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Biovision team Helping visually impaired people Multi scale modeling of the retina

Bruno Cessac

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Multi scale modeling of the retina

Bruno Cessac

Bi**vision team**

Helping visually impaired people

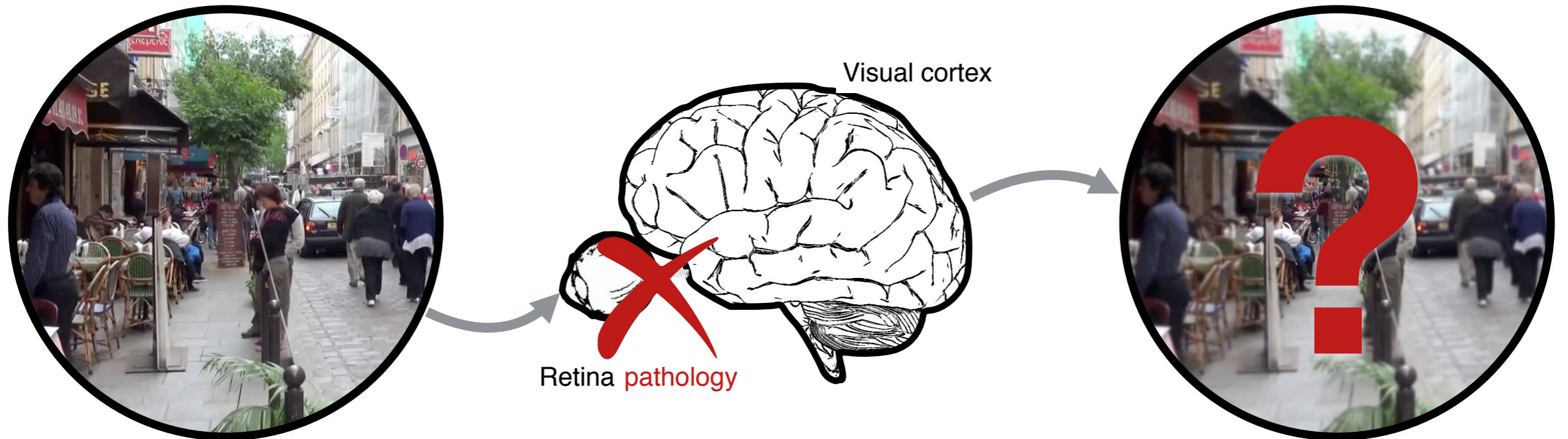
inria
informatics mathematics

Helping visually impaired people

285 millions, x3 in 2050

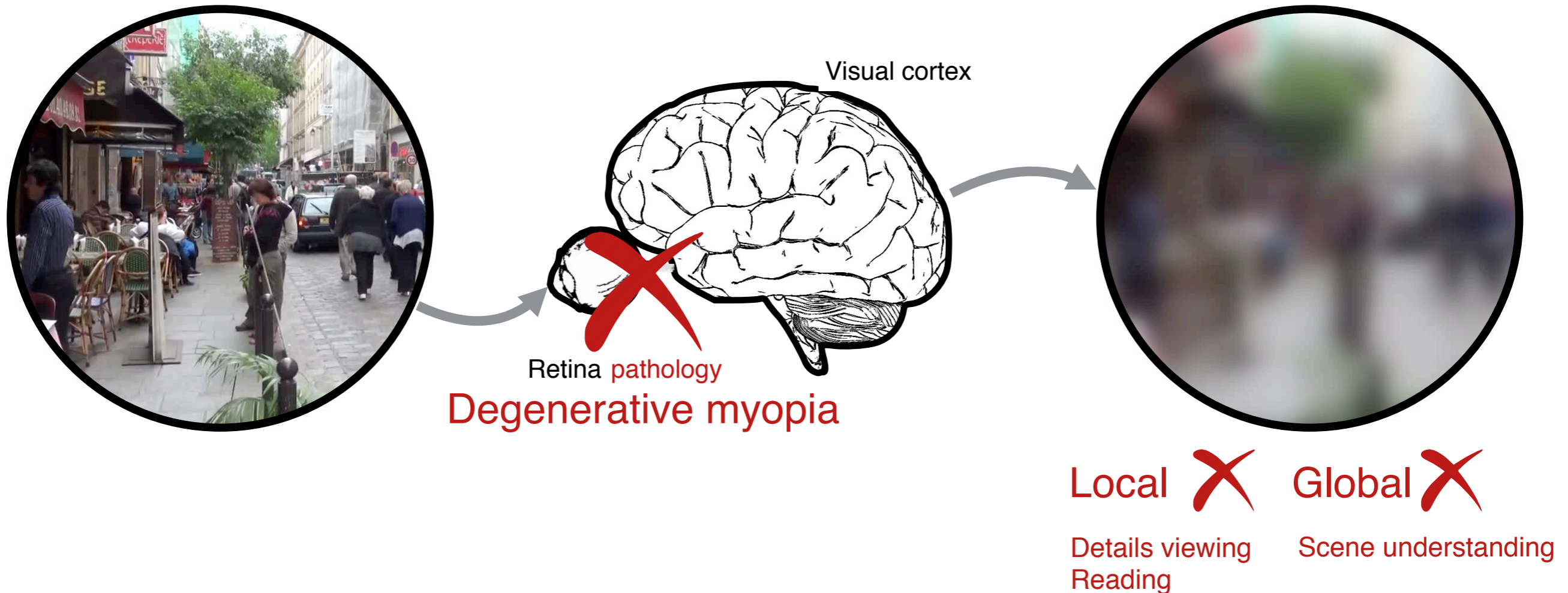
Helping visually impaired people

285 millions, x3 in 2050



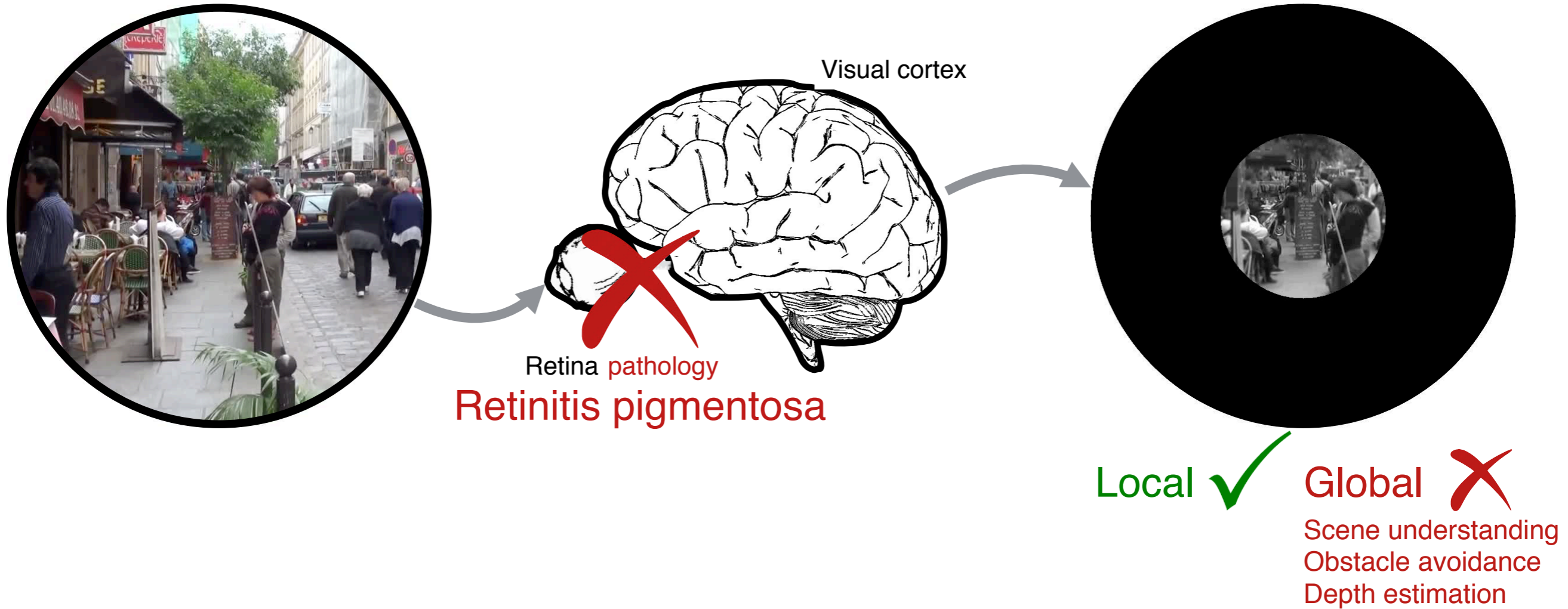
Helping visually impaired people

285 millions, x3 in 2050



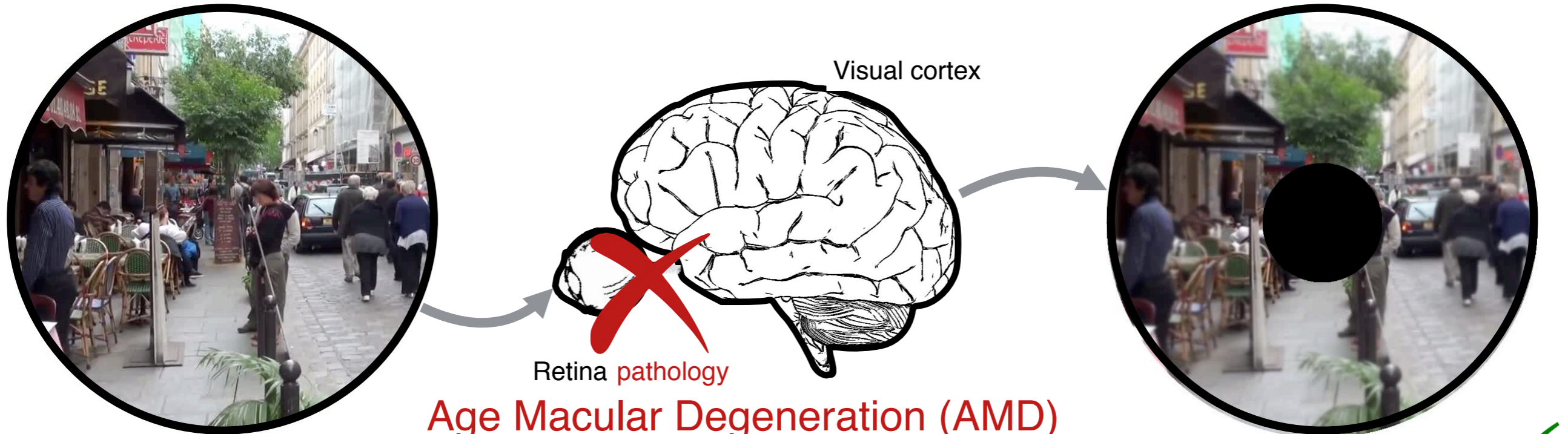
Helping visually impaired people

285 millions, x3 in 2050



Helping visually impaired people

285 millions, x3 in 2050



Visual cortex

Retina pathology

Age Macular Degeneration (AMD)

France: DMLA
1st cause, 1.5M, 1/4 after 75 y.o.

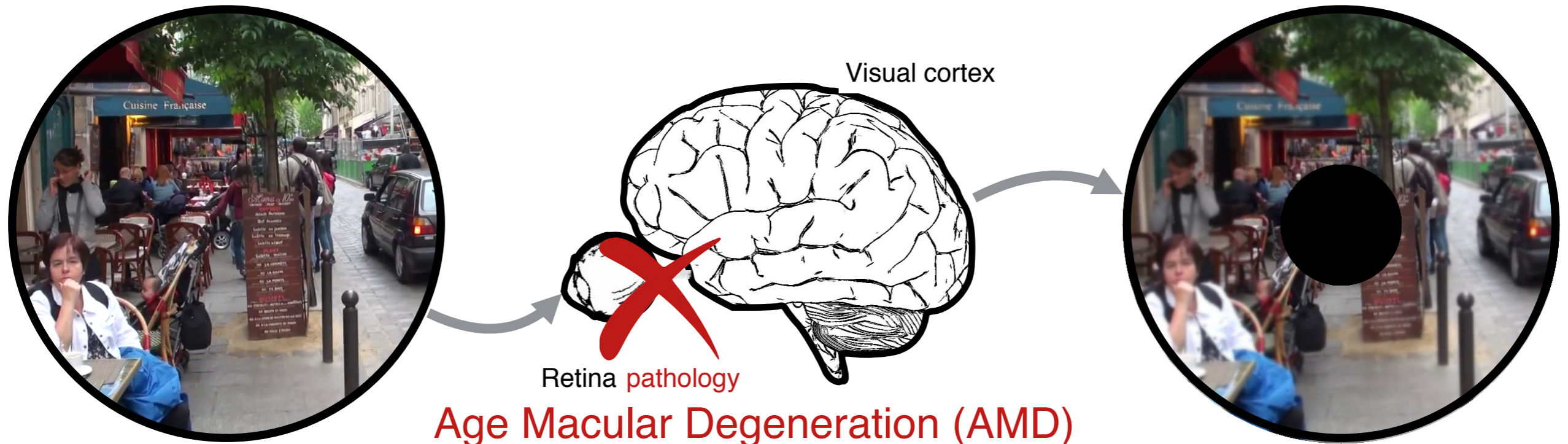
Local X

Global ✓

Details viewing
Reading

Helping visually impaired people

285 millions, x3 in 2050



New technics are emerging to help people use their remaining vision, slow down or even reverse vision loss

- New scientific and technological challenges
- New paradigms to understand vision
- New technological breakthroughs

