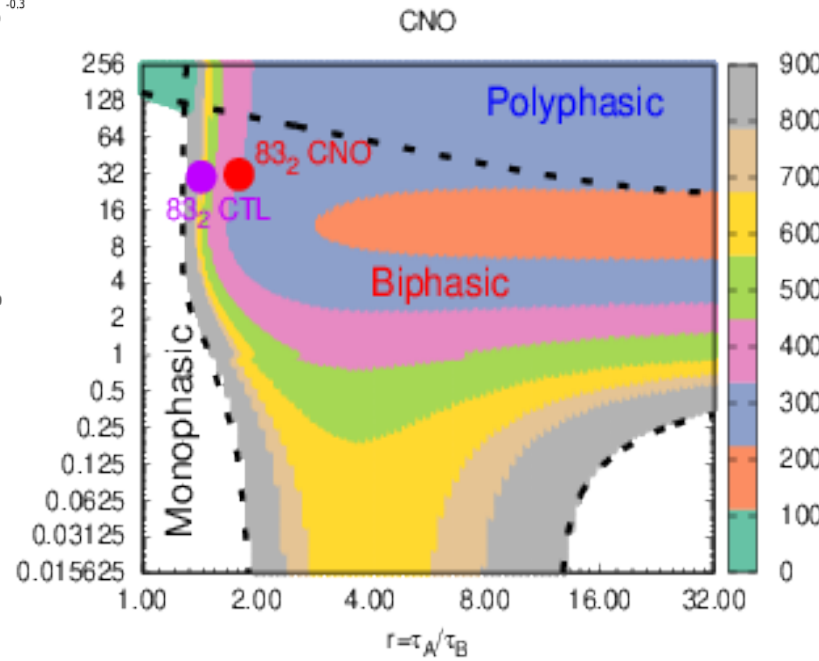
CNO



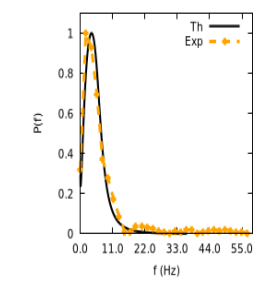
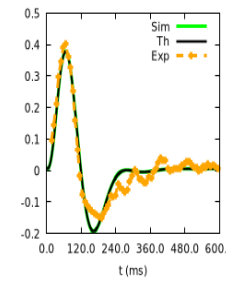
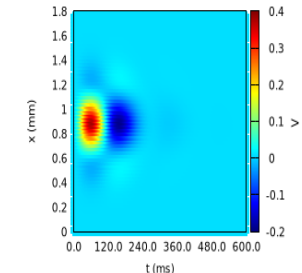
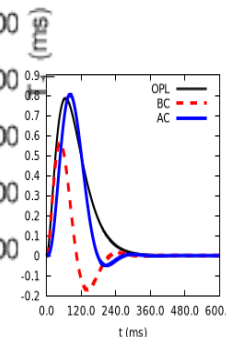
How does lateral inhibition shape the response to moving stimuli ?



$$s = w_A w_B$$

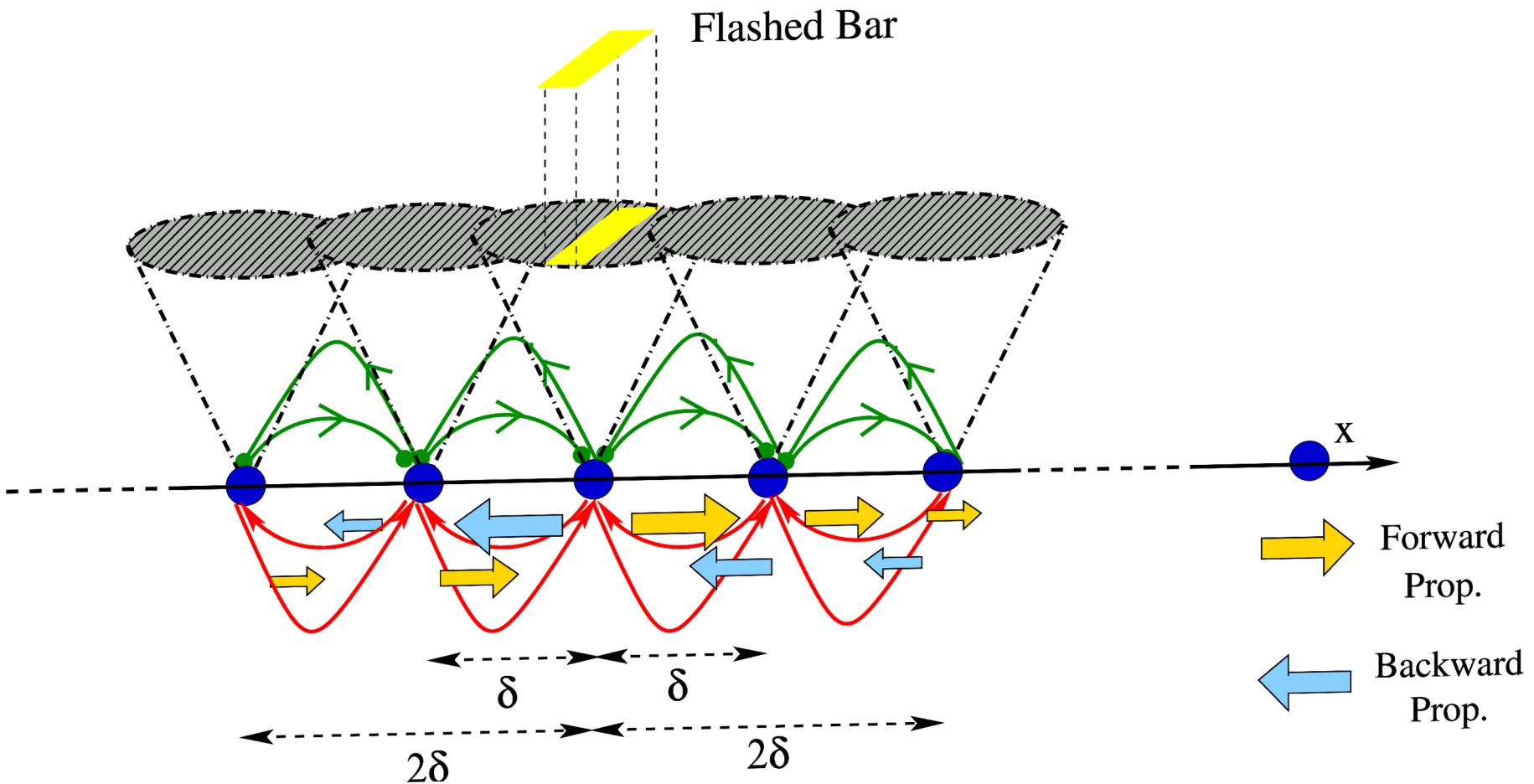


CNO

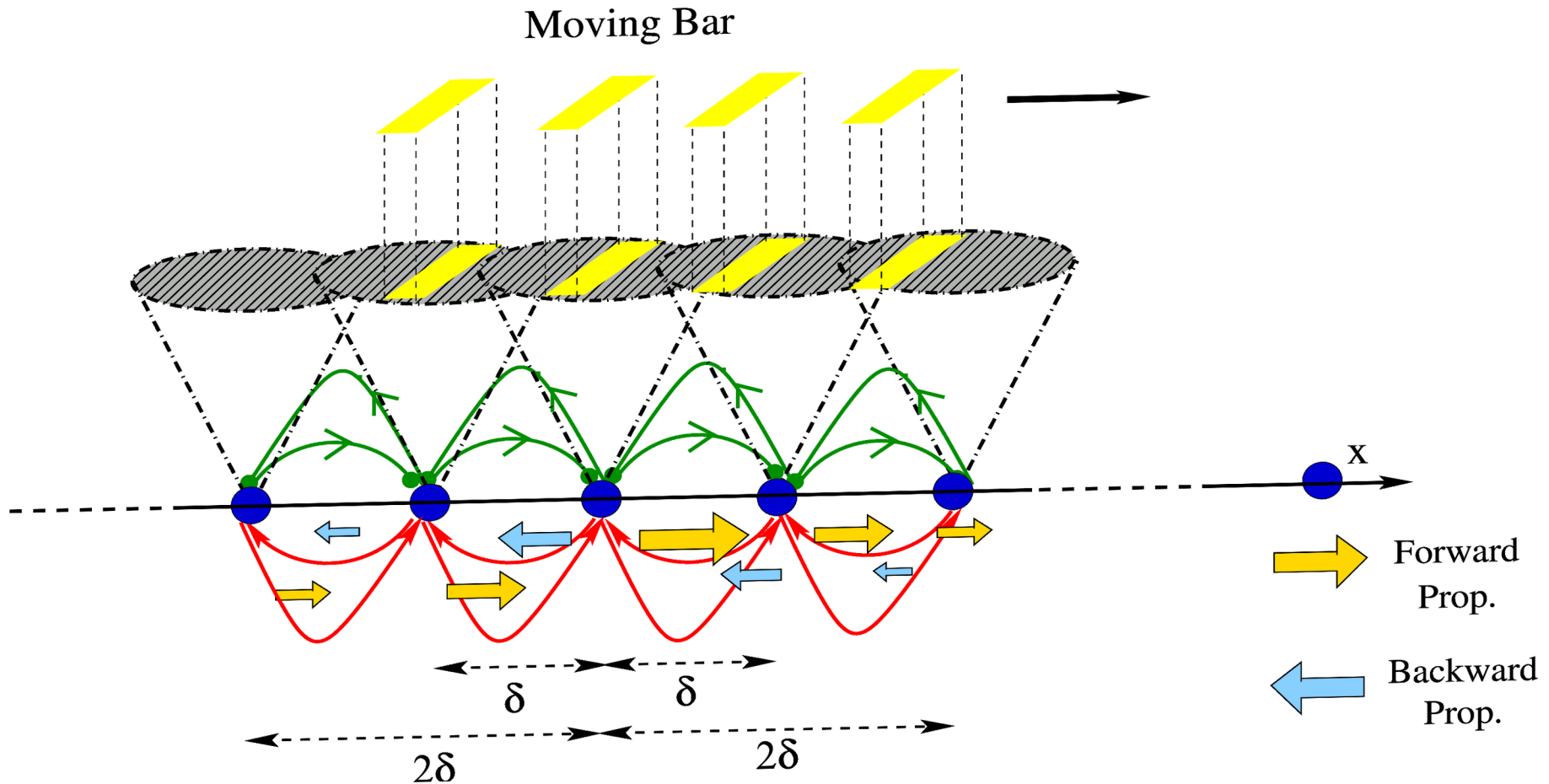


Control condition

How does lateral inhibition shape the response to moving stimuli ?



How does lateral inhibition shape the response to moving stimuli?



How does lateral inhibition shape the response to moving stimuli ?



How does lateral inhibition shape the response to moving stimuli ?



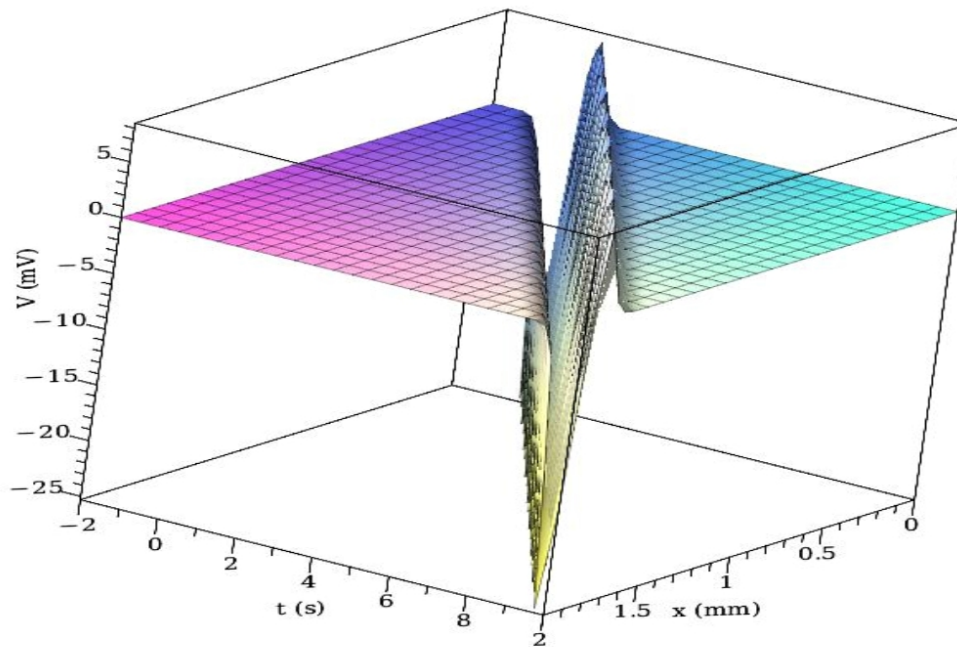
Conjecture :

A moving object triggers **waves of activity** in the retina (and in the visual cortex).

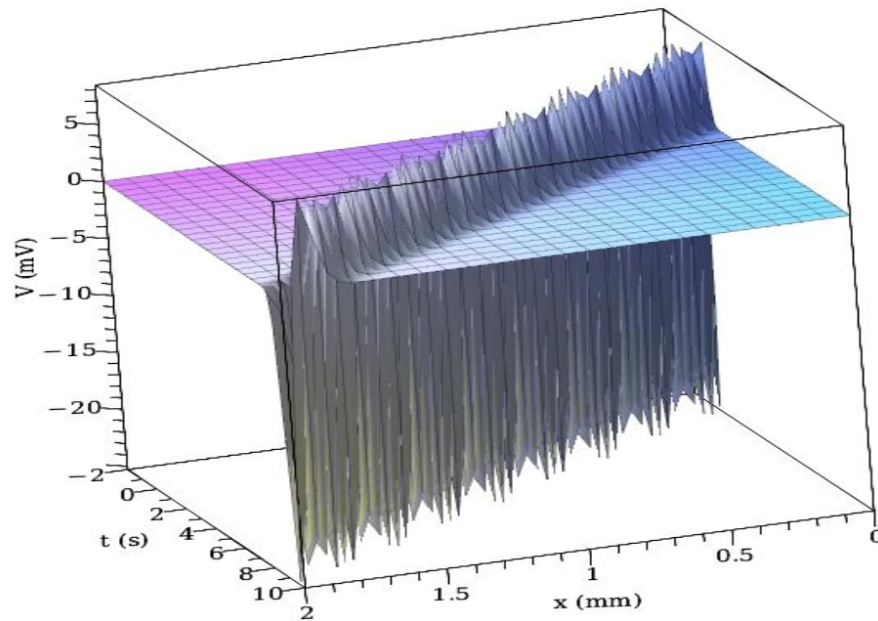
These waves are shaped and modulated by **lateral inhibition**.

The conjunction of the moving stimulus and of the forward/ backward and excitatory/inhibitory effects **selects** spatial wave lengths and temporal frequencies leading to **specific responses** and **resonance effects**.

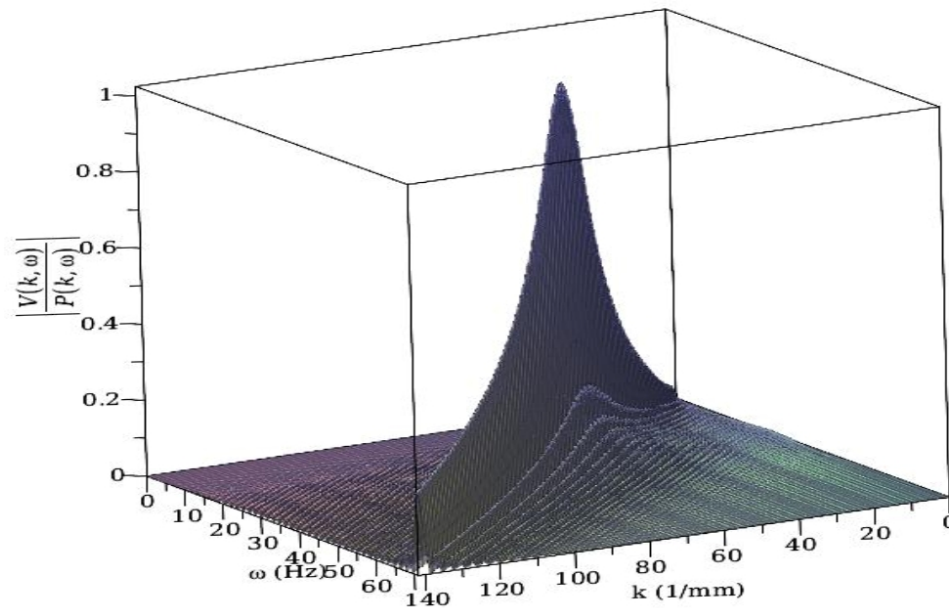
How does lateral inhibition shape the response to moving stimuli ?



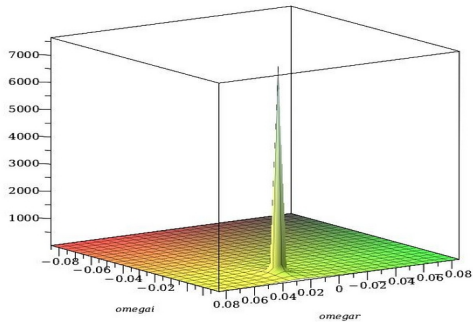
How does lateral inhibition shape the response to moving stimuli ?



How does lateral inhibition shape the response to moving stimuli ?



