



HAL
open science

Probing retinal function with a multi-layered simulator

Evgenia Kartsaki, Bruno Cessac, Gerrit Hilgen, Evelyne Sernagor

► **To cite this version:**

Evgenia Kartsaki, Bruno Cessac, Gerrit Hilgen, Evelyne Sernagor. Probing retinal function with a multi-layered simulator. The Rank Prize Funds - Symposium on The retinal processing of natural signals, Jun 2019, Grasmere, United Kingdom. hal-02389076

HAL Id: hal-02389076

<https://hal.science/hal-02389076>

Submitted on 2 Dec 2019

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.

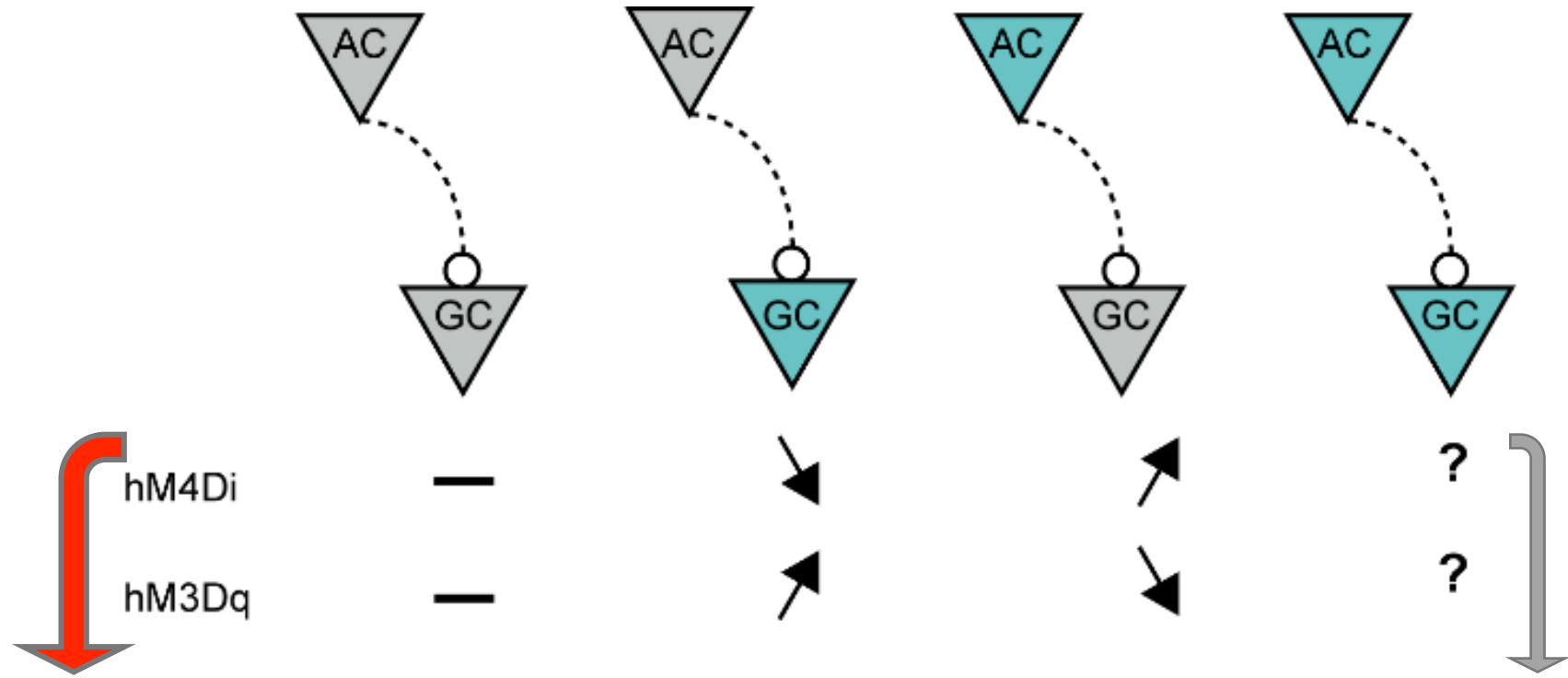


Probing retinal function with a multi-layered simulator

Evgenia Kartsaki^{1,2}, Bruno Cessac¹, Gerrit Hilgen², Evelyne Sernagor²

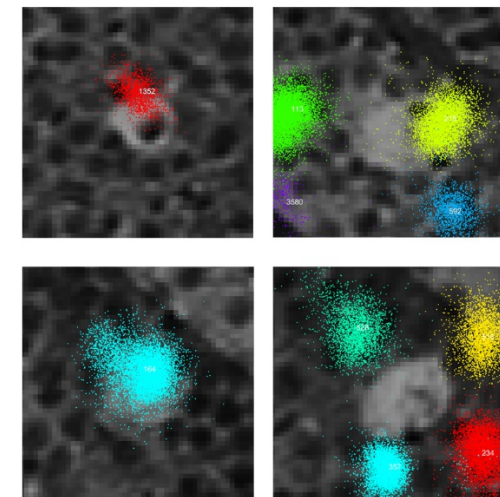
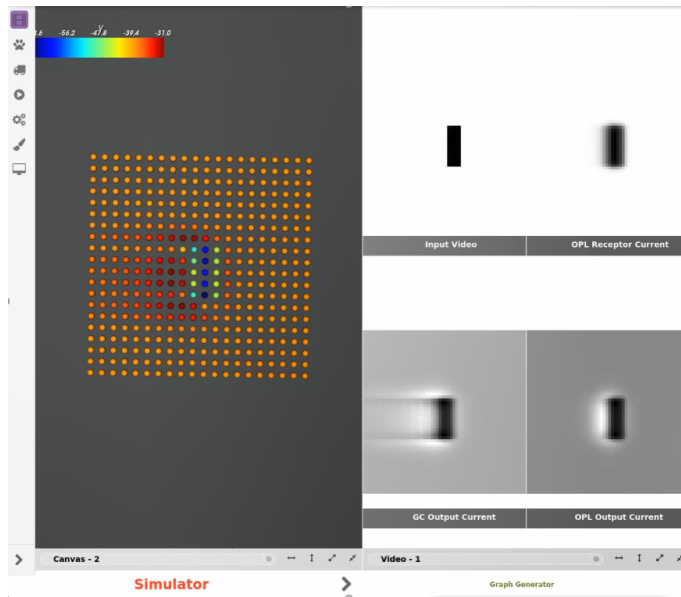
¹Université Côte d'Azur, Inria, France