Biovision team

Main goals

Models

Propose models of the visual system, normal and impaired

Simulation

Develop simulation tools for the early visual system + motion

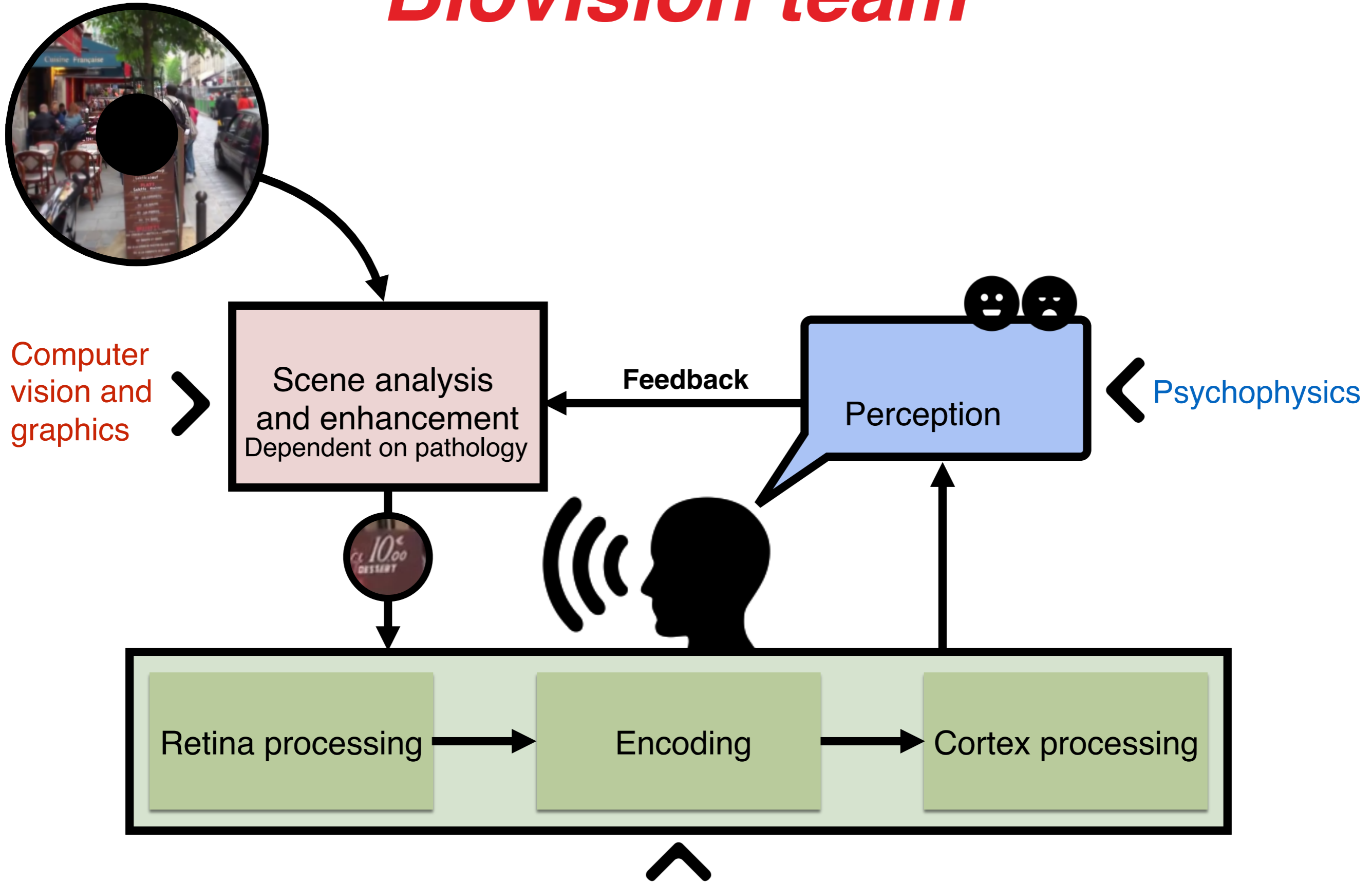
Therapy

Help improving rehabilitation strategies (models, algorithms, software)

Accessibility

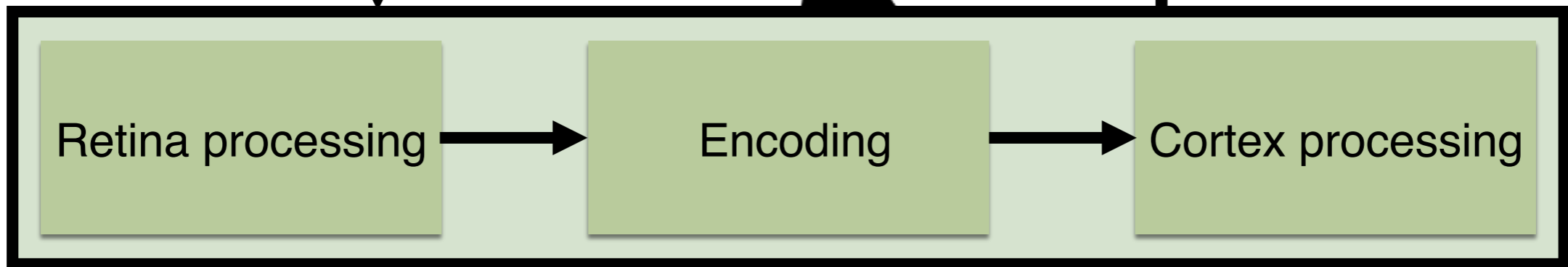
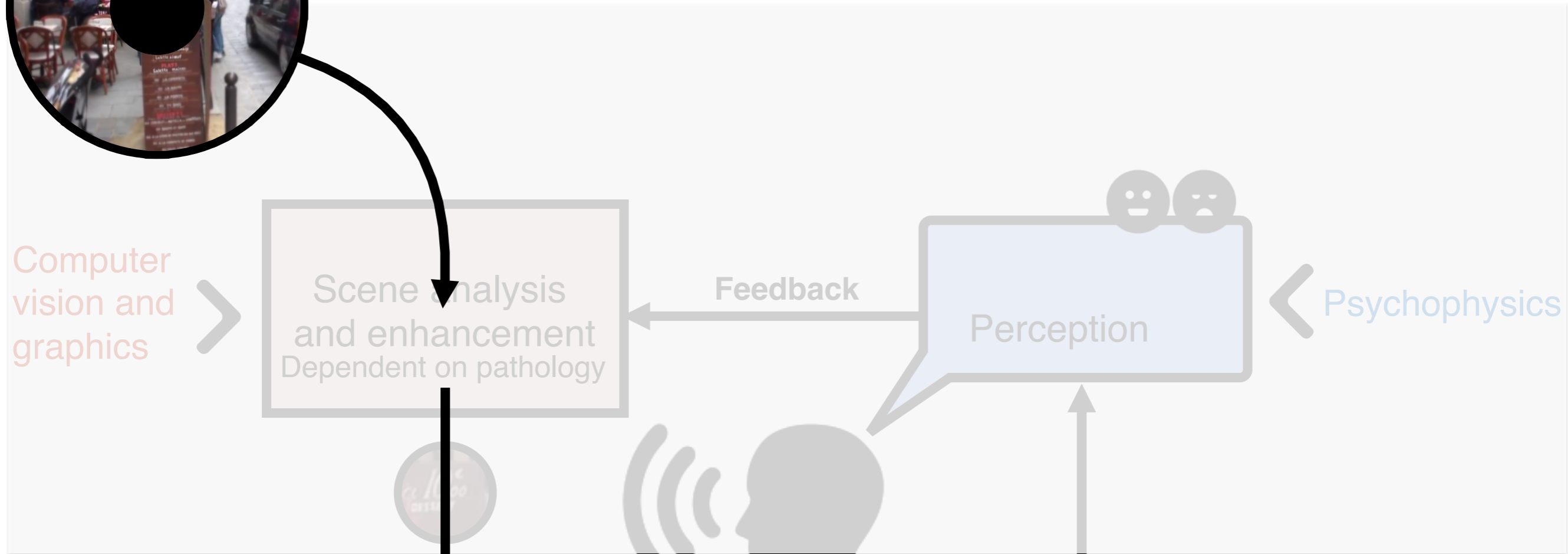
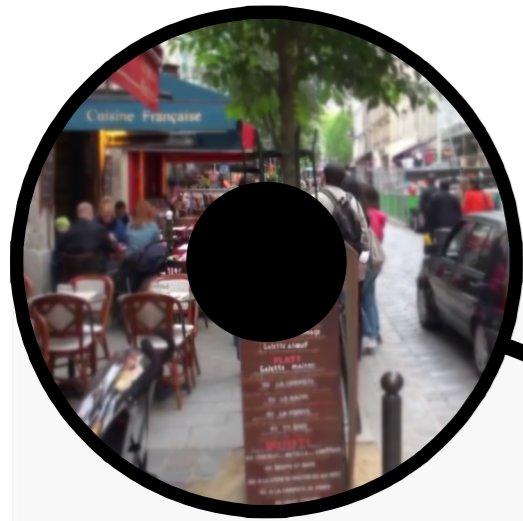
Design vision-aid systems to help patients in daily living activities

Biovision team



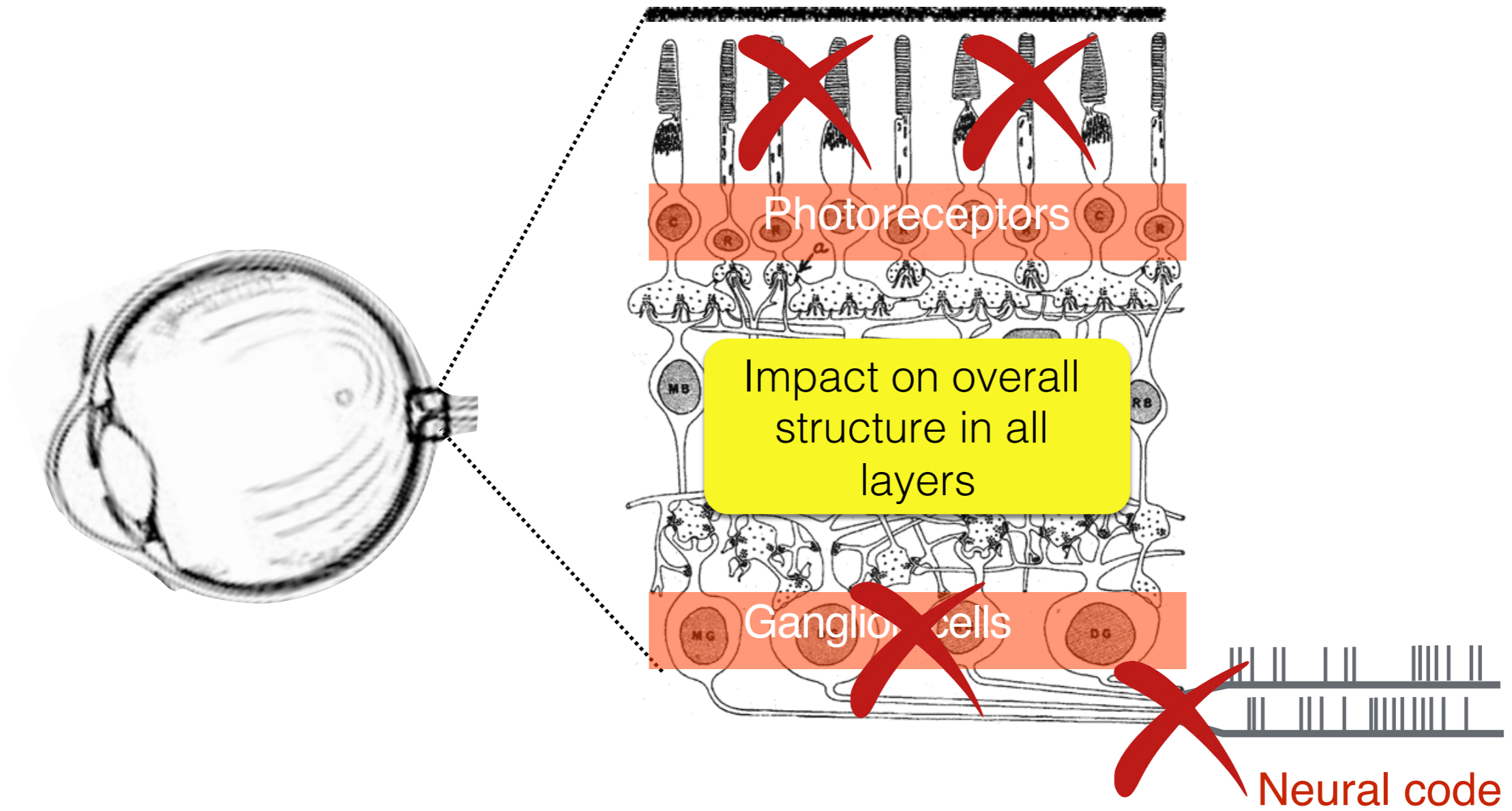
Biophysical modeling, model analysis, visual system emulation

Biovision team



Biophysical modeling, model analysis, visual system emulation

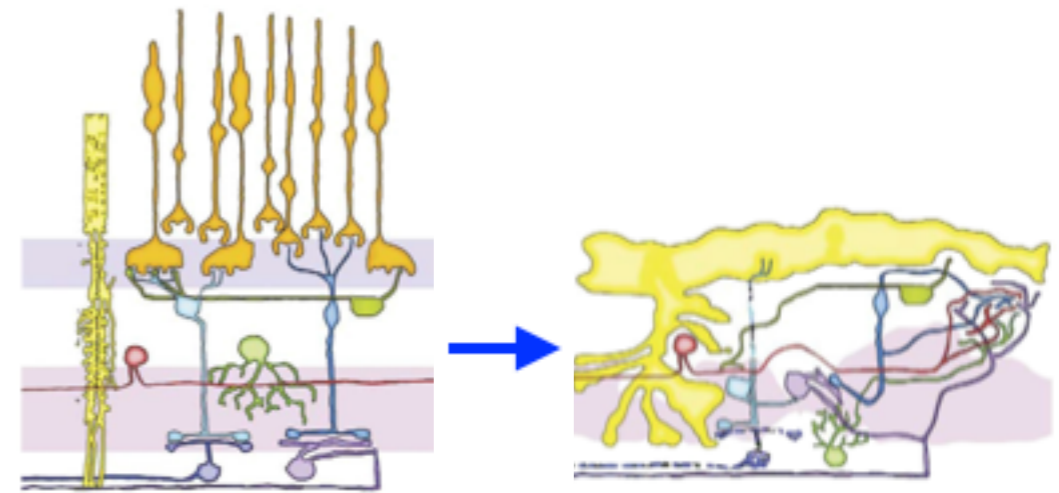
The retina



Modeling retina pathologies

Software development and modelling

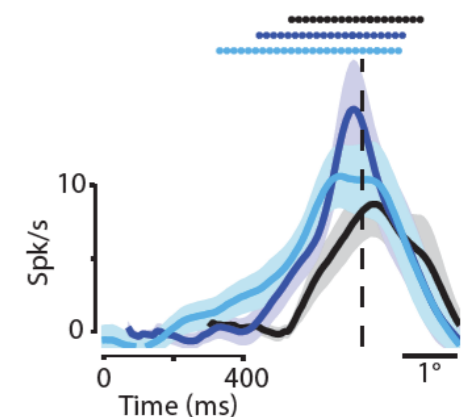
From healthy retinas to impaired ones



Multi-scale modelling and simulation

Individual cells characterisation
Collective activity and coding
Mesoscopic description

