

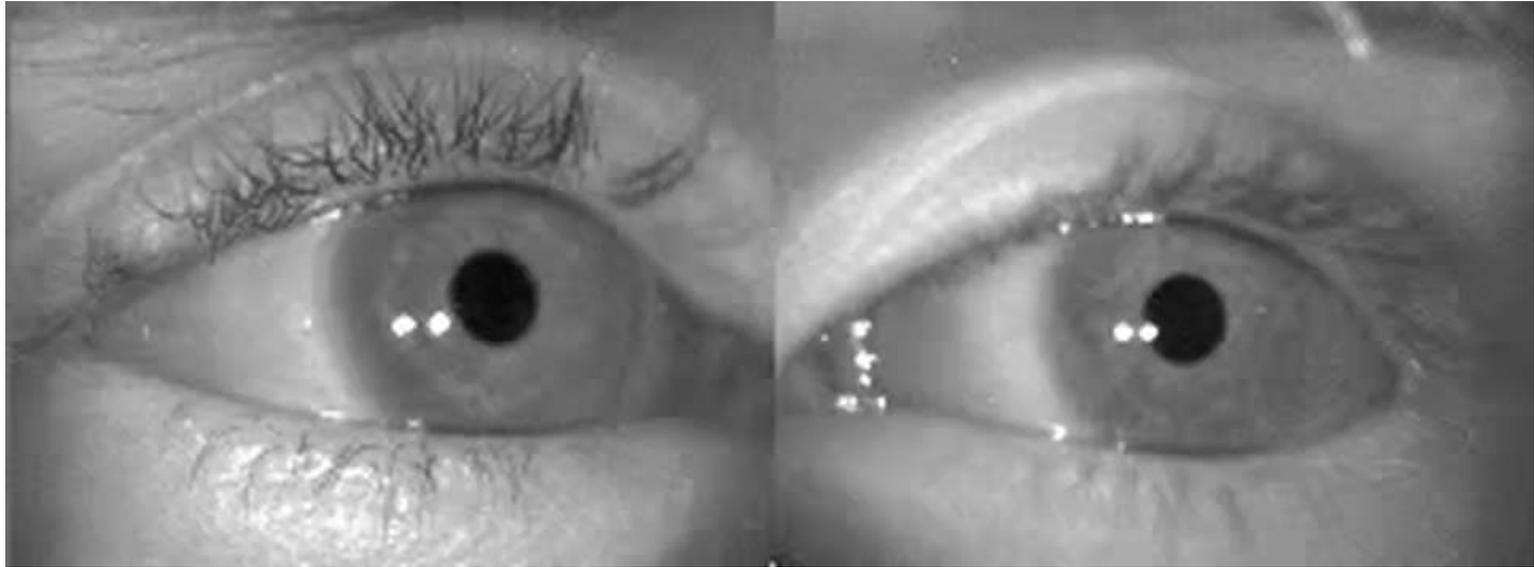
# Understanding distributed neural computation using connectomics and theory