²Institute of Neuroscience, University of Newcastle, UK

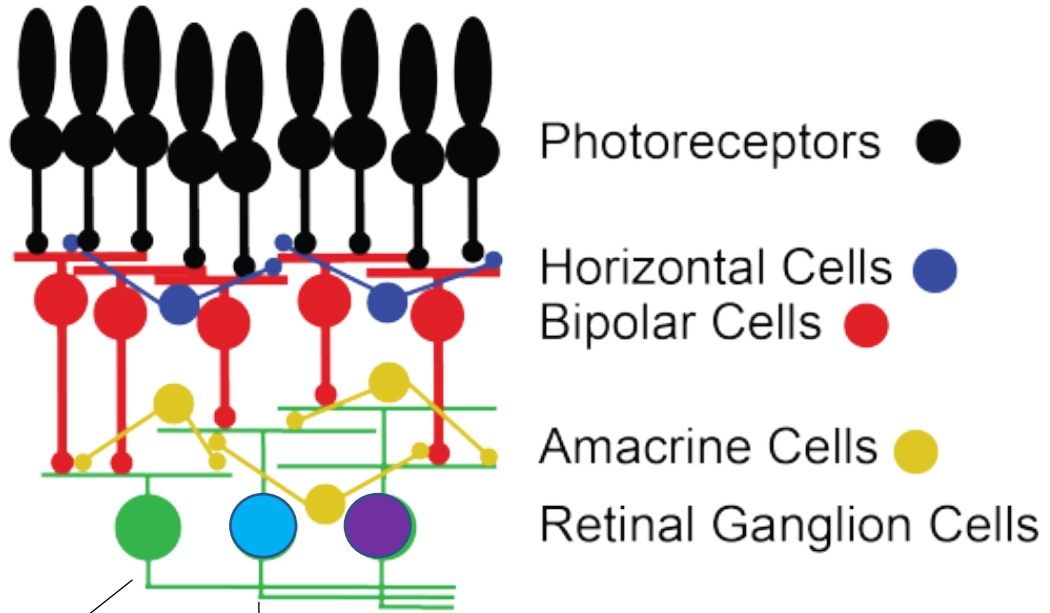


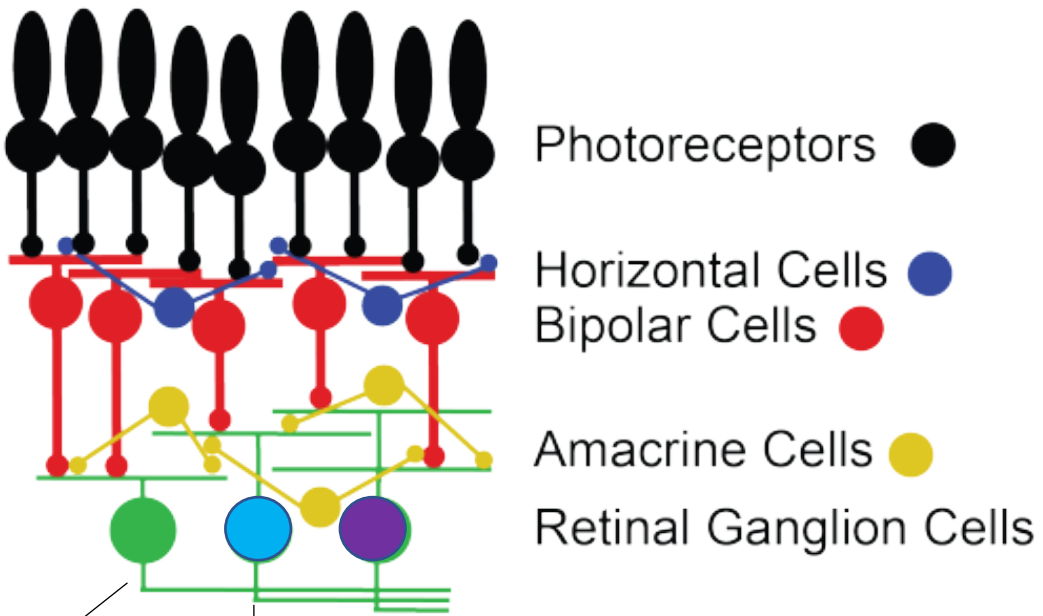
Retinal Simulator

Electrophysiology & IHC



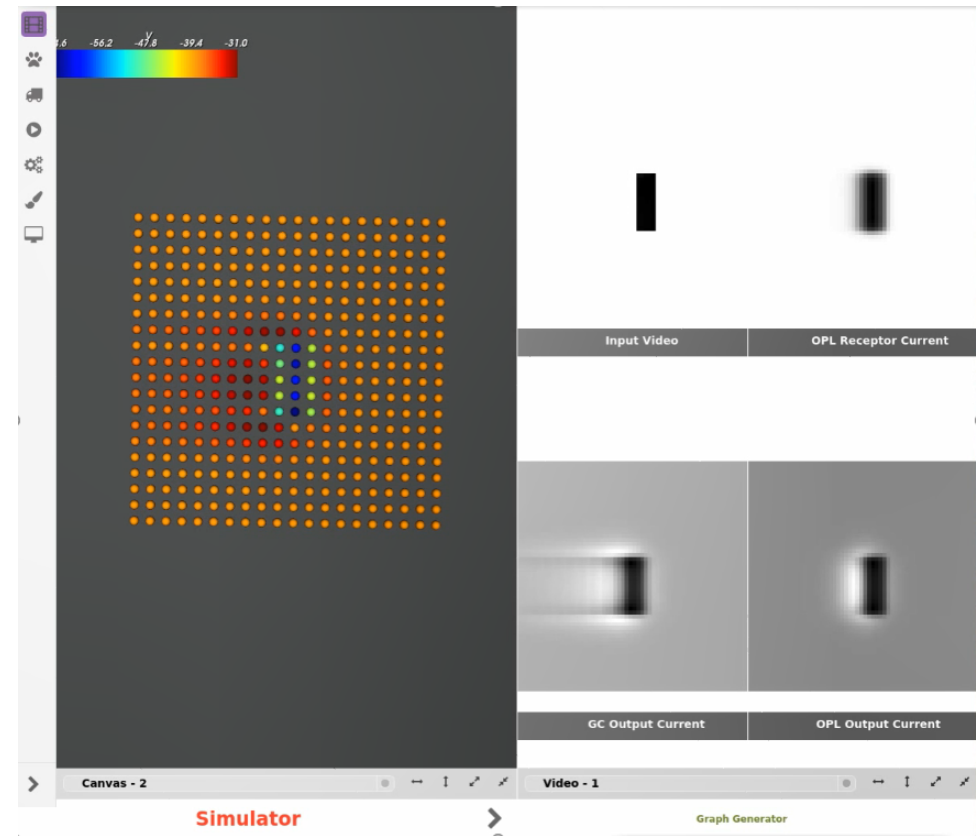
Gerrit Hilgen



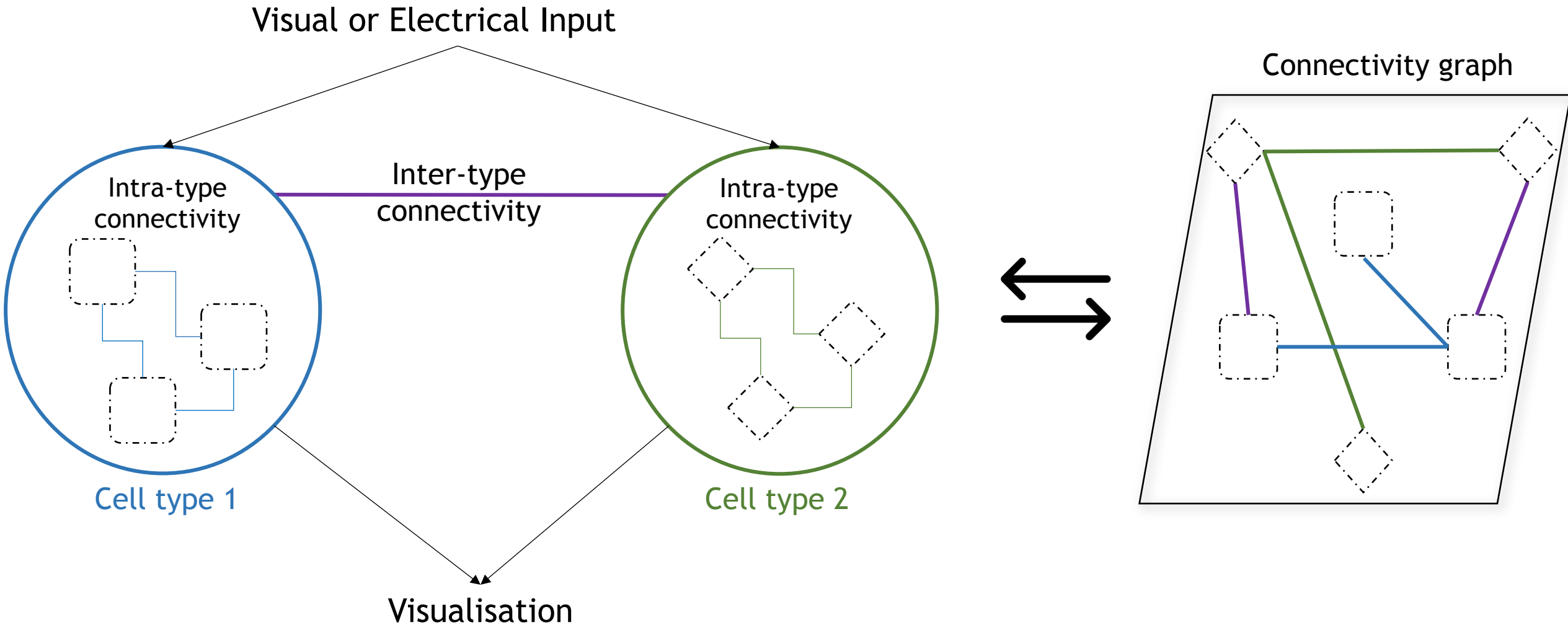