Focus on motion and anticipation





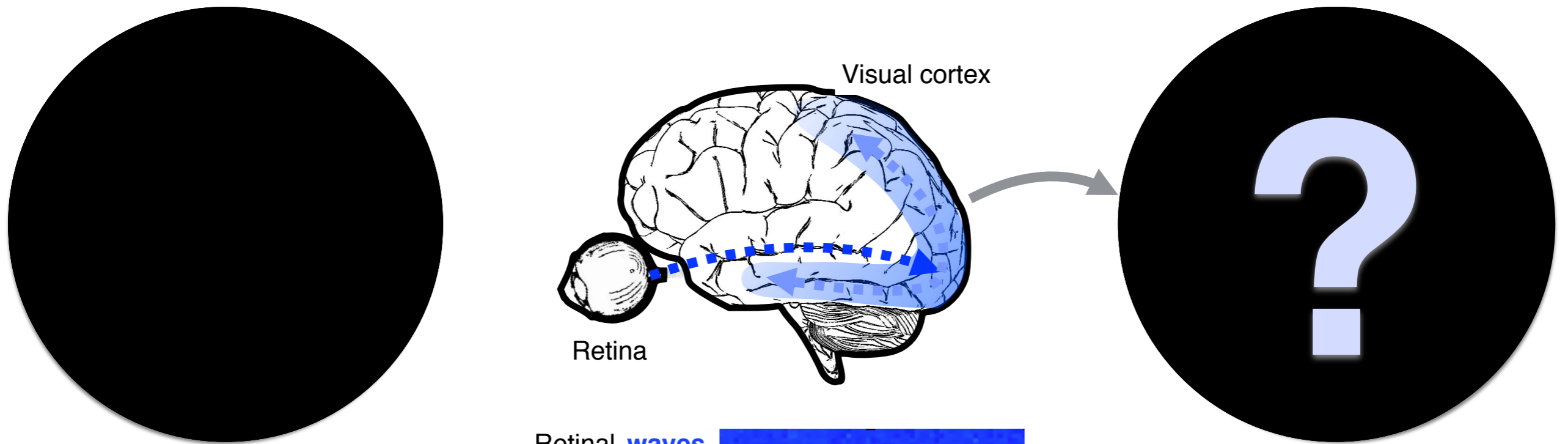
Mesososcopic modelling of the retina

Collab.: Institut de la Vision, INLN-InPhyNi

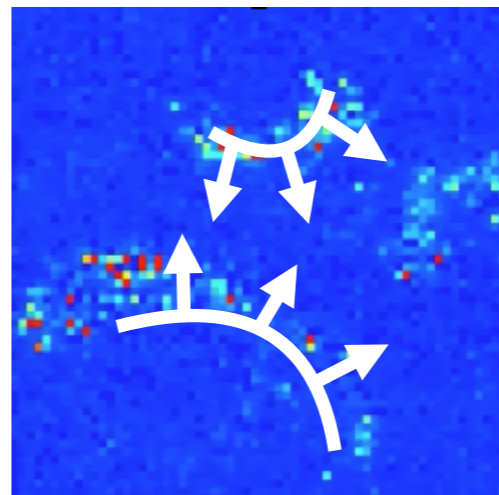


Visual system (re)-shaping: Retinal waves

Collab.: Institut de la Vision, INLN



Retinal **waves**
during development
Courtesy E. Sernagor
University of Newcastle

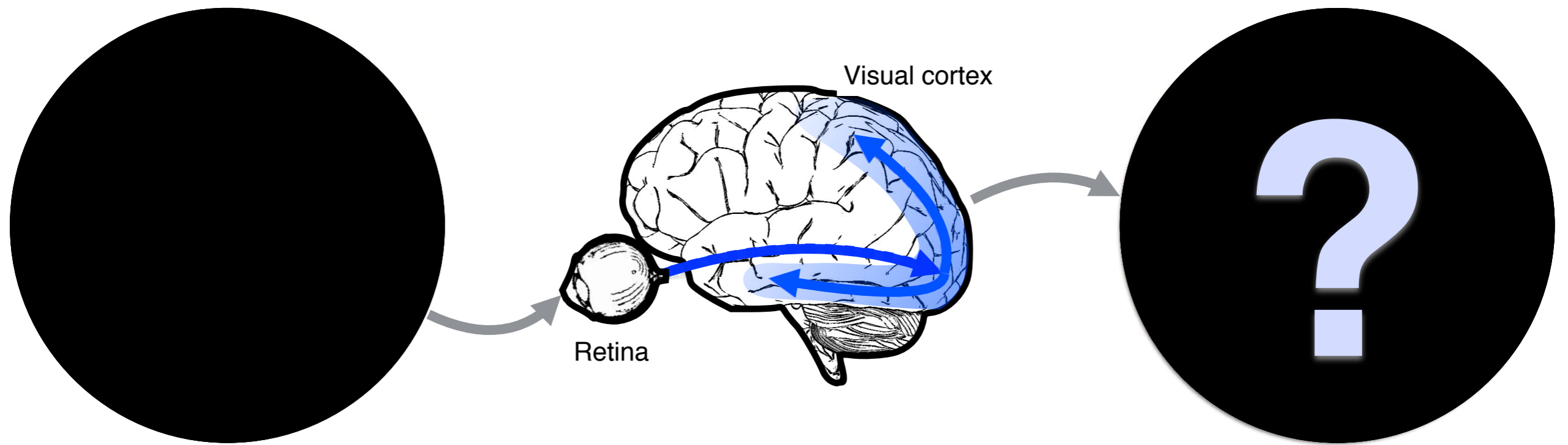


Retina: evolving medium with
ongoing spatio-temporal activity



Visual system (re)-shaping: Retinal waves

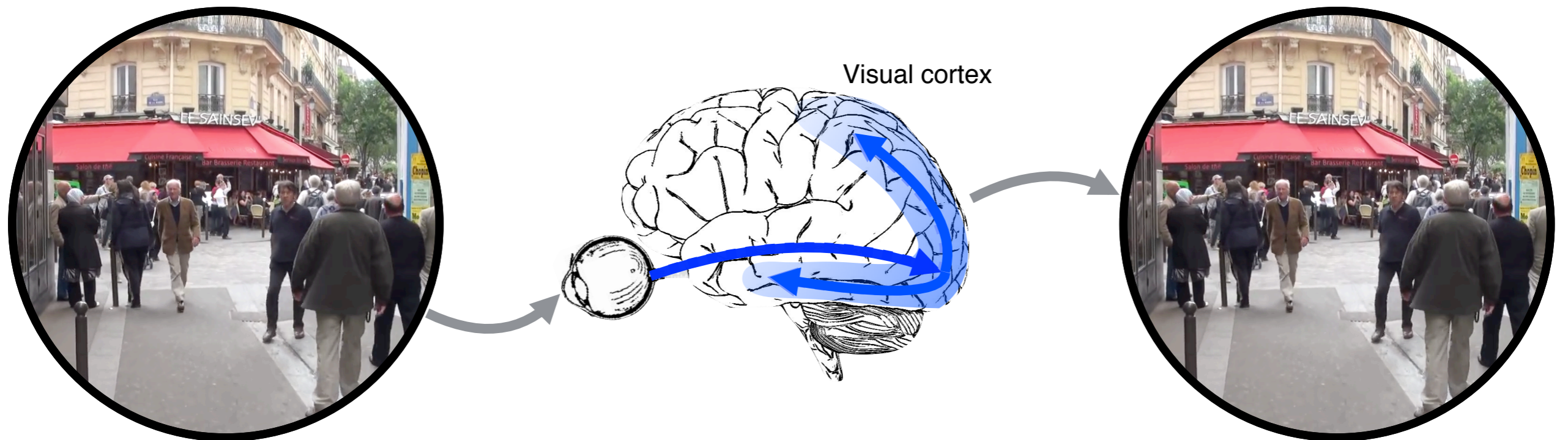
Collab.: Institut de la Vision, INLN





Visual system (re)-shaping: Retinal waves

Collab.: Institut de la Vision, INLN

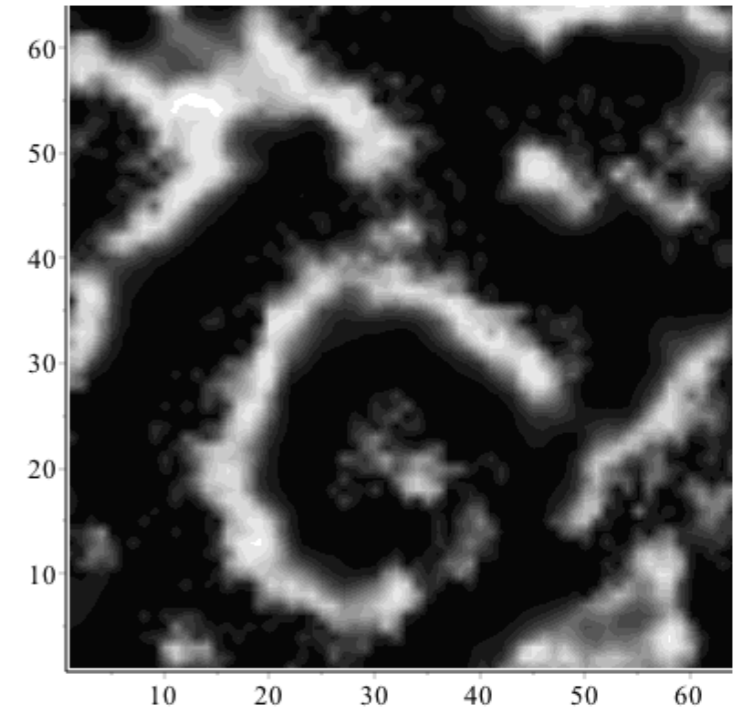
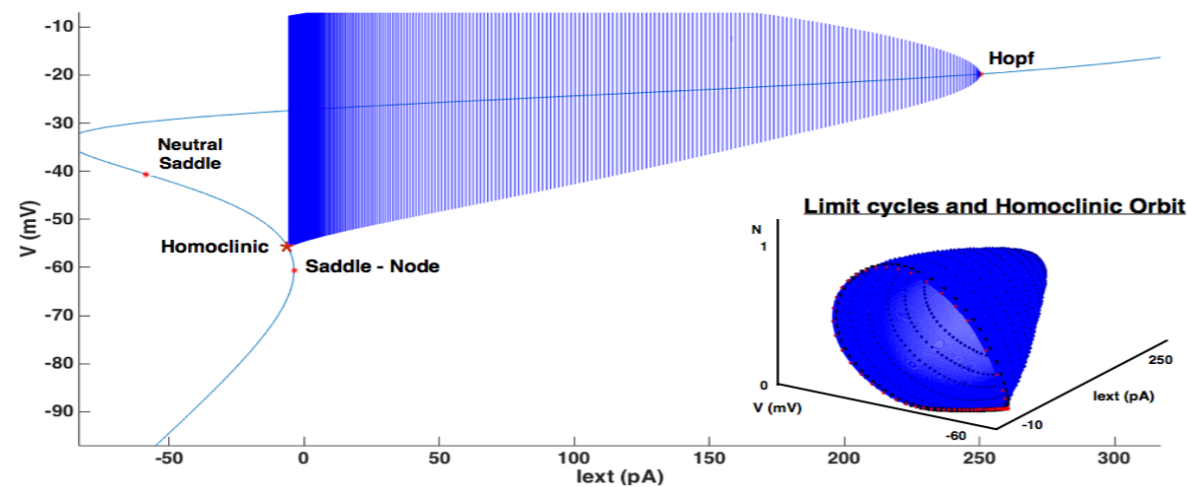




Visual system (re)-shaping: Retinal waves

Collab.: Institut de la Vision, INLN

Biophysical modelling (in agreement with experiments)
Dynamical system analysis



Dora Karvouniari, Lionel Gil, Olivier Marre, Serge Picaud, Bruno Cessac, A biophysical model explains the oscillatory behaviour of immature starburst amacrine cells (under review)

Toward a mesoscopic description of retina activity

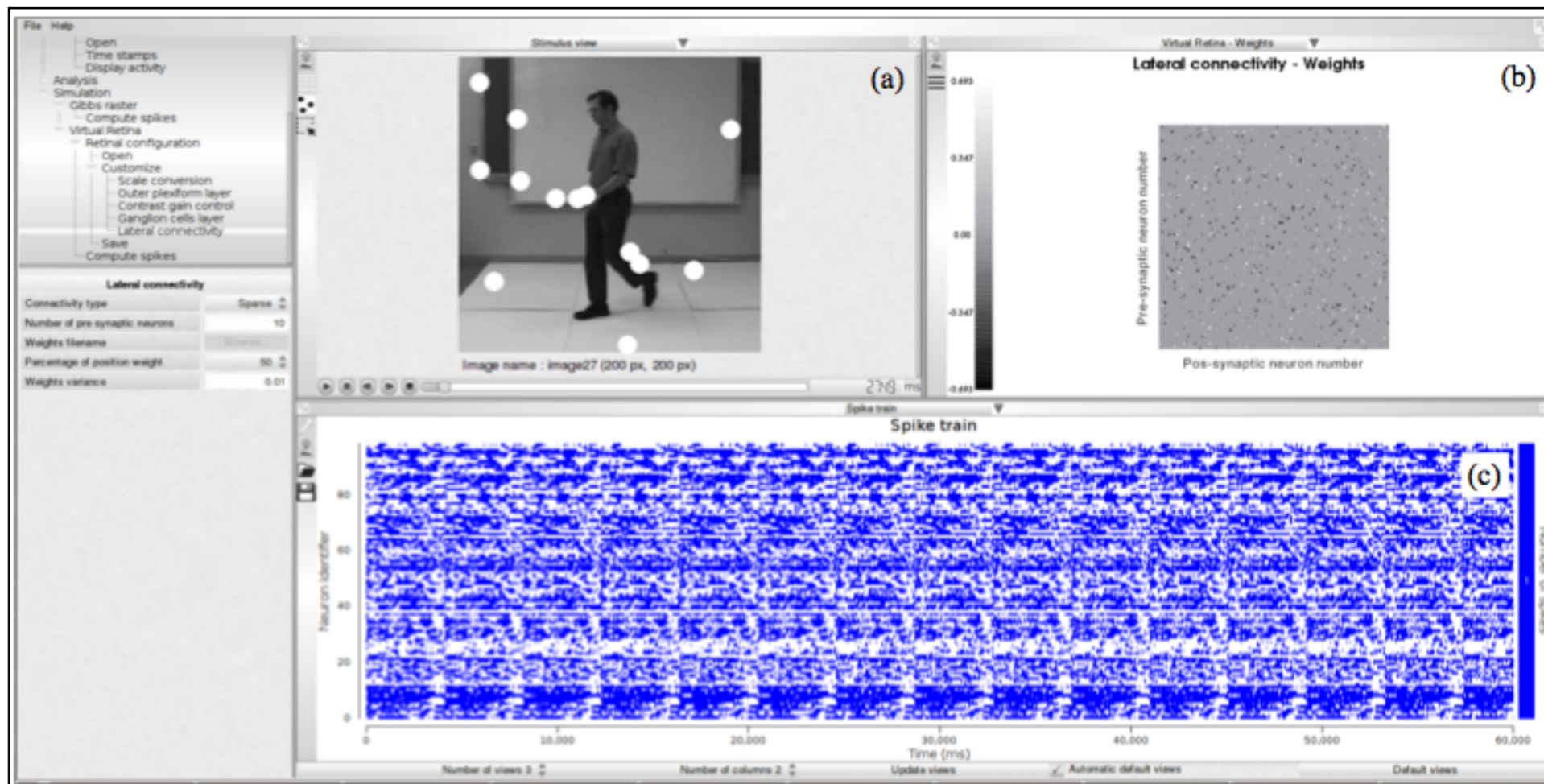
- Reduced equations, reduced parameters (« Reynolds like » number)
- Generic mechanisms of transport as a function of biophysical parameters

$$\frac{\partial G_A}{\partial t} = g_A D_M \left[(\nabla G_S, \nabla G_A) D_H^2 \begin{pmatrix} \nabla G_S \\ \nabla G_A \end{pmatrix} + \frac{\partial H}{\partial G_S} \Delta G_S + \frac{\partial H}{\partial G_A} \Delta G_A \right] + S(G_S, G_A).$$