Dmitri “Mitya” Chklovskii  
Simons Center for Data Analysis  
New York City



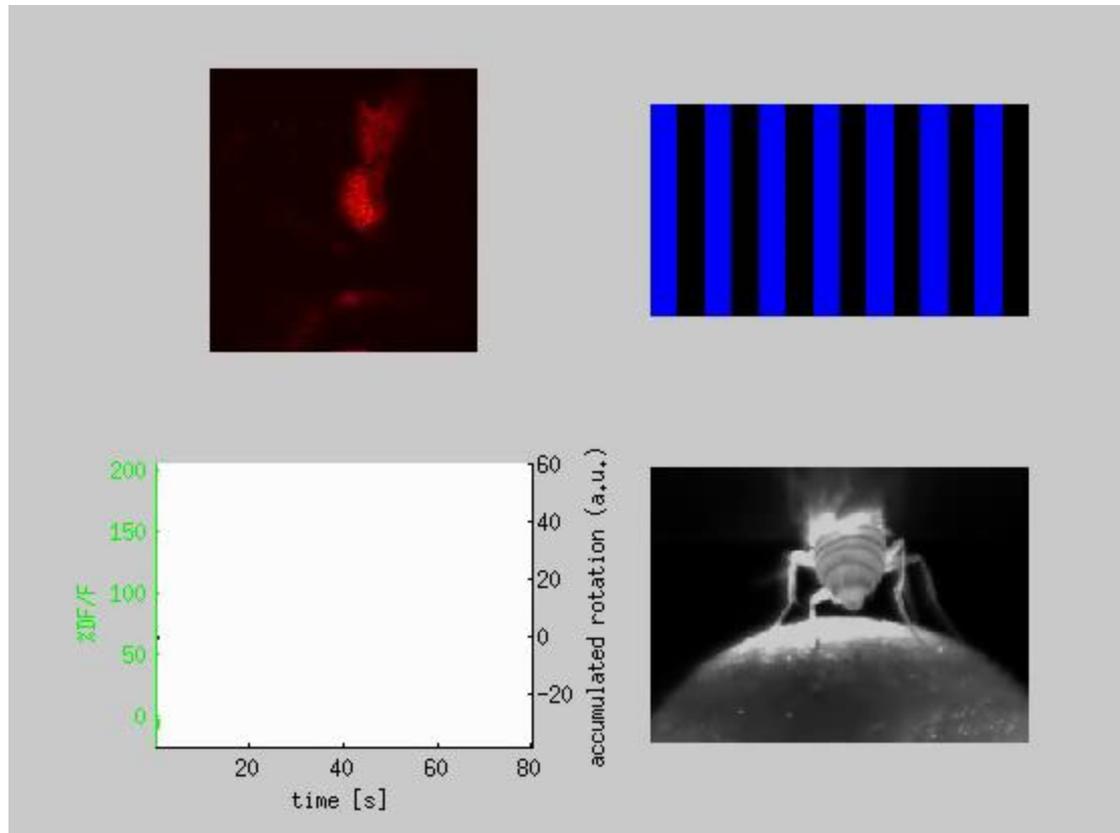
(c) 2009 hiromon

# Optokinetic response



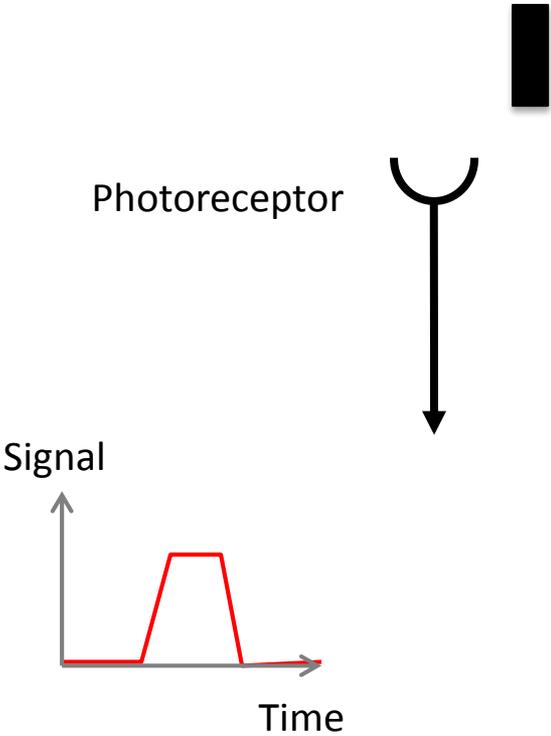
# Optomotor response in fruit fly

neuron HS

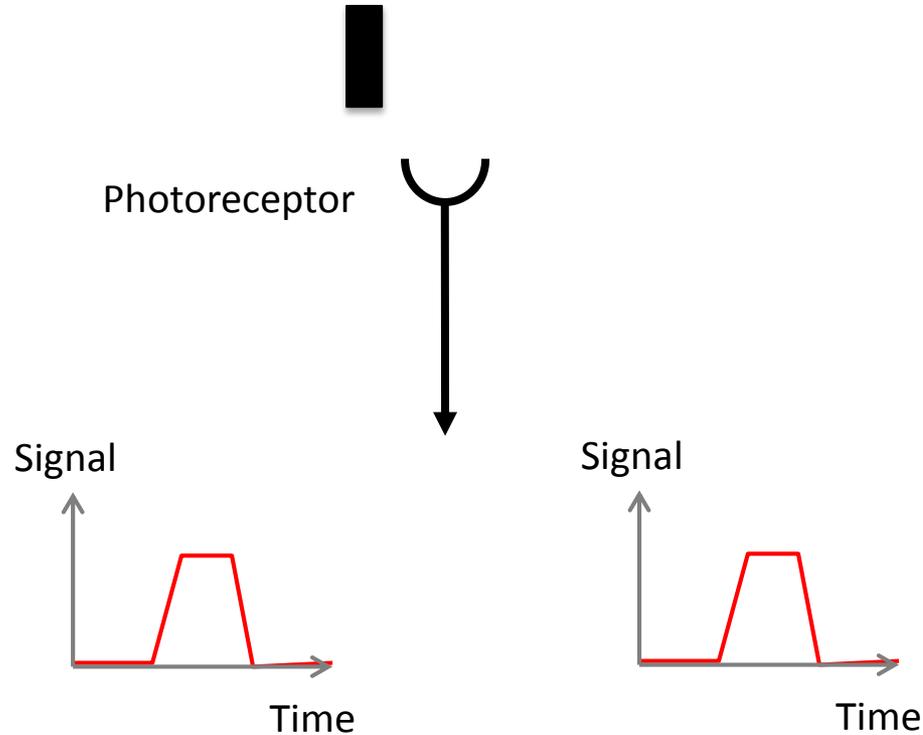


*Seelig et al, 2010*

# How do animals see motion?



# How do animals see motion?



Single photoreceptor cannot signal motion direction

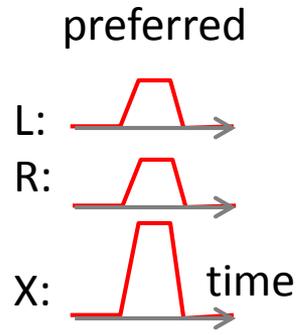
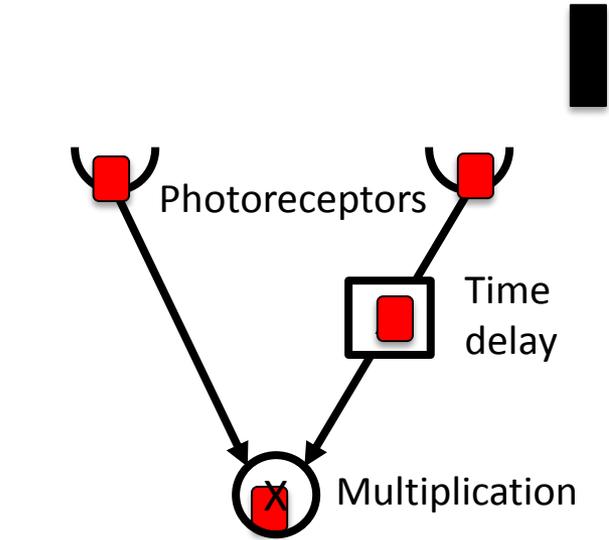
  
Photoreceptors

?



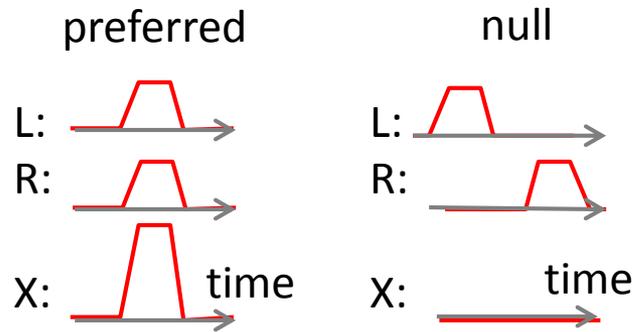
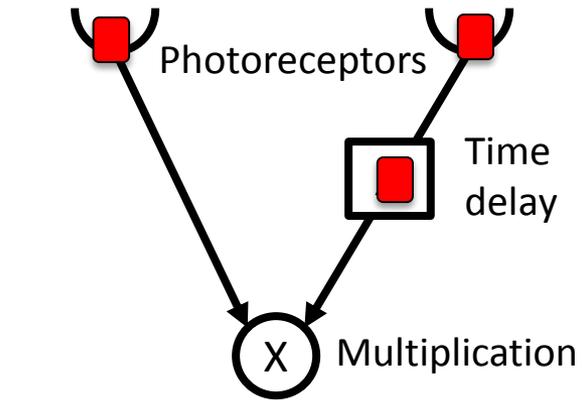
Directional selectivity

# Elementary motion detector



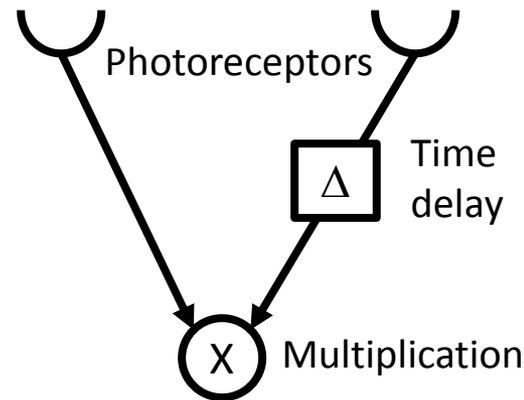
*Hassenstein & Reichardt (1956)*

# Elementary motion detector

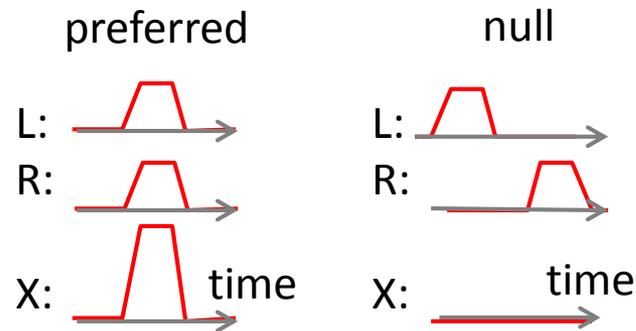


*Hassenstein & Reichardt (1956)*

# Elementary motion detector



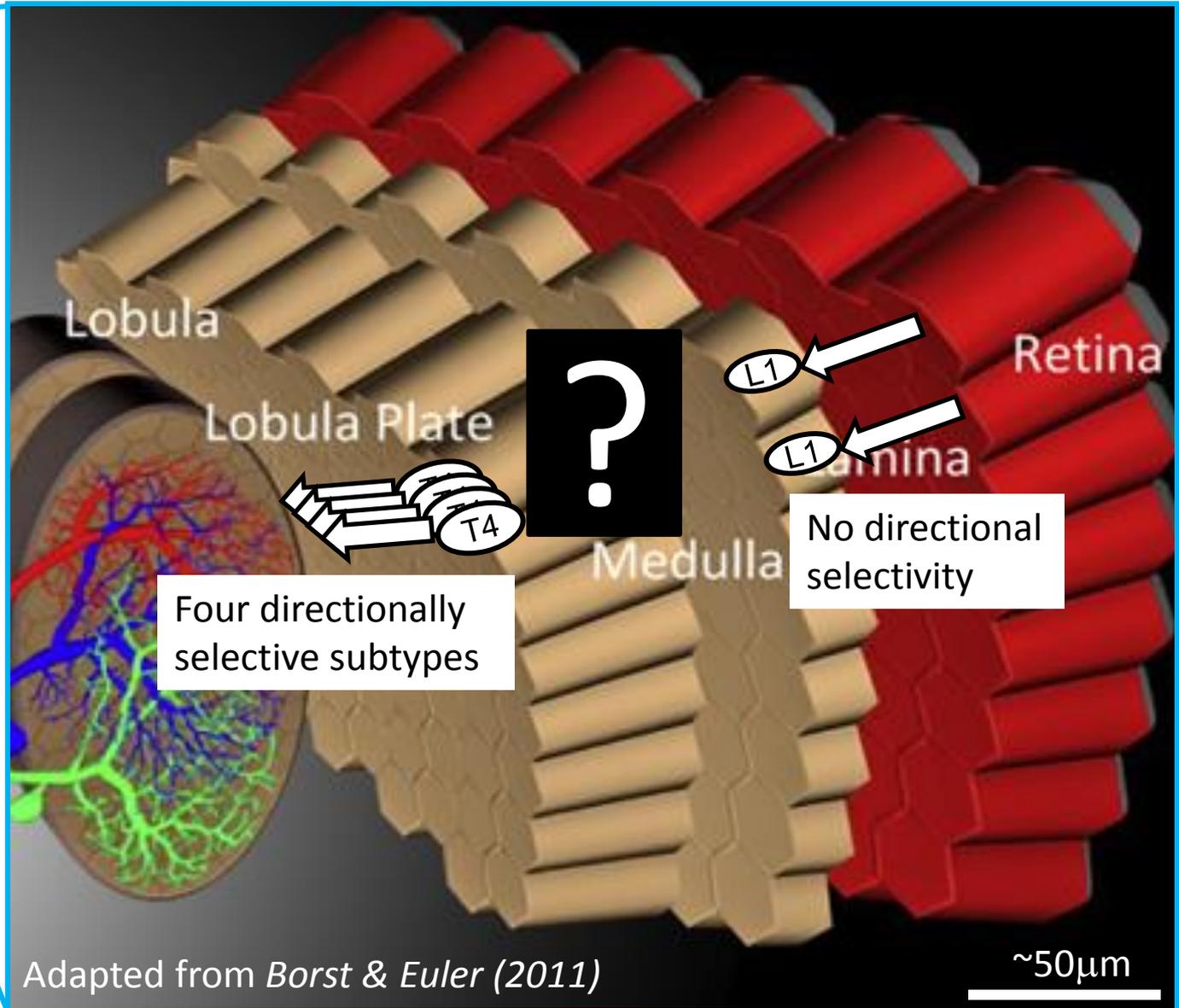
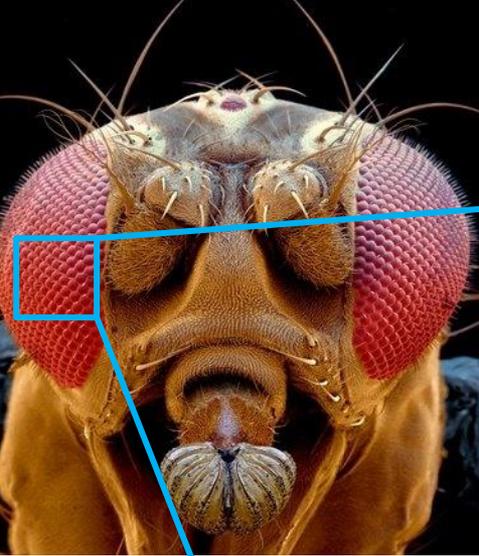
1. Spatial offset
2. Temporal offset
3. Nonlinearity