$$\frac{dy}{dx}$$

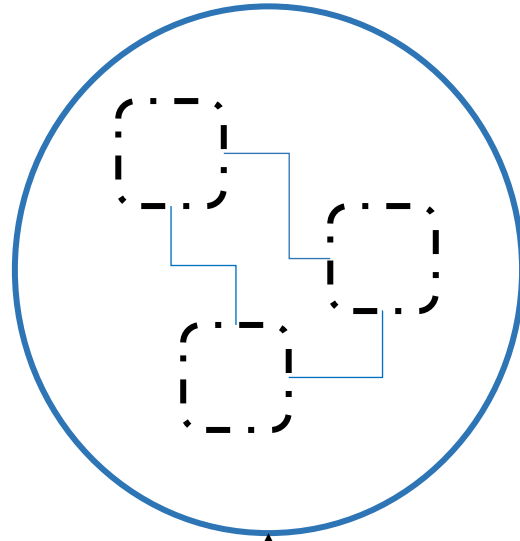
Macular



General structure



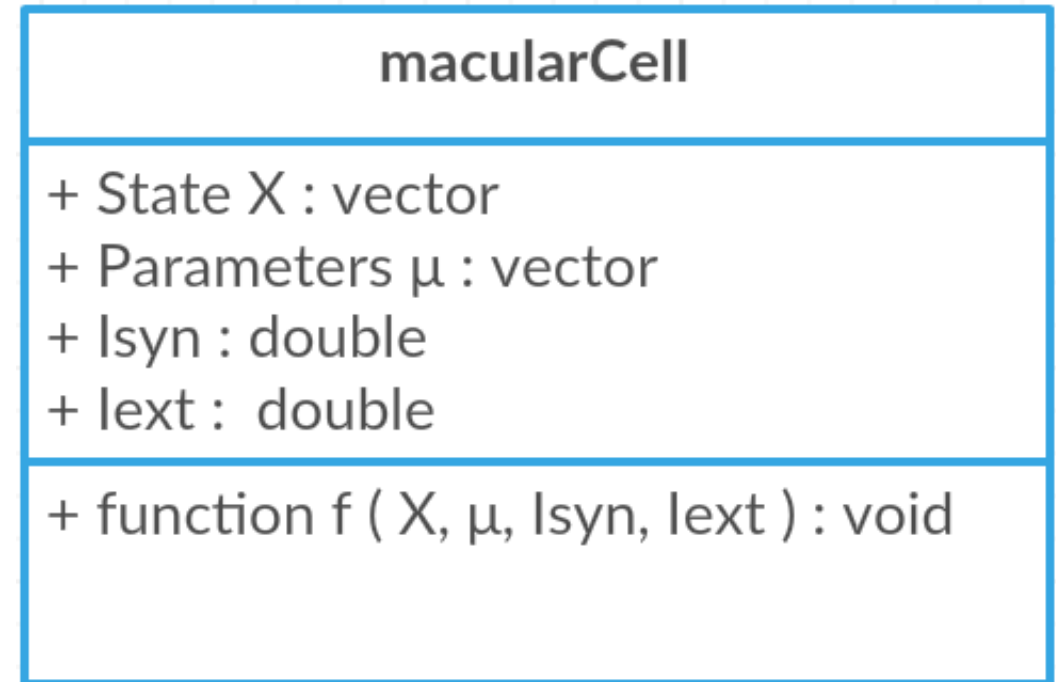
Basic building blocks - cell



Visual or Electrical Input

Cell

- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.