Pharmacologically controlling the arousal of retinal waves in adults

Mesososcopic modelling of the retina

Producing software for biologists and physicians

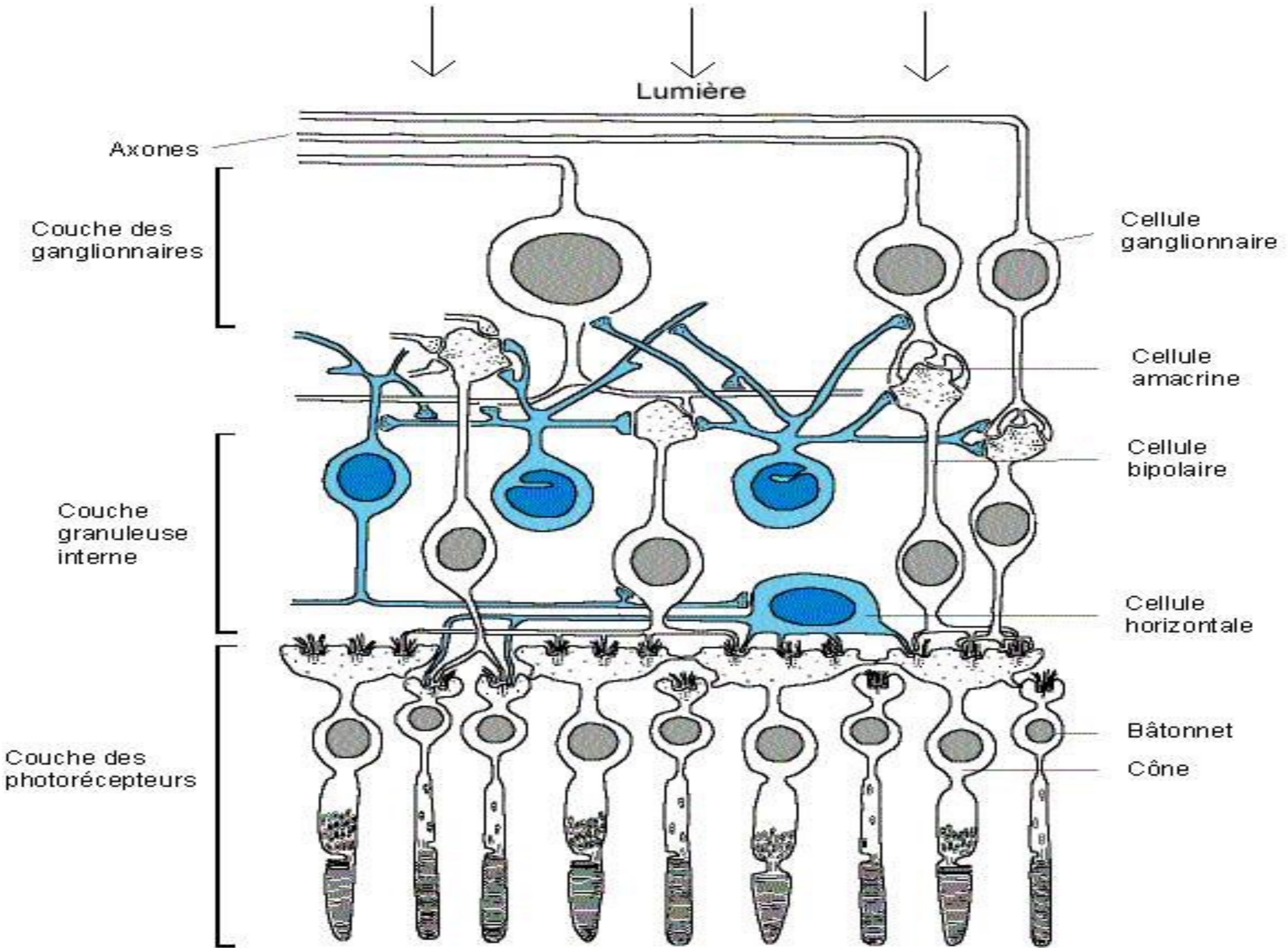


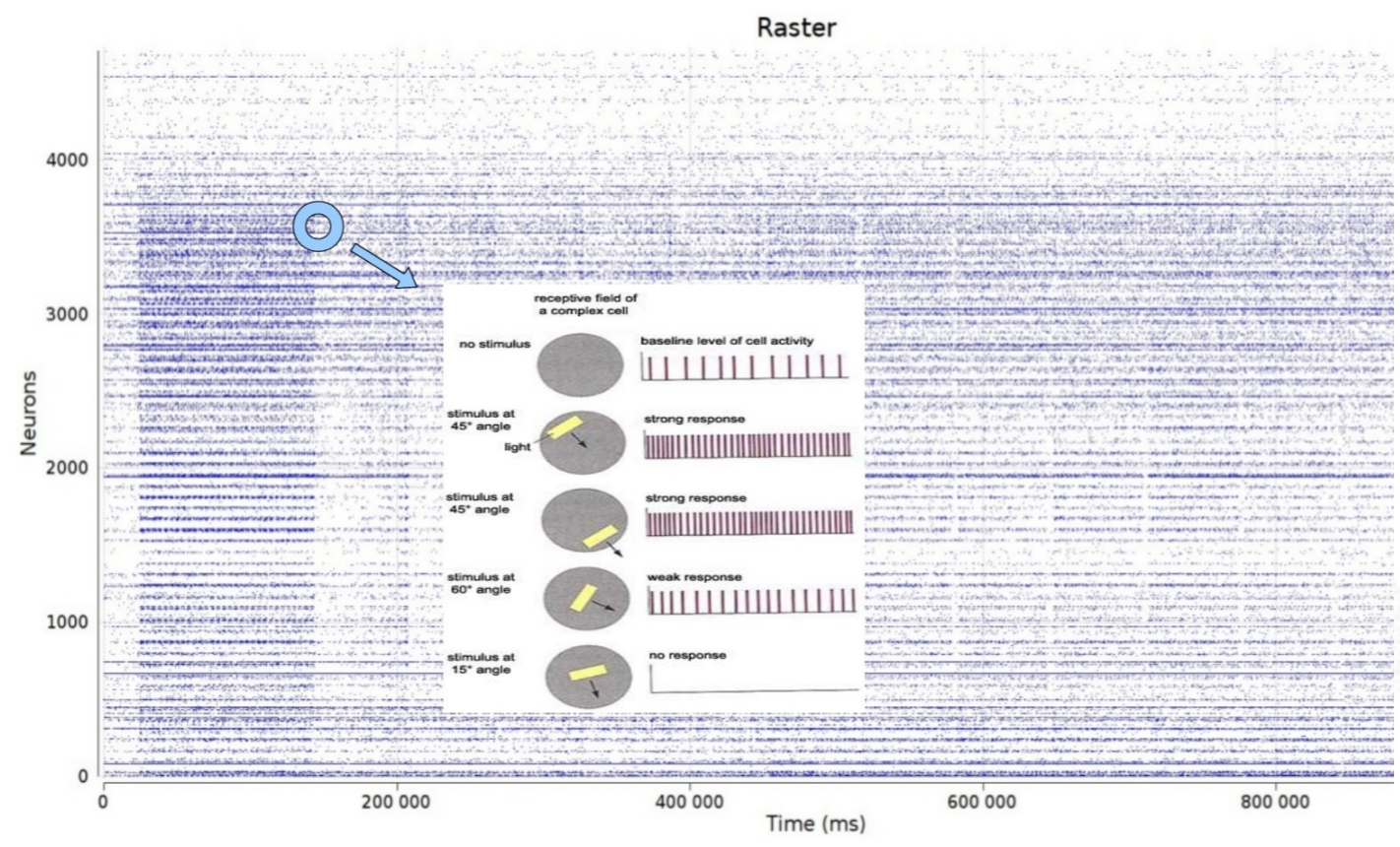
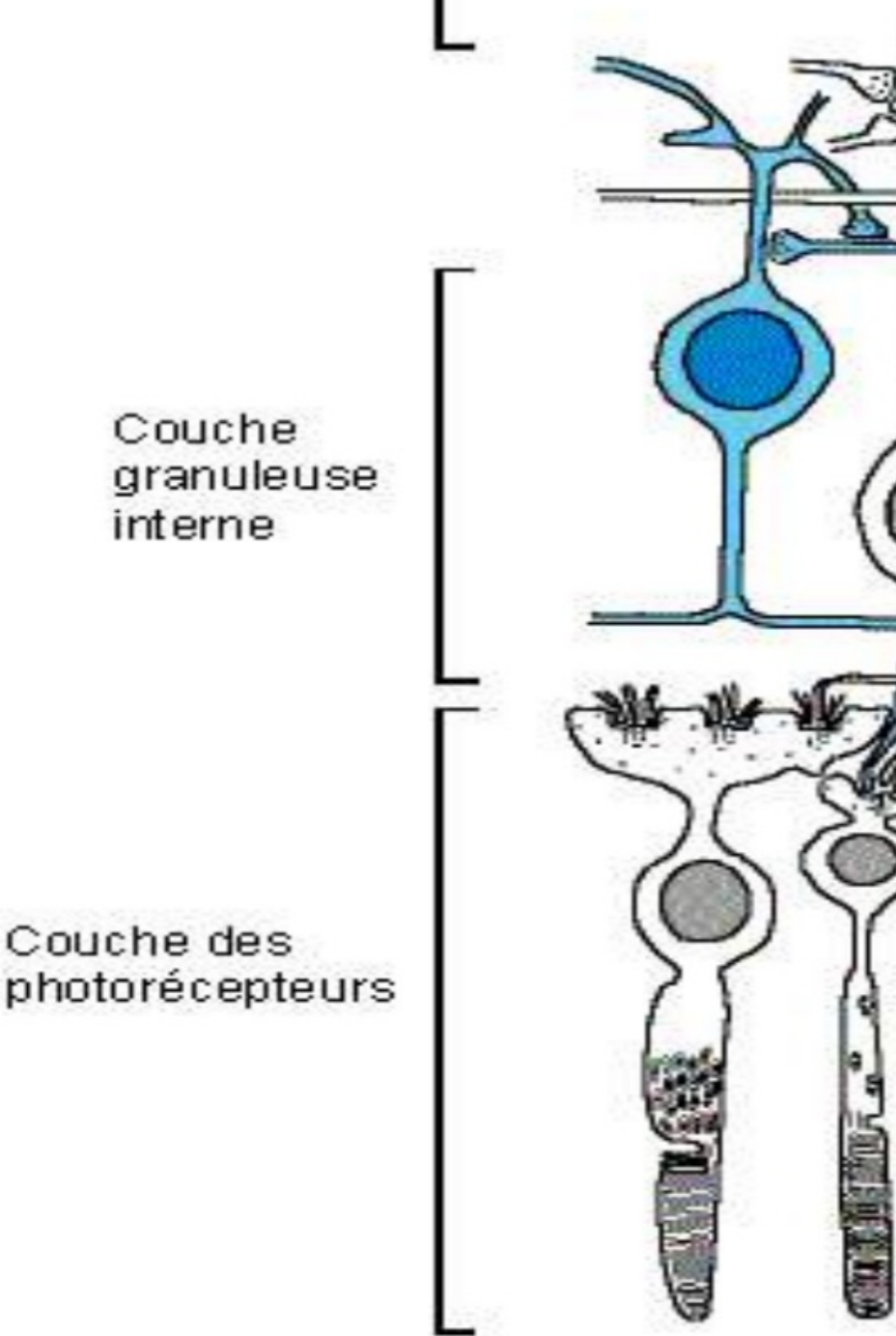
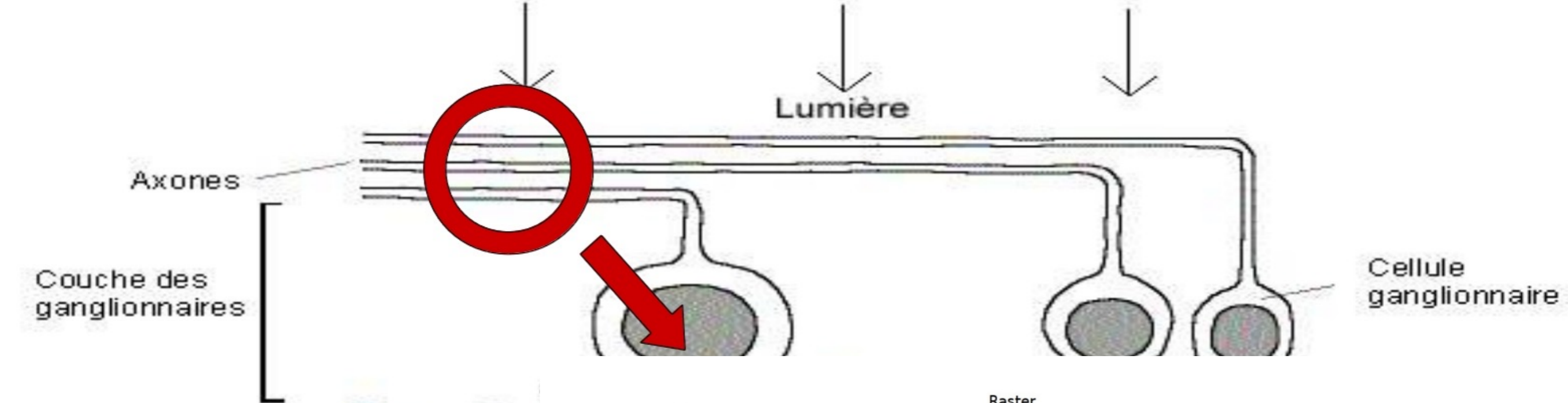
PRANAS: Platform for Retina ANalysis And Simulation

B. Cessac, P. Kornprobst, S. Kraria, H. Nasser, D. Pamplona, G. Portelli and T. Viéville, PRANAS: a new platform for retinal analysis and simulation, *Frontiers in Neuroinformatics*, 2017