*Hassenstein & Reichardt (1956)*

Other models: *Barlow & Levick, 1965; Torre & Poggio, 1978; Adelson & Bergen, 1985; Mizunami, 1990; Potters & Bialek, 1994; ...*

# Drosophila visual system



Four directionally selective subtypes

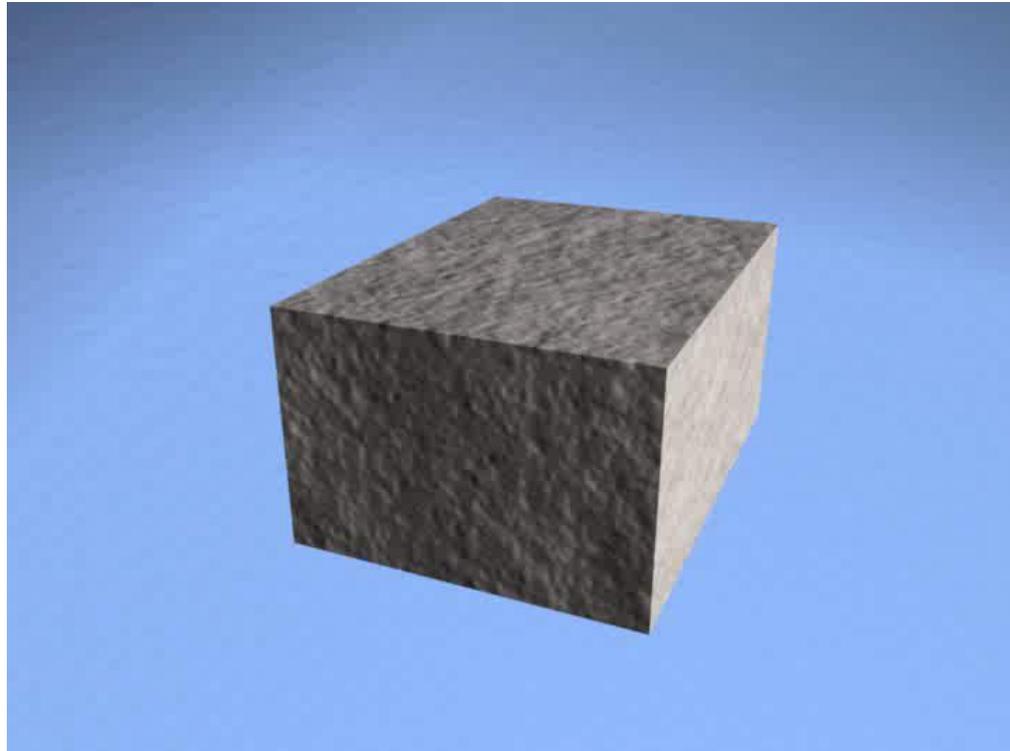
No directional selectivity

Neural superposition & chiasmatic inversion not shown

Adapted from *Borst & Euler (2011)*

~50µm

# How to reconstruct a connectome



Synapse-level wiring diagrams from serial electron microscopy (EM)

6 x 5 x 4  $\mu\text{m}^3$  of rat hippocampus

*Mishchenko ...Harris, Chklovskii, 2010*

- Tissue preparation and sectioning ~ week
- Manual image acquisition ~ month
- Manual connection tracing ~ year **x100**