Cell

- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.
- ✓ A set of **parameters** that constrain the cell's evolution : e.g. conductance, reversal potential, membrane capacitance, characteristic time of a channel's activity

macularCell
+ State X : vector
+ Parameters μ : vector
+ I_{syn} : double
+ I_{ext} : double
+ function $f (X, \mu, I_{syn}, I_{ext}) : void$

Cell

- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.
- ✓ A set of **parameters** that constrain the cell's evolution : e.g. conductance, reversal potential, membrane capacitance, characteristic time of a channel's activity
- ✓ A function controlling the cell's evolution with a differential equation

macularCell
+ State X : vector
+ Parameters μ : vector
+ I_{syn} : double
+ I_{ext} : double
+ function $f (X, \mu, I_{syn}, I_{ext}) : void$

Cell

- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.
- ✓ A set of **parameters** that constrain the cell's evolution : e.g. conductance, reversal potential, membrane capacitance, characteristic time of a channel's activity
- ✓ A function controlling the cell's evolution
- ✓ **Isyn** : A synaptic input corresponding to synaptic connections with other cells

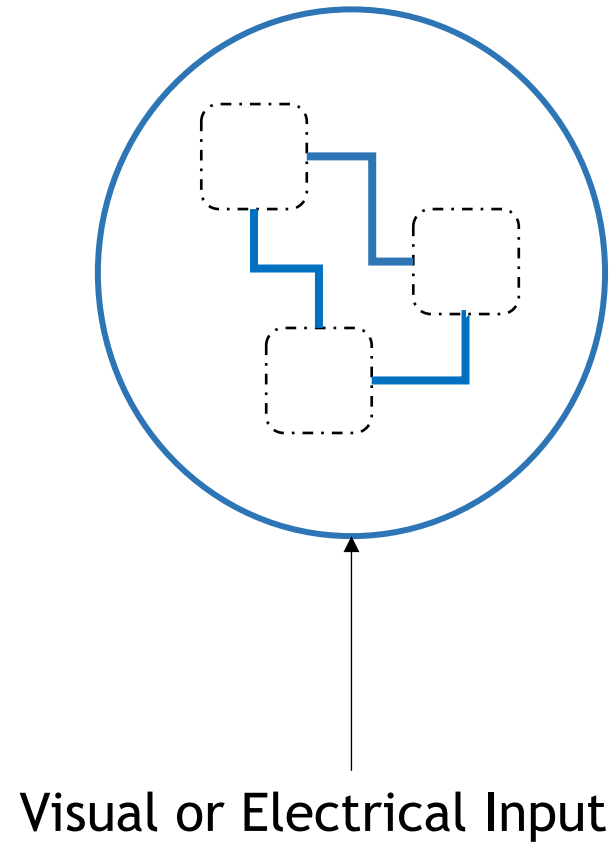
macularCell
+ State X : vector
+ Parameters μ : vector
+ Isyn : double
+ Iext : double
+ function $f (X, \mu, Isyn, Iext) : void$

Cell

- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.
- ✓ A set of **parameters** that constrain the cell's evolution : e.g. conductance, reversal potential, membrane capacitance, characteristic time of a channel's activity
- ✓ A function controlling the cell's evolution
- ✓ **Isyn** : A synaptic input corresponding to synaptic connections with other cells
- ✓ **Iext** : An external input corresponding either to a visual input or the electric current provided by an electrode

macularCell
+ State X : vector
+ Parameters μ : vector
+ Isyn : double
+ Iext : double
+ function $f (X, \mu, Isyn, Iext)$: void

Basic building blocks - synapse



Synapse

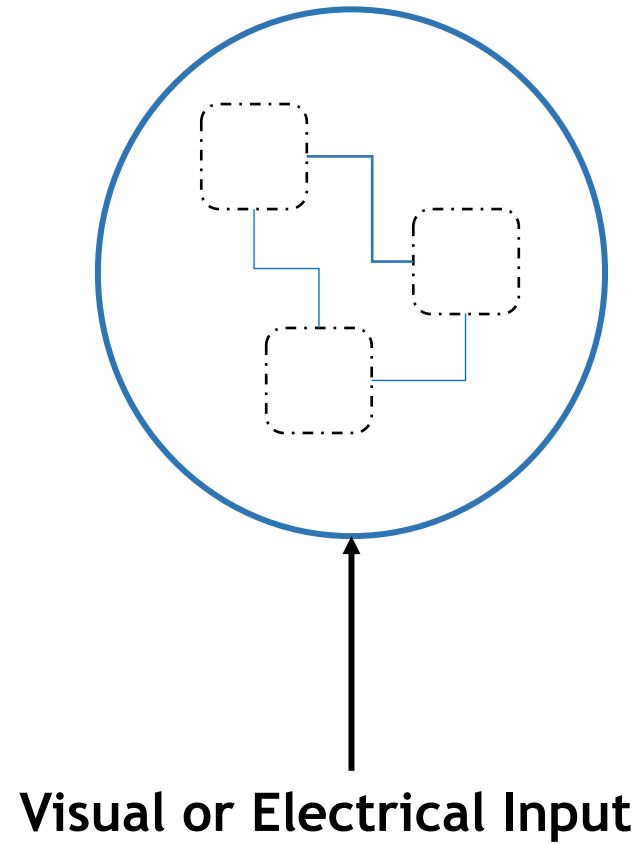
macularSynapse

+ Variables X : vector
+ Parameters μ : vector

+ computeSynapticCurrent (X , μ , pre, post) : void

- ✓ Chemical or electrical (gap junction)
- ✓ A set of variables that evolve in time : e.g. conductance
- ✓ A set of parameters : e.g. synaptic weight