<https://pranas.inria.fr/>

MACULAR: Numerical platform for large scale simulations of the retina in pathological conditions





Cellule amacrine

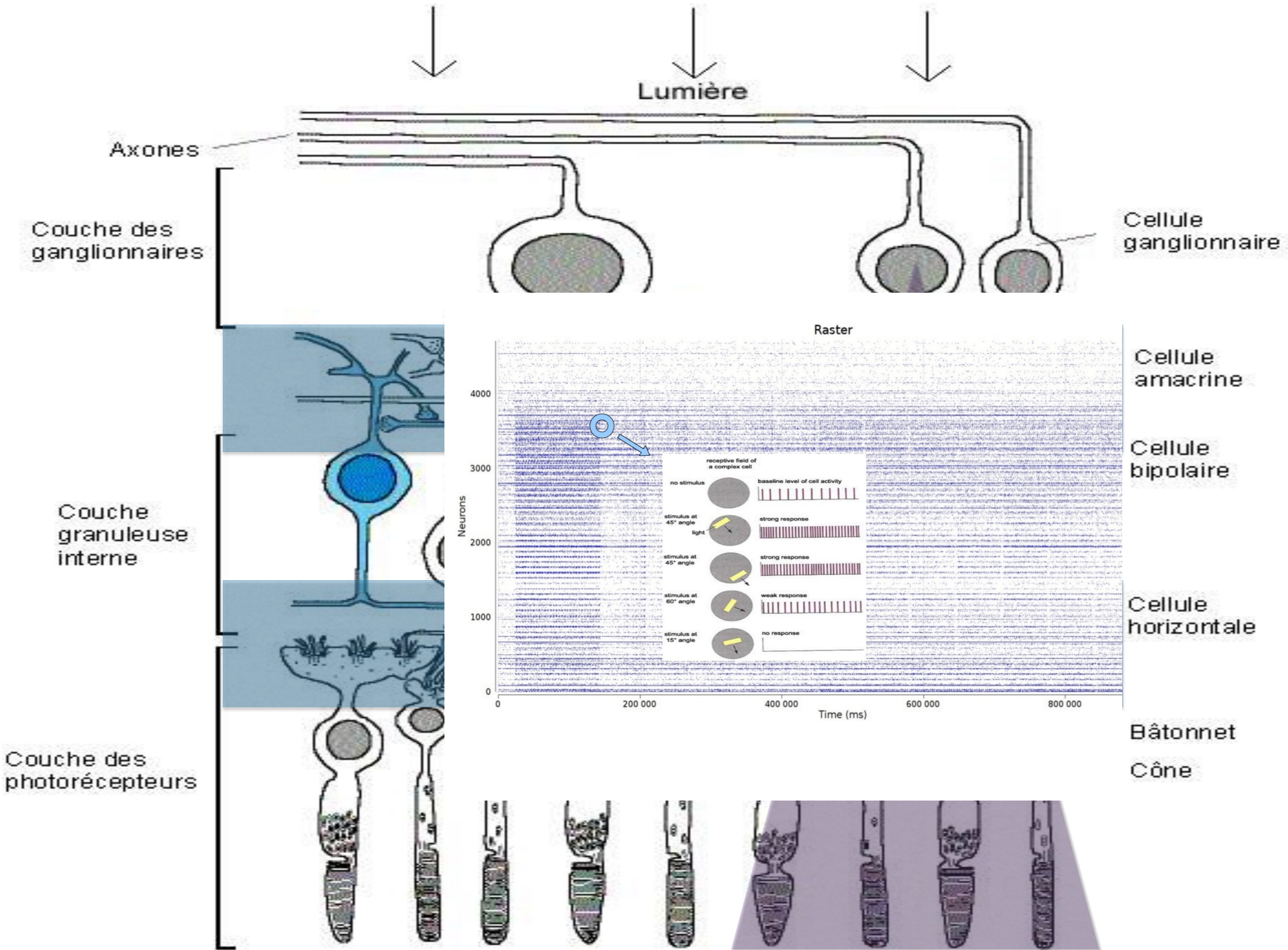
Cellule bipolaire

Cellule horizontale

Bâtonnet

Cône





Lumière

Axones

Couche des ganglionnaires

Cellule ganglionnaire

Couche granuleuse interne

Raster

Cellule amacrine

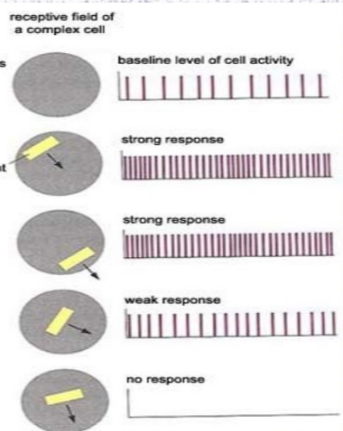
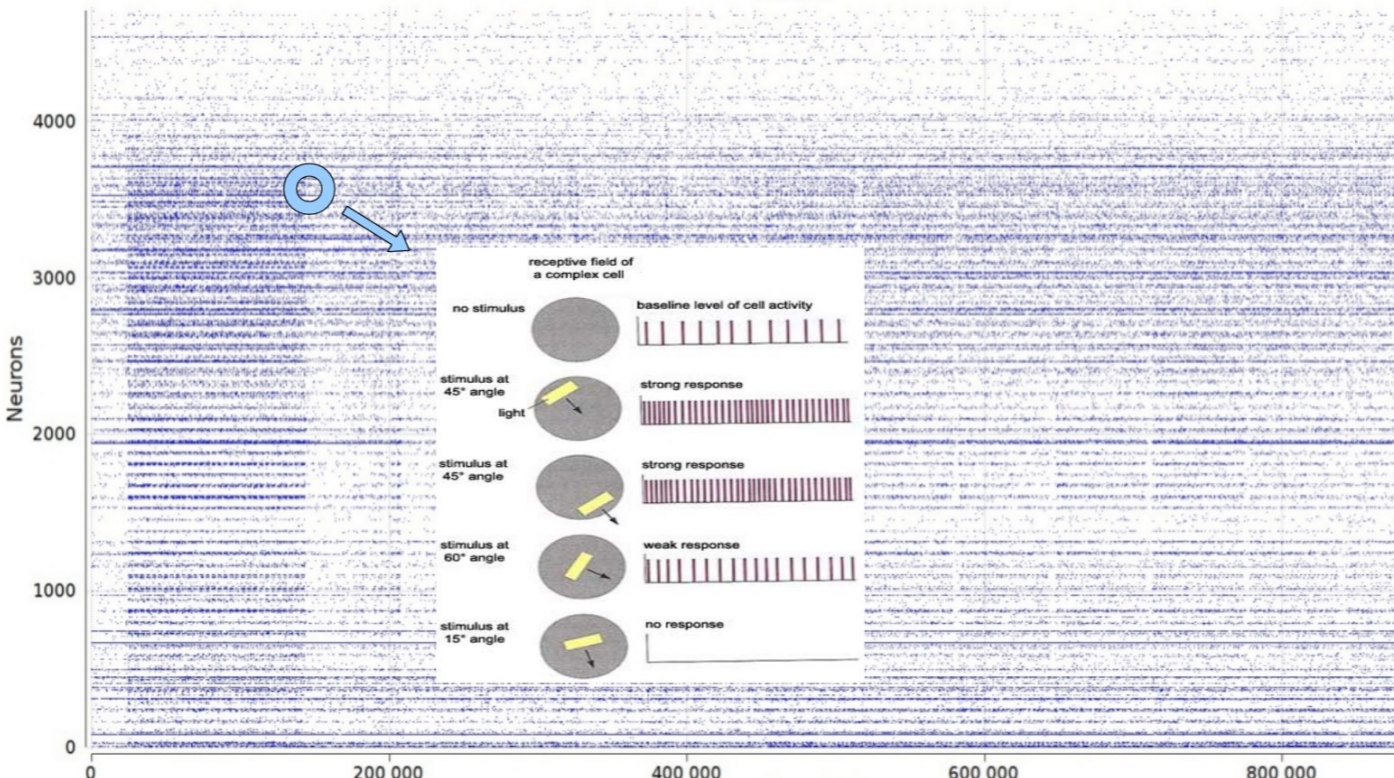
Cellule bipolaire

Cellule horizontale

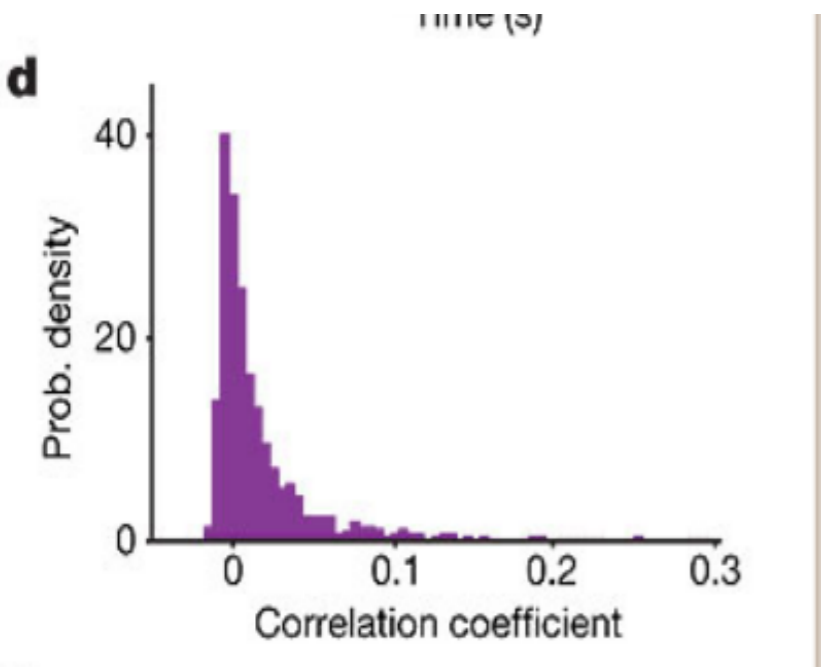
Bâtonnet

Cône

Couche des photorécepteurs

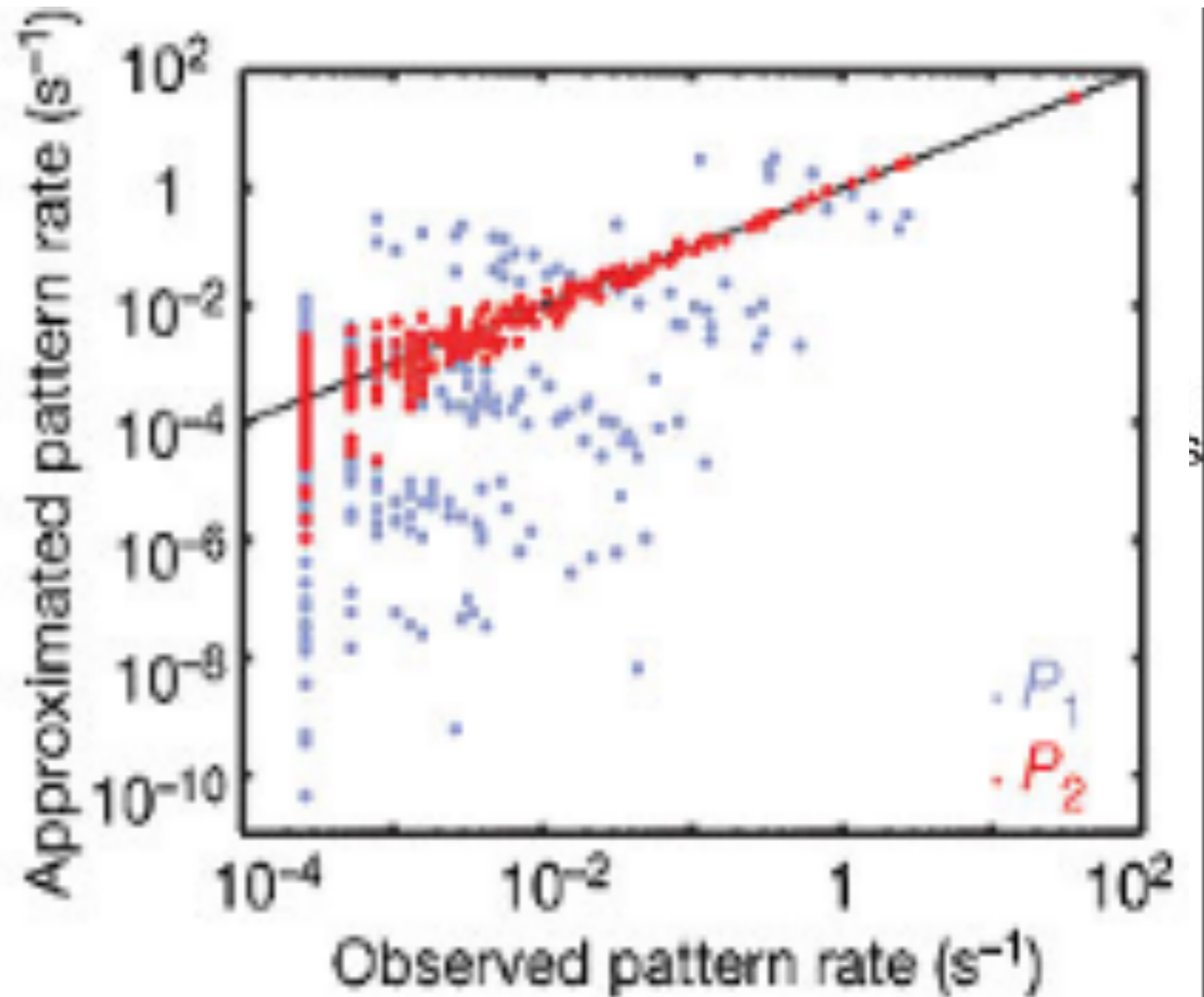


Reading the retinal neural code



Maximizing the statistical entropy under constraints

Ising model



Berry-et al, Nature, 2006

Extension to more general correlations

Stationary: Extended Gibbs distribution

(Vasquez-et-al, 2011; Nasser et al 2013, Coffré-Cessac; 2014)