# Real-world EM dataset

*Drosophila* medulla  
90 x 90 x 110  $\mu\text{m}^3$

*Takemura et al, 2013*

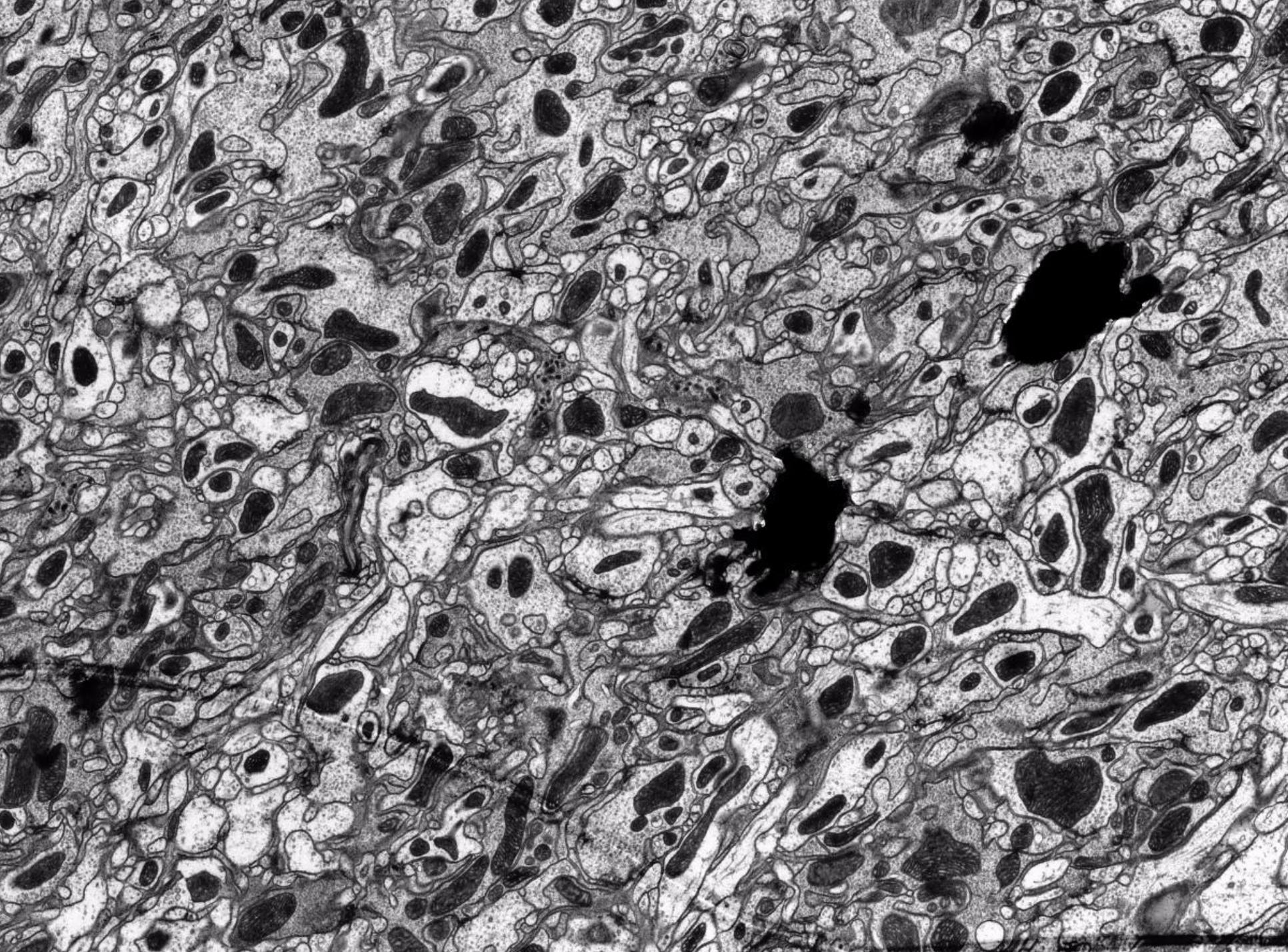
Pre-synaptic



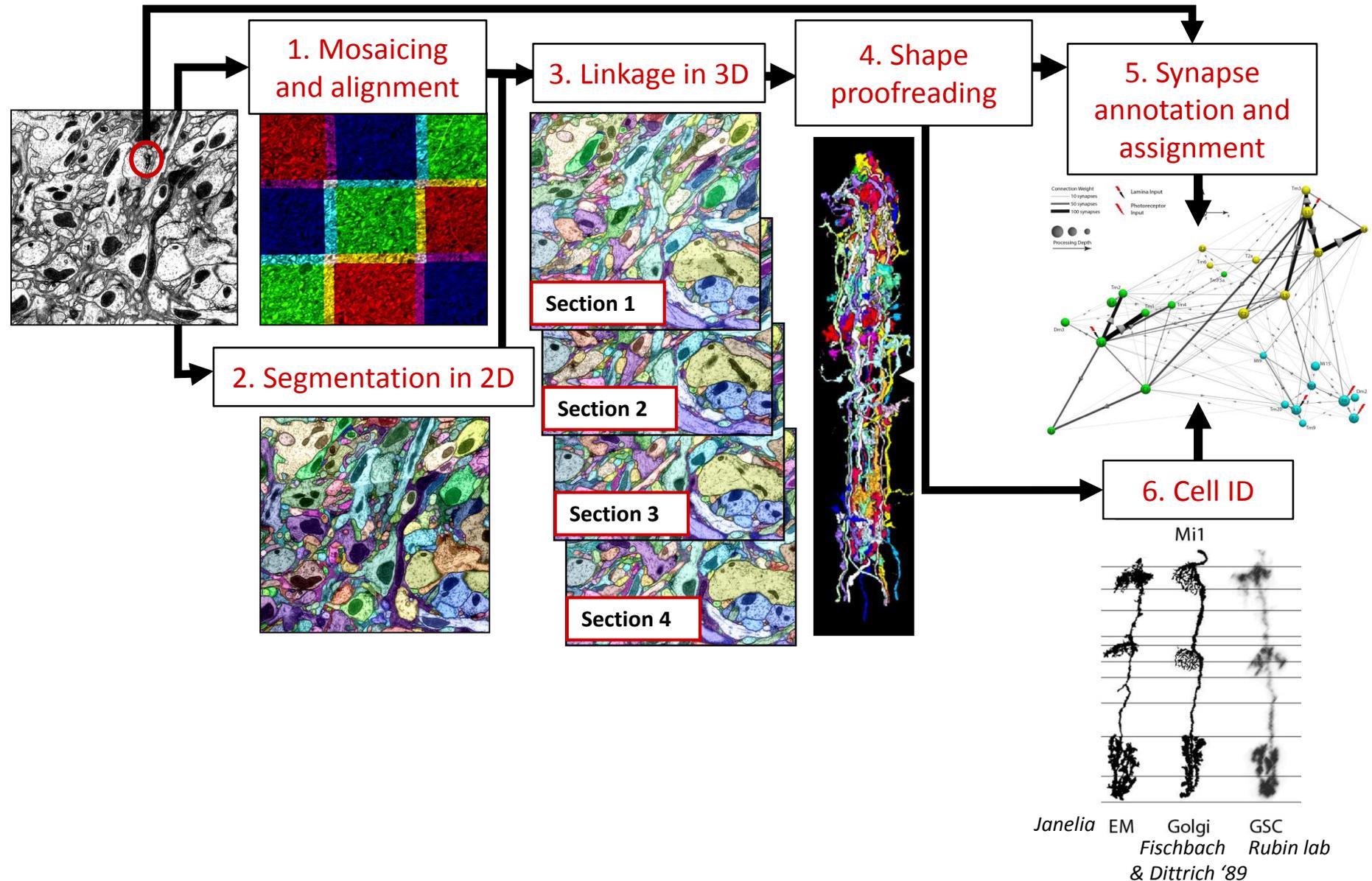
Post-synaptic

.3 $\mu\text{m}$

2769 of 40nm-thick  
sections imaged at  
3nm x 3nm per pixel  
Total size: 2TB

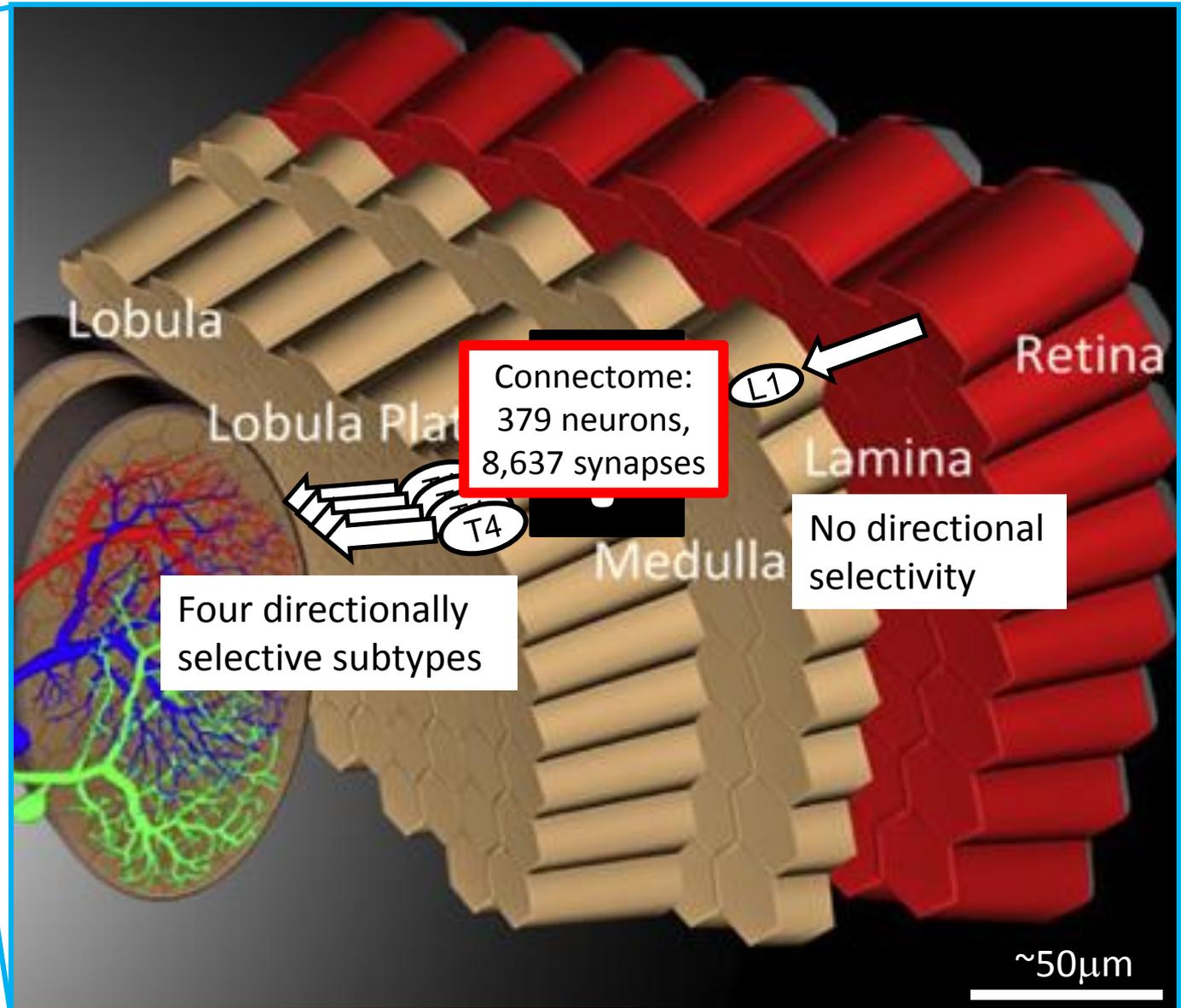
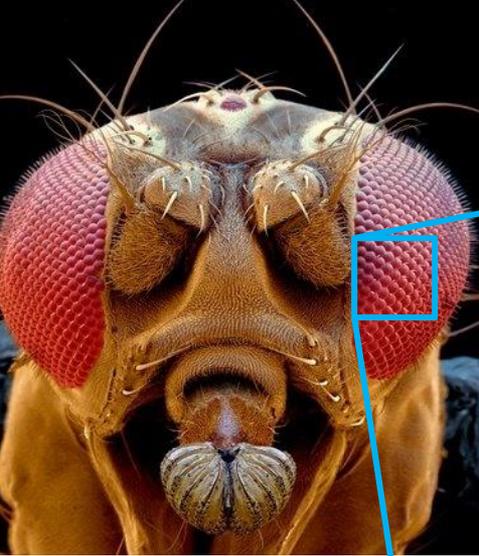