Basic building blocks - External Input



External Input



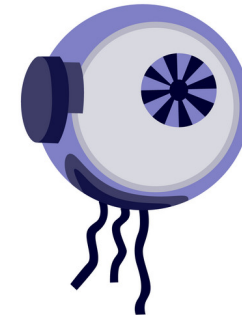
Visual Input



Virtual Retina module

- ✓ Emulate the outer plexiform layer (OPL) current

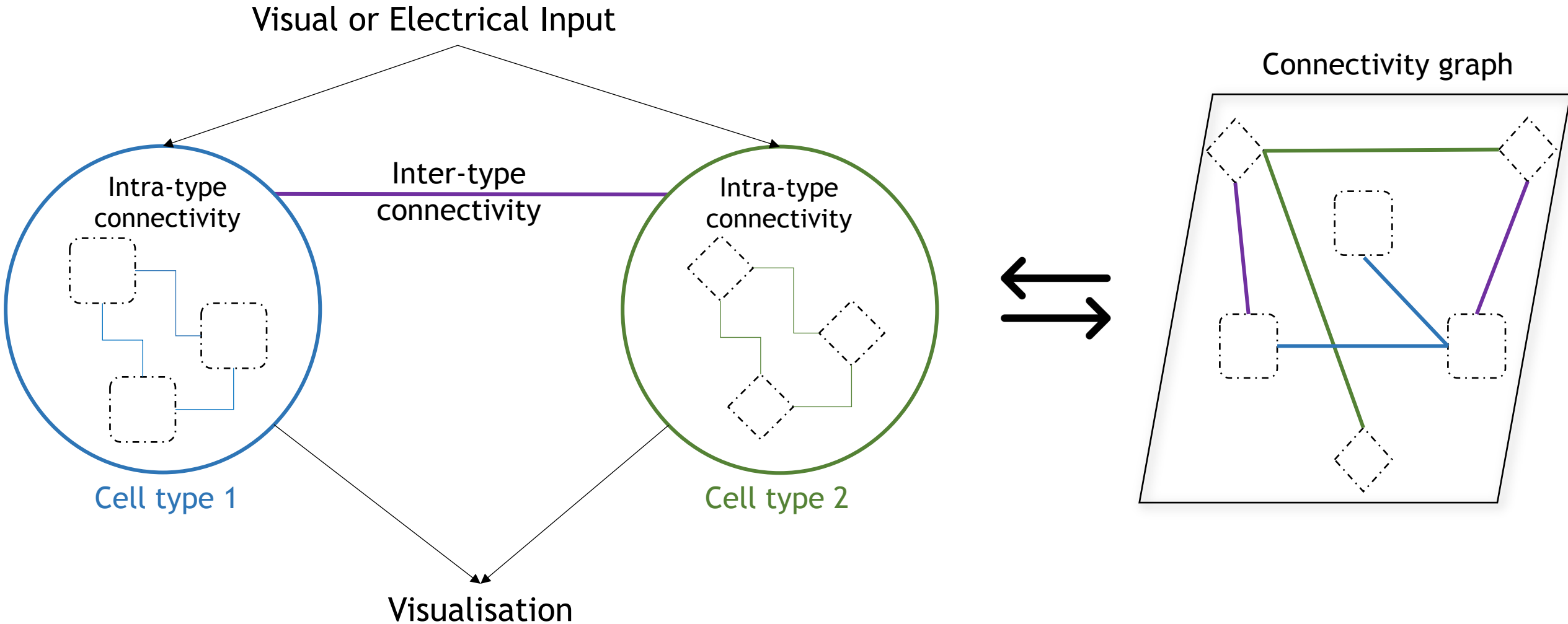
A.Wohrer et al., 2009



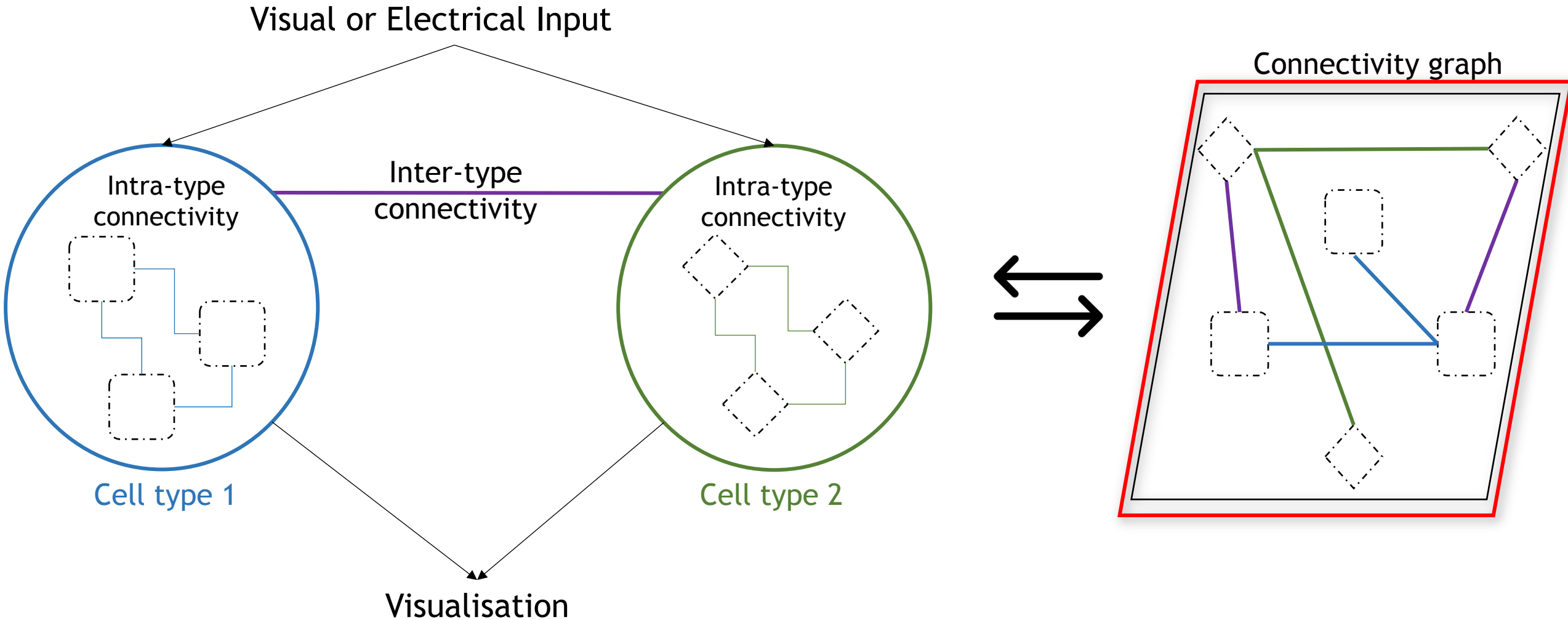
Retinal prosthesis

- ✓ Emulate the electric current provided by an electrode

General structure



General structure



Graph

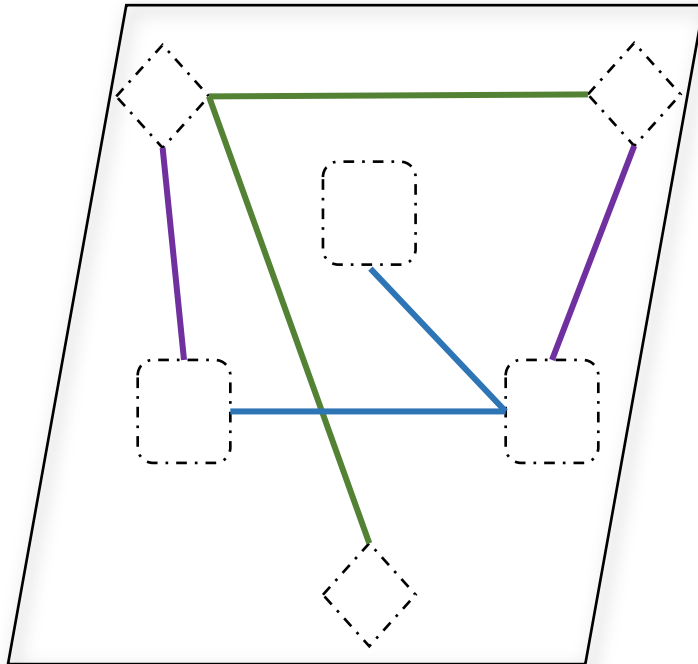
macularGraph

+ cells : macularCell
+ synapses : macularSynapse
+ CellCoordinates: vector
+ SynapseIndices: vector