Non stationary: Linear response theory

Cessac-Coffré, 2017

Non stationary: Spatio-temporal correlations modified by a moving object

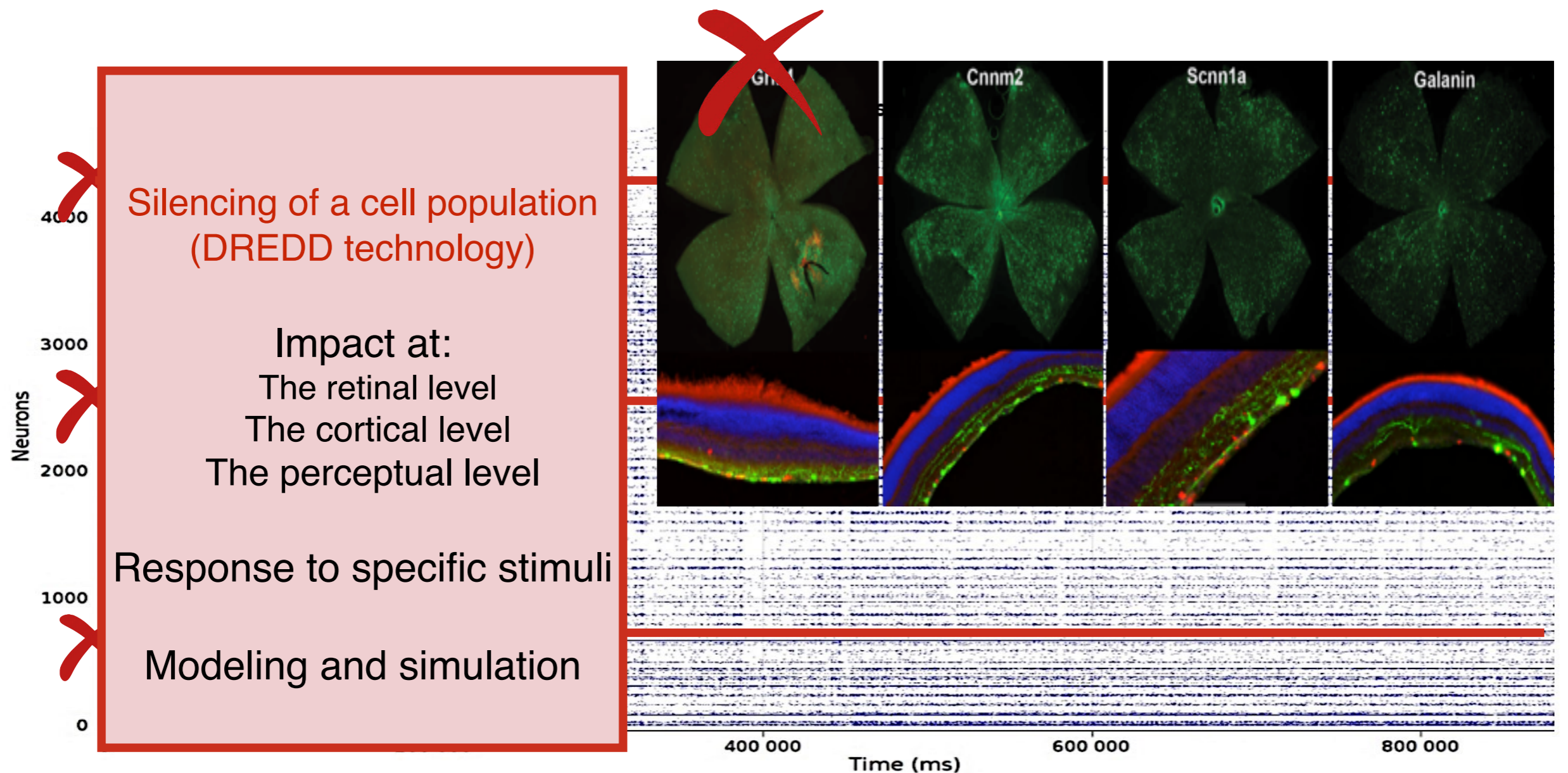
Souihel et al, in progress



Pharmacologically induced pathologies

Population level: switching on and off cell types

Collab.: University of Newcastle, University of Edinburgh
Leverhulme Funding (2017-2020)





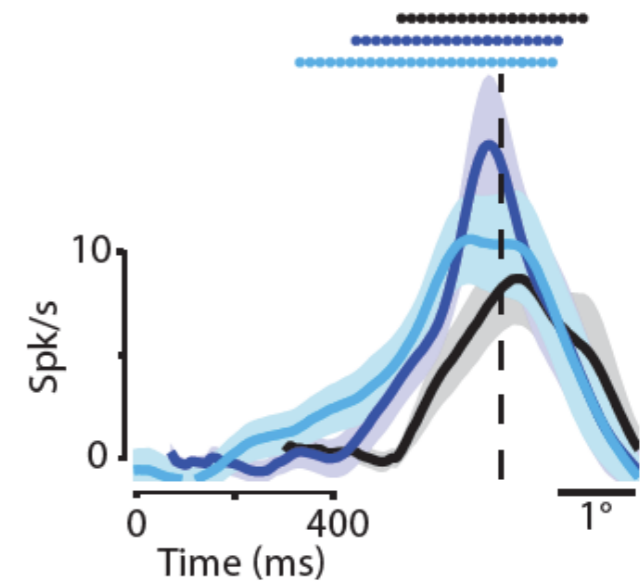
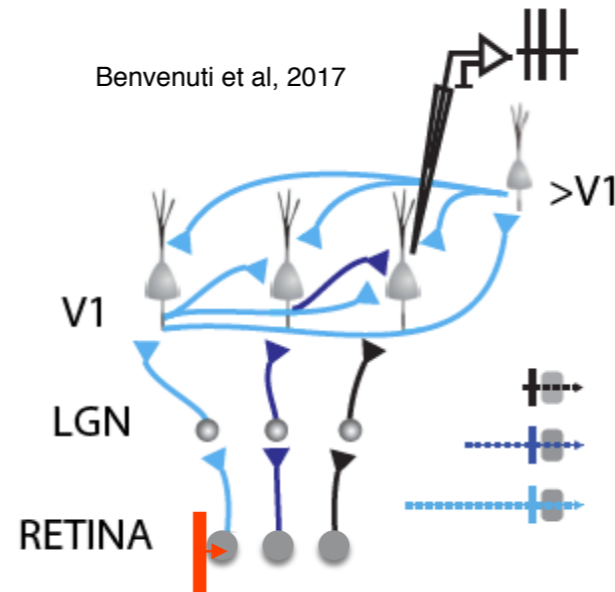
Motion anticipation

Collab.: INT Marseille, IdV Paris, University of Valparaiso
ANR Trajectory (2016-2020)



Motion anticipation

Collab.: INT Marseille, IdV Paris, University of Valparaiso
ANR Trajectory (2016-2020)

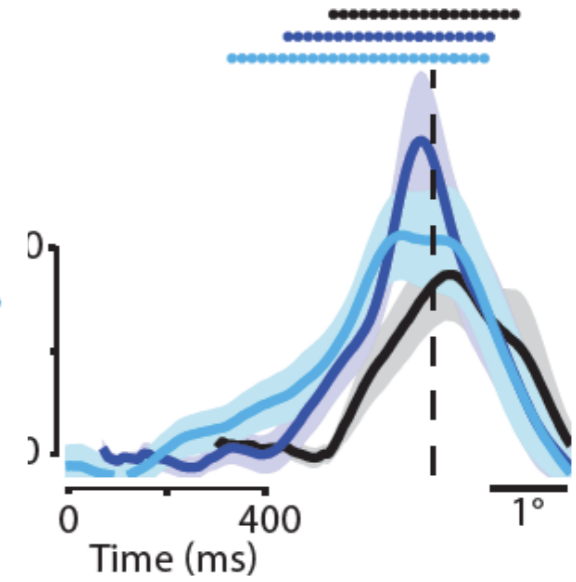
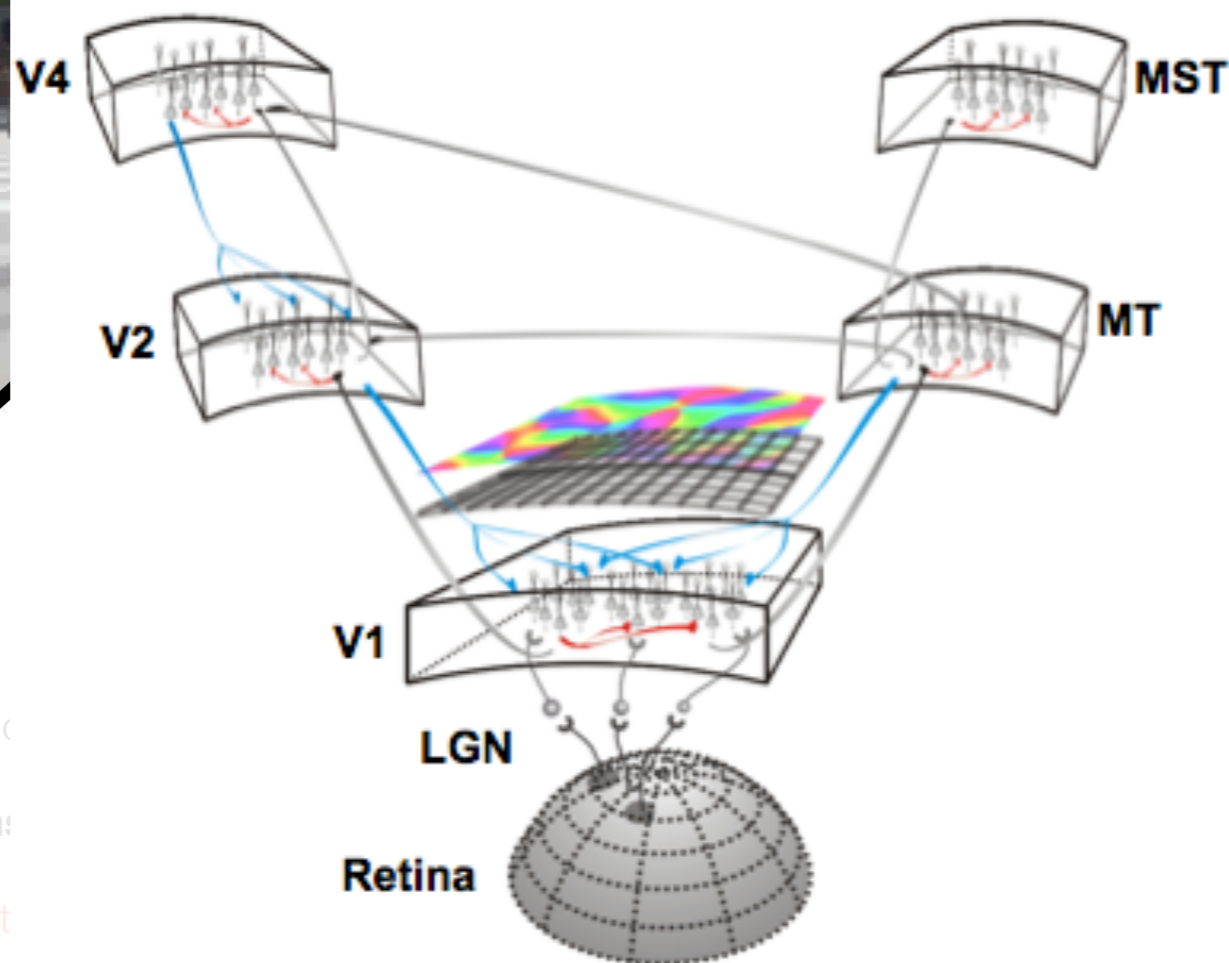


From retina ... to cortex



Motion anticipation

Collab.: INT Marseille, IdV Paris, University of Valparaiso
ANR Trajectory (2016-2020)



At a population c

Spatio-temporal correlation:

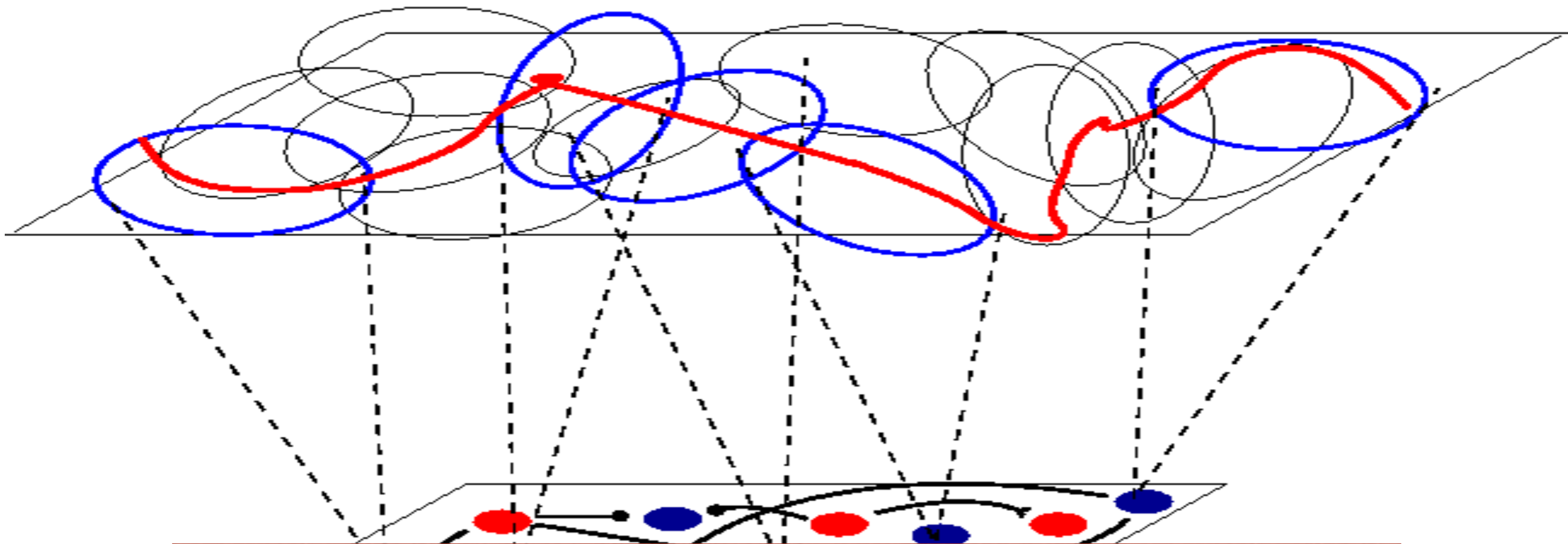
Cessac et

PRANAS => **realistic entry** to a V1 model.