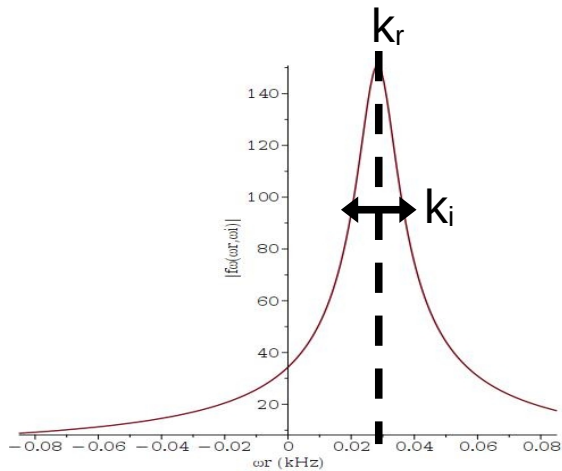
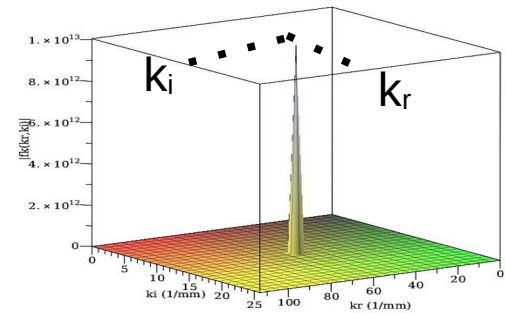
Poles and resonances



$$f(k) = \frac{1}{k - k^*}$$

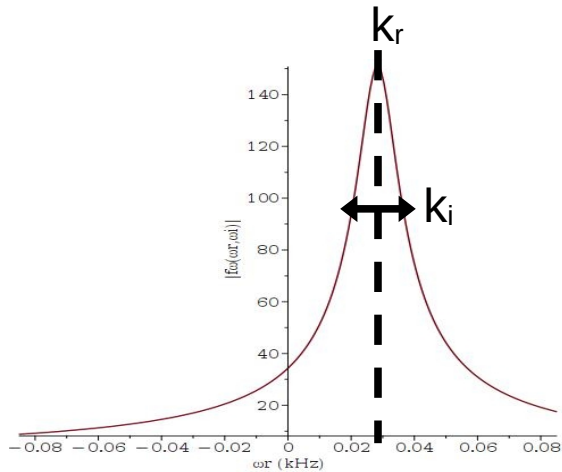
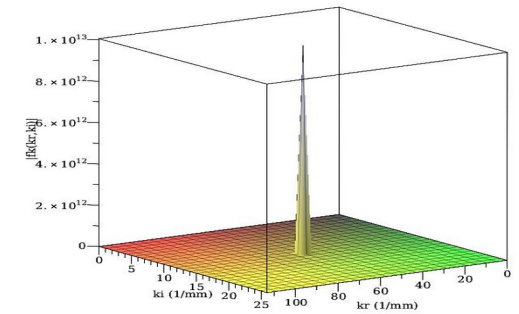
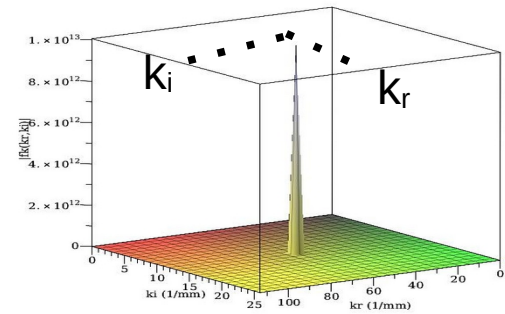
Poles and resonances

$$f(k) = \frac{1}{k - k^*}$$



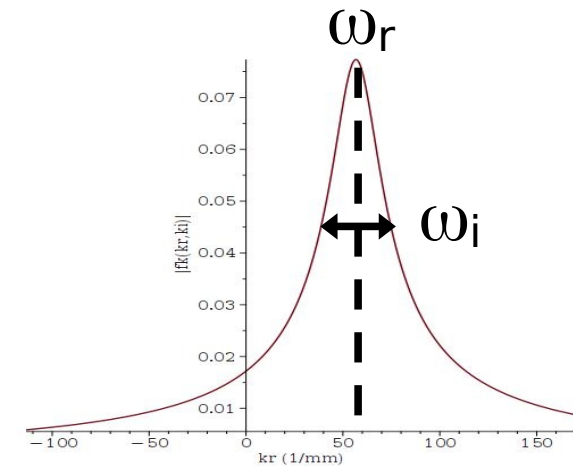
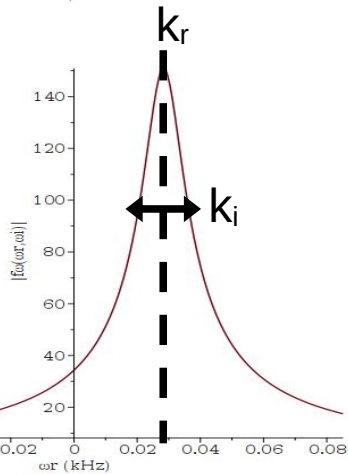
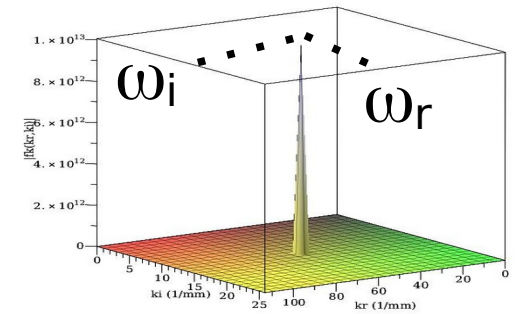
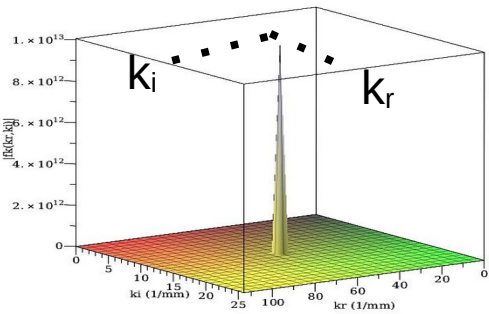
Poles and resonances

$$f(\omega) = \frac{1}{\omega - \omega^*}$$



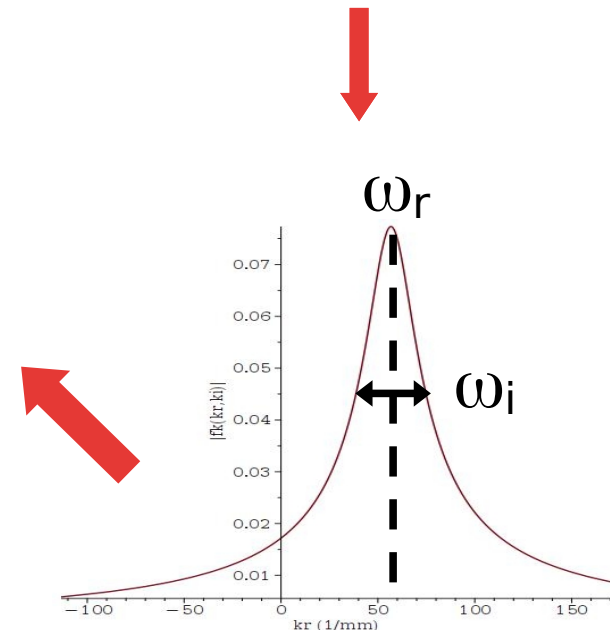
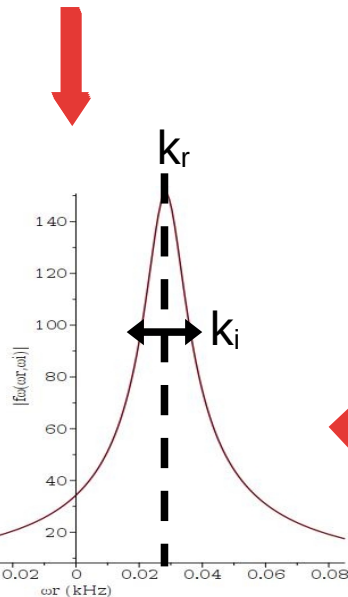
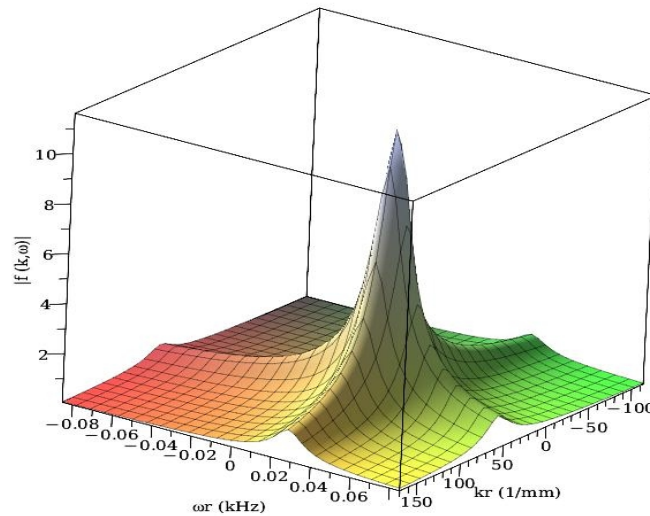
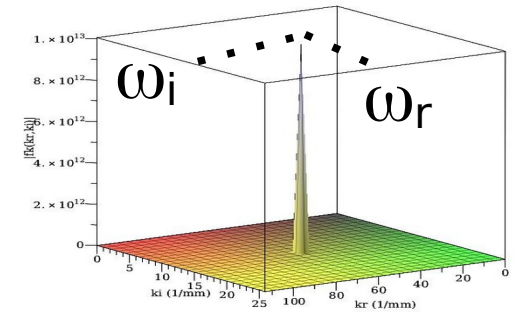
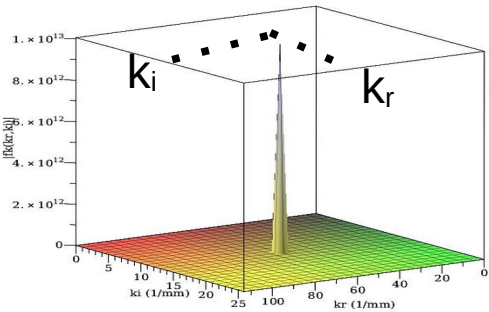
Poles and resonances

$$f(\omega) = \frac{1}{\omega - \omega^*}$$



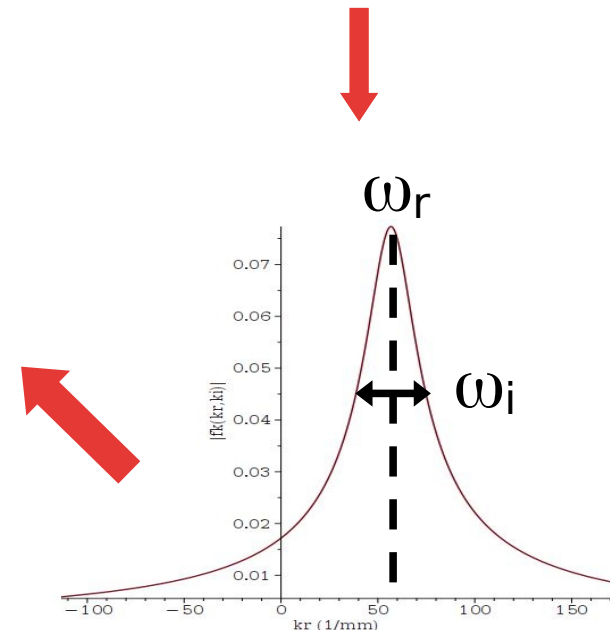
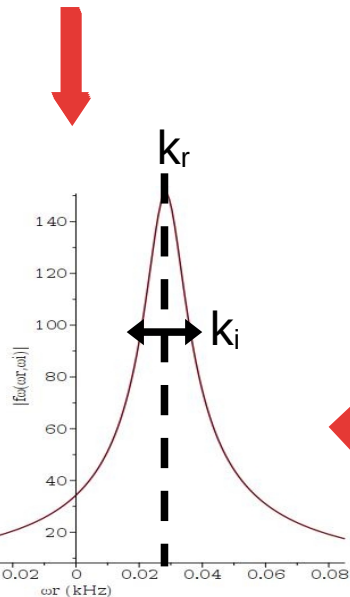
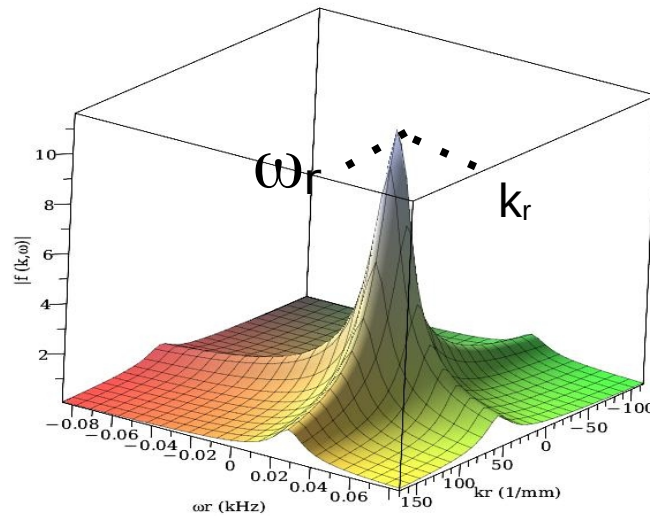
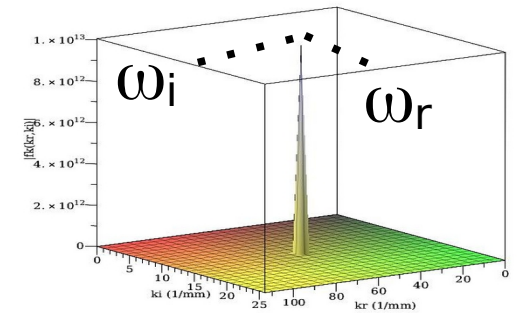
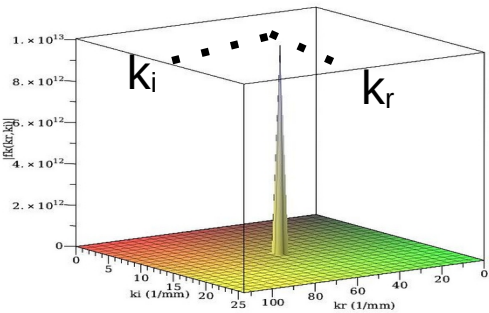
Poles and resonances

$$f(k, \omega) = \frac{1}{k - k^*} \frac{1}{\omega - \omega^*}$$

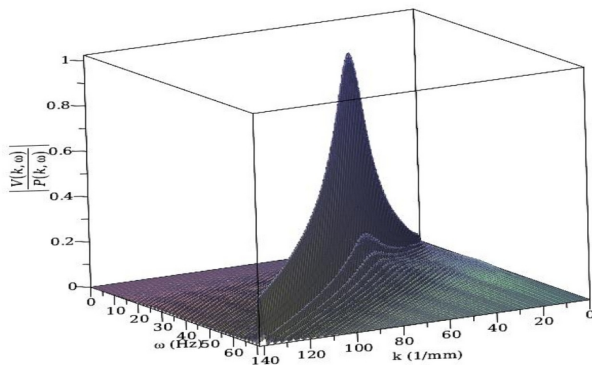
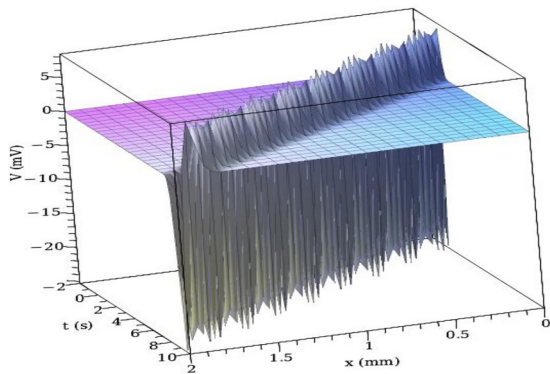


Poles and resonances

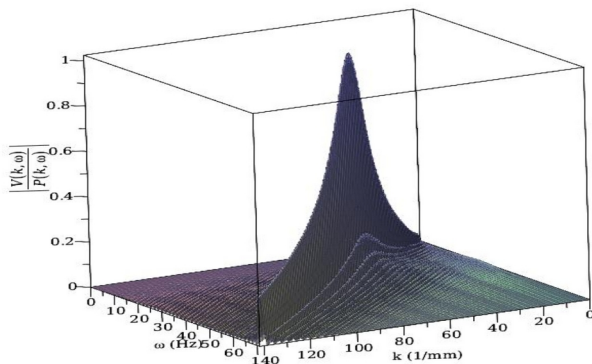
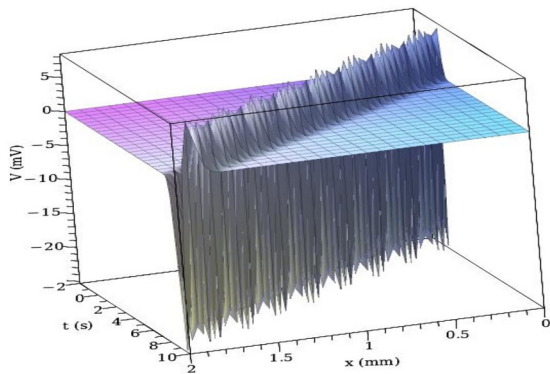
$$f(k, \omega) = \frac{1}{k - k^*} \frac{1}{\omega - \omega^*}$$



How does lateral inhibition shape the response to moving stimuli ?

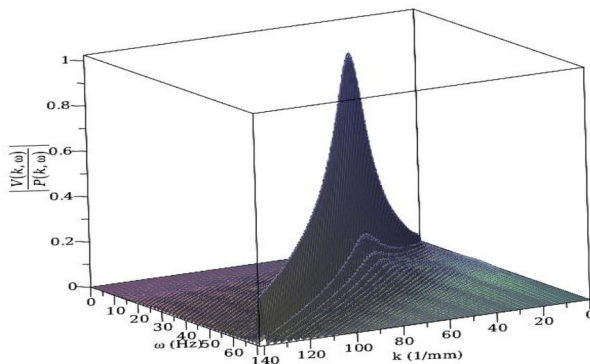
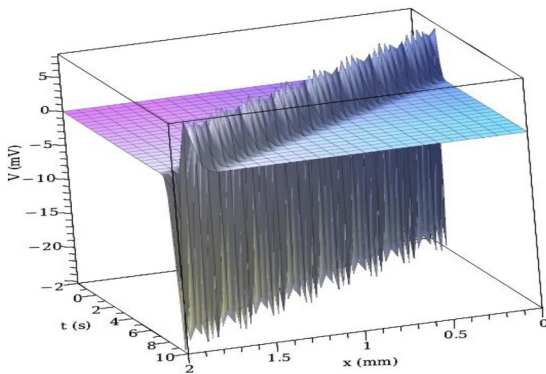


How does lateral inhibition shape the response to moving stimuli ?