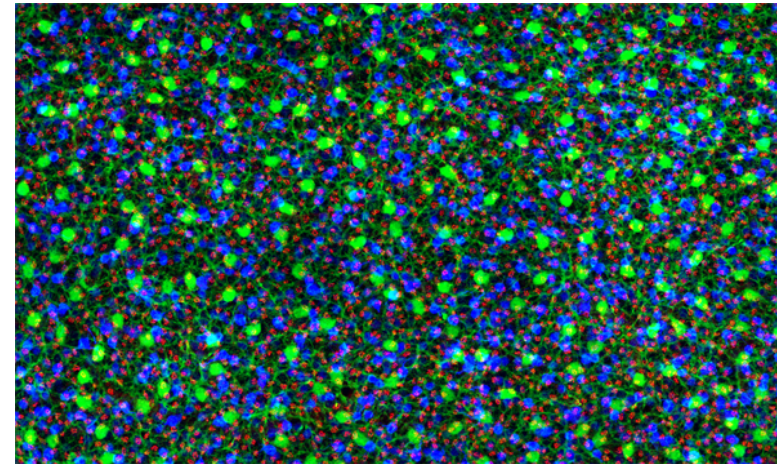
- ✓ Cell types
- ✓ Synapse types
- ✓ Cell coordinates
- ✓ Synapse indices

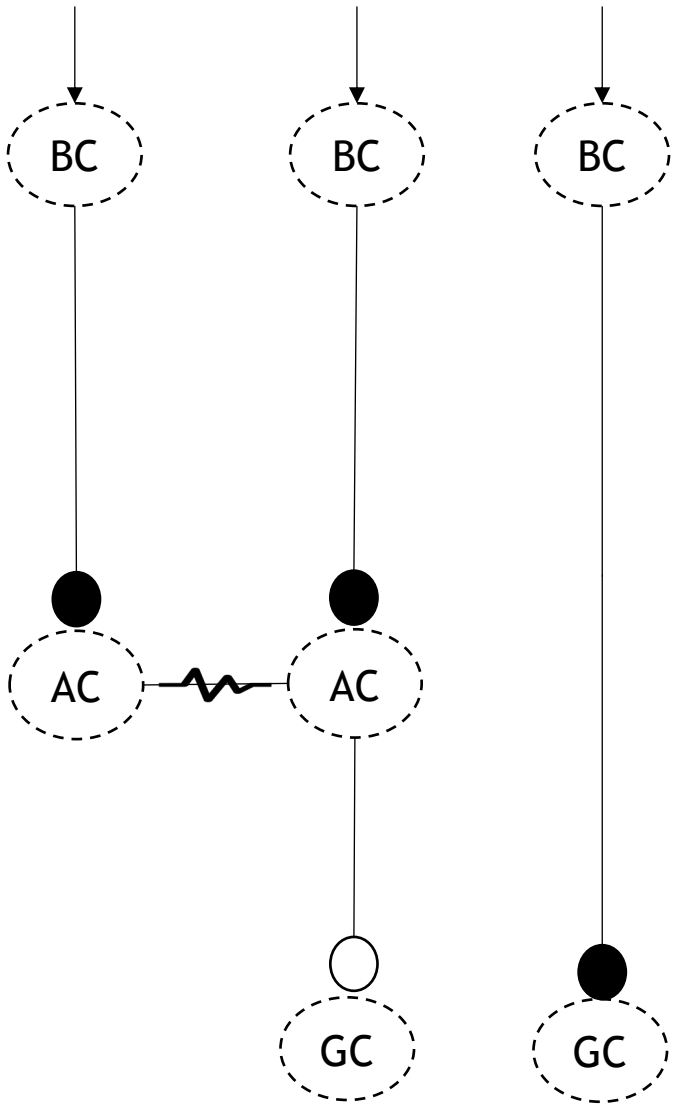
Graph

Connectivity graph

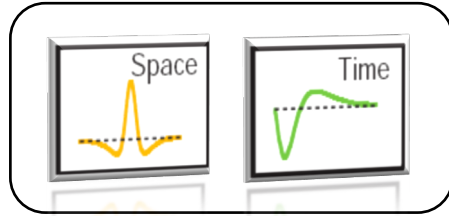
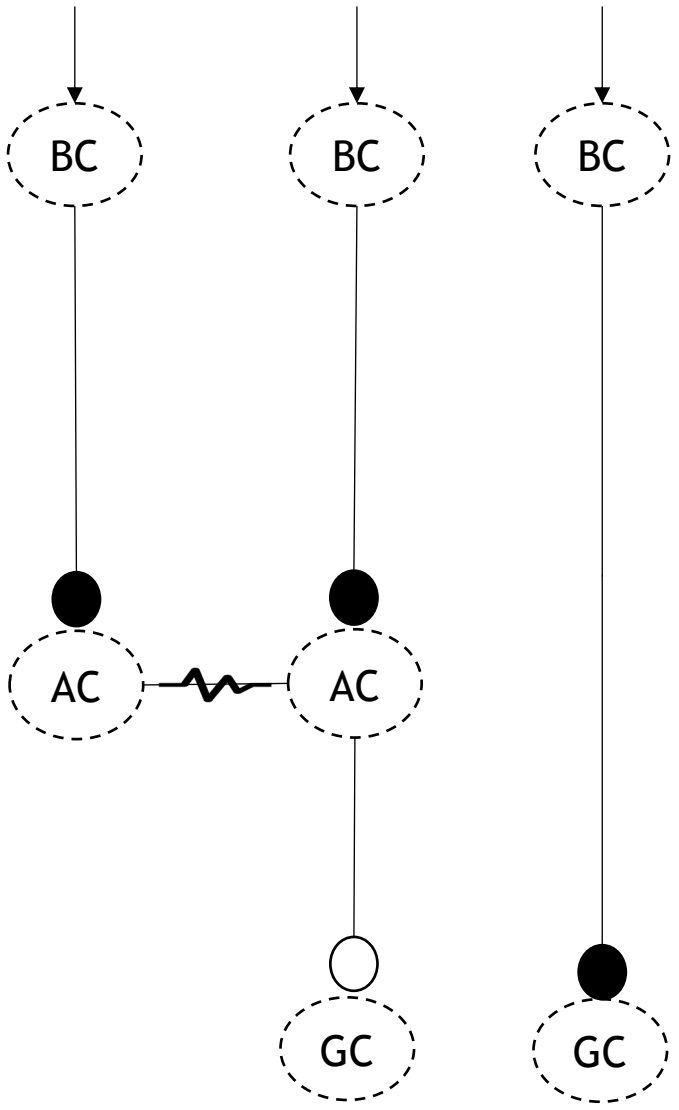


- Design a local circuit with specific connectivity patterns
- Deploy it to the whole retina