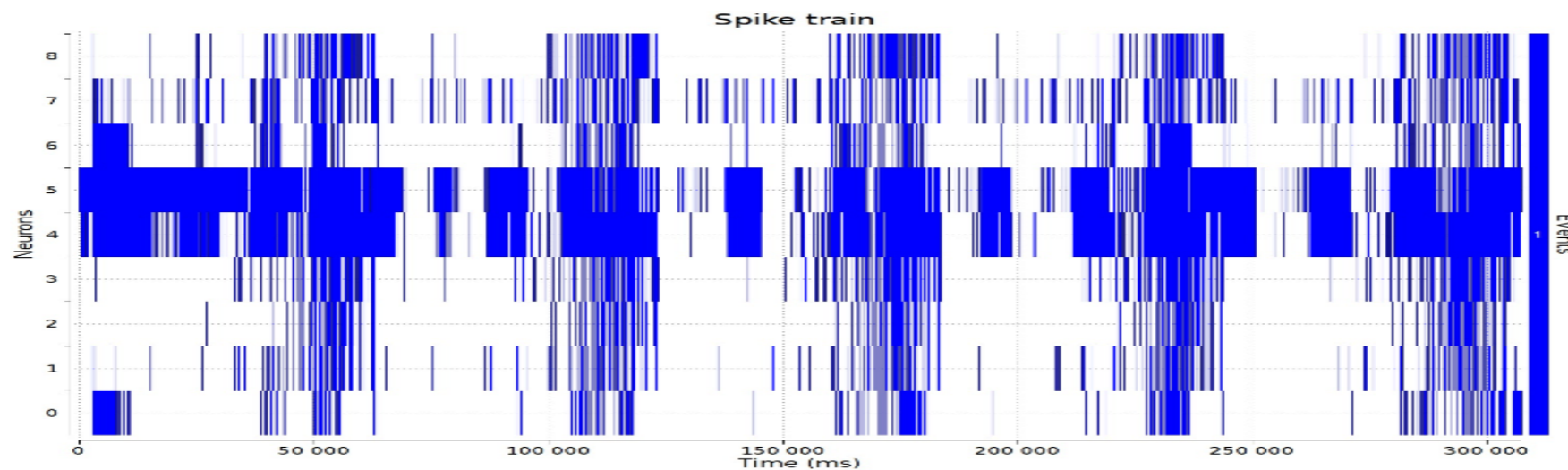
na to cortex

ended model with a realistic **retino-**
cating cortical activity (**VSDI**) in V1.

- Hierarchical model of the visual cortex motion areas.



How is motion imprinted in the spike train ?

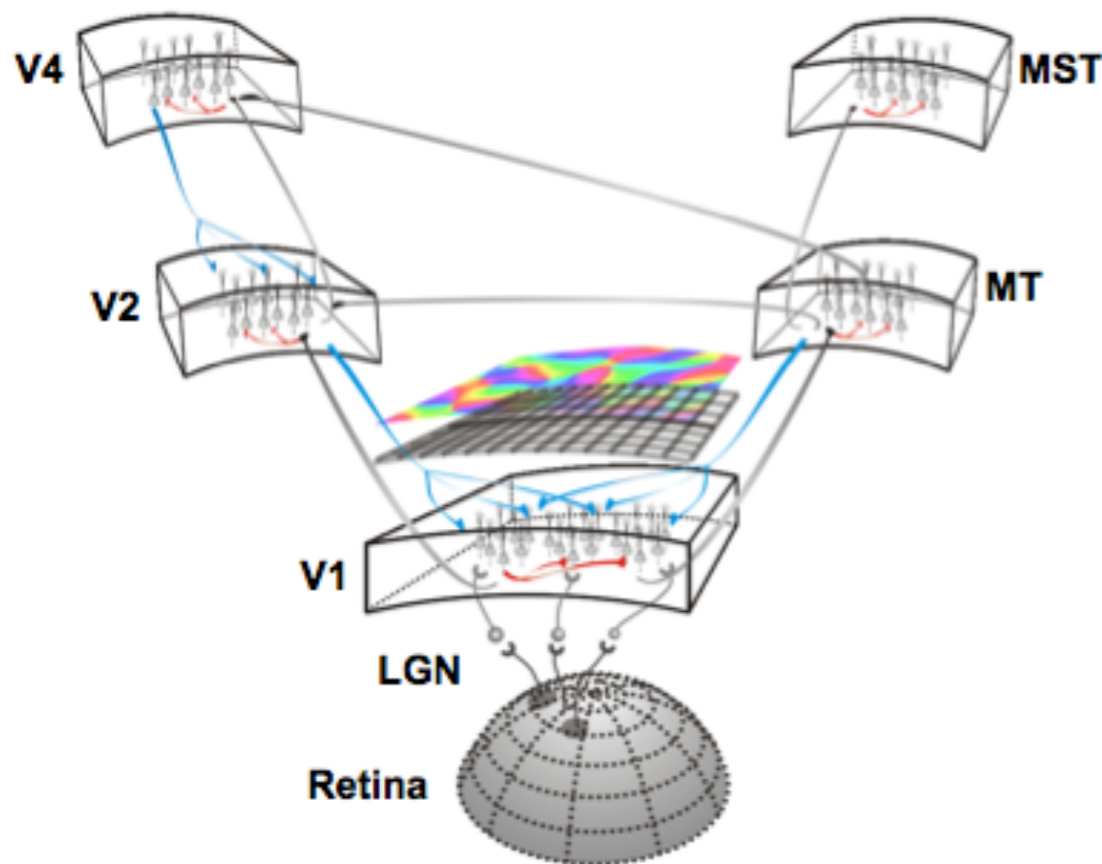




Motion anticipation

Collab.: INT Marseille, IdV Paris, University of Valparaiso
ANR Trajectory (2016-2020)

From retina ... **to cortex**



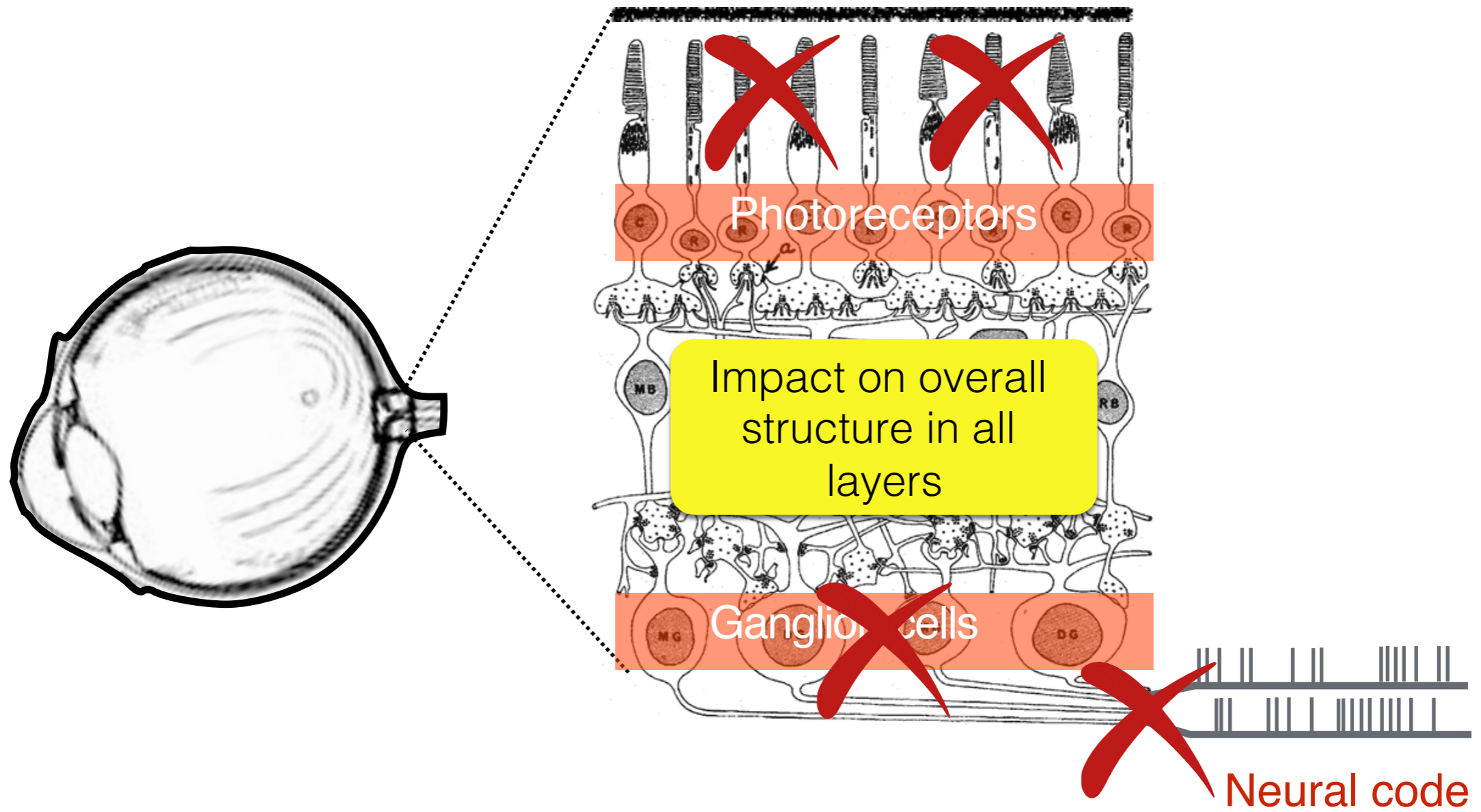
Realistic input

- Integrated models: From retina to cortex

Model:

- Reduced spatially extended model with a realistic **retino -thalamic** input reproducing cortical activity (**VSDI**) in V1.
- Hierarchical model of the visual cortex motion areas.

The retina



Blindness

Existing emerging therapeutic methods

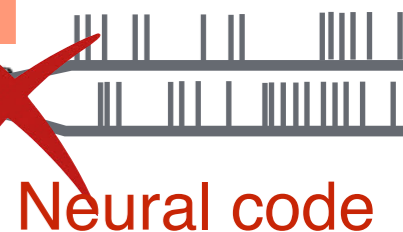
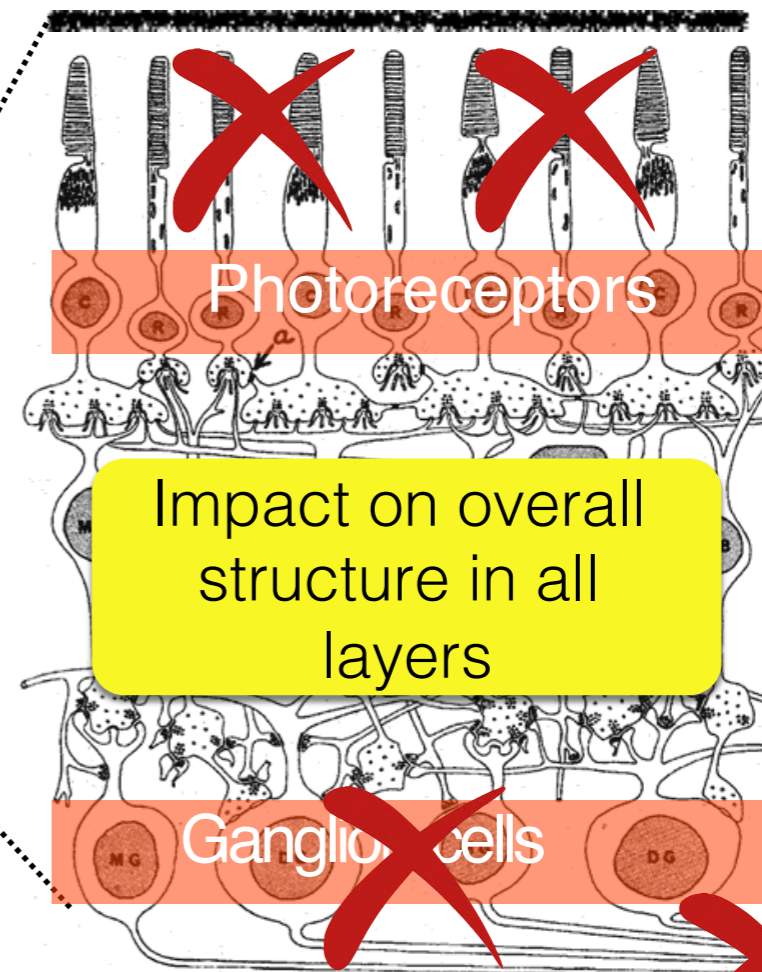
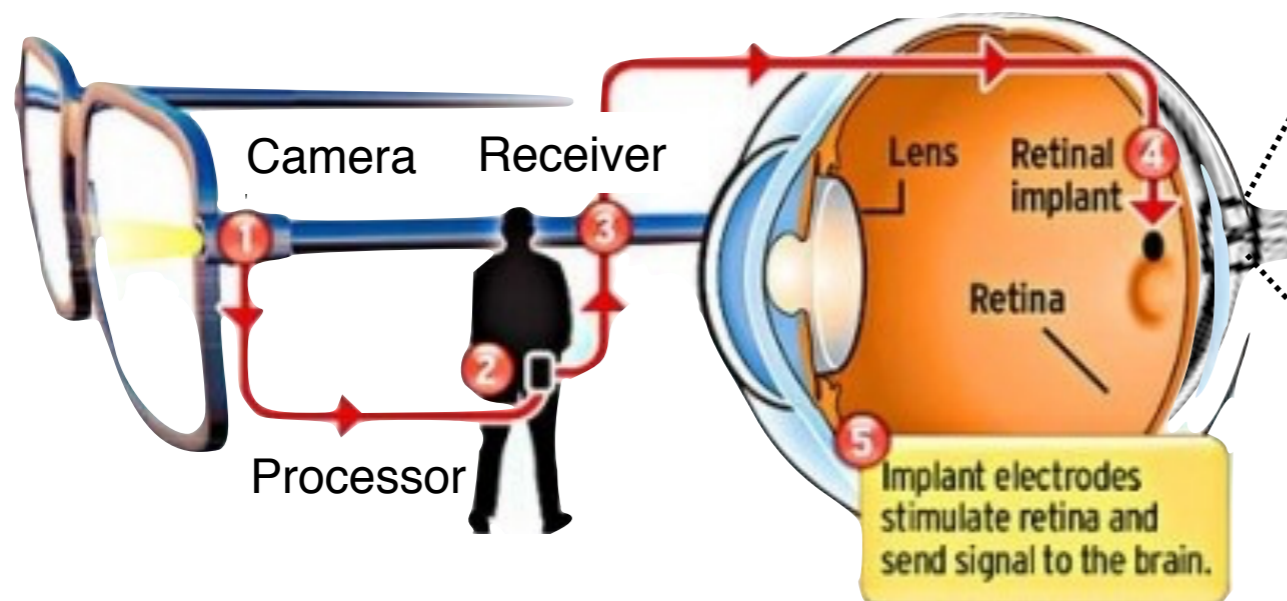
Gene therapy