# Semi-automated EM reconstruction pipeline (*Chklovskii et al, 2010*)



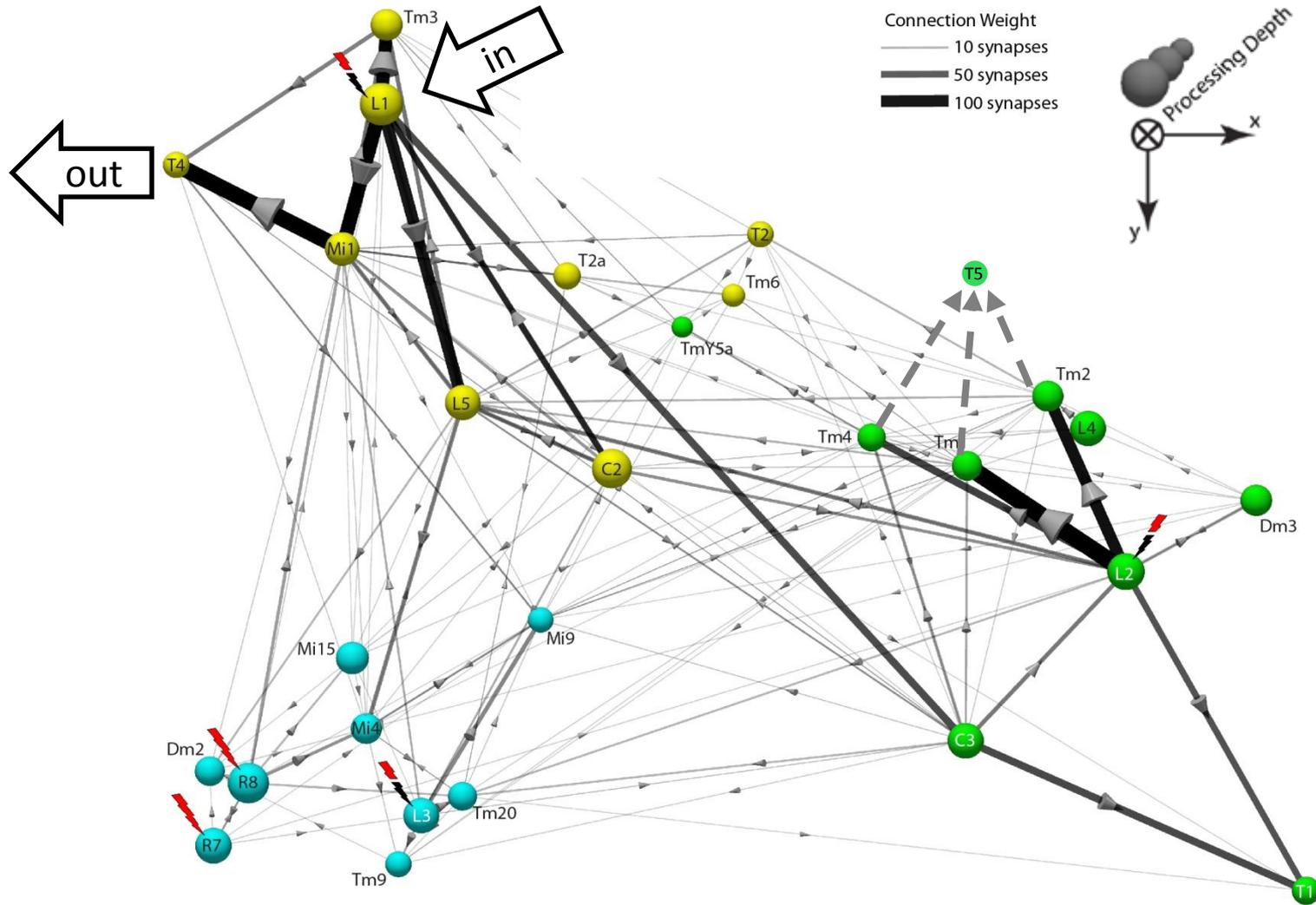


# *Drosophila* visual system



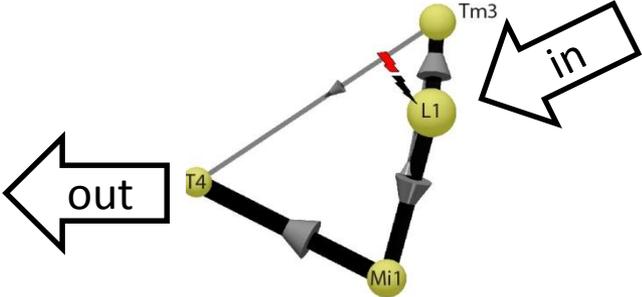
Neural superposition  
& chiasmatic inversion  
not shown

# Repeating module of the medulla (type-to-type connectome)

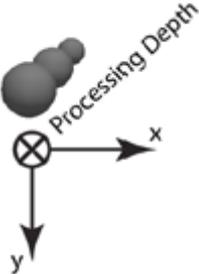


Takemura et al, 2013

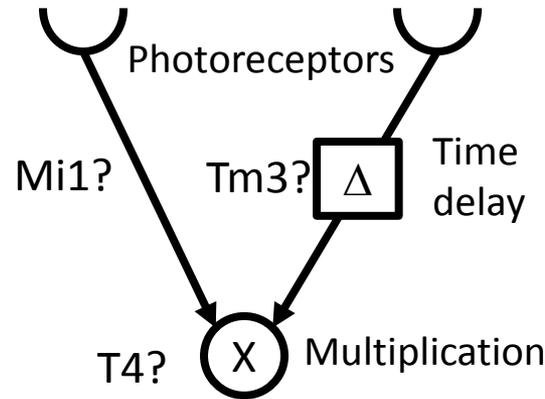
# Shortest paths from L1 to T4 (type-to-type connectome)



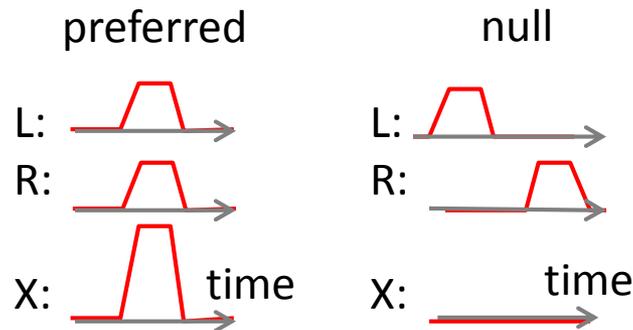
Connection Weight  
— 10 synapses  
— 50 synapses  
— 100 synapses



# Elementary motion detector

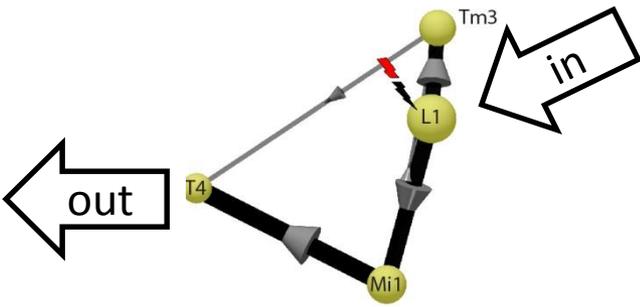


1. Spatial offset
2. Temporal offset
3. Nonlinearity

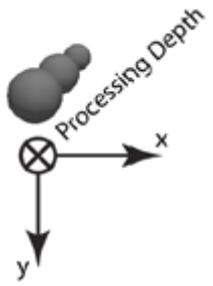


*Hassenstein & Reichardt (1956)*

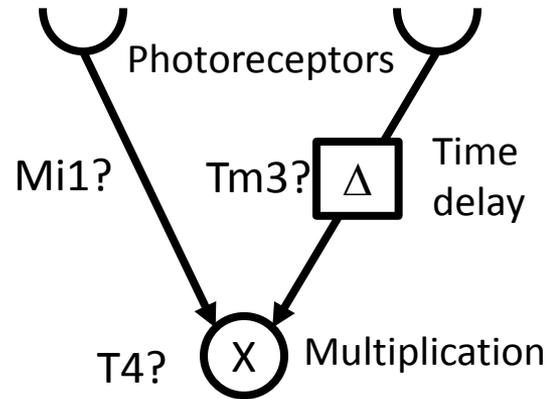
# Shortest paths from L1 to T4 (type-to-type connectome)



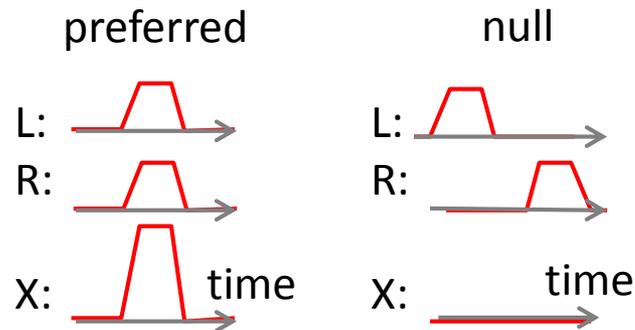
Connection Weight  
— 10 synapses  
— 50 synapses  
— 100 synapses