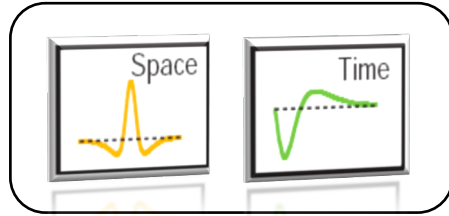
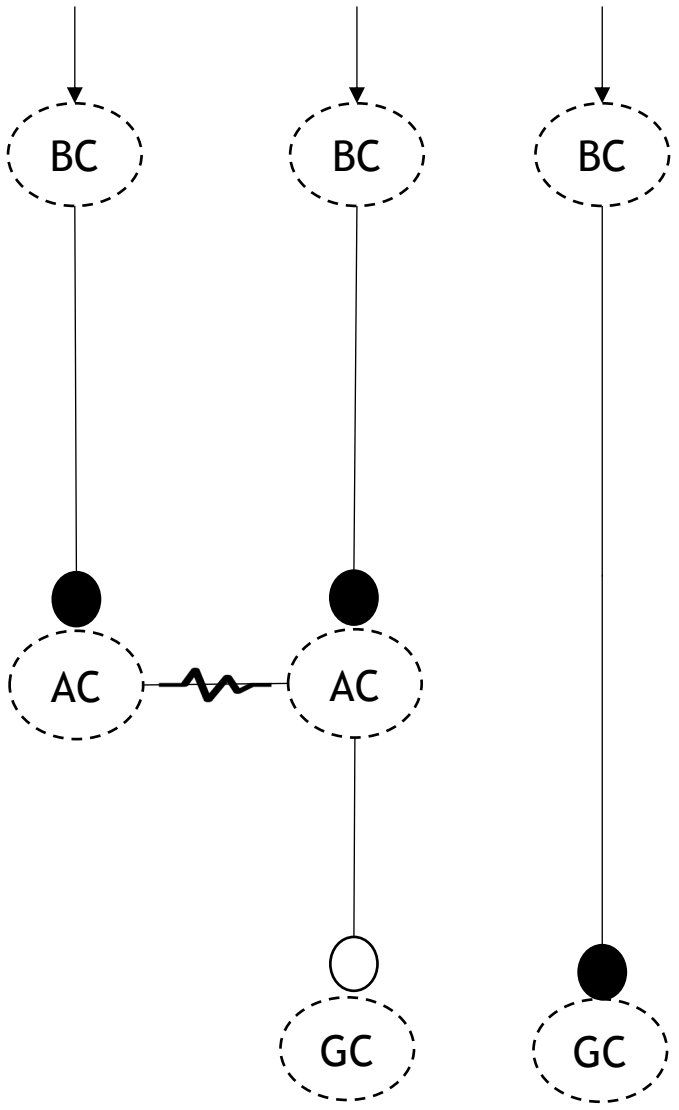


● ○ Chemical synapse
~ Electrical synapse



$$K(x, y, t) = K_S(x, y)K_T(t)$$

$$\int (S * K)(x, y, t)$$



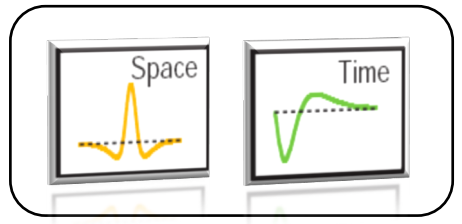
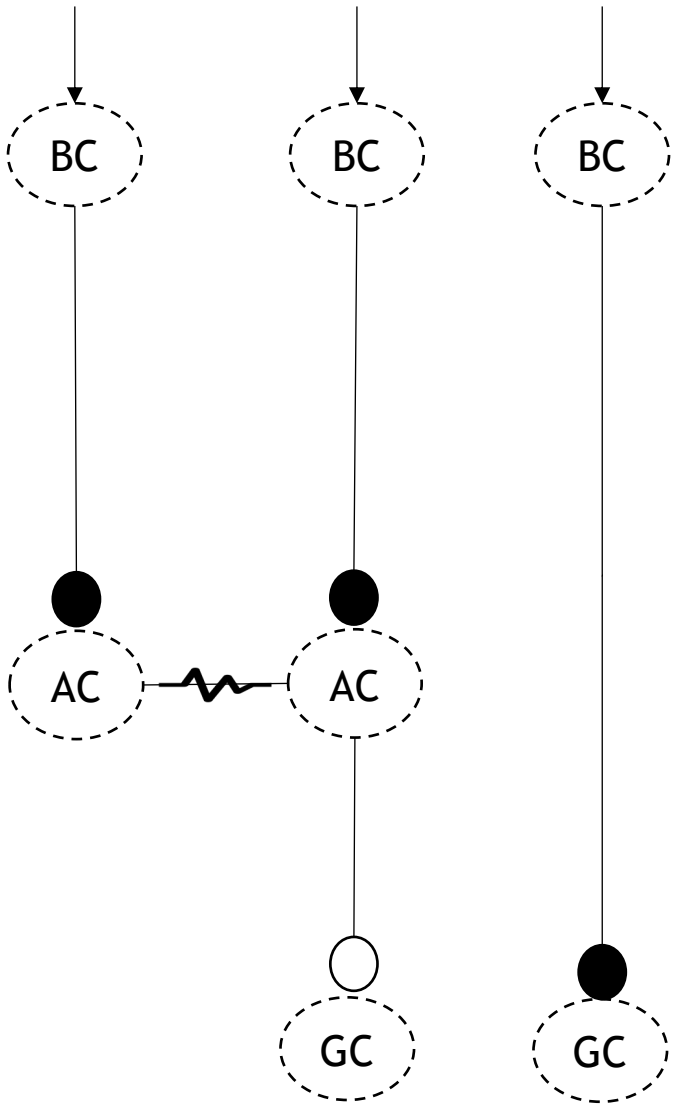
● ○ Chemical synapse
 ~~~~~ Electrical synapse

$$K(x, y, t) = K_S(x, y)K_T(t)$$

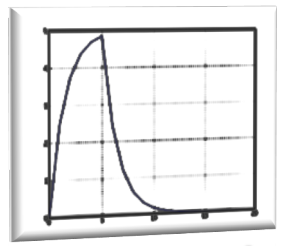
$$\int (S * K)(x, y, t)$$

$$I_{syn} = -g_{syn} (V_{post} - E_{syn})$$

$$I_{GAP} = -g_{GAP} (V_{post} - V_{pre})$$



● ○ Chemical synapse  
 ~~~~~ Electrical synapse