Stem cells

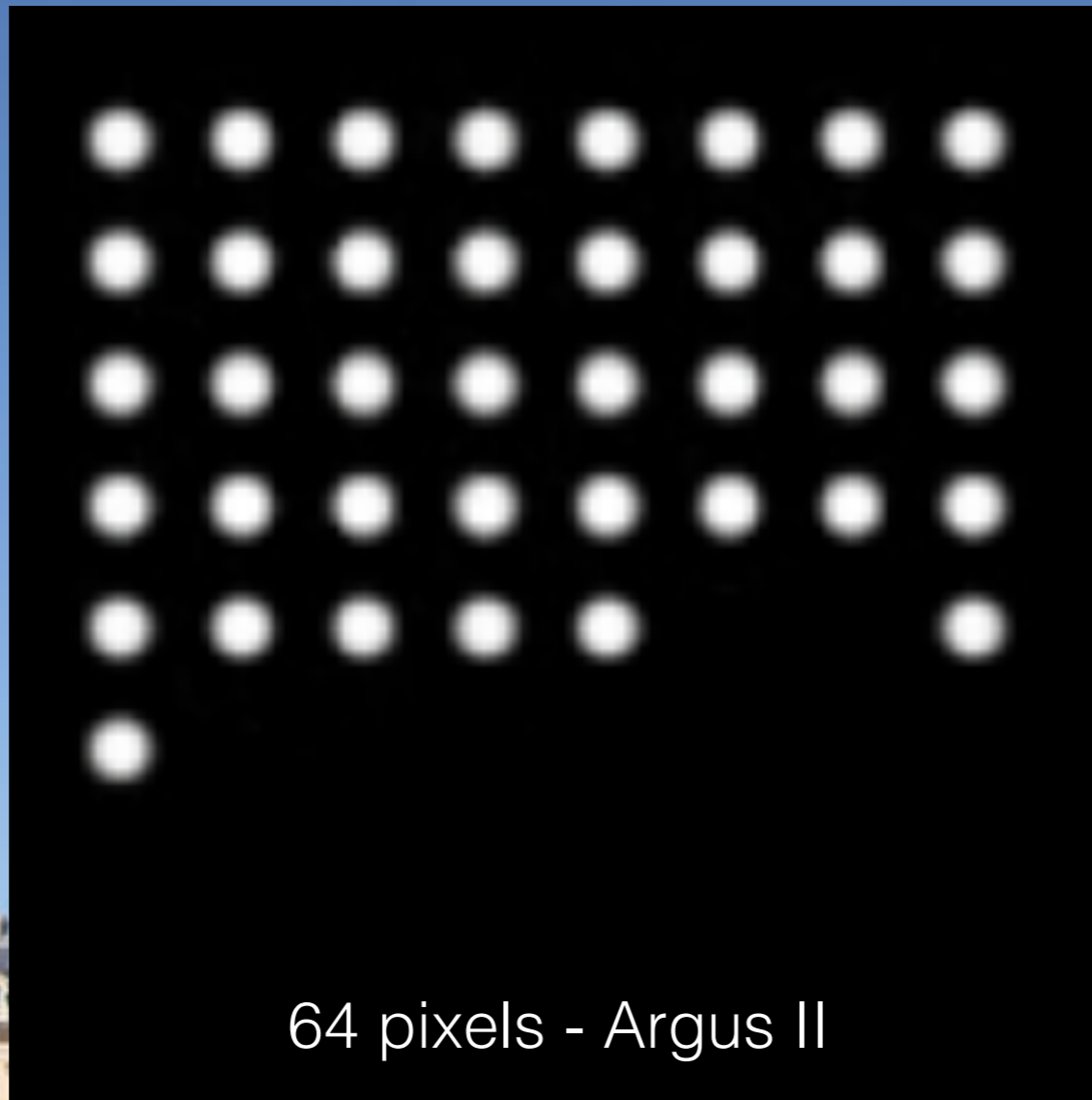
Cell transplantation

Retinal prostheses

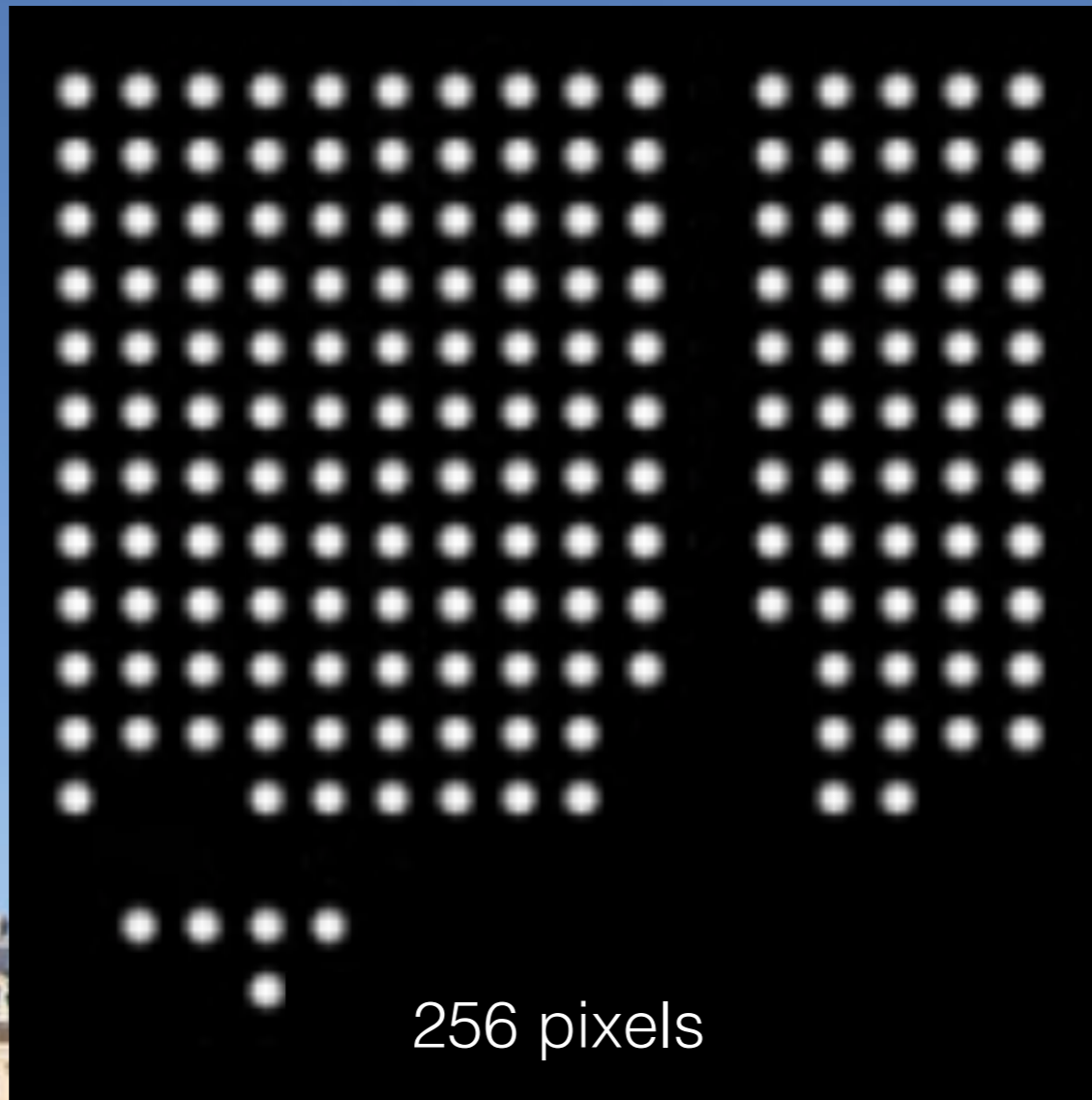
(electric, optoelectronic, optogenetic)



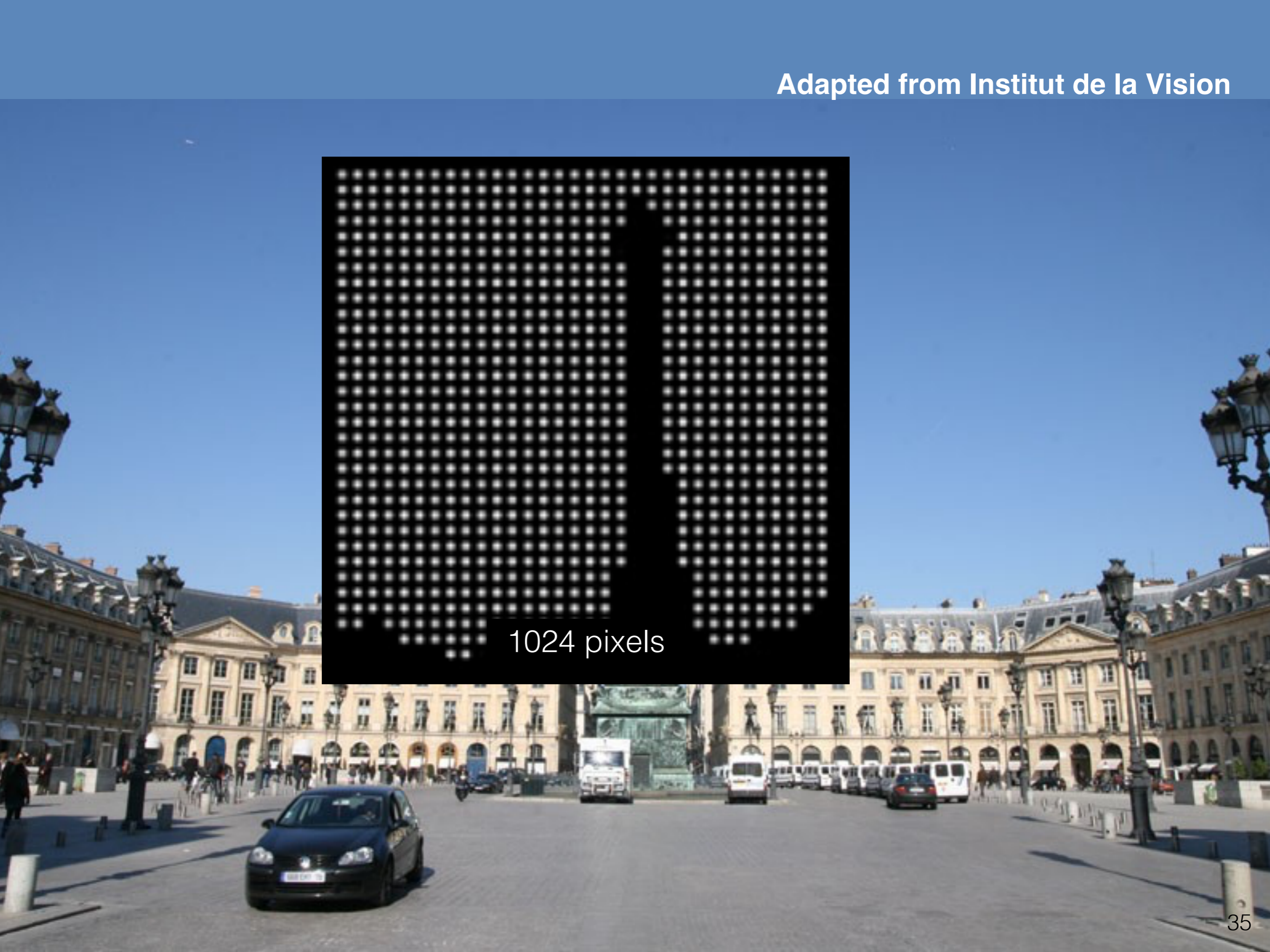
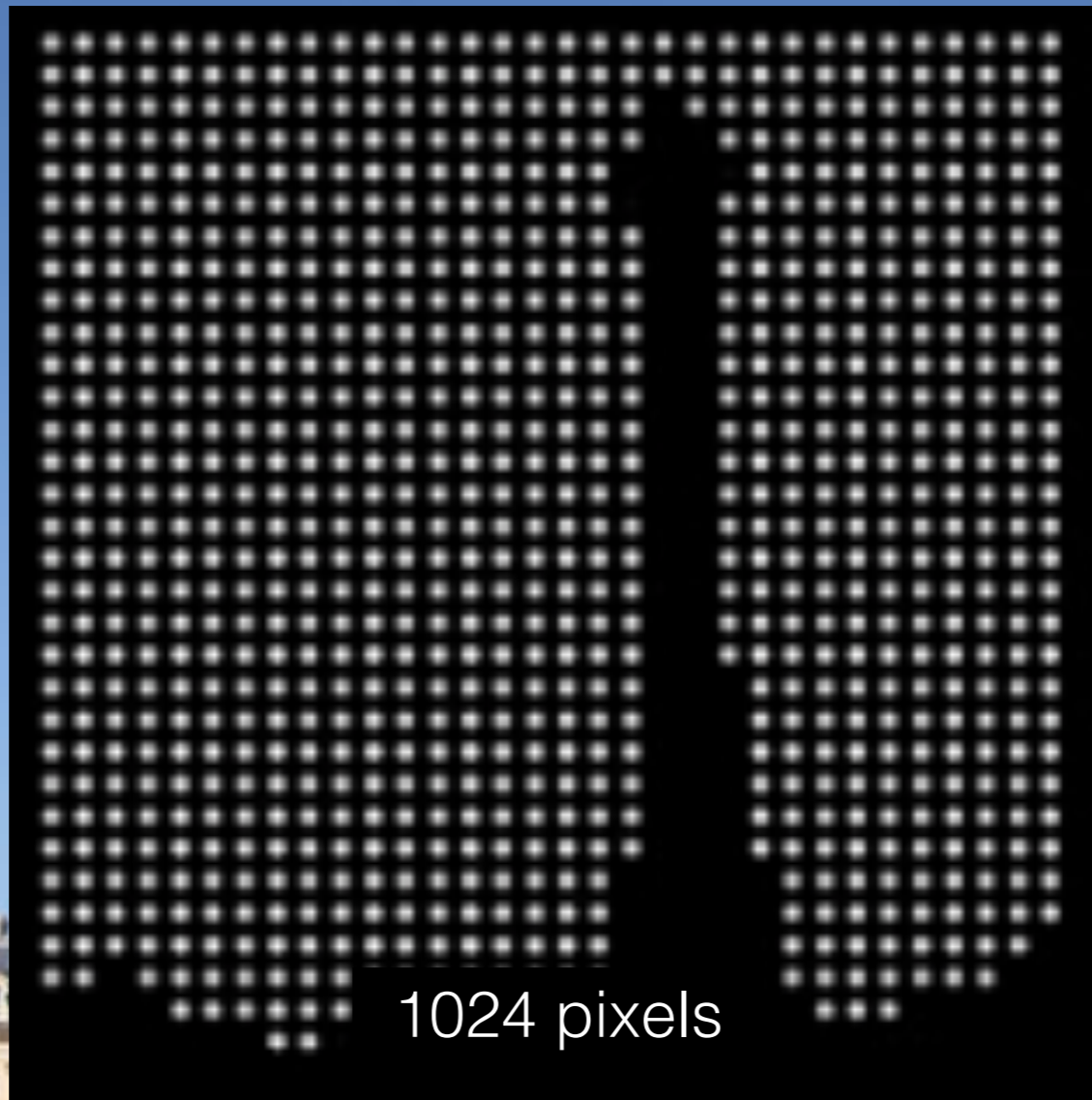




64 pixels - Argus II



256 pixels





Extract content from
a visual scene

Adapted processing

Static vs motion