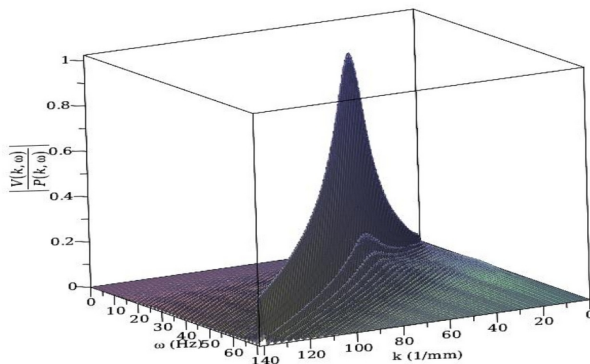
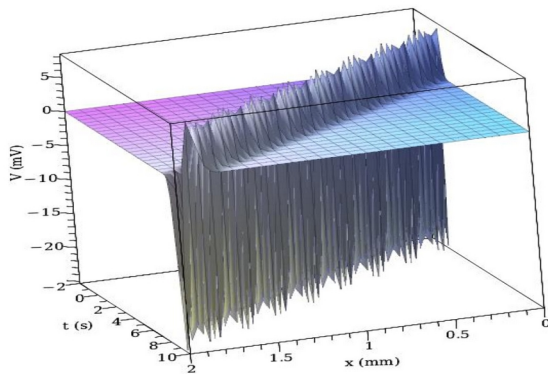
- The spatio temporal response to moving stimuli is characterized by **poles** in the **complex space** (k,ω) .

How does lateral inhibition shape the response to moving stimuli ?



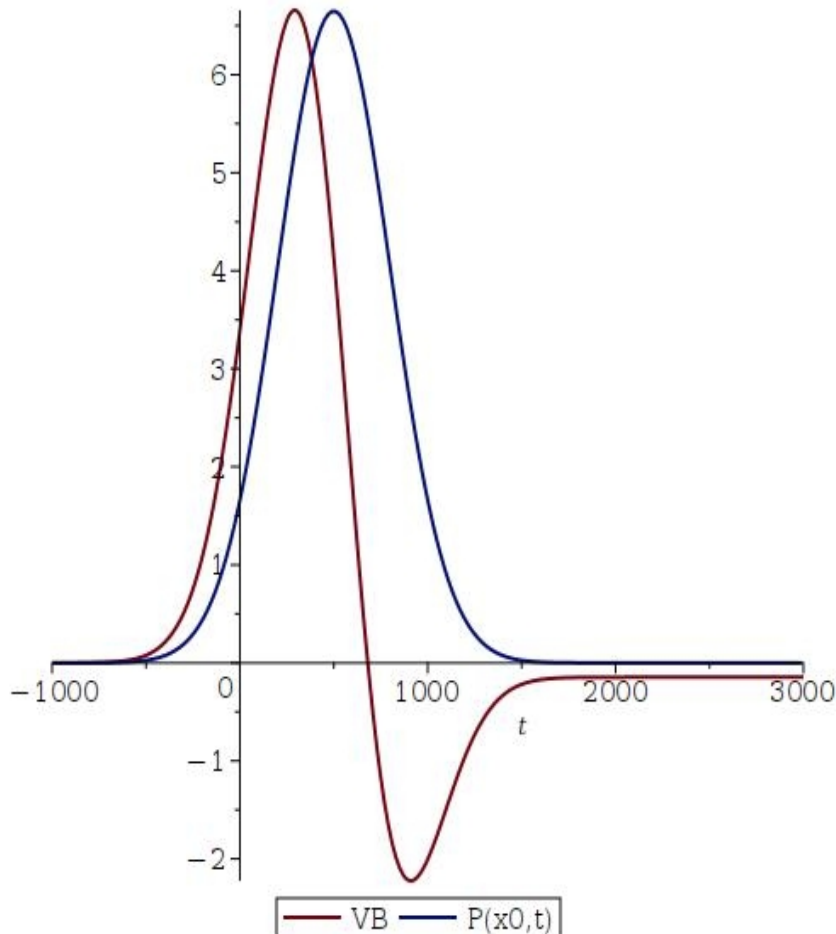
- The spatio temporal response to moving stimuli is characterized by **poles** in the **complex space** (k,ω) .
- Each pole is characterized by four numbers $(k_r, k_i, \omega_r, \omega_i)$ that can be extracted from the power spectrum *provided the resolution is large enough*.

How does lateral inhibition shape the response to moving stimuli ?



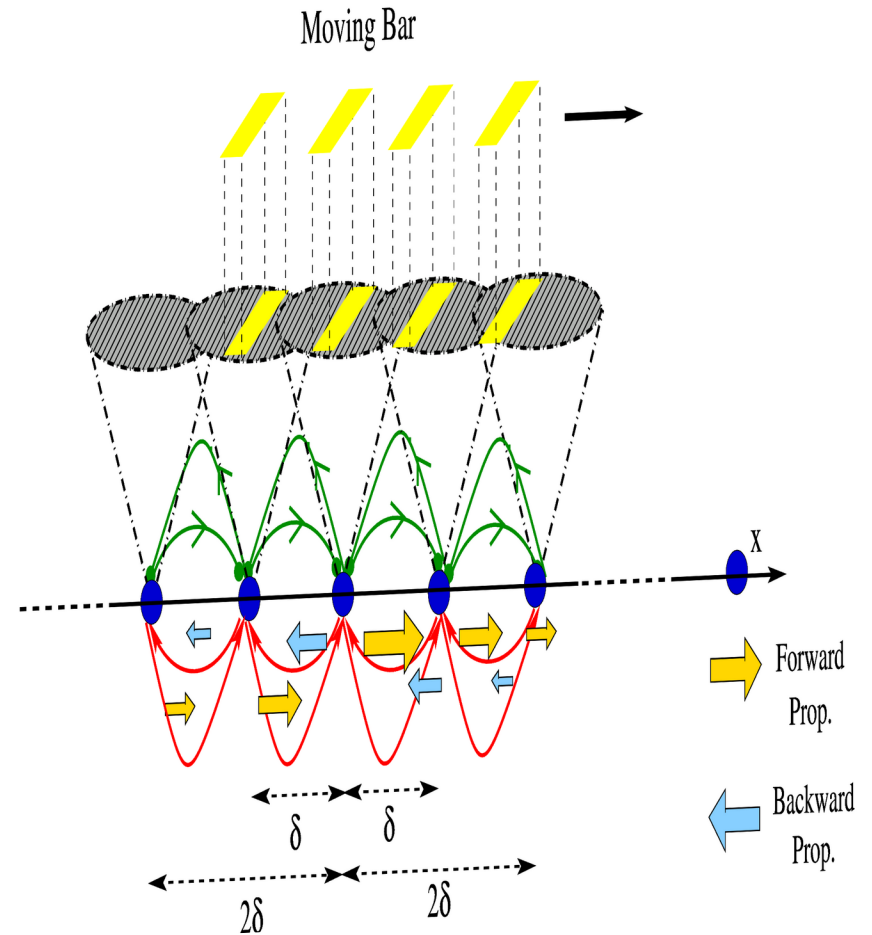
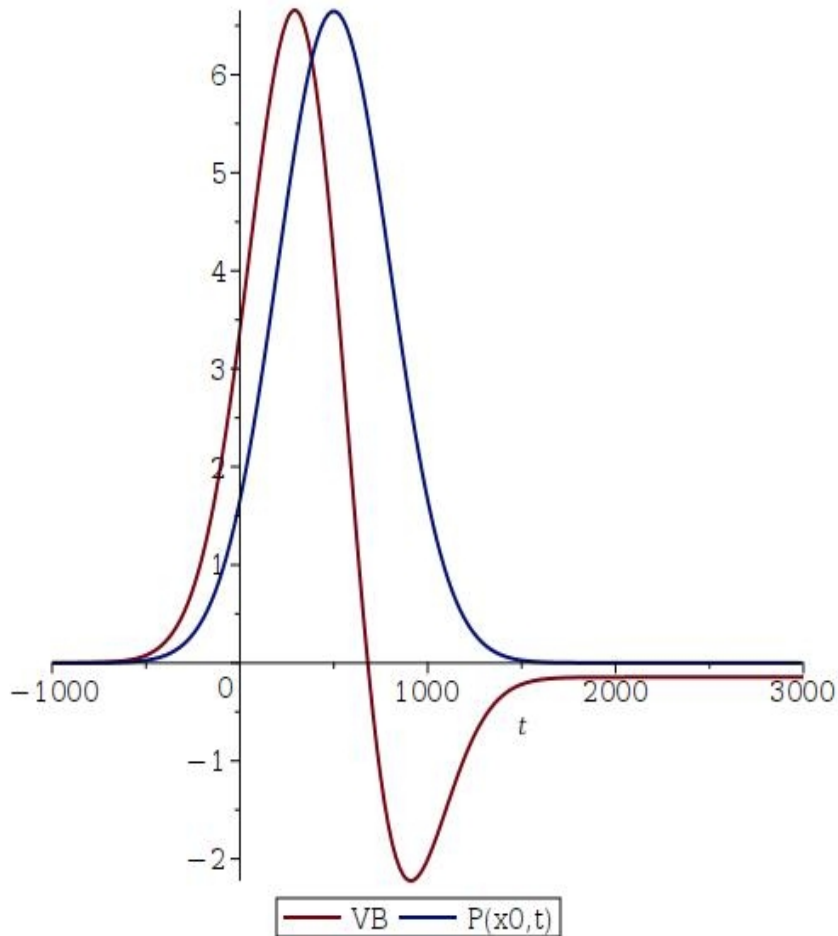
- The spatio temporal response to moving stimuli is characterized by **poles** in the **complex space** (k,ω) .
- Each pole is characterized by four numbers $(k_r, k_i, \omega_r, \omega_i)$ that can be extracted from the power spectrum *provided the resolution is large enough*.
- The location of the poles in the complex space give rise to **different type of dynamical responses**.

Lateral inhibition can induce retinal anticipation



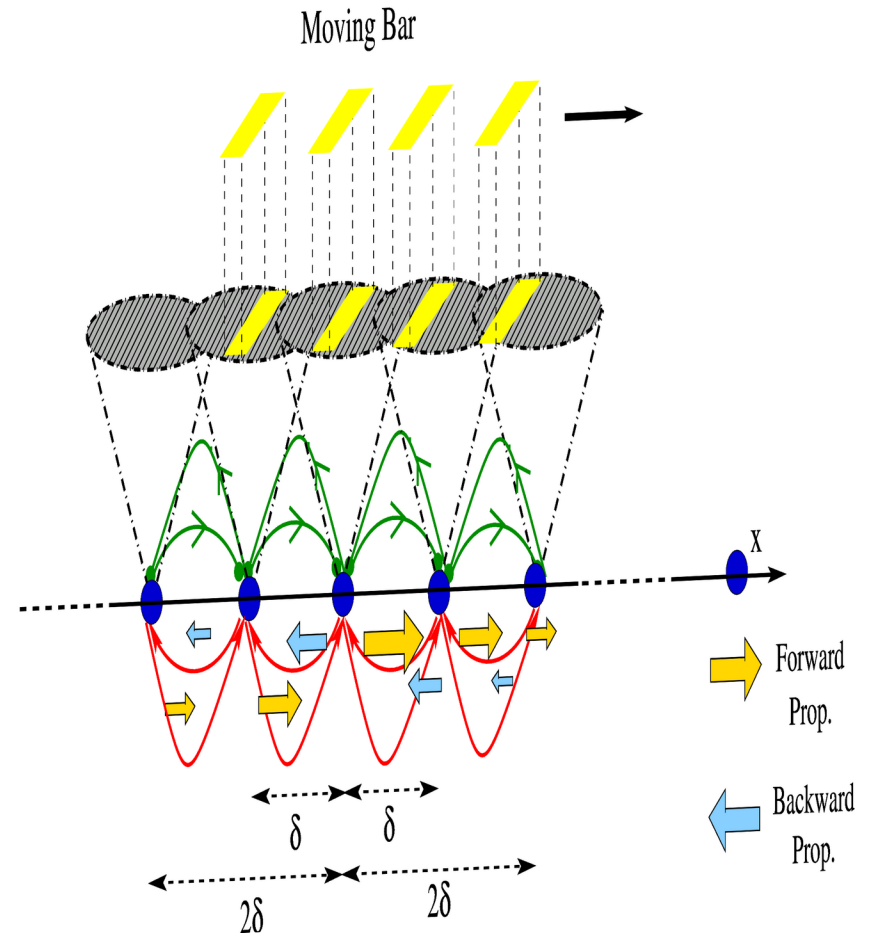
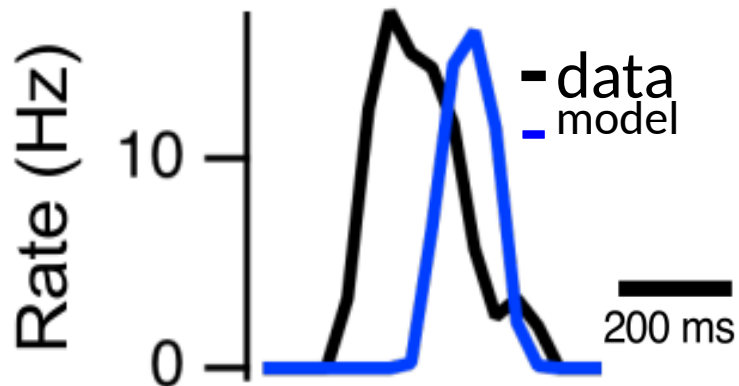
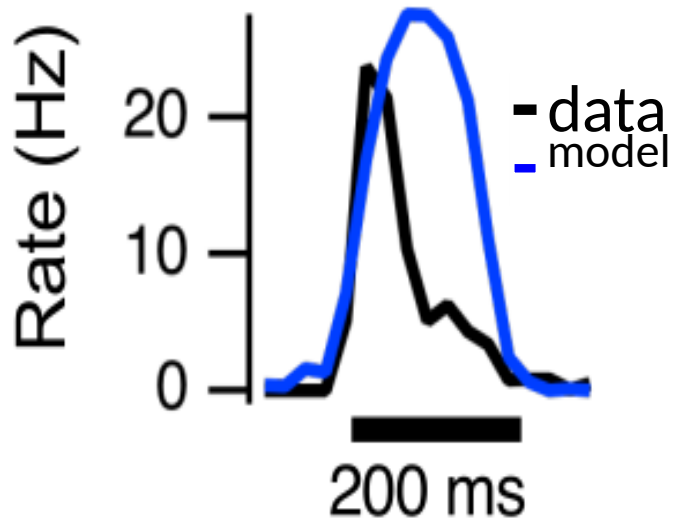
- The spatio temporal response to moving stimuli is characterized by **poles** in the **complex space** (k, ω) .
- Each pole is characterized by four numbers $(k_r, k_i, \omega_r, \omega_i)$ that can be extracted from the power spectrum *provided the resolution is large enough*.
- The location of the poles in the complex space give rise to **different type of dynamical responses**.

Lateral inhibition can induce retinal anticipation

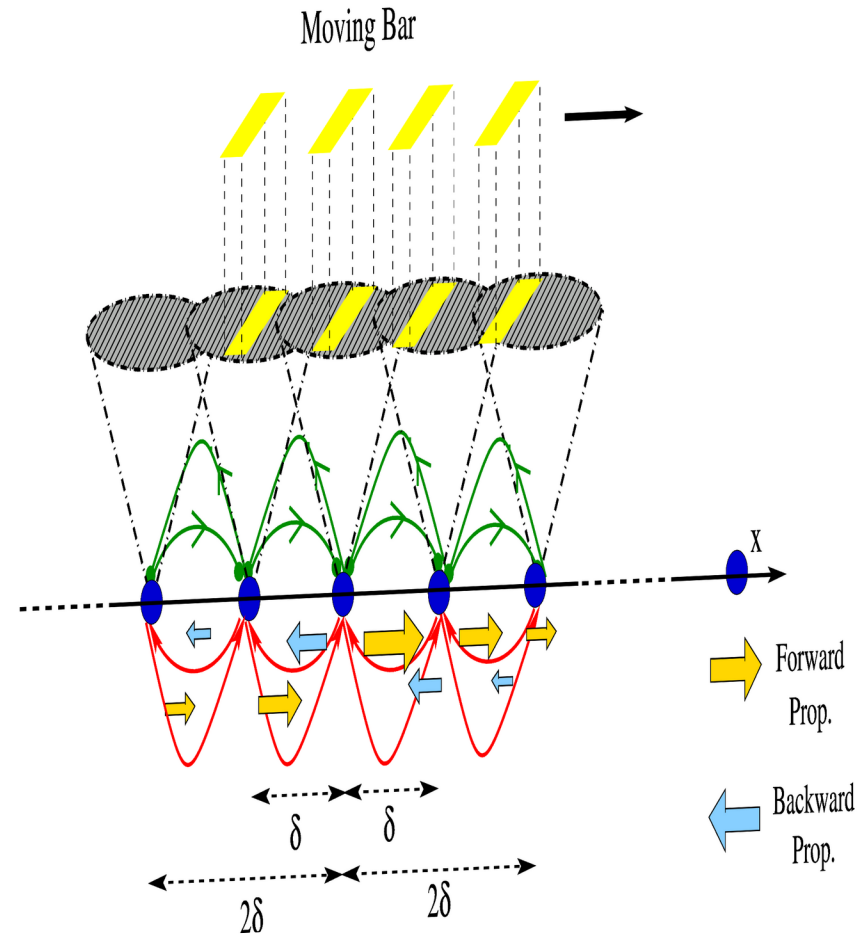
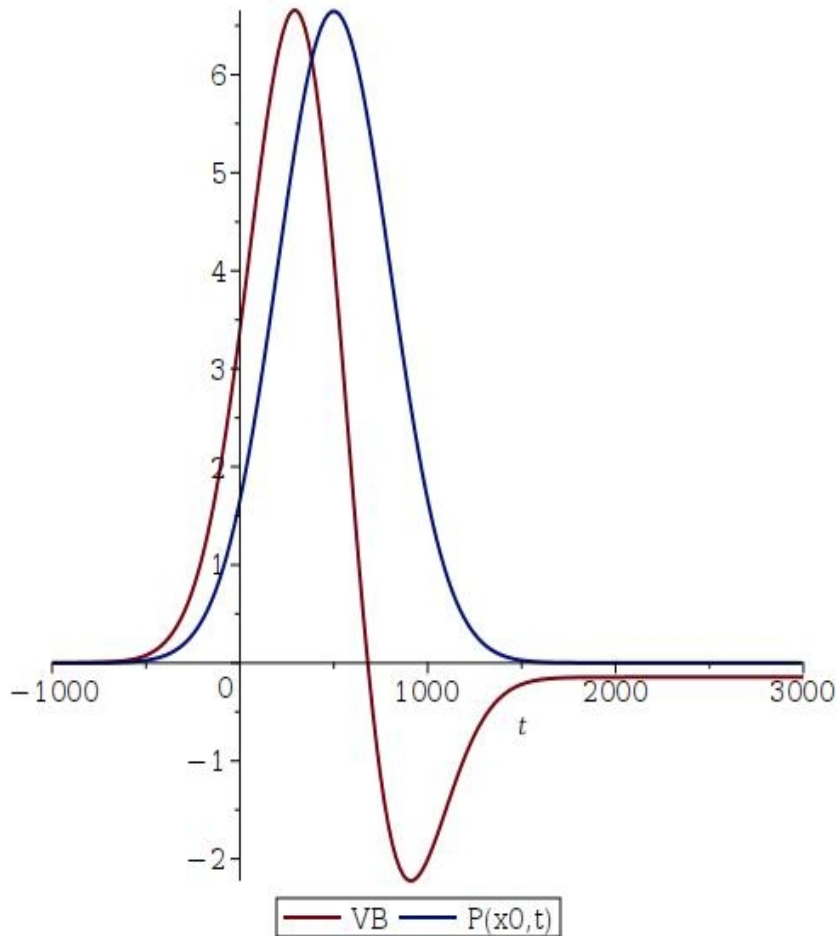