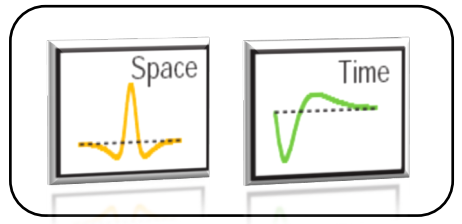
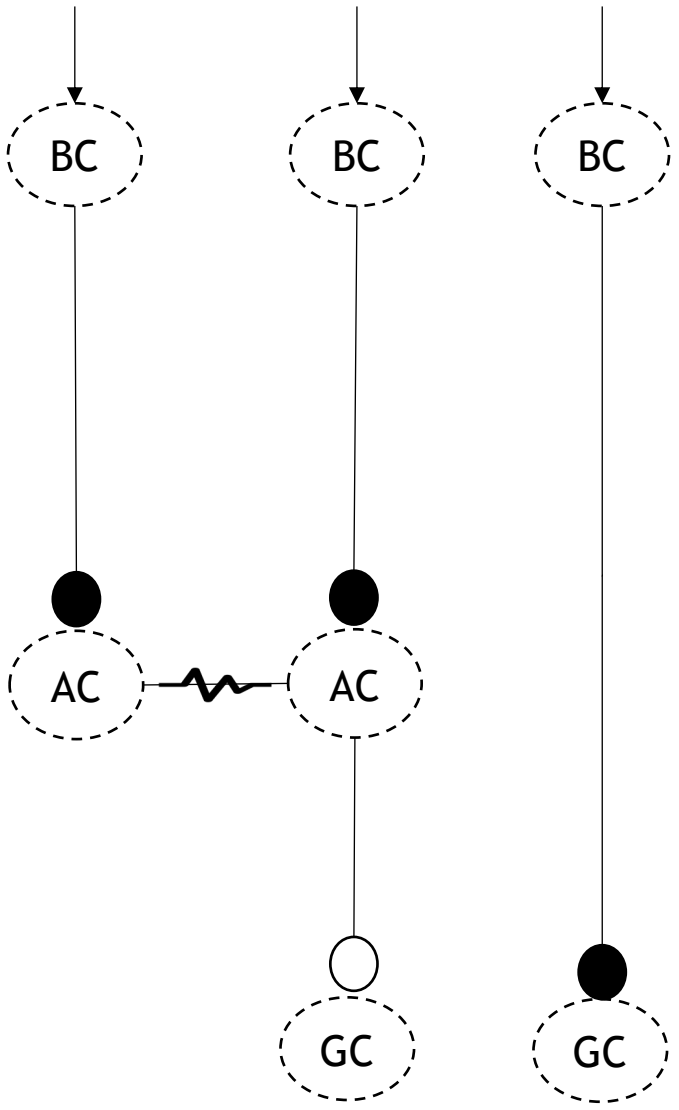
$$K(x, y, t) = K_S(x, y)K_T(t)$$

$$\int (S * K)(x, y, t)$$

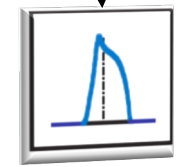
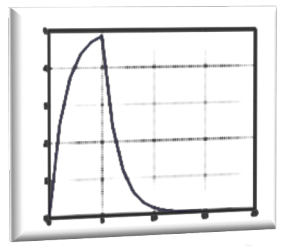
$$I_{syn} = -g_{syn} (V_{post} - E_{syn})$$

$$I_{GAP} = -g_{GAP} (V_{post} - V_{pre})$$

$$C \frac{dV}{dt} = -g_L (V - V_L) + I_{syn} + I_{ext} + I_{CNO}$$



● ○ Chemical synapse
 ~~~~~ Electrical synapse



$$K(x, y, t) = K_S(x, y)K_T(t)$$



$$\int (S * K)(x, y, t)$$


$$I_{syn} = -g_{syn} (V_{post} - E_{syn})$$

$$I_{GAP} = -g_{GAP} (V_{post} - V_{pre})$$

$$C \frac{dV}{dt} = -g_L (V - V_L) + I_{syn} + I_{ext} + I_{CNO}$$

$$N_G(V) = \begin{cases} 0, & \text{if } (V \leq 0) \\ \alpha(V - \theta), & \text{if } (\theta \leq V \leq \frac{N_{max}}{\alpha + \theta}) \\ N_{max}, & \text{otherwise} \end{cases}$$


 **All Items**

Identifier Acetylcholine  
 Settings  
 Extend


**Macular repository** macular

Model functions

gAch(A, gA, gammaA)

doc Actylcholine conductance for nicotinic receptors


format SymPy


 Edition  $gA * A^{**2} / (gammaA + A^{**2})$   
 Formula


All

Acetylcholine


+ New

 File

 Themes

 Choose Theme >

Model synaptic current

 Cancel Save



Ganglions

Video



**Simulator**



Graph Generator

0.00 0.00 0.00 0.00 0.00

Canvas - 2

Simulator

| Input Video       | OPL Receptor Current |
|-------------------|----------------------|
|                   |                      |
| GC Output Current | OPL Output Current   |
|                   |                      |

Video - 1

**All Items**

Video Input

Browse Video **test\_small**

Graph Input

**object\_motion\_graph3**

Worker settings

Cone Bipolar On >

Cone Bipolar Off >

Rod Bipolar On >

Prosthesis >

Controls

Run Simulation **Run**

Reset Simulation **Run**

Frame Rate **10**

Integration timestep **105000**

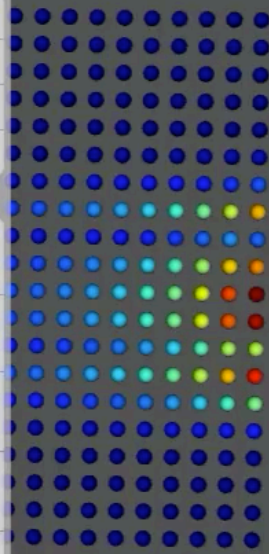
Save/Restore parameters

Save frequency **0**

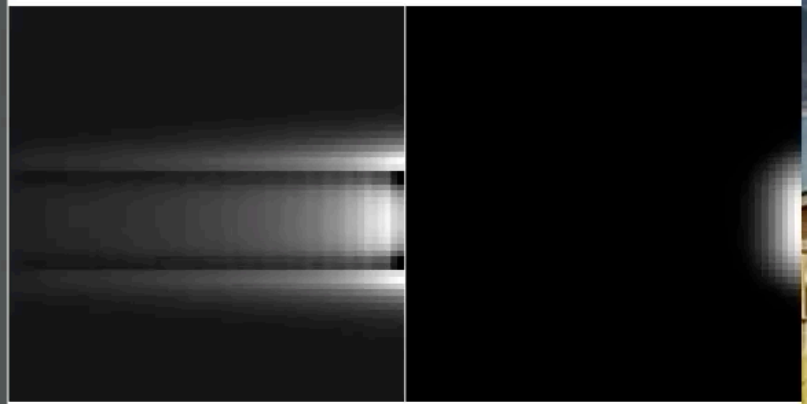
Model **Prosthesis**

Parameters

- MorrisLecar >
- HodgkinHuxley >
- SAC >
- BipolarGainControl >
- MorrisLecarAch >



Input Video      OPL Receptor Current



GC Output Current      OPL Output Current

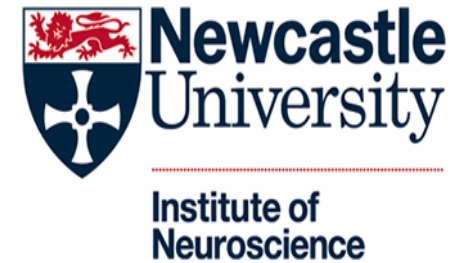
Video - 1

Simulator

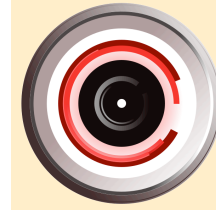
Applications | File Explorer | Taskbar icons (clock, search, etc.)

# Acknowledgements

Prof. Evelyne Sernagor  
Dr. Gerrit Hilgen



Biovision team



Dr. Bruno Cessac  
AMDT team

LEVERHULME  
TRUST \_\_\_\_\_



**Thank you!**

**Questions?**