# Elementary motion detector

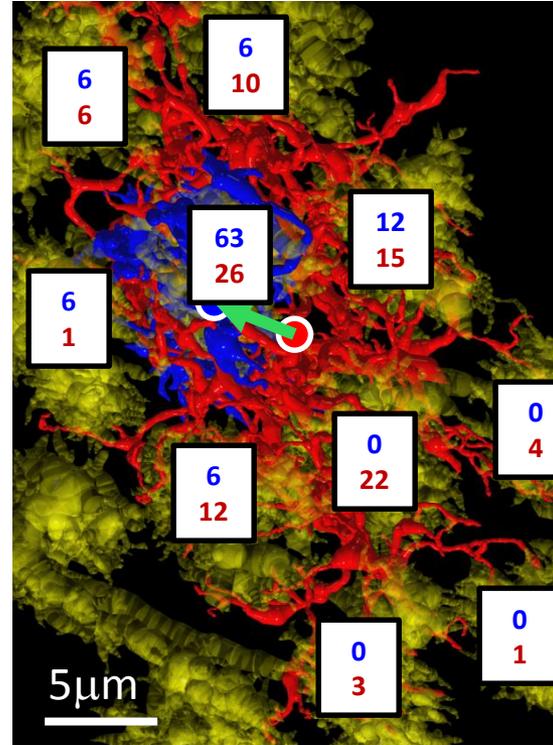
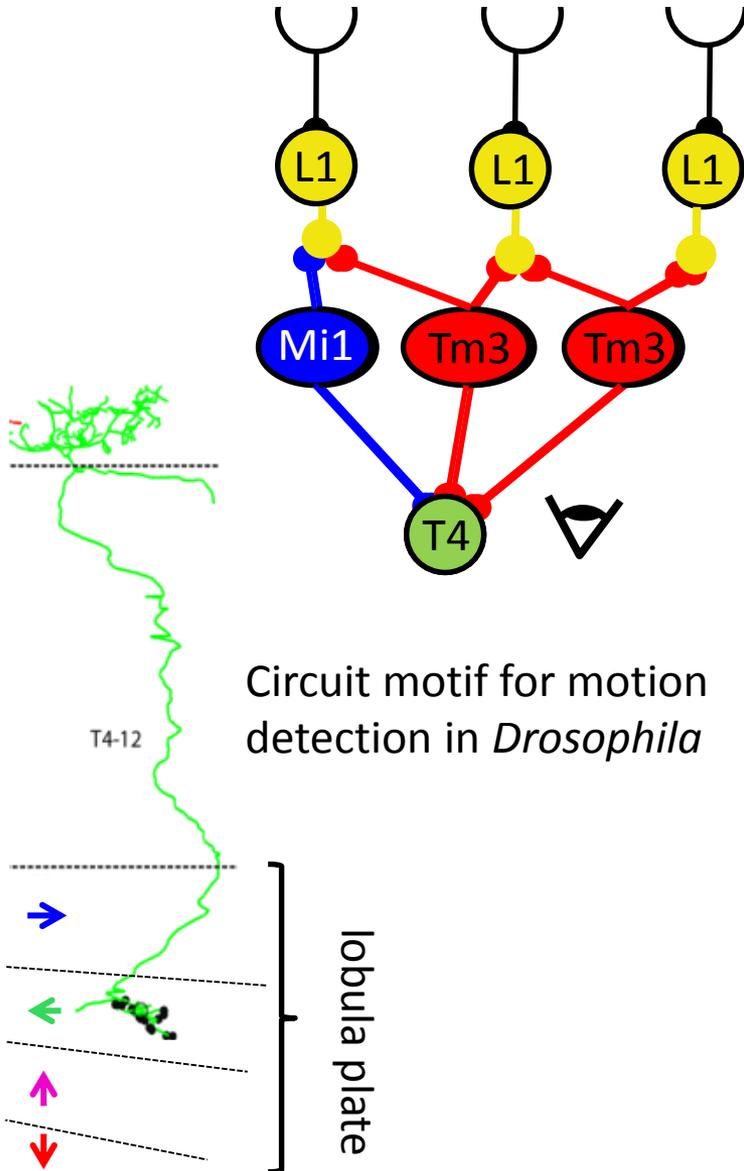


1. Spatial offset
2. Temporal offset
3. Nonlinearity

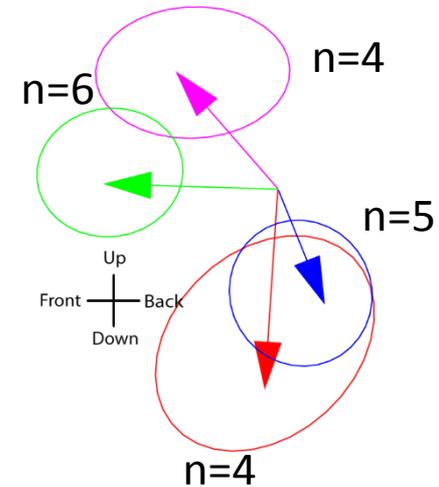


*Hassenstein & Reichardt (1956)*

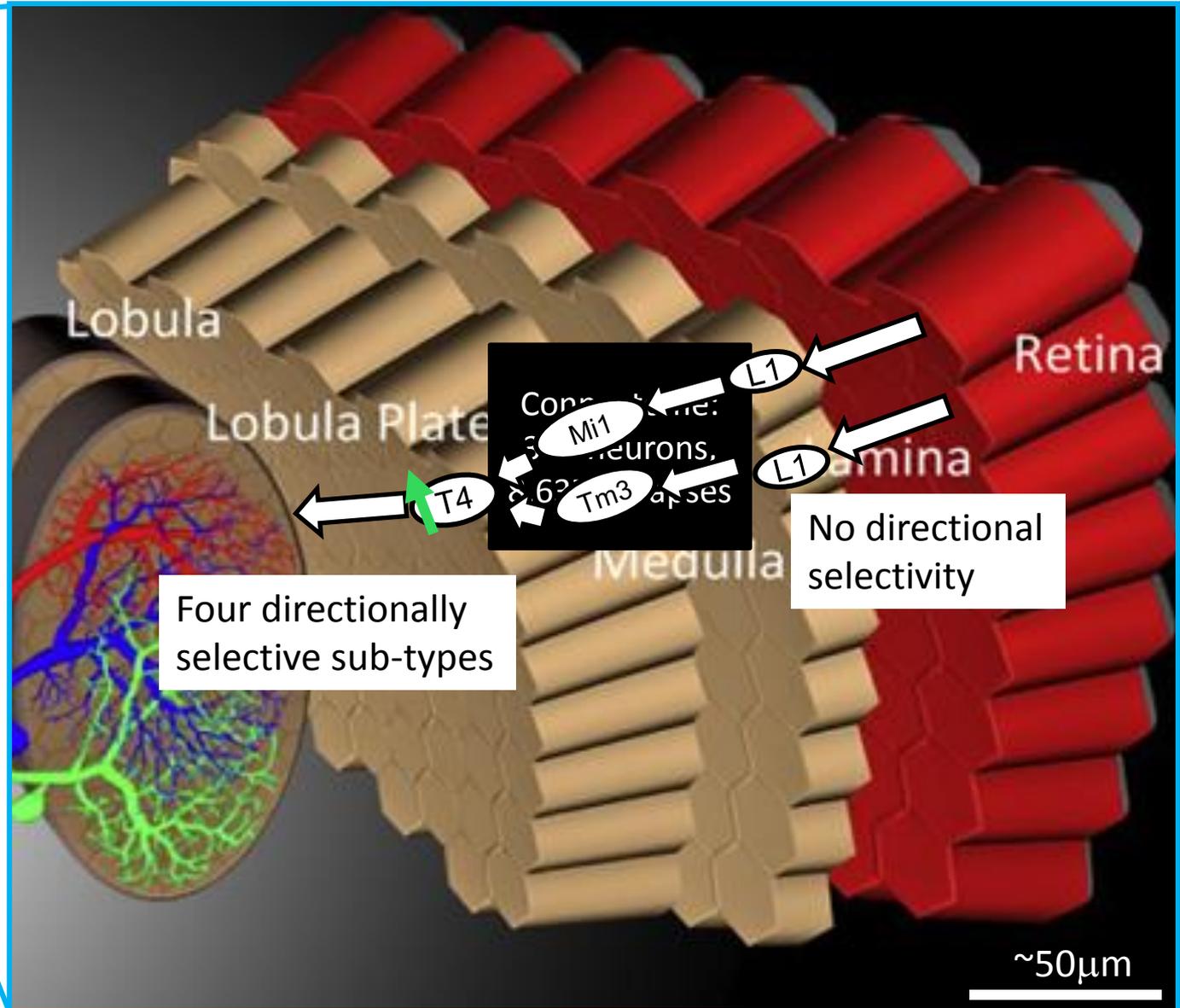
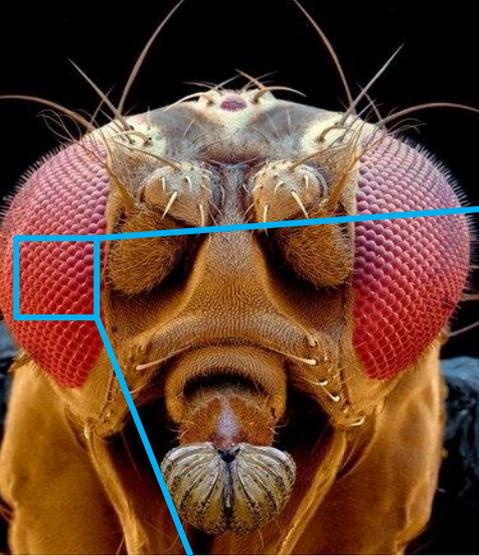
# Spatial offset between **Mi1** and **Tm3** inputs is consistent with directional preference