Lateral inhibition can induce retinal anticipation

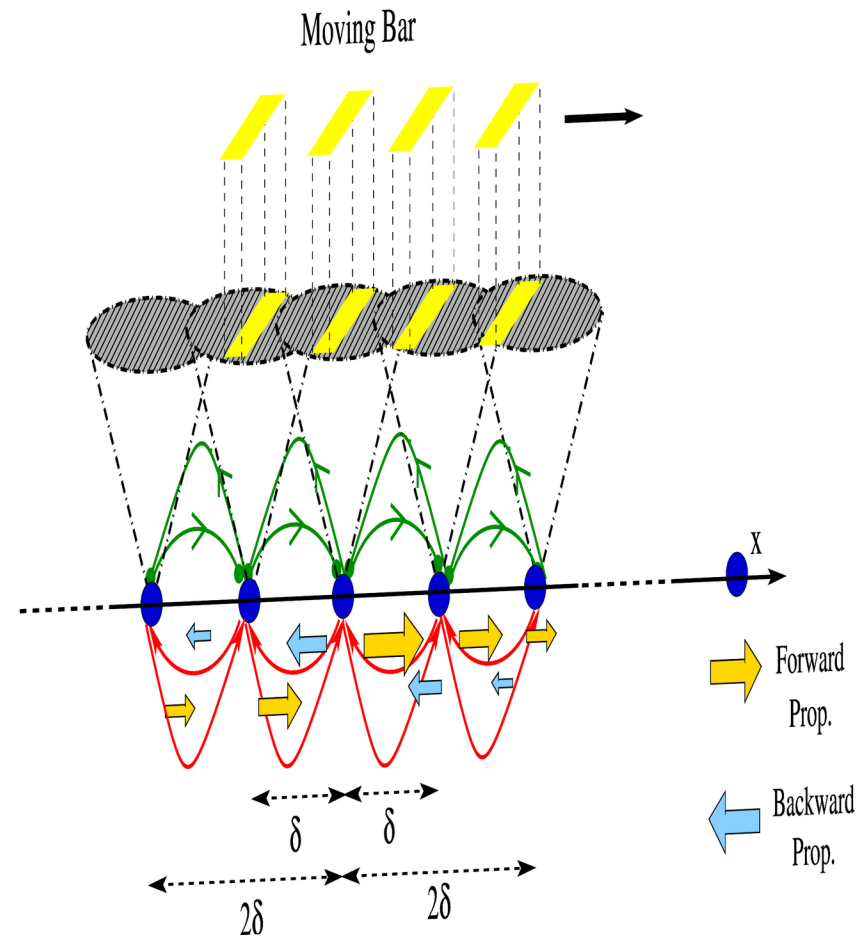
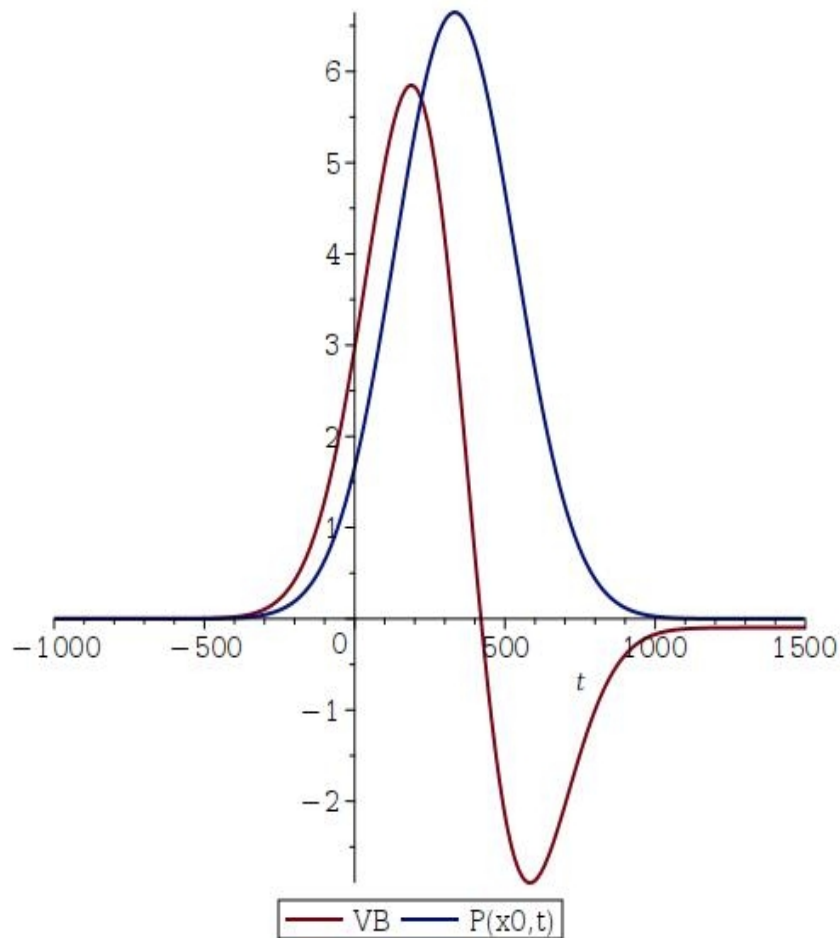
Adapted from M. Menz et al., bioRxiv (2020)



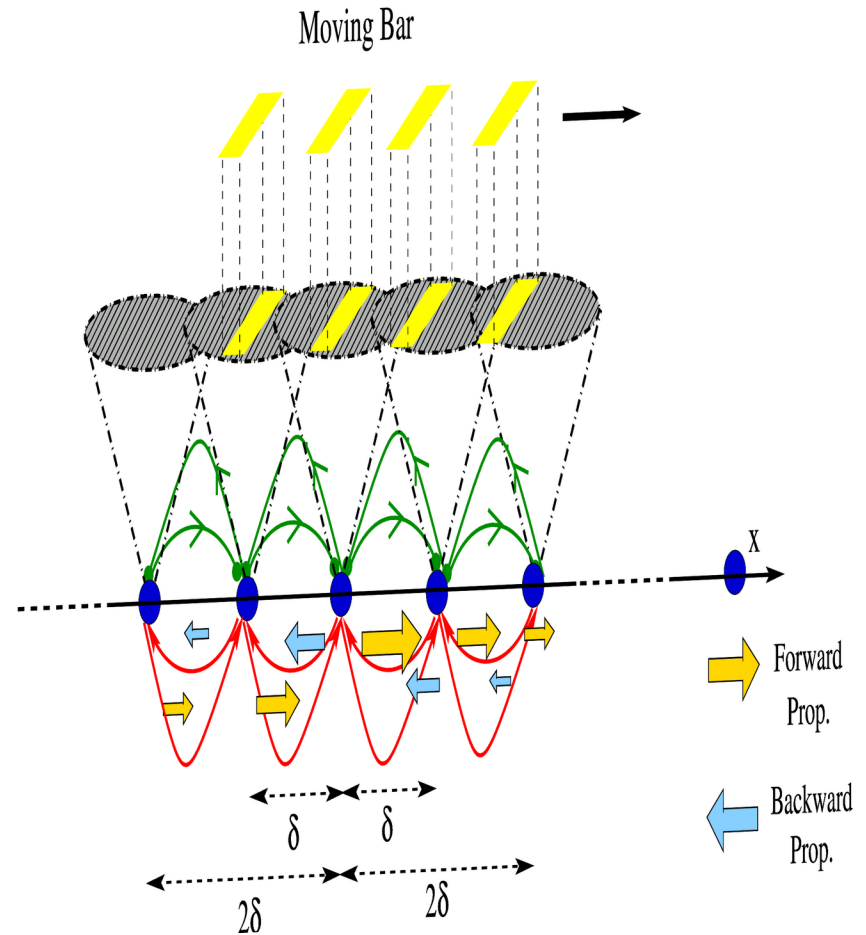
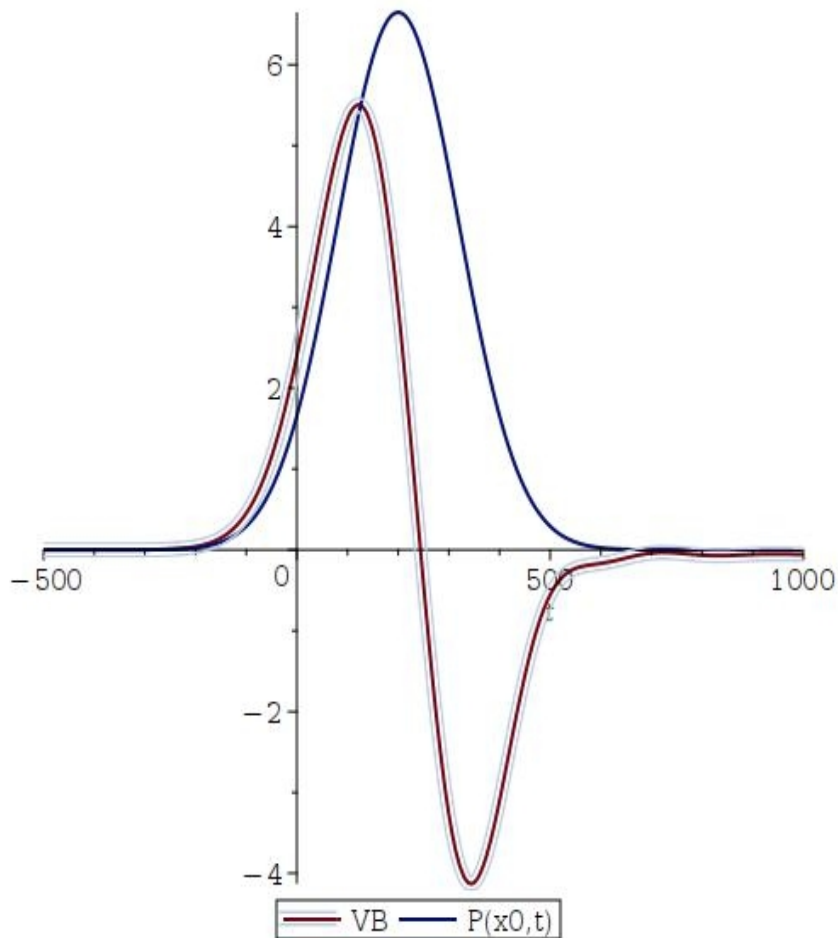
The spatio-temporal response pattern depends on the stimulus speed



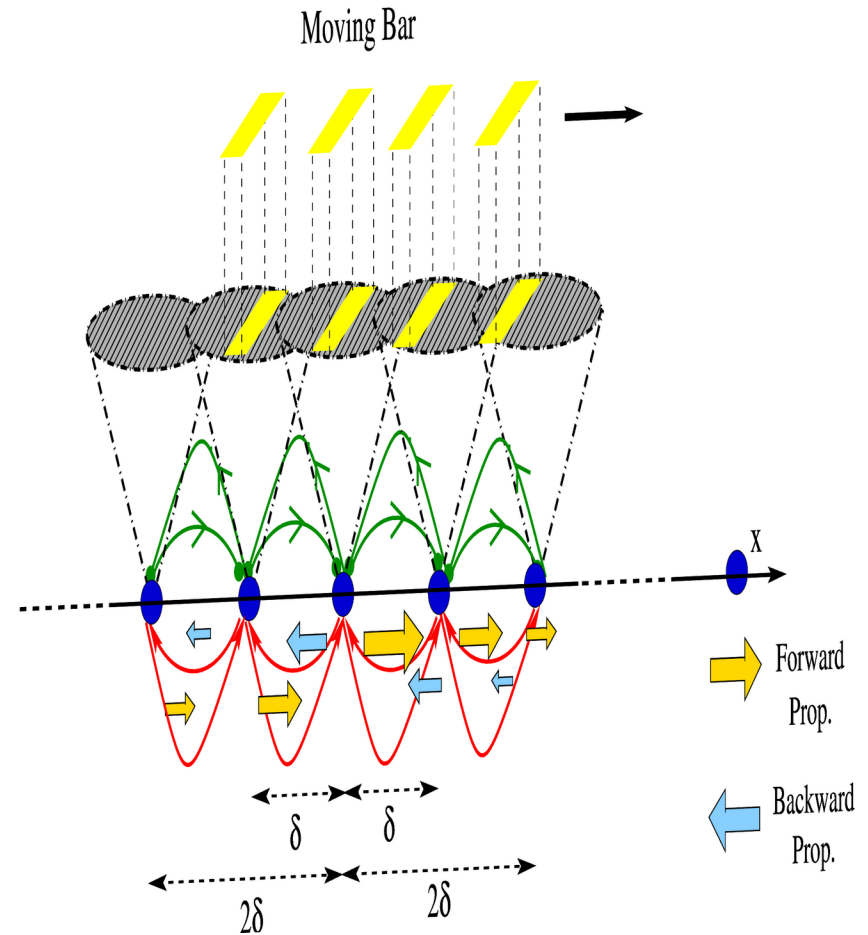
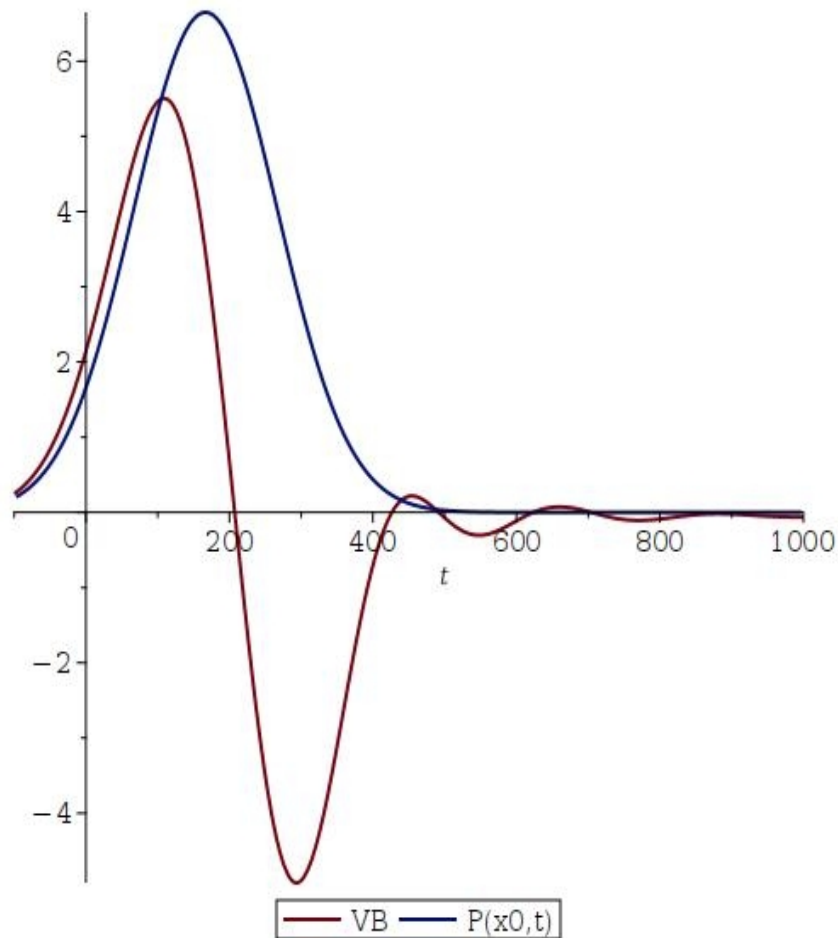
The spatio-temporal response pattern depends on the stimulus speed



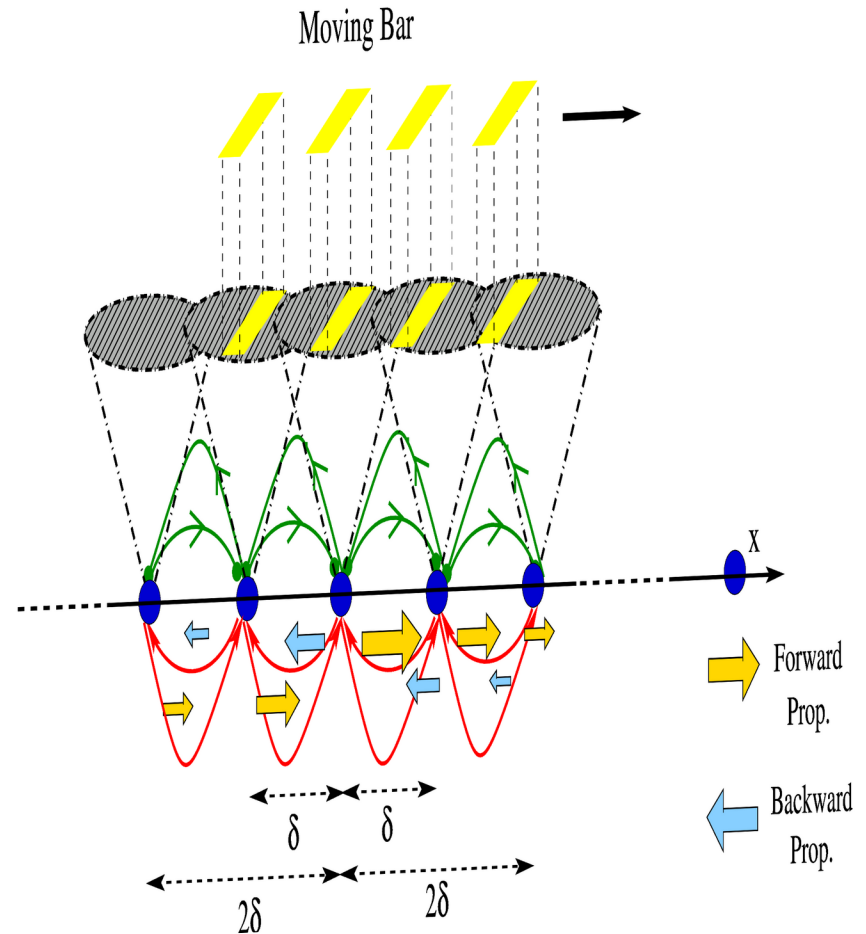
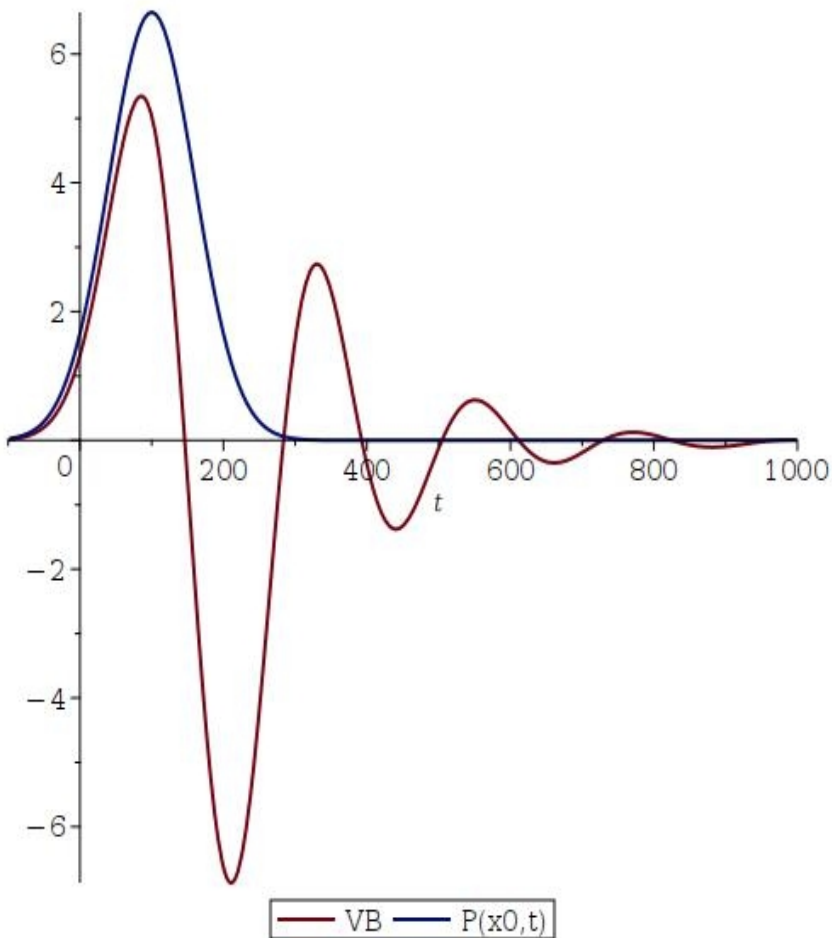
The spatio-temporal response pattern depends on the stimulus speed



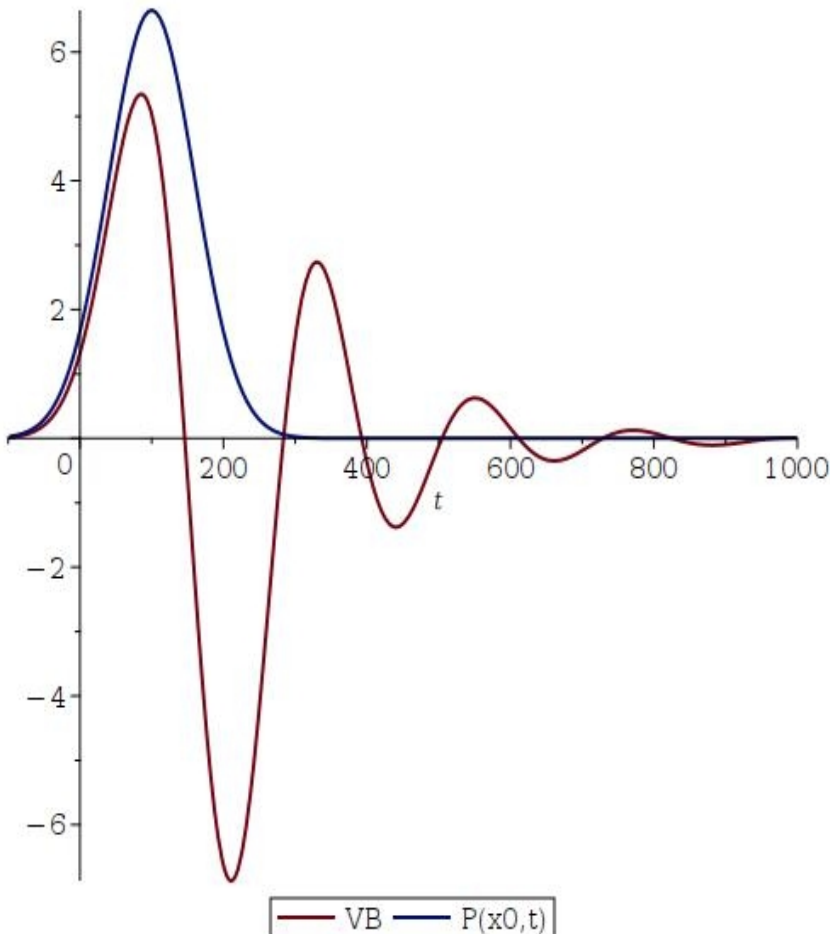
The spatio-temporal response pattern depends on the stimulus speed



The spatio-temporal response pattern depends on the stimulus speed



The spatio-temporal response pattern depends on the stimulus speed



- The spatio temporal response to moving stimuli is characterized by **poles** in the **complex space** (k, ω) .
- Each pole is characterized by four numbers $(k_r, k_i, \omega_r, \omega_i)$ that can be extracted from the power spectrum *provided the resolution is large enough*.
- The location of the poles in the complex space give rise to **different type of dynamical responses**.

How does lateral inhibition shape the response to moving stimuli ?



A moving object triggers **waves of activity** in the retina .

These waves are shaped and modulated by **lateral inhibition**.

The conjunction of the moving stimulus and of the forward/ backward and excitatory/inhibitory effects **selects** spatial wave lengths and temporal frequencies leading to **specific responses** and **resonance effects**.

These effects are characterized by **poles** in the complex plane, appearing in the **spatio-temporal Fourier transform**.



ESTHETICS/FUSION Projects

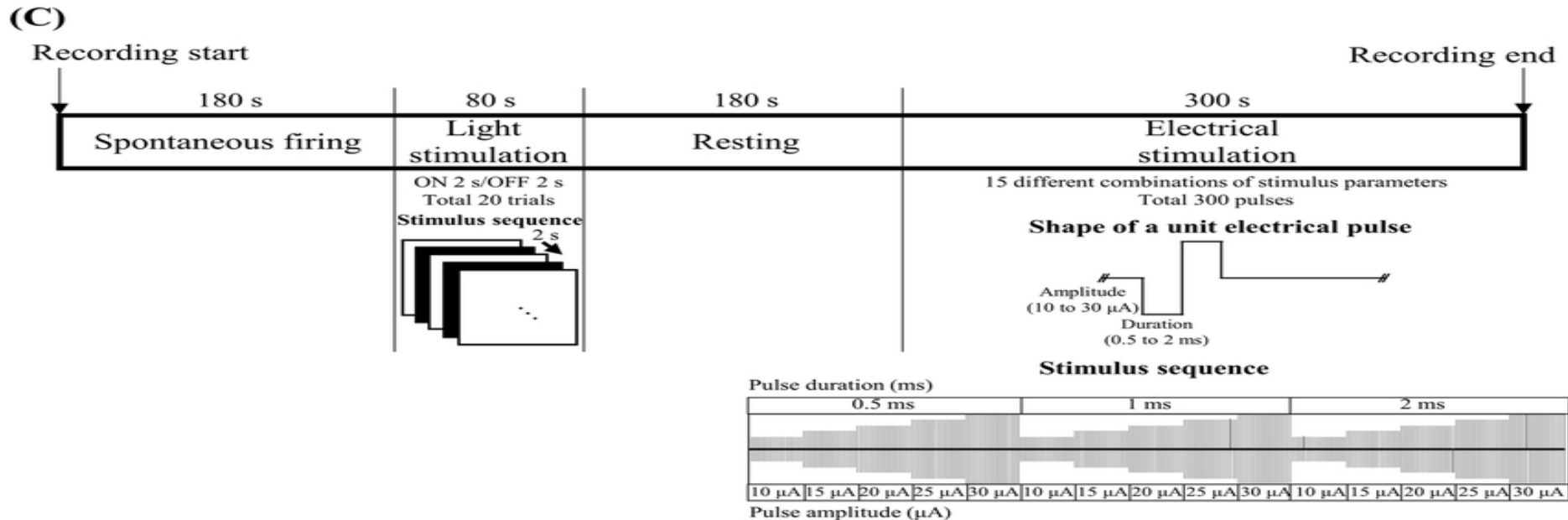
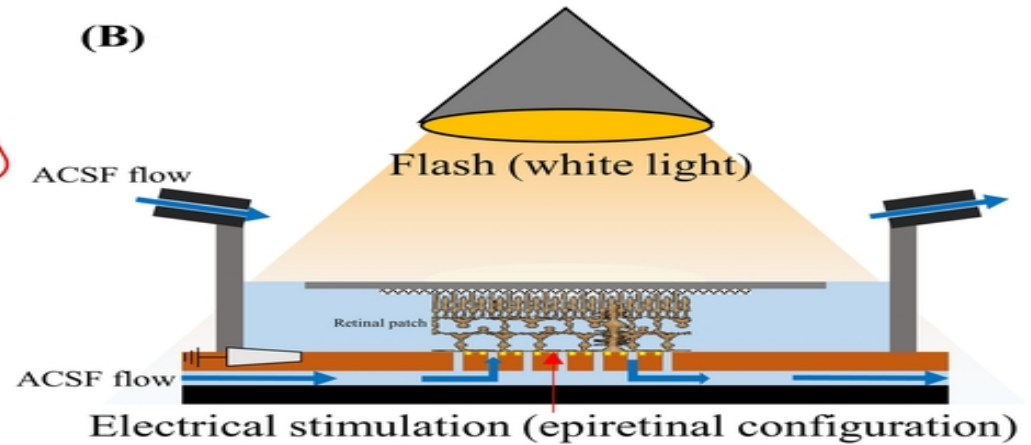
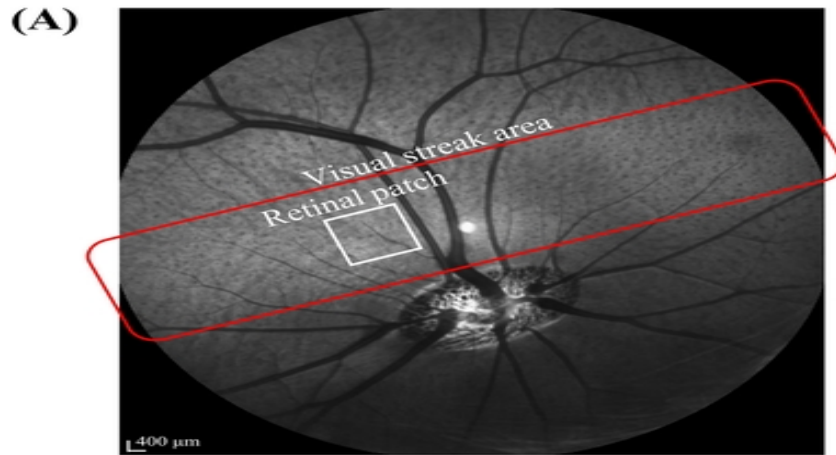
Exploring the functional structure of the retina with closed loop Stimulation. A physiological and computational approach

Centro de Neurociencia de Valparaiso, Chile
Universidad Santa-Maria, Valparaiso, Chile

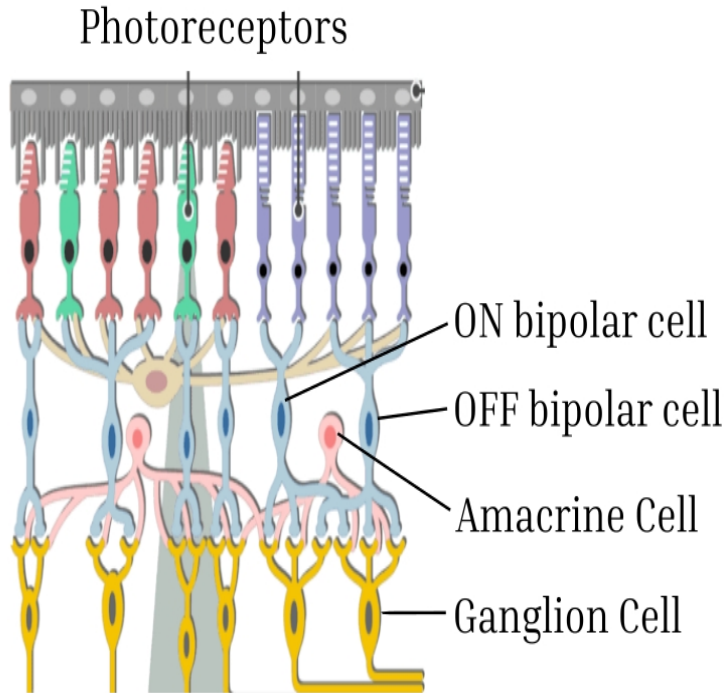
MacTao team, Inria
I3S, CNRS, Université Côte d'Azur

Biovision team, Inria

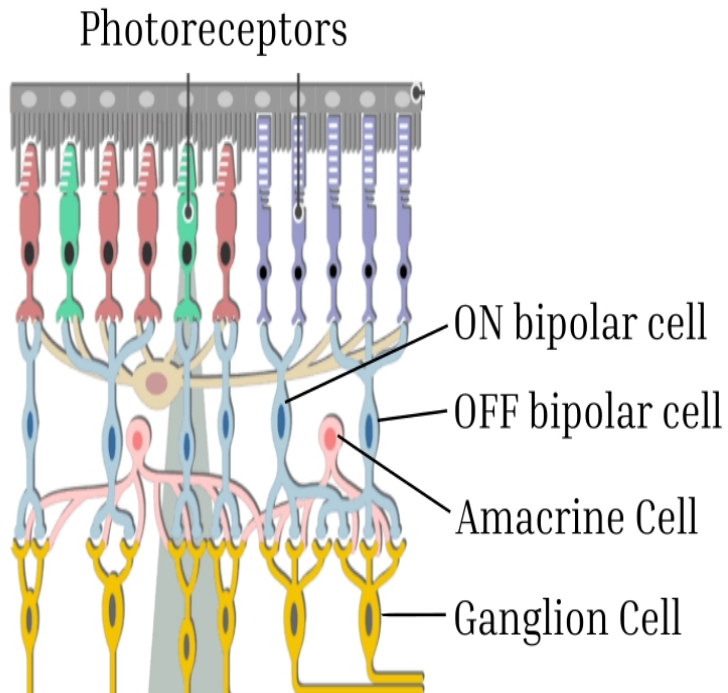
Exploring the retina structure and functions



Exploring the retina structure and functions

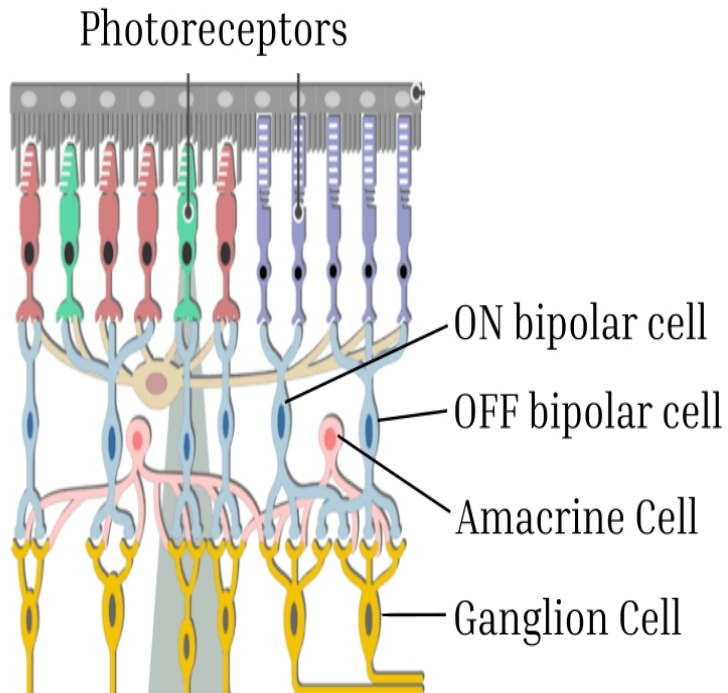


Exploring the retina structure and functions



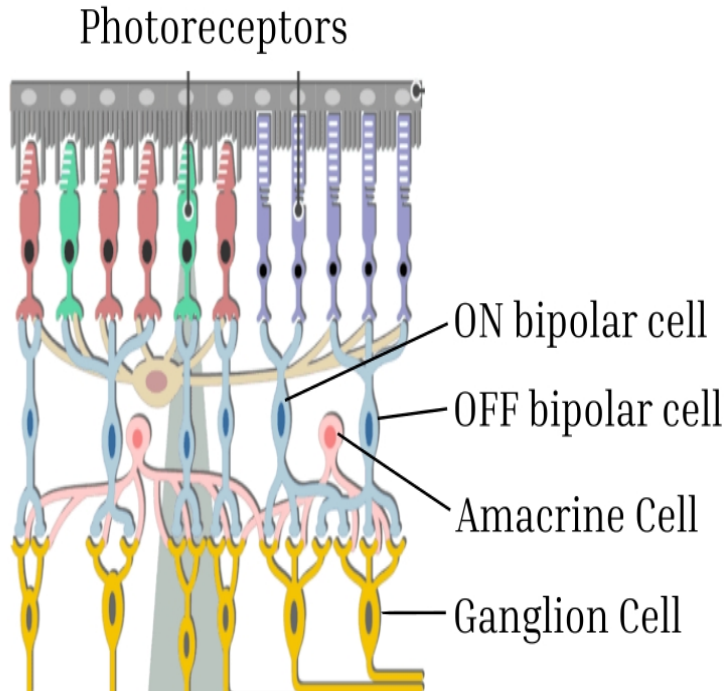
1 The retina is a highly structured dynamical network.

Exploring the retina structure and functions



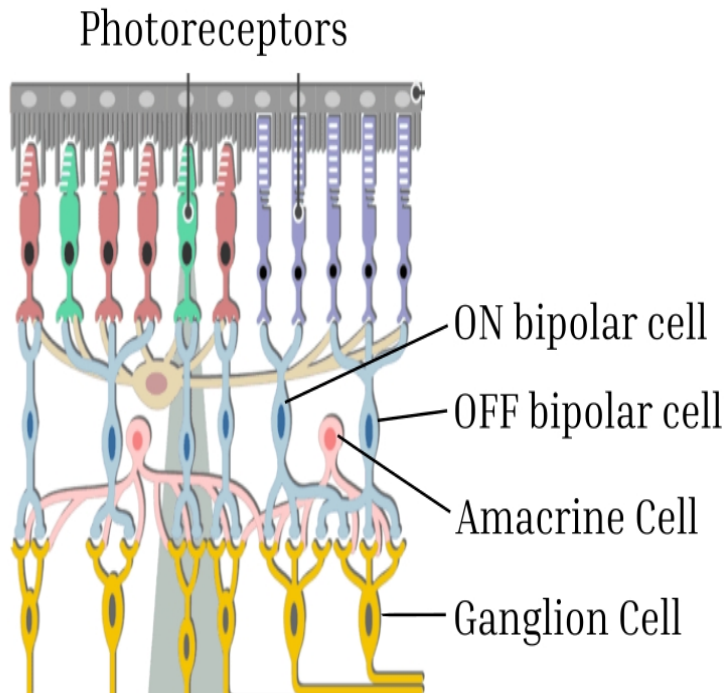
- 1 The retina is a highly structured dynamical network.
- 2 It is designed to respond optimally to complex **spatio-temporal** visual scenes (*motion*).

Exploring the retina structure and functions



- 1 The retina is a highly structured dynamical network.
- 2 It is designed to respond optimally to complex **spatio-temporal** visual scenes (*motion*).
- 3 The currently used stimuli have, either :
 - a rather simple spatio-temporal structure (flashes, white noise, gratings, periodic illumination), or ;
 - Too complex a structure (natural movies).
 - Intermediate cases start to be analysed (moving bars).

Exploring the retina structure and functions



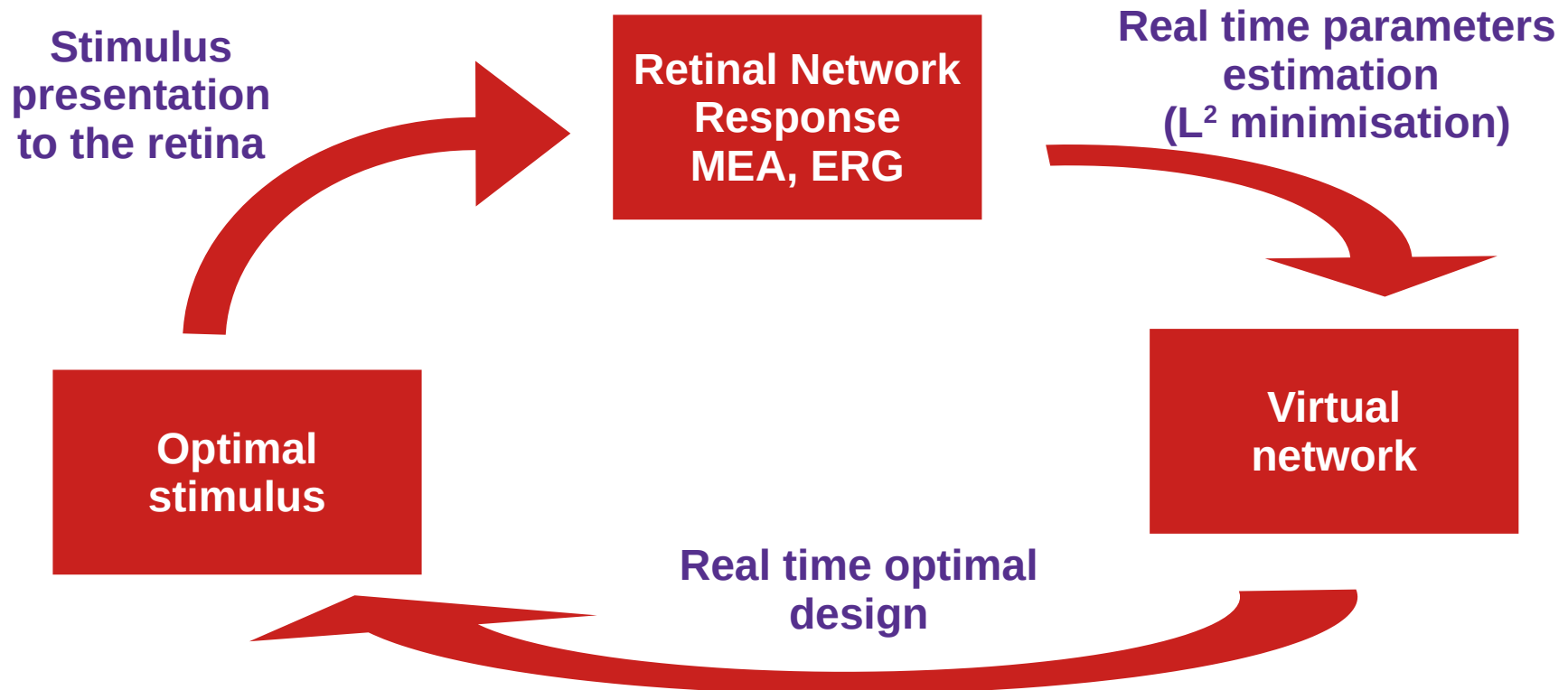
- 1 The retina is a highly structured dynamical network.
- 2 It is designed to respond optimally to complex **spatio-temporal** visual scenes (*motion*).
- 3 The currently used stimuli have, either :
 - a rather simple spatio-temporal structure (flashes, white noise, gratings, periodic illumination), or ;
 - Too complex a structure (natural movies).
 - Intermediate cases start to be analysed (moving bars).

*Develop a new strategy, combining experiments and modeling, to better understand the retinal **network dynamics** using appropriate **spatio-temporal** stimuli and **closed loop** experiments.*

Context

*Develop a new strategy, combining experiments and modeling, to better understand the **retinal network dynamics** using appropriate **spatio-temporal stimuli** and **closed loop** experiments.*

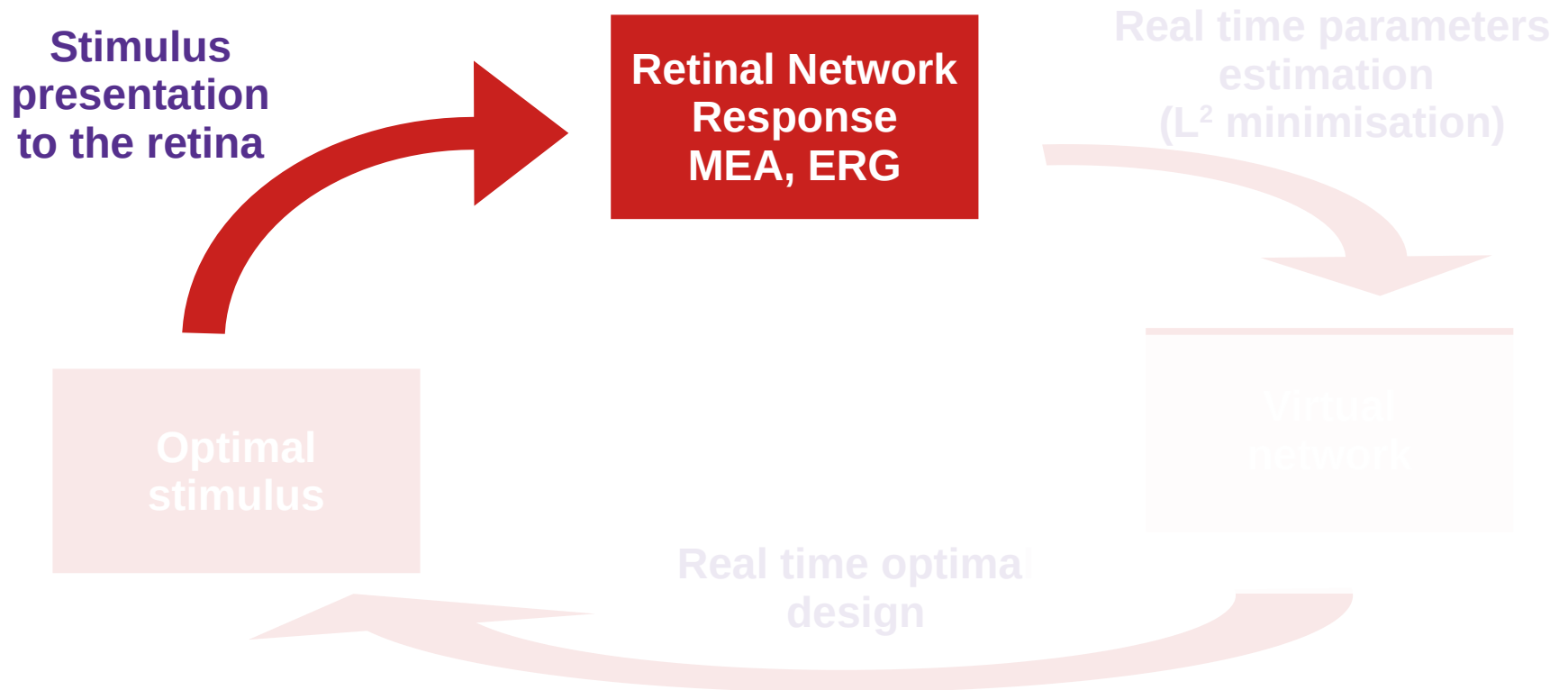
Fundings : RISE, DocWalker, Associated INRIA Team Fusion, EDSTIC



Work already done

1 Stay of S. Ebert in Valparaiso (DocWalker, Oct.-Nov. 2023) :

- Design of simple stimuli;
- Experiments;
- First analyses.



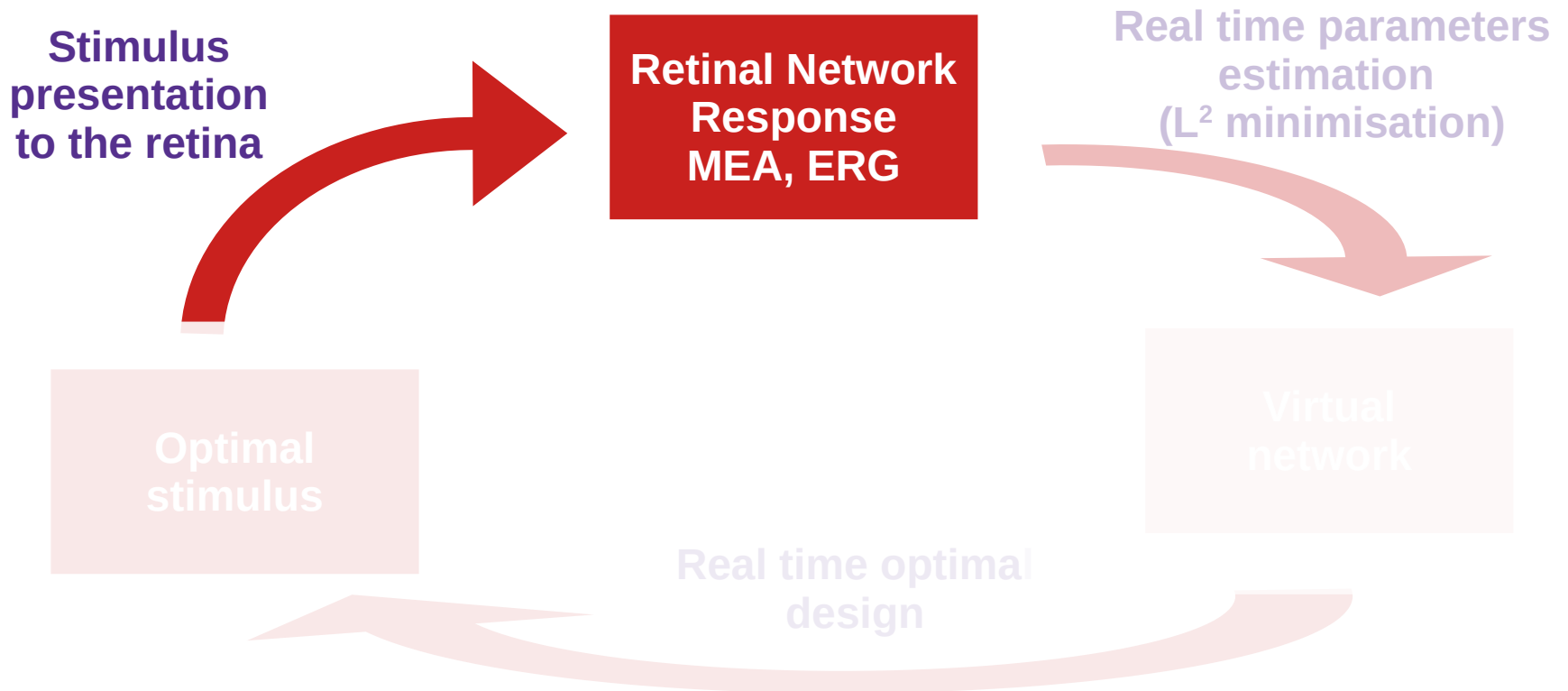
Work already done

1 Stay of S. Ebert in Valparaiso (DocWalker, Oct.-Nov. 2023) :

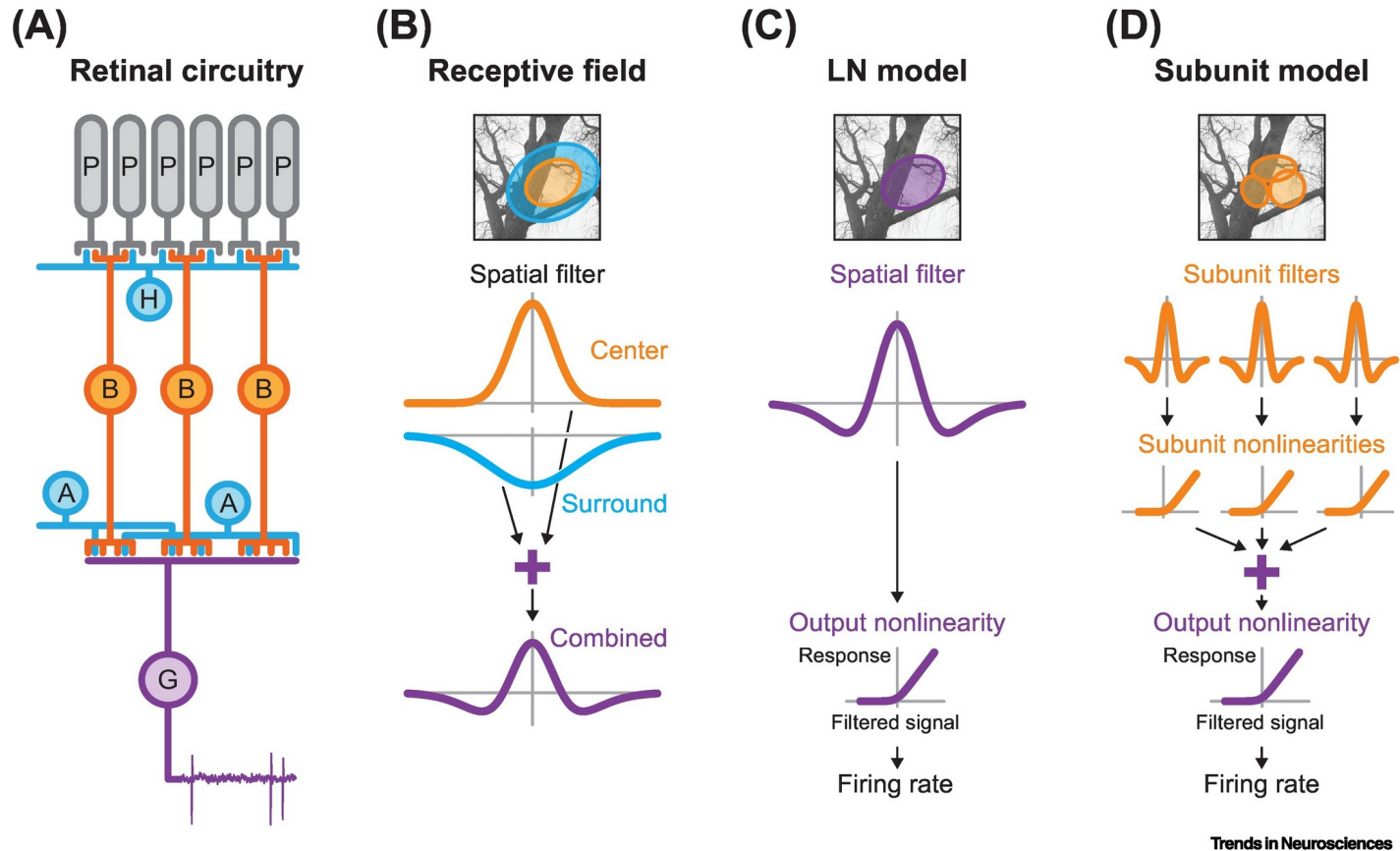
- Design of simple stimuli;
- Experiments;
- First analyses.

2 Venue of F. Miqueles and J. Portal-Diaz at INRIA (Esthetics, Feb.-Apr. 2024):

- Tools to analyse the spatio temporal information provided by raw data;
- Spatio temporal FFT, attempts to characterize a convolution kernel;
- Spikes in ERG;
- Parameters estimation + stimulus design.



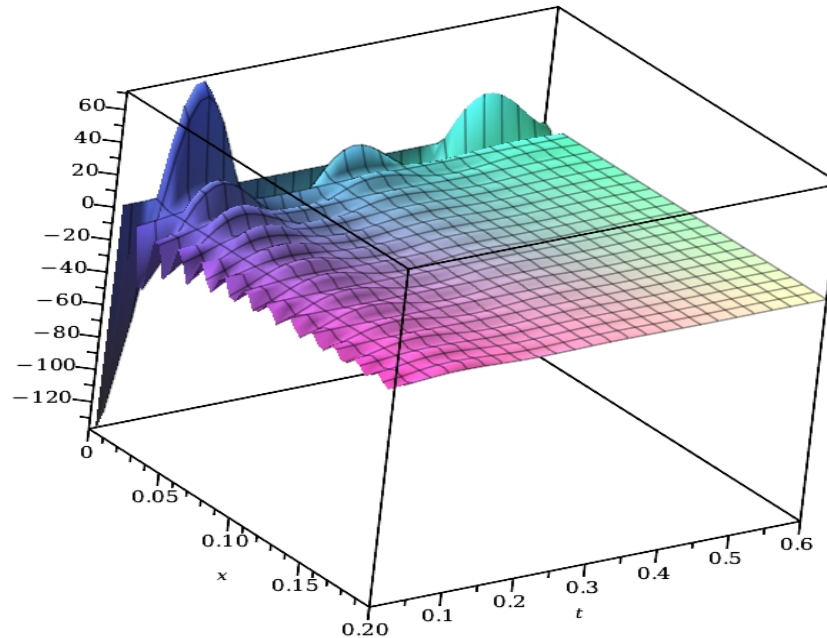
Linear response



Zapp, Sören J. et al. Trends in Neurosciences, Volume 45, Issue 6, 430 - 445

The behaviour of individual retinal cells is characterized by a cascade of convolutions and weak non linearities.

Linear response



S. Souihel, B. Cessac, *Journal of Mathematical Neuroscience*, 2021, 11

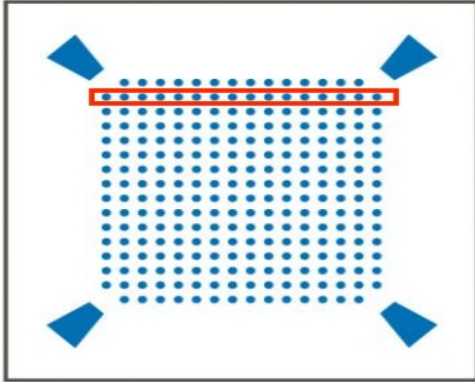
B. Cessac, *Journal of Imaging*, 2022, 8 (1)

E. Kartsaki, G. Hilgen, E. Sernagor, B. Cessac, *Neural Computation*, 2024, 36 (6)

S. Ebert, T. Buffet, B. S. Sermet, O. Marre, B. Cessac, *Nature Com.*, 2024, 15 (6118)

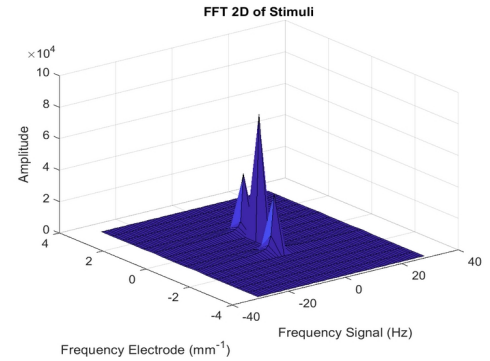
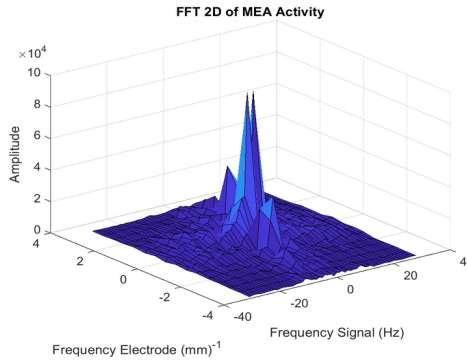
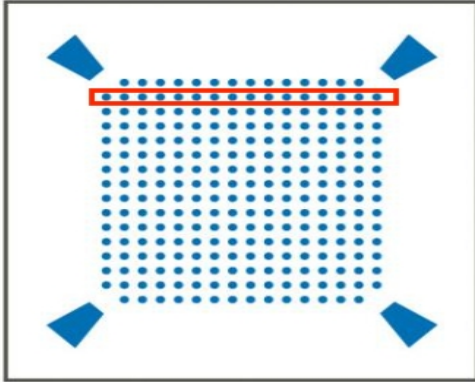
The behaviour of the **retinal network** is characterized by a cascade of convolutions and weak non linearities.

Linear response



A Multi-Electrode Array naturally provides a space-time sampling of the retinal response.

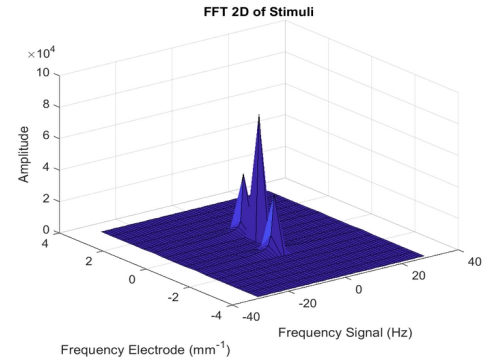
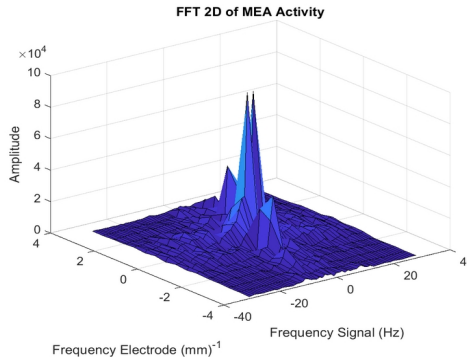
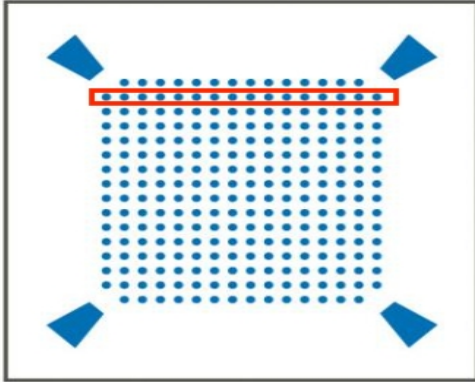
Linear response



A Multi-Electrode Array naturally provides a space-time sampling of the retinal response.

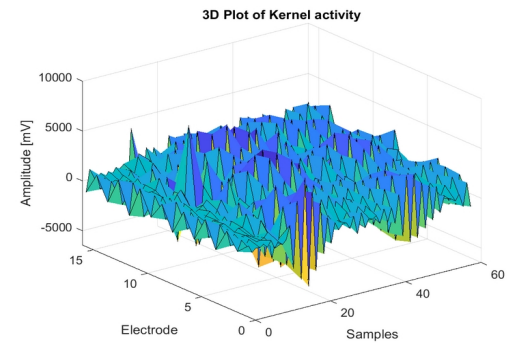
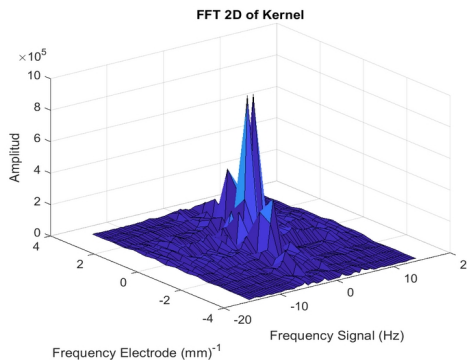
$$V_{MEA}(t) = \left[K_{MEA}^{x,y,t} * \mathcal{S} \right] (t)$$

Linear response

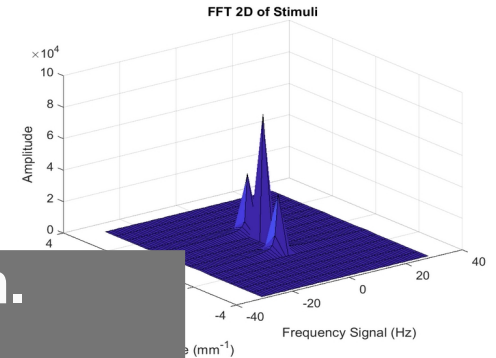
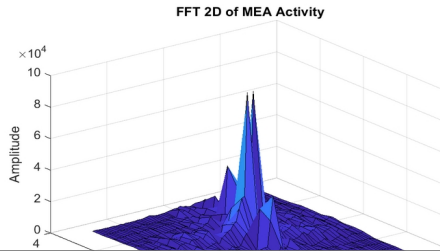
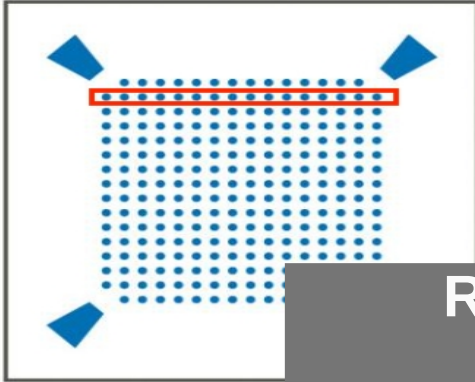


A Multi-Electrode Array naturally provides a space-time sampling of the retinal response.

$$V_{MEA}(t) = \left[K_{MEA}^{x,y,t} * \mathcal{S} \right] (t)$$



Linear response

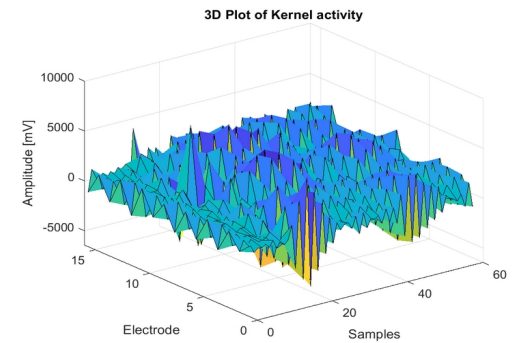
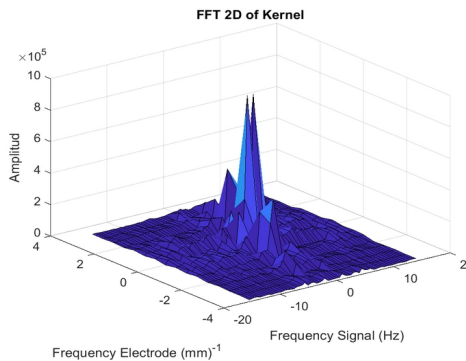


Resolution is not good enough.

Improve it ? How ?

Which features in the Fourier spectrum can be exploited ? $\mathcal{S}](t)$

A Multi-Electrode Array naturally provides time sampling of the response.



Work already done

1 Modelling the retinal response to moving stimuli (S. Ebert, L. Piovano)

- Explicit computation of a spatio-temporal kernel featuring the retina response
- Property of the Fourier Transform
- Existence of spatio-temporal **resonances**.



Virtual
network

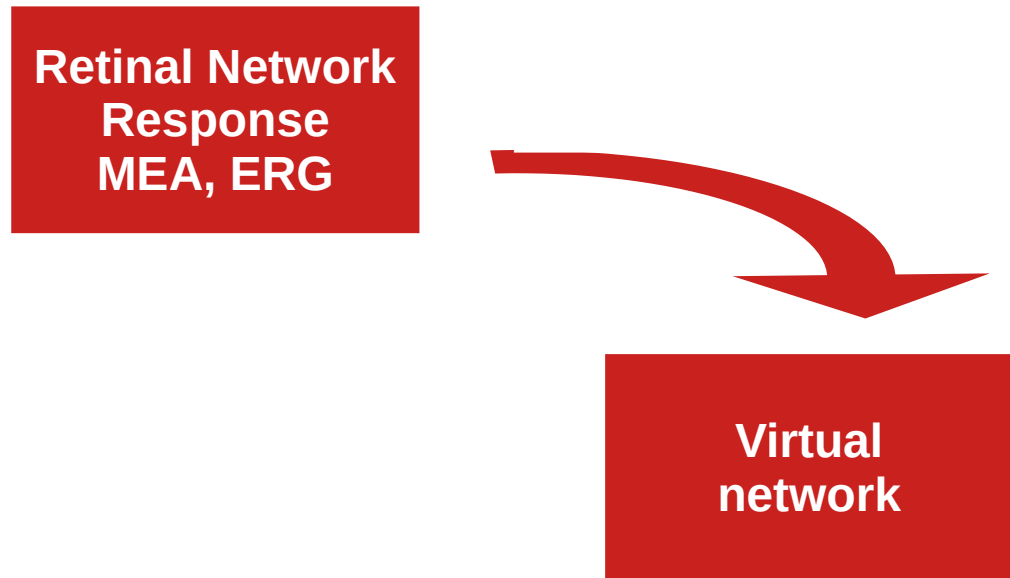
Work already done

1 Modelling the retinal response to moving stimuli (B.C, S. Ebert, L. Piovano)

- Explicit computation of a spatio-temporal kernel featuring the retina response
- Property of the Fourier Transform
- Existence of spatio-temporal **resonances**.

2 E. Petit thesis (funding EDSTIC)

- Parameters estimation from experiments in a simplified retina model
- Simulations on the Macular simulator.



Work already done

1 Modelling the retinal response to moving stimuli (B.C, S. Ebert, L. Piovano)

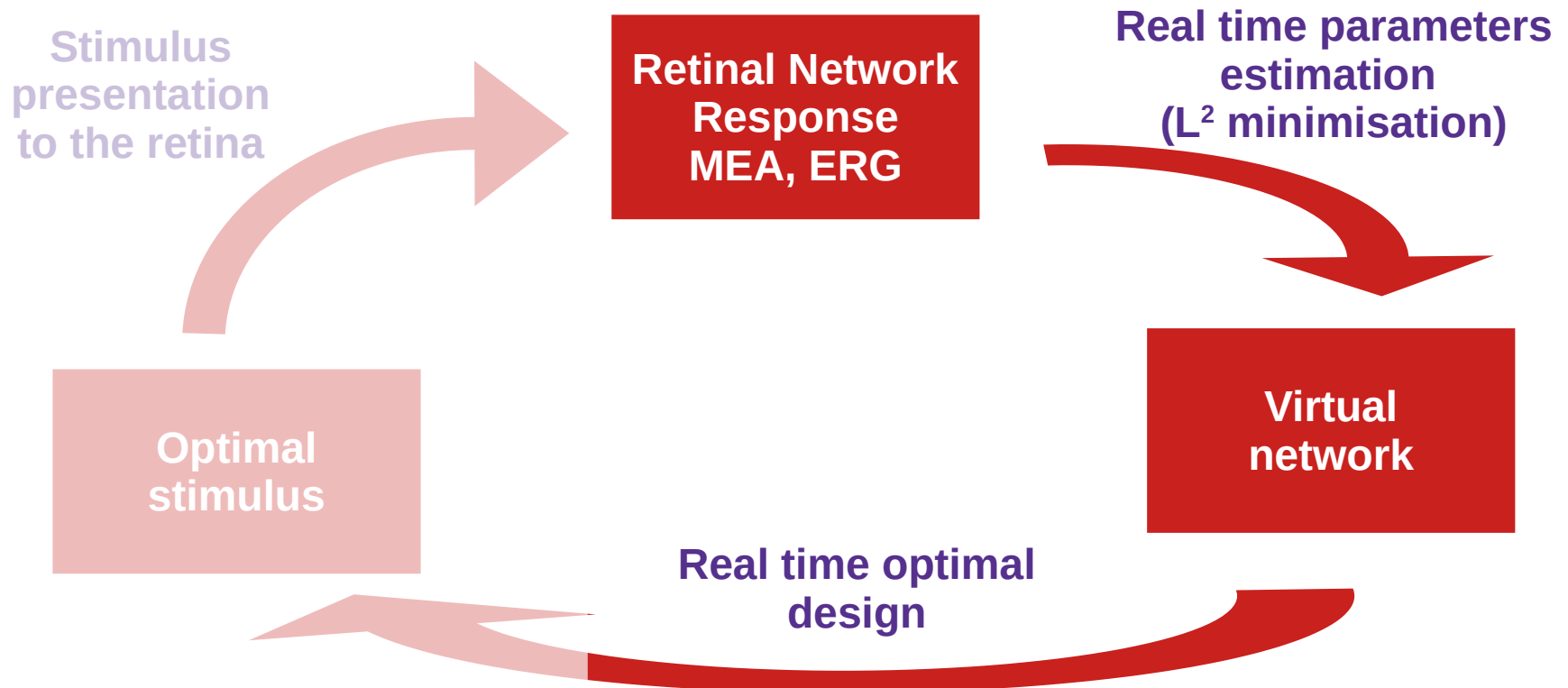
- Explicit computation of a spatio-temporal kernel featuring the retina response
- Property of the Fourier Transform
- Existence of spatio-temporal **resonances**.

2 E. Petit thesis (funding EDSTIC)

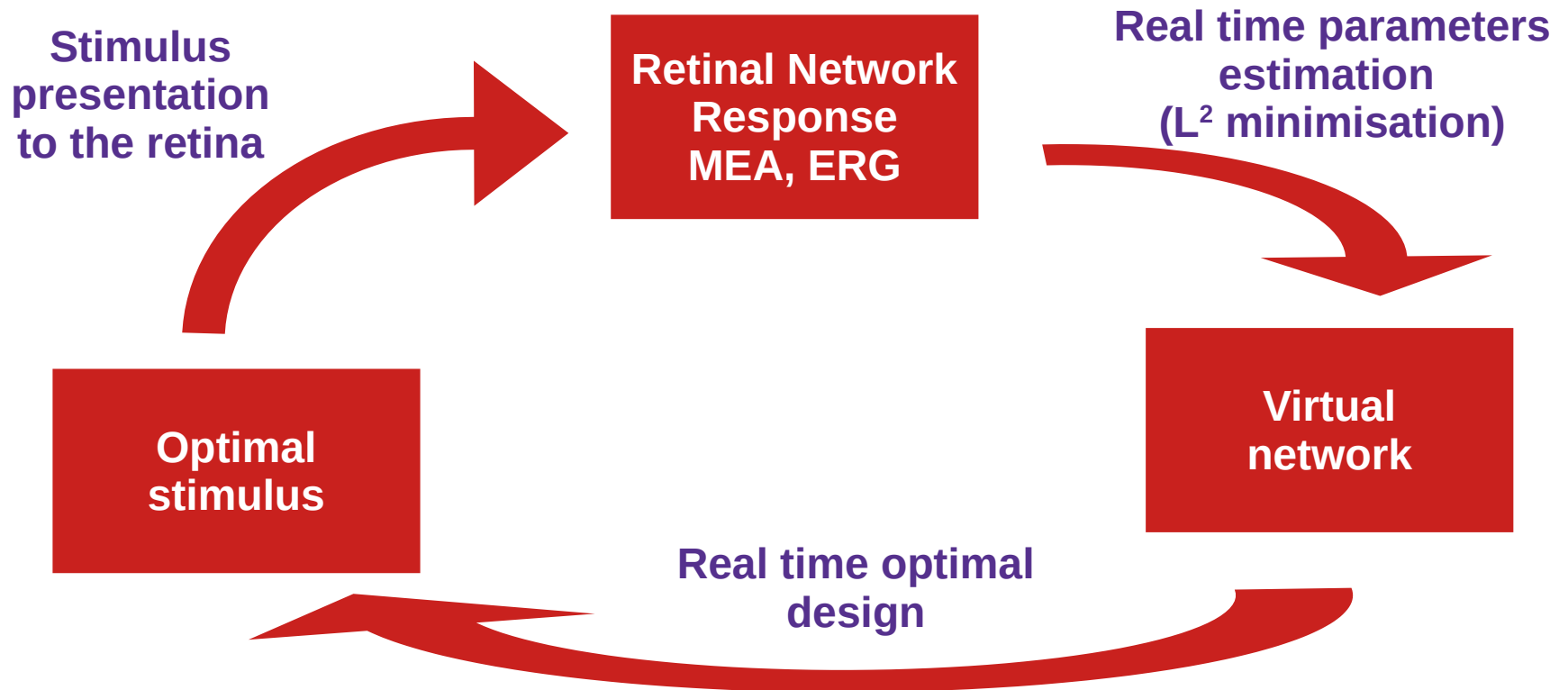
- Parameters estimation from experiments in a simplified retina model
- Simulations on the Macular simulator.

3 Mathematical study of optimal design (L. Sacchelli, INRIA - L. Pronzatto, I3S)

- Exploring different criteria for optimal design (KL divergence, information)
- ANR project lead by L. Sacchelli



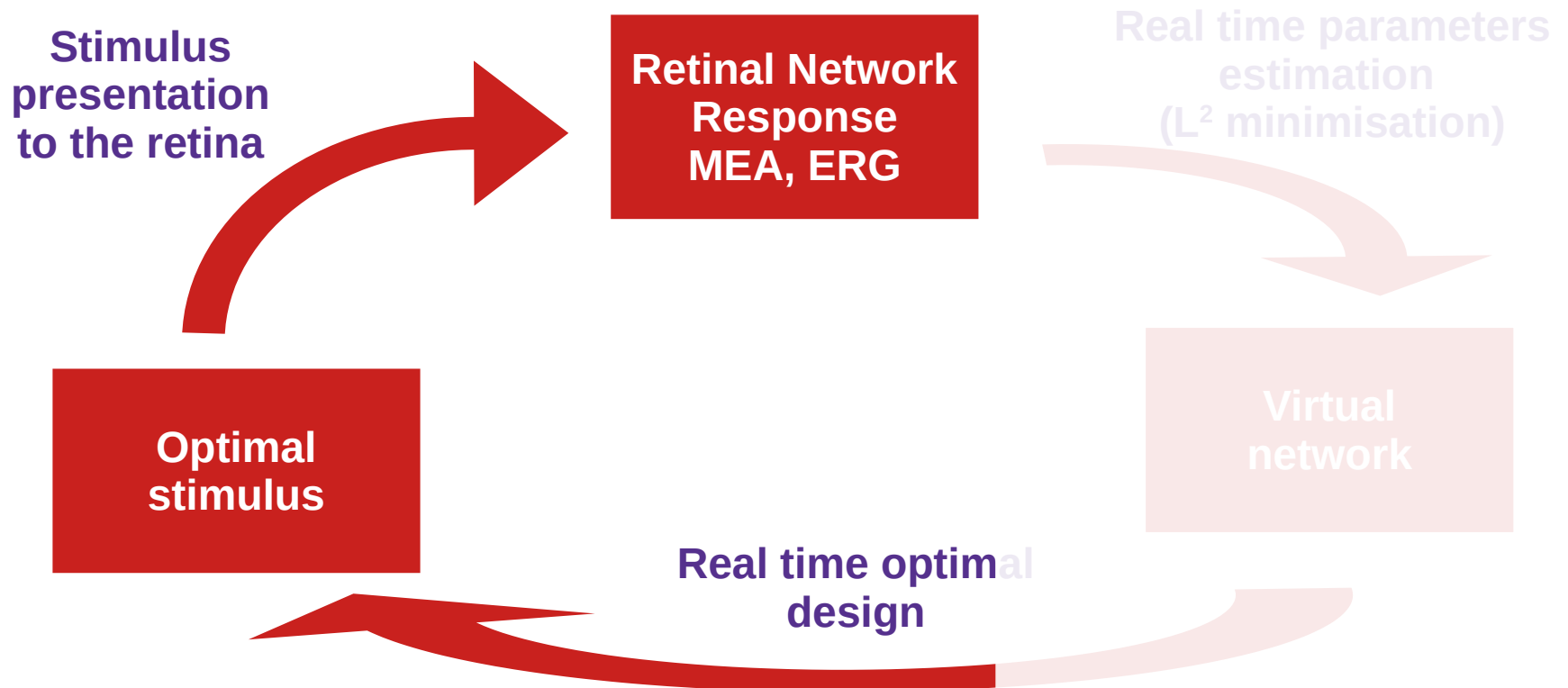
Next steps



Next steps

1 Stay of E. Petit, B. Cessac in Valparaiso (January 2025)

- Attending the *Laconeu Sumer School*.
- Attend experiments, learn how to handle data, how to efficiently interact given the distance.
- Discuss the problem of *MEA resolution*
- Stimuli design.



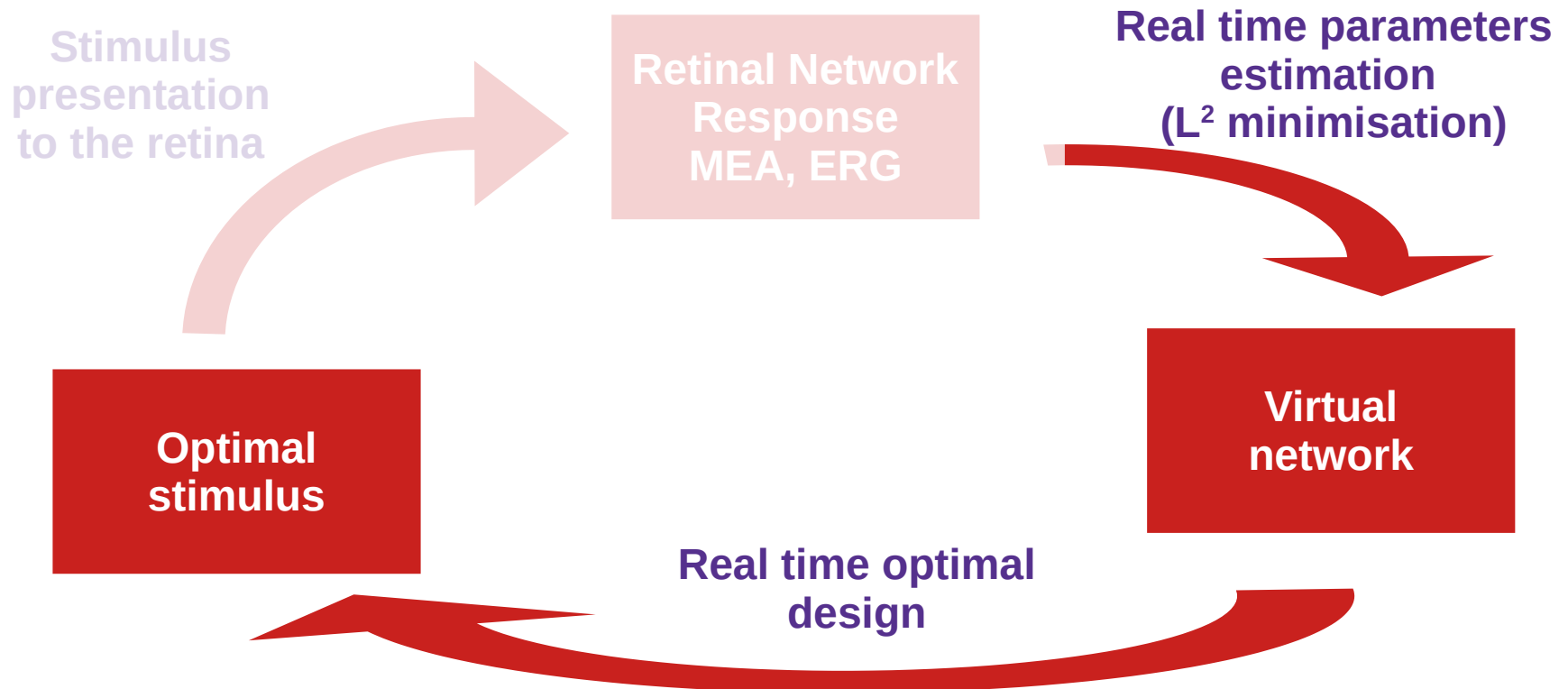
Next steps

1 Stay of E. Petit, B. Cessac in Valparaiso (January 2025)

- Attending the *Laconeu Sumer School*.
- Attend experiments, learn how to handle data, how to efficiently interact given the distance.
- Discuss the problem of *MEA resolution*
- Stimuli design.

2 Co-supervised internship with L. Sacchelli

- contribution of *geometric control theory* to experimental design



Next steps

1 Stay of E. Petit, B. Cessac in Valparaiso (January 2025)

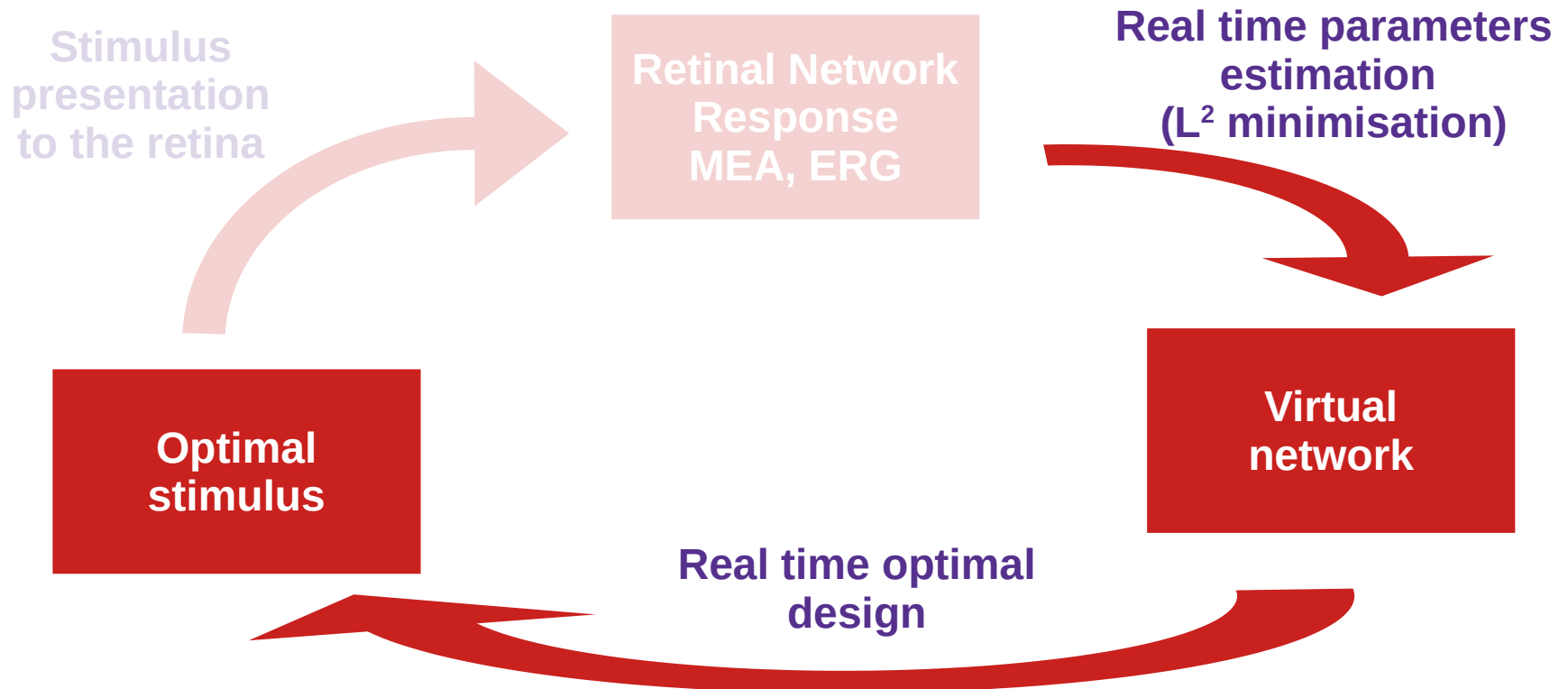
- Attending the *Laconeu Sumer School*.
- Attend experiments, learn how to handle data, how to efficiently interact given the distance.
- Discuss the problem of *MEA resolution*
- Stimuli design.

2 Co-supervised internship with L. Sacchelli

- contribution of *geometric control theory* to experimental design

3 Mathematical study of optimal design (L. Sacchelli, L. Pronzatto)

- Exploring different *criteria* for optimal design (KL divergence, information)



Bibliography

1. « *Closed loop strategy to characterize the retinal network: preliminary steps* », B. Cessac, S. Ebert, M.J. Escobar, F. Miqueles, A. Palacios, E. Petit, J. Portal-Diaz, Inria research report. In progress.
2. « *Parameters estimation in a retinal network model* », B. Cessac, L. Pronzato, L. Sacchelli. In progress.
3. « *On the retinal response to a moving bar* », B. Cessac, S. Ebert, L. Piovano, In progress.
4. « *Temporal refinement of spatiotemporal pattern prediction via short-term plasticity* », B. Cessac, S. Ebert, In progress.

Conclusions

- Visual entries are **neither stationary**, nor **spatially regular**.

Conclusions

- Visual entries are **neither stationary**, nor **spatially regular**.
- The « **longitudinal** » retinal pathways PhotoReceptors => Bipolar cells => Ganglion cells efficiently encode the visual information into **parallel flows**.

Conclusions

- Visual entries are **neither stationary**, nor **spatially regular**.
- The « **longitudinal** » retinal pathways PhotoReceptors => Bipolar cells => Ganglion cells efficiently encode the visual information into **parallel flows**.
- On the basis of biophysical modelling + mathematical analysis we found that Amacrine cells may generate, from a **moving stimulus**, **spatio-temporal correlations (waves)** contributing to better encoding a visual scene (e.g. **anticipation**).

Conclusions

- Visual entries are **neither stationary**, nor **spatially regular**.
- The « **longitudinal** » retinal pathways PhotoReceptors => Bipolar cells => Ganglion cells efficiently encode the visual information into **parallel flows**.
- On the basis of biophysical modelling + mathematical analysis we found that Amacrine cells may generate, from a **moving stimulus**, **spatio-temporal correlations (waves)** contributing to better encoding a visual scene (e.g. **anticipation**).

Waves could be the fundamental key to understand the visual processing.

How does the brain efficiently decode a flux of spikes with multi scale spatio-temporal correlations ?

Thanks