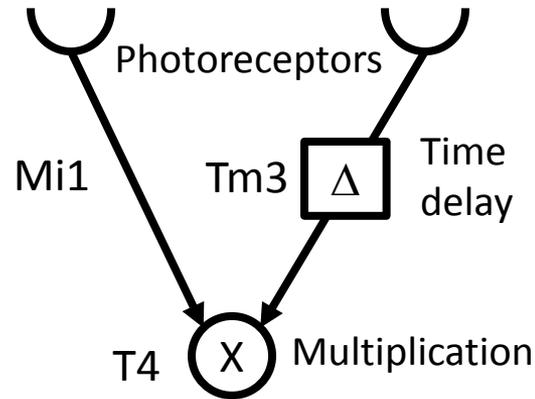
Spatial offset of synaptic inputs to **Mi1** and **Tm3** presynaptic to T4-12



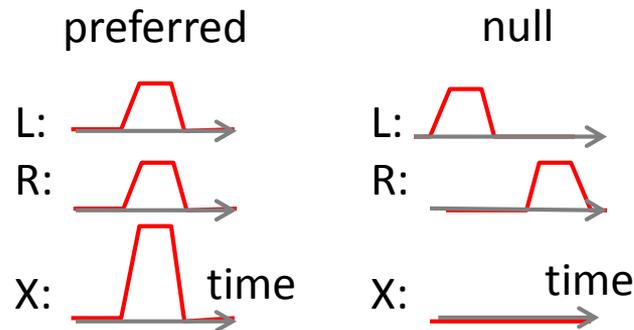
# *Drosophila* visual system



# Elementary motion detector

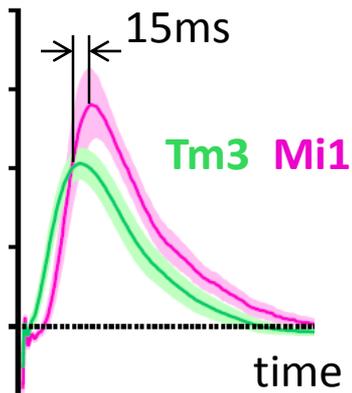


1. Spatial offset
2. Temporal offset
3. Nonlinearity

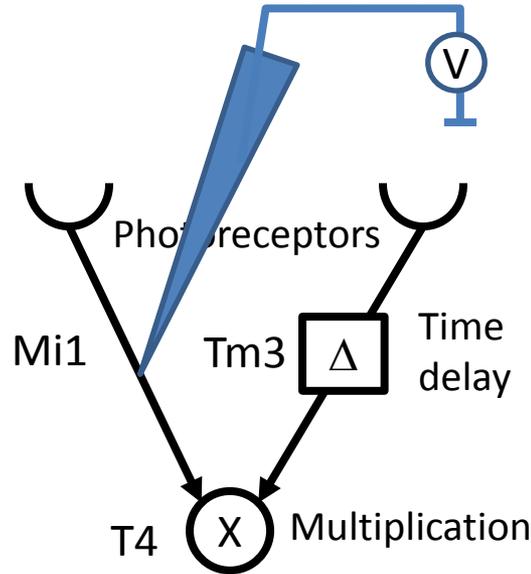


*Hassenstein & Reichardt (1956)*

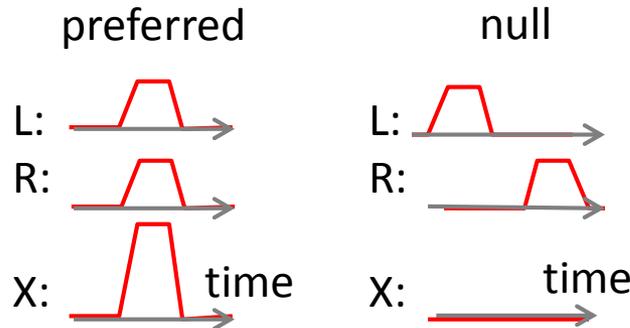
# Connectomics-enabled electrophysiology



Temporal filters (*Behnia, Clark, Carter, Clandinin & Desplan, 2014*)

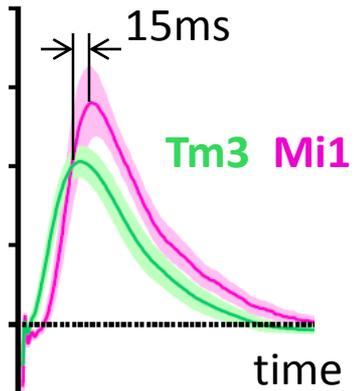


1. Spatial offset
2. Temporal offset
3. Nonlinearity

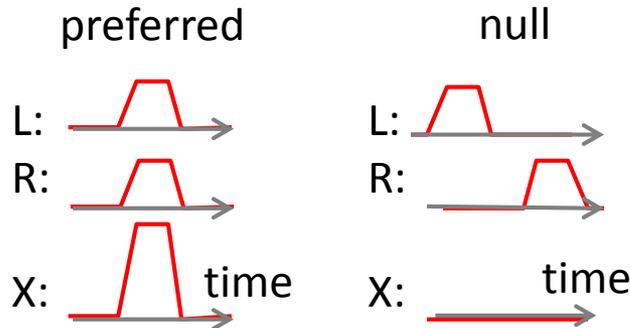
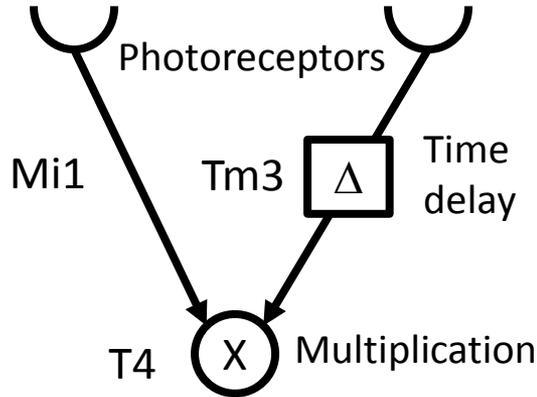


*Hassenstein & Reichardt (1956)*

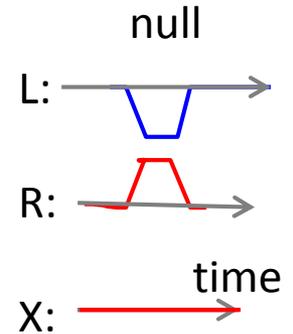
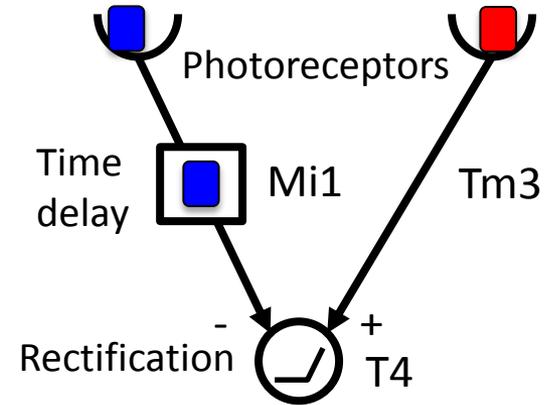
# Elementary motion detector



Temporal filters (*Behnia, Clark, Carter, Clandinin & Desplan, 2014*)

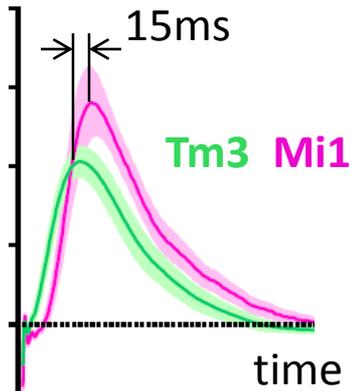


*Hassenstein & Reichardt (1956)*

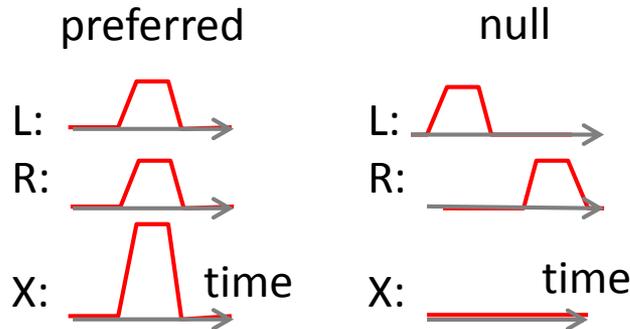
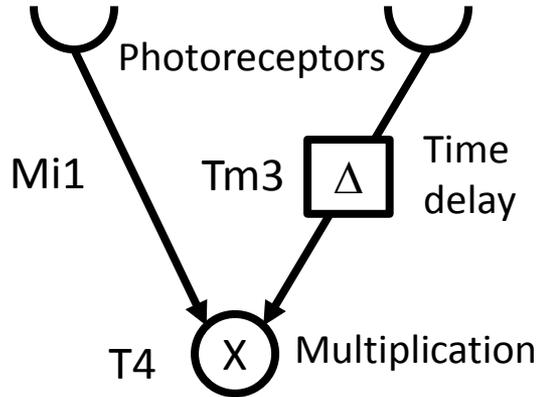


*Barlow & Levick (1965) \**

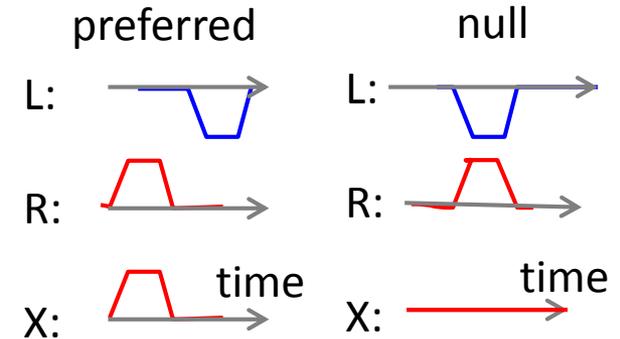
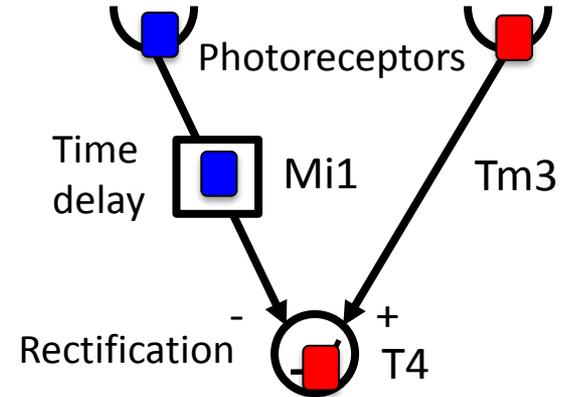
# Elementary motion detector



Temporal filters (*Behnia, Clark, Carter, Clandinin & Desplan, 2014*)

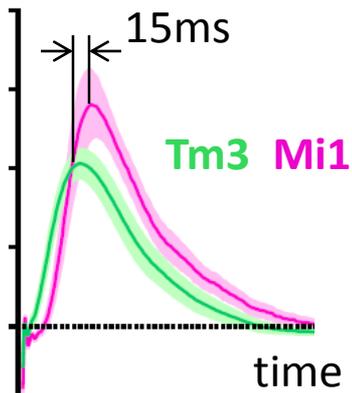


*Hassenstein & Reichardt (1956)*

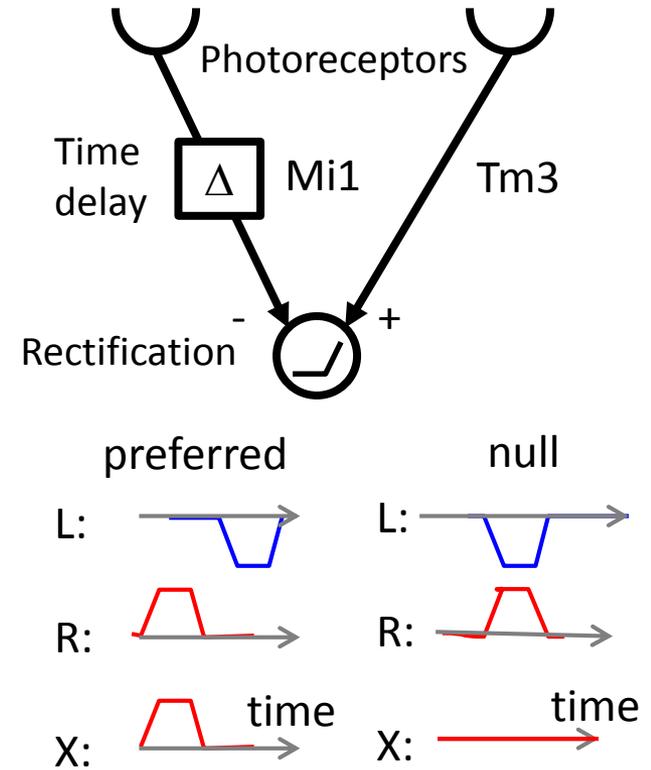


*Barlow & Levick (1965) \**

# Elementary motion detector



Temporal filters (*Behnia, Clark, Carter, Clandinin & Desplan, 2014*)



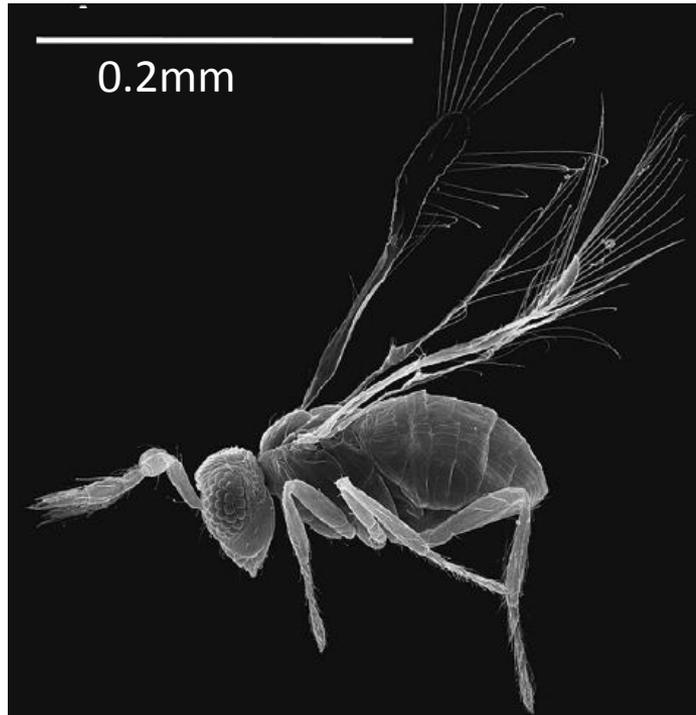
*Barlow & Levick (1965) \**

Remaining possibilities:

1. HR among Tm3 cells
2. Kim et al (2014)

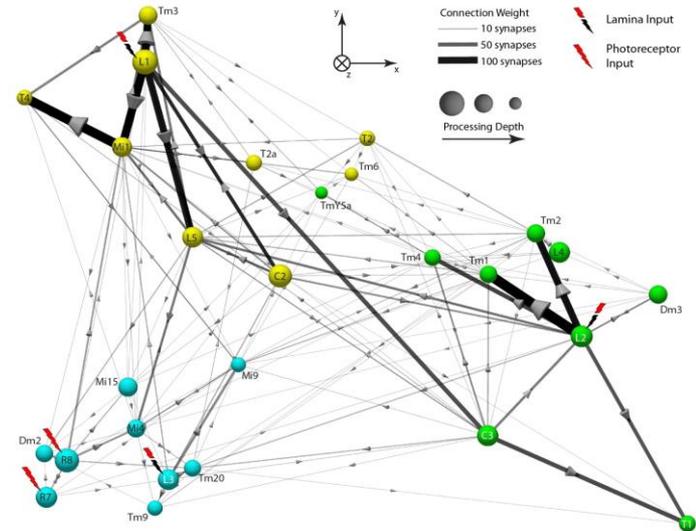
# Future directions

Whole-body connectomics reconstruction



Mini-wasp *Megaphragma mymaripenne* (Polilov, 2012)

Theoretical framework of neural computation



$$\min_{Y \geq 0} \left\| X^T X - Y^T Y \right\|_F^2$$

Positions available in the Chklovskii group at the Simons Center for Data Analysis, New York City

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Omotara Ogundeyi  
Victor Shapiro  
Gerry Rubin  
Pat Rivlin

Shin-ya Takemura